El Niño and La Niña amplitude asymmetry caused by atmospheric feedbacks

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Introduction

Interannual variability of tropical Pacific sea surface temperatures (SST) has an asymmetry with stronger positive events, El Niño, and weaker negative events, La Niña, which is generally attributed to ocean processes. We present evidence from a new hybrid coupled model that this asymmetry can be caused by nonlinear atmospheric feedbacks. The model consists of the atmospheric general circulation model ECHAM5 coupled to the 2-dimensional linear recharge oscillator ocean model in the tropical Pacific. Despite the models simplistic and, by construction, linear representation of the ocean dynamics, it is able to simulate the main statistical features of El Niño.

RECHOZ Model

- **Atmospheric part**:
  ECHAM5, 19 vertical levels, $3.75^\circ \times 3.75^\circ$
- **Oceanic part outside the tropical Pacific**:
  Single column mixed layer ocean model [Dommenget and Latif, 2008]
- **Oceanic part in the tropical Pacific**:
  - The ocean grid is replaced against the low-order 2-dimensional recharge oscillator model [Jin, 1997]:

$$\frac{dT}{dt} = a_{11}T + a_{12}h + \xi_1 \quad (1)$$

$$\frac{dh}{dt} = a_{21}T + a_{22}h + \xi_2 \quad (2)$$

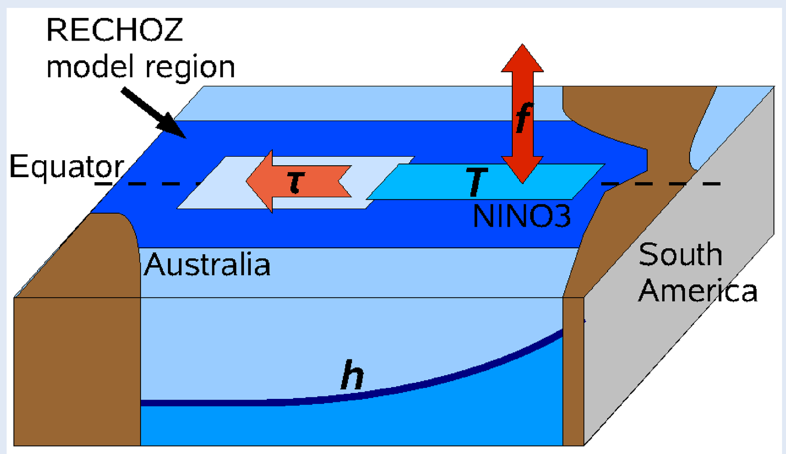
T - NINO3 SST anomaly
h - mean equatorial Pacific thermocline depth
ξ_1 and ξ_2 - stochastic forcings

  - The stochastic forcings can be assumed to be the central Pacific zonal wind stress anomaly τ and the NINO3 heat flux anomaly f.
  - τ and f can be deconstructed into two parts. One part is linearly depending on T and is already included in the parameters a_{11} and a_{21}. So these parameters must be deconstructed:

$$\frac{dT}{dt} = (a_{11_O} + a_{11_A})T + a_{12}h + \xi_1 \quad (3)$$

$$\frac{dh}{dt} = (a_{21_O} + a_{21_A})T + a_{22}h + \xi_2 \quad (4)$$

The other part is independent of T and represents stochastic forcing.



Schematic representation of the model variables.

  - The values of the atmospheric parameters a_{11_A} and a_{21_A} can be estimated from the linear regression between τ and f and the NINO3 SST anomalies from a reference run.
  - Thus in the hybrid coupled model the forcings can be replaced by τ and f:

$$\frac{dT}{dt} = a_{11_O}T + a_{12}h + a_{12}w\tau + \frac{1}{mc}f \quad (5)$$

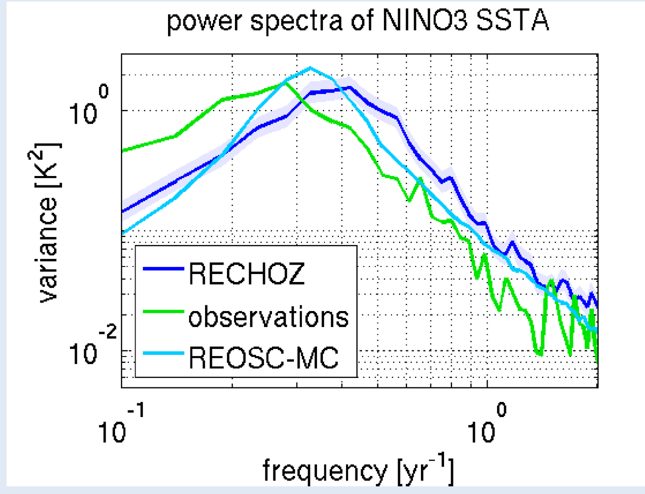
$$\frac{dh}{dt} = a_{21_O}T + a_{22}h + \frac{a_{22}}{2}w\tau \quad (6)$$

w - proportionality factor for the zonal wind stress
mc - heat capacity of the mixed layer

