yet been compared with lab data. Large scale laboratory experiments planned under NEES will allow for the validation of numerical predictions for wave velocities and forces, the extrapolation from small scale lab experiments, and the translation of force predictions to construction standards. It is anticipated that the latter will include performance guidelines for the design of seawalls, wharfs, piers, and structures to mitigate both direct and indirect tsunamigenic losses. References Borrero, J.C., 2002, *Analysis of Tsunami Hazards in Southern California*, PhD thesis, USC, 262p. Eskijian, M.S. Heffron, R.E., Dahlgren, T., 2003.. *Engineering Standards for Marine Oil Terminals*, in Submarine Landslides and Tsunamis, Yacliner, A. et al (eds), NATO Science Series, Kluwer Academic Publishers. Yeh, H. Liu, P.L-F., Synolakis, *Long Wave Runup Models*, World Scientific. *Marine Oil Terminal Engineering and Maintenance Standards*, (MOTEMS), July 2003, published by the California State Lands Commission.

OS21A-04 0900h

Tsunami Inundation Mapping for the State of California

Jose C Borrero[1] (213 740 5129; jborrero@usc.edu)

Costas E Synolakis[1] (213 740 5129; costas@usc.edu)

Richard K Eisner[2] ((510) 465-4887; rich_eisner@oes.ca.gov)

[1]University of Southern California, Dept. of Civil Engineering 3620 S. Vermont Ave, KAP210, Los Angeles, CA 90089-2531, United States

[2]Governor's Office Of Emergency Services, 724 Mandana Boulevard, Oakland, CA 94610-2421, United States

Since the International Tsunami Symposium held in Seattle, Washington in August 2001, significant progress has been made in tsunami inundation mapping for the state of California. While the mapping effort continues to focus on creating a "worst case scenario" for use by emergency management in evacuation planning and guidance, the modeling technologies being developed will be instrumental in creating a future generation of tsunami hazard prediction that include probabilities of occurrence. Significant progress over the last two years has been achieved with the completion of a uniform, 3 arcsec combined bathymetry and topography data set that extends from San Diego County to north of San Francisco Bay. This data set also includes a 1 sec resolution grid over the San Francisco Bay region. Over the last two years, the inundation mapping program has continued to focus on near–shore tsunamis sources. These include submarine mass movements, offshore thrust faulting and complex ruptures on near–shore strike slip faults. Sources recently modeled include the Palos Verdes debirs avalanche, the Catalina Island restraining bend, the Lasuen Knoll uplift structure and the San Mateo Thrust Fault. These sources in particular that showed a significant time lag for a variety of near–shore sources for first wave arrival in to the Ports of Los Angeles and Long Beach. Numerical modeling has confirmed that this lag can be more than 20 minutes, leaving room for the possibility of a local tsunami warning system - something previously assumed to be of little use due to the proximity of the tsunami generation sources to the Ports. Thus far the inundation mapping program has completed inundation maps for Los Angeles, Santa Barbara, and San Diego Counties. As well as the Pacific side of San Francisco and the Monterey Bay area. Final maps for Ventura, Orange and San Luis Obispo county will be completed by year's end with the remainder of the state to be mapped in the coming year. Other projects being undertaken in this effort include examining sources within San Francisco Bay to investigate the tsunami hazard for marine oil transfer terminals located inside the Bay.

URL: http://www.usc.edu/dept/tsunamis

OS21A-05 0915h

M-TSU: Direct evaluation of an earthquake "mantle" magnitude from ocean-bottom pressure records of tsunami waves

Vasily Titov[1] (titov@pmel.noaa.gov)

Emile A. Okal[2] (emile@earth.nwu.edu)

[1]PMEL-NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, United States

[2]Northwestern Univ., Locy Hall, Evanston, IL 60208, United States

We apply the concept of the mantle magnitude M sub m, developed by Okal and Talandier [1989], to tsunami records obtained by ocean-bottom pressure sensors of the DART project. Our goal is to devise an algorithm to use these tsunami waveforms on the high seas, unaffected by the later interaction of the wave with coastlines, to infer the characteristics of the parent earthquake in the ultra-low frequency band, which may be improperly rendered by seismic mantle waves. Because tsunamis constitute a branch of the spheroidal oscillations of a self-gravitating Earth, it is straightforward to apply normal mode theory in order to derive a simple variant of the M sub m algorithm, to be used with tsunamis. The source correction is predicted from the theoretical expression of normal mode excitation coefficients in the range 300-6000 seconds. The distance correction is simplified from the case of seismic waves by the elimination of the effect of anelasticity (finite Q) which becomes irrelevant in the case of tsunami waves. The locking constant, still predicted theoretically, is simply adapted to the measurement of a different physical quantity – pressure rather than displacement, and to the choice of units. We will present examples of computation of M sub TSU from actual records at DART stations.

