Workshop on the Mixing and Circulation of the Andaman Sea
A Cooperative Myanmar and US Program

March 16-18, 1998
Diamond Jubilee Hall, University of Yangon
Yangon, Union of Myanmar

Prepared by the Workshop Participants
Edited by Arnold L. Gordon and Swe Thwin

29 June 1998

Sponsored and funded by:

USA: Grant INT 96-04942 from the National Science Foundation

Myanmar: Ministry of Education. Department of Higher Education

A Cooperative Myanmar and US Program

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I Introduction:

The Earth is an oceanic planet, the ocean effects us all. It is in the interest of all nations to improve the collective knowledge of the ocean. Such improvement will lead to sustained management of marine and coastal resources and to a better predictive capability of climate variability. Of particular concern are the ENSO and Monsoon phenomena which greatly influence societies of Asia, where some 40% of the human race live.

The sea surface temperature (SST) pattern, a product of coupling with the atmosphere and with the sub-surface ocean, directs the winds and acts to provide moisture that supports the monsoon. Improved understanding of the ocean role and climate phenomena will lead to better prediction of inter-annual changes in rainfall allowing nations to better manage resources and minimize the hardships of drought and floods on their societies. Understanding of the ocean has many other benefits, from fisheries and ecosystem management, to pollution control, transport and oil/gas recovery.

Each ocean region plays a role in the larger scale climate system. The Andaman Sea (Fig. 1) SST may be a factor in premonsoon character of S.E Asia. The Andaman Sea SST is controlled by unique set of processes, that are not well simulated in larger scale ocean or in climate models. These processes include voluminous river runoff; strong tideal mixing and internal waves ; and exchange of surface water across the shallow passages linking the Andaman and Bay of Bengal; and sill depth overflow into the Andaman Sea depths from the Bay of Bengal.

The Ayeyarwady plume is influenced by the seasonal wind field and volume flux of the river water. However, the vigorous tidal mixing of the Andaman Sea may be a major factor controlling the river plume pattern, and possibility the general circulation. The recent acquisition of satellite SAR data (Fig. 2) more clearly portrays the distribution of energetic internal wave trains that seem to emanate from the Andaman Island arc passages, span the deep ocean to the coastal shelf, where they may be reflected back to sea. The nature of their behavior at the shelf break, the ratio of reflection to transmission onto the shelf is not known, and is of fundamental importance to studies of ocean mixing. The strong tidal and internal wave induced mixing processes at work in the Andaman Sea may impose a signature on the Bay of Bengal stratification via the ocean channel links or by atmospheric telecommunication and have significant influence on the SST of the Bay of Bengal and on the Asian monsoon.

II Workshop Goal Objectives:

The Workshop Goal is to formulate a research program designed to build a quantitative understanding of the circulation and mixing within the Andaman Sea and to develop an appropriate regional model. While this task is basically one of physical oceanography, such a model will have board application, from biological productivity studies; to research which requires a predictive capability of the spreading and mixing of river runoff; to sediment transport; to studies of climate that require an understanding of the forces that control the sea surface temperature, including the unique mechanisms of vertical mixing at work within the Andaman Sea. It will form the basic for further ocean science research in Myanmar waters.

The research goal will be met through an integrated effort of models, remote sensing and in situ observations. Contributions from both the US and Myanmar sides are envisioned. The research plan will be carried out in a series of phases that will move towards meeting the overall goals of the program. The speed in which we progress along the planned phases will be determined by the resources that are made available by both nations. In both countries the process involves proposing the project to appropriate governmental agencies, who then determine possible allotment of resources.

III Overview of Myanmar Oceanographic Research.

Prepared by Dr. Swe Thwin

[A] Background:

The Union of Myanmar has a long coastline of 3060 km. with a large number of estuaries and islands. The continental shelve covers an area of about 230,000 sq. km. and EEZ of about 470,000 sq. km. It shares common maritime boundaries with India and Bangladesh in the Bay of Bengal and with India and Thailand in the Andaman Sea.

The coastal zones of Myanmar can be divided into three main geographical sub-areas namely Rakhine Coast, Ayeyarwady Delta and Taninthayi Coast which are likely to represent main ecological divisions. Many rivers flow into the coastal zones such as Mayu and Kaladan rivers in the Rakhine coastal area, two large rivers Ayeyarwady and Thanlwin in the Delta area and Ye and Dawei rivers in the Taninthayi area.

The Rakhine Coast bordering the Bay of Bengal with a narrow shelf and few islands extends about 740 km. from the mouth of Naaf River down to Mawdin point about 16° lat. N . The upper part of the coastline is shallow and delta. The southern part is more or less rocky. The area between Myengun Kyunn point (Baronga point) and Nantha Kyunn is volcanic, the last eruption reported was in 1952.

Hydrographic conditions of the Rakhine Coast is heavily influenced by the Monsoon. During the wet season (May to October) the surface waters are extensively mixed with fresh water originating from runoff from the rivers. The southward flow of diluted sea water reduces the salinity to 18 ppt. in the near shore areas whereas in the dry season (November to April) a northward flow of high salinity water (34 ppt.) was recorded. Indications of local up welling was recorded near Mun Aung (Cheduba) Island during North East winds. Organic production is also higher during this period.

Ayeyarwady delta lies between Mawdin point and Gulf of Martaban. Ayeyarwady river enters the Andaman sea by nine principal mouths together with Sittang and Thanlwin rivers, depositing enormous quantities of sediments. This area has a wide continental shelf of about 60 nautical miles width The length of the coastline is about 469 km.

The annual sediment discharge of the Ayeyarwady River has been estimated at 250 million tons. The Ayeyarwady delta is building seaward at the rate of 5 km every hundred years, and the sea-ward advance of the gulf of Martaban at its 40 m depth contour is estimated at 55 km every hundred years.

Ayeyarwady delta is characterized by enormous sediment discharge and the data from recent hydrographic survey shows that there are four newly formed islands. There is about 7 km. seaward advance of 10 m. depth contour at the eastern part of the delta during the period of 1873 -1994. No appreciable change was observed at the western part of the delta.

