Bundesministerium
für Verkehr, Bau
und Stadtentwicklung

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

German
Climate Observing Systems

Inventory report on the Global Climate Observing System (GCOS)

Imprint

Editor and publisher
Deutscher Wetterdienst, Frankfurter Straße 135, 63067 Offenbach a. M.
www.dwd.de

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(Deutscher Wetterdienst, Offenbach a. M.)

Layout
Karin Borgmann Grafikdesign (Offenbach a. M.)

Printed by
Atelier Maiberger (Stockstadt a. M.)

Citation recommendation
Deutscher Wetterdienst, 2013: German Climate Observing Systems.
Inventory report on the Global Climate Observing System (GCOS).
Self-published by DWD, Offenbach a. M., 130 pages.

Cover image
DWD climate reference station at Hohenpeissenberg,
Stefan Gilge/DWD

ISBN
Print: 978-3-88148-462-6
Electronic: 978-3-88148-463-3
Note: This report was previously published in German language,
ISBN 987-3-88148-460-2

Internet reference
www.gcos.de

Last updated
January 2013

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Foreword

For considering necessary measures and their effects, political and economic decision-makers require a wealth of up-to-date and wide-ranging information. It is most important to have profound knowledge of the state of the climate system in the past, today and in the future. To further develop this know-how, research is similarly dependent on robust data and information. The provision of such information requires long-term, scientifically sound collection and storage of data.

Continuous long-term observation of all climate system components and the scientific processing of the data gathered are indispensable to identify changes in the climate, deepen the understanding of the causes and warn in good time of any extreme events or sweeping impacts. Long, uninterrupted measurement series and observations alone make it possible to strive for such early identification of any change in the climate system and any related changes in the frequency and intensity of extreme weather events.

The first steps towards worldwide observation of weather and climate were made in Germany back in 1780 with the foundation of the Societas Meteorologica Palatina. Germany thus has a particularly long tradition of systematic and standardised recording of climate-relevant parameters. In a federal country, such as Germany, for example, where the responsibilities for monitoring the different components of the climate systems are distributed among the Federation and the Länder, it therefore is of paramount importance to have an inventory of all ongoing measuring and observing programmes.

The present report gives for the first time a full overview of all programmes running in Germany to collect climate variables that are relevant to our country. Selection of the variables was made according to the list of 'Essential Climate Variables' (ECV) issued by the Intergovernmental Panel on Climate Change (IPCC) and the Global Climate Observing System (GCOS). This report will make a contribution to generally facilitating the access to these data and their interdisciplinary use.

Michael Odenwald,
State Secretary at the Federal
Ministry of Transport, Building and
Urban Development (BMVBS)

Summary

The foundations for all observation of meteorological phenomena on a global scale were laid in 1780 with the foundation of the Mannheim Societas Meteorologica Palatina. So Germany has a very long tradition of climate observation, including the longest time series of near-surface temperature and air pressure taken at the world's oldest mountain station at Hohenpeissenberg since 1781. Furthermore, there are continuous monthly climate data available starting in 1881 in the form of precipitation amounts from 59 stations and mean temperatures from 43 stations.

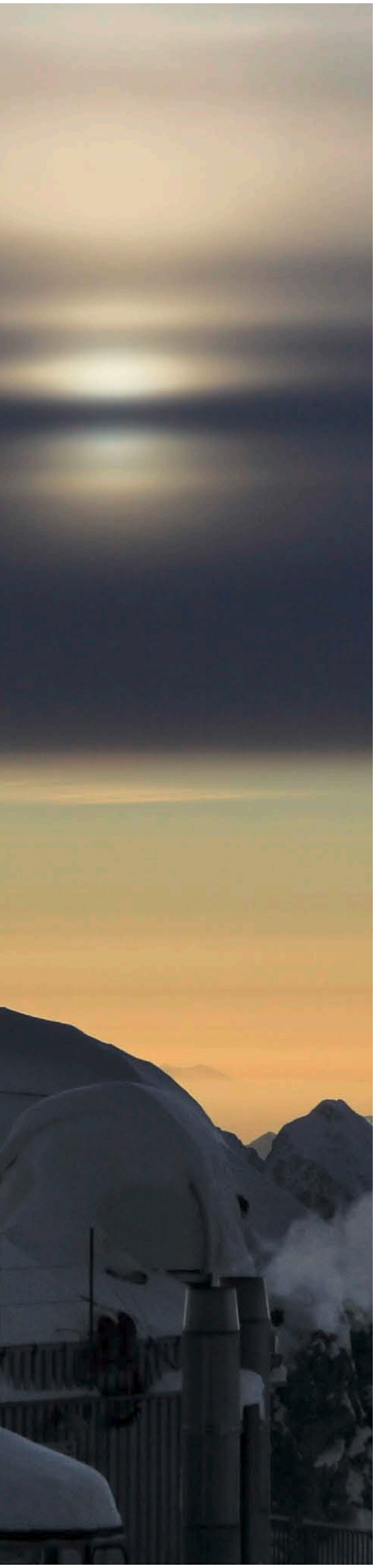
Germany holds long time series of atmospheric and hydrological climate variables, the continuation of which is well secured into the future. However, sustainability is not always secured especially for ocean and terrestrial observations.

Even though not all relevant data are available at national level in a standardised form, the wealth of measured data allows for most accurate statements on the climate in Germany and its development.

The challenges ahead are to further standardise observing systems and ensure the availability of Germany-wide data, together with fulfilling the Herculean task of digitizing existing historical paper data.

A necessary prerequisite to efficiently and sustainably implement the German Action Plan for Adaptation under the German Adaptation Strategy of the Federal Government is to have an integrated view of all relevant climate variables.

This inventory report on national climate observing systems gives a detailed overview of climate-relevant variables of atmosphere, ocean and land measured in Germany. It is the first ever broad compendium of German climate observation addressing to climate research and decision-makers.



Zusammenfassung

Die 1780 in Mannheim gegründete Societas Meteorologica Palatina legte den Grundstein zur globalen Wetter- und Klimaüberwachung. Aus diesem Grund verfügt Deutschland am Hohenpeißenberg, die älteste Bergstation der Welt, über eine seit 1781 durchgehende Zeitreihe der bodennahen Lufttemperatur und des Luftdrucks. Außerdem liegen seit 1881 durchgehende Monatsdaten von immerhin 59 Stationen zur Niederschlagssumme und 43 Stationen zur Mitteltemperatur vor.

Deutschland verfügt im Bereich der atmosphärischen und hydrologischen Klimadaten über lange und weitestgehend auch für die Zukunft gesicherte Beobachtungsreihen. Vor allem bei Ozeanbeobachtungen und einigen terrestrischen Beobachtungen ist die Nachhaltigkeit jedoch nicht ausreichend gesichert.

Auch wenn längst nicht alle Daten deutschlandweit standardisiert verfügbar sind, können – basierend auf instrumentell erhobenen Daten – hinreichend genaue Aussagen über den Verlauf des Klimas in Deutschland gemacht werden.

Die weitere Standardisierung der Messverfahren und die Bereitstellung ganz Deutschland abdeckender Datenreihen stellen zusammen mit der Herkulesaufgabe der Digitalisierung historischer Papierdaten die Herausforderungen der näheren Zukunft dar.

Eine integrierte Sicht auf alle für Deutschland relevanten Klimavariablen ist eine notwendige Voraussetzung um den Aktionsplan Anpassung im Rahmen der Deutschen Anpassungsstrategie der Bundesregierung effektiv und nachhaltig umsetzen zu können.

Der vorliegende Inventarbericht der nationalen Klimabeobachtungssysteme gibt einen detaillierten Überblick über die hierzulande gemessenen klimarelevanten Größen in Atmosphäre, Ozean und im Bereich der Landoberflächennutzung und stellt somit erstmals ein breitgefächertes Kompendium über Klimabeobachtungen in Deutschland für Klimaforschung und Entscheidungsträger bereit.

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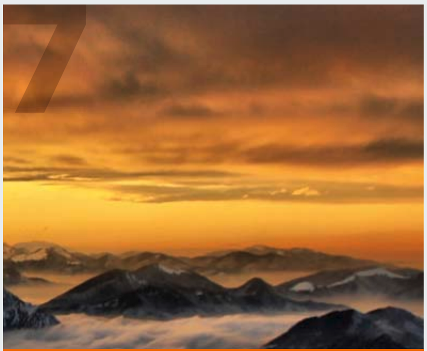

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1.
Introduction

Since the adoption of the Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro in 1992, climate protection has become a major focus of public attention. However, decision-making for climate protection and adaptation to the unavoidable climate change requires long-term high-quality observations of the main climate parameters. With this aim in mind, the Global Climate Observing System (GCOS) was established shortly after the Rio Earth Summit. The objective of GCOS is to enhance climate observation around the world, taking account of users' requirements.

Climate system and climate observations

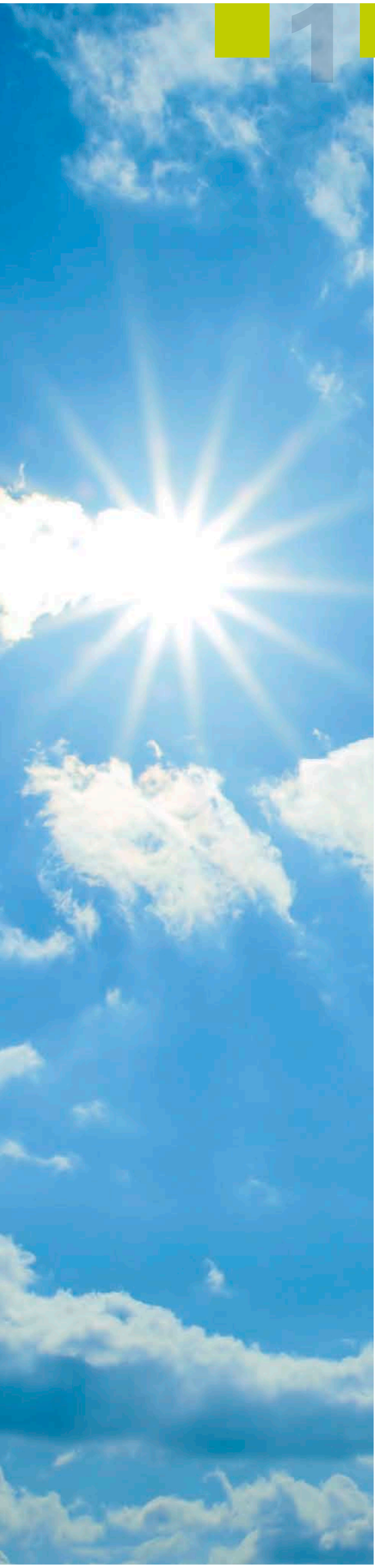
'Climate' is generally understood as the average of weather conditions observed at a certain place over a sufficiently long period of time to be described using statistical values. The internationally agreed period of time over which statistical values, such as means and averages (e.g. of near-surface temperature), frequencies (e.g. the exceeding or not of thresholds) or extremes, are calculated is 30 years. As a rule, the longer the periods under examination, the more representative the statistical statements are.

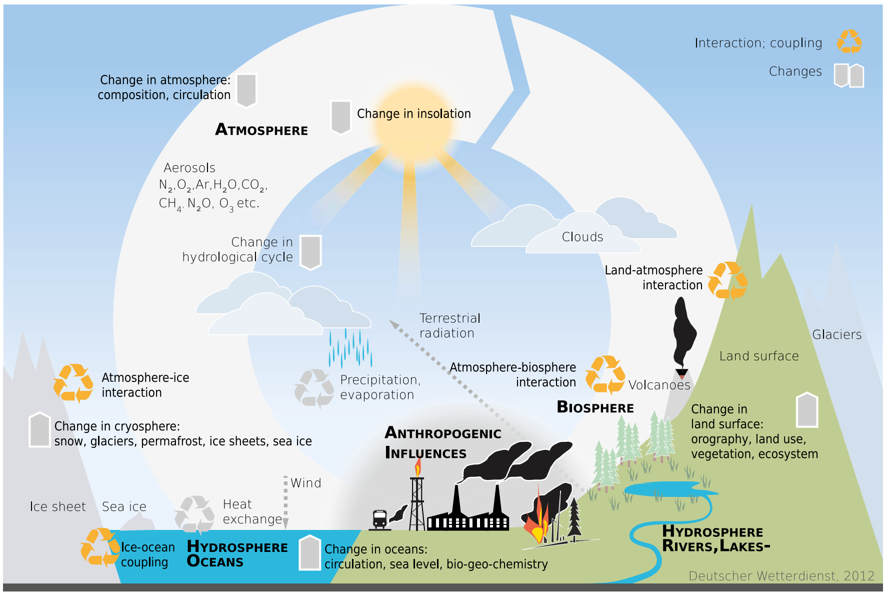
The climate in a certain place depends on a number of processes and developments. To understand the interrelationships that make up the climate system, not only the state of the atmosphere needs to be observed and described over long time periods but also the state of the oceans and land surfaces and all related changes. The climate system consists of the atmosphere, oceans and land surface. With many changes in these components being influenced or even triggered by man, socio-economic facts must also not be ignored. The graphic on page 9 gives an overview of the physical, chemical and biological interactions in the climate system.

Observations – in this case of the climate system – allow researchers to develop model-like visions of the interactions and their effects. Understanding this is the prerequisite that enables us to reconstruct the observations by means of mathematical/physical models (i.e. climate models), to validate predictions and, on this basis and taking into account certain assumptions, to produce reliable projections of future developments.

The four assessment reports (1990, 1995, 2001, 2007) by the Intergovernmental Panel on Climate Change (IPCC) give evidence of how our knowledge of the climate system and climate modelling has developed over the last decades. Many of the new findings that aid our understanding of the climate system as well as the ensuing model improvements result from the availability and extensive analysis of observational data.

The IPCC's first assessment report had already pointed out the necessity of improving systematic observation of climate-relevant parameters at the global level (IPCC, 1990). The participants of the Second World Climate Conference (WCC-2) then called for the establishment of a 'Global Climate Observing System' (WMO, 1990). As a result, the Global Climate Observing System (GCOS)





▲

Components of the climate system and their physical, chemical and biological interaction
Source: DWD

was jointly established in 1992 by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ICSU). Since then, various reports have been compiled within the scope of GCOS to analyse the state of global climate observing systems, elaborate plans for remedying deficiencies in the observing systems, and document the progress made in the implementation of these plans.

Requirements for climate observations

The basic requirements to be met by the GCOS programme were specified at the time of the system's foundation in 1992. A more sophisticated definition of these requirements was presented in a detailed report on the adequacy of global climate observing systems (WMO, 2003a). The requirements are grouped as follows:

(1) **Characterising the state of the global climate system and its variability:**
In order to describe the climate system, a wide variety of atmospheric, oceanic and land variables need to be collected. To obtain exact estimations of temporal parameter variability and attribute the causes, the measurement series must be highly accurate, with good homogeneity and long-term continuity.

(2) **Monitoring the forcing of the climate system, including both natural and anthropogenic contributions:**
In the past centuries and millennia, climate variability resulted from variations in natural factors such as solar irradiation and volcanic activity. Today, anthropogenic causes, such as greenhouse gas emissions and air pollution as well as changes in land use, add to these.

(3) **Supporting the attribution of the causes of climate change:**
Climate monitoring as described in (1) and (2) also helps to improve the understanding of the interactions between different elements and attribute the causes of changes. This is done by using the observational data to develop models for investigating in experiments the causes and interrelations and enable anthropogenic and natural causes to be differentiated.

Climate component		Essential Climate Variables
Atmosphere	Surface	Air temperature, precipitation, air pressure, surface radiation balance, wind speed, wind direction, water vapour
	Free atmosphere	Radiation balance (including solar radiation), temperature, wind speed, wind direction, water vapour, clouds
	Composition	Carbon dioxide, methane, ozone, other greenhouse gases, aerosols, *pollen*
Oceans	Surface	Surface temperature, salinity, sea level, sea state, sea ice, currents, water colour, partial pressure of carbon dioxide
	Intermediate and deep waters	Temperature, salinity, currents, nutrients, carbon, trace substances, phytoplankton
Land surface		Runoff, lakes and seas, ground water, water use, *isotopes*, snow cover, glaciers and ice caps, permafrost, albedo, land cover (including type of vegetation), leaf area index, photosynthetic activity, biomass, forest fire, soil moisture, *phenology*

GCOS Climate Monitoring Principles	
1.	The impact of new systems or changes to existing systems should be assessed prior to implementation.
2.	A suitable period of overlap for new and old observing systems is required.
3.	The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data themselves.
4.	The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5.	Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6.	Operation of historically-uninterrupted stations and observing systems should be maintained.
7.	High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8.	Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9.	The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10.	Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

◀ Table 1:
Essential Climate Variables (ECVs) in accordance with the GCOS Implementation Plan (WMO, 2010) as well as those variables that are additionally relevant to Germany (in italics)

◀ Table 2:
The ten Principles were considered at the 5th Conference of the Parties (COP 5) to the United Nations Framework Convention on Climate Change (UNFCCC, 2000) and adopted by the 14th WMO Congress in May 2003 (WMO, 2003b).

(4) **Supporting the prediction of global climate change:**
Climate prediction requires us to look not only at the development of the factors referred to in (2), but also at the initial state of the climate system. In addition, long data series of the main climate variables help us to assess and further develop climate models.

(5) **Projecting global climate change information down to regional and national scales:**
The effects of climate change and adaptation to them require action particularly at national and regional level. This is why additional, more detailed information is needed at this level to complement the variables mentioned under (1) in order to develop regional climate models and better understand how the climate affects natural systems.

(6) **Characterising extreme events for the assessment of impacts, risk and vulnerability**
Climate observation data are aimed at enabling classification of extreme events, such as flooding, heat and storms, in order to run corresponding impact analyses and work out guidelines, adaptation strategies and action plans.

In order to satisfy these requirements, GCOS has defined, in co-operation with the IPCC and the World Climate Research Programme (WCRP), a number of essential climate variables (ECVs, see Table 1). Further to the scientific requirements, the selection has also taken into account the extent to which observation of these ECVs can be implemented on a global scale for the purposes of climate monitoring. New research findings, advances in measurement technology and new user requirements, may enable new variables to be included, if needed.

Along with the global ECVs, which were first defined in 2003, it may be necessary to observe other climate variables at a national level, which are not part of the ECVs but have been recorded for a long time on a systematic basis and have been of significance for characterisng the climate and its variability at local levels. In Germany, these include pollen, isotopes in precipitation and phenological parameters.

To make sure that long time series of national in situ observations take account of large-scale changes only, if possible, and that these are comparable at international level, GCOS has laid down ten basic principles for monitoring the climate, known as the GCOS Climate Monitoring Principles (see Table 2, Karl et al., 1995; WMO, 2003a).

Germany has a long tradition of climate observation. The foundations date back to Alexander von Humboldt (1769–1859) and to around 1780, when the Societas Meteorologica Palatina, also known as the Meteorological Society of Mannheim, came into existence. Since then, German institutions have contributed to systematic observation of the climate system at national and international level.

Systematic observation activities relevant to Germany currently comprise almost all ECVs (see Table 1).

The data are generally subject to strict quality checks and are, for the most part, transmitted to international data centres, some of which are operated by German institutions. From there, they are available to international research groups for integrated global studies, notably on climate change, and to operational institutions. German institutions thus help to improve international collaboration and standardisation of measurement data.

In order to co-ordinate national efforts and support the international activities of GCOS, a national GCOS Secretariat for Germany was installed a the Deutscher Wetterdienst (DWD) as early as in autumn 1992, immediately after the establishment of the GCOS programme. Shortly after that, the brochure 'GCOS – The German View' was published, giving a first overview of German contributions to GCOS.

Since 1998, national GCOS meetings have taken place to enhance co-operation between all institutions in Germany that are responsible for making climate observations and to co-ordinate German contributions to GCOS.

The purpose of this report

Historically, Germany has a very long tradition of observing climate-related parameters. The collection of historical data represents a veritable treasure trove for the responsible institutions and bodies, which is of great scientific significance for climate research at national and international level. These data are one of our cultural assets which, if lost, can never be recovered again.

Preserving and continuing long time series of observations is a continuous challenge for all those who bear the responsibility. Particularly at risk are those observation series the collection of which depends on temporally limited research funds.

Another, different kind of risk results from the fact that many data still only exist in paper form or on old data storage devices and thus are not available for modern analysis. Without any counter measures, there is a risk of losing these historical data forever.

In addition, the monitoring of climate-related parameters in Germany is distributed among multiple research institutions and authorities at federal and regional levels. The purpose of this report is to provide an overview of the current situation and information about the sustainability of these observations into the future. A particular focus will be given to data sets at possible risk.

Methodology of the report

Under the commitments of the UNFCCC, the Federal Government regularly draws up national inventory reports on the activities undertaken by Germany towards the implementation of the Convention. The reports all have a chapter describing research and systematic observation measures in Germany. The 3rd National Report (Bundesregierung, 2002) was the first to give a more detailed presentation of Germany's contribution to systematic climate observation. The 5th National Report incorporates, for the first time, an entire report of its own about Germany's contribution (Deutscher Wetterdienst, 2009). All these reports give only a very broad overview which follows a very strict structure to enable comparison at the international level; they are designed as a summary of the contributions Germany makes to global observation networks.

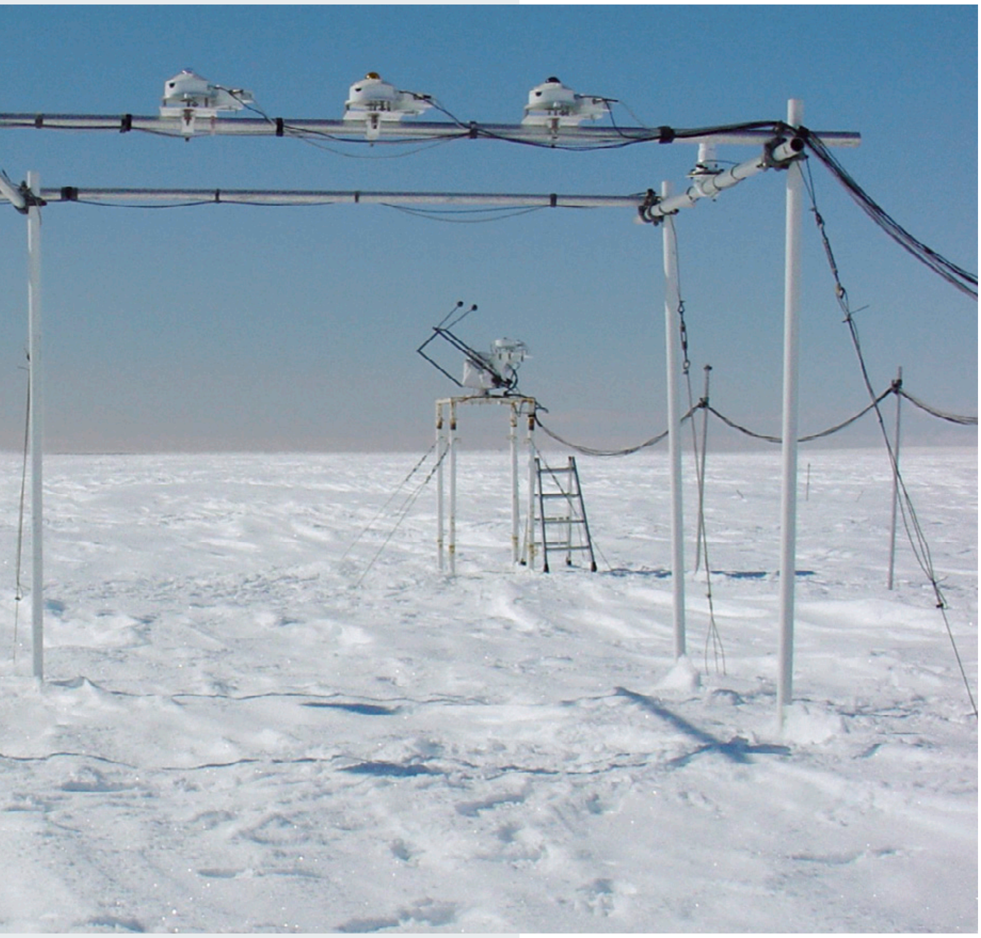
With a view to providing the first ever comprehensive and descriptive survey of climate observation in Germany, it was agreed at the 6th national GCOS meeting held in March 2011 to publish a special brochure on climate observations in Germany. A good example here is the inventory report of the Swiss government entitled 'National Climate Observing System (GCOS Switzerland)' (Seiz and Foppa, 2007).

Structure of the report

Essential climate variables are presented separately, with some combined into one section if closely related. Chapters 2 to 4 deal with the atmospheric and oceanic variables and terrestrial observations.

The description of each parameter is complemented by information about the legal framework, observed trends, international context and scientific significance as well as the resources needed. Chapters 5 and 6 describe the international data centres existing in Germany and Germany's observation activities abroad or outside its territorial waters. Chapter 7 closes the report by summarising the major findings and giving an outlook on the future of Germany's national climate observing system GCOS-DE.

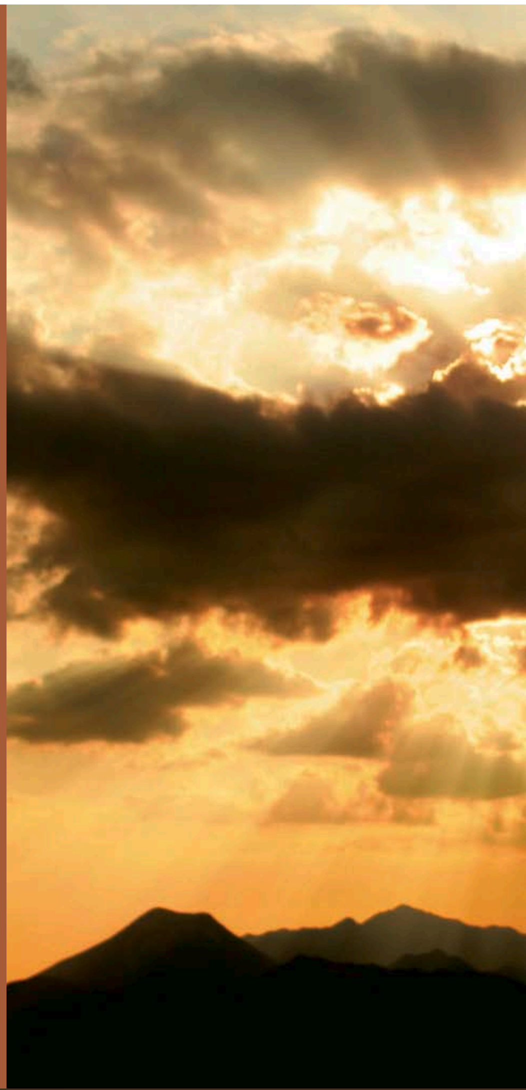
1 Introduction



▲
BSRN observation field at AWI Neumayer station in the Antarctic
(BSRN = Baseline Surface Radiation Networks, AWI = Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research)

2.1
Temperature

Temperature is one of the main indicators for describing the climate and its variability. In the context of expected anthropogenic climate warming the observation and analysis of this parameter is of special importance.



Climate trends

The times series of area averages derived from the gridded fields allow meteorologists to discern climatological trends regardless of any lack of homogeneity that might exist in the records of single stations. They reveal a warming of about 1.1°C (linear trend) during the last 130 years. However, this trend is not uniform over the entire time series. Instead, there was an increase in temperature up into the 1940s, followed by a decrease until around 1970 and then a very pronounced increase until the year 2000. In the last decade, the annual mean temperature remained at this high level. Thus, the time series for Germany widely corresponds to the global trend, but with a somewhat stronger warming.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.

Measurements in Germany

The Deutscher Wetterdienst (DWD) operates a network of weather and climate stations, of which about 500 currently measure temperature. This dense network has existed for about 60 years.

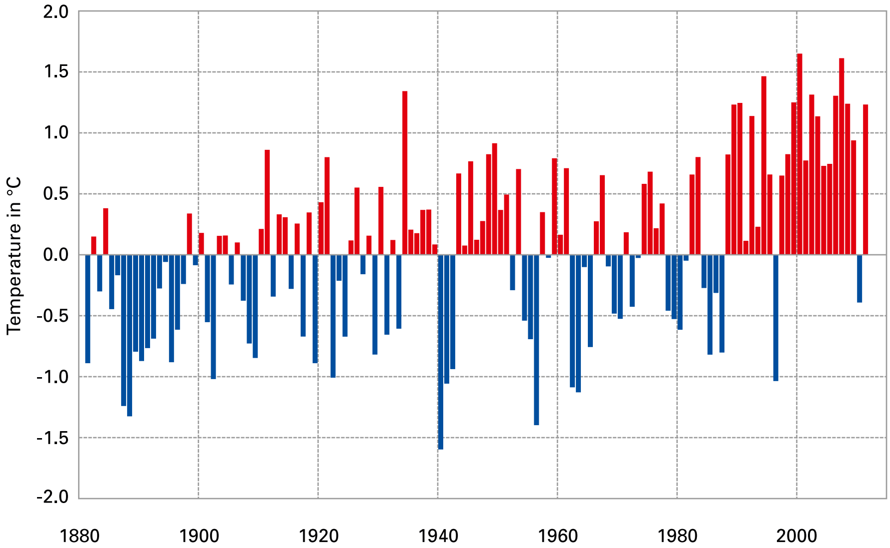
Alongside the DWD stations, additional measurements of temperature are taken by other institutions and individual persons. However, only minor parts of these series are included in the DWD's database, as they often do not meet the high standards of representativeness, measurement methods or continuity of operation.

Before 1950, the number of stations was considerably lower and often only monthly data exist, which have now been digitised up to World War II. But many of the daily values have been lost. Monthly values are available from a relatively dense network of more than 130 stations dating back to 1881, thus enabling grid fields to be compiled (by interpolation) and spatial mean values to be computed.

Before that date, only a few single time series exist, which often lack homogeneity due to differences in measurement methods and observation programmes. The longest of these time series (Berlin) dates back to 1719.

A first uniform and well-documented network was established in 1781 in the context of the Societas

Annual mean temperature for Germany for the period 1881–2011



Negative deviation from the long-term mean 1961–1990

Positive deviation from the long-term mean 1961–1990

▲ The time series shows a significant temperature increase, especially in the 1980s and 1990s, of nearly 1°C higher than in the period 1961–1990.

Meteorologica Palatina by the prince-elector of the Palatinate. This network collapsed after about ten years in the turmoil of the French Revolution and the following wars. But some of the observers continued their measurements, providing continuous climatological time series, such as the one for Hohenpeissenberg near Weilheim in the Alpine foothills since 1781, which could be successfully homogenised to a large extent.

Between 1995 and 2005, in the context of the general automation of the networks, the equipment used for measuring temperature widely changed from mercury thermometers and bimetal recording instruments to digital electronic thermometers. Fortunately, no significant inconsistencies in the time series of monthly and annual means resulted.

At eleven reference stations, where long time series exist, conventional analogue measurements continue to be taken in parallel with the new digital measurements by automatic systems.

International context

The synoptic reports from 180 stations are distributed worldwide on a routine basis. For a selected number of these stations, quality-checked monthly climatological information is made available in the form of CLIMAT reports. The stations at Frankfurt, Hamburg, Hohenpeissenberg and Lindenberg are part of the GCOS Surface Network (GSN).

Required resources

Because of the legal mandate given to the DWD the operation of the existing measuring stations can generally be considered as secured. But to meet the requirements to save resources, the DWD continues to optimise and automate its networks. The continuation of long time series at selected climate reference stations is secured. Manning of stations will be further reduced and be limited to stations at airports and to reference stations. Current digitisation activities must be continued in order to make further long time series available.

http://www.dwd.de

2.2
Wind

Wind is an essential indicator for describing the climate for the purposes of different areas of application. Its importance is growing particularly in the context of the use of renewable energies, but also because of the potential for damage during extreme storm events.

Legal framework
The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.

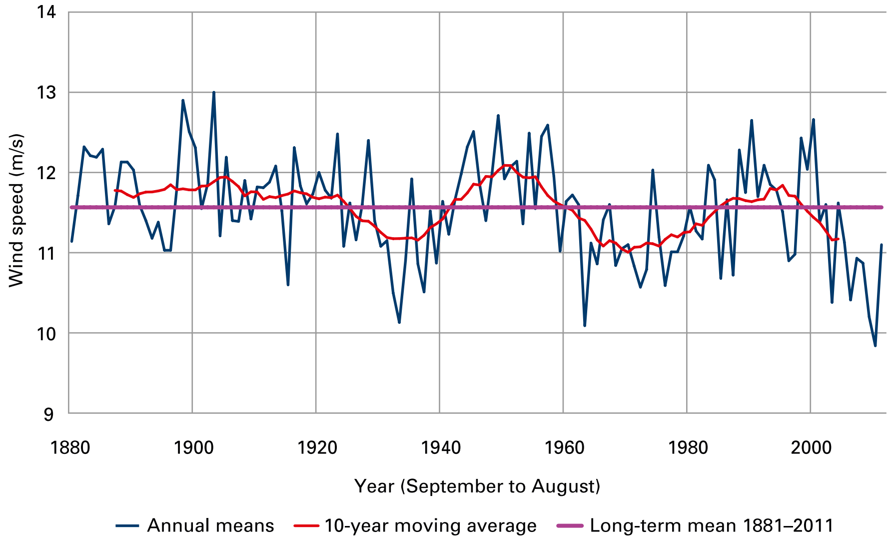
Wind stations in Germany (2011)

Measurements in Germany
The Deutscher Wetterdienst (DWD) operates a monitoring network of weather and climate stations, of which about 300 currently take wind speed and wind direction measurements. This dense network has existed for about 20 years. Going back to before that time, the coverage of wind measurements becomes gradually coarser; however, there are wind estimates available from secondary stations.

From before 1950, there exist only a few single measurement series. Some time series of wind estimates go back to the 19th century.

Due to different measuring and evaluation methods, the longer time series often contain considerable inconsistencies, but which can partly be corrected regarding the wind speeds.

Annual means of geostrophic wind in the German Bight



▲
Annual means of geostrophic wind speed in m/s in the German Bight for 1881–2011 with 10-year moving average (September to August)

Climate trends

There are no clear trends to be seen from the station time series for wind speed. Longer time series derived from air pressure measurements (geostrophic wind) also show no significant trends. But it appears that Germany experiences an oscillation of weaker and stronger wind speed periods with a periodicity of about 40 years. For the area of the German Bight, there is evidence of a phase of low wind speed in the 1960s and 1970s, while the 1980s and 1990s saw a slight increase in wind speed.

International context

The synoptic reports (including wind measurements) from 180 stations are distributed worldwide on a routine basis. For a selected number of these stations, quality-checked monthly climatological information is made available in the form of CLIMAT reports. The stations at Frankfurt, Hamburg, Hohenpeissenberg and Lindenberg are part of the GCOS Surface Network (GSN).

Required resources

The operation of the existing measuring stations can generally be considered as secured.

http://www.dwd.de

2.3
Air pressure

Air pressure is one of the main indicators for describing the climate as its spatial distribution determines the general circulation of the atmosphere. It is the variable which characterises the high and low pressure areas that influence the weather.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.

Climate trends

The time series of air pressure reveal no significant climate trends, although, with the exception of the years 2009 and 2010, the last three decades are characterised by relatively high air pressure (see graph on page 19).

However, there are currently no statistical trend analyses of air pressure for the entire area of Germany available. Earlier studies (Schönwiese and Rapp, 1997) of 100- and 30-year time series show largely varying seasonal patterns.

The warming in winter during the last decades of the 20th century is apparently not only accompanied by a strengthening of the zonal westerlies over Europe but also by a northward shift of the subtropical high and thus an increase in surface pressure over central Europe.

Air pressure changes are often manifested through changes in the frequency and intensity of large-scale weather patterns (known as ‘Großwetterlagen’). For example, periods of dry weather are usually associated with high pressure systems, rainy periods with low pressure activity. A trend in the climate variable air pressure can therefore explain changes in other climate variables, but not give the reasons.

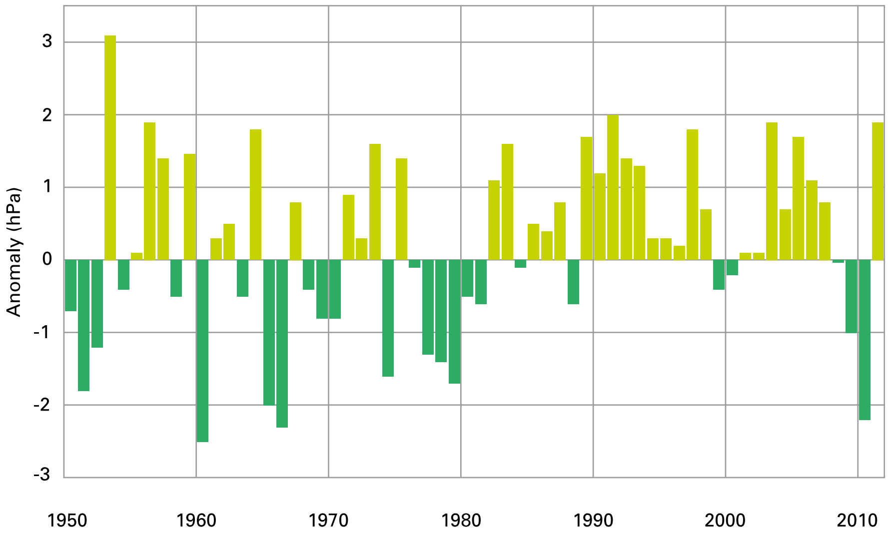
Measurements in Germany

As the spatial distribution of air pressure generally is quite homogenous, the network of measurement stations requires here a lower density than for other climate variables. The Deutscher Wetterdienst (DWD) operates a network of weather and climate stations, of which about 180 currently take air pressure measurements. This network has existed for about 60 years.

Going back to before 1950, the station density was much coarser; from before about 1930, there exist only a few single measurement series which often contain inconsistencies due to different measurement methods and observation programmes.

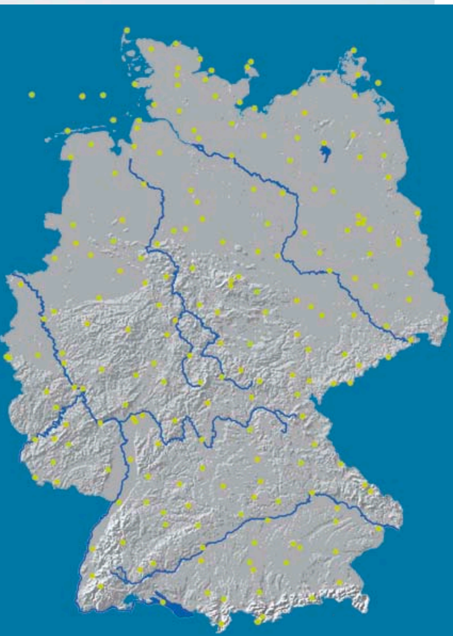
A first uniform and well documented network was established in 1781 in the context of the Societas Meteorologica Palatina by the

Annual mean air pressure deviation in Frankfurt am Main for the period 1951–2011



- Negative deviation from the long-term mean 1961–1990
- Positive deviation from the long-term mean 1961–1990

▲ Negative (dark green) and positive deviations (light green) from the long-term mean air pressure at sea level (1961–1990)



prince-elector of the Palatinate. This network collapsed after about ten years in the turmoil of the French Revolution and the following wars. But some of the observers continued their measurements, providing continuous climatological time series since 1781 such as the one for Hohenpeissenberg near Weilheim in the Alpine foothills.

Between the years 1995 and 2005, in the context of the general automation of the networks, the measurement equipment changed from manually operated mercury barometers and analogue aneroid barometers to digital devices. Fortunately, no significant inconsistencies in the time series were found.

International context

The synoptic reports from 180 stations are distributed worldwide on a routine basis. For a selected number of these stations, quality-checked monthly climatological information is made available in the form of CLIMAT reports. The stations at Frankfurt, Hamburg, Hohenpeissenberg and Lindenberg are part of the GCOS Surface Network (GSN).

Required resources

Because of the legal mandate given to the DWD, the operation of the existing measuring stations can generally be considered as secured. A systematic continuation of the digitisation activities is required to make further long time series available for scientific assessments and model-based reanalysis.

http://www.dwd.de

2.4

Precipitation

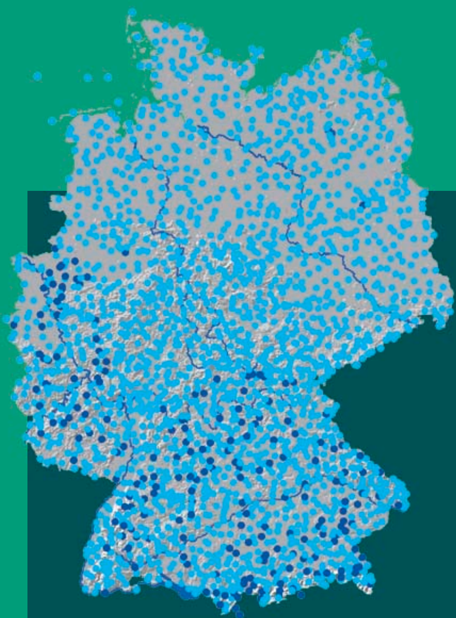
Alongside temperature, precipitation is the key indicator for describing the climate and its variability. It is also an important parameter for both water cycle and water budget, with accordingly high relevance for agriculture and water management. Thanks to its climate data archive, the Deutscher Wetterdienst (DWD) can provide reliable analyses of the spatio-temporal behaviour of precipitation back to the year 1881 also in the context of anthropogenic climate change. For the most recent decades, precipitation data collected by remote sensing add to the ever-growing number of in situ measurements of high temporal resolution.

Climate trends

The grid-based reanalysis of in situ precipitation measurements allows for discerning climatological trends since 1881 irrespective of any inconsistency that might exist in the time series of single stations (see graph on page 21). The average annual precipitation in Germany shows an increase of 10% over the last 130 years. The increase is concentrated in the winter half-year, whereas the summer half-year totals do not show any significant trends. This national trend can differ in magnitude – and sign – in specific regions and by season.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.



Precipitation stations of the DWD

Other precipitation stations

▲

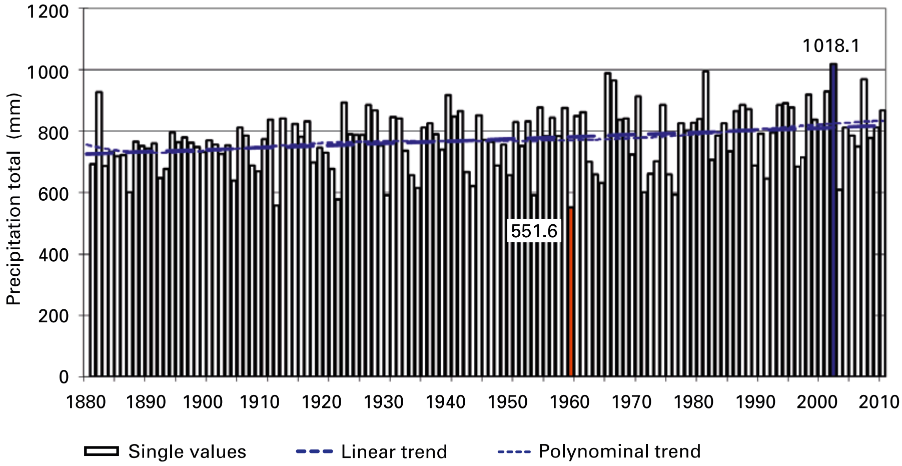
Precipitation stations included in the DWD archive (as of August 2012)

Measurements in Germany

The DWD operates a network of around 2,000 weather and climate observation stations (see map above), where precipitation data are collected at least on a daily-total basis. Since around 1995, precipitation measurements have been taken increasingly by digital systems allowing for improved temporal resolution – even into the minute range (see top graph on page 23). Moreover, more than 1,000 of the stations have already been changed to automatic measurement methods. Most non-automated stations used to and continue to record one daily measurement (at 7:00 am), whereas until 2000 all of the nearly 500 climate stations registered three measurements per day, at 7:00, 14:00 and 21:00 LMT. Since that date, all climate stations have successively been automated. In addition to these, several hundred analogue rain gauges provide hourly precipitation totals.

This dense daily precipitation measurement network has been operated this way for approximately 60 years and comprised from 1951–2004 (1969–2000) more than 3,000 (4,000) stations (see top graph on page 23). Most of the stations, however, were manned, which made a high demand on human resources. If only monthly totals are required, the DWD has recourse to a network of more than 2,000 stations with data records going back the last 100 years; to find fewer than 1,000 stations, one

Average annual precipitation totals for Germany 1881–2010



▲
Average annual precipitation totals based on an ensemble of about 400 German precipitation stations

has to return more than 120 years back to 1891. Extending the period for another ten years back to 1881, there is still a network of several hundred stations available, good enough to interpolate reliable monthly gridded fields and area totals. Before 1881, the availability of time series is sporadic and lacks homogeneity due to differences in measurement methods and observation programmes.

Alongside the DWD stations, there exist additional precipitation measurements which are carried out by other institutions or individual persons. However, only minor parts of these series are included in the DWD's database, as they often do not meet the high standards of representativeness, measurement methods or continuity of operation or are just not available to the DWD.

International context

Besides to other data centres, all data registered at the precipitation stations are forwarded to the Global Precipitation Climatology Centre, hosted by the DWD (see Chapter 5.1). Moreover, the precipitation parameter is one of the nine essential climate variables (ECVs) which the DWD processes as part of its function as Regional Climate Centre on Climate Monitoring (RCC-CM) of the Regional Association VI (RA VI, Europe) of the World Meteorological Organization (WMO). The DWD is actively engaged in international bodies (e.g. WMO and EUMETNET/ ECSN as well as GMES, GEO, GEOSS), which reflects its significant status in the fields of European and global climate monitoring.

Required resources

The sustained operation of existing measurement stations can be regarded as substantially secured. However, the level of automation must be driven further, the high number of staff further reduced and limited to observations at air fields and climate reference stations. Precipitation monitoring in the era of climate change needs to work at high levels of resolution and availability and comprise Germany and its adjoining relevant river catchments; it requires at the same time the sustained operation of reference stations with essential (i.e. long) measurement series. Persistent data digitisation activities are required in order to make further long data series available for scientific studies.

http://www.dwd.de

Significance of long data series

Systematic, station-based recording of precipitation in Germany and the operation of the corresponding station networks are closely connected to the institutions and bodies that operate them. The result is a heterogeneous picture in terms of geography and time, given the fact that the first national meteorological service, the Reichswetterdienst, did not come into existence until 1934. Before then, and until the foundation of the DWD, precipitation observation was the responsibility of regional meteorological services or the meteorological services of the Länder, which is the reason for the multitude of networks. The longest uninterrupted precipitation time series in Germany started at the station in Aachen in 1844, originally operated by the Royal Prussian Meteorological Institute and which has, for this reason, been designated as one of the eleven climate reference stations of the DWD.

DWD climate reference stations

The progressing automation of weather observation calls for investigation and quantification into the impact of the switch to digital recording methods on data series. At eleven climate reference stations in Germany, digital recording takes therefore place parallel to manual observations carried out by well-trained weather observers using conventional measuring and observation techniques. At least ten years of comparative measurements will prevent misinterpretation of the data series collected by the DWD with regard to climatological and climate change issues. With its climate reference stations system, the DWD has taken a pioneer role and is a renowned contact for many European meteorological services. The ultimate goal is to build a similar Europe-wide network of climate reference stations. The sites chosen by the DWD (see map below) are characteristic of their geographic and climatic environment.

▲
Position of the eleven climate reference stations of the DWD

Data rescue projects of the DWD

Since early 2005, the DWD has been running the KLIDADIGI project to digitise historical daily precipitation data existing only on paper in order to make them available for climate monitoring and research, in particular with regard to climate change, and to rescue them from their ultimate disintegration and loss. The green shaded area in the top graph on page 23 shows the number of precipitation stations with monthly values, but which also hold daily data yet to be digitised, in contrast to the comparatively small amount of daily precipitation data already digitised up to August 2011 (red area). Digitisation of the paper documents covering the whole 165,000 precipitation station-years plus a total of 23,000 station-years from DWD climate stations would require a work force of 790 person-years. Between now and 2025, the DWD plans to digitise, and thus rescue, about 25% of these documents, with a major focus on the longest and most complete series.

Further worldwide historical precipitation records from more than 1,500 overseas stations have been made available by the Hamburg-based Deutsche Seewarte (German Maritime Observatory). The majority of these mostly 12-hourly measurements (taken twice per day) cover the periods 1884–1918 and 1930–1943, with the stations spread across all continents, mainly in the former German colonies and protectorates in Africa, China and the tropical Pacific (Bismarck Sea) and the southern Pacific. Their complete digitisation will require about another 40 person-years.

Within the framework of the analysis of short-duration extreme precipitation, the DWD has digitised the pluviograph records of around 200 stations. The resulting data series are of different lengths; they all start no earlier than 1951. For 60 of the 200 station data series, digitisation could be extended until 2010.

New requirements resulting from anthropogenic climate change

In the context of the expected anthropogenic global warming, the relevance and requirements of quality and geo-temporal resolution of the monitoring of variability and trends in precipitation, regional particularities included, have further grown. For example, adaptation to changing hydro-meteorological conditions constitutes one of the major challenges in enhancing the resilience of societies to the impact of climate change.

