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14. ABSTRACT

The Arlingo Project is an ongoing joint oceanographic research endeavor of Indonesia and the United States. The field phase of Arlindo began in 1993 with Arlindo Mixing. Phase II of the program, Arlindo Circulation, is jointly funded by NSF and ONR. The ONR contribution to Phase II of Arlindo contributed to the collection and analysis of CTD data collected during the Arlindo Circulation mooring deployment cruise which was carried out in November-December 1996. This includes Aasert.

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Stratification Mixing and Circulation of the Indonesian Sea
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LONG-TERM GOALS

The magnitude and variations of the Pacific to Indian Ocean throughflow within the Indonesian Seas are considered to be key elements in the thermohaline balance of the Indian and Pacific Oceans, and perhaps to the global climate system. Local variability of the Indonesian Seas may influence ENSO by governing the transfer of the warm tropical water between the Pacific and Indian Oceans. Furthermore, advective and tidal induced mixing may influence the SST and sea-air coupling, with feedback on ENSO. The Arlindo Project is a joint oceanographic research endeavor of Indonesia and the United States. Arlindo's goal is to resolve the circulation and water mass stratification within the Indonesian Seas in order to formulate a thorough description of the source, spreading patterns, inter-ocean transport and dominant mixing processes within the Indonesian Seas.

OBJECTIVES

The specific objectives of Arlindo are incorporated in each of its three phases:

Arlindo Mixing (phase I, 1993/94 completed): to identify the source and pathways of the throughflow and to define the mixing enroute, for both monsoons.

Arlindo Circulation (phase II, 1996/98): to resolve the throughflow transport and velocity field across the central passages of the Indonesian Seas; extend the Arlindo 1993/94 CTD/CFC coverage both temporally and regionally. Deployment of the Arlindo Circulation moorings was carried out in November and December 1996 (Arlindo Circulation Deployment); recovery was done in February/March 1998 (Arlindo Circulation Recovery). The Arlindo Circulation moorings, based on Arlindo Mixing results, measure the mean and variable current and thermohaline stratification associated with the inter-ocean throughflow for a 14 month period. Funds received under this award contributed to the execution of CTD stations obtained on the Arlindo Circulation deployment cruise, and partially funded the analysis of the CTD data collected during this cruise.

Arlindo Monitoring (Phase III, to be proposed 1999 to 2007): provide a long term data set of the throughflow to enable study of the oceanographic conditions within the Indonesian Seas at time scales of ENSO events. The results of the earlier phases of Arlindo will be crucial in designing the sustained measurement program envisioned for the Arlindo Phase III.

APPROACH

The approach of Arlindo Circulation (Phase II of Arlindo) is to deploy moorings in key throughflow passages to measure currents, internal waves, mean water column temperature and sea floor pressure variability. An array of CTD and tracer chemistry stations extend the time series obtained in 1993 and 1994.

Moorings: The current meters will measure the mean and variable throughflow within the Makassar Strait and Lifamatola Passage. The flow in the upper 150 m is measured by upward-looking ADCPs; below that depth, the flow is measured by a series of Aanderaa RCM-8 current meters. IESs, which measure the mean temperature of the water column, were deployed in Makassar Strait. The mean temperature responds to internal thermocline oscillations and changes in water column heat content, which can then be related to circulation changes and internal tide activity. The deep pressure gauges accompanying the IES sensors (PIES) measure the changing pressure burden of the water column. Data collected from PIES may be used to relate variations in the along-axis pressure gradient flow in the Makassar Strait, which can then be correlated with the measured currents. Earlier Arlindo CTD data reveal the presence of energetic internal waves and tides, as well as thermohaline steps. These features are theorized as being fundamental to the enhanced vertical mixing characteristic of the region. During the Arlindo Circulation mooring period, internal waves and tides will be monitored by temperature measurements at the three mooring sites with temperature pods (self-contained temperature recorders). The collected data will greatly enhance the ability to resolve the internal wave activity and associated vertical mixing processes at the mooring sites.

