U.S. CLIVAR
September 2008, Vol. 6, No. 2
VARIATIONS

Is It Me, or Did the Oceans Cool?

A Lesson on Global Warming from my Favorite Denier

Josh K. Willis
joshua.k.willis@jpl.nasa.gov
Jet Propulsion Laboratory
California Institute of Technology

Call me Embarrassed. Some years ago—never mind how long precisely—having little or no time left in my postdoc, I co-authored a paper with two colleagues that documented a rapid and recent cooling in the watery part of the world (Lyman et al., 2006). Our results were met with a certain amount of surprise and skepticism by the climate science community, but they caused a great deal of excitement among deniers of global warming.

The paper was eventually noticed by none other than Rush Limbaugh, the most famous conservative personality in all of American talk-radio. Rush pointed to our surprising result as proof that scientists had no idea what the climate would do. As he mulled over our paper on his nationwide radio show, he offered a number of juicy sound bites. In one of my favorites, he said that global warming was nothing more than "the musings of a few idiot leftist scientists." The experience was eye-opening, to say the least.

So you can imagine how I felt when I finally discovered that the result was wrong. After more scrutiny of the data, we eventually showed that the cooling was caused by a small warm bias in the old ocean observing system, along with a huge cold bias among a few instruments in the new one (Willis et al., 2008a). When the dust finally settled, rapid ocean cooling was gone (Figure 1). But one lesson stayed with me from our brush with Rush: oceanography isn't just for oceanographers anymore.

Now that humans have become a major force in the Earth's climate, it is of paramount importance to build and maintain observing systems that can keep track of our ever-increasing impact. The most sensitive yardstick of human influence on the climate is the rise in globally-averaged sea level. On climate-relevant time-scales, total sea level rise equals the sum of the melt water from glaciers and ice sheets, plus the thermal expansion of seawater caused by absorption of excess heat. The first effect represents the response of the ice to a warming atmosphere. The second is directly related to the balance of incoming and outgoing energy of the Earth as a whole. That's because 80 – 90% of the excess energy from anthropogenic forcing winds up warming the oceans (Levitus et al., 2005). But sea level rise has a more pedestrian importance too. Everyone who visits the beach would like to know: how fast is sea level rising? Between Rush Limbaugh, the beachgoers and other climate scientists, oceanographic data has a lot more customers these days than just oceanographers.

Given this newly realized importance, where does our ocean observing

Reaching out to the broader community

by David M. Legler, Director

The 2008 U.S. CLIVAR Summit can be best characterized by the interesting science presented during the opening symposium (What can we say about climate predictions for 2018?), reporting of the incredible productivity of our Working Groups, and the diligent efforts of our Panels to move community research planning and activities forward. With so many new scientific findings, ideas for new activities, and opportunities for leading the research community in addressing key research questions, our biggest challenge may be to find enough time and energy to act on everything we discussed!

One of our aims for the U.S. CLIVAR Working Groups is to engage the wider community in pursuit of a list of attainable objectives. All of our Working Groups have accomplished this through various means such as open workshops and Working Group publications. What we didn't expect, but have been simply delighted with, is that all of our Working Groups have established a community of scientists who not only succeeded in achieving their goals, but continue to work

Continued on Page Two

IN THIS ISSUE

Continued from Page One

together long after their Working Group formally ended. Members of the Salinity Working Group are currently working on designs for an Aquarius Salinity Mission validation experiment. The MJO Working Group is working with the prediction community for routine reporting of MJO diagnostics. There is even discussion of an MJO group to continue activities on an international level.

The U.S. Working Groups have also given rise to increased international interest and participation in relevant scientific activities. So much so that just recently we began discussions for internationally coordinated research activities targeting drought and its monitoring/prediction within WCRP. This internationalization is due in part to the interest generated through efforts of the Drought Working Group and the momentum U.S. CLIVAR has generated in implementing new drought-focused prediction/predictability research.

During the next four months we will be holding two important workshops: one on drought (see *Variations* V6N3) and the other on Western Boundary Currents and their role in climate (see V7N1). We anticipate these will provide the opportunity to further motivate continued research investment, gauge success of current efforts, identify research challenges, and suggest ways forward.

Variations

Published three times per year
U.S. CLIVAR Office
1717 Pennsylvania Ave., NW
Suite 250, Washington, DC 20006
(202) 419-3471
usco@usclivar.org

Staff: **Dr. David M. Legler**, *Editor*
Cathy Stephens,
Assistant Editor and Staff Writer

This newsletter is supported through contributions to the U.S. CLIVAR Office by NASA, NOAA—Climate Program Office, and NSF.

system stand? In fact, it has dramatically improved over the past decade. In situ measurements from Argo and the drifting buoy network, now complement satellite-based measurements of sea surface height, temperature, water mass and soon sea surface salinity. Despite recent improvements, however, the global ocean observing system is not complete or robust. Gaps remain, especially in our ability to observe changes in the deep oceans, and in maintaining absolute calibration of our observing system over time. Nevertheless, a central core of a climate-relevant ocean observing system is now in place. The next great challenge will be to maintain and calibrate it.

A few of the more prominent components of the global ocean observing system are discussed in the list below. Although it is by no means comprehensive, these components make up some of the most essential elements of the global ocean observing system in the context of our changing climate.

Argo

The global array of approximately 3000 autonomous profiling floats (Figure 2) now provides temperature and salinity observations for the upper 2000 meters of the global oceans (Roemmich and Gilson, 2008) . In addition, subsurface velocity observations from Argo are beginning to provide global estimates of the mid-depth circulation (Lebedev et al., 2007). Such an array is essential for producing global estimates of sea level rise caused by thermal expansion and the net uptake of heat by the oceans (Willis et al., 2008b). These quantities are of primary importance for monitoring the progress of global warming and anthropogenic climate change.

Altimeters

Since the launch of TOPEX/Poseidon in 1992, satellites have observed changes in the height of the sea surface with accuracies of a few centimeters. These satellites provide a critically important estimate of global sea level rise (Beckley et al., 2007), but they have also helped to identify and explain large-scale changes in ocean circulation that have impacts on regional climate, such as El Niño and La Niña (Lombard et al., 2005), the Pacific Decadal Oscillation (Cummings et al., 2004) and the spin down of the North Atlantic Subpolar Gyre (Häkkinen and Rhines, 2004).

GRACE

Since 2002, the GRACE satellites have measured large-scale changes in the Earth's gravity field. Estimates of ocean bottom pressure have been used to track seasonal and interannual changes in currents such as the Antarctic Circumpolar Current (Zlotnicki et al., 2007). However, from an ocean climate perspec-

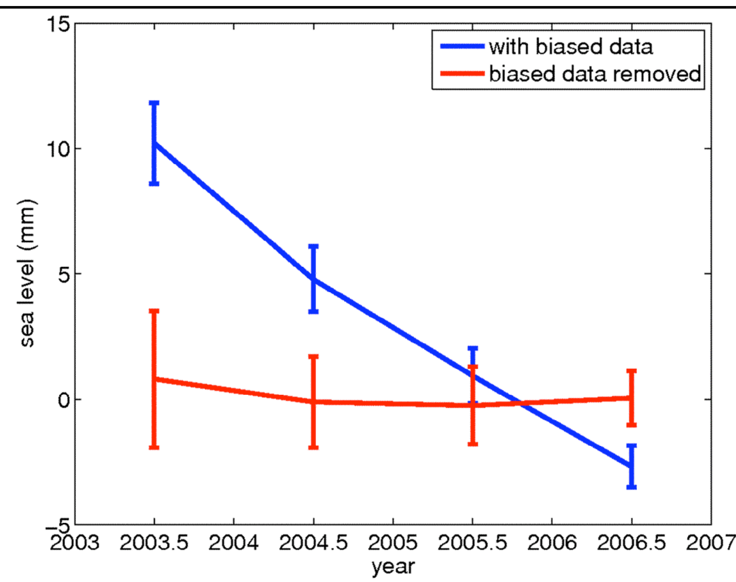

Figure 1.Change in sea level due to thermal expansion before and after removal of biased profile data. Biases were found in both the XBT observations as well as a small number of Argo floats. Adapted from Willis et al. (2008a).