Taninthayi Coastal zone covers an area south of the Gulf of Martaban up to the mouth of Pakchan River and includes Myeik Archipelago and the Andaman sea. The length of the mainland coastline is about 1200 km. Myeik Archipelago extends from Mali Island to Similand Islands. It contains about 800 islands covering an area of about 34340 sq. km. Coral reefs surround the outer islands and mangroves cover much of the inner islands. Surveys conducted by the Department of Marine Science indicate that during the last 15 years, many reefs south of 11°N have suffered much destruction. Dynamite fishing by foreign poachers, anchor damage, trampling, and over fishing have devastated the marine flora and fauna associated with the reefs. Sedimentation caused by erosion from the main land and from the islands also smother corals and associated animals by burying them. The law relating to fishing rights of foreign fishing vessels (1984) and Myanmar Fisheries Law (1990) clearly prohibit the use of explosives, poisons and toxic chemicals, harmful agents and damaging gears. However, the difficulty in having access to remote areas, lack of adequate infrastructure, insufficient funding and lack of trained personnel are some of the major constraints in the effective management of the resources.

The coastal zones of Myanmar are unique in their own natural conditions. Though narrow in width, the Rakhine continental shelf has pronounced geophysical features and a comparatively high productivity. Ayeyarwady Delta area with its seaward advancing delta and high river discharge may need more detail studies.. With numerous islands and a wide continental shelf, the Myeik Archipelago in Taninthayi offers an opportunity for better understanding of coral reefs and related ecosystems. Therefore Myanmar would like to encourage countries, both within and outside of the region to facilitate the establishment and conduct of collaborative projects for better understanding of the oceanography of the Bay of Bengal and the Andaman Sea.

[B] Marine Science Educational and Research Facilities

Like most of the developing countries in the region, Myanmar lacks the expertise in the field of Oceanography and integrated management of the marine environment. The department of higher education has established the department of Marine Science at Mawlamyine University in 1973. It is offering undergraduate and graduate courses in the fields of Oceanography, Marine Ecology, Fishery Science and Aquaculture. The department has a research station with running sea water facilities at Setse on the Gulf of Martaban. The station is at present used mainly for training and research in Aquaculture. The department also conducts regular research cruises with the 16 m. training and research vessel contributing basic data on physical oceanography, chemical oceanography, and fish population studies. The Marine Science Department could serve as a core department in Myanmar for the training of marine scientists, resource managers and planners for marine affairs.

[C] Oceanographic Expeditions:

Union of Myanmar has been conducting oceanographic studies within her capabilities by coordinated efforts of Governmental departments, and Universities. In 1965 the Oceanographic Research Council was formed, to co-ordinate research activities. To promote Oceanographic activities, a technical committee for IOC was formed after Myanmar became a member in 1988.

Three Oceanographic research cruises were conducted locally with R.V.Thutaythi and R.V. 802 of Naval Hydrographic Department, Training and Research Vessel Annawatheikpan of the Department of Marine Science, University of Mawlamyine is also conducting regular cruise programs in the Mon-Tanintharyi coastal area.

Joint Fishery and Oceanographic cruises were also carried out as follows-

i 1966 Joint Myanmar-Soviet cruise of Fisheries Oceanography research vessel Academic Nipovich in Andaman Sea and Bay of Bengal

ii 1979-1980 Joint Myanmar-Norway cruise of Fisheries Research Vessel Dr.Fridtjof Nansen in Myanmar waters

iii 1989 Joint Myanmar-Thailand cruise of Fisheries Training and Research Vessel Chulabhorn

iv 1995 Joint Myanmar-US cruise of Oceanographic Research Vessel Knorr in Myanmar waters (Rakhine coast)

IV Andaman Sea circulation and mixing research program:

Discussions in plenary and in smaller working groups lead to a series of research recommendations. These are organized into three parts: [A] summary; [B] research schedule; [C] Modeling; [D] Mixing; [E] Bay of Bengal links.

[A] Summary: Prepared by A. L. Gordon and Swe Thwin.

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US-Myanmar joint study of the Andaman Sea Circulation and Mixing.

1. Time Table

Year 1 (1998)

Initial workshop, Yangon, March 1998

Gathering of available in situ and satellite data on the Andaman Sea. Mawlamyine University vessel to start CTD sections in the Delta and Gulf of Martaban.

Year 2 (1999)

Mellor- POMS model initial development

Gordon & Hacker- Initial CTD/Hull & Lowered ADCP survey

Second workshop, in the USA, mutually agreed upon time and place.

Myanmar students apply to participating US Universities

Year 3 (2000)

Mellor-POMS model development

Gordon & Hacker- CTD/ADCP data analysis; instrument and tech support for Myanmar seasonal CTD/LADCP survey;

Year 4 (2001)

Gordon/Hacker- Full CTD/LADCP (design of which will be based on initial CTD/Hull & Lowered ADCP results)

Murray- Bay of Bengal links

Gregg- mixing

Year 5-6 (2002-2003)

Data analysis

Establishment of a Myanmar Ocean Time Series array.

2. Initial (1999) CTD/ADCP Research Program, Summer 1999

There are no modern oceanographic data in the Andaman Sea north of 10°N. The 10°N line was obtained in October as part of the WOCE Indian Ocean experiment (WHP line I-1). We do not have a clear view of the stratification and river plume distribution within the northern Andaman Sea. Satellite data reveals the presence of internal waves, but we have not yet measured these features with in situ methods, and do not know what effect they have on mixing within the Andaman Sea.

During summer SW monsoon, 1999 CTD (conductivity-temperature-depth) stations with Hull and Lowered ADCP (Acoustical Doppler Current Profiler) survey (Fig. 3) is proposed for the Andaman Sea north of 10°N survey will be made from a US vessel. Stations along roughly along 14°N, a meridional line from land southwards to 12°N along 95.5°E , and a Zonal line from 95.5°E to the eastern coastal line of the Andaman Sea. Time series observations CTD and Hull and LADCP (what is referred to as yo-yo station, at which the CTD is repeatedly lowered and raised between the surface and a depth below the thermocline) will be done over a period of a diurnal tidal period over the deep Andaman Sea. During the time of this field program, we will attempt to hang a line of thermisters from the UNOCAL Oil rig on the continental shelf in the eastern Andaman Sea. The offshore and shelf data will enable some evaluation of the reflection and transmission of internal waves at the shelf break.

