

# IndOOS (Indian Ocean Observing System):

Present status and recent highlights  
on air-sea interactions in the Indian Ocean



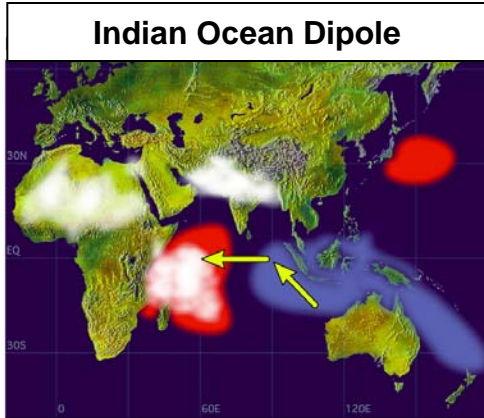
Yukio Masumoto  
(RIGC, JAMSTEC)

# Outline

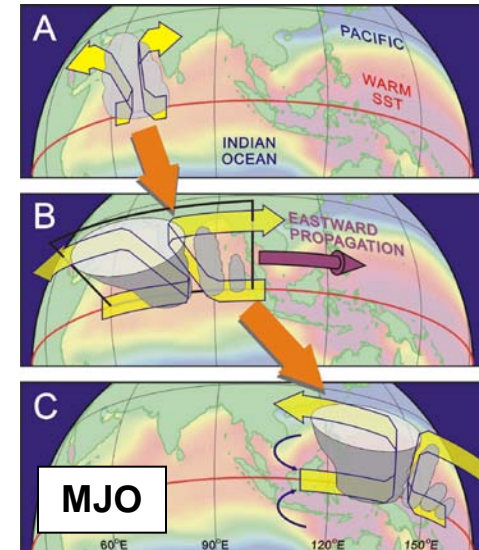
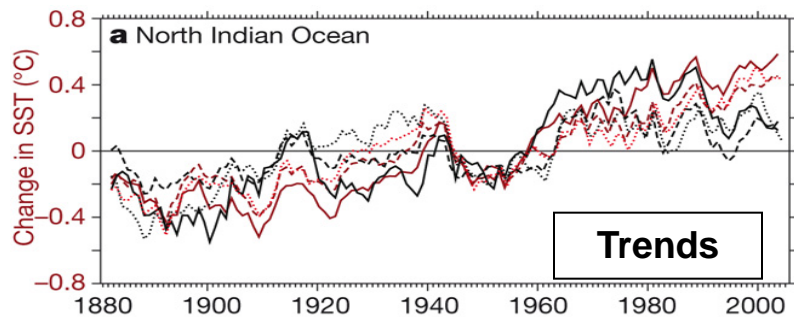
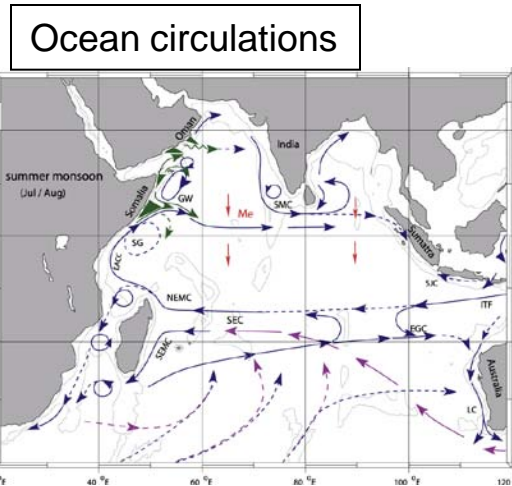
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- Indian Ocean Observing System
  - Background and present status
- Examples of key phenomena observed by IndOOS
  - Ocean responses and air-sea interactions associated with cyclone Nargis
  - Strong upwelling in the equatorial Indian Ocean during MISMO
  - IOD variations

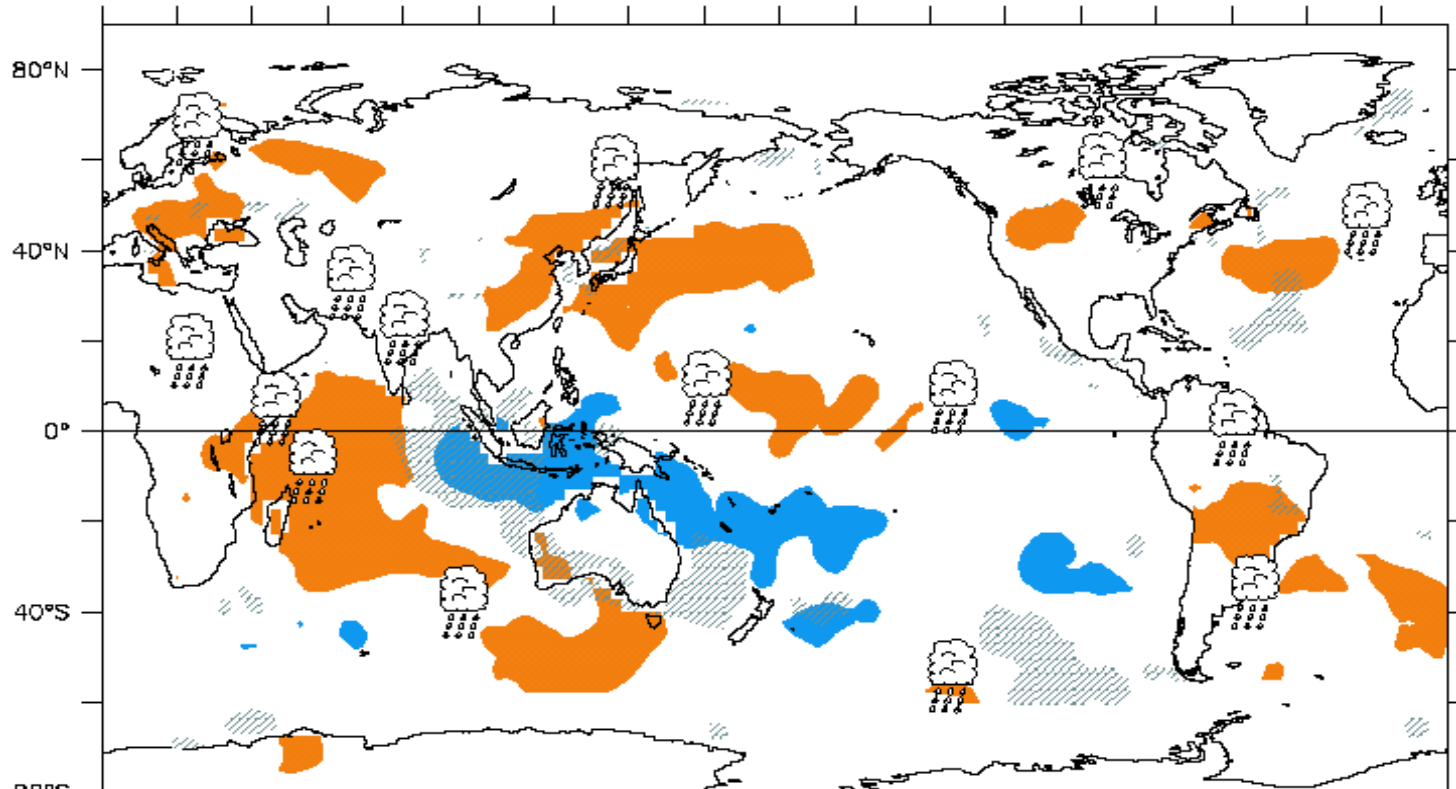
# Indian Ocean Science Drivers



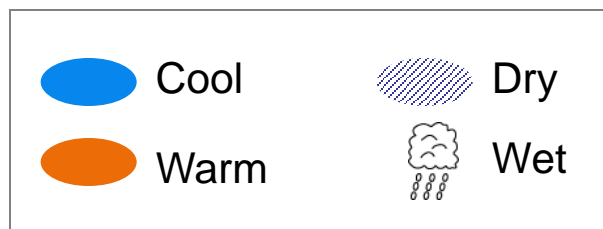
- Seasonal monsoons
- Severe weather events & cyclones
- Intraseasonal (30-60 day) variations, Madden Julian Oscillation
- Interannual variations: the Indian Ocean Dipole, Influence of ENSO
- Decadal variability and warming trends
- Ocean circulations and biogeochemistry



# Impacts of positive IOD during boreal summer

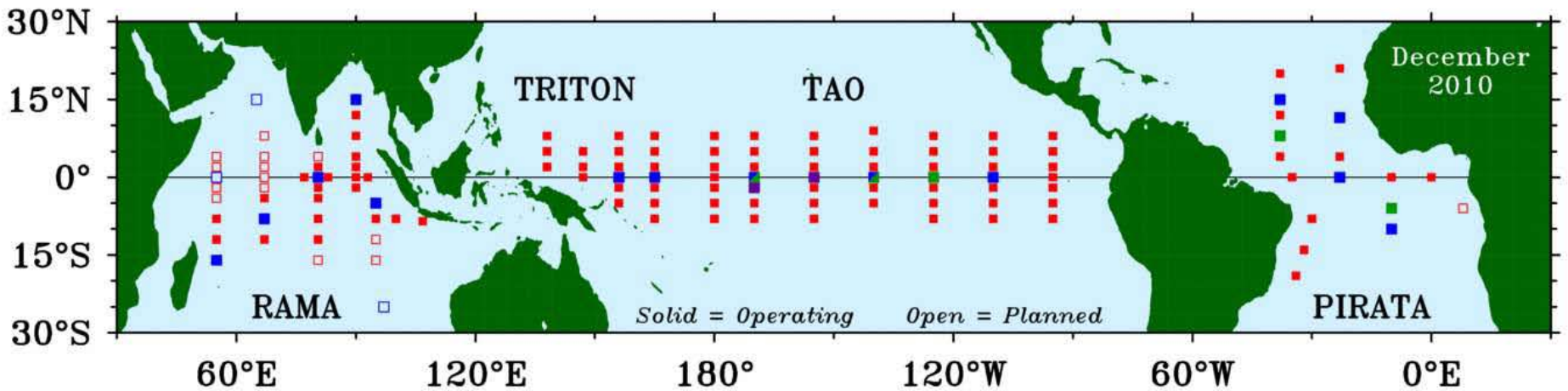
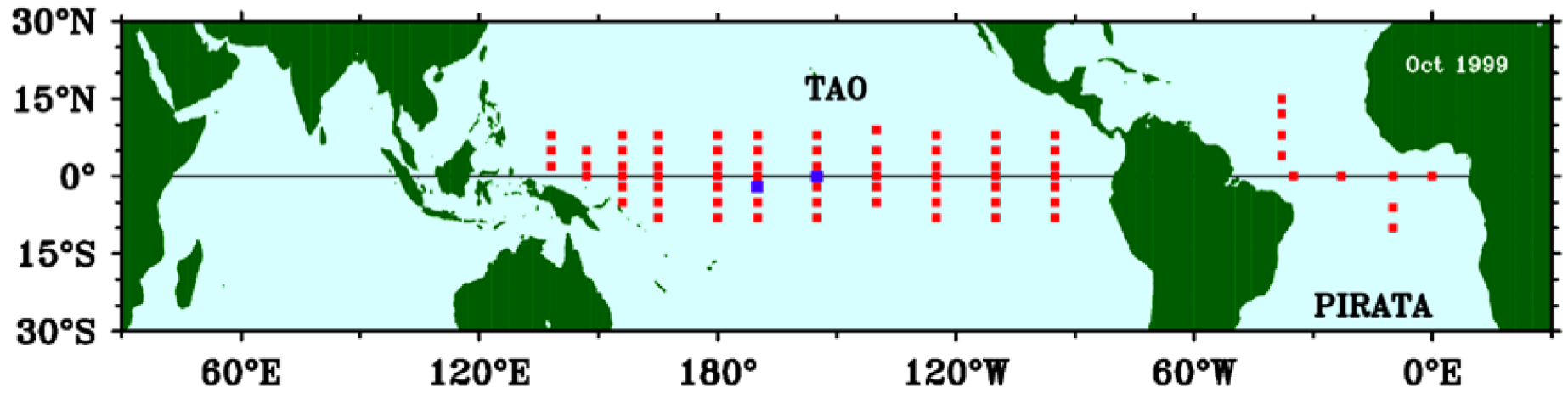