OS21A-06 0930h

1992-2002: Perspective on a decade of tsunami field surveys

Emile A. Okal[1] (emile@earth.nwu.edu)

Costas E. Synolakis[2] (costas@mizar.usc.edu)

Jose C. Borrero[2] (jborrero@mizar.usc.edu)

. Members of ITST[3]

[1]Northwestern Univ., Locy Hall, Evanston, IL 60208, United States

[2]Dept. Civil Engineering, Univ. Southern Calif., Los Angeles, CA 90089, United States

[3]All, over, the world

The past decade has seen the systematic deployment of international field survey teams (ITST), following damaging regional tsunamis. Fourteen such surveys have been carried out: Nicaragua (1992), Okushiri (1993), Mindoro (1994), Java (1994), Flores (1994), Kuriles (1994), Mexico (1995), Biak (1996), Chimbote (1996), PNG (1998), Izmit (1999), Fatu Hiva (1999), Vanuatu (1999), Peru (2001) and PNG (2002). In addition, similar techniques have been applied to the survey of important historical tsunamis such as Aleutian (1946) and Amorgos (1956). The primary goal of the field surveys is to obtain a reliable, quantitative dataset of run-up and inundation measurements, which can be used in simulation experiments based on hydrodynamic modeling, in order to unravel the mechanism of generation of the tsunami. One of the most important results obtained from the compilation of such datasets has been the emergence of the aspect ratio of the distribution of run-up in the near field as a most promising discriminant between generation by the seismic dislocation (e.g., Nicaragua; Peru, 2001; PNG 2002) and by an underwater slump (e.g., Aleutian 1946, PNG 1998). Surveying also reveals localized enhancement of run-up, controlled on a smaller scale by occasional underwater landslides (Flores, 1992), splashes against cliffs (Mexico, 1995; Peru, 2001) or interaction with steep coastal valleys (Okushiri, 1993). Field surveys have also provided insight into engineering and societal factors controlling the extent of human and property losses, such as coastal land use, building codes and materials, and public education and awareness. To foster the latter, the teams constantly repeat simple messages on tsunami mitigation during one-on-one interviews with local residents, as well as town meetings. In this respect, the successful self-evacuation at Bay Mairtele, Vanuatu in 1999 is a gratifying example of the value of education.

OS21A-07 0945h

Field Survey of the 30 December 2002 Stromboli Tsunami

Stefano Tinti[1] ((39)05120-95025; steve@ibogfs.df.unibo.it); Anna Manucci[1] ((39)05120-95059; anna@ibogfs.df.unibo.it); Gianluca Pagnoni[3] ((39)05120-95003; anna@ibogfs.df.unibo.it); Emile A Okal[2] ((1) 847 491 3194; emile@earth.nwu.edu); Ahmet Yalciner[3] ((90) 847 471 0006; yalciner@metu.edu.tr); Costas Emmanuel Synolakis[4] (213 740 5129; costas@usc.edu)

[1]Univesita di Bologna, Dipartimento di Fisica, Settore di Geofisica, Bologna 40127, Italy

[2]Northwestern University, Department of Geological Sciences, Evanston, ILL 60208, United States

[3]Middle East Technical University (METU), Department of Civil Engineering, Ankara 06531, Turkey

[4]University of Southern California, Department of Civil Engineering, Los Angeles, CA 90089, United States

