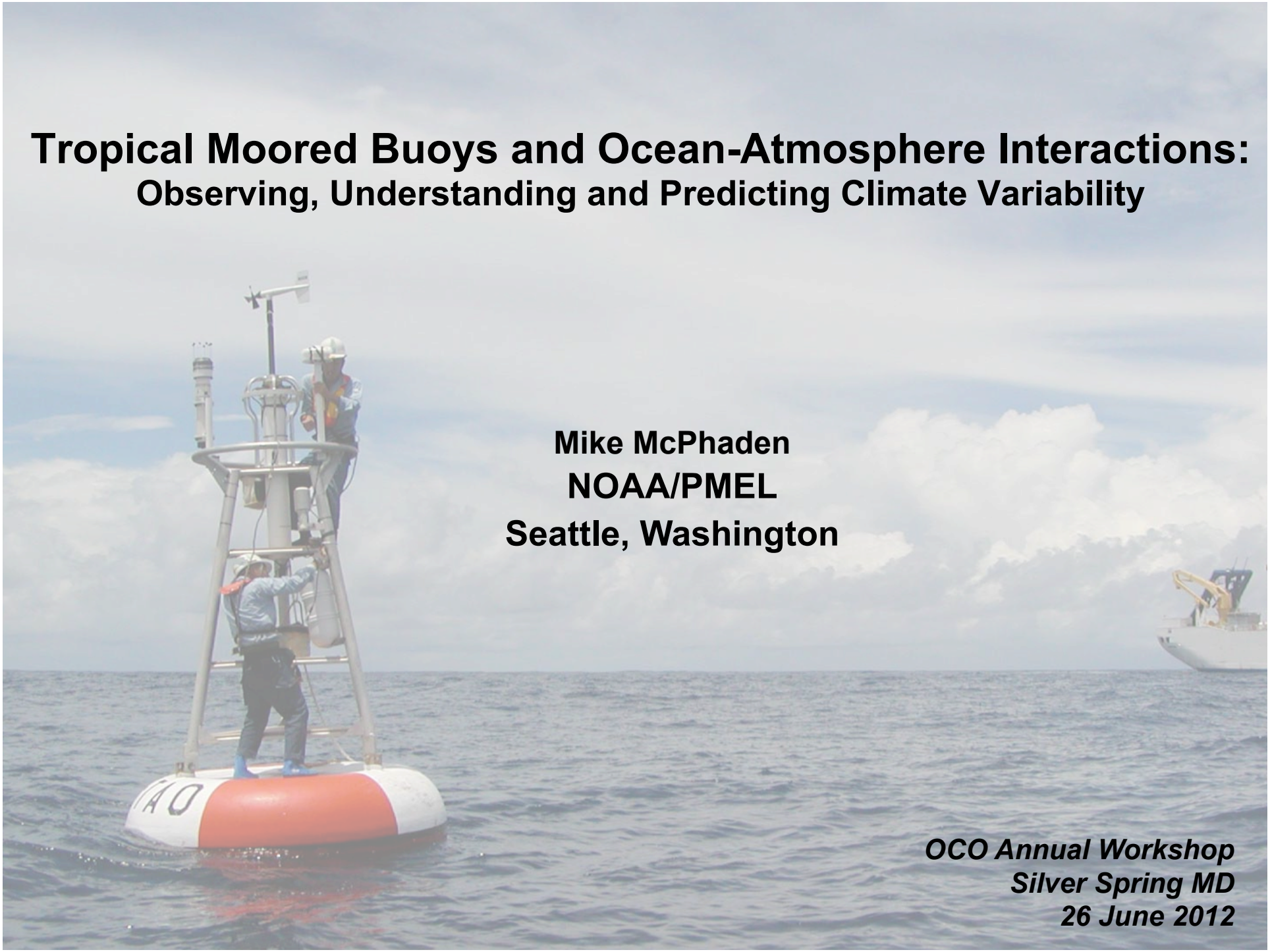
Tropical Moored Buoys and Ocean-Atmosphere Interactions:
Observing, Understanding and Predicting Climate Variability

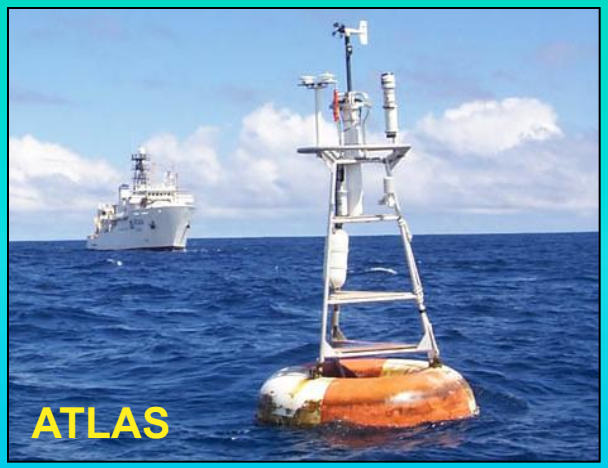


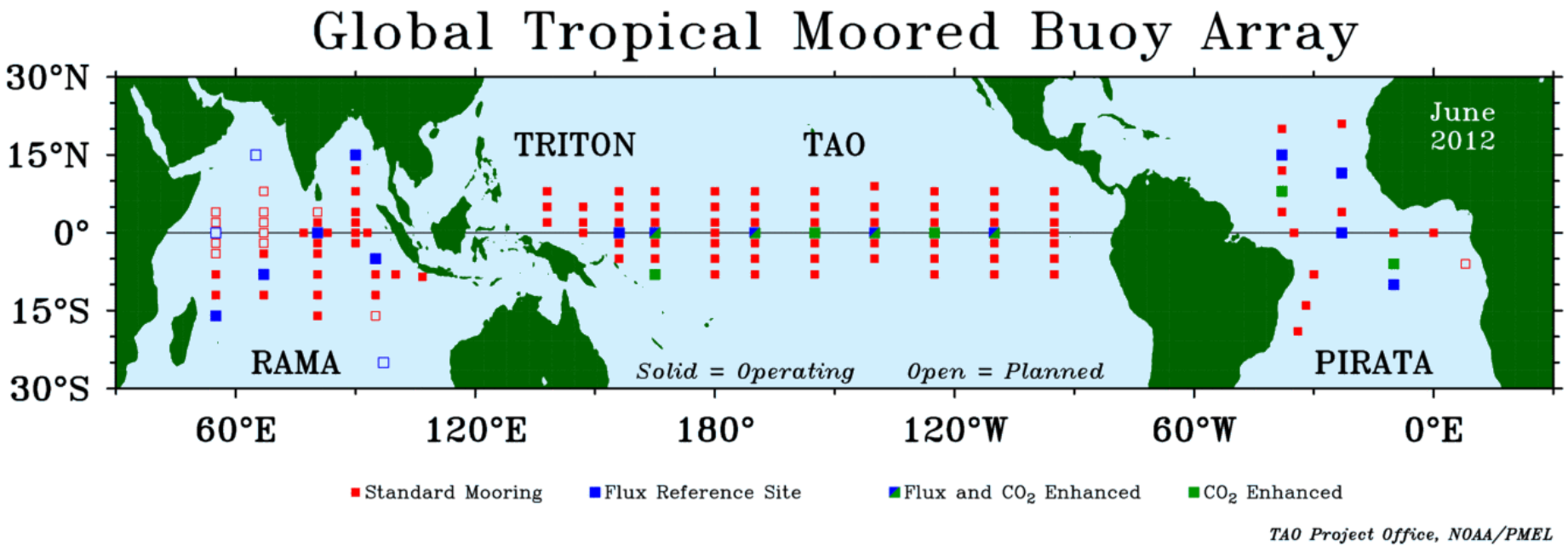
Mike McPhaden
NOAA/PMEL
Seattle, Washington

OCO Annual Workshop
Silver Spring MD
26 June 2012

Global Tropical Moored Buoy Array:

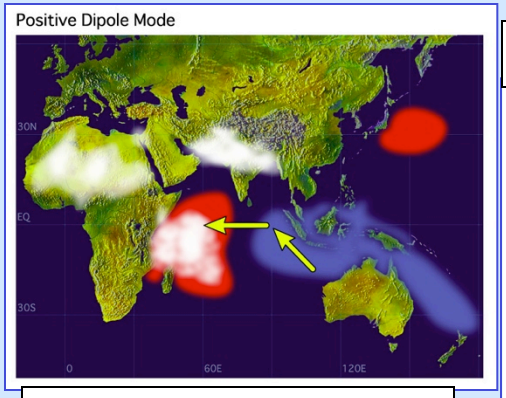
A coordinated, sustained, multi-national effort to develop and implement tropical moored buoy observing systems for climate research and forecasting