Four Myanmar scientists are invited to participate in the 1999 cruise. They will join the ship in Singapore or if the ship schedule allows, in Yangon. Myanmar is responsible for the travel of these members to the US ship. Two Myanmar scientists will be invited to the US (Lamont and Hawaii) to participate in the data analysis. The US side will pay for local per diem costs but Myanmar will be responsible for international travel.

In the year 2000 this survey work will be continued as a time series from the research vessel of Mawlamyine University. It is proposed that the US provide in situ light weight CTD instrumentation for use on the Myanmar ship and technical training to the Myanmar scientists.

In the year 2001, a more extensive CTD/ADCP survey from a US ship is proposed, to be integrated with the mixing and channel components of the program.

US group will propose the initial CTD/ADCP cruise of the summer 1999 to the National Science Foundation (NSF) of the USA. It is important to point out that the US oceanographers are having difficult times, and many investigators have no grants at all. Only about 15% of proposals are funded by NSF. Many of those turned down are rejected owing to the lack of funds, not for faulty science.

[B] Research Schedule - Prepared by Peter W. Hacker

Year 1, 1998 Initial requirements for designing observational and modeling experiment.

1. Provide a working map for cruise planning including national boundaries.

2. Identify river run-off data sets and digitize.

3. Identify existing time series of (a) wind (b) sea level stations.

4. Myanmar to initiate pilot CTD survey during NE Monsoon.

5.. Develop (US side) NSF proposal

Year 2 (1999)

1. Identification and analysis of archived hydrographic and satellite data.

2. Analysis of Radarsat images for soliton description and statistics in the Andaman Sea and the Bay of Bengal.

3. Model development (variable resolution),identification of forcing fields and data needs.

4. An initial limited survey of thermohaline stratification and velocity profiles (CTD & LADCP) from a US research vessel. Conduct a pilot CTD/ADCP survey (US ship) during the Southwest monsoon to provide a basic description of T, S, u and v in the northern Andaman Sea.

5. Identify collaborations: satellite products, biological studies, etc.

6. Develop international linkages: JASMINE, (A developing research program designed to study the Asian Monsoon, see appendix D), Thailand, India.

7. Second US Myanmar workshop, proposed for US site.

Year 3 (2000)

1. Myanmar begins hydrographic time series section with US assistance. Transfer of instrumentation and technology to Myanmar for initiation of time series cruises.

2. Analysis of 1999 survey and design of next phase of field work.

3. Mellor-POMS Model development

Year 4 (2001)

1. Deploy current meter moorings to obtain time series within the Andaman Sea and in the connecting channels with the Bay of Bengal, for model testing and soliton specification.

2. Full CTD/LADCP station array within the Andaman Sea; design of which will be based on 1999 initial CTD/Hull & Lowered ADCP results.

3. Continue time series program development.

4. Continue model development and testing.

Years >4

1. Comprehensive analysis of Andaman Sea observational and model data.

2. Reporting results in international symposium and journals.

[C] Modeling: Prepared by George L. Mellor

Numerical modeling of the Andaman Sea and adjacent Bay of Bengal.

The Princeton Ocean Model should be able to emulate many of the physical processes thought to be extant in the Andaman Sea, but it will be an exacting test of model performance. And, in fact, an anticipated result of the proposal study will be an assessment of the degree to which the model does or does not simulate the circulation and the physical processes characteristic of the Andaman Sea.

The basic model grid will cover both the Bay of Bengal and the Andaman Sea with an open boundary at 6°N stretching from the southern end of Sri Lanka to the northern end of Sumatra. The curvilinear grid will be focused in the Andaman Sea; we will aim for grid resolution of about 10 km in the Sea itself expanding to about 20 km in the western Bengal basin.

The surface forcing will be wind stress and either heat flux or surface temperature with provision made to separate out penetrative solar radiation. Forcing data will derive from ECMWF and the follow-on NSCAT satellite.

E-P estimates will be made and the large river runoff flows, importantly including the Ayeyarwady river, will be provided by the Myanmar Meteorological office.

Tidal astronomical forcing will be an interior body force and open boundary forcing will be derived from TOPEX POSEIDON analyses and, possibly, global numerical tide models. Mean external mode, open boundary forcing will be derived from a combination of TOPEX POSEIDON and ERS-2 altimetry, assuming a reasonably accurate geoid is available, and global model simulations. Open boundary temperature and salinity sections in conjunction with a WOCE section at 10°N will provide the thermodynamic open boundary condition. The mean, internal mode internal velocities at the 6°N section will be geostrophic. Since the 10°N WOCE section include a rich ADCP data source, the calculated velocities can be immediately compared with these data. Other data will be sought and an Indian Ocean workshop in September 1998 may reveal additional data sources.

In the first phase, the model will be run for, say, five years; the general circulation will be obtained including model estimates of the flow through the island chain openings and, of significance to the Phase II observational study, model variability will be evaluated. Model climate drift will be assayed. TOPEX POSEIDON and ERS-2 altimetry will be compared with model calculations. Although we have discussed the primary model, it should be understood that lower resolution model runs will be performed. These can also be run by Myanmar scientists as well as smaller domain model (e.g. the Andaman Sea itself, the Gulf or Martaban, Yangon harbor).

We will develop diagnostics to present mixing and dissipation developed by the model in the surface mixed layer and in the tidal driven bottom boundary layer. The internal wave climatology developed by the model has been paid scant attention in the past. We therefore plan a very high resolution two-dimensional (x -z) model process study along the 10°N transact to access the role of model resolution on external tide to internal wave production, reflection and dissipation processes. Non-hydrostatic calculations may be necessary. This exercise should provide insight into the importance of internal waves per se and provide guidance for the possible parametric modeling of these processes in the larger scale, Bengal-Andaman model and for modeling in general.

[D] Ocean mixing: Prepared by Michael C. Gregg

Mixing measurements needed in the Andaman Sea (year 2001)

Owing to the solitons and large tides observed in the Andaman Sea, mixing is expected to be much more intense than in more typical locations. Consequently, accurate modeling of the circulation and stratification requires understanding enough about the mixing to accurately parameterize the turbulent eddy diffusivity. The Andaman Sea also seems to be a unique place for studying aspects of solitons.

