

## The Science of Climate Change in Hawai'i

By Kevin Hamilton

Hawai'i's dominant industries - first agriculture and then tourism - have been crucially linked to its generally favorable weather. Hawai'i has also on occasion displayed its vulnerability to extreme adverse weather, including droughts, flash floods and tropical cyclones. The islands' extensive coastal regions leave them particularly vulnerable to both extreme individual events such as hurricanes and to effects of gradual environmental change. Hawai'i's isolated location makes its fresh water resources completely dependent on local rainfall. Not surprisingly, there is great public interest in how anticipated climate change may affect the natural, economic and cultural resources of Hawai'i. A great deal of relevant research on this issue is now being performed at the IPRC and elsewhere.

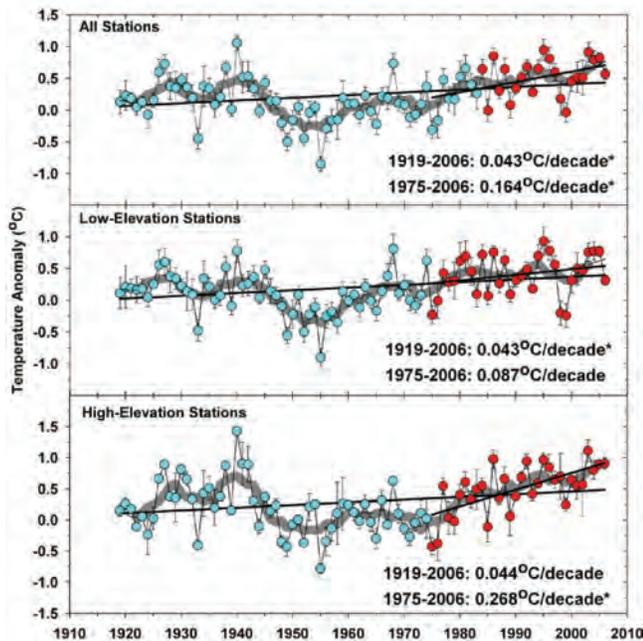


Fig. 1. Annual mean surface air temperature anomalies averaged over Hawaiian stations with elevation above 800 m (bottom), below 800 m (middle) and a weighted average of the low and high-elevation stations (top). The smooth curves are 7 year running means. The asterisks beside the linear regression trends in each panel indicate statistical significance. Adapted from Giambelluca et al., *Geophys. Res. Lett.*, 2008.

At the initiative of Dean **Brian Taylor** of the University of Hawai'i School of Ocean and Earth Science and Technology (SOEST), a symposium was held January 19 and 20, 2011, to review research on the science of climate change in Hawai'i and to discuss avenues for future progress. The IPRC took the lead as host of the meeting, which was intended for IPRC scientists, colleagues elsewhere in SOEST and in other units of the university, as well as scientists from local Hawai'i partners such as the US Geological Survey, NOAA, and the East-West Center. To keep the meeting scope manageable, the focus was on observing and attributing the physical climate changes over roughly the last century and projecting such changes for the next century.

The meeting produced ample evidence for changing Hawaiian climate in the recent past. Figure 1 presented by **Tom Giambelluca** (UH Geography Department) shows temperature indices based on daily air temperature observations at several surface stations on Kaua'i, O'ahu, Mau'i, and the Big Island of Hawai'i. The tendency for rising temperatures since about 1975 is apparent, and indeed the trends based on 1975 – 2006 observations are quite large, particularly for high-elevation stations. The behavior over the full ~90 year record is more complicated, however, and may be affected by long-period natural variations. The difficulty of separating long-term trends that may be reasonably attributed to anthropogenic forcing from other long-period sources of variability is apparent in other climate variables as well. However, an overall long-term trend toward drier conditions over the islands, with reduced rainfall and flow in Hawai'i's streams, was apparent in the observations discussed by **Delwyn Oki** (US Geological Survey) and others at the Symposium. **Roger Lukas** (Oceanography Department) presented a summary of observed trends in the oceans near Hawai'i, making use of the long Hawai'i Ocean Time Series of measurements at Station ALOHA north of O'ahu. A trend in recent decades to warmer and more saline surface waters is apparent in these data.

Several talks at the meeting aimed to present the local climate changes seen in Hawai'i in a broader regional (i.e., tropical and subtropical Pacific) context. A particular issue identified was the quality of available meteorological data over the large ocean areas, as both global reanalysis data and raw

ship-report data are suspect in some ways. The lack of reliable observations complicates even such basic aspects as determination of trends in the strength of the regional-scale surface winds.

A critical practical issue for an island state like Hawai'i is sea level rise. A long record from a tide gauge at Honolulu presented by **Mark Merrifield** (Oceanography Department) reveals a rather relentless increase of the sea level for the past century, but at a relatively modest and constant rate. By contrast the best estimates of global sea level suggest an acceleration of the rising trends in the last couple of decades. Of course, the local sea level trend at any location depends on a number of factors and will be driven to a significant extent by changes in the regional-scale surface winds. Satellite data for the last 2 decades show substantial regional trends in sea level across the Pacific, with Hawai'i located in a region characterized by relatively modest rising trends.

