

ARGOS, MONITORING THE IMPACTS OF CLIMATE CHANGE

**OVER 35 YEARS
OF ENVIRONMENTAL DATA COLLECTED**

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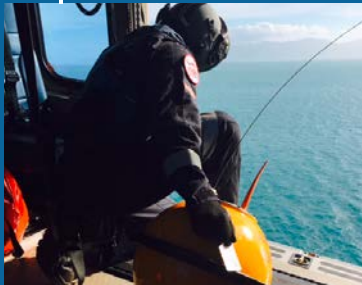


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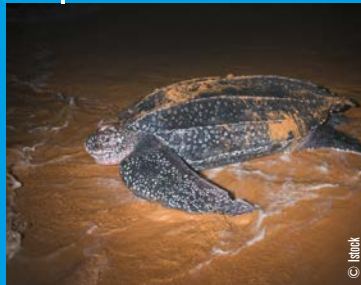
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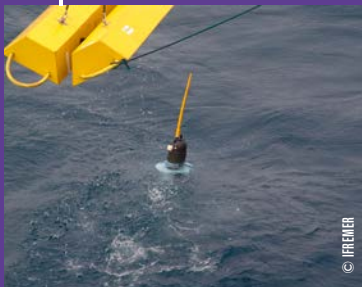


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Head, JCOMMOPS Intergovernmental Oceanographic
Commission of UNESCO, World Meteorological Organization

One of the biggest challenges in climate science is obtaining enough observations of the ocean in time and space to obtain a truly global picture of the ocean system. In order to better understand the role of the oceans in climate, the IOC coordinates ocean observation and monitoring through the Global Ocean Observing System (GOOS), a unified network providing information and data exchange on the physical, chemical, and biological aspects of the ocean. The IOC's GOOS serves as the ocean component of the Global Climate Observing System (GCOS), which supports the Intergovernmental Panel on Climate Change (IPCC).

Within GOOS, the Argos satellite system has provided continuous observations of the global oceans for over 35 years. It has contributed to understanding ocean circulation and regional sea level rise by providing the invaluable in situ measurements that validate the space-based measurements of the ocean surface within climate science.

As the international community gears up for the COP21 conferences in Paris, and as IOC/UNESCO is working on including the ocean in the conference agenda, scientists will continue to require sustained ocean observing systems governed on an international and intergovernmental level. The Argos system will undoubtedly continue to be a part of these systems, at the forefront of the technologies required for climate change studies. Ocean is our future, and as said by Irina Bokova, Director General UNESCO, "the sustainability of the planet depends on the health of the ocean."

All ARGOS publications are available at:
www.argos-system.org

#COP21CLS

USING ARGOS TO UNDERSTAND THE RESPONSE OF POLAR BEARS TO A CHANGING ARCTIC

Mother polar bear in her den.

By George Durner, U.S. Geological Survey, Alaska Science Center



© USGS

The polar bear (*Ursus maritimus*) is an iconic apex predator whose specialized adaptations for capturing seals from the surface of the sea ice has allowed them to flourish in the Arctic marine environment for at least 500,000 years. Polar bears occur only in northern hemisphere seas that are frozen for most of the year. Recent atmospheric warming has profoundly altered the global climate – but especially in northern latitudes as a result of “Arctic amplification” – and has caused reductions in sea ice. Sea ice loss has displaced bears from optimal hunting habitat, altered the distribution of maternal denning, and increased their energetic costs. The USGS Alaska Science Center has used the Argos system to track and study polar bears for 30 years. George Durner of the USGS explains some of the way and their behavior has changed in response to the changing Arctic climate.

Research to understand the response of polar bears to climate change began in the early 1990s. Because polar bears range across a vast environment where humans seldom venture, direct observations could provide data only during a small part of the year and their potential range. Beginning in 1985, platform transmitter terminals (PTT) attached to radio collars provided unbiased location and sensor data regardless of the time of year or where PTTs were deployed. This data collection through the Argos system continues, building a legacy of data that has allowed the USGS to assess the response of polar bears to a changing Arctic.

Habitat loss and 21st century projections

Satellite-derived imagery has provided consistent data on the extent, composition, and dynamics of sea ice since 1979. By merging this environmental data with Argos PTT-derived data, the USGS developed models which identified sea ice habitats preferred by polar bears. Models show loss of optimal sea ice habitat in much of the Arctic basin during the recent past (Fig. 1a).

Applying these habitat models to general circulation model predictions of future sea ice, the USGS projected a 5% per decade loss of optimal polar bear habitat through the 21st century (Fig. 1b). Because polar bear population health is closely tied to sea ice, projections of continued habitat declines indicate negative impacts on polar bear populations through the 21st century. This research was pivotal for informing the U.S. Secretary of the Interior’s decision in 2008 to list polar bears as a threatened species under the Endangered Species Act.

Changes in maternal den distribution

Most of what we understand about maternal denning – the critical activity during which pregnant polar bears shelter in dens of snow to give birth to and nurture their young during the harsh Arctic winter – has been gleaned through location and sensor data collected from PTT-equipped female bears. Before 1995, polar bears in the southern Beaufort Sea were unique among other populations in that most dens (62%) each year occurred on pack ice instead of land. In subsequent years this pattern was largely reversed as only 37% of dens were observed on pack ice.

As the composition of pack ice changed from thick and strong multiyear floes which could remain intact through the months of den tenure, to pack ice that was primarily thin first year ice which was more vulnerable to breakage from the actions of winds and currents, a stable sea ice platform necessary for the 4 months required for denning became harder to find. Argos data captured this change in polar bear reproductive behavior to mostly land-based denning in response to a changing Arctic.



USGS placing an Argos collar on a female polar bear.

© USGS

Long-distance swimming

The increased duration and extent of Arctic summertime ice-free waters raises questions of the energetic consequences to polar bears as they negotiate an ocean that was formally largely solid underfoot. Polar bears readily swim between floes and between land and ice but before 1997 the duration and distance of swims were relatively short. PTT data showed increased frequency of long distance swimming by polar bears during 2004-2009. In particular, during the summer of 2008 when ice retreated up to 600 km from the northern Alaska coast, PTT data revealed that an adult female polar bear swam >400 km through icefree waters from land to the pack ice in 9 days.

As swimming is energetically expensive, increased frequency of long-distance swimming may impose an energetic burden additional to that caused by displacement from hunting habitat due to sea ice declines.

Conclusions

This essay highlights three examples how Argos was used to assess the impacts of climate change on polar bears. The USGS continues to collect satellite-retrieved data to refine and expand upon our understanding on the response of polar bears to a changing Arctic.



GEORGE DURNER

George Durner is a research zoologist with the US Geological Survey, Alaska Science Center polar bear research program. He entered this position in 1991 and currently works with a team of USGS scientists to identify and describe the mechanisms that drive the response of polar bears to a changing Arctic ecosystem. His research focus is on polar bear habitat relationships, particularly on how polar bears have and will respond to declines in sea ice. Hence, his research has been reliant on a 29 year history of polar bear location data gained through the Argos Data Collection and Location System. Much of his research results were used to inform the United States Secretary of the Interior's decision in 2008 to list polar bears as a threatened species under the Endangered Species Act.

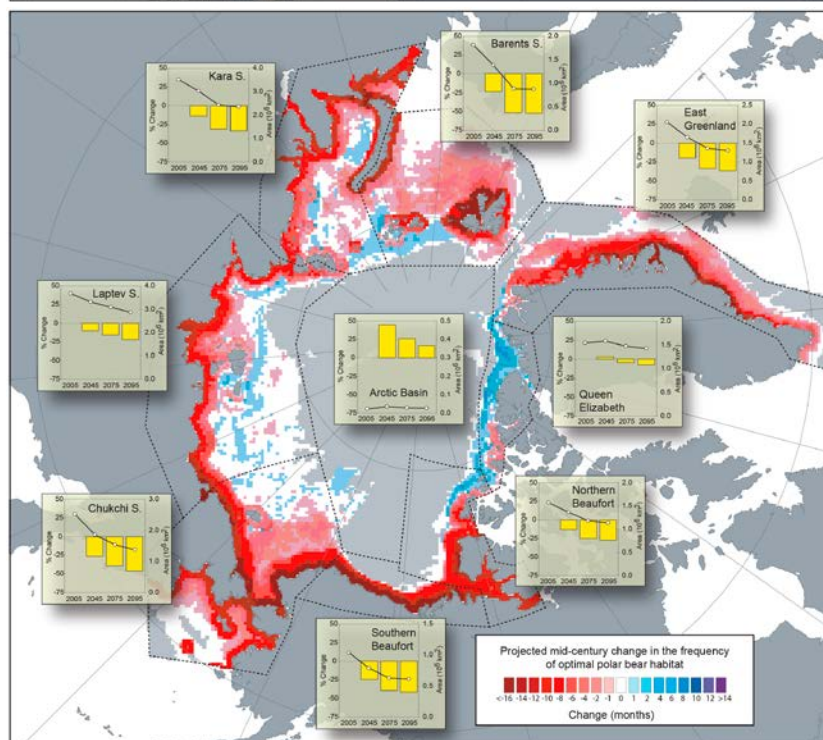
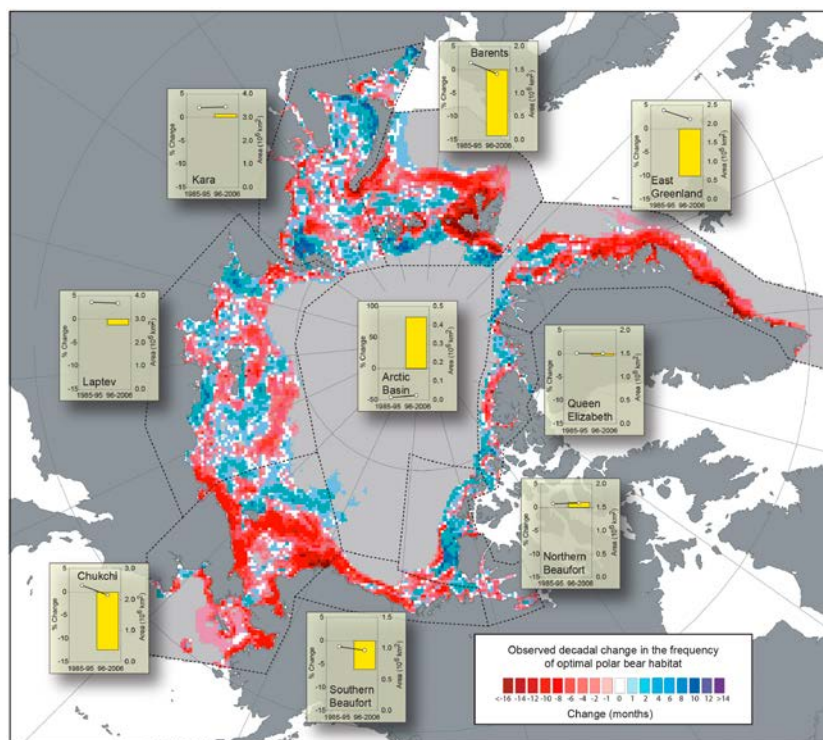


Figure 1. Change in the cumulative number of months of polar bear optimal sea ice habitat:

- ▲ a) observations comparing 1985-1995 to 1996-2006;
 - ◀ b) projections comparing 2001-2010 to 2041-2050.
- Inserted histograms show habitat change by polar bear subpopulation. From Durner et al. 2009, Ecological Monographs 79 (1): 25-58.

ARGOS-ACOS: A NEAR REAL-TIME CLIMATE OBSERVATION SYSTEM FOR HIGH LATITUDES



ARGOS-ACOS station at Bulgan, Mongolia.

