Exciting the Delayed-Action Oscillator of the Tropical Pacific Climate with Small Decadal Solar-Irradiance Variations

USGS science for a changing world

Michael Dettinger*(1)* & Warren White*(2)*
(1) US Geological Survey; (2) Scripps Institutions of Oceanography

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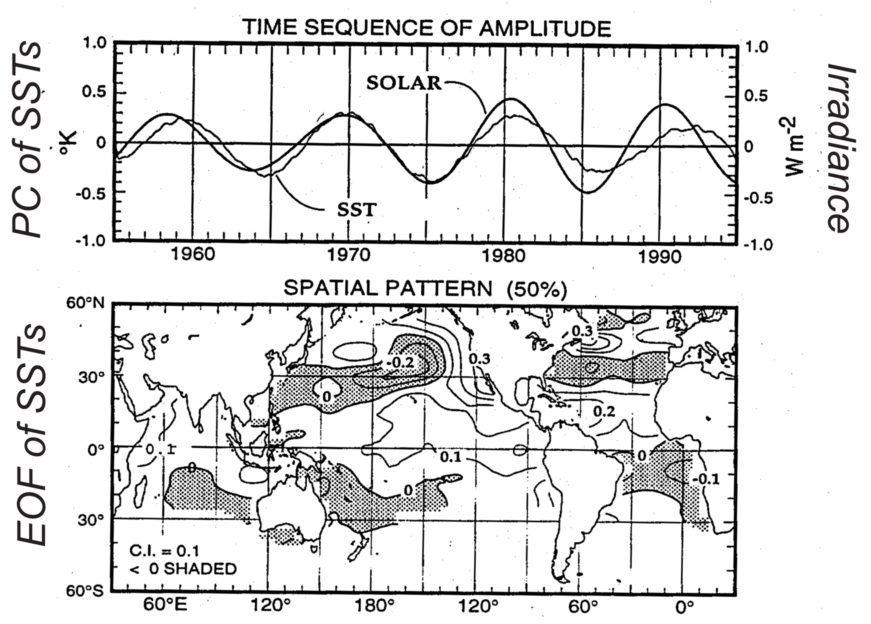
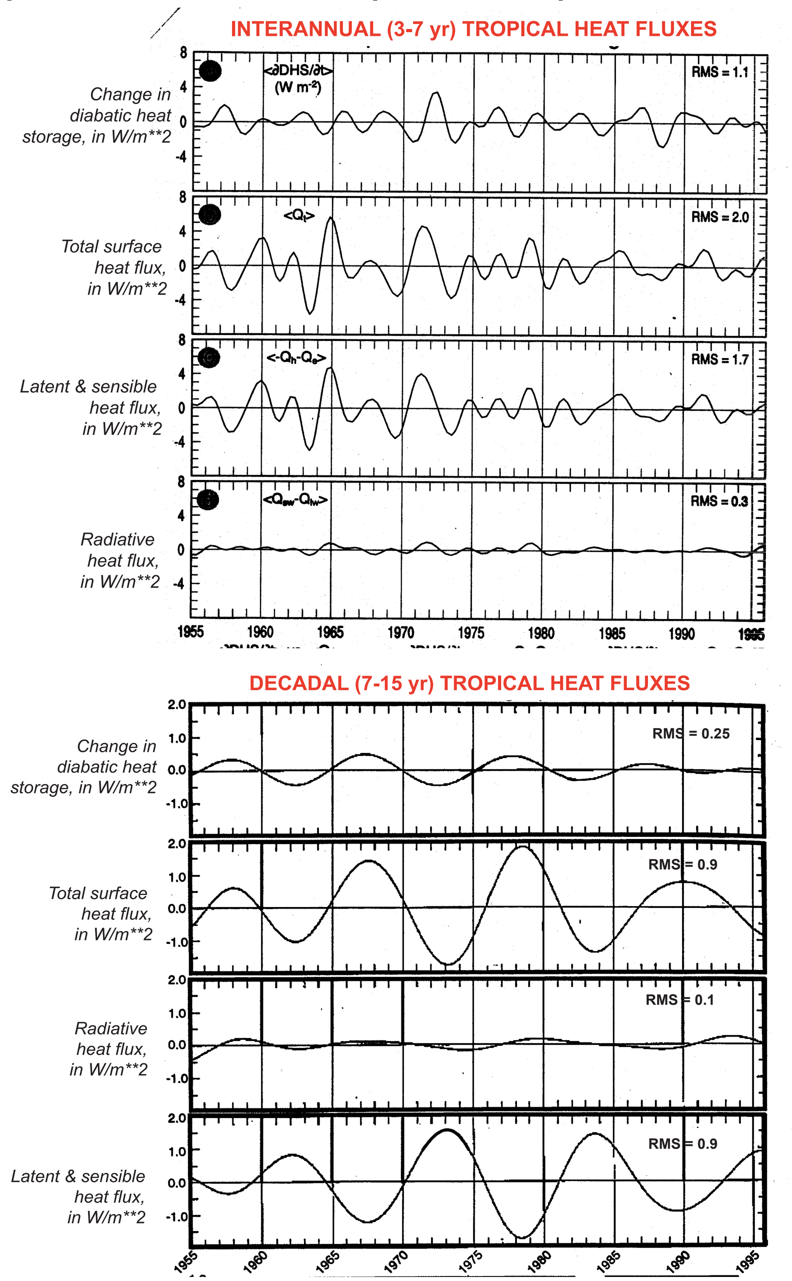
OBSERVATIONS OF AIR-SEA VARIATIONS ASSOCIATED WITH DECADAL SOLAR-IRRADIANCE CHANGES

