NOAA AOML QUADRENNIAL REVIEW

March 18-20, 2008

Charge to Reviewers: Review of Presented Projects

Physical Oceanography Division

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The Meridional Overturning Circulation
M. Baringer

Studies at AOML related to the meridional overturning circulation (MOC) have focused on understanding the physical processes and mechanisms that control the pathways, water mass transformation and interocean, interhemispheric exchanges of the MOC.

Significant Accomplishments, recent advances, findings, results:

- IPCC models predict a decrease in the MOC associated with increases in atmospheric CO2 concentrations leading to reduced warming over the North Atlantic Ocean and important regional changes in precipitation patterns.
- Development of an integrated, comprehensive MOC observing system for the ocean
- Discovery of the large variability in the MOC strength influenced by multiple processes including deep water production, open ocean wind stress and wind stress curl and dynamics internal to the ocean (e.g. ring shedding).

Relevance to NOAA Strategic plan and Mission Goals

- NOAA Strategic Planning element to "Examine the whole of the ocean as a reservoir of both heat and carbon dioxide to address a major source of uncertainty in climate models."
- NOAA Strategic Planning element to "Enhance global observing and data systems required to provide data for the initialization and validation of model predictions of seasonal to interannual climate variations."
- Climate Mission Goal (GRPA): Increased number of Ocean Climate Variables Reported in the Annual State of the Climate Report (BAMS) (Cumulative total number reported)
- Climate Mission Goal (NPRO): Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship
- Climate Mission Goal (NPRO): Improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions.
- Climate Mission Goal (NPRO): Reduce uncertainty in climate projections through timely information on the forcing and feedbacks contributing to changes in the Earth's climate.
- Climate Mission Goal (GPRA): Reduce the Error in Global Measurement of Sea Surface Temperature

Societal Relevance:

- The recent interagency Ocean Priorities Plan has identified better understanding of the Atlantic Meridional Overturning Circulation (AMOC) as a key short-term priority because many climate models have shown that large-scale rapid climate change may be associated with a change in the AMOC. Rapid climate change is likely to have vast impacts on coastal property values (sea-level rise), agricultural futures and other economic areas. Data collect at AOML are needed to improve climate models and predict any future changes in the global climate system.

New Technology

- MOC related cruises conducted at AOML have been providing a test-bed for several years in the development of better processing techniques for Acoustic Doppler Current Profiler (ADCP) data, in both the lowered and hull-mounted designs, and these

development activities are continuing. These cruises are also being used for the development of the next generation of ocean dropsonde floats and for design testing of a quasi-real-time data transmission system for subsurface moored instruments.

Challenges:

- Improving technologies to reduce dependence on ever dwindling open ocean ship resources.

Evidence of collaboration:

- The MOC observing system and the Western Boundary Time Series Program are part of an international collaborative study negotiated between the funding agencies of the United Kingdom, Germany, and the USA seeking to monitor the complete meridional overturning circulation in the Atlantic. In the South Atlantic AOML is collaborating with South Africa, France, and Argentina in conducting a zonal line to measure meridional heat transport. Jointly AOML is plannig monitoring sites for the SAMOC

Contributions of data to national and GEOSS-related data bases:

- All MOC related data collected by AOML is available in near real-time (e.g. Florida Current transport) and submitted in delayed mode to NODC. The 26N MOC data is just starting to be assimilated in the MIT/ECCO numerical models and demonstrates improvement to the model through extended regions. AOML published quarterly reports on the State of the Ocean, meridional heat transport in the North and South Atlantic.

Who would miss this work if not done?

- This would impair an interagency project funded by NOAA/OGP Office of Climate Observations, the National Science Foundation/Ocean Sciences and the United Kingdom's Rapid Watch Program, adversely impact research partners from several major U.S. and U.K. oceanographic institutions, interrupt time series measurements and eliminate the first complete observational time series of the strength of the MOC.
- Failing of this program would limit NOAA's response to the interagency Ocean Priorities Plan, specifically the response to improve understanding of the Atlantic Meridional Overturning Circulation, one of the four key short-term priorities identified in the Ocean Priorities Plan.