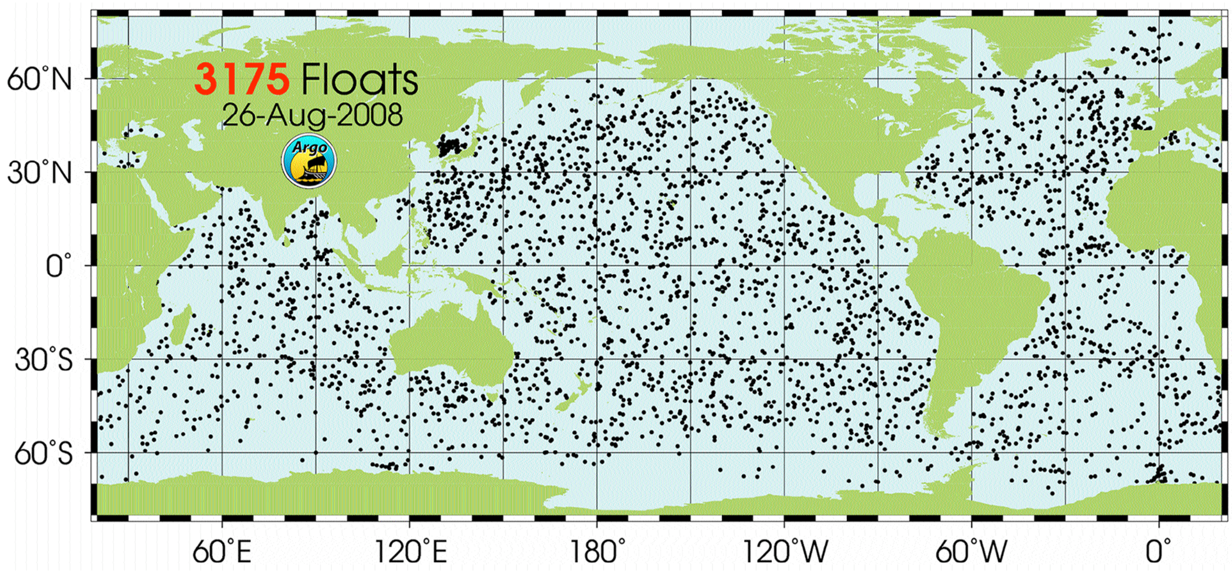

Figure 2. Distribution of autonomous profiling floats maintained by the Argo project (http://www.argo.ucsd.edu)

tive, the most important contributions from GRACE are the estimates of rising sea level from added water (Willis et al., 2008b) and the loss of mass from glaciers and ice sheets (Veliconia and Whar, 2006; Chen et al., 2006) that cause it.

High-resolution XBT Network

Despite the enormous volume of upper ocean temperature data provided by the Argo array, it has not completely supplanted the old system of eXpendable BathyThermograph (XBT) observations. The network of repeat, high-density XBT cruises (Figure 3) resolves boundary current and eddy variability that is much too fine to be resolved by the Argo array (Roemmich and Gilson, 2001). Furthermore, the coast-to-coast span of these cruises allows for the calculation of upper-ocean transports (Douglass et al., 2006). These provide insight into the ocean's ability to store and redistribute heat, a critical part of the ocean's role in our warming climate.

Hydrographic Sections

The World Ocean Circulation Experiment (WOCE) of the 1990s included a vast network of top to bottom observations of, among other things, temperature and salinity. Since the end of WOCE, repeat sections have begun to show the size and extent of changes in the deep ocean (Johnson and Doney, 2006). These high-quality measurements also serve as all-important references for calibration of new observing systems. An important part of the absolute calibration of data from the XBT network and Argo array ultimately relies on comparisons with hydrographic data.

Tide Gauges

Despite the new era of satellite oceanography, the network of tide gauges remains an important part of our system for measuring sea level rise. Tide gauges not only continue to provide a means of independent calibration of satellite measurements of sea level (Leuliette et al., 2004), they also provide a link to the long-term record of sea level rise (Church and White, 2006).

As we continue to drive the climate out of equilibrium, it becomes increasingly important to maintain fidelity in the historical record of ocean variability. The ever-increasing forcing means that heat gained during the 1990s, for instance, is unlikely to be lost from the ocean on human-relevant time scales. Under these conditions, the state of the ocean at any given time is unique. Cyclic climate events, like El Nino, provide many opportunities for observation, but global warming does not. This places an even greater responsibility on the observing system.

Not only must observations be continuous, but care is also needed to avoid introducing biases as old observing systems inevitably give way to new. It was this type of transition that gave us "rapid ocean cooling" and our hard-learned lesson from Rush. As the old XBT network gave way to Argo, the primary source of temperature data changed from warm-biased XBTs to Argo floats, some of which had problems of their own. The result was a false ocean cooling. And because it involved errors in both datasets, it proved very difficult to detect.

Such errors are not new to climate science, or even to oceanography. In 1994, satellite observations from the new altimeter TOPEX/Poseidon (Nerem, 1995) showed an alarmingly high rate of global sea level rise. Eventually, a software error was discovered in the processing of the data and the rate was revised downward (Nerem, 1997). As a result of the error, however, techniques were developed for comparing sea level rise from the altimeter with independent observations from tide gauges (Mitchum, 1998). The tide gauge network remains a powerful tool for detecting systematic errors in the altimeter data, and numerous drifts and biases have been discovered and corrected as a result.