The amplitudes (PCs) of the first EOF of filtered global sea-surface temperatures (SSTs) are remarkably coherent with the filtered solar-irradiance series and lagging it by 1 or 2 yrs (both filtered to 7-15 yr before analysis), and the associated SST EOF is strongly PDO/ENSO-ish.



Also, at ENSO and decadal time scales , the mixes and amplitudes of heat fluxes to and from the tropical oceans are quite comparable.



Thus there seems to be some deep compatibility & connection between the "forced" climatic response to solar variations and the "unforced" ENSO mode. Perhaps, infact, climate responses to solar variations are by excitation of the ENSO modes. We illustrate and test this hypothesis here by modifications to a simple ENSO MODEL.

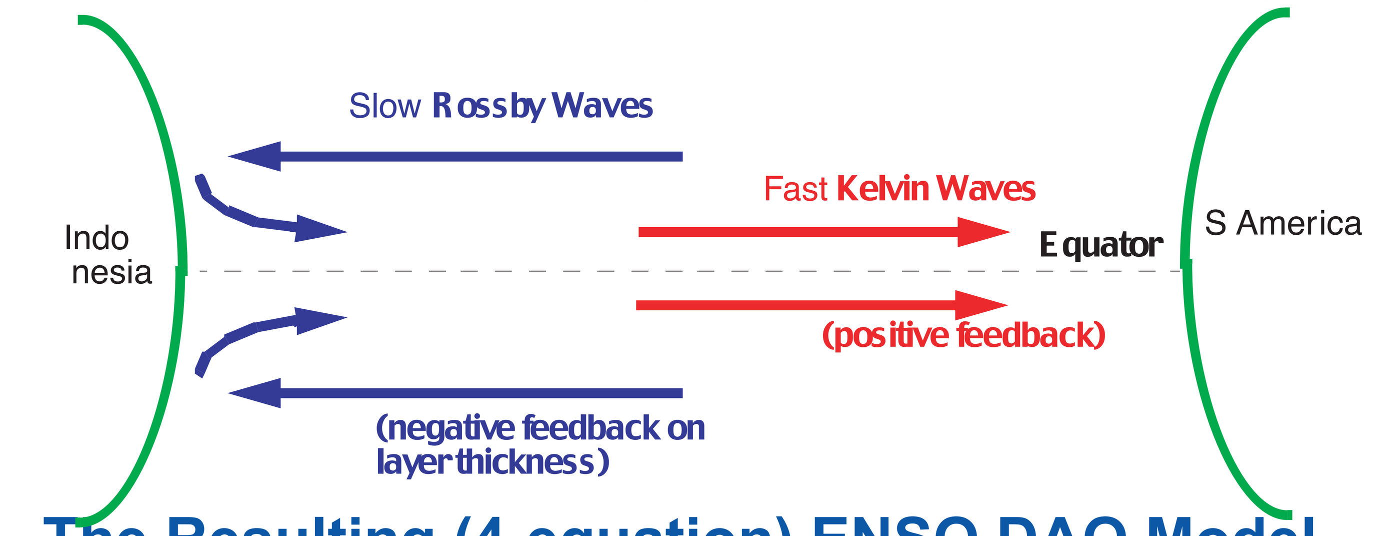
START WITH GRAHAM & WHITE's (1988) DELAYED-ACTION OSCILLATOR (DAO) MODEL

STEP 1: Anomalous warming of equatorial SST induces anomalous westerlies in tropical wind fields

STEP 2: Westerlies excite fast, equatorial, eastward Kelvin waves and slow, off-equatorial, westward Rossby waves in upper ocean

STEP 3: These waves affect upper-ocean layer thickness, with Kelvin waves reinforcing the SST perturbations and the reflected Rossby waves reversing them (however, the reflected Rossby waves reach the El Nino region many months after the original Kelvin waves!)

STEP 4: Reversal of layer thickness by reflected Rossby wave reverses equatorial SSTs to begin the 2nd half of the ENSO cycle.



The Resulting (4-equation) ENSO DAO Model

$$EULT_t = a\, ZWS_t + \square\, CULT_{t-d}$$
$$ESST_t = b\, EULT_t$$
$$CULT_t = -c\, ZWS_t$$
$$ZWS_{t+1} = \square\, (ab)^{-1}\, ESST_t + \square_t$$

where EULT and ESST are the upper-ocean layer thickness and SST anomalies in the eastern equatorial Pacific Ocean; ZWS is the zonal wind-stress anomaly in the central equatorial Pacific; and CULT represents the upper-ocean layer-thickness anomaly in the central off-equatorial Pacific. Subscripts are time indices with a monthly time step, and the constants a, b, and c are observed positive values inferred from observed relations in the Pacific. The parameter □ is a reflection coefficient controlling the fraction of CULT that is transmitted into the equatorial wave guide and reflected as Kelvin waves into the equatorial eastern Pacific Ocean. The parameter □ damps the system. The variable □ represents stochastic atmospheric forcing of the system (weather).