On December 30, 2002 a series of slumps occurred in Stromboli, an active volcanic island in the Tyrrhenian sea, north of Sicily, Italy. The slumps triggered a moderate tsunami, that struck the village of San Vincenzo in the island with very destructive waves. The mass movements originated from magma intrusion, opening of new vents and lava accumulation in Sciara del Fuoco in the NW side of the island, and lava flows to the sea were continuing at least up to late June. The tsunami was reportedly noticed as far as the Straits of Messina. We present observations from one of four field surveys of the Stromboli 2002 event from Stromboli and Panarea and we report inundation measurements. Earlier surveys by al. (2003), Maramai et al. (2003) have allowed for the modelling of Tinti et (2003), while Fumihiko Imamura (pers. comm.) also surveyed the site and provided measurement. We attempt to approximately model the source of the tsunami and find that it refracted around the island, Fatu Hiva like (Okal et al, 2002). Maramai, A., Tinti, S., Graziani, L., Armigliato, A., Pagnoni, G., Manucci, A., Zaniboni, F., 2003, *Quantitative observations of the physical effects of the Stromboli tsunami occurred on December 30, 2002*, paper EAE03-A-09880, Geophysical Research Abstracts, Vol.5, EGS (abstract). Okal, E.O., Fryer, G.J., Borrero, J.C., Ruscher, C., 2002, *The landslide and local tsunami of the 13 September 1999 on Fatu Hiva* , Bull. Soc. Geol. Franc., 359-367. Tinti, S., Pagnoni, G., Zaniboni, F., Armigliato, A., 2003, *Simulations of the 30 December 2002 Stromboli tsunami, Italy,* paper EAE03-A-10994, Geophysical Research Abstracts, Vol.5, EGS (abstract).

OS21B MCC: Level 2 Tuesday 0830h

The Arctic and North Atlantic Oscillations: Past, Present, and Future II Posters *(joint with A, H, PP, C)*

Presiding: **D A Darby,** Old Dominion University**; L Mysak,** McGill University

OS21B-1120 0830h POSTER

The not so ice-free Norwegian sea, and its Connection to the Arctic Ocean

Jens F Bischof (7576835987; jbischof@odu.edu)

Dennis A Darby (7576834701; ddarby@odu.edu)

The Norwegian Sea is usually considered ice-free year round. It thus came as a surprise that Holocene pelagic sediments more than 700 km south of the maximum ice margin and 400 km from the nearest land contained in part large quantities of coarse, ice rafted rock and mineral fragments. The quantities of these grains drop from an early Holocene maximum to a mid-Holocene minimum, corresponding to a powerful Norwegian Current, and then rise again to the present. The composition of these grains is incompatible with a derivation from Norway or Iceland, and is also profoundly different from debris deposited by the East Greenland Current. The presence and type of coal places its origin to either the East Siberian Islands or to NW Alaska. In either case, the grains document a strong, periodic southward extension of the Transpolar Drift. Cores from the western Arctic Ocean replicate this pattern in an opposite sense, from an early Holocene low to a mid-Holocene high and back. Superimposed on this long-term dynamic are shorter directional changes at ca. 1000 year spacing, documented by highs and lows in the abundance of chert. The Arctic ice intrusions into the Norwegian Sea most likely occur on much shorter time scales, perhaps on the order of only a few decades.

OS21B-1121 0830h POSTER

High Latitude Climate Variability During the Last Glacial Maximum

Camille CM Li[1] (camille@atmos.washington.edu)

Summer Rupper[2] (sbr3@u.washington.edu)

Justin J Wettstein[1] (justinjw@atmos.washington.edu)

Eric J Steig[2] (steig@ess.washington.edu)

David S Battisti[1] (david@atmos.washington.edu)

[1]Department of Atmospheric Sciences, University of Washington, 408 ATG Building, Box 351640, Seattle, WA 98195, United States

[2]Department of Earth and Space Sciences, University of Washington, 63 Johnson Hall, Box 351310, Seattle, WA 98195, United States

The annular modes are instrinsic patterns of variability in the extratropical atmospheric circulation observed in both the Northern and Southern Hemispheres.

OS

Research into the possibility of climate forcings projecting onto these annular modes has generated much excitement in recent years. Many studies to date have focused on the forced response of the annular modes to anthropogenic CO_2 and ozone changes over the past few decades as suggestive of potential future climate outcomes. There have also been attempts to describe the variability in proxy records of past climate in terms of preferred phases of the annular modes. However, most of this work has assumed that the spatial signatures of the annular modes have remained stationary over time despite changes in the mean state of the climate system. Due to insufficient paleoclimate records and the complicated relationships between their proxy variables and measured variables (such as temperature and precipitation), observations are typically inadequate to resolve the issue of stationarity. In this study, we address the issue through general circulation model simulations of the last glacial maximum (LGM). The LGM (21 kyr BP) presents an opportunity to explore the sensitivity of climate variability patterns during a relatively well-documented interval of Earth's history in which the climate system was significantly altered by the presence of large, land-based ice sheets in the Northern Hemisphere. We ran a series of experiments using the NCAR CCM3.6 with LGM orbital parameters, CO_2 levels, and topography coupled to a data ocean of CLIMAP sea surface temperatures (SSTs) and found Northern Hemisphere high latitude variability to be qualitatively different than that in the modern day. As there is uncertainty over details of the glacial world, we explored the sensitivity of the leading mode of variability to changes in ice sheet topography and tropical SST patterns. Preliminary results indicate that key factors include the influence of the Laurentide ice sheet on stationary waves in the Northern Hemisphere, and the influence of the tropical ocean on teleconnections to the midlatitudes. The range of possible spatial patterns found under different boundary conditions has interesting implications for the interpretation of paleoclimate data. Future work will aim to use these results as an objective platform on which to test the many and varied hypotheses invoked to explain climate variability on a range of time scales.

