Addressing Tropical Biases in GFDL's Global Coupled Climate Models

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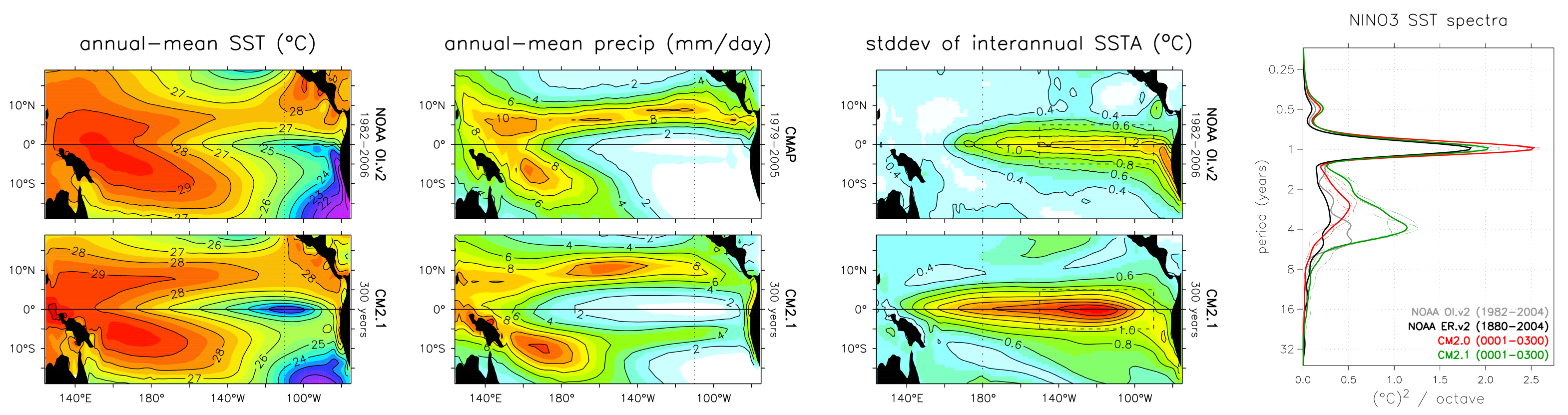
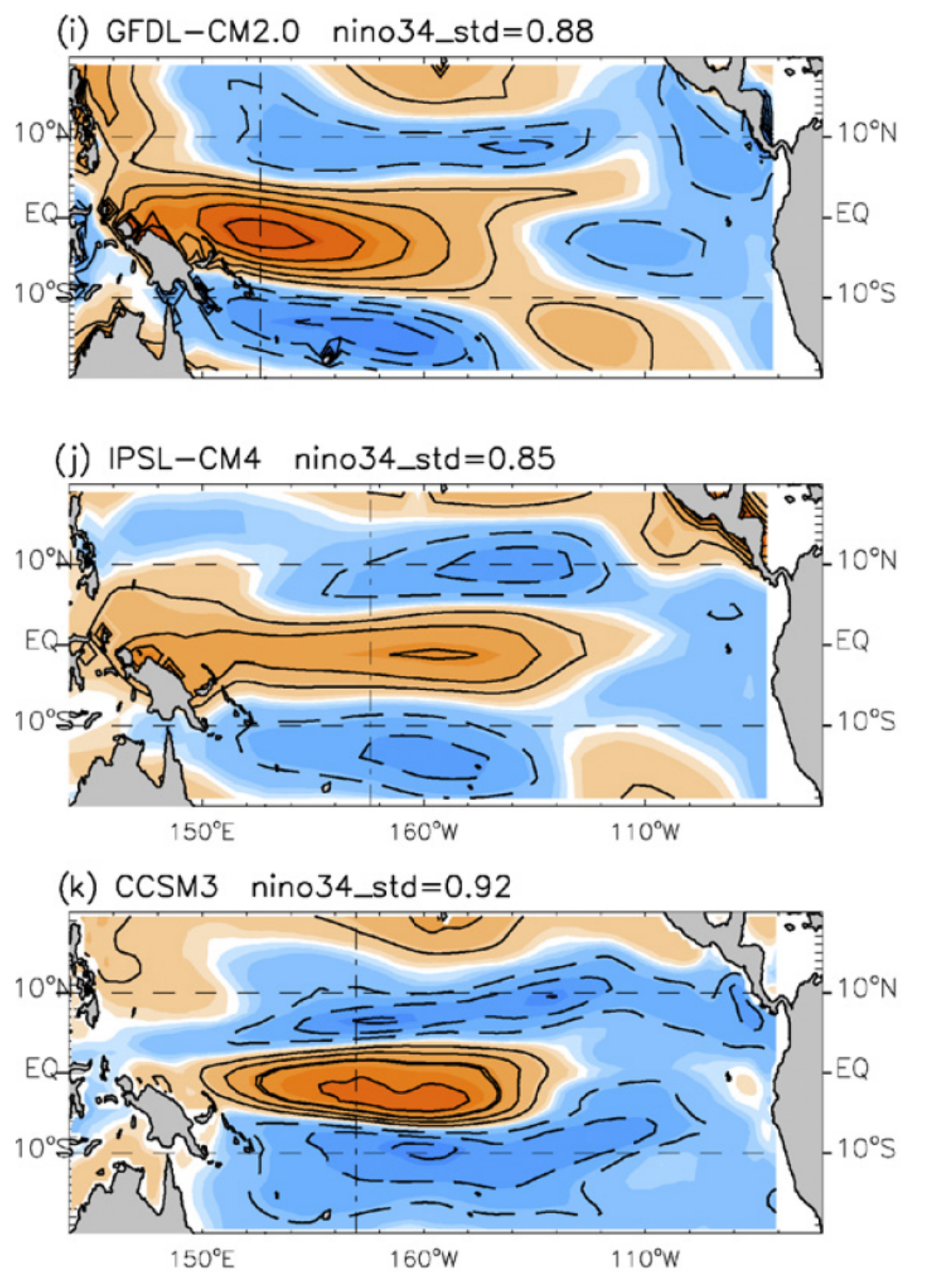
1. Introduction