Mixing Questions:

1. What are the levels of mixing in deep water when soliton are not present? That is, do the strong tides elevate the internal wave back ground above the Garrett and Munk level, and does this proportionately increase the mixing?

2. How much mixing do the soliton produce in deep water? Does this mixing vary as the waves evolve with distance from their source?

3. Do soliton generated at passages on the west side of the Andaman Sea propagate onto the shelf on the east side? How much energy is reflected, dissipated, and transmitted at the shelf break? Are transmitted waves important missing agents in the shelf?

4. Are solitons generated by tides flowing into deep water from the continental shelf? If so, are they important mixing agents?

5. Do tides on the shelf produce tidal mixing fronts? Where and when are these fronts formed?

6. Does the large seasonal variation in fresh water input affect answers to any of the questions above?

Process Questions:

1. What can be learned about soliton dynamics by observing:
   a. reflections from the shelf break?

   b. collisions between waves propagating in opposite directions?

   c. are the periods long enough to allow them to be resolved by microstructure profiles requiring 15 minutes to sample to 300 m?

Measurements:

Pilot Program:

1. Take a series of expendable current profiles (xCPS) over deep water simultaneously with a series of CTD casts to 1600 m. These will allow compassion on the internal wave shear and displacement spectra with the Garrett and Munk spectrum. One profile every hour for 12 hours would be adequate to assess leads at one time and place. A second 12-hour series several days later or at a different place would greatly improve the applicability of the estimate

2. Also, analyzing the ship's ADCP would provide estimate over a larger area if there are enough CTD; to 300 m provide realistic estimates of the stratification allow the track.

3. Archives of SAR images should be overlaid on the bathymetry to locate where solitons are generated, reflected and dissipated.

Process Program:

Based on what is learned from the pilot program, several types of micro structure mass measurements should be made.

1. Time series at several sites in deep water allow a line between mooring with upward ADCPs and sea cats. These will show how missing varies as the solitons evolve. If the array is placed properly, it will also be useful for examining what happens when opposite-directed solitons collide.

2. Micro structure sections should be made across the shelf break where satellite images show solitons being either reflected or generated.

3. Micro structure sections and-or a time series should be made on the shelf where tides produce strong direct mixing. If a tidal mixing front exists, sections should be taken across it.

The micro structure data should be supplemented by simultaneous measurements of currents with a broad band ADCP and with high-frequency acoustic backscatter to image soliton and other small structures.

[E] Program for Moored Observation of Circulation and Mixing in the Andaman Sea, (year 2001) Prepared by Stephen P. Murray

1. Background

The long term mean circulation (and its seasonal and lower frequency fluctuations) through the Andaman Sea are essentially unknown. Strong monsoon wind forcing over the region, however, and the seasonal cycle of the Ayeyarwady river discharge would suggest a dramatic difference in circulation between the Northwest and Southwest monsoon seasons. Additionally the now well known generation of discrete packets of well developed internal waves presumably by intense tidal currents at the entrance sills are a fundamental component of the dynamics of the Andaman Sea.

2. Objectives

As little to no historical data exists on either the circulation on the internal waves it is essential to obtain some preliminary measurements with the following objectives.

a: to assess the magnitude and variability of the circulation through the deep northern passages

b: to assess the magnitude and characteristics of the internal wave packets as they impact the continental shelf break; these direct observations will assist in the initializations of the numerical model of the region being developed by G. Mellor , and will provide essential data in design of micro structure work by M. Gregg.

3. Experimental Design:

In the South Preparis a near bottom acoustic doppler current profiler will be deployed for six months. The ADCP shell resolve both tidal and subtidal flow oscillations and be capable of ranging to the sea surface . The data from this mooring will;

a. shed light on the generative stage of the internal soliton packets especially as to when in the fortnightly tidal cycle such packets are released and

b. provide the first solid data on the vertical structure and temporal variability for data assimilation into the Mellor numerical model .

On the Myanmar shelf-slope deploy two moorings (in the vicinity of 96° 30' E, 11°N) to determine the change in characteristics of internal wave packets as they impact and reflect off the shelf-slope. Both moorings will be equipped with ADCP and salinity-temperature recorder for high frequency time series measurements to resolve individual internal waves. One mooring will be on the upper slope and one on the outer shelf in order to characterize the evolution of the internal wave field as it impacts the shelf-break.
Final selection of mooring sites will be determined after study of radar imagery of internal wave packets propagation patterns in the Andaman Sea.

4. Calendar

Ideally pilot moorings will be deployed from a large vessel during the SW monsoon and recovered from a smaller Myanmar or Oil industry supply boat 6 months later during the NE monsoon.

5. Data analysis will focus as:

a. obtaining initial understanding of strength and structure of the mean flow through the Preparis Channel for the purpose of guiding numerical model development and designing a full observational array and

b. determining characteristics of internal wave packet or the impact on the shelf break.

[F] Capacity Building

As part of the US/Myanmar joint research it is recommended that highly qualified students of Myanmar apply to graduate school at any one of the Universities represented by the US delegation.

We will send application packets to the Ministry of Education. When Myanmar selects a candidate for graduate student, it is recommended that student contact a member of the US delegation must closely related to their interests for adverse on the filing of their application.

While each of the US Universities can provide general training in Physical Oceanography, students with specific interest may apply to the most appropriate one. For example, Princeton (Gregg Mellor) is most appropriate in Ocean Modeling; Columbia (Arnold Gordon) in observation of Ocean properties and inferred circulation and mixing and climate research; University of Washington (Michael Gregg) for ocean mixing ; University of Hawaii (Peter Hacker) for directly measured ocean currents; Louisiana State University (Steve Murray) for flow through straits and coastal oceanography.

Please contact Arnold L. Gordon for guidance concerning the selection and application to a US University.

Myanmar students should have strong background in Physics and Math.

VI Other research interests within Myanmar

The following suggestions for Andaman Sea research from the Myanmar scientists, offer additional opportunities for joint US/Myanmar research. The readers of the report are urged to disseminate this information in the hopes of generating interest among counterpart US scientists.

[A] Preliminary Proposal from the Department of Geology, University of Mawlamyine and Yangon.