**Indian Ocean is the most poorly sampled region of the tropics**



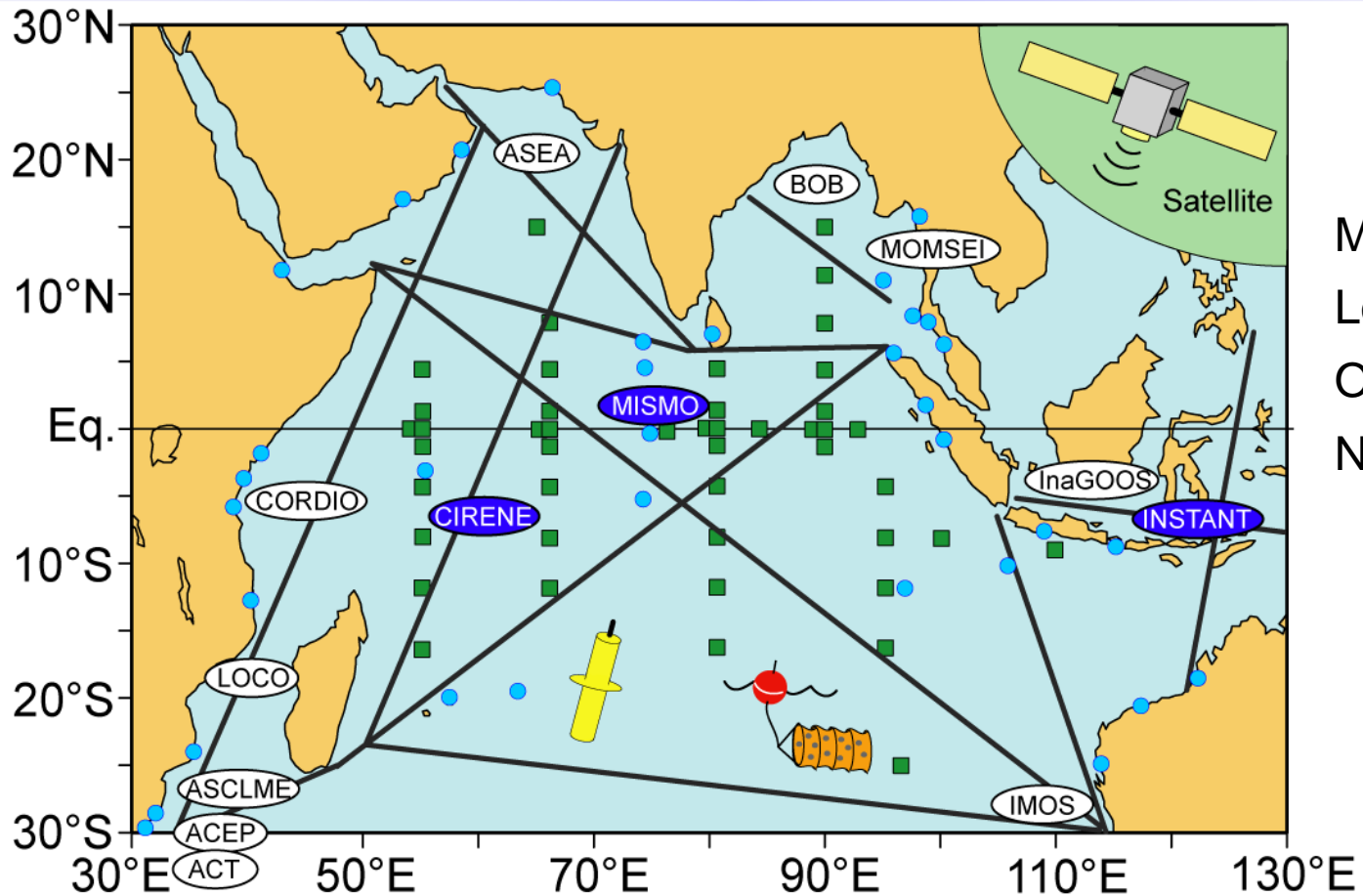


# Global Tropical Moored Buoy Array



- Standard Mooring
- Flux Reference Site
- Flux and CO<sub>2</sub> Enhanced
- CO<sub>2</sub> Enhanced
- CO<sub>2</sub> and Bio-Chem Enhanced

# Indian Ocean Observing System (IndOOS)



Multi-platform  
Long-term  
Observation  
Network

■ RAMA

— XBT/XCTD lines

● Surface drifting buoy array

● ARGO float array

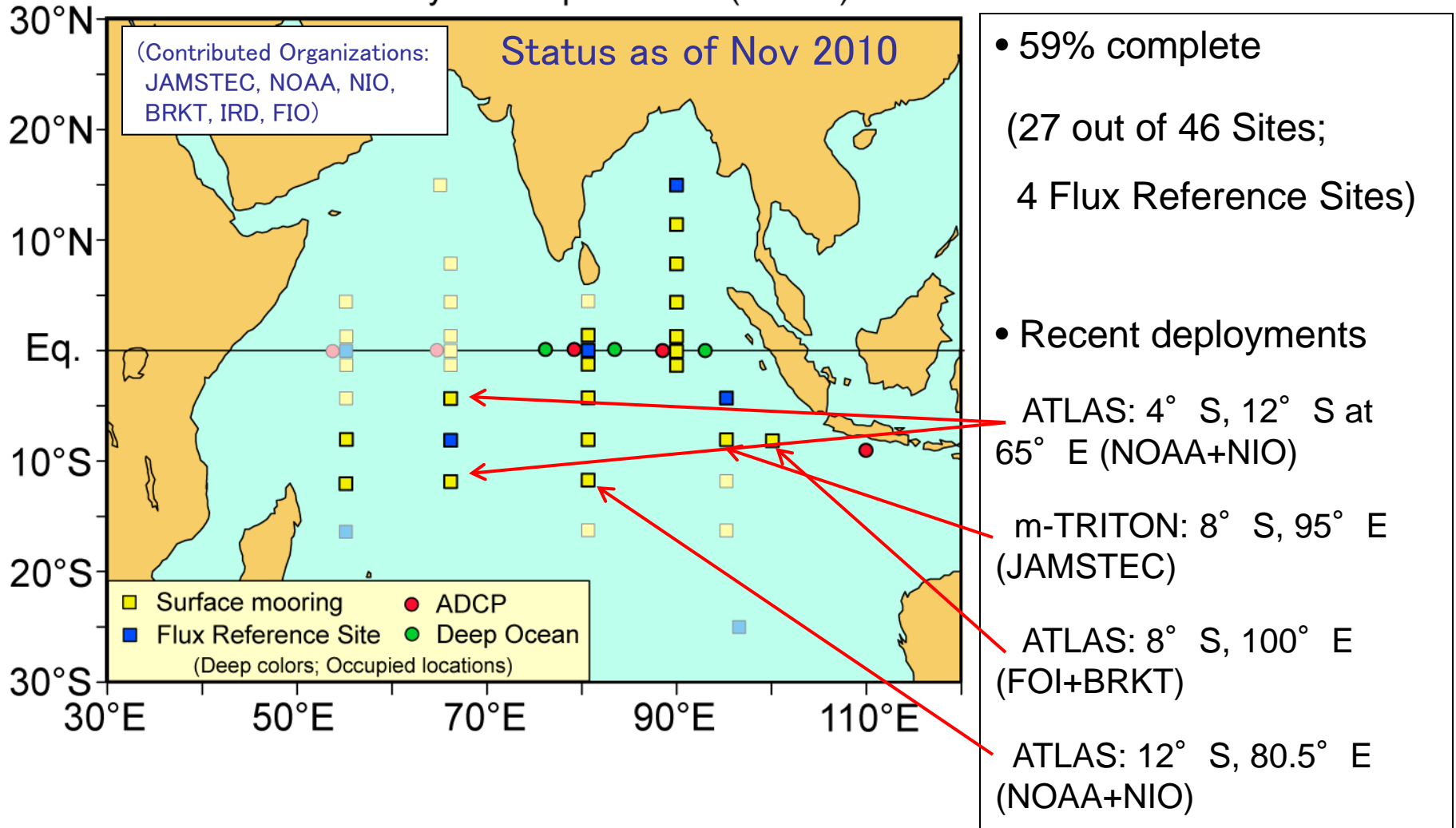
● Real-time and near real-time tide gauge network  
(including the tsunami buoy network)

● PS Process Studies

○ ROOS Regional Ocean Observing Systems

# Mooring Array: Present Status

Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA)



- 59% complete (27 out of 46 Sites; 4 Flux Reference Sites)

- Recent deployments

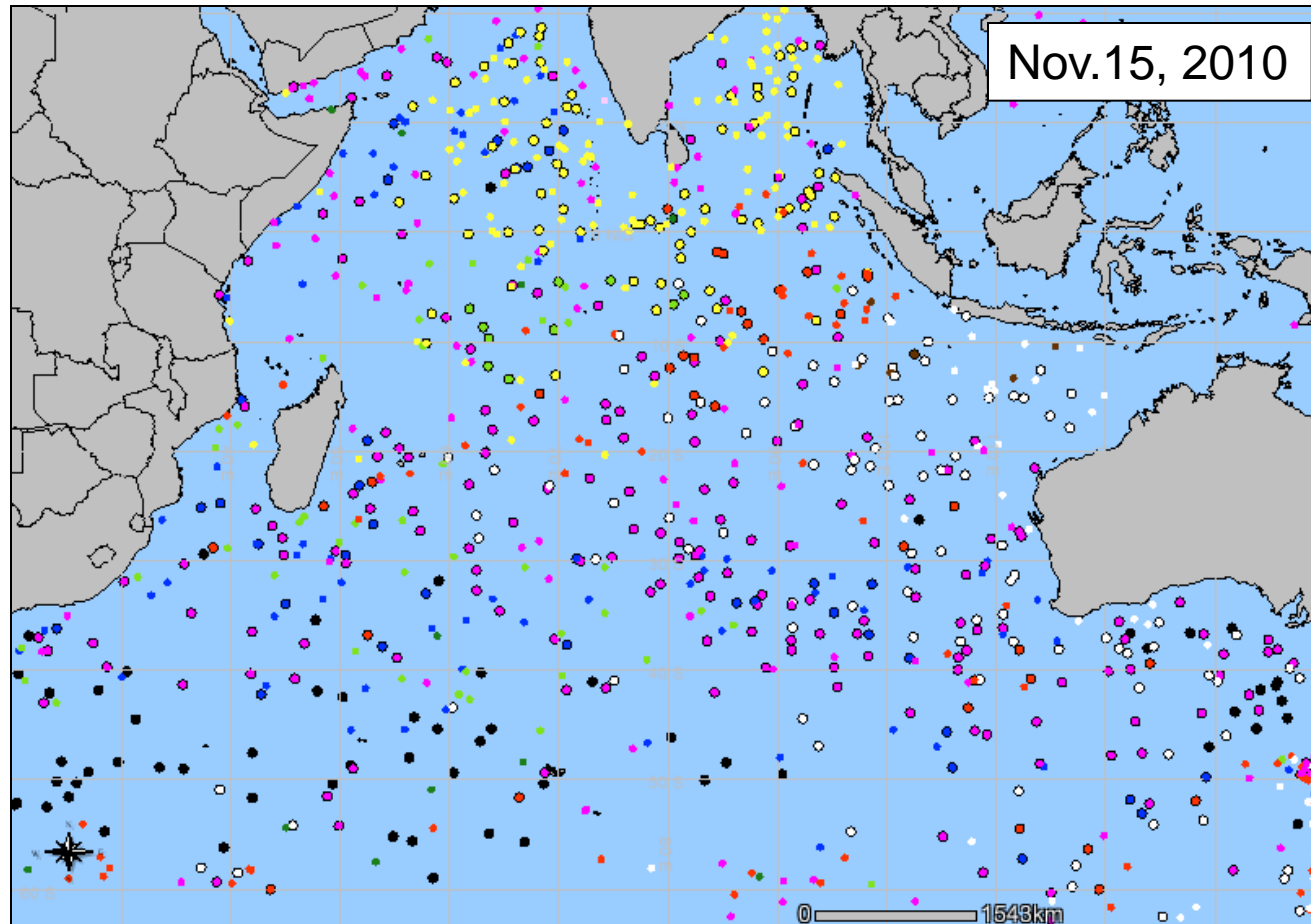
- ATLAS: 4° S, 12° S at 65° E (NOAA+NIO)