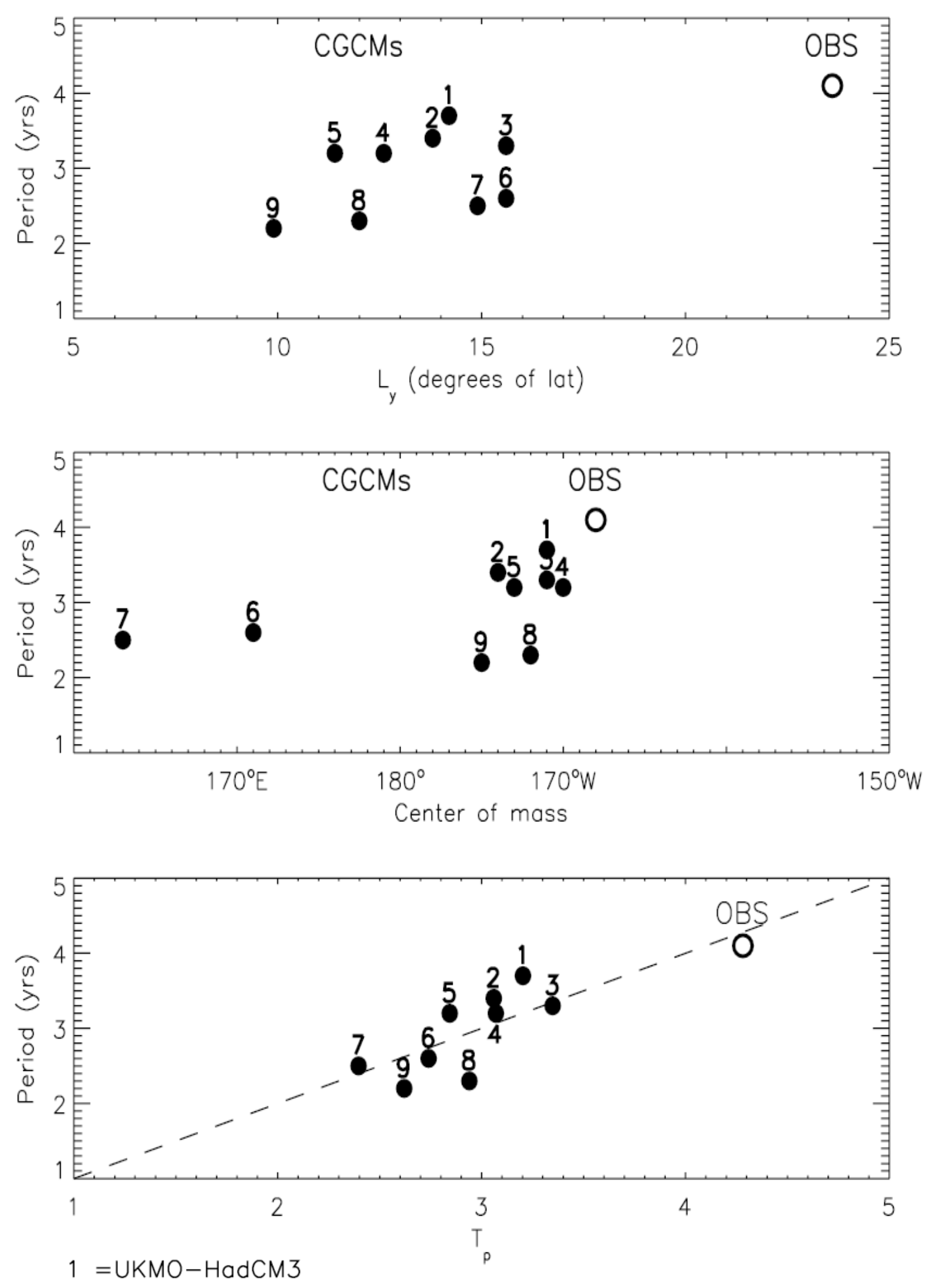
The CM2.0 and CM2.1 global coupled GCMs from the Geophysical Fluid Dynamics Laboratory (GFDL) performed very well in model intercomparisons connected with the IPCC Fourth Assessment (AR4). But like all current CGCMs run without flux adjustments, the GFDL models retain substantial biases in their simulated tropical climate and variability (Wittenberg et al. 2006). To address these biases we have taken three promising avenues, illustrated here with a focus on the ENSO problem.