Outstanding Papers:

- Enfield, D. B., S.-K. Lee and C. Wang 2008: Differential ocean warming linked to a weakened Atlantic overturning circulation may lead to decreased Atlantic hurricane activity, submitted to Geophysical Research Letters.
- Kanzow, T, S. A. Cunningham, D. Rayner, J. J-M. Hirschi, W.E. Johns, M. O. Baringer, H. L. Bryden, L. M. Beal, C. S. Meinen, J. Marotzke, 2007. Observed flow compensation associated with the meridional overturning circulation near 26.5ºN in the Atlantic. *Science*, 17 August 2007 317: 938-941 [DOI: 10.1126/science.1141293].
- Cunninghman, S. A., T. Kanzow, D. Rayner, M. O. Baringer, W. E. Johns, J. Marotzke, H. R. Longworth, E. M. Grant, J. J-M. Hirschi, L. M. Beal, C. S. Meinen and H. L. Bryden, 2007. Temporal Variability of the Atlantic Meridional Overturning Circulation at 26.5ºN. *Science*, 17 August 2007 312: 335-938 [DOI: 10.1126/science.1141304].

- Baringer, Molly O. and Silvia L. Garzoli, 2007. Meridional Heat Transport using Expendable Bathythermographs. Part I: Error Estimates from model and hydrographic data, *Deep Sea Research, (Part 1),* DOI information doi:10.1016/j/dsr.2007.03.011
- Garzoli, Silvia L. and Molly O. Baringer, 2007. Meridional Heat Transport using Expandable Bathythermographs Part II: South Atlantic Transport. *Deep Sea Research (Part 1),* DOI information doi:10.1016/j.dsr.2007.04.013.
- Lumpkin, R., K. Speer and K. P. Koltermann, 2008: Transport across 48ºN in the Atlantic Ocean. *J. Phys. Oceanogr*., **38** (4), 733—752.
- Lumpkin, R. and K. Speer, 2007: Global Ocean Meridional Overturning. *J. Phys. Oceanogr.,* **37** (10), 2550-2562.
- Lumpkin and Speer, 2003. Large-scale Vertical and Horizontal Circulation in the North Atlantic Ocean. *J. Phys. Oceanogr*., **33** (9), 1902-1920.
- Baringer, M. O. and C. S. Meinen, 2007. Thermohaline Circulation *in* Supplement to State of the Climate in 2006, A.Arguez, ed., *Bulletin of the American Meteorological Society:* Vol. 88, No. 6, pp. s1–s135, doi: 10.1175/BAMS-88-6-StateoftheClimate.
- Meinen, C. S., M. O. Baringer and S. L. Garzoli, 2006. Variability in Deep Western Boundary Current transports: Preliminary results from 26.5°N in the Atlantic, *Geophysical Res. Letters*, 33, L17610, doi:10.1029/2006GL026965, 2006.

Large Scale Climate Research
David Enfield

Climate relationship involving the Atlantic Ocean and its effects on rainfall and hurricanes have resulted from 12 years of analysis of global climate data and experiments involving forced ocean and atmospheric GCMs.

Significant Accomplishments:
• Relationship of Atlantic Multidecadal Oscillation to rainfall and hurricanes in the Western Hemisphere
• Showed how tropical Atlantic variability combines with Pacific SST to affect rainfall
• Demonstrated the large interannual variability of the Western Hemisphere warm pool (WHWP)
• Showed how WHWP has affected rainfall and hurricanes using data and models
• Provided the basis for science & implementation plan for future research on the Intra-Americas Sea and climate
• Provide climate mentoring and guidance for Florida water managers
• Most recently, help to clarify the relationship of global warming to Atlantic hurricane activity

Relevance to NOAA Strategic plan: Supports NOAA's climate goal by laying a framework for future research that promises to improve the ability of climate models to predict summer rainfall and hurricane activity for the Western Hemisphere.