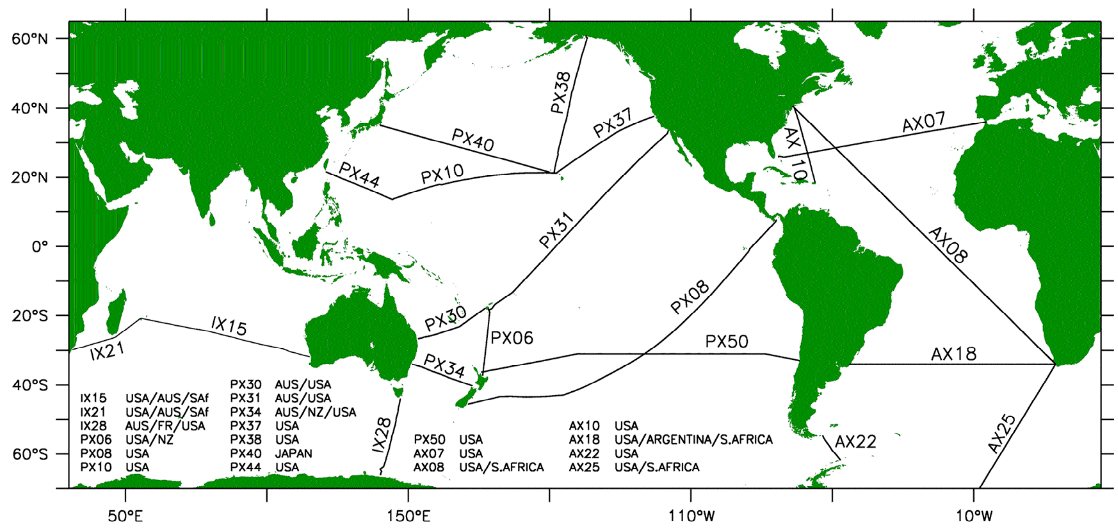

Figure 3. Transects maintained as part of the High-Resolution XBT Network. Figure created by John Gilson and Lisa Lehmann.

Much as the tide gauges are used to help maintain the accuracy of the altimeter, a system is needed to ensure the long-term accuracy of ocean temperature observations. Because temperature data from the Argo array and XBT network contribute so directly to our ability to measure humankind's impact on the climate, the need is urgent. Wijffels et al. (2008) showed that high-quality CTD data could be used to help track slow changes in the long-term accuracy of the XBT network, and that the altimeter could provide a powerful tool for comparing temperature data from different instrument types. Such efforts to maintain the accuracy of the ocean temperature observing system must continue to be developed. An organized effort to collect and rapidly release CTD data for comparison with XBT and Argo profiles would provide an anchor for the temperature observations and help to ensure their long-term accuracy. Without such efforts, the lesson from Rush will go unheeded and we will be doomed to repeat our calibration errors of the past.

Acknowledgements

Thanks to Herman Melville for writing the greatest opening sentence ever, long enough ago to be free from copyright restriction. Thanks also to Rush Limbaugh for a funny but true story, the Argo Project for Figure 2, and John Gilson and Lisa Lehmann for Figure 3.

References:

Beckley, B. D., F. G. Lemoine, S. B. Luthcke, R. D. Ray, and N. P. Zelensky (2007), A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimetry based on revised reference frame and orbits, Geophys. Res. Lett., 34, L14608, doi:10.1029/2007GL030002.

Church, J. A., and N. J. White (2006), A 20th century acceleration in global sea-level rise, Geophys. Res. Lett., 33, L01602, doi:10.1029/2005GL024826.

Cummins, P. , Lagerloef, G.S.E., and G. Mitchum (2005), A regional index of northeast Pacific variability based on satellite altimeter data, Geophys. Res. Lett., 32, L17607, doi:10.1029/2005GL023642.

Johnson, G. C., and S. C. Doney (2006), Recent western South Atlantic bottom water warming, Geophys. Res. Lett., 33, L14614, doi:10.1029/2006GL026769.

Häkkinen, S., and P. B. Rhines (2004), Decline of subpolar North Atlantic circulation during the 1990s. Science, 304, 555–559.

Lebedev, K. V., H. Yoshinari, N. A. Maximenko, and P. W. Hacker. YoMaHa'07 (2007), Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface, IPRC Technical Note No. 4(2), June 12, 2007, 16p.

Leuliette, E. W., R. S. Nerem, and G. T. Mitchum (2004), Results of TOPEX/Poseidon and Jason-1 calibration to construct a continuous record of mean sea level, Mar. Geod., 27, 79–94.

Levitus, S. J., I. Antonov, and T. P. Boyer (2005), Warming of the world ocean, 1955–2003, Geophys. Res. Lett., 32, L02604, doi:10.1029/2004GL021592.

Lombard, A., A. Cazenave, P. Y. L. Traon, and M. Ishii (2005), Contribution of thermal expansion to present-day sea level rise revisited, Global Planet. Change, 47 (1), 1-16.

Lyman, J. M., J. K. Willis, and G. C. Johnson (2006), Recent cooling of the upper ocean, Geophys. Res. Lett., 33, L18604, doi:10.1029/2006GL027033.

Mitchum, G. T. (1998), Monitoring the Stability of Satellite Altimeters with Tide Gauges, J. Atmos. Oceanic Technol., 15(3), 721-730.

Nerem, R. S. (1995), Global Mean Sea Level Variations from TOPEX/POSEIDON Altimeter Data, Science, 268, 708, DOI: 10.1126/science.268.5211.708.

Nerem, R. S. (1997), Global Mean Sea Level Change: Correction, Science, 279, 1049-1053, DOI: 10.1126/science.275.5303.1049i.

Roemmich, D., J. Gilson (2001), Eddy Transport of Heat and Thermocline Waters in the North Pacific: A key to understanding interannual/decadal climate variability? J. Phy. Oceanogr., 31, 6757-687.

Roemmich, D. and J. Gilson (2008), The 2004 – 2007 mean and annual cycle of temperature, salinity and steric height in the global ocean from the Argo Program, Progress in Oceanography, submitted.

Wijffels S. E., Willis J., Domingues C. M., Barker P., White N. J., et al. (2008): Changing eXpendable Bathythermograph Fall-rates and their Impact on Estimates of Thermosteric Sea Level Rise, Journal of Climate, In Press.

Willis, J.K., J.M. Lyman, G.C. Johnson, and J. Gilson (2008a) In Situ Data Biases and Recent Ocean Heat Content Variability, J. Atmos. Oceanic Technol., accepted.

Willis, J. K., D. P. Chambers, and R. S. Nerem (2008b), Assessing the globally averaged sea level budget on seasonal to interannual timescales, J. Geophys. Res., 113, C06015, doi:10.1029/2007JC004517.

Velicogna, I., and J. Wahr (2006), Measurements of time-variable gravity show mass loss in Antarctica, Science, 311(5768), 1754–1756, doi:10.1126/science.1123785.

Zlotnicki, V., J. Wahr, I. Fukumori, Y. T. Song (2007), Antarctic circumpolar current transport variability during 2003-05 from GRACE, J. Phys. Oceanogr., 37, 230–244.

Marine Ecosystems and their Climate Connection

David Mountain
(mountain.email.arizona.edu)

Climate change has significant implications for marine ecosystems – their species community structure and their productivity. Predictions of future climate conditions could provide the ability to predict future ecosystem conditions in areas where the linkages between climate forcing and ecosystem response are sufficiently understood. Over the past 10-15 years considerable research has studied the response of marine ecosystems to environmental and climate variability. In particular, the US GLOBEC program (www.usglobec.org), funded jointly by NSF and NOAA, has focused on obtaining a process level understanding of how climate variability and change influence marine ecosystems. The program conducted regional studies on Georges Bank in the northwest Atlantic Ocean, in the Gulf of Alaska and the California Current in the northeast Pacific Ocean and near the west Antarctic Peninsula in the Southern Ocean. It is currently in its final synthesis phase. With understanding gained through US GLOBEC and other research efforts, decadal climate predictions by CLIVAR could be applied to predict future conditions in specific marine ecosystems.