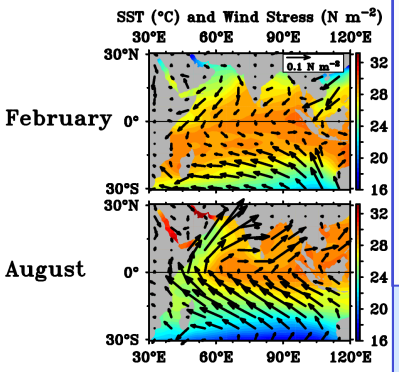
A contribution to GOOS, GCOS, and GEOSS

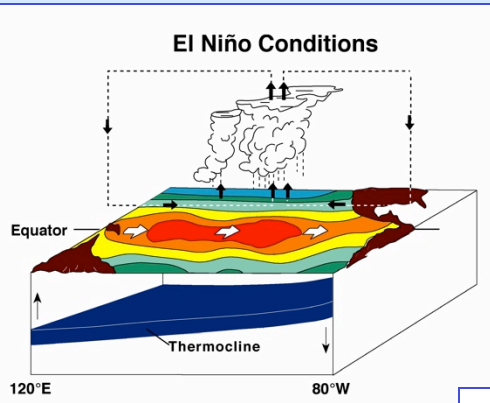
Science Drivers

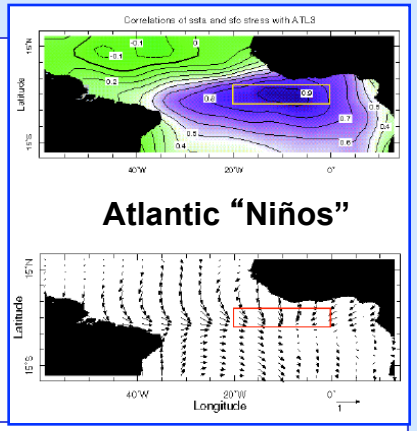


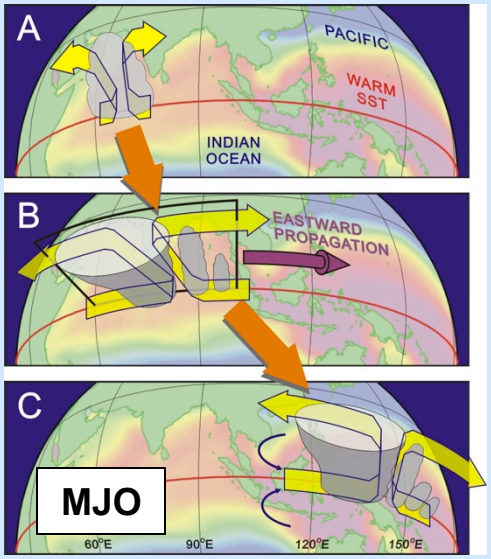
Indian Ocean Dipole

Monsoons

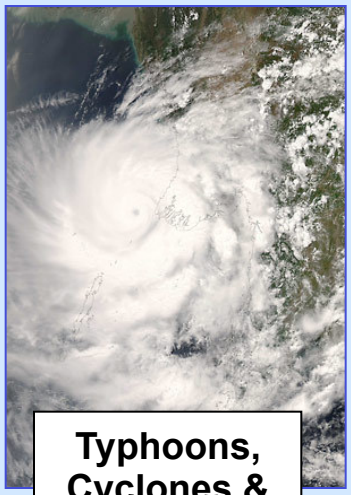




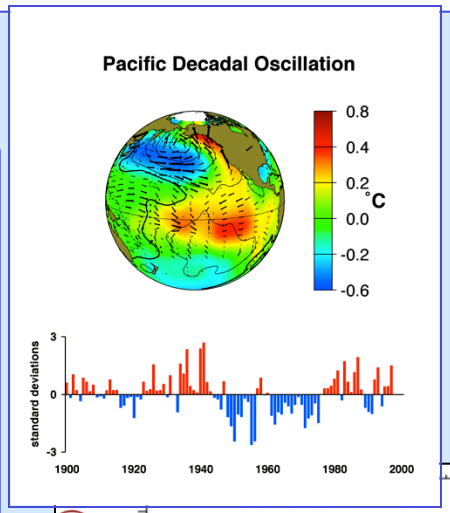


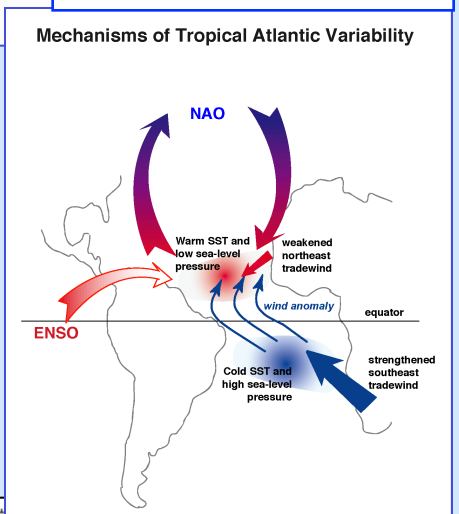


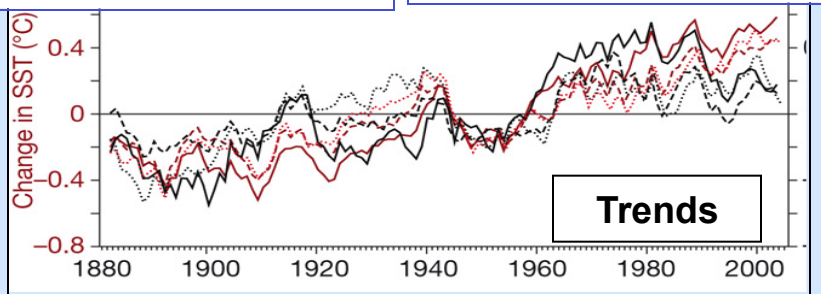
MJO



Typhoons, Cyclones & Hurricanes



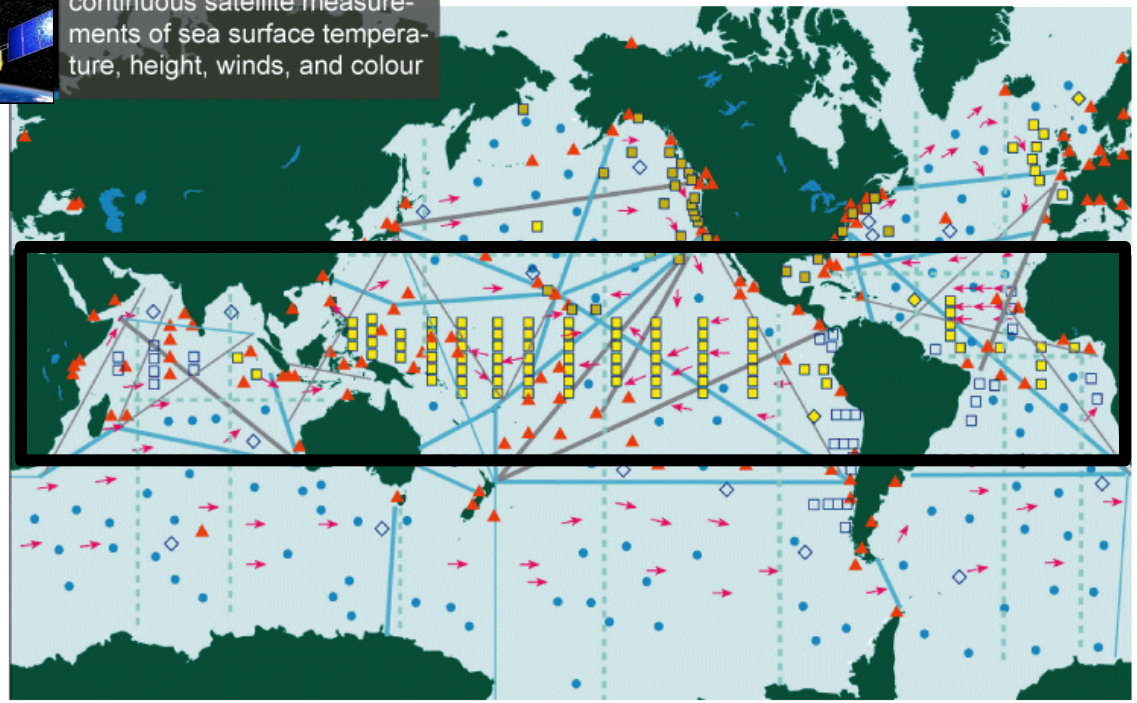




Trends

The Legacy of TOGA and WOCE:
In Situ Global Ocean Observing System for Climate

continuous satellite measurements of sea surface temperature, height, winds, and colour



87% **Surface measurements** from volunteer ships (VOSclim)

200 ships in pilot project

100% Global **drifting surface buoy** array

5° resolution array: 1250 floats

62% **Tide gauge** network (GCOS subset of GLOSS core network)

170 real-time reporting gauges

81% **XBT** sub-surface temperature section network

51 lines occupied

100% **Profiling float** network (Argo)

3° resolution array: 3000 floats

43% Repeat **hydrography** and **carbon inventory**

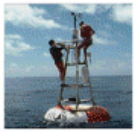
Full ocean survey in 10 years

Reference time series 24%

58 sites

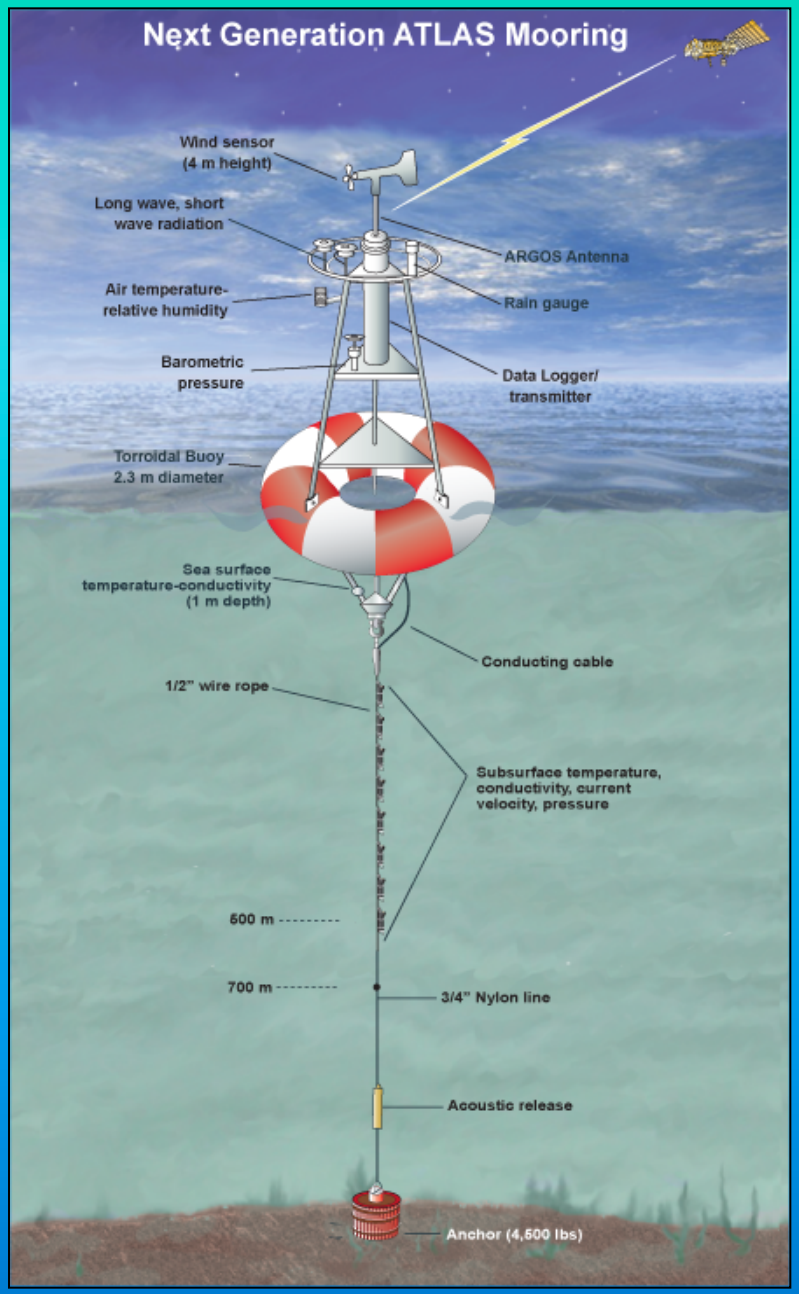
48% Global **reference mooring** network

29 moorings planned



79% Global tropical **moored buoy** network

119 moorings planned



ATLAS Mooring

- ✓ **Ocean and atmosphere**
- ✓ **Rapid continuous sampling**
- ✓ **Low cost**
- ✓ **Real-time data**

