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Author Contributions
J.B. conceived the study and gathered data from the National Capital Commission. J.S. simulated future weather data using MarkSim. J.B., in consultation with J.S. and M.H., conducted the analysis and wrote the manuscript. J.S. and M.H. edited the manuscript.

Additional information
Supplementary information is available in the online version of the paper.

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COMMENTARY:

Institutional coordination of global ocean observations

Wenju Cai, Susan K. Avery, Margaret Leinen, Kenneth Lee, Xiaopei Lin and Martin Visbeck

A sustainable global ocean observation system requires timely implementation of the framework for ocean observing. The recent Qingdao Global Ocean Summit highlighted the need for a more coherent institutional response to maintain an integrated ocean-observing system.

Approximately 93% of the additional heat associated with global warming is stored in the ocean[1], and recent discoveries show that an enhanced heat storage in the subsurface ocean over the past decades contributed to the global surface warming hiatus[2–5]. This is just one example that highlights the importance of ocean observations in understanding, monitoring and detecting global climate change, and providing the basis to assess the impacts of climate and environmental change on the ocean.

Ocean observations, the 'bread and butter' of ocean and climate change science, are predominantly conducted by a limited number of large ocean research institutions. At the international level, the World Climate Research Program (WCRP) provides the framework to coordinate climate and ocean science, the Partnership for Observing the Global Ocean (POGO) and the intergovernmental Group on Earth Observations (GEO) offers a venue for discussion and collaboration on ocean observing, and the Global Climate Observing System (GCOS) with its Global Ocean Observing System (GOOS) produces a framework to identify and globally coordinate observations that are critically needed. However, the level of global commitment to sustained ocean observing is falling short of the requirements. This challenge was highlighted at the recently held Global Ocean Summit, on 25–26 October in Qingdao, initiated by newly elected member of the Chinese Academy of Sciences, Lixin Wu of the Ocean University of China. We call for such a summit to continue.

At the summit, leaders from 61 universities and research institutions, from both developing (22 institutions) and developed (39 institutions) nations, presented their needs and capabilities in ocean science and the required underpinning ocean observations. Their work in the development of new technologies and their ocean observation activities in the open ocean (surface and deep) and below sea ice, both on-going and planned, was highlighted at this summit. Importantly, leading world ocean researchers discussed collaboration methods for inter-institutional scientific and logistic coordination. Such coordination is particularly challenging because of the differences in funding cycles between nations. However, a globally coordinated effort will reap enormous benefits — improved international coordination will help to deliver both a great return on investment and strong science outcomes, and facilitate the emergence of technologies and capabilities for observing deep and unknown parts of the ocean. The international Argo program[6] provides an example of the success of such coordination. A collaborative partnership of more than 30 nations, the Argo program has built a global array of more than 3,500 free-drifting profiling floats that measure the upper 2,000 metres of the ocean every 10 days. This program, for the first time, allows continuous monitoring of ocean temperature and salinity on a global scale, with all data relayed and made publicly available within hours after collection. The 10 years of data with over 1,000,000 profiles have been used widely, including studies that examine the distribution and changes in heat and water cycles[7–9].

Such international collaboration is rare though and there is much a regular global ocean summit could do. Firstly, it can be a forum to promote implementation and coordination of the existing framework of ocean observations[10]. This framework (Fig. 1) was established as a result of the OceanObs'09 conference (http://www.oceanobs09.net), which took place 21–25 September 2009 in Venice, Italy, and brought together more than

