RECTIFICATION OF THE MADDEN-JULIAN OSCILLATION INTO THE ENSO CYCLE

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What does give start to El Niño?

El Niño is preceded by a “recharging phase”, built up by Trades, during which we have high sea level warm pool in the west Pacific (state representing a source of energy for the event itself).

El Niño is the manifestation of relaxation of this condition and once it starts it is self-sustained, thanks to the ocean-atmosphere coupling, until the system reach the “flat state” (small temperature contrast and sea level difference between E and W Pacific).

There are two hypothesis on how these events start:

- Pacific ocean-atmosphere system **already has** an intrinsic natural frequency of oscillation, that appears irregular because happens to be perturbed by chaotic processes (weather conditions of which MJO is just one component)

- the system, found in the “recharging phase”, **needs** to be perturbed by an external random forcing in order to start the sloshing back to east Pacific. This forcing is identified with MJO (essential starting event)

MJO (Madden-Julian Oscillation)

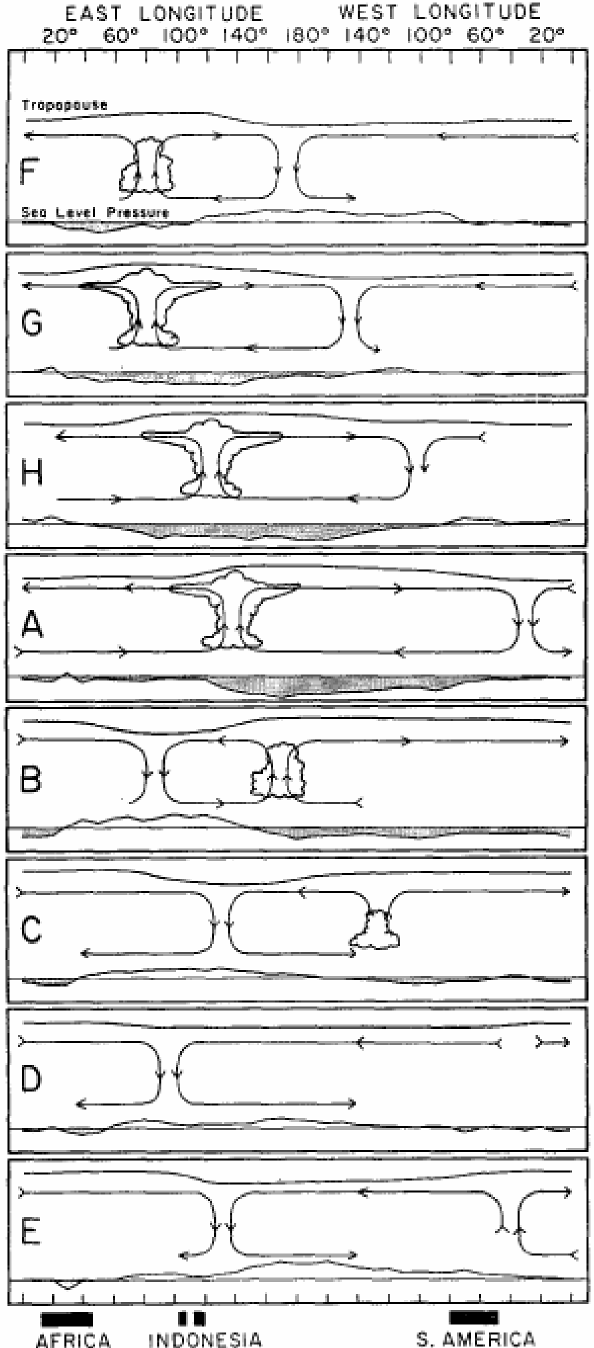
- 1971: Roland Madden and Paul Julian identify a 40-50 days oscillation analysing zonal wind anomalies in the tropical Pacific

- Intraseasonal fluctuation (30-60 days periodicity) of convective anomalies propagating eastward in the Tropics.

