Temporal Structure of ENSO in 20th Century Climate Simulations

Antonietta Capotondi, NOAA Earth System Research Laboratory & CIRES Climate Diagnostics Center, Boulder, CO
Antonietta.Capotondi@noaa.gov
Andrew Wittenberg, NOAA Geophysical Fluid Dynamics Laboratory, Princeton NJ, *Andrew.Wittenberg@noaa.gov*
Simona Masina, Istituto Nazionale di Geofisica e Vulcanologia, Bologna Italy, *Masina@bo.ingv.it*

Introduction

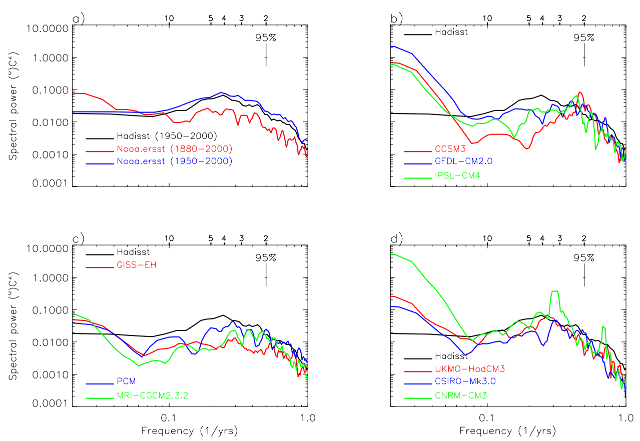
Climate general circulation models (CGCMs) have ENSOs which tend to occur too regularly, and are often characterized by a dominant timescale shorter than observed. Here we examine the temporal structure of ENSO in simulations of the 20th century performed with the latest generation of climate models used for the Intergovernemental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). Previous studies (Kirtman 1997, An and Wang 2000, Wittenberg 2002) have emphasized the importance of the structure of the anomalous zonal wind stress (τ_x') in determining the ENSO timescale. In particular, the **meridional width (L_y)** and the **longitudinal position** (C) of τ_x' appear to be the key aspects: the meridional width determines how far from the equator extra-equatorial Rossby waves are generated, thus affecting the adjustment time of the equatorial thermocline (Kirtman 1997); the longitudinal position of τ_x' determines whether the zonal advective feedback ($-u'\overline{T}_x$) promotes ENSO growth or phase transition (An and Wang 2000). Here we examine the structure of τ_x' , and the dominant modes of thermocline variability in the CGCMs. The ocean analysis developed at the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Bologna, Italy) is used to validate the CGCMs. The INGV analysis is forced with the NCEP/NCAR Reanalysis over the period 1958-2000.

The models

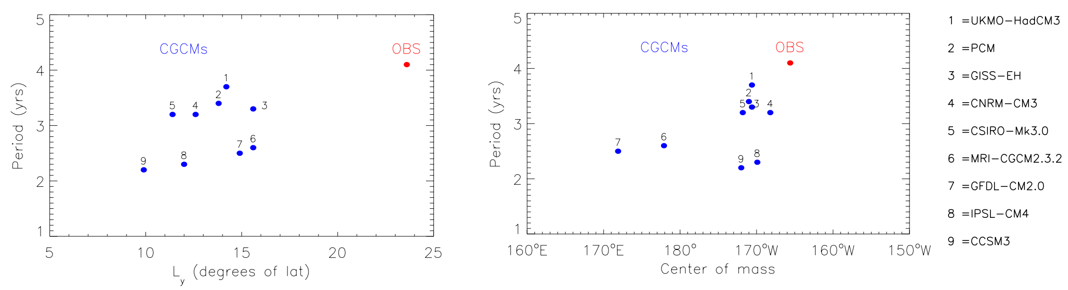
(T-=ENSO timescale, C=central longitude of τ_x', Ly= meridional width of τ_x')

