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Cover Story: **Global Projections of Tropical Cyclone Activity for the Late 21st Century from Dynamical Downscaling of Global Warming Scenarios**

FALL 2015

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Global Projections of Tropical Cyclone Activity for the Late 21st Century from Dynamical Downscaling of Global Warming Scenarios

Robert Tuleya

When global warming effects were first hypothesized a few decades ago, one of the first effects envisioned was that tropical cyclones were going to have a dramatic increase in both frequency and intensity due to their strong observed relationship with sea surface temperature (SST). Atmospheric models were looked at with suspicion in simulating global warming scenarios by skeptics. Ironically, those same models now indicate that tropical cyclone behavior in globally warmed scenarios is not straight-forward. Most modeling studies now indicate that overall there will be significant decreases in tropical cyclone frequency and a possible small increase (~5%) in intensity of intense storms.

Since coming to CCPO as a visiting NOAA scientist, I've continued my strong collaboration with my GFDL/NOAA colleagues including Tom Knutson, the leader of GFDL's Climate Impacts group, to further pinpoint the evolution of tropical cyclones in global warming scenarios. My main contribution is that of designing downscaling experiments with the GFDL hurricane model from global (re)analyses, GCM models, or coarse regional basin models. A paper in *Science* was a result of one such effort where this was accomplished for the Atlantic basin and results showed stronger but less frequent storms. My current work is an extension of

this research to other tropical cyclone basins throughout the world. As mentioned, this work is a broad collaborative effort including scientists at GFDL/NOAA as well as scientists from Princeton University, University of Rhode Island, and the University of Iowa. This current work in a more thorough extent will be published in the *Journal of Climate*.

Using a downscaling framework and the GFDL Hurricane Model, we have improved the intensity distributions of tropical cyclones compared to the host HiRAM model. The HiRAM C180 global atmospheric model provides a fairly realistic tropical cyclone genesis distribution as the initial step in the downscaling but fails to capture tropical cyclones with winds of Category 4 and 5 intensity which we believe is important for late 21st century climate change projection studies. In this framework, all incipient storms of the HiRAM model are taken as initial conditions for five-day simulations using the GFDL Hurricane Model. The inclusion of ocean provides an important additional physical process that is not included in most other climate impact studies. Moreover, this framework reproduces fairly well both the observed global distribution of storm intensity and outer storm size and their inter-basin variability (see Figure 1). (*Cont'd. on page 2*)

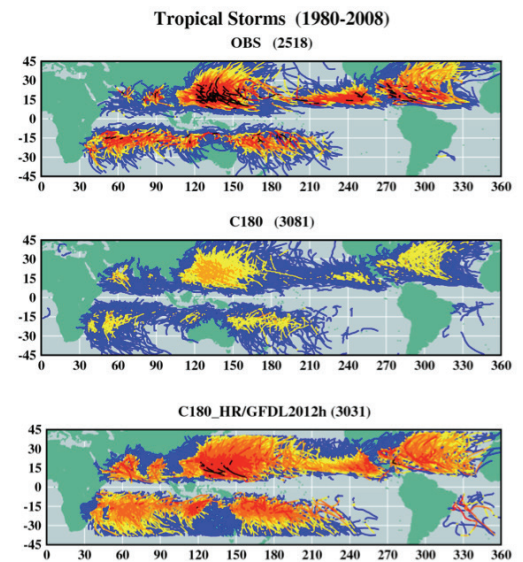


Fig. 1. a) Tracks of observed tropical cyclones for the years 1980–2006. b) Simulated tropical cyclone tracks for 1980–2006 obtained using the HiRAM C180 global atmospheric model running over observed SSTs. c) Simulated tropical cyclone tracks obtained using the GFDL Hurricane model to re-simulate tropical cyclone cases at higher resolution. These cases in (c) used the HiRAM C180 simulation to provide initial conditions and boundary conditions for the individual storm cases to the higher resolution model. Storm categories on the Saffir-Simpson scale are depicted by the track colors, varying from tropical storm (blue) to Category 5 (black; see legend).

Letter from the Director

Diversity is an important characteristic of our organization. Based on the articles in this newsletter, CCPO displays diversity in subjects being considered. While the core of our original focus was coastal physical oceanography, the center has always been interested in applying its quantitative skills to other topics such as climate change, tropical cyclone dynamics, sea level changes, high latitude environments, biological models, and diseases of marine organisms. This expansion requires us to be open to diverse perspectives, form new ideas and further develop our techniques.