This article addresses three topics. First, examples of how climate variability influences marine ecosystems are presented. Then the climate parameters or aspects of climate predictions that would be most important for applying the predictions to marine ecosystems are considered. Finally, suggestions on how marine ecosystem interests and CLIVAR might collaborate in developing and applying climate predictions are presented.

Climate Influence on Marine Ecosystems

Climate can affect marine ecosystems through a variety of mechanisms, many of which have been widely reported in the popular media. Marine organisms generally are adapted to fairly narrow ranges of temperature and can be very sensitive to climate-induced warming. At elevated temperatures corals lose their symbiotic algae, turn white (or 'bleach') and die. Large and widespread coral morality events have occurred in recent years due to warmer water temperatures (Christensen et al., 2008). Coral reef ecosystems support numerous other species and the loss of corals can have catastrophic consequences for the populations of many other marine organisms. Warming temperatures also have been linked to the recent, significant loss of sea ice in the arctic (IPCC, 2007), with adverse effects on polar bear populations and contributing to the listing of the polar bear as endangered. Increased uptake of CO2 by the ocean as atmospheric CO2 levels rise can cause a lowering of surface water's pH. This acidification of the ocean could interfere with the ability of calcareous organisms to form their skeletons or shells (Orr et al., 2005), and disrupt the structure of large oceanic ecosystems.

In the northwest Atlantic the US GLOBEC program has identified changes in the Georges Bank/Gulf of Maine ecosystem associated with changes in the two major inflows to the region caused by changes in advection patterns in the North Atlantic basin. A sharp drop in the North Atlantic Oscillation (NAO) in 1996 resulted in the advection of Labrador Slope Water

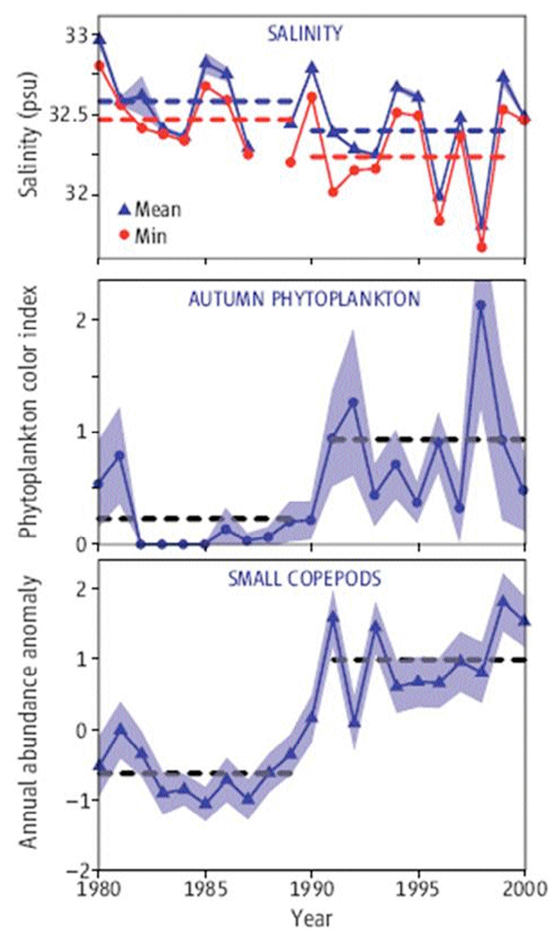

Figure 1.Shift in decadal means (1980-1989 and 1990-1999) for salinity (top), autumn phytoplankton abundance (middle) and small copepod abundance (bottom) for the Gulf of Maine/Georges Bank region (adapted from Greene and Pershing, 2007). Shading represents the 95% confidence intervals.

(LSW) in the slope region from the tail of the Grand Banks westward to enter the Gulf of Maine in early 1998 (MERCINA, 2001). The LSW is relatively low in nutrients and likely contributed to lower chlorophyll values in the Gulf during 1998 (Thomas and Townsend, 2003). Steele et al. (2007) show that during the late 1960's – when the NAO was low and LSW filled the deep layers of the Gulf of Maine - Georges Bank exhibited lower overall production than in recent decades and suggest this was due to fewer new nutrients entering the system with the LSW. During the 1990's the surface layer inflow of water from the Scotian Shelf (SSW) doubled from that measured in the 1980's (Smith et al., 2001), leading to a significant reduction in salinity throughout the Gulf and on Georges Bank. The lower salinity caused changes in vertical stratification/mixing processes and has been associated with changes in the chlorophyll patterns and zooplankton community structure throughout the region (Pershing et al., 2005; Kane, 2007; Ji et al., 2007) (Figure 1). The salinity reduction is believed to have originated at high latitude (Houghton and Fairbanks, 2001) and in part from the increased outflow of freshwater from the arctic (Greene and Pershing, 2007).

In the northeast Pacific Ocean variations in climate have been associated with 'regime shifts' in the biological communities. In 1976-1977 major changes occurred in the populations of dozens of fish and other species (Hare and Mantua, 2000) suggesting the ecosystem shifted from one regime or community structure to another. These changes were associated with a shift in the Pacific Decadal Oscillation (PDO) from a cold to a warm phase. Other similar changes in the ecosystem have been identified and associated with both the PDO and with the North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al., 2008). The specific mechanistic connections between the atmosphere, ocean and marine populations are not fully understood. However, Di Lorenzo et al. (2008) used surface wind stress and heat flux to force a model of the northeast Pacific Ocean which included a simple nutrient-phytoplankton-zooplankton-detritus (NPZD) ecosystem model. The model reproduced the large-scale ocean response to variable forcing in terms of the PDO and the NPGO, as well as changes along the California coast in SST, SSS, nitrate and chlorophyll (Figure 2). The indication is that the variation in large-scale atmospheric forcing over the northeast Pacific Ocean drives changes in the ecosystem along the California coastal region. Much of the production in the California Current ecosystem is supported by seasonal upwelling which brings nutrients from depth into the photic zone. In 2005 the transition to upwelling-favorable winds that usually occurs in April-May was delayed until July (Schwing et al., 2006). This delay is believed responsible for a disruption in the coastal spring production cycle with adverse effects on a number of marine populations. In particular it is believed responsible, at least in significant part, for poor survival of young Chinook salmon that entered the shelf system in the spring of 2005 looking for food – and contributed to a closure of salmon fishing along the Pacific coast in 2008. The northern California Current system in recent years also has experienced unprecedentedly low dissolved oxygen values, with actual anoxic conditions observed in 2006 (Chan et al., 2008). These conditions are believed to result from a combination of upwelling of water with lower oxygen values onto the shelf, greater stratification on the shelf (possibly associated with higher surface water temperatures) that promotes both increased surface production and an inhibition of ventilation of the shelf bottom waters by vertical mixing. The low oxygen values caused high morality among many benthic organisms.