The issue of projecting climate changes into the future was also addressed in a number of presentations. The current climate projections from global coupled atmosphere-ocean models have limited direct application to Hawai'i, as most very long climate forecast integrations have been performed using atmospheric component models with effective horizontal grid-spacings of ~200 km. This is a significant issue for representing many aspects of the atmospheric circulation, but is a particular problem for Hawai'i where the climate is strongly affected by the steep topography present on all the major islands. Typical global models represent all the Hawaiian Islands as a single land grid-box or even ignore Hawai'i entirely. With-

out further analysis, the predicted changes in climate variables from such models are made at a resolution far too coarse to provide input into typical application studies. There are comparable issues in modeling climate impacts on local and regional ocean circulation. Presentations by **Axel Lauer** (IPRC), **Yi-Leng Chen** (Meteorology Department) and **Brian Powell** (Oceanography Department) addressed the current state of regional atmospheric and ocean modeling for application to the climate change problem in Hawai'i.

While current coupled models used in extensive climate integrations have relatively coarse horizontal resolution, some experimental global warming projections have been made using higher resolution global atmospheric models forced by ocean surface-temperature changes simulated in lower resolution coupled models. Presentations by **Tim Li** (IPRC) and IPRC visitor **Hiroyuki Murakami** discussed applications of such high-resolution global model projections to study the effects of global warming on the climatology of tropical cyclones that could affect Hawai'i.

Held at the East-West Center's Imin Conference Center, the meeting attracted a standing-room-only audience, and a telecast to another seminar room helped accommodate the overflow crowd of climate science enthusiasts. The scientific program was organized by IPRC Director **Kevin Hamilton** and SOEST Associate Dean **Chip Fletcher**. IPRC staff members **Ron Merrill**, **Dave Burns**, and **Jeanie Ho** provided critical technical and administrative assistance. The full program can be viewed at [http://iprc.soest.hawaii.edu/meetings/workshops/11\\_01\\_SOESTSymposium\\_final.pdf](http://iprc.soest.hawaii.edu/meetings/workshops/11_01_SOESTSymposium_final.pdf)



Participants at the Science of Climate Change in Hawai'i Symposium.

## Charting the Origin and Fate of Marine Debris

By Audine Laurian

Rubbish in the ocean is endangering marine ecosystems and shipping. *The 5<sup>th</sup> International Marine Debris Conference* in March 2011 at the Waikiki Beach Marriott Resort & Spa dealt with the manifold issues arising from such debris. IPRC's Senior Researcher **Nikolai Maximenko**, who is studying the ocean currents that gather the floating debris in patches, organized a workshop with **Kara Lavender Law** (Sea Educational Association/Woods Hole Oceanographic Institution) on *Hydrodynamics of Marine Debris* for the opening day of the conference. The workshop aimed to quantify the major sources and sinks of marine debris and their variability, pathways and effects on ecosystems. Over 70 people from various disciplines and countries shared their knowledge of observed and modeled marine debris and discussed efforts needed to determine the global inventory of marine debris and how it changes over time.

**Doug Woodring** (Kaisei) reported how trash and refuse are collected in rivers, making rivers the main source of land rubbish that ends up in the ocean. How debris in the ocean is swept back to shore by tides and storms was described by **Scott Wilson** (Centre for Environmental Management, Australia) and **Chris Pallister** (Gulf of Alaska Keeper). In the past 24 years of sampling the North Atlantic Garbage Patch region, Kara Lavender Law and her students estimated that

1100 tons of microplastic had accumulated in the area. With increased plastic production over those years, the amount of plastic dumped into the ocean has very likely increased, but surprisingly, Lavender Law found no increasing trend in her yearly samples. Is the plastic deposited on shores or on the ocean floor? Is it ingested by marine organisms? Studying the distribution of marine debris within the mixed layer, **Giora Proskurowski** (Woods Hole Oceanographic Institution) found that strong winds mixed the plastic down to 10–20 meters, decreasing temporarily surface concentration of debris.

To locate the debris in the ocean, computer models are crucial. **Mary Crowley**, an experienced sailor from the Ocean Voyages Institute, has been sampling worldwide marine debris ranging from microplastic to derelict fishing gear. When she tested equipment designed to collect microplastic in the North Pacific Garbage Patch last August, the model projections by Maximenko and IPRC's **Jan Hafner** guided her in finding the debris.

Scientists study near-surface ocean currents using Lagrangian drifters, which include a surface float and a drogue centered at 15-meter depth. Such equipment behaves like abandoned fishing gear and **Luca Centurioni** (Scripps Institution of Oceanography) and **Andrew Sybrandt** (Pacific Gyre) suggested that drifters help to understand the movements of bulky marine debris. Such drifters also furnished the data for the model that Maximenko developed and which showed the pathways the debris from the March 11 tsunami in Japan may take: first it will flow eastward in the North



Participants at the Hydrodynamics of Marine Debris Workshop.

