



PMEL

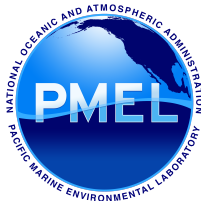
Pacific Marine Environmental Laboratory

Climate Theme

Global Tropical Moored Buoy Array: Observing, Understanding and Predicting Climate Variability and Change

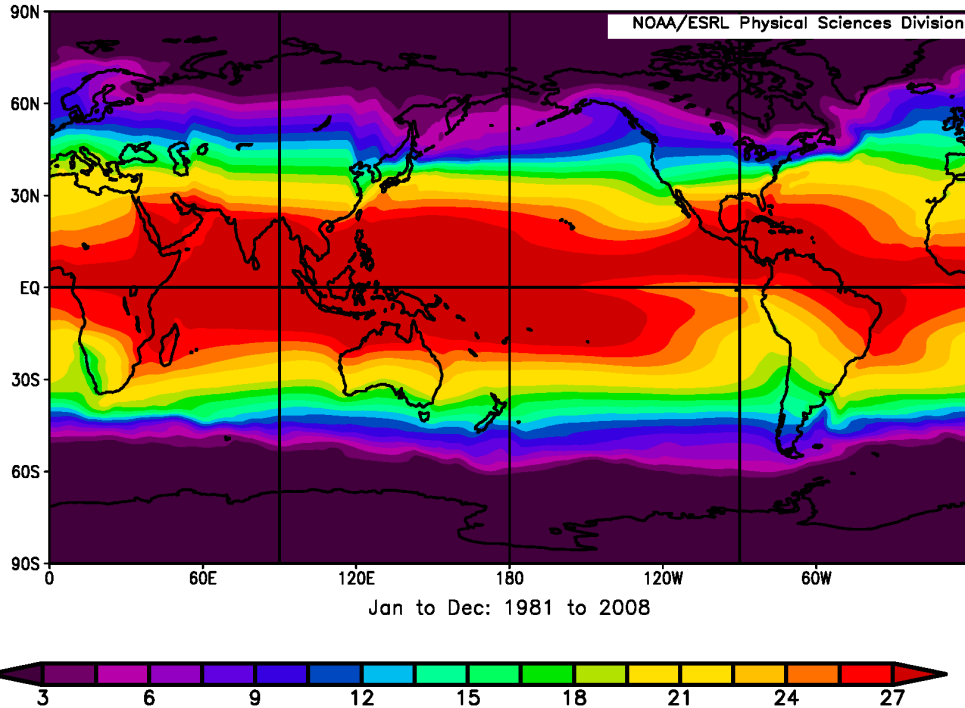
Mike McPhaden
& Project Staff

NOAA & Cooperative Institute Partners
Collaborators on Six Continents



Background

Surface Temperature (°C)

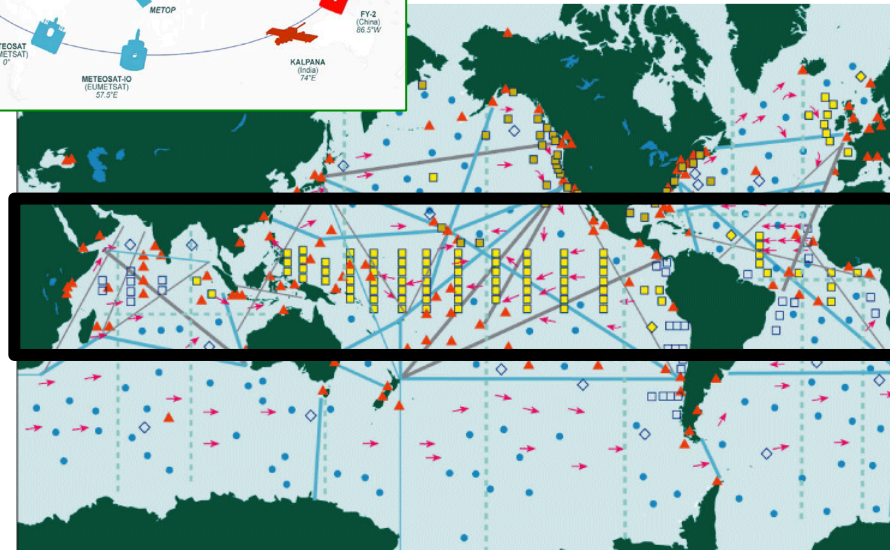
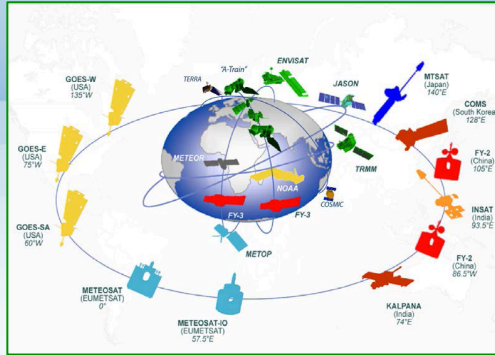


The Tropics:

- Driver of the global heat engine
- Vigorous ocean-atmosphere interactions
- Global impact via atmospheric teleconnections
- Seasonal climate predictability

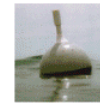
Background

Global Ocean Observing System for Climate



Surface measurements from volunteer ships (VOSclim)

200 ships in pilot project



Global drifting surface buoy array

5° resolution array: 1250 floats



Tide gauge network (GCOS subset of GLOSS core network)

170 real-time reporting gauges



XBT sub-surface temperature section network

51 lines occupied



Profiling float network (Argo)