Dr. Pe Maung Than
Professor and Head
Department of Geology
Mawlamyine University
Mawlamyine (Mon State)
Union of Myanmar (Burma)

1. Coastal sedimentation studies (field and lab) -covering source of sediments, transportation patterns into the Andaman Sea and deposition processes.

2. Recent shelf sedimentation-covering sample collection, lab-observations and interpretation, facie models.

3. Micropaleontological studies on the Tertiary and Post-Tertiary foraminiferal assemblages, distribution, age determination and correlation, paleoecological aspects etc.

4. Geochemical analyses on the collected samples (lab-techniques).

5. Exploration of sea bed-possible utilization of mineral resources (should be accompanied by Geochemical and Geophysical data collected within the region)

6. Geomorphological modeling of the Andaman Sea, using high-resolution topographic/bathymetric data.

7. Geotectonic mechanism of 90°E. (Ninety East Ridge). Active tectonic features in relation to the continental Ridge.

8. Mixing of sea water (supported by biological / physical/ chemical factors) in relation to the pattern of motion of the continental Rise in the Andaman Sea.

N.B. : these proposals are only preliminary and very temporal. Some are possible either to be deleted or expanded with the progress to be gained both from the field cruises and lab-results.

[B] Preliminary Proposal from the Department of Physics, Yangon University.

Prof. Dr. Sein Htoon
Department of Physics
Yangon University

Objective: Participation in Physical Oceanography Program.

Status: Have Computational Physics Program & Mathematical Physics Program up to the Ph. D level.

Related Research Interests: Meteorology Program that has to be expanded.

Departmental Facilities: Mainly Computational Physics Facilities & a Tracer Technology Rig as part of Nuclear Physics IAEA Research Program; have ten to twenty staff who can devote to this work.

[C] Preliminary Proposal from the Department of Mathematics, Yangon University.

Prof. Dr. Mya Oo
Department of Mathematics
Yangon University
&
U Sein Win
Associate Professor
Department of Mathematics
Dagon University

From mathematical point of view-

1. It is required to locate the area which is the most important to meet our objectives.

2. To predict the true nature of "circulation" and "mixing" of the Andaman Sea ,it is necessary to get the reliable initial data such as temperatures, velocities,
salinity, river discharge etc. at the located area layer by layer to a certain extent.

3. To set up the mathematical model, it is also necessary to get boundary conditions such as the topographic properties of Andaman Sea basin and related coastal area.

4. According to our knowledge, the Mathematical model equation will be non-linear PDE and to get a good approximation, it is necessary to make numerical simulation with computing facilities.

In the Department of mathematics; those who are working on fluid dynamics and water wave especially interested in internal waves and solitary wave Andaman Sea can participate on this project to a certain extent.

[D] Preliminary Proposal from the Department of Mathematics, University of Mawlamyine

Prof. U Kyin Ko
Department of Mathematics

University of Mawlamyine

For the successful implementation of the project we feel that we should

1. have accessibility to the current literature on the ocean modeling (preferably the POM).

2. have sample computer programs for simulation of the model.

3. know computational aspect of the problem (whether the PC will be sufficient or whether high speed computers will be necessary).

[E] Preliminary Proposal from the Department of Geography, University of Mawlamyine

Prof. U Maung Maung Aye
Head of the Department
Department of Geography
University of Mawlamyine

As regards the joint-research work on the circulation and mixing in the Andaman Sea sponsored by the Department of Higher Education and the US Oceanographers, the following studies could be conducted by geographers if all the field instruments and budget required were sufficiently provided:

1. The coastal geomorphological processes and their related land forms.

2. Ecological studies in the coastal regions of Myanmar.

3. The analytical studies of waves, tides and currents along the coast of Myanmar.

4. The relationship between the average annual precipitation and sediment discharge in certain drainage basins of Myanmar.

5. A geographical analysis on the formation and growth of the Ayeyerwady Delta.

6. Transportation and deposition of fluvial streams in certain coastal regions of Myanmar (particularly in the Ayeyarwady Delta Region, Mon and Tanintharyi Coastal Regions).

7. Studies of Anthropogenic Geomorphology and its impact upon the influxes of fluvial deposits in the near shore and offshore regions of Myanmar.

8. Impact of land utilization and other human activities upon the rate and mass of sediment transport of certain coastal streams in Myanmar.

9. Studies on littoral flows and long-shore drifts in the Andaman Sea.

10. Analytical studies on the spatial distribution of sea surface temperature, salinity and density in the Andaman Sea.

[F] Preliminary Proposal from the Department of Physics, University of Mawlamyine

Dr. Myint Thein
Associate Professor
Department of Physics
University of Mawlamyine

Suggestions:

Our Department has the following facilities:

1. Alpha, beta, gamma, x-rays Measurements { Ge, Si (Li) detectors and XRD diffractometers }.
2. Electronics lab.
3. Computation lab.

So, after we have gained some knowledge about oceanography, we may be able to give assistance.

[G] Preliminary Proposal from the National Commission for Environmental Affairs

Daw Kyi Kyi Myint
Head of Branch
National Commission for Environmental Affairs

Environmental point of view:

to include the marine environment data of Andaman Sea in the Report of the State of the Environment of Myanmar

Appendices

Appendix A: Agenda
Workshop on the Mixing and Circulation of the Andaman Sea, A Cooperative Myanmar and US Program

March 16-18, 1998
PLACE Diamond Jubilee Hall Yangon, Union of Myanmar

16 March, Monday

0800-0845 Registration at Yangon University, Diamond Jubilee Hall

0900-0930 Opening Ceremony

Opening address

H.E. Dr. Than Nyun, Deputy Minister of Education.

Dr. Arnold L. Gordon, Professor of Oceanography, Columbia University.

0930-1000 Refreshments

1000-1230 Lecture Session

Andaman Sea relationship to the large scale oceanography of the Northeastern Indian Ocean. Arnold Gordon, Columbia University.

1230-1330 Lunch.

1330-1500 Some considerations of the Andaman Sea Oceanography. Peter Hacker, University of Hawaii.

Mixing in the Indian Ocean. Michael Gregg, University of Washington.

1500-1515 Coffee Break

1515-1630 Lecture Session

Measurement of flow through Straits. Steve Murray, University of Louisiana.

Modeling procedures appropriate to Andaman Sea. George Mellor, Princeton University.