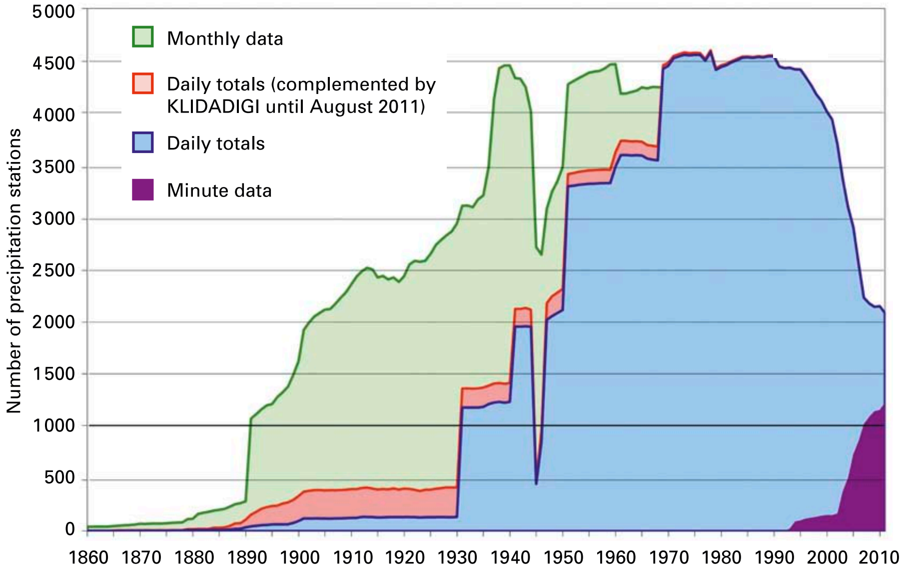
Due to their high accuracy and the length of time series, station-based precipitation data continue to be the back-bone of precipitation monitoring. With station-based data, however, there are the problems of representativeness and homogeneity. Moreover, even the national network of more than 4,000 stations that was operated in the years 1969–2000 was nowhere near dense enough to detect extreme, small-scale precipitation events. This problem of detection is worse in remote regions where the question of inaccessibility leads to reduced density of stations. This is sufficient reason to use remote sensing (satellite and radar)-based precipitation measurements also for hydro-climatological applications, although at least the radar-based measurements had originally been introduced for real-time applications only. Meanwhile, satellite- and radar-based precipitation data sets have respectively entered the multi-decadal and decadal scales in temporal coverage and exist at geo-temporal resolutions in the hourly and kilometre scales, thus offering the potential for high-resolution precipitation reanalysis for climatological purposes through means, variances, extremes and trends.

Radar-based quantitative precipitation monitoring

The DWD's RADOLAN software system for real-time online calibration of radar-based quantitative precipitation data by means of automated surface-based rain gauges supplies high-resolution quantitative precipitation data for the whole of Germany in real time. The real-time calibration takes place on the basis of precipitation data collected in the DWD's operational radar network of 17 C-band Doppler radar devices (see map below) and the in situ measurements from the network of automated gauges jointly operated by the DWD and the German Länder (see map on the right). In standard mode, the 'precipitation scan' provides precipitation data in 5-minute intervals, covering a radius of 150 km maximum around the radar site. The hourly in situ precipitation totals of more than 800 automated DWD rain gauges and about 300 auxiliary stations operated by the Länder are utilised for online calibration of the radar data.

The RADOLAN software system has been in operation since 2005 and has since been enhanced several times. As the input data (radar and rain gauges) had already been available since January 2001, the DWD is currently running a decadal, geo-temporally homogeneous and high-resolution quantitative precipitation reanalysis covering the period from 1 January 2001 until the present day. This will lay the foundation for a nationwide radar-based precipitation climatology that is updated on a regular basis.

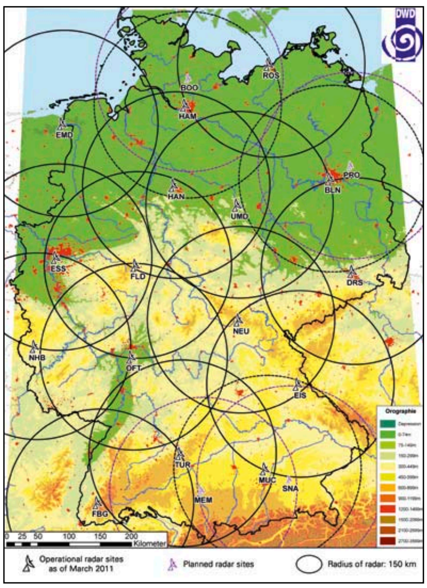
Temporal coverage of precipitation data at monthly, daily and minute scale, complemented by daily totals from the KLIDADIGI project



▲ Map of automated rain gauges of the DWD and the German Länder (blue dots)

Direct measurements taken at sea

Although the code for the dissemination of meteorological data at sea includes precipitation as a parameter of observation, the fleet of voluntarily observing ships, buoys and lightship substitution systems in the North and Baltics Seas does not register precipitation due to the lacking reliability of such measurements. The continuous movement of the vessels driven by wind and waves strongly affects the measurements, as does spray. Among the German research ships, FS Polarstern and FS Meteor are equipped with rain gauges, although their data records are also prone to error and too incomplete to be used for climatological assessment.



◀ C-band radar network of the DWD (station radius: 150 km)

2.5

Radiation

The radiation balance at the earth's surface is an important factor in the energy budget of the earth-atmosphere system. Spatial and temporal differences in the radiation balance generate the weather and have a decisive influence on our climate. Global radiation, one of its most important and most commonly measured components, is the amount of energy potentially available at the earth's surface from our principal energy source, the sun, for all weather and life processes, as well as for technological uses.

Climate trends

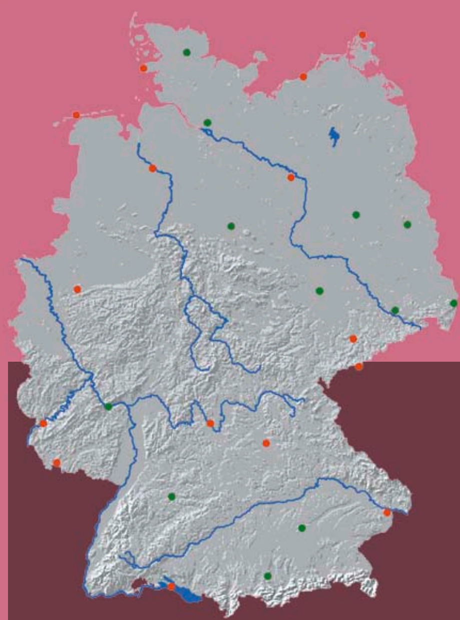
Only continuous measurements over long periods of time allow conclusions to be drawn about climate change. To this end it is important to analyse changes in radiation parameters in relation to other meteorological variables and/or environmental parameters measured at the same station.

There are measurement series of global radiation spanning 50 or more years at nine stations. Examples of annual amounts of global radiation from four stations in different climate zones are shown in the graph on page 25. Regional differences are clearly visible, but also the worldwide phenomenon of 'global dimming' that occurred in the middle of the 1980s and the subsequent 'global brightening'.

In this respect, it is worth noting that complex climatological analysis is particularly reliant on long time series of relevant meteorological parameters from reference weather stations.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.



Measurement of global and diffuse solar radiation

Measurement of global and diffuse solar radiation and atmospheric thermal radiation

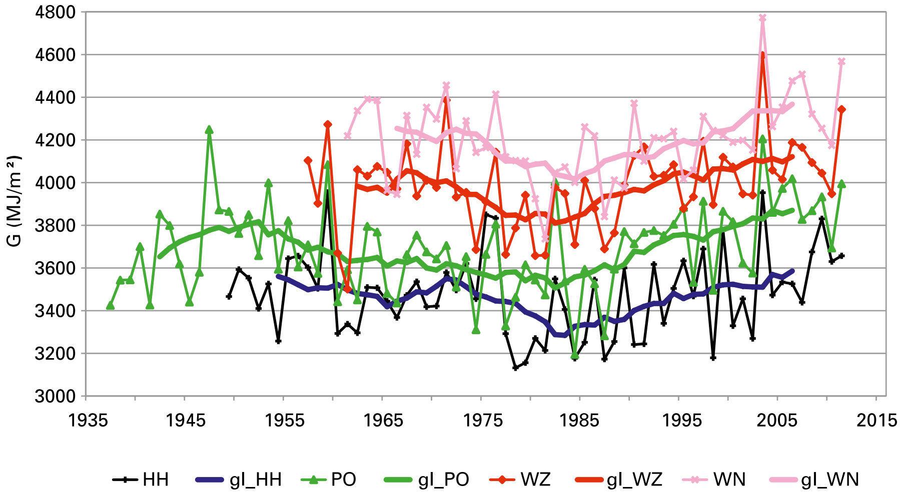
Measurements in Germany

Continuous, comprehensive recording of short-wave global radiation and long-wave atmospheric thermal radiation, which are the most important components of the radiation balance, is currently undertaken using pyranometers by the DWD's ground-based observing network at 26 manned stations, which also measure diffuse solar radiation. Twelve of these stations also measure atmospheric thermal radiation using pyrgeometers. Samples at 1 Hz are taken from all radiation measurement devices around the clock and one-minute averages are stored in the database.

Radiation from the lower atmosphere, reflected short-wave radiation and long-wave thermal radiation emitted from the earth's surface are currently recorded only at the boundary-layer field site of the Lindenberg Meteorological Observatory – Richard Assmann Observatory (MOL-RAO), which is in continuous operation 24 hours a day.

The earliest (quasi-)continuous measurement of global radiation dates from 1937, when it was initiated at the former Potsdam Meteorological Observatory. The International Geophysical Year (IGY) of 1957–58 provided the impulse for the establishment of a global radiation measurement network in Germany consisting of ten stations; one of the key aims of the IGY was to promote radiation measurement for the study of the conversion of energy in the earth-atmosphere system and its spatial and temporal variation. The network in Germany has expanded over the course of time. Modernisation has also taken place, from the adoption of a stand-alone system with plotter to the current system of electronic

Annual amounts of global radiation and 11-year moving averages



▲ Annual amounts of global radiation (G, in MJ/m²) and 11-year moving averages (gl) from stations at Hamburg (HH: 1949–2011), Potsdam (PO: 1937–2011), Würzburg (WZ: 1957–2011) and Weihenstephan (WN: 1961–2011)

data capture and centralised transmission and validation of data.

Since October 1994, in the framework of the Baseline Surface Radiation Network (BSRN), the MOL-RAO has collected data on short- and long-wave radiation in the upper atmosphere, with a high temporal resolution and low measurement uncertainty (≤ 2%).

The worldwide comparability of German radiation data continues to be ensured by the calibration of measurement devices at the National Radiation Centre at the MOL-RAO.

The spatial coverage of all components of the radiation balance has recently been consolidated by intensive use and processing of satellite data made available by the Satellite Application Facility on Climate Monitoring (CM SAF).

International context

The IGY played an important role in promoting global co-operation in the radiation sector. Since 1964, radiation data obtained by the DWD network have been regularly transmitted to the World Radiation Data Centre (WRDC) set up by the World Meteorological Organization (WMO) at the Main Geophysical Observatory in St. Petersburg.

Through the DWD station at Lindenberg and the Ny Ålesund and Neumayer stations operated by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Germany makes an important contribution to the BSRN, which was established in the framework of the World Climate Research Programme (WCRP) and is now the reference radiation network for GCOS. The data obtained are also forwarded to the World Radiation Monitoring Center (WRMC) hosted by the AWI in Bremen (see Chapter 5.3).

The high-quality radiation data sets derived from satellite data in the framework of the CM SAF are also highly significant for further research to verify climate change, particularly because of their comprehensive coverage.

Required resources

Ground-measured and satellite-derived radiation data are of key importance for understanding the causes of climate change.

To this end, it is necessary to maintain the ground-based reference stations that already have long time series of complex data sets, including radiation measurements. In future, their operations should be extended to include the collection of spectral radiation data.

In addition, it will be important to redress the current shortfall in professional capacity for analysis of satellite data, ground-measured data and combined data sets. Part of this problem is the inadequate basic funding for universities, which undermines their capacity for sustainable research.

http://www.dwd.de

2.6
Sunshine duration

Sunshine duration is one of the main indicators for describing the climate for the purposes of different areas of application. In particular, it is an approximate indicator of radiation, for which only few long time series exist but which is of increasing importance in the context of the use of renewable energies.

Climate trends

The measurements from the area-covering network were interpolated from 1951 onward on a regular grid, which allowed the computation of area average series. These enable the identification of climatological trends, and this largely irrespective of any inconsistency that might exist in the time series of single stations. The annual average of sunshine duration in Germany shows considerable variation from year to year, but so far there is no significant long-term trend to be seen.

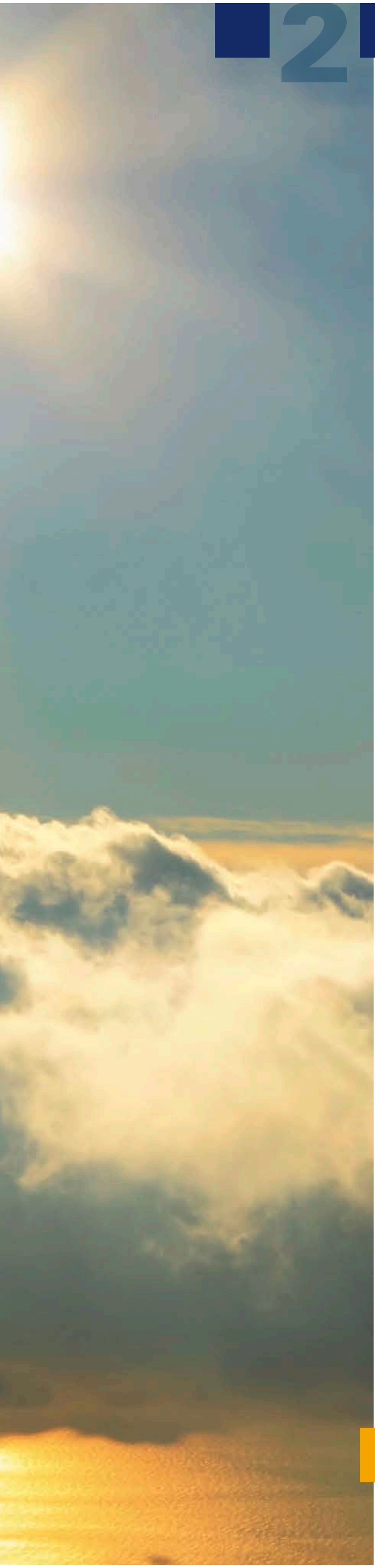
Measurements in Germany

The Deutscher Wetterdienst (DWD) operates a monitoring network of weather and climate stations, of which about 500 currently measure sunshine duration. This dense network has been in place for about 60 years.

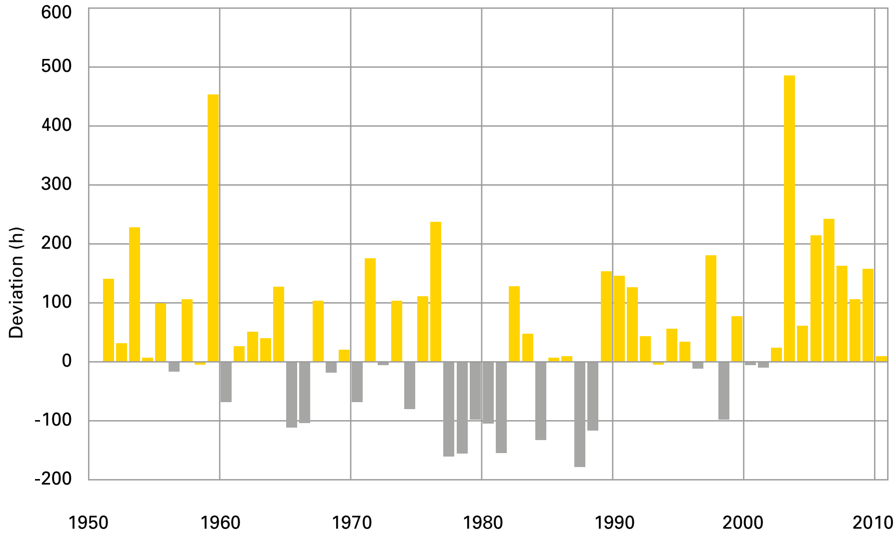
Going back to before that time, there exist only single time series which often contain inconsistencies due to differences in measurement methods and observation programmes.

Between 1995 and 2005, in the context of the general automation of the networks, most of the stations were changed from Campbell-Stokes instruments based on the magnifying glass effect to automatic measurement equipment.

As opposed to conventional observations, which were analysed visually and only provided hourly values at large time delays and partly with large uncertainties, the data from automated weather stations are now available digitally, in real time and with high temporal resolution. The different measurement and analysis methods, however, have partly resulted in considerable inconsistencies in the time series.



Annual mean sunshine duration in Germany for the period 1951–2011



Positive deviation from the long-term mean 1961–1990

Negative deviation from the long-term mean 1961–1990

▲ Positive (yellow) and negative (grey) deviations from the long-term mean (1961–1990) of annual sunshine duration for Germany

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.

International context

The synoptic reports (including sunshine duration data) from 180 stations are distributed worldwide on a routine basis. For a selected number of these stations, quality-checked monthly climatological information is made available in the form of CLIMAT reports. The stations at Frankfurt, Hamburg, Hohenpeissenberg and Lindenberg are part of the GCOS Surface Network (GSN).

Required resources

The operation of the existing measuring stations can generally be considered as secured.

http://www.dwd.de

2.7

Temperature, wind and water vapour in the atmosphere

The layer of the atmosphere relevant for weather and climate extends to an altitude of more than 30 km. Over this range, temperature, wind, water vapour and pressure vary greatly and may be subject to abrupt changes over the time. Vertically resolved measurements of these parameters throughout this altitude range are essential not only for short-term weather forecasting, but also for observing the long-term development of the climate.

Legal framework
The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems. Within this context DWD supports numerous measurement programmes for long-term climate observations, defines climate reference sites, and assures the continuity of long-term data series.

Climate trends
Temperature trends in the troposphere and in particular in the stratosphere are of great importance for the long-term understanding of atmospheric processes. The graph on page 29 shows the time series for temperature at 850 hPa (including the data from kite ascents during the first half of the 20th century). The red line indicates monthly mean values, the green curve a 12-month running mean, and the blue line a simple linear trend. Data for the lower stratosphere (at 100 hPa) rely on balloon soundings only and reveal a significant cooling of 0.5 K per decade (not shown) as opposed to the clearly increasing trend in the troposphere, where the mean temperature trend shows a warming of roughly 0.1 K per decade.

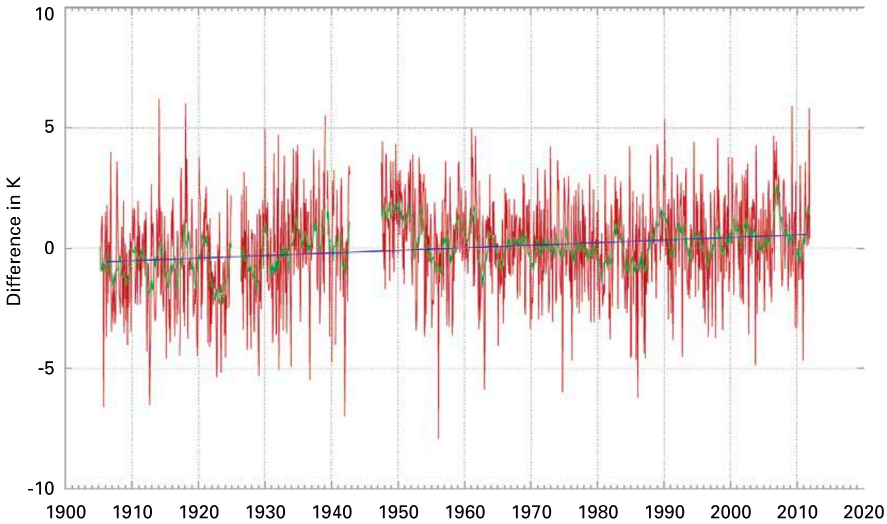
Historical trends in tropospheric water vapour are impacted by large uncertainties and only limited statements about temporal variations can be derived. Better estimates of changes in tropospheric water vapour are expected with the implementation of GUAN and, in particular, of GRUAN, and with ongoing improvements in measurement technology. Long-term trends in stratospheric water vapour over several decades have been measured at only one station in the world. The observations, which began at the Meteorological Observatory Lindenberg – Richard Assmann Observatory (MOL-RAO) over six years ago, form another anchor for estimations of trends in stratospheric water vapour.

Measurements in Germany
Vertical profiles of temperature, wind and water vapour are measured using radiosondes in Germany at 14 stations. Nine of these stations are operational radiosonde sites managed by the DWD; the other five are run in co-operation with the Bundeswehr. The standard observational programme of the DWD requires two radiosonde launches per day. Only at the MOL-RAO, four radiosondes are launched each day operationally. Other sites may increase their sounding frequency to four soundings per day if needed during special weather conditions.

MOL-RAO is the only station in Germany belonging to the GCOS Upper-Air Network (GUAN). It is also the Lead Centre for the GCOS Reference Upper-Air Network (GRUAN) and the only GRUAN site in Germany.

Measurements in these networks strive for best possible homogeneity and continuity. As part of GRUAN, traceability to international standards

Air temperature deviation from the long-term average at 850 hPa



International context

The scientific investigations of temperature and water vapour at MOL-RAO are conducted in close co-operation with the international scientific community. The observatory plays a leading role in observation techniques, both internationally and in projects conducted in co-operation with other GRUAN and GUAN stations. Data are shared through a number of different data centres and are processed and analysed in close scientific partnerships. These observations are the basis of recommendations to decision-makers in policy and administration at national and international level.

DWD observatory
DWD upper-air station
BW geoinformation site

▲
Upper-air stations in Germany

and a vertically resolved quantification of the uncertainty of measurements are of great importance.

Changes in stratospheric water vapour have large impacts on the surface climate. Regular measurements within the altitude range from 10 km to 25 km take place only at the MOL-RAO.

In addition, vertical profiles of water vapour are measured using a LIDAR, which under favourable meteorological conditions may provide data on the variability of water vapour at different altitudes with high temporal resolution.

Vertically resolved observations of temperature at Lindenberg started as early as 1905; however, only within the last ten years have measurements of atmospheric humidity reached a level of quality sufficient for studying long-term trends in water vapour.

Required resources

Long-term climate observations are currently threatened by austerity measures. The value of climate time series is strongly susceptible to interruption for which reason financial continuity of the observation programmes is required. Reduced funding particularly impacts observations of the free atmosphere through in-situ soundings, which so far are the only technology for climate reference data. These observations must be continued without interruption and with sufficient overlap when system changes occur, requiring continuous resource allocations.

http://www.dwd.de

2.8
Clouds

Clouds are essential for the energy and water balance of the atmosphere and therefore have a significant impact on weather and climate. Classical visual observations of clouds have been carried out at many locations, in some cases for more than 100 years. However, neither can small-scale spatial structures be captured, nor can the microphysical properties of clouds be inferred, which is why space-borne and ground-based remote sensing systems for cloud observation are gaining in importance.

Climate trends

Only continuous monitoring over extended periods of time allows conclusions on climate change. Since these changes can be very small, the homogenisation of time series is very important, whereby changing methods of observation and measurement instruments must be considered.

At the DWD's climate reference stations, visual observations are performed at the same time as ceilometer measurements with the aim of producing consistent data sets. For the homogenisation of measurement data from satellites the products are reprocessed within the CM SAF.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for

- short- and long-term registration, monitoring and evaluation of meteorological processes and the structure and composition of the atmosphere,
- for the operation of the required measurement and observing systems as well as
- for the provision, storage and documentation of meteorological data and products.

For the fulfilment of its duties, the DWD is engaged in scientific research in the field of meteorology and related sciences and contributes to the development of corresponding standards and norms.

International context

Germany makes the largest contribution to all European satellite programmes of ESA, EUMETSAT and other EU-relevant climate monitoring activities. Processing of satellite data for the purposes of climate monitoring is done at EUMETSAT through the CM SAF. The World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT, see Chapter 5.5) is located at the German Aerospace Center (DLR), from where the data are available to the scientific community.

To establish new satellite-borne and ground-based observation methods with active instruments (radar and lidar), Germany participates in numerous European research programmes such as Cloudnet, ACTRIS, $HD(CP)^2$ and EarthCARE. In addition, Germany is represented on numerous committees of the WMO.

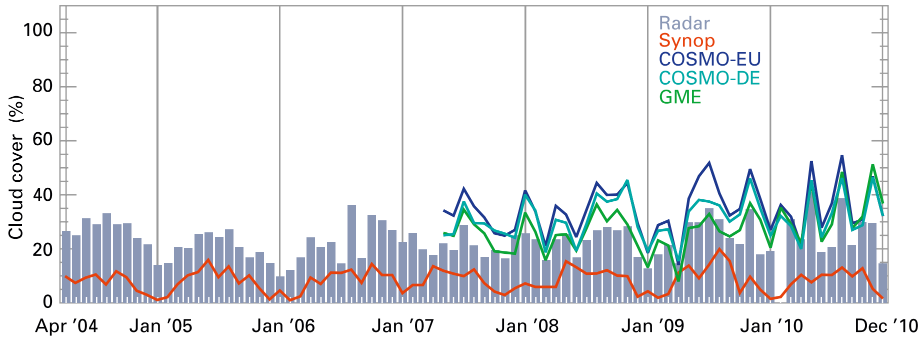
Measurements in Germany

Visual observations are operationally performed at 81 weather stations of the DWD and at 35 stations of the Geophysical Service of the Bundeswehr, several of which operate round the clock.

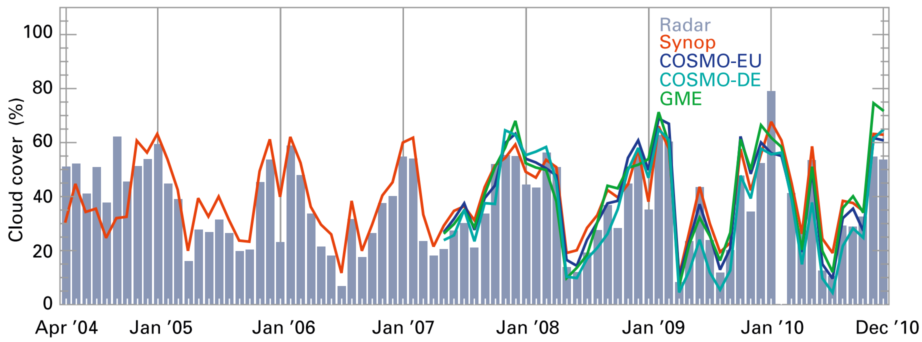
Observables include cloud type, cloud cover and cloud base. The time series go back to the 1940s, at some stations even to the 19^{th} and 18^{th} centuries. For precise determination of the cloud base, laser ceilometers have been used since the 1990s.

Widespread observation of clouds from space began about 50 years ago. Co-ordinated by Germany, Eumetsat's Satellite Application Facility on Climate Monitoring (CM SAF) is committed to exploiting the measurements made by various passive instruments on geostationary and polar-orbiting satellites (e.g. Meteosat, Metop) for essential climate variables, such as cloud parameters, surface albedo, radiation fluxes and temperature and humidity profiles. Important cloud parameters, which have been determined operationally

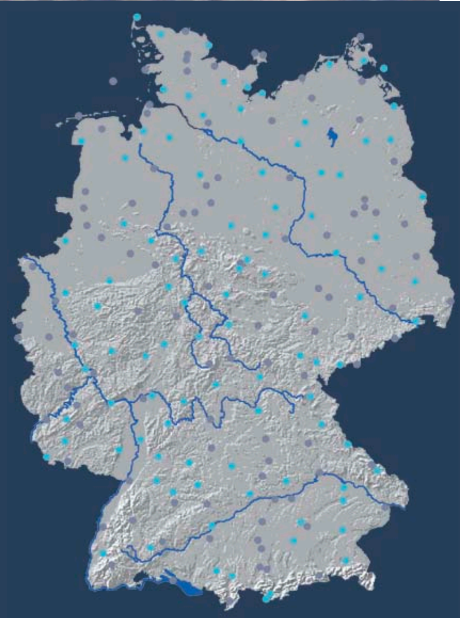
Mean monthly high cloud cover



Mean monthly low cloud cover



▲ The time series is derived from the measurements made with the 35-GHz radar at Lindenberg as compared with visual observations (synop) and simulations of the three weather forecasting models of the DWD, COSMO-EU, COSMO-DE and GME, for high cloud cover (cloud base > 6 km) and low cloud cover (< 2 km).



● Visual observations
● Automatic weather observations

since 2004, are: cloud cover, cloud type, cloud optical thickness, cloud phase and cloud top. Continuous quality control is achieved by means of evaluation of the data against ground-based in situ and indirect measurements.

The DWD's Lindenberg Meteorological Observatory – Richard Assmann Observatory (MOL-RAO) has been continuously measuring the fine structure of clouds with a 35 GHz radar since 2004. Due to the low attenuation of electromagnetic signals at this wavelength in both cloud-free and cloudy atmospheric conditions, the radar is able – in contrast to optical instruments – to detect multi-layered clouds in their full vertical extent and to detect structures (particles) above optically thick clouds.

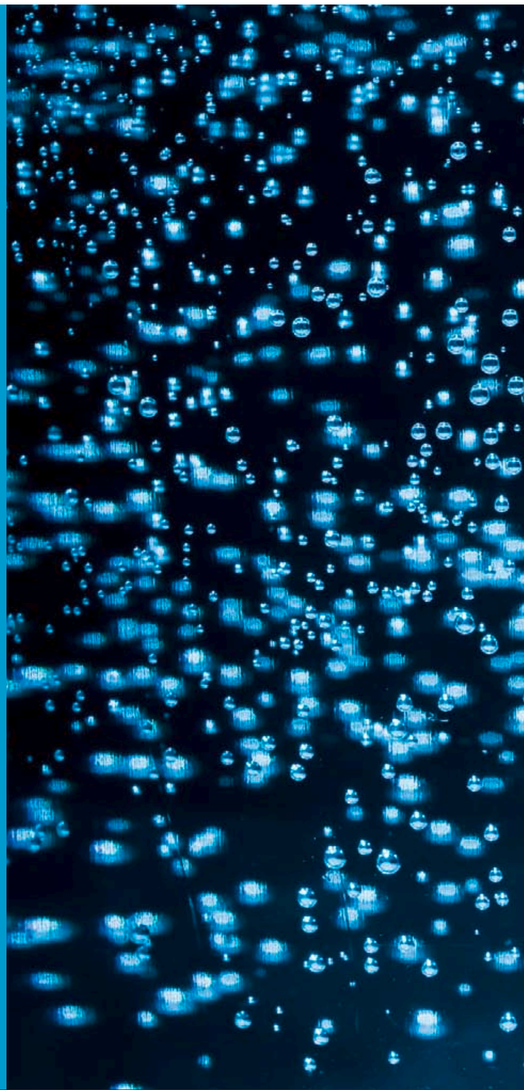
By comparing model-simulated cloud distributions and properties with observations important insights can be obtained to improve cloud parameterisation in weather forecast and climate models.

Required resources

In the future, visual observations will only be made at DWD reference stations, selected locations of the Geophysical Service of the Bundeswehr and at airports. Ground-based and satellite-based measurement methods can not only fill the gap, but can provide data on macro- and microphysical cloud properties, which visual observations would never be able to provide. In addition to investments in new systems, the development of appropriate retrieval methods, quality assurance over long time periods and the analysis and homogenisation of data require additional human resources.

http://www.dwd.de http://cmsaf.eu

2.9
Carbon dioxide



Greenhouse gases produced by humans are the most important cause of global warming. Apart from water vapour, carbon dioxide (CO_2) is the most important climate-forcing gas, due to its high concentrations in the atmosphere. Since the start of industrialisation around 1750, global concentrations of atmospheric CO_2 have risen by 40%. In contrast, over the previous 10,000 years, CO_2 concentrations were nearly constant. The current rate of increase of atmospheric CO_2 is about 100 times faster than at any time in the past.

Climate trends

Long CO_2 time series are a reliable measure of the global increase in carbon dioxide. They provide continuous documentation of the effect of fossil fuel burning on the atmosphere. Because these measurements are very precise, scientists are able to distinguish the effect of fossil fuel burning from the annual fluctuation of CO_2 in the biosphere. This provides a reliable basis for the use of climate models to analyse long-term changes in the atmospheric burden of CO_2 and calculate future scenarios. Whereas in the 1950s the mean annual increase in atmospheric CO_2 was still only 0.55 ppm, differences in mean annual values over the past decade point to an increase of about 1.9 ppm per year. Thus, global CO_2 production has increased more than threefold compared to the 1950s.

Legal framework

In the framework of the German contribution to the international Global Atmosphere Watch (GAW) programme of the World Meteorological Organiziation (WMO), the Federal Environment Agency (UBA) is the partner agency responsible for the measurement of carbon dioxide. Germany has further statutory obligations in the context of national emissions trading, for which precise statistical emissions surveys and reliable and accurate time series of existing CO_2 concentrations are needed. Article 192 Par. 1 of the *Treaty on the Functioning of the European Union* provides the legal framework for the new regulation 2011/0372 (COD), which updates the EU system in place since 2005 for monitoring greenhouse gas emissions.

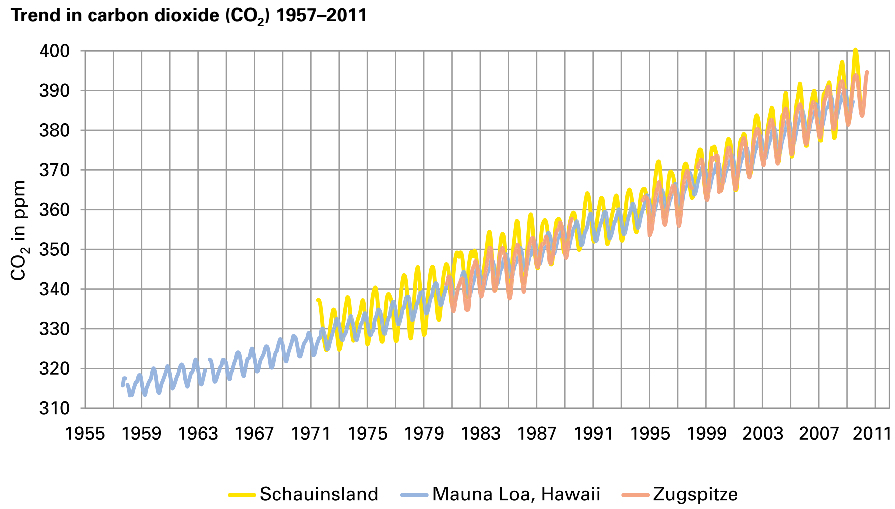
Measurements in Germany and abroad

High-precision in situ measurements of CO_2 in the ambient air, like those initiated by C. D. Keeling at Mauna Loa, Hawaii, in 1958, have been carried out at the mountain station on Schauinsland since 1972 and at the stations on Zugspitze and at Neuglobsow since 1981. They are complemented by flask sampling at Hohenpeissenberg, which has been carried out since 2006 in the framework of the worldwide programme co-ordinated by the National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA/ESRL). Data from GAW stations in Germany are retrievable from the World Data Centre for Greenhouse Gases (WDCGG), based in Tokyo.

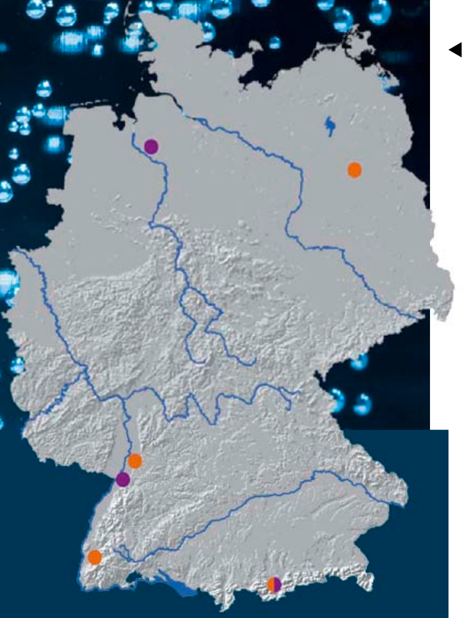
Since 2004, measurements of CO_2 concentrations using solar absorption spectroscopy have been carried out at approximately 20 stations around the world. This technique provides data on total column concentration of CO_2, from the observation point on the ground to the upper boundary of the atmosphere. In Germany, these measurements are carried out in Bremen, Karlsruhe and Garmisch-Partenkirchen. The work is co-ordinated by the Total Carbon Column Observing Network (TCCON) and contributes to the GAW programme of WMO.

Since 1996, Heidelberg University has measured the climate-forcing gas CO_2 in urban surroundings. It has been shown that long and high-precision time series of measurements from semi-polluted sites can be used successfully for independent verification of statistically based reports on regional greenhouse gas emissions, for example those produced for the United Nations Framework Convention on Climate Change (UNFCCC).

In the framework of the German contribution to the GAW programme, Heidelberg University has taken CO_2 flask samples at the Neumayer GAW Global station in the Antarctic since 1994. TCCON measurements under German lead management are conducted in Spitzbergen (Norway), Białystok (Poland), Orléans (France) and on Ascension Island.



▲ Time series of CO_2 measurements at the German GAW stations Schauinsland and Zugspitze, in comparison with the world's longest CO_2 time series from Mauna Loa, Hawaii



◀ Orange symbols: the three German GAW sites, Neuglobsow, Schauinsland and Zugspitze, and Heidelberg University, where atmospheric CO_2 is measured in situ
Purple symbols: Bremen, Karlsruhe and Garmisch-Partenkirchen sites, where CO_2 in the total atmospheric column is measured for the TCCON

Since 2003, the global distribution of atmospheric CO_2 has also been determined by satellite. Although less accurate than ground-based measurements, satellite data give a representative overview of the large-scale spatial distribution of CO_2. A particular interest in this case is to determine natural CO_2 emissions as well as those caused by humans on a global scale with the best possible spatial and temporal resolution. This requires satellite measurements highly sensitive to changes in CO_2 levels close to ground, thus close to the emission sources. The first satellite instrument to fulfil these requirements is SCIAMACHY, aboard the European environmental satellite ENVISAT, which was developed under German lead management.

International context

Together with the Regional stations Schauinsland and Neuglobsow, the GAW Global station Zugspitze/Hohenpeissenberg makes the core German contribution to CO_2 data for GCOS. In the framework of the 'D-A-CH' co-operation between Germany, Austria and Switzerland, time series of CO_2 measurements from the mountain stations Zugspitze, Hohenpeissenberg, Hoher Sonnblick and Jungfraujoch are analysed together to enhance the reliability and spatial representation of the results. Data measurements are transmitted to the WDCGG on a regular basis. The measurements are based on the GAW's standard reference scale provided by the NOAA's agencies in Boulder, Colorado, for CO_2 measurements. Quality assurance is reviewed regularly by round-robin tests carried out in the framework of the CarboEurope project and WMO/GAW programmes. Total column measurements contribute to the international effort co-ordinated by the TCCON.

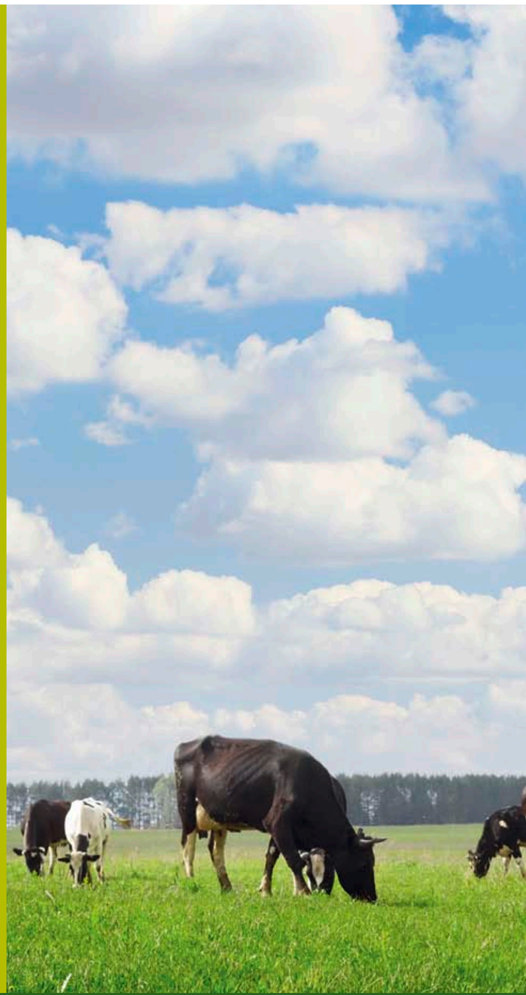
Required resources

CO_2 measurements at the three GAW stations in Germany receive long-term funding from the UBA. The stations are under-staffed. At present, the cost of TCCON measurements is only partly covered by institutional funding and these activities are dependent on additional finance from third-party funded projects. Long-term funding is urgently required in order to ensure the continuity of operations.

http://www.dwd.de/gaw

2.10 Methane

Since the pre-industrial era, the presence of methane (CH_4) in the atmosphere has increased by 270% as a result of human activity. Among long-lived greenhouse gases, CH_4 makes the second largest contribution, after carbon dioxide, to global warming. Concentrations of methane in the earth's atmosphere are higher today than at any time in the past 650,000 years. Although the rise slowed after 1990 and concentrations remained stable at a high level until 2005, climate models predict an accelerated increase in methane concentrations with increasing global warming. Since 2007, global networks and satellites have observed a renewed sharp rise in CH_4.



Climate trends

Long high-precision time series provide a reliable picture of methane concentrations, which are the overall result of interactions between sources and sinks. Although the sources of CH_4 are known, trends in sources and their interaction with sinks cannot be fully explained. While CH_4 continues to show an upward trend, the rate of increase in its concentrations has steadily declined in the last two and a half decades; the reasons for this, and the consequences for future global warming, are not yet sufficiently understood. Long and reliable time series are fundamental for efforts to improve our understanding of the interaction of sources and sinks.

Legal framework

Within the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) – a component of GCOS that monitors essential climate variables related to atmospheric composition – the German Federal Environment Agency (UBA) is the partner responsible for measurement of methane. Article 192 Par. 1 of the *Treaty on the Functioning of the European Union* provides the legal framework for the new regulation 2011/0372(COD), which updates the EU system for monitoring greenhouse gas emissions.

Measurements in Germany and abroad

In Germany, in situ measurements of atmospheric methane have been carried out at the Schauinsland mountain station since 1991 and at the stations on Zugspitze and at Neuglobsow since 1994. They are complemented by flask sampling at Hohenpeissenberg, which has been carried out since 2006 in the framework of the global programme co-ordinated by the National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA/ESRL). Data from GAW stations in Germany are retrievable from the World Data Centre for Greenhouse Gases (WDCGG), based in Tokyo.

Since 1996, Heidelberg University has measured CH_4 concentrations in urban surroundings. It has been shown that long and high-precision time series of measurements from such locations can be used successfully for independent verification of statistically based reports on regional greenhouse gas emissions, for example those produced for the United Nations Framework Convention on Climate Change (UNFCCC).

Since 2004, measurements at about 20 stations worldwide have been using solar absorption spectroscopy and new kinds of instruments to measure CH_4 concentrations in the near-infrared spectrum. This technique provides data on concentrations in the total column, from the observation point on the ground to the upper boundary of the atmosphere. An average concentration in the troposphere can be derived from this data. The work is co-ordinated by the Total Carbon Column Observing Network (TCCON). In Germany, these measurements are carried out in Bremen, Karlsruhe and Garmisch-Partenkirchen. In addition, since 1995, long-term Fourier Transform Infrared Spectroscopy (FTIR) measurements in the traditional mid-infrared spectrum have been carried out on Zugspitze. These form part of the activities of the Network for the Detection of Atmospheric Composition Change (NDACC) and also provide highly precise data on total column concentrations of methane. The measurements contribute to the GAW programme of WMO.

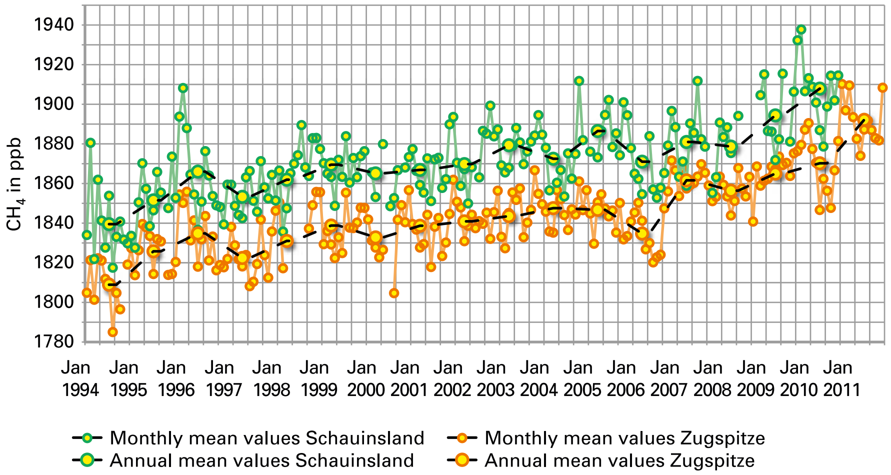
In the framework of the German GAW contribution, Heidelberg University has taken flask samples

of CH_4 at the GAW Global station Neumayer in the Antarctic since 1987.

TCCON measurements under German lead management are conducted in Spitzbergen (Norway), Białystok (Poland), Orléans (France) and on Ascension Island.

Since 2003, the global distribution of atmospheric CH_4 has also been determined by satellite.

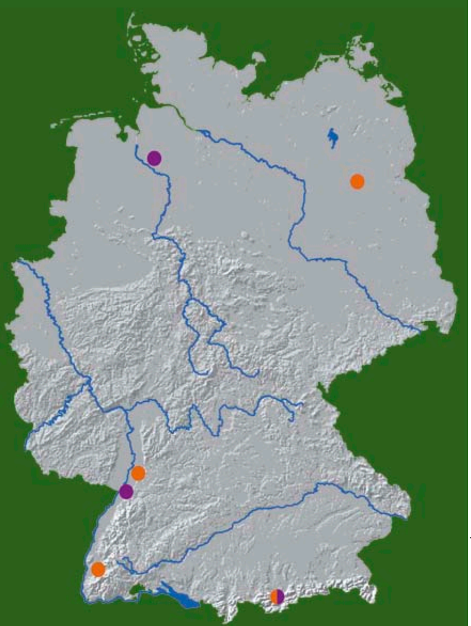
Methane concentrations 1994–2011 (Schauinsland and Zugspitze)



▲ Methane (CH_4) time series measured at Schauinsland (green) and Zugspitze (orange) stations. CH_4 concentrations are higher at Schauinsland because this station is at a lower altitude; however, even here, the trend in the free troposphere is discernable.

International context

Together with the GAW Regional stations Schauinsland and Neuglobsow, the GAW Global station Zugspitze/Hohenpeissenberg makes the core German contribution to methane data for GCOS. In the framework of the 'D-A-CH' co-operation between Germany, Austria and Switzerland, time series of CH_4 measurements from the mountain stations Zugspitze, Hohenpeissenberg, Hoher Sonnblick and Jungfraujoch are analysed together to enhance the reliability and spatial representation of the results. Data measurements are transmitted to the WDCGG on a regular basis. The measurements are based on the GAW's standard reference scale provided by the NOAA's agencies in Boulder, Colorado, for CH_4 measurements. Quality assurance is reviewed regularly by round-robin tests carried out in the framework of the CarboEurope project and WMO/GAW. Total column measurements contribute to the international effort co-ordinated by the TCCON.



◀ Orange symbols: the three German GAW sites, Neuglobsow, Schauinsland and Zugspitze, and Heidelberg University, where CH_4 is measured in situ, i.e. in the ambient air

Purple symbols: Bremen, Karlsruhe and Garmisch-Partenkirchen sites, where CH_4 in the total atmospheric column is measured for the TCCON

Required resources

Methane measurements at the three GAW stations in Germany receive long-term funding from the UBA. The stations are under-staffed. Atpresent, the cost of TCCON measurements is only partly covered by institutional funding and these activities are dependent on additional finance from third-party funded projects. Long-term funding is urgently required in order to ensure the continuity of operations.

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2.11

Other greenhouse gases

Even without its most important members, carbon dioxide (CO_2) and methane (CH_4), the group of long-lived climate forcers (LLCFs) still makes a very large contribution to the greenhouse effect. The most important LLCFs are nitrous oxide (N_2O), sulphur hexafluoride (SF_6) and climate-relevant halogenated compounds. This group includes some extremely long-lived substances such as SF_6 and NF_3, with lifetimes of 3,200 years and approximately 640 years respectively, which will continue to affect the global climate for a very long time.

Climate trends
Among long-lived greenhouse gases, N_2O makes the third-largest contribution to global warming. Its atmospheric abundance has increased only by 20% compared to pre-industrial times (1750). However, at a time horizon of 100 years, N_2O has a global warming potential 300 times as large as that of CO_2! About 40% of N_2O amounts emitted into the atmosphere result from human activity. The remainder comes from natural sources. Atmospheric N_2O levels show a slight north-south gradient, largely explained by the larger proportion of land area in the northern hemisphere and the use of artificial fertilizers in the mid-latitudes. Long high-precision series from both the northern and southern hemispheres are a key requirement for improved understanding of sources and forecasting of future trends. To do so, the in situ time-series data must be measured with a very high degree of accuracy (0.03%), which is close to the maximum technically achievable today.

Legal framework
As part of its official participation in the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) – a component of GCOS that monitors essential climate variables related to atmospheric composition – Germany carries out measurements of N_2O, SF_6 and hydrogen (H_2) as well as climate-relevant halogenated compounds. In accordance with the EU's obligations under the Kyoto Protocol, the proposed EC regulation 2011/0372(COD) of November 2011 revises the system in place since 2005 for monitoring greenhouse gas emissions. Important objectives are to improve the monitoring and verification of emissions by sources and removals by sinks.

Measurements in Germany and abroad
In Germany, in situ measurements of N_2O, SF_6 and the indirect greenhouse gas H_2 are carried out by the Federal Environment Agency (UBA) at the GAW stations Schauinsland and Zugspitze and by Heidelberg University in an urban surrounding.

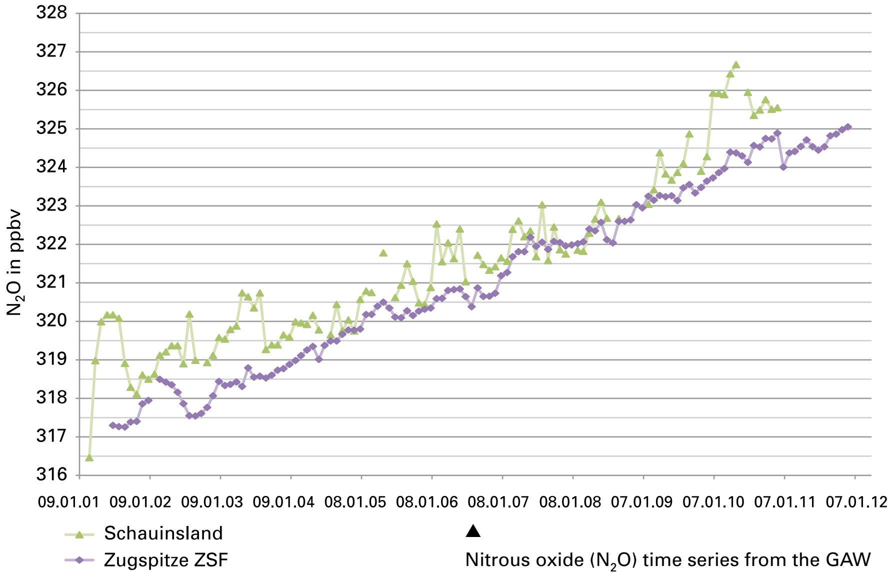
Data from GAW stations in Germany are retrievable from the World Data Centre for Greenhouse Gases (WDCGG), based in Tokyo.

