On extended wind stress analyses for ENSO

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GFDL/NOAA
Global Impacts of ENSO
Forecasts of the 1997/98 El Niño
(Landsea & Knaff 2000)

- Statistical Models
  - Persistence Forecasts
  - Linear Inverse Forecasts
  - ENSO-CLIPER Forecasts
  - Constructed Analogue Forecasts
  - Canonical Correlation Forecasts
  - Neural Network Forecasts
  - Singular Spectrum & MEM Forecasts
  - Consolidation Forecasts

- ICMs
  - BMRC Forecasts
  - Lamont-Doherty Forecasts
  - Oxford Coupled Forecasts

- HGCMS
  - Scripps-Max Planck Forecasts
  - COLA Forecasts
  - NCEP Coupled Model Forecasts

- CGCMs
The wind observing network

Fig. 2. Mean number of (a) ship and (b) buoy pseudostress values per month for the tropical Pacific Ocean. Averages based on COADS data for the period Jan 1988 through Dec 1997. Means were calculated in 1° bins, then were contoured with magnitudes shown in the color bar. (Smith et al., 2004)
A wide variety of products

Annual-mean NINO4 zonal wind stress (dPa)

FSU subjective analysis

NCEP/NCAR Reanalysis
Annual-mean zonal stress (dPa)
Annual-mean meridional stress (dPa)
Wind stress generates mean oceanic upwelling:

\[ w|_{z=H_m} \approx \frac{H - H_m}{\rho H (\tilde{y}^2 + 1)} \left[ \frac{\beta}{r_s^2} \left( \frac{\tilde{y}^2 - 1}{\tilde{y}^2 + 1} \tau_x - \frac{2\tilde{y}}{\tilde{y}^2 + 1} \tau_y \right) + \frac{\text{div}(\tau)}{r_s} + \frac{\tilde{y} \text{curl}(\tau)}{r_s} \right] \]

\[ \tilde{y} = \frac{\beta y}{r_s} \]

and a mean thermocline slope:

\[ \partial_x h \approx \frac{\tau_x}{g H \Delta \rho} \]

Both affect the coupled mean state and ENSO.
Zonal stress anomalies regressed onto NINO3 SSTAs
Hybrid coupled model ENSO, using various flux products

Harrison et al. (MWR, 2002)
CM2 Sensitivities: Cumulus Momentum Transport

$\tau_x$ regressed on NINO3 SSTA

NINO3 SST spectra

CM2.1 without CMT (0101–0160)
CM2.1 with CMT (0001–0200)
NINO4 zonal stresses

FSU1

(a) FSU NINO4 $\tau^\prime$: $\sigma = 0.19$ dPa, $\phi_x = 0.72$

(b) Spectral density ($\sigma^2$ octave$^{-1}$ century$^{-1}$)

(c) Time averages

(d) Scale integrals

NCEP1

(a) NCEP NINO4 $\tau^\prime$: $\sigma = 0.10$ dPa, $\phi_x = 0.82$

(b) Spectral density ($\sigma^2$ octave$^{-1}$ century$^{-1}$)

(c) Time averages

(d) Scale integrals
Sub-annual zonal stress anomalies
AGCM wind stress decomposition

Linear Model

Ens Mean Resid

Noise

\( \tau' \) (dPa, 5oS–5oN, T>12mo)

1980 120°E 180° 120°W

82% 11% 8%
Impact of wind noise & nonlinearity on ENSO forecasts
Daily western Pacific zonal stresses, from 10 AMIP runs

- **Obs SST forcing**
- **Warm East Indian**
- **Cool West Pacific**
Annual cycle of variance

(a) Full anomalies

\( \sigma = 0.19 \text{ dPa}, \phi_1 = 0.72 \)

(b) Interannual

\( \sigma = 0.14 \text{ dPa}, \phi_1 = 0.97 \)

(c) Subannual

\( \sigma = 0.10 \text{ dPa}, \phi_1 = 0.00 \)

FSU

\( \sigma = 0.10 \text{ dPa}, \phi_1 = 0.82 \)

\( \sigma = 0.08 \text{ dPa}, \phi_1 = 0.97 \)

\( \sigma = 0.05 \text{ dPa}, \phi_1 = 0.05 \)

NCEP

\( \sigma = 0.92^\circ \text{C}, \phi_1 = 0.91 \)

\( \sigma = 0.82^\circ \text{C}, \phi_1 = 0.97 \)

\( \sigma = 0.27^\circ \text{C}, \phi_1 = 0.12 \)

SST

J ASO ND J F M AM J

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J ASO ND J F M AM J
Correlation of FSU1 and NCEP1 zonal stress anomalies
Anomaly correlation of NINO4 zonal stress and NINO3 SST
Conclusions

- **Wind stress is critical to ENSO**
  - Mean, anomalies, & noise

- **“True” stresses are hard to estimate**
  - Nonlinearity & sparse historical obs

- **Popular analyses disagree substantially**
  - Mean, trend, ENSO patterns, spectra, seasonality

- **Things are gradually improving**
  - Satellites, bulk formulae, reanalyses, merged products
References

- Wittenberg et al. (2005, submitted to JC)
- Zhang et al. (2005, submitted to MWR)
- Wittenberg (2004, J. Climate 17, 2526-2540)
  - www.gfdl.noaa.gov/~atw/research/thesis
Simulated annual-mean climate

Temperature (°C) at Equator
Assim (1980–1999), CM2.0 (bias shaded)

(b) Subsurface U (cm/s) at equator
CM2.0, CM2.1 vs. TAO obs (ADCP & fixed-depth)
Modulation of ENSO

(a) CM2.0 NINO3 SST

(b) Spectral density (°C² octave⁻¹)

(c) Mean spectra, early/late epochs
CM2.0 response to increasing CO$_2$
Simulated changes: 4xCO2 minus 1860

(a) Surface temperature (°C)

(b) Precipitation (mm/day)

(c) SST minus 50m temperature (°C)

(d) Temperature of top 300m (°C)

NINO3 SST spectra

ERSST obs (1880–2004)
CM2Q-Control-1860-d2 (0001–0500)
CM2Q-Control-1990-e2 (0001–0300)
CM2Q-Control-1990-e3 (0001–0300)
CM2Q-d2-1PctTo2x-i1 (0001–0280)
CM2Q-d2-1PctTo4x-j1 (0001–0300)