OS21B-1122 0830h POSTER

A Physically Consistent Long-term Reconstruction of the Northern Annular Mode Using Tree Rings

Justin J Wettstein[1] ((206)685-3602; justinjw@atmos.washington.edu)

John M Wallace[1] ((206)543-7390; wallace@atmos.washington.edu)

[1]Joint Institute for the Study of Atmosphere and Ocean, University of Washington Box 354235, Seattle, WA 98195, United States

The Northern Annular Mode has a robust wintertime surface temperature signature that is used here to generate a physically plausible Northern Annular Mode reconstruction based on select tree species responsive to winter temperature. Ring width data from these species is shown to adequately record local temperature conditions in regions where the Northern Annular Mode surface temperature signal is especially strong. Cross-validated results for the reconstruction compare favorably with existing North Atlantic Oscillation reconstructions and are straightforward to physically interpret. Using other annually-resolved proxy data to extend this work may more clearly describe the evolution of Northern Hemisphere climate variability and imply physical constraints to the range of possible future climate outcomes.

OS21B-1123 0830h POSTER

Multi-Century Greenland Ice Sheet Accumulation Variability and the North Atlantic Oscillation

Mary F Glueck[1] (520-621-9108; maryg@hwr.arizona.edu)

Roger C Bales[2] (209-724-4348; rbales@ucmerced.edu)

[1]Department of Hydrology and Water Resources, University of Arizona, P.O. Box 210011, Tucson, AZ 85737, United States

[2]School of Engineering, University of California, Merced, P.O. Box 2039, Merced, CA 95344, United States

The Greenland Ice Sheet is a unique natural recorder of climate variability in the North Atlantic region. However, limitations in data coverage have made it difficult to obtain an overall assessment of accumulation and accumulation-climate relationships across the Greenland Ice Sheet. We have investigated accumulation variability across the ice sheet and accumulation-climatic index (e.g., North Atlantic Oscillation) relationships using a recently compiled, comprehensive, high-quality set of annually dated multi-century Greenland ice sheet accumulation records. The series include primarily data from recent multi-century cores, records from Danish archives, and other historical coring efforts from across Greenland. The common period of record for the 35 multi-century series initially available is 1966-1781 (core dates range from 1998 to the past several millennia). Based on similarities evident in core-core comparisons, geographic location, and core-NAO relationships, we reduced the 35 initial accumulation series to 21 representative series. Core-core correlations between the final series indicate that when significant correlations exist, they tend to be strongest in the 1850-1950 period. However, in general, sliding correlation analysis indicates that correlation strength varies noticeably over time and between cores. Significant correlation is also apparent between the annual NAO and multiple accumulation series. Specifically, the highest significant NAO-accumulation correlations were obtained for Azores-Iceland NAO indices and accumulation series from central and northwest Greenland (r = -0.26 to -0.34). Based on statistical analysis of similarities in accumulation characteristics, the 21 series can also be clustered into regional groups and stacked to form eight composite regional series, six of which include at least 700 years of data (common period: 1244-1984). Results of our initial NAO-regional composite series analyses indicate that the west-central and northwestern regions are most strongly correlated with the annual instrumental NAO while the southern series shows only weak correlation with NAO.