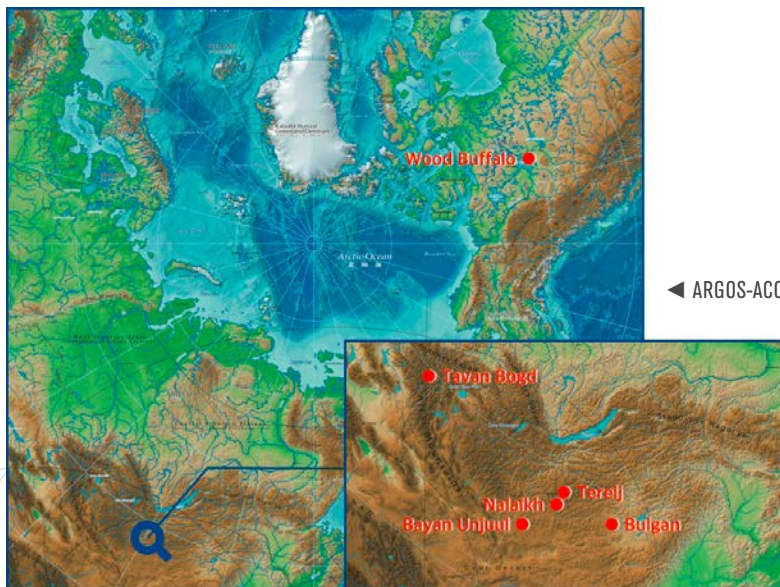
By Yoshihiro Iijima, Institute of Arctic Climate and Environmental Research, JAMSTEC

The Arctic is warming at a rate of almost twice the global average. Remote responses to the warmer Arctic on surrounding continents have been observed in the last decade and have become the focus of climate studies. Scientists observe that cold events and other seasonal climatic influence propagate from the Arctic to the continents with a weekly to half-monthly time lag. This is why near real-time climate data acquisition has such a high potential to validate medium-range forecasting and aid understanding of atmosphere/land surface interaction in continents, as Yoshihiro Iijima, of JAMSTEC's Institute of Arctic Climate and Environmental Research explains.

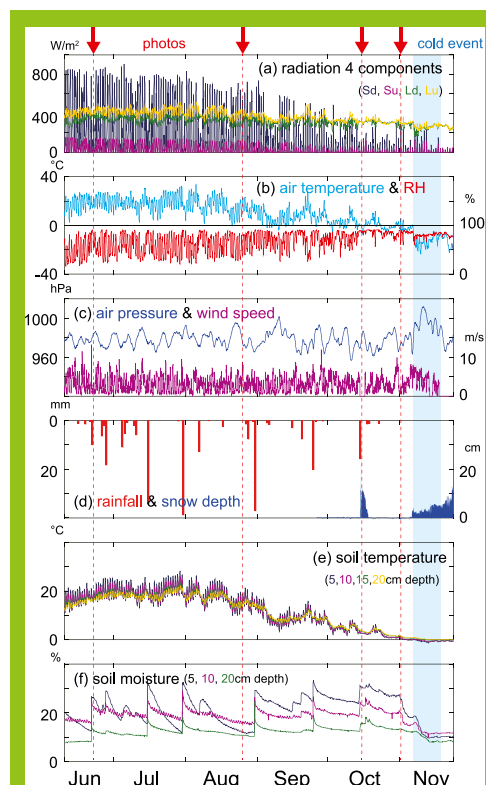
International cooperation

Since summer 2012, Argos data transmission has been implemented at four sites in Mongolia connected to the Automatic Climate Observation System (ACOS) operated jointly by JAMSTEC (Japan Agency for Marine-Earth Science and Technology) and IMHE (Institute of Hydrology, Meteorology, and Environment) of Mongolia. In 2014, another ACOS was set up at Wood Buffalo National Park (WBNP) in Northwest Territories (NWT) of Canada, in cooperation with Parks Canada.

These sites are used for the analysis of land surface processes in both high-latitude steppe and boreal forest ecosystems, both highly impacted by Arctic and sub-Arctic climate change. In addition, the archived dataset will be utilized to validate land surface modeling to fit cryospheric processes (snow accumulation, soil freezing and thawing, etc.).



◀ ARGOS-ACOS sites in Mongolia and Canada.



Transmitted climatological data at WBNP in 2014.

Argos provides crucial data

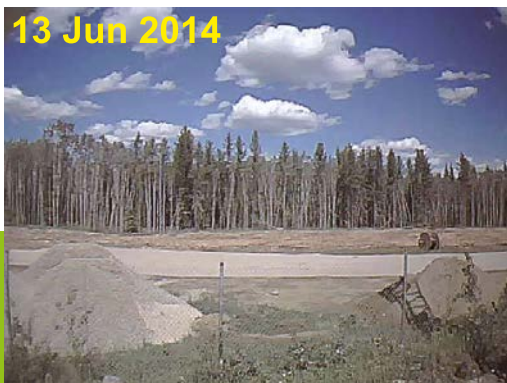
According to observations made at the WBNP site, periodic intrusions of cold events after October 2014 occurred along with snow fall events. Rapid reduction in air temperature (less than -10°C) accompanied by continuous snow accumulation took place after November 6, 2014. The strong cold advection continued severely over North America with a great cold wave during subsequent weeks. The NCEP / NCAR Reanalysis data showed that an abnormal cyclone in Alaska reproduced a "ripple" pattern of jet stream and subsequent cold air advection from the Arctic. The snow fall/ cold event combination

effectively intensified ground freezing which is one of the unique processes to carry over the soil moisture anomaly as climatic memory in this region.

A photographic record

The everyday JPEG images could monitor day-to-day and seasonal changes in landscape in relation to climatic conditions. Detection of a dry spell in late August (many buffalos in the photos) with continuous reduction in soil moisture would also be informative for rating the danger of forest fire in this national park.

13 Jun 2014



24 Aug 2014



15 Oct 2014



1 Nov 2014

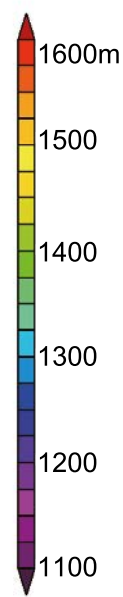
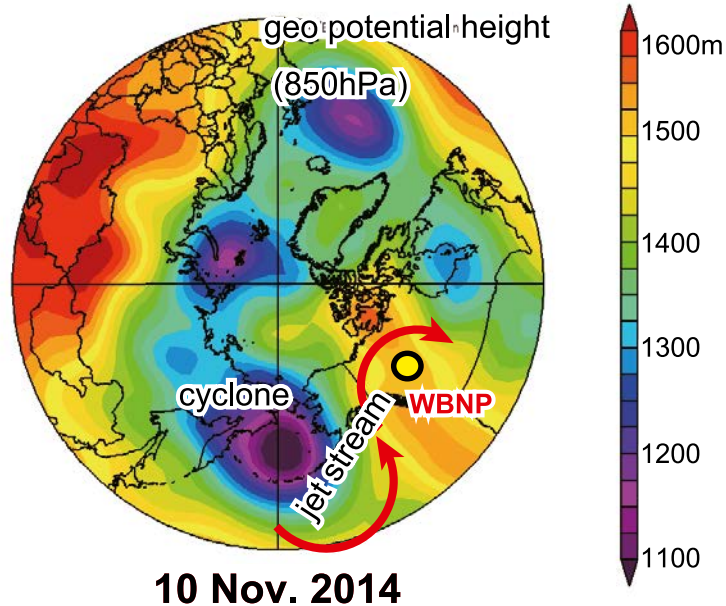
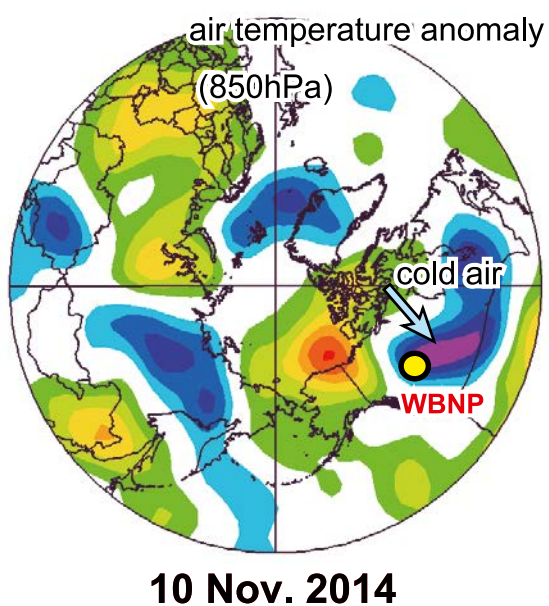


YOSHIHIRO IIJIMA

Yoshihiro Iijima is a climatologist and a senior scientist at Institute of Arctic Climate and Environmental Research, JAMSTEC, he observes land surface processes in relation to Arctic and sub-Arctic climate change in steppe, boreal and tundra landscapes.

◀ The JPEG camera uses Argos-3 high data rate to transfer pictures. Here, the four seasons in WBNP.

▼ Atmospheric pattern during the cold event over North America, November 2014.



TRACKING DESERT WATERBIRDS: BOOM-BUST NOMADS IN A CHANGING CLIMATE



© Ben Parkhurst

By Reece Pedler, PhD candidate, Dr. Raoul Ribot, Research fellow, and Andy Bennett, Professor, Centre for Integrative Ecology, Deakin University

In a world of increasingly variable climate, the Australian outback has long been known for its climatic extremes with its 'droughts and flooding rains'. In this vast inland region of the Australian continent, rainfall is not only low – on average – but also highly unpredictable and gives rise to the 'boom-bust' life history strategies seen in many plants and animals occurring there. These species make the most of the short-lived good times, but then weather-out or move elsewhere during the bad. Despite the area's aridity, it supports many ephemeral aquatic habitats and a range of waterbirds which make long distance nomadic movements between waterbodies. Understanding the movement strategies of these species is vital for their conservation, especially in a world of changing climate, as Reece Pedler, Raoul Ribot and Andy Bennett explain.

The Australian arid zone and its variable climate

Currently long-term climatic cycles such as the El Niño-La Niña Southern Oscillation and Indian Ocean Dipole describe much of the climatic variability in inland Australia. During the northern tropical monsoon, the tail of cyclones sometimes drive far inland and deliver intense rainfall which inundates normally dry salt lakes and meandering inland riverbeds. Climate change predictions suggest that these tropical cyclones are likely to become more frequent and intense, with wet times in the inland set to get wetter, but countered by the dry times, which will be longer and harsher. Essentially, one of the world's most variable and unpredictable climates is set to become even more so.

Desert waterbirds and their mysteries

Life in these desert areas has developed many strategies to exploit unpredictable climatic conditions and a range of waterbird species present good examples of this behaviour. The Banded Stilt, a small endemic shorebird, is often observed in coastal and temperate wetlands in southern Australia where it survives during the frequent times that the inland is dry. When the big rains reach central Australia and flood dry salt lakes, Banded Stilts somehow detect this from hundreds of kilometres away and depart their coastal refuge areas. After arriving at recently flooded lakes, they hurriedly find a mate, construct nests and lay eggs, forming nesting colonies totalling tens of thousands of pairs to make the most of the short-lived favourable conditions. For decades

the detail of this behaviour has been unknown, with knowledge limited to the observation that the birds have disappeared from the coast only occasionally followed by discoveries of breeding colonies on tiny inlands in vast and inaccessible tracts of flooded desert.

Using Argos to solve these mysteries

Over the last 3 years, tracking of these birds has revealed much about the behavioural strategies that waterbirds use to survive in these environments. Nearly 50 Banded Stilts (*Cladorhynchus leucocephalus*) have been fitted with 5 g solar-powered Argos PTTs (Microwave Telemetry USA) at inland and coastal sites. Tracking of these birds has captured a wealth of information on their fascinating movements (as recently published in *Biology Letters*: Pedler, Ribot and Bennett 2014). It turns out that these desert waterbirds are amongst the most mobile nomads, travelling hundreds or sometimes thousands of kilometres each year. Following flooding rains in the inland, the tracked Banded Stilts have been quick to respond; leaving coastal temperate wetlands within 5-15 days. The birds have also demonstrated remarkable flexibility; occupying and moving between a range of inundated saline wetlands while conditions last. In several instances tracked individuals have moved hundreds of kilometres in a single night to reach recently flooded wetlands. One extreme example involved a tagged bird that flew over 2,000 km across the continent in just two nights towards recently flooded desert salt lakes.