We are also engaged in teaching the next generation of ocean scientists. This involves working with graduate students, mostly, but we also engage the attention of enthusiastic undergraduate students who pursue summer projects as part of the NSF-funded Research Experience for Undergraduates (REU) program. We host undergraduate students every year and each group brings diverse educational backgrounds to apply to their projects. We hope you will benefit from the diversity of activities at CCPO.

Global Projections of Tropical Cyclone Activity for the Late 21st Century from Dynamical Downscaling of Global Warming Scenarios (*Cont'd.*)

The dynamical downscaling framework then provides a scenario-based assessment, including for very intense tropical cyclones, of changes in tropical cyclone frequency, precipitation, size, and intensity characteristics, in response to the large-scale climate change (late 21st century) projection as simulated by a CMIP5 13-model ensemble using the RCP4.5 scenario.

Salient features of the projected changes include a substantial reduction in global tropical storm frequency (-16%) (See Figure 2), but an increase in the frequency of the most intense storms (+24% for Category 4-5 and +59% for tropical cyclones with maximum winds exceeding 65 m s⁻¹; see Figure 3). This is consistent with the results from earlier downscaled studies using the GFDL Hurricane Model that were confined to only the Atlantic basin (Bender et al., 2010). There is a larger fractional increase in the number of Category 4-5 days (+35%) compared to their frequency increase. Global averaged intensity of tropical storms and hurricanes increased by about 4%. Global aggregate activity measures (ACE and PDI, i.e., accumulative cyclone energy and potential destruction index) show decreases of -13% and -10%, indicating the dominating influence of the overall tropical cyclone frequency reduction over the influence of increased average intensity. Projected median storm size is found to remain nearly constant globally. One important caveat here the PDI does not include the critical impact of sea level rise in increasing coastal destruction for landfalling storms. (*Cont'd. on page 3*)

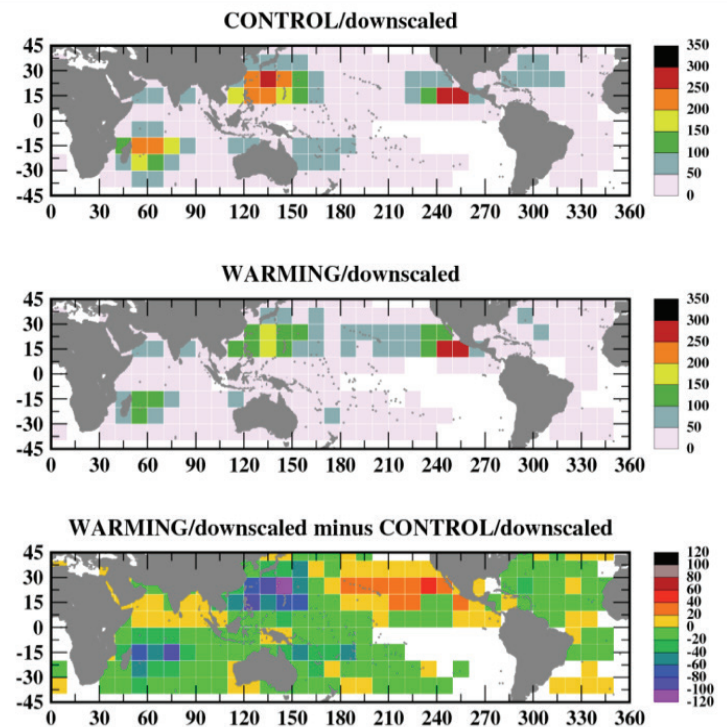


Fig. 2. Simulated occurrence of all tropical storms (tropical cyclones with winds exceeding 17 m s⁻¹) for: a) present day or b) late 21st century (RCP4.5; CMIP5 multimodel ensemble) conditions. Occurrence refers to the number of days, over a 20-year period, in which a storm of at least 17 m s⁻¹ intensity was centered within the 10x10o grid region. c) Difference in occurrence rate between late 21st century and present day, ((b) minus (a)). White regions are regions where no tropical storms occurred in the simulations (a,b) or where the difference between control and warming is zero (c).

