Evidence of ENSO modulation through radiative forcing

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The big question: How will ENSO evolve in a greenhouse world?

El Niño-like?
Timmermann, 1999:
trend towards El Niño-like mean state, increased ENSO variance

response due to cloud albedo feedbacks?
(Meehl & Washington, 1996)
La Niña-like?
Cane et al, 1997: “ocean thermostat” (Clement et al., 1996) leads to increase of Pacific zonal SST gradient

annual mean SST, begin uniform heating
SST increases in West, but SST in East is buffered by upwelling of cool waters, zonal SST gradient increases
Bjerknes feedback: trades strengthen, zonal SST gradient increases

Cane-Zebiak model w/ uniform heating
El Niño
La Niña
So results are extremely model-dependent
(Collins et al., 2000b, 2004)
Paleo-analogues: has radiative forcing affected paleo-ENSO?

We can examine three different time-scales:

1. orbital (Milankovitch forcing)
2. abrupt climate change (stage 3 & Younger Dryas)
3. last millennium
Orbital forcing – Cane-Zebiak model w/ precessional forcing

Warm period NINO3, more frequent, regular

Cool period NINO3, less frequent, irregular

Time-averaged NIÑO3 over last glacial cycle

*Clement et al., 1999

*ENSO vs. ENSO-like change
Paleo-ENSO over the last glacial cycle from fossil corals

Fossil coral ENSO strength

Coral evidence suggests that mean state (glacial vs. interglacial) may be important does not confirm or deny precessional control

CZ model NIÑO3 power

Tudhope et al., 2001
Eastern equatorial SST record from LGM to present

SST proxy record bears resemblance to precession, but noisy

Koutavas et al., 2002
Abrupt climate change in the Cane-Zebiak model – non-linear response to smooth radiative forcing

Idea: change in ENSO from “warm” precessional characteristics to “cool” precessional characteristics can lead to locking of seasonal cycle

Clement et al., 2001
Abrupt climate change recorded in tropical Pacific proxy records
Stage 3

Positive salinity excursions during warm interstadials

warm North Atlantic = El Niño-like Pacific?

Stott et al., 2002
Abrupt climate change recorded in tropical Pacific proxy records Younger Dryas

~0.5 to 1°C cooling in West Pacific Warm Pool, no change in East Pacific hints at El Niño-like change during Younger Dryas?

Kienast et al., 2001; Koutavas et al., 2002
The last millennium – volcanic eruptions and El Niño link?

- Composited NINO3 evolution before and after known eruptions
- El Niño event statistically more likely following medium to large volcanic eruption
- Mechanism: ocean thermostat?
The last millennium – volcanic and solar forcing effects on ENSO

(a) CZ ensemble mean response to volcanic forcing

- **decreased radiative forcing** over tropical Pacific causes increase in Nino3 SST
  
  *explanation: ocean thermostat*

Mann et al., 2005

(b) Increased radiative forcing over tropical Pacific causes decrease in Nino3 SST

(c) CZ ensemble mean response to solar forcing

- **solar forcing**
Combined response to Solar + Volcanic Forcing

Ensemble mean Nino3 (100 realizations of CZ model)

40 year smooth

Model mean (with ensemble spread)

Palmyra coral isotopes (standardized to have same mean and standard deviation as Nino3 composite series)

Mann, M.E., Cane, M.A., Zebiak, S.E., Clement, A., Volcanic and Solar Forcing of the Tropical Pacific Over the Past 1000 Years, Journal of Climate 18: 447-456
New Palmyra coral data, with 1σ error, combined response to Solar + Volcanic Forcing. Palmyra coral isotopes (standardized to have same mean and standard deviation as Nino3 composite series).

Mann, M.E., Cane, M.A., Zebiak, S.E., Clement, A., Volcanic and Solar Forcing of the Tropical Pacific Over the Past 1000 Years, *Journal of Climate* 18: 447-456
The Palmyra coral reconstruction to date

- Confirmation of cooler, drier conditions early in the millennium
- Most intense El Niño activity (still) in the mid 17th century

Cobb et al., 2003
Did radiative forcing (solar or volcanic?) play a role in this shift, or is this another example of intrinsic variability?
Lessons relevant to ENSO in a greenhouse world

* if the “ocean thermostat” theory is right, then mean state should be moving towards La Niña-like response, all else being equal

* ENSO models and Palmyra corals show that abrupt changes in ENSO properties are fundamental to the tropical Pacific ocean-atmosphere system (whether forced or unforced)

* the tropical Pacific definitely played a role in abrupt climate change events during MIS 3 and the deglacial, whether as amplifier or trigger

There are still more questions than answers…. 

Does radiative forcing explain a significant amount of ENSO variance – keep looking for unambiguous case of ENSO response to radiative forcing in paleo-record

How does mean state affect the response of TP climate to radiative forcing? (incorporate both models and paleo)