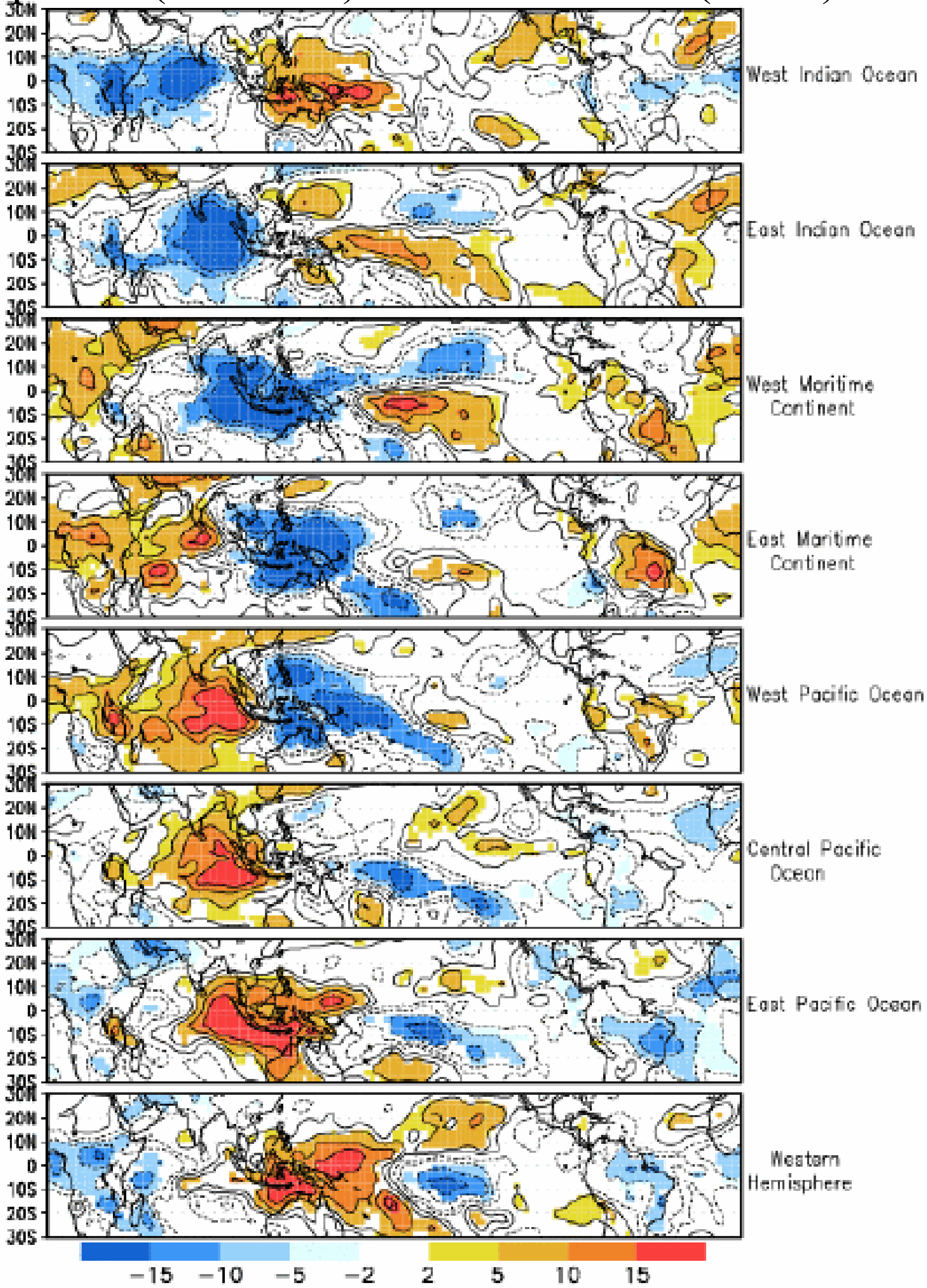
- Being a perturbation in the upper atmosphere, it travels all around the world but it leaves also a surface signature over Indian and western Pacific oceans where the warm SST leads to lower-atmosphere heating and moistening and consequently to deep convection (and rainfall).

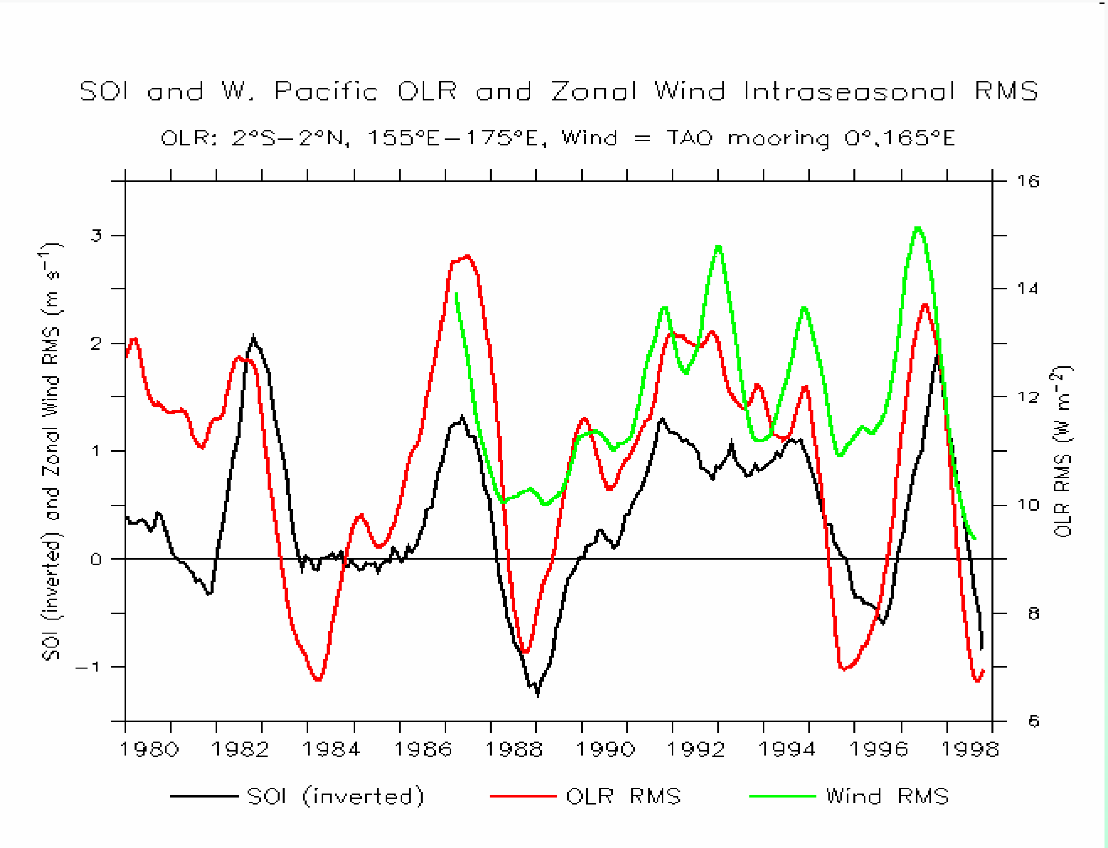
- Tropical rainfall is convective and convective cloud tops are “cold” (emitting little longwave radiation). So the signature of the MJO can be seen from satellite infrared sensor measuring OLR (outgoing longwave radiation)

Madden and Julian (1972, Journal of Atmospheric Sciences)



8 phases (Nov-Mar): OLR anomalies (W/m^2)





- Early stages of El Niño events are associated with significant increase of intraseasonal activity over the warm pool.
- Which kind of process can produce coupling between MJO and ENSO cycle? Observing that they are respectively intraseasonal and interannual events, a **nonlinear** process is necessary to couple such different frequencies.