© Reece Pedler

A banded stilt fitted with a 5 g solar-powered argos tag at an inland salt lake.

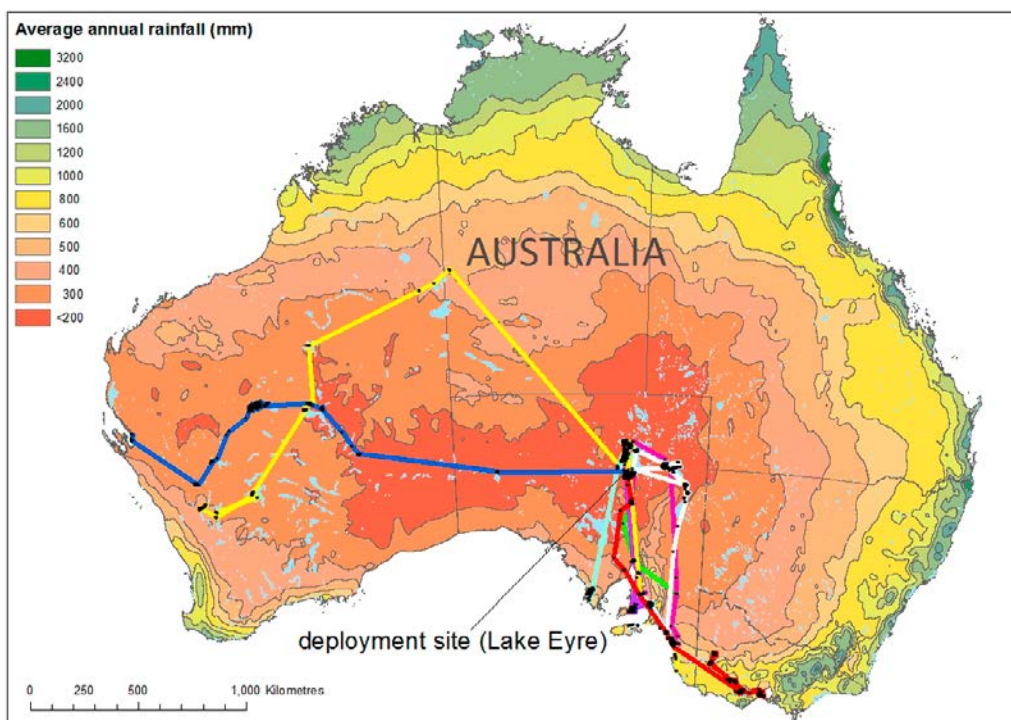
Banded stilts: Able to adapt to climate change?

As desert salt lakes inevitably dry and temporary brine shrimp food declines, Banded Stilt rapidly retreat to refuge coastal wetlands in overnight flights of up to 800 km. During extended dry periods, the stilts have concentrated in refuge wetlands near the coast, highlighting the important sites that support their populations between inland breeding opportunities.

So how will these desert waterbirds survive in more unpredictable climate? Will the more frequent intense wet periods create further opportunities for them to breed or will these benefits be outweighed by more intense droughts? Flexible and nomadic behaviour in the face of unpredictable and extreme climate may well help this species to persist, while others narrowly adapted to predictable climates decline.



▲ Banded Stilts at a large salt lake in inland Western Australia.



▲ Figure 1: Nomadic movements by ten Banded Stilts captured and fitted with 5 g solar-powered Argos transmitters at Lake Eyre, during a flood event in 2012.

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REECE PEDLER

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ANDY BENNETT

Professor Andy Bennett is an avian behavioural and sensory ecologist. He runs a research program on satellite tracking and navigation of Australian waterbirds from Deakin University's Centre for Integrative Ecology. He is President of the Australasian Society for the Study of Animal Behaviour.

TRITON MOORINGS FOR THE TROPICAL OCEAN CLIMATE

By Iwao Ueki, Tatsuya Fukuda, Takayuki Hashimukai, JAMSTEC

The El Niño / Southern Oscillation (ENSO) is Earth's largest interannual climate signal, with an impact on weather, ecosystems, societies and economies. ENSO modulation is thus one of the hottest topics in tropical climate study. Since its beginnings, the TAO/TRITON array has been a crucial component of the sustained ENSO observing system, providing valuable surface and subsurface observations of El Niño events, as Iwao Ueki, Tatsuya Fukuda and Takayuki Hashimukai of JAMSTEC explain.

Identifying El Niño events

In July 2015, satellite observation of sea surface temperature distribution in the tropical Pacific Ocean indicated a typical El Niño structure from East to West, as described in Figure 1. In addition to satellite observation, the TAO (Tropical Atmosphere and Ocean)/ TRITON (Triangle trans-ocean buoy network) mooring array, which consists of approximately 70 moorings in the tropical Pacific Ocean (Figure 2), provides in-situ observations of these phenomena.

Building the TAO/TRITON array

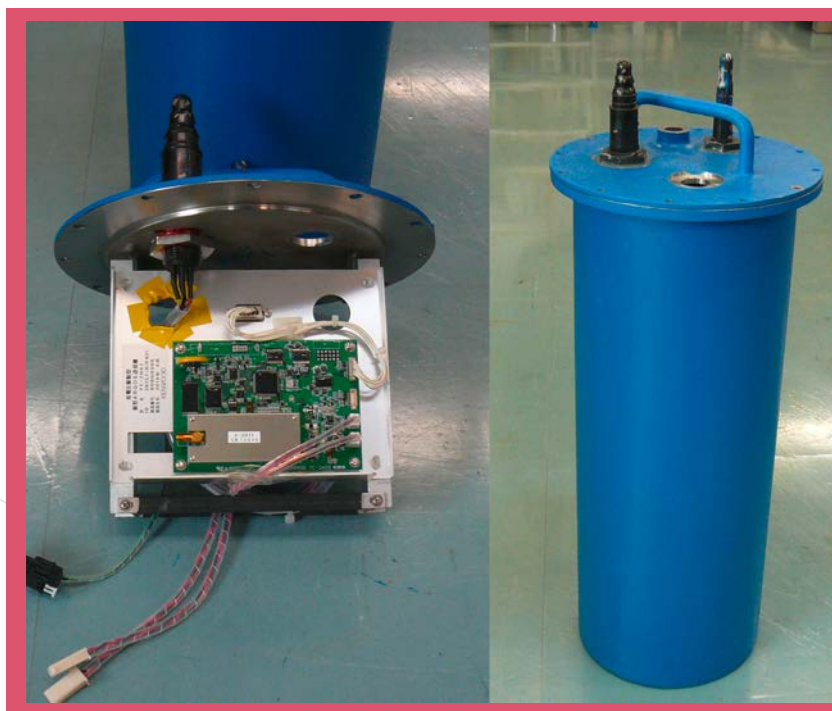
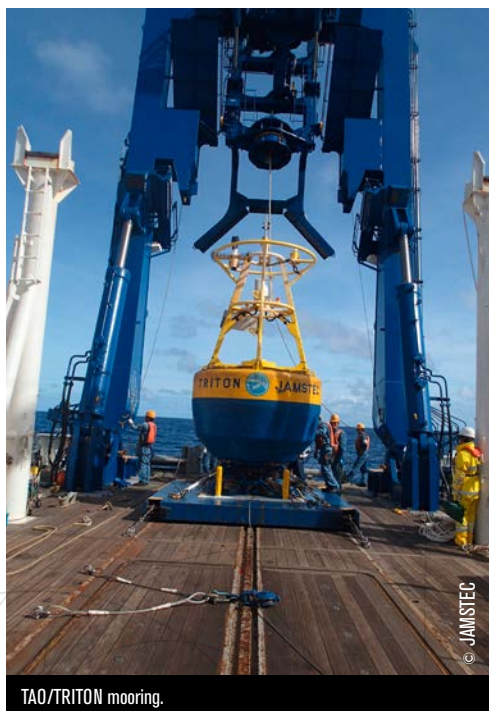
The TAO array was completed by PMEL (Pacific Marine Environmental Laboratory)/NOAA (National Oceanic and Atmospheric Administration) in 1994. JAMSTEC (Japan Agency for Marine Earth Science and Technology) began installing more than 10 TRITON moorings (see below) in the western part of the array in 2000.

The TAO/TRITON array is a major component of ENSO (El Niño and Southern Oscillation) observing system. Advantages of the mooring array are real-time, simultaneous and wide-area coverage observation for ocean subsurface conditions

and heat flux at the surface. Daily updated data from TAO/TRITON array are used for research and forecasting of ENSO and related phenomenon. In addition, there are more than 15-years time series of basin-wide observation by TAO/TRITON array, providing material to study decadal modulation of ENSO in addition to individual El Niño events.

Argos, providing timely in situ data

Appropriate transmission of the observed data is a critical issue for timely monitoring and forecasting for ENSO conditions. For that purpose, we use the Argos satellite system.



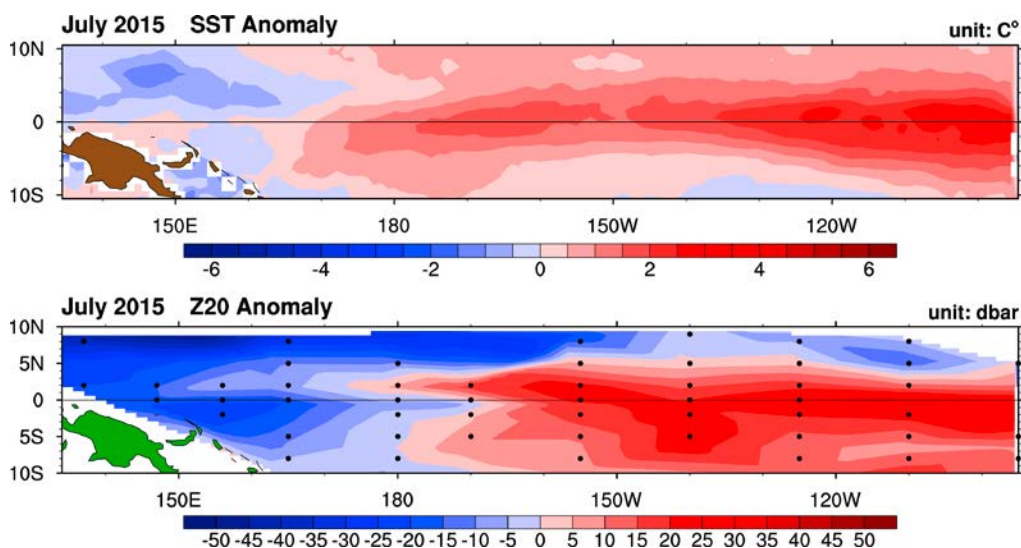
ARGOS transmission system (left) and watertight container (right) used in TRITON mooring.

For TRITON moorings, we transmit more than 40 observed hourly elements; such as wind, air temperature, relative humidity, barometric pressure, temperature and salinity in the upper ocean, currents at 10 m depth, and so on, with 3 messages. Each mooring typically sends 500-650 messages per day. The transmitted data are quality-controlled and disseminated to the research community, weather forecasting agencies, and the general public.