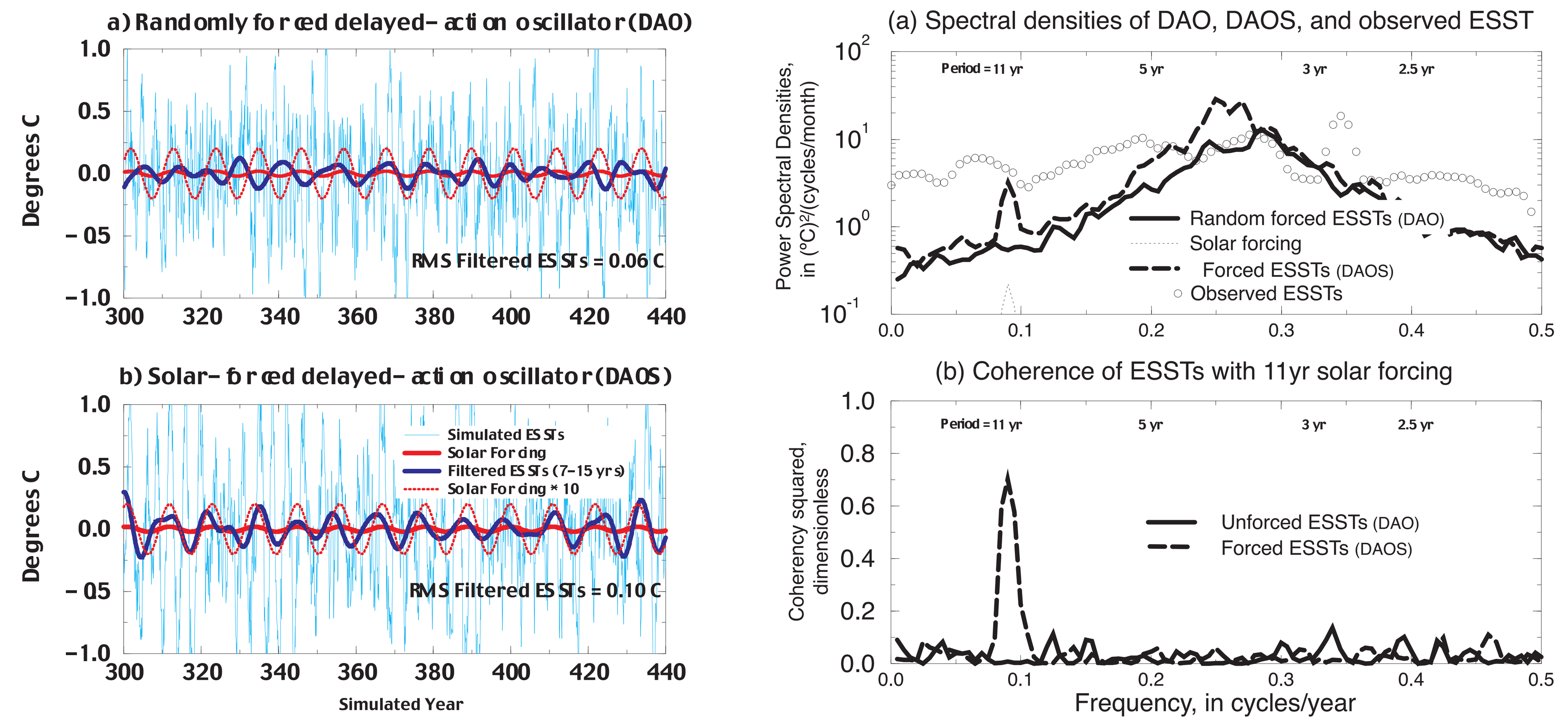
AND MODIFY IT TO INCLUDE A TINY SOLAR FORCING

The ENSO DAO Model with Solar Variations (DAOS)

$$EULT_t = a\, ZWS_t + \square\, (\square_j\, CULT_{t-d,j})$$
$$ESST_t = b\, EULT_t + s_o \sin(2\square t/11\ yr) - K\, ESST_{t-1}$$
$$CULT_t = -c\, ZWS_t$$