- m-TRITON: 8° S, 95° E (JAMSTEC)

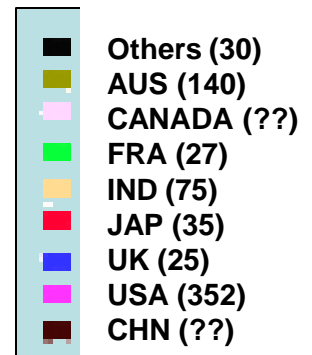
- ATLAS: 8° S, 100° E (FOI+BRKT)

- ATLAS: 12° S, 80.5° E (NOAA+NIO)

# Present status of Argo in the Indian Ocean sector



Active Number  
of floats: 674





# IndOOS Data Portal & RAMA Data sites

indOOS  
Indian Ocean Observing System

You are Here: indOOSHome

Indian Ocean Observing System (IndOOS)

In-Situ

Remote Sensing

Contact Webmaster

IndOOS data portal maintained by INCOIS, India

All the available data for IndOOS are listed with links to sources

Home | Project overview | Data display and delivery | El Niño & La Niña | Site Map

T·A·O Data display and delivery

Find

TAO/TRITON (Pacific) | PIRATA (Atlantic) | RAMA (Indian)

Learn About RAMA

De-Select Sites

Time Series | Profiles | Time Section | Lat Lon Map | Depth Section

One Variab | One Site | Separate Plot | Overlay

SW Rad | LW Rad | Rain | Wspd | Uwnd | Vwnd | Wdir | Wnd Ve | RH

Air T | SLP | SST | T(z) | SSS | S(z) | SSD | D(z) | Heat

Dyn Ht | 20C | Ucur | Vcur | Cur Vec | Uadcp | Vadcp | Long | Lat

2004 | October | 2.. | 2010 | June | 2.. | Monthly

files by site | ascii | None

Definitions | Availability | Clear | Deliver | Display

Problems? | Non-JAVA Version | Old Data Display | Old Data Delivery | Comments or Suggestions?

Mac OS X Users: Safari and Firefox are the recommended browsers

Acknowledgment for use of TAO, PIRATA, and RAMA data

Home | Project overview | Data display | Data delivery | El Niño & La Niña | Site map

TAO Project Office  
NOAA | Pacific Marine Environmental Laboratory  
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Seattle, WA 98115  
oar.pmel.taotech@noaa.gov  
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LINE PLOTS

Time series

Longitude

Latitude

HOFBAUER PLOTS

Longitude-time

Latitude-time

Date: Oct 14 2008 00

Analyz analysis

start | 1216 Indoon D... | Incois Argo Pre... | IndOOS\_data\_p... | 1094-Feb03-2008 | 102205 LIVE AC... | 9:29 PM

## RAMA Data site maintained by PMEL

Tropical Atmosphere Ocean project

Home | Project overview | Data display and delivery | El Niño & La Niña | Site Map

T·A·O Data display and delivery

Find

To select mooring sites, click orange boxes to select lines of sites, click and hold on your mouse to draw a box around sites, or click single sites. Red indicates which sites are selected. Solid squares show where all selected variables are available. Half filled squares show where some are available. Empty squares show where none are available. This page may take a few moments to load on slower networks and computers.

TAO/TRITON (Pacific) | PIRATA (Atlantic) | RAMA (Indian)

Learn About RAMA

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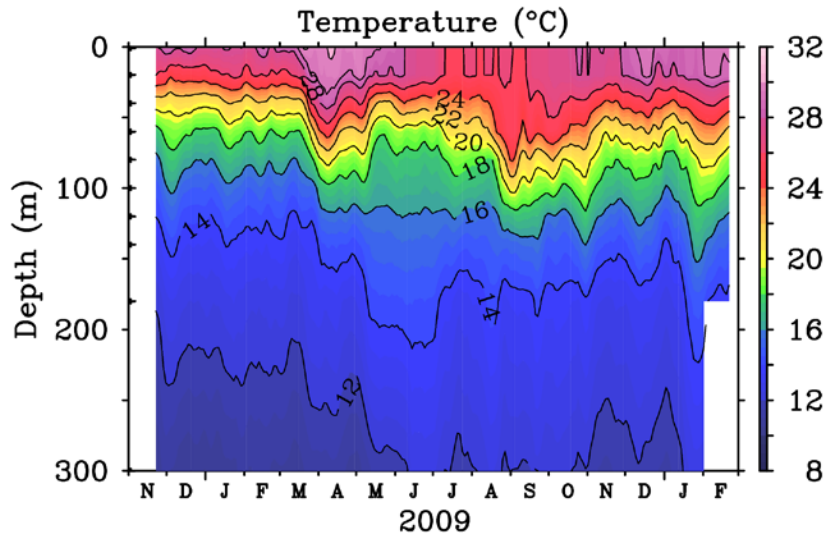
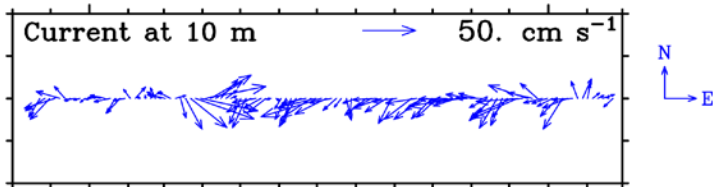
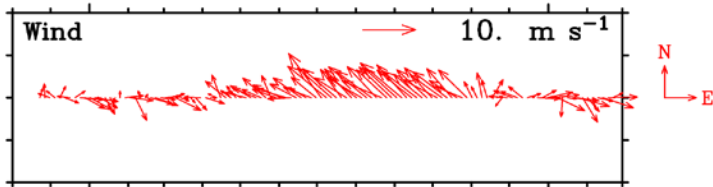
TAO Project Office  
NOAA | Pacific Marine Environmental Laboratory  
7600 Sand Point Way NE  
Seattle, WA 98115  
oar.pmel.taotech@noaa.gov  
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# Two Examples of RAMA Data

## Thermocline Ridge in the southwestern tropical IO

8°S, 55°E

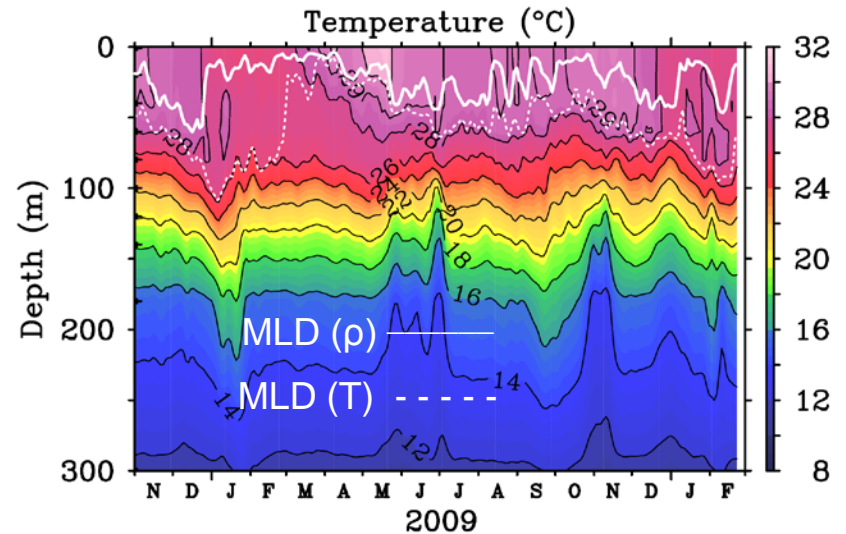
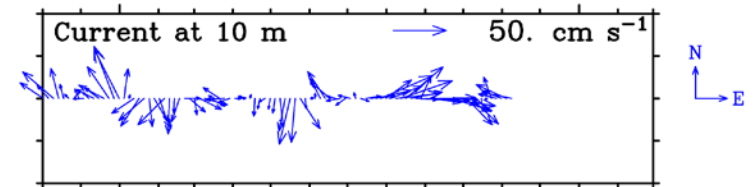
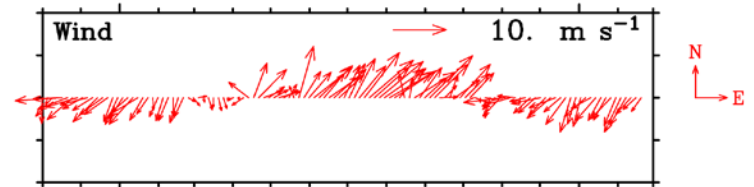
Five-Day Wind, Current, and Temperature Data



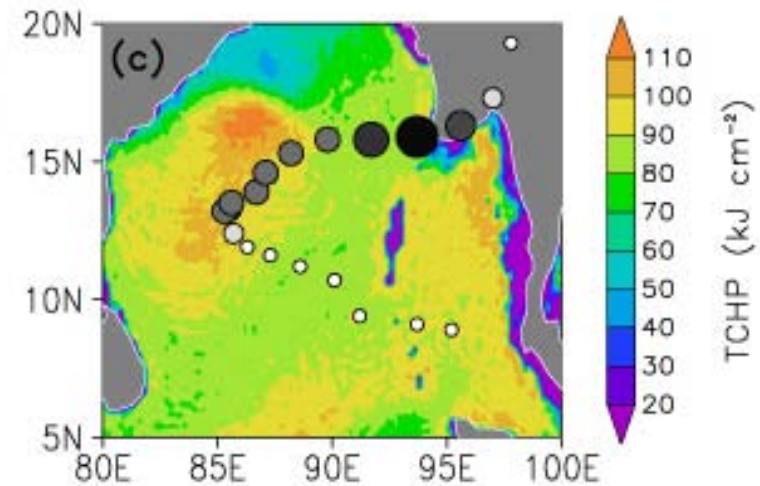
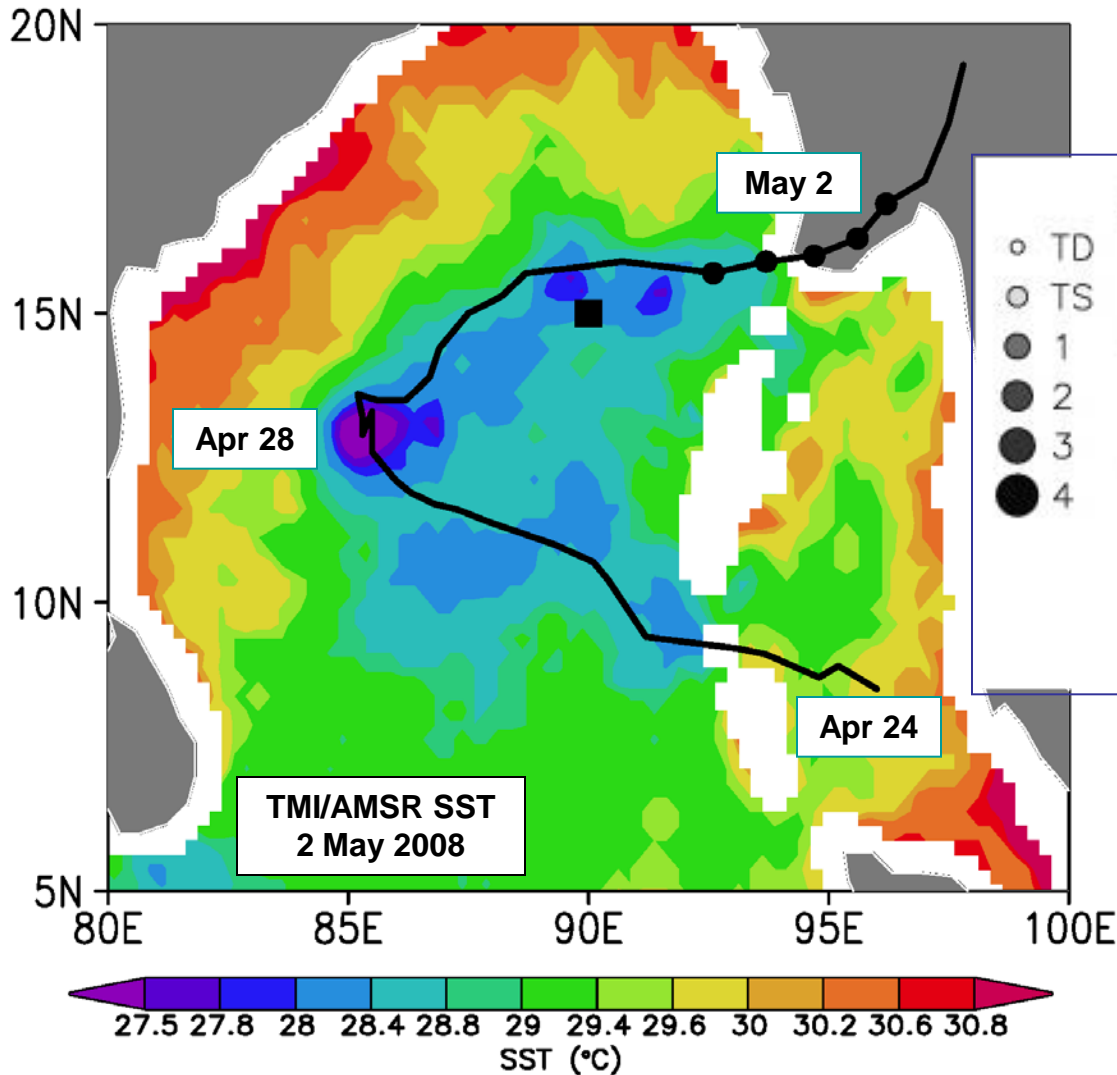
## Bay of Bengal