3° resolution array: 3000 floats



Repeat hydrography and carbon inventory

Full ocean survey in 10 years

Reference time series



58 sites



Global reference mooring network



29 moorings planned



Global tropical moored buoy network

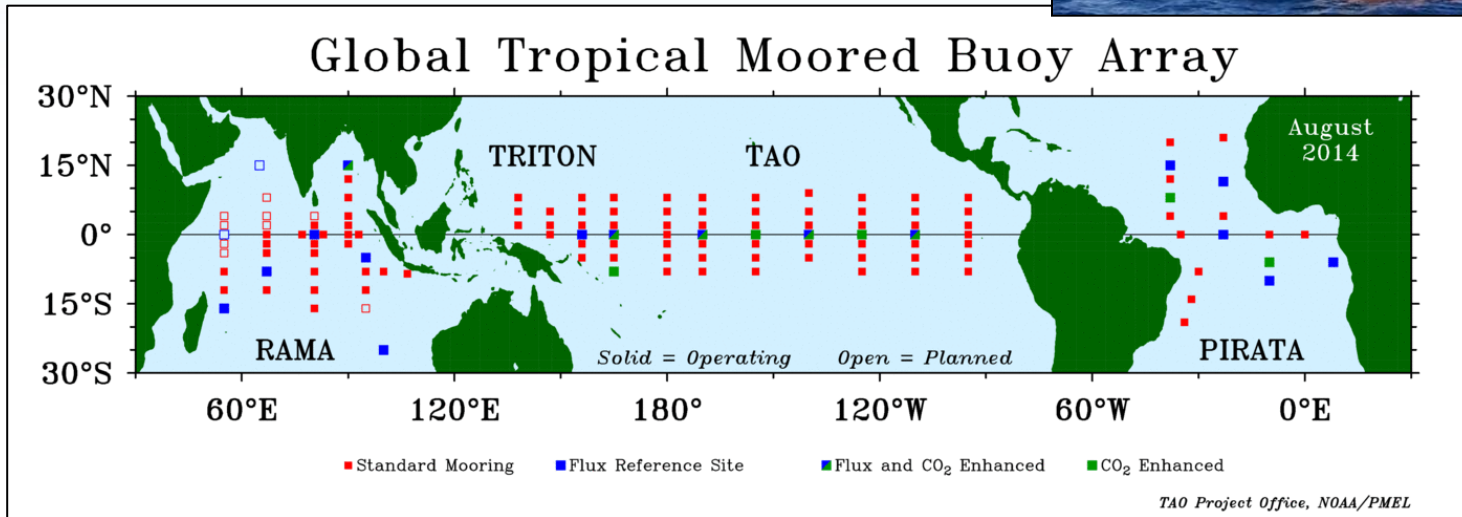
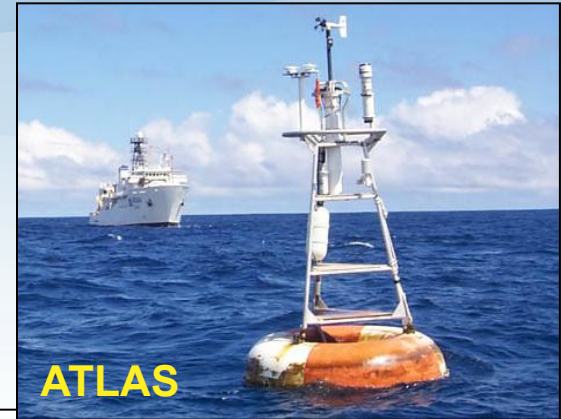


119 moorings planned

Performance

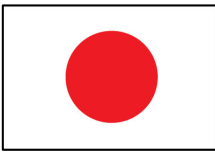
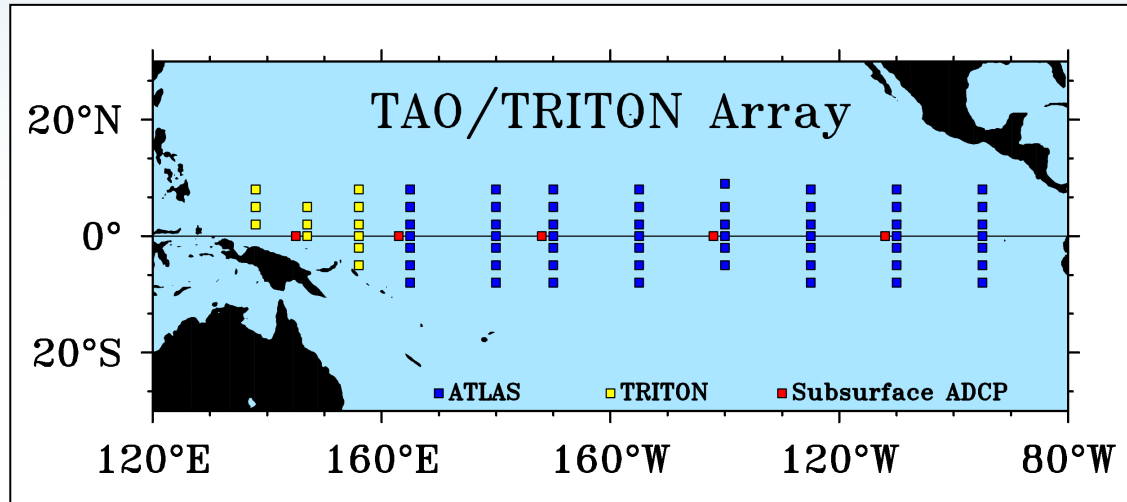
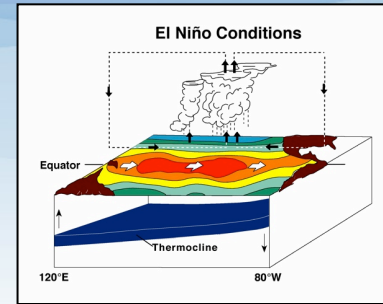
Global Tropical Moored Buoy Array:

A coordinated multi-national effort to develop and sustain moored buoy observing systems for climate research and forecasting throughout the tropics, in support of PMEL's, OAR's, and NOAA's strategic plans

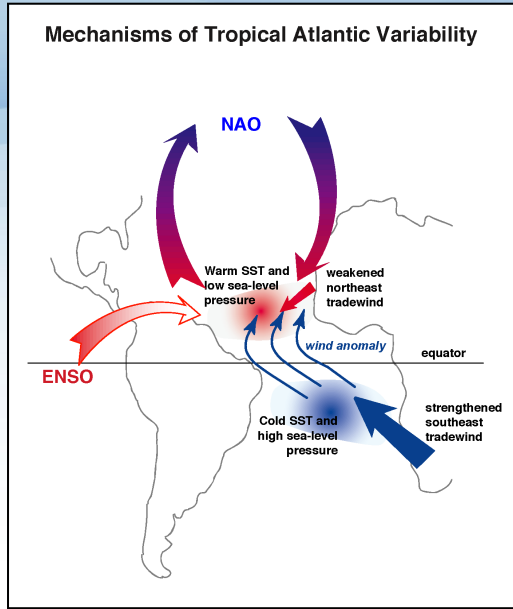


Performance

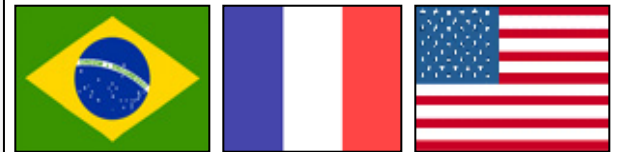
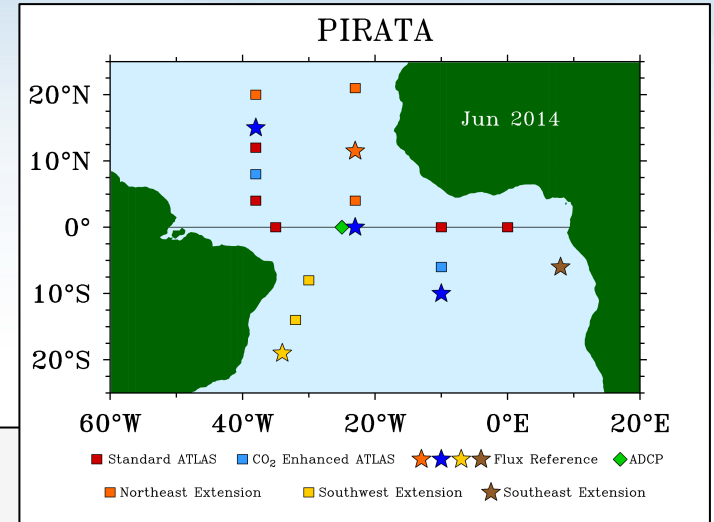
TAO/TRITON: The Cornerstone for ENSO Research and Forecasting