Model	Institution	T (yrs)	L_y (° lat)	C (°E)
INGV	INGV (Italy)	4.1	23.6	194.4
UKMO-HadCM3	Hadley Center (UK)	3.7	14.2	189.4
PCM	NCAR (USA)	3.4	13.8	189.0
GISS-EH	NASA/GISS (USA)	3.3	15.6	189.4
CNRM-CM3	CNRM (France)	3.2	12.6	191.8
CSIRO-Mk3.0	CSIRO (Australia)	3.2	11.4	188.2
MRI-CGCM2.3.2	MRI (Japan)	2.6	15.6	177.9
GFDL-CM2.0	GFDL (USA)	2.5	14.9	171.9
IPSL-CM4	IPSL (France)	2.3	12.0	190.1
CCSM3	NCAR (USA)	2.2	9.9	188.0

Spectra

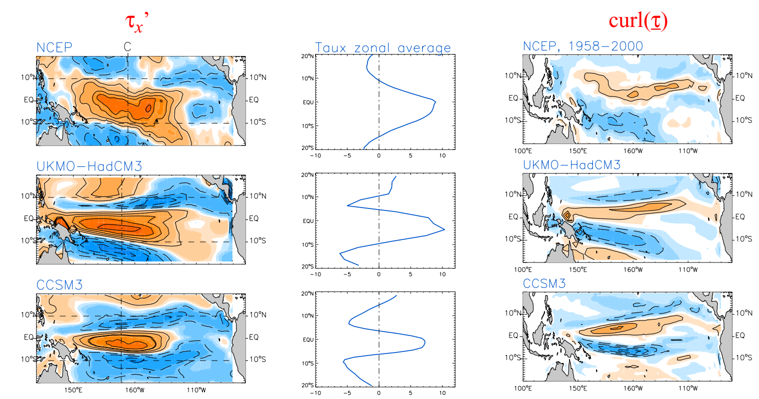


What is the spatial structure of τ_x' in the CGCMs compared with observations?



All the CGCMs have τ_x' more closely confined about the equator than the NCEP/NCAR Reanalysis. The "center of mass" C of the τ_x' anomalies is displaced westward than in the observations. Both factors may lead to a shorter ENSO timescale.

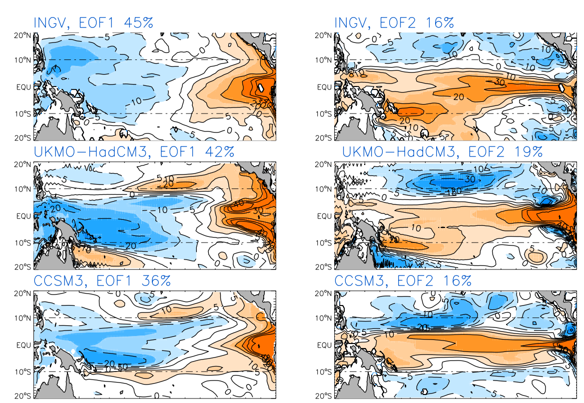
Regression of τ_x' and curl(τ) upon the Niño3.4 index for NCEP, UKMO-HadCM3, and CCSM3

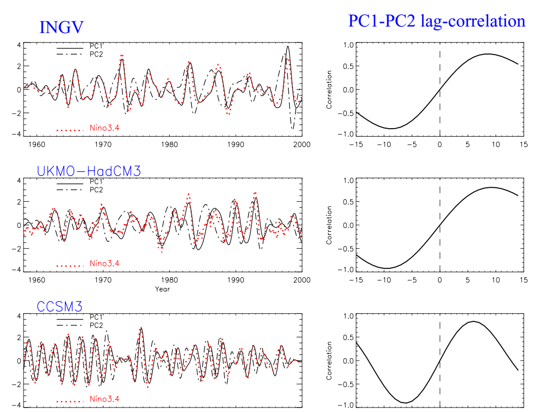


The structure of τ_x' determines the latitudes along which curl(τ) maximizes. Extra-equatorial Rossby waves are forced by the curl of the wind stress. Their phase speeds decrease with increasing latitude, so that the adjustment time of the equatorial thermocline becomes longer when Rossby waves are excited further away from the equator. The meridional width of the **thermocline depth anomalies** (see figures below) is larger when τ_x' has a broader meridional scale, and the ENSO timescales becomes longer.