15°N, 90°E

Five-Day Wind, Current, and Temperature Data



# Cyclone Nargis



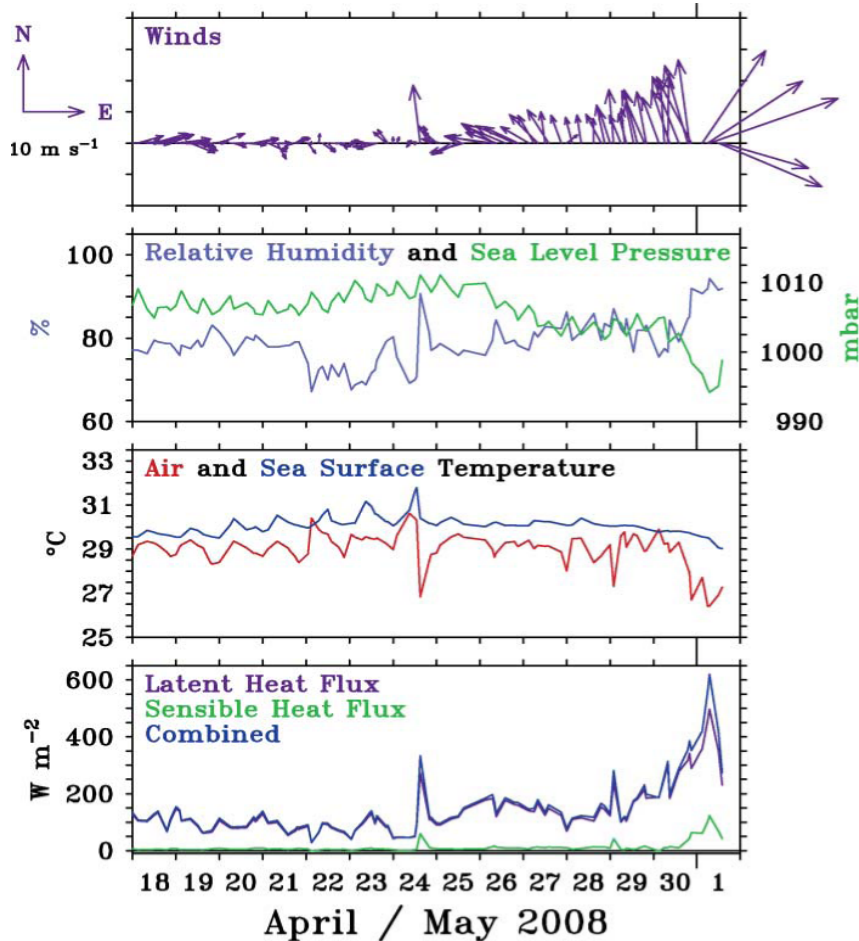
**Tropical Cyclone  
Heat Potential  
(April Climatology)**

TCHP: the amount of heat stored  
above the 26° C isotherm



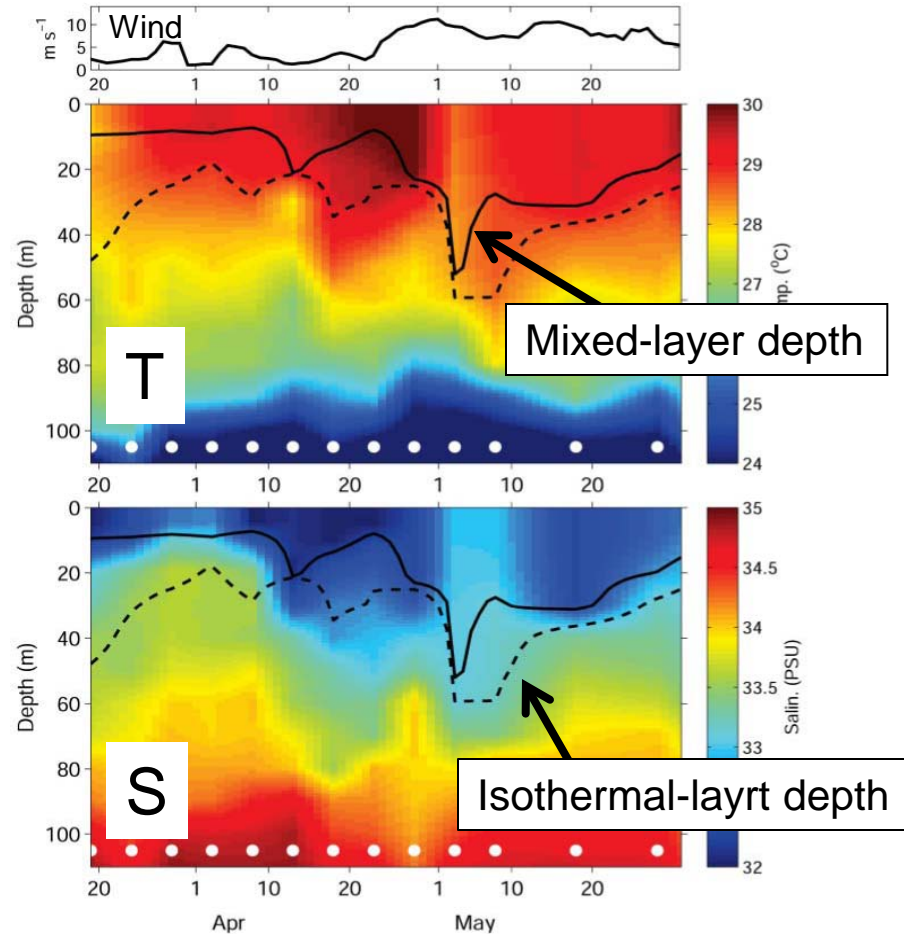
# Variability associated with Cyclone Nargis

Surface meteorological data & estimated surface fluxes from the buoy at 90E, 15N



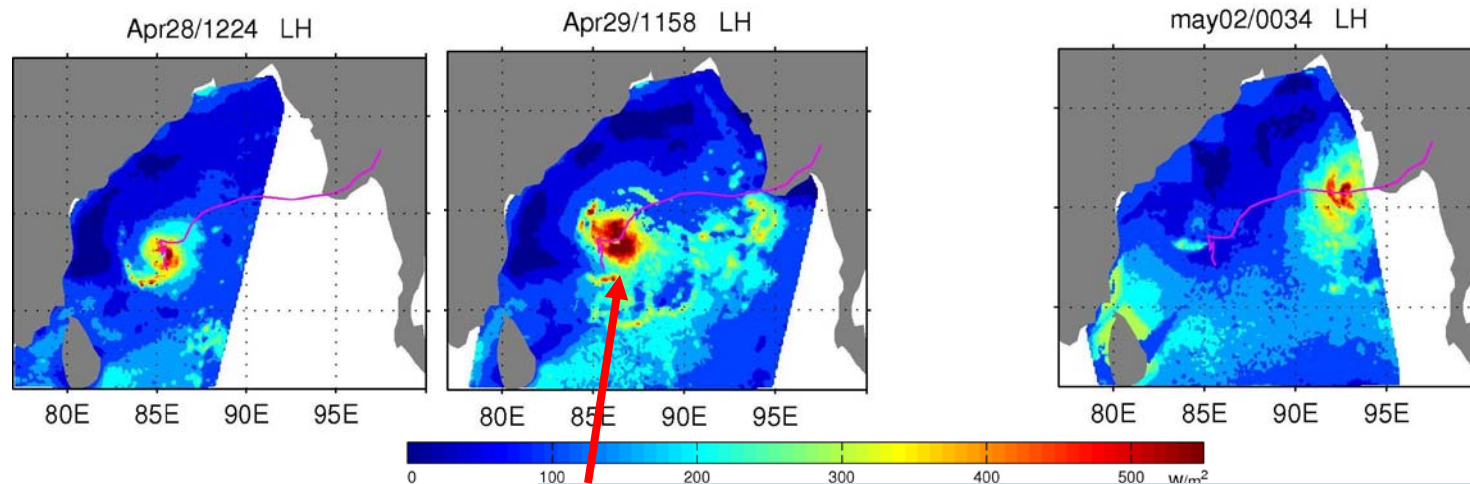
ATLAS buoy measures large variability in the surface fluxes