Global Projections of Tropical Cyclone Activity for the Late 21st Century from Dynamical Downscaling of Global Warming Scenarios (Cont'd. from page 2)

In terms of regional distribution, the increase in Category 4-5 occurrence is fairly widespread in the northern hemisphere basins, with largest increase in tropical cyclone activity in the central North Pacific, including in the vicinity of Hawaii, which is qualitatively similar to that reported in previous studies (Murakami et al., 2013). In contrast, there is decreased occurrence in some regions—especially the Southwest Pacific and eastern Indian Ocean basins. Projected median storm size increases in most basins, but this is offset by a decrease in the West Pacific, resulting in only a slight increase (+1%) globally. Notable increases occur in the East Pacific (+15%) and North Atlantic basins (+11%) in these simulations. In addition, the tropical cyclone precipitation results indicate with a pronounced increase (~13% for the rainiest storms) in the warmer climate, are consistent with earlier studies (e.g., Knutson et al., 2010; 2013; Villarini et al., 2014). A physical mechanism suggested by the results is that enhanced tropospheric water vapor in the warmer climate enhances moisture convergence and thus rainfall rates, but that in a basin where the average intensity of tropical cyclones decreases, the reduced circulation intensity can offset the higher water vapor content and even produce a small decrease in tropical cyclone precipitation rates in that basin.

The projected tropical cyclone metric changes vary by basin, with the inter-basin spread being explained to a large extent by variation between the regions in the magnitude of SST change. Most other metrics, including PDI, have a substantial correlation with the basin-wide SST changes, ranging from 0.64 to 0.9. This finding highlights the importance of reliable projections of the inter-basin variations or patterns of future SST change from climate models, in addition to the overall tropical mean magnitude of the warming, for future tropical cyclone changes. Future research will continue to address the issue of

robustness of projections to the use of different downscaling frameworks such as Emanuel (2013). Nonetheless, our results suggest that narrowing uncertainties of the large-scale climate change inputs to the downscaling frameworks (e.g., SST change patterns) is an important research task for reducing uncertainty in future tropical cyclone projections worldwide.

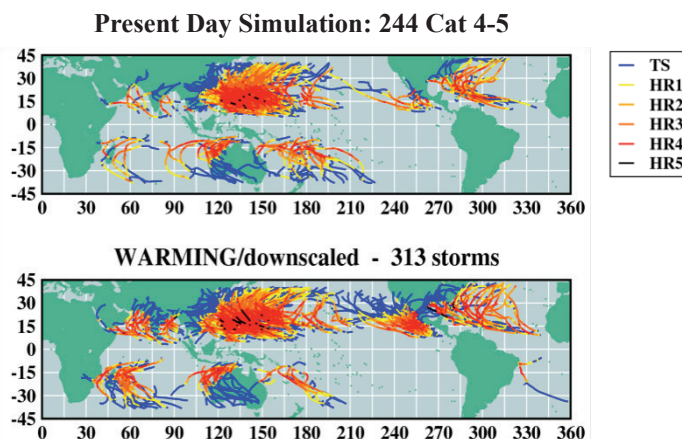


Fig. 3. Cat 4-5 tracks. Tracks of simulated Category 4 & 5 tropical cyclones for: a) present day or b) late 21st century (RCP4.5; CMIP5 multimodel ensemble) conditions. Simulated tropical cyclone tracks were obtained using the GFDL Hurricane Model to re-simulate (at higher resolution) the tropical cyclone cases originally obtained from the HiRAM C180 global model. Storm categories or intensities are shown over the lifetime of each storm, according to the Saffir-Simpson scale. The categories are depicted by the track colors, varying from tropical storm (blue) to Category 5 (black; see legend).

ohjustswimmingly.com

Just Swimmingly: Top 3 Blog Posts of Summer

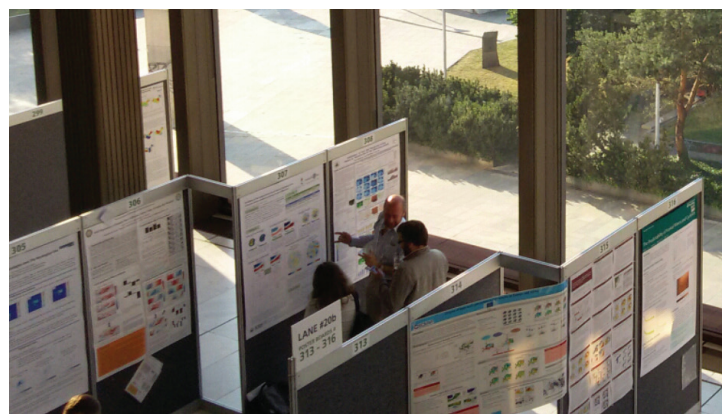
Stefanie Mack Presents: Tales of grad student life in oceanography. A mix of science and survival skills.

