Understanding and Predicting El Niño and the Southern Oscillation

Mike McPhaden

NOAA/PMEL
Seattle, Washington USA
Topics

- ENSO & Climate Impacts
- Observing ENSO
- 2015-16 El Niño
  - Description
  - Dynamics
  - Predictability & Prediction
- ENSO in a changing climate
El Niño and the Southern Oscillation (ENSO)

El Niño—Warm phase of ENSO
La Niña—Cold phase of ENSO
Every few years, the trade winds weaken...
**ENSO: A Result of Coupled Ocean-Atmosphere Interactions**

**El Niño** = NINO3.4 $\geq 0.5^\circ$C for 5 months

**La Niña** = NINO3.4 $\leq -0.5^\circ$C for 5 months
Atmospheric Teleconnections During El Niño

Heavy Rain = Atmospheric Heating

Shifts in tropical rainfall patterns affect global atmospheric circulation via long range teleconnections

After Wallace & Gutzler, 1981

PSA Pattern JJA

Karoly, 1989
El Niño Alters Global Atmospheric Circulation
**El Niño & La Niña Impacts on Global Patterns of Weather Variability**

El Niño and La Niña shift the probability for droughts, floods, heat waves, extreme weather events around the globe.
Impacts on Tropical Storms

- El Niño tends to suppress the formation of Atlantic hurricanes
- El Niño tends to enhance intensity and geographic range of Pacific hurricanes
- Opposite tendencies occur during La Niña
Observing ENSO
Global Ocean Observing System for Climate

In Situ Components

Why we measure (the 5 D’s):
Definition, Detection, Diagnostics, model Development, preDiction
ATLAS Mooring:
✓ Ocean and atmosphere
✓ Rapid continuous sampling
✓ Real-time data

TAO/TRITON Array built up over 1985-94 during international Tropical Ocean Global Atmosphere (TOGA) program
2015-16 El Niño
"Godzilla" El Niño could be Strongest on Record

"Godzilla" El Niño

Dec 2015
December 2015
SST & Precipitation Anomalies

Precipitation Anomalies

Atmospheric Teleconnections
2015-16 El Niño in the News

Monsoon 2015 ends with 14% shortfall

Indonesian Forest Fires Out of Control

Flooding 'worst in 50 years', as 150,000 flee in Paraguay, Argentina, Brazil and Uruguay
An ENSO Index

El Niño = NINO3.4 ≥ 0.5°C for 5 months

La Niña = NINO3.4 ≤ -0.5°C for 5 months
2015–16 vs. Past El Niños

NINO 3.4

Average of 15 El Niños from 1957-58 to 2015-16
December 2015 vs December 2016

**TAO/TRITON Monthly Data**

**SST (°C) and Wind**

**Major El Niño**

**Weak La Niña**

29°C

Global Tropical Moored Buoy Array Program Office, NOAA/PMEL

Feb 15 2017
December 2015 vs December 2016

http://www.pmel.noaa.gov/gtmba/
December 2015 Anomalies

TAO/TRITON Monthly Data December 2015
SST (°C) and Wind

Means

Anomalies

Global Tropical Moored Buoy Array Program Office, NOAA/PMEL

Feb 15 2017

TAO/TRITON Array

ATLAS
2015-16 El Niño: a hybrid EP/CP event of extreme amplitude
ENSO Dynamics Governed by Multi-Time Scale Processes

- 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) weather noise forcing
  - Westerly winds bursts most prominent
  - Introduces irregularity (timing, duration, amplitude)
Upper Ocean Heat Content as a Precondition (Recharge Oscillator Theory, Jin 1997)

- 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 event.
- The time between El Niños is determined by the time to recharge.

Depth Averaged Temperature Anomalies (0/300m) and NINO 3.4 SST (5°N–5°S, 120°E–80°W)

Exceed Threshold → El Niño

Heat content (~average temperature anomaly in upper 300 m)
From TAO/TRITON, Argo, XBT
Upper Ocean Heat Content (“ENSO Fuel”)

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Heat content (~average temperature anomaly in upper 300 m)
From TAO/TRITON, Argo, XBT
Westerly Wind Bursts ("The Spark")
2014, 2015, 2018

5-Day Zonal Wind Anomalies
2°S to 2°N Average

Fuel + Spark = El Niño
Evolution: Jan 2015-Dec 2016

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)

"State-dependent noise forcing"

Cooling by Air-Sea Heat Flux  Warming by Zonal Advection  Warming by Downwelling Kelvin Waves

TAO Project Office/PMEL/NOAA
El Niño and La Niña are Predictable

- First successful El Niño prediction in 1986
- ~20 organizations around the world now regularly issue ENSO forecasts
- Forecast models are reasonably accurate up to 6-9 months in advance
- Predictability based variations in upper ocean heat content
- Predictability limited by weather noise, model bias, errors in initial conditions
“There is a greater than 90% chance that El Niño will continue through Northern Hemisphere winter 2015-16, and around an 85% chance it will last into early spring 2016.”

NOAA/NCEP
13 August 2015
DJF 2016 Precipitation Forecast vs Historical El Niño Pattern

IRI Multi-Model Probability Forecast for Precipitation for December-January-February 2016, Issued August 2015

Colors show probability of most likely category
Dark blue indicates climatology
D Dry season (no forecast)

El Niño and Rainfall
El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the general shifts remain fairly consistent in the regions and seasons shown on the map below.