- ✓ Pilot ATLAS deployments in 1984
- ✓ Implemented during TOGA (1985-94)
- ✓ Became TAO/TRITON in 2000 (NOAA/JAMSTEC)
- ✓ NDBC assumes operational responsibility in 2005
- ✓ PMEL delivers 334 ATLAS systems to NDBC, 2005-13
- ✓ PMEL ends involvement in 2013



PIRATA: Centerpiece of the Tropical Atlantic Ocean Observing System

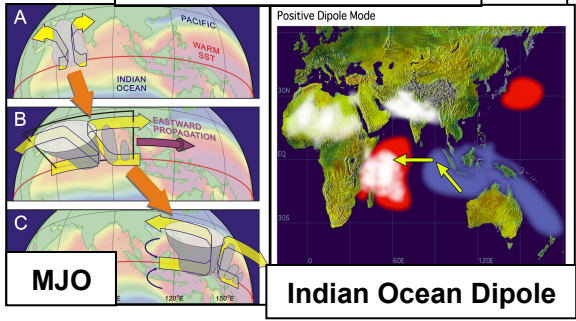
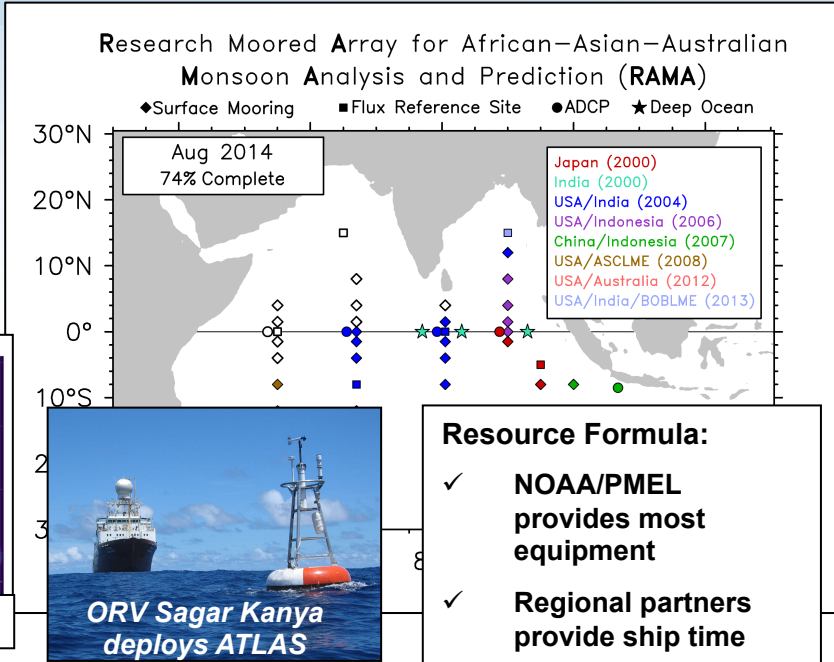
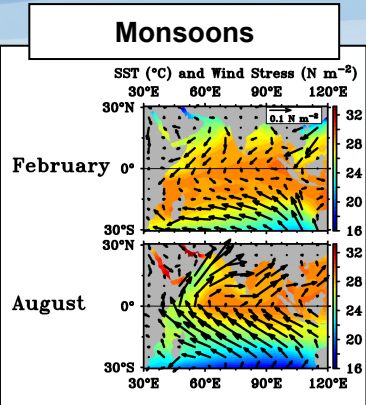
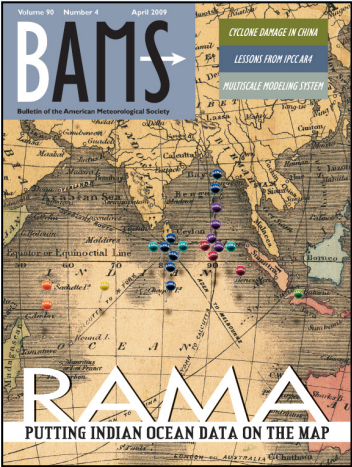


PIRATA: Prediction and Research Moored Array in the Tropical Atlantic

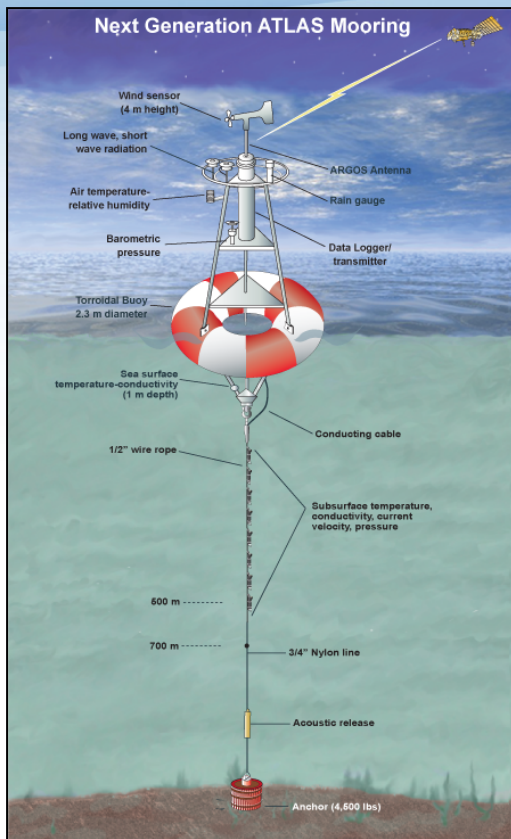
- ✓ Established in 1997 by France, Brazil and the US
- ✓ Brazil & France provide logistic support & most ship time
- ✓ USA (NOAA) provides most mooring equipment & data processing

Performance

RAMA: Moored buoy array in the data-sparse Indian Ocean provides measurements to advance monsoon research and forecasting



Performance



ATLAS Mooring:

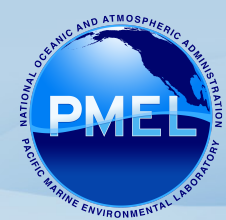
- ✓ Ocean and atmosphere
- ✓ Rapid continuous sampling
- ✓ Low cost
- ✓ Real-time data
- ✓ Design lifetime of 1 year

Designed and built at PMEL

Original ATLAS: 1984

ATLAS-II (Nextgen): 1995

ATLAS-III (T-Flex): 2015



Performance Measures

1 July 2008-30 June 2014

Moorings 623

(PMEL 433)