1830-2000 Welcome Dinner hosted by H.E. Dr. Than Nyun, Deputy Minister of Education at Kandawgyi Palace Hotel.

17 March, Tuesday

0900-1015 Lecture Session and Group Discussion

Review of the oceanographic facilities of Myanmar.
Swe Thwin University of Mawlamyine

Plenary Discussion of a Research Plan for study of the Andaman Sea that would meet the workshop objectives.

1015-1030 Break

1030-1200 Group Discussion
Working group meetings to prepare components of the Research Plan.

1200-1300 Lunch

1300-1430 Group Discussion

1430-1445 Break

1445-1630 Group Discussion

18 March, Wednesday

0900-1015 Working Group reports.

1015-1030 Break

1030-1200 Working Group reports.

1200-1300 Lunch

1300-1415 Plenary session
Discussion of outcome group reports and evaluation of the primary research plan establish a time table and identify the next steps for implementation of the plan.

1415-1430 Break

1430-1500 Closing Ceremony

1830-2000 Dinner hosted by HE. U Than Aung, Minister of Education at Mya Yeik Nyo Royal Hotel

Appendix B List of Participants

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Appendix C Abstracts of presentations:

Note. For more details about the papaers in this section please contact the authors.

Andaman Sea relationship to the large scale oceanography of the Northeastern India Ocean:

Arnold L. Gordon
Professor
Lamont-Doherty Earth Observatory of Columbia University

Each ocean region plays a role in the larger scale climate system. The Andaman Sea SST is controlled by unique set of processes, that are not well simulated in larger scale ocean or in climate models. These processes include voluminous river runoff; strong tides with associated mixing and internal wave generation; and exchange of surface water across the shallow passages linking the Andaman and Bay of Bengal; and sill depth overflow into the Andaman Sea depths from the Bay of Bengal. The Andaman Sea thermohaline stratification is a product of these factors.

The specific interest in the Andaman Sea stems from the effects of energetic internal wave and tidal induced elevated vertical mixing processes. This mixing is expected to influence the regional vertical stratification and circulation pattern. Ship hull ADCP measurements during the WHP Cruise I9°N in February 1995 revealed very intense internal wave activity in the eastern Bay of Bengal. Internal Wave energy is believed to be even stronger in the Andaman Sea (Osborne & Burch, 1980, Science 208, 2 May, 451-460). The recent acquisition of satellite SAR data more clearly portrays the distribution of internal wave trains that seem to emanate from the Andaman Island arc passages, span the deep ocean to the coastal shelf, where they may be reflected back to sea. The nature of their behavior at the shelf break, the ratio of reflection to transmission onto the shelf is not known, and is of fundamental importance to studies of ocean mixing.

CZCS images reveal that in the northern Andaman Sea, the outflow from the Ayeyarwady River turns to the east. One might expect it should turn to the west in the northern hemisphere, but perhaps the downward mixing of the plume water by elevated vertical mixing in the Andaman Sea reverses the course of the plume (personal communication with Dick Ou, Lamont). Additionally, the Bay of Bengal stratification shows the river water close to the continental shelf mixes downward to temperatures far cooler than that of the river water, a sign of elevated mixing, to at least the 12°C isotherm, at 300 m. The river plume spreading and attenuation is influenced by the seasonal wind field and volume flux of the river water. The vigorous tidal mixing of the Andaman Sea may be a major factor controlling the river plume spreading, and possibility the general circulation.

The strong mixing processes at work in the Andaman Sea may impose a signature on the Bay of Bengal stratification and SST and have some impact on the SST of the Bay of Bengal and on the Asian monsoon.

Some considerations of Andaman Sea Oceanography:

Dr. Peter W. Hacker
Researcher
Hawaii State of Geophysics and Planetology
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa

Our knowledge of the circulation pathways within the Bay of Bengal sector of Indian Ocean is based on a few historical data sets, climatological studies, numerous modeling studies, and recent observations from the world ocean circulation experiment (WOCE) Hydrographic Program. In addition, altimeter observations of sea surface elevation provide Indian Ocean wide coverage and suggest the coupling between Andaman Sea phenomena and larger scale processes. The purpose of this talk is to provide an overview of the climatological data, recent WOCE data, some basin-wide satellite altimeter products, and some recent high-resolution model results.

Climatological products provide both a mean pictures of atmospheric, air-sea flux, and oceanographic fields and monthly fields, from which one study the annual evolution of the fields. Relevant fields include surface wind stress, air-sea heat and fresh water fluxes, surface currents based on ship drift, mixed layer depth, temperature and salinity. The annual evolution of these field is associated with the changing monsoon conditions including the northeast monsoon (January-March) and the southwest monsoon (May-August). Variability with the Bay of Bengal and the Andaman Sea is in large part the result of basin-wide response within the Indian Ocean to the changing monsoon wind.

Recent data from the WOCE expedition in the Indian Ocean provide detailed information on circulation pathways within the Bay of Bengal during the northeast monsoon-WOCE line I9°N, and allow 10°N at the end of the southwest monsoon, WOCE line I1. These data suggest vigorous circulation features with a great deal of spatial variability. High resolution models demonstrate some success in simulating the observed spatial variability. Further comparison and model testing is planned. Some recent WOCE results are shown in Figures 1-4. Results allow I9°N include observations of intense circulation features outside (to the west) of the southern passages to the Andaman Sea, observations of strong internal solitons to the west of the Andaman Islands, and observations of a Preparis eddy associated with flow out of the Andaman Sea. Results from the I1 line show strong eddy-like features within the Andaman Sea with short vertical scales, which offer a challenge to appropriate numerical models. Within the Andaman Sea, previous observations have shown the presence of internal solitons, which may well be important for mixing within the sea.

A series of satellite altimeter maps of sea surface elevation for the Indian Ocean shows the movement of anomalies from the western to the eastern boundary, and then north ward through the Bay of Bengal and the Andaman Sea. This data product will be valuable in future studies of Andaman Sea variability. Another topic, of particular interest to air-sea interaction studies, is the structure and evolution of the mixed layer in the Bay of Bengal and Andaman Sea. Recent WOCE data suggest the importance of the fresh water lens, and document the small horizontal and vertical structures within the upper ocean layer. Finally, we have begun to analyze model simulations from the NRL 3-1/2 layer model and the JAMSTEC Modular Ocean Model with 55 layers. The models provide valuable information on the possible spatial context of our quasi-synoptic survey lines, and on the possible annual evolution and inter-annual variability of observed current features. At the same time, the recent and future high-resolution observations can be used to evaluate and improve model simulations.