Approach to the problem

- In order to identify the signature of the MJO on the western Pacific conditions the idea is to compare two parallel runs of the same model:
  - one forced entirely with climatological annual cycle wind stress (control run)
  - the other with climatological winds plus idealized intraseasonal anomalies (MJO run)

- The experiment was conducted with two models:
  - **OGCM**: an ocean general circulation model was used to investigate the effects on ocean of the MJO;
  - **Intermediate coupled model**: forced with the resulting rectified SST pattern to evaluate the effects on the coupled system during the onset of El Niño.

- Then model results were compared with observation from TAO buoy array placed along the equatorial Pacific area.

Basic features of OGCM

EQUATIONS: fully nonlinear momentum/conservation equations (mass, energy), though the model uses a simplified linear equation of state (density is assumed to depend linearly from temperature while salinity variation are neglected)

STRUCTURE
- Active upper layer (~400m depth) → Surface Boundary Layer + 8 Sigma-layers
- Motionless abyss
- Solid walls at 30°N and 30°S
- Realistic E and W coasts

RESOLUTION
- GRID: finest along E and W edges and within 10°N and 10°S
- TIME STEP: 1h

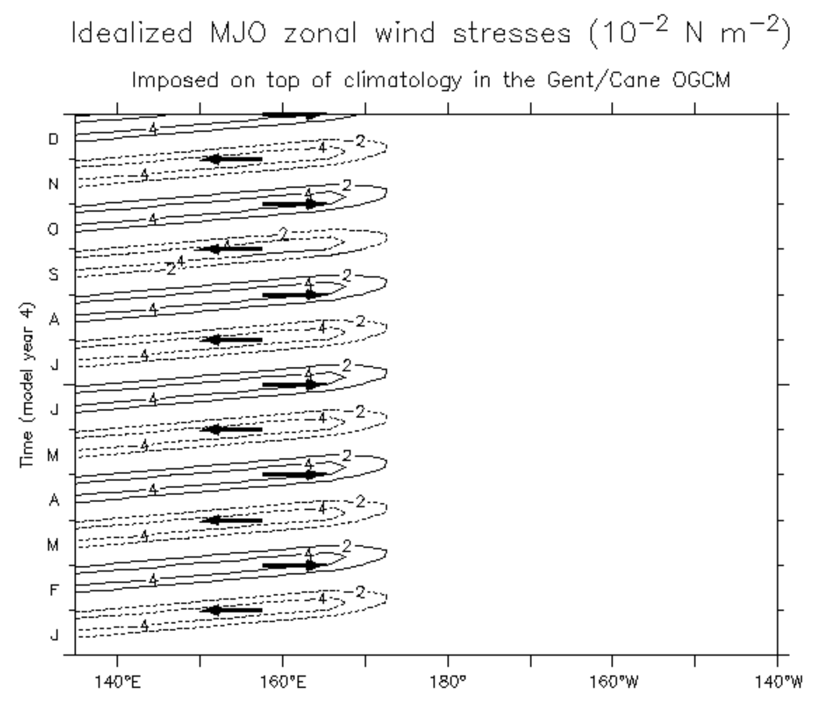
INITIAL CONDITIONS
- Levitus (1982) mean temperature
- Zero currents

BOUNDARY CONDITIONS: average annual cycle forcing fields
- Wind stress
- Clouds + solar radiation