Climate Predictions for Marine Ecosystems

To predict the response of marine ecosystems to a changing climate, information on different aspects of the atmospheric and oceanic conditions would be important. First are the 'usual suspects' - e.g., winds, temperature, solar insolation, atmospheric pressure, precipitation (and river input of fresh water to the coastal ocean). Also important would be esti-

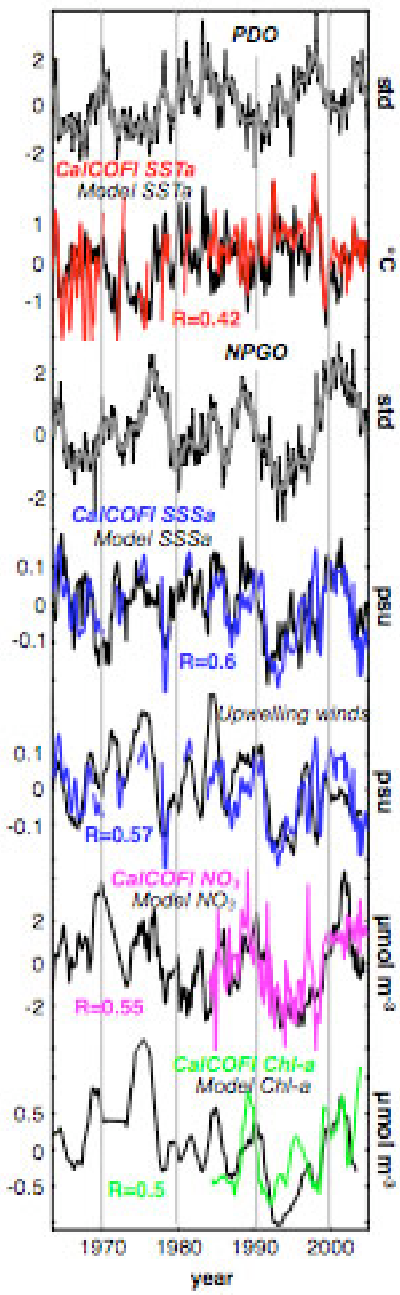

Figure 2. Modeled vs observed time series for the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) in the North Pacific Ocean, and for the surface temperature anomaly, surface salinity anomaly, upwelling winds, nitrate concentration and chlorophyll-a abundance in the CalCOFI region of the California Current system (adapted from Di Lorenzo et al., 2008 for more information see http://www.ocean3.org/npgo)).

mates of the large-scale atmospheric and oceanic indices – e.g., PDO, NPGO, PO, NAO, AO, ENSO – all of which have been associated with ecosystem variability in one marine region or another.

Societal interest in marine ecosystems focuses primarily on continental shelf regions where biological production is high and economically important fisheries exist. Having the horizontal resolution in the predictive models to resolve the atmospheric forcing and oceanic response on the continental shelves is critical. As suggested by a number of the examples above, having the vertical resolution and appropriate physics to represent stratification, mixing, upwelling and convection within the ocean also will be important in order to include the basic processes through which climate often influences marine ecosystems.

In predicting the implications of a changing climate for marine organisms, estimates of the range or likelihood of extreme values for certain environmental parameters could be more important than prediction of changes in the mean. For example, knowing the probability that water temperature would exceed a threshold value for corals could be more important than knowing that the average temperature would increase by some non-lethal amount; or if a population might die due to anoxic conditions in the summer, having a high average oxygen value for the whole year really wouldn't matter. Also, marine organisms are well adapted to the characteristic seasonal patterns of their local environment. Predictions of change in the seasonal timing of major environmental conditions or events (e.g., upwelling, stratification) would be important for anticipating the response of marine ecosystems to a changing climate.

CLIVAR – Marine Ecosystem Collaborations

Decadal predictions of future climate by the CLIVAR program could be combined with understanding of marine ecosystems gained through recent research efforts to evaluate the implications of climate change for selected ecosystems. Collaboration between CLIVAR and marine ecosystem interests could include a focus on modeling techniques and on the modeling of specific regions.

As indicated above, application to marine ecosystems will require models with finer scale horizontal and vertical resolution than found in most climate-scale models. Techniques for one-way and two-way coupling of fine-scale model grids within coarser-scale grids have advanced considerably in recent years. A CLIVAR-marine ecosystem effort could provide the opportunity to employ, test and further develop these techniques in a coupled bio-physical framework.

Regionally, the results of Di Lorenzo et al. (2008) in the northeast Pacific suggest that the climate-ecosystem connections are fairly well understood in the California Current system, making it a good candidate for the application of climate predictions. In the north Atlantic a new program is being developed to address the effects of climate change on ecosystems in and around the North Atlantic basin: Basin-scale Analysis, Synthesis and INtegration (BASIN) (http://web.pml.ac.uk/globec/structure/multinational/basin/basin.htm). This program builds on the results of GLOBEC-like programs in Germany, the United Kingdom, Norway, Iceland, Canada and the United States. BASIN could offer a good opportunity for international collaboration between CLIVAR and marine ecosystem interests in the application of climate predictions.

References:

Chan, F (and 6 co-authors). 2008. Emergence of anoxia in the California Current Large Marine Ecosystem. Science, 326, 920.

Christensen, T, M Eakin, J Bruno. 2008. "Coral bleaching, satellite observations, and coral reef protection." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment).

Di Lorenzo, E (and 10 co-authors). 2008. North Pacific gyre oscillation links ocean climate and ecosystem change. Geophysical Research Letters, 35, L08607, doi:10:1029/2007GL032838.

Greene, CH and AJ Pershing. 2007. Climate drives sea change. Science, 315, 1084-1085.

Hare, SR and NJ Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography, 47m 103-145.

Houghton, RW, RG Fairbanks. 2001. Water sources for Georges Bank. Deep Sea Research Part II: Topical Studies in Oceanography, 48(1-3): 95-114.

IPCC. 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning,

Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ji, R. (and 5 co-authors). 2007. Influence of ocean freshening on shelf phytoplankton dynamics.Geophysical Research Letters, 34, L24607, doi: 10.1029/2007GL032010.

Kane, J. 2007. Zooplankton abundance trends on Georges Bank, 1977–2004. – ICES J. Mar. Sci. 64: 909–919.

MERCINA. (2001). Oceanographic responses to climate in the Northwest Atlantic. Oceanography, 14, 76–82.

Orr, JC (and 26 co-authors). 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calci - fying organisms. Nature, 437, 681-686 | doi:10.1038/nature04095

Pershing, AJ, CH Greene, JW Jossi, L O'Brien, JKT Brodziak, BA Bailey. 2005. Interdecadal variability in the Gulf of Maine zooplankton community with potential impacts on fish recruitment. ICES Journal of Marine Science. 62: 1511-1523.

Schwing, FB, NA Bond, SJ Bograd, T Mitchell, MA Alexander, N Mantua. 2006. Delayed coastal upwelling along the U.S. west coast in 2005: a historical perspective. Geophysical Research Letters, 33, L22S01, doi:10.1029/2006GL026911.

Smith, P.C., R.W. Houghton, R.G. Fairbanks and D.G. Mountain. 2001. Interannual variability of boundary fluxes and water mass properties in the Gulf of Maine and on Georges Bank: 1993-97. Deep Sea Res. II, 48, 37-70.

Steele, JH (and 12 co-authors). 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. Progress in Oceanography, 74, 423-448.

Thomas, AC, DW Townsend, R Weatherbee. 2003. Satellite-measured phy - toplankton variability in the Gulf of Maine. Continental Shelf Research 23 (2003) 971–989.

