equatorial eastern Pacific. However, high SST anomalies existed in the equatorial central Pacific from boreal summer to autumn in 1994, and the same characteristics of the atmospheric variables as the El Niño years were found over the Pacific and the Indian Ocean. The results of our analyses indicate that the IODM triggered by the high SST anomalies over the equatorial central and eastern Pacific exists.

OS12C-167 1330h POSTER

Sub-seasonal, Seasonal and Interannual variability of western Arabian Sea Surface Temperature

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During the Southwest Monsoon strong upwelling and distinctive oceanic eddy structures form adjacent to and off of the coast of Somalia and further north in the Arabian Sea. Research vessel cruises have identified very cold water (<20°C) in filaments and fronts in this area, but our knowledge of their space-time structure and evolution is incomplete. These structures appear in high-resolution ocean general circulation model simulations, but are not present in the NCEP SST weekly analysis.

Using the TRMM microwave SST data we provide a view of these structures and their evolution, in weekly SST. The satellite data indicate that both the climatological seasonal cycle of SST and its interannual variability are larger than indicated from COADS or the NCEP SST product. Based on the TRMM microwave SST, accurate monthly mean SST over the western Indian Ocean can be obtained only if the cold feature data are incorporated. Interannual variability of the ocean processes that control the spin up and evolution of the "Great Whirl" and other western Indian Ocean eddy structures may thus determine interannual SST variability in the region.

Our present understanding of the low frequency variance of SST in the region and the covariability of SST over the Indian basin need to be revisited in light of these results.

OS12C-168 1330h POSTER

Vertical Structure of Mesoscale Ocean Currents: LADCP observations in the Indian Ocean

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Simple linear Rossby wave theory suggests that most of the open-ocean geostrophic velocity field, primarily mesoscale eddies, should have a first baroclinic mode vertical structure, and that the barotropic and baroclinic modes should be uncorrelated with each other in space and time. Surveys of moored current meter records by Davis, Wunsch, and others have suggested, however, that the barotropic and first baroclinic modes are in fact correlated; the first baroclinic mode alone is not a good approximation to the dominant vertical structure of ocean eddies. In the present study, we revisit this topic through vertical normal mode and empirical orthogonal function (EOF) analysis of 523 lowered ADCP (LADCP) profiles from the WOCE Hydrographic Program survey in the Indian Ocean. Profiles in water less than 4000 m deep are excluded. At high latitudes, most of the LADCP kinetic energy is in the barotropic mode; in mid latitudes, the barotropic and baroclinic modes each contain about 25% of the total; and near the equator the energy is spread into higher modes, with a weak peak in the second mode at the equator. In middle and high latitudes, the barotropic and the first baroclinic mode are correlated. The first EOF mode, with 80% of the variance in the Southern Ocean and 42% of the variance in latitudes from 5–35°, resembles a sum of barotropic and first baroclinic modes, with the velocity decreasing throughout the water column from its maximum at the surface. In middle latitudes the first EOF velocity decays to zero near the bottom of the profile, but in high latitudes it remains in the direction of the surface velocity throughout the water column.

OS12D HC: Hall III Monday 1330h

Synthesis of the Arabian Sea Expeditions II

Presiding: **S L Smith,** University of Miami

OS12D-169 1330h POSTER

Biophysical Modeling of Plankton Dynamics off Somalia and Oman

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A nutrient-phytoplankton-zooplankton-detritus (NPZD) model is coupled to the Miami Isopycnic Coordinate Ocean Model (MICOM) configured for the Arabian Sea. The physical model is a primitive equation model consisting of 16 layers, including an upper mixed layer (UML), which is forced by monthly atmospheric climatologies. The NPZD model consists of a set of local conservation equations, which are coupled by the predator-prey dynamics. Namely, the growth rate of phytoplankton depends on nutrient concentration and diurnally varying light penetration. Zooplankton feeds on phytoplankton, zooplankton and detritus. The maximum growth of phytoplankton, and zooplankton feeding and metabolism are functions of temperature. Detritus, consisting of zooplankton fecal pellets and senescent phytoplankton, is allowed to sink in the model. Nutrient is regenerated from zooplankton excretion and the remineralization of detritus.