Science in Prague I & II:

Over the summer I had the chance to attend an international meeting on earth science in Prague, Czech Republic. My experience was very positive, and I've recorded some of my adventures and thoughts about the conference.

Mixed Layer Depth:

The concept of mixed layer depth is key for understanding the surface layer of the ocean that is in direct contact with the atmosphere. While the idea is simple, the depth at which all water above is well mixed; defining mixed layer depth analytically is not so straightforward. There are many options for which formula and criteria to use, and while I found the one that works best for my research, it is not necessarily the best for every application.



Poster session at the Prague Conference Center

Read the full blogs at
ohjustswimmingly.com

RCN Marine Disease Modeling and Transmission Workshop

Dr. Eileen Hofmann

In May, CCPO hosted the fourth in a series of workshops that are part of a NSF-funded Research Coordination Network (RCN) project focused on evaluating the effects of a changing ocean on the management and ecology of infectious marine diseases. The workshop, organized by CCPO professor Eileen Hofmann and Eric Powell, professor, University of Southern Mississippi, was designed to evaluate and implement approaches for modeling marine disease, with emphasis on disease transmission processes.

The plenary presentations provided overviews of the current understanding of marine disease processes, transmission dynamics, the genetics of disease resistance, and the social and management implications of marine diseases. Prior to the workshop, a suite of models was developed that describe interactions between a host population, a pathogen, disease transmission, and environmental conditions. Workshop participants learned to implement the models using data sets that were developed from studies of withering syndrome in several abalone species. An important product from the workshop is the availability of models that can be adapted to consider dynamics of many other marine host-pathogen systems.

The workshop participants ranged from senior researchers to early career scientists, to REU undergraduate student interns from the University of Southern Mississippi. Social events, one of which included sampling of Chesapeake Bay oysters (provided by R. Carnegie and S. Ford), provided opportunities for informal interactions among all participants. More information about the workshop is available at <http://www.ccpo.odu.edu/RCNworkshop2015/>



Participants in the RCN workshop on marine disease modeling and transmission

Summer '15 CCPO REU Experience

Miasia Osbey, Editor

Katherine Filippino, OEAS research assistant and REU director, served along with Dr. Rodger Harvey, OEAS chair, as co-principal investigators for this summer's Research Experience for Undergraduates (REU) program funded by the National Science Foundation (NSF). This year, the students focused on climate change and sea level rise. The Department of Ocean, Earth and Atmospheric Sciences selected 10 students through a competitive application process. The Center for Coastal Physical Oceanography (CCPO) and the Mitigation and Adaptation Research Institute (MARI) hosted three students.

These students focused specifically on sea level changes: local Virginia change, global change and Antarctic glacial melt. Our students, Zachary Wolff, Jin-Si Over and Sara Doermann, came from various universities along the East Coast of the U.S. in which their localities are constantly affected by sea level changes, much like Norfolk, Va.

Each student is expected to participate in REU program group activities, but are also expected to remain active and engaged with their research and faculty mentors.

The REU students shared research space with current CCPO and MARI students: **Stefanie Mack**, **Praveen Kumar** and **Brett Buzanaga**. Stefanie and Praveen are both in the oceanography Ph.D. program and Brett is pursuing his master's in oceanography. Sharing the graduate research space gave the REU students a sneak peek of life in graduate school. Check out the REU Spotlight profiles to learn more about the students and their CCPO/MARI research.

A Summer of Fun & Research



Photo Credit: Jin-Si Over



CCPO REU Spotlight Jin-Si Over

Jin-Si will be a junior this fall at UNC at Wilmington and she has a passion for unicycling. She is interested in studying the dynamics of climate change and coastal evolution in the past and present.

Her REU mentor for the summer was **Dr. Hans-Peter Plag**. “Contribution of sea surface height changes and subsidence

to local sea level changes at the U.S. east and west coasts” was her summer research topic. Jin-Si integrated GPS, tide gauge, and satellite altimetry data in order to examine local sea level changes. The study also investigated the need to co-locate GPS and TG stations for more accurate measurements. A local finding for the Hampton Roads area was that about half of the local sea level change is due to subsidence, which is a major contribution to the observed larger-than-average sea level rise.