SPIN UP: 3 years

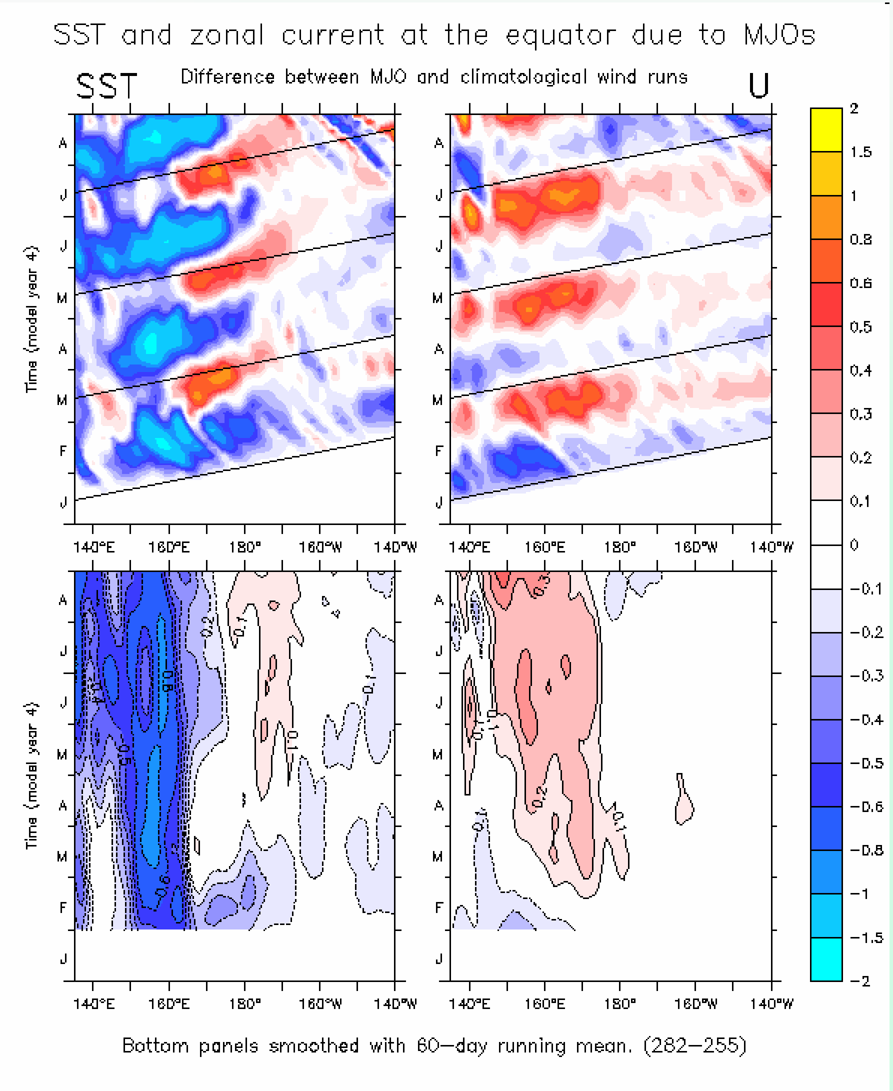
Idealized MJO wind stress anomalies

- gaussian about the Equator (with a narrow meridional scale that will efficiently force oceanic equatorial waves)
- sinusoidal in longitude and time (oscillating regularly in time and across the Pacific) with amplitude 3.5 x10^{-2} N/m^2. Note: forcing has zero mean otherwise it would produce a direct effect not separable from the rectified effects.
- damped linearly from W to E (so that at E is zero)
- advancing eastward at 5m/s
- period of oscillation of 60 days



<u>Remark</u>: these hypothesis are chosen to approximately match the observed characteristics of the MJO winds, but other reasonable values could be possible. It will be necessary to check how much the model is sensitive to the characteristics chosen for MJO.

Results from OGCM parallel runs



- Considering successive MJO events we see that easterly winds spin up a westward current and westerlies spin up an eastward current. Observing the 60-day running mean the net result is an eastward current (~ 0.2m/s).
- With respect to the effects of MJO on SST we notice a cooling during easterly wind period and a warming during the westerlies. The net effect of this oscillation is of surface cooling (~0.4°C).
- Both unfiltered signals (temperature and velocity) are propagating eastward close to the first baroclinic mode Kelvin wave speed (~ 3m/s).