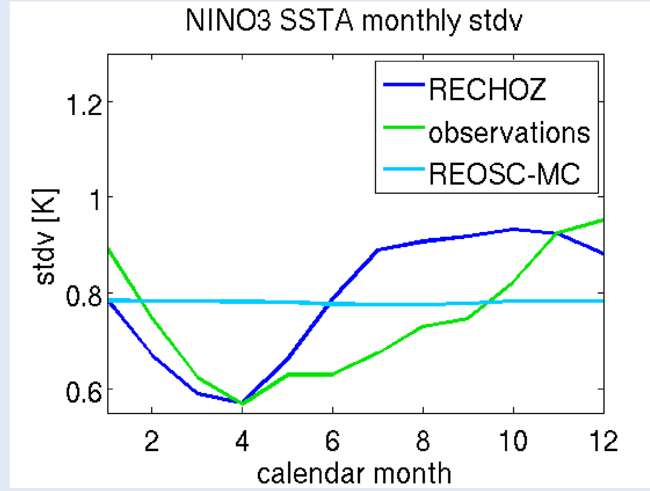
  - The resulting new temperature anomaly is multiplied with the pattern of the first EOF of the tropical Pacific and observed Pacific seasonal mean SST values are added.
  - The recharge oscillator ocean model in eqs. [1 and 2] is also forced with white noise forcings as a Monte Carlo reference model (REOSC-MC)

El Niño in the RECHOZ model

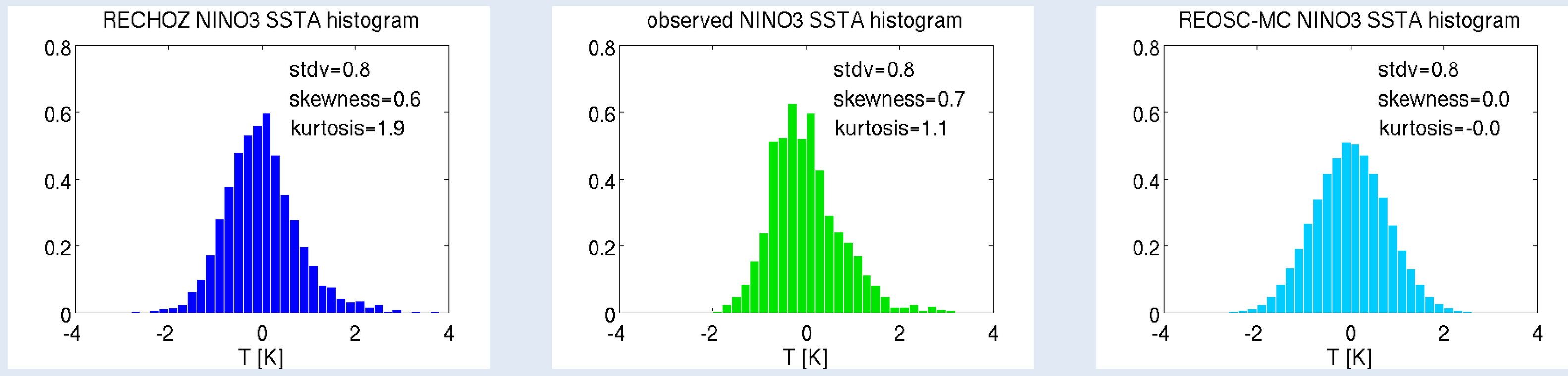
The analysis of a 500 years long simulation shows that the model captures the main features of ENSO quite well:



- Spectra of NINO3 SST anomalies (SSTA) for the RECHOZ model (blue), observations (green) and a 10000 years simulation of the REOSC-MC model (cyan).



- Seasonal dependence of NINO3 SSTA standard deviation in the RECHOZ model (blue) compared to observations (green) and the REOSC-MC model (cyan).

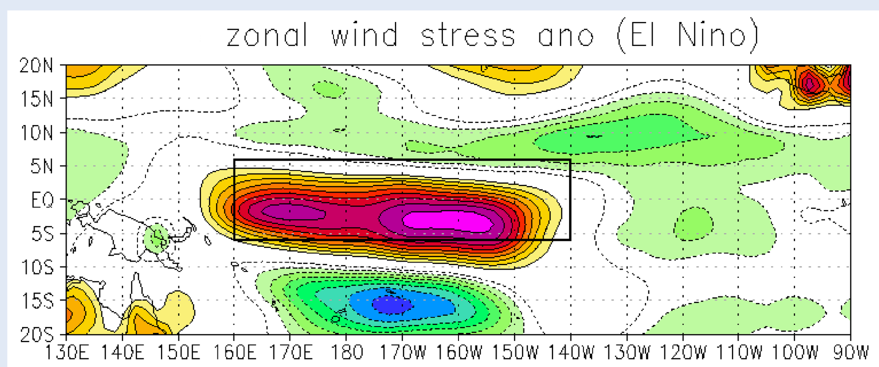


- NINO3 SSTA histograms of the RECHOZ model (blue), observations (green) and the REOSC-MC model (cyan).