Since 2004, long-lived climate-relevant trace gases have been measured at about 20 stations around the world using solar absorption spectroscopy. This technique provides data on total column gas concentrations, from the observation point on the ground to the upper boundary of the atmosphere. The work is co-ordinated by the Total Carbon Column Observing Network (TCCON). In Germany, these measurements are carried out in Bremen and Garmisch-Partenkirchen. The potential and limitations of this technique for measuring total column concentration of N_2O are currently being analysed.

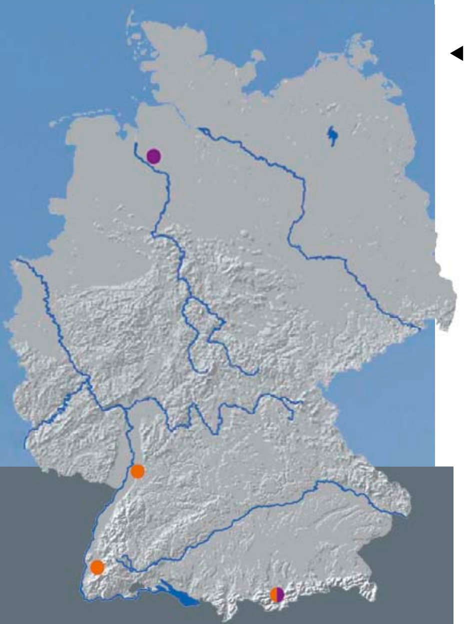
Since 1990, similar measurements using solar absorption spectroscopy have been carried out in spectral regions other than those used in the TCCON, which allows numerous other substances to be detected including SF_6. These measurements are performed by the Network for the Detection of Atmospheric Composition Change (NDACC) at sites including the German NDACC station Zugspitze.

The long-term influence of water vapour, which is the most important greenhouse gas, on climate change is being studied at the Zugspitze/Schneefernerhaus site. On clear nights, tropospheric water vapour

In situ concentrations of nitrous oxide: monthly mean values at Schauinsland and Zugspitze



▲ Nitrous oxide (N_2O) time series from the GAW Regional station Schauinsland (green) and Zugspitze Plattform at the GAW Global station Zugspitze/Hohenpeissenberg (purple)



◀ Orange symbols: the two German GAW stations Schauinsland and Zugspitze, and the urban surrounding site of Heidelberg University, where N_2O, SF_6 and H_2 are measured Purple symbols: TCCON sites at Bremen and Garmisch-Partenkirchen and NDACC site Zugspitze, where the total column of N_2O is measured. Water vapour vertical profiles up to an altitude of 12 km (which currently is being extended to 30 km) are measured at Zugspitze on a long-term basis.

profiles up to an altitude of 12 km have been measured at this site since 2007 using infrared (IR) differential absorption lidar (DIAL).

Since 1996, Heidelberg University has taken measurements of the greenhouse gases N_2O and SF_6 and the indirect greenhouse gas H_2 in urban surroundings. It has been shown that long and high-precision time series of measurements from such locations can be used successfully for independent verification of statistically based reports on regional greenhouse gas emissions, for example those produced for the United Nations Framework Convention on Climate Change (UNFCCC).

Required resources

At present, the costs of TCCON and NDACC measurements are only partly covered by institutional funding and these activities are dependent on additional finance from third-party funded projects. Long-term funding is urgently required in order to ensure the continuity of operations. Until now, Germany has not collected continuous time-series data on halogenated greenhouse gases in the ambient air (in situ). The UBA assumed responsibility for this activity in 1998. It has the requisite measurement technology; however funding is still lacking for a scientist and a technician to perform the measurements at the GAW Global station Zugspitze/ Hohenpeissenberg.

International context

Together with the GAW Regional station Schauinsland, the GAW Global station Zugspitze/Hohenpeissenberg makes the core German contribution to N_2O and SF_6 measurement for GCOS. Data measurements are transmitted to the WDCGG on a regular basis. The measurements are based on the GAW's standard reference scale provided by the NOAA's agencies in Boulder, Colorado, for N_2O and SF_6 measurement, and on the reference scale for H_2 maintained by the Max Planck Institute in Jena. Quality assurance is reviewed regularly by round-robin tests carried out in the framework of the Carbo-Europe project and WMO. Total column measurements contribute to the international efforts co-ordinated by TCCON and NDACC. The major importance of these measurements is that they can be used to validate satellite instruments, which have similar viewing geometry and also measure the total column. Airborne measurement campaigns were conducted to adjust the TCCON total column measurements to existing in situ measurements. Both TCCON and NDAAC measurements are accepted by GAW/WMO.

http://www.dwd.de/gaw

2.12
Ozone

The colourless and poisonous gas ozone (O_3) is one of the most important trace gases in the atmosphere. Most of this gas (more than 90%) is found in atmospheric layers above 10 km (stratosphere). The stratospheric ozone layer protects the earth from harmful ultraviolet radiation from the sun. In lower atmospheric layers, the gas is present as ‘background ozone’, as a result of hemispheric transport and natural ozone production, which makes it a focus of attention in this context. Additional ozone is created in strong sunshine by chemical processes from precursor pollutants. Furthermore, ozone is a greenhouse gas and thus contributes to global warming of the earth’s atmosphere.

Legal framework

Monitoring of air quality – including ground-level ozone – is carried out in Germany according to EU air quality regulations, which are incorporated into German law through a Regulation Pertaining to the *Federal Immission Control Act* (39. BImSchV). This regulation sets ozone target values for the protection of human health and vegetation. Information and alert thresholds are established in order to counter the risks to human health associated with short-term exposure to high ozone concentrations.

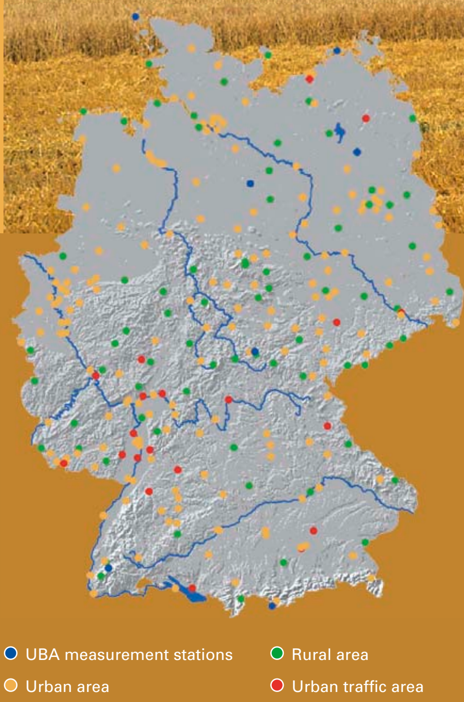
International context

All ozone data collected in Germany in the framework of European air quality guidelines are transmitted to the European air quality database AirBase, established and managed by the European Environment Agency (EEA). From there, the data can be retrieved for use all over Europe in research, statistical analysis and by projects, and as a source of real-time data.

The UBA measurement stations are also part of the European Monitoring and Evaluation Programme (EMEP) for the investigation of pollutant concentrations in air masses transported over long distances and across national frontiers. Data from the GAW’s Global station Zugspitze/Hohenpeissenberg and Regional stations Schauinsland and Neuglobsow contribute to the GAW programme.

Measurements in Germany

Measurements of ground level ozone concentrations in Germany were initiated in the mid-1970s. By 1990, there were already 194 ozone measurement stations, distributed over the whole of Germany. Currently (August 2012), ozone concentrations are measured at 270 locations, in towns and conurbations and in rural areas. In accordance with the Federal Immission Control Act, the German Länder are responsible for monitoring air quality, and measurement networks have been established for this purpose. In order to check international activities and compliance with clean air strategies the Federal Environment Agency (UBA) operates its own measurement network, consisting of seven measurement stations that measure pollutant concentrations in air masses transported over long distances and across national frontiers. These stations are located as far away as possible from local sources of air pollution.



The ozone measurement programme at Hohenpeissenberg Observatory

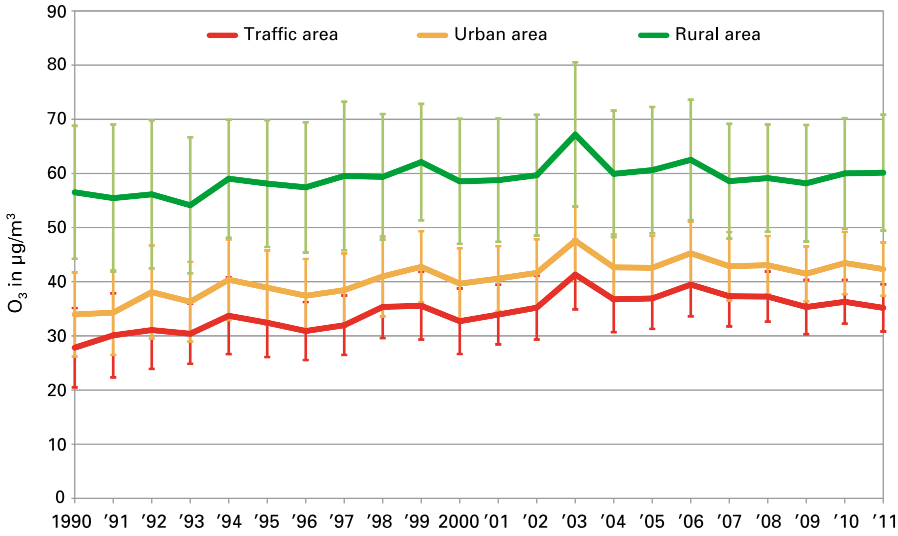
Ozone measurements on a routine basis were started at the Hohenpeissenberg Meteorological Observatory (MOHp) in 1966/67. Ozone sampling using Brewer-Mast ozone sondes coupled to radiosondes was initially carried out on a weekly basis. Since 1978, samples have been taken twice a week in summer and three times a week in winter. The sampling ensemble is transported by a balloon to an

altitude of more than 30 km and provides continuous measurements of ozone partial pressure during the ascent, including in the stratospheric ozone layer.

In 1967, measurements of total ozone concentrations were initiated using Dobson spectrometers. The Dobson and sonde technologies are the foundation of the observatory's long and homogenous ozone data series. The measurement programme was expanded through the incorporation of a Brewer spectrophotometer and a laser radar (lidar) device. Thanks to the maintenance from the start of strict quality controls, the ozone data set at Hohenpeissenberg is unique in the world. Since 1999, Hohenpeissenberg has hosted the European Dobson Calibration Center.

The Hohenpeissenberg ozone measurements contribute to the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO).

Trends in annual average ozone concentrations 1990 to 2011



▲ Source: UBA, incorporating data from measurement networks operated by the Länder and the UBA

Climate trends

Since 1990, there have been notable reductions both in the maximum level of ozone concentrations and the frequency of occurrence of very high levels of ozone. Emission reduction measures introduced in the 1990s to combat 'summer smog' have proved to be effective. In comparison with levels in 1990, emissions of ozone precursors – nitrogen oxide and unstable organic compounds, excluding methane – have declined by 54% and 66% respectively. However, target levels for the protection of human health continue to be exceeded. In contrast to maximum levels, annual average ozone concentrations have risen in the same period. Measurement stations in urban locations – that is in typical residential areas – and in urban traffic areas provide evidence of a highly significant rise in average ozone concentrations from 1990 to 2011, while ozone levels have also risen significantly in rural locations (see graph). During the observation period, a shift from low to medium concentrations has taken place. The cause of this trend is the reduction in nitrogen oxide emissions. As nitrogen oxide is predominantly emitted in the form of nitrogen monoxide (NO), the reduction in NO emissions leads to a weakening of the titration effect, by which ozone is broken down and converted to nitrogen dioxide in an oxidation reaction with locally emitted NO. This increases the lifetime of ozone. The rise in average annual ozone levels in cities is the result of a falling number of low ozone values, together with a rise in the number of medium ozone values. The increase in average annual values in rural areas is primarily explained by the increasing proportion of the ozone burden arising from northern hemisphere transport.

Required resources

Due to the legal obligation to monitor ground level ozone concentrations in Germany, long-term continuity of these programmes is assured.

http://www.umweltbundesamt.de/luft/schadstoffe/ozon.htm http://www.dwd.de/ozon

2.13 Aerosols

Aerosols have a predominantly cooling effect on the atmosphere. The exception is black carbon (BC, also referred to as soot), which belongs to the short-lived climate forcers. When it lies on snow or ice it reduces the albedo down to a few per cent and causes a strong warming effect. What is more, the impacts of aerosols on the global climate are not as well explored as those of climate-forcing gases, with the aerosol time series being much shorter than those of climate-forcing gases.

Legal framework

Directive 2008/50/EC of the European Parliament and the Council of 21 May 2008 on ambient air quality and cleaner air for Europe has superseded the previous council directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management and three subsidiary directives (1999/30/EC, 2000/69/EC and 2002/3/EC), in which threshold values for SO_2, NO_2, NO_x and PM10 and further gaseous air pollutants were given. Thus, in the entire EU, up to now no directives exist that set threshold values for short-lived climate-forcing aerosols such as black carbon. Threshold values exist only for ultrafine aerosols and PM10, and for the latter so far no definite connection with temperature warming is known (Kuttler, 2011).

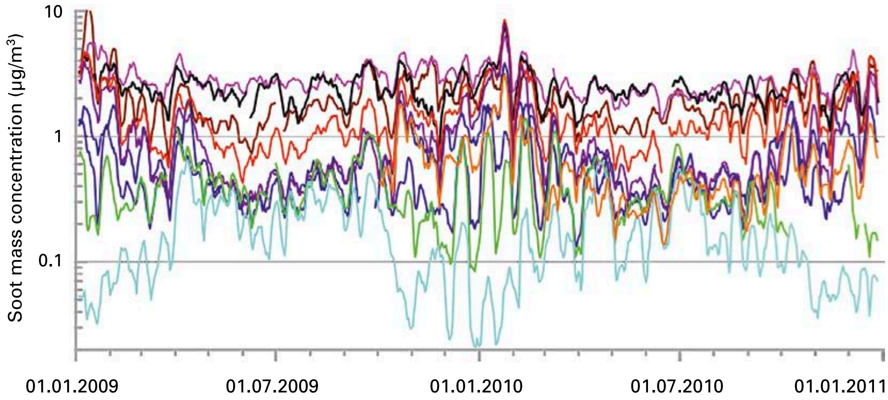
Climate trends

Similar to the particle mass, there is a great difference in levels of soot measured between urban and rural areas. One well-known source of soot is traffic (especially from diesel vehicles), which is the reason for the high values at sites close to traffic, with mean values around to 2-4 µg/m³. At rural sites, the figures are considerably lower, around 0.5 µg/m³, and in the summer at mountain stations they are even lower. The lowest value is observed at the Zugspitze, where soot mass concentrations drop to 0.02 µg/m³. The level of soot at a specific measuring site, just as the number of ultrafine particles, functions as a sensitive indicator of the influence of local burning sources. Analogous to the particle mass, a strong annual variation in concentration of soot can be observed. In flat country, the highest values (peaking at 10 µg/m³) occur in winter whereas in mountainous country they occur in summer. This is caused by the annual variation in the height of the mixing layer. During the summer, the mixing layer is considerably higher, up to more than 3.5 km. This results in good mixing of gases and particles, resulting in similar summertime levels of around 0.5 µg/m³ at all rural measurement sites. During the winter, layers are inverted and this reduces dispersion, allowing concentrations to increase in flat country. But then, the inverted mixing layer is often lower than the mountain measuring stations, for which reason they report considerably lower concentrations (Ufoplan, 2011).

Measurements in Germany

In addition to investigations into size distributions and aerosol chemistry, black carbon has been measured continuously in Germany at 19 different sites within the framework of the German Ultrafine Aerosol Network (GUAN) since October 2008. The GUAN network was established on behalf of the Federal Environment Agency (UBA) by the Leibniz Institute for Tropospheric Research

Moving weekly averages of the aerosol optical measurement of soot



▲ Moving weekly averages of the aerosol optical measurement of soot, measured as mass concentration in µg/m³
Source: Ufoplan, 2011

in the context of a project to determine the typical exposure of the population to fine and ultrafine aerosols.

In Germany, continuous nephelometer measurements of forward and backward scattering from aerosols at three wavelengths are taken at both sites of the Zugspitze/Hohenpeissenberg GAW Global station. Those data also serve for determining single-scattering albedo, which can be used to establish the extent of the transportation of particles from volcanoes and the Sahara.

Elemental carbon and organic carbon have been measured by the UBA since June 2011 at the GAW Regional stations Schauinsland and Neuglobsow as well as at its own measurement sites Schmücke and Neuglobsow.

PM10 concentrations in ambient air are measured in Germany at the three official GAW measurement sites at Neuglobsow, Schauinsland and Zugspitze and at all stations of the UBA's air measurement network (Westerland, Zingst, Waldhof and Schmücke). PM10 is also measured in the air-quality monitoring networks of the German Länder at more than 330 stations, which are mostly situated in more densely populated or urban areas.

◄ Locations of the 19 stations of the German Ultrafine Aerosol Network (GUAN).
The colours characterise site environment: red: traffic oriented, orange: urban context, green: rural context and light blue: alpine area.

International context

The GUAN network is part of the continuing European measurement programmes and projects such as EMEP, EUSAAR and ACTRIS. In accordance with normal practice, GUAN data can be retrieved from the EBAS database of the Norwegian Institute for Air Research (NILU).

Required resources

Funding of the GUAN network is secured from 2008 until the end of 2013 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Funding of current nephelometer measurements is secured permanently by the UBA and the Deutscher Wetterdienst (DWD), the funding of PM10 by the German Länder.

http://wiki.tropos.de/index.php/GUAN

2.14 Pollen

About 20 million people in Germany suffer from pollen allergies – this is about one quarter of Germany's total population (Ring et al., 2010). The tendency is increasing. Pollen production and release by plants are decisively influenced by the weather with all its complex characteristics. Continuous and long-term pollen counts can document changes in the start and total length of the pollen season and identify increasing or decreasing pollen concentrations or the occurrence of new invasive pollen species at an early stage. Potential changes are important indicators for the impact of climate change on main allergy triggers.

Climate trends

Trends caused by climate change are apparent already in all regions of Germany (Kaminski and Glod, 2011). Taking grass pollen in southern Germany as an example, the pollen season starts earlier and lasts longer (see graph). In north-eastern and southern Germany, the birch pollen concentration is increasing significantly.

The largest changes to the start of the pollen season and to pollen concentrations have occurred in southern and north-eastern Germany.

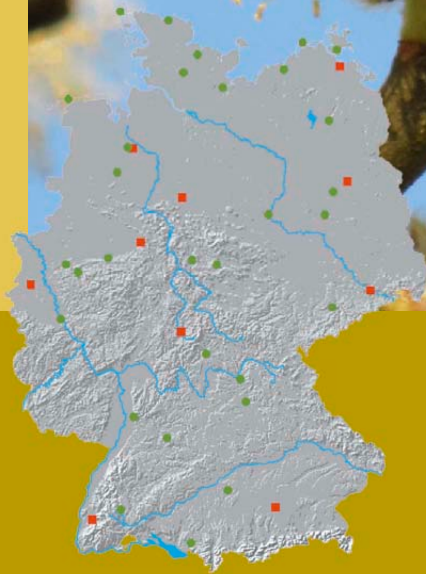
In all regions under consideration, it is evident that tree pollen allergies are becoming increasingly important, compared to plant pollen allergies, due to a greater increase in tree pollen. The main reasons for this are climatic changes (rise in CO_2 concentrations and in temperature) as well as changes in land use (destruction of grass surfaces and increased cultivation of trees).

New types of pollen such as olive and wall pellitory will be more significant in the future. The highly allergenic pollen of ragweed reaches Germany predominantly by long-distance transport from southern France and Hungary (Kaminski et al., 2010). But the evident spread of this plant in Germany will cause the concentrations of its pollen in the atmosphere to rise as well. All in all, allergies will increase continuously; therefore surveillance of pollen occurrence is becoming more and more important.

Measurements in Germany

The Pollen Information Service Foundation (PID) was established in 1983. The PID's pollen network covers at present about 45 stations for continuous sampling of pollen in ambient air. Most of the stations have been run since the mid-1980s. Germany's reunification in 1990 enabled the pollen network of the Federal Republic of Germany to be expanded to the new Länder. During the pollen season from spring to autumn, pollen emission measurements are performed by trained personnel. There are ten reference stations where pollen counts are recorded throughout the whole year. All stations are equipped with Burkard traps and the operating procedures for the preparation and evaluation of the samples are uniform for all stations.

Since 1986, the Deutscher Wetterdienst (DWD) has been publishing, in close co-operation with the PID, pollen forecasts for Germany as part of its statutory task to provide services for the protection of life and property. The forecasts consider the seven most allergenic pollen taxa: hazel, alder, birch, grasses, rye, mug-



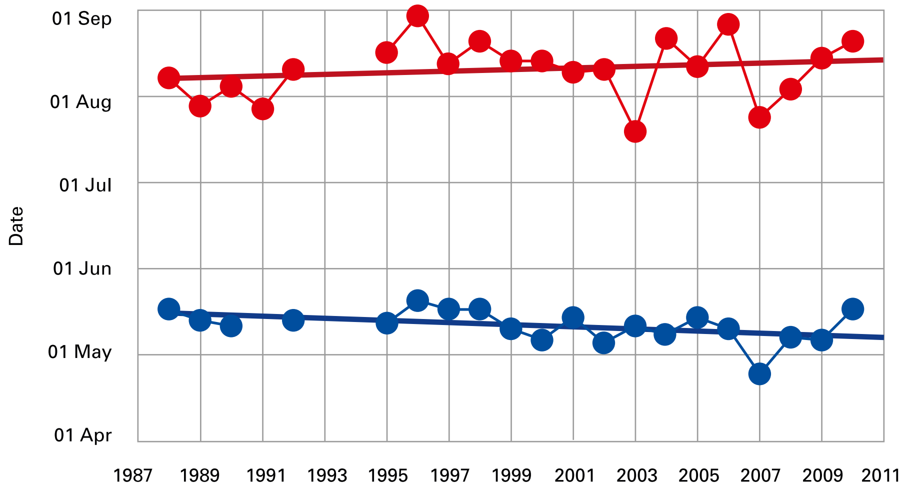
○ Operational pollen station of PID (seasonal analysis)
□ PID reference station (yearly pollen analysis)

▲
Pollen network of the Pollen Information Service Foundation (PID)
The DWD runs a reference station at the Centre for Human Biometeorological Research (ZMMF) in Freiburg, where the pollen forecasts are issued.

wort and ragweed. Due to the allergenic relevance of ash pollen, a forecast will soon be added for this plant as well.

Depending on the weather in autumn and winter, pollen forecasts mostly start with the first occurrence of hazel pollen at the end of January or beginning of February, sometimes even as early as December. They are issued until about the middle of October when ragweed pollen release has ended. In 2007, DWD introduced a newsletter for information on pollen release. The number of copies dispatched illustrates the importance attached by the public to this information. Up to 2011, the numbers dispatched increased steadily to over 10,000 per day.

Start and end of the grass pollen season in southern Germany 1988–2010



▲ Compared to 1988, the grass pollen season in southern Germany now starts earlier and ends later. Its total length has extended by 24 days.

Legal framework

The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for the provision of meteorological services for the general public or individual customers and users in the area of public health. The PID, based in Berlin, operates the pollen network and provides the DWD (based on a bilateral agreement) with the data needed to issue and disseminate pollen forecasts for the public.

International context

As pollen dispersal does not respect national borders, international data exchange is required. For this purpose, the European Aeroallergen Network (EAN) database was established in 1988, with 152 users from 48 countries including Germany connected to it. It includes pollen count data of 170 pollen types from 557 stations across Europe, which are available free of charge for research purposes. The database includes valuable information about the spatial and temporal development of pollen concentrations in the air over Europe. In addition, German pollen data are stored in the PID's own database.

Required resources

Apart from the DWD measurement station in Freiburg all other stations are placed at medical facilities. Pollen counters receive an expense allowance from PID for their work. The fail-safe operation of these stations depends on external boundary conditions, which are difficult to control.

Due to the high significance of pollen measurements, a basic level of finance for the pollen network would be useful to guarantee continuous measurement of high quality in the future.

As pollen counting is extremely time-consuming, efforts are being made to automate pollen measurement in order to save resources.

http://www.dwd.de/pollenflug http://www.pollenstiftung.de/

3.1

Ocean temperature

Sea surface temperature provides an integral measure of meteorological forcing and the resulting changes in the climate and ecology of the North Sea region. For more than 40 years, the Federal Maritime and Hydrographic Agency (BSH) has been performing weekly analyses of sea surface temperature. The growing data archive documents the dynamic development of this key oceanographic variable.

Climate trends

The behaviour of the non-linear climate system is, amongst other things, marked by abrupt temperature changes at all time scales. The time series of annual mean temperature in the North Sea shows a temperature climate which is characterised by abrupt regime changes on intra- to inter-decadal time scales. A linear trend of +0.3 K per decade suggests a gradual increase in temperature, but this is not what occurred. Interestingly, synchronous abrupt displacements of winter atmospheric circulation in the northern hemisphere have been reported (Watanabe and Nitta, 1999). In particular, regime shifts in ocean temperatures, concurrent but opposite to those occurring in the North Sea, have been observed in the North Pacific, where – as in the North Sea (Weijermann, 2005) – they give rise to major changes in the marine ecosystem (Hare and Mantua, 2000). The simultaneous and quasi-global appearance of these phenomena is evidence of interactions between the dominant dynamical modes of the climate system: the El Niño Southern Oscillation (ENSO), Pacific/North American circulation pattern (PNA), Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO) (Wang et al., 2009).

Legal framework

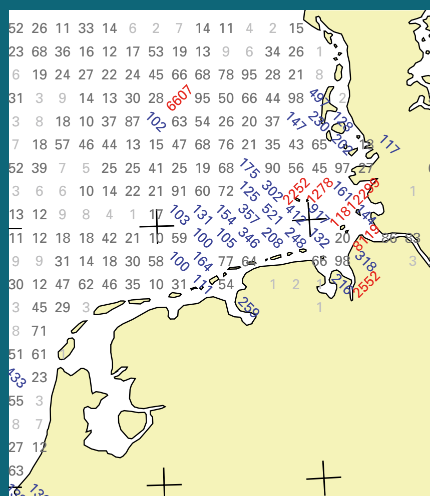
Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG, § 1), the BSH is responsible for oceanographic surveys, monitoring of changes in the marine environment and provision of hydrographic services. The publication of sea surface temperature charts is one of the services provided by the BSH, drawing on the results of its survey and monitoring activities.

Measurements in Germany

Worldwide, sea surface temperature (SST) is the most closely monitored of all oceanographic variables. It is also a very important climate variable that, together with near-surface air temperature, is used to describe global temperature trends over the past 160 years.

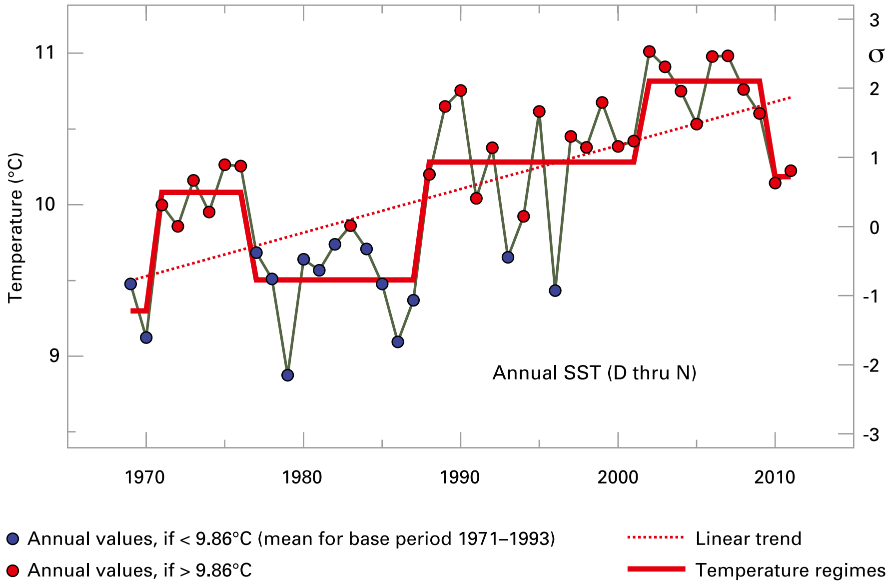
Historical ocean temperature time series exist, for example, for the German Bight and the western Baltic Sea. Some of these records date back to the 1870s, i.e. to the foundation of the 'Deutsche Seewarte' (German Maritime Observatory), predecessor of the Maritime Meteorological Office and the BSH. These early measurements, carried out aboard light vessels, are continued today by the ten automatic measuring stations that make up the BSH's Marine Environmental Monitoring Network in the North Sea and Baltic Sea (MARNET).

In addition, regular monitoring cruises are undertaken in the North and Baltic Seas by the BSH itself or other agencies on its behalf. Ocean temperature measurement is part of the standard programme during these cruises. The measurements are obtained through thermosalinographs, conductivity, temperature and depth sampling and towed oceanographic systems and provide a quasi-synoptic view of spatial and



Number of WMO Voluntary Observing Ships ▶ in the German Bight in 2002, shown per square on a 20-km grid

Sea surface temperatures (SST) in the North Sea 1968/69–2010/11



▲
Time series of annual North Sea sea surface temperatures (SST, December to November), together with linear trend and regime shifts (stepped line). Blue if < 9.86°C (mean of base period 1971–1993), otherwise red. The right-hand y-axis shows the standard deviation from the mean (sigma = 0.46 K). The linear trend (0.3 ± 0.1 K/decade) is a misleading representation of how SST has changed over time. In fact, SST history is characterised by jumps between temperature regimes, within which no clear trends can be discerned.

depth variations in ocean temperature. The data sets are used to calculate other variables, such as the heat content of the water column and the depth of the thermocline.

All these in situ temperature measurements are recorded and archived by the German Oceanographic Data Centre (DOD) at the BSH. The majority of the data is distributed over the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO). The ocean temperature data, together with other international ship and buoy data that are obtained ready-processed from the Deutscher Wetterdienst (DWD), are used by the BSH to carry out a weekly operational analysis of sea surface temperatures in the North Sea. Although the fleet of Voluntary Observing Ships (VOS) of the WMO has halved in size to less than 4,000 vessels since the 1980s, the density and frequency of data collection in the North Sea have remained stable or even increased.

International context

Ocean temperature data obtained by MARNET and the monitoring cruises are transmitted in the framework of various co-operation agreements, networks, projects and programmes to the databases and data portals of international organisations. These include, among others, the North West European Shelf Operational Oceanographic System (NOOS) and the corresponding Baltic Operational Oceanographic System (BOOS), both of which, as regional components of the European Global Ocean Observing System (EuroGOOS) and the Global Ocean Observing System (GOOS), respectively, are part of the wider network of GCOS. The BSH is currently developing a central geodata infrastructure (GDI-BSH) as the maritime component of the German federal geodata infrastructure (GDI-DE), that in turn is intended to form part of the common European geoportal INSPIRE (Infrastructure for Spatial Information in Europe).

Furthermore, ocean temperature data distributed over the GTS finds its way into climate data sets, such as the International Comprehensive Ocean-Atmosphere Data Set (ICOADS).

Required resources

The operation of MARNET is a fixed component of the BSH budget. Ongoing BSH funding also finances the regular monitoring cruises and operation of nautical and hydrographic services.

http://www.bsh.de

3.2
Salinity

Salinity is a property of the ocean known as a 'conservative' one (that only changes through mixing) and is therefore of great importance in oceanography for the identification of water masses. At the sea surface, salinity is modified through evaporation, precipitation and fresh water from the land (river runoff, glacial melt). Thus, it can be expected that climatic changes in the hydrological cycle of the atmosphere will be manifested in changes of surface salinity.

International context
All measurements within German territorial waters must be provided to the German Oceanographic Data Centre (DOD) for archiving. All data are available from there for national or international analysis free of charge. Additionally, the DOD provides salinity data to international projects, such as MyOcean, the European Coastal sea Operational observing and forecasting system (ECOOP), the North West European Shelf Operational Oceanographic System (NOOS) and the free-drifting float programme Argo.

Legal framework
Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG), the marine environment in general as well as the occurrence of changes in the marine environment is to be monitored by the German Federal Government. This includes the participation in inspections made by the European Union or other international organisations of which Germany is a member state insofar as such inspections are necessary to implement legal instruments of the European Union or fulfil the international commitments of the Federal Republic of Germany.

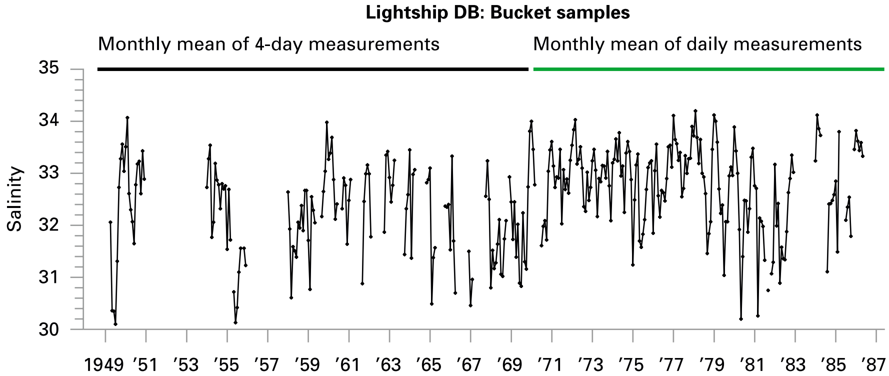
Climate trends
Long-term records of surface salinity exist for various areas and regions in the North Sea, but most of these suffer from a severe lack of homogeneity regarding, in particular, data accuracy in the past and data gaps during the two world wars. Additionally, most long-term salinity measurement stations in the North Sea are influenced by continental runoff and the associated extremely high salinity variability is making it difficult to detect any correlations between changes in the hydrological cycle and changes in the climate (increased flow of fresh water due to glacial melt or higher precipitation).

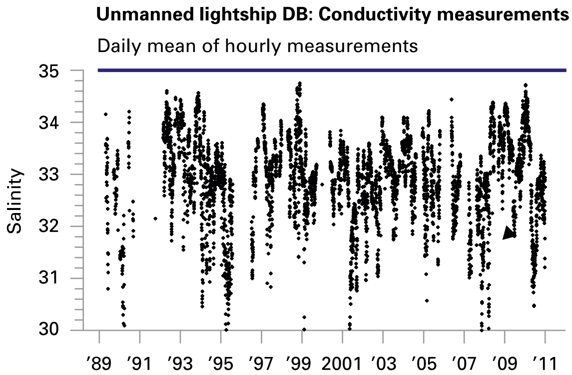
A typical example of long-term salinity records is the time series of the 'Helgoland Reede' (Helgoland Roadstead) which has been sampled since 1873. Here, the high variability in salinity is strongly associated with continental runoff (Elbe plume) and meteorological conditions in the German Bight. These measurements, carried out in the past manually on weather ships in the German exclusive economic zone (EEZ), are now performed by automated systems. Long-term records of salinity and other parameters are essential to detect and evaluate changes in the marine ecosystem.

Measurements in Germany
Continuous and up-to-date information about salinity in the German EEZ (North and Baltic Seas) is gathered within the framework of the regular monitoring activities of the Federal Maritime and Hydrographic Agency (BSH) and in co-operation with the Leibniz Institute for Baltic Sea Research, Warnemünde (IOW) at the automated MARNET stations (see link to web page). Salinity measurements are also collected by the BSH during monitoring cruises. Further monitoring cruises are carried out by various authorities and research institutes of the coastal Länder, mostly as part of project-related measurement campaigns. All these data are archived at the DOD. In recent years, additional automatic measurement stations have been installed in connection with off-shore wind farms.

The northern part of the North Sea is dominated by Atlantic waters, while its southern parts are influenced by the Baltic outflow and the runoff of major European rivers, such as Thames, Rhine and Elbe,

Surface salinity at the position of the lightship 'Deutsche Bucht' (DB)





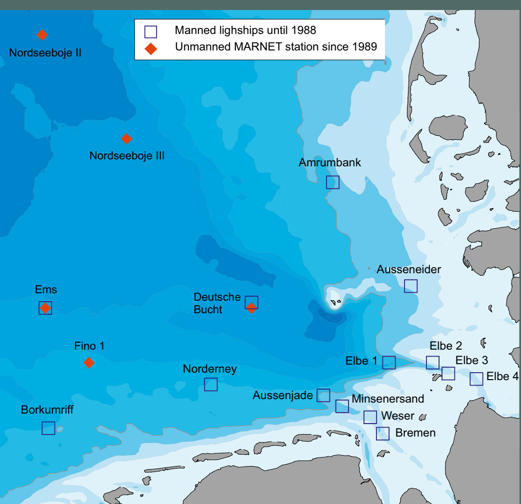
▲ ◄ Surface salinity at the position of the lightship 'Deutsche Bucht' (DB) 1949–2011 (manned until 1986, thereafter unmanned with measurement chain)

with the consequence of great variability at all time scales. Autonomous profiling systems (floats) have been collecting salinity measurements in the world's oceans in real time since 2000 within the Argo programme. In this context, responsibility for the co-ordination of Germany's contribution lies with the BSH. Up-to-date and comprehensive salinity information is an essential prerequisite for fulfilling the task of monitoring the marine environment.

Recently, Germany and international co-operation partners have started to analyse ocean salinity using satellite data from the ESA's Soil Moisture and Ocean Salinity satellite (SMOS) and the more recent joint NASA/Argentinian Aquarius/SAC-D satellite. Both missions have delivered first data sets the technology of which, however, needs continued improvement before the data can be scientifically analysed and used in model studies. The first results look promising but the development of high-quality products will need more time and much more and sustained scientific research.

Positions of manned and unmanned measurement stations

▼



Required resources

The operation of measurement stations requires large logistical and personnel resources. All measurement and maintenance activities depend mainly on the meteorological conditions at sea, for which reason it is not always possible to perform regular maintenance. The measuring system is quite often subject to technical difficulties or loss of equipment.

Additional resources are also needed to validate and improve satellite-based measurements of salinity and to ensure that these data can be assimilated in numerical circulation models.

http://www.bsh.de/Vorlagen/ressources/nav_de/navigation2.jsp

http://www.bsh.de/de/Meeresdaten/Beobachtungen/MARNET-Messnetz/MARNET.jsp

3.3 Sea level

Changes in sea level provide an important indicator for changes in the climate of the earth. The reasons for changes in sea level are very complex and arise mainly from the interaction between thermal expansion due to warming, changes in the volume of the ocean due to the melting of polar ice sheets, changes to glaciers and changes in the ocean circulation. Regional changes in sea level can differ substantially from the global mean due to, among other things, vertical movements of the solid earth (glacial isostatic adjustment, GIA).

Climate trends

In view of the high internal variability of sea level due to natural fluctuations in air pressure and wind forcing, long time series of sea-level measurements are needed to detect statistically significant anthropogenic changes. Scientific analysis has shown that records going back at least 50 years are necessary to resolve the decadal variability properly (Haigh et al., 2009).

Within the framework of the AMSeL project of the German Coastal Engineering Research Council (KFKI), the time series of 13 tide gauges along the entire German North Sea coast have been combined in a high-quality synthetic time series which represents the entire German Bight and spans the period 1843–2008. Most of the individual time series included are much shorter, however, and it is of the utmost importance to continue those measurements on a long-term basis and additionally increase the length of the time series by digitising historical records from the archives in order to obtain a better regional differentiation of sea-level change. This applies in particular to the continuation of the measurements from satellite altimetry.

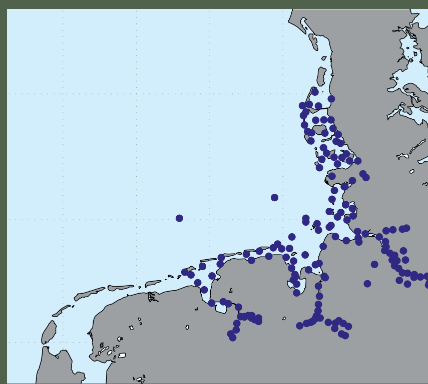
Legal framework

Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG, § 1, par. 9, in the version of 26 July 2002 (Federal Law Gazette I 2876)), the marine environment of the North and Baltic Seas is to be monitored by the German Federal Government and the Länder. Germany's exclusive economic zone (EEZ) is under the jurisdiction of the Federal Government. The tasks defined include the implementation of legal instruments of the European Union (e.g. water framework directive) as well as the fulfilment of international commitments made by the Federal Republic of Germany (UNFCCC, Kyoto protocol, GEOSS, GMES, GCOS).

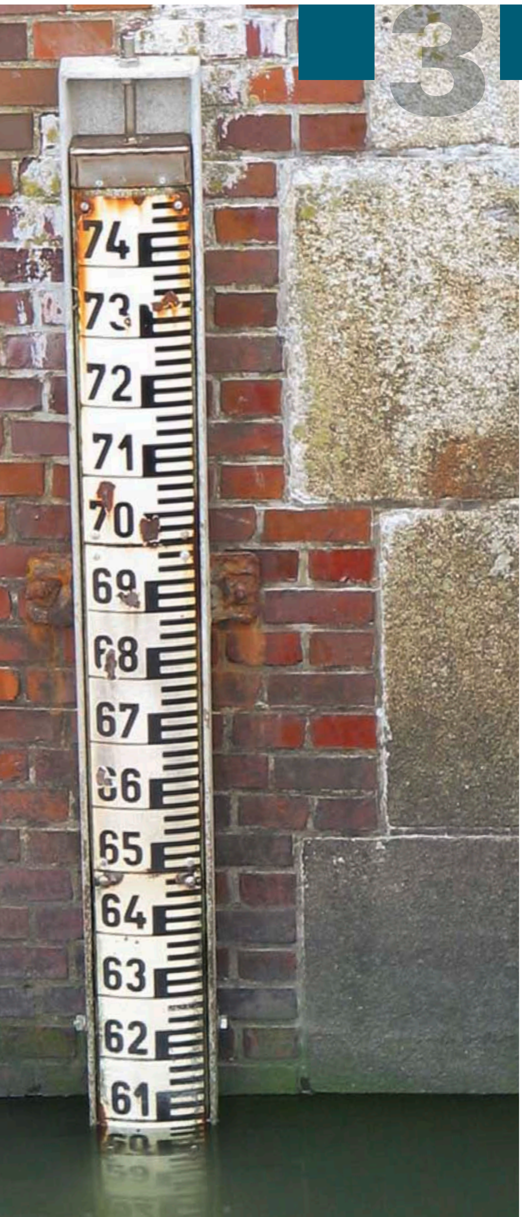
Measurements in Germany

Ensuring the safety of the German coasts requires a system of local tide-gauge stations to be in place to monitor regional and local changes in sea level. In addition to the tide gauges, satellite altimeter observations of sea level need to be provided on a continuous basis. Systematic sea-level measurements that date back to 1843 come from the tide gauge station at Cuxhaven. While the older time series only contain coarsely resolved data of tidal high and low waters, modern tide gauge stations with digital recording technology offer high-resolution data at minute intervals. Currently, tide gauge measurements are carried out by the Water and Shipping Offices (WSA) and other regional authorities at 165 stations along the German North Sea coast and in the tidally influenced parts of the rivers. Over the years, measurement technology has changed continually, from staff gauges to floating gauges with graphical and digital recording, acoustic gauges, pressure and radar gauges, all of which are still in use.

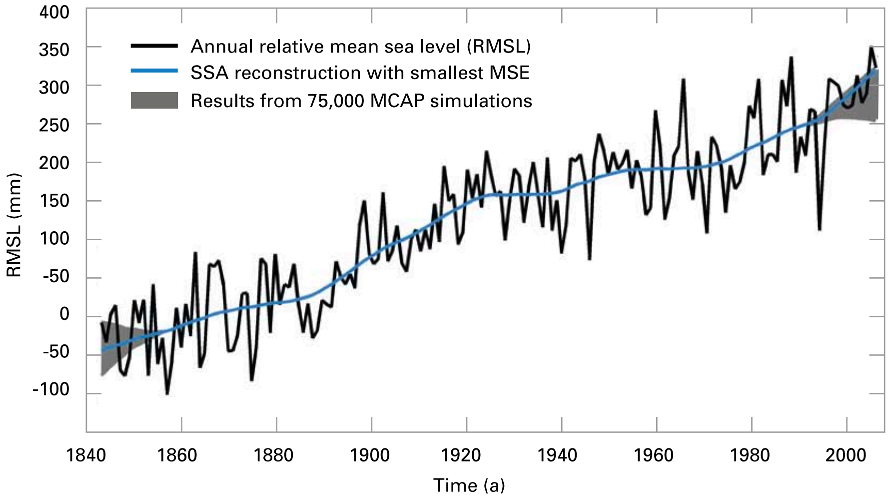
During the last 20 years, satellite altimetry has come to offer global coverage of sea-level measurements



▲ Location of the tide gauges along the German coast and in the tidally influenced parts of the rivers



Synthetic time series of mean sea level (mm) in the German Bight from 1843–2008



▲ The combined time series is based on the records from 13 selected tide-gauge stations with high-quality, verified data (Wahl et al., 2011). The graph shows annual means (black) and the adjusted non-linear trend (blue). The increase in sea level is relative to the land surface and takes account of the effects of uplift or subsidence.

from space. In the deeper parts of the oceans and areas outside the continental shelves, the satellite data allow the determination of sea level and its variability to an accuracy of one centimetre. The algorithms for using the satellite data to calculate sea levels in coastal areas continue to be refined within the framework of international research projects.

An important aspect of regional analysis of sea level in the North Sea is the large-scale distribution of vertical land movements, which are an after-effect of the last ice age. Large-scale land uplift and subsidence are superimposed on local water level changes and show mostly linear trends on centennial scales. The Federal Institute of Hydrology (BfG) has therefore begun to monitor vertical land movement and has equipped selected tide gauges with GPS antennas allowing direct measurements of land uplift and subsidence.

International context

Sea-level measurements along the German coast are part of the international tide gauge network GLOSS (Global Sea Level Observing System) which is operated under the auspices of the World Meteorological Organization (WMO) and the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of WMO and IOC (Intergovernmental Oceanographic Commission of UNESCO). It is the aim of GLOSS to provide high-quality sea-level data for use in both climate research and coastal research. The core network comprises 289 stations worldwide. Germany contributes station data from the tide gauge at Cuxhaven.

Required resources

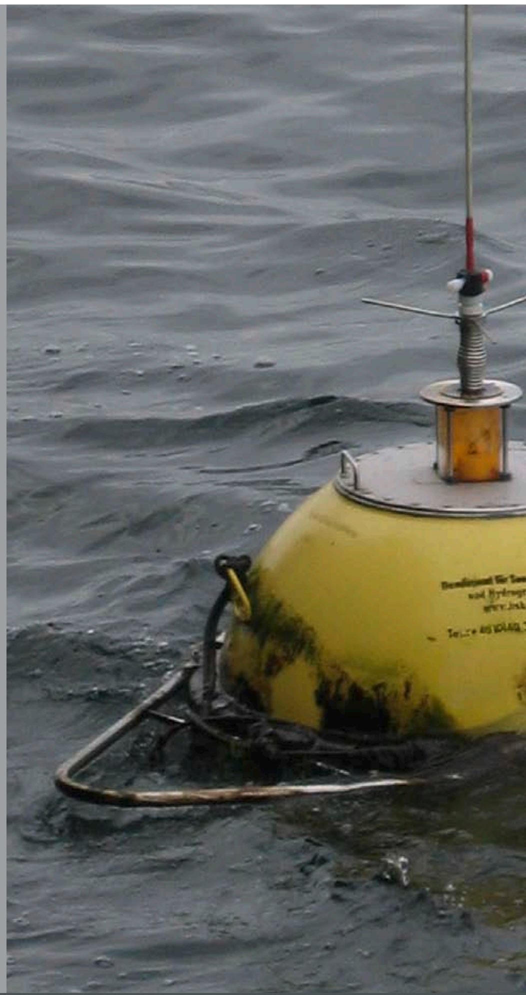
The monitoring of the marine environment in the North and Baltic Seas is regulated by the Maritime Shipping (Federal Competences) Act. However, a substantial part of the development and service work is still financed through national and international projects within the framework of university research. To secure the sustainability of such services it is necessary to establish long-term funding.

It is also essential for coastal protection that the satellite altimetry missions of the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) are continued and receive the necessary investment in infrastructure. To sustain coastal applications of satellite altimetry it is necessary to provide sufficient funding to develop and refine the required algorithms.

http://www.gloss-sealevel.org/

3.4
Sea state

Sea state is the term used for the height of wind-generated waves on the sea surface. Changes in wind conditions and storm intensity have a direct impact on the sea state. It is thus not a primary indicator of climate change, but constitutes an important parameter affecting adaptation strategies in maritime transport and coastal defence and in the offshore industry.



Wave-measuring buoy with flash light ▶ and antenna, 90 cm diameter

Climate trends

Records of sea state observations by seafarers have existed since the middle of the 19th century; the beginning of systematic shipboard observations dates back about 60 years. Many of the statistical analyses so far are based on such visual observations.

However, long-term data series with a length comparable to that of atmospheric parameters do not yet exist for wave measurements. Current monitoring stations were established primarily for the benefit of shipping, pilotage services and coastal defence, but the data are also available for the purposes of research institutions and industry.

The statistical-climatological importance of these data series still lies mainly in the validation of numerical wave models and their results. Models, unlike the few monitoring stations, allow the generation of long, continuous time series covering large areas.