3-day averaged QSCAT wind (upper), Argo T (middle) & S (lower) profiles

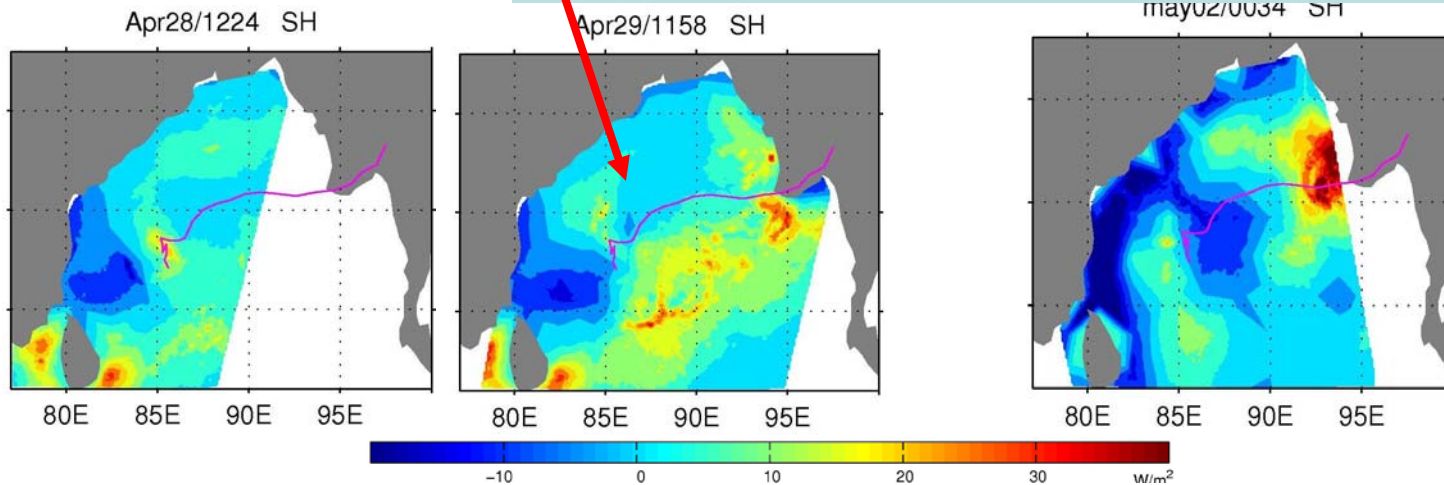


Argo buoys capture large variability in the surface mixed-layer T, S

# OAFlux estimation of Nargis latent and sensible heat fluxes



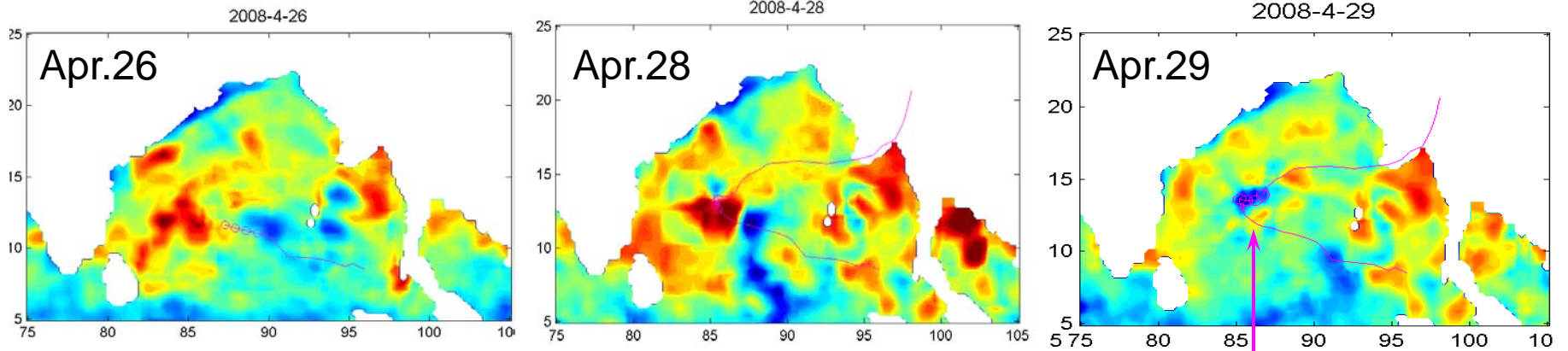
Large LHF associated with the cyclone  
SHF can be negative, i.e. heat is transferred from air to the ocean



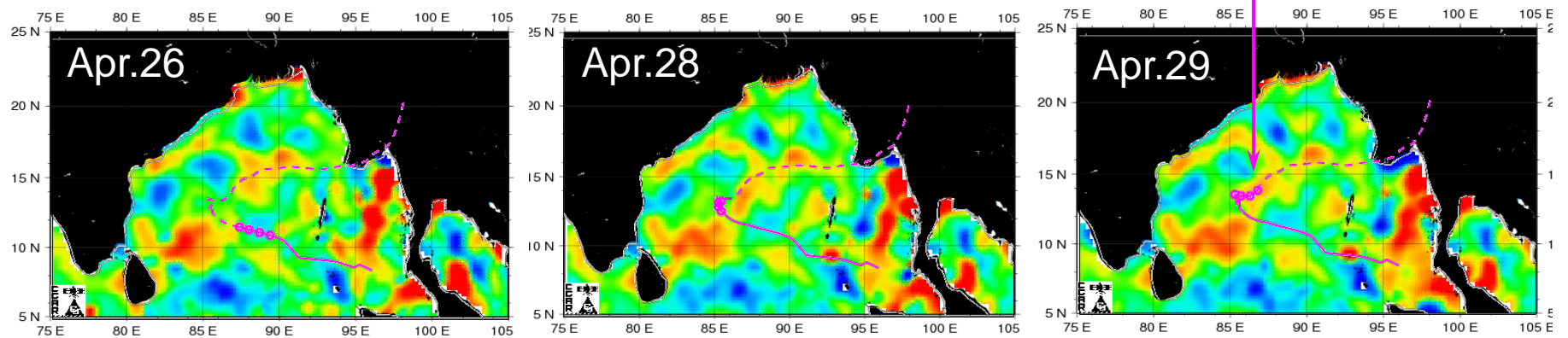


# Warm core ring signature in SST

## SST



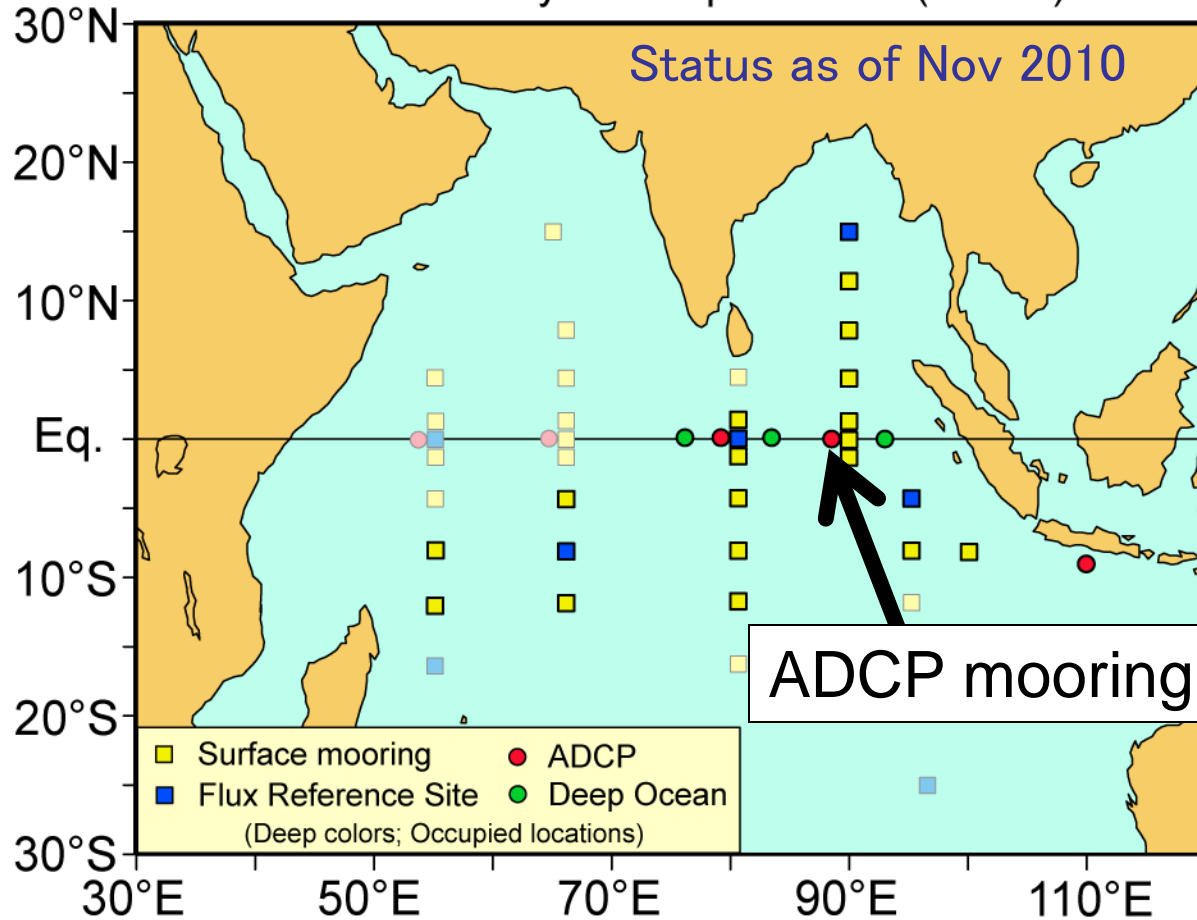
## SSH



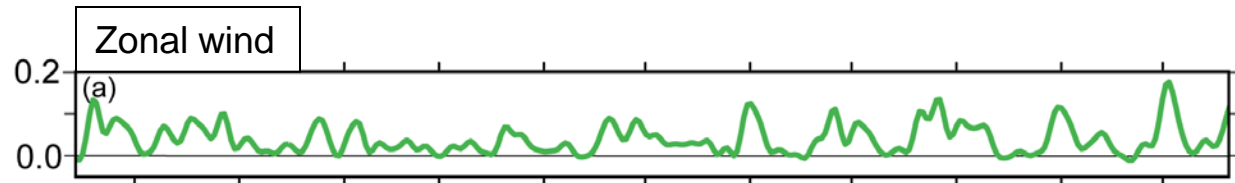
(Yu,2009; Lee 2009, personal communication)

# Mooring Array: Present Status

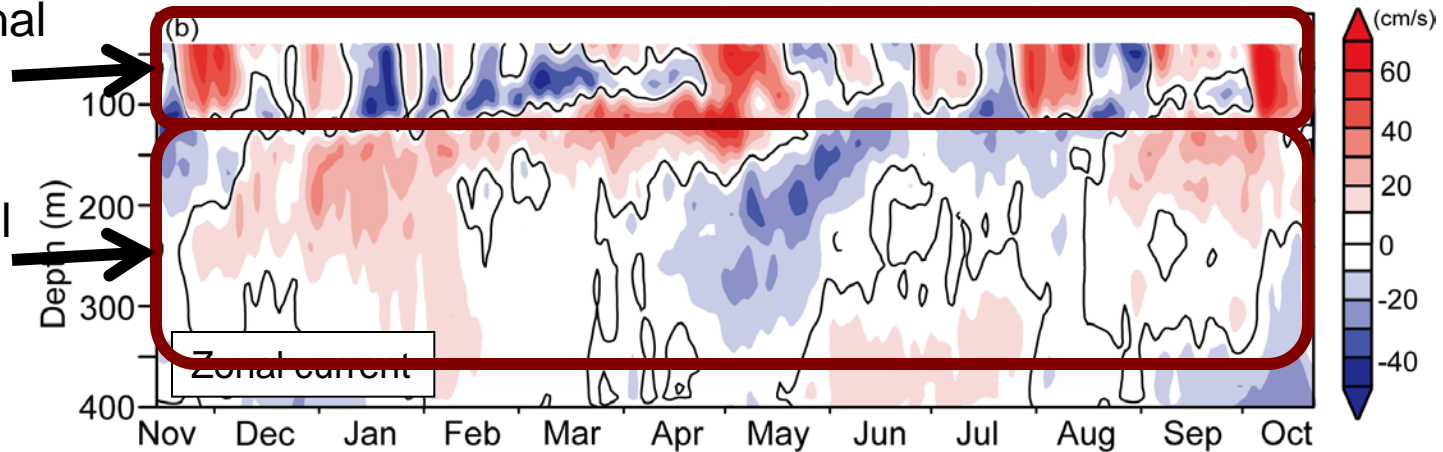
Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA)



# Current variability at 90E on the equator

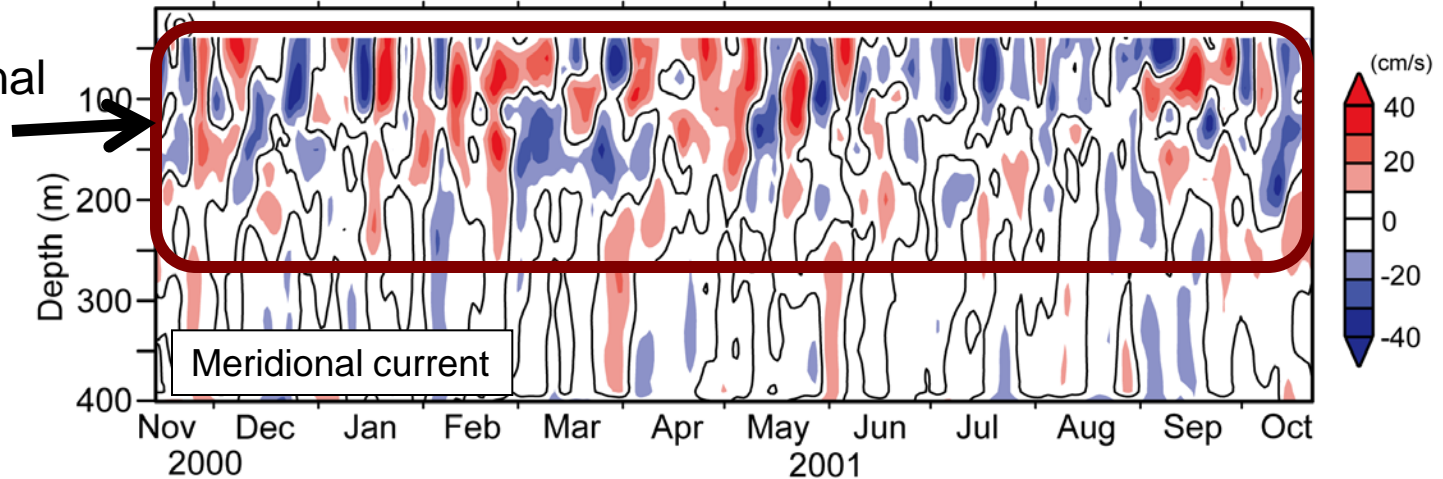


Intraseasonal  
variations  
(30-60 days)