CCPO REU Spotlight Zachary Wolff

Zachary Wolff is a senior at Penn State University studying meteorology with a focus on atmospheric science. Zachary conducted research under the direction of

Dr. John Klinck, focusing on mesoscale eddies in the Ross Sea. This project is part of an ongoing research project to better understand the mesoscale processes in the Ross Sea.

This summer Zachary worked with Python to find the length scale of the eddies as determined by observations provided by a research cruise Dr. Klinck took in 2012. Zachary then compared the length scales calculated from the observations to those produced by a numerical model for the Ross Sea. The results showed that the observations and the model were similar, providing evidence that the model is an accurate representation of these processes. Zachary plans to present this research at a conference in the near future.



CCPO REU Spotlight Sara Doermann

Sara Doermann joined CCPO this summer through the REU program under the mentorship of **Dr. Ben Hamlington**. Sara is a senior at the University of South Carolina studying in the bachelors program for marine science. She has always

been greatly interested in the mechanics of the ocean in all regards and wanted to learn more about sea level change in relationship to global climate change.

She originally hails from Mechanicsville Iowa, a small rural community, where she grew up living on a farm. After obtaining her bachelors degree she will further her education in a graduate program.

Sara, with the guidance of Dr. Hamlington, focused on finding the global mean sea level (GMSL) through quantitative steps involving clustering of the tide gauges data set. Clustering was based on a function of geographical distance and correlation. Her results will be used in further calculation of the anthropogenic effect on sea level rise as well as attributing to present calculations of sea level trend.

Just the Facts

CCPO Faculty & Student Publications, Presentations, Awards & Recognition

Publications

Dinniman, M.S., J.M. Klinck, L-S Bai, D.H. Bromwich, K.M. Hines and D.M. Holland, 2015. The effect of atmospheric forcing resolution on delivery of ocean heat to the Antarctic floating ice shelves. *Journal of Climate*, 28, 6076-6085, doi:10.1175/JCLI-D-14-00374.1.

Feng, Y., M.A.M. Friedrichs, J. Wilkin, H. Tian, Q. Yang, **E.E. Hofmann**, J.D. Wiggert, R. R. Hood, 2015, Chesapeake Bay nitrogen fluxes derived from a land-estuarine ocean biogeochemical modeling system: Model description, evaluation and nitrogen budgets, *Journal of Geophysical Research – Biogeosciences*, DOI: 10.1002/2015JG002931.

Flynn, K. J., M. St John, J.A. Raven, D.O. Skibinski, J.I. Allen, A. Mitra, A., **E.E. Hofmann**, 2015, Acclimation, adaptation, traits and trade-offs in plankton functional type models: reconciling terminology for biology and modelling. *Journal of Plankton Research*, fbv036.

Knutson, Thomas R., Joseph J. Sirutis, Ming Zhao, **Robert E. Tuleya**, Morris A. Bender, Gabriel A. Vecchi, G. Villarini, and D. Chavas, in press: Global projections of intense tropical cyclone activity for the late 21st century from dynamical downscaling of CMIP5/RCP4.5 scenarios. *Journal of Climate*. DOI:10.1175/JCLI-D-15-0129.1. 7/15.

Munroe, D.M., E.N. Powell, S.E. Ford, **E.E. Hofmann, J.M. Klinck**, 2015, Outcomes of asymmetric selection pressure and larval dispersal on evolution of disease resistance: a metapopulation modeling study with oysters, *Marine Ecology Progress Series*, 531:221-239, doi:10.3354/meps11349.

Powell, E.N., **E.E. Hofmann**, 2015, Models of marine molluscan diseases: trends and challenges, *Journal Invertebrate Pathology*, doi:10.1016/j.jip.2015.07.017.

Powell, E.N., **J.M. Klinck**, D.M. Munroe, **E.E. Hofmann**, P. Moreno, R. Mann, 2015, The value of captains' behavioral choices in the success of the surfclam (*Spisula solidissima*) fishery on the US Mid-Atlantic coast: a model evaluation, *Journal Northwest Atlantic Fisheries Science*, 47:1-27.

Queste, B.Y., K.J. Heywood, W.O. Smith, Jr., D.E. Kaufman, T.D. Jickells and **M.S. Dinniman**, 2015. Dissolved oxygen dynamics during a phytoplankton bloom in the Ross Sea polynya. *Antarctic Science*, 27, 362-372, doi:10.1017/S0954102014000881.

Presentations

Graham, J., **J. Klinck** and **M. Dinniman**, "Modelling on-shelf ocean heat transport along the West Antarctic Peninsula." 2015 International Glaciological Society Meeting, Cambridge, UK, August 2015.