The model is able to clearly reproduce nutrient upwelling and phytoplankton/zooplankton blooms off the coasts of Somalia and Oman during the summer Southwest Monsoon. Off of Somalia, coastal upwelling begins in May as the Great Whirl develops leading to elevated concentrations of phytoplankton and zooplankton in the UML. As the monsoonal atmospheric forcing progresses, filaments of high phytoplankton and zooplankton concentrations develop in the UML that extend eastward (offshore of the coast) during June. Off the coast of Oman, upwelling of nutrients begins in May but is less extensive than occurs off the Somali coast in the UML. Areal extent of the phytoplankton/zooplankton bloom increases as the Southwest Monsoon progresses, with filament formation of high phytoplankton and zooplankton concentrations extending southward and offshore of the coast. During the Northeast Monsoon period, phytoplankton blooms were occurring in December and January in the southern Gulf of Oman and off the eastern Omani coast in the Arabian Sea. Offshore blooms developed along the equator in the winter months. We discuss the implications of physical forcing on plankton dynamics in the Arabian Sea where the system is dominated by seasonally reversing atmospheric conditions.

OS12D-170 1330h POSTER

Episodic Primary Production and Export Carbon Fluxes in the Arabian Sea

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A continuous bio-optical assessment of ocean productivity in the central Arabian Sea by WHOI ASI mooring demonstrated that the primary production was dominated by a succession of short-lived, intense blooms. The timing and relative amplitude of the primary production closely matched the time-series variability of export flux of organic, inorganic carbon and biogenic silica in the oceans interior. This study suggests that primary production in other world oceans must also be episodic as seen in the majority of long-term, time-series export flux data gathered globally. Peaks in primary production were observed with the passage of eddies and in association with the re-stratification and shoaling of the mixed layer. Infrequent ship-board primary production measurements that currently define our understanding of CO2 often fail to detect intense blooms. The large organic carbon export event that peaked during the 8. 5-day sampling interval between March 11 and 19 observed at both the 2229-m and 3474-m traps corresponded to the primary production bloom that peaked on March 11. This shows that the particulate organic carbon that settled from this bloom reached the 3. 5-km-deep layer within one 8. 5-day open period. The cumulative primary production from October 15, 1994 to October 20, 1995, as estimated by the bio-optical method, is 37.7 moleC m-2. However, the organic carbon export collected at the 2229-m and 3578-m trap from November 11, 1994 to December 25, 1995 is 346 and 294 mmoleC m-2, respectively.

OS12D-171 1330h POSTER

An Analysis of the Arabian Sea Surface Heat Budget Using Satellite and In-Situ Multiannual Data Sets

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The air-sea interaction of the Arabian Sea is investigated in an analysis of the heat budget from a variety of satellite measurements and in-situ data sets. An improved understanding of the surface heat budget is important in understanding the evolution of the sea surface temperature (SST) and its spatio-temporal variations. These variations are influenced by surface current heat transfers, solar energy absorption, evaporative cooling due to high winds, and upwelling. In the Arabian Sea all of these phenomena are a function of space and time, and the heat budget reflects the monsoonal circulation.

Multi-year estimates of monthly fields representing the spatial and temporal structure of the various components of the heat budget of the Arabian Sea throughout a year are constructed from the following interannual monthly averaged atmospheric and oceanic data sets: Pathfinder (SST from 1985-1995); CZCS (water leaving radiances from 1979-1986); UWM/COADS (air temperature, humidity, and cloud amount from 1960-1989); FSU (heat fluxes from 1960-1989).

The net radiative heat flux calculated compares well with previous studies (Hastenrath and Lamb, 1979; Duing and Leetma, 1980; Ramanadham et al, 1981; Mc Phaden, 1982; Ray, 1984; Reddy et al, 1984; Rao et al, 1985; Babu et al, 1991; Mohanty et al, 1996; Varma and Kurup, 1996; Prasanna Kumar and Prasad, 1996; Weller et al, 1998). Net radiative heat flux is positive over the entire basin during most of the year. The only radiative cooling occurs in November through January north of 10° N, during May south of 10° N (small cooling), and during June in the central Arabian Sea.

The change in SST due to horizontal surface advection is mostly negative during the northeast monsoon. During the southwest monsoon months, there is advection of cold upwelled waters north of 15° N, and transport of warm surface waters south of 10° N across the basin. Cooling due to entrainment is less than 2 degrees per month for most of the basin during most of the year. Only during July through October does entrainment cool more than 10 degrees per month (along the Somali and Arabian coasts). The effect of advection on SST dominates most of the basin during December through February, and June through August. Entrainment dominates in March through May, and October through November. During September, the center of the basin is dominated by advection, with entrainment dominating the coastal areas.