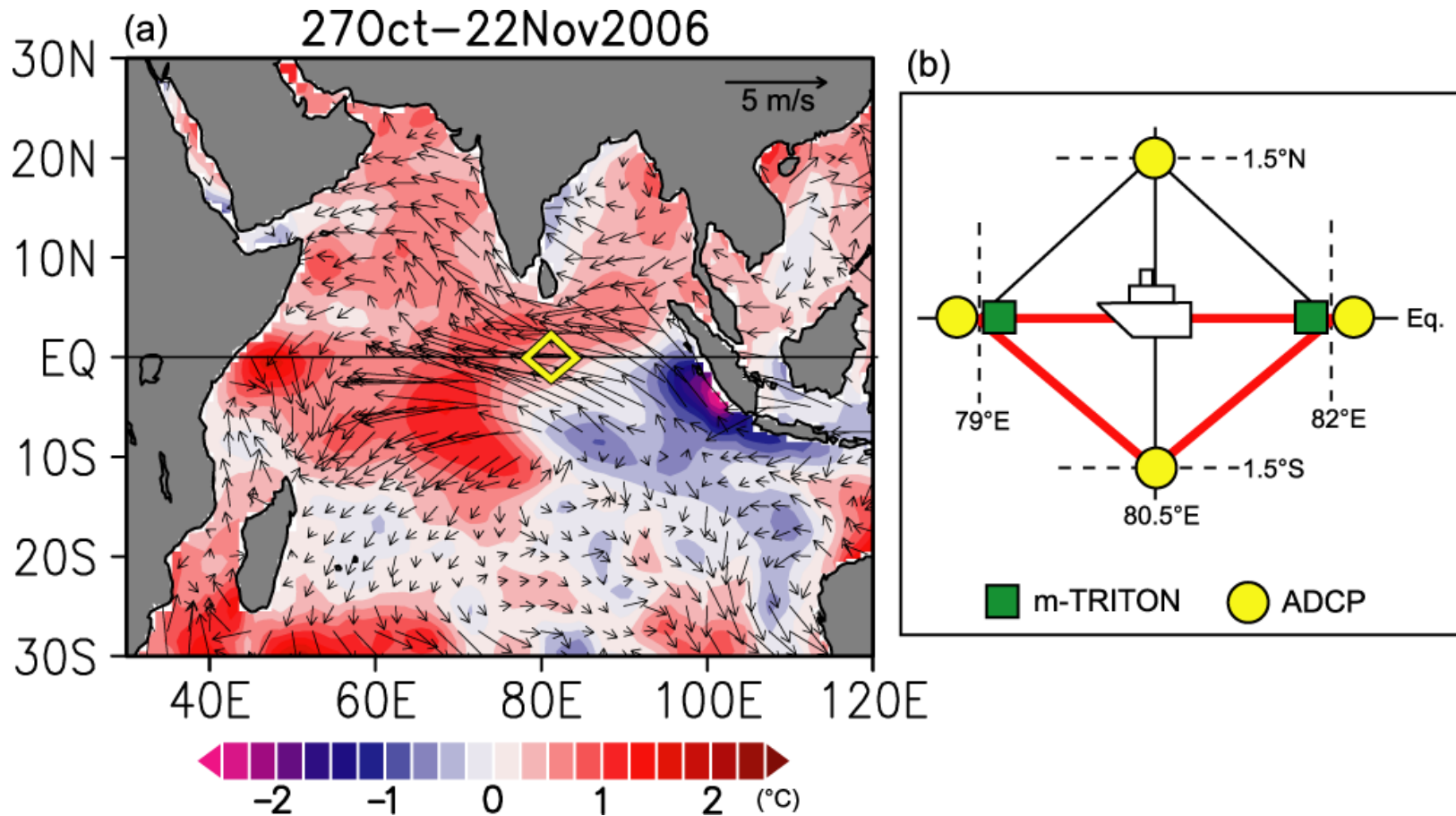


Semiannual  
signal

Intraseasonal  
variations  
(10-20 days)

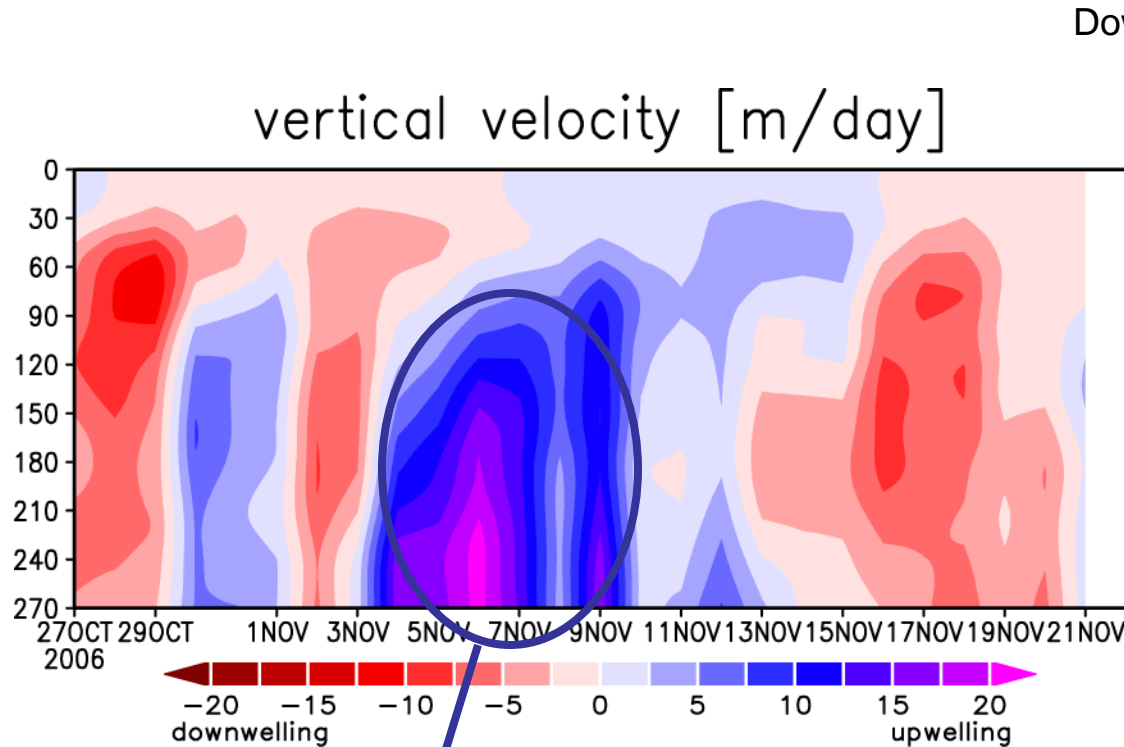


# MISMO Observations and Large-scale Background Conditions



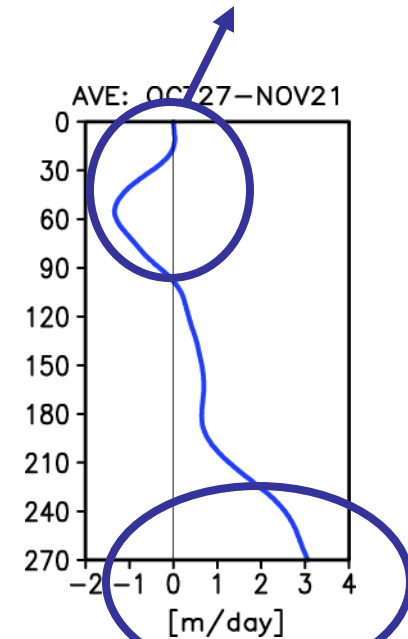
MISMO observations were conducted during the height of 2006 IOD event.

# Vertical Profile of $w$



Strong upwelling/downwelling of 10 m/day occurred sporadically at intraseasonal time scale

Downwelling in the top 100m depth

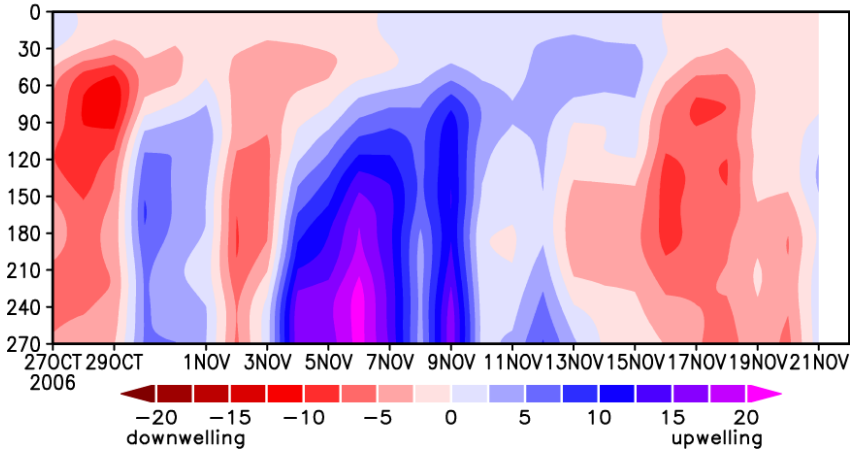


Mean value of  $\sim 2$  m/day is about the same magnitude with previous studies in the Pacific Ocean

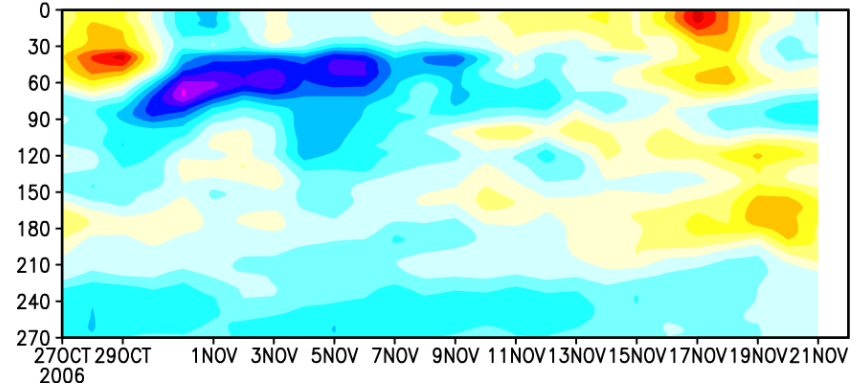


# Causes of strong upwelling

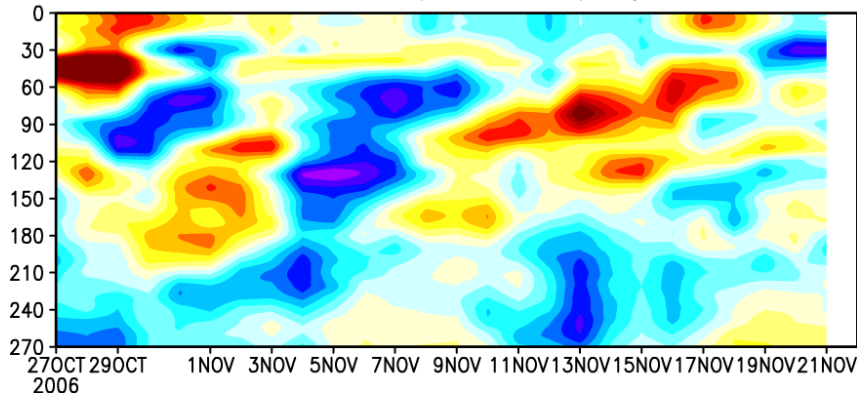
vertical velocity [m/day]