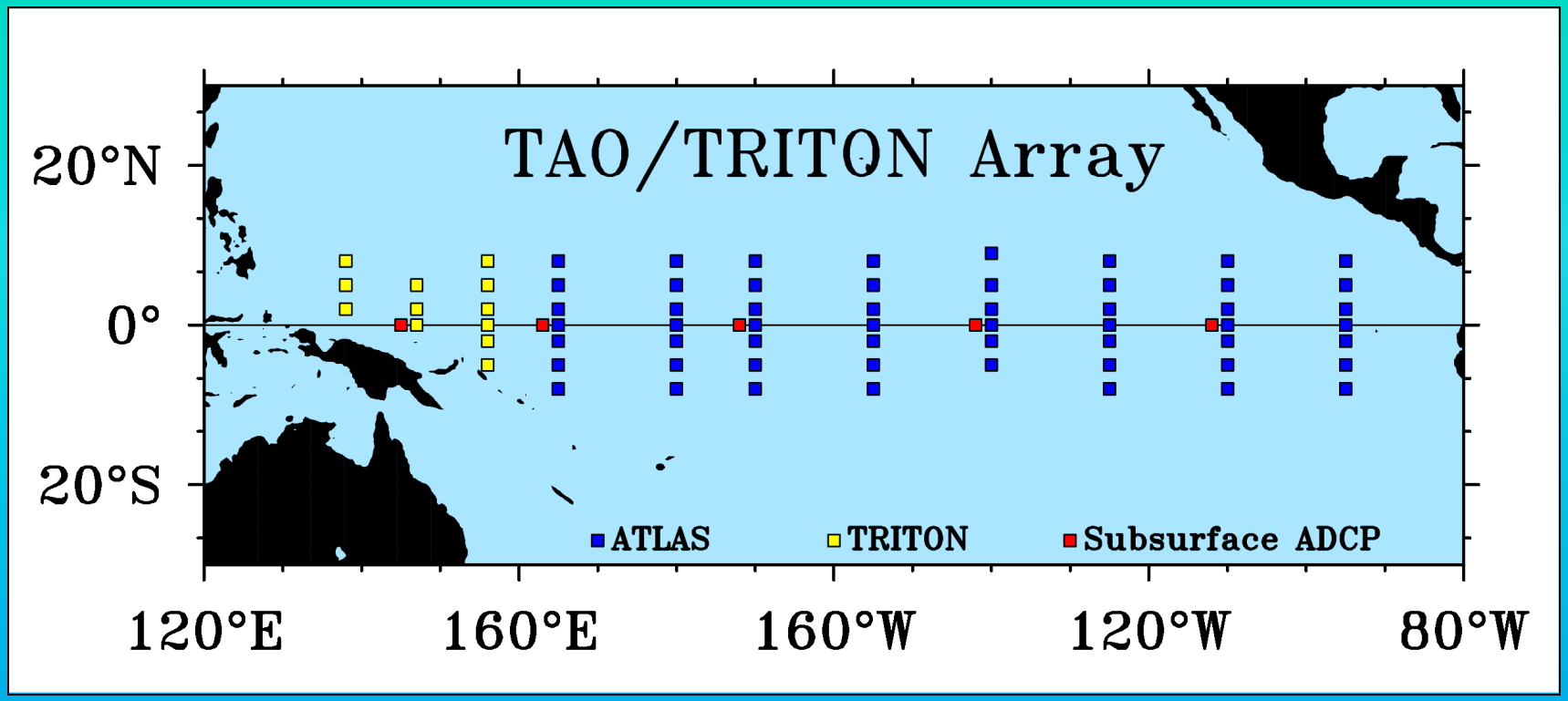
Tropical Moored Buoy Systems

"ATLAS-B"

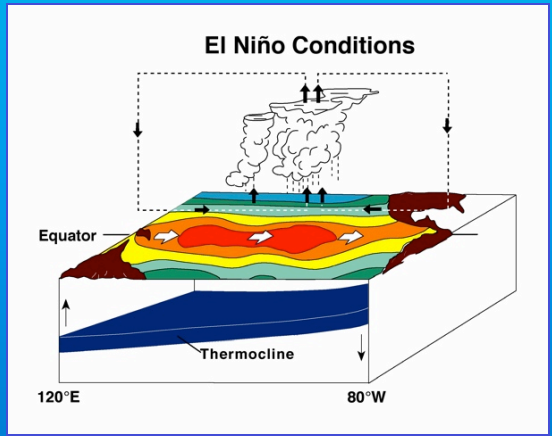
Mini-TRITON

Compatibility & continuity of data sets requires:

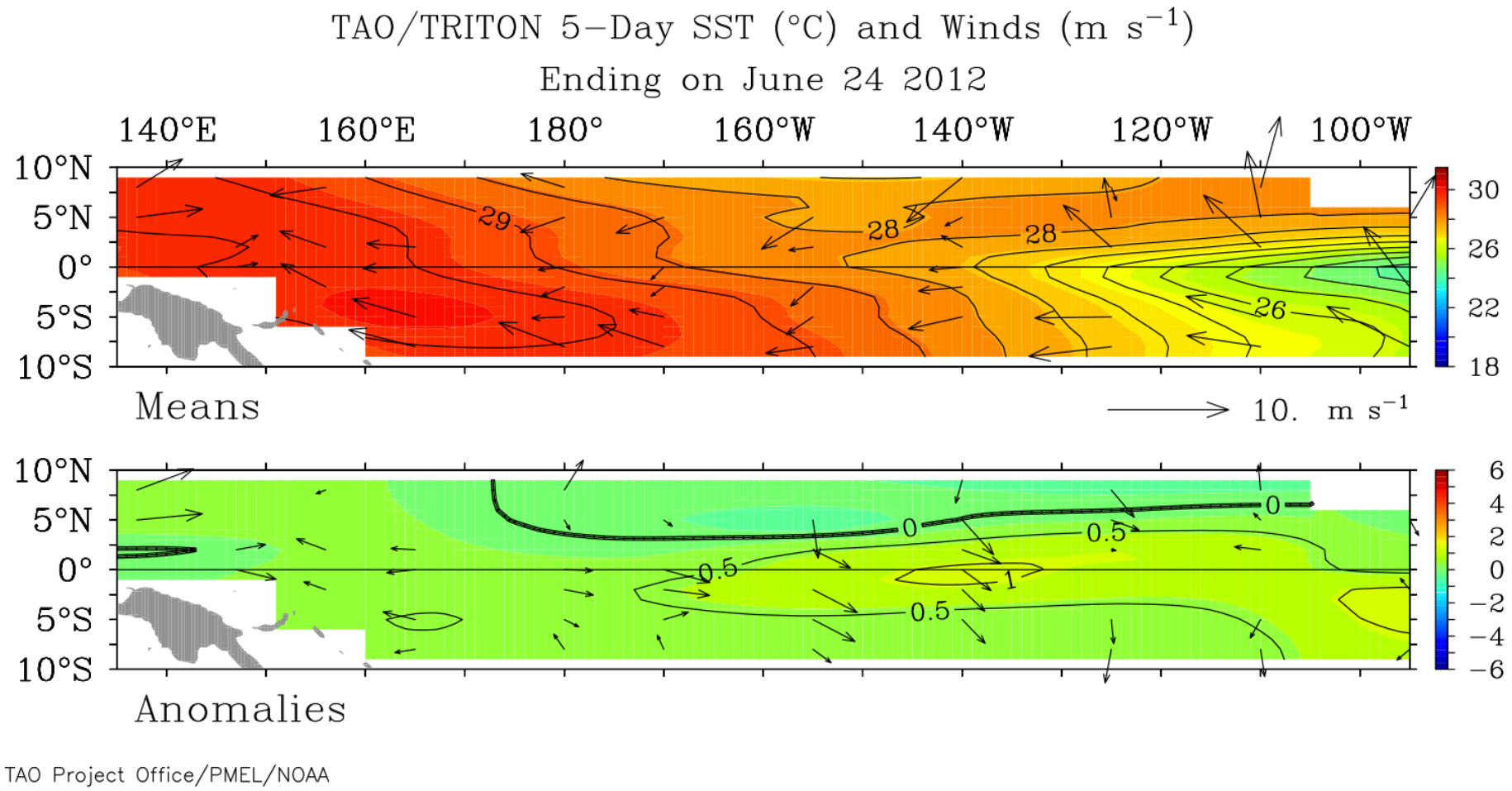
- Common measurement standards
- Common calibration protocols
- In situ comparison between established and new systems



- ✓ Pilot deployments begin in 1984
- ✓ Implemented during TOGA (1985-94)
- ✓ Became TAO/TRITON in 2000 (NOAA/JAMSTEC)
- ✓ NDBC responsible for operations in 2005
- ✓ Transition complete in 2013-14 (?)