OS21B-1124 0830h POSTER

Summer Circulation in the Barents Sea Derived as a Variational Inverse of the Climatological Data

Gleb Panteleev[1] (gleb@iarc.uaf.edu)

Dmitri Nechaev[2] ((228) 688 2573; dnechaev@ssc.usm.edu)

Motoyoshi Ikeda[3] (mikeda@ees.hokudai.ac.jp)

[1]University of Alaska Fairbanks, 930 Koyukuk Dr.,P.O. Box 757335, Fairbanks, AK 997775, United States

[2]University of Southern Mississippi, Department of Marine Science, Stennis Space Center, MS 39529, United States

[3]Department of Earth and Environmental Sciences, Hokudai University, Sapporo 065, Japan

The time dependent summer (July, August, September) circulation in the Barents Sea is reconstructed from climatological data via data assimilation procedure into non-linear ocean circulation model. Data assimilation includes three steps. First, for each month of climotological data, optimal open boundary conditions are defined through the 3-dimensional variational data assimilation into a steady state version of the model. The obtained set of open boundary conditions is interpolated linearly for the whole summer period. These open boundary conditions together with climatological surface fluxes data are utilized to prepare a time-dependent first guess solution for 4d variational data assimilation. Finally, the optimal non-stationary summer circulation is derived as a variational inverse of the available hydrophysical data and non-linear ocean circulation model, controlled through the initial, surface and open boundary conditions. The obtained hydrophysical fields are dynamically balanced within the frames of the applied model and can be treated as an optimal summer state of the Barents Sea.

OS21B-1125 0830h POSTER

Role of the Polar-night Jet Oscillation on the formation of the Arctic Oscillation in the northern hemisphere winter

Yuhji Kuroda[1] (+81-29-853-8603; kuroda@mri-jma.go.jp)

Kunihiko Kodera[1] (kodera@mri-jma.go.jp)

[1]Meteorological Research Institute, 1-1 Nagamine, Tsukuba 305-0052, Japan

The coupling between the Polar-night Jet Oscillation (PJO) and the Arctic Oscillation (AO) was examined using observational data. It was found that positive and negative AO indices tend to appear with a specific phase of the time evolution of the PJO, and the lifetime of the AO tends to be longer when the AO is coupled with the PJO. To examine how the AO signal appears with the time evolution of the PJO, we performed lagged regression analysis for the Eulerian mean wave forcing. It is found that the AO signal is created through the meridional circulation driven by a combination of mechanical and thermal eddy forcing at the AO stage. Approximately 40% of the polar sea-level pressure (SLP) change comes from thermal forcing, and half of it comes from the stratosphere, whereas 60% of the polar SLP change comes from the mechanical forcing that originates in the troposphere. In both forcings, the contribution from the wave of the zonal wavenumber 1 component is very important, especially for the SLP in the polar cap region. Waves of zonal wavenumber 2 and 3 components also have significant contributions for the tropospheric forcing. This is in contrast with the typical AO, which is driven almost solely by the mechanical forcing of wavenumber 2 and higher waves.

OS21B-1126 0830h POSTER

Impact of the Wintertime NAO on the Summertime Atmospheric Circulation and its Solar Cycle Modulation

Masayo Ogi[1] (ogi@ees.hokudai.ac.jp)

Koji Yamazaki[1,3] (yamazaki@ees.hokudai.ac.jp)

Yoshihiro Tachibana[2,3] (tachi@rh.u-tokai.ac.jp)

[1]Graduate School of Environmental Earth Science, Hokkaido University, Kita-10, Nishi-5, Sapporo 060-0810, Japan

[2]Liberal Arts Education Center, Tokai University, Kitakaname 1117, Hiratsuka 259-1292, Japan

[3]IARC, FRSGC, Kanazawa-ku, Showa-machi, Yokohama 236-0001, Japan

The summer high-latitude climate in the Northern Hemisphere is influenced by the NAO of the previous winter. We find this influence in the summertime surface air temperature, the geopotential height, the sea surface temperature (SST), sea-ice/continental snow cover extent fields as well as in the zonal mean geopotential height and zonal wind fields. This summertime NAO signal is annular but its meridional scale is much smaller than the winter annular mode. We suggest that the sea-ice, SST and snow cover anomalies provide the memory allowing the winter NAO to affect the summer climate. In addition, the 11-year solar cycle modulation of the winter-to-summer linkage is examined. During the solar maximum years, the winter NAO has a significant relation with the spring-summer climate, while the linkage is very weak during the solar minimum years. During the solar maximum years, the winter NAO affects spring snow cover over the Eurasian continent and sea ice over the Barents Sea.