$$ZWS_{t+1} = \square\, (ab)^{-1}\, ESST_t + \square_t$$

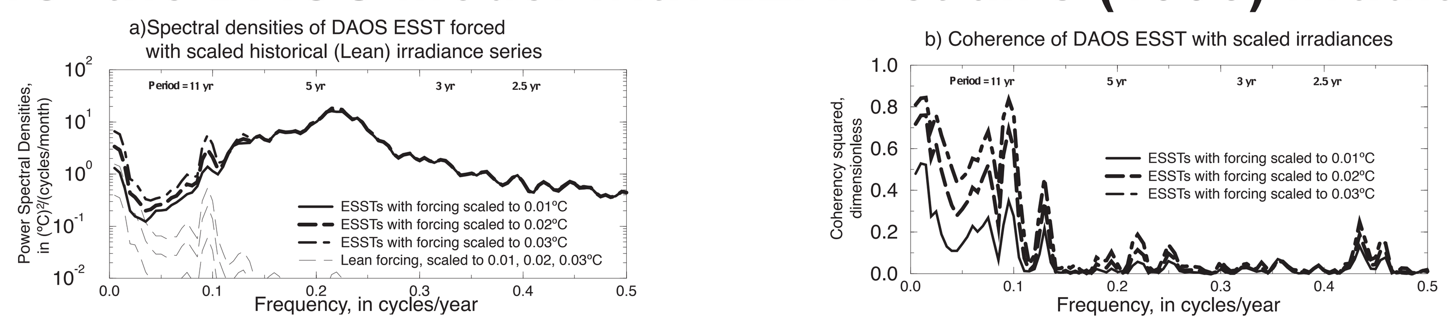
where the summation allows for multiple Rossby wave transit times and reflection coefficients; s_o is a direct solar (or other) forcing of the equatorial SST anomalies; and -K is a Stefan-Boltzmann long-wave cooling coefficient.