Research Cruises 113

Ships 27

Countries 13

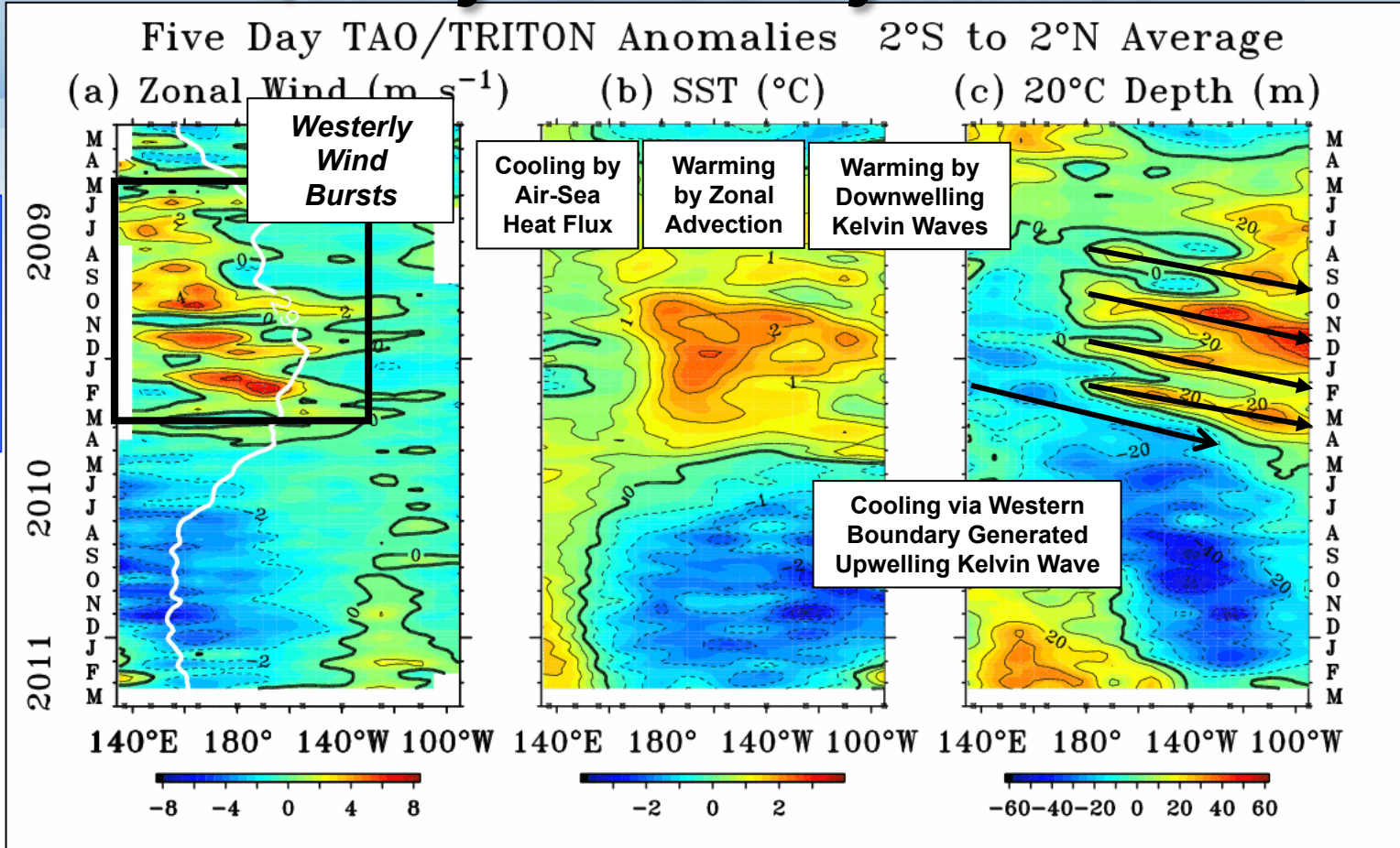
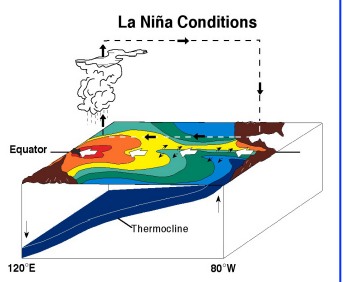
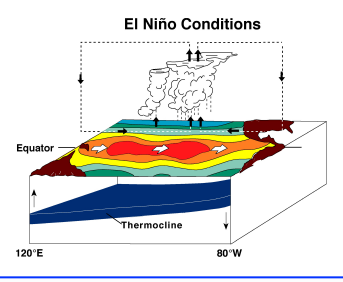
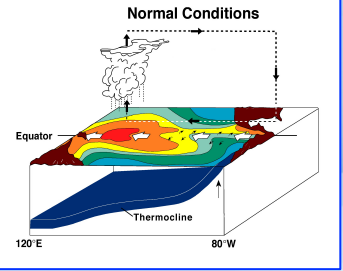
Sea Days 3238

(Non-US: 1958=\$60M)

Quality: ENSO Dynamics

Five Day TAO/TRITON Anomalies 2°S to 2°N Average

(a) Zonal Wind ($m s^{-1}$) (b) SST ($^{\circ}C$) (c) 20°C Depth (m)

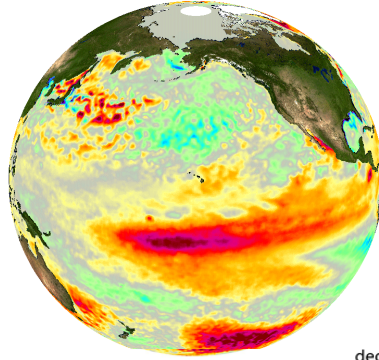


Classical El Niño: maximum warming in the eastern-equatorial Pacific (EP)

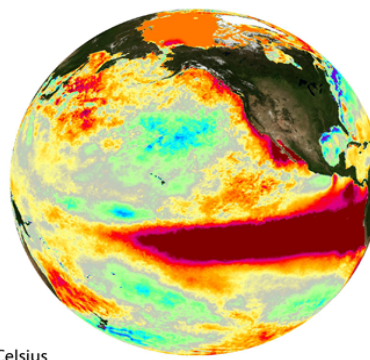
A new type of El Niño: maximum warming in the central-equatorial Pacific (CP)