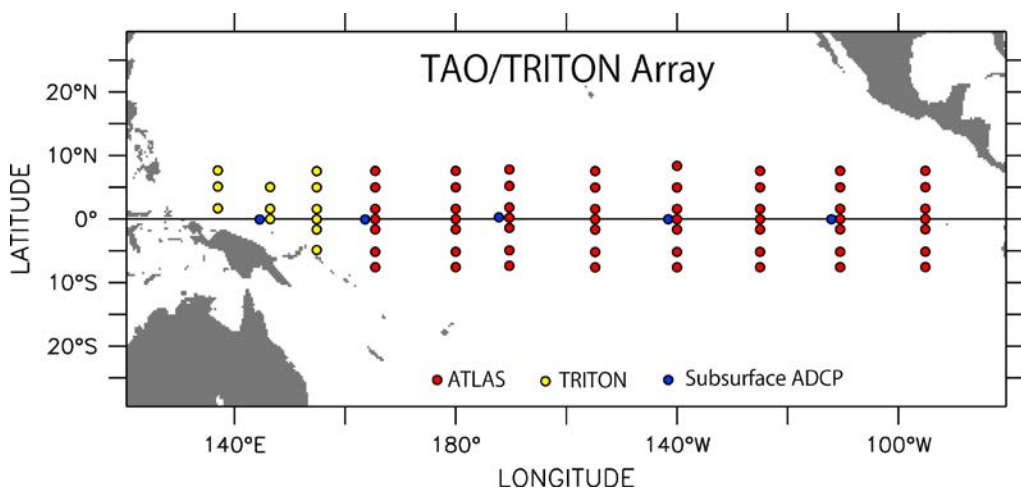
For mooring observations in the open ocean, sensors and control systems are installed in very severe conditions; high temperature, high humidity, high frequency vibration, risk of submergence, etc. Considering these severe conditions, we put the data transmission system in a watertight container (see below), which is installed in a surface buoy. We also use the Argos system for detecting surface buoy positions in case of failure of the main transmission system due to vandalism. The robustness of the Argos system is a great advantage for sustained observing systems.

The future of the Tropical Pacific Observing System

The current ENSO observing system lead to great progress in understanding ENSO and improving ENSO forecasting. However, the system is now over 20-years old and may need to be renewed, to reflect scientific progress of ENSO and the development of new technology, (ARGO float, underwater glider, and other robotics). In 2014, GOOS (Global Ocean Observing System) and OOPC (Ocean Observing Panel for Climate) established TPOS (Tropical Pacific Observing System)-2020 as a focused, finite-lifetime project to oversee the transition of the TPOS to become more robust, integrated and sustainable, and to meet future needs until 2020 (<http://tpos2020.org>). TPOS2020 just started discussion for redesign of TPOS by several task teams' member. The redesign may contain new observation technology, which in turn will require an efficient and robust transmission system.



▲ Figure 1: Distribution of monthly averaged SSTA (upper) and 20°C isotherm depth anomaly (lower) in July 2015, observed by satellite and TAO/TRITON array.



▲ Figure 2: TAO/TRITON array.



IWAO UEKI

Iwao Ueki is a physical oceanographer at the Research and Development Center of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). He has been involved in the TRITON project for 15 years especially for data management and dissemination. His main goal is to develop a better understanding of the tropical ocean climate through observational research.



TATSUYA FUKUDA

Tatsuya Fukuda is an engineer at Marine Technology Center of JAMSTEC. His work concerns development and improvement of mooring buoy systems. In particular, he contributed to improvement of the satellite telecommunication system.



TAKAYUKI HASHIMUKAI

Takayuki Hashimukai is an operator for data quality management at Department of Marine and Earth Sciences of Marine Works Japan Ltd. He and his colleagues conduct quality control of transmitted data from each mooring every day, and also carry out calibration of sensors before development and after recovery of moorings. Their great efforts lead to dissemination of high quality data.

SHARPENING CLIMATE CHANGE PREDICTIONS FOR MARINE FISHES

By Gen Del Raye, University of Hawaii and Kevin Weng, Virginia Institute of Marine Science



Climate change will impact fishes in complex ways, from high-energy-demand species such as yellowfin tuna, to more sedentary animals such as tilapia. While the ability to predict these impacts is essential to adapting to climate-change, our current understanding of the effects of ocean acidification, deoxygenation and warming is too limited to be of widespread use. Our team is implementing a plan to develop species-specific models that could be used as one part of a new generation of climate change predictors. As Gen Del Raye and Kevin Weng explain, these models will include Argos tracking data, physiological experiments/observations, and climate variables to provide a roadmap for fisheries scientists and conservationists.

Tuna—fragile in a changing ocean

Tunas are known among fishers and scientists alike as finely tuned physiological machines capable of extraordinarily high metabolic rates. These, in turn, allow tunas to sustain extraordinarily high rates of growth and reproduction. Tracking tuna and measuring their environment as well as metabolic processes with Argos pop-up tags has revealed the strong preference of tuna species for certain temperatures. Coupled with their high oxygen demand, this indicates that they could be strongly affected by ocean warming and/or deoxygenation both predicted to occur under climate change. The large range shifts in tunas, also recorded via Argos data, during past climate anomalies such as El Niño underscore this vulnerability. Because tunas support a large fishing industry in large economies and small island nations, any such changes would require fishers and managers to implement drastic measures to adapt.

The sooner researchers can deliver detailed predictions of how climate change is likely to affect the distribution and abundance of tunas, the more effective and less disruptive this adaptive process is likely to be.

In contrast, tilapias are among the hardiest of fishes and thus provide an interesting contrast to tunas. In fact, in some extreme environments such as California's Salton Sea, tilapia continue to prosper under conditions that have killed off nearly every other fish species. Yet "survive" is not the same as "thrive". Sub-lethal effects of changes in temperature, oxygen and CO₂, especially when occurring simultaneously, could affect the ability of even the hardy tilapia to grow and reproduce. This is important because many tilapia are prominent aquaculture species, and some show special promise for culture in inshore marine environments, likely to be critical to future aquaculture in freshwater-poor nations.

Aerobic scope of yellowfin

Our team has conducted physiological experiments on both yellowfin tuna (*Thunnus albacares*) and Mozambique tilapia (*Oreochromis mossambicus*), and gathered previously published data in an attempt to understand how these disparate species will react to a spectrum of climate change conditions (Del Raye et al. 2015). Importantly, these data capture the species-specific responses to a combination of the three important climate variables – temperature, dissolved oxygen, and CO₂. These environmental parameters all affect the physiological parameter known as "aerobic scope", which is a measure of the ability of an animal to raise its metabolic rate above the minimum rate needed for survival. Aerobic scope is important because it is within the aerobic scope that all energy demanding life processes (e.g., growth, reproduction, and migration) must occur. Therefore, any reduction in aerobic scope resulting from climate change necessitates a reduction in one (or more) of these life processes. By modeling changes in aerobic scope it is possible to integrate the effects of climate change into a single meaningful metric of habitat suitability. This metric can then be incorporated into large-scale ecosystem models to arrive at specific predictions of distribution or abundance. For example, our results indicate that the volume of the oceans habitable for yellowfin tuna could decrease in the future (Figure 1).



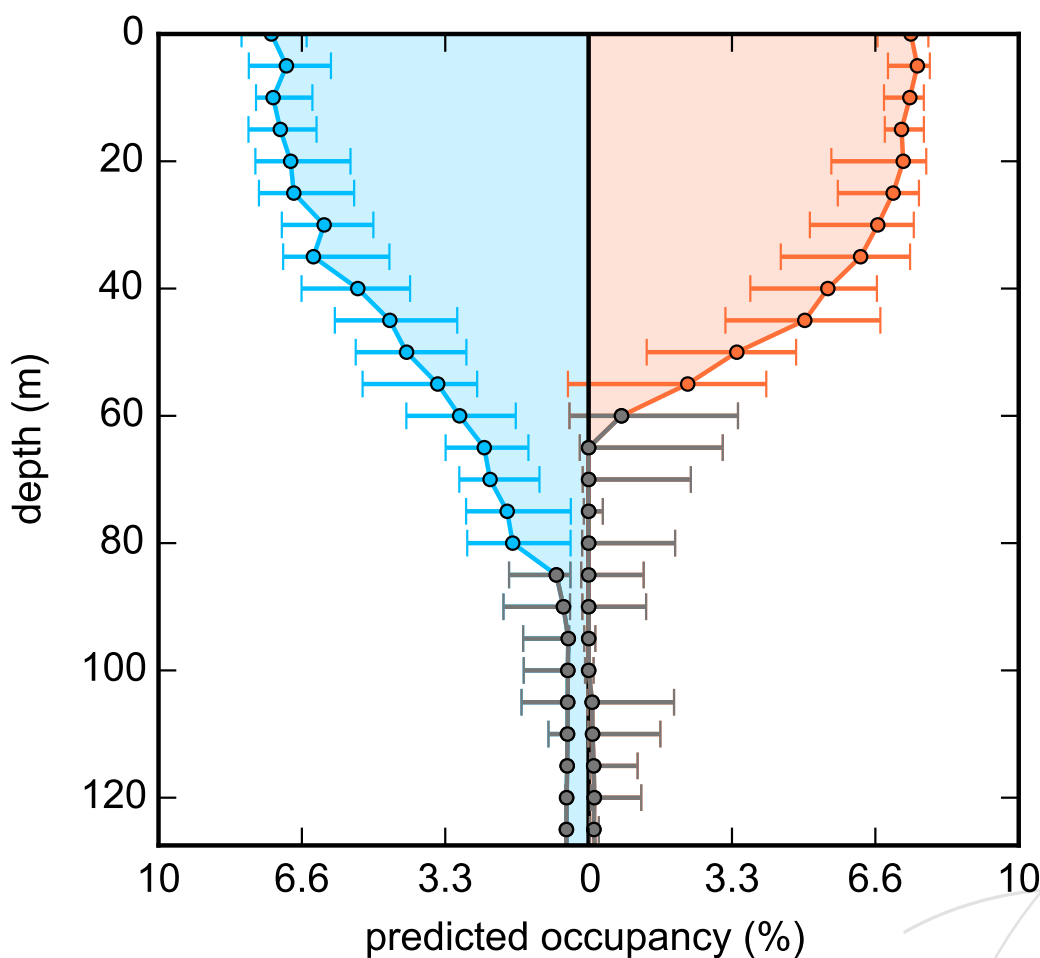
A tuna with a PSAT Argos tag.

Guiding decision-makers and conservation

In conclusion, although climate change is complex and its impacts diverse, the set of variables that stakeholders can use to guide resource conservation policies and fisher's behaviors are much more limited. It is necessary to find some method of incorporating the full complexity of climate projections (including temperature, dissolved oxygen, and CO₂) into a physiologically informed prediction of population impacts. By demonstrating a roadmap for integrating multiple climate stressors into predictions of changes in aerobic scope and, in turn, the distribution and abundance of species such as yellowfin tuna and tilapia, the team's research will help provide this information to those who need it most.

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▲ Figure 1: Predicted vertical habitat of yellowfin tuna (*Thunnus albacares*) off the Galapagos Islands under current (blue) and simulated end-century (orange) climate change conditions. The model shows a pronounced vertical habitat compression, possibly leading to increased catchability in this habitat which would require specific adaptations in the way managers calculate stock sizes from fisheries catch data.

Reprinted from Deepsea Research II, Vol. 113, Del Raye, G., and Weng, K., 2015, Using Aerobic Scope to Model Interacting Effects of Ocean Acidification, Warming, and Deoxygenation on Marine Fish: p. 280-290) with permission from Elsevier.



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Gen Del Raye is a PhD candidate at the University of Hawaii at Manoa. He studies the effects of climate change on fish physiology. Specifically, he studies the ways in which oxygen, temperature, and carbon dioxide perturbations interact to affect metabolism both by measuring metabolic rates of fishes in controlled environments and by constructing physiologically-informed habitat models.



KEVIN WENG

Assistant Professor, Virginia Institute of Marine Science, College of William & Mary

Kevin is a fish biologist at the Virginia Institute of Marine Science. He is interested in how the world's oceans will respond to major perturbations of the anthropocene – enormous removals of fish biomass, coupled with warming, stratification, deoxygenation and acidification – and how we should be managing ocean resources. High marine connectivity, which dominates the early life history of myriad taxa, belies the spatial ecology of many species during adult phases – the phases in which humans are likely to target them. In order to supply gametes, marine organisms must have viable adult populations, and we must understand their habitat requirements, and their scales in space and time.