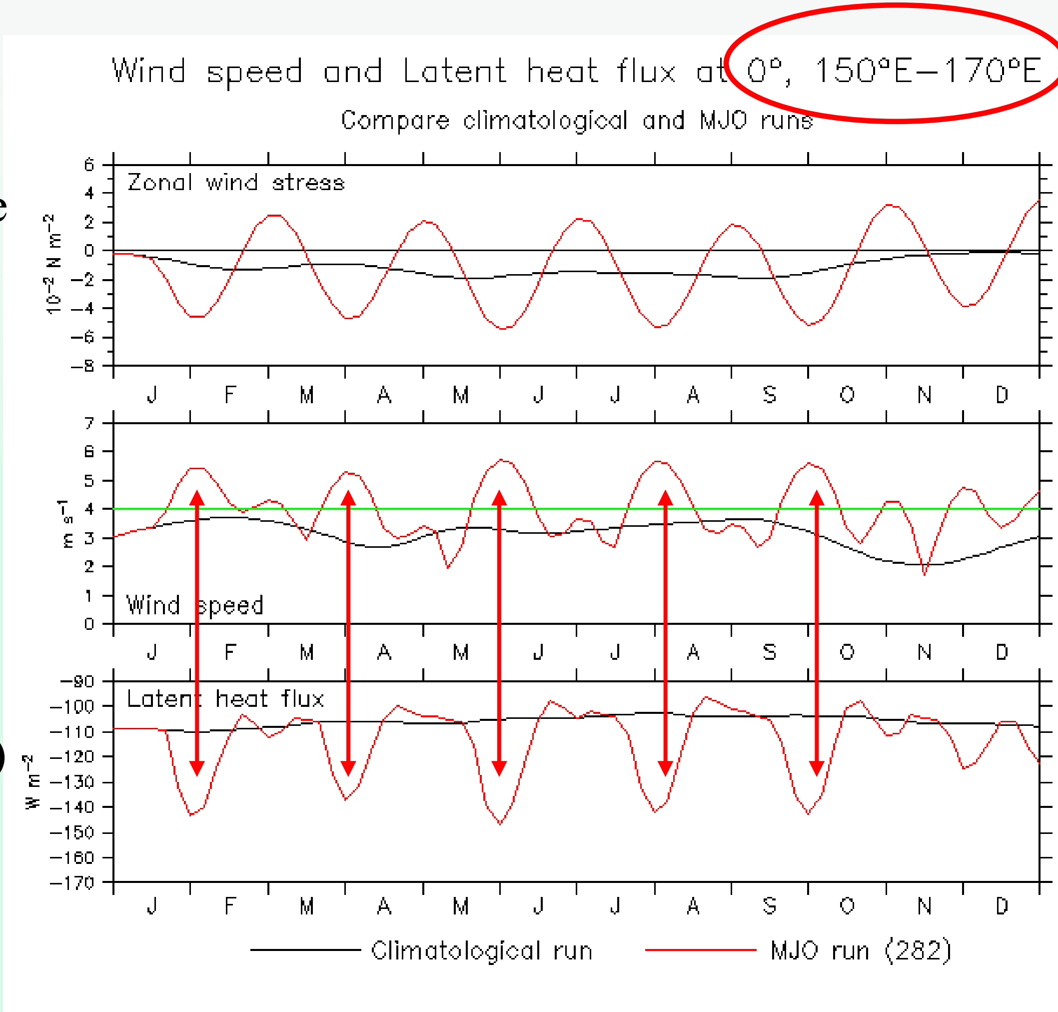
Responsible mechanisms

- <u>EVAPORATIVE COOLING</u>:

- Latent heat flux is taken to be a function of wind speed and SST (since humidity varies little over the west Pacific warm pool and variations of wind speed are more important).

- In order to evaluate the effects of high-frequency (small spatial-scale) winds on evaporation and mixing, a gust factor is fixed at 4m/s (represents the minimum value assumed for wind speed and the unresolved wind events) for the control run LHF evaluation.

- The imposed MJO wind stresses produce speeds usually larger than climatological winds.

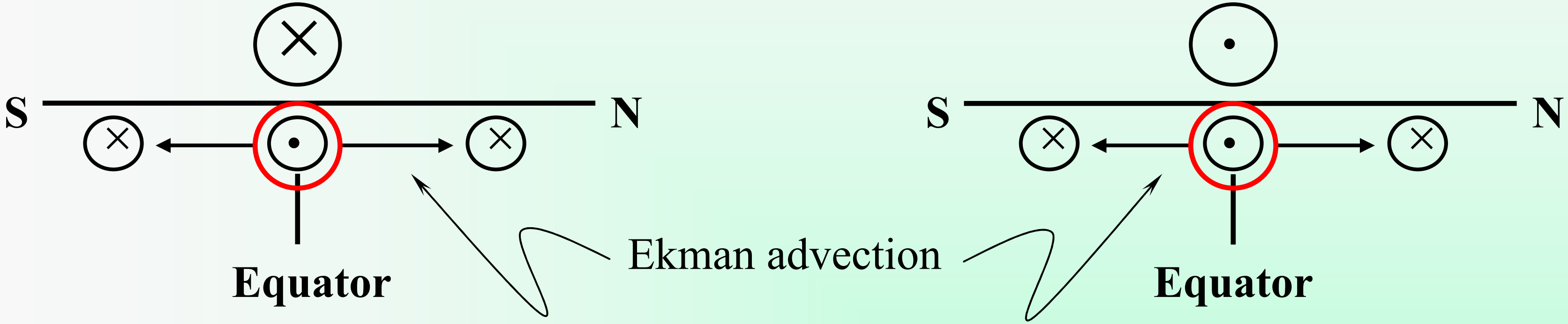


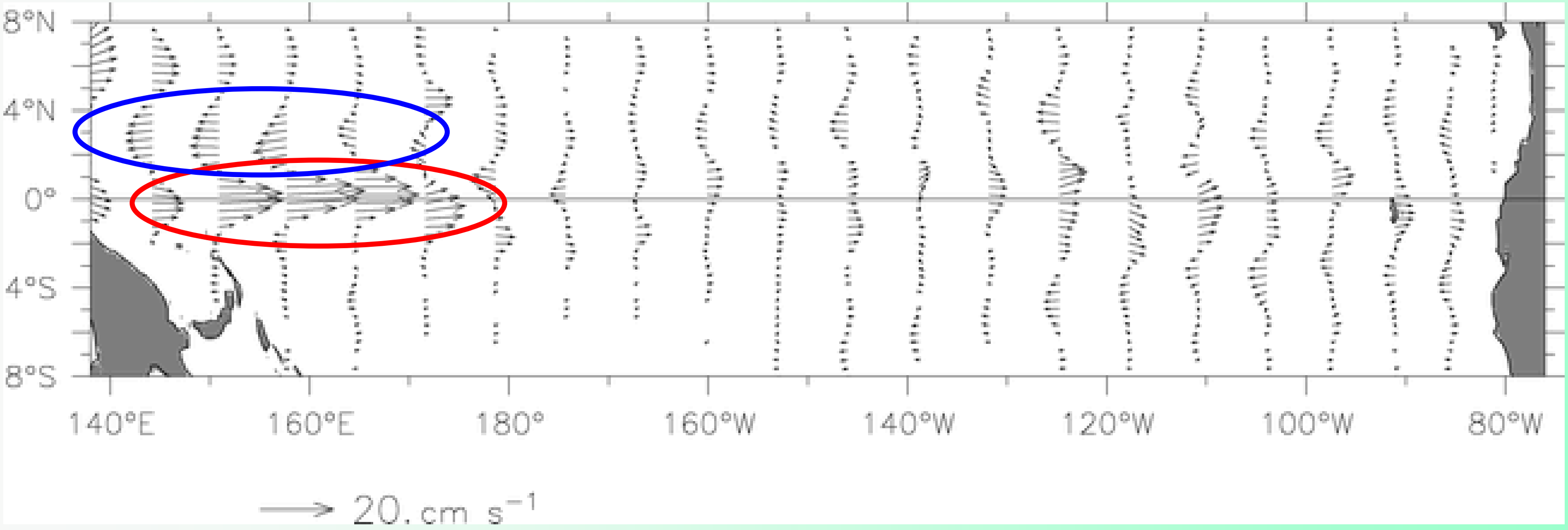
Warm pool region

- **Thus MJO usually enhances heat flux cooling (LHF magnitude larger than climatological winds effect).**