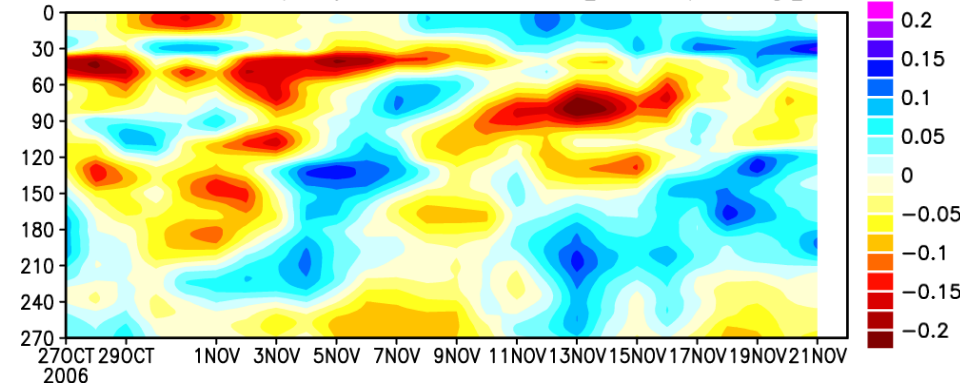
ADCP  $\partial u/\partial x$  82E-79E [ $\text{ms}^{-1}/\text{deg}$ ]



ADCP  $\partial u/\partial x + \partial v/\partial y$

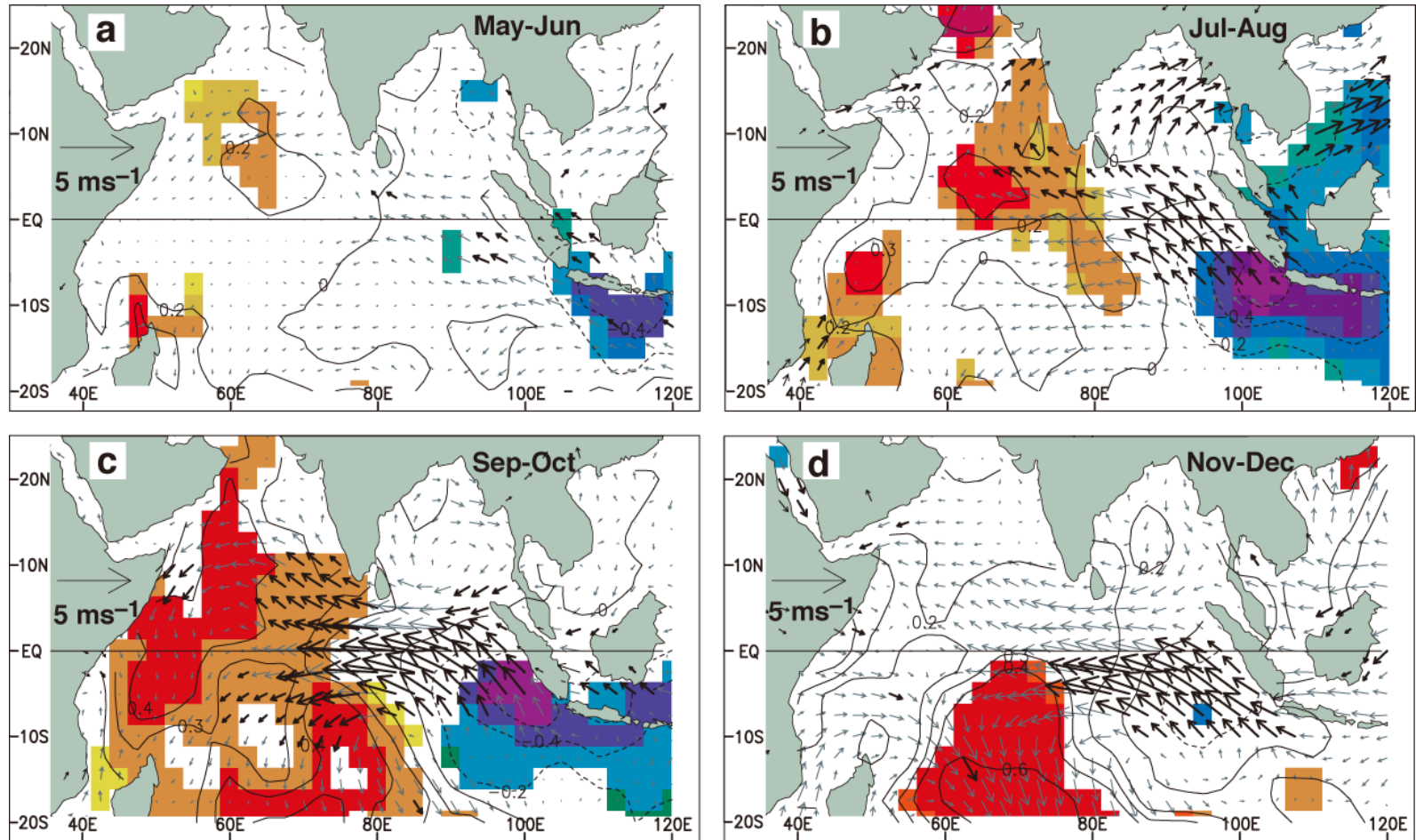


ADCP  $\partial v/\partial y$  EQ-1.5S [ $\text{ms}^{-1}/\text{deg}$ ]



- Large amplitude vertical motion is associated with the subsurface meridional current divergence at the intraseasonal time scale

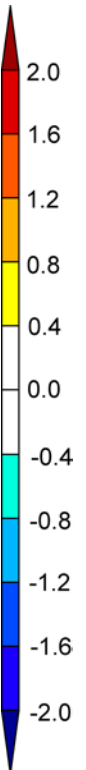
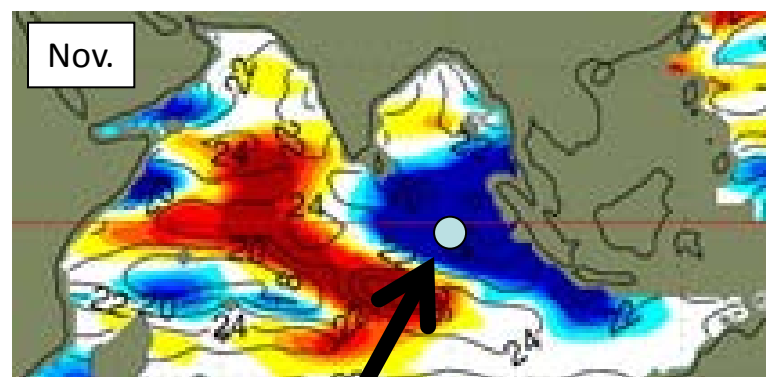
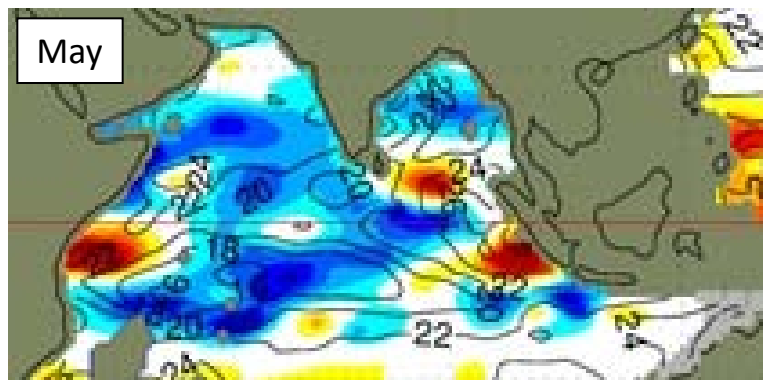
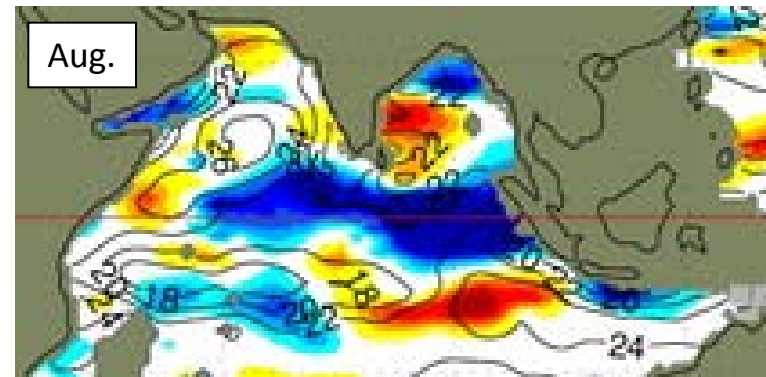
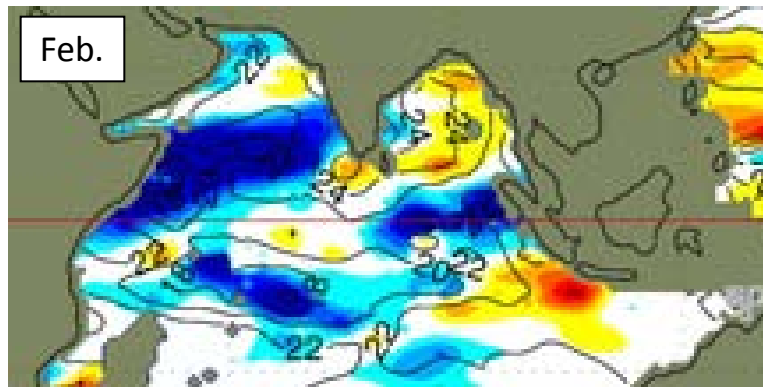
# Evolution of IOD



(Saji et al., 1999)

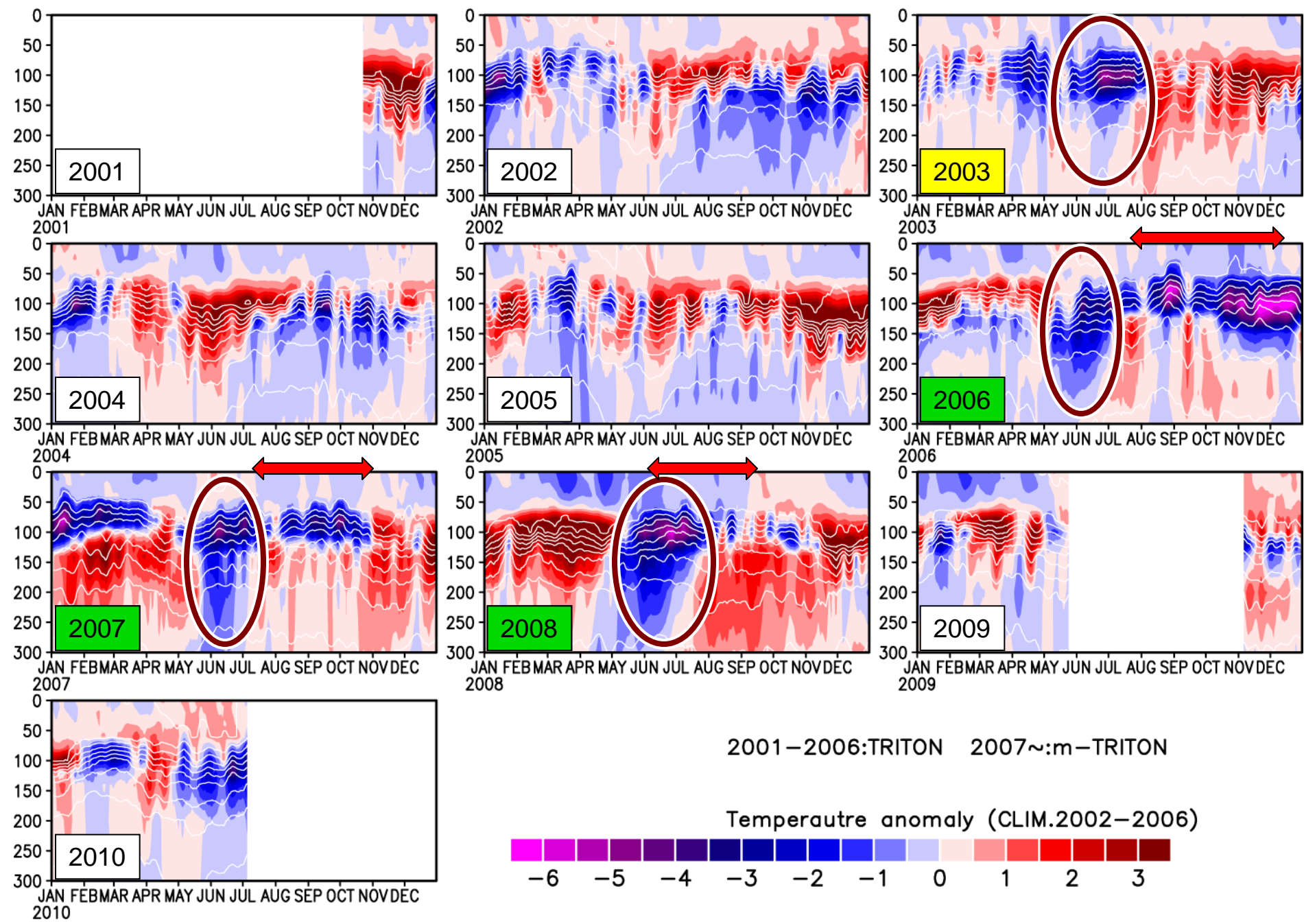
# Argo detecting 2006 IOD evolution

(Monthly mean temperature anomaly at 100m depth)