OS12E HC: Hall III Monday 1330h

Arctic System Studies I

Presiding: **M Baskaran,** Wayne State University

OS12E-172 1330h POSTER

Shelf-Basin Interaction of Pacific-Origin and Atlantic-Origin Waters on the Shelf-Break of the Chukchi Sea: An Approach Using the NO/PO Ratio.

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Modification processes of water masses on the shelf-break of the Chukchi Sea are examined by using the NO/PO ratio. The data used here are collected by the R.V. Mirai in 1999 and 2000 and by the R.V. Alpha Helix in 1996. The World Ocean Database (1998) is also used. The NO/PO ratio is high ($\sim$1) in the Atlantic-origin water and low ($<$0.85) in the Pacific-origin water. Furthermore, the Pacific-origin water has distinct NO/PO ratios within the Chukchi shelf. Therefore, the ratio is a useful tool to understand the water circulation and modification.

First, extension of bottom water of the Barrow Canyon to the Chukchi shelf-break is studied. The Barrow Canyon is one of major pathways of the Pacific-origin water. The bottom water, which is characterized by a vertical minimum of the NO/PO ratio, can be traced to the Chukchi shelf-break just above the upper halocline water (UHW) identified by a vertical nutrient maximum. This indicates that the nutrient maximum layer continuously appears from the bottom of the Barrow Canyon to the UHW in the Canada Basin has different origins between the canyon and the basin. The former water is produced at the bottom of the Barrow Canyon in summer, and the latter water is formed at shelves in winter.

Second, focusing on the difference of the NO/PO ratio between the Pacific-origin and Atlantic-origin waters, mixing of these two waters along the Chukchi shelf-break is investigated. A vertical boundary of the two waters, i.e., a sharp vertical gradient of the NO/PO ratio, appears around 200 m. Taking notice of this boundary, the vertical gradient of the NO/PO ratio is larger in the interior of the Canada Basin than the shelf-break, and the gradient decreases eastward along the shelf-break. That is, the boundary of the Atlantic-origin and Pacific-origin waters becomes obscure toward the east along the shelf-break. This must be the result of vertical mixing of the Atlantic-origin and Pacific-origin waters, the stage of which develops toward the east. The vertical mixing of the two waters, which occurs effectively along the shelf-break, would be due to coastal upwellings of the Atlantic-origin water along the shelf-break.

OS12E-173 1330h POSTER

Circulation of Atlantic and Halocline Waters in the Arctic Ocean

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We discuss the circulation and variability of Atlantic (AW) and halocline (HW) waters in the southern Canadian Basin. The appearance of AW warmer than 1 deg.C was first observed near the Mendeleyev Ridge in 1993 from CCGS Henry Larsen and USS Pargo (Carmack et al., 1995; Morison et al., 1998). During the SHEBA experiment in 1997-1998, this warm variety of AW was found on the flanks of Chukchi Plateau. In 2000, aboard the R/V Mirai, warm AW was observed to reach the southern end of the Northwind Ridge. This gGreat Temperature Anomalyh thus traveled from the Mendeleyev Ridge to the Northwind Ridge in about 7 years, yielding an advective speed of about 1cm/s along the flanks of the Chukchi Borderland. However, direct ADCP current measurements from drifting buoys in two periods (1992-1994 and 1997-1998) show flows of about 3cm/s in both periods, and thus do not match the estimate of the advective speed. On the other hand, the flow on the eastern flanks of the Northwind Ridge was southward at 3cm/s in the 1992-94 data, and northward at 1-2cm/s in the 1997-98 data. This reversal in flow along the ridge may thus explain the difference the advective speed and measured flow. We conclude that the circulation pattern of AW is strongly affected by the depth to which the wind driven circulation penetrates within the water column, and this, in turn, is dependent on ice cover. As the result of such interannual variability, the incoming AW may detach at the northeastern tip of the Northwind Ridge and enter the interior Canada Basin, or it may continue southward the to Alaskan Beaufort shelf slope. Thus, two warm spots of AW may form in the Canada Basin; indeed, such warm spots appear in the EWG Arctic Ocean Atlas. The associated spreading of halocline waters (winter shelf water) of Pacific-origin and Eurasian shelf-origin is also revealed in T/S patterns. Here, lower halocline waters are classified into two types according to the salinity (33psu versus 34psu) at which the upper minimum temperature occurs. The former one is originated from the western Arctic shelf the other from eastern Arctic shelf. These two types of the halocline water are identified by the second vertical derivative of salinity or density (i.e., derivative of potential vorticity). On the other hand, the upper halocline water originated from the summer shelf water in the Chukchi Sea is identified by the second vertical derivative of temperature. We discuss the spreading of both the upper (summer) and lower (winter) halocline waters using CTD data in 1990s and EWG Arctic Ocean Atlas.