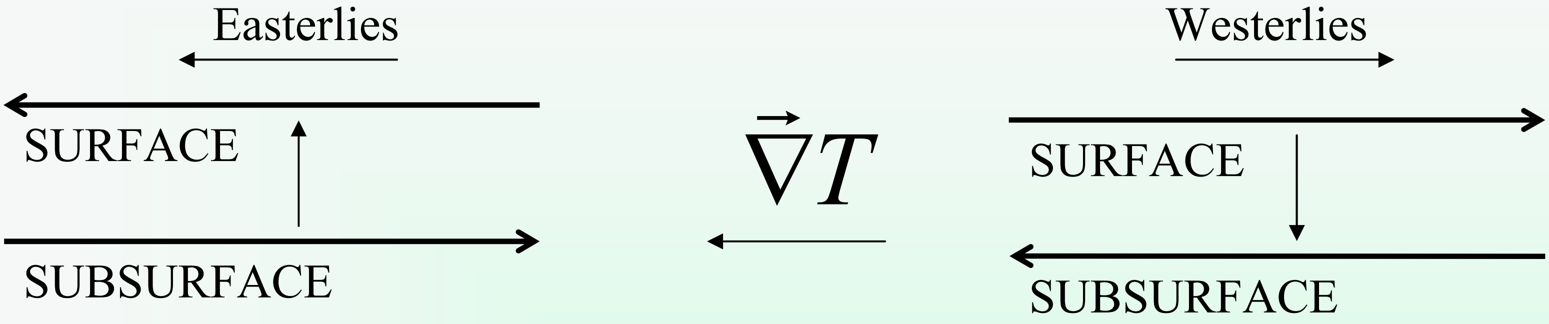
- NONLINEAR ZONAL CURRENT FORCED BY OSCILLATING ZONAL WINDS

Oscillating zonal wind stress anomalies of the MJO run produces
as a first-order **NONLINEAR** effect
eastward equatorial zonal currents whatever the sign of the wind:





• CHANGES IN VERTICAL PROFILES OF TEMPERATURE AND ZONAL CURRENT



Cooling of surface (spinup 8-10 days)
warming of subsurface (spinup 10-15 days)

Leads to the **weakest vertical T gradient** during the maximum westerly winds (15 days further lag from the current advective signal)

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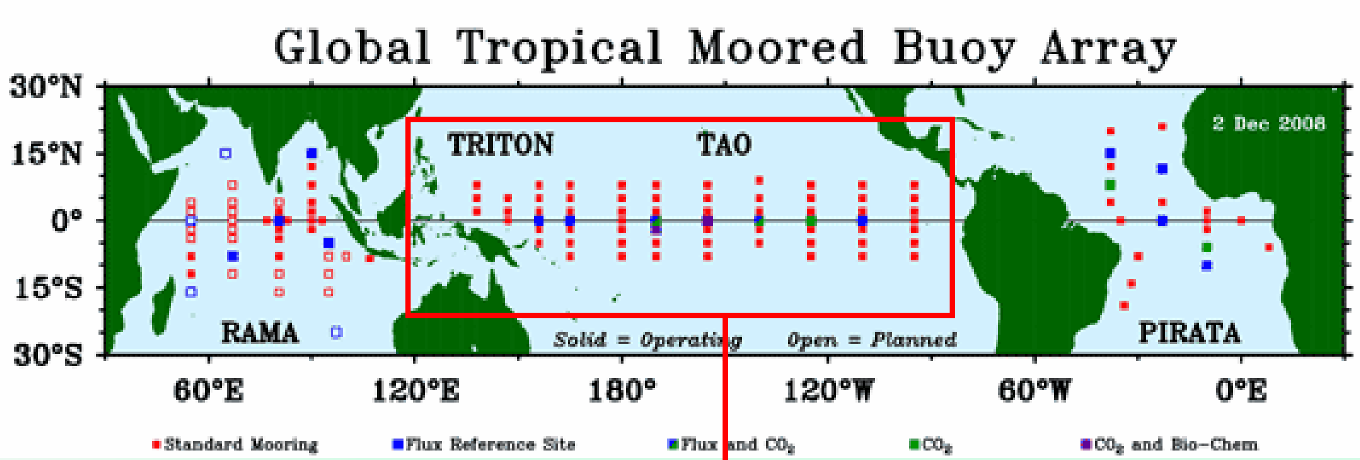
Unbalanced cold upwelling cools the surface more than would be expected based on the background gradient.