Ocean mixing:

Dr. Michael C. Gregg
Professor
School of Oceanography
College of Ocean and Fishery Sciences
University of Washington

A Survey of Mixing in the World Ocean

Mixing has been measured directly for 30 years using micro structure profilers. Observations have been taken from enough locations to reveal the outlines of a geography of mixing. That is influencing representations of mixing in numerical models of ocean circulation.

The vertical eddy diffusivity, K, is estimated from micro structure by determining the variance of Shear and temperature gradients over vertical relatively of 0.5 to 1.0 m. These parameters give the rates at which thermal diffusion and viscosity dissipate these gradients:

$$E = 7.5\, n \left(\frac{du'}{dz}\right)^2 \text{ [W kg]} \quad \text{and}$$

$$K_T = 2\, KT \left(\frac{dT'}{\quad}\right)^2 \text{ [}K^2 s^{-1}\text{]}$$

dZ

where n is the kinematic viscosity, and KT is the thermal

By assuming that the local dissipation of turbulence balances its rate of production, the balance equations for turbulent kinetic energy and for temperature variance permit estimation of diffusivity:

$$K_p \backslash< \frac{0.2E}{N2} \; [\, m^2 s^{-1}], \text{ and}$$

$$KT = \frac{K}{2\,(\,dT/dz)^2} \; [\, m^2 s^{-1}].$$

These estimates have been confirmed by comparison with the rates of thickening of artificial streaks of tracers and are believed accurate within a factor of 2.

Figure 1 shows profiles of average diffusivity in places not known to be influenced by topography or mesoscale features such as eddies and fronts. Kp varies from 2x10-4 m^{2s-1} to 3x10-7. Most values are much less than the maximum. The profile labeled PATCHEX was taken where internal waves are at the back ground state described by Ganett and Monk's internal wave model. Hence, this level of 3x10-6 m^{2s-1} is characteristic of turbulent diffusion throughout much of the ocean. By comparison, the molecular diffusivity of heat is 1.4x10-7 m^{2s-1}, and Monk's "Abyssal Recipes" inferred that 1x10-4 m^{2s-1} characterizes much of the thermocline.

Much larger diffusivities are found where strong tidal currents flow over rough topography and where packets of internal solitons pass through. For example, Figure 2 compares three Kp profiles taken on the continental shelf south of New England in water 70 m deep.

(The vertical axis is plotted versus pressure. 0.1 m Pa is the pressure change over 10 m depth change.) In the central thermocline, near 0.3 m Pa, Kp was 10 times higher on day 235, when a strong soliton packet passed through, than it was on day 236, when there was no packet. Day 231 had a packet of intermediate strength which produced an intermediate diffusivity.

Because very strong soliton packets propagate across the Andaman Sea, mixing there will be even more dependent on these packets than it is on the New England shelf. The magnitude is likely to exceed 10-4 m^{2s-1}. Consequently, to be realistic, numerical models will need to include accurate parameterization of K.

Measurement of flow through straits:

Stephen P. Murray
Professor
Coastal Studies Institute and

Department of Oceanography and Coastal Sciences
Louisiana State University

Moored observations of velocity and water mass transport

Recent studies of marginal seas and linking straits have shown the importance of moored acoustic Doppler current profile (ADCP) and salinity-temperature moorings in understanding variability in transport in straits and channels.

The seasonal changes of the winds and the inflow/ outflow strength and structure in the Bab el Mandab strait are illustrated in Figure 1, using the 10 month ADCP record. The first part of the record is characterized by a 2 layer exchange flow typical of conditions found in winter time studies. Deep outflow fro the strait extends ~75 m off the bottom with speeds up to 0.8 m/s, and surface inflow occurs in the overlying layer with about half that strength. By early July the 2 layer winter regime ceases and is replaced by a 3 layer flow structure with weak (occasionally vanishing) deep outflow in the lowest 25 m, a thick intermediate inflow layer of cold low salinity water from the Gulf of Aden, and outflow in the near surface layer (upper 20 m). The reduced deep outflow presumably results from cessation of deep water formation in the northern Red Sea in late spring, while the surface outflow has been attributed to the seasonal wind reversal over the southern Red Sea to northwesterly during the summer monsoon (May-September) Figure 2.

In early October this 3 layer regime gives way again to the 2 layer winter regime that builds to full strength by November. Maximum exchange occurs in February with lower layer outflow speeds greater than 1.2 m/s and inflow speeds of ~0.6 m/s. In late March 1996 there is weakening of the 2 layer flow, which possibly signals an early transition to the summer regime in 1996 or relates to a shorter term fluctuation.

Throughout the record, there are fluctuations in inflow/outflow intensity on time scales of many days to about one month that are related to variations in along-channel wind forcing. Note, e.g., the northwesterly wind intensifications of both July and August (Figure 3) that drive the surface outflow and reduce maxima of 0.4 cm/s in the intruding cold water intermediate layer. The major deceleration of the southeasterly wind in January 1996 is similarly reflected in decreases of current speed in both upper and lower layers. It is clear that seasonal and intraseasonal fluctuations in regional winds strongly modulate exchange magnitude in the Straits.

Note how closely the salinity field Figure 4. The thinning of the high salinity lower layer evidenced by the plunging isohalines in the 37-40 psu range closely tracks the decrease in the lower layer out flow speeds from 0.6-0.2 n/sec from June mid-July. The dominance of the current associated with the gulf of Aden intrusion in July- September in Figure 3b is also clearly reflected in a low salinity signal (36.2-37.5) during the same time interval. The moored temperature data (not shown) indicate this intrusion decreased to 18°C by late August.