By Clara Péron, Postdoctoral fellow, University of Tasmania

Predicting the impact of future environmental changes on biodiversity is today a major challenge for ecologists. This is particularly true in the polar regions, where climate change is faster and more severe than anywhere else on the planet. In an article originally published in the *Proceedings B of the Royal Society of London* in 2012, Clara Péron looked at the impact of future warming of the Southern Ocean on a population of king penguins living on Crozet Island, a remote French subantarctic island. She used a unique database of Argos tracking data, collected from 1992 to 2008 by Charles-André Bost from the French CNRS (Centre National de La Recherche Scientifique), to construct habitat models and project the effect of global warming on king penguin foraging behavior. The results suggest that the warming of the Southern Ocean could represent a major challenge for these oceanic top-predators.



A king penguin from the Crozet Islands with an Argos tag.

This study is based on a unique long-term Argos tracking dataset of king penguins breeding on Possession island (Crozet Island). A total of 42 king penguins were tracked during the incubation period (January-February) and 21 during brooding period (February-March), from 1992 to 2008.

This dataset was used to characterize and model the foraging habitat of king penguins and predict how projected warming of the Southern Ocean would affect their foraging range over the 21st century. To do so, key oceanographic variables driving the foraging distribution were identified to model spatial patterns of habitat use and investigate interannual variability in penguin's accessibility to marine resources. Projections of Sea Surface Temperature (SST) from a set of Global Climate Models contributing to the IPCC Fourth Assessment report were used to predict king penguins foraging range over the 21st century.

Characterizing and modeling the foraging habitat of king penguins

As king penguins are central place foragers when breeding, their foraging success is strongly constrained by the swimming distance to food resources.

Argos tracks showed that king penguins from Possession Island mainly exploit pelagic waters located 300–500 km south of the colony, an area corresponding to the polar front, a thermal boundary where their preferred prey, myctophid fish, congregate. Since 4–5 °C Sea surface Temperature isotherms, a proxy of the polar front, was the most important variable predicting the foraging effort of king penguins and the only one available through IPCC climate models at a suitable resolution, this oceanographic

parameter was used to predict the future distribution of penguins' foraging effort using habitat models.

Southward shift

Models captured the southward shift of the polar front as the summer season progressed and the inter-annual variations in the position of the polar front. Penguins have to swim further south during the brooding period and during years of warmer conditions to track the seasonal movement of the polar front. A demographic study conducted at the Crozet Islands revealed that breeding success decreased during warmer years. This decrease was supposed to be the result of reduced foraging efficiency during warmer years. During historic warm events such as the 1997–1998 El Niño event, king penguins had to considerably increase their range, the mean foraging distance being doubled with respect to favourable years, Bost et al. 2015).

How a warmer Southern Ocean will impact the penguins

Under the more pessimistic IPCC scenario tested in this study (A2) surface waters will warm at a rate of 0.184°C per year at Crozet island. A direct consequence of this warming would be a latitudinal shift of approximately 400 km in the position of the polar front by 2100 south of the Crozet Islands. King penguins from the Crozet Islands would have to travel, on average, 43.4 km further south per decade to reach profitable foraging zones during the chick rearing period. Such a shift is far beyond the usual summer foraging range of king penguins and would undoubtedly have drastic consequences on the Crozet Islands population.

Changing penguin population dynamics

The minimal distance to foraging zones is a crucial factor affecting king penguin population dynamics. Previous studies indicated that chick survival was greatly reduced after an absence of the provisioning parent exceeding 22 days during the brooding period. This fast duration corresponds to a maximal foraging range of 722 km before breeding failure occurred (Bost et al., 2015). Our predictive model suggested that such a distance could frequently occur from the year 2050 onwards, which may cause chronic decreases in the average breeding success and result in the long-term decline of the Crozet Islands population.

SPECIAL THANKS TO C.A. BOST

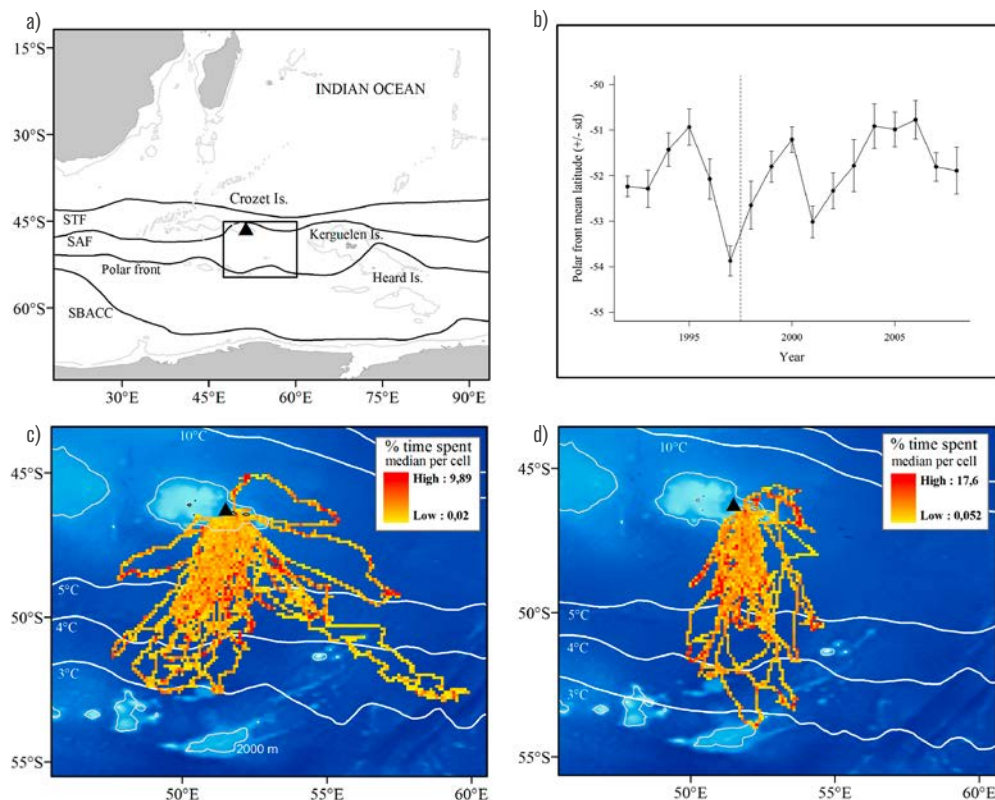
Charles-André Bost, CEBC-CNRS, is a leader in the study of the foraging ecology of marine top-predators, conducting research for 25 years in the Southern Ocean with special emphasis on the impact of the climatic variability on sub-Antarctic marine food webs. He has also developed the approaches using marine predators borne as autonomous platforms to investigate physical changes in the Southern environment and monitor resource availability. His Argos tracking database was the backbone of this study.



CLARA PÉRON

Clara Péron is a marine biologist that studied the impact of climate change on seabird spatial distribution during her PhD at the Centre d'Etudes Biologiques de Chizé in France (CNRS UMR 7372). She worked with Henri Weimerskirch on flying seabirds, such as albatrosses and petrels, and Charles André Bost on King penguins. She is currently working as a postdoctoral fellow at the University of Tasmania, in Australia. Her research interests are the movements, migrations and habitat preferences of marine species, and understanding how these relate to climate change and threats from human activities at sea.

Reprinted from the Proceedings of the Royal Society of London B, Vol. 279, Clara Péron, Henri Weimerskirch and Charles André Bost, Poleward shift of king penguins' (*Aptenodytes patagonicus*) foraging range at the Crozet Islands, southern Indian Ocean, Pages 2515- 2523, May 25, 2012, with permission from Rightslink.



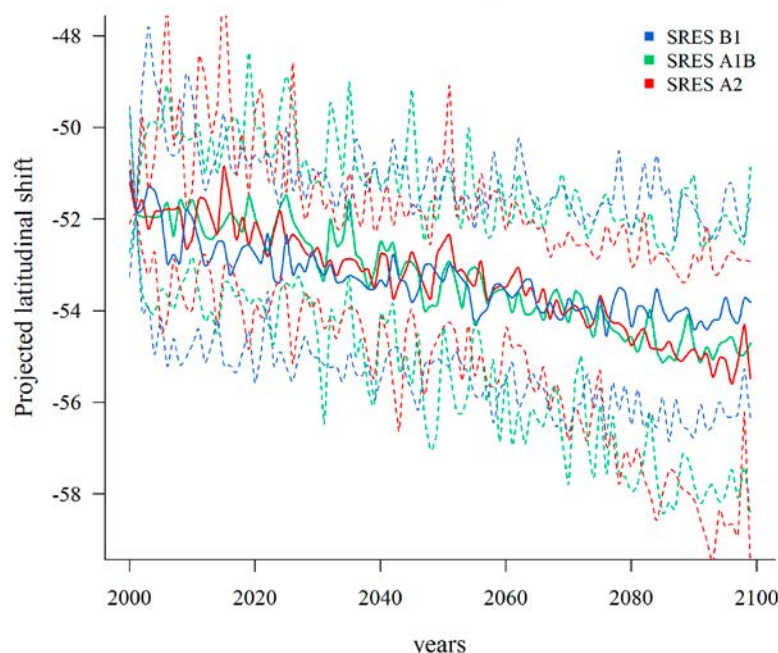
▲ Figure 1: (a) Map of the study area and king penguins' range (47–60° E, 45–54° S). The mean annual position of the fronts (STF: subtropical front, SAF: sub-Antarctic front and SBACC: southern boundary of the Antarctic circumpolar current) are illustrated following Moore et al. and Park et al. (b) Time series of the mean position of the 4°C isotherm corresponding to the polar front. The mean latitudinal position (+s.d.) was calculated for February within king penguins' longitudinal range (47–60° E). (c,d) Observed habitat use of king penguins tracked from 1998 to 2008 during the incubation and brooding period, respectively. Bathymetry and mean annual position of the isotherms (1998–2008) are displayed in the background. Triangle corresponds to Crozet Island.

► Figure 2: Projected changes in the mean latitudinal position of the 4°C isotherm (i.e. polar front) under the scenarios B1, A1, B and A2. These future trends and 90% CI were calculated in January within king penguins' range from a multi-model dataset. Blue line, B1; green line, A1B; red line, A2.

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Future trends in polar front position





By Daryl Metters, John Ryan and Grant Millar, Coastal Impacts Unit, Queensland Department of Science Information Technology and Innovation

One of the consequences of climate change is that the intensity and frequency of severe weather events such as tropical cyclones is predicted to change into the future. Of particular concern to coastal communities in Queensland, Australia is that the intensity of tropical cyclones is forecast to increase by 2 to 11 % by the year 2100 (Knutson T.R. et al, 2010). In order to model and forecast the impacts of severe tropical cyclones on coastal communities, the physical parameters of typical cyclones and their associated influence on local water levels and wave height must be determined. Miniaturized buoys, deployed in the event of a storm, can be a valuable tool for doing so, as Daryl Metters, John Ryan and Grant Millar of the Coastal Impacts Unit (DSITI) demonstrated during the 2015 Tropical Cyclone Nathan.

Identifying El Niño events

The Coastal Impacts Unit (CIU) of Queensland, Australia, utilises moored waverider buoys to monitor and measure wave heights under normal conditions. Any one buoy may record the effects of a tropical cyclone if the cyclone passes close to the buoy's moored position. During the passage of tropical cyclones, CIU deploys an additional resource for capturing wave information: a miniaturised version of the moored

waverider buoy utilised as a free drifting device and fondly referred to as BOB (Baby Ocean Buoy).

As severe Tropical Cyclone (TC) Nathan meandered off the east coast of far north Queensland, the CIU was busy organising the deployment of a buoy of this type. On the evening of Tuesday 17 March, BOB was transported by air from Brisbane to the Cairns to be ready for deployment. The forecast track for TC Nathan at that time was for landfall about 150 km north of Cairns.

Valuable wave height data collected by Argos

The Argos satellite tracking system was used to track BOB's movement from the moment of deployment until being washed ashore in the wake of TC Nathan. BOB drifted freely northward for 90 km with the prevailing tides and currents, recording and transmitting data over two days. Valuable data on wave heights and water circulation was gathered by BOB and transmitted via the Argos system. These data were used by the Bureau of Meteorology and Queensland Government counter disaster groups.

