OS12C HC: Hall III Monday 1330h

Indian Ocean and Indonesian Throughflow Variability From Models and Observations II

Presiding: **R Murtugudde,** ESSIC/Univ of Maryland**; J T Potemra,** University of Washington

OS12C-161 1330h POSTER

Coral Radiocarbon as a Tracer for Meridional Transport in the Western Indian Ocean

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The distribution of natural and anthropogenic (bomb) radiocarbon in the ocean is a sensitive indicator of vertical exchange and lateral redistribution of water masses. Radiocarbon measurements in hermatypic corals have been shown to represent radiocarbon levels of dissolved inorganic carbon (DIC) in the water in which they grew, and therefore their skeleton contains a continuous record of surface water radiocarbon. We have made bimonthly AMS-14C measurements on a coral from Watamu on the coast of Kenya (30S, 39E). Pre-bomb (1947-1955) values average -61 per mil with no discernable seasonality. In 1955 values begin to rise in response to increasing atmospheric values as a consequence of atmospheric weapons testing. The post-bomb maximum occurs in 1973/-74 with a value of 121 per mil. Seasonality increases in the coral radiocarbon record from 10-12 per mil to 16 per mil.

The absence of a distinct subannual radiocarbon signal in the pre-bomb record in conjunction with more positive values when compared to previous Indian Ocean prebomb radiocarbon studies indicates that open and coastal upwelling is negligible off the coast of Kenya. Instead, the primary source of depleted radiocarbon is the upwelled, nutrient rich waters off the coast of Oman and Somalia. Equatorward merdional advection resulting from monsoon reversals in the Somali Current is believed to be responsible for subannual changes in the coral radiocarbon time series.

OS12C-162 1330h POSTER

Indonesian Throughflow Variability from WOCE IX1 and Two POP Simulations.

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The Indonesian seas act as the tropical conduit between the Pacific and Indian Oceans of properties that impact the circulation of the two basins on a variety of temporal scales. The variability of the Indonesian Throughflow (ITF) is investigated using global eddy-permitting and eddy-resolving Parallel Ocean Program (POP) simulations. Both models are forced with daily momentum, heat, and freshwater fluxes. The eddy-permitting (1/3-degree, 32-levels) model was run for the period 1979-1997, which corresponds closely to the duration of the repeat XBT line (WOCE IX1) between Java and Northwestern Australia. To understand the ability of the model to reproduce observed ITF variability on scales up to decadal, model temperatures colocated with the data were used to calculate mass and heat transports, and empirical orthorgonal functions. These quantities were then compared with those derived from the observations. The eddy-resolving (0.1-degree, 40-levels) sumulation is currently spinning up and output from the end of the first decade of the run will be examined in terms of high-frequency variability. Preliminary model analyses indicate that the water mass composition, routing, and volume transports of the Throughflow are in general agreement with observations. These two efforts contribute to our understanding of the usefulness of POP in short-term climate studies and in a future high-frequency prediction system.

URL: http://www.oc.nps.navy.mil/navypop

OS12C-163 1330h POSTER

Seasonal Carbon Variability and Estimates of new Production in the Indian Ocean

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To understand the role of the Indian Ocean as a potential sink for atmospheric carbon dioxide (CO_2), we have developed a model to quantify the oceanic carbon cycle in the mixed layer. Seasonal variations in dissolved inorganic carbon (DIC) in the mixed layer were used to determine the seasonal contributions of CO_2 gas exchange, changes in salinity, vertical diffusivity and entrainment, advection, and biological activity. This carbon mass balance was determined each season on a 1^o degree resolution scale for the Indian Ocean. DIC concentrations and CO_2 fluxes were calculated using a multiple linear regression model based on WOCE data. The regression was then applied to the NODC World Atlas 98 (WOA98) hydrographic data. The vertical diffusivity coefficient was calculated from the vertical gradient of WOA98 density data at the mixed layer depth and vertical entrainment was assumed to result from deepening of the mixed layer. Basinal estimates of new production were then produced for the four seasons and the two monsoon regimes, and compare to field data collected for example, during the JGOFS Arabian Sea program.