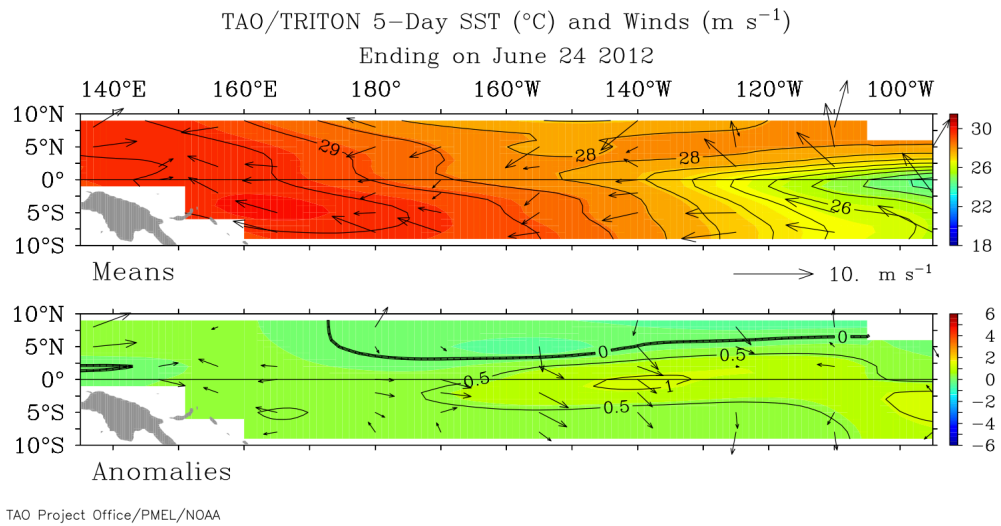
Current Conditions

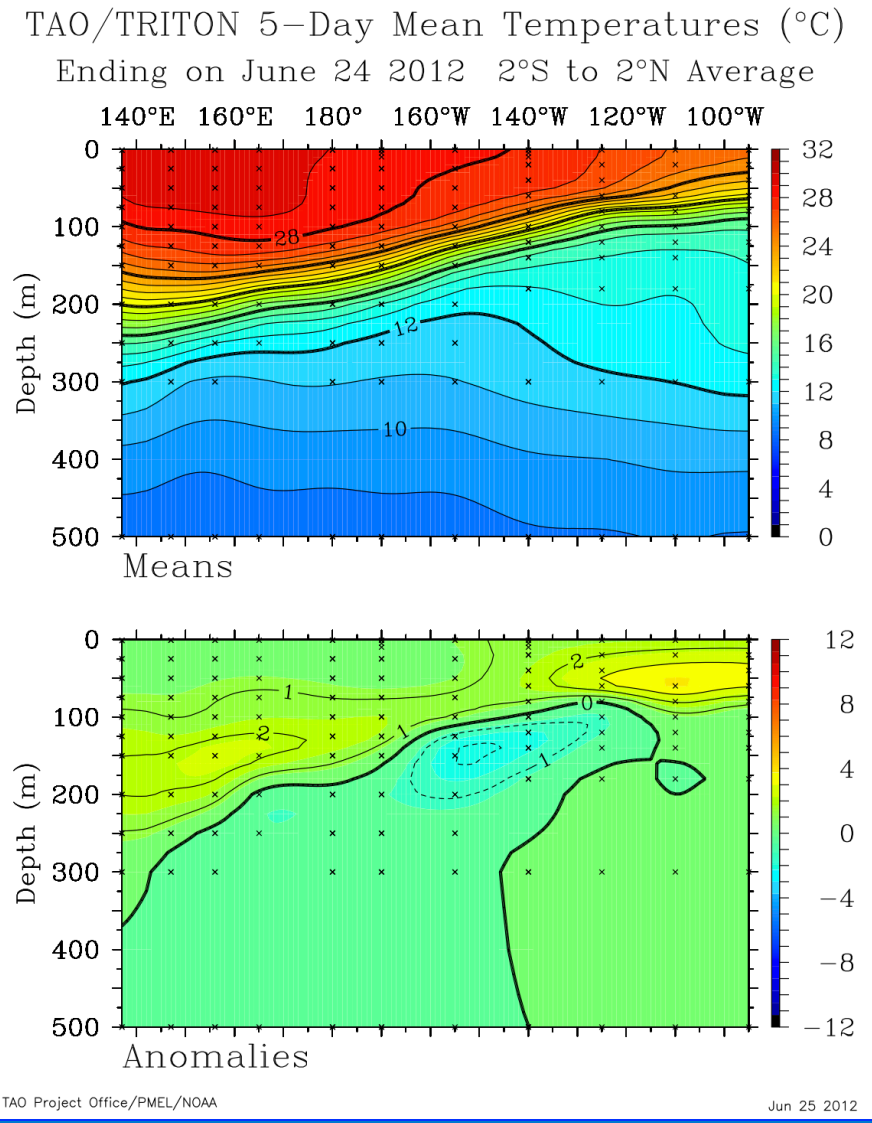


TAO Project Office/PMEL/NOAA

http://www.pmel.noaa.gov/tao/

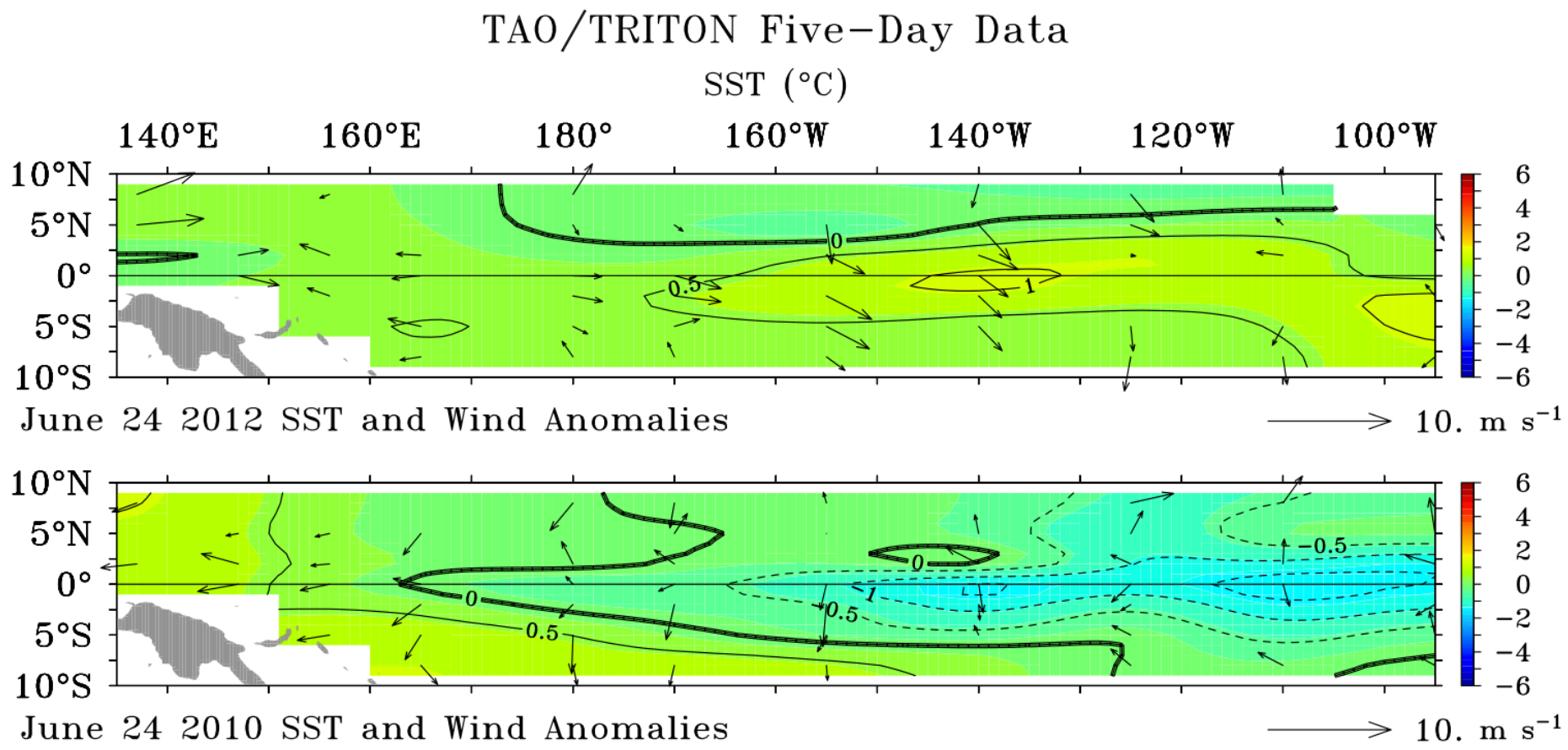
Current Conditions





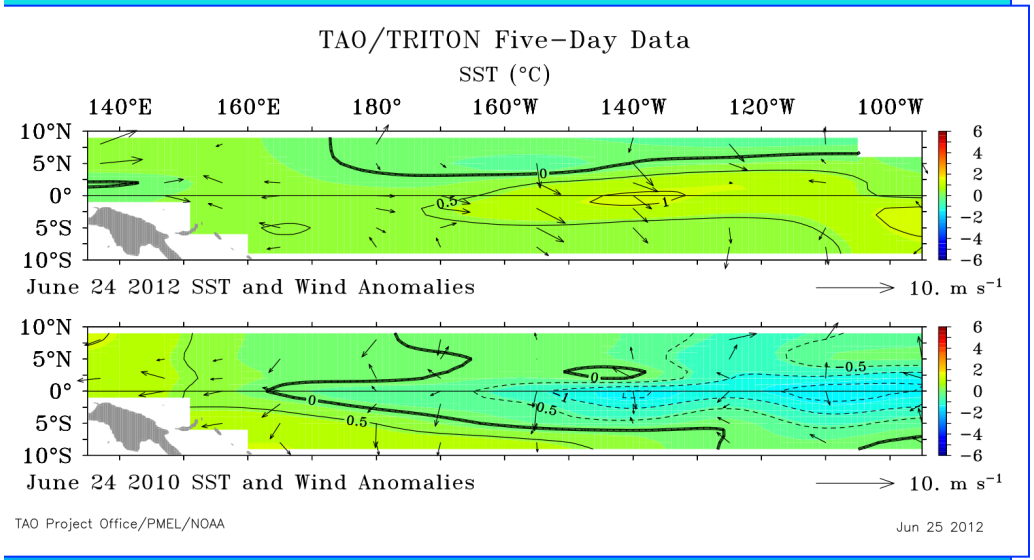
http://www.pmel.noaa.gov/tao/

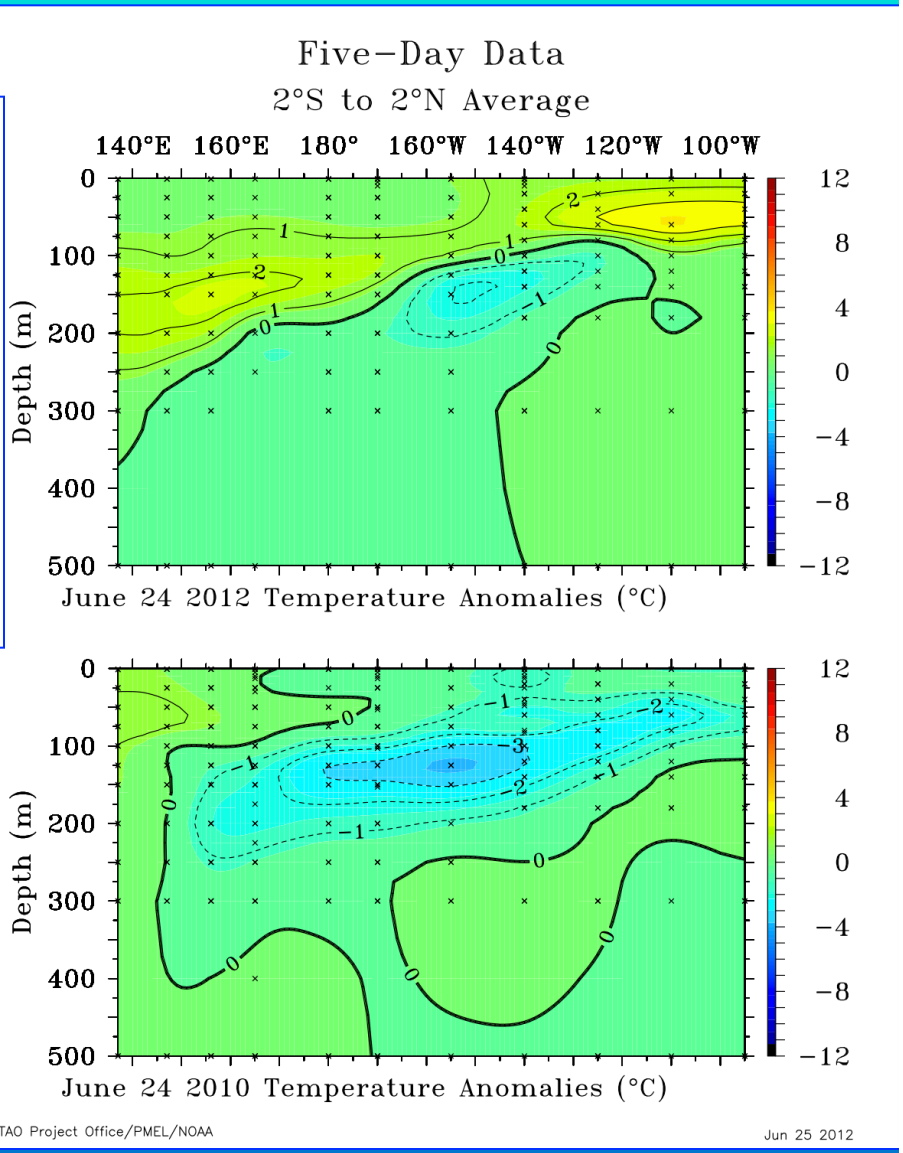
2012 El Niño(?) vs 2010 La Niña



http://www.pmel.noaa.gov/tao/

2012 El Niño(?) vs 2010 La Niña

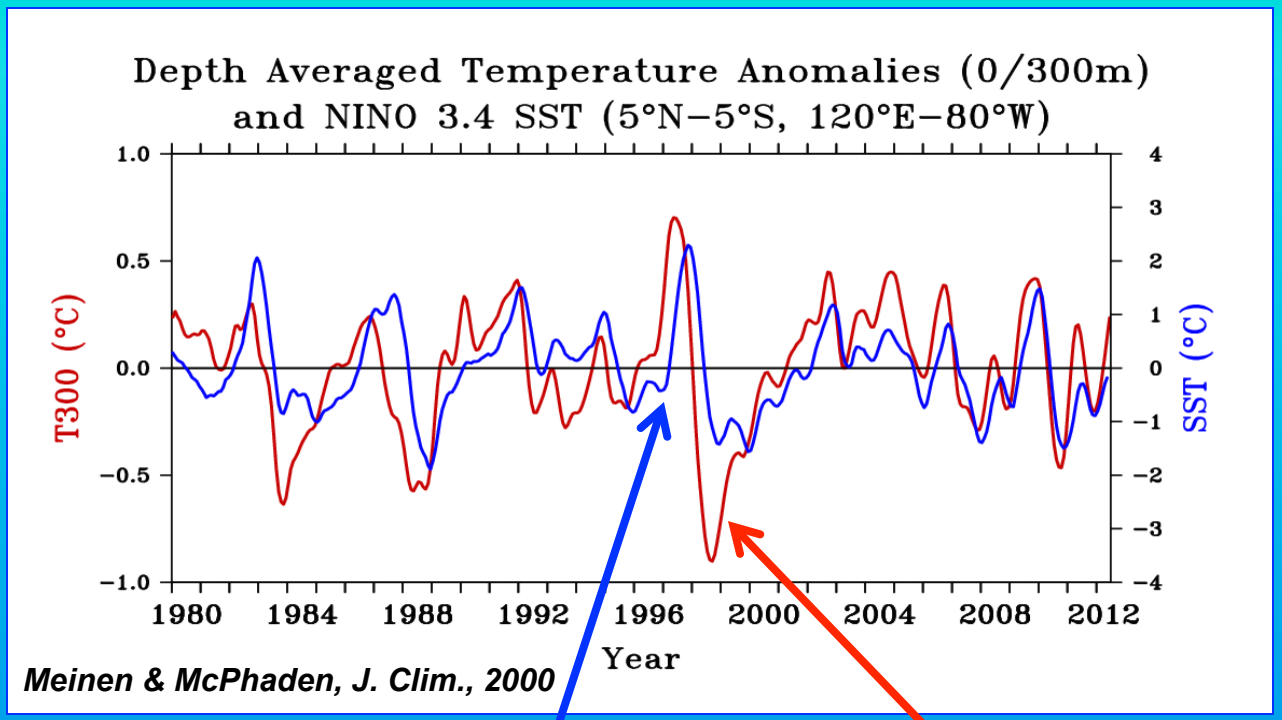




http://www.pmel.noaa.gov/tao/

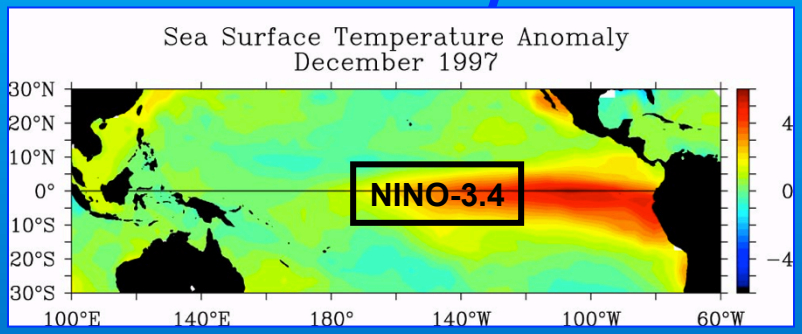
Upper Ocean Heat Content as a Predictor

Based on "Recharge Oscillator Theory" (Jin, 1997)