Evidence of collaboration: David Enfield has been the lead author for the IASCLIP science and implementation plan for the IASCLIP program, a multi-year American Monsoons (CLIVAR-VAMOS) climate program that will begin in FY09. Dr. Enfield is a member of the VAMOS Science Steering Panel. Dr. Enfield has made many trips to water management districts to give talks and collaborate with water engineers, and co-authoring a publication with them. The South Florida Water Management District now uses these climate relationships in their 20-year operating plans, which they are required by Florida statute to update every 5 years.

Decision support tools for water managers: We have published a method for estimating the conditional probability of a future (AMO) climate regime shift within a given time frame. This is valuable for stakeholders with long time horizons, such as water managers and insurance actuaries.

Who would miss this work if not done? Without the research that we have done on the AMO and the warm pool, it would have been much more difficult to craft a science and implementation plan for IASCLIP, the American Monsoons (CLIVAR-VAMOS) experiment on the climate of the Intra-Americas Sea that is programmed for execution in FY09-FY14 with support from the NOAA Climate Programs Office. It is very likely that IASCLIP could not have mustered sufficient interest or gone on to the programming stage without this groundwork. Moreover, the collaboration with and climate mentoring of Florida water managers, and the design of decision support tools for them, could not have materialized.

Outstanding Papers
Over the 1997-2008 period, at least 25 peer-reviewed papers have been published on Atlantic climate variability and warm pool research. These papers have garnered hundreds of citations.

Climate and Atlantic Hurricane Activity
C. Wang

The climate-hurricane research is to investigate how and why climate changes on various timescales affect Atlantic hurricane activity and to thus improve NOAA's hurricane outlook program.

Significant Accomplishments:

- Global warming could reduce U.S. landfalling hurricanes.
- Whether future global warming increases Atlantic hurricane activity will depend on relative warming role of the three tropical oceans.
- The influence of the Atlantic multidecadal oscillation on Atlantic hurricane activity is to operate through the mechanism of the Atlantic warm pool-induced atmospheric changes.
- The Atlantic warm pool reduces vertical wind shear in the hurricane main development region and increases the moist static instability of the troposphere, both of which favor Atlantic hurricane activity.
- The Saharan air layer can act to suppress tropical cyclone intensity.

Relevance to NOAA Strategic plan:
The climate-hurricane research supports the Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond by advancing our understanding of the relationships between climate and hurricanes and hurricane outlooks.

Societal Relevance:
Research results can be transitioned into NOAA's hurricane outlook program. Improvements of the understanding and predicting of U.S. landfalling hurricanes will directly benefit American people.

Who would miss this work if not done?
Without the research that we are currently doing on the climate-hurricane, our understanding of the influences of the Atlantic warm pool and Atlantic multidecadal oscillation could not be matured. Our continuous efforts to better understand the climate-hurricane connectivity is essential for improving NOAA's hurricane outlook capability on seasonal to multidecadal time scales.

Outstanding Papers:
Wang, C., and S.-K. Lee, 2008: Global warming and United States landfalling hurricanes. *Geophys. Res. Lett.*, **35**, L02708, doi:10.1029/2007GL032396.

Wang, C., S.-K. Lee, and D. B. Enfield, 2008: Climate response to anomalously large and small Atlantic warm pools during the summer. *J. Climate*, **21**, in press.

Wang, C., D. B. Enfield, S.-K. Lee, and C. W. Landsea, 2006: Influences of the Atlantic warm pool on Western Hemisphere summer rainfall and Atlantic hurricanes. *J. Climate*, **19**, 3011-3028.

Global ocean trends and variability
G. Goni

Studies carried out at AOML and CIMAS on the investigation of trends in sea surface height (SH), sea surface temperature (SST), eddy kinetic energy (EKE) and surface winds during 1993-2006 are focused to understand the spatial variability of the global trends and their implication in regional and basin upper ocean dynamics.