OS12C-164 1330h POSTER

Mass Storage in the Savu Sea Estimated from in-Situ and Remote Observations and a Numerical Model

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Results from a recent deployment of pressure gauges surrounding the Savu Sea will be presented. The gauges were part of the three year Shallow Pressure Gauge Array (SPGA) study and were designed to measure surface geostrophic flow through five passages in the Lesser Sunda Islands known collectively as Nusa Tengarra. Results from six gauges spanning the three main outflow straits (Lombok, Ombai and Timor) have been used to estimate variations in the Indonesian throughflow. Now, the data from three additional gauges will be used to examine mass convergence in the Savu Sea. A pair of gauges on the northeastern side (N. Ombai and S. Ombai) are used to estimate inflow from the Banda Sea, and two pairs (Sumbawa/N. Sumba and S. Sumba/Roti) are used to estimate outflow to the Indian Ocean. The data are used in conjunction with numerical model results to show that at times there is a 2 *Sv* imbalance between the inflow and the outflow. Most of the variability in estimated convergence occurs intraseasonally, and the annual cycle of convergence is relatively small. Lower frequency variations are consistent with satellite derived sea level and sea surface temperatures in the sea. The implications of convergence in the Savu Sea for water mass characteristics and oceanic heat fluxes will be presented.

OS12C-165 1330h POSTER

A Model Study of the Seasonal Variability and Formation Mechanisms of the Barrier Layer in the Eastern Equatorial Indian Ocean

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The presence of Barrier Layer (BL) modifies mixed layer thickness. This causes a significant impact in the air-sea interactions. As the BL observations in the tropical Indian Ocean (IO) are sparse, except few data in Bay of Bengal and off Sumatra, we employed the "OPA" OGCM to investigate seasonal variations and formation mechanisms of the BL. We, first, validated the OGCM outputs with observations. In the eastern equatorial area, model thermohaline structure is in close agreement with the observations (salinity differences lower than 0.2 psu) and follows interannual variability of the equatorial IO. A robust and thick BL (more than 40 m) is observed seasonally in the eastern equatorial IO with a maximum horizontal extent (about 1500km) in November. Second, we explore the formation mechanisms of BL that corresponds to a merging of two BLs. The first BL is formed as the Wyrtki Jet (WJ) propagates towards the east. The WJ deepens the thermocline while zonally advecting a salinity subsurface maximum above the thermocline. As the jet penetrates further towards the east, a second BL appears off Sumatra: a westward surface current trapped in the thin mixed layer advects fresh water from the coastal area and, in addition, significant upwelling further raises the halocline. In-situ observations support these complex and three-dimensional formation mechanisms. The timing, thickness and shape of BLs follow the strong interannual variability of the WJ. However, despite these variations, the formation mechanisms remain robust. At last, we focus on the impact of salinity and the BL on the fall dynamics of the eastern IO. Off Sumatra, the SSS gradient, present to the west side of the fresh pool, is strengthened when the WJ reaches this region. The pressure gradient associated with the salinity front becomes then larger than the eastward wind stress forcing, and initiates the westward surface current that is involved in the BL formation. The BL affects the equatorial circulation through a complex combination of processes. By analyzing the momentum equations, we show that the BL favors a stronger fall WJ that extends further east.

OS12C-166 1330h POSTER

Seasonal modulation in a linkage between the Indian Ocean Dipole Mode and the El Niño/Southern Oscillation

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We examine the seasonal characteristics of statistical relationship between the Indian Ocean Dipole Mode (IODM) and the El Niño/Southern Oscillation (ENSO) by using observational data.

The IODM dominates during October and November, while the ENSO dominates from October to January. The results of our statistical analyses show that the IODM is closely related to the ENSO only from boreal summer to autumn, while the relationship can not be found if the correlation is calculated using datasets consisting of all calendar month. The regressed SST and surface wind anomalies in the tropical Indian Ocean onto the Niño3 SST anomaly index show the east-west dipole SST pattern and the westward surface wind from boreal summer to autumn.

The case analyses of 1963, 72, 82 and 97, when the IODM and the El Niño occurred simultaneously, show that the climatological easterlies in the equatorial eastern Indian Ocean are accelerated by the anomalous easterlies associated with the negative phase of the Southern Oscillation from boreal summer to autumn. As a result, the zonally asymmetric structure of SST anomalies in the equatorial Indian Ocean is induced by westward wind anomalies along the equator and alongshore wind anomalies off Sumatra. Meanwhile, in case of the IODM in 1994, the El Niño did not occur in the

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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.