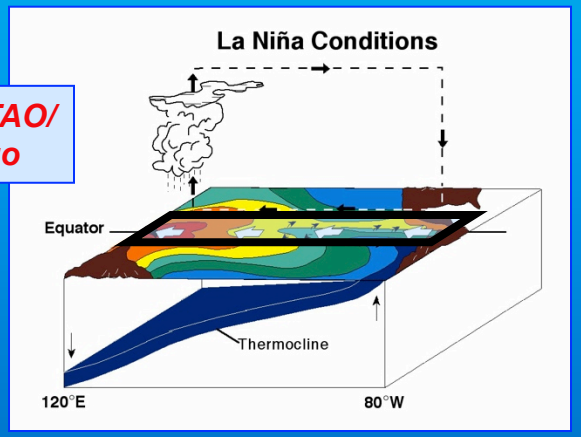


Meinen & McPhaden, J. Clim., 2000

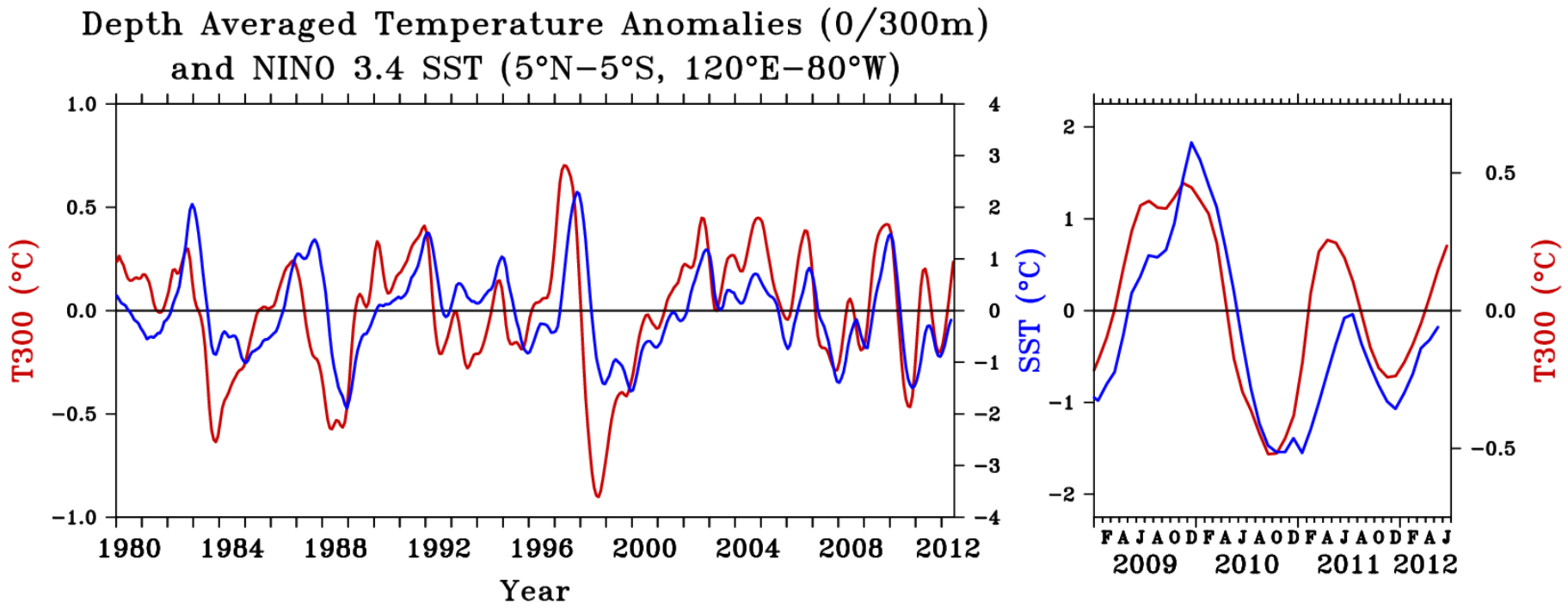
- **Build up of excess heat content along equator is a necessary precondition for El Niño to occur.**
- **El Niño purges excess heat to higher latitudes, which terminates the event.**
- **The time between El Niños is determined by the time to recharge.**



Heat content based on TAO/ TRITON, XBT, and Argo

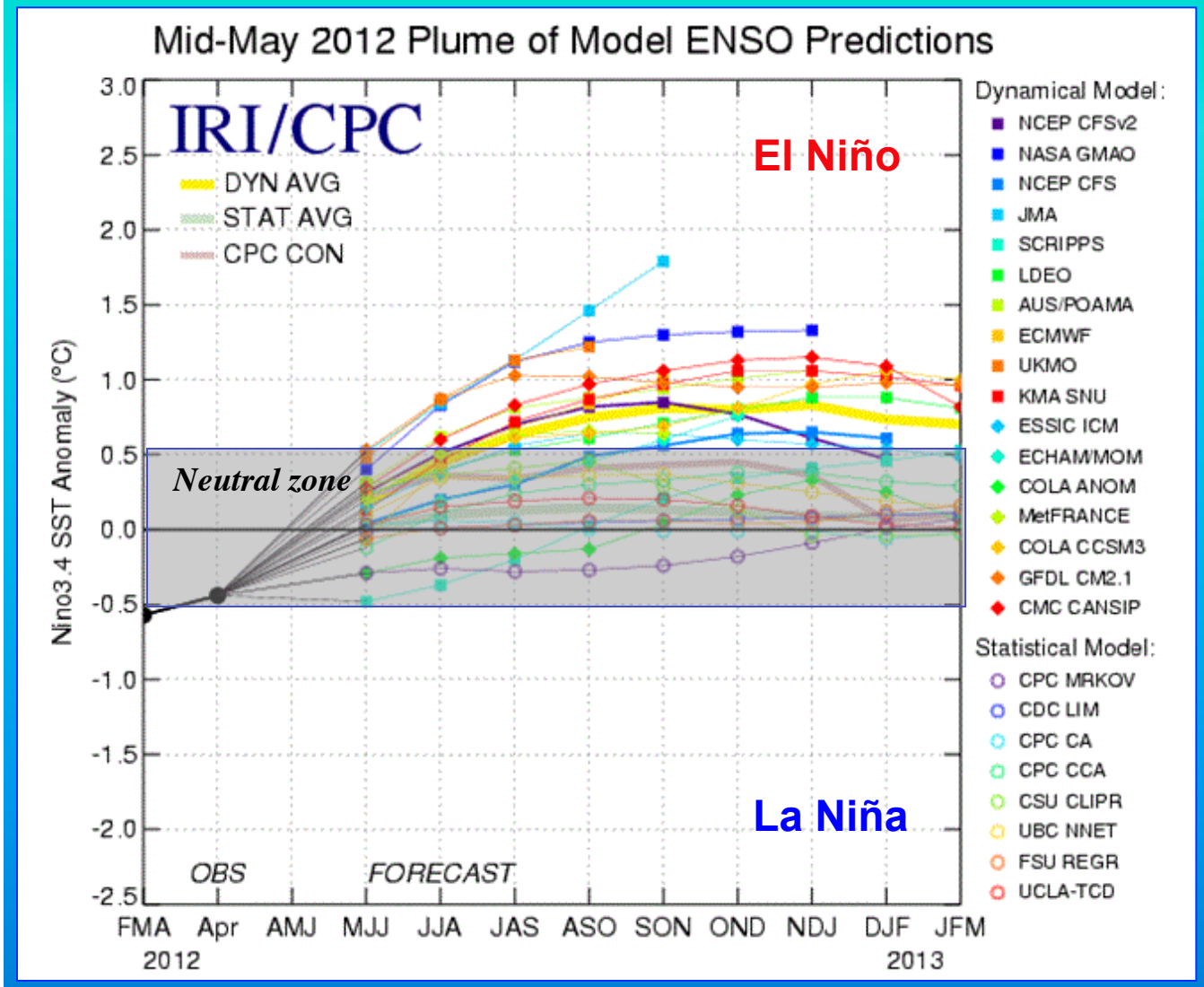


Upper Ocean Heat Content as a Predictor



Upper ocean heat content variations are the source of predictability for the ENSO cycle