2. Intercomparisons with Other CGCMs

Different CGCMs exhibit a variety of patterns for zonal wind stress anomalies regressed onto NINO3.4 SSTAs (see right). Prior studies with simple models (Kirtman 1997; An & Wang 2000; Wittenberg 2002) suggest that the ocean adjustment time and ENSO period should be linked to the meridional width (L_y) and zonal position (C) of the equatorial westerly anomalies. Capotondi et al. (2006) explore this in CGCMs by regressing the ENSO periods (T) from the AR4 20th-century simulations onto the L_y & C values estimated from the models' ENSO zonal wind stress regression patterns.





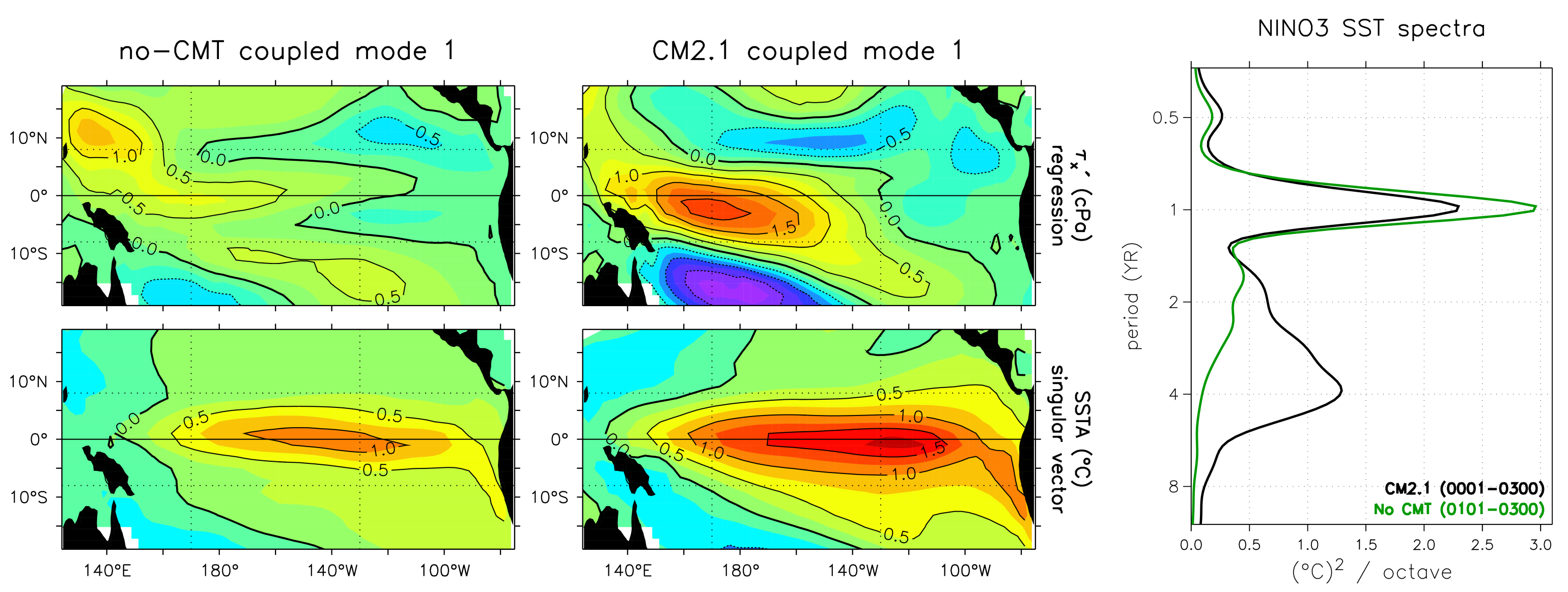
All the models have too short a period for ENSO, with stress anomalies that are too far west and meridionally too narrow. Regressing T onto L_y & C gives the equation below for T_p (best-fit solution and 90% bootstrap confidence interval shown for each fitted parameter). Despite the small sample, we can infer -- for these CGCMs at least -- that the period does tend to lengthen with increasing L_y & C. Given the many large differences among these CGCMs, T_p is a surprisingly good predictor of T.

$$correl(T_p, T) = 0.82 \pm 0.15$$

$$T_p = \begin{bmatrix} 3.4 \\ 3.1 \\ 2.7 \end{bmatrix} yr + \frac{L_y - \begin{bmatrix} 16 \\ 14 \\ 13 \end{bmatrix}^o}{\begin{bmatrix} 20 \\ 10 \\ 4 \end{bmatrix}^o} + \frac{C - \begin{bmatrix} 188 \\ 184 \\ 179 \end{bmatrix}^o}{\begin{bmatrix} 77 \\ 30 \\ 14 \end{bmatrix}^o}$$