CTD/Tracer array: The objectives of the Arlindo Circulation 1996 CTD array were to investigate interannual variability (in comparison with the 1993 and 1994 data) and to sample the region east of the Banda Sea, into the Aru Basin. Ship engine problems resulted in lost time, curtailing the extension of CTD measurements in the far eastern regions. However, the array does allow for study of interannual variability and does extend into the eastern Banda Sea. During the 1996 cruise, water samples were obtained at each CTD station for salinity, oxygen, nutrient, and CFCs. The study of satellite-based remote sensing (e.g., from TOPEX/POSEIDON, Advanced Very High Resolution Radiometer, and Special Sensor for Microwave Imager) will provide regional views of sea surface temperature and sea level during the Arlindo Circulation period. These Arlindo measurements will, in turn, provide ground-truth information to help interpret the satellite data.

WORK COMPLETED

From November to December 1996, participants in the Arlindo Circulation phase of this program successfully deployed from the Indonesian research vessel, Baruna Jaya IV, an array of current meters (e.g., upward-looking acoustic Doppler current profilers (ADCP); Inverted Echo Sounders (IES); bottom pressure sensors; temperature pods) within key throughflow pathways. They also occupied a series of CTD (conductivity, temperature and density) and chlorofluorocarbon (CFC) oceanographic stations (Figure 1 and Table 1). The mooring recovery cruise is planned for February 1998.

Table I The Arlindo Circulation Moorings and
Inverted Echo Sounder Sites (site depths)

Mooring	Latitude	Longitude	Depth	Sensors
MAK-1	2.86 S	118.45 E	2138m	ADCP, 5 CM, 11 T-Pods,
MAK-2	2.853 S	118.629 E	1610m	ADCP;4 CM;1 T-Pods
LIF-1	1.814 S	126.953 E	1919m	ADCP, 6 CM, 15 T-Pods
PIES-3	1.90S	118.30 E	2228m	IES, pressure gauge
PIES-2	2.97S	118.50 E	2147m	IES, pressure gauge
PIES-1	3.91S	118.40 E	1993m	IES, pressure gauge