However, precise measuring methods are required to record extreme events and particularly high, dangerous single waves.

Some years of the time series shown on page 51 cannot be analysed statistically because of too many data gaps. Over the two decades, there is no clear trend, neither in the mean wave heights nor in the 95th percentile (P_{95}). Slightly higher annual maxima in the last years are probably due to shorter measuring intervals, which allow the exact time of the highest sea state during a storm to be recorded more precisely.

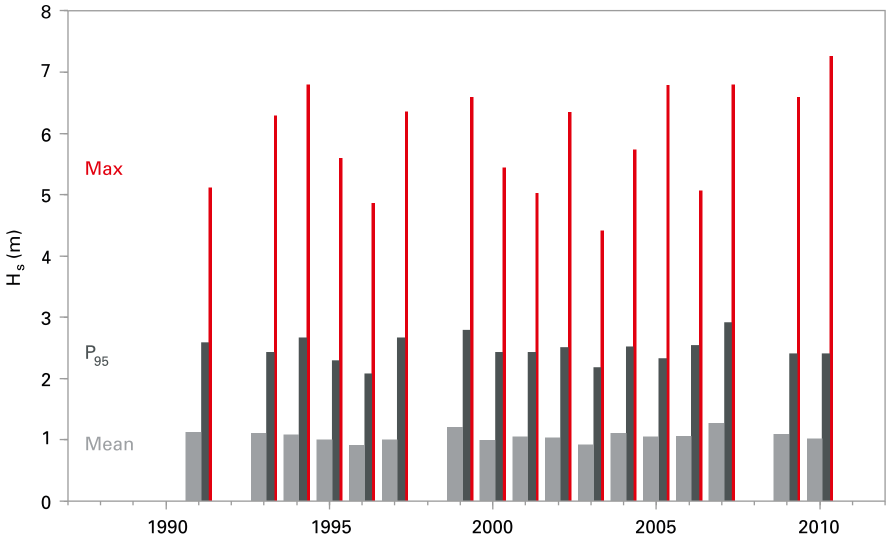
Measurements in Germany

Reliable wave measuring technology did not exist until the 1960s. The longest German time series originates from Helgoland station. Beginning in 1989, it meets the 20-year criterion of GCOS for a climatological time series. Other monitoring stations started operation later: Elbe in 1991, NSB-2 in 1993, Sylt in 2002, FINO-1 in 2003 (and Darßer Schwelle and Arkona Becken in the Baltic Sea in 1991 and 2002 respectively).

Additional wave measurements are carried out by the Länder authorities and by research institutions at numerous sites in the coastal area, mostly in connection with projects and using different instrumentation. In recent years, additional monitoring stations have been established in connection with offshore wind farms. Besides these sea surface measurements, remote sensing data from satellite-based measurements using radar altimeters have been available since the 1980s. These global radar data are available from ESA (www.globwave.org).

Location of permanent wave monitoring stations in the German Bight and western Baltic Sea: the station 'Sylt' is operated by Schleswig-Holstein's government-owned company for coastal defence, national parks and ocean protection (LKN-SH), the station 'Darßer Schwelle' by the Helmholtz-Zentrum Geesthacht (HZG), all other by the BSH.
▼

Significant wave heights at Helgoland 1991–2010



▲ Light grey: annual means;
dark grey: percentile P_{95} (significant wave height not exceeded during 95% of the year);
red: maximum annual significant wave height
Due to data gaps, the figures do not necessarily reflect the annual maximum that has actually occurred.

All monitoring stations (see map) use wave-following buoys that are elastically moored. The measurement data are transmitted to shore by radio, in some cases via satellite, and processed automatically. They are made available on the Internet in near-real time at www.bsh.de/en/Marine_data/Observations/Sea_state/.

The measurements record the waves' energy spectrum from which important wave parameters, e.g. significant wave heights, mean wave period and wave direction, can be calculated by means of standardised procedures. Some stations also record highest single waves. The significant wave height is the mean height computed from the highest third of all single waves measured.

All these time series are thus homogeneous with respect to position, measuring method and data analysis, with the exception of the measuring interval. Measurements were initially made every three hours, but improved data transmission has reduced the interval to 30 minutes currently. This allows extreme situations to be recorded more easily.

International context

The data from the permanent monitoring stations, together with other oceanographic data, are exchanged within the framework of the European Global Ocean Observing System (EuroGOOS) with the regional sections of NOOS for the North Sea and BOOS for the Baltic Sea, both part of the GCOS ocean observing system. However, none of the stations belong to the specifically designed GCOS Surface Network (GSN). Data transmission is automatic on an hourly basis. The data are also transmitted hourly to the Deutscher Wetterdienst (DWD), which distributes them through the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO). The Marine Environmental Monitoring Network in the North Sea and Baltic Sea (MARNET), an automated monitoring network operated jointly with the Leibniz Institute for Baltic Sea Research (IOW) and the DWD to record oceanographic and other physical and chemical parameters, is an important tool for measuring sea state. Responsibility for the national centre for maritime geospatial data, i.e. the German Oceanographic Data Centre (DOD), lies with the BSH, which also co-ordinates international data exchange.

Legal framework

In support of sustainable development of shipping and maritime uses and the protection of the marine environment, the Federal Maritime and Hydrographic Agency (BSH) collects and analyses maritime data and makes them available to the public. The general legal basis for these tasks is the *Maritime Shipping (Federal Competences) Act* (SeeAufgG).

Required resources

There are good prospects that operation of the existing monitoring stations can be continued in future. Measurements at sea are very expensive and technically demanding, and the risk of equipment failure or loss is high. Maintenance of the systems cannot always be carried out on schedule. This is reflected in numerous gaps in the data series. To keep data loss at a minimum, improved logistics and more personnel will be required.

http://www.gloss-sealevel.org/

3.5 Sea ice

In polar regions, the ice on the sea has a strong influence on albedo and thus also on the energy budget. Sea ice acts as an insulating layer that reduces heat and nutrient exchange between the ocean and the atmosphere. Ice changes relatively slowly and, since the sea ice cover is relatively well known, it provides a good indicator of variability occurring at seasonal to longer time scales.

Legal framework

According to the *Maritime Shipping (Federal Competences) Act* (SeeAufG), the German Federation is responsible for the provision of ice information services in German seawaters. The German Ice Service provides advice to shipping all over the world and is based in the Federal Maritime and Hydrographic Agency (BSH). Its history goes back to the end of the 19th century and the 'Deutsche Seewarte' (German Maritime Observatory). According to the Antarctic-Environmental Protocol Implementation Act (AntarktUmwSchProtAG), the BSH is also responsible for issuing Antarctic shipping permits.

Climate trends

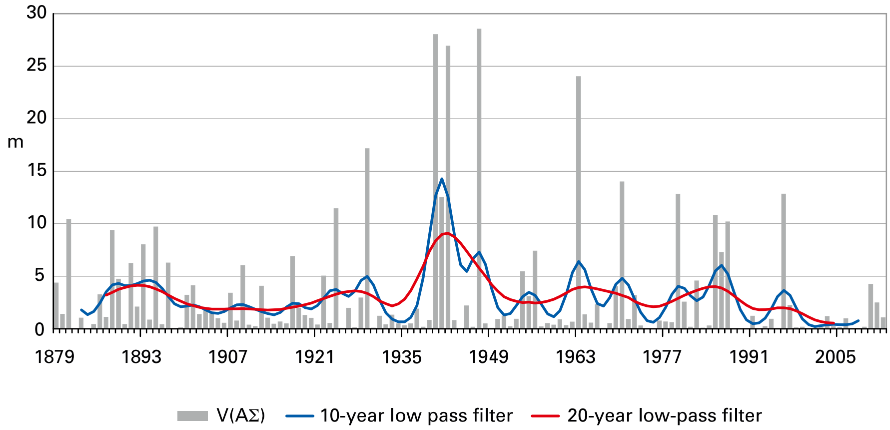
Although relatively short, satellite-based time series of ice cover that first became available at the end of the 1970s are widely known to the public as they show a dramatic retreat of Arctic sea ice, which is very probably connected with anthropogenic climate warming. Direct observation of ice conditions along the German coast dates back to the end of the 19th century. Estimates of the annual maximum extent of ice cover in the whole of the Baltic Sea date back to the year 1720 and continue to be updated. For the German Baltic Sea coast the severity of ice winters can be reconstructed as far back as 1300 with the help of historical documents. Long time series like these already provide evidence of longer-term climate fluctuations, such as the mediaeval warm period and the little ice age.

Measurements in Germany

Continuous ice observations have been carried out along the German coast since the end of the 19th century. Since the winter of 1927/28, ice maps of the German coast and the whole of the Baltic Sea have been compiled at least once a week.

▲
Overview map of ice in the Baltic Sea dated 4 April 1929, i.e. the 87th ice map published in the second season

Total volume of sea ice in relation to the area on the German Baltic Sea coast from 1879 to 2011



▲
Distribution of total volume of sea ice in relation to the area on the German Baltic Sea coast from 1879 to 2011
Source: Schmelzer & Holfort, 2011

The most important ice parameters measured are coverage and thickness; others include shipping conditions and the form of the ice. The data and the maps are archived at the BSH, some of which already in digital form. Information about current ice conditions is available free on the BSH website.

For the last few years, global ice coverage has been continuously determined by the universities of Bremen and Hamburg from satellite data, with the results being disseminated free of charge on the Internet. Scientific studies of sea ice are undertaken by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven and a few universities. Many of these are process studies, with a global coverage, but not carried out on a continuous basis. Long-term measurements are performed mainly in the Fram Strait and to the north of this region.

International context

The close co-operation among Baltic Sea ice services dates back to 1925. For decades, even during the cold war, daily data and reports were exchanged. Today, regular meetings are held and the ice services have a common website. On a global scale, there is a good level of collaboration among members of the International Ice Charting Working Group (IICWG), which organises international meetings where not only operational but also scientific issues are discussed. The ice services rely to a great extent on satellite data and work closely with remote sensing agencies, such as the European Space Agency (ESA) and the National Oceanic and Atmospheric Administration (NOAA). The international regulation and standardisation of operational ice information services is undertaken by the Expert Team on Sea Ice of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). The Global Digital Sea Ice Data Bank (GDSIDB) maintains two international archiving centres for ice maps and other information, located at the Arctic and Antarctic Research Institute (AARI) and the National Snow and Ice Data Center (NSIDC).

Required resources

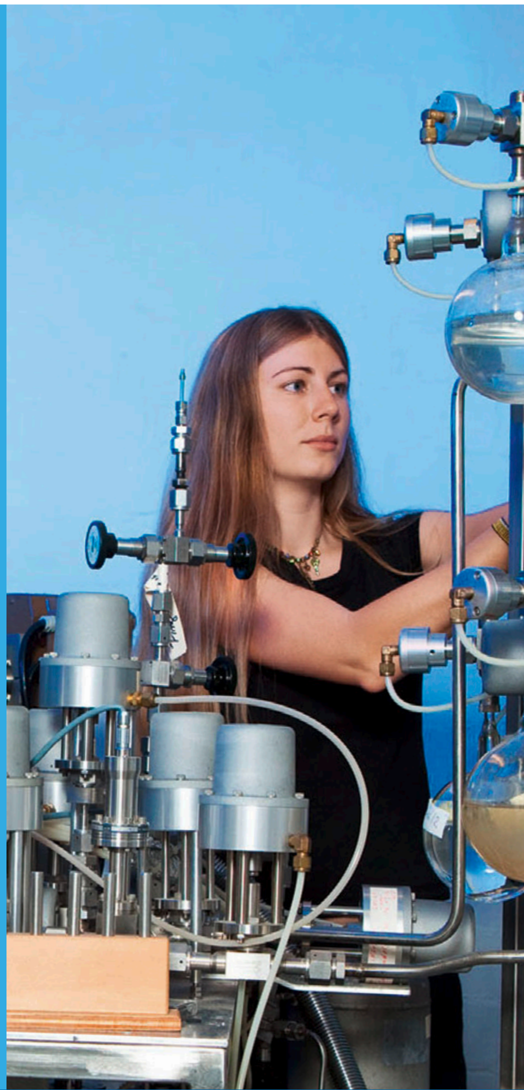
Due to statutory obligations, funding for the fundamental work of the Ice Service is relatively secure for the future. Some of the satellite maps used by the BSH's Ice Service are compiled by staff and student assistants at universities, who provide this service on a voluntary basis. Other services and scientific studies rely on additional funding, mostly from the public sector, i.e. the Länder, the Federation and the EU. In most cases, however, the continuity of this funding is not secured. The continuation of satellite missions is of key importance, especially but not exclusively those carrying Synthetic Aperture Radar (SAR) instruments, as well as the continued free availability of satellite data for use by the ice services and scientists working in the field.

http://www.bsh.de

3.6

Deep water formation

Surface water sinks into the abyss in a few key regions in the Atlantic, as part of the oceanic meridional overturning circulation. The volume of water transferred into the deep, i.e. the water mass formation rate, determines the capability of the ocean to absorb and store heat, fresh water and climate-relevant gases such as CO_2. As it is not possible to measure the formation rates directly, temporal changes in the oceanic inventory of trace gases, such as chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF_6), are used to infer these formation rates.



Analysis of trace gas measurements at the Institute of Environmental Physics (IUP), University of Bremen

Climate trends

The oceanic key regions react very sensitively to changes in the atmospheric forcing. Global warming is thus expected to significantly affect the formation of deep water and the meridional overturning circulation. This would have a great impact on the storage and transport of heat, fresh water and anthropogenic CO_2 in the ocean – with considerable consequences for the sea level and climate in Western Europe. This high sensitivity is also the reason for the ocean's high natural variability in response to natural fluctuations in the atmosphere – which hampers the detection of fluctuations of anthropogenic origin. Long data series are therefore needed to distinguish between natural variability and long-term trends.

Legal framework

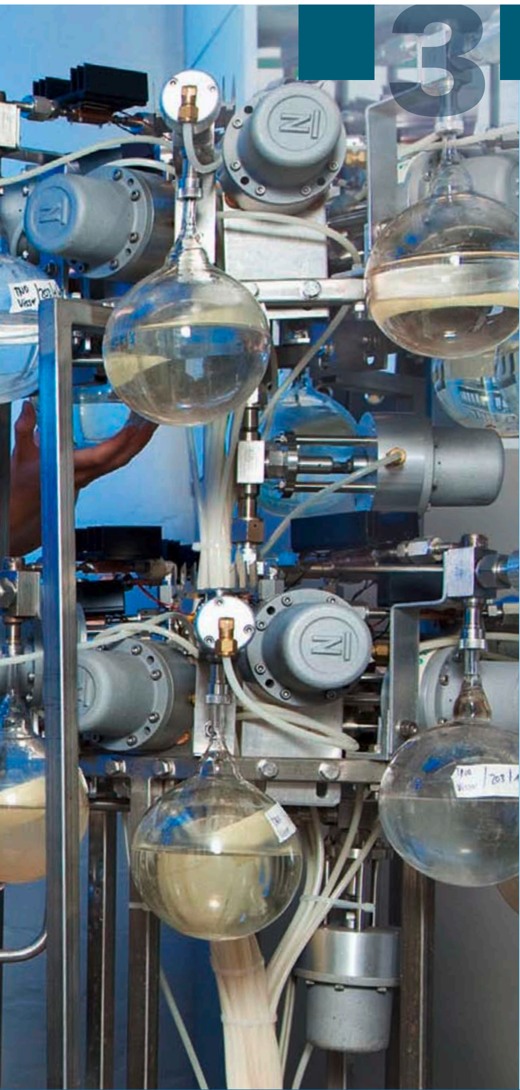
There is no legal framework. The measurement of trace gases in the ocean is part of the basic research of universities and research institutes. The activity is funded by national and European third parties.

German measurements

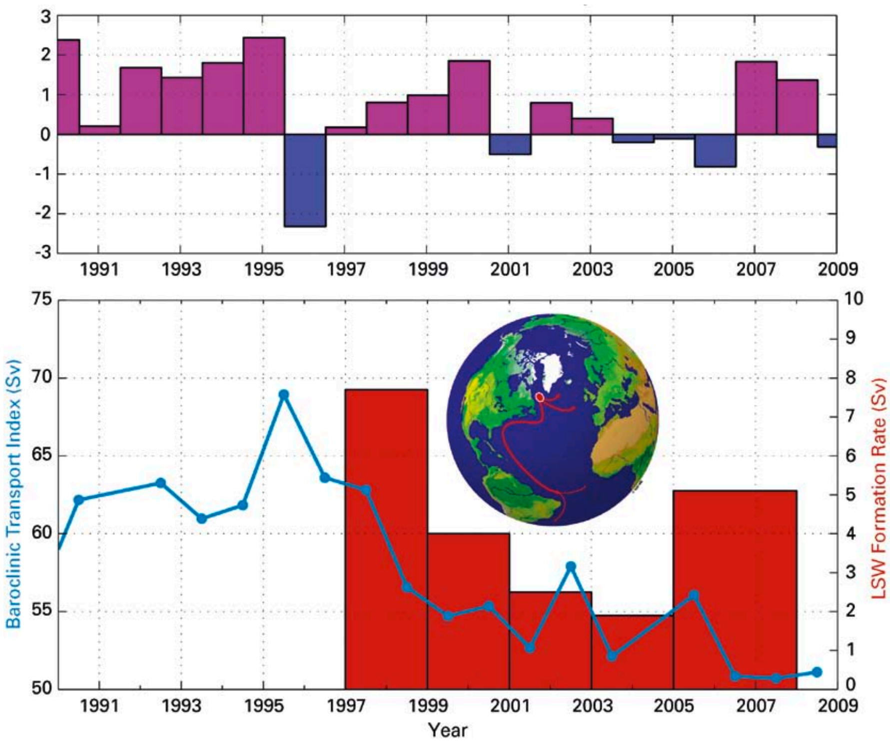
Trace gas data (CFC-11, CFC-12 and SF_6) are used to calculate deep water formation rates. The reason is threefold: these gases have a long life in the atmosphere, show increasing atmospheric concentrations and behave in the ocean like noble gases. They are transferred into the surface water through air-sea gas exchange, sink with the surface water masses into the abyss in a few regions and are distributed in the ocean's interior by large-scale circulation. Since these gases are chemically and biologically inert, their concentrations depend only on the year the water mass left the surface and on how they are mixed in the depths. The tracking of anomalies in the concentrations is used to infer how quickly climate signals are spreading in the ocean. Climate models predict a weakening of formation rates and related circulation, which would have a significant impact on the climate in Western Europe.

German measurements focus on the key regions of deep water formation in the Atlantic, i.e. the key regions of oceanic circulation.

- In the subpolar North Atlantic, changes in the deep water formation rates have been subject to study since 1997. About every two years, the distribution of trace gases is measured for changes to calculate changes in the formation rate. At every survey, about 2,000 to 3,000 tracer samples are analysed, partly directly on board the ship, partly in the home laboratory. The availability of suitable research vessels, such as the FS Meteor and FS Merian, is essential.
- In 1986, trace gas measurements were carried out for the first time along the prime meridian in the Southern Ocean; they have been repeated since then every 2 to 3 years thanks to the research icebreaker FS Polarstern. This trace-gas time series is also one of the longest in the world. Further measurements have also been made in the whole Atlantic in order to study the pathways of newly formed deep water and estimate the speed of its spreading.



Strength of the circulation (NAO index) and rate of deep water formation



▲ Top: Atmospheric fluctuations over the North Atlantic expressed as the air pressure difference in winter between the Icelandic low and the Azores high (North Atlantic Oscillation (NAO) index)
Bottom: Time series of the formation rate of Labrador Sea Water (LSW), a main component of the North Atlantic Deep Water (red), and the transport index for the eastward transport in the upper 2,000 m between Bermuda and the Labrador Sea (blue). The inset globe shows the LSW formation area and the main spreading pathways. Transports and formation rates are given in Sverdrups (Sv; 1 Sv = 10^6 m^3/s) (update from Rhein et al., 2011).

■ A further application of large-scale trace gas measurements is the calculation of storage of anthropogenic CO_2 in the ocean. Like the other trace gases already mentioned (CFCs or SF_6), it enters the ocean via air-sea gas exchange, bound up, however, in chemical and biological processes that are difficult to assess. Therefore, an internationally proven method to calculate the amount of anthropogenic CO_2 relies on the distribution of trace gases. In the Atlantic, Germany is leading in the analysis and interpretation of trace gas data, as well as in the number of measurements.

The German oceanic trace-gas data are part of European and international data archives, and of the national archive PANGAEA®.

International context

The national measurement of trace gases is part of international research activities, such as the WCRP's CLIVAR programme, which focuses on climate variability and predictability and the coupling between ocean and atmosphere. Additionally, the measurement is part of European research projects such as CARBOOCEAN and CARBOCHANGE.

Required resources

The measuring of oceanic trace gases including some of the technical personnel required and technological development are funded through temporary research projects; its continuity is therefore not secured. Also, the measurements cannot be carried out without ship time on suitable research vessels (FS Meteor, FS Merian, FS Polarstern).

http://www.ocean.uni-bremen.de

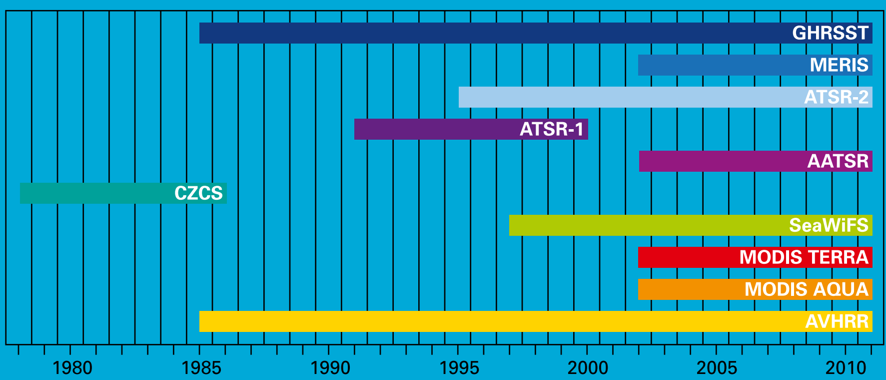
3.7
Ocean colour

'Ocean colour' is a collective term for various physical and biological parameters derived from multispectral optical remote sensing data. Some of the most important parameters for monitoring the ocean are concentrations of chlorophyll, yellow substance (also known as gelbstoff or coloured dissolved organic matter) and suspended matter as well as turbidity and transparency or Secchi depth. The regular availability of information about the variability of these parameters over space and time is also of great importance for the detection and assessment of climate-related changes in the marine environment.

Climate trends

Satellite-borne optical remote sensing began in the late 1970s. A greater variety of optical sensor has become available over the last 10 to 15 years. Therefore, time series long enough for climatological analysis are not yet available. However, for several marine areas consistent time series covering the last decade can be constructed.

Availability of the various satellite-borne optical sensors
Source: Brockmann Consult
(see list of abbreviations)
▼



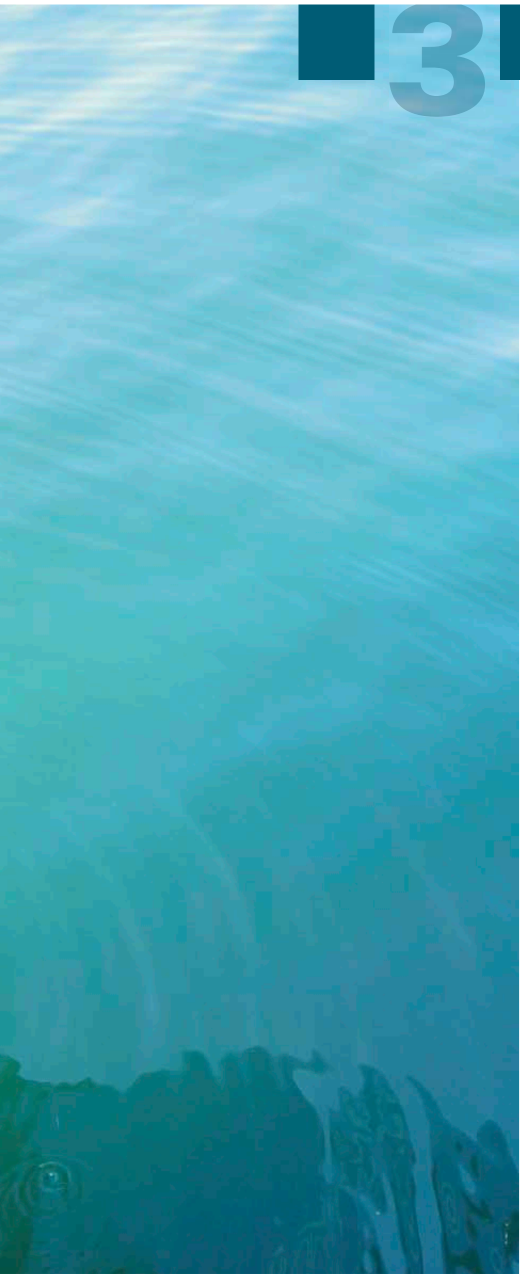
Legal framework

Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG), the marine environment in general as well as the occurrence of changes in the marine environment is to be monitored by the German Federal Government. This includes the participation in inspections made by the European Union or other international organisations of which Germany is a member state insofar as such inspections are necessary to implement legal instruments of the European Union or fulfil the international commitments of the Federal Republic of Germany.

Measurements in Germany

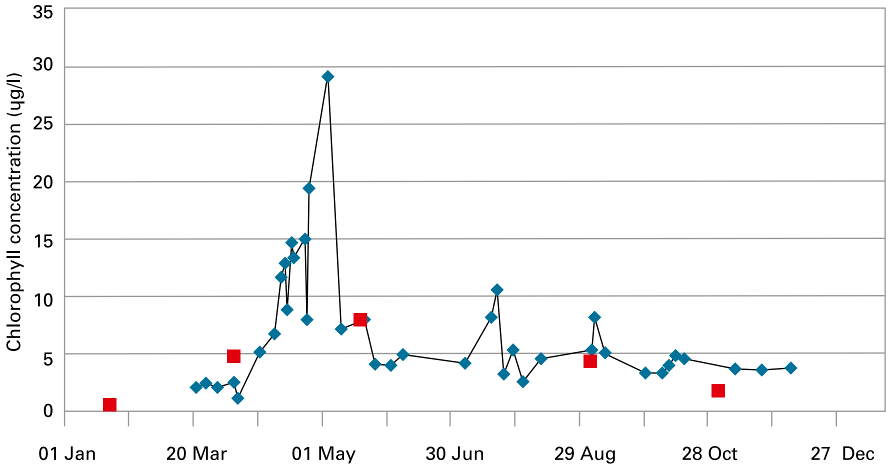
Optical satellite-borne measurements of ocean colour have been used for more than ten years for ocean monitoring in German waters, especially in the North and Baltic Seas and the adjacent North Atlantic. Concentrations of chlorophyll, yellow substance and suspended matter as well as turbidity and transparency or Secchi depth can be derived from multispectral optical data. Due to the different characteristics of marine water masses, algorithms must be applied that take account of local optical properties. Validation with in situ data allows provision of estimates of the difference between the two measurement methods.

Because the availability of remote sensing data is limited by cloud cover, moving multi-day, weekly and monthly averages are used for monitoring purposes. These data cover



the whole seasonal cycle with the exception of the winter months (due to the low angle of the sun) and, thanks to the spatial information included, support the interpretation of data from fixed monitoring stations, such as buoys and platforms. The data support the validation and development of numerical ocean models, especially suspended matter and ecosystem models, and constitute, together with the model and in situ data, an important observation component.

Seasonal chlorophyll-a distribution in 2010 at Helgoland station



Source: IOW/BSH 2010

International context

Many ocean colour products have been developed in the framework of international projects (e.g. ESA, EUMETSAT) and are provided directly or via a local service provider (German Aerospace Center (DLR)), research institutes, universities). The European Global Monitoring for Environment and Security (GMES) initiative has contributed substantially to the development of satellite-borne products. As well as the development of methods and user-specific products, an infrastructure for the validation of data and GMES downstream services (validation bureaus) has been established. In parallel with the operational use of the data, the algorithms are being improved and refined and derived products are being further developed in research projects.

Required resources

Today, a great part of the developing work and services is still financed by national and international research projects. To ensure the sustainability of the services, the users must share a part of the costs in the medium term. It is of extreme importance for measurement of ocean colour that the Sentinal-3 mission is launched as soon as possible which will bring the replacement of the MERIS sensor on ENVISAT. The space component is secured until 2020; however, the funding of the ground component and downstream services is still under discussion.

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3.8 Nutrients in the ocean

The nutrient substances nitrate, nitrite, ammonium, phosphate and silicate are of vital importance for the natural balance of the oceans, and without them biological growth would be impossible. Inputs from agriculture, industry and traffic, however, lead to increased primary production (eutrophication), which causes oxygen deficiencies and changes in the species composition. Meanwhile, there is good evidence that the effects of eutrophication are influenced by climatic changes.

Climate trends

Phosphate levels in riverine discharges and in German Bight sea water have clearly decreased since the mid-1980s. Owing to this development, current coastal concentrations are only about 60% above the assessment level of 0.6 µmol/L (Brockmann et al., 2007).

Riverine discharges and winter concentrations of dissolved inorganic nitrogen (DIN) have also decreased since the mid-1980s. However, current levels still clearly exceed the assessment level of 12 µmol/L (Brockmann et al., 2007) by a factor of 3.

The yearly variations in silicate concentrations are a reflection of the natural variability.

Long-term trends indicate that the measures taken to reduce nutrient loads have been effective even though assessment levels have not yet been reached.

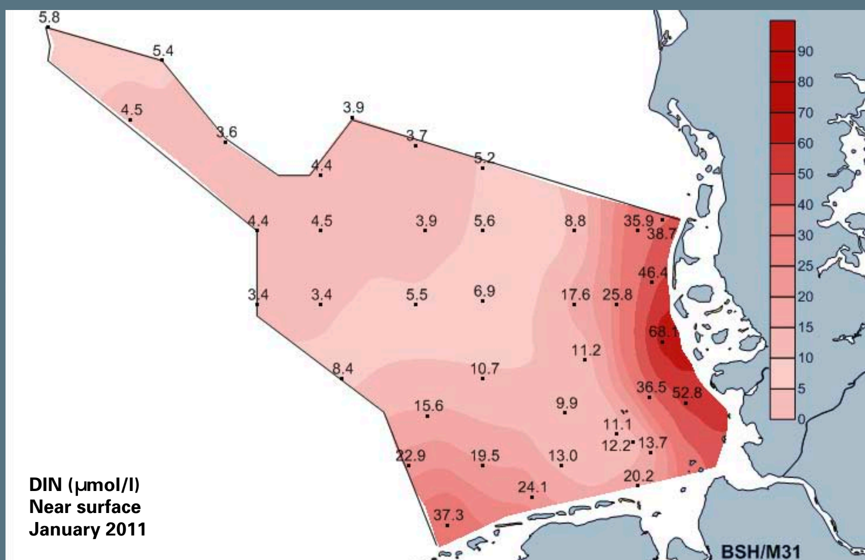
Legal framework

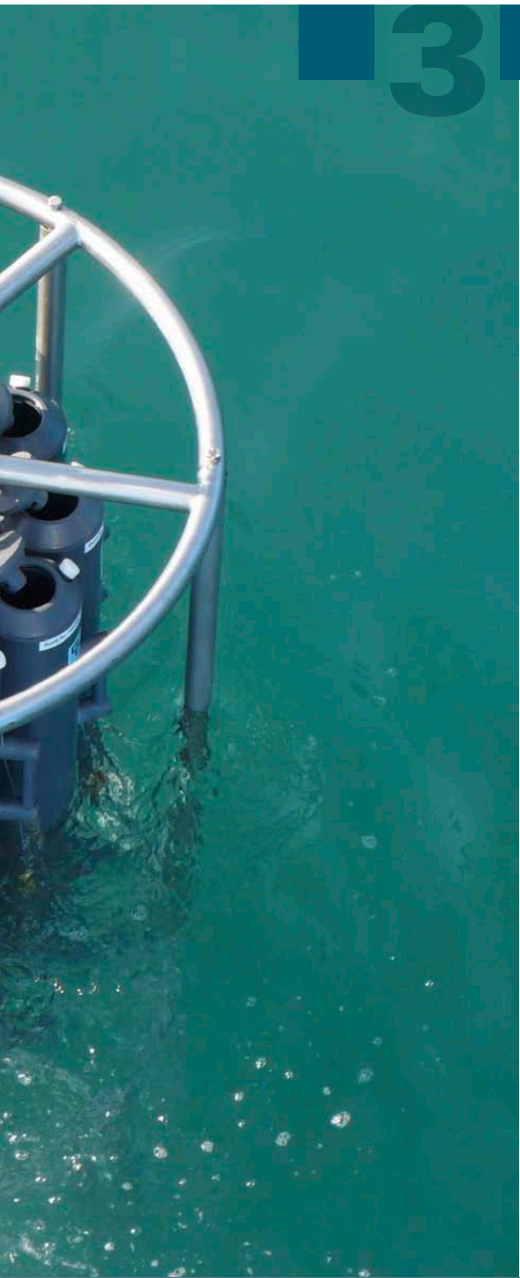
Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG, § 1, par. 9 and 11, § 5, par. 1, No. 4 and 5) in the version of 26 July 2002 (Federal Law Gazette I 2876), the marine environment of the North and Baltic Seas is to be monitored by the German Federal Government and the Länder. Germany's exclusive economic zone lies under the jurisdiction of the Federal Government. Chemical and physical monitoring is carried out by the Federal Maritime and Hydrographic Agency (BSH), which operates an automated monitoring network and routinely carries out monitoring cruises.

Fulfilment of national obligations is governed by the German Marine Monitoring Programme for the North Sea area (BLMP), international obligations by agreements made under the Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and, since recently, the Marine Strategy Framework Directive (MSFD).

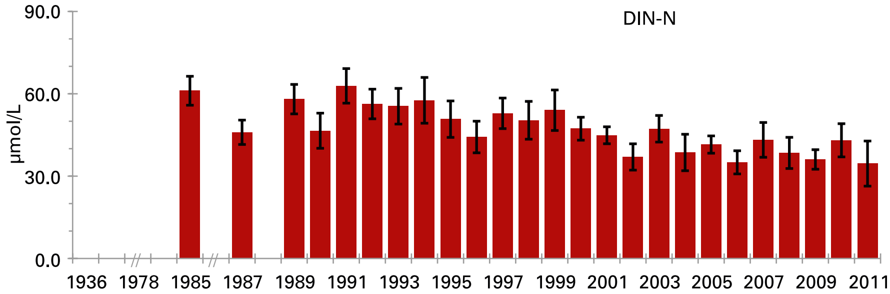
Nutrient measurements in the German Bight: the distribution of the nutrients is representative of the entire water column, which is well mixed in winter due to storm events.

▼





DIN nutrient concentrations in winter in the coastal waters of the German Bight



▲ Time series of winter nutrient concentrations in the coastal waters of the German Bight at a salinity of 30 and confidence interval (interval forecast) of 95%

International context

Marine environmental protection is an issue of global concern. With the adoption of the corresponding implementation act, the OSLO-PARIS Convention (OSPAR) came into effect for the North Sea in 1998, obliging the contracting states to regular reports to the Commission. To meet this requirement, Germany makes the data contained in the Marine Environmental Database (MUDAB) available at EU level.

Another legal basis for the protection of the marine environment in Europe is the EU Water Framework Directive (WFD), which, however, lacks detailed regulations concerning the marine environment due to the fact that the directive was developed especially for inland, transitional and coastal waters as well as groundwater.

Consequently, a special marine strategy has been developed for all European waters in the form of Directive 2008/56/EC of the European Parliament and of the Council establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) adopted on 17 June 2008.

Measurements in Germany

The BSH has routinely carried out nutrient measurements in the German Bight for more than 30 years in order to monitor the nutrient situation and, in particular, changes of nutrient inputs and their direct and indirect impacts on the marine environment. The data collected allow assessment of the effects of nutrient inputs (e.g. from agriculture, industry and transport) and possible climate changes.

The spatial distribution of dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium) shows a pattern which is typical for all soluble nutrient parameters. High nutrient levels are found close to the coast, mainly as a result of significant nutrient inputs from the Weser and Elbe rivers. In the central German Bight, levels are clearly lower due to dilution with North Sea water.

Nutrient concentrations are influenced primarily by hydrodynamic processes resulting from the mixing of river water and sea water, causing salinity distribution to be influenced by the interaction of different parameters, such as riverine discharges, the direction of net transports (residual currents) and increasing dilution. This is apparent from the inverse linear correlations between salinity and nutrient levels and which are suitable for interannual comparisons and trend estimates (Körner and Weichert, 1991).

Required resources

Monitoring of the marine environment is assured under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG). Fulfilment of national obligations is additionally governed by the German Marine Monitoring Programme (BLMP) whereas international agreements are ruled by the Oslo-Paris Convention. As an internationally co-ordinated monitoring programme, the BLMP will in future be integrated into the MSFD.

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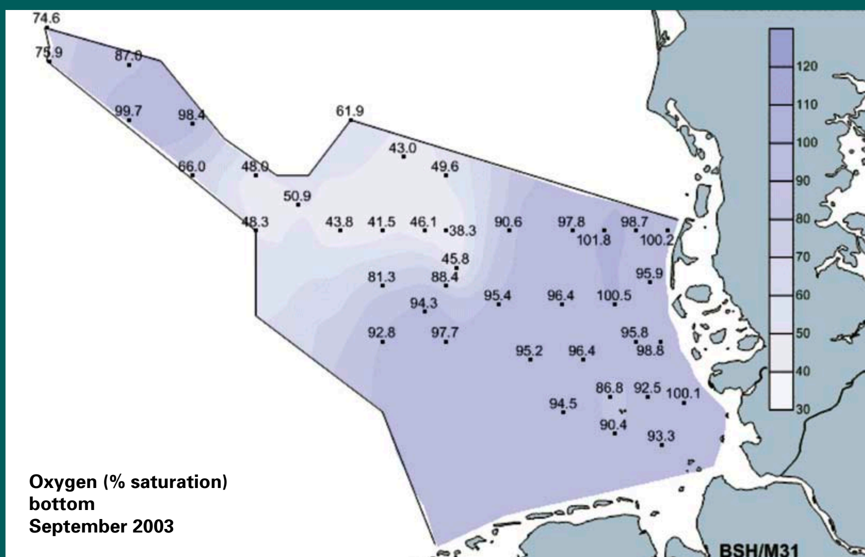
3.9
Oxygen conditions in the North Sea

All higher life in the ocean depends on oxygen dissolved in water. The amount of oxygen dissolved in water is much smaller than that in air. One litre of water contains only about 1/20th of the amount of oxygen in the same volume of air. Surface water is usually well supplied with oxygen. If there are prolonged periods of good weather during the period of algal growth in spring, oxygen supersaturation is even possible. During the second half of the year, the decomposition of organic material, a process that consumes oxygen, may lead to a deficiency of oxygen in the bottom layer.

Legal framework
Under the *Maritime Shipping (Federal Competences) Act* (SeeAufgG, § 1, par. 9 and 11, § 5, par. 1, No. 4 and 5) in the version of 26 July 2002 (Federal Law Gazette I 2876), the marine environment of the North and Baltic Seas is to be monitored by the German Federal Government and the Länder. Germany's exclusive economic zone lies under the jurisdiction of the Federal Government. Chemical and physical monitoring is carried out by the Federal Maritime and Hydrographic Agency (BSH), supervised by the Federal Ministry of Transport, Building and Urban Development (BMVBS), by autonomous monitoring stations and regular monitoring journeys.

Measurements in Germany
Since 1964, oxygen levels have been routinely measured by the BSH during its North Sea monitoring journeys. Additionally, oxygen sensor measurements with a high temporal resolution have been conducted since 1989 at the BSH's unmanned lightship stations UFS TW Ems and UFS German Bight.

The data provide information about current oxygen levels in the water column. They are included in the international eutrophication assessment of OSPAR (OSPAR Comprehensive Procedure, 2005-3) and in the initial assessment of the German North Sea (implementation of the Marine Strategy Framework Directive (MSFD), Directive 2008/56/EC of



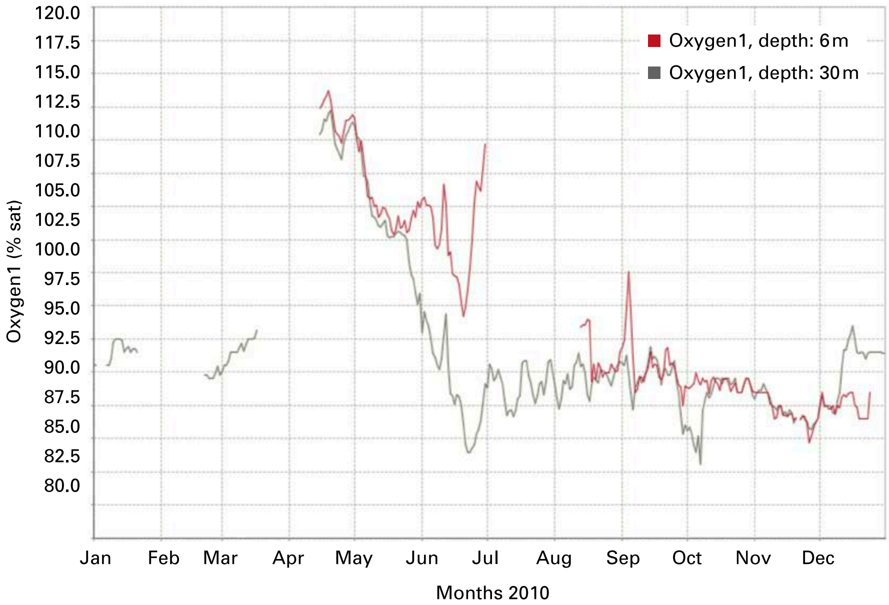
Oxygen (% saturation)
bottom
September 2003

the European Parliament and of the Council of 17 June 2008).

Dissolved oxygen concentrations in bottom water decrease throughout the summer due to microbial decomposition of dead organic material (remineralisation), which may lead to oxygen deficiency. A stable thermocline preventing oxygen transport from upper water layers may cause severe oxygen depletion in the near-bottom layers. Oxygen saturation below 80% may have a negative impact on the growth of bottom fauna. Oxygen concentrations below 20% saturation cause mortality (Bauerfeind et al., 1986; Rosenberg et al., 1991).

◀ In summer 2003, a prolonged heatwave and calm weather led to near-bottom oxygen levels of 38% (3.2 mg/l) in the outer German Bight. Conditions for benthic organisms living in sediment and on the seabed, e.g. crabs, clams, snails, sea urchins and worms, became increasingly difficult.

Oxygen saturation measurements at the unmanned lightship TW Ems



▲ 2010 oxygen saturation/oversaturation (in %) at 6 m and 30 m at the unmanned lightship UFS TW Ems in the North Sea

Climate trends

The first oxygen measurements in the North Sea were made as far back as the beginning of the last century (Gehrke, 1916). Records from that time show the occurrence of oxygen undersaturation at about 50–60% due to typical summer stratification in the water column.

Sensor data of high temporal resolution from UFS German Bight and UFS TW Ems monitoring stations, which have been recorded since 1989, continuously reflect the prevailing oxygen conditions. These data are essential for international assessments of eutrophication and in the global climate change debate.

International context

All measurement data collected within the framework of the German Marine Monitoring Programme (BLMP) are stored in the MUDAB Marine Environmental Database and reported to the International Council for the Exploration of the Sea (ICES). The data are thus available for international eutrophication assessments and climate debates.

In future, the data will be compiled in international Reporting Sheets as part of the MSFD.

Required resources

Monitoring of the oxygen situation in the marine environment is assured under the Maritime Shipping (Federal Competences) Act. National obligations are specified in the German Marine Monitoring Programme (BLMP) and will be integrated into an internationally co-ordinated monitoring programme under the MSFD.

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4.1
Runoff

The most comprehensive data possible on water resources, in addition to their importance today for climate studies and climate-impact research, have long been essential in the context of a wide range of socioeconomic and ecological concerns. The validity of statements about these issues depends on the quality of the data material from which they are derived: outputs cannot be better than the data on which they are based.

Climate trends

Ancient civilisations constructed water gauges and documented the observations made from them. This was often a prerequisite for the existence of societies that depended on the organised and efficient use of water, the basis of life. There is a 52-year time series of water levels of the Nile from as long ago as 2800 B.C. In Germany, water gauges have been used since the 18th century. The oldest and longest time series of water levels are from the Elbe at Magdeburg (since 1727) and the Rhine at Düsseldorf (since 1766).

Long runoff time series are also essential for today's technological society. They enable spatial and temporal variation of runoff to be analysed, usable water resources and high and low water risks to be calculated, and the impacts of human activities (climate change, changes in land use) to be investigated. They provide the basis for the development and deployment of water management strategies, concepts and decisions.

Legal framework

As a federal country and member of the European Union (EU), the Federal Republic of Germany is subject to water-related regulations under EU law (Water Framework Directive, High Water Framework Directive) and has to respond to federal concerns as well as to those of the Länder. The *Federal Water Act* (WHG) is the basic legislation, which comprises the opening clauses of many of the regulations drawn up by the Länder. Federal navigable waterways, together with their water level and high water information services, are regulated by the *Federal Waterways Act* (WaStrG). The use of data is regulated by the *Federal Environmental Information Act* (UIG).

Measurements in Germany

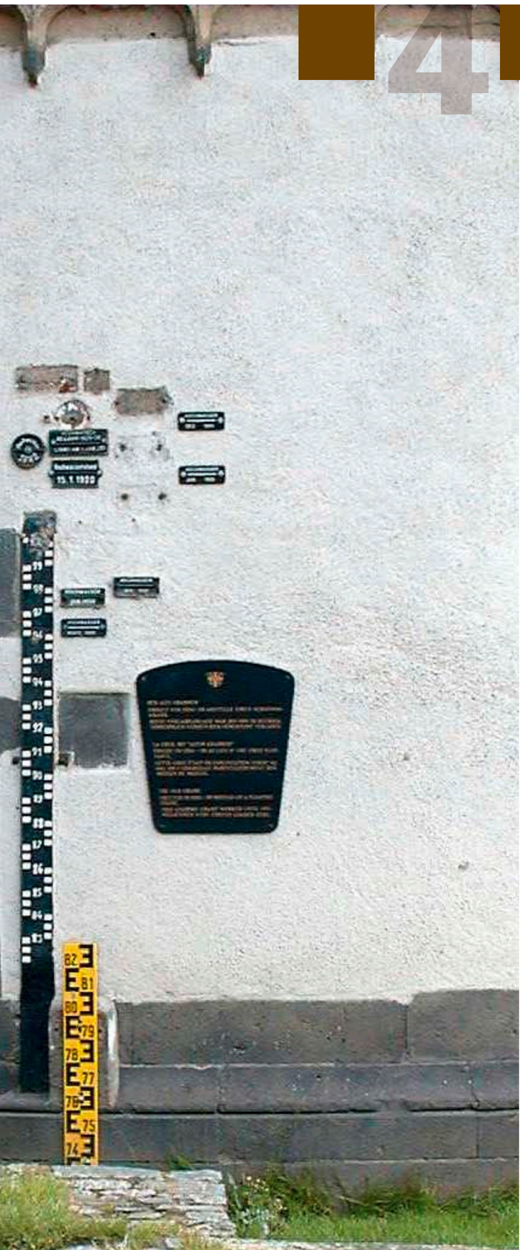
The hydrological measuring network in Germany comprises the overarching federal water gauge network, operated by the German Federal Waterways and Shipping Administration (WSV), as well as the measuring stations operated by 15 of the German Länder or local authorities and third parties (e.g. water utility companies). It consists of about 4,250 hydrological gauges, of which about 3,000 also provide throughflow measurements. This network monitors and keeps records on the entire inland waterways system (down to the level of ditches), in total around 500,000 km of waterways.

The WSV supervises the large shipping waterways in the basins of the rivers Rhine, Danube, Elbe, Oder, Weser and Ems, where it operates about 620 water gauges, of which 163 also measure runoff or throughflow.

The German Hydrological Yearbook (DGJ) publishes daily data from 1,172 water gauges on runoff alone, corresponding quarterly and long-term totals, and information from a large number other measuring stations, including data series for water levels, tides, water temperature and suspended matter.

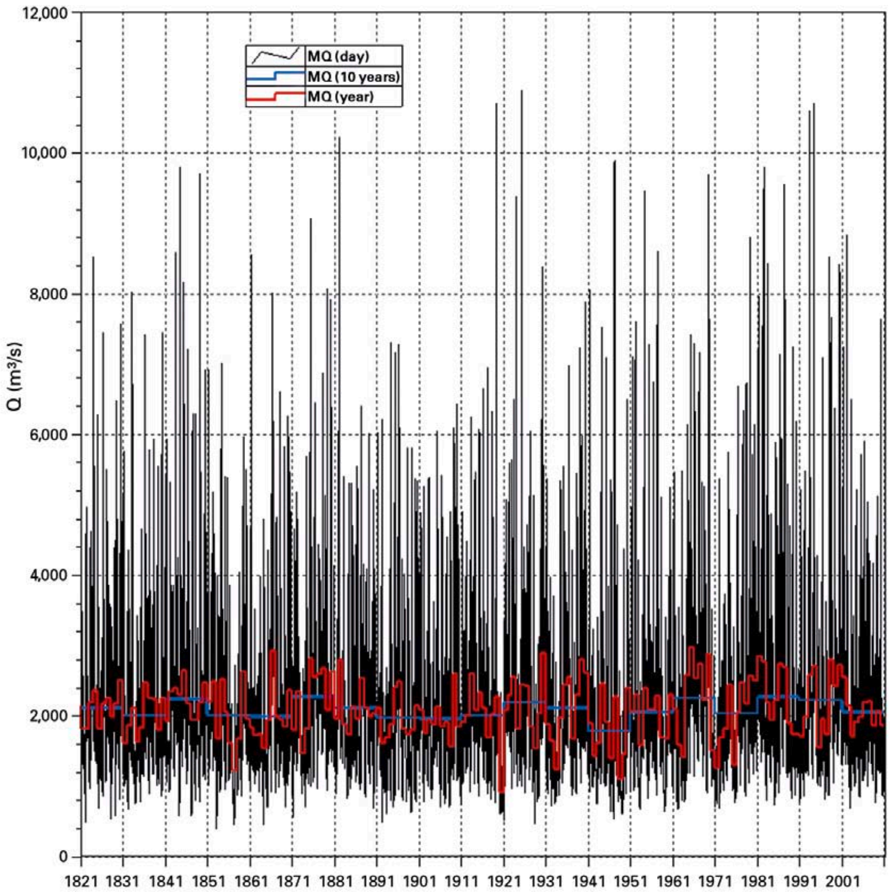
The average length of runoff time series in the DGJ is 55 years. However, as standard practice, the time series are cut off at 1931, even when older data exist: in almost all basins, for example, there are observational records from water gauges going back more than 100 years; the largest number are in the Rhine (20 stations), Danube (17) and Elbe (15) basins.