OS21B-1127 0830h POSTER

Seasonal variation of the northern hemisphere annular mode and its winter-to-summer linkage

Koji Yamazaki[1,3] (yamazaki@ees.hokudai.ac.jp)

Masayo Ogi[1] (ogi@ees.hokudai.ac.jp)

Yoshihiro Tachibana[2,3] (tachi@rh.u-tokai.ac.jp)

[1]Graduate School of Environmental Earth Science, Hokkaido University, Kita-10, Nishi-5, Sapporo 060-0810, Japan

[2]Liberal Arts Education Center, Tokai University, Kitakaname 1117, Hiratsuka 259-1292, Japan

[3]IARC, Frontier Research Systems for Global Change, Kanazawa-ku, Showa-machi, Yokohama 236-0001, Japan

The seasonal variations of the Northern Hemisphere annular mode (NAM) are examined by applying an empirical orthogonal function (EOF) analysis of the zonally averaged geopotential height fields for each calendar month separately. The summer NAM has a smaller meridional scale compared to the winter mode. In summer, the Arctic action center of the NAM is located over the Arctic Ocean, while in winter it is located over Greenland. The winter NAM affects the following summer atmospheric circulation, and this summer pattern linked to the winter NAM is similar to the summer NAM. The winter-to-summer linkage is interpreted as a preferable transition from one phase of the winter-dominant mode to the same phase of the summer-dominant mode.

OS21B-1128 0830h POSTER

A "nodal line" in tropical SST forcing of the North Atlantic Oscillation and its implications.

Joseph J Barsugli[1] (303-497-6042; joseph.barsugli@colorado.edu)

Sang-Ik Shin[1] (sangik.shin@noaa.gov)

Prashant D Sardeshmukh[1] (prashant.d.sardeshmukh@noaa.gov)

[1]Climate Diagnostics Center, University of Colorado, 325 Broadway, Boulder, CO 80305, United States

The sensitivity of Northern Hemisphere circulation patterns, including the North Atlantic Oscillation (NAO), to tropical SST changes is investigated using

the NCAR CCM3.10. An array of localized SST anomalies is specified throughout the Tropics, and the responses to these experiments are summarized in "sensitivity maps" (e.g. Barsugli and Sardeshmukh, J. Climate, Dec. 2002). For the JFM season we find that warm SST anomalies in the Indian Ocean lead to a circulation pattern which projects onto the NAO and AO patterns. In contrast, warm SST anomalies in the western Pacific warm pool produce roughly the same pattern with opposite polarity. This circulation pattern is associated with large surface air temperature anomalies that have a non-zero global mean. SST anomalies in the tropical Atlantic produce an atmospheric response over the North Atlantic which, even though it projects onto the NAO, is structurally quite different. The relevance of these sensitivities is confirmed when limited regions of the observed 1950-1999 SST trend patterns are used to force the GCM. The global trend patterns that are tropically forced result mainly from cancellation of the responses to SSTs in the Indian and western Pacific Oceans. The implication is that regional patterns of climate change, and even the global mean signal, will depend sensitively on the spatial pattern of historical and projected SST change across a "nodal line" of sensitivity separating the tropical Indian and Pacific Oceans.

OS21B-1129 0830h POSTER

Dynamical Nonlinearity in the Atmospheric Response to Atlantic Sea Surface Temperature Anomalies

Walter A Robinson[1] (217 333-2292; robinson@atmos.uiuc.edu)

Shuanglin Li[2] (shuanglin.li@noaa.gov)

Shiling Peng[2] (Shiling.Peng@noaa.gov)

[1]Department of Atmospheric Sciences University of Illinois at Urbana-Champaign, 105 South Gregory Street, Urbana, IL 61801, United States

[2]NOAA-CIRES Climate Diagnostics Center, R/CDC1 325 Broadway, Boulder, CO 80305-3328, United States

Large ensembles (100 members) of atmospheric general circulation model experiments are forced throughout the Northern Hemisphere cold season by four different sea surface temperature (SST) fields: the observed climatology, the so-called SST tripole pattern, and its subcomponents. Late winter responses to the component anomalies are of modest amplitude but are, because of the large ensemble size, significant. Despite their modest amplitudes, the responses display additive nonlinearity, in that the sum of the separate responses to the component anomalies differs significantly from the response to the tripole. Neither the heating field nor the basin averaged zonal winds display this nonlinearity. It is most evident in a sub-basin scale wave train, and most significant in its impact on the amplitude of the geopotential response. These results indicate that even for modest forcing, responses to patterns of SST anomalies cannot necessarily be understood as the sums of responses to constituent anomalies.