TRITON mooring

# TRITON & m-TRITON (1.5S, 90E) TEMPERATURE

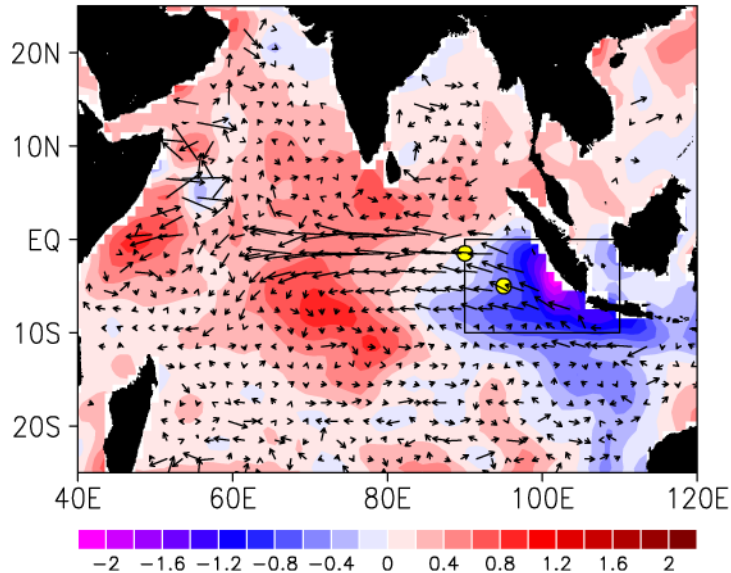




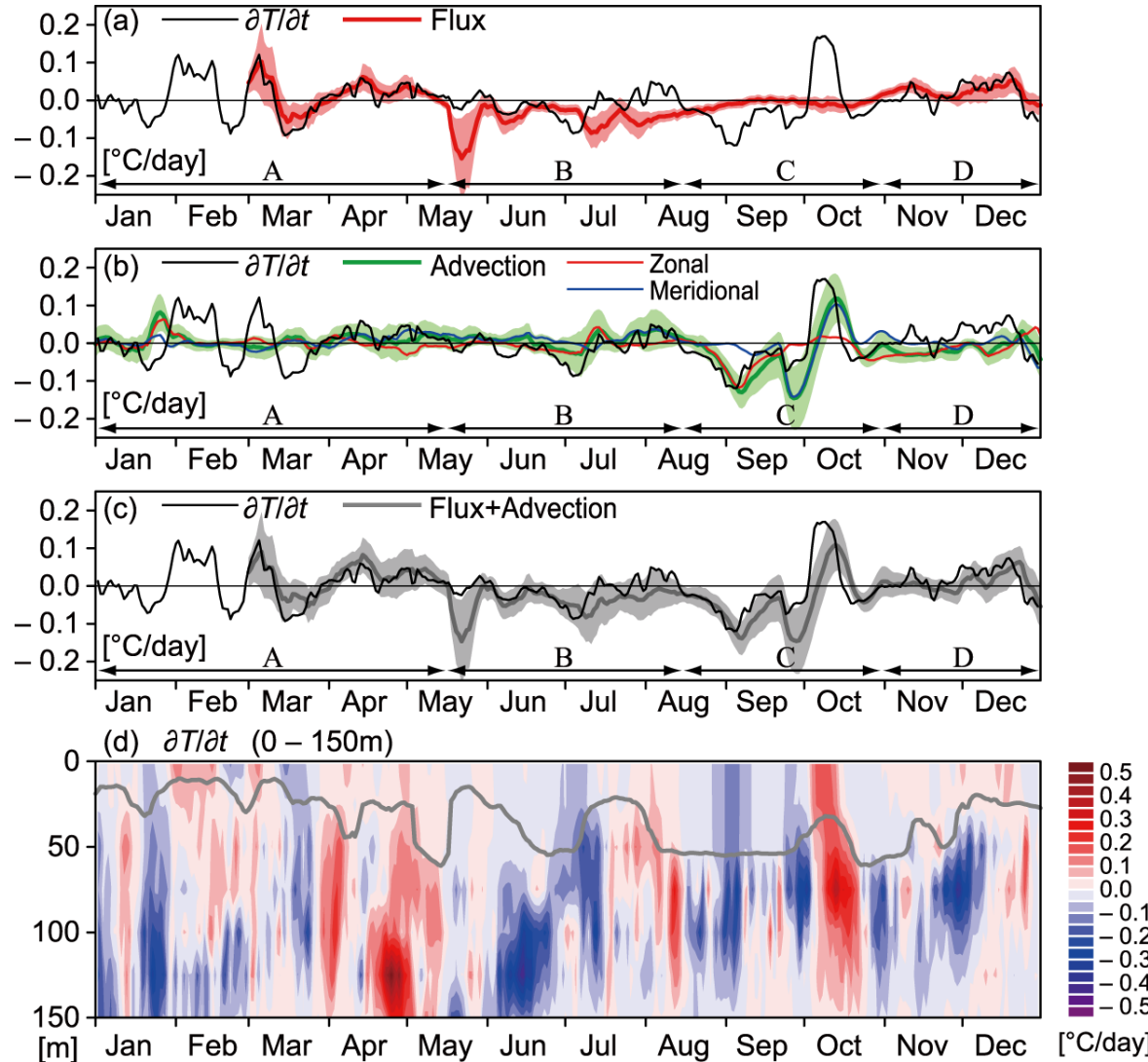
# Heat Budget Analysis at the eastern pole of IOD

Aug-Nov, 2006

SST & Upper current anomaly  $\overrightarrow{50}$  [cm/s]



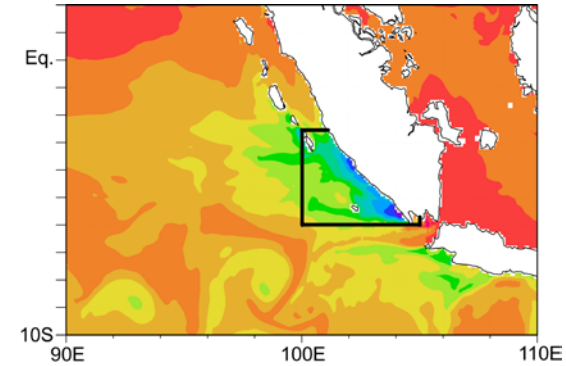
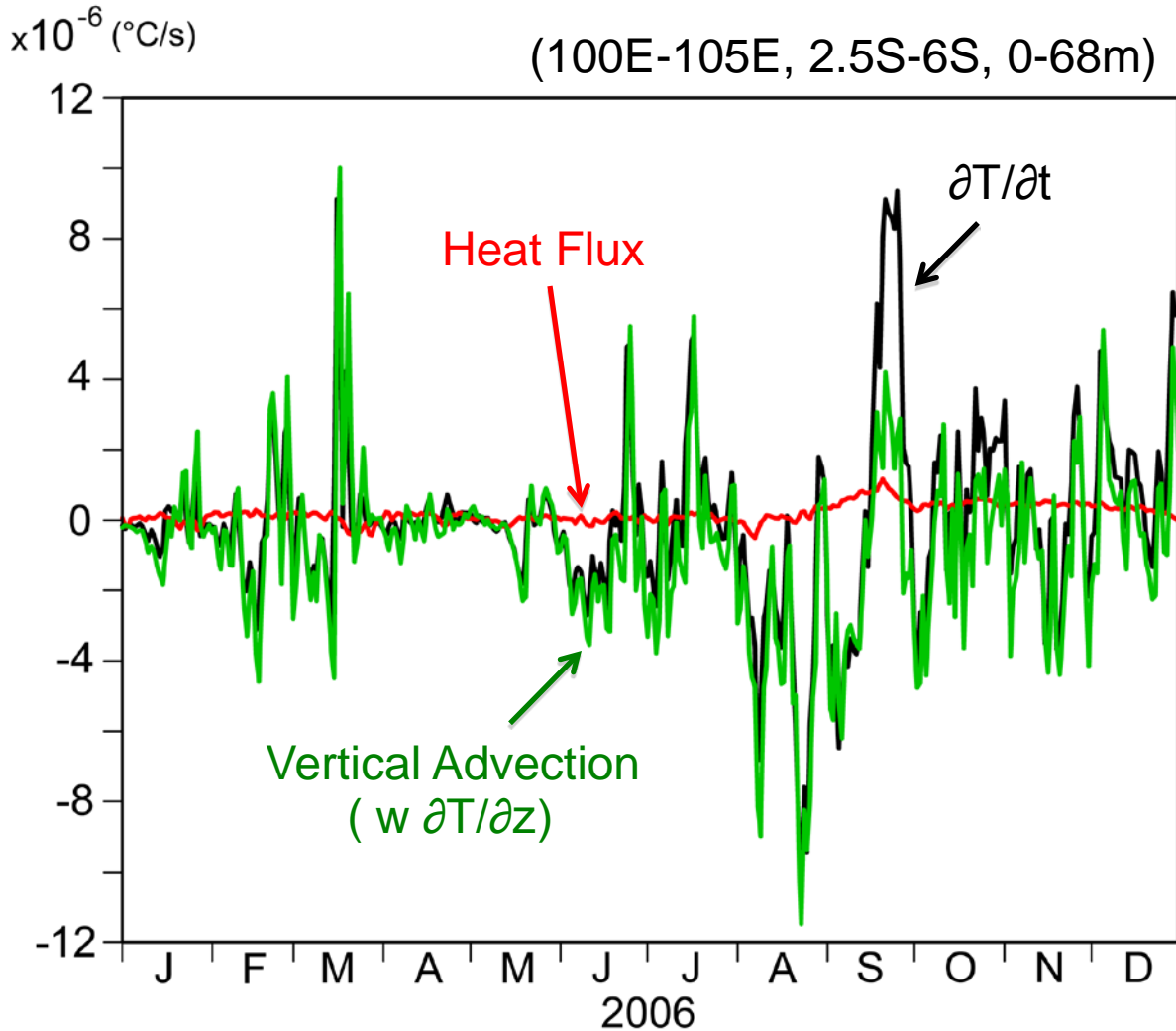
**Horii et al., 2009**, Mixed layer temperature balance in the eastern Indian Ocean during the 2006 Indian Ocean Dipole, *J. Geophys. Res.*, 114, C07011, doi:10.1029/2008JC005180.





# Heat Budget Analysis at upwelling region off Sumatra

< Analysis of eddy-resolving OGCM output >



- Large negative  $\partial T / \partial t$  in Aug. with strong intraseasonal variability
- No contribution from heat flux
- Mostly explained by vertical advection

# Summary

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- IndOOS is expanding
  - RAMA: 27 sites of 46 sites occupied; 4 flux reference sites (increase 5 sites, including 1 flux site, in past year)
- Data flowing via the web and via the GTS
- Exciting science emerging
  - Heat content and barrier layer in the Bay of Bengal could be important factor for cyclone activity and ocean responses to it
  - Strong upwelling associated with the Mixed Rossby-gravity waves in the equatorial Indian Ocean
  - IOD variations; importance of the intraseasonal variability and horizontal advection