Thermocline Variability

EOF1 of thermocline depth is characterized by an east-west dipole, describing changes in the zonal slope of the thermocline. Positive values indicate deeper thermocline, and *vice versa*. EOF2 has the same sign across the basin, describing the deepening and shoaling of the equatorial thermocline as a whole. EOF2 is associated with mass recharge/discharge to/from the equatorial thermocline. The structure of the modes, and their phase relationships (right panels) are consistent with the recharge oscillator paradigm for ENSO.

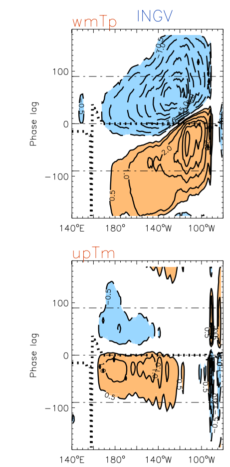


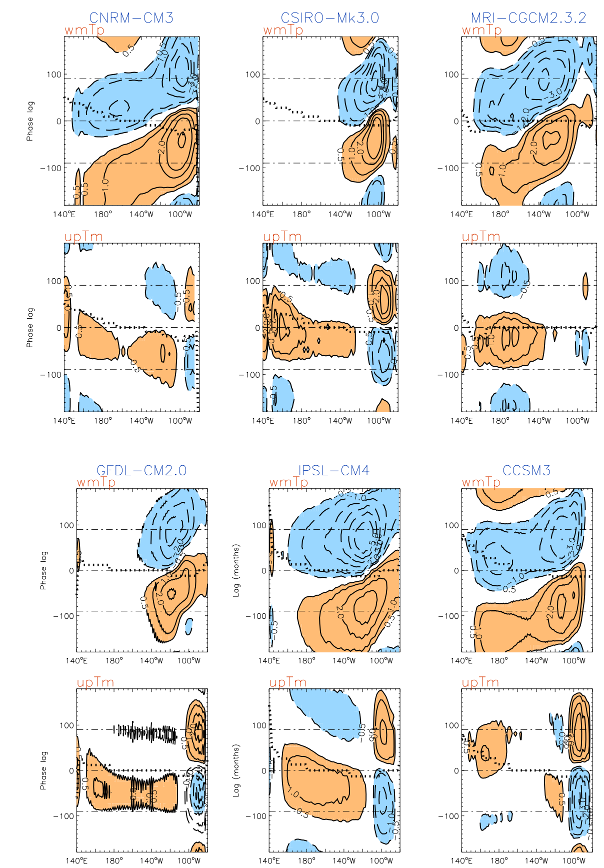


PC1 is in phase with the Niño3.4 index. PC1 and PC2 are approximately in quadrature in all three cases.

How realistic are ENSO's advective tendencies in the CGCMs?

The leading advective terms in the heat balance of the equatorial Pacific surface layer are the mean vertical advection of temperature anomalies (wmTp), and the anomalous zonal advection of mean temperature gradients (upTm). Here we regress both tendencies along the equator upon the Niño3.4 index, and display them as function of longitude and phase lag. Since advective tendencies affect the local heat balance, the lags of max. correlation between local SSTs and Niño3.4 are shown by the dotted line. Tendencies that are in phase with the SST tend to promote the SST growth, while a quadrature relationship (dot-dash lines) is indicative of a transitioning influence. Contour interval is 0.1 mo^{-1}. Values larger than 0.05 mo^{-1} in absolute value are shaded.





The wmTp feedback is relatively larger in the eastern basin. It is generally weaker in the CGCMs than in the ocean analysis. In some cases (IPSL-CM4, CCSM3) the largest component of the wmTp tendency is in quadrature with SST, and tends to promote ENSO phase transition. The upTm feedback is relatively more pronounced in the central-western Pacific. Its longitudinal distribution and phase relationship with SST is model dependent.