Water Resources Decision-Makers and their needs for Decadal Climate Prediction

Andrea J. Ray, NOAA Earth Systems Research Lab and NOAA-CIRES Western Water Assessment

The 2008 U.S. CLIVAR Summit hosted a Science Symposium on "Climate Predictions for 2018" continuing a discussion on advancing understanding of decadal variability and predictability that began at the 2007 Summit (see Vimont and Newman 2007). This article is based on a presentation in the session on "Use and Value of Decadal Predictions" that also included presentations on decisionmaking under uncertainty among California water resource managers and climate change in marine ecosystems.

Prediction of climate variability on decadal time scales is a particularly rich arena for applications because many natural resource management decisions are made in the context of decadal and multi-year variations in climate because the resources themselves have decadal-scale lifecycles. CLIVAR seeks to identify the potential for predictions of the upcoming decade and through 2018 For example, what key predictands are prime targets for skillful decadal forecasts, and what phenomena possess potential predictability? Key questions on the applications side include what societal issues are sensitive to climate at these time scales, what climate information is useful, whether there actions that could be taken to minimize adverse affects or take advantage of opportunities, and what are the pathways for integrating decadal-scale forecasts into decisionmaking?

These answers then are the jumping off point for interactions between climate and applications researchers and potential users of this research. Figure 1 illustrates how applications researchers look for high potential arenas for connecting users with predictions that may not exist yet. Although the decadal prediction problem is still in its infancy (Vimont and Newman, 2007), discussions at this stage among climate and applications scientists and potential users of decadal predictions will allow two-way learning in which scientists learn about users' needs, and users learn about what is predictable and are involved in the development of prediction products. In developing successful applications of climate information, iterative, two-way interactions between scientists and users has been shown to be successful in producing usable science (Lemos and Morehouse, 2006).

There are many opportunities for use of climate information in water-related sectors, including agriculture – in particular, permaculture (vineyards, orchards), drought mitigation/planning, fire management, and public health. This article describes two examples of interactions with Colorado reservoir managers and municipal water managers, and reflects on some of their needs and opportunities for use of decadal information.

Managing the Colorado River

The U.S. Bureau of Reclamation manages the Colorado River under the Colorado Compact of 1922. That compact, ironically, divided the river's supply based on decadal-scale period of higher than average flows in the early 20th century (Figure 2). There have been multi-year and decadal periods of high and low flows since, and in previous centuries as well (see Meko, et al 2007). Reservoirs were designed as a buffer against periods of low flow, allowing the Upper Basin to consistently use its allocation under the compact even during drought. Wet years and periods refill storage, and extended decadal and longer periods of above and below average flow determine system yield more than long-term averages (Bureau of Reclamation, 2007). In the summer of 1999, Lake Powell was essentially full with reservoir storage at 97 percent of capacity; inflow that water year (a water year is October 1st-September 30th) had been 109% of average. But from 2000 through 2008, inflow to Lake Powell was below average in all but two years (2005 and 2008), reflecting the drought conditions experienced in the Upper Colorado River basin.

This drought and concerns about climate change have peaked the interest of Reclamation managers in the climate of the next decade and beyond. Although reservoir storage increased in 2008 to about 58% of capacity, it will take years, perhaps decades, for the system to recover to capacity, because average inflows are closely balanced with releases to meet compact requirements (Fulp, 2005). Reclamation's planning process includes several key time scales from days to the two-year "24-month

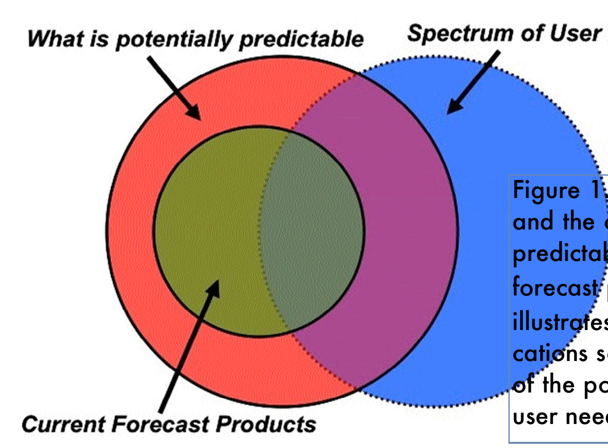

Figure 1: Spectrum of user needs and the overlap with potentially predictable climate and existing forecast products. This schematic illustrates the arena in which applications scientists work, the overlap of the potentially predictable with user needs.

study" which is updated monthly, to decades (Figure 3). These river operations and planning studies are the basis for estimating storage in individual reservoirs and the Colorado River system as a whole. These studies use NOAA reservoir inflow outlooks for the current water year, but rely on historic average flows beyond the current year. The inflow outlooks incorporate seasonal climate outlooks when they add skill; and have sometimes been qualitatively adjusted to persist known drought conditions (Brandon, 2005). Reclamation scientists are currently assessing methods for incorporating climate information beyond two years, and are very interested in interannual-to-decadal information (Bureau of Reclamation, 2007a). This process results in estimates of storage and reservoir levels, and operating plans for releases from the reservoirs for the next two years, which then feed into other planning, triggers for shortage or surplus sharing, "equalization" of storage at Lakes Powell and Mead, and the Western Area Power Authority's hydropower contracts and marketing plans. Recreation is also affected as in the case of Hite Bay Marina on Lake Powell which became inoperable in 2003. Low levels at Lake Mead have closed several boat ramps and over $10 million has been spent to keep others open (Fulp, 2005).

The operating guidelines for the river were recently revised to include interim operating criteria out to 2026 for managing shortages due to drought (Bureau of Reclamation, 2007b). The planning process took advantage of new paleoclimate reconstructions of streamflow to extend the record of climate variability used in evaluating the risks of long- term drought. A Climate Technical Workgroup developed an appendix on incorporating climate change information into Reclamation's Colorado Basin planning studies and is the most extensive use yet of climate information (Bureau of Reclamation, 2007b). In this process, Reclamation was very concerned with testing new operations under a wider range of possible droughts, including decadal scale droughts (BOR, 2007b).

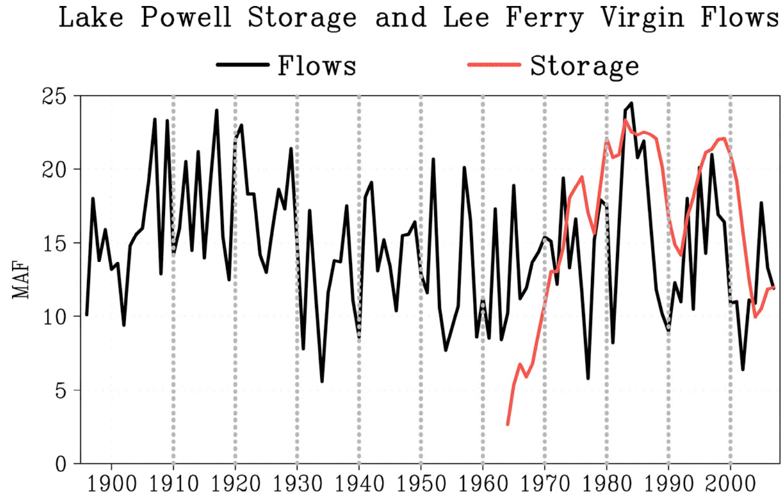

Figure 2. Annual storage, or maximum contents in Lake Powell plotted with annual inflows at Lee Ferry. Illustrates the decadal variability of flows into Lake Powell, represented by Lee Ferry flows. The reservoir took longer than anticipated to fill (until 1982), partly attributed to a below average period in the 1960s and 1970s. 1965 was the first full water year for Lake Powell operations; flow data begins in 1896; the average flow into the reservoir over this period is about 15 million acre-feet, although the longterm average is the subject of debate (USGS, 2004). Flow data from the Upper Colorado River Commission, Storage data from USBR.