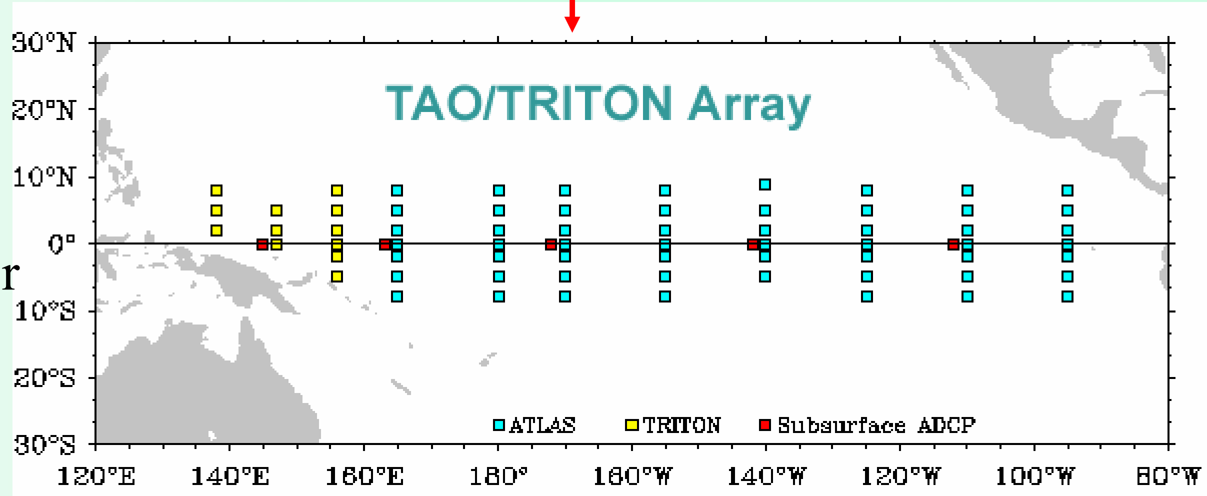
Cooling of the west Pacific and warming of the central Pacific

- Provides data in real-time for climate research and forecasting.

- Major components include: TAO/TRITON array in the Pacific, PIRATA in the Atlantic, and RAMA in the Indian Ocean.

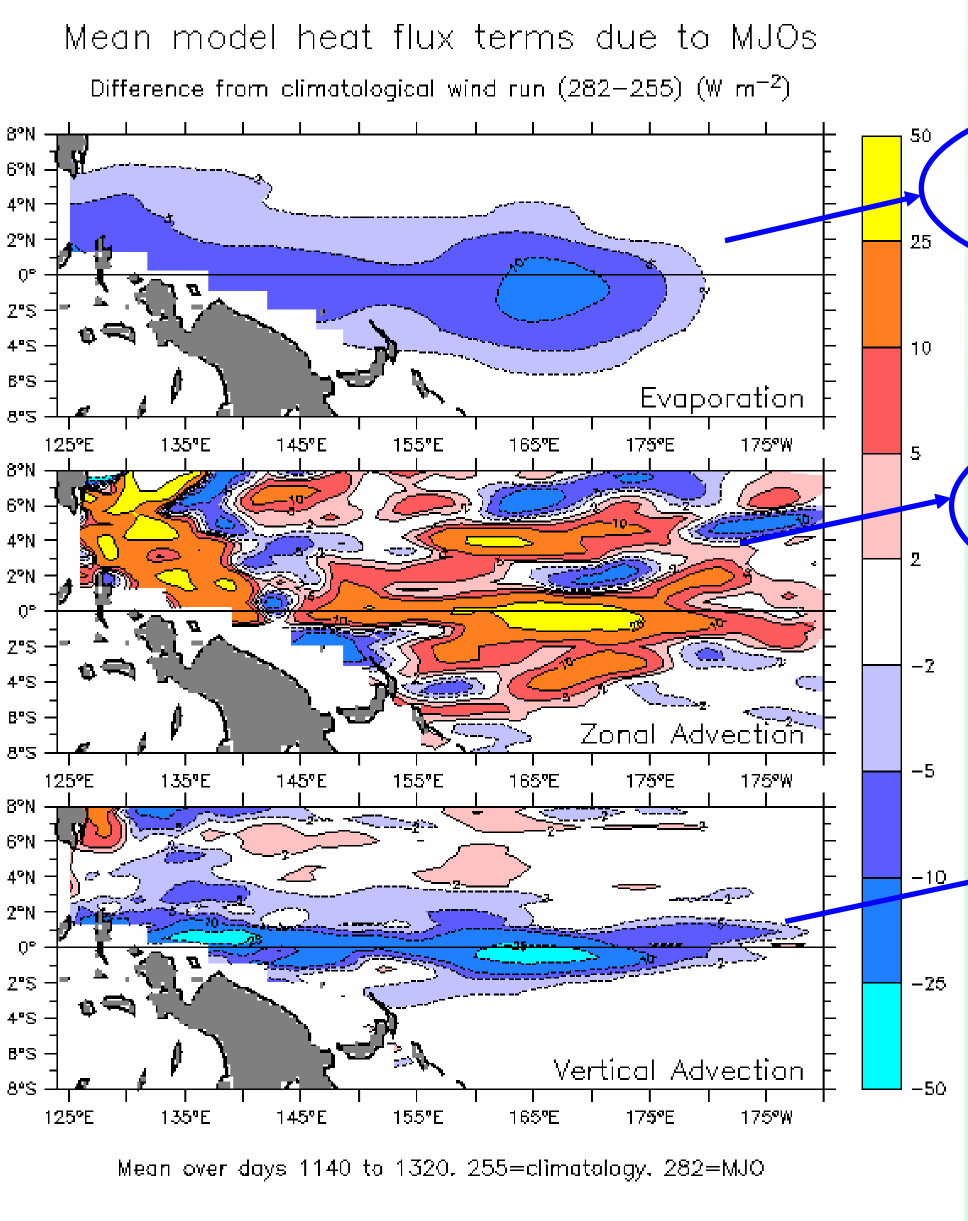


- ~ 70 moorings arranged in pickets 15° lon apart across equatorial Pacific. Each picket has moorings at Equator, ±2°, ±5°, ±8° lat for measuring atmospheric characteristics and surface/sub-surface ocean properties.