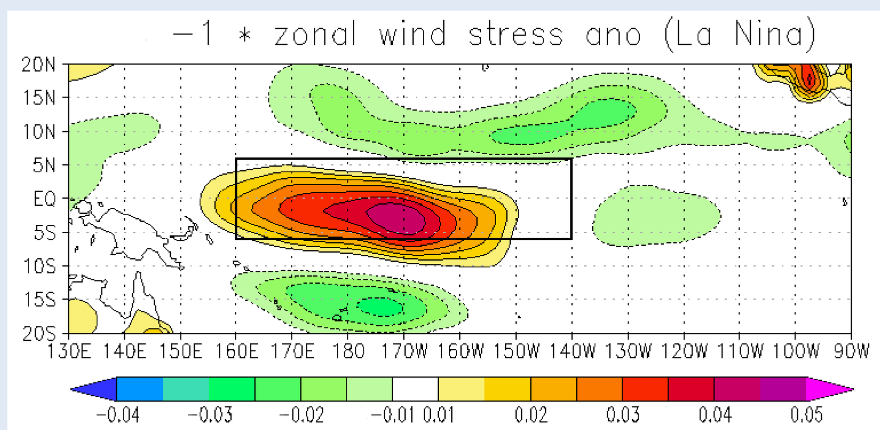
(As observational data the HadISST data set for the period from 1870 to 2003 is taken).

Atmospheric nonlinearity

A possible mechanism for the El Niño and La Niña amplitude asymmetry is a nonlinear relationship between the zonal wind stress anomalies and the SST anomalies.

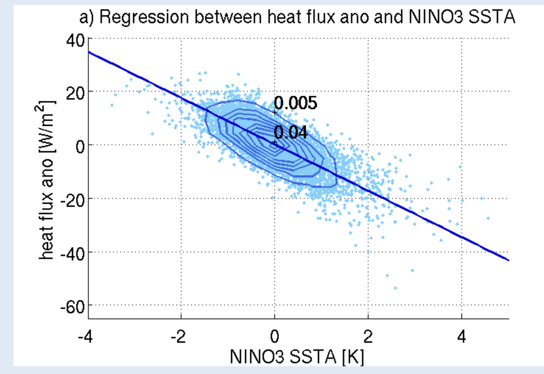


- RECHOZ model composite mean values of zonal wind stress anomalies for all El Niño years ($T(december) > \sigma(T)$) averaged from December to May of the following year.

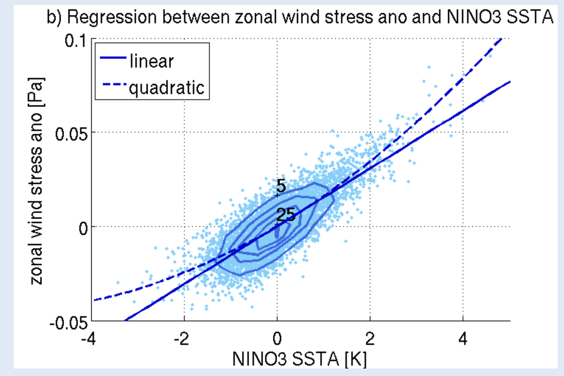


- The same as above but for all La Niña years ($T(december) < -\sigma(T)$) multiplied by -1.

Atmospheric nonlinearity

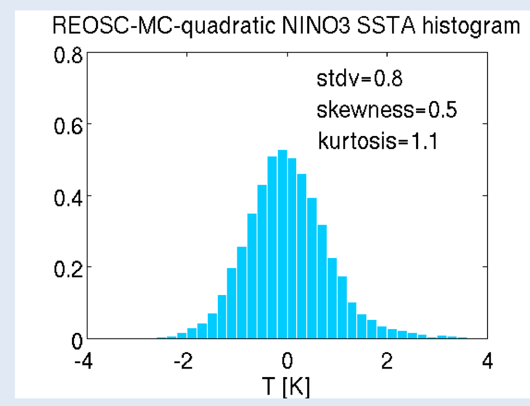


- Scatter plot of NINO3 heat flux anomalies over NINO3 SST anomalies from the RECHOZ model with the linear regression line.



- As before but for the central Pacific zonal wind stress anomalies. Additionally the regression curve resulting from a quadratic fit is displayed.

To test , whether this quadratic relationship between the central Pacific zonal wind stress anomalies and the NINO3 SST anomalies could cause the nonlinearities in the RECHOZ model, we included this quadratic relationship in the REOSC-MC model.



- Histogramm of monthly mean NINO3 SST anomalies resulting from the REOSC-MC simulation with the quadratic relationship included.

Results

- Although the RECHOZ model only has a minimum complex representation of ENSO it gives a very good representation of it.
- The model is able to simulate the main characteristics of ENSO like variance, seasonality, skewness, and kurtosis.
- The REOSC-MC model is only able to simulate the ENSO asymmetry if one includes a nonlinear response of central Pacific zonal wind stress anomalies to NINO3 SST anomalies.
- So the orign of these characteristics in the RECHOZ model has to lie in the atmospheric forcings.
- The asymmetry between eastern Pacific SST anomalies during El Niño and La Niña events can be explained by a nonlinear atmospheric response to equal-strength but opposite SST anomalies.

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