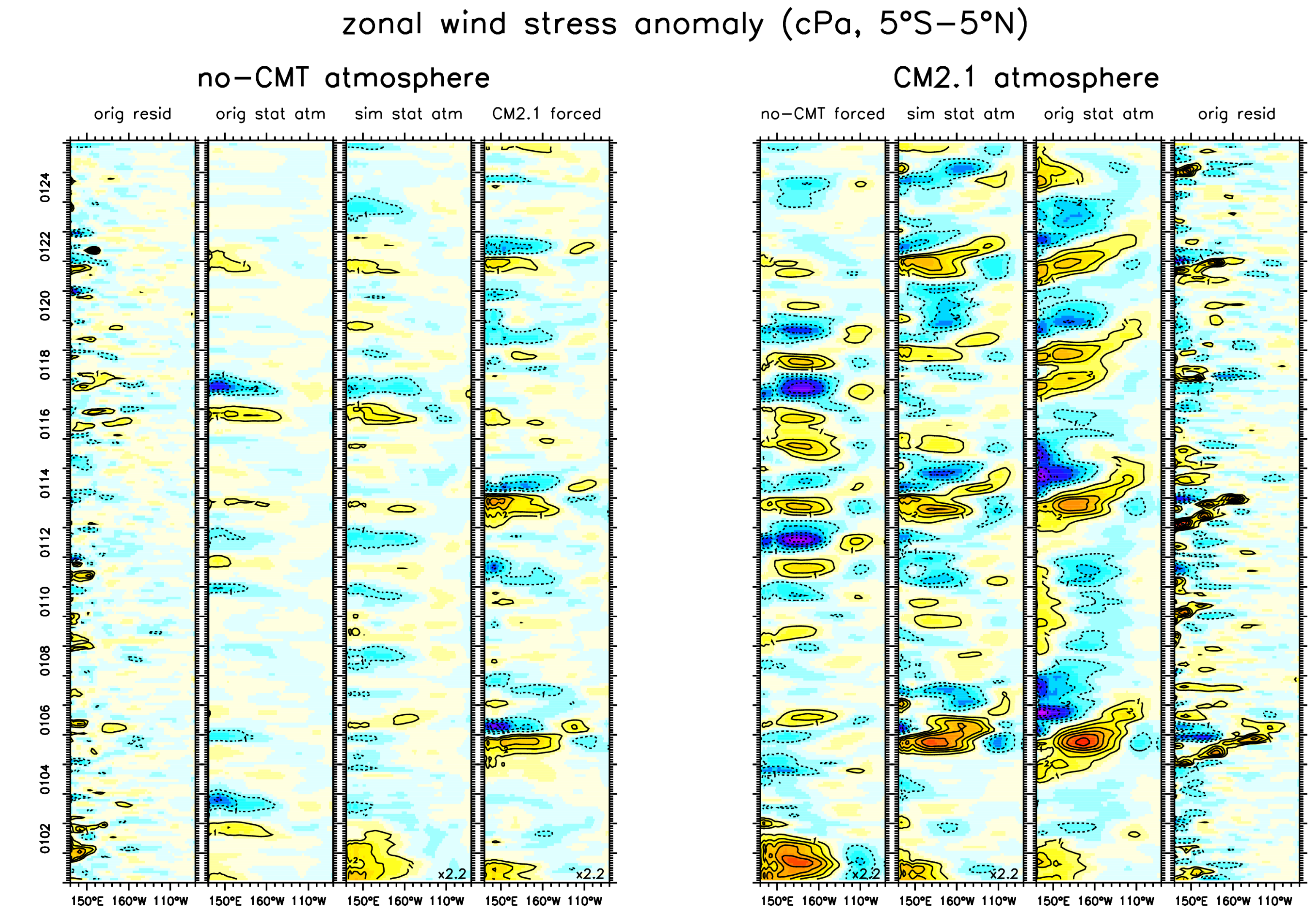
3. Hybrid Coupled Framework

Multi-scale coupled interactions complicate the attribution of biases in full CGCMs. To address this, we have developed a hybrid model consisting of the CM2.1 ocean coupled to a statistical atmosphere that is fit to a long run of CM2.1. Individual components of the surface fluxes can then be partially coupled, or swapped with other simulations, isolating the impacts of the climatological background, anomaly coupling, and quasi-stochastic flux forcings on the simulated ENSO. The hybrid model thus provides a fast, controllable testbed for isolating coupled sensitivities, intercomparing CGCMs, and evaluating new model components and data assimilation systems.



Here we consider two runs of CM2.1, which differ only by inclusion of parameterized subgrid-scale atmospheric cumulus momentum transport (CMT). Compared to the no-CMT case, the control CM2.1 ENSO is stronger, has a longer period, and has a very different pattern of wind stress coupling.

The statistical atmosphere extracts from the wind stress a part which depends linearly on large-scale tropical Pacific SSTAs, leaving behind a noisy, nonlinear residual forcing. The hybrid model driven by the residual forcing recovers the actual CGCM wind stress patterns fairly well. Swapping just the SSTA-regressed stress feedbacks of the CM2.1 and no-CMT hybrid models strongly alters the ENSO behavior, with the CM2.1 stress feedbacks favoring stronger oscillations & more eastward propagation than the no-CMT stress feedbacks.