OS21B-1130 0830h POSTER

Granger Causal Analysis between the NAO and SSTs in the North Atlantic basin

Weile Wang[1] (617/358-3233; wlwang@bu.edu)

Bruce Anderson[1] (617/353-4807; brucea@bu.edu)

Robert K. Kaufmann[1] (617/353-3940; kaufmann@bu.edu)

Ranga B. Myneni[1] (617/353-5742; rmyneni@bu.edu)

[1]Boston University, Department of Geography, 675 Commonwealth Avenue, Room #457, Boston, MA 02215

This paper uses Granger causality test techniques to investigate the causal order of the air-sea interactions between the anomalous NAO index and the NCAR/NCEP SST anomalies over the northern hemisphere. Compared to the simple lead/lagged correlation, the Granger causality analysis is generally more reliable since it ensures that any apparent oceanic influence upon the atmosphere is uniquely provided by the ocean and is not related to preceding anomalies in the atmosphere itself (and vice versa when looking at the atmospheric influence upon the ocean). Using this technique, it is found that on seasonal timescales, preceding SST anomalies around the Gulf Stream region show significant Granger causality with the wintertime NAO. In contrast, the preceding NAO anomalies' influence on the wintertime SST field is rather restricted. Additional findings show that regions of the SST field can cause up to 20% of the variance in the winter NAO. Importantly the regions that show significant causality with the wintertime NAO are limited to the Gulf Stream extension. In contrast to simple correlation analysis, our analysis does not show significant causality related to SST anomalies in either the Greenland or subtropical regions. These results suggest that the Gulf Stream SSTs have an important influence in initiating disturbances of the atmospheric circulation over the wintertime North Atlantic. The dynamics related to this influence still need to be investigated further.

OS21B-1131 0830h POSTER

The wintertime AO influence on early season Indian Ocean Monsoon intensity

Wolfgang Buermann[1] (510-6439371; buermann@atmos.berkeley.edu)

Benjamin R. Lintner[1] (ben@atmos.berkeley.edu)

Celine J. Bonfils[1] (celine@atmos.berkeley.edu)

[1]Berkeley Atmospheric Sciences Center and Department of Earth and Planetary Sciences, 395 McCone Hall, University of California, Berkeley, CA 94720, United States

The Indian Ocean Monsoon (IOM) exhibits considerable year-to-year to variations that have previously been attributed to a number of forcing mechanisms including the El Niño/Southern Oscillation (ENSO) and Eurasian snowcover anomalies. In this study, we analyze spatial data of Eurasian spring land surface temperatures, summer IOM precipitation, and summer IOM 850 mb zonal winds for the 1979-99 period to isolate well correlated modes of variability. The results indicate the existence of a prominent mode that appears to be related to the boreal winter Arctic Oscillation (AO); this mode projects strongly on the June precipitation and 850 mb zonal wind fields in the vicinity of the IOM region. Its projection on the temperature fields shows springtime surface warming and drying in the region to the north and west of the Indian subcontinent and cooling over the higher Eurasian latitudes during years of anomalously intense June monsoon rainfall. Such surface signatures are consistent with the negative phase winter AO. It is hypothesized that preconditioning of the spring season surface conditions may be associated with an AO-induced quasistationary tropospheric circulation anomaly: the impact of this anomaly is to displace the mid-Eastern jet polewards during AO-negative phases, resulting in anomalous surface heating and drying that persists into the later spring season and finally affects the rainfall over the IOM region in June.

OS21C MCC: Level 2 Tuesday 0830h

Changes in the Heat and Fresh Water Budget of the Ocean From Decades to Centuries III Posters *(joint with H, C, GC)*

Presiding: **I Yashayaev,** Bedford Institute of Oceanography**; A Proshutinsky,** Woods Hole Oceanographic Institution**; B Dickson,** Centre for Environment, Fisheries and Aquaculture Science**; R W Schmitt,** Woods Hole Oceanographic Institution

OS21C-1132 0830h POSTER

Ocean Evidence for a Shifting Atlantic Fresh Water Balance Over the Past Four Decades

Ruth G. Curry[1] (508-289-2799; rcurry@whoi.edu)

Robert R Dickson[2] (r.r.dickson@cefas.co.uk)

Igor Yashayaev[3] (YashayaevI@mar.dfo-mpo.gc.ca)

[1]Woods Hole Oceanographic Institution, MS #21, Woods Hole, MA 02543, United States