Probability (%) of Most Likely Category
- Below-Normal: 40, 45, 50, 55, 60, 65, 70
- Normal: 40
- Above-Normal: 40, 45, 50, 55, 60, 65, 70
Precipitation Forecast vs Verification

IRI Multi-Model Probability Forecast for Precipitation for December-January-February 2016, Issued August 2015

Forecast

Verification

Colors show probability of most likely category. White indicates climatology. "D" dry season (no forecast).

Probability (%) of Most Likely Category

Below-Normal: 40, 45, 50, 55, 60, 65, 70
Normal: 40
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Comparison of 2014 and 2015 Nino3.4 Forecasts

Compiled by the International Research Institute for Climate and Society (IRI)
ENSO and Global Warming
The Climate is Changing

Other indicators: increasing tropospheric temperatures; increasing ocean heat content, sea level rise, disappearing arctic sea ice, glacial ice loss...
Humans are the Main Driver of Climate Change

CO₂ warms the planet. More CO₂ warms the planet more.
Earth Sets a Temperature Record for the Third Straight Year

Earth reached its highest temperature on record in 2016, trouncing a record set only a year earlier, which beat one set in 2014

Melting Arctic Sea Ice

Global Land and Ocean Temperature Anomalies, January-December

ENSO affects Global Warming
How does Global Warming affect ENSO?

1. Have anthropogenic greenhouse gas emissions affected the ENSO cycle already? 
   Possibly, but the impact is small and difficult to detect.

2. Will ENSO change in the future?
Has Global Warming Affected ENSO Already?

Nino3.4 Instrumental Record, 1865-Present

Wittenberg, 2009, GRL

Need ~500 yrs of data to see forced signal emerge from background of natural variability using 2000 year simulation of GFDL CM2.1 model
How does Global Warming affect ENSO?

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2. Will ENSO change in the future?
   Probably. Exactly how is highly uncertain. Extreme ENSO events may increase in frequency by the end of the 21st century.
Combined effects of El Niño and global warming contribute to high impact climate extremes in 2015-16
Record Coral Bleaching Event 2014-16

Australia's Great Barrier Reef hit by 'worst' bleaching

93% bleached
22% dead

The Great Barrier Reef is the world's largest living structure and can be seen from space.

Evidence that Australia's Great Barrier Reef is experiencing its worst coral bleaching on record has renewed calls for the UN to list it as "In-danger".

The National Coral Bleaching Taskforce says 95% of reefs from Cairns to Papua New Guinea are now severely bleached.

- Longest, most widespread bleaching on record
- > 40% of global reefs affected
- Previous global bleaching events in 1997-98 & 2009-10
2015: A Record Year for Tropical Storms in the Pacific

Hurricane Patricia: Strongest Storm Ever Measured to Hit Mexico

The Northern Hemisphere Just Set a Cyclone Record

- Record ACE
- 20 storms ≥ Cat4

30 Aug 2015

Three Category 4s

Chan-Hom

22 Oct 2015

“...caused by El Niño...but more extreme because of anthropogenic forcing...”

-- Zhang et al, 2016, BAMS
Summary

ENSO is the most powerful and predictable year-to-year fluctuation of the climate system.

Advances in understanding, measurements and prediction systems make skillful ENSO forecasts routinely possible 2-3 seasons in advance.

Many challenges remain: 1) understanding ENSO diversity; 2) sources and limits of predictability; 3) effects of greenhouse gas forcing.

Combined effects of the very strong El Niño and global warming contributed to high impact climate extremes in 2015-16.
Challenges

- Understanding what accounts for ENSO diversity. Can we reliably predict different types of El Niño and their impacts?
- Understanding the sources and limits of ENSO predictability.
- Understanding the effects of greenhouse gas forcing on the ENSO cycle.
Global Impacts

1997-98 El Niño

Fatalities: 23,000
Economic Losses: US$ 36 Billion

NOAA, 1999

- **Negative**
  - 189 fatalities
  - $4-5 billion in economic losses

- **Positive**
  - 850 lives saved
  - $20 billion in economic gains

Examples of positive impacts:

1) **Reduced Atlantic hurricane damage/fatalities**
2) **Warmer 1997-98 winter in the Midwest**
   - lower winter heating bills
   - fewer deaths from exposure
   - more commerce

Changnon, 1999, BAMS
Tahiti minus Darwin surface pressure: A measure of trade wind strength.
Three Major El Niños Since 1980:

- Dec 1982
- Dec 1997
- Dec 2015

Probably not!

Tremendous amount of natural variability to the ENSO cycle based on historical record, paleo-data and model simulations.

Still an active area of research.
2015-16: The Compounding Impacts of El Niño and Climate Change

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Three Category 4s

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--Zhang et al, 2016, BAMS
Indonesian Forest Fires
July-October 2015

“The combination of heat [from greenhouse gas forcing] and drought [from El Niño] contributed to fires across much of the country....

--King et al, 2016, BAMS
Global SST Anomalies
December 2015

Monthly Average Sea Surface Temperature Anomaly
11/29/2015 - 12/27/2015

NOAA/ESRL/PSD
Base Period: 1981-2010

-4 -3.0 -2.0 -1.0 -0.25 0.25 1.0 2.0 3.0 4.0 °C
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