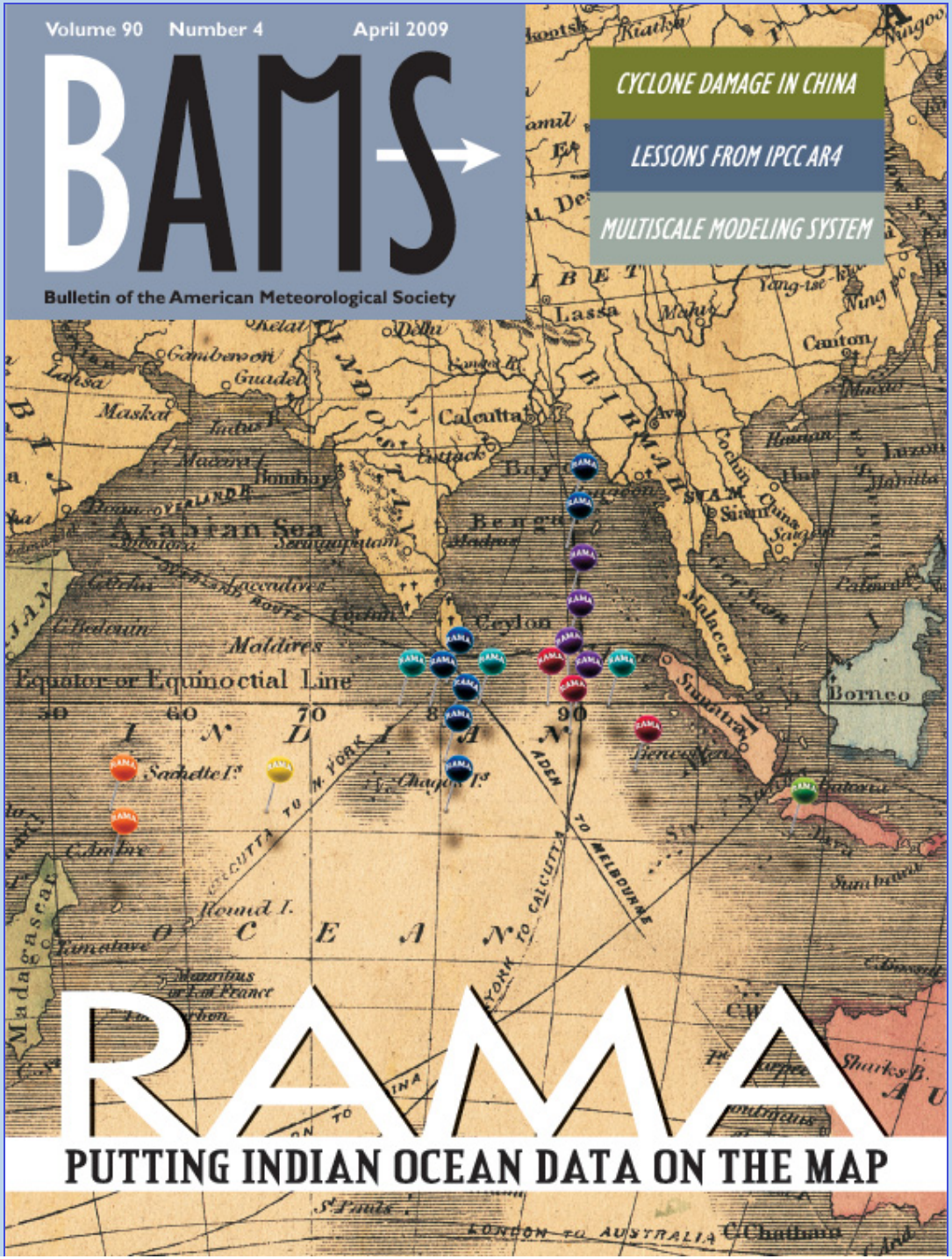
Niño-3.4 Predictions From May 2012



"There is a 50% chance that El Niño conditions will develop during the second half of 2012"

NOAA/NCEP
El Niño Watch
7 June 2012

Compiled by the International Research Institute for Climate and Society (IRI) and NOAA's Climate Prediction Center (CPC)



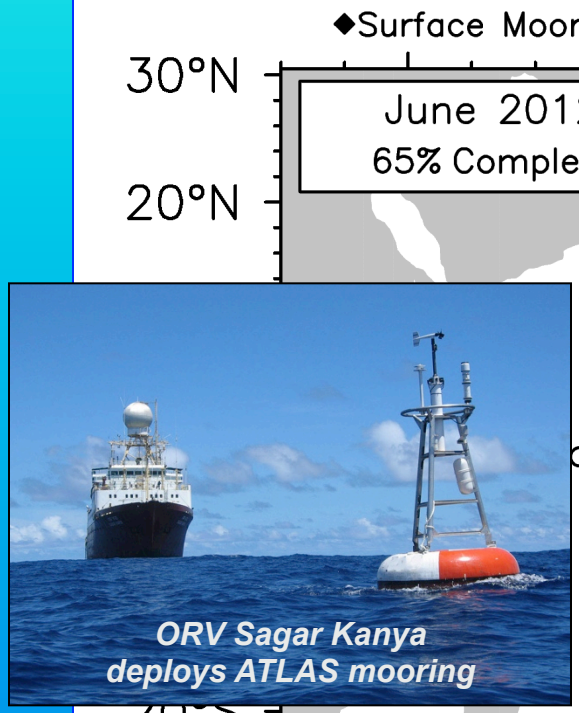
"A new moored buoy array in the data-sparse Indian Ocean provides measurements to advance monsoon research and forecasting"

Ancient king of India and hero of the epic Ramayana

McPhaden, M.J., G. Meyers, K. Ando,Y. Masumoto, V.S.N. Murty, M. Ravichandran, F. Syamsudin, J. Vialard, L. Yu, and W. Yu, 2009: RAMA: The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction. *Bull. Am. Meteorol. Soc.*, 90, 459-480.

RAMA

Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (**RAMA**)

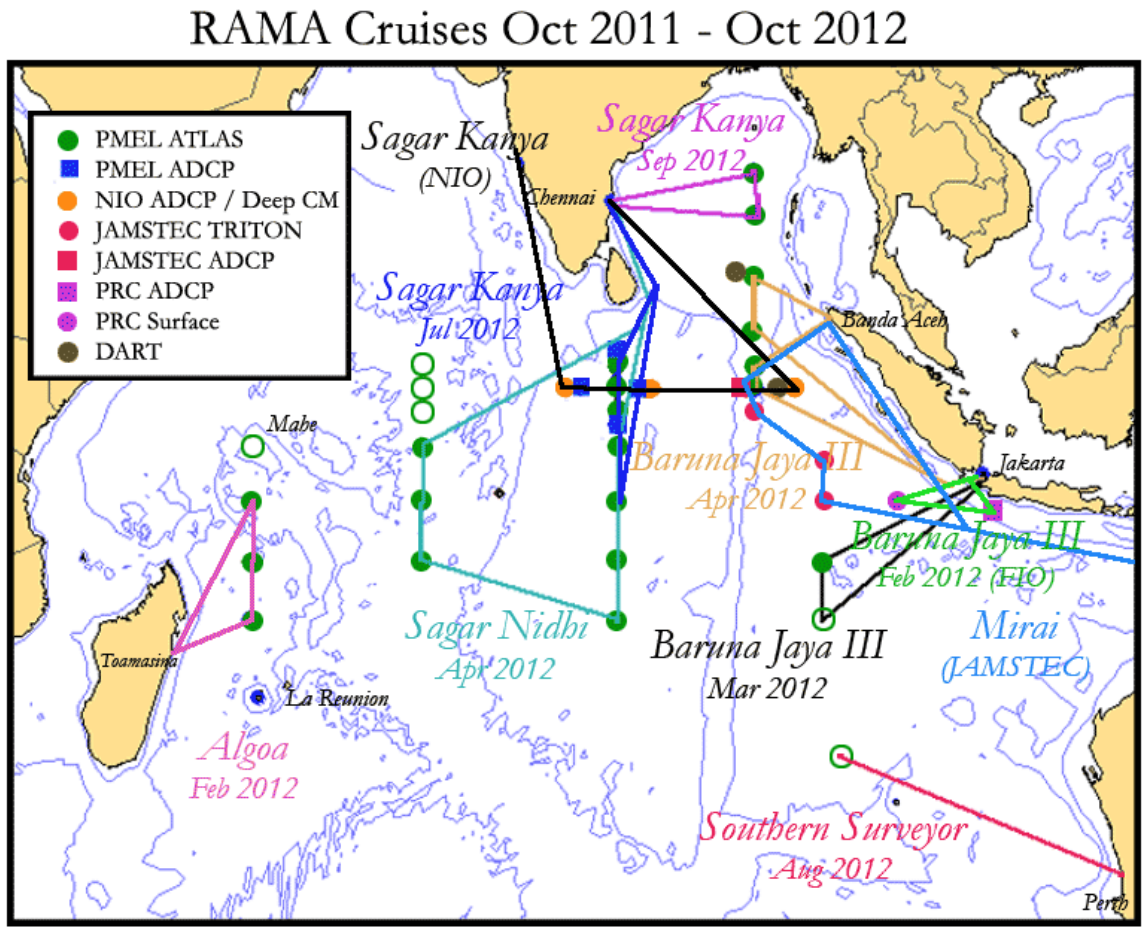


Resource Formula:

- ✓ **NOAA/PMEL provides most equipment**
- ✓ **Regional partners provide ship time**

65% of sites established (30 of 46)