TC Nathan made landfall on the Queensland coast about 90 km north-north west of Cooktown at 7am on 20 March. BOB came within 20 km of TC Nathan and reported a maximum wave height of 9.6 metres. The nearest permanently moored wave monitoring buoy is at Cairns where the maximum wave height was reported to be 2.93 metres. The drift speed of BOB increased dramatically from about 2 km/h to 10 km/h as the radius of maximum winds approached the inside reaches of the Great Barrier Reef.



Daryl Metters, John Ryan and Grant Millar (left to right) with a Baby Ocean Buoy.

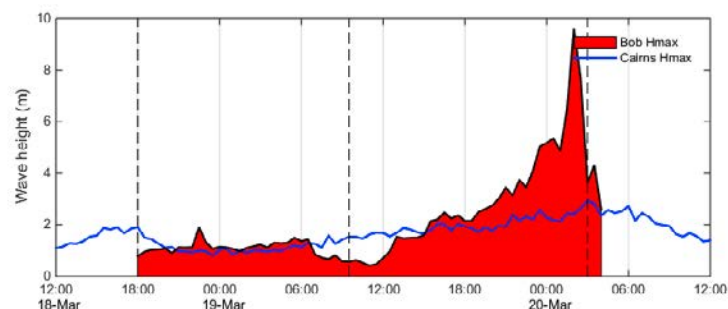
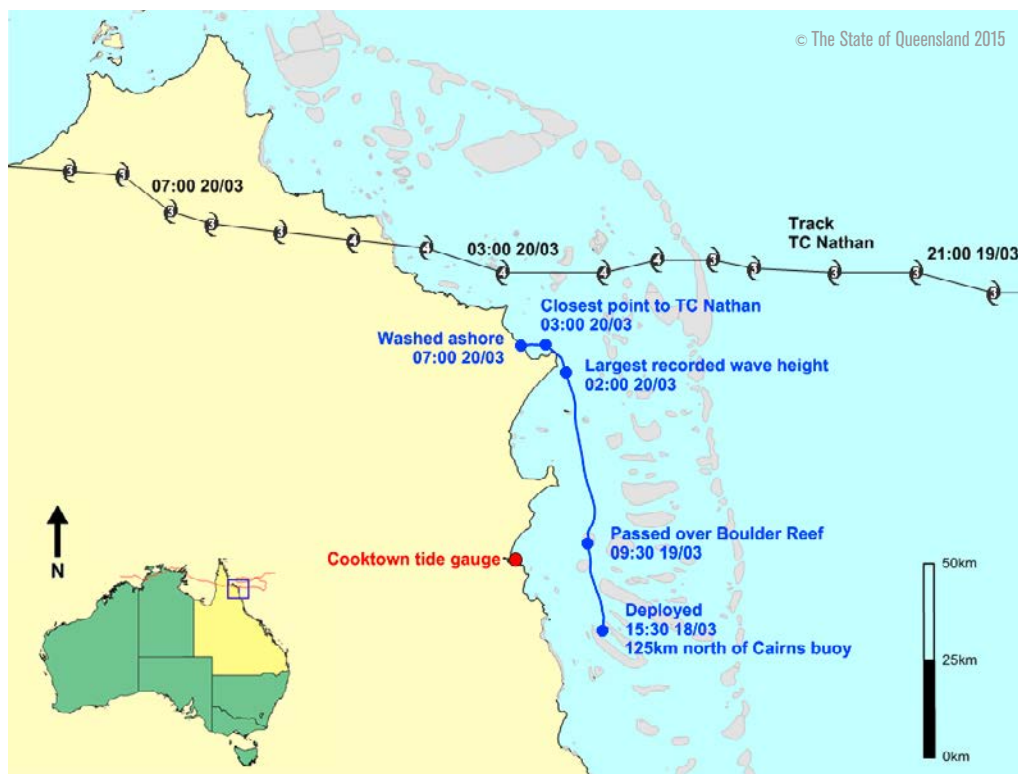
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Better insight into wave height

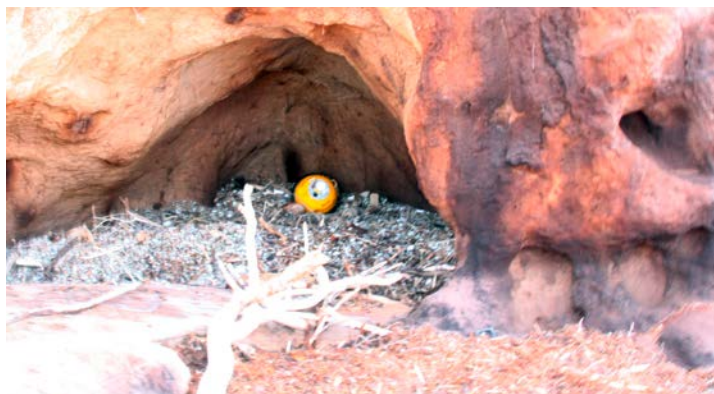
The significant difference in wave height data collected from BOB and the permanent Cairns buoy during TC Nathan highlights the necessity of real time wave data in the vicinity of a cyclone to better inform marine operations and disaster management. In the case of TC Nathan, increased wave activity was localised and outside of DSITI's network of moored buoys.

The data collected by BOB provides a better insight into cyclone generated wave growth within the Great Barrier Reef lagoon, as well as wave interaction with individual reefs. Such information will provide for better coastal planning and emergency management.



▲ Figure 1: Drift Track of BOB and TC Nathan.

◀ Figure 2: Maximum wave height for BOB and the moored wave monitoring buoy.



◀ After the cyclone passed, data transmission became intermittent. BOB was eventually recovered on 10 April by Coastal Impacts Unit technical staff member Grant Millar. The buoy was found snuggled within a small cave on the beach and the final resting place within a cave explains why the location and data transmission became intermittent when it did.

FURTHER INFORMATION

Additional information about storm tide and wave monitoring data for TC Nathan can be found in the Severe Tropical Cyclone Nathan Factsheet.

Additional information about DSITI's storm tide and wave monitoring networks can be found on the Queensland Government webpages:

www.qld.gov.au/tides and www.qld.gov.au/waves



DARYL METTERS

Daryl Metters is a Senior Scientist in the Coastal Impacts Unit within the Queensland Government Department of Science, Information Technology and Innovation. Daryl has a BSc (Hons) in Marine Science from Flinders University. Daryl has worked in the National Tidal Centre, Australian Bureau of Meteorology as a Tidal analyst, and as Manager Spatial Information (Tidal services) in Maritime Safety Queensland. His work includes monitoring sea levels in Australia and the South Pacific region, data management and operational aspects of tide gauge and wave monitoring networks in Queensland.



JOHN RYAN

John Ryan is a Principal Scientist in the Coastal Impacts Unit within the Queensland Government Department of Science, Information Technology and Innovation. John has a BEng in Mechanical Engineering from Queensland University of Technology. John has worked in a number of different fields: exploration drilling, copper smelter, metal tube cutting systems, wireless internet services and now manages the Queensland Government's storm tide and wave monitoring networks.



GRANT MILLAR

Grant Millar is Acting Principal Technical Officer with the Coastal Impacts Unit of the Queensland Department of Science, Information Technology and Innovation. Grant has a BSc in Environmental Science from Griffith University. After working for the Queensland Government for eight years, he started his own company to fill the void of installing scientific instrumentation. Having managed projects across Australia and into Indonesia and Papua New Guinea, from flood prediction to water quality and weather stations, he has returned to government service to assist the team of technical officers that maintain the storm tide and wave monitoring network.

HOW LEATHERBACK TURTLES WILL REACT TO CLIMATE CHANGE



© iStock photo

By Ellen Willis-Norton, University of California Santa Cruz's Ecology and Evolutionary Biology Department

Pacific leatherbacks, a species that is already in sharp decline due to development on nesting beaches, illegal egg harvesting and fisheries bycatch, may also be vulnerable to climate change. In a study lead by Ellen Willis-Norton, Argos tracking data collected from 46 nesting females between 2004-2007 is an important resource for understanding the impact that climate change may have on Eastern Pacific leatherback populations.

Migratory species and climate change

The impact of climate change on migratory species is difficult to predict. Unlike resident species, they travel long distances, increasing their exposure to regions that will likely be affected by climate change (Robinson et al., 2009). On the other hand, migratory species have acclimated to various habitats to complete their seasonal or interannual journeys; thus, they may be able to adapt to climate fluctuations (Robinson et al., 2009).

The Intergovernmental Panel on Climate Change (IPCC) generated six climate change scenario families based on several hypothetical futures characterized by varying levels of greenhouse gas emissions (IPCC, 2000). The six potential scenario families projected an average sea surface temperature rise of 1–6 °C by 2100. Temperature changes will most likely affect marine ectotherms more directly than other species because they already occupy the entirety of their thermal tolerance range, i.e. the extent of their latitudinal habitat based on their temperature tolerance (Sunday et al., 2012).

Impact of long generation times

Leatherback sea turtles (*Dermochelys coriacea*) are the largest living turtle and among the largest living reptiles (Paladino et al., 1990). They are a late-maturing, long-lived species (Hawkes et al., 2009; Avise et al., 1992). Leather-

backs utilize their large body size, blood flow regulation, and changes in swimming speed and activity to regulate internal temperatures (Paladino et al., 1990; Bostrom and Jones, 2007; Bostrom et al., 2010).

Argos provides valuable data

For this study, female leather back sea turtles were instrumented with either a Sea Mammal Research Unit (SMRU) Satellite Relay Data Logger (SRDL) tag (n=36) or a Wildlife Computer Smart Position Only (SPOT) tag (n=10) from 2004 to 2007 (Shillinger et al., 2008).

The SRDL tags were programmed to transmit position, temperature, dive data, and tag diagnostic information. The SPOT tags were programmed to collect position data. The satellite transmitters were mounted on the turtles during ovi position using a harness technique (Eckert, 2002). Data from the tags were transmitted via radio signals sent to the Argos satellite system.

Final position estimates were generated at six hour intervals based on the mean number of raw locations per day using a switching state-space model (SSSM), which was applied to the raw Argos position data.

The SSSM incorporated the measurement error in Argos telemetry data to improve position estimates (Jonsen et al., 2007; Shillinger et al., 2011; Bailey et al., 2012).

Remotely sensed environmental data were obtained for both the leatherback and Correlated Random Walk (CRW) tracks using Xtractomatic (<http://coastwatch.pfsl.noaa.gov/xtracto/>). The datasets included time-series of SST, chl a, SSH, SSHRMS, wekm, SST frontal probability index (FPI), bathy, and bathyRMS.

In order to compare oceanographic parameters along the leatherback and CRW tracks, a binary presence/absence model with a negative binomial link function was used. Generalized additive mixed models (GAMMs) were constructed to analyze the statistical correlation between the eight oceanographic parameters described above and leatherback presence/absence (Wood, 2006).

The full model included all eight oceanographic parameters as a preliminary exploration of satellite data and was robust. The five variables that were primarily attributed to leatherback presence were: sea surface temperature (SST), surface chlorophyll-a (chl a) concentration, sea surface height (SSH) variability (rootmean square, SSHRMS), vertical current due to Ekman pumping (wekm), bathymetry (bathy), and rugosity (bathyRMS).

For this study, both SST and chl a were considered to be the most important proxies for leatherback habitat. Therefore, eastern Pacific SST and chl a values from 2001 to 2010 model output were plotted to visualize preferred leatherback habitat conditions. The model revealed that the tagged leatherbacks preferred cooler SSTs (< 25 °C) and lower chl a levels (< 1 mg/m³) than were available as potential habitat. The change in SST and chl a over time was also plotted by subtracting 2080–2100 SST and chl a values from 2001 to 2020 levels.

The model compared preferred leatherback habitat to forecasted SST and chl a values to reveal changes in leatherback's pelagic habitat out to 2100.

Model projections indicate that there will be a net loss in Eastern Pacific leatherbacks' core habitat: over the next century, Eastern Pacific leatherbacks core pelagic habitat in the south Pacific is predicted to decrease by around 15%, according to model projections and IPCC scenarios (see Figure 1 & 2).