What decadal climate information would be useful for reservoir management? From the vantage point of 2008, managers are interested in an indication of where in the drought cycle the system might be, i.e. what is the likelihood of the drought continuing, and what is the likelihood of a wet period that could refill the reservoirs? Reclamation develops "shorter look-ahead" studies for less than 20 years that anticipate the potential for shortage sharing, for example. "Longer look ahead" studies beyond 20 years are also conducted and both could benefit from decadal-scale information in anticipating surpluses or shortages, improving hydropower planning, and anticipating recreation opportunities or obstacles.

Moving forward

Reservoir management is a water resources issue that is sensitive to climate at decadal scales, and has potential responses to minimize adverse affects of drought or take advantage of water surplus. This example illustrates the blue part of the Venn diagram in Figure 1.

Decadal-scale information in several related areas would be highly useful for reservoir managers and planners. As a bottom line need, reservoir managers would like to improve estimates of inflows, and thus storage, for "look-ahead" horizons out to about 20 years (including the upcoming decade), to 2026 (the horizon of the interim guidelines, BOR, 2007b), and beyond 20 years in order to better anticipate and mitigate potential shortages. Inflow estimates on longer time scales require temperature and precipitation projections to drive hydrologic models. Although decadal (e.g. 10-year) averages of temperature and precipitation would be of some use, longer interannual outlooks other than the 13-month CPC outlooks would be more useful in evaluating the risk of interannual-to-decadal runs of wet and dry years.

Other useful information includes: potential shifts of extreme events from the base period of the recent record (e.g. 1950-1999), as relatively small shifts in average climate can substantially change the risk of extreme events (described in IPCC, 2007, Figure X); interannual-to-decadal wet or dry periods, persistence of current long-term drought conditions, and above average termperatures (even in the absence of skillful information about precipitation); multiyear averages

Calendar of CLIVAR and CLIVAR-related meetings

Further details are available on the U.S. CLIVAR and International CLIVAR web sites: www.usclivar.org and www.clivar.org

International Council for Exploration of the Seas Annual Science Conference
22-25 September 2008
Halifax, Nova Scotia
Attendance: Open
Contact: http://www.ices.dk/iceswork/asc/2008/index.asp

CLIVAR Working Group on Coupled Modeling
22-24 September 2008
Paris, France
Attendance: Invited
Contact: http://www.clivar.org

NOAA CPPA PI Meeting
29 September - 1 October 2008
Silver Spring, MD
Attendance: Invited
Contact: http://www.climate.noaa.gov

International Conference "Regional Climate Change and its Impacts"
30 September - 3 October 2008
Tarragona, Spain
Attendance: Open
Contact: http://www.aeclim.org/AEC2008_presentacion.htm

Third CLIVAR/GODAE Meeting on Ocean Synthesis Evaluation
6-7 October 2008
Tokyo, Japan
Attendance: Invited
Contact: http://www.clivar.org

SCOR/IAPSO workshop on Deep Ocean Exchange with the Shelf (DOES)
6-8 October 2008
Cape Town, South Africa
Attendance: Open
Contact: https://www.confmanager.com/main.cfm?cid=1293&nid=9421

Second Symposium on The Ocean in a High-CO2 World
6-9 October 2008
Monaco
Attendance: Open
Contact: http://www.highco2world-ii.org/main.cfm?cid=975

CLIVAR Drought Workshop and NOAA Climate Diagnostics and Prediction Workshop
20-24 October 2008
Lincoln, Nebraska
Attendance: Open
Contact: http://www.cpc.ncep.noaa.gov/products/outreach/CDPW33.shtml

AGU Chapman Conference on Atmospheric Water Vapor and its role in Climate
20-24 October 2008
Kona, Hawaii
Attendance: Open
Contact: http://www.agu.org/meetings/chapman/2008/ecall/

Arctic Research Symposium
4-6 November 2008
Tokyo, Japan
Attendance: Open
Contact: http://www.jamstec.go.jp/iorgc/sympo/isar1/index.html

European Science Foundation International Conference on Global Change
5-10 November 2008
Porquerolles, France
Attendance: Open
Contact: http://www.entre-sciences.msh-paris.fr

GODAE Symposium on Ocean Synthesis Evaluation
12-15 November 2008
Nice, France
Attendance: Invited
Contact: http://www.godae.org/

IMBER Integrating Biogeochemistry and ecosystems in a changing ocean
9-13 November 2008
Miami, Florida
Attendance: Open
Contact: http://www.confmanager.com/main.cfm?cid=1185

Conference on Teleconnections in the Atmosphere and Ocean
17-20 November 2008
Trieste, Italy
Attendance: Open
Contact: http://cdsagenda5.ictp.it/full_display.php?email=0&ida=a07177

AGU Fall Meeting
15-19 December 2008
San Francisco, California
Attendance: Open
Contact: http://www.agu.org

89th AMS Annual Meeting
11-15 January 2009
Phoenix, Arizona
Attendance: Open
Contact: http://www.ametsoc.org

U.S. CLIVAR Western Boundary Current Workshop
15-17 January 2009
Phoenix, Arizona
Attendance: Open
Contact: http://www.usclivar.org/WBCWorkshop2009.php

CLIVAR Working Group on Seasonal to Interannual Prediction
12-14 January 2009
Miami, Florida
Attendance: Invited
Contact: http://www.clivar.org

of temperature, since temperature alone is important in driving runoff anomalies (Hoerling and Eischeid, 2006); and qualitative scenarios for climate in the planning horizon (e.g. within the next 10-20 years, depending on the planning study purpose).

This decadal-scale information could then be used to either qualitatively hedge management decisions, or in a combination of qualitative and quantitative analysis.

Finally, it should be noted that Reclamation managers and planners recognize that there are uncertainties inherent in General Circulation Models used in projections of climate, as well as in relating these projections to hydrologic projections for operations (BOR, 2007a). They recognize that specific forecasts on long time horizons are not likely to be available in the long term. Two ways of incorporating climate information are to use quantitative sensitivity analyses on operations response to projected climate predictands, and planning studies might involve a "qualitative discussion" of interannual-to-decadal variability within a given study's time horizon, especially if the role of the climate of the next 20 years is critical to the planning purpose. Qualitative analysis of projections might be complemented by a quantitative sensitivity study based on paleoclimate and instrumental data (BOR, 2007a).

Decadal climate outlooks also potentially have a role in managing water in the context of changing climate, i.e., water adaptation strategies. Identifying usable products on the decadal timescales will require continuing interaction with these and other user communities. Pathways for this interaction include the NOAA-funded Regional Integrated Science and Assessment programs (RISAs), which worked with Reclamation on the Climate Technical Workgroup. The RISAs are actively engaged with users across water and other sectors. These projects use a variety of mechanisms to elicit and understand user needs, by focusing on the users' decision processes and key issues, including drought, hydropower, multi-purpose reservoir management.