Monthly Averaged Sea Surface Temperature Anomaly

December 2009
 Blended AMSR-E and MODIS SSTA



December 1997
 Pathfinder AVHRR SSTA

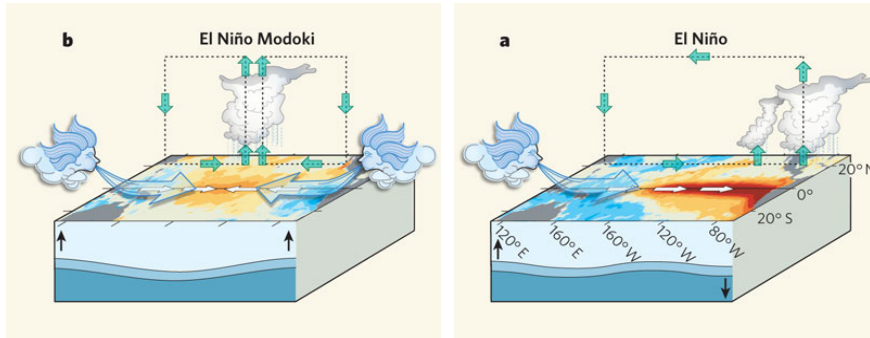


degrees Celsius
 -2.5 0.0 2.5

The strongest CP-El Niño in the past 3 decades

The strongest EP-El Niño in the past 3 decades

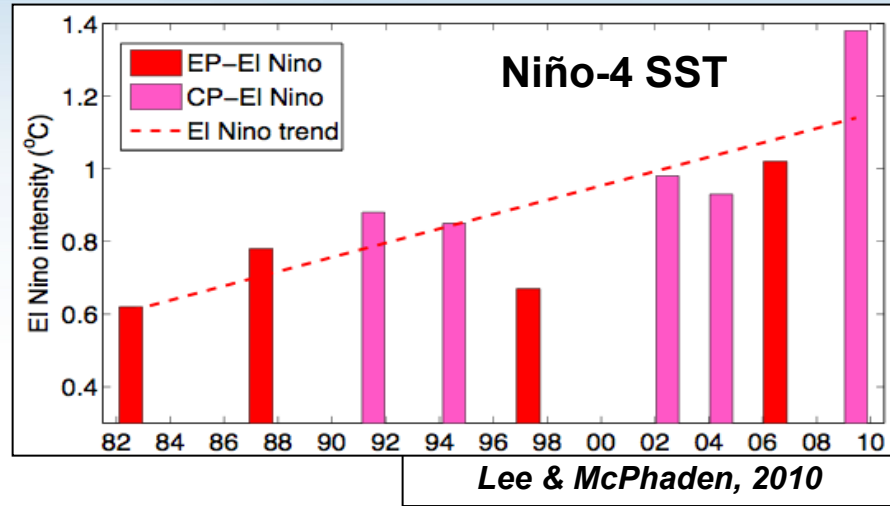
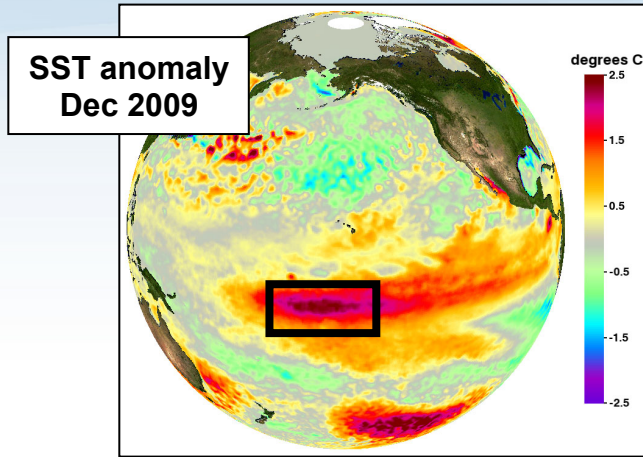
Image Credit:
 PO.DAAC, NASA JPL



Ashok, 2009

Quality

Trends in Central Pacific El Niño SSTs



Central Pacific El Niños are increasing in frequency and amplitude

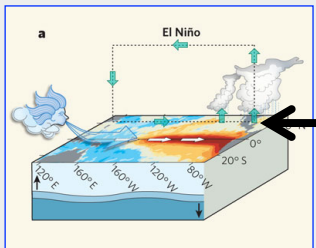
Yeh et al, 2009, Nature: Due to global warming

Yeh et al, 2011; McPhaden et al, 2011; Newman et al, 2011: A natural variation

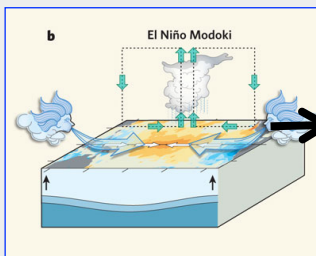
Relevance

Differing Effects of EP and CP El Niños on the Tropical Atlantic & NE Brazil Rainfall

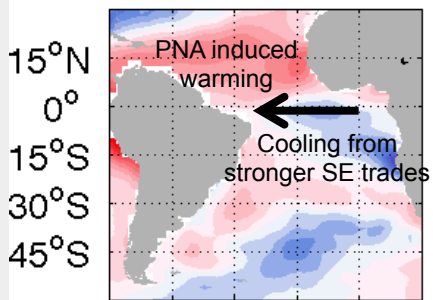
Eastern Pac El Niño



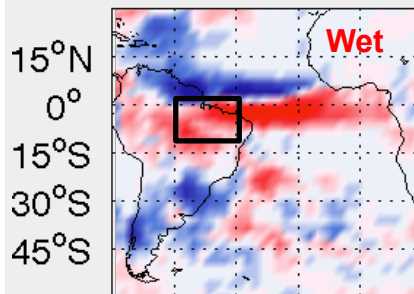
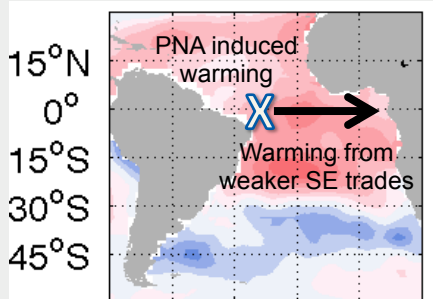
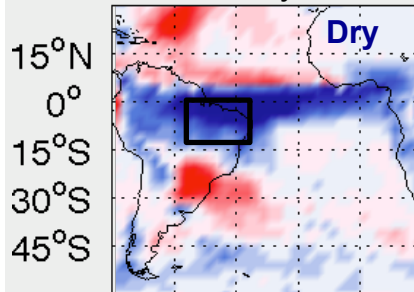
Central Pac El Niño



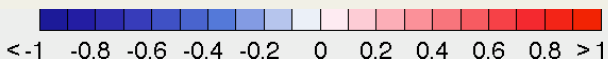
March-May SST



March-May Rain

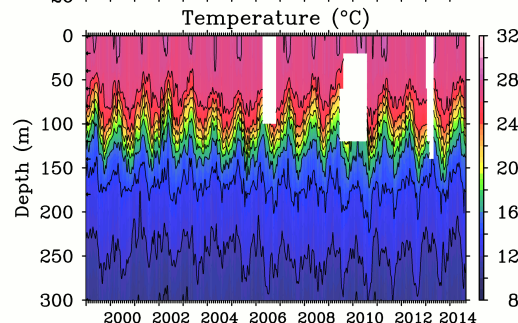
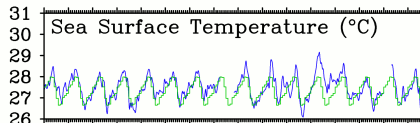
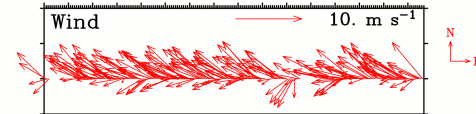


80°W 40° 0° 80°W 40° 0°

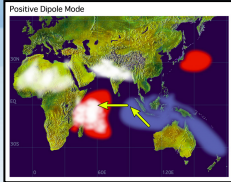


PIRATA

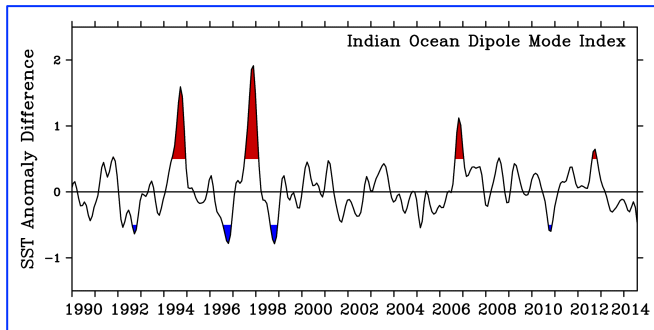
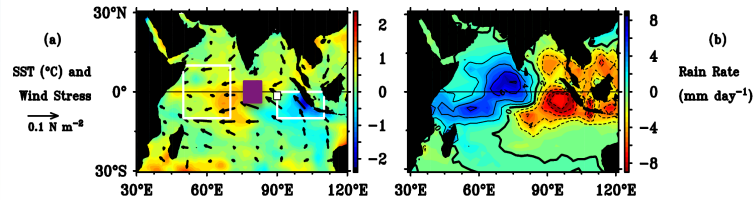
0°, 35°W
Monthly Wind and Temperature Data