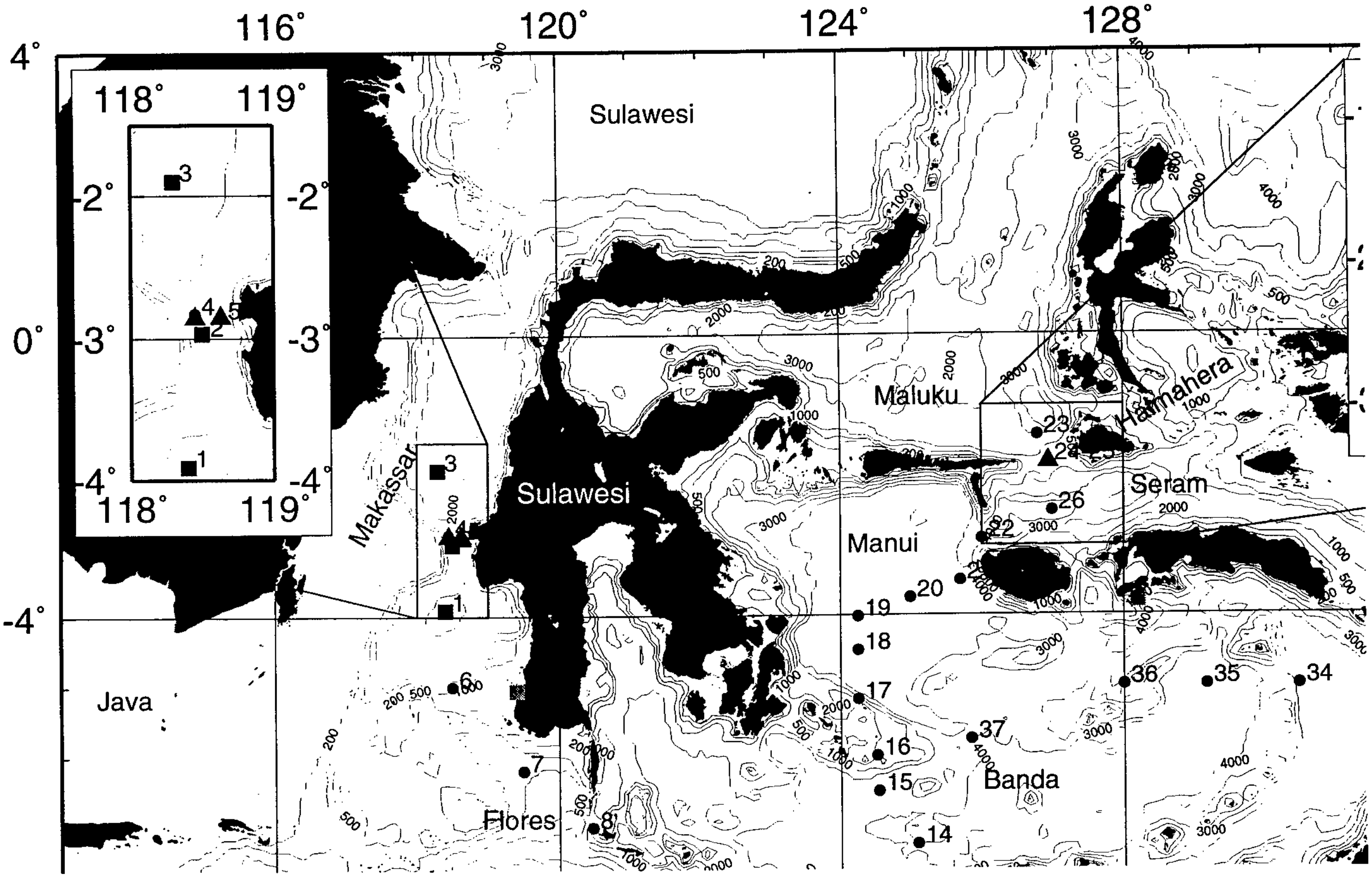

Figure 1. CTD stations(circles) and mooring locations (squares-PIES; triangles-CM/Tpod Moorings) for Arlindo Circulation 1996 cruise.

RESULTS

1. The 1996 CTD data are providing some interesting information.

The 1996 CTD data reveal differences from data obtained during Arlindo in August 1993 and February 1994. These differences possibly are attributable to a change in the El Niño/Southern Oscillation (ENSO) phase. In August 1993 and February 1994 the Southern Oscillation Index (SOI) was negative: -10 and -5, respectively. In November 1996 it was +5. The 1993 and 1994 data were obtained during a prolonged El Niño (negative SOI extends from mid 1990 to late 1995); the November 1996 data represents a La Niña phase, when throughflow transport is expected to be larger than the climatic mean. In comparing Meyers' (Meyers, 1996) time series of throughflow estimates (based on XBT data in the Indonesian-Australian Bight with the centroid of the western Pacific warm pool - Yan et al., 1997), one sees a qualitative relationship: the further west and north the centroid, the greater the throughflow. This relationship may be understood in terms of variability of the expected driving force for the throughflow - the Pacific to Indian pressure head. High sea level at the entrance of the throughflow in the region between the Philippines and New Guinea would occur during the La Niña phase when the warm pool was pressed against the western boundary, forcing increased throughflow.