In addition to the DGJ, other important archives and distribution centres of data from water gauges on federal waterways include the databases of the regional WSV offices and the overarching data



archives held by the Federal Institute of Hydrology (BfG). The Länder maintain their own databases for stations that they operate.

Mean runoff at Cologne water gauge (Rhine) since 1821



▲ Daily, yearly and decadal runoff averages (Q in m³/s) since 1821 (part of a time series going back to 1816) recorded by the water gauge on the River Rhine at Cologne (MQ = average runoff)

International context

The Global Runoff Data Centre (GRDC, see Chapter 5.2), based in Germany, receives runoff data from more than 800 stations operated by federal authorities and the Länder, which sustain the GRDC database and contribute to the water data archives of research groups in the EURO-FRIEND water programme of UNESCO. The GRDC is the conduit for contributions to the Global Terrestrial Network for River Discharge (GTN-R) maintained by GCOS, the Global Terrestrial Observing System (GTOS) and the World Meteorological Organization's (WMO) programme for Hydrology and Water Resources. Selected real-time data on water levels and runoff are used for medium- and long-term flood warnings by the European Flood Awareness System (EFAS), based at the EU's Joint Research Centre in Ispra, Italy.

Required resources

The demand for hydrological statistics is growing, due to the ever-increasing importance of hydrological parameters for politics and society. To this end, there is an urgent need to develop modern methods for statistical analysis of hydrological data, as well as for improved resource provisioning.

http://www.bafg.de

4.2

Water use

In Germany, demographic and technological developments as well as changes in the climate will heavily influence the demand for water and its availability, so that knowledge about trends in water consumption by the main user groups, i.e. industries, private households and agriculture, is gaining in importance.

Trends

Long time series of data illustrate the temporal variations in water uses and provide a basis for further analyses and studies.

Over the past 20 years, the volumes of water withdrawn by thermal power stations, mining and processing industries as well as public water supplies have decreased by roughly 30%. This is because of technological advances as well as systems of multiple water utilisation and recycling.

Public water supplies provide about 99% of private households and small businesses with drinking water, which is mainly withdrawn from groundwater. The daily drinking-water consumption in private households was around 122 litres per inhabitant and day in the year 2007 and thus has been reduced by 25 litres per person since 1990. This development can be explained mainly by changed consumer behaviour. Average consumption figures in the German Länder reveal a wide range, from 135 litres per inhabitant and day in North Rhine-Westphalia to 85 litres in Saxony.

Legal framework

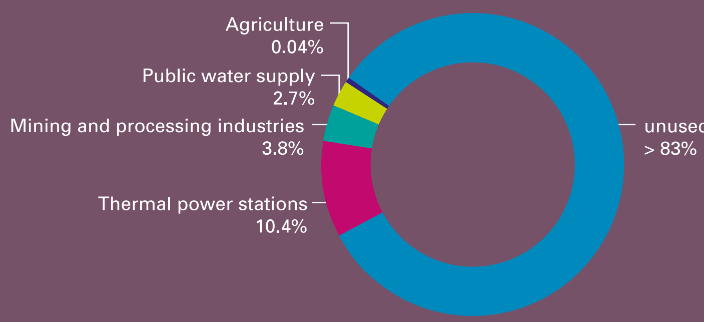
Water use in Germany is ruled at an overall federal level by the *Federal Water Act* (WHG) of July 2009 (latest amendment in December 2011), which implements the *European Water Framework Directive* (WFD) and – along with subsidiary national directives – regulates the protection and management of groundwater and surface-water resources. The aim of sustainable water management in accordance with the WHG is the preservation of the ecological functions of water for the benefit of the general public and in the interest of individuals. Any use of water, including abstraction for different purposes, requires an official permit. The WHG defines the nationwide applicable requirements that are enforced by the authorities of the Länder.

Measurements in Germany

Data on water abstraction by municipal enterprises for supplies to private households and small businesses as well as by all types of processing and manufacturing industries, power utilities and agricultural businesses are collected at Länder level by the corresponding statistical offices. Processing and evaluation of the data at the federal level is done by the Federal Statistical Office (DeStatis). Surveys are conducted every three years. The current legal basis is the Environmental Statistics Act of 16 August 2005. The data are evaluated for different administrative and non-administrative area units and are used for public information and as an aid to political decision-makers in matters of water conservation. The main users of these data are national and international authorities, institutions and associations, as well as interested private persons.

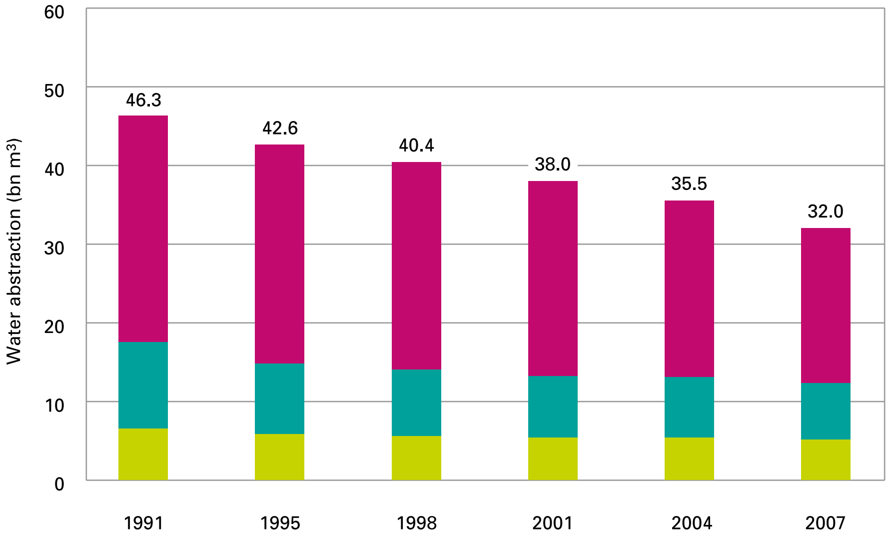
Water resources and water use in Germany in 2007

Potential water resources 188 billion m³ = 100%



Source: Federal Environment Agency (UBA), 2009
Data: DeStatis, 2009; Federal Institute of Hydrology (BfG), 2006

Water abstraction for public water supply, industries and thermal power plants



Source: DeStatis, 2009

The water user groups industry (including power utilities), private households and agricultural businesses withdraw different volumes of water from aquifers and surface water bodies. Industrial and agricultural businesses often operate their own water-tapping facilities to meet their demands, while private households are usually supplied by municipal waterworks.

The greatest group of water users are thermal power plants, which abstract water for cooling purposes and return nearly the whole amount after use back into the natural water cycle. The second rank among water users is held by mining and processing industries.

Thus, the total volume of water abstraction of 32.1 billion m³ corresponds to less than 20% of the potential water resources. This means that presently more than 80% of the water resources remain unused.

International context

Scientific assessments of water scarcity and water shortage investigate the ratio between water resources and water demand. International institutions, such as the Organization for Economic Cooperation and Development (OECD), the European Commission (EC) and the European Environmental Agency (EEA), evaluate the national data from certain angles in order to highlight problems in the water sector and to derive recommendations for action. At the same time, they pool the data provided by the individual states in international databases and make this information tool available to all interested users worldwide.

The German data on water quantities are transmitted to these organisations every other year as part of the joint questionnaire project of the EU's statistical office Eurostat and the OECD (Questionnaire on the state of the environment in the EU's Member States). These results are also made available to the EEA and the United Nations Environment Programme (UNEP).

Required resources

In publications on non-public water supply, data about water abstraction for agricultural irrigation should appear as an economic sector of its own.

It would be desirable to adapt the frequency of national data polls to European standards.

http://www.bafg.de http://www.uba.de

4.3 Groundwater

Groundwater meets about 75% of Germany's demand for drinking water. The groundwater resources that are annually recharged by precipitation are unevenly distributed among the regions of the country. Therefore, large conurbations in Germany are often connected to remote public water supplies. In order to safeguard the use of available water resources, the German Länder are responsible for the monitoring and evaluation of groundwater, including both quantity and quality. Maintaining the good chemical status of groundwater requires not only the protection of groundwater quality but also the prevention of damage to groundwater-dependent surface water bodies and terrestrial ecosystems. The river basin management plans drawn up by the Länder describe the current condition of the aquifers and define goals and actions in the context of EU regulations.

Trends

It is relatively difficult to determine long-term trends in Germany from long time series of groundwater levels, because most measuring stations are impacted by human activity. In one of its studies, for example, the North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection (LANUV) could use only 416 measuring wells out of 4,000 for such purpose. In the period 1970 to 2008, trends at these sites were very uneven, with nearly equal numbers of positive and negative trends and no distinct regional pattern. In summary, results showed more negative trends, i.e. decreasing groundwater levels, in the months from April to July and an opposite tendency in August and September. However, the variations detected amounted to only a few millimetres per year and are therefore of purely statistical interest.

More significant changes were observed at 130 observation wells unimpacted by human activity in Saxony between 1976 and 2006. The graph shows a clear, mainly negative trend through the whole year as well as through the seasons.

In Mecklenburg-Western Pomerania, the overall trend in groundwater levels was also more or less negative from 1980 to 2006, although it should be noted that in this case not all observation wells were unaffected by human activity.

Measurements in Germany

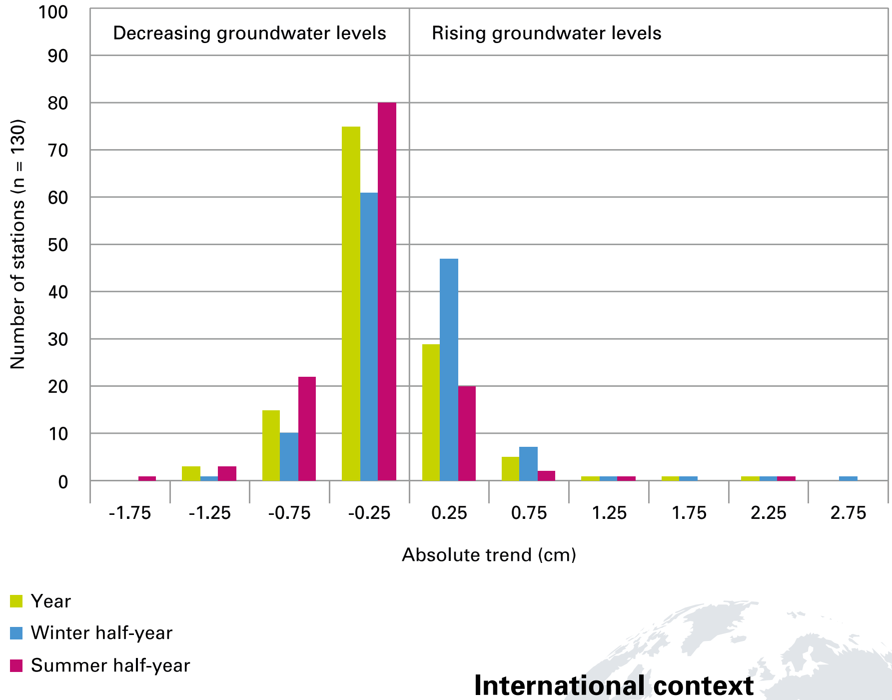
The Groundwater Services of the Länder operate full-coverage groundwater observation networks. The data are pooled, managed and made available by databases maintained by the responsible agency in each Land (e.g. the Agency for the Environment and Geology in Hesse). These Land-specific databases are mostly web-based geo information applications and in some cases can be accessed by the public on the Internet.

Key activities of these networks include monitoring groundwater levels, groundwater quality and untreated water in drinking-water protection areas. The networks collect data on water use for enforcement of the Water Usage Payment Act (also known as 'water penny'), and on aquifers in accordance to the Water Framework Directive (WFD) of the European Commission.

Observed data for water-management are a key prerequisite for planning by water utility companies and for the definition and enforcement of standards by the authorities.

To monitor the chemical condition of groundwater, the Länder operate 5,682 observation wells as background stations in undisturbed aquifers and another 3,979 operational stations in aquifers affected by the environment. A further 8,960 wells are used to monitor quantitative indicators of groundwater condition. A monitoring network consisting of about 800 stations provides data for reports to the European Environment Agency (EEA).

Analysis of trends in Saxony from 1976 to 2006



Legal framework

The *Water Framework Directive* (WFD) and its daughter, the *Groundwater Directive* (2006/118/EC, GWD), constitute the principal legal foundation for groundwater protection in Germany. At a national level, groundwater protection is regulated by the *Federal Water Act* (WHG) and the *Federal Soil Protection Act* (BBodSchG). Since the reform of the German Constitution in 2006, the Federation has had competing legislative powers on issues relating to the water budget, which means that legislation enacted by the Länder may be overridden by federal acts. The legal basis for quantitative and qualitative monitoring and evaluation of the groundwater situation in the Länder is given by the corresponding water legislation adopted by each Land in response to the WHG and the amended Groundwater Ordinance of 2010.

International context

The Federal Institute for Geosciences and Natural Resources (BGR) is a partner in the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), an initiative of UNESCO and the World Meteorological Organization (WMO) carried out in co-operation with the International Groundwater Resources Assess-ment Centre (IGRAC). The aim of the programme is to produce a global map of groundwater resources. On the basis of this map, a geo information system (GIS) will be developed to make all groundwater-relevant data available in digital form. At the European level, the information network EUROWATERNET, established by the European Environment Agency (EEA) in collaboration with the European states, has been in operation since 1998.

Required resources

Modern methods for processing spatial data using GIS are required and will become increasingly important, alongside Internet-based user-friendly interfaces for evaluation and presentation of the data.

http://www.bafg.de

4.4 Stable isotopes in precipitation

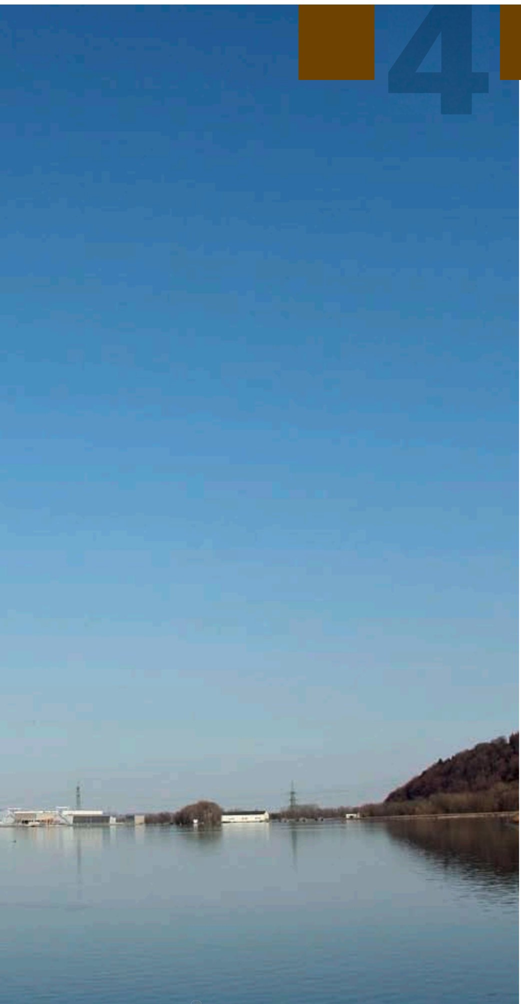
Ratios of the most frequently occurring stable isotopes of water in precipitation (i.e. $^{18}O/^{16}O$ ($\delta^{18}O$) and $^{2}H/^{1}H$ (($\delta^{2}H$)) vary over space and time, depending on the source of the water and the conditions (moisture and temperature) during cloud formation and rainfall. Absolute ratios and seasonal variations in the distribution of water isotopes measured in precipitation at individual locations reflect local temperature, continentality, latitude and altitude. Stable isotopes thus provide information about the sources of water, the history of the rainfall event and air mass trajectories as well as temperature changes and climate change effects.

Climate trends
Long-term data on stable isotopes at high spatial and temporal resolutions are of great importance when studying seasonal differences in precipitation and changes in air mass trajectories. Stable isotopes of water in precipitation are also used as environmental tracers in hydrological modelling. To obtain accurate results, this requires input time series that correspond to at least four to five times the mean residence time of water in the system. The empirical, linear relationship between temperature and stable isotopes in precipitation, which can be safely identified only from long-term data sets, allows us to identify regions impacted by climate change.

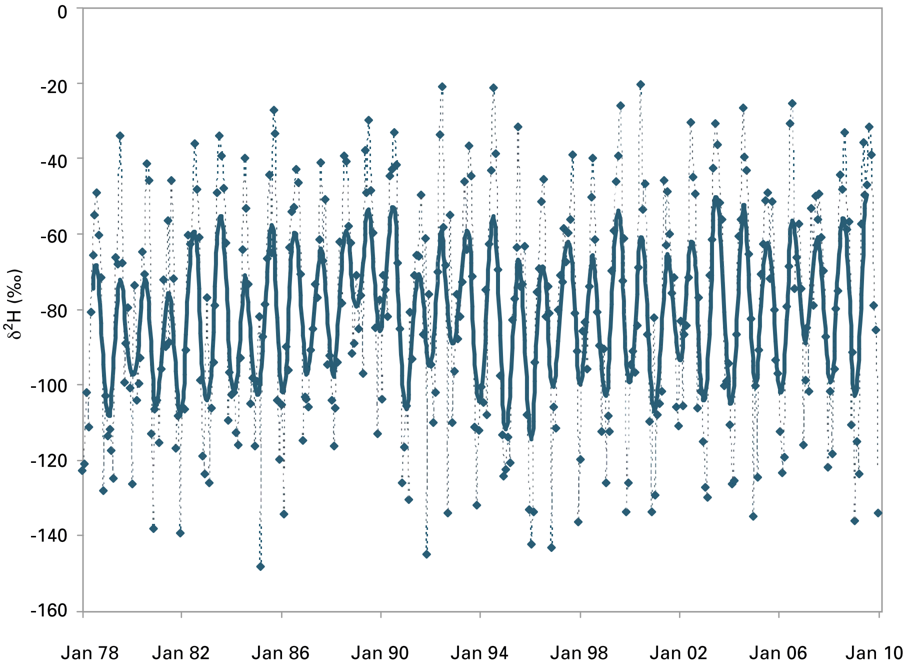
Legal framework
Since 1997, stable water isotopes in precipitation have been measured at the Institute of Groundwater Ecology (IGOE) at the Helmholtz Zentrum München - German Research Center for Environmental Health (HMGU) according to a contractual agreement between the HMGU and the Deutscher Wetterdienst (DWD). The data obtained are the property of the IGOE and are available to the DWD upon request. Publication of IGOE data needs approval by the contact person; data are freely available to the public after publication.

Measurements in Germany
Samples taken monthly or when precipitation events occur have been collected for isotope analysis at 29 meteorological stations all over Germany from 1973 to the present (see map). Since 1978, 16 of these stations (Cuxhaven, Braunschweig, Berlin, Bad Salzuflen, Emmerich, Koblenz, Wasserkuppe, Hof, Trier, Würzburg, Karlsruhe, Stuttgart, Regensburg, Konstanz, Weil am Rhein, Garmisch-Partenkirchen) have been operated within the Global Network for Isotopes in Precipitation (GNIP), a joint programme of the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO). Since 1997, monthly samples have been collected at nine stations (Schleswig, Fehmarn, Neubrandenburg (replaced by Greifswald in 2002), Seehausen, Artern, Dresden, Görlitz, Kahler Asten, Passau) and event-based samples at three stations (Arkona, Norderney, Hohenpeissenberg), all operated by the DWD. Event-based samples are also taken at the institute's own station in Neuherberg.

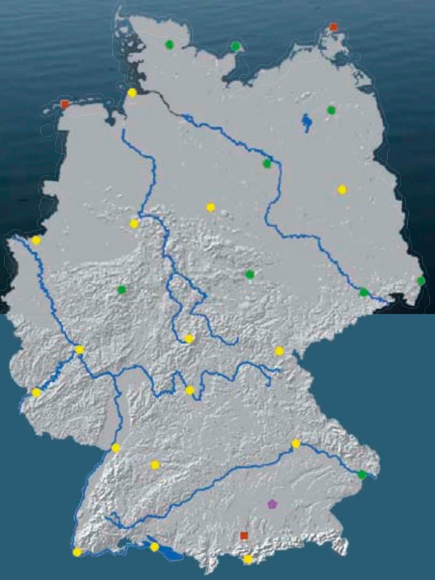
To obtain a monthly, mixed sample, a station's daily precipitation samples are accumulated and mixed over the month in a 5,000 ml PE bottle. Every month, a volume of 1,000 ml is taken of this cumulative sample and stored separately in 1,000 ml PE bottles to be sent to the IGOE for analysis once a year. During sampling and shipping, care is taken that the lids are closed properly to avoid evaporation. All precipitation samples are analysed at the IGOE for $\delta^{18}O$ ($\pm$0.15‰) and $\delta^{2}H$ ($\pm$1‰) contents in triplicate.



Monthly δ²H concentrations in precipitation over Berlin (measured and calculated values)



▲
Monthly measured δ²H concentrations in precipitation over Berlin (diamond dots and dashed line) with calculated 12-month running mean (solid line)



- Monthly samples since 1973 (GNIP)
- Monthly samples since 1997 (DWD)
- Daily samples since 1997 (DWD)
- Daily samples since 1997 (HMGU)

▲
Sampling network for the analysis of water isotopes in precipitation (yellow: stations that have been monitored on a monthly basis since 1973 and are part of the GNIP database; green and red: stations operated by the DWD on a monthly and event basis, respectively; purple: event-based station Neuherberg, operated by the IGOE since 1997 with daily sampling)

International context

The findings of the German isotope network are included in the IAEA's and WMO's joint Global Network for Isotopes in Precipitation (GNIP). After publication, the data are available online through the Water Isotope System for Data Analysis, Visualization and Electronic Retrieval (WISER), which contains time series of stable isotopes in precipitation around the globe. Without a doubt, the German data set of water isotopes in precipitation is unique in the world on account of its quality and continuity, with high temporal (monthly to daily data, partly covering more than 35 years) and spatial resolution (29 stations equally distributed across the country).

Required resources

Analysis of the stable isotopes in water at the IGOE will be continued. The IGOE offers the infrastructure (analytical instruments) and manpower (technical assistant) to analyse δ¹⁸O and δ²H precipitation samples of the DWD free of charge. The data have been used for ongoing research at the IGOE (Maloszewski et al., 2006; Stumpp et al., 2007; Stumpp et al., 2009; Stumpp and Maloszewski, 2010) and in collaborative studies with other research partners (e.g. University of Freiburg, Technical University Dresden, Karlsruhe Institute of Technology).

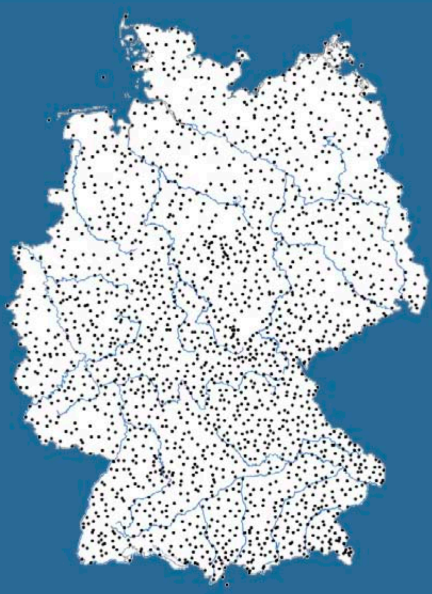
http://www-naweb.iaea.org/napc/ih/IHS_resources_isohis.html

4.5
Snow cover

Snow cover is a major factor influencing the climate. Therefore, the parameters snow depth and new snow depth as well as the related parameters type of snow cover, state of soil and water equivalent are of particular interest in the context of the expected anthropogenic climate warming, especially in the fields of tourism, water management and transport.

Climate trends
Against the backdrop of global climate warming, most stations have recorded a decrease in the snow cover season, but with large variations from year to year depending on the total amount of precipitation, which by its nature is also highly variable. The few outliers in the one or other direction (such as in 2010 or 1989) have no effect on the general trend towards less snow cover, especially in the last 20 years.

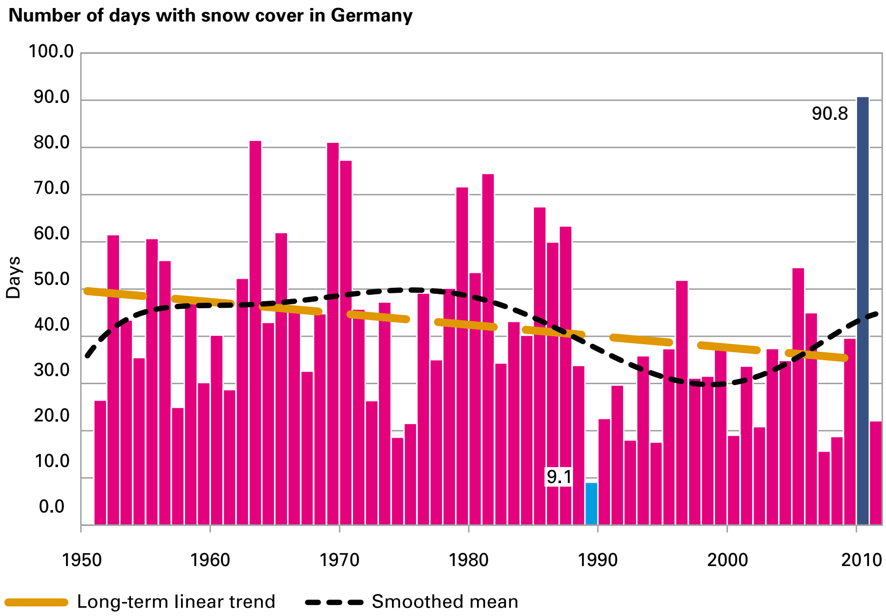
Legal framework
The *Law on the Deutscher Wetterdienst* (§ 4) gives the DWD responsibility for short- and long-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and for the operation of the required measurement and observing systems.



▲
Distribution of stations where snow depth and other snow parameters are recorded

Measurements in Germany
The Deutscher Wetterdienst (DWD) operates a network of surface weather stations classified into climate and precipitation stations, of which about 2,000 currently take snow measurements. The number of DWD stations, from which snow measurements are available, varies over the time and depending on the monitoring programme. On average, the availability of digital data of snow parameters from climate stations starts in 1951. The precipitation stations in the former Federal territory have registered and archived data on soil state, weather events and snow depth since about 1979. The data archive includes snow data from stations in the territory of former East Germany in electronic format since about 1991.

Other snow measurements are only available in paper form and are currently being digitised and archived



▲ Area averages of the annual number of days with snow cover in Germany for the period 1951–2011

in the framework of various projects. From before 1950, the data archive therefore contains no more than a couple of time series and from before 1935 only very few single digitised time series of snow measurements.

Alongside the DWD stations, there exist additional snow measurement programmes which are carried out by other institutions or individual persons. However, only minor parts of these data series are included in the DWD's database, as they often do not meet the high standards of representativeness, measurement methods and continuity of operation.

The snow depth is measured manually using a snow measuring board with snow stake or measuring stick. With the change to automated weather stations, manual measurement was replaced by snow depth sensors.

International context

The synoptic reports from 180 stations are distributed worldwide on a routine basis. For a selected number of stations, quality-checked monthly climatological information is made available in the form of CLIMAT reports. The stations at Frankfurt, Hamburg, Hohenpeissenberg and Lindenberg are part of the GCOS Surface Network (GSN).

Required resources

The sustained operation of existing measurement stations can be regarded as substantially secured. However, the level of automation must be driven further, the high number of staff further reduced and limited to observations at air fields and climate reference stations. The resulting change in the measurement methods from spatially averaged measurements to sensor recording at single ground points is expected to cause inconsistencies in the time series of snow cover.

http://www.dwd.de

4.6

Glaciers and permafrost

The results of alpine glacier research show clear evidence of climate change. Whereas the glacier retreat during the first half of the 20th century can be related to non-anthropogenic influences, the rapid decline over the past 30 years proves the influence of mankind on glaciers and climate, with consequences also for permafrost in mountain regions.

Climate trends

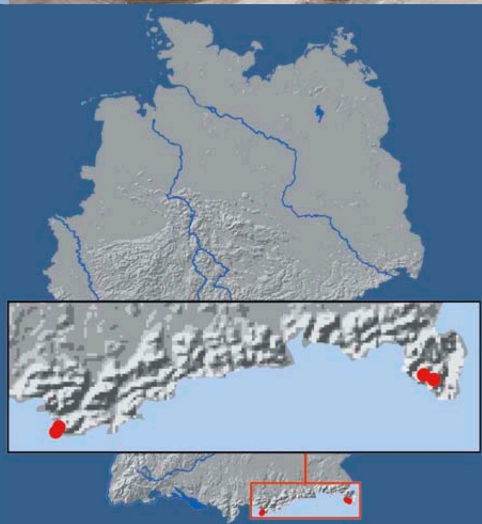
The mapping of the Bavarian glaciers, the results of which suit the application of the geodetic method, began in 1889 for Blaueis, in 1892 for Northern and Southern Schneeferner and in 1897 for the Watzmann Glacier. The shortest time series is that for Höllentalferner, starting in 1949. Stretching from 2,368 m to 1,910 m in altitude (1999), Blaueis is the lowest and northernmost alpine glacier (Hagg, 2008). The geodetic method shows a loss of 80% in area for Southern Schneeferner and 73% for Northern Schneeferner between 1892 and 2009. Watzmann Glacier lost 79% of its area between 1897 and 2009; the area of Blaueis shrank from 16 ha in 1889 to 8 ha, and that of Höllentalferner has lost 18% since 1950. The mean thicknesses lie between 16.8 m (Northern Schneeferner) and 3.8 m (Blaueis). Northern Schneeferner had the greatest losses in volume between 2006 and 2009, Watzmann Glacier the largest gains between 1970 and 1980 (Hagg et al., 2008). These changes in mass correlate well with the results for other glaciers of the eastern Alps (see Chapter 6.2).

Legal framework

The Glaciology department of the Commission for Geodesy and Glaciology (KEG) of the Bavarian Academy of Sciences and Humanities (BAdW) is the sole national institution that studies the behaviour of German glaciers over the long term. The legal framework for the Commission's work comprises § 2 par. 1-3 and § 19 par. 2 of the statute of the BAdW. The observation of permafrost falls within the legal competence of the Bavarian Environment Agency (*Law on the competence of state development and ecological questions*, § 5) for the treatment of questions in the field of geological engineering.

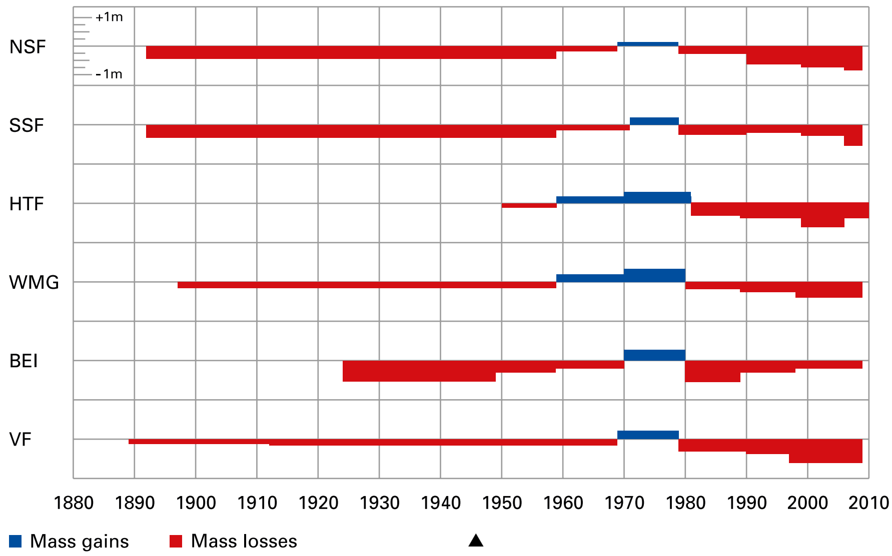
Measurements in Germany

The KEG monitors all five Bavarian glaciers – Northern and Southern Schneeferner, Höllentalferner on Zugspitze and Watzmann and Blaueis in the Berchtesgaden region – using the geodetic method. This method is based on the comparison of geodetic measurements made approximately every ten years, which provide the changes in glacier area and surface, thus enabling the calculation of the mean altitudinal change over the given period. Assuming a mean ice density, the mass balance is thereby derived (see graph). For the period 1962/63 to 1968/69, the direct glaciological method was also applied to one of the five glaciers, namely Northern Schneeferner. This method supplies annual mass balance sums for the glaciological year (from 1 October to 30 September of the following year) derived from the difference between mass gains (mainly due to precipitation in winter) and losses (mainly due to melting in summer). For all Bavarian glaciers, measurements of ice thickness are available that have been carried out between 2006 and 2010 using georadar technology.



http://www.lfu.bayern.de/geologie/massenbewegungen/projekte/

Time series of geodetically determined mass balances of the five Bavarian glaciers and Vernagtferner in Austria



◄ Zugspitzplatt with Northern Schneeferner (August 2011)

▲

NSF = Northern Schneeferner
SSF = Southern Schneeferner
HTF = Höllentalferner
WMG = Watzmann Glacier
BEI = Blaueis (near Berchtesgaden)
VF = Vernagtferner (Austria)

The thickness of the bars represents the average mass change per year (unit: cm water equivalent per year) for the given period, calculated from altitudinal variations (m/a) by applying a mean ice density of 900 kg/m³. One can clearly recognise the mass gains phase in the seventh and eighth decade of the 20th century (blue), the periods of losses of glacier mass (red) after 1889 and 1980 and the close-to-balance period for Blaueis between 1889 and 1924. The bottom row shows the values for Vernagtferner in the Ötztal Valley, Austria (see Chapter 6.2).

Permafrost, i.e. continuous underground temperatures below 0°C, plays only a small role in Bavaria. Its thawing can result in damaging rockfalls and settlements. In a study within the Alpine Space project PermaNET, Zurich University ran a model which showed that the area mainly affected by permafrost is the northern rocky sides of the region, with a total area of approx. 65 km². The dimensions have for the first time been presented on a map that depicts the probability of permafrost using different shades. The Bavarian Environment Agency (LfU) has run an observatory station on the Zugspitze summit since 2007, which will supply long-term documentation of changes in permafrost.

International context

The results of glacier measurements made by the KEG are regularly presented in the two most important publication series for glaciological data. These are issued by the World Glacier Monitoring Service (WGMS) in Zurich, Switzerland, and by the Institute of Arctic and Alpine Research (INSTAAR) and the National Snow and Ice Data Center (NSIDC) in Boulder, USA. The German results are thus made available to the most important international organisations: UNEP, WMO, UNESCO and ICSU. Very close co-operation exists with the universities of Innsbruck (Austria), Zurich (Switzerland) and Milan (Italy). Research projects are undertaken together with national and international groups in Central Asia. The permafrost surveys are carried out by the LfU in co-operation with universities, agencies and governmental departments in Austria, Switzerland, Italy and France within the framework of the Bavarian PermaNET component.

Required resources

Currently, the glaciological work at the BAdW is funded through the Academies Programme of the Union of the German Academies of Sciences and Humanities. This funding ends with 2015 and the BAdW is striving to transfer funding responsibility to the Bavarian state; this is not as yet secured.

http://www.permanet-alpinespace.eu http://www.bayerische-gletscher.de

4.7

Albedo

Surface albedo represents an important component of the radiation balance at the earth's surface. Trends in surface albedo influence radiation from the earth's surface and thus also the climate system. Effective cloud albedo defines the albedo of clouds relative to cloudless sky. Even a small percentage change in effective cloud albedo would have an effect comparable in magnitude to the anthropogenic greenhouse effect; a long-term change would therefore have huge consequences for the interpretation of temperature measurements.

Legal framework

The work of the Satellite Application Facility on Climate Modelling (CM SAF) is embedded, on the one hand, in the legal framework of the Deutscher Wetterdienst (DWD); on the other, it is undertaken in accordance with contractual agreements between the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the DWD. CM SAF is tasked with long- and short-term registration, monitoring and evaluation of meteorological processes as well as the structure and composition of the atmosphere, and with the provision, archiving and documentation of corresponding meteorological data and other products in accordance with § 4 of the *Law on the DWD*. Detailed work plans and task specifications are set out in accordance with these aims in a five year contract between EUMETSAT and the DWD, with the participation of the concerned partner organisations of CM SAF.

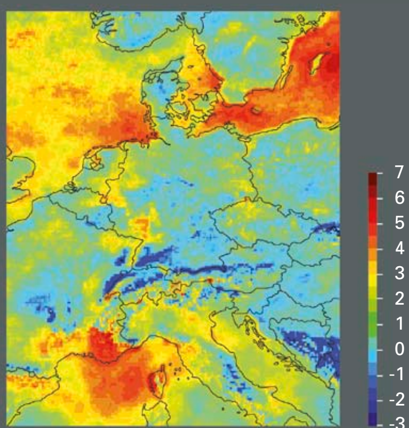
Climate trends

The CM SAF (see Chapter 5.9) currently has a 23-year time series for surface albedo and effective cloud albedo, which will be extended to 30 years within the framework of the EUropean Reanalysis and Observations For Monitoring (EURO4M) project (www.euro4m.eu). Long series enable trends and extremes of surface albedo to be analysed, which, in Germany, are generally related to variations in winter snow cover. This may be the reason why, on the basis of the 23-year time series, no clear trend in surface albedo can be discerned.

By contrast, trends in effective cloud albedo can be clearly identified. The inset map shows that the magnitude of the trends in solar irradiance can be in the order of several W/m² per decade. Until now, however, this parameter has been hardly taken into account by climate monitoring programmes. The main reason for this has been the lack of data. Effective cloud albedo cannot be determined from surface measurements.

Measurements in Germany and in Europe

Comprehensive data on surface albedo of a sufficiently high quality are only obtainable from satellite or reanalysis data. Currently available reanalysis data have a very coarse spatial resolution (> 50 km²). Comprehensive high-resolution data are at present only available from satellite observations. In Europe, provision of high-quality data on surface albedo at high temporal and spatial resolutions is assured by Satellite Application Facilities (SAFs), financed by the national meteorological ser-



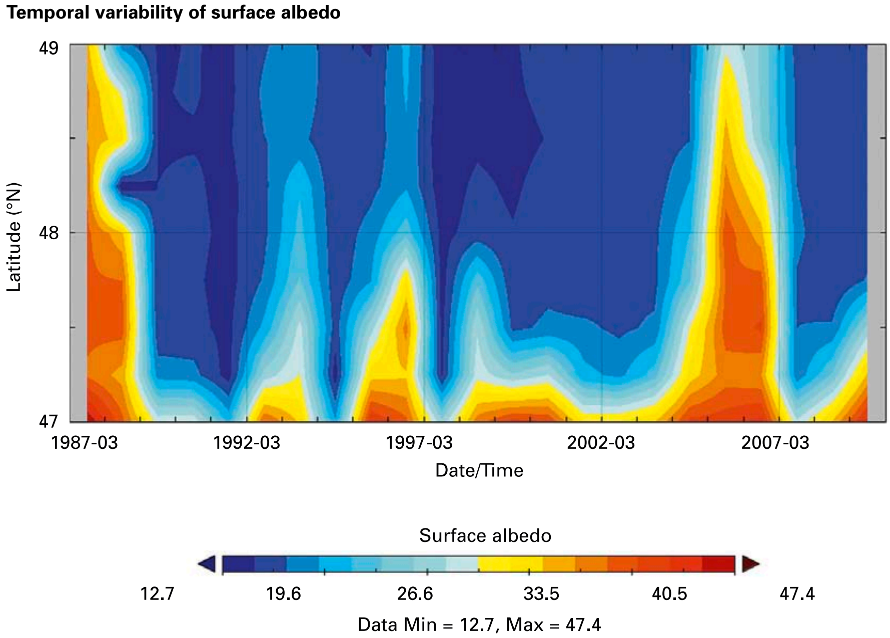
Trends in solar irradiance (1982–2005) ▶ resulting from long-term changes in effective cloud albedo

vices and EUMETSAT, such as those on Land Surface Analysis (LSA SAF) and Ocean and Sea Ice (OSI SAF).

Long time series of surface albedo, the basis for analysis of climatologically relevant trends and extremes, are currently only available from CM SAF and EUMETSAT (Govaerts, 2008).

The creation of comparable quality raster data from surface measurements is not possible due to the low spatial density of measuring stations. In Germany, there is only one adequately equipped measuring station with long-term data on surface albedo (Falkenberg), which is operated by the DWD.

Comprehensive data on effective cloud albedo of a sufficiently high quality are only obtainable from satellite or reanalysis data. With respect to reanalysis data, the above comments on surface albedo apply here as well.



▲ Hovmüller diagram of temporal variability of surface albedo in the pre-alpine region (areal average over latitude 9.9° to 12.9°E) for the month of March from 1987 to 2009. The marked temporal and spatial variation in snow cover in the pre-alpine region is clearly revealed by periods of high surface albedo (yellow/red colours).

International context

The products and procedures of the CM SAF not only serve the aims of GCOS, but are also relevant for other international programmes such as the World Climate Programme (WCP) and the World Climate Research Programme (WCRP). They are essential for the activities undertaken by the Group of Earth Observations (GEO) and Global Monitoring for Environment and Security (GMES). CM SAF is also involved in European initiatives, such as the European Space Agency's (ESA) Climate Change Initiative and several other EU projects (such as EURO4M).

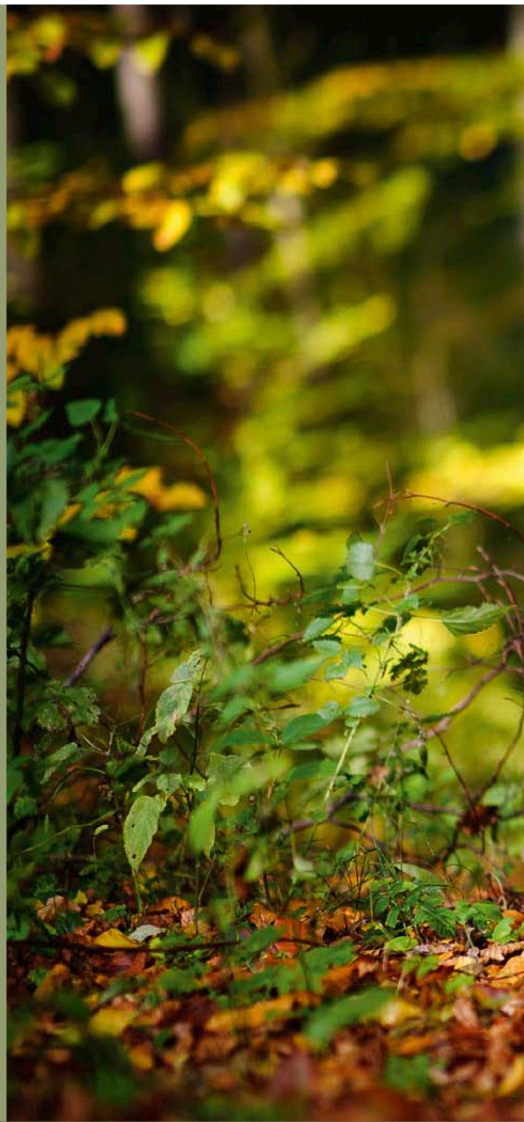
Required resources

A general problem consists in the lack of scientific capacity for analysis of the data sets. This is essentially due to lack of core funding for university appointments, which makes sustainable research almost impossible. Creating a long time series of albedo measurements from satellite data would require about 48 person-months as well as several terabytes of digital storage capacity. A one-off analysis of the data set would require a further 48 person-months.

http://www.cmsaf.eu http://landsaf.meteo.pt/ http://www.osi-saf.org/

4.8

Soil carbon



Vast amounts of carbon are tied up in the soil. Large and/or long-term changes in soil carbon reservoirs and their release as carbon dioxide (CO_2) or methane (CH_4) into the atmosphere could have serious consequences for the climate. The largest soil carbon reservoirs are found in wetlands and peatlands. These are mostly located in permafrost regions or in the tropics. The total mass of soil carbon is however still very uncertain and recent estimates of the carbon content of different soil layers are urgently required.

Trends

On the basis of data from the national forest soil survey (BZE Wald), carbon reservoirs in Germany can be extrapolated and annual rates of change calculated. Data on changes in carbon reservoirs in forest soils were presented in the National Inventory Reports (NIRs), but not taken into consideration for the accounts. Further research into the effects of forest conversion and forest management on the carbon budgets of forest soils is not possible. Given that no further inventory will be conducted until 2025, changes between 2006 and 2025 are difficult to predict.

The German agricultural soil survey (BZE-LW) is an ongoing project and includes a one-off sample survey. At present, there are no plans for follow-up inventories. The first regional interim results of this project will be available from the end of 2012.

Legal framework

Under the terms of the United Nations Framework Convention on Climate Change (UNFCCC), Germany has committed itself to report on anthropogenic sources and sinks of greenhouse gases, and on reservoirs of carbon in soil and biomass (UNFCCC Art. 3.3, 4.1, 4.2 and Decision 3/CP.5), including soils used for agricultural purposes. The international regulatory framework (IPCC 1996, 2000, 2003) requires countries to provide data on major carbon sources. In Germany, these include soils used for agriculture and forestry, as well as built-up areas and certain land use changes. However, there is no consistent legal basis for collection of soil carbon data.

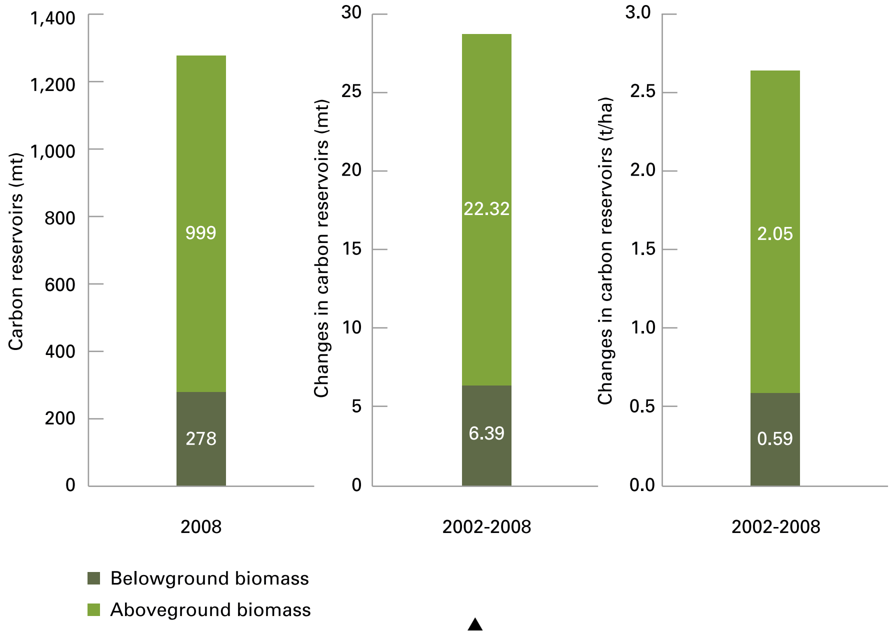
BZE Wald is legally prescribed by the *German Federal Forest Act* (§ 41a) and also provides inputs for reports submitted within the framework of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) of the United Nations Economic Commission for Europe (UNECE). The agency responsible for BZE Wald is the Federal Ministry for Food and Agriculture and Consumer Protection (BMELV). The Ministry has charged the Thünen Institute of Forest Ecosystems with nationwide co-ordination and evaluation of the survey.

There are no regulations governing the BZE-LW, which is conducted by the Thünen Institute of Climate-Smart Agriculture under the auspices of the BMELV.

Measurements in Germany

BZE Wald is a component of the National Soil Survey (BZE), which undertakes surveys of representative areas and intensive long-term monitoring of case study areas (Level II plots). BZE Wald records data at about 2,000 sampling points throughout the entire country on a systematic 8 × 8 km grid. Measurements were taken at the sampling points for the first inventory (BZE Wald I) carried out between 1987 and 1993, and for the second inventory (BZE Wald II) between 2006 and 2008. The Länder collected and analysed data on soils, crown condition, vegetation, foliage and forest nutrition; the results were passed to the Thünen Institute of Forest Ecosystems for evaluation at a national level.

Carbon reservoirs in above- and belowground biomass



▲

Carbon reservoirs in above- and belowground biomass in 2008 (left); total changes in carbon reservoirs (middle) and changes per hectare (right) between 2002 and 2008

Source: Inventory Study 2008 and Greenhouse Gas Inventory for forests

The agricultural soil survey BZE-LW is the first nationwide, consistent and representative survey of carbon reservoirs in the upper 100 cm of agricultural soils. It records the soil carbon reservoirs at about 3,200 sampling points in arable lands, pastures, gardens and specialised crop areas throughout the whole of Germany. Sampling points were selected using a nationwide, randomly generated, systematic 8 × 8 km grid.

Germany plans to contribute to the European research infrastructure 'Integrated Carbon Observation System' (ICOS) through a project of its own, ICOS-D.

International context

At a European level, a 16 × 16 km grid is used to examine a subsample of the BZE Wald data in a comparative analysis within the framework of the ICP Forests programme. Standard data collection methods for international comparison are set out in the ICP Forests Manual. German laboratories have successfully taken part in international ring tests, which ensure that the data is comparable.

Parties to the UNFCCC are undertaking partially comparable inventory and monitoring programmes; however, there is no internationally standardised methodology. This limits the extent to which data sets from different countries can be compared and evaluated. At a European level, the Land Use/Cover Area Frame Survey (LUCAS) will also provide uniform baseline data on carbon reservoirs in soils.