TICKLING the DAOS Model with a TINY (idealized) SOLAR FORCING



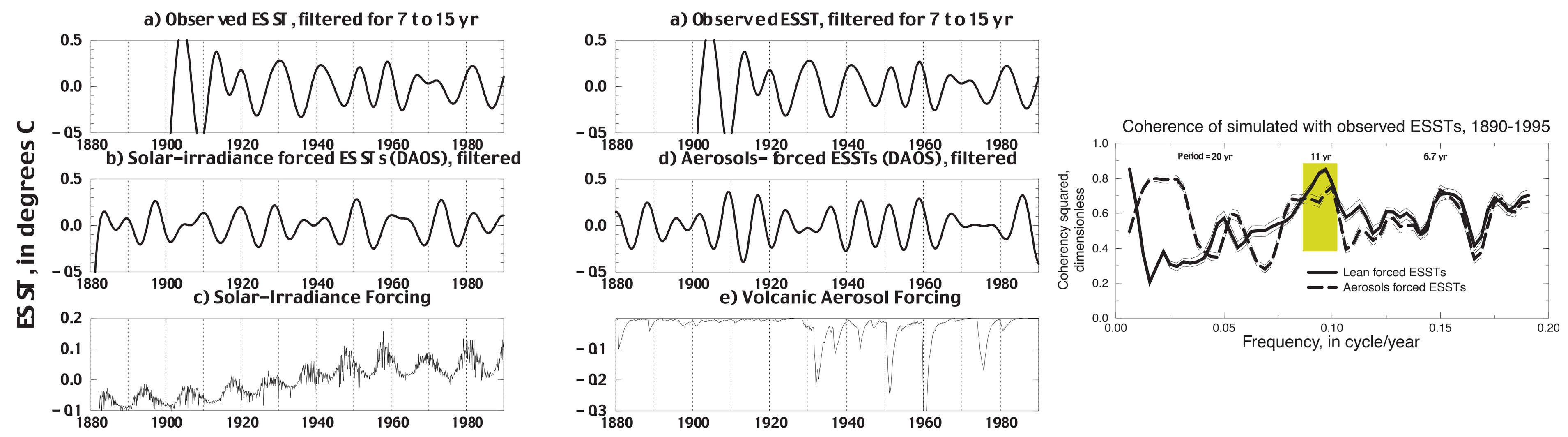
A simple delayed-action oscillator model of ENSO "tickled" with a small (0.02C) periodic decadal forcing responds with much larger decadal variations that are coherent with the small forcing, as the low-frequency force entrains the internal ENSO oscillations of tropical climate (simply by predisposing the onsets of ENSOs toward its decadal calendar).

DRIVING the DAOS Model with LEAN et al.'s (1995) irradiances



When more Rossby waves are included and the model is forced by Lean solar-irradiance estimates (instead of a pure 11-yr sinusoid), decadal SST variations with amplitudes like those observed are simulated, coherent with and lagging solar forcing by only 1-2 yrs.

DAOS Responses to Irradiance vs. Volcanic Aerosol Variations



The simulated ESST response to Lean irradiances is somewhat more historically "correct" than are responses of the same model to historical volcanic aerosol effects.

CONCLUSION: Solar-cycle excitation of the internal ENSO oscillations of the climate system provides a simple, but globally powerful, mechanism for observed decadal solar-climate linkages. Although it is likely that other broad-band internal modes of the climate system could likewise be stimulated by small periodic solar-irradiance changes, the historical patterns of decadal climate variation that most strongly parallel decadal solar forcings are distinctly ENSO-like. We therefore favor some form of ENSO-solar interaction, along the lines presented here, to explain observed solar-climate connections.