600 participants from 36 countries to focus on defining a collective vision of ocean observations for societal benefits. The framework aims to establish an enhanced global ocean-observing system, and to ultimately integrate new physical, biogeochemical and biological observations while sustaining present observations. Informed by scientific and societal issues, the framework builds on our existing observing units, networks and systems, such as satellites, Argo network, ships of opportunity, and a global array of moorings (OceanSites). It also identifies essential ocean variables, such as ocean temperature, salinity and velocity, as the ocean contribution to the climate-observing requirements. These requirements are expressed in GCOS plans (http://www.ioc-goos.org), the implementation of which has been adopted by the United Nations Framework Convention on Climate Change (http://unfccc.int/2860.php). Through this United Nations process, buy-ins from nations occur. Data streams, products and new knowledge from independent observing units or networks measuring different essential ocean variables are used to inform climate research and climate-related societal issues — which originally set the requirements — in an important feedback loop that ideally keeps the observing system 'fit for purpose'. However, there is inadequate integration of these observing assets and no timely mechanism for implementing the framework in a manner that addresses fast-emerging scientific and societal drivers requiring a coherent global response, such as understanding the global warming hiatus, sea-level variability, upper ocean heat-content change, or deep ocean warming. The Global Ocean Summit would support global coordination and integration mechanisms.

Secondly, the Global Ocean Summit highlighted new research areas in ocean science that are important in addressing societal issues. The societal relevant science questions require sustained ocean observations to address issues such as loss of biodiversity, ecosystem health and protection, regional and global fisheries restoration and sustainability, ocean renewable energy potential, and sustainable economic development of the ocean. Many of these issues will be impacted by long-term changes in the ocean (for example, extreme climate events[11], ocean warming, sea-level rise[12], changing ocean circulation, loss of subsurface oxygen[13] and ocean acidification[14,15]), and will need long-term physical, biogeochemical and biological observations for system understanding,

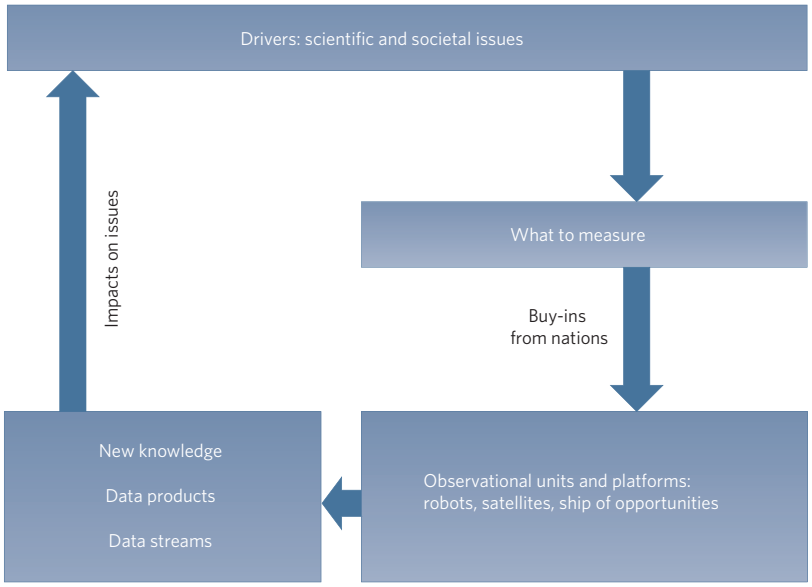

Figure 1 | A global ocean observation framework. Scientific and societal issues determine variables to measure, attracting investment from nations through their research institutions. The outcome of the observations, that is, data, products and new knowledge, inform both existing and new issues, and a feedback loop that keeps the observation system 'fit for purpose'.

modelling and assessment. Many institutions that attended the summit are major research entities already engaged in such interdisciplinary research and are therefore champions, within their nation, of an extension of the approaches and international collaboration. Expansion of the number of essential ocean variables to include chemical, biological and ecosystem variables, will increase available data and enhance realistic modelling of ocean and climate responses. An enhanced observation system could broaden its funding base by generating impact on more issues. Experience with the tropical ocean and atmosphere arrays suggests a narrow funding base decreases the stability and sustainability of an observation system[16].

Thirdly the summit called for a step change in long-term capacity building and capability development in developing countries and emerging economies. Institutions from developing countries with emerging economies, of which 22 were in attendance, are a driving force for identifying scientific and societal issues, informing policy decisions and delivering data streams and products in their countries. Capacity building and capability development not only enhances the value of the ocean observation system, but also has the potential to entrain eventual buy-ins from the emerging economies, which is essential for broadening the support base for an integrated ocean-observing system.