Significant Accomplishments, recent advances, findings, results:

- The trends in SST, SH and EKE are highly variable.
- Trends of SSTs in the northern hemisphere are positive, while negative in the southern hemisphere.
- Trends of SH are positive in both hemisphere
- Trends in EKE indicate a change in position and/or intensity of major currents.
- The South Atlantic subtropical gyre has experienced a continuous expansion to the South and East, and its mean temperature has increased in the upper 1000 m.
- The separation of the Brazil Current from the continental shelf has shifted approximately 200 km to the south during the last 13 years.

Relevance to NOAA Strategic plan and Mission Goals

- NOAA Strategic Planning element to "Examine the whole of the ocean as a reservoir of both heat and carbon dioxide to address a major source of uncertainty in climate models."
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Societal Relevance:

- Changes in the location and intensity of major surface currents are critical to investigate interocean and interbasin mass and heat exchanges, key components of the MOC.
- Climate models have indicated that large-scale rapid climate changes may be associated to changes in the MOC.

New Technology

- Development of new techniques to jointly analyze in situ and satellite observations.

Challenges:

- Keep satellite missions going, in particular altimetry eddy resolving missions able to resolve mesoscale signals.

Evidence of collaboration:

- This work is a collaboration between AOML and University of Miami scientists.

Contributions of data to national and GEOSS-related data bases:

- Results obtained from this work are posted on the web.

Who would miss this work if not done?

- Climate models need to be validated using results such as the ones obtained from this research.
- Global estimates usually neglect regional changes, such as the ones obtained in this research, and that may be indicative of large variability in surface currents.

Outstanding Papers:

- Investigation of the variability of the North Brazil Current retroflection and North Equatorial Countercurrent, C. Fonseca, G. Goni, W. Johns and E. Campos, Geophys. Res. Let, vol 31, L21204, doi:10.1029/2004GL020901, 2004.
- Observed variability of the South Atlantic subtropical gyre, G. Goni, F. Bringas and P. DiNezio, *J. Geophys. Res*, 2008 (submitted).
- Global comparison of sea surface current fields derived from drifter observations and altimetry estimates, *J. Ocean and Atm. Tech.*, 2008 (in preparation).

Small Scale Ocean Processes and Climate
Rick Lumpkin

Proper representation of mesoscale processes is necessary for coupled, non-eddy-resolving models to reproduce the observed sea surface temperature distribution in the Tropical Atlantic, and thus to gain future forecasting skill in seasonal rainfall for the surrounding regions. Surface and subsurface observations in this region, particularly from floats, drifters, and the moored PIRATA array, can be used to calibrate satellite observations and to quantify the impact of mesoscale activity such as Tropical Instability Waves (TIWs). Observations from the new PIRATA Northeast Extension, a joint AOML/PMEL project, show that TIWs dominate intraseasonal fluctuations, and that strong interannual modulation of TIW activity may have significant implications for the lower frequency role of these waves in heat exchange between the Atlantic equatorial cold tongue and the Tropical North Atlantic. Upper ocean heat budgets at higher latitudes may also be strongly influenced by the time-mean role of eddy fluxes, for example along the northern edge of the Subantarctic Front where the upper limb of the meridional overturning circulation is closed by buoyancy gain and the associated formation of Southern Ocean mode waters. Observations from NOAA's Integrated Ocean Observing System, and in particular from the drifters, have recently become capable of resolving ocean stirring at scales from a few hundred meters to gyre scale. An ongoing analysis of these observations at AOML reveals behavior qualitatively different from predictions based on quasigeostrophic turbulence theory, potentially indicating the dominant role of submesoscale features in governing ocean stirring at scales of a kilometer to the local baroclinic Rossby radius. The global array of drifters shows the distribution of inertial and superinertial energy at the ocean surface, including the diurnal and semidiurnal tides; this energy input is a major source of interior ocean mixing that closes the lower limb of the MOC, and these observations will help us better understand the spatial and temporal variability of this energy input. AOML products based on these observations include gridded, monthly-mean current fields for research, ocean operations and educational purposes, and maps of effective eddy diffusivities that non-eddy-resolving models must reproduce if they are to accurately reproduce the effect of these subgridscale processes upon the large-scale fields.