Required resources

There is still insufficient research into the impacts of climate change, and mitigation measures, on forest soils. In particular, intensive effort should be made to research the soil water balance. Existing forest monitoring programmes can provide the data required. Within the framework of BZE Wald, medium-term evaluation of the second forest soil condition survey is assured. A follow-up survey is currently planned for 2025.

The German agricultural soil survey (BZE-LW) is an ongoing project and includes a one-off sample survey. At present there are no plans for follow up inventories.

http://icos-infrastruktur.de/

http://www.lucas-europa.info/

4.9
Forest fires

In Germany, the pine forests of the eastern regions, which have a more continental climate, are most at risk of forest fires. A relatively dry state of vegetation, which may occur after a sufficiently long rainless period, is one of the preconditions of a forest fire. It is expected that with climate change summers will become dryer, causing the combustibility of forest floors to increase.

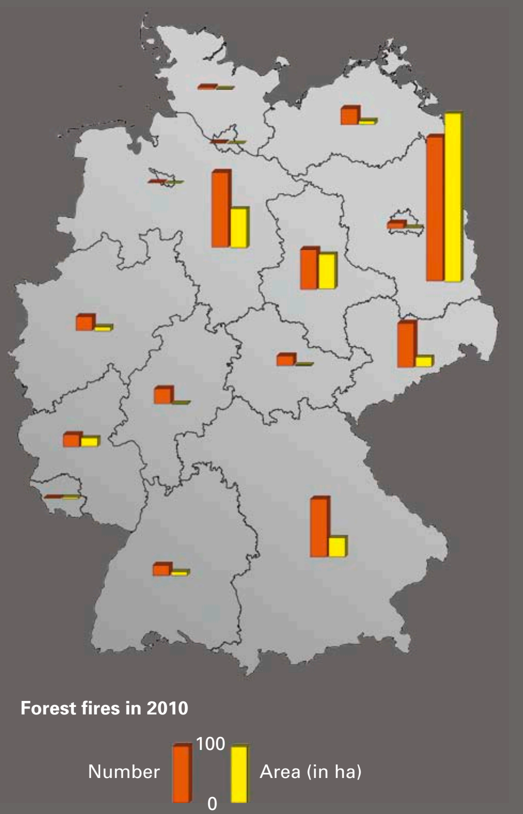
Trends
With some limitations, it is possible to extract information on combustibility of vegetation, climate impact, speed of response and efficiency of prevention measures (i.e. the success or failure of early warnings, fire detection and fire fighting) from the long-term records of the number of forest fires and extent of burned areas. For a more comprehensive climatological interpretation long-term data sets of forest-fire indices, which rate weather-dependent combustibility of forest floors, are also needed. The indices are calculated using fire-danger rating models populated with meteorological data relevant for forest fires (e.g. air temperature and humidity, precipitation and wind). The frequent occurrence of a very large number of fires with large extents of burned area can be a sign of deficits in the technical equipment of fire fighters and a proof of the necessity to restructure forest-fire suppression activities, initiate forest conversion measures and improve early-warning models.

Legal framework
According to article 70 of the German Basic Law, responsibility for fire protection and emergency management lies with the Länder. Their laws on fire protection regulate how to control fire hazards while forest laws enable the banning of open fires and entry into forests when the danger of fire is high. Special regulations control the burning of plant waste and preventive burning of fields. In accordance with various administrative agreements, the Deutscher Wetterdienst (DWD) provides forecasts of fire-weather danger.

Measurements in Germany
Information on forest fires, i.e. place of ignition, extent, cause, time when the alarm was raised and firefighting begun, canopy type and extent of damage are registered by fire brigades and forest authorities of the Länder and are condensed to monthly summaries. Excerpts are forwarded to the Federal Office for Agriculture and Food (BLE), which issues the annual statistics for Germany. These statistics provide a valuable summary of the fire situation in all German Länder and serve to support the strategic focus on fire prevention and fire suppression.

After the once-in-a-hundred-years fires in Lower Saxony in August 1975, annual fire information became more important. As a consequence, the current advisory and statistical frameworks have been developed.

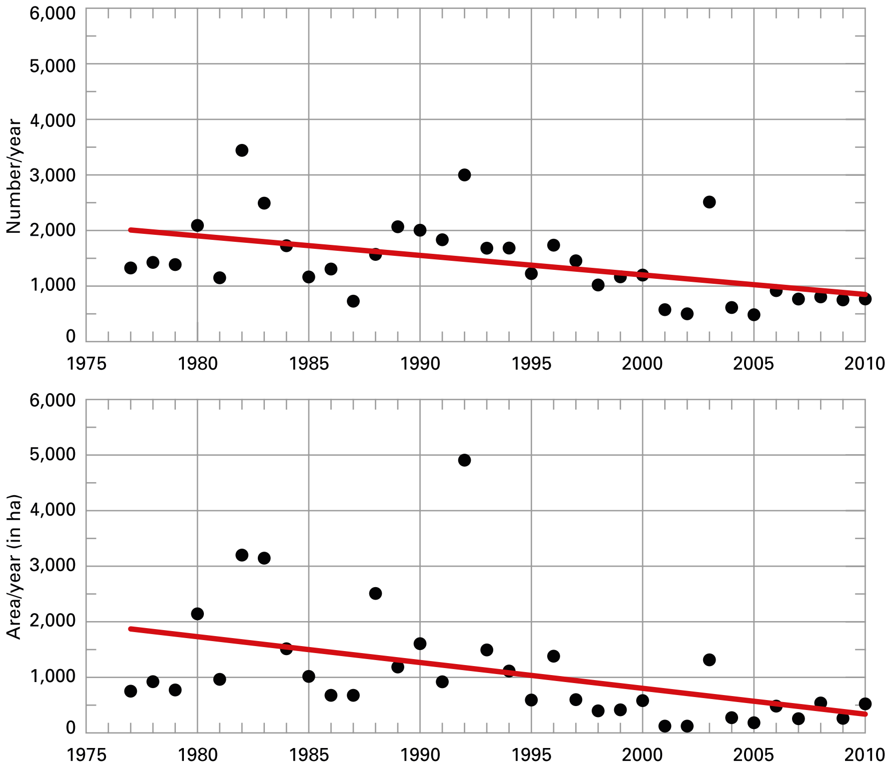
During recent years, the establishment of the camera-based FireWatch system has significantly improved automatic forest-fire detection and



Forest fires in 2010

Source: BLE

Annual number and area of forest fires in Germany during the period 1977–2010 according to the forest-fire statistics for the whole of Germany



Source: BLE

◀ Forest fire near Ossendorf on 20.07.2006

reporting. To provide a modern infrastructure for fire detection and suppression and see to continuous maintenance and improvement of the detection and reporting systems is a permanent key task in the provision of services for the protection of life and property.

▲ Digital camera of the FireWatch system for forest-fire detection
Source: Ministry for Food, Agriculture and Consumer Protection of Lower Saxony

International context

Once a year, in accordance with the specifications of the European Forest Fire Information System (EFFIS), all forest-fire data from moderately to highly fire-prone regions of Germany are reported to the European Commission's (EC) Joint Research Centre (JRC) in Ispra, Italy, where the data of the Member States are reprocessed, quality checked and merged into European forest-fire statistics. Based on these data sets, a European regional risk classification is made in order to manage financial support for forest protection. In addition, EFFIS data are used for model validation.

Independently of EFFIS, the website of the Global Fire Monitoring Center (GFMC) in Freiburg, Germany, provides information on the forest-fire situation in Germany.

Required resources

The registration of statistical information on forest fires is done at local and regional level by forest authorities and fire departments as part of their routine work. The costs are borne by the Federation and the Länder, which are also responsible for the compilation, presentation and distribution of data. The funds needed are considered as secured. The costs for meteorological forecasting of forest-fire danger are borne by the DWD.

http://www.dwd.de http://www.fire.uni-freiburg.de/ http://effis.jrc.ec.europa.eu

4.10

Soil moisture

Soil moisture is a central parameter for weather forecasting, climate research, agricultural and forest meteorology, hydrology and flood forecasting. Area-covering information on soil moisture is an important initial condition for the development of operational weather forecasting models, especially of precipitation. Knowledge of current and future soil water availability in agricultural and forest areas as a function of the influence of soil type and climate is an essential basis for planning current and future management measures. Knowledge of the spatial distribution of soil moisture is indispensable for flood forecasting by the competent authorities.

Climate trends

Continuous measurement of soil moisture using techniques that automatically record measurements has only been possible since about 1991–1992. A summary of the current state of measurement technology can be found in Stacheder et al., 2009, for example. Continuous series of soil moisture measurements are important for the further development and testing of soil moisture budget models, such as Hydrus-1D (Simunek et al, 2008), and for testing the soil module of the DWD's small-scale weather forecasting model for Germany, COSMO-DE.

Legal framework

The activities of the Deutscher Wetterdienst (DWD) are governed by the *Law on the DWD*. Long-term monitoring of soil moisture in agricultural and forest areas is carried out in accordance with the provisions of German soil protection law and EU regulations.

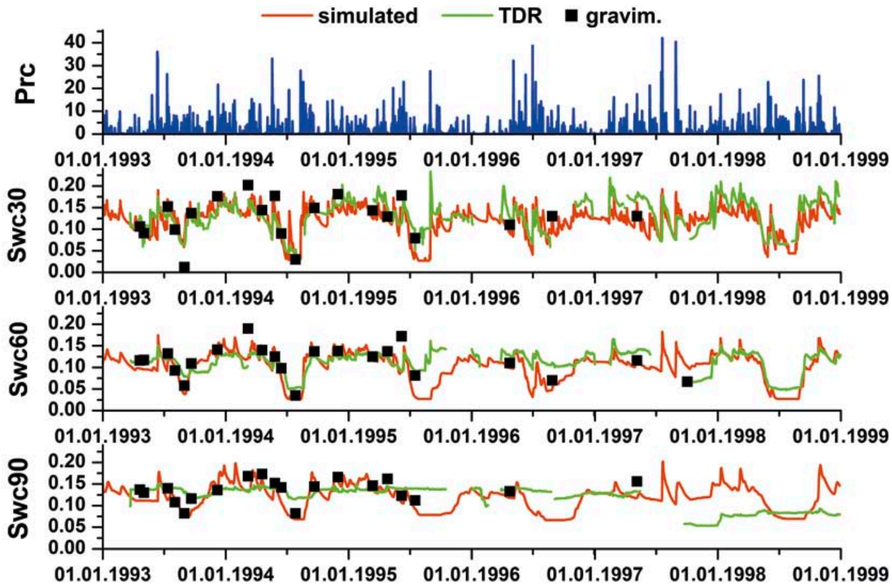
Measurements in Germany

Measurement and model calculations of soil moisture and its temporal dynamics are undertaken not only by the DWD but also at permanent agricultural and forest soil observation plots (BDF II) by regional agencies. In addition, university and non-university research institutions, such as the Leibniz Centre for Agricultural Landscape Research (ZALF), conduct measurements and model calculations on experimental plots (e.g. Wegehenkel, 2005)

Despite the development of time domain reflectometry (TDR) and other automatic recording techniques, continuous measurement of soil moisture at different soil profile depths is expensive and requires great effort. Since 1998, measurements of this kind have been conducted by the DWD's Lindenberg Meteorological Observatory – Richard Assmann Observatory (MOL-RAO) at the Falkenberg intensive measurement site (Beyrich et al., 2006). The DWD calculates daily integrated values for soil moisture at 0–60 cm depth for different crops and soils on a year-round basis at about 500 weather stations, using the agrometeorological model for the calculation of current evapotranspiration (AMBAV) developed by the DWD's Braunschweig Agrometeorological Research Centre (ZAMF). Direct, nationwide measurement of soil

http://www.gosic.org **http://www.zalf.de**

Daily precipitation and soil moisture totals measured at the experimental plot in Müncheberg



▲
Daily precipitation (Prc) in mm/d; soil moisture, simulated and calculated using time domain reflectometry (TDR) and gravimetry (gravim.), in cm^3/cm^3 at depths of 0–30 cm (swc 30), 30–60 cm (swc 60) and 60–90 cm (swc 90) from 01.01.1993–31.12.1998 at Müncheberg experimental plot (altitude 62 m a.s.l.; geographical coordinates: 52°51.5'N, 14°07'E)

moisture at a higher spatial (30 × 30 m) and temporal resolution, by radar satellites such as the environmental satellite ENVISAT, is still impossible or subject to severe limitations (e.g. Koyama et al., 2010). For the moment, directly measured soil moisture data at coarser spatial resolutions (10 x 10 km) are available from satellite platforms, such as the ESA's Soil Moisture and Ocean Salinity (SMOS) satellite. More information can be found at www.bit.ly/1bgSh8R. In the field of numerical weather forecasting, areal data on regional soil moisture are calculated from models using measured land surface temperatures. For examples of the data generated see www.eumetsat.int/website/home/Data/Products/Land/index.html.

International context

Internationally, area-covering soil moisture analyses are assured, inter alia, by the Satellite Application Facility on Land Surface Analysis (LSA SAF); data can be accessed via the Global Observing Systems Information Center (GOSIC, www.gosic.org/).

Measurement series from experimental and permanent soil observation plots in Germany are not always gathered by data centres. A global data centre and international soil moisture measurement series are available at www.gosic.org/content/gcos-terrestrial-ecv-soil-moisture. A further international data centre that holds data on soil moisture is located at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT, www.eumetsat.int/website/home/Data/Products/Land/index.html).

Required resources

Measurement and evaluation of soil moisture data requires considerable material and human resources.

http://www.umweltbundesamt.de/themen/boden-landwirtschaft/boden-schuetzen/boden-beobachten-bewerten

4.11 Phenology

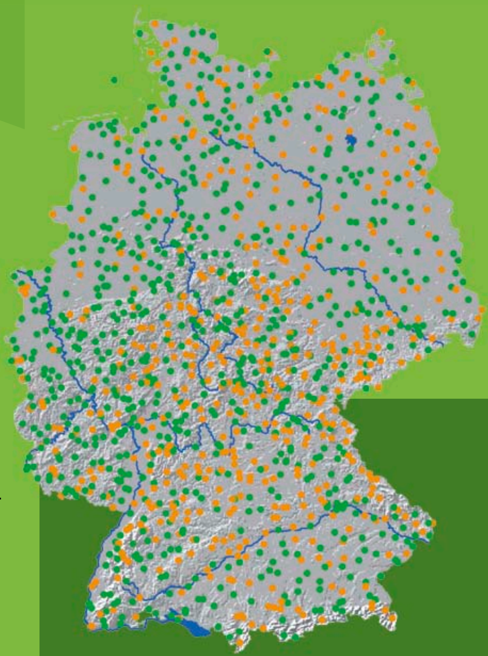
Phenology has to do with the periodically recurring patterns of growth and development of plants over the course of a year. The onset dates of characteristic phases of plant development (phenological phases) are observed and recorded. These are closely related to weather and climate and are therefore important indicators of the impact of climate change on the biosphere.

Climate trends

Among the stations in the phenological data bank held by the Deutscher Wetterdienst (DWD), 474 have records of observations covering more than 50 years, in 164 cases even more than 60 years (between 1951 and 2010). However, the existence of records over a number of years does not mean that all phenological phases were continuously observed during the period. It was possible to reconstruct data sets before 1951 from historical observations. Some phenological records held by the research station at Geisenheim on the river Rhine go back to before 1896. These show a marked shift towards earlier flowering times over the past 60 years.

Legal framework

In addition to ruling the responsibility for the operation of measurement and observing systems for recording meteorological processes, the *Law on the DWD* (§ 4(1), No. 5) also enjoins the registration of meteorological interactions between the atmosphere and other areas of the environment as another duty of the DWD.



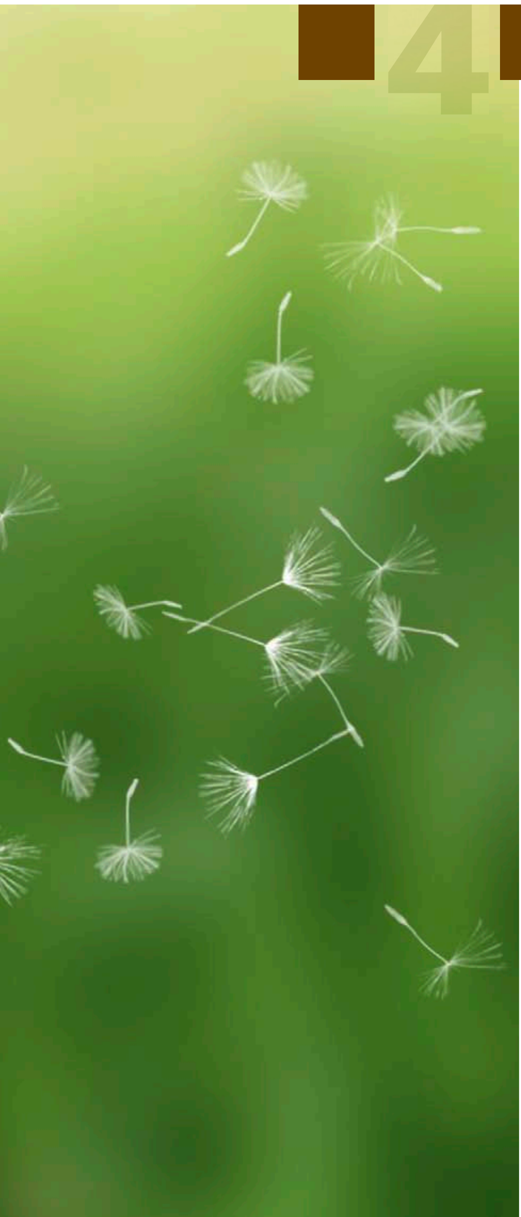
At least 1 year of observations
50 or more years of observations

Measurements in Germany

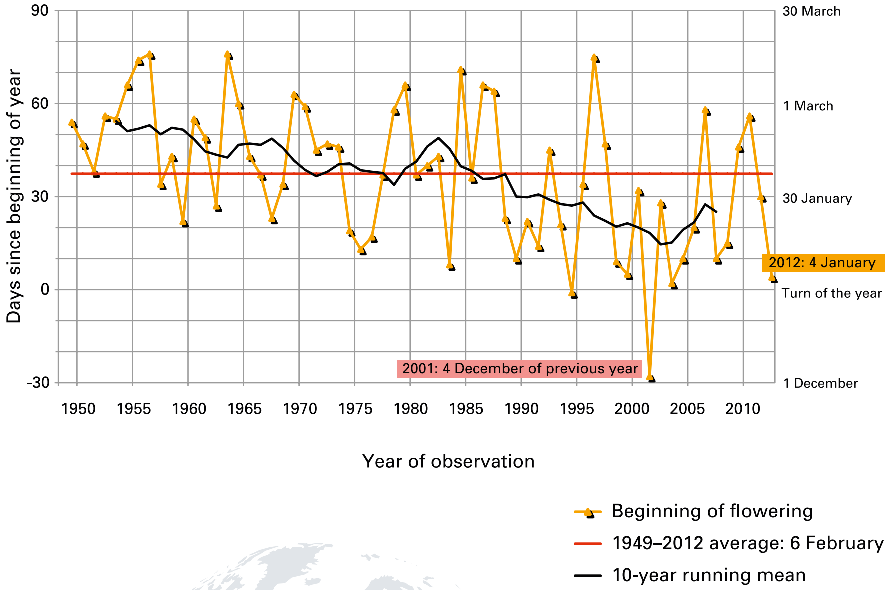
The Societas Meteorologica Palatina carried out systematic phenological observations as early as between 1781 and 1792. However, the real breakthrough in phenology occurred in 1882, when the German university professor Herrmann Hoffmann and his colleagues drew up and published guidelines for the observation of phenological phases, thereby laying the foundations for standardised observations, not only in Germany, but also in other European countries. This gave rise to a Europe-wide monitoring network, as well as a number of regional networks in Germany.

The first long-term nationwide phenological observation network in Germany was set up by the Biological Institute for Agriculture and Forestry of the Reich in 1922. The network was run by this institute until 1936, when it was taken over by the Meteorological Service of the Reich and further developed by Dr. Fritz Schnelle.

In 1946, phenological observations were resumed by the meteorological services in the US and Soviet zones. Subsequently, these monitoring networks were run by the Meteorological Service of the former German Democratic Republic (MD) and the DWD founded in 1950 and 1952, respectively. The two monitoring networks and their data archives were brought together in 1990.



Onset of flowering of hazel in Geisenheim since 1950



Thus, the DWD has an extensive archive of phenological data at its disposal. Alongside annual observations, the database collects immediate data, i.e. records submitted as soon as the phenological phase under observation occurs. These data, that provide up-to-date information on plant development, are used primarily for pollen count forecasts and advice to farmers.

The annual observations, which are used for climate research, are contained in the DWD's data bank and cover the period 1951 to the present. Currently, about 1,300 phenological observers contribute to the monitoring programme, which provides information on about 160 phenological phases of wild plants, agricultural crops, fruit trees and bushes, and grape vines.

Co-operation in Europe

Germany is a member of the European Phenological Network (EPN) and also contributes, through observations in 32 gardens, to the monitoring programme of International Phenological Gardens (IPG). In 1996, responsibility for German participation in this monitoring network was transferred from DWD to the Humboldt University in Berlin. In 2003, the DWD was heavily involved in the initiation of the European Cooperation in Science and Technology project COST725, whose main task was to establish a European-wide reference data base of phenological observations. The DWD also participates in the follow-up project, the Pan European Phenology database (PEP725), which was set up by the Austrian Central Institute for Meteorology and Geodynamics (ZAMG), the Austrian Federal Ministry of Science and Research and the Economic Interest Grouping of European National Meteorological Services (EUMETNET). The main aim of PEP725 is to promote and support phenological research by making available an annually updated pan-European data bank, providing unlimited open access to phenological data for science, research and training (www.pep725.eu).

Required resources

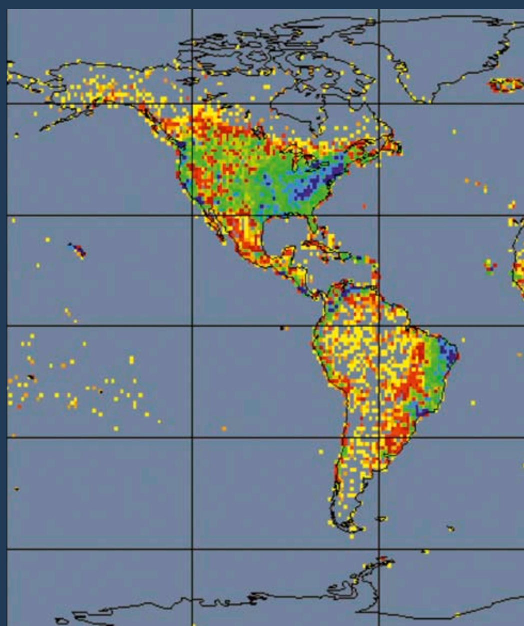
The phenological monitoring network relies largely on volunteers. However, their number has declined over past decades; there are currently about 1,250 honorary observers. A few years ago, about 60 main phenological observer positions were established at DWD weather stations to complement the work of the volunteers. In order to continue to benefit from people's willingness to assume honorary posts of this kind, appropriate publicity measures are required. The IPG monitoring network is also run by volunteers.

5.1
The Global Precipitation Climatology Centre

With its archive of quality-controlled monthly in situ (rain gauge-based) precipitation observation series, the largest in the world, the Global Precipitation Climatology Centre (GPCC), operated by the Deutscher Wetterdienst (DWD), has built up a unique and worldwide renowned capacity in the field of global land surface precipitation analysis and monitoring. The GPCC offers a number of different analysis products tailored to various requirements of its users, such as, for example, the 'Full Data Reanalysis' products (some of which extend back as far as 1901). All GPCC products are freely available on the Internet and have gained reference status for a wide spectrum of hydro-climatological applications.

Significance for GCOS
Because of the high importance of a reliable precipitation diagnosis for the quantitative assessment of the global water cycle, the World Meteorological Organization (WMO), upon recommendation by its Commissions for Climatology (CCl) and Hydrology (CHy), has initiated the setting up of the Global Precipitation Climatology Project (GPCP) as a contribution to the Global Energy and Water Cycle Experiment (GEWEX) and the World Climate Research Programme (WCRP). Given the limited quality of purely satellite-based precipitation monitoring over land, the GPCC was mandated to provide a monthly grid-based precipitation monitoring product which uses the rain gauge/in situ observations exchanged through the WMO's Global Telecommunication System (GTS). The GPCC fulfilled its terms of reference, stipulated in WMO's Technical Document WMO/TD No. 367, well enough to become a permanent component of GCOS. Within the joint GCOS/GTOS activities, the GPCC also is a partner centre for the Global Terrestrial Network for Hydrology (GTN-H); on grounds of its evaluations of the CLIMAT reports collected through the GTS, it furthermore acts as the German GCOS Surface Network Monitoring Centre (GSNMC) in issues regarding the precipitation parameter.

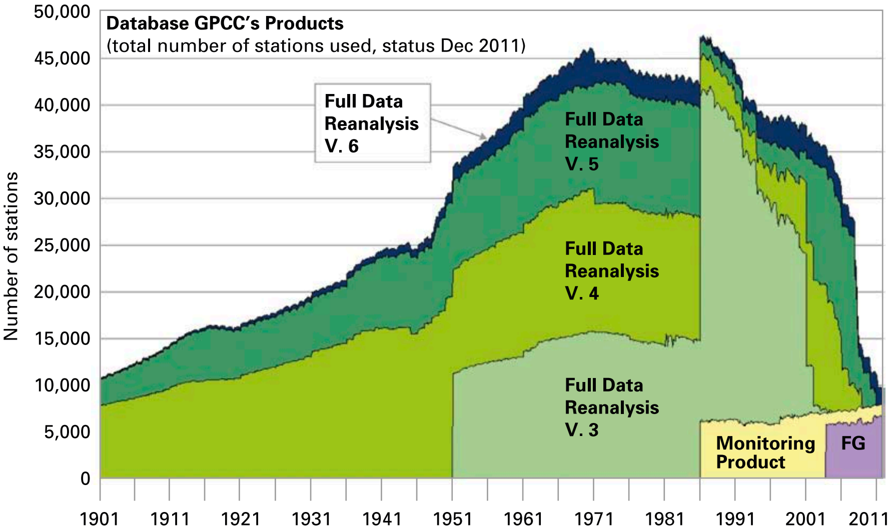
Global measurements



Spatial distribution of the 67,283 stations available for the GPCC's precipitation climatology (December 2011) in terms of density of stations on a 1° evaluation grid

http://gpcc.dwd.de

Data coverage of the different GPCC products across the last 110 years



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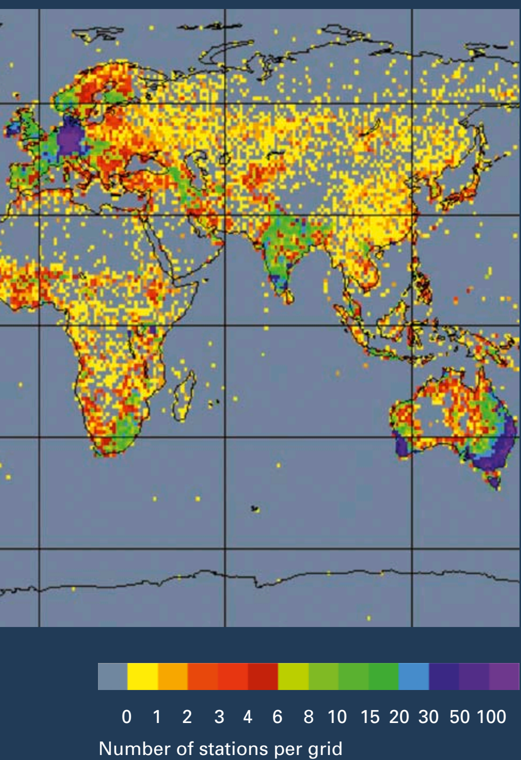
Shown in colours: regularly issued First Guess (FG) and Monitoring products and the continuously growing data coverage of the Full Data Reanalysis product from version 3 to 6 released in 2005, 2008, 2010 and 2011 (1987 is the foundation year of the GPCC)



International context

The GPCC conducts global climate monitoring for the atmospheric Essential Climate Variable (ECV) 'precipitation'. As a member of the Atmospheric Observation Panel for Climate (AOPC), the GPCC reports annually to this advisory body of GCOS. In addition, the GPCC is a component of the Global Terrestrial Observing System (GTOS), co-sponsored by WMO, the United Nations Educational Scientific and Cultural Organization (UNESCO), the International Council for Science (ICSU), the United Nations Environment Programme (UNEP) and the United Nations Food and Agriculture Organization (FAO). With its monthly monitoring product, the GPCC is established as a long-term partner in the GEWEX project of the WCRP. Moreover, its reliable provision of station-based reference precipitation products has made it an essential partner of the International Precipitation Working Group (IPWG), a joint working group of WMO and the Coordination Group for Meteorological Satellites (CGMS), which is an association of all satellite operating agencies and was founded 40 years ago with the goal of keeping measurements comparable across platforms. The GPCC's preliminary 'first guess' product is utilised by the FAO for the purposes of drought warning. The global full data reanalysis data set supports the agendas of the International Hydrology Programme (IHP) of UNESCO and the Hydrology and Water Resources Programme (HWRP) of WMO. The homogenised VASClimo V1.1 data set and its successor, the Homogenized Precipitation Analysis (HOMPRA) data set, are suitable for climate research in the field of global precipitation trend analysis for recent decades.

Required resources

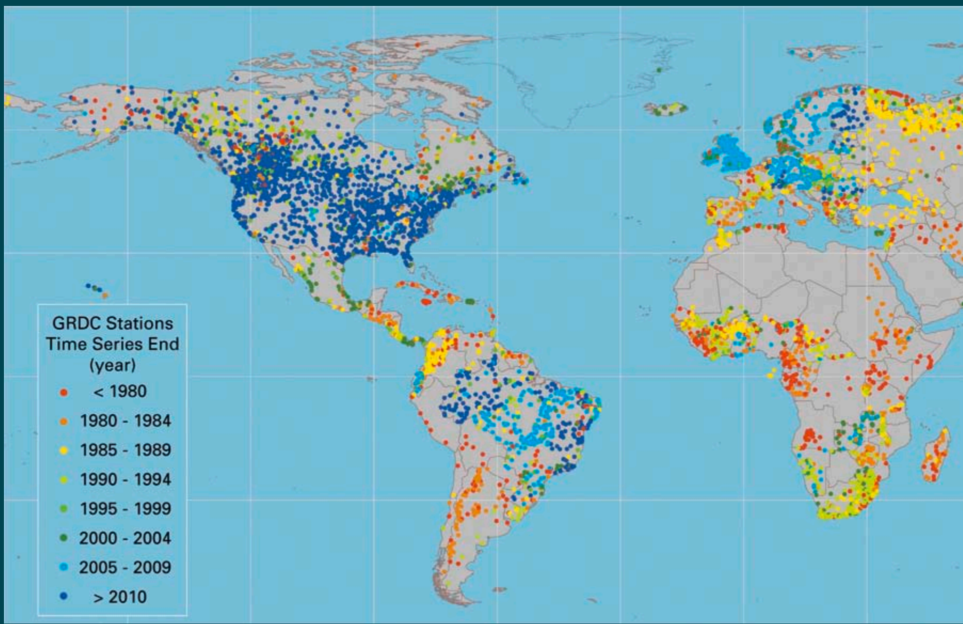
The GPCC has been operated by the DWD without interruption since 1989, demonstrating the sustained character of the engagement. No change in the status quo is currently foreseeable.

5.2
The Global Runoff Data Centre

The Global Runoff Data Centre (GRDC) currently holds mean daily and monthly river discharge data for more than 8,000 stations globally. These data are collected and maintained in direct support of the climate-related programmes and projects of the United Nations system and the international research community working on climate change and cross-boundary water resources management.

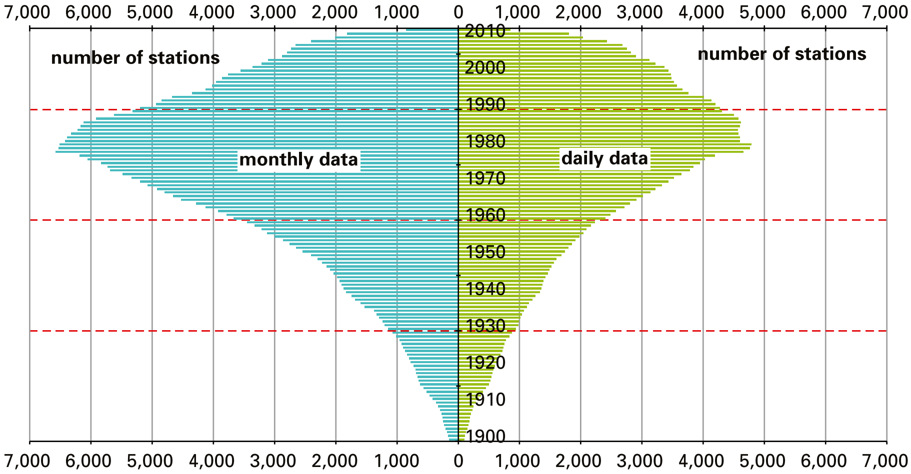
Significance for GCOS
River discharge plays an important role in driving the climate system, as the freshwater flow to the oceans may influence the thermohaline circulation. The statistics for river discharge are an indicator for climatic change and variability, as they reflect changes in precipitation and evapotranspiration and are influenced in the longer term by changing land use. River discharge data are also required for the calibration and validation of global climate and impact models, trend analyses and socio-economic investigations. Monthly records of river discharges are generally sufficient to estimate continental runoff into the ocean, while statistical analysis of river discharge data and impact evaluation of extreme events require data at daily resolution. The GRDC has conceived a network of river discharge stations near the downstream ends of the largest rivers of the world. Today, this network, known as the Global Terrestrial Network for River Discharge (GTN-R), forms a baseline network for GCOS and the Global Terrestrial Observing System (GTOS).

Global measurements

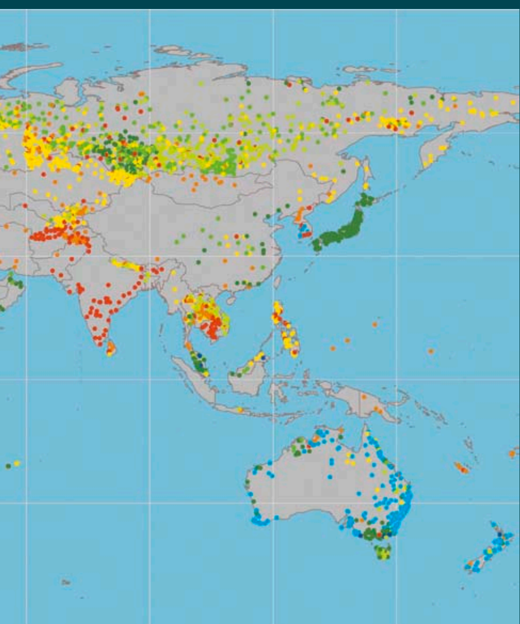


Global distribution and availability
of the 8,131 GRDC discharge stations providing monthly data
(as of 5 January 2012)

Availability of historical discharge data in the GRDC database



▲ Availability of historical discharge data in the GRDC database (number of stations per year providing monthly data (left) and daily data (right))



International context

The GRDC was formally established in 1988 at the Federal Institute of Hydrology (BfG) and operates under the auspices of the World Meteorological Organization (WMO). It is a German contribution to the World Climate Programme - Water (WCP-Water) of WMO and the United Nations Educational Scientific and Cultural Organization (UNESCO). The activities of the GRDC are monitored by an international steering committee with members from WMO, UNESCO, the United Nations Environment Programme (UNEP), the International Association of Hydrological Sciences (IAHS) and partner data centres advising it on the basic orientation of its work. Resolutions 21 (WMO Congress XII, 1995) and 25 (WMO Congress XIII, 1999) mandate the GRDC to collect river discharge data at global level in a free and unrestricted manner and close co-operation with the national hydrological services. The GRDC contributes its river discharge data to a number of international research programmes, such as the Global Energy and Water Exchanges Project (GEWEX) and the Climate and Cryosphere (CliC) project of the WMO's World Climate Research Programme (WCRP). Through its contribution to the Global Terrestrial Network – Hydrology (GTN-H), the GRDC is linked to the Global Earth Observation System of Systems (GEOSS).

Required resources

The BfG is responsible for running the GRDC. This ensures the funding of the GRDC's core functions. Additional resources are required to extend data acquisition activities, to further develop the GTN-R baseline network and to develop the full potential of the GRDC and its relevance to the scientific community working on climate variability and global change.

http://grdc.bafg.de

5.3

The World Radiation Monitoring Center

The World Radiation Monitoring Center (WRMC) is the central archive of the Baseline Surface Radiation Network (BSRN). The objective of the BSRN is to provide data on short and long-wave surface radiation fluxes of the best possible quality currently available to support the research programmes of the World Climate Research Programme (WCRP) and other scientific projects.

Dome of a pyranometer ▶

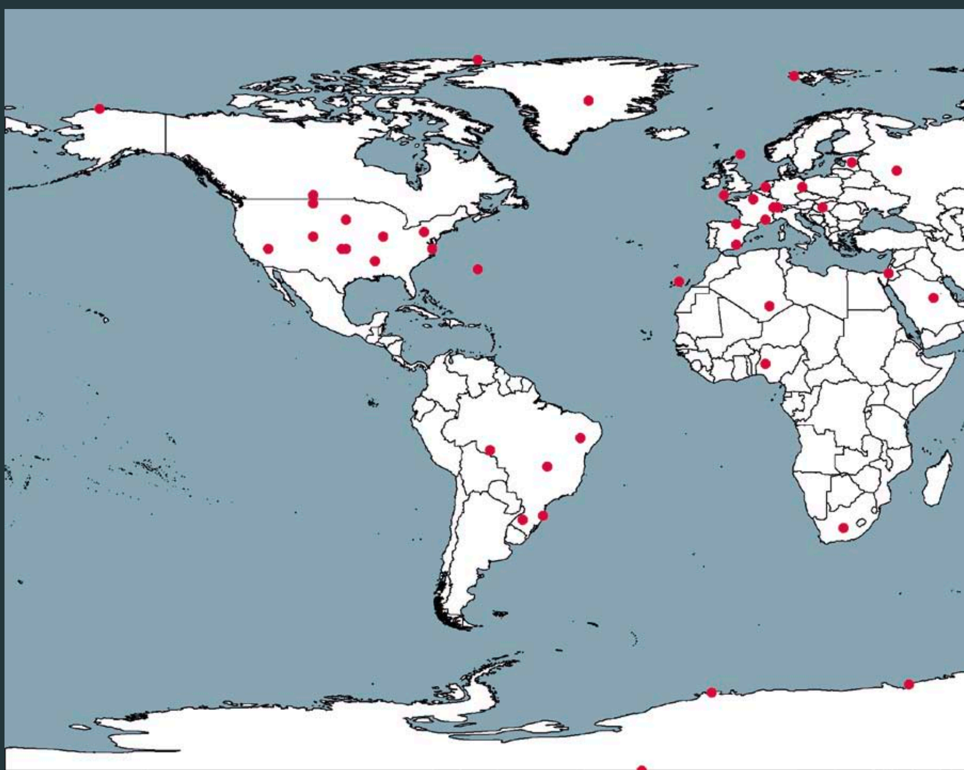
Significance for GCOS

In 2004, the BSRN was designated as the 'global baseline network for surface radiation' for GCOS. The high-quality, uniform and consistent measurements throughout the BSRN network are used to:

- monitor the short-wave and long-wave radiative components and their changes with the best methods currently available;
- validate and evaluate satellite-based estimates of the surface radiative fluxes; and
- verify the results of global climate models (GCMs).

The BSRN/WRMC started in 1992 with nine stations. By November 2011, more than 6,000 station-months of data from 54 stations all over the world were available in the archive (see www.bsrn.awi.de/). Although the WRMC was originally designed especially for the needs of climate researchers, the archive is being used more and more in the context of research into solar energy.

Global measurements

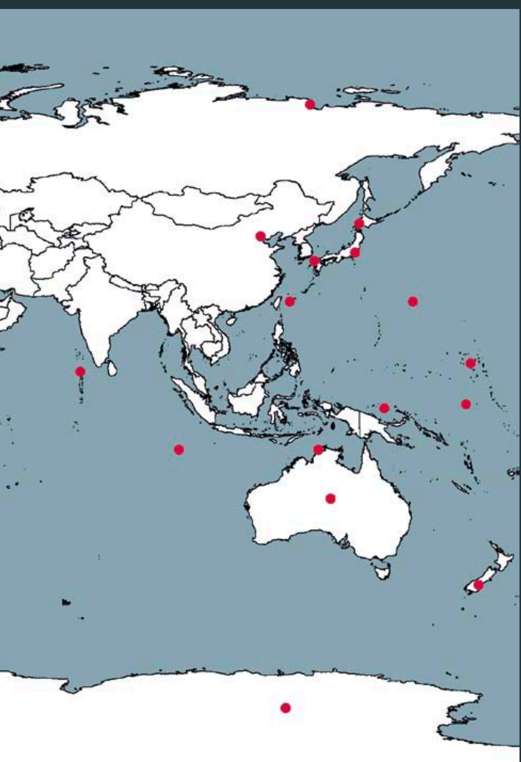


Currently active and planned BSRN stations (November 2011)

Qualitative tendencies in incoming surface solar radiation in various regions of the world

Region	1990 to 1999	2000 to 2005
USA	↗	↗
Central America	↗	↘
Europe	↗	↗
China/Mongolia	↗	↘
Japan	↗	→
Korea	↗	↗
India	↘	↘
Antarctica	↗	→

Source: Wild et al., 2009



International context

The BSRN/WRMC was initiated by the World Climate Research Programme (WCRP). It is affiliated to the Radiation Panel of the WCRP's Global Energy and Water Cycle Experiment (GEWEX) and is part of GCOS. In 2011, the BSRN/WRMC and the Network for the Detection of Atmospheric Composition Change (NDACC, see www.ndacc.org) formally agreed to form a co-operative network. To ensure the close co-operation between the scientists at the 54 BSRN stations and the customers of BSRN data, a joint meeting takes place every second year.

Required resources

In order to ensure effective operation of the WRMC at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), in Bremerhaven, about two scientists and one data curator are needed. Additionally, technical support from the AWI computing centre and from experts of PANGAEA® (Data Publisher for Earth & Environmental Science, see www.pangaea.de) and MARUM (Center for Marine Environmental Sciences, www.marum.de/en/) is indispensable. At the moment, the AWI carries all the corresponding costs.

http://www.bsrn.awi.de http://www.ndacc.org http://www.pangaea.de http://www.marum.de

5.4

The World Data Center for Climate at the German Climate Computing Centre

The World Data Center for Climate (WDC-Climate) is maintained by the German Climate Computing Centre (DKRZ), whose mission is to provide users from the climate research community in Germany with access to high-performance computing and technical support. Emphasis is placed on data from climate model calculations, but corresponding observational data from a variety of projects are also available.

High-performance mass storage system ▶ at the DKRZ

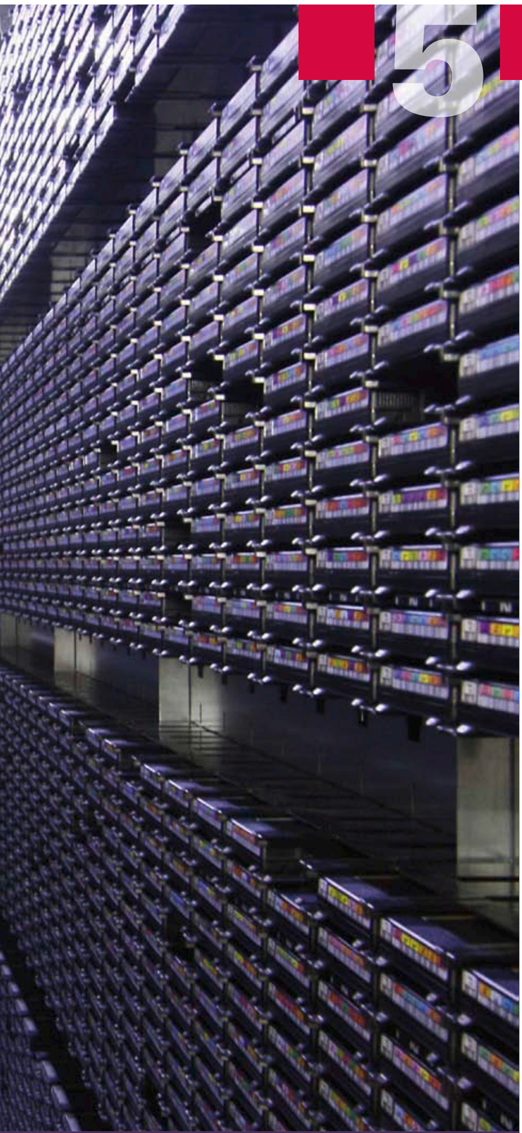
Overview of DKRZ data pool

Project		Coverage	Data type
Caribic	B	Flight routes between Frankfurt and the Caribbean 1997 to 2002	Upper atmosphere variables
CCLM	M	Europe 2001 to 2100	Numerous variables on a 20-km grid, monthly means and hourly data
CMIP5	M	Global data for model comparisons from various time periods	Numerous variables from international centres
ECMWF reanalyses (ERA)	M	Global 1957 to the present day	Numerous variables with up to 80-km resolution
REMO-UBA	M	Germany 2001 to 2100	Numerous variables on a 10-km grid, monthly means and hourly data

Significance for GCOS

The WDC-Climate collects, archives and disseminates climate (model) data and products and provides these free of charge to the international research community. With a view to establishing a well organised network of data centres for earth sciences, there is close co-operation with numerous institutions dedicated to related branches of study, such as earth observation, meteorology, oceanography, paleo-climatology and environmental research.

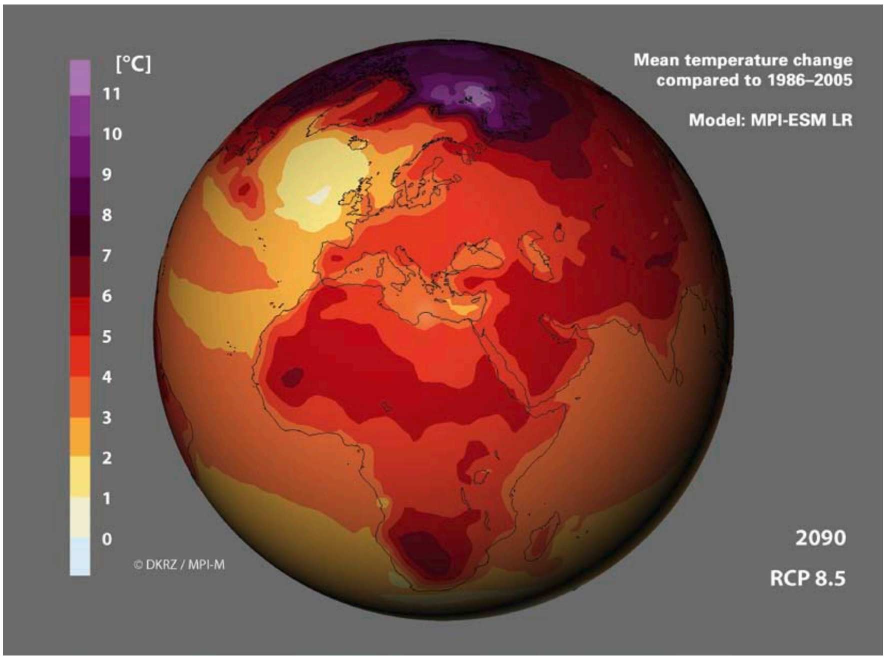
Blizzard high-performance computer ▶ at the DKRZ Photo: DKRZ



Model data include global as well as continental and national data sets (see table). Disk storage capacity of 1,500 terabytes is available plus more than 100 petabytes on magnetic tapes.

During recent years, data life cycle management has become more and more important. This includes advising the project partners during proposal-writing as well as during the lifetime of the project and the concluding data publication and dissemination phase, and on long-term archival of results. These long-term archived data can be marked with persistent digital object identifiers (DOI), which allow users to quickly locate the data even after several years.

Mean temperature increase until 2090



▲
Temperature increase between 1986–2005 and 2090 for scenario RCP 8.5 of the Fifth Assessment Report of IPCC, model MPI-ESM-LR
Source: DKRZ

International context

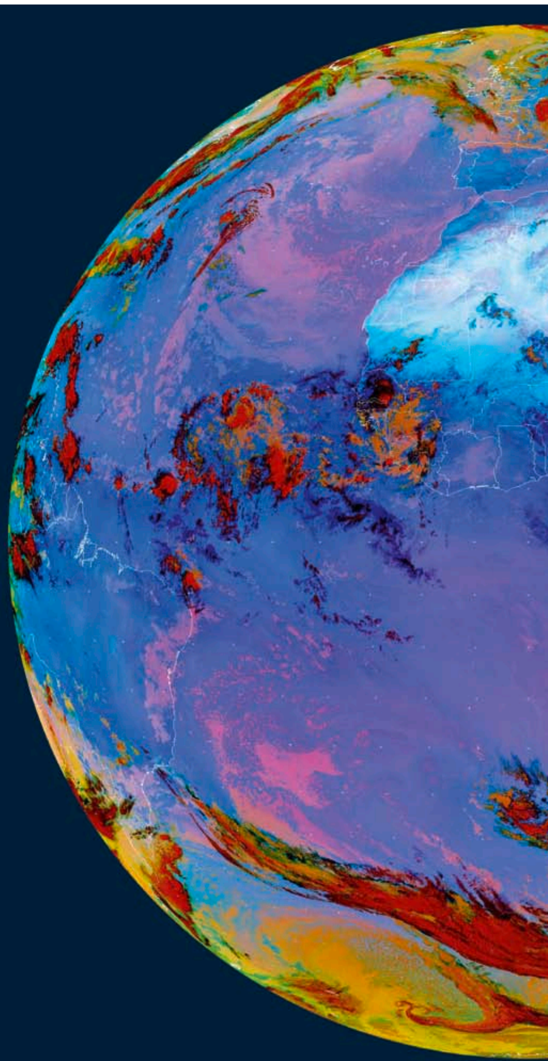
Although the WDC-Climate has an international orientation and is open to scientists from all over the world, most data are accessed from the research community in Germany. Here, co-operation with universities and major research centres and with institutes of the Max Planck Society or the Deutscher Wetterdienst (DWD) is equally important. International co-operation also exists for the utilisation of data for the preparation of the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). The WDC-Climate, which is situated in Hamburg, is involved as part of the IPCC's Data Distribution Centre (DDC). It is one of the internationally leading data centres providing data for model comparison projects (e.g. CMIP5). In addition, software solutions from user interfaces to storage of data sets on magnetic tapes are jointly developed in international collaborations.