Finally, the Global Ocean Summit promoted new globally coordinated research efforts on sustainable use of ocean resources in a changing ocean. Participants gave support for the establishment of a stand-alone ocean sustainable development goal[17] with a sustained and integrated global ocean observation system that allows diagnosis of the long-term health of the global ocean. Pressure on the Earth system, including the ocean, has reached a scale where abrupt global environmental change can no longer be excluded. To ensure we live and operate safely, we must avoid critical thresholds in the system, and respect the nature of the planet's climatic, geophysical, atmospheric and ecological processes. The underpinning science to ensure that our generation meets our present needs, without jeopardizing the ability of future generations to meet their needs, is not well developed. This body of science must include reconstructing past climate to understand the thresholds of change, climate projection science to evaluate future pressure under plausible scenarios, and development of risk-assessment tools to inform decision making and hazard response options. All these issues require ocean observations to detect changes, benchmark models and validate strategies. Many summit-attending institutions were universities, where knowledge development is a core business, and who are well positioned to be at the forefront of ocean science.

The inaugural Global Ocean Summit facilitated a dialogue between institutions across the world. At the summit the Qingdao Consensus[18] was adopted by acclimation, calling for an accelerated and improved development of ocean science and observing technologies, and fast and widespread dissemination of ocean information and scientific knowledge and increased partnerships in capacity building in developing maritime nations. The regular convening of such a summit holds potential for improved cross-institutional coordination of global ocean issues and, in doing so, realizing the vision of the inaugural summit — to build an ocean of peace, cooperation and harmony to bring prosperity for generations to come. ❐

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COMMENTARY:

Responding to adaptation emergencies

Jim W. Hall, Frans Berkhout and Rowan Douglas

The impacts of extreme events are triggering action and reaction — sometimes in unexpected ways. Confronted by 'adaptation emergencies', the private sector is rapidly innovating climate risk management, but governments must also fulfil their responsibilities.

Recent extreme weather events have demonstrated the vulnerability of people, infrastructure and economies in many parts of the world: droughts and bushfires in the USA, Russia and Australia; floods in Kashmir, Thailand and the UK; Superstorm Sandy and Hurricane Haiyan; landslides in Japan and China. These events have claimed many lives and generated catastrophic economic losses with global impacts, including systemic disruption to supply chains and hikes in the prices of products from grain to computer chips[1]. Unexpected weather extremes have exposed the fragility of many social and economic systems and the frailty of adaptation responses at local, regional and global levels. Governments have been taken by surprise. These events have also shown that climate change is deeply unfair in its impacts, which brings into sharp relief the winners and the losers, globally and regionally. This generates a new class of governance problems for governments, businesses and international organizations.

We call these large-scale crises that emerge as a result of insufficient capacity to cope with changing patterns of climate-related risks 'adaptation emergencies'. These may be expressed at a local and regional level, or at a global level, where multiple connected extreme events and impacts generate global-scale emergencies.

The private sector is responding

Confronted by the scale of damage, business interruption, price volatility and dented investor confidence, the private sector is responding. Over the past two decades, assessment of natural catastrophe risk by insurers has transformed from being based on historical records of losses to model-based risk assessment, employing large multi-disciplinary analytical teams and managing massive datasets on major IT platforms. Specialist catastrophe-risk modelling firms have emerged as part of this new information ecosystem, supplying risk information to the insurance and finance sectors.

Quantified risk assessment and regulatory requirements are now co-evolving. Advanced valuation techniques are providing the basis for new capital requirements and reporting standards. The Solvency II regulations in the European Union have established the convention of a 1:200 level of confidence. This means that an insurance company should have access to sufficient capital (either directly or through

Correction

In the Commentary 'Institutional coordination of global ocean observations' (*Nature Clim. Change* **5,** 4–6; 2015) ref. 18 was omitted from the reference list. This has been corrected after print 7 January 2015.