Cruises Oct 2011-Oct 2012

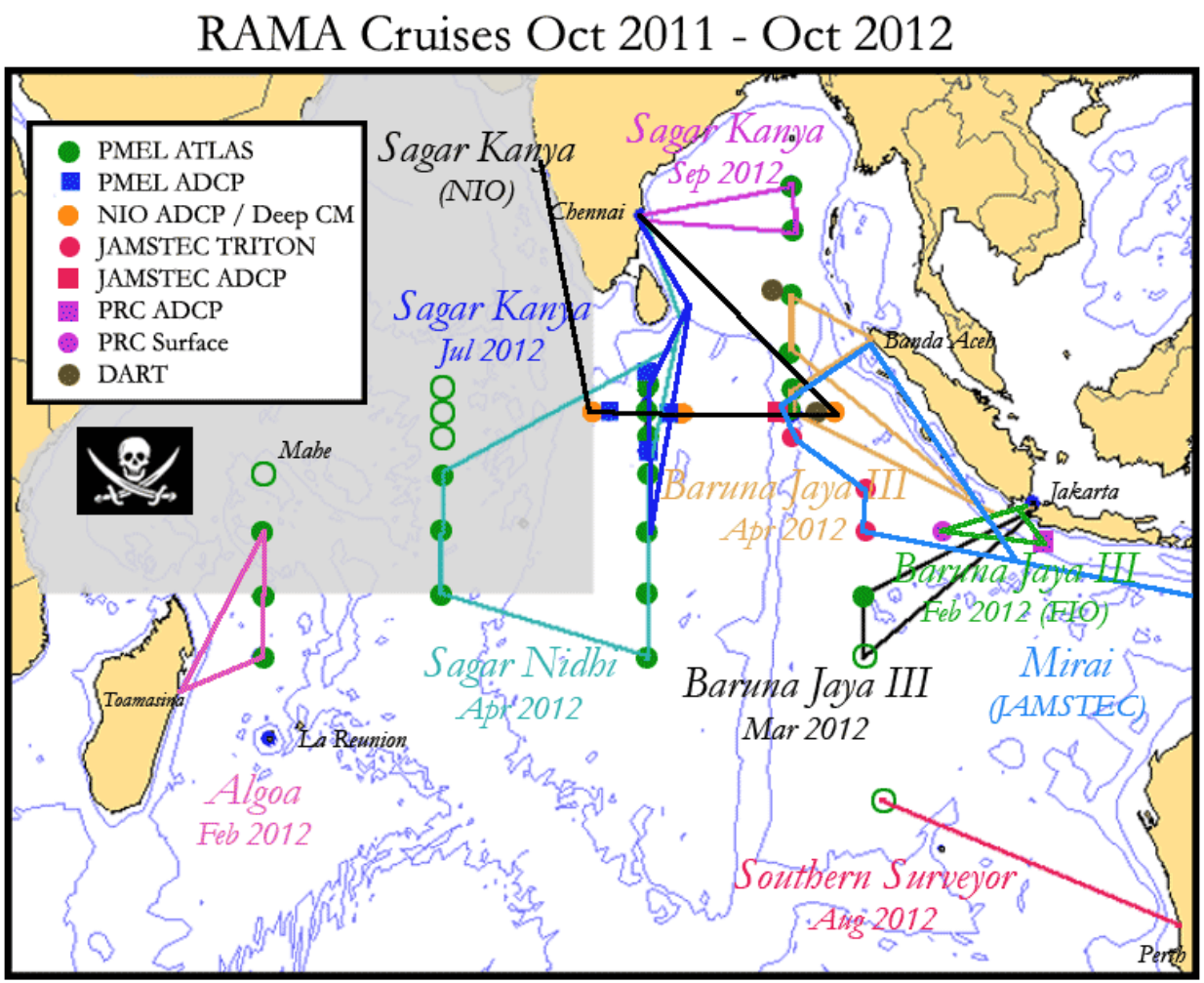


- **10 Cruises**
  6 ships
  5 nations
- **227 sea days**
- **Maintain 30 existing sites**
- **Add 1 new site (25°S, 97°E)**

RV Southern Surveyor

PI: Nathan Bindoff, CSIRO/UTAS
Co-PIs: Helen Phillips, UTAS; Ming Feng, CSIRO; Eric Schultz, BOM

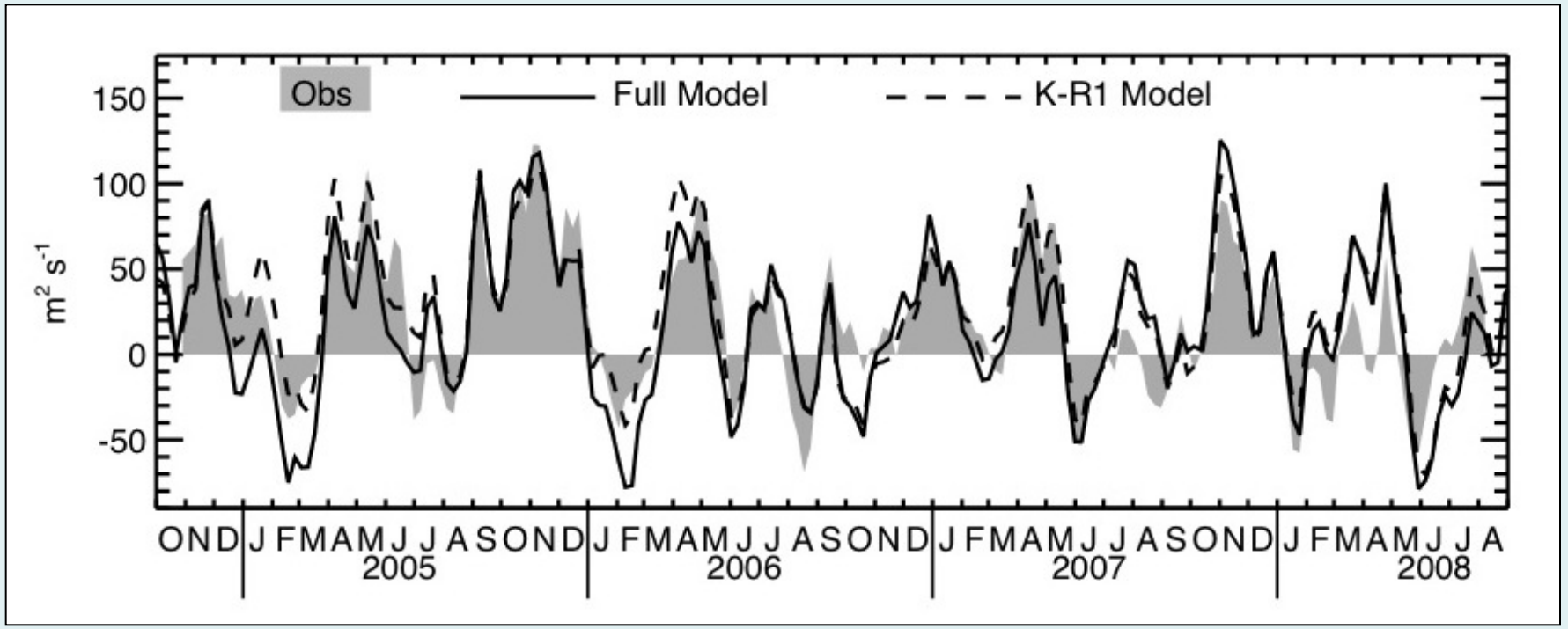
The Threat of Piracy



Exclusion zone declared by Lloyds of London (to 12°S, 77°E):

Security required

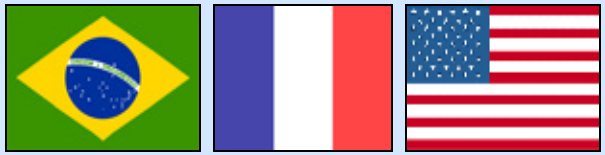
Linear Equatorial Wave Model Validated with Observed RAMA Transports (0-100 m) at 0°, 80.5E



Dynamics of ocean circulation near the equator governed by the Kelvin + 1st meridional mode Rossby wave of the two gravest vertical modes

Nagura and McPhaden, 2010-12, J. Geophys. Res.

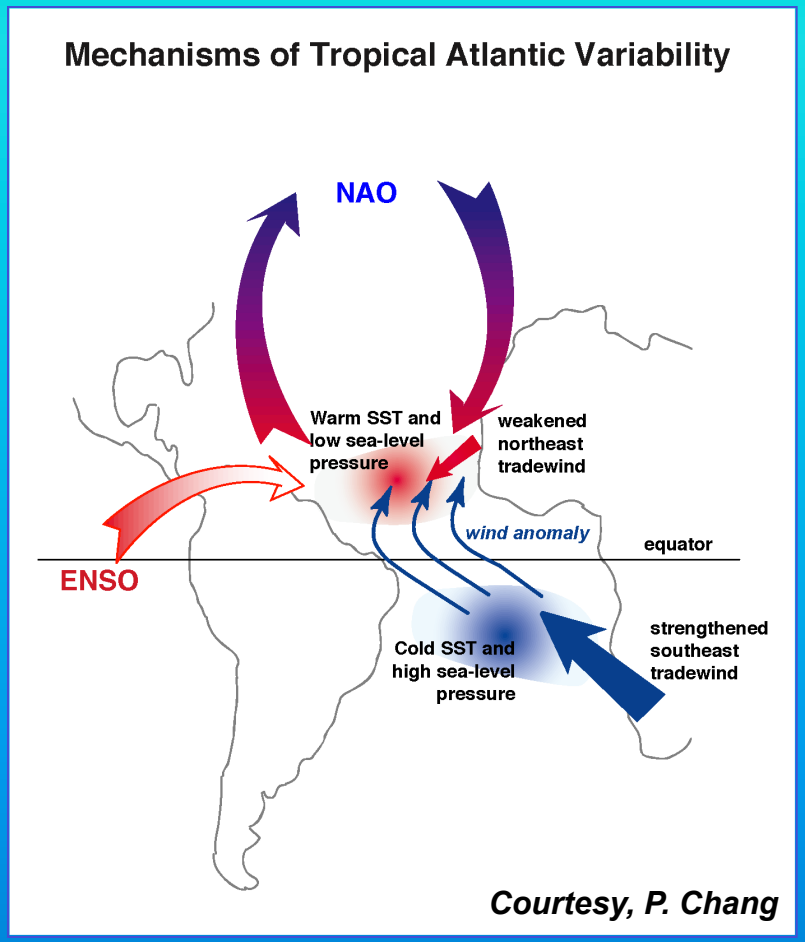
PIRATA



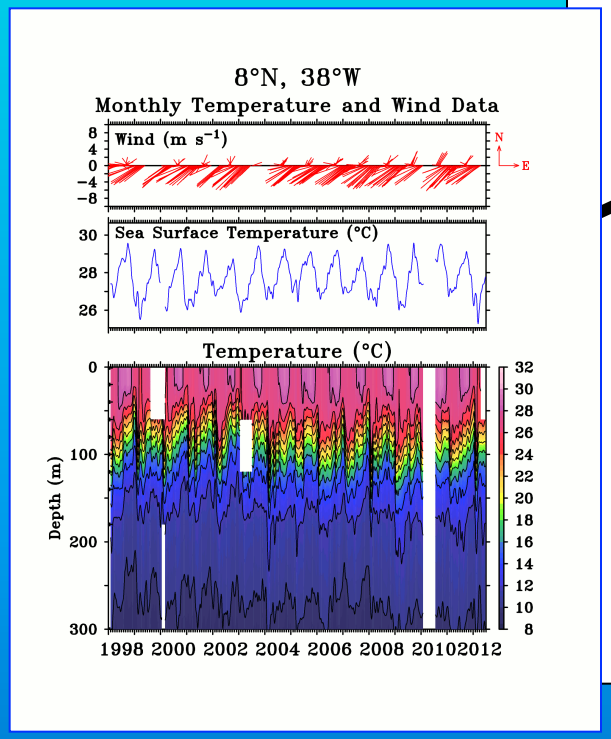
- ✓ Established in 1997 by France, Brazil and the US
- ✓ Brazil & France provide logistic support & most ship time (91 sea days in FY2011)
- ✓ USA (NOAA) provides most mooring equipment & data processing