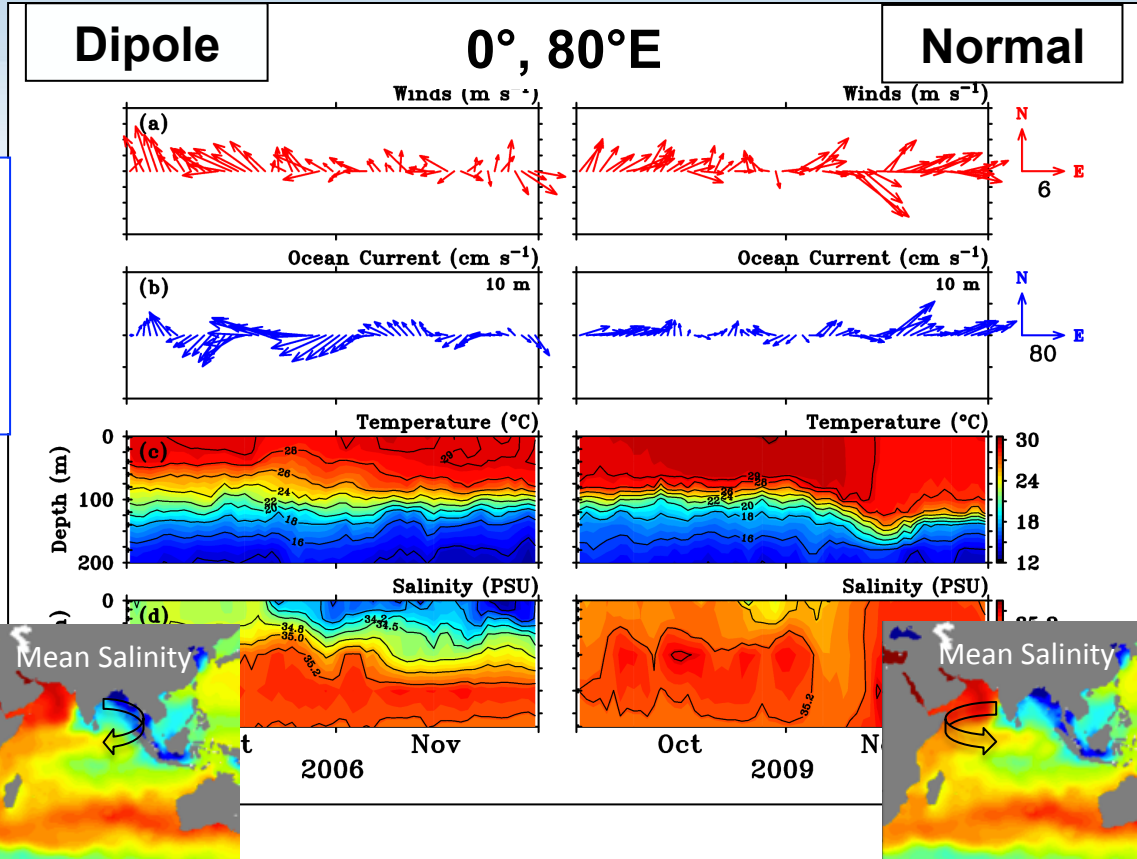
Quality: Indian Ocean Dipole Processes

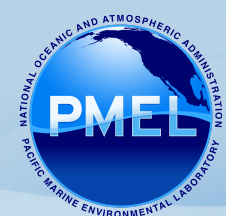


November 2006 Anomalies



McPhaden et al, 2009, BAMS





PMEL and the TAO Project Pioneered Free, Open & Immediate Access to Ocean-Climata Data

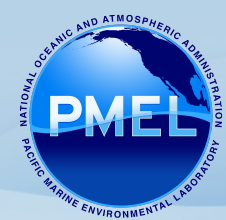
Measures of Relevance

1 July 2008-30 June 2014

- Web page hits: 92,670,248
- Data files delivered*: 6,411,092
 - ✓ Web user interface—1,839,549
 - ✓ FTP—4,571,543
- Refereed journal articles: 267

*GTMB data also freely available from:
 NODC, NCDC, OceanSITES, NDBC, CORIOLIS,
 ICOADS, INCOIS, JAMSTEC and via the Global
 Telecommunications System (GTS)

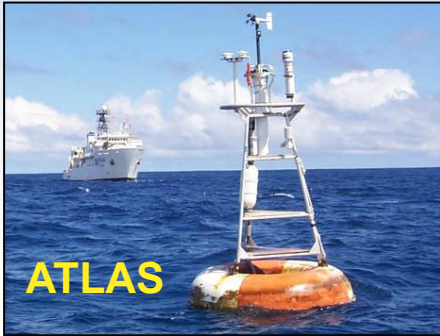
<http://www.pmel.noaa.gov/tao/>



Measures of Relevance

- **Widely used in ocean reanalysis products:**
SODA, GFDL, GODAS, ECCO, MERCATOR, ORA, POAMA, GODAE...
- **Widely used in atmospheric reanalysis products:**
NCAR-NCEP, ECMWF, FNMOC, Goddard...
- **Real-time GTS data used worldwide for operational ocean, weather and climate analysis and forecasting:**
NCEP, FNMOC, ECWMF, JMA, Meteo-France, UKMO, BOM, CPTEC, Guam Typhoon Warning Center...

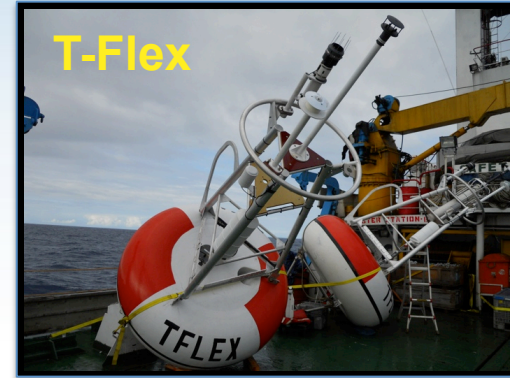
T-Flex: PMEL Designed ATLAS Update



Changeover To
Begin in 2015



7 side-by-side field
comparisons since 2011

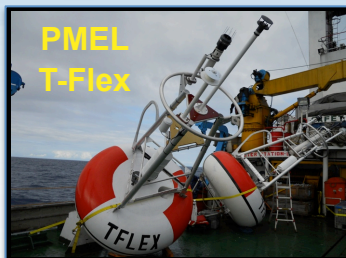


T-Flex Advantages:

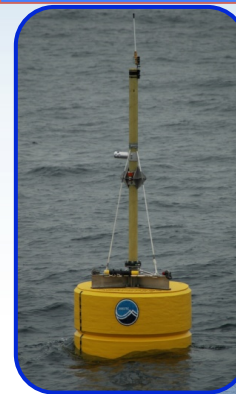
- Uses commercially available components
- Increased temporal resolution of telemetered data (Argos→Iridium)
- Includes flexibility to directly incorporate new instrumentation
- Comparable or better data accuracy
- Decreased losses due to vandalism
- Improves GTS data latency for synoptic weather forecasting

Quality

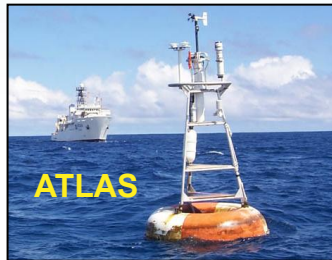
Transferring Technology & Setting Standards



Mini-TRITON



TRITON



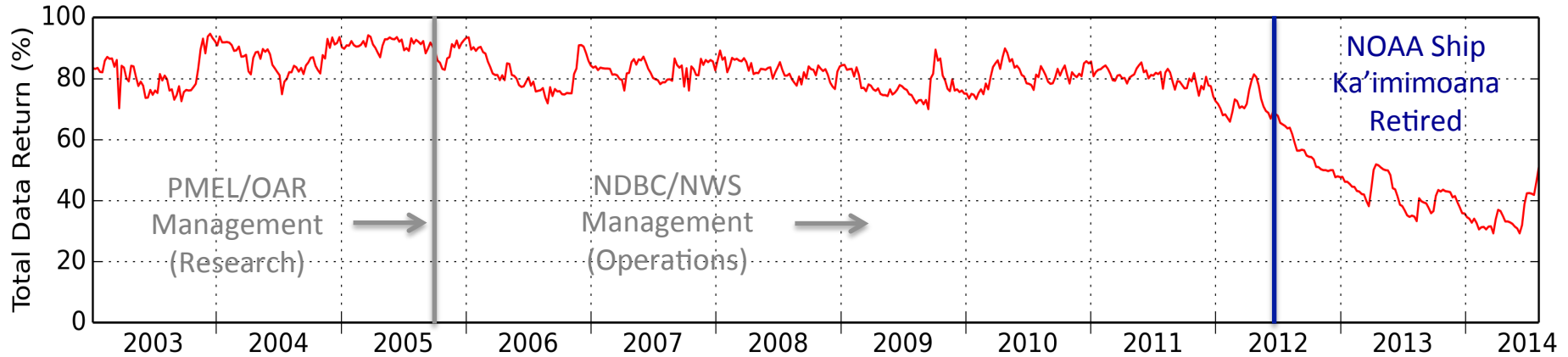
Compatibility & continuity of data sets requires:

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

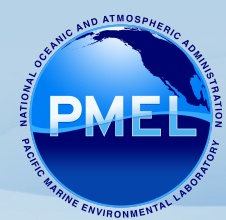
The Collapse of TAO

**TAO Array Data Return
 January 2003 - August 2014**

Data Source: NOAA/PMEL



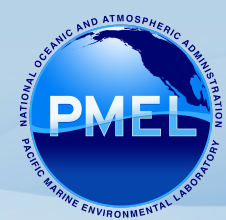
Tropical Pacific Ocean Observing System (TPOS) Workshop, La Jolla, CA, 27-30 Jan 2014
 ➔ Recommends TPOS2020 Project to redesign the Pacific Observing System



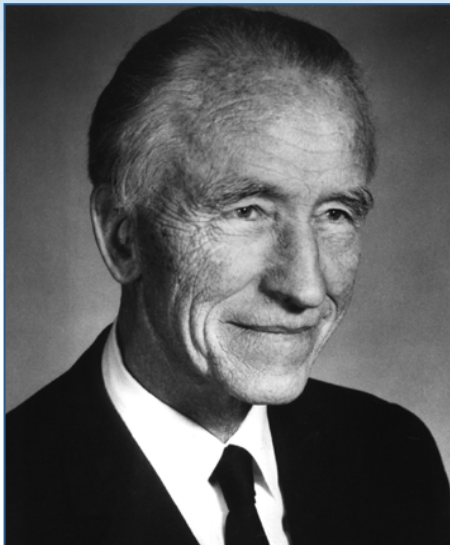
Future Directions:

- Complete RAMA***
- Implement transition from ATLAS to T-Flex***
- Enhance multi-disciplinary measurements***
- Contribute to the development of IIOE-2 (2015-20)****
- Guide development of a new tropical Pacific Ocean Observing System (TPOS) for climate***
- Conduct research to expand the frontiers of ocean and climate science***

*Hood, R. H., M. J. McPhaden, E. Urban, 2014: The Second International Indian Ocean Expedition (IIOE-2). *EOS, Trans. Am. Geophys. Union*, in press (16 Sept 2014).



Vision



“In the future, we can visualize...a **worldwide service of...monitoring buoys reporting by way of communication satellites**...such data which enter into...electronic computers...for global long-range dynamical predictions of...the coupled circulations of the atmosphere and ocean.”

