Research and Operational Achievements of TAO/TRITON

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1. History
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3. ENSO Predictability and Prediction
4. Decadal Variability and Climate Change
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Global Tropical Moored Buoy Array: A coordinated, sustained, multi-national effort to develop and implement moored buoy observing systems for climate research and forecasting throughout the global tropics

A contribution to GOOS, GCOS, and GEOSS
El Niño and the Southern Oscillation (ENSO)

El Niño=ENSO warm event
La Niña=ENSO cold event

Jacob Bjerknes
1897-1975
El Niño and La Niña shift the probability for droughts, floods, heat waves, extreme weather events around the globe.
1982-83 El Niño:

- Strongest of the 20th century
- Not predicted
- Not detected until nearly at peak:
  - Satellite SSTs biased cold by El Chichon
  - No real-time data from the ocean

El Chichon, Mexico
March-April 1982
A Major Goal of Tropical Ocean Global Atmosphere (TOGA) Program:
“To provide the scientific background for designing an observing and data transmission system for operational prediction...”
Next Generation ATLAS Mooring

- Low cost
- Real-time data
- Data every day
- Ocean and atmosphere

Designed by NOAA/PMEL

ATLAS Mooring

Tropical Atmosphere Ocean (TAO) Array built up over the 10-year (1985-94) TOGA Program
"...the crowning achievement of TOGA was the development of the Tropical Atmosphere/Ocean (TAO) array..."

EOS Transactions AGU, 1997
2009-10 El Niño and 2010-11 La Niña

http://www.pmel.noaa.gov/tao/
2009-10 El Niño and 2010-11 La Niña

http://www.pmel.noaa.gov/tao/
**ENSO Evolution Governed by Multi-Time Scale Interactions**

- Deterministic seasonal time scale dynamics
  - Coupled feedbacks between ocean and atmosphere
  - Wind forced changes in ocean circulation that redistribute heat in the upper ocean

- High frequency (days to weeks) stochastic forcing
  - “Westerly winds bursts” and other weather noise
    - Introduces irregularity (timing, duration, amplitude)
El Niño/La Niña Cycle, 2009-2011

Five Day TAO/TRITON Anomalies 2°S to 2°N Average
(a) Zonal Wind (m s\(^{-1}\))
(b) SST (°C)
(c) 20°C Depth (m)

- Westerly Wind Bursts
- Cooling by Air-Sea Heat Flux
- Warming by Zonal Advection
- Warming by Downwelling Kelvin Waves
- Cooling by Western Boundary Generated Upwelling Kelvin Wave ("Delayed Oscillator")

http://www.pmel.noaa.gov/tao/
TAO/TRITON: Over 30 Years of Data

Temperature at 0°, 110°W

Depth (m)


TAO/TRITON Array

http://www.pmel.noaa.gov/tao/
- 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.
El Niño and La Niña are Predictable

- Predictability based on slow evolution of upper ocean heat content
- First successful El Niño prediction in 1986
- Forecast models are reasonably skillful at up to 6-9 month lead times
- Predictability limited by model bias, errors in initial conditions, and weather noise
Niño-3.4 Predictions From August 2009

El Niño is expected to strengthen and last through Northern Hemisphere Winter 2009-10.

NOAA/NCEP
10 Sept 2009

Compiled by the International Research Institute for Climate and Society (IRI)
"A straightforward explanation of these results is that the improved observing system, notably the TAO array and altimetry, is responsible for a large part of the forecast improvement."