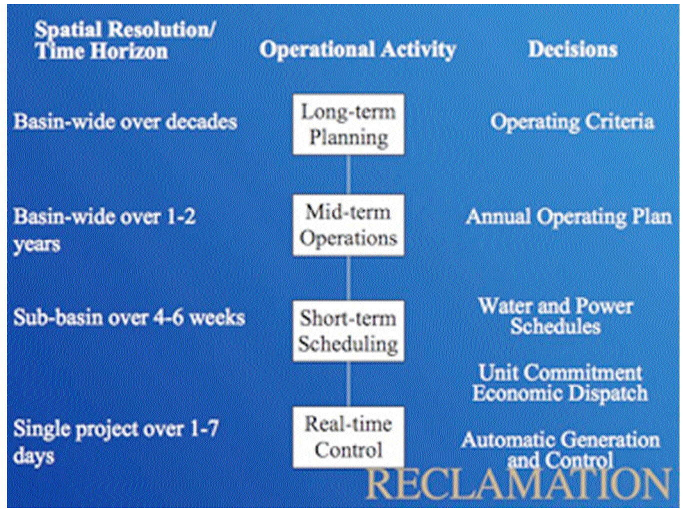

Figure 3. Schematic of the USBR planning process from days to decadal scale, linked to general operational and planning decisions.

More work needs to be done, both to identify the potentially predictable aspects of decadal climate and to identify the types of information that would be useful, and how to translate predictands such as temperature and precipitation into user-oriented hydrologic projections and drought outlooks. More work is also needed on methodologies for incorporating information qualitatively and quantitatively in planning studies. However, these efforts are likely to pay off in useable decadal-scale information that can impact water management decisions and reduce the risks of decadal variability to society.

Acknowledgements:

Thanks to Amy Solomon, Michael Alexander, and Robert S. Webb for their discussions on this presentation and this article, and J. Eischeid for creating Figure 2.

References:

Brandon, D. 2005. Using NWSRFS ESP for Making Early Outlooks of Seasonal Runoff Volumes into Lake Powell. Special Session on Hydrology of Arid and Semi-Arid Regions AMS Annual Meeting, San Diego, CA, Jan 9-13, 2005.

Bureau of Reclamation. 2008. Glen Canyon Dam Operations, August 27, 2008. http://www.usbr.gov/

-. 2007a. Climate Technical Work Group Report: Review of Science and Methods for Incorporating Climate Change Information into Bureau of Reclamation's Colorado River Basin Planning Studies, eds. L. Brekke, B. Harding, T. Piechota, B. Udall, C. Woodhouse, and D. Yates, prepared as Appendix U in: Final EIS Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, Bureau of Reclamation, U.S. Department of the Interior, 118pp.

-, 2007b, Record of Decision Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. December 2007.

Fulp, T. 2005. How low will it go? Southwest Hydrology 4: 16-18.

Hoerling, M., and J. K. Eischeid, 2006: Past peak water in the southwest. Southwest Hydrology, 35, 18–19.

IPCC 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., et. al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Lemos, M. C. and B. J. Morehouse, 2005: The Co-production of science and policy in integrated climate assessments. Global Env. Change, 15, 57-68.

Meko D. M., et. al., (2007). Medieval drought in the Upper Colorado River Basin. Geophys. Res. Lett. 34(10, L10705), 10.1029/2007GL029988.

Vimont, D.J. and M. Newman. 2007. Decadal variability and predictability. U.S. CLIVAR Variations, 5: 1-4.

U.S. Geological Survey. 2004. Climatic Fluctuations, Drought, and Flow in the Colorado River Basin. USGS Fact Sheet 2004-3062, August 2004.cs

Webb, R.S., A.J. Ray, et. al., 2003, Rapid response to the 2002 drought in Colorado: an experiment in regional climate services. 82nd Annual Meeting of the American Meteorologic Society, Long Beach CA.

A New Reanalysis in the CISL Research Data Archive

NCAR, in partnership with the Japanese Meteorological Agency (JMA), now offers the Japanese Re-Analysis 25-year (JRA-25) dataset to the public for research and education. The JRA-25 has global coverage, spans the period 1979 to 2004, and is regularly extended operationally with the JMA Climate Data Assimilation System (JCDAS). The JRA-25/JCDAS collection is now current through January 2008.

These data are managed as part of the CISL Research Data Archive (RDA). There are over 20 different products available at a 6-hourly temporal resolution and typically at both high and low spatial resolutions (approximately 1.125 and 2.5 degrees) in GRIB 1 format. In parallel, companion monthly mean products in netCDF are also available in the RDA. Details about the gridded parameter fields within each product, and the JMA model, assimilation system, and conventions, are readily available on the website.

The complete JRA-25/JCDAS collection, roughly 10TB, can be accessed from the RDA web server or the NCAR Mass Storage System. Registration and acceptance of the JMA prescribed data use policy is required and electronically logged as part of a user's first access session.

The JRA-25 is the fifth major reanalysis in the RDA. It, much like each of the processors when taken in sequence, has improved output data quality in several areas. The steady improvement results from a combination of better assimilation methods, forecast models, and enhanced input data.

Reanalyses are highly valued reference datasets for climate, weather, and related science studies. Dave Stepaniak (davestep@ucar.edu) has lead responsibility for JRA-25/JCDAS and works in combination with Chi-Fan Shih (chifan@ucar.edu) to acquire, archive, and document ongoing updates to JRA-25/JCDAS from JMA. An animation of JCDAS reanalyzed surface winds, mean sea level pressure, and convective precipitation associated with Typhoon Sepat in August 2007 is provided, and comparison to a NASA Terra-Modis satellite image taken 16 August 2007 is also shown.
http://dss.ucar.edu/datasets/ds625.0/docs/jra-25_typhoon_sepat.html

WESTERN BOUNDARY CURRENT WORKSHOP

The U.S. CLIVAR Western Boundary Current (WBC) Ocean-Atmosphere Interaction Workshop will be held on January 15-17, 2009, in Phoenix, AZ. The Workshop is sponsored by the U.S. CLIVAR WBC Working Group (http://www.usclivar.org/wbc.php) and the U.S. CLIVAR Program. The timing of the Workshop will overlap with (by one day), and follow, the AMS's 89th Annual Meeting of January 11-15, 2009, in Phoenix, AZ (see http://www.ametsoc.org/meet/annual/).

The overall objective of the Workshop is to seek better understanding of WBC ocean-atmosphere interaction that can improve the decadal and longer timescale predictability of the climate system, and to assess our present knowledge and to explore future directions/opportunities in studies of WBC ocean-atmosphere interaction. The Workshop will feature focused oral sessions with a mix of invited and contributed presentations, thematic poster sessions, and a round-table discussion.

Abstract deadline is November 1, 2008. Register now at: http://www.regonline.com/Checkin.asp?EventId=650479

U.S. CLIVAR Climate Variability & Predictability

U.S. CLIVAR OFFICE
1717 Pennsylvania Avenue, NW
Suite 250
Washington, DC 20006

Subscription requests, and changes of address should be sent to the attention of the U.S. CLIVAR Office (cstephens@usclivar.org)

WCRP World Climate Research Programme

U.S. CLIVAR contributes to the CLIVAR Program and is a member of the World Climate Research Programme

CLIVAR Climate Variability & Predictability World Climate Research Programme