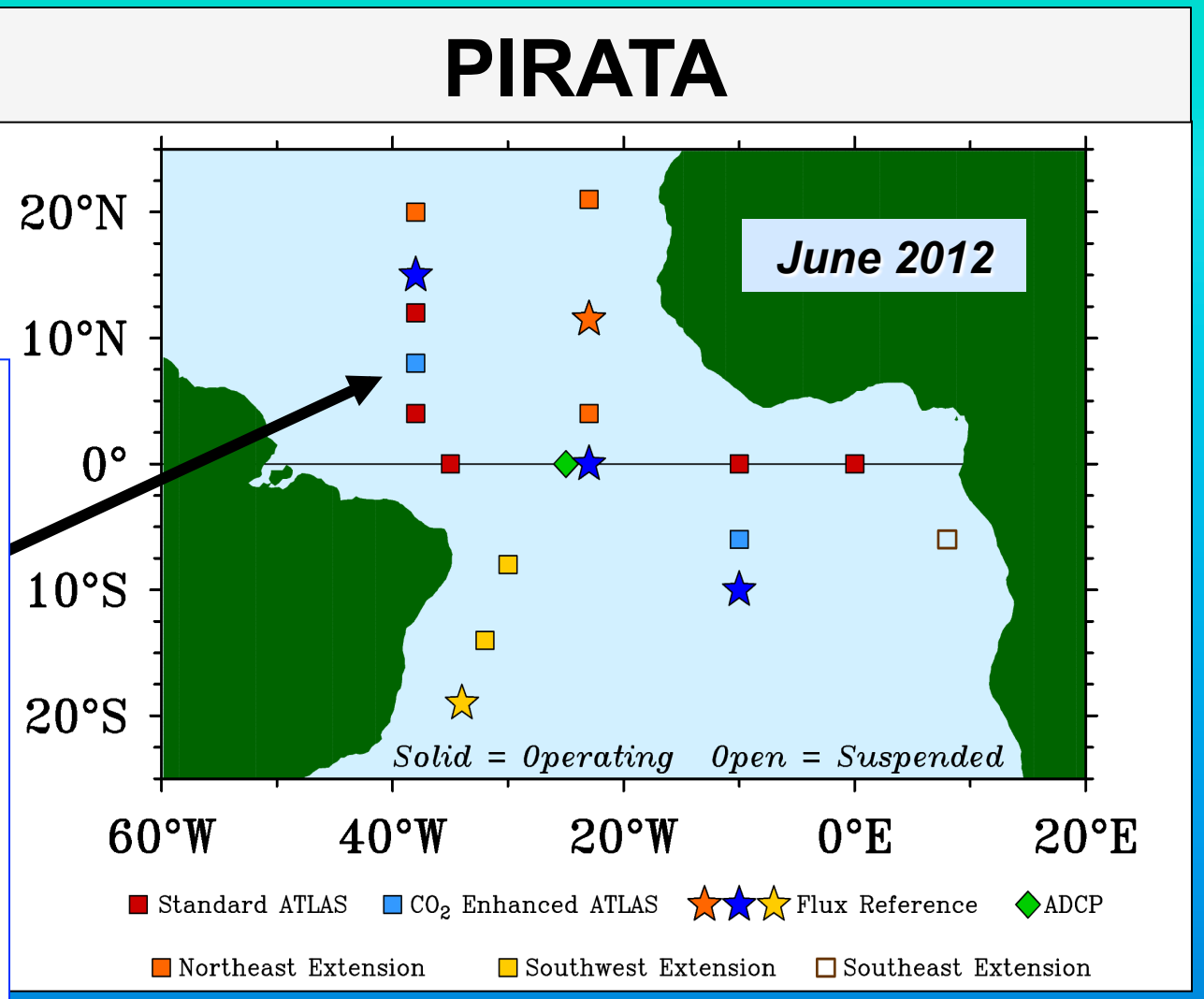
Goals:

1) Describe, understand and predict processes controlling SST
2) Understand the role of ocean-atmosphere interactions in West African Monsoon, NE Brazil drought & Atlantic hurricane activity
3) Identify internal vs remote climate influences in the tropical Atlantic

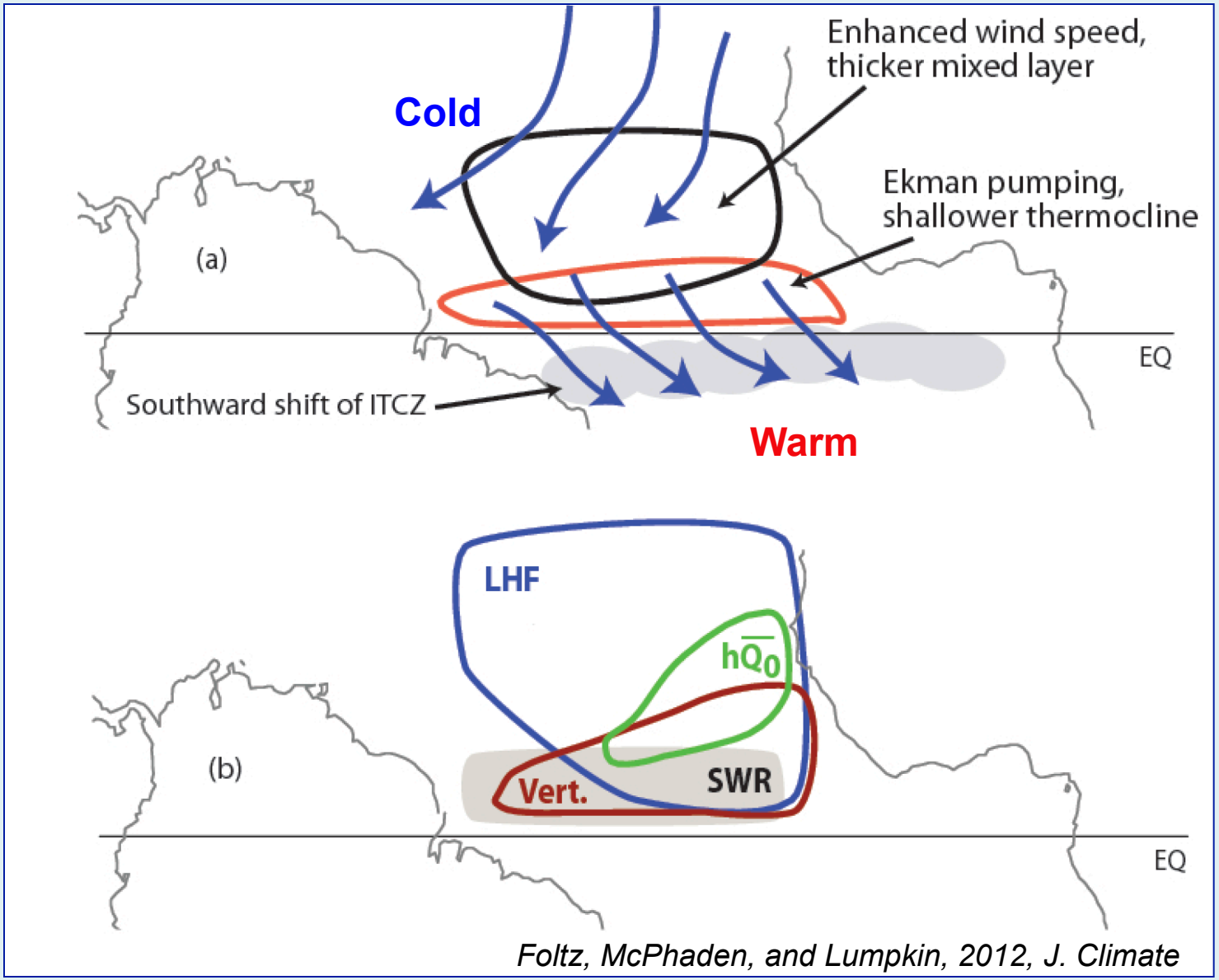


PIRATA


8°N, 38°W
Monthly Temperature and Wind Data
Wind (m s⁻¹)
Sea Surface Temperature (°C)
Temperature (°C)
Depth (m)
1998 2000 2002 2004 2006 2008 2010 2012


June 2012
20°N
10°N
0°
10°S
20°S
60°W
40°W
20°W
0°E
20°E
Solid = Operating
Open = Suspended
Standard ATLAS
CO2 Enhanced ATLAS
Flux Reference
ADCP
Northeast Extension
Southwest Extension
Southeast Extension

Ocean Mixed Layer Dynamics and the Atlantic Meridional Mode

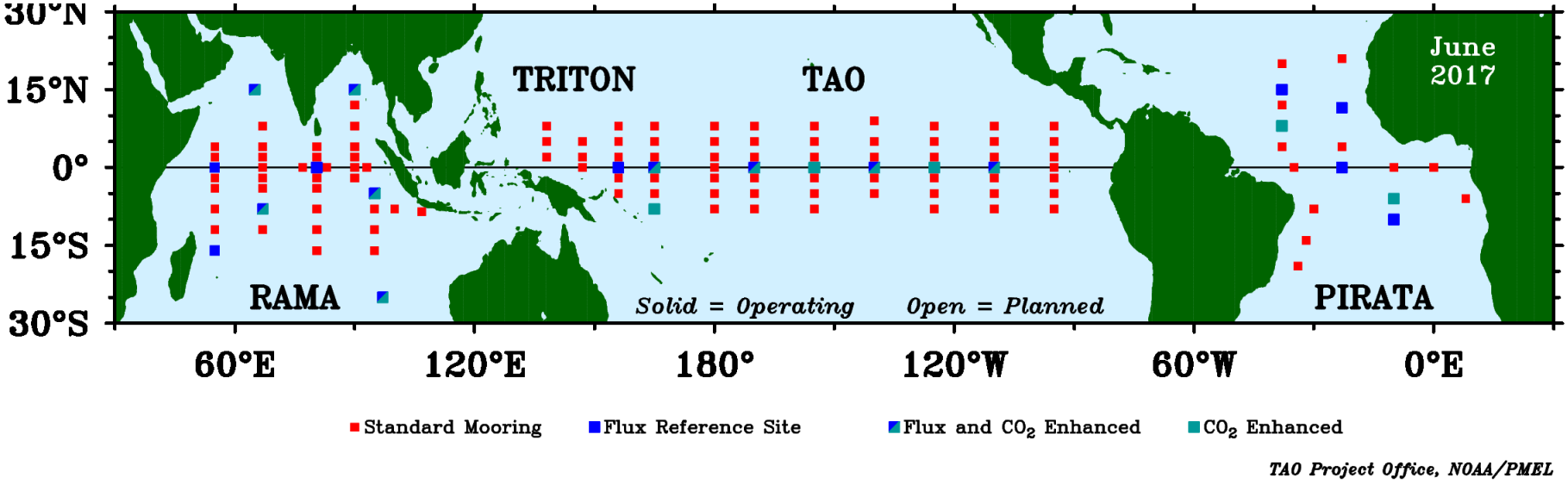


Foltz, McPhaden, and Lumpkin, 2012, J. Climate

Measures of Success

- **Sustained effort to build and maintain moored buoy observing system for climate in the Pacific-Atlantic-Indian Oceans**
- **Can observe evolving oceanic and atmospheric conditions in the tropics in real-time**
- **We can predict El Niño and La Niña**
- **Fundamentally advanced our understanding of oceans role in climate (~800 refereed journal publications using moored buoy data)**

Global Tropical Moored Buoy Array in 2017



- Completed, sustained, enhanced for biogeochemistry
- Provide unique data to fundamentally advance climate science
- Supports improved ocean & atmospheric analysis systems
- Essential for climate forecasting in all three oceans