Pacific Subtropical Gyre; in about a year and a half, some will wash up on Hawai'i's beaches; much will continue to circulate in the gyre toward the US West Coast, then equatorward and westward, reaching the eastern Hawaiian coasts in about 5 to 6 years.

IPRC's **Jim Potemra** described other state-of-the-art models that simulate trajectories of marine debris, and **Kathleen Dohan** (Earth & Space Research) gave details of the currently most popular model, the Ocean Surface

Current Analyses - Real time (OSCAR). Finally, IPRC's Jan Hafner showed how an ocean surface-current-model driven by satellite wind and altimetry data can reveal changes in the position of high marine-debris concentration. Models, Hafner said, need to be extended to include the vertical structure of marine debris, coastal processes, and marine debris deposition mechanisms.

During the workshop and the following days of the conference, the observational scientists and modelers

seized the opportunity to talk together and form partnerships for future studies on marine debris trends, the three-dimensional distribution of marine debris and its dynamics, and the development of remote-sensing techniques for better observation of marine debris.

With the help of IPRC's **Ron Merrill**, **Oleg Melnichenko**, **Ali Reda Bel Madani**, and **Audine Laurian** the workshop was broadcasted and materials are available at: <http://iprc.soest.hawaii.edu/users/nikolai/2011/HMD/>

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## A "Hot Spot" in the Climate System: Air-Sea Interaction during the East Asian Monsoon

By Yu Kosaka

The midlatitude ocean was thought to be a rather passive player in climate, but in recent years, high-resolution satellite data and modeling have revealed that the western boundary currents supply the midlatitude atmosphere with intensive heat and moisture, conditions that make for strong climate events. One such "hot spot" in the extratropical climate system is the Kuroshio/Oyashio in the Northwest Pacific.

**Hisashi Nakamura** (The University of Tokyo and JAMSTEC) leads a Japanese nation-wide project on the Northwest Pacific hot spot. Nakamura and his collaborators on this project **Atsuhiko Isobe** (Ehime University), **Youichi Tanimoto** (Hokkaido University), **Yoshimi Kawai**, **Masami Nonaka**, **Wataru Ohfuchi** and **Bunmei Taguchi** (JAMSTEC) visited the IPRC in December 2010, and IPRC scientists took this opportunity to hold the workshop *Air-sea interaction and climate variability over the Northwest Pacific*. **Shoshiro Minobe** (Hokkaido University) joined the meeting by making a presentation from Japan via Skype. The hot-spot project team described their research plans and preliminary results

from their recent studies on the project. They are using regional and global models and a wide variety of observations from satellites, research vessels, buoys, radiosondes, and aircraft to investigate atmosphere-ocean-ecosystem interactions over the Kuroshio/Oyashio extensions. Scientists from the IPRC and the UH Mānoa Department of Oceanography discussed their related work on air-sea interaction, decadal variability, and the East Asian monsoon. At the end of the workshop, the scientists talked over possible future collaborations between the hot spot project and work at IPRC, including joint ship observations over the Northwest Pacific.



Hot Spot scholars. Project leader Hisashi Nakamura with lei.

## Atmospheric Gravity Waves and their Effects on Global Circulation

By Kevin Hamilton

Inertia-gravity waves account for a significant fraction of the observed variability in the atmosphere with periods from tens of minutes to tens of hours. The wind and temperature variance associated with high-frequency gravity waves is generally observed to increase with height from near the ground up to the lower thermosphere, and studies of gravity waves in the upper atmosphere have been a staple of middle and upper atmospheric dynamics for many years. Gravity waves act to exchange mean horizontal momentum between the earth's surface and the atmosphere and among different layers of the atmosphere, and so they play a role in forcing the global-scale atmospheric circulation. Recent work on dynamical coupling of the troposphere with the middle

atmosphere has made it clear that gravity waves have a significant influence on the general circulation even in the lower atmosphere. Global climate simulation models, therefore need to adequately treat the effects of atmospheric gravity waves that are not explicitly resolved.

In order to review recent developments in this rapidly evolving field, the IPRC hosted an American Geophysical Union (AGU) Chapman Conference on *Atmospheric Gravity Waves and their Effects on General Circulation and Climate*, which was held February 28–March 4.

The meeting was organized by Northwest Research Associates Senior Research Scientist **Joan Alexander**, University of Tokyo Professor **Kaoru Sato**, and IPRC Director **Kevin Hamilton**, and it attracted over 90 participants from around the world. The meeting was held at the East-West Center's Imin Conference Center and was cosponsored by the National Science Foundation, the World Climate Research Programme (WCRP), the



Program organizers **Kaoru Sato**, **Kevin Hamilton**, and **Joan Alexander**.

WCRP Stratospheric Processes and their Role in Climate (SPARC) project, the University of Tokyo School of Science, the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) and the International Commission on the Middle Atmosphere (ICMA). The program and files with the presentation slides and posters from the conference are at [http://iprc.soest.hawaii.edu/meetings/workshops/11\\_02\\_Chapman\\_Conference](http://iprc.soest.hawaii.edu/meetings/workshops/11_02_Chapman_Conference).



Scientists at the Atmospheric Gravity Waves and their Effects on Global Circulation Conference.