4. Facilitating Model Assessment, Engaging the Community

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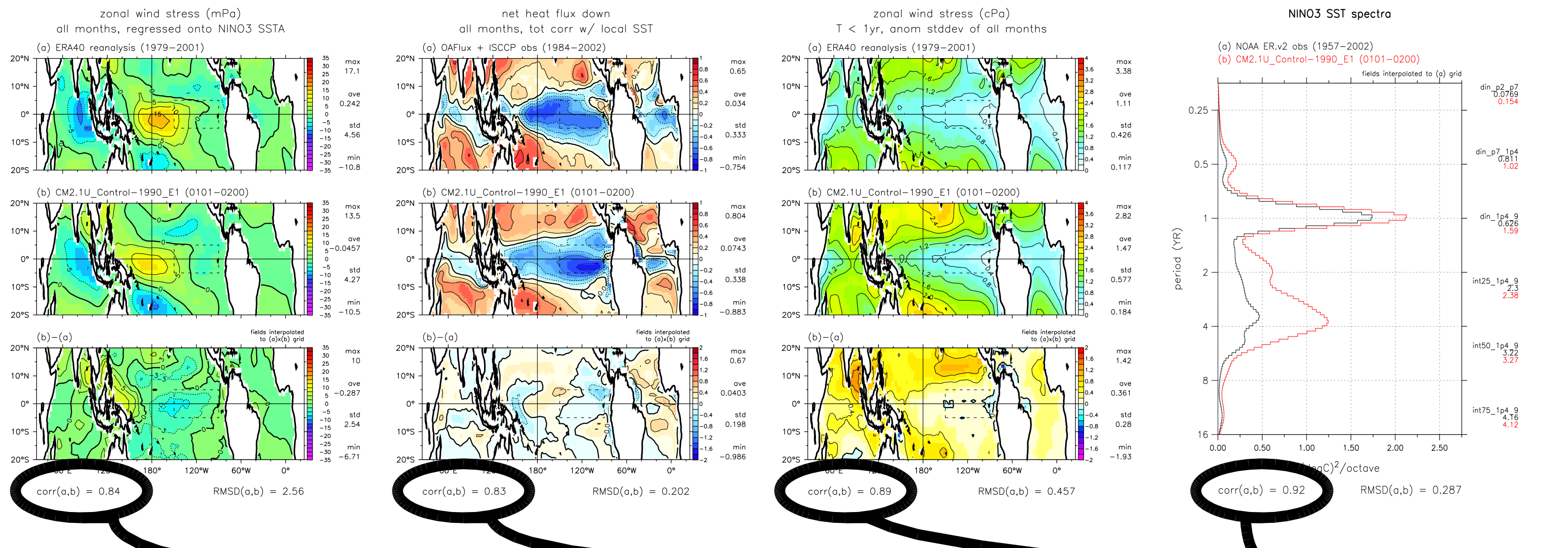
The XML file used at GFDL to describe an experiment -- all code, compiler options, namelist settings, input files, and postprocessing -- also directs automated scripts to generate diagnostic figures and summary statistics as the model runs. The resulting figure archives are invaluable for rapid assessment & intercomparison of new simulations, and they help expose errors early.