Stockdale et al, 2011

"All the observing systems contribute to the improvement of seasonal forecast skill almost everywhere. The moorings having a dominant effect in the equatorial Pacific…"

Balmaseda & Anderson, 2009
Thirty Year Records Capture Decadal Variability

Warm Water Volume (5°N–5°S, 120°E–80°W) and NINO 3.4 SST Anomaly

After 2000:
- Lower amplitude
- Higher frequency
- Shorter lead time (3 seasons → 1)

Heat content based on TAO/TRITON, XBT, and Argo data
**ENSO and the PDO**

Nino 3.4 Sea Surface Temperature Anomalies
(5°N–5°S, 120°W–170°W)

- **Warm Phase**
- **Cold Phase**

- **NINO3.4 ≥ 0.5° C** for 5 months = El Niño
- **NINO3.4 ≤ -0.5° C** for 5 months = La Niña
Global Warming Hiatus Linked to the Phase of PDO (IPO)

A new type of El Nino: maximum warming in the central-equatorial Pacific (CP)
Classical El Nino: maximum warming in the eastern-equatorial Pacific (EP)

The strongest CP-El Nino in the past 3 decades

The strongest EP-El Nino in the past 3 decades

Image Credit: NASA JPL

Ashok, 2009
More CP El Niños Since 2000

1980-99: 4 EP+2 CP
2000-10: 3 CP+1 EP

Composites of Reynolds SST anomalies for DJF of El Niño years
**EP vs CP El Niño Mechanisms**

**DJF El Niño Anomalies**

- **SST (°C)**
  - Thermocline Feedback
  - Zonal Adv Feedback

- **Z\textsubscript{20°C} (m)**
  - Thermocline Feedback
  - Zonal Adv Feedback

*Decadal Composites from ERSST, ECMWF winds, BMRC 20° C*

*McPhaden et al, 2011*
Does Climate Change Affect ENSO?

Today

**The La Niña and El Niño Weather Patterns...**

No compelling evidence that greenhouse gas forcing has affected the ENSO cycle to date

In the future?

ENSO may be affected in the future, e.g. frequency of extreme El Niños may double by the end of the 21st century (Cai et al, 2014)

Today

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Global Ocean Observing System for Climate

**In Situ Components**

- **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
- **Global reference mooring network** 48%
  - 29 moorings planned
- **Global tropical moored buoy network** 79%
  - 119 moorings planned
One Key to the Success of TAO:
A Dedicated Ship
Plummeting Data Return Since June 2012

Challenge in the 1980s: How do we design and implement an ocean observing system for climate?

Challenge today: How do we sustain ocean observing systems for climate to ensure continuity of the climate record?

Number of buoys reporting data
History of TAO/TRITON

**TAO**
1985-1994: TOGA Period
   Array Development

1994-2000: International Collaboration (US, Japan, French, China etc)

2000-present: US-Japan T/T Framework

2005: Transition in NOAA

2012: TAO crisis starts by ship retirement

**TRITON**
1987-1994: JENEX and JAPACS

1998-2003: Array Development

1999-2000: TRTION in place
2000- present: US-Japan T/T Framework

2013: Start TRITON shrink by funding shrink

Future
Background of TRITON

International:
TAO buoy array was the central player, and maintained by international efforts (US, Japan, France, etc..)

Domestic progress in Japan:
In 1992, by the 4th Policy Report of the Council for Ocean Development of the Japanese Government, the TRITON buoy project was initialized as one of fundamental projects, and launched to develop in JAMSTEC.

This 4th report also addressed a need to develop ocean research vessel, of today R/V Mirai.
TRITON (TRIangle Trans-Ocean buoy Network) was originally named by being expected to expand our buoy array in a Triangle shaped region with three apexes of tropical Pacific Ocean, tropical Indian Ocean, and Kuroshio mid-latitude region.

Goals of TRITON buoys in the tropical region was to understand the generation and dissipation mechanisms of the warm pool in the tropical Pacific and Indian Oceans.
TRITON Buoy System

Adjusting to ATLAS system with additional sensor

Dimensions of surface float
Diameter 2.4m
Weight 2.4t
Development and decay of TRITON buoy array

Stop operation at February, 2013

Plan to stop operation at February, 2014

- March, 1998
- March, 1999
- March, 2000
- March, 2001
- March, 2002
- August, 2002
Development of Technology

- JAM-MET sensors
- JTD-CTD sensor

- Countermeasures to vandalism
- TRTION family: m-TRITON, K-TRITON, Antarctic buoy, Tsunami buoy
The End