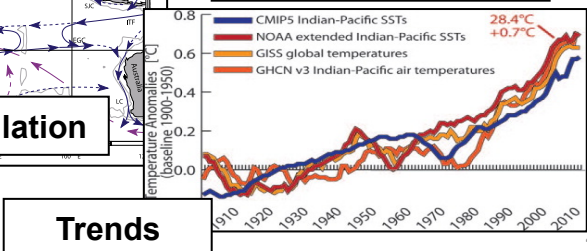
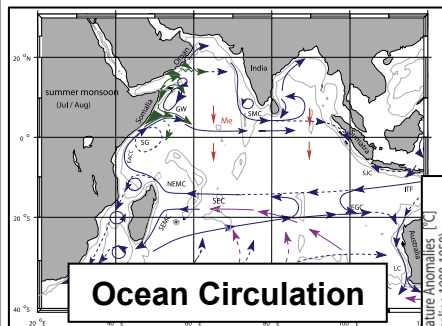
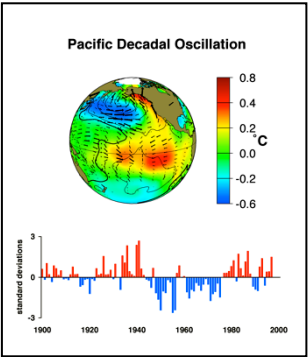
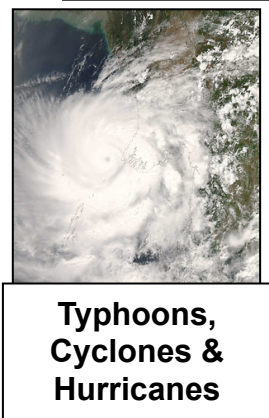
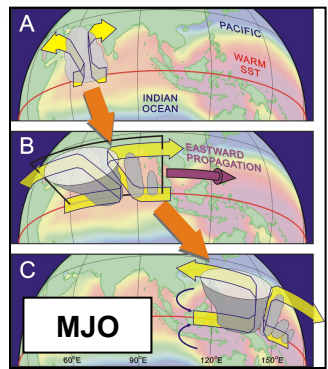
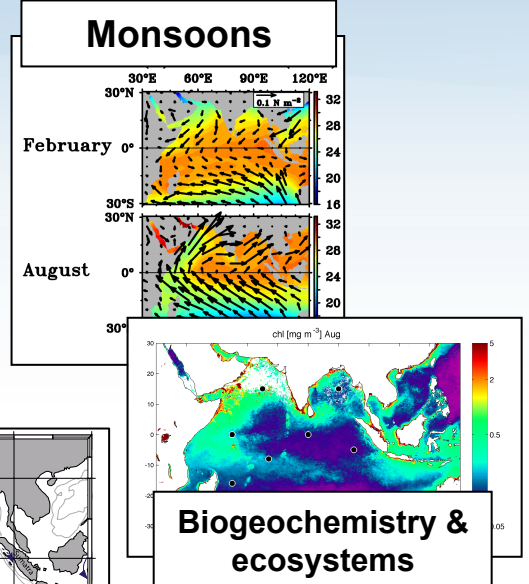
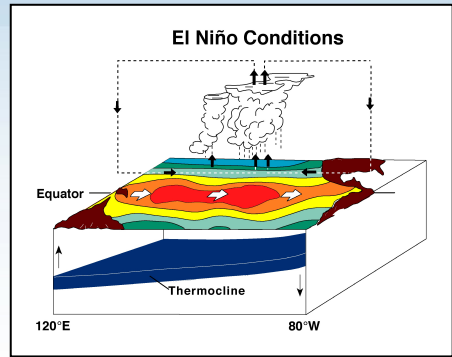
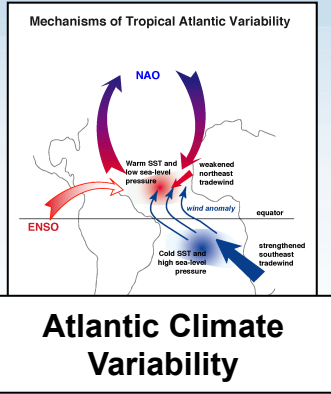
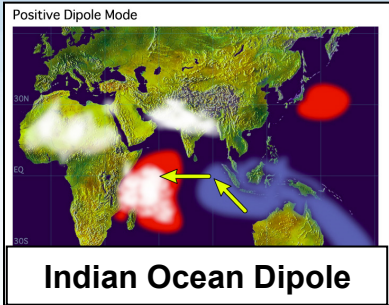
***--Jacob Bjerknes
1969***

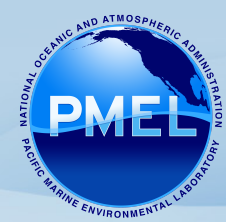


Extras

Background

Interacting Variations in Time and Space

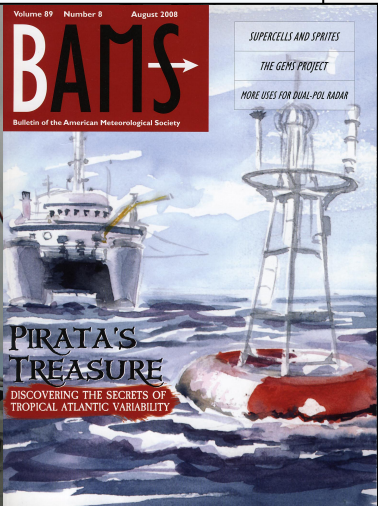




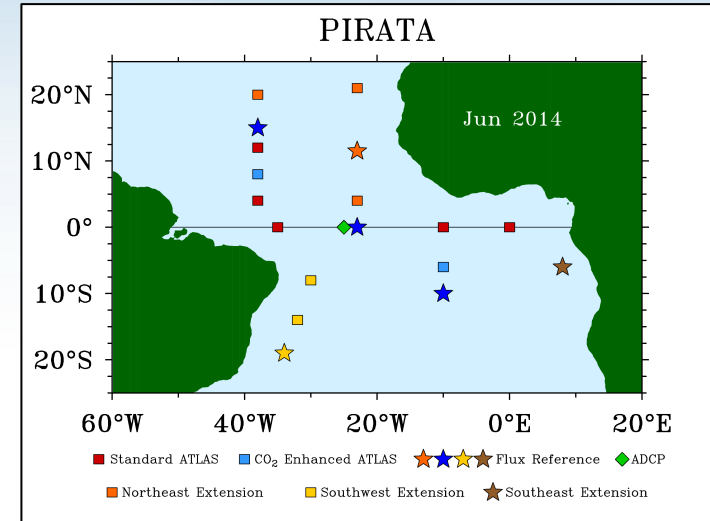
Performance

PIRATA Since 2008:

- P=Prediction (2008) rather than Pilot (1998)
- TACE (2008-13) and EU PREFACE (2013-17) built around PIRATA
- O₂ added to 4°N & 12°N, 23°W (2008)
- Three new flux sites (2008-2013)
- Enhancements implemented for NASA SPURS program (2012-13)
- 6°S, 8°E re-established (2013)
- Ocean Tracking Network partnership established with Dalhousie U. (2013)
- OSU Chi-Pods added (2014)
- US/FR/BR MOU renewed 5-yr (2014)



PIRATA: Centerpiece of the Tropical Atlantic Ocean Observing System

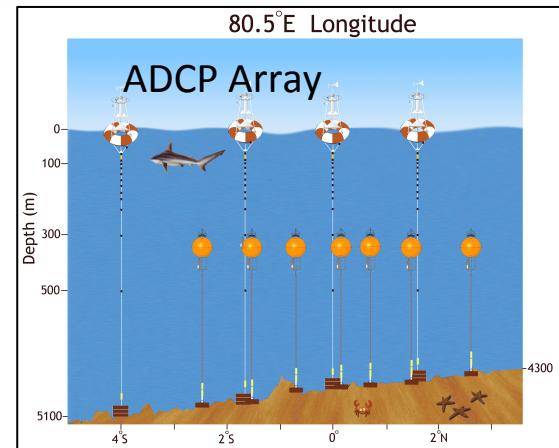


Performance

RAMA Since 2008:

- Three new partners added
- 20 → 34 moorings
- ADCP array along 80°E (2008 to present)
- Meteo-France adds BP @ 4 sites for cyclone forecasting (2010)
- Ocean color added to two sites by U. Tasmania (2010/13)
- CINDY/DYNAMO (2012), International study of the MJO, built around RAMA
- Ocean Acidification mooring deployed @ 15°N, 90°E (Nov 2013)

Bay of Bengal
 Ocean
 Acidification
 Mooring





Quality Indicators since 2008

- **AGU Fellow, 2014**
- **AGU President, 2010-12**
- **Priestley Lecturer, CSIRO, Australia, 2012**
- **Fridtjof Nansen Medal, EGU, 2010**
- **Refereed publications: 81**
- **Supported 6 postdocs+4 MS/PhD students**
- **Citations-ISI: >4700 (>10000 overall, H-index 53)**
- **Editor, *Bulletin of the American Meteorological Society***
- **Scientific collaborators on six continents**
- **Member or chair of review panels, steering groups, organizing committees**
- **Outreach via media interviews & public lectures**