In the winter months, the deep outflow entering the Strait at Hanish has salinities of 40.5-40.65 psu, essentially undiluted Red Sea deep water. In early February, during maximum outflow, the 40 psu contour bulges up to 60 m and is accompanied by speed in excess of 1 m/s in the outflow layer at Perim (Figure 3.b). Salinity in the surface layer (Figure 2) also follows an intricate seasonal March. In Mid-July the surface layer salinity decreases to ~6.6 psu under the influence of the leading edge of the cold low salinity intrusion centered at intermediate depths. As summer progresses, the surface outflow increases in thickness, amplifies in speed, and increases in salinity to ~8.0 psu. With the shift in the monsoon wind to southeasterly mid-September, the return of Gulf of Aden surface water gradually reduces salinity to ~36.5 psu by mid-December.

Modeling:

Dr. George L. Mellor
Professor Emeritus
Princeton University
Atmospheric and Ocean Science

The Princeton Ocean Model

The Princeton Ocean Model (POM, Blumberg and Mellor,1982) is a free sea surface, three-dimensional, sigma coordinate model with a turbulence closure sub-model demonstrated to be affective in modeling surface and bottom boundary layers in the ocean. Tidal induced bottom mixing may well be an important process in the current application. The model has been deployed in many applications around the globe by over 300 users who, through the Internet and workshops share information and modeling experience. Over 200 published papers using POM may be accessed on the POM web homepage (http://www.aos.Princeton.edu/htducs.POM).

Appendix D

JASMINE

The Joint Air-Sea Monsoon Interaction Experiment

Hypothesis: Intraseasonal variability (20-40 day) of the Asian-Australian monsoon system is the result of coupled ocean-atmosphere interaction in a region of very strong cross-equatorial pressure gradient force.

Objectives:

- Determine the dynamics & thermodynamic structure of the intraseasonal variations of the monsoon system.

- Assess the variability of the SST relative to the migrations or oscillations of the intraseasonal variability in the monsoon system;

- Measure ocean-atmosphere interactions during intraseasonal transitions including variations of the surface energy budget and the manner in which these are manifested in the thermodynamical structure through the atmospheric column;

- Determine the degree of predictability of the intraseasonal variability and its extension as a predictable signal to larger space and time scales.

Executive Summary

During the last decade there e has been considerable progress towards understanding the intrannual variability of the global tropics, especially in the Pacific Ocean. A combination of diagnostic, theoretical and modeling studied have isolated some of the basic physics of the coupled ocean-atmosphere system. Investigators have used this knowledge to begin predicting aspects of climate variability associated with the ENSO cycle. An ancillary conclusion emerging from diagnostic studies and the variability in the quality of the climate forecast is that intrannual variability in the Pacific Ocean is not isolated but linked in a fundamental manner with the evolution of other major heat sources and sinks, particularly those associated with the Asian -Australian monsoon complex.

Within the monsoon system, and integral to its intrannual variability, is a strong intraseasonal variation . Even a cursory analysis reveals that rather than period of prolonged precipitation, the wet phase of the monsoon is comprised of alternating periods of strong precipitation with lulls in between on time scale of 10 to 30 days. These intraseasonal variations have important agricultural, economic and social implications. For their inherent social and agricultural importance, the forecasting of these events is an important task. However, because of their apparent role in the intrannual variability of the monsoon, understanding and predicting the intraseasonal variability assumes as added importance.

Previous experiments in the monsoon regions concentrated on other aspects of the monsoon phenomenon. For example the summer Monsoon Experiment in the late 1970s attempted to gain a description and an understanding of phenomena in the Arabian Sea, cross-equatorial flow (e.g., the Somali Jet) and storms in the Bay of Bengal. An emphasis on the longer term variability of the monsoon was not attempted because of other interests, logistical constraints, and, because the concept of active break periods of the monsoon as dynamic-thermodynamic entities in themselves was not recognized. However, there is recent recognition that active and break periods are very large-scale and coherent entities with ubiquitous life cycles. Furthermore, there is reason to believe that the warm pool of the eastern Indian Ocean is a critical region for development of intraseasonal variability and a region from which global climate signals radiate . A decade ago, a similar recognition of EL Nino as a coherent part of a basin-wide coupled ocean-atmosphere phenomena led to significant advancements in understanding basic physical processes that control the phenomena and, to its prediction. We are similarly posed at this juncture to make equal progress in the realm of the monsoon.

The aim of this paper is to discuss the concept of an investigation of the Asian-Australian summer monsoon. The ideas presented here, and the initial experimental design, represent the results of preliminary discussions between diverse group of meteorologists and oceanographers. We propose a multiyear investigation termed JASMINE (Joint Air-Sea Monsoon Investigation). JAS-

MINE is based on the following hypothesis:

Intraseasonal variability of the Asian-Australian monsoon system is the result of coupled ocean-atmosphere interaction in a region of very large cross equatorial surface gradient. .

Relative to the hypothesis there are a number of scientific objectives. These are to:

(I) *Determine the dynamic and thermodynamic structure of the intraseasonal variations of the Asian - Australian monsoon system in the location of maximum variability*

(II) *Assess the variability of the SST relative to the migrations of the intraseasonal variability in the monsoon system;*

(III) *Measure the ocean-atmosphere interactions during intraseasonal transitions including variations of the surface energy budget and the manner that these are manifested in the thermodynamic structure through the atmospheric column;*

(IV) *Determine the degree of predictability of the intraseasonal variability of the monsoon and its extensions as a predictability signal to larger space and time scales; and*

(V) *provide data for diagnostic studies, model evaluation, parameterization and predictability experiments.*

JASMINE includes the following elements;

(I) *Diagnostic and empirical studies using existing data sets to define the bstructure of intraseasonal variations of the monsoon intraseasonal variations;*

(II) *Modeling studies to investigate physical processes involved in the intraseasonal variability of the monsoon and to help define an observational strategy for the investigations of intraseasonal variability of the monsoon;*

(III) *Field experiments in the eastern Indian Ocean to gather data to discern the nature of coupled ocean-atmosphere during the life cycle of intraseasonal variability;*

(IV) *Modeling and empirical studies to develop predictive techniques for intraseasonal variability of the monsoon and its impact on intrannual variability.*

In this document the current understanding of intraseasonal variability of the monsoon is discussed. This description is followed by plans for extending these ideas which may lead, eventually, to a predictive capability. It is proposed that this document serve as a starting point for the development of a thorough investigation of the monsoon and its relationship with the global climate. It is proposed that a workshop be held to discuss future directions and progress during the last quarter of 1997.