Gwyther, D., E. Cougnon, B. Galton-Fenzi, **M. Dinniman**, J. Roberts and J. Hunter, "Using idealized models to explore uncertainties in ice-shelf-ocean interaction." 2015 International Glaciological Society Meeting, Cambridge, UK, August 2015.

Hofmann, E.E., Host-pathogen proliferation models, RCN Marine Disease Modeling and Transmission Workshop, CCPO, Norfolk, VA, May 11-15, 2015.

Hofmann, E.E., IMBER and Future Earth, OCB Summer Workshop, Woods Hole Oceanographic Institution, Woods Hole, MA, July 20-23, 2015.

Mack, S., M. Dinniman, J. Klinck, Effect of tides and eddies on Ross Ice Shelf basal melt from a regional ocean model. Poster presentation, 26th IUGG General Assembly, Prague, Czech Republic, June 22-July 2, 2015.

St-Laurent, P., M.A.M. Friedrichs, R.G. Najjar, and M. Herrmann, "Comparing the impact of atmospheric nitrogen deposition and wind mixing on biological productivity during storm events." 2015 Ocean Carbon and Biogeochemistry Summer Science Workshop, Woods Hole, MA, July 2015.

Research Funding

St-Laurent, P., E.E. Hofmann, and D. Dickerson, NSF OPP, PLR-1443657, "Investigating the role of mesoscale processes and ice dynamics in carbon and iron fluxes in a changing Amundsen Sea (INSPIRE)," \$154,951, July 15, 2015-June 30, 2017.

Conference Committee Appointment

T.B. Gatski, Organizing Committee, Turbulence, Heat and Mass Transfer (THMT), Sarajevo, Bosnia Herzegovina, September 15-18, 2015.

The Center for Coastal Physical Oceanography &
The Mitigation & Adaptation Research Institute Present:

Fall 2015 Seminar Series

Join us on Mondays at 3 p.m. for a reception prior to the 3:30 p.m. seminar to hear expert speakers address topics focused on aspects of our changing climate.

September 14

Malcolm Bowman
Stony Brook University

September 21

Patricia Yager
University of Georgia

September 28

James Maughan
CH2M Hill, University of
Massachusetts and U.S. Department
of Transportation

October 5

Ryan Carnegie
Virginia Institute of Marine Science

October 19

Carolyn Currin
NOAA/NCCOS Center for
Coastal Fisheries & Habitat

October 26

Sandra Fatorić
North Carolina State University

November 2

Johanna Rosman
Institute of Marine Sciences
University of North Carolina

November 9

Melissa Kenney
University of Maryland

November 16

Robert Condon
University of North
Carolina at Wilmington

November 23

Mike Dinniman
CCPO

November 30

James Haluska
CCPO

For additional info,
contact Julie Morgan
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For abstracts and biographies, visit ccpo.odu.edu/seminars

Photo Credit: Teresa Updyke

Antarctic research opens collaboration between Chilean scientists and CCPO

Dr. Andrea Piñones, CCPO Graduate '11

CONICYT, the Chilean funding agency for science and technology, has recently announced the creation of a new FONDAP (priority areas funds) research center that will focus on Antarctic and sub-Antarctic science. The new “Research Center: Dynamics of High Latitude Marine Ecosystems” (IDEAL acronym in Spanish for Centro de Investigación: Dinámica de Ecosistemas Marinos de Altas Latitudes) is a synergistic, multidisciplinary and highly integrated proposal with attention on the biogeochemical processes and species-specific adaptation linked to global change and ecosystem services. The IDEAL center will be hosted

by the Universidad Austral de Chile, with administrative and operational headquarters in Valdivia and Punta Arenas, respectively.

The proposal will address four main research topics: 1. connectivity between the Chilean Southern Patagonia and the Antarctic Peninsula; 2. biological interactions modulated by environmental stress in Antarctic and sub-Antarctic systems; 3. impact of global changes at species-specific (ecophysiology of key benthic and planktonic species) up to community (pelagic and benthic) levels; and 4. the human dimension of the ecosystem

services. IDEAL has a strong modeling component that will bring collaboration between Chilean scientists and researchers at CCPO, specifically **Eileen Hofmann**, **John Klinck**, and **Mike Dinniman**. This will be a great opportunity for students and young researchers interested in Antarctic science.

For the official press release, visit: <http://www.conicyt.cl/fondap/2015/08/20/2165/>



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