Required resources

The shareholders of DKRZ are the Max Planck Society and the Land Hamburg (University of Hamburg) as well as the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) and the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research (HZG). Financial support is also provided by the Federal Ministry of Education and Research (BMBF) for the procurement of the large-scale technology.

http://www.dkrz.de

5.5
The World Data Center for Remote Sensing of the Atmosphere



Since 2003, the World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT) has been hosted and operated by the German Remote Sensing Data Centre (DFD) at the German Aerospace Center (DLR) under the auspices of both the World Meteorological Organization (WMO) and the non-governmental International Council for Science (ICSU). An external advisory board with experts from space agencies such as the European Space Agency (ESA), national meteorological services such as the Deutscher Wetterdienst (DWD) and scientific community bodies, such as the DLR and the Helmholtz Association of German Research Centers (HGF), was established in 2006 to help the WDC-RSAT to achieve its mission goals and serve user requirements. Currently, this advisory board is being extended to also include representatives from EUMETSAT, NASA and WMO.

Significance for GCOS

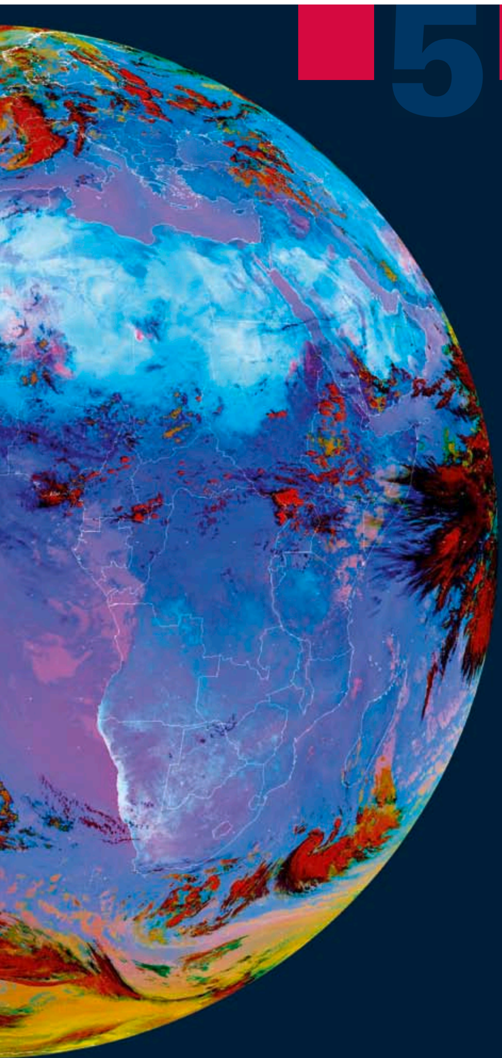
The WDC-RSAT offers, not just to scientists but also to the public, simple and free access to a continually growing collection of satellite-based data of the atmosphere and related products and services.

The data products are available online and include raw data as well as higher level value-added products. The current WDC-RSAT data-base provides information on trace gases, aerosols, clouds, land and sea surface parameters and solar radiation.

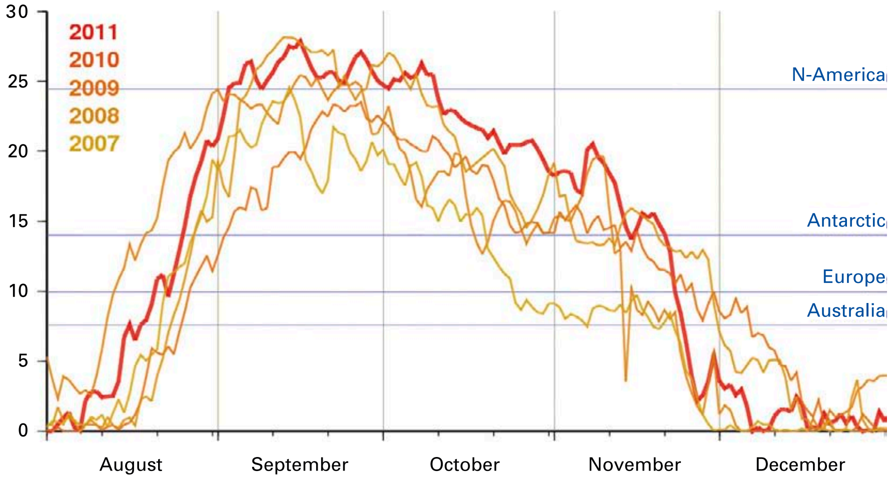
Service for the scientific community

The WDC-RSAT is the most recent member in the WMO system of world data centres. Particularly in the context of the IGACO[1] within the WMO's Global Atmosphere Watch programme (GAW) and in line with the GAW strategy plan 2008–2015, it is concerned with linking different GAW-relevant data sets with each other and with model data. In this context, the WDC-RSAT not only handles satellite data but also data from other sources that are important for validation purposes. Additionally, strategies and techniques are being developed and tested for this validation, taking account of, among other things, different assimilation methodologies. The data centre is also addressing the variability of the atmosphere at different time and space scales ('miss-integration error'). It operates as a one-stop shop that gives access to space-borne observations of the chemical composition of the atmosphere, at first, however, with a focus on a limited number of parameters, particularly those concerning ozone and aerosols. This is achieved by either direct access to the centre's data collection or indirectly by a portal of links to relevant satellite data and data products of other providers. Following the recommendations of the Committee on Earth Observation Satellites (CEOS), the WDC-RSAT is currently developing an Atmospheric Composition Portal (ACP[2]) in co-operation with the National Aeronautics and Space Administration (NASA), which will eventually be integrated into the Global Earth Observation System of Systems (GEOSS). Similar co-operation is planned with the French Space Agency (CNES) and the French National Center for Scientific Research (CNRS). The

1) Integrated Global Atmospheric Chemistry Observations (IGACO)
2) http://wdc.dlr.de/acp
3) http://wdc.dlr.de/ndmc
4) http://www.schneefernerhaus.de



Trend of the size of the ozone hole for the years 2007 to 2011 (10^6 km²)



▲

The area is derived by assimilating the total ozone concentrations from Metop/GOME2 measurements using the ROSE/DLR chemical transport model. The size of the ozone hole is defined as the area where the total ozone concentration is below 220 Dobson units.
Sources: WDC, EUMETSAT, DLR

WDC-RSAT is designated to play an important role within the recently established international and global Network for the Detection of Mesopause Change (NDMC[3]). For this, international co-operation with scientific groups actively investigating the mesopause region (in ~80–100 km altitude) will be supported to detect long-term trends in airglow. The centre will also serve as a communication and data management platform for ground-based measurements from around the world. In addition, the WDC-RSAT supports the data management of the German environmental research station Schneefernerhaus (UFS[4)]) on Zugspitze (2,650 m a. s. l.), which is also a GAW station. It is planned to establish a virtual association between the research station and the Norwegian ALOMAR observatory.

International context

The World Data Center for Remote Sensing of the Atmosphere is part of the ICSU-WDC family and is therefore closely linked to all other world data centres. Further, the development of a sub-network of WDCs, which will focus on relevant aspects of the earth system, will lead to increased synergy between the various data providing bodies. Such a co-ordinated approach, in which WDC-RSAT is involved, aims to give answers to questions on climate change and weather extremes. This is of basic importance for economic well-being and the understanding of both natural and man-made causes of climate variability. A large amount of data is necessary to describe the climate system and how it is changing, because it is determined by conditions and changes in the atmosphere and surface parameters of land and ocean. Much of the needed data are collected and archived by four ICSU world data centres, amongst others the WDC-Climate (hosted by the German Climate Computing Centre, DKRZ) or by the Publishing Network for Geoscientific & Environmental Data PANGAEA® (operated by the Alfred Wegener Institute (AWI) and the University of Bremen, see Chapter 5.7). In 2004, the four German ICSU WDCs (Climate, Mare, Terra and RSAT) established the WDC-Cluster on Earth System Research to promote interdisciplinary research related to earth sciences.

The WDC-RSAT also co-operates with various partners in the field of information technology (e.g. Grid) to improve the networking between providers and users. Remote sensing data sets and products now each have a digital object identifier (DOI) and can be unambiguously and effectively referenced and cited in scientific publications. The WDC-RSAT has also been designated as a Data Collection and Production Center (DCPC) within the WMO Information System (WIS).

http://wdc.dlr.de/

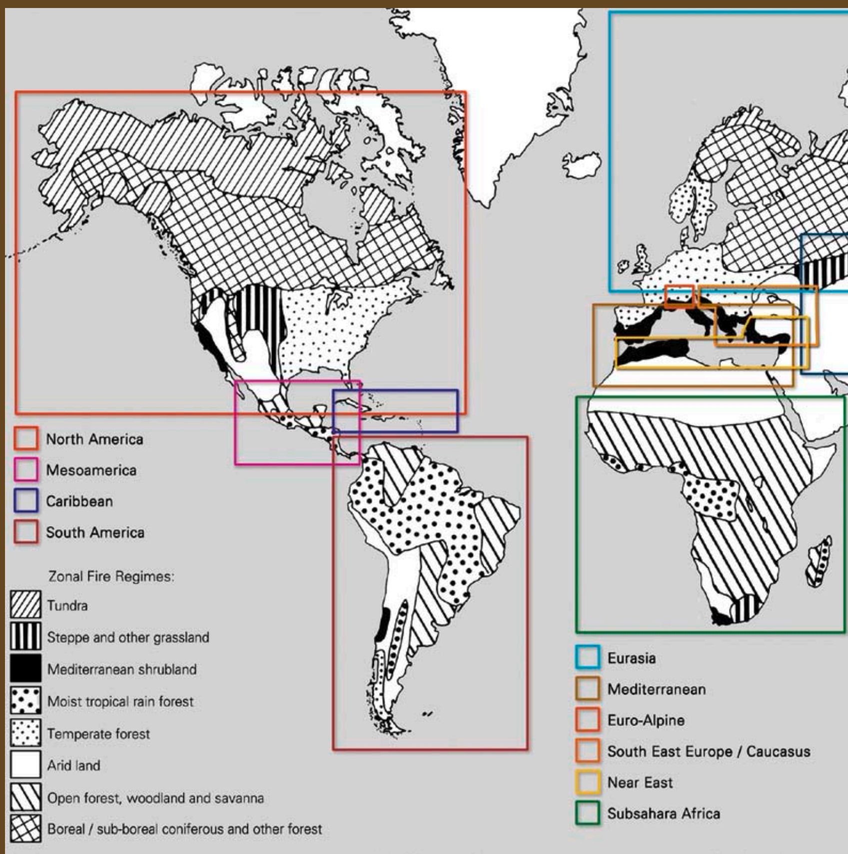
5.6
The Global Fire Monitoring Center

The Global Fire Monitoring Center (GFMC) provides a global archive and portal for documentation and information about vegetation fires, including information on early warning and monitoring. National and global metadata about vegetation fires are compiled through an international network of co-operating institutions and are publicly accessible on the Internet.

Significance for GCOS

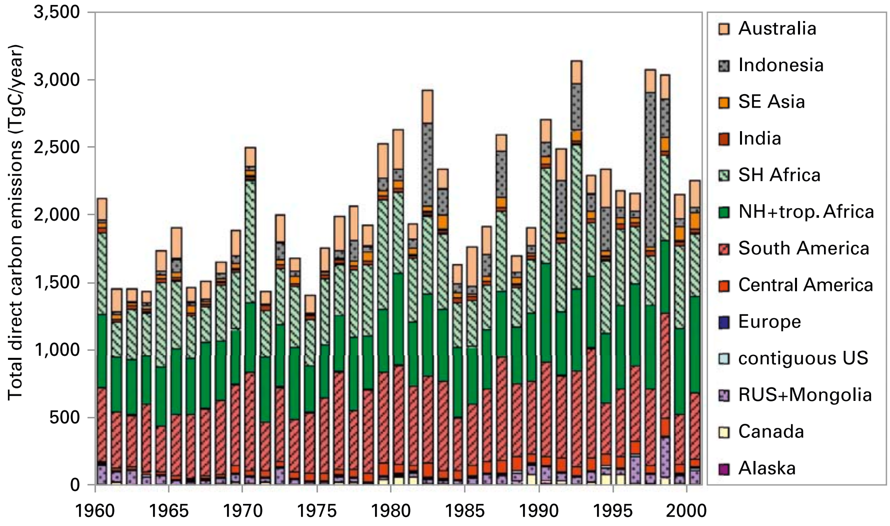
Vegetation fires represent an essential climate variable and influence other climate variables, e.g. the composition of the atmosphere, by gaseous and particle emissions (radiation budget, cloud formation and precipitation). Terrestrial variables directly influenced by fire include, amongst others, hydrological regime, albedo and terrestrial biomass and carbon pools. Examples of indirectly impacted variables include ice and snow cover (by deposition of emitted black carbon) and permafrost regimes (through the modification of vegetation cover). However, fires also have a long-term stabilizing influence on natural and anthropogenic fire-adapted or fire-dependent ecosystems. The most important cause of vegetation fires is the application of fire in traditional land-use systems and for land-use changes. An understanding of the complex interactions between fire, biosphere and atmosphere and their consequences for the climate system are a prerequisite for the definition and interpretation of earth observations within the GCOS framework.

Global measurements



Global Wildland Fire Network of the United Nations Office for Disaster Risk Reduction (UNISDR)

Total carbon emissions from vegetation fires from 1960 to 2000



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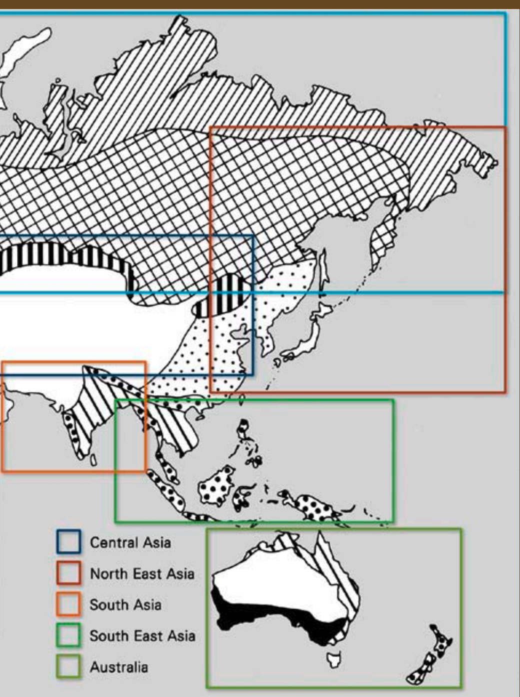
Time series and regional contributions of total direct carbon emissions from vegetation fires from 1960 to 2000
Source: RETRO Model, Schultz et al., 2008



Regions of
the UNISDR Global Wildland Fire Network
Zonal, socio-economic or political entities

International context

The GFMC is involved in a number of natural and social sciences research projects and programmes. A key mission of the GFMC is the application of scientific knowledge for the purposes of administration and policy. This is achieved by direct co-operation with national stake-holders and international organisa-tions whose task it is, through legal provisions and development of international agreements as well as by taking account of global proces-ses, to enable countries to deal with the climate variable fire in order to avoid the destructive effects of fire and co-ordinate the use of natural fire and sustainable prescribed fire practices. The GFMC has taken a leading role and some functions of relevant thematic working groups in the UN system (UNISDR Global Wildland Fire Network and Wildland Fire Advisory Group; UNECE/FAO Team of Specialists on Forest Fire, and others) and is an Associate Institute of the United Nations University. The GFMC is co-chair of the Fire Implementation Team of Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) and its 'Implementation of a Fire Warning System at Global Level' project (GEO Task DI-09-03B).

Required resources

Basic institutional funding of the GFMC through the Max Planck Insti-tute for Chemistry is secured until October 2014. The continuation of the GFMC's work beyond 2014 is not yet secured. An urgent solution is needed to secure the continuation and expan-sion of the application of scientific knowledge. A cross-sector embedding in the UN system would be preferred.

http://www.fire.uni-freiburg.de

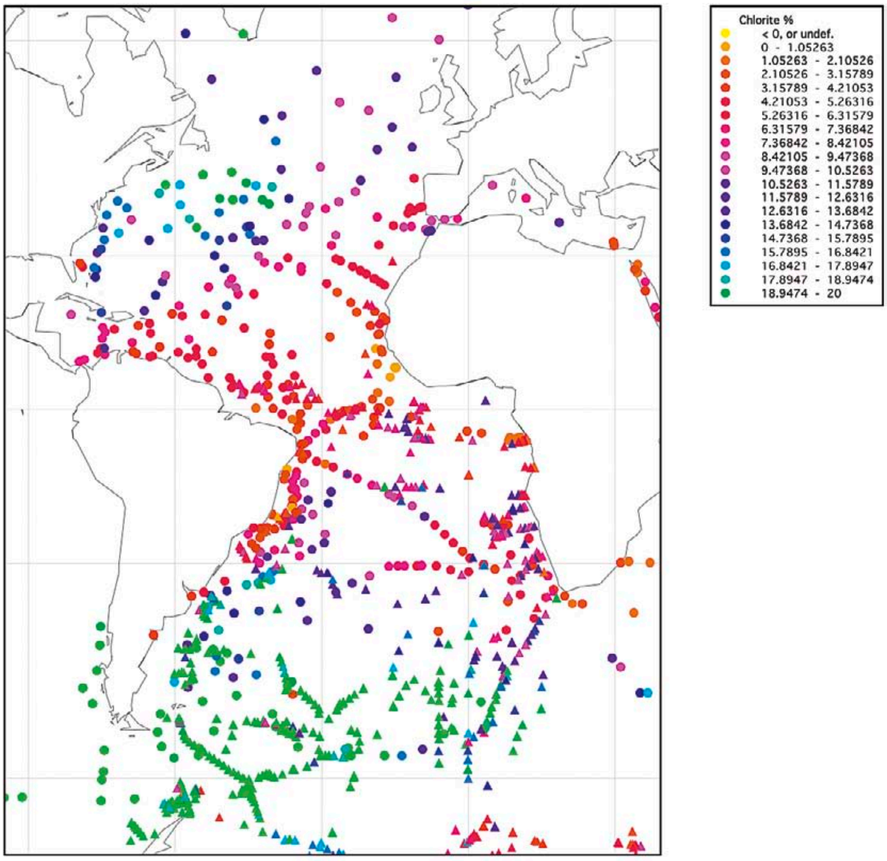
5.7 The ICSU World Data Centre PANGAEA®

The ICSU World Data Center PANGAEA® – Data Publisher for Earth & Environmental Science (the former WDC-Mare) is a facility for the acquisition, processing, long-term storage and publication of geo-referenced data related to earth science fields. PANGAEA® currently holds around 500,000 data sets comprising 6.5 billion data items from all earth environments.

Significance for GCOS
PANGAEA® holds an extensive collection of climate-related data, making it a valuable partner for climate research. As a designated data archive of both the International Council for Science (ICSU) and the World Meteorological Organization (WMO), PANGAEA® supports the free and unrestricted availability and distribution of climate-related data according to the ICSU's rules for World Data Centers (WDCs) while at the same time protecting intellectual property by consequently using digital object identifiers (DOI) when publishing the data.

International context
PANGAEA® is part of the ICSU World Data System, holding the position of Vice-Chair in the Scientific Committee. Since the 5^{th} European Framework Programme, PANGAEA® has been partner in more than 120 mainly high-level projects at global, EU and national scales covering all fields of environmental sciences (see www.pangaea.de/projects/). Long-standing collaboration exists with the Integrated Ocean Drilling Program (IODP). Co-operation with science publishers (Elsevier, Springer, Wiley, Oxford, AGU and Nature) has been established and extended.

Global clay mineral distribution in surface sediments of the Atlantic (in %)



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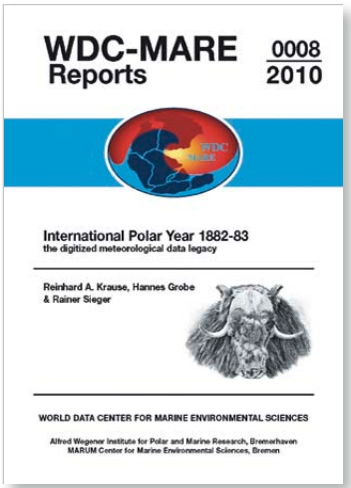
Source: adapted from Biscaye (1964) and Petschick et al. (1996), doi:10.1594/PANGAEA.55955

Publication series 'WDC-Mare Reports'

▼



Required resources

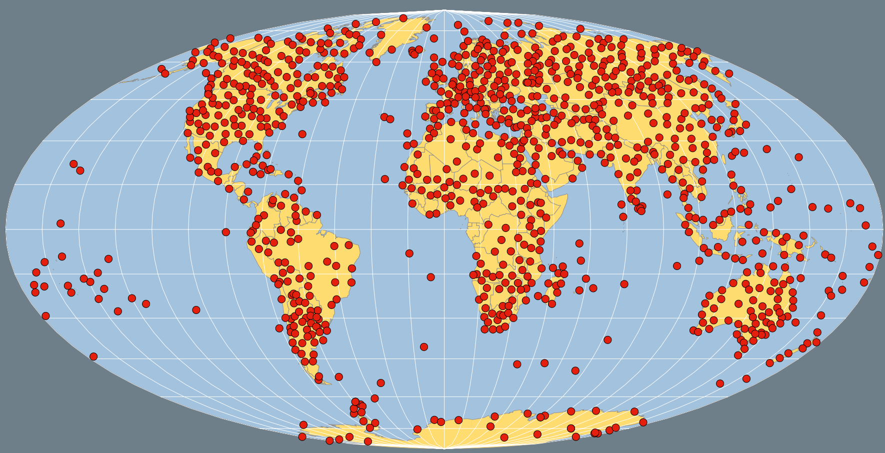
PANGAEA® is operated jointly by the Center for Marine Environmental Sciences (MARUM) in Bremen and the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), in Bremerhaven. The two partners provide together four full-time positions for one data librarian, two data curators and one system manager. Eight additional data curators and three software engineers are funded by third parties.

Further funding comes from the European Commission (EC), the Federal Ministry of Education and Research (BMBF), the German Research Foundation (DFG) and the International Ocean Drilling Program (IODP).

http://www.pangaea.de

5.8
Data quality assurance centres of GCOS

Launch of a balloon with several radiosondes during a comparison study



GCOS Surface Network in 2012

GCOS Surface Network (GSN)
The GCOS Surface Network (GSN) is a subset of the Regional Basic Climatological Network (RBCN) that collects monthly world climate data (CLIMAT reports) from the lower atmosphere near the earth's surface and publishes it shortly after the end of each month. GSN consists of more than 1,000 land surface observation stations and stations on mid-oceanic islands. These were selected according to strict criteria, including length and quality of the time series, geographical representativeness of the observations and range of available parameters. A high degree of commitment is expected from GSN stations with regard to the continuity of observations and the quality of the monthly data reports. GSN data provide a basis for assessing climate variability and climate change, as well as for climate modelling and forecasting. However, coarse network density limits the applicability of the GSN to a restricted range of climate data products (gosic.org/content/purpose-gsn).

In 1999, two GCOS Surface Network Monitoring Centres (GSNMC) were set up to oversee the performance of the GSN, one at the Deutscher Wetterdienst (DWD) and the other at the Japan Meteorological Agency (JMA). These monitor the availability, timeliness and formal accuracy of inputs from GSN stations, and check the data provided on mean monthly temperature, mean monthly maximum and minimum temperatures (JMA) and monthly precipitation (Global Precipitation Climatology Centre, GPCC). A range of monitoring products and the monthly climate data can be accessed at www.gsnmc.dwd.de.

With the aim of improving the quality and availability of the data from the GSN and the GCOS Upper-air Network (GUAN), nine CBS Lead Centres for GCOS were designated by the World Meteorological Organization's (WMO) Commission for Basic Systems (CBS) in 2006/2007. Their principal task is to liaise with the National Focal Points for GCOS to bring problems that have been detected in their areas of responsibility to the attention of the National Meteorological and Hydrological Services (NMHSs) (www.wmo.ch/pages/prog/gcos/index.php?name=CBSLeadCentres). The DWD is responsible for Europe (WMO Region RA VI). In 2011, following the decisions by GCOS' Atmospheric Observation Panel for Climate (AOPC) and the Executive Council of WMO, the responsibility of the CBS Lead Centres will be

extended to include all stations in the RBCN. All CLIMAT data exchanged worldwide will be checked, completed and archived by the DWD.

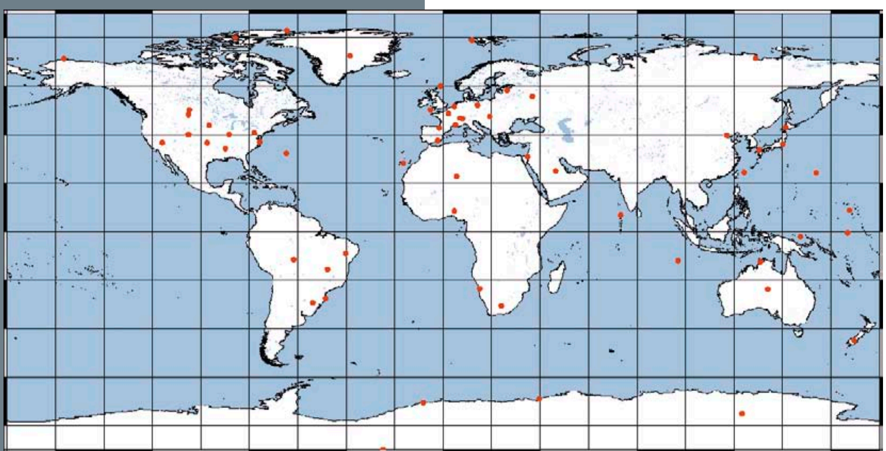
The GCOS Reference Upper-Air Network (GRUAN)

The GCOS Reference Upper Air Network (GRUAN) is the reference network for observations of essential climate variables in the free atmosphere. The GRUAN stations conduct vertically resolved measurements of the parameters temperature, atmospheric water vapour, wind and pressure. GRUAN currently consists of 15 stations worldwide, with plans for expansion to about 30 to 40 stations. GRUAN stations provide data at the highest quality standards to be used for the purposes of long-term climate observation, validation of satellite observations and the study of atmospheric processes. This goal is achieved through an explicit quantification of measurement uncertainty as well as through well-defined operational requirements.

The reference status of GRUAN is achieved through traceability of measurements to SI units or internationally accepted standards. Regular redundant measurements and additional ground checks guarantee that the measurement error, analysed along with the measurements themselves, are internally consistent. Key components are a detailed analysis of systematic and random measurement errors starting from raw data and transparent processing.

The GRUAN Lead Center was set up in 2008 at the Lindenberg Meteorological Observatory – Richard Assmann Observatory of the Deutscher Wetterdienst (DWD) to implement GRUAN and co-ordinate the establishment of the network. Two additional scientist positions were created at the DWD to support this effort. The Lead Center plays a central role in the definition and realisation of reference observations, co-ordinates the flow of data from the stations and assures that all metadata, which are essential attributes of the measurements, are included. Complete metadata descriptions of the data series as well as storage of all raw data guarantee that current data will be comparable in the future and that observations are homogeneous across the network. This extensive storage also guarantees that new insights into data analysis can be applied to the older data. The Lead Center provides regular reports and updated information about GRUAN at www.gruan.org.

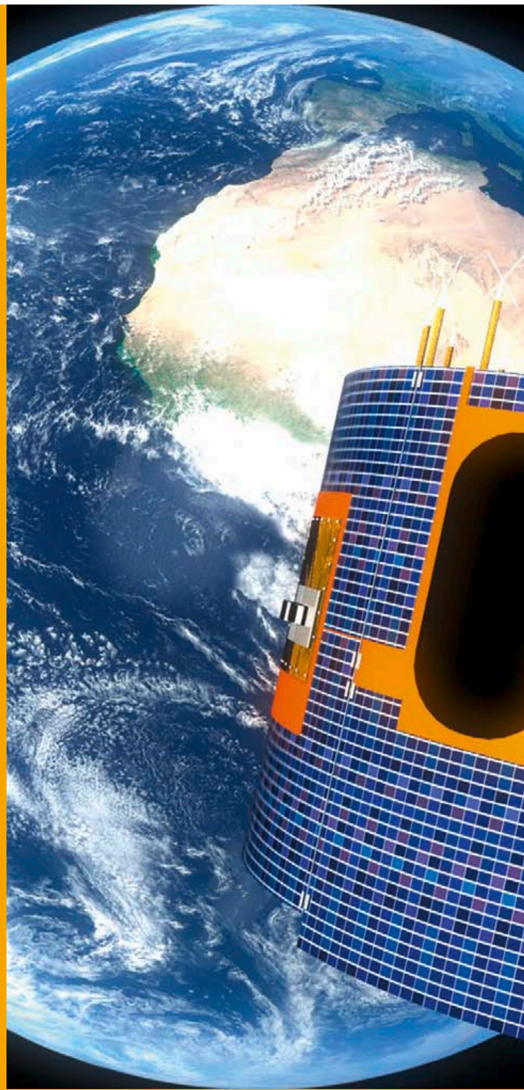
The GRUAN Lead Center co-operates closely with relevant committees of the World Meteorological Organization (WMO), such as the Commission for Instruments and Methods of Observation (CIMO), the Commission for Basic Systems (CBS) and the Commission for Atmospheric Sciences (CAS), as well as with a number of other national meteorological services and universities to improve observations at sites that are not directly connected to GRUAN. Furthermore, the Lead Center participates in international radiosonde comparison events and conducts independent tests and laboratory experiments on sounding equipment.



◀ Current and planned BSRN stations (as of September 2012)
Source: AWI

www.gsnmc.dwd.de **www.gruan.org**

5.9 The Satellite Application Facility on Climate Monitoring



Concerns about the changing global climate have highlighted the need for further development of climate monitoring activities at regional and global levels. To this end, only satellite-based observations provide the necessary geographical coverage of timely, high-quality data. Especially over the oceans and in sparsely populated areas, satellites are generally the only source of data. The aim of the Satellite Application Facility on Climate Monitoring (CM SAF) is to provide the satellite-based geophysical data sets that are required for climate monitoring. The CM SAF is part of the network of Satellite Application Facilities (SAF), which in turn forms an integral part of the Application Ground Segment of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

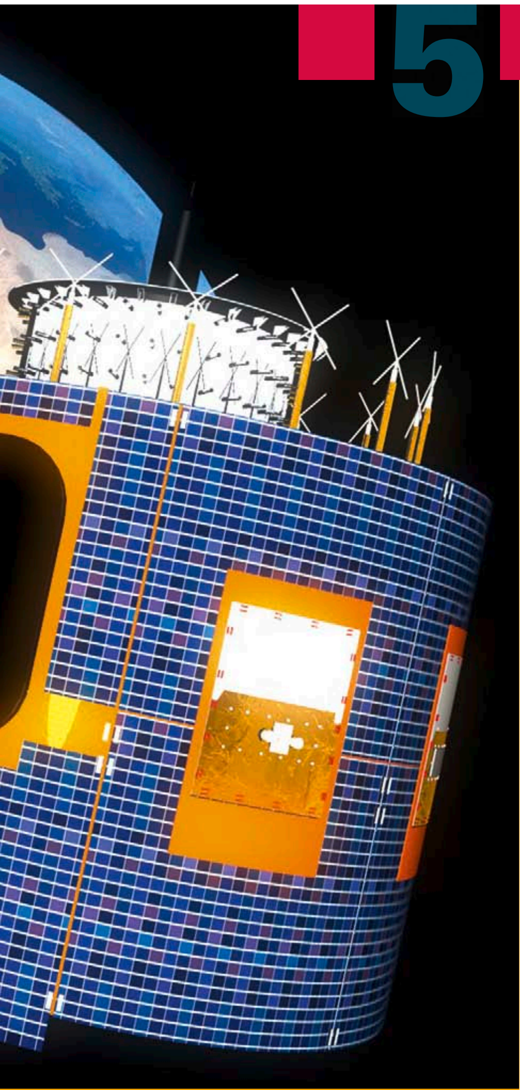
Significance for GCOS

The CM SAF provides a range of climatological parameters addressing some of the 'Essential Climate Variables' (ECV) called for by the GCOS Implementation Plan in support of the United Nations Framework Convention on Climate Change (UNFCCC). According to GCOS' second report on the adequacy of the global observing systems for climate, the CM SAF focuses on the provision of geophysical parameters describing elements of the energy and water cycle, in compliance as far as possible with GCOS Climate Monitoring Principles. The CM SAF provides regional products with a comparatively high spatial resolution as well as global products that complement ongoing international activities.

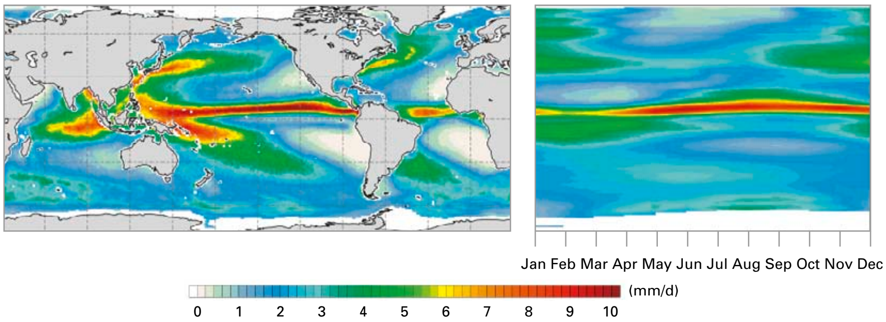
Organisation

The CM SAF is part of the SAF network of EUMETSAT, which consists of eight competence centres, each one dedicated to a specific scientific question. The operations and further development of the CM SAF are led by the Deutscher Wetterdienst (DWD) in collaboration with the Royal Meteorological Institute of Belgium (RMI), the Finnish Meteorological Institute (FMI), the Royal Netherlands Meteorological Institute (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI) and the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss). The UK's Met Office joined the CM SAF at the beginning of the current project phase in March 2012.

▲
Dark blue: CM SAF Consortium: DWD, Germany (leader); FMI, Finland; KNMI, Netherlands; MeteoSwiss, Switzerland; Met Office, United Kingdom (entry 2012); RMI, Belgium; SMHI, Sweden
Light blue: other EUMETSAT Member and Co-operating States



Mean precipitation totals according to the HOAPS-3 data set (mm/d)



▲ Mean precipitation totals (mm/d) for the period 1981 to 2008 (left: global distribution; right: zonal mean annual cycle)

Products and services

The CM SAF provides geophysical data sets for climate monitoring, deriving from measurements by different instruments on geostationary and polar-orbiting meteorological satellites. The data products of the CM SAF include monitoring data obtained in near real time and long-term data sets based on carefully calibrated inter-sensor radiances. The homogenous sets of high-quality data help scientists to investigate climate variability and its long-term changes.

The CM SAF's expanding product suite is designed to address applications focussing on the earth's atmospheric water and energy cycles at both global and regional scales, including:

- macro and microphysical cloud properties
- surface radiation parameters, including surface albedo
- top-of-the-atmosphere radiation parameters
- water vapour and temperature

An example of these is the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) climate data record (see graph). This data set of ocean parameters derived from passive Special Sensor Microwave Imager (SSM/I) measurements for the period 1987 to 2008 enables climate studies into ice-free oceans.

The CM SAF offers all its products free of charge to the scientific community, including comprehensive documentation and information about validation. User services are provided through the website at www.cmsaf.eu. Access to available CM SAF data is provided by an online order platform that makes it easy for users to identify the products, data and additional services they need for a selected region of interest (see wui.cmsaf.eu).

International context

The products and procedures of the CM SAF not only respond to the aims of GCOS, but also contribute to other international programmes such as the World Climate Programme (WCP) and the World Climate Research Programme (WCRP). CM SAF data are essential for activities of the Group on Earth Observations (GEO) and the Global Monitoring for Environment and Security (GMES) programme. The DWD also participates in European activities such as the ESA Climate Change Initiative and various EU-funded projects (e.g. EURO4M) that interface with CM SAF.

http://cmsaf.eu

6.1

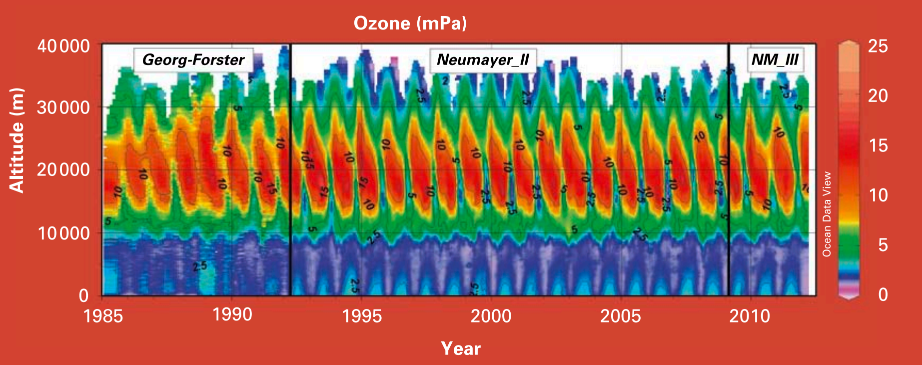
Ozone soundings at Neumayer station in the Antarctic

Since 1992, weekly ozone soundings have been performed at the German Antarctic research station Neumayer. The project is ongoing. It continues the time series started in 1985 at the neighbouring German Georg Forster research station. Combined together, the two data sets form the longest time series of ozone soundings in the Antarctic and clearly show the development of the ozone hole.

Significance for GCOS

The ozone hole over the Antarctic was discovered in 1985. The supposition that chlorofluorocarbons (CFCs) from refrigerators and spray cans damage the ozone layer had been a subject of discussion among experts for a long time. However, the first measurable decline in the ozone layer was detected over the Antarctic of all places – far away from all anthropogenic CFC sources on the earth.

This discovery turned out to be of great significance far beyond Antarctica since it led to the Montreal Protocol in 1987, in which the signatory states agreed to the complete elimination of ozone-depleting substances. Worldwide CFC production is now almost at an end and the regeneration of the ozone layer is expected to take place within the coming decades.



▲ Time-altitude section of ozone partial pressure above the Antarctic Georg Forster and Neumayer research stations. The ozone layer lies at altitudes between 10,000 and 25,000 m, identifiable by the high ozone values shown in yellow and red. During the Antarctic spring between September and November, the ozone layer regularly weakens, displaying local minimum values in some years (blue) instead of maximum values (red).
Source: Gert König-Langlo

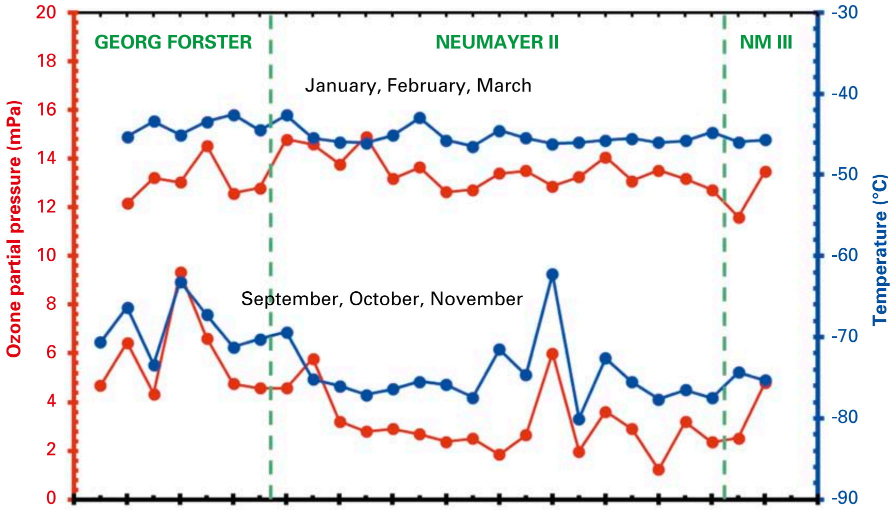
http://www.awi.de/en/go/meteorological_observatories

▲
Neumayer station (70°40′S, 008°16′W) on the Ekström Shelf Ice (Antarctica) shortly after the rebuilding was finished in 2009. On top of the station, the balloon-filling hall can be seen.

Required resources

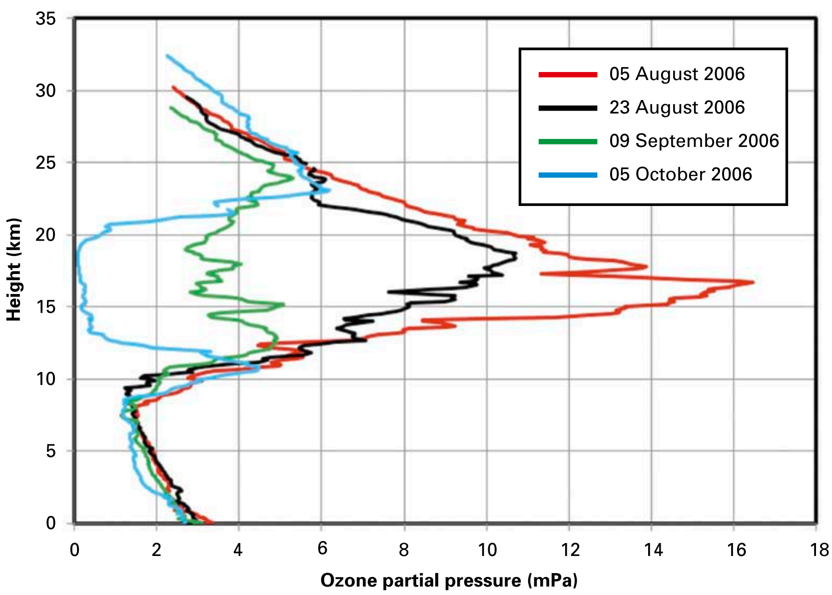
The Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven runs the Antarctic Neumayer research station including its meteorological observatory and ozone-sounding programme (see www.awi.de/en/go/meteorological_observatories). The station was rebuilt in 2009. It has a design life of approximately three decades. The ozone-sounding programme is ongoing. The AWI carries all necessary costs.

Time series of seasonal averaged stratospheric parameters (at 70 hPa)



▲
Time series of average ozone partial pressure (red) and temperature (blue) from September to October at 15 to 18 km above the Georg Forster and Neumayer stations
Source: Gert König-Langlo

Ozone altitude profiles above Neumayer station



▲
The dramatic ozone destruction in the Antarctic spring led to the complete depletion of the ozone layer in October 2006.
Source: Gert König-Langlo

6.2 Glacier monitoring abroad

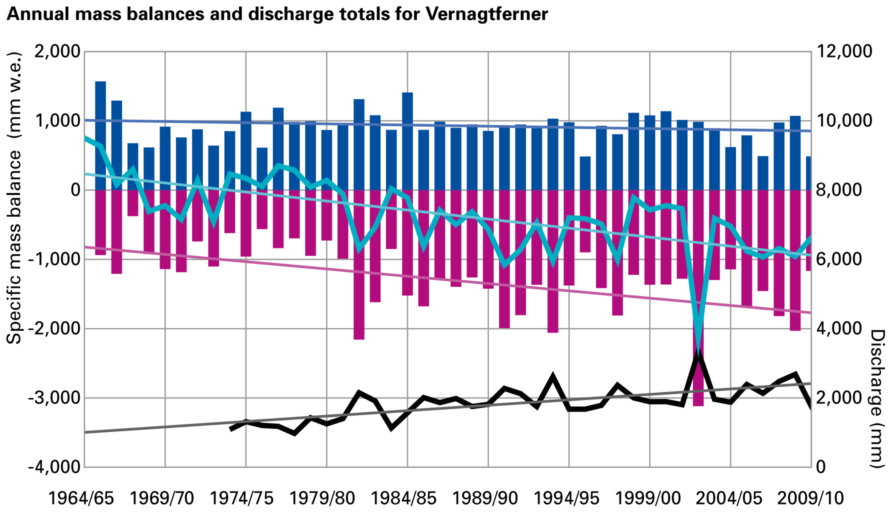
The Glaciology department of the Commission for Geodesy and Glaciology (KEG) of the Bavarian Academy of Sciences and Humanities (BAdW) has determined the changes in area of ten Austrian glaciers since 1889 at 10-year intervals. In addition, the annual sums of mass balance for the Vernagtferner Glacier in the Ötztal Valley have been analysed since 1964 and hourly values of the total glacier discharge recorded since 1974.

Description of measurements
Ten of the fifteen Eastern Alpine glaciers monitored by the KEG lie in Austria and are predominantly surveyed with the geodetical method. Four glaciers are in the Ötztal Valley (Vernagt, Guslar, Hintereis and Gepatsch), two in the Stubai Valley (Sulzenau and Grünau) and four in the Zillertal Valley (Schwarzenstein, Horn, Waxegg and Schlegeis). The longest data series is available for Vernagtferner (see graph and measurement description in Chapter 4.6), the second longest series for Hintereisferner (going back to 1894). Gepatschferner and all the glaciers in Zillertal Valley have been monitored since 1921, the Stubai glaciers since 1932. All series of changes in mass show a similar time pattern, with high losses until around 1950, slight gains between 1960 and 1980 and finally even higher losses than in the first half of the century. The mean loss in thickness of Vernagtferner between 1889 and 1969 was about 30 cm/a, with a loss in area from 11.58 km^2 to 9.56 km^2. In 2009, the total area amounted to 7.92 km^2 and the glacier had split into two parts. Measurements of the ice thickness with geo-radar in 2007 gave a mean value of 31 m.

Since 1964, the direct glaciological method has been used to determine the mass balance of Vernagtferner for the accumulation and ablation periods separately (see graph, top part). The separate analysis of winter and summer figures shows that the high loss of ice mass does not result from lower precipitation in winter, but from higher amounts of melting during summer. The series shows a mean total loss of 16.2 m water equivalent for the period 1964 to 2010, with the highest losses in 2003.

In 1973, the Vernagtbach gauge and climate station was installed which, at 2,640 m, is the highest discharge measuring point in the Eastern Alps. The station is unmanned, with monthly maintenance controls between April and November. Between 1974 and the mid-1980s, meteorological and hydrological parameters were recorded mainly during the summer, but measurements have been carried out practically all year for about the last 25 years. The data include hourly

Annual mass balances and discharge totals for Vernagtferner



◀ Photo of the central part of Vernagtferner (taken with an automatic camera on 17.08.2011)

▲ The figure shows both the annual mass balances determined for Vernagtferner in the Ötztal Valley using the direct glaciological method (top part) since 1964/65 and the annual discharge totals recorded at Vernagtbach gauge station since 1974 (bottom part) (Escher-Vetter, 2011). In addition to the total mass balance (continuous turquoise line), winter and summer balances (blue and red columns respectively) are presented (Escher-Vetter et al., 2009). Linear trends are included for all parameters. The discharge trend shows an increase from 1,280 mm to 2,410 mm, a near-doubling of the total discharge between 1974 and 2010. The increase in the mass balance in summer is even greater, with absolute values of around -800 mm water equivalent (mm w.e.) in 1964 and -1,750 mm w.e. at the end of the period. Thus, summer losses due to melting have more than doubled. In contrast, winter mass balance, i.e. the amount of precipitation in winter, shows only a slight decline from approx. 1,000 mm w.e. to 880 mm w.e.

values for discharge, precipitation and air temperature, as well as the four radiation components, air pressure, air humidity, snow height and various other hydrological parameters. Daily photographs of the glacier are available for the summer months going back to 1976, direct ablation measurements on the ice surface since 2005. All meteorological and hydrological data sets can be obtained free of charge from the PANGAEA® database at www.pangaea.de.

Required resources

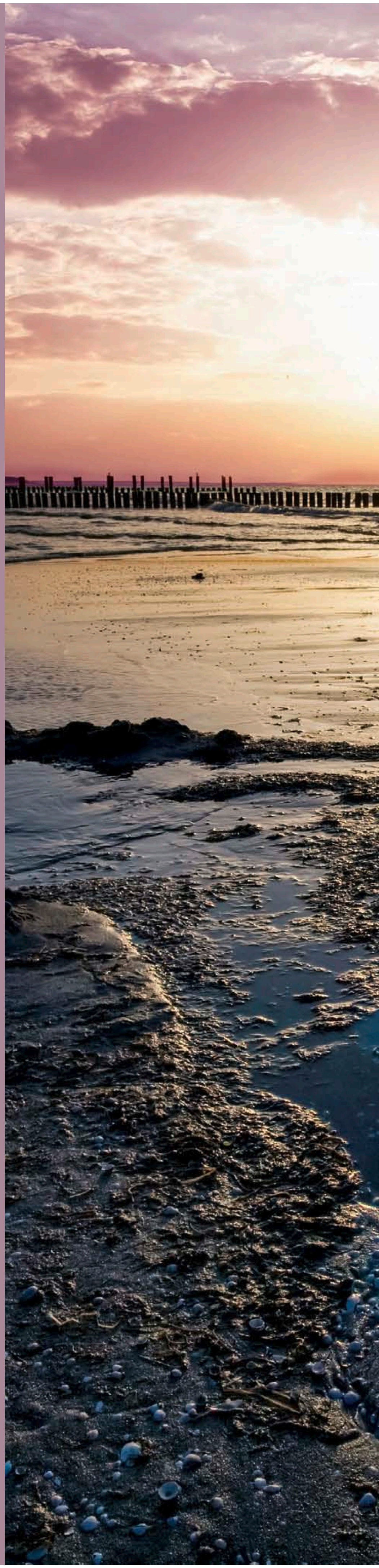
Due to the uncertainty surrounding the financing of the KEG after 2015 (see Chapter 4.6) future monitoring of the Vernagt Glacier is greatly endangered. In addition, the amount of data collected during the last decades is so vast that additional staff is required in order to process all the parameters and publish the results.

http://www.glaziologie.de

6.3

International tide gauge observations

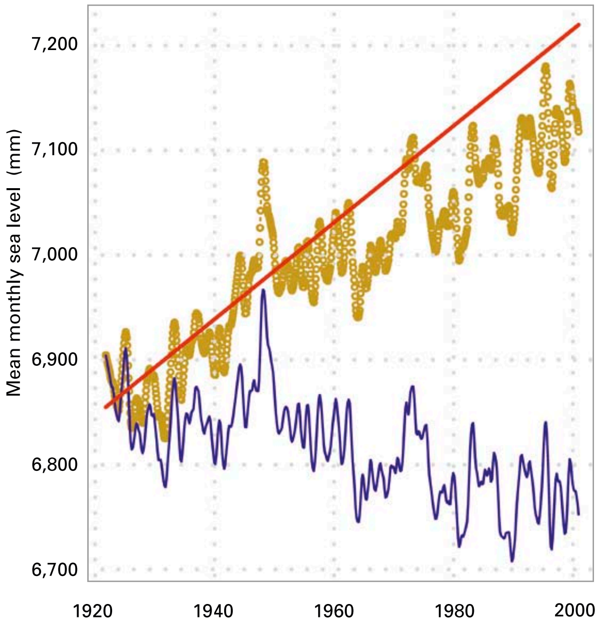
For about ten years now, international analysis centres, co-ordinated by the Helmholtz Centre Potsdam – German Research Centre for Geosciences (GFZ), have been evaluating all freely available GPS measurements taken by tide gauges and referenced to tide gauge zero. In the framework of the Tide Gauge Benchmark Monitoring project (TIGA), co-ordinated by GFZ, results are made available in the form of time series of sea height changes and mean vertical movements.