The first indication of interannual changes was detected in Makassar Strait. The 1996 temperature profile is warmer than in 1993 and 1994 by 1°C in the 75 to 250 m interval. The deeper thermocline in 1996 may be a response to the positive ENSO phase, where the warm pool in the western Pacific is thicker. A second indicator is found in the eastern seas. In the Banda and Seram Seas, the 1996 CTD data indicates a greater presence of North Pacific salinity maximum water from 70 to 170 db than does the 1993 and 1994 data. In 1993 and 1994 the North Pacific thermocline salinity maximum was absent in the Banda Sea. This may be taken as evidence of greater intrusion of this water into the Banda Sea during the positive phases of ENSO.

Study of the spatial distribution shows that its Banda presence is derived from the Maluku Sea, not from the Makassar throughflow pathway.

2. Gordon and McClean (submitted to JPO) compare the Arlindo Mixing observational data set of 1993 and 1994 with the simulation used of the Los Alamos parallel ocean program (POP) 1/6 degree (on average) global model, forced by ECMWF wind stresses for the period 1985 through 1995. The Indonesian Seas' throughflow with it's complex topography falling near the division of the North Pacific and South Pacific water mass fields, represents a severe challenge to modeling efforts. The model temperature structure shows discrepancies from the observed profiles; for example, the model temperature is between 200 to 1200 dbar warmer by as much as 3°C than the observed temperature. The model salinity is excessive within the 5° to 28°C temperature interval, often by more than 0.2. The model density, dominated by the temperature profile, is less than the observed density from 200 to 1200 dbar, denser at other depths. In the Makassar Strait the model results show a North Pacific water column down to about 250 dbar, in agreement with observations. The model sill depth in the Makassar Strait of 200 m, rather than the observed 550 m sill depth, shields the model Flores Sea from Makassar Strait lower thermocline water allowing the Flores lower thermocline to be dominated by salty water from the Banda Sea. In the Maluku, Seram, and Banda Seas the model thermocline is far too salty, due to excessive amounts of South Pacific water. Observations show that the bulk of the Makassar throughflow turns eastward into the Flores and Banda Seas, before exiting the Indonesian Seas near Timor. In the model, South Pacific thermocline water spreads uninhibited into the Banda, Flores, and Timor Seas and ultimately into the Indian Ocean. The model throughflow transport is about 7.0 Sv in August 1993 and 0.6 Sv in February 1994, which is low compared to observationally based estimates. However, during the prolonged El Niño of the early 1990s throughflow is suspected to be lower than average, and indeed the model transports for the non-El Niño months of August 1988 and February 1989 are larger. It is suspected that aspects of the model bathymetry, particularly that of the Torres Strait, which is too open to the South Pacific, and the Makassar Strait which is too restrictive, may be the cause of the discrepancies between observations and model.

IMPACT/APPLICATIONS

The impact of the Arlindo research is better understanding of the processes that shape the thermohaline stratification of the Indonesian Seas, the energetic tidal and internal wave induced mixing, and intensity and source of the inter-ocean throughflow. Such products are used for the development of regional and global ocean circulation models; large scale coupled ocean/atmosphere models sufficient for prediction of climate and global change; understanding of the environmental conditions within the Indonesian Seas and improved understanding of the factors that affect primary productivity within Indonesian waters.

TRANSITIONS

The Gordon and McClean (submitted) study has revealed the importance of bottom topography in model studies of the Indonesian Seas. The internal wave activity produces large vertical fluxes of heat and freshwater, which have climate impact.

RELATED PROJECTS

The Arlindo Research is funded mainly by NSF, which also funds the Indonesian research of Amy Ffield (temperature pods), Dale Pillsbury (current meters) of Oregon State University and Rana Fine (CFCs) of Rosenstiel School for Marine and Atmospheric Science. The Arlindo PIES research of Silvia Garzoli (LDEO) is funded by ONR. Remote sensing research is supported by NASA: Chet Koblinsky and Joey Comiso at the Goddard Space Flight Center. Nancy Bray (CSIRO, Hobart and Scripps Institution of Oceanography) is using shallow pressure sensors to monitor the time variability of the throughflow outflow in the Timor Sea.

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