Article reprinted from Deep Sea Research II, Vol 113, Ellen Willis-Norton, Elliott L. Hazen, Sabrina Fossette, George Shillinger, Ryan R. Rykaczewskif, David G. Foley, John P. Dunneg, Steven J. Bograd, Climate change impacts on leatherback turtle pelagic habitat in the Southeast Pacific, Pages 260-267, Copyright March 2015, with permission from Elsevier.

Figure 1

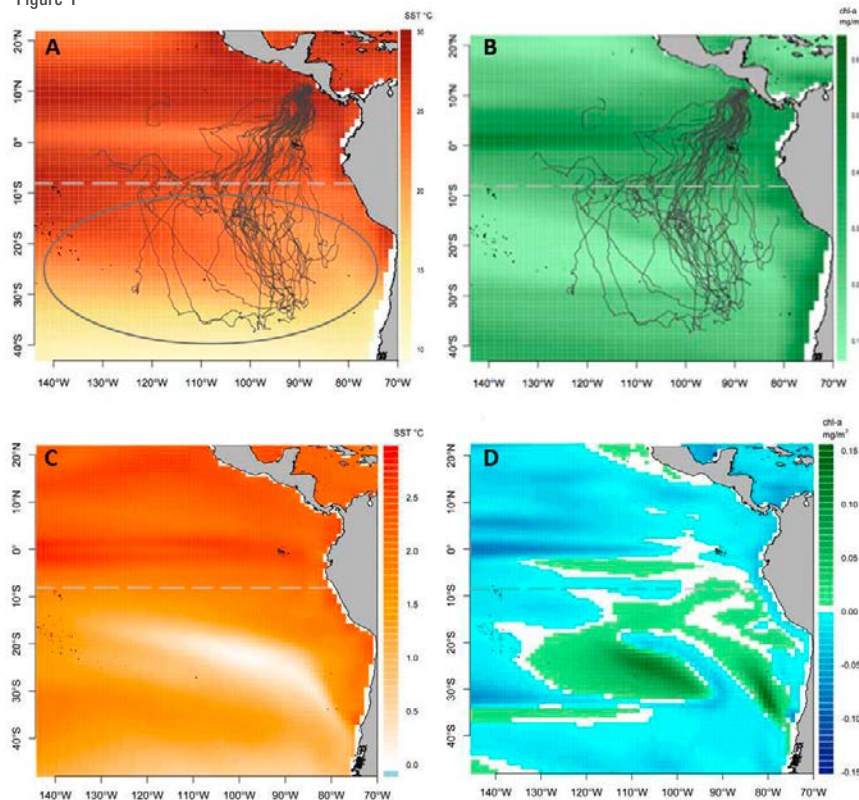
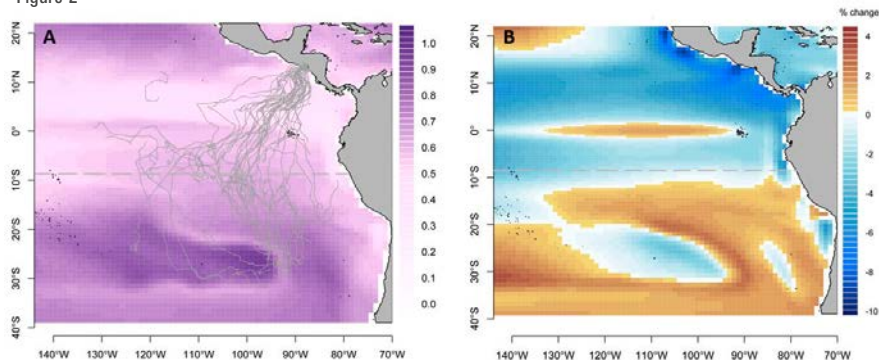


Figure 2



This in turn may force the population to shift west or south of their current foraging habitat to regions where there is a predicted habitat gain over the next century. Eastern Pacific leatherbacks cold thermal tolerance boundary is currently around 37°S (i.e. 14 °C; Shillinger et al., 2011) but with increasing SSTs, the population could expand further south.

Leatherbacks may be able to expand their range into new regions; however, the predicted habitat gains may not be significant enough to compensate for the habitat loss. In addition, behavioral and physiological adaptation may be difficult for the Eastern Pacific leatherbacks as climate change progresses.

To counteract the impacts of climate change and reduce the population's decline, flexible and dynamic adaptive management strategies are needed. Conservation programs at nesting beaches have been employed since the 1950s and need to be strengthened, but marine conservation strategies based on intergovernmental cooperation need to be implemented.

This spatial analysis provides a first step to allow conservation managers to identify regions where the establishment of pelagic protected areas might be the most effective as marine ecosystems shift.

▲ Figure 1: (a) Average SST (°C) from 2001 to 2010 (gray circle indicates the South Pacific Gyre), (b) average chlorophyll a level from 2001 to 2010, (c) change in SST over the next century (average SST from 2080 to 2100 subtracted from the average SST from 2001 to 2020), and (d) change in chl a over the next century (average chl a from 2080 to 2100 subtracted from the average chl a from 2001 to 2020) all from GFDL climate model output. Dark gray lines represent the 46 tagged leatherback tracks. Dashed gray line separates the migration habitat (north of 8°S) and foraging habitat (south of 8°S).

▲ Figure 2: (a) Current leatherback habitat, the darker the purple the higher the probability of leatherbacks occupying the area (scale of 0 to 1). Dark gray lines represent the 46 tracks. (b) Change in the likelihood of an area being leatherback habitat (in percent). A decrease in habitat is represented by a darker blue while an increase is shown in a darker brown. Dashed gray line separates the migration habitat (north of 8°S) and foraging habitat (south of 8°S).



ELLEN WILLIS-NORTON

Ellen Willis-Norton is a graduate student in University of California Santa Cruz's Ecology and Evolutionary Biology Department. She received her BA in Biological Sciences and Environmental Studies from Wellesley College in 2012. From 2012 to 2015 she worked as an Environmental Analyst for the San Francisco Estuary Institute's Clean Water Program. Ellen is interested in how climate change will affect the availability of suitable habitat for top predators and west coast fisheries. The focus of her research is on creating climate envelope models to predict potential habitat shifts, contractions, and expansions.

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INTERNATIONAL ARGO PROGRAM: A REVOLUTION IN CLIMATE RESEARCH

By Howard Freeland, Argo Program Director, Mathieu Belbeoch, Argo Program coordinator

Argo float technology is recognized within the climate community as a huge step in the climate observing system, providing essential observations of the ocean down to 2000 metres. But over the past 15 years, what have these oceanographic robots really taught us about the Earth's climate, and what does the future hold? Howard Freeland and Mathieu Belbeoch take a closer look....

The oceans play a central role in the earth's climate. Yet continuous observations of the ocean are difficult to obtain, especially below the sea surface. The Argo program is a network of 3,700+ autonomous profiling floats that are programmed to gather temperature, pressure and salinity measurements of the ocean as they dive down to 2,000 metres below the sea surface, sampling as they go. The first floats were launched in 1999 and full global coverage was achieved in 2007, with an array of 3,000 floats evenly distributed over the world's oceans. Designed to complement other measurements, the Argo program provides the crucial, uniform in time and space, in situ observation profiles of the ocean.

Argos and Argo, historic partners

Today, the Argos system provides communications and GTS data processing services for 60% of the active Argo profiling floats, and Argos will continue to be an important system for data transmission in the future, contributing to the program's long-term sustainability. With 90% of data available within 24 hours after collection, the Argo program assists climate studies, coupled ocean/atmosphere climate models, and ocean analysis and seasonal forecasting systems.

While Argo has contributed significantly to the global ocean observing system, climate studies require 30 years of high quality

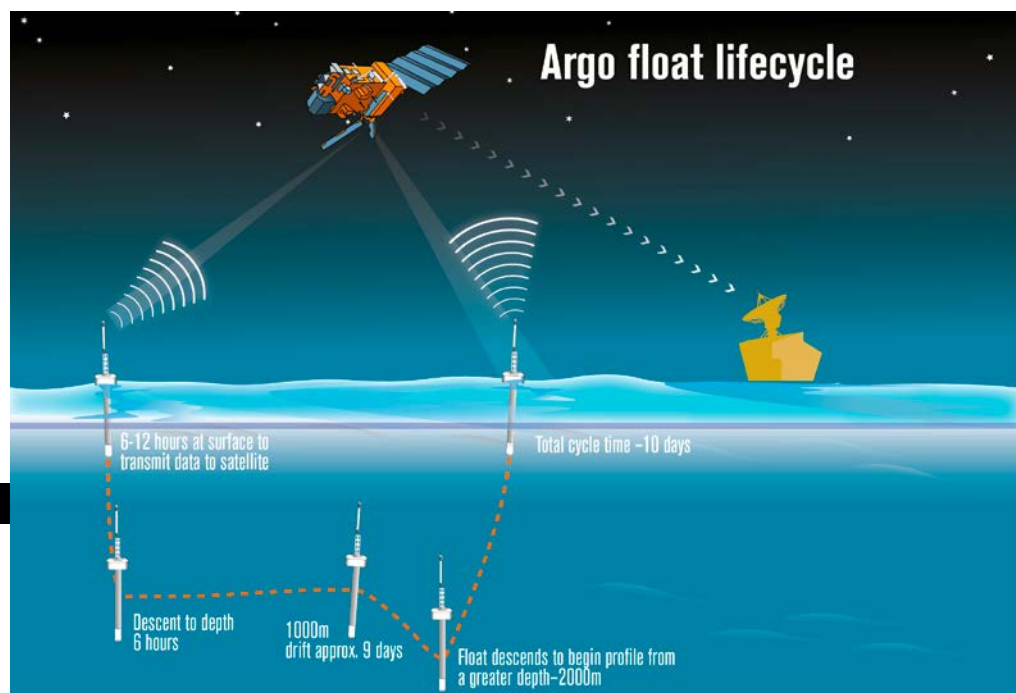
data, so we need to continue to observe. There are a number of areas where technological improvements will ensure that Argo provides a high quality dataset for future generations.

Continuing to be at the forefront of climate science

1/Sea-ice observations. New technology allows Argo profiling floats to measure below the ice cover in polar regions. The new "smart" floats recognize that there is sea ice above and do not try to surface. Instead, they continue to profile the ocean and transmit all of their data in the summer, when the sea ice has

melted. This new technology is of crucial importance because there is currently a warm-bias in the Argo data. It is a strong goal of the Argo program to reach full coverage in the polar regions/high latitudes in the near future.

2/Ocean biogeochemistry observations. About 300 Argo floats today are able to measure biogeochemical variables such as dissolved oxygen, nitrate, chlorophyll, and pH. These floats contribute to climate state studies, by shedding light on the biogeochemical cycle of carbon, ocean de-oxygenation, and ocean acidification (Johnson et al., 2009).



Argo float lifecycle

Argo profiling floats are programmed to gather temperature, pressure and salinity measurements of the ocean as they dive down to 2,000 metres below the sea surface, sampling as they go.

3/Deep ocean measurements. In future, Argo floats will be capable of sampling the deep ocean (-4,000 to -6,000m), where studies indicate the ocean stores heat. Prototypes are currently being tested in Europe, the United States and Japan.

4/Regional expansions. Following recommendations from the OceanObs'09 conference, Argo plans to double the density of the array in the Western Boundary Currents regions, in the equatorial band and Marginal Seas.