Data extracted: subsurface temperature, SST and surface meteorology moorings

Weight of the three contributions



Mean model heat flux terms due to MJOs

Difference from climatological wind run (282–255) (W m^{-2})

Mean over days 1140 to 1320. 255=climatology. 282=MJO

Mean latent heat flux cooling tendency is about 5-10 W/m^2 larger than that in the climatological run

The magnitude of the rectified warming, averaged over 4 MJO cycles is about 10 W/m^2

Vertical advection mean difference is tightly confined to the equator with a magnitude of about 15 W/m^2. Same magnitude of evaporation cooling effect but localized along the equator.

Basic features of intermediate coupled model

EQUATIONS: describe the coupling between ocean and atmosphere retaining only those physical processes though responsible for large-scale, low-frequency behaviour in tropical Pacific

Gill atmosphere → atmosphere responds to SST by developing convection

Long wave approximation in ocean → expressing the essential dynamics of low-frequency interior ocean circulation.

SST equation → allows only for the thermocline perturbation and not for horizontal advection

COUPLING: exchange of
- SST anomalies (produced by ocean)
- Wind stress anomaly (produced by atmosphere)

INITIAL CONDITIONS: 1 January 1997 (CONTROL RUN)
- Wind
- Subsurface data

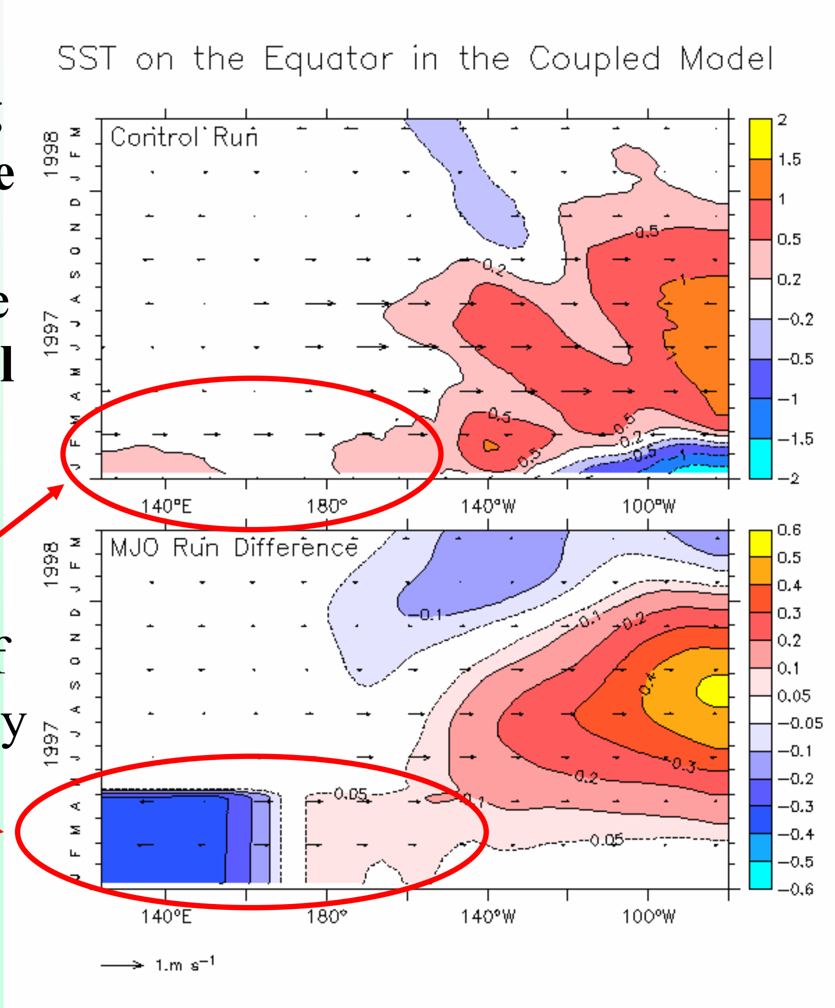
INITIAL CONDITIONS: control run IC + rectified SST output OGCM over 4 MJO cycles (MJO RUN)

Effects of the SST rectification on the coupled model

- The most important effect in the cooling of the western Pacific, and the slightly warming of the eastern region, is the **weakening of the zonal SST gradient**, since it is a major influence driving equatorial easterlies. By the **weakening of the background easterlies, El Niño is enhanced to grow**.

- To test this idea two parallel runs are performed: the first with initialization to 1 January 1997 (just before the rapid growth of 97-98 El Niño) and the second with externally imposed rectified SST.

- Comparing of results shows that the MJO SST introduced amplifies ENSO events thanks to the intensification of westerlies over the Tropical Pacific.



- <u>Actually at the end of 1996 several forecasts (without MJO) predicted an El Nino weaker than its observed intensity during 1997-98</u>.

Conclusions

- Strong oscillating winds associated with MJO activity over the Pacific leads to a rectified cooling of the western part of the basin and a slight warming in the east region.
- Three mechanisms were identified to occur:
  - cooling due to evaporation;
  - warming in the east due to nonlinear advection;
  - cooling due to cold upwelling.

- The most important consequence is the weakening of the zonal SST gradient, since it is a major influence driving equatorial easterlies.
- The easterly weakening in the coupled model enhances the growth of El Niño.
- If MJO interacts constructively with ENSO cycle, then it introduces a further element of unpredictability of El Niño events being related to weather variability.