Significant Accomplishments:
• Quantification of eddy heat fluxes linking the Atlantic cold tongue to the Tropical North Atlantic, and of air-sea flux variations associated with the migration of the Intertropical Convergence Zone.
• Mixed layer heat budget accounting in the Southern Ocean: large imbalances indicate regions where unresolved mesoscale variability may be significantly impacting the budget, with profound implications for the MOC buoyancy gain here.
• Atmospheric simulations quantifying the role of ocean mesoscale features on rainfall distributions.
• Quantification of oceanic stirring from the observed dispersion of drifters, including validation of effective diffusivities needed to simulate these effects in non-eddy-resolving models.
• Quantification of the spectral energy at subinertial, near-inertial and superinertial velocities from surface drifter data, revealing for the first time a global band of cyclonic energy at subinertial, sub-mesoscale; the distribution of inertial energy as a function of latitude and season; and the rotary spectral characteristics of the superinertial energy, consistent with internal gravity wave characteristics.

Relevance to NOAA Strategic plan: Supports NOAA's Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond, by providing observations and analysis that can validate eddy-resolving models, and assess eddy parameterization schemes for non-eddy-resolving models.

Evidence of collaboration: R. Lumpkin is on the PIRATA Science Steering group, helping to guide the Brazil/France/United States effort. Analysis of the PIRATA data is being conducted in collaboration with researchers at PMEL. Lumpkin manages the Global Drifter Program in collaboration with Scripps Institution of Oceanography, and numerous national and international partners who deploy the drifters. CLIMODE is a multi-institution project that includes Lumpkin as one PI. PhOD has also published papers in 2007—2008 in collaboration with researchers at University of Miami, Florida State University, Bundesamt fur Seeschiffahrt und Hydrographie (Germany), and IFREMER (France).

Contributions of data to national and GEOSS-related data bases: Drifter data is quality controlled and interpolated to regular intervals at AOML, and is distributed from AOML; these data are also archived at MEDS (Canada) and at the National Ocean Data Center. These data are used to calibrate satellite SST, and in the future will be a valuable contribution to calibrating satellite salinity.

Who would miss this work if not done? Hundreds of peer-reviewed research papers have included analysis of drifter data, and many more rely on the quality of satellite-based SST products that use these data. Many drifters are used as opportunistic platforms for barometers, and both the SST and air pressure measurements go onto the Global Telecommuncation System in real time and are the overwhelmingly dominant source of these data off the major shipping lanes for Numerical Weather Prediction. The logistics of maintaining the global drifter array, including deployments and shipping, is managed at AOML.

Outstanding Papers

Elipot, S. and R. Lumpkin 2008: Spectral description of oceanic near-surface variability. *Geophys. Res. Letters*, **35**, L05605, doi:10.1029/2007GL032874.

Griffa, A., R. Lumpkin and M. Veneziani, 2008: Cyclonic and anticyclonic motion in the upper ocean. *Geophys. Res. Letters*, 35, L01608, doi:10.1029/2007GL032100.

Dong, S**.**, S.T. Gille, and J. Sprintall, 2007: An assessment of the Southern Ocean mixed layer heat budget. *J. Climate*, 20(17):4425-4442.

Lumpkin, R. and M. Pazos, 2007: Measuring surface currents with Surface Velocity Program drifters: the instrument, its data, and some recent results. Chapter 2 of "Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics", ed. A. Griffa, A. D. Kirwan, A. Mariano, T. Özgökmen and T. Rossby, Cambridge University Press.

Lumpkin, R. and S. L. Garzoli, 2005: Near-surface circulation in the tropical Atlantic Ocean. *Deep-Sea Research, Part I,* **52**(3), 495-518.