CLIMATE VARIABILITY IN INTERANNUAL TIME SCALES

PROCESSES INVOLVED

- Air-sea-interactions in the tropics
- Tropical-extratropical interactions
- Air-sea interactions in the extratropics
- Air-land interactions

AIR-SEA INTERACTIONS IN THE TROPICS

a) Introduction

- At large scales each medium is strongly controlled by the other and thus a large fraction of tropical climate variability may be attributed to air-sea interactions:
  - the large-scale upper ocean circulation is largely determined by wind stress
  - the major features of the tropical atmospheric circulation, averaged over timescales longer than a month or two, are largely determined by SST. The tropical SST determine the locations of regions of persistent precipitation.
- The internal variability of the tropical atmosphere shows sufficiently short time-scales so that a separation can be made between atmospheric internal variability and that associated with slower evolution communicated by SST.
A given wind change generates stronger response at the equator than at higher latitudes; equatorial waves are less susceptible to the destructive influences of friction and mean currents.

(Fig. 10, from Harries 1994; Figs. 11, 12; Fig. 18, from Niiler 1993; Figs. 19, 20; Fig. 23, from Harries 1994)
b) Pacific & ENSO

Climatology of the Tropical Pacific

→ The SSTs drive direct thermal circulation cells in this region: the Hadley cell and the Walker circulation. Both contribute an easterly component to the surface winds.

→ Convection tends to organize over the warmest SST, producing the ITCZ, and the strong convection over the Maritime Continent.

→ The westward wind stress is balanced by pressure gradient associated with a sea level gradient of about 40cm and a corresponding slope in the thermocline.

→ The westward surface currents and deflection due to Coriolis force to either side of the equator drives a narrow band of upwelling in the eastern/central Pacific.

→ The upwelling and shallow thermocline produces the equatorial cold tongue in the east, while the deep thermocline in the west is associated with the western Pacific warm pool.

→ The low SSTs in the cold tongue region are caused by wind-driven ocean dynamics rather than by differences in surface heating.

The ENSO cycle

ENSO arises as a self-sustained cycle: an initial SST anomaly in the eastern Pacific produces wind anomalies that enhance the initial SST perturbation in a positive feedback, which can lead to instability.

However, what are the mechanisms for the turnabout from the state with warm SST anomalies through a state with little SST signature, to the subsequent cold phase?
The explanation uses some features of the equatorial ocean dynamics that governs the variations in the upper tropical ocean over time scales of a few years or so. For the time and space scales relevant to El Nino only two types of wave motions matter: long Rossby waves and equatorial Kelvin waves.

→ Kelvin waves: only in the equatorial region and propagate eastward at least three times faster than the Rossby waves. Caused by the vanishing of the Coriolis force on the equator.

→ Long Rossby waves: propagate energy westward

→ A Kelvin wave reflects into Rossby waves at an eastern boundary and Rossby waves reflect into a Kelvin wave at a western boundary.

Initially: warm SST anomaly in the eastern Pacific (deeper thermocline than normal).

Westerly wind anomaly, forcing a Kelvin wave packet in the ocean that further depress the thermocline in the east.

When the Kelvin wave hits the eastern boundary, it reflects as a sum of Rossby waves: some act to extend the equatorial wave-guide up and down the eastern boundary and those at low latitudes carry much of the mass and energy brought east by the Kelvin waves back toward the west.

The excess of warm water in the east must be compensated by a region of colder water (shallower thermocline). This is made in the form of equatorial Rossby wave packets, which propagate westward. At the western boundary (much later than the Kelvin waves reach the eastern boundary) they are reflected as cold equatorial Kelvin waves, which propagate eastward across the ocean to reduce the SST there. Thus the original warm signal is accompanied by a cold signal - but with a delay → delayed oscillator.

ENSO irregularity: a possible chaotic behavior, perhaps arising from the interaction of the slow components of the ocean-atmosphere system with the seasonal cycle, or stochastic forcing by uncoupled atmospheric variability (weather noise).
b) Atlantic

- The annual movement of the ITCZ and the amount of seasonal rainfall in the underlying semi-arid regions, display coherence with the sea surface temperatures gradient across the equator.
- The strength of this gradient varies inter-annually due to large-scale SST anomalies that form on both sides of the equator.
- These tropical sea-surface temperature anomalies may vary out of phase with one another in a quasi periodic manner of 10-13 years, forming what is known as the Tropical Atlantic Dipole.
- Impacts of the variability of the north south SST gradient: rainfall in Northeastern Brazil, distribution and intensity of hurricanes in Gulf of Mexico and North America seaboard.
- Is the dipole really a mode of variability? On interannual time scales the SST variability across the equator is not correlated, but the dipole seems stronger on interdecadal time scales.
- On the interannual time scales there are ENSO-induced Atlantic SST fluctuations that lag their Pacific counterparts by 4-5 months and this probably disrupts the dipole. The ENSO influence is transferred through the atmospheric perturbations (for instance, the Walker cell, PNA, etc.).

(Fig. 24, from PACS Implementation Plan)

Two hypotheses to explain the variability of the cross-equatorial SST gradient:

- it stems from regional ocean-atmosphere positive feedbacks involving primarily SST and wind-induced latent-heat flux that acts to enhance SST variability both north and south of the equator in the tropical Atlantic Ocean, while ocean processes set the slow time scale of variability.
- The other hypothesis says that the SST anomalies on either side of the equator are dynamically independent and controlled by processes in each hemisphere Therefore, the variability of the cross-equatorial SST gradient would be largely stochastic in nature.