wind stress coupling

heat flux damping

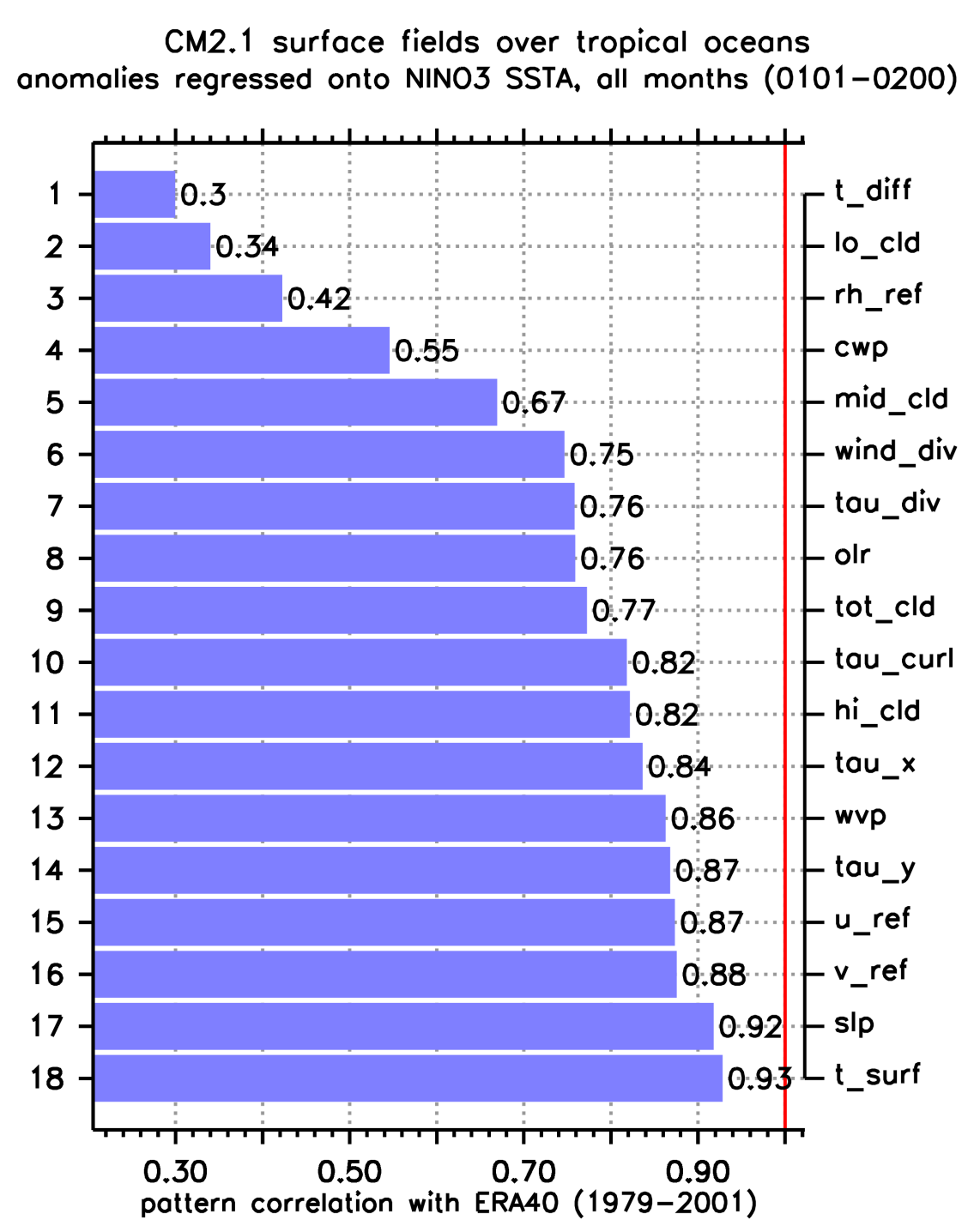
stochastic forcing

ENSO spectra



Elements from ENSO theory have analogues in the automated diagnostics, enabling tests of ENSO mechanisms, and building bridges between CGCMs and conceptual models. Multiple observational products are used to help characterize the large flux uncertainties.

Summary statistics -- such as the model's pattern correlations with observations -- are gathered up by meta-tools to highlight problem areas and differences among models. These statistics can then be fed into objective cost functions to measure simulation quality. The end result is an interconnected tree of information that allows one to quickly grasp the model results at various levels of detail.



cost functions

A final challenge is to balance competing priorities to design useful cost functions -- and improve the scientific understanding and observational footing needed to optimize them. Both will require a sustained community-wide effort spanning observations, theory, and models.

References

An, S.-I., and B. Wang, **2000**: Interdecadal change of the structure of the ENSO mode and its impact on the ENSO frequency. *J. Climate*, **13**, 2044-2055.

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