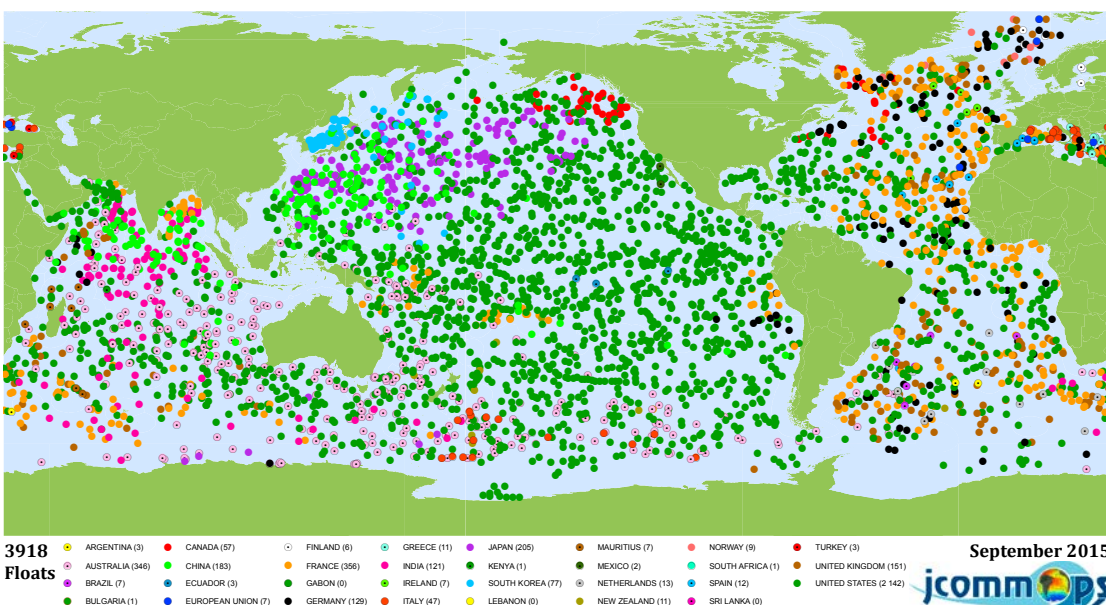
Ensuring the future of Argo

Argo has first to sustain and secure its core array of 3,000 units, then it will slowly move to the global and multidisciplinary Argo. But government support to Argo is not progressing that well. Actually some major Argo players see their contribution decreasing because of budget cuts or simply because of inflation. Float lifetime progressed a lot in the early years but since 2005 it has slightly decreased. Even if almost 4,000 units are operating today, we will soon observe a slow degradation of the array.

We hope the current dynamic around the climate conference COP21 will result in increased support for Argo, and all other elements of the Global Ocean Observing System. The IOC/UNESCO is working hard to include the ocean in the agenda of the COP21 and relay our message.

We also seek partners from civil society and industry to provide us some additional logistics to deploy our 1,000 units per year, and also promote our activities. An example of what international cooperation can provide was to have all skippers of the Barcelona World Race 2014-2015 deploy a float during the race for the first time.

▼ State of the Argo network as of September 2015. A total of 613 floats were launched this year, another 159 launches are expected by the end of 2015.



Ocean and Argo

We hope that the dynamic created by the COP 21 will bring greater support to Argo, as well as to the other components of GOOS. For Argo will continue to take the pulse of the ocean for a long time, and its greatest contribute to climate studies is yet to come, when at least fifteen years of high quality data will have been collected.

TO LEARN MORE:

Cheng, L. et al. Distinctive ocean interior changes during the recent warming slowdown. *Sci. Rep.* 5, 14346; doi:10.1038/srep14346 (2015).

Durack, P., Gleckler, P., Landerer, F., & Taylor, K. Quantifying underestimates of long-term upper ocean warming. *Nature Climate Change*, doi:10.1038/NCLIMATE2389 (2014).

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Ren, L. & Riser, S. Seasonal salt budget in the northeast Pacific Ocean. *Journal of Geophysical Research*, 114, doi:10.1029/2009JC005307 (2009).

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Roemmich, D, Gould, W.J., & Gilson, J. 135 years of global ocean warming between the Challenger expedition and the Argo Programme. *Nature Climate Change*, 2, 425-428 (2012).

Roemmich, D. et al. Unabated Planetary Warming and its Anatomy since 2006. *Nature Climate Change*, 5, 240-245 (2015).



HOWARD FREELAND, ARGO PROGRAM DIRECTOR

Howard Freeland is an emeritus scientist at the Institute of Ocean Sciences in Sidney, British Columbia, Canada. Since his retirement he is volunteering his time as part-time Argo Director. Howard was previously one of the Argo co-chairs and has been involved in the Argo program since its very beginning. Howard has a B.A. from the University of Essex in England and a PhD in oceanography from Dalhousie University (Halifax, Nova Scotia).



MATHIEU BELBEPOCH, ARGO PROGRAM COORDINATOR

Mr. Belbeoch is the Technical Coordinator of the international Argo programme since 2001 and the leader of the JCOMM Observations Programmes Support Centre. With a mathematical engineer background, applied to numerical modeling in oceanography, and after a short experience in web development projects leading, he has supported the development of the revolutionary ocean observing programme Argo and developed more generally the support to main in-situ ocean observing systems within the JCOMMOPS initiative. Beyond the expertise on Argo, on the global in situ networks, international/intergovernmental issues and JCOMM associated panels, he has developed an innovative real-time monitoring system and metadata management for the evaluation of the performance of these networks. He has raised JCOMMOPS from an embryo state, to a firm operational Centre with proper staff and means.

ARGOS: AN ENABLING TECHNOLOGY FOR CLIMATE RESEARCH



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By Bill Woodward, Business Development Manager of Environmental Monitoring, CLS America

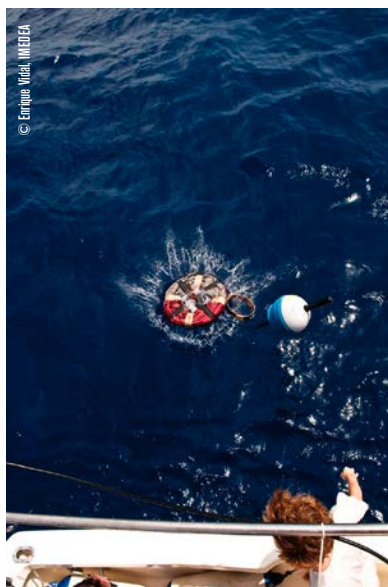
The arrival of Argos in the late 1970's coincided perfectly with an exciting shift of emphasis in ocean and meteorological research. Single discipline studies were being replaced with a multi-discipline approach aimed at describing the physical processes that couple the oceans and atmosphere, as well as understanding the mechanisms behind them. Related research goals included improving the accuracy of medium range weather forecasting and increasing the understanding of the physical basis of climate.

Observational systems were an essential component of these research programs, as was demonstrated by the First GARP Global Experiment (FGGE), implemented in 1978 under the joint WMO and ICSU Global Atmospheric Research Program (GARP). The FGGE observing system included, for example, the Southern Hemisphere (drifting) Buoy System and the Tropical Constant Level Balloon System. These observing systems supplied sea-level SST/ air pressure measurements and upper level wind measurements respectively. The capability of Argos to not only collect data in near real time but to also geo-locate remote platforms made it an excellent choice for data retrieval from the many hundreds of buoys and balloons deployed in FGGE. Argos supported these observing systems

very successfully for the year-long FGGE observing period, and thus began an historic, multi-decadal legacy of serving the metocean research community with satellite-based operational data collection and location services.

The First World Climate Conference (1979) provided the momentum for the programmatic transition of GARP into the World Climate research Program (WCRP). From its beginning, the WCRP made outstanding contributions towards advancing climate science and ocean-atmosphere interaction. Most notably these included the Tropical Ocean Global Atmosphere (TOGA) Program and the World Ocean Circulation Experiment (WOCE). Driven by these large-

scale global climate science programs the available in-situ observational technology became increasingly more capable and sophisticated. Argos kept pace in the 1980's and 1990's with these evolving measurement capabilities and data requirements, and continued to provide reliable operational data collection and location services during that time for virtually all of the WCRP in-situ observational systems: Shipboard XBTs, Drifting Buoys, Tropical Moored Buoys (ATLAS-TAO), Long Time Series Stations, and Arctic/ Antarctic Ice Buoys.



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Then, in the early 2000's, Argos partnered with the WMO Joint Technical Commission for Oceanography and Marine Meteorological (JCOMM) Services in order to strengthen the base of Argos services and contributions to the research and operational communities. Today, 37 years after FGGE began, Argos is still a strong partner with the ocean climate community. Argos is serving both the international Argo Program and the Global Drifter Program by providing communications and GTS data processing services for 60% of the 3881 currently active Argo profiling floats and for 72% of the 1468 currently active GDP drifting buoys.

In addition to physical climate studies, assessing the impacts of climate change on wildlife populations has become an increasingly higher priority in the wildlife biology community during the last decade. Tracking wildlife with Argos is allowing the scientific community to develop an understanding of the response and adaptation of wildlife populations to climate variability.

Since the 1980's more than 100,000 animals have been tracked using Argos. Because the first Argos wildlife transmitters were quite large, biologists were limited to tracking elephants, polar bears, and caribou. This has

changed dramatically over time as wildlife tags have become significantly smaller while at the same time progressively more capable. The smallest tag that is manufactured today weighs only 2 - 2.5 grams.

With these more sophisticated Argos tags it is increasingly possible to track greater numbers of marine species - fish, eels, sharks, jellyfish - plus an ever larger diversity of lighter-weight migratory birds. Nearly 60% of migratory species identified by the Convention on Migratory Species have been tracked using Argos.

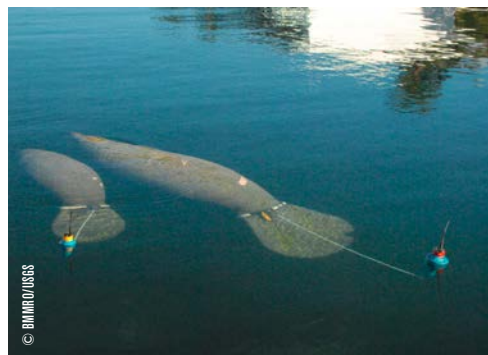
For several decades, Argos has provided the essential science-based data needed to understand animal behavior. This data is a fundamental element of animal behavior models designed to understand the impact of climate change on wildlife.

The Argos system is a robust, user driven enabling technology for science that has been in operation for nearly 40 years, and which continues to be an extraordinary model of successful and sustainable intergovernmental cooperation for climate and the environment.

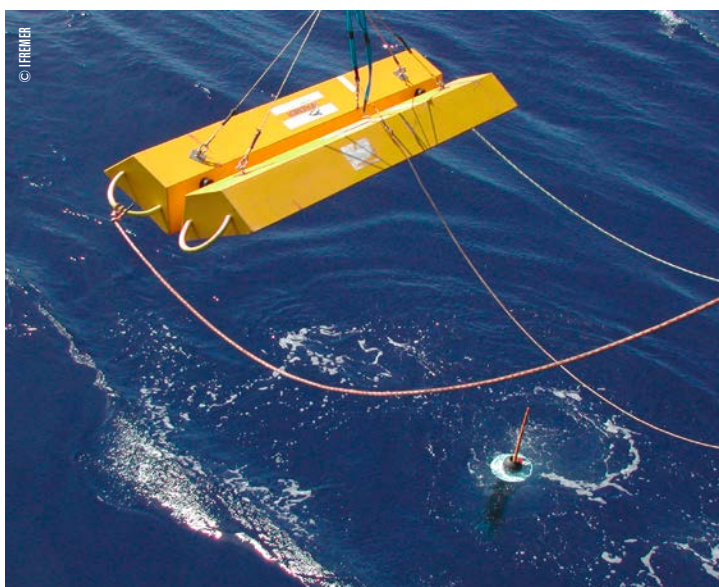


BILL WOODWARD

Bill joined Service Argos Inc. in January 1999 as a Senior Scientist and was the President and CEO from 2000-2014. Bill now serves as the Business Development Manager of Environmental Monitoring. Prior to joining Argos, he worked for 28 years at NOAA. With undergraduate and graduate degrees in electrical engineering and ocean engineering, his responsibilities at NOAA included developing and testing ocean instruments and advanced ocean technology, and managing several shipboard and in-situ global ocean and meteorological observation programs. Prior to this Bill served at the United States Naval Oceanographic Office's National Oceanographic Instrumentation Center.



Nearly 40 years of climate study with Argos



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