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OS12E-174 1330h POSTER

Observationally Based Assessment of Polar Amplification of Global Warming

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Arctic variability is dominated by a low-frequency, multidecadal oscillation (LFO). Incomplete sampling of the large-amplitude LFO results in oscillatory arctic surface-air temperature (SAT) trends. Modulated by the LFO, these trends are amplified relative to northern hemisphere trends. Over the 125-year record we identify periods when arctic SAT trends were actually smaller or of opposite sign than northern hemisphere trends. Arctic and northern hemisphere air-temperature trends during the 20th century (when positive LFO phases nearly offset negative LFO phases) are similar, and do not support predicted two-fold polar amplification of global warming. The potential moderating role of arctic sea-ice, which may act to suppress polar amplification,cannot be conclusively identified with existing data. This analysis reinforces the idea that intrinsic variability in the arctic obscures possible long-term changes, and places a strong limitation on our ability to recognize and identify the complex positive and negative feedbacks in the arctic climate system.

OS12E-175 1330h POSTER

Regional Patterns of Oxygen and Nutrients found in the Russian Arctic Seas

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The Hydrochemical Atlas of the Arctic Ocean holds many of the oxygen, silicate, nitrate, nitrite, phosphate, pH, and alkalinity measurements taken from the Kara, Laptev, East-Siberian and Chukchi seas during the past fifty years. Summer data, which were obtained from the open waters of the shallow Arctic seas, predominate in the data set. During the ice-covered winter, observations were conducted from airborne expeditions and at the coastal observatories. Additionally, unique data from the Laptev Sea were obtained from the Russian-German TRANSDRIFT expeditions (1993-2000).

This report is focuses on typical spatial distributions of the chemical parameters to demonstrate a beauty and complexity of hydrochemical structure of the water column in the well-stratified arctic seas. The theory of structural zones and concepts of water mass formation are applied and developed to explain mosaic pattern of oxygen, nutrients and other chemical parameters distributions. The influence of ice conditions and river run-off on the regional peculiarities of spatial distributions of the hydrochemical parameters is discussed in detail.

Ice conditions (fast ice, polynya, drift ice, ice margin etc.) influence the chemical properties of surface waters and the vertical distributions of oxygen and nutrients. Ocean processes include enormous river run-off, shelf/basin water mass interactions, the advection of the Atlantic and Pacific Waters in conjunction with the complex and variable circulation pattern, and seasonally variable biological conditions. Ice and ocean processes result in the formation of many hydrochemical anomalies: e.g., oxygen supersaturation near ice margins, extreme of oxygen and silicate concentrations in the intermediate structural zone, and oxygen depletion/high nutrient concentrations in the stagnant water masses.

OS12E-176 1330h POSTER

Temperature Evolution in the Arctic Ocean Atlantic Water: 1995 to 2001

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Ocean temperature and salinity have been measured annually from 1995 to 2001 along transects across the central Arctic Ocean using submarine-launched expendable CTD probes. Data from these probes have been integrated with data acquired from surface vessels over the same period. These data, which encompass the major transocean ridges and circulation gyres interior to the Arctic Ocean, are used to assess interannual variations across the basin. The overall trend was for continued warming of the Atlantic Water (AW) layer throughout the period. In particular, AW temperatures increased in the Amundsen and Makarov basins and over the Chukchi Rise in the Canadian Basin. This pattern was however somewhat patchy both spatially and from year to year. For example, some early cooling was evident in the upper 200 m of the AW layer overlying the Lomonosov Ridge and extending slightly into the Makarov Basin, however, the Makarov side of the Lomonosov Ridge showed warming in 2001. Persistent warming in the western Amundsen and Makarov basins probably reflected preferential input to these regions of warmer water from the warm, eastward slope current north of Siberia. Other features, more ephemeral, likely show system responses to fluctuations in the regional wind field and, by association, the Arctic Oscillation.

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