[2]CEFAS, Pakefield Rd, Lowestoft NR33 OHT, United Kingdom

[3]Bedford Institute of Oceanography, BIO, Dartmouth, NS B2Y 4A2, Canada

Two long meridional transects through the western and eastern deep basins respectively are used to investigate salinity differences throughout the water columns of the North and South Atlantic Ocean over the past forty years. Toward both poleward limits of these sections we observe freshening over much of the water column, while within the intervening tropics and subtropics, the upper water column in particular has become markedly more saline. Where the dataset permits, it supports the idea that this growing contrast between high and low latitudes is the result of a progressive, if non-steady, evolution throughout the time period examined. For the low latitudes, an evaluation of the amount of annual fresh water loss that could be attributed to evaporation-minus-precipitation (E-P) changes suggests a 5-10% increase in net evaporation rates in recent decades. The radical freshening of the Northern subpolar seas is linked, at least in part, to enhanced efflux of ice and freshwater from the Arctic. In the South Atlantic, freshening is observed in the watermasses that are ventilated in regions where precipitation dominates evaporation. Combined with recent studies in the Mediterranean, Indian and Pacific Oceans, the present investigation extends the evidence that shifts in ocean salinity and fresh water distributions are occurring globally in ways that could reflect an amplification of the hydrologic cycle in recent decades.

OS21C-1133 0830h POSTER

Changes in the deep and intermediate waters of the sub-polar gyre of the North Atlantic since the 1950s

Allyn Clarke[1] ((902) 426-4880; clarkea@mar.dfo-mpo.gc.ca)

Igor Yashayaev[1] ((902) 426-9963; yashayaevi@mar.dfo-mpo.gc.ca)

[1]Bedford Institute of Oceanography, 1 Challenger Drive, P.O.Box 1006,, Dartmouth, NS B2Y 4A2, Canada

A retrospective analysis of water mass properties along the northern boundary of the North Atlantic shows that the sustained freshening of the deep waters during the past 4 decades was preceded by a decade of increasing salinity (the late 1950s through the late 1960s). These decadal-scale signals can be traced from the various sills around the sub-polar gyre to the Newfoundland Basin, however the interannual oscillations seen in the Denmark Strait Overflow Water (DSOW) in the upstream regions fade out after the overflow passes south of Flemish Cap. This highlights a key role of the deep inter-gyre recirculation in the southward transport of cold and fresh waters. Successive hydrographic sections indicate that the volume of DSOW increases after entering the Newfoundland Basin while its vertical stratification decreases. Both this volume increase and the smoothing out of the interannual variation in properties are likely a consequence of further entrainment and mixing of DSOW in the Newfoundland Basin that is associated with recirculation in the deep layers. Maps of temperature and salinity on selected density surfaces for different decades show how the recent freshening of the deep layers is carried around the subpolar gyre by the deep western boundary current and is then returned to the northeast by the North Atlantic Current. The freshening has extended into the subtropical gyre and is also being returned to the subpolar gyre through the Gulf Stream - North Atlantic current exchange. While the dramatic salinity changes in the water mass properties are, to a large extent compensated by inverse changes in their temperatures, there have also been profound changes in the density distributions in the sub-polar gyre. The thickness of the density layer associated with the Labrador Sea waters have increased significantly between the 1960s and the 1990s. The waters in the upper 1.5 km have become denser while those deeper than 2 km have become less dense as this thick mass of intermediate water formed in the early 1990s has displaced the waters both lighter and denser than itself. Since these changes are largely confined to the sub-polar gyre, they impact the strength and deep structure of the North Atlantic current. By comparing volumetric T-S analysis of the subpolar gyre from the 1960s and the 1990s, we estimate that the average gain of fresh water over the intermediate to bottom waters exceeds 4 metres. The Labrador Sea Water has gained about 2.52 metres, while the Northeast Atlantic Deep and DSOW have gained 0.63 m and 0.31 m, respectively.

OS21C-1134 0830h POSTER

Modelling changes in the North Atlantic caused by long-term variability in freshwater input

Igor Yashayaev[1] ((902) 426-9963; yashayaevi@mar.dfo-mpo.gc.ca)

Youyu Lu[1] ((902) 426-9963; luy@mar.dfo-mpo.gc.ca)

Dan Wright[1] ((902) 426-9963; wrightdg@mar.dfo-mpo.gc.ca)

[1]Bedford Institute of Oceanography, 1 Challenger Drive, P.O.Box 1006,, Dartmouth, NS B2Y 4A2, Canada

Our recent studies have revealed a large scale freshening in the North Atlantic since the 1960s and documented the contemporaneous changes in the density