Description of measurements
In the history of the earth, the sea level has oscillated in response to climate fluctuations between warm and cold periods by up to 200 m. Although sea level height has remained fairly constant during the last 2,000 years, it has risen globally since the middle of the 19th century. Before the introduction of the first satellite-based radar altimeters in the 1980s, coastal gauges were generally used to monitor changes in sea level. The first systematic tide gauge measurements were conducted by the Royal Society of London after 1660; continuous time series have been available for about 150 years. However, estimation of the sea level rise from these measurements is problematic, since the gauges themselves can move in relation to sea level as a result of processes such as land uplift and subsidence. The development of space-based geodetic monitoring techniques, such as GPS, has enabled the vertical movement of coastal gauges to be tracked systematically using new, cost-effective methods, and be taken into account in the analyses. Since the beginning of the 1990s, international organisations, including the International GNSS Service (IGS), the Permanent Service for Mean Sea Level (PSMSL), UNESCO's Global Sea Level Observing System (GLOSS) and number of other research institutes, have defined the scope and aims of an international service for correction of the vertical movement of coastal gauges. In this work, Global Navigation Satellite System (GNSS) techniques, i.e. GPS, GALILEO and GLONASS, will have a particularly important role to play. At the 7th session of the IOC/GLOSS Group of Experts in 2001, the GFZ presented a draft project to set up a pilot service (the TIGA project) to operate under the auspices of the IGS. Since then, international analysis centres, co-ordinated by GFZ, have been evaluating all freely available GPS measurements continuously taken by tide gauges and referenced to the tide gauge zero. In the framework of the GFZ-co-ordinated TIGA project results are made available in the form of time series of sea height changes and mean vertical movements.

▲
Network of GPS stations at tide gauges (green triangle: TIGA observing stations; red star: stations in the test phase)

Mean monthly sea level (mm)



◀ An example of the effects of the correction for vertical land movement is the gauge in Charleston (South Carolina, USA). The gauge data, recorded over a period of almost a century, show an upward trend, which takes a slightly negative turn if the vertical movement rate (assumed to be constant in the past) is determined and corrected by GPS. Graphic: Nana Schön, GFZ

The goals and tasks of TIGA can be summarised as follows:

1. Provision of high-quality data to calculate GNSS station coordinates and velocities at or near coastal gauges. The analyses are regularly repeated using the latest methods and models and incorporating all newly available station data.
2. Maintenance of the global network of GNSS stations at tide gauges
   - monitoring the existing network of GNSS stations at tide gauges, and densification and expansion of the network, especially in the southern hemisphere;
   - analysis of GNSS data streams with different latencies;
   - support for initiatives to increase network density by integrating continuously operating GNSS stations into the TIGA network;
   - linking up the TIGA network based on GNSS stations with stations that use other methods to determine vertical movements, such as Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) stations, Satellite Laser Ranging (SLR) stations and stations that are connected through relative or absolute gravity measurements.
3. Investigations leading to the implementation of a global reference system, stable over the long term, to improve the accuracy of the vertical components. To this end, parts of the IGS network will be reanalysed in addition to the repeated analyses within the TIGA network. The results of the analysis currently under way will be published in 2013.

Significance for GCOS

Three German institutes take part in the work of the TIGA project: the German Federal Agency for Cartography and Geodesy (BKG), which combines the results of the European Geodetic Reference Frame (EUREF) network, the German Geodetic Research Institute (DGFI) and the GFZ. The results made available internationally over the past years through the work of TIGA and its analysis centres have given rise to and provided support for numerous studies. The latest studies show, for example, a high degree of consistency among GPS-corrected estimates of the trend of sea level rise. The analyses of the TIGA project have also contributed to methodological improvements in mathematical reconstructions of sea level trends and variations over the last decades, and in the calibration of satellite-based radar altimeters.

http://adsc.gfz-potsdam.de/tiga/

6.4

CO_2 partial pressure in the ocean

Observation of marine carbon circulation is one of the most important tasks of marine research (Riebesell et al., 2009; Gruber et al., 2010). The focus of attention is the take-up and storage of anthropogenic CO_2, climate-driven changes in the natural carbon cycle and the effects of CO_2 take-up on the marine ecosystem (ocean acidification).

Description of measurements

The observations required to provide answers to scientific and social questions raised by these issues exceed the capacity of a single monitoring system. A network of harmonised and co-ordinated observations is required. The most important components of this co-ordinated effort include the following:

- a network of commercial vessels operating as voluntary observing ships (VOS) which provide continuous autonomous measurements of CO_2 partial pressure (pCO_2) and other relevant sea surface para-meters;
- a network of oceanic time-series stations in key regions (Send et al., 2010);
- an international programme of regular sampling of selected hydrographic sections (Repeat Hydrography Program) (Hood et al., 2010)

Germany makes an important contribution to all three network components through its participation in the international monitoring system co-ordinated by the International Ocean Carbon Coordination Project (IOCCP).

1. VOS network:

- Transatlantic VOS line between Europe and North America: this VOS line crossing the subpolar North Atlantic was incorporated in 2002 and has been operated since then with some interruptions by the GEOMAR Helmholtz Centre for Ocean Research in Kiel.
- Baltic VOS line between Germany and Finland: this line, which was initiated in 2003, is operated by the Leibniz Institute for Baltic Sea Research, Warnemünde (IOW) and is part of the institute's long-term monitoring programme. It has a strong trace gases component.
- Polarstern VOS line: following the installation of an automated pCO_2 measurement system on the research ship Polarstern, autonomous measurements are routinely conducted during research cruises.

2. Time-series stations:

- Cape Verde Ocean Observatory (CVOO): this oceanic time-series station, situated off the Cape Verde Islands, formerly known as Tropical Eastern North Atlantic Time Series Observatory (TENATSO) and part of the EuroSITES network (www.eurosites.info), represents a significant extension of the international monitoring network.
- Hausgarten Observatory: in the framework of ICOS-D (the German contribution to ICOS), the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), in collaboration with GEOMAR, intends to upgrade the Hausgarten long-term monitoring station and include a sea surface CO_2 monitoring component.

3. Hydrographic research cruises:

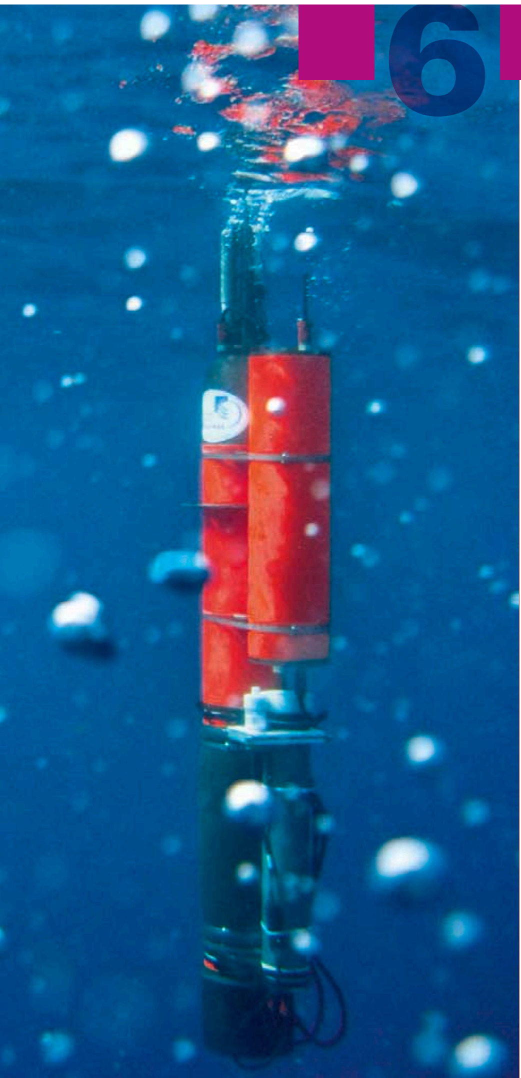
- Germany has undertaken hydrographic sections in the Weddell Sea (e.g. SO_2, SO_4) and in the subpolar North Atlantic (A01, A02) and plans to continue to participate in this activity on a limited basis.

Alongside the data portals that are operated by single research institutes, the collected data are stored and made available in the international PANGAEA® data bank, jointly operated by AWI and the Center for Marine Environmental Science (MARUM).

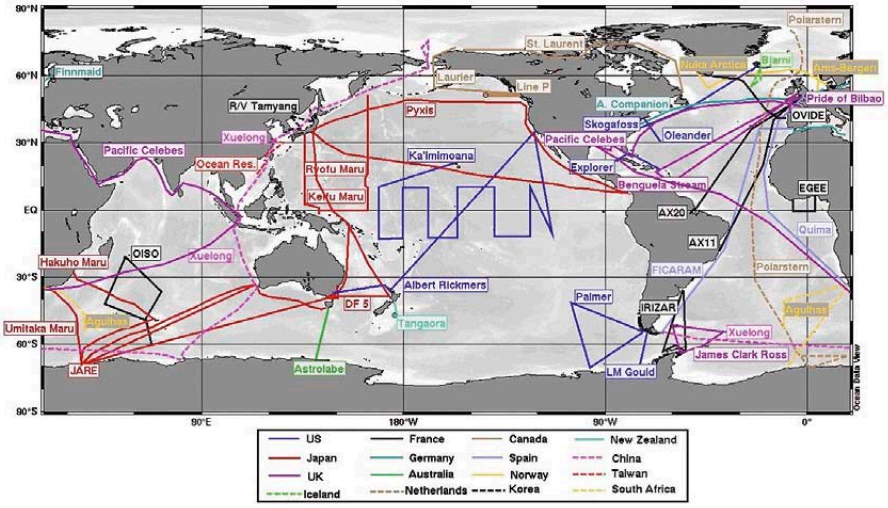
The collected data on CO_2 are also passed on to the international data banks operated by the Surface Ocean CO_2 Atlas (SOCAT), the Carbon Dioxide Information Analysis Center (CDIAC) and the CARbon Dioxide IN the Atlantic Ocean (CARINA) project.

Measurements of pCO_2 in near-surface ocean water have been undertaken sporadically since the

http://www.icos-infrastructure.eu



Present VOS network for measurement of pCO_2 at the sea surface



▲

Continuous, autonomous measurement of partial pressure of CO_2 (pCO_2) and other relevant sea surface parameters by voluntary observing ships (VOS)
Source: adapted from Monteiro et al., 2010; Watson et al., 2008

end of the 1960s; today, measurements are assured through the international VOS network that has developed since the 1990s, and above all in the last decade. The famous, periodically updated pCO_2 climatology of Taro Takahashi (Takahashi et al., 1995, 1997, 2002, 2008) was based on this data set. The Surface Ocean CO_2 Atlas (SOCAT), which has been under construction since 2007, currently represents the largest global data series, incorporating to date a total of 6.7 million measurements from 1,851 research cruises undertaken in the period 1968–2007.

Long data series from oceanic time-series stations are essentially limited to the Bermuda Atlantic Time-series Study (BATS), the Hawaii Ocean Timeseries (HOT, ALOHA), and the European Station for Time series in the Ocean at the Canary Islands (ESTOC) (Bates, 2007; Santana-Casiano et al., 2007; Dore et al., 2009).

Legal framework

At present, there is no legal obligation to monitor the carbon cycle; however, it is regulated by international agreements.

International context

The activities were, or still are components of the EU programmes EuroSITES (IP, FP7) and CARBOCHANGE (IP, FP7), and are part of the German contribution to ICOS. Internationally, they are co-ordinated by the IOCCP and the OceanSITES initiative.

Required resources

Measurement of CO_2 on the three above-mentioned VOS lines (subpolar North Atlantic, Baltic Sea, Artic/Antartic) and at the two long-term monitoring stations in the tropics (CVOO) and the Arctic (Hausgarten) are currently financed by the Federal Ministry of Education and Research (BMBF) within the pilot and demonstration phase (2012–2013) of the collaborative project ICOS-D, which will be followed by a two-year implementation phase (2014–2015), also BMBF funded. In the long-term, it is intended that resources for long-term operations should be made available by the institutions in charge.

http://www.socat.info http://cdiac.ornl.gov http://www.go-ship.org http://www.pangaea.de

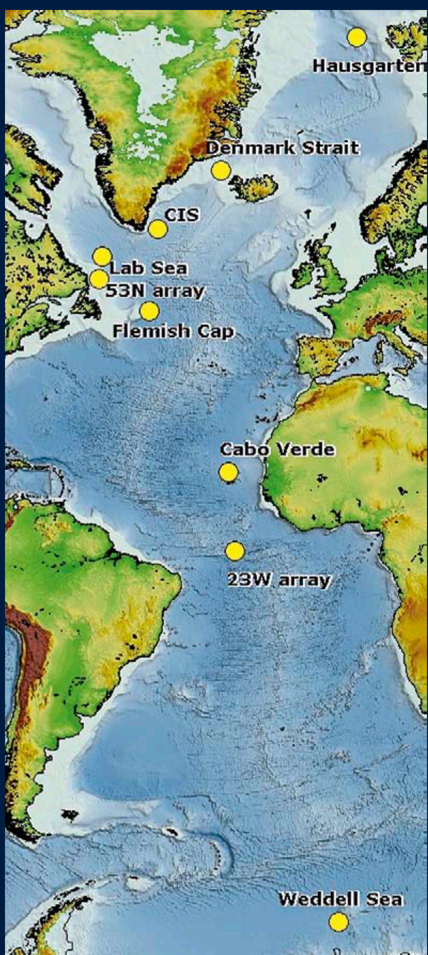
6.5

Deep ocean currents

Ocean currents are important for the distribution of heat, fresh water and matter around the world. Deep ocean currents are driven mainly by horizontal density differences. These currents, and especially the meridional overturning circulation (MOC) that carries warm water northwards and returns cold, deep waters southwards, are key variables and important components of the climate over longer (decadal) time scales. However, deep ocean currents are recorded only in a few selected places and long-term records are extremely rare.

Description of measurements

Measurement of deep ocean currents by German research groups focuses on long-term moored observation at key locations in the global ocean circulation system. Measurements in the straits between ocean basins play a central role. In the north, the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) maintains a mooring array in the Fram Strait, where flows between the Arctic Ocean and the European North Sea are recorded. The neighbouring oceanic sill is the Denmark Strait,where the Institute of Oceanography of the University of Hamburg (IFM Hamburg) has measured the overflow for many years. In addition, oceanic boundary currents are measured at all depth layers at various points across the globe. The most well-known arrays include those measuring outflow from the Labrador Sea at 53°N and at the Flemish Cap, and, in the tropics, boundary currents and the Equatorial Circulation (GEOMAR Helmholtz Centre for Ocean Research). Within the ocean basins, a number of observation stations

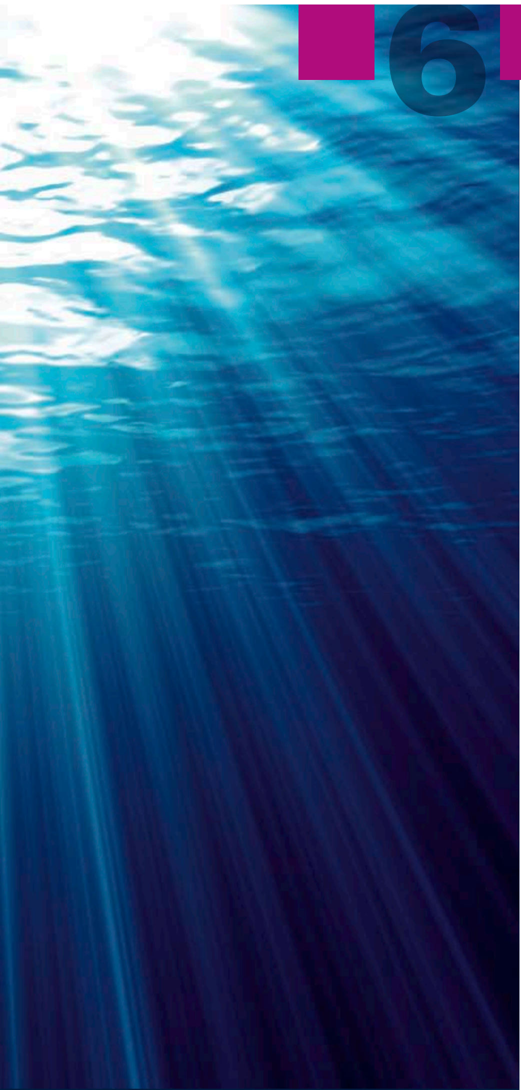


carry out long-term monitoring. Most of these are equipped with sensors to record a variety of parameters, including flow-meters for the production of long-term statistics on velocity fields.

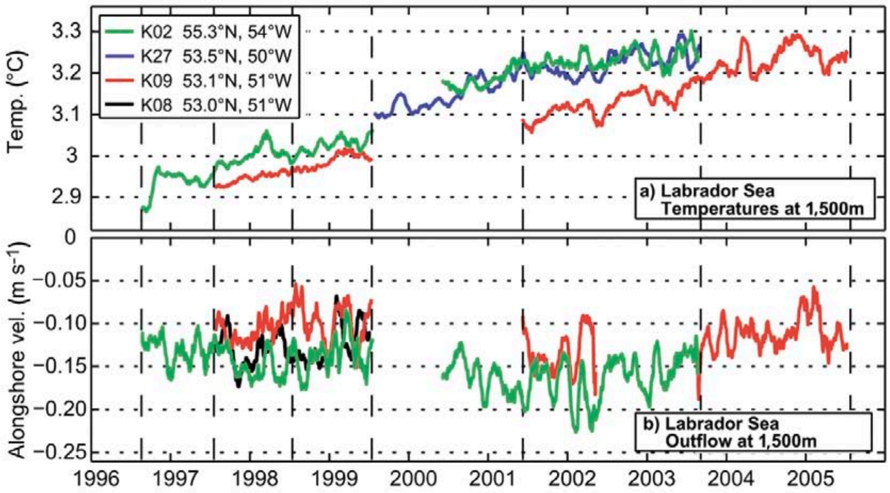
These stations are located in the Irminger Sea, the Labrador Sea and in the tropics (Cabo Verde), and form part of wider national and EU initiatives. In the far southern Ocean, in the Weddel Sea, the AWI is conducting long-term measurements of currents in the Weddel Gyre, by means of anchored and free-drifting Argo floats equipped with a special ice sensing algorithm.

Alongside the anchored systems, the currents at 1,000 to 1,500 m depth are measured globally by Argo deepwater drifting sensors based on international initiatives.

In the 1990s, the World Ocean Circulation Experiment (WOCE) recorded and described ocean circulation patterns under average conditions. Afterwards, the focus shifted more to the variability of climatically relevant parameters, of which ocean circulation is one. With the focus



Decadal changes in deep-water parameters in the Labrador Sea



▲
Top: Deep-water temperature at the Labrador Sea outflow
Bottom: Corresponding deep sea currents, showing short-term fluctuations but no discernable trend

now on climate and climate variability, exemplified by WOCE's successor project Climate Variability and Predictability (CLIVAR), there has been a further shift of emphasis towards measurement of long-term fluctuations of the climate system. Long time series are essential to investigate ocean-climate interactions, such as weakening of the MOC, sea-level rise, the provisioning of oxygen minimum zones, etc.

The available data are very variable, with respect to the length of the records and set of variables recorded by the different stations shown in the map. As an example, the time series of measurements at 1,500 m depth by four anchored floats in the 53°N array (illustration above) over ten years show a fairly clear trend in the temperature of the deep-water current; by contrast, breaks in the time series make it impossible to discern a long-term trend. This illustrates the need for sustained data collection at key locations in the ocean current system.

International context

Studies of long-term fluctuations of the boundary current system and oceanic straits as well as those aimed at the quantification of the MOC are very time-consuming and expensive. For this reason, ocean current monitoring networks are the subject of international agreements and a joint international effort is required to install them. German participation is essentially through EU programmes – in which national collaborative projects funded by the Federal Ministry of Education and Research (BMBF) and the German Research Foundation (DFG), e.g. in the form of ship times or Collaborative Research Centres (SFB), play a central role. Data storage and the timely availability of data records to the international research community (e.g. through the OceanSITES initiative) are important considerations. The definition of standards, quality assurance and compatibility of measurement data are all particularly important for long-term monitoring and require international networking through programmes, such as OceanSITES.

Required resources

Long times series are the basic requirement for detection of climate change on earth; the Keeling Curve showing the long-term rise in atmospheric CO_2 concentrations provides a well-known example. In this respect, the German contribution is important and internationally recognised. However, the sustainability of the observations is not secured, and long time series run the risk of being discontinued at short notice due to financial constraints. To mitigate this risk a new approach is required and suitable funding mechanisms need to be put in place.

http://www.clivar.org **http://www.awi.de** **http://www.geomar.de**

7.

Conclusions and outlook

This report is the first to present a truly comprehensive overview of the current state of climate data collection at the regional and national levels in Germany based on long-term data series of the various climate variables. As such, it documents Germany's contribution to GCOS. The report provides an outline of the legal foundations and points out deficiencies in the sustainability of observation activities (see Table 3 on pages 114 ff.) It thus constitutes an important planning basis for maintaining and further enhancing Germany's national climate observing system, GCOS-DE.

Conclusions

The GCOS Implementation Plan sets forth how strongly GCOS as a global system depends on well-functioning components at the national level. Through its Resolution 29, the World Meteorological Organization (WMO) has therefore urged its Member States at its 16th Congress (WMO, 2011)

"[…]
(1) to strengthen their national atmospheric, oceanographic and terrestrial climate observing networks and systems, including networks and systems for the hydrological and carbon cycles and the cryosphere within the framework of GCOS and in support of user needs;
(2) to assist other Members to strengthen their observing networks;
(3) to ensure, to the extent possible, the long-term continuity of the critical space-based components of GCOS;
(4) to establish GCOS National Committees and to identify GCOS National Coordinators
[…]."

Besides the Essential Climate Variables (ECVs) defined for data analysis at global, regional and national levels, other, locally specific climate parameters may be of additional interest. In Germany, for example, the variables pollen, isotopes in precipitation and plant phenology have been identified as of specific national interest. In some cases there also exist Europe-wide observation networks for these additional variables.

Not all processes and interactions in the climate system are known yet. Further to carrying out new, target-oriented studies, the sustainable continuity of long-term series of observations is needed to build up a large body of data for research and for further development and enhancement of climate models. This will help to further reduce the uncertainties about the future of our climate.

One of the aims of this report therefore is to enhance the continuity of long-term series of observations, especially those for the ECVs. Table 3 highlights those areas where there exists no legal framework for running climate observations or where no such framework is discernible as well as those where the

continuity of the observations is not secured or the necessary funding is missing. This classification relies on an analysis and assessment carried out on the basis of the information provided by the various expert authors and contributors to this report.

The observation of most atmospheric, oceanic and terrestrial ECVS (Chapters 2 to 4) has a legal foundation. In addition to these, the Federal Republic of Germany has to meet its commitments arising from international conventions and treaties, such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, the Global Earth Observation System of Systems (GEOSS), the Global Monitoring for Environment and Security (GMES) initiative and GCOS. However, the observations of some ECVs are considered as ‘not secured’. Other activities are only partly secured or secured until a certain date, with great uncertainty regarding their continuity. And what adds to this is that the data may not be exploited or analysed to their full extent due to the lack of resources or that there may be large gaps, either of which makes climatological analysis of the data very difficult.

Measures should therefore be taken to sustain all climate observations prescribed by law, but at the very least the observation of all climate variables relevant to Germany as described in this report. This applies to both in situ and remote sensing observations and must include data analysis as well as quality assurance, data storage and availability and accessibility of the data. In this context, operators of observing systems must report on how they meet the GCOS Climate Monitoring Principles (WMO 2003b, see Table 2).

Germany also makes valuable contributions to GCOS in the fields of international data and product centres. These centres provide the various application areas with data sets and products that are of the highest quality and in many respects unique. Most of the international data centres can be considered as secured. Only the Global Fire Monitoring Centre (GFMC) requires action to be taken from 2014 onwards.

Alongside the collection of information about the state and history of the climate system, six areas of action outside German territory where Germany contributes to GCOS activities have been defined. With the exception of the observations at the Neumayer station in the Antarctic, the future of all of these is considered as ‘not secured’ (see Table 3). The long-term records of atmospheric processes continuously gathered over centuries have proven to be a treasure trove of scientific data, needed for understanding the climate. To detect and understand critical changes, e.g. in connection with ocean acidification or the intensity of thermohaline circulation, as early as possible, we must continue to aim for sustainable observation of all ECVs including the oceans and at the ocean surface.

Evaluation

On the whole, the German GCOS segment GCOS-DE can be evaluated as good. This applies to the quality of the data collected just as much as to the sustainability of the observation programme – with a few exceptions.

However, a large deficiency still exists where sustainable observations of greenhouse gases as key climate drivers are concerned. For this reason, in particular those programmes should become permanent under which greenhouse gases are observed both because of their importance as core parameters for the description of the climate system and with a view to successful climate protection.

As an additional need for data analysis is reported for several of the climate variables, the resources allocated should be reviewed to ensure optimal exploitation of the data.

With the responsibilities for some of the climate variables being distributed widely, the compilation of this most comprehensive overview of climate observation in Germany required the collaboration of many experts and authors. A national GCOS programme would facilitate greater transparency, streamlined

Climate variable			Legal framework	Institution(s) in charge
Measurements in Germany				
Atmospheric observations				
Near surface	2.1	Temperature	exists	DWD
	2.2	Wind	exists	DWD
	2.3	Air pressure	exists	DWD
	2.4	Precipitation	exists	DWD
	2.5	Radiation	exists	DWD
	2.6	Sunshine duration	exists	DWD
Free atmosphere	2.7	Temperature, wind and water vapour	exists	DWD
	2.8	Clouds	exists	DWD
Atmosphere composition	2.9	Carbon dioxide	exists	UBA
	2.10	Methane	exists	UBA
	2.11	Other greenhouse gases	exists	UBA
	2.12	Ozone	exists	Länder
	2.13	Aerosols	exists	UBA
	2.14	Pollen	exists	DWD and PID
Ocean observations				
Sea surface	3.1	Ocean temperature	exists	BSH
	3.2	Salinity	exists	BSH
	3.3	Sea level	exists	BSH and Länder
	3.4	Sea state	exists	BSH
	3.5	Sea ice	exists	BSH
Open ocean	3.6	Deep water formation	none	Within the framework of basic research at universities and research institutes
Ocean composition	3.7	Ocean colour	exists	BSH
	3.8	Nutrients in the ocean	exists	BSH and Länder
	3.9	Oxygen conditions in the North Sea	exists	BSH and Länder
Terrestrial observations				
Hydrosphere	4.1	Runoff	exists	BfG and Länder
	4.2	Water use	exists	BfG implementation: Länder
	4.3	Groundwater	exists	BfG implementation: Länder
	4.4	Stable isotopes in precipitation	none	HMGU, DWD
Cryosphere	4.5	Snow cover	exists	DWD
	4.6	Glaciers and permafrost	exists	BAdW and LfU
Biosphere	4.7	Albedo	exists	DWD
	4.8	Soil carbon	exists	Thünen Institute for Forest Ecosystems, the Federation, Länder
	4.9	Forest fires	exists	DWD and Länder
	4.10	Soil moisture	exists	DWD and Länder
	4.11	Phenology	exists	DWD and Länder

Sustainability of observations (funding)
largely secured
largely secured
largely secured
largely secured
largely secured
largely secured
largely secured
largely secured
partly secured
partly secured
not secured
largely secured
partly secured
not secured
largely secured
largely secured
largely secured
largely secured
largely secured
not secured
not secured
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largely secured
largely secured
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largely secured
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largely secured
not secured after 2015
largely secured
partly secured
largely secured
largely secured
partly secured

approaches and co-ordinated implementation strategies, with the aim of establishing the German Climate Observing System (GCOS-DE) to its full extent. In agreement with Resolution 29 of the 16th WMO Congress (WMO, 2011), it is therefore planned to establish a steering body for GCOS-DE (i.e. a national GCOS committee), based on the national GCOS meeting.

An overall, Internet-based climate information system that can provide an always up-to-date overview of the state and development of the climate in Germany, present the findings obtained through GCOS-DE and list all responsible institutions would be a useful support tool for political and economic decision-making and a valuable contribution towards implementing the Framework Convention on Climate Change. It should therefore be installed in the medium term.

◀ Table 3:
Overview of the Essential Climate Variables and their status in terms of legal framework, institution(s) in charge and funding
(in red: measurement series and data centres whose continuity is endangered)

Outlook

The primary aim should be to secure the sustainability and continuity of those German climate observations that are of major importance. Germany's National GCOS Coordinator, who is based at the Deutscher Wetterdienst (DWD), will continue to strive for this goal. To support these efforts, the establishment of a National GCOS Committee for Germany is currently being discussed. In this context, special attention is being paid to respecting the Climate Monitoring Principles of GCOS (see Table 2 on page 10) to assure that data are free from any undesired interference signals. In addition, accurate documentation of the metadata must be guaranteed to assure the correct assessment of data now and in the future.

In addition to in situ observations, remote sensing-based data (e.g. satellite and radar data) are increasingly used for climatological applications. Provided that GCOS' special principles for satellite-based climate observation are followed properly, the resulting data are a good complement to in situ data due to the additional information they provide. Satellite data are especially well suited for filling spatial data gaps in global climate observation coverage as well as for the derivation of global data sets (see Table 1; WMO, 2006; WMO, 2011).

The list of ECVs is not static; advancing climate research and measurement technologies will enable new variables to be added to it. New requirements from the users, e.g. in the context of the planning of adaptation to climate change, may also cause changes to the list. The significance of new ECVs for Germany must be verified and co-ordinated as part of the implementation of the GCOS Implementation Plan (WMO, 2010).

The parties to the United Nations Framework Convention on Climate Change have, until the beginning of 2014, to submit their latest report on their contribution to systematic climate observation. On the basis of these reports, combined with the 5th IPCC Assessment Report, a new review of the adequacy of the Global

Climate variable	Legal framework	Institution(s) in charge
International data centres		
5.1 Global Precipitation Climatology Centre (GPCC)	not required*	DWD and Länder
5.2 Global Runoff Data Centre (GRDC)	not required*	BfG
5.3 World Radiation Monitoring Center (WRMC)	not required*	AWI
5.4 World Data Center for Climate at the German Climate Computing Centre (WDC-Climate)	not required*	Max Planck Society, Land Hamburg (Hamburg University), AWI, HZG, BMBF
5.5 World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT)	not required*	DFD, DLR
5.6 Global Fire Monitoring Center (GFMC)	not required*	Max Planck Institute for Chemistry
5.7 ICSU World Data Center PANGAEA®	not required*	MARUM, AWI
5.8 Data quality assurance centres of GCOS	not required*	DWD
5.9 Satellite Application Facility on Climate Monitoring (CM SAF)	not required*	DWD with EUMETSAT and other partners
*usually by self-commitment of the Federation		
Observations abroad		
6.1 Ozone soundings at Neumayer station in the Antarctic	exists	AWI
6.2 Glacier monitoring abroad	not required	KEG
6.3 International tide gauge observations	exists	BKG, DGFI, GFZ
6.4 Partial pressure of CO_2 in the ocean	exists	GEOMAR
6.5 Deep ocean currents	not required	AWI, IFM Hamburg, GEOMAR

Sustainability of observations (funding)
largely secured
largely secured
largely secured
largely secured
largely secured
not secured after 2013
largely secured
largely secured
largely secured
largely secured
not secured after 2015
not secured
not secured after 2014
not secured

Climate Observing System, GCOS, will commence to assess its suitability and coverage.

The discovery of any synergies between the measuring networks could indicate some potential for optimising observation activities and help to improve the understanding of the climate system as a whole. In this context, integrated analyses of several climate variables could be valuable.

For this reason, a well-functioning national climate observation system also is an important pillar for national implementation of the Global Framework for Climate Services (GFCS).

◀ Table 3:
Overview of the Essential Climate Variables and their status in terms of legal framework, institution(s) in charge and funding (in red: measurement series and data centres whose continuity is endangered)

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Abbreviations

AARI	Arctic and Antarctic Research Institute
AATSR	Advanced Along-Track Scanning Radiometer
ACP	Atmospheric Composition Portal
ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network
AGU	American Geophysical Union
AirBase	European Air quality dataBase
ALOHA	A Long-term Oligotrophic Habitat Assessment
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AMBAV	Agrarmeteorologisches Modell zur Berechnung der aktuellen Evapotranspiration (Agrometeorological model for the calculation of current evapotranspiration)
AMSeL	Mean Sea Level and Tidal Analysis at the German North Sea Coastline
Antarkt-UmwSchProtAG	Gesetz zur Ausführung des Umweltschutzprotokolls vom 4. Oktober 1991 zum Antarktis-Vertrag (Act implementing the Protocol of Environmental Protection to the Antarctic Treaty of 4 October 1991)
AOPC	Atmospheric Observation Panel for Climate
Aquarius/SAC-D	Fourth satellite of the Argentinian SAC scientific satellite series
ARGO	Global array of 3,000 free-drifting profiling floats that measures the temperature and salinity of the upper 2,000 m of the ocean
ATSR-2	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
BAdW	Bavarian Academy of Sciences and Humanities
BATS	Bermuda Atlantic Time-series Study
BBodSchG	Bundesbodenschutzgesetz (Federal Soil Protection Act)
BC	Black carbon
BDF II	Boden-Dauerbeobachtungsfläche II (permanent soil observation plot, type II)
BfG	Bundesanstalt für Gewässerkunde (Federal Institute of Hydrology)
BGBl	Bundesgesetzblatt (Federal Law Gazette)
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BKG	Bundesamt für Kartographie und Geodäsie (German Federal Agency for Cartography and Geodesy)
BLE	Bundesanstalt für Landwirtschaft und Ernährung (Federal Office for Agriculture and Food)
BLMP	Bund/Länder-Messprogramm Meeresumwelt (German Marine Monitoring Programme)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BMELV	Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (Federal Ministry of Food, Agriculture and Consumer Protection)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development)
BOOS	Baltic Operational Oceanographic System
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency)
BSRN	Baseline Surface Radiation Networks
BW	Bundeswehr (Federal Armed Forces)
BZE	Bodenzustandserhebung (national soil survey)
BZE-LW	Bodenzustandserhebung Landwirtschaft (German agricultural soil inventory)
BZE Wald	Bodenzustandserhebung im Wald (national forest soil survey)
CARBOCHANGE	EU FP7 Project on Changes in carbon uptake and emissions by oceans in a changing climate
CarboEurope	Integrated Project CarboEurope-IP – Assessment of the European Terrestrial Carbon Balance
CARBOOCEAN	Integrated project on marine carbon sources and sinks assessment
CARIBIC	Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container
CARINA project	CARbon dioxide IN the Atlantic Ocean data synthesis
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems

CCI	WMO Commission for Climatology
CCLM	COSMO Climate Limited-area Modelling
CDIAC	Carbon Dioxide Information Analysis Center
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CH_4	Methane
CHL	Chlorophyll
CHy	WMO Commission for Hydrology
CIMO	WMO Commission for Instruments and Methods of Observation
CliC	Climate and Cryosphere project
CLIMAT	A code for reporting monthly climatological data
CLIVAR	WCRP Programme on Climate Variability and Predictability
Cloudnet	Network of stations for the continuous evaluation of cloud and aerosol profiles in operational NWP models
CMIP5	Coupled Model Intercomparison Project Phase 5
CM SAF	EUMETSAT Satellite Application Facility on Climate Monitoring
CNES	Centre National d'Études Spatiales (French Space Agency)
CNRS	Centre national de la recherche scientifique (French National Center for Scientific Research)
CO_2	Carbon dioxide
Copernicus	European Earth observation programme Copernicus, previously known as GMES
COSMO-DE	COSMO small-scale model for Germany
COSMO-EU	COSMO small-scale model for Europe
COST	European Cooperation in Science and Technology
CTD	Climate Technology and Development Project
CVOO	Cape Verde Ocean Observatory
CZCS	Coastal Zone Color Scanner
D-A-CH	Refers to co-operation initiatives between Germany, Austria and Switzerland
DCPC	Data Collection and Production Centre
DDC	Data Distribution Centre
DeStatis	Statistisches Bundesamt (Federal Statistical Office)
DFD	Deutsches Fernerkundungsdatenzentrum (German Remote Sensing Data Centre)
DFG	Deutsche Forschungsgesellschaft (German Research Foundation)
DGFI	Deutsches Geodätisches Forschungsinstitut (German Geodetic Research Institute)
DGJ	Deutsches Gewässerkundliches Jahrbuch (German Hydrological Yearbook)
DIN	Dissolved inorganic nitrogen (nitrate, nitrite and ammonium))
DKRZ	Deutsches Klimarechenzentrum (German Climate Computing Centre)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DOD	Deutsches Ozeanographisches Datenzentrum (German Oceanographic Data Centre)
DOI	Digital Object Identifier
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DU	Dobson unit
DWD	Deutscher Wetterdienst (German Meteorological Service)
EAN	European Aeroallergen Network
EarthCARE	Earth Clouds, Aerosols and Radiation Explorer
EBAS	Database of atmospheric chemical composition and physical properties
EC	European Community
ECMWF	European Centre for Medium-Range Weather Forecasts
ECOOP	European COastal sea OPerational observing and forecasting system
ECSN	European Climate Support Network
ECV	Essential Climate Variable
EEA	European Environment Agency
EEZ	Exclusive economic zone
EFAS	European Flood Awareness System

EFFIS	European Forest Fire Information System
EMEP	European Monitoring and Evaluation Programme
ENSO	El Niño Southern Oscillation
ENVISAT	ESA Environmental satellite
EPN	European Phenological Network
EPS	Ensemble Prediction System
ESA	European Space Agency
ESRL	NOAA Earth System Research Laboratory
ESTOC	European Station for Time series in the Ocean, Canary Islands
EU	European Union
EUMETNET	Economic Interest Grouping (EIG) of European National Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUREF	European Geodetic Reference Frame
EURO4M	EUropean Reanalysis and Observations For Monitoring project
EuroGOOS	European Global Ocean Observing System
EuroSITES	European Ocean Observatory Network
Eurostat	Statistical office of the European Union
EUROWATERNET	The European Environment Agency's Monitoring and Information Network for Inland Water Resources
EUSAAR	European Supersites for Atmospheric Aerosol Research
FAO	Food and Agriculture Organization of the United Nations
FINO1	Research platform in the North Sea
FMI	Finnish Meteorological Institute
FP7	Seventh Framework Programme for Research of the European Union
FRD	EU Flood Risk Directive
FS	Lightship, research ship
FTIR	Fourier Transform Infrared Spectroscope
Galileo	European Satellite Navigation System
GAW	Global Atmosphere Watch
GCM	General Circulation Model
GCOS	Global Climate Observing System
GDI	Geodateninfrastruktur (Geo Data Infrastructure)
GDSIDB	Global Digital Sea Ice Data Bank
GEO	Group on Earth Observations
GEOMAR	GEOMAR Helmholtz Centre for Ocean Research Kiel
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Exchanges Project
GFMC	Global Fire Monitoring Center
GFZ	Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum GFZ (Helmholtz Centre Potsdam – German Research Centre for Geosciences)
GHRSST	Group for High Resolution Sea Surface Temperature
GHz	Gigahertz
GIA	Glacial Isostatic Adjustment
GIS	Geographic information system
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema, Russian satellite navigation system
GLOSS	Global Sea Level Observing System
GME	Global Model Extended (global numerical weather forecasting model of the DWD)
GMES	Global Monitoring for Environment and Security, now renamed Copernicus
GNIP	Global Network for Isotopes in Precipitation
GNSS	Global Navigation Satellite System
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOME	Global Ozone Monitoring Experiment
GOOS	Global Ocean Observing System
GOSIC	Global Observing Systems Information Center
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GPS	Global positioning system
GRDC	Global Runoff Data Center
GRUAN	GCOS Reference Upper-Air Network
GSN	GCOS Surface Network
GSNMC	GCOS Surface Network Monitoring Centre
GTN-H	Global Terrestrial Network - Hydrology

GTN-R	Global Terrestrial Network for River Discharge
GTOS	Global Terrestrial Observing System
GTS	WMO Global Telecommunication System
GUAN	GCOS Upper-Air Network
GWB	Groundwater body
GWD	Groundwater directive
HCFC	Hydro-chlorofluorocarbon
$HD(CP)^2$	High definition clouds and precipitation for advancing climate prediction
HGF	Helmholtz-Gemeinschaft Deutscher Forschungszentren (Helmholtz Association of German Research Centers)
HMGU	Helmholtz Zentrum München – German Research Center for Environmental Health
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
HOMPRA	GPCC Homogenized Precipitation Analysis
HOT	Hawaii Ocean Time-series
hPa	Hektopascal
HWRP	WMO Hydrology and Water Resources Programme
Hz	Hertz
HZG	Helmholtz-Zentrum Geesthacht Zentrum für Materialforschung und Küstenforschung (Centre for Materials and Coastal Research)
IAEA	International Atomic Energy Agency
IAHS	International Association of Hydrological Sciences
ICES	International Council for the Exploration of the Sea
ICOADS	International Comprehensive Ocean-Atmosphere Data Set
ICOS	European research infrastructure "Integrated Carbon Observation System"
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ICSU	International Council for Science
IFM Hamburg	Institut für Meereskunde, Universität Hamburg (Institute of Oceanography, University of Hamburg)
IfT	Leibniz-Institut für Troposphärenforschung e.V. (TROPOS) (Leibniz Institute for Tropospheric Research (TROPOS))
IGACO	Integrated Global Atmospheric Chemistry Observations
IGY	International Geophysical Year
IGOE	Institut für Grundwasserökologie (Institute of Groundwater Ecology)
IGRAC	International Groundwater Resources Assessment Centre
IGS	International GNSS Service
IHP	UNESCO International Hydrological Programme
IICWG	International Ice Charting Working Group
in situ	Measurements in specific places
INSPIRE	Infrastructure for Spatial Information in the European Community
INSTAAR	Institute of Arctic and Alpine Research
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOCCP	International Ocean Carbon Coordination Project
IODP	Integrated Ocean Drilling Program
IOW	Leibniz-Institut für Ostseeforschung Warnemünde (Leibniz Institute for Baltic Sea Research, Warnemünde)
IP	Integrated project
IPCC	Intergovernmental Panel on Climate Change
IPG	International Phenological Gardens
IPWG	International Precipitation Working Group
IUP	Institut für Umweltphysik, Universität Bremen (Institute of Environmental Physics, Bremen University)
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
JMA	Japan Meteorological Agency
JRC	EU Joint Research Centre
K	Kelvin
KEG	Kommission für Erdmessung und Glaziologie (Commission for Geodesy and Glaciology)
KFKI	Kuratorium für Forschung im Küsteningenieurwesen (German Coastal Engineering Research Council)
KLIDADIGI	KLImaDAten DIGItalisierung (DWD project on the digitisation of climate data)
KMI	Koninklijk Meteorologisch Instituut (Royal Meteorological Institute of Belgium)
LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection)
LfU	Bayerisches Landesamt für Umwelt (Bavarian Environment Agency)

LIDAR	Light Detection And Ranging
LKN-SH	Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein (Schleswig-Holstein's Government-Owned Company for Coastal Protection, National Parks and Ocean Protection)
LLCF	Long-lived climate forcers
LMT	Local mean time
LMU Munich	Ludwig-Maximilians-Universität München (Ludwig Maximilian University of Munich)
LSA SAF	EUMETSAT Land Surface Analysis Satellite Application Facility
LSW	Labrador Sea Water
LUCAS	Land use/cover area frame survey
MARNET	Marines Umweltmessnetz in Nord- und Ostsee (Marine Environmental Monitoring Network in the North Sea and Baltic Sea)
MARUM	Zentrum für Marine Umweltwissenschaften (Center for Marine Environmental Science)
MCAP	Monte-Carlo autoregressive padding
MD	Meteorological Service of the former GDR
MERIS	Programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range
MOC	Meridional overturning circulation
MODIS Aqua	EOS PM satellite with moderate-resolution imaging spectroradiometer
MODIS Terra	EOS AM satellite with moderate-resolution imaging spectroradiometer
MOL-RAO	Lindenberg Meteorological Observatory - Richard Assmann Observatory
MPI	Max Planck Institute
MPI-ESM LR	MPI Earth System Model with Low Resolution
MSE	Mean squared error
MSFD	Marine Strategy Framework Directive
MUDAB	Marine Environmental Data Base
MyOcean	Ocean Monitoring and Forecasting service project under Copernicus (former GMES)
N_2O	Nitrous oxice, laughing gas
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NDMC	Network for the Detection of Mesopause Change
NILU	Norwegian Institute for Air Research
NIR	National Inventory Report
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Administration
NOOS	North West European Shelf Operational Oceanographic System
NSB-2	North sea buoy 2
NSIDC	National Snow and Ice Data Center
OceanSITES	Worldwide system of long-term, deepwater reference stations
OECD	Organisation for Economic Co-operation and Development
OSI SAF	EUMETSAT Satellite Application Facility on Ocean and Sea Ice
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Convention)
PANGAEA®	Data Publisher for Earth & Environmental Science
pCO_2	CO_2 partial pressure
PDO	Pacific Decadal Oscillation
PEP	Pan European Phenology database
PEP725	Pan European Phenology project 725
PermaNET	Permafrost Monitoring Network
PID	German Pollen Information Service Foundation
PM10	Fine particulate matter
PNA	Pacific/North American circulation pattern
PSMSL	Permanent Service for Mean Sea Level
RADOLAN	Radar online calibration method
RBCN	Regional Basic Climatological Network
RCC-CM	WMO Regional Climate Centre Network (RA VI) Offenbach Node on Climate Monitoring
RCP	Representative Concentration Pathways
REMO	Regional model REMO
RMSL	Relative mean sea level
ROSE/DLR	Global 3D-chemistry-transport model used to derive vertically resolved ozone distributions from ERS2-GOME total column ozone and ENVISAT ozone profile measurements

SAF	EUMETSAT Satellite Application Facility
SAR	Search and Rescue
SeaWiFS	NOAA Sea-viewing Wide Field-of-view Sensor project
SeeAufgG	Gesetz über die Aufgaben des Bundes auf dem Gebiet der Seeschifffahrt (Maritime Shipping (Federal Competences) Act)
SF_6	Sulfur hexaflouride
SFB	DFG Collaborative Research Centre
SI	International standard units
SLR	Satellite Laser Ranging
SMHI	Swedish Meteorological and Hydrological Institute
SMOS	ESA Soil Moisture and Ocean Salinity satellite
SOCAT	Surface Ocean CO_2 Atlas
SSA	Singular System Analysis
SSM/I	Special Sensor Microwave Imager
TCCON	Total Carbon Column Observing Network
TDR	Time domain reflectometry
TENATSO	Tropical Eastern North Atlantic Time Series Observatory
TIGA	Tide Gauge Benchmark Monitoring project
UBA	Umweltbundesamt (Federal Environment Agency)
UFS	Umweltforschungsstation (environmental research station)
UFS	Unbemanntes Feuerschifff (unmanned lightship)
UFS TW Ems	Unmanned deep water way lightship Ems
UIG	Umweltinformationsgesetz (Federal Environmental Information Act)
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
VASClimO	DWD Variability Analysis of Surface Climate Observations project
VF	Vernagtferner glacier
VOS	Voluntary Observing Ships
WasEG	Wasserentnahmeentgeltgesetz (Water usage payment act)
WaStrG	Bundeswasserstraßengesetz (Federal Waterways Act)
WCC	World Climate Conference
WCP	World Climate Programme
WCRP	World Climate Research Programme
WDC-Climate	World Data Center for Climate
WDCGG	GAW World Data Centre for Greenhouse Gases
WDC-Mare	World Data Center for Marine Environmental Sciences
WDC-RSAT	World Data Center for Remote Sensing of the Atmosphere
WDS	ICSU World Data System
WFD	EU Water Framework Directive
WGMS	World Glacier Monitoring Service
WHG	Wasserhaushaltsgesetz (Federal Water Act)
WHYMAP	World-wide Hydrogeological Mapping and Assessment Programme
WISER	Water Isotope System for Data Analysis, Visualization and Electronic Retrieval
WMO	World Meteorological Organization
WMO RA VI	WMO Regional Association VI (Europe and Middle East)
WMO TD	WMO Technical Document
WOCE	World Ocean Circulation Experiment
WRDC	World Radiation Data Centre
WRMC	World Radiation Monitoring Center
WSA	Wasser- und Schifffahrtsamt (Waterways and Shipping Office)
WSV	Wasser- und Schifffahrtsverwaltung (German Federal Waterways and Shipping Administration)
ZALF	Leibniz-Zentrum für Agrarlandschaftsforschung (Leibniz Centre for Agricultural Landscape Research)
ZAMF	Zentrum für Agrarmeteorologische Forschung Braunschweig (Braunschweig Agrometeorological Research Centre of DWD)
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (Central Institute for Meteorology and Geodynamics, Austria)
ZMMF	Zentrum für Medizin-Meteorologische Forschung (DWD Centre for Human Biometeorological Research)

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