A global 4D-Var data assimilation experiment with a fully coupled GCM

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A four-dimensional variational (4D-Var) data assimilation system with a fully coupled global ocean-atmosphere-land surface model has been successfully developed with an aim to better define both mean structure and temporal evolution of coupled seasonal to interannual phenomena. By using oceanic and atmospheric adjoint codes with special considerations for preventing from the blow-up of fast growing sensitivities [Hoteit *et al.*, 2005], the system optimizes the oceanic initial conditions and the adjustment factors for bulk formulae of mass and heat and momentum exchanges [Mochizuki *et al.*, 2007] so as to fit the (9-month long) trajectories of the model's coupled field to the observational data for both ocean and atmosphere (see Table 1 for the experimental setting). Application to state estimation of global climate during the 1990s shows, for example, that the structure in the tropical Pacific region becomes extremely realistic (Figs. 1b and 2) and hence the atmospheric condition associated with El Nino events is better represented (Fig.3). And, in the analysis field (Fig. 1c), the departures of the ensemble mean from the observation are comparable to the ensemble spread, which means that the analysis field is well optimized by the system. Also the errors do not grow in the 9-month long assimilation windows, which means that the system works properly as a smoother and seasonal to interannual evolution is well constrained by the observation. An optimal synthesis of observational data and coupled model provides suitable oceanic initial conditions to the El Nino evolution together with the adjustment of coupling intensities regarding the air-sea exchange of fresh water, momentum, and heat. These data well reflect the realistic trend of seasonal to interannual variabilities, thereby enabling us to offer almost 1.5year-long lead predictability for the El Nino (Fig. 4), at least in the preliminary studies for the period from 1996 to 1998. These results suggest that our 4D-Var coupled data assimilation system has an ability to provide superior state representation and forecast potential than earlier assimilation methods.

Table 1. The experimental setting of coupled data assimilation

Coupled model	CFES (coupled model for the earth simulator) [Ohfuchi *et al*., 2004], [Pacanowski and Griffies, 1999]. Resolutions are T42L24 for atmosphere, and 1degree by 1degree with 45 vertical levels for ocean.
Preliminary parameter tuning	Green's function method [Menemenlis *et al.*, 2005]
Assimilation method	4D-variational method equipped with both oceanic and atmospheric adjoint codes.
Control variables	Oceanic initial conditions, and the adjustment factors for bulk formulae.
Observational data	WOD 2001 data, FNMOC data, OISST data, T/P sea surface height anomaly, NCEP's BUFR data, and SSM/I wind data, together with our ocean reanalysis product [Masuda *et al.*, 2006].
Assimilation window	9-month long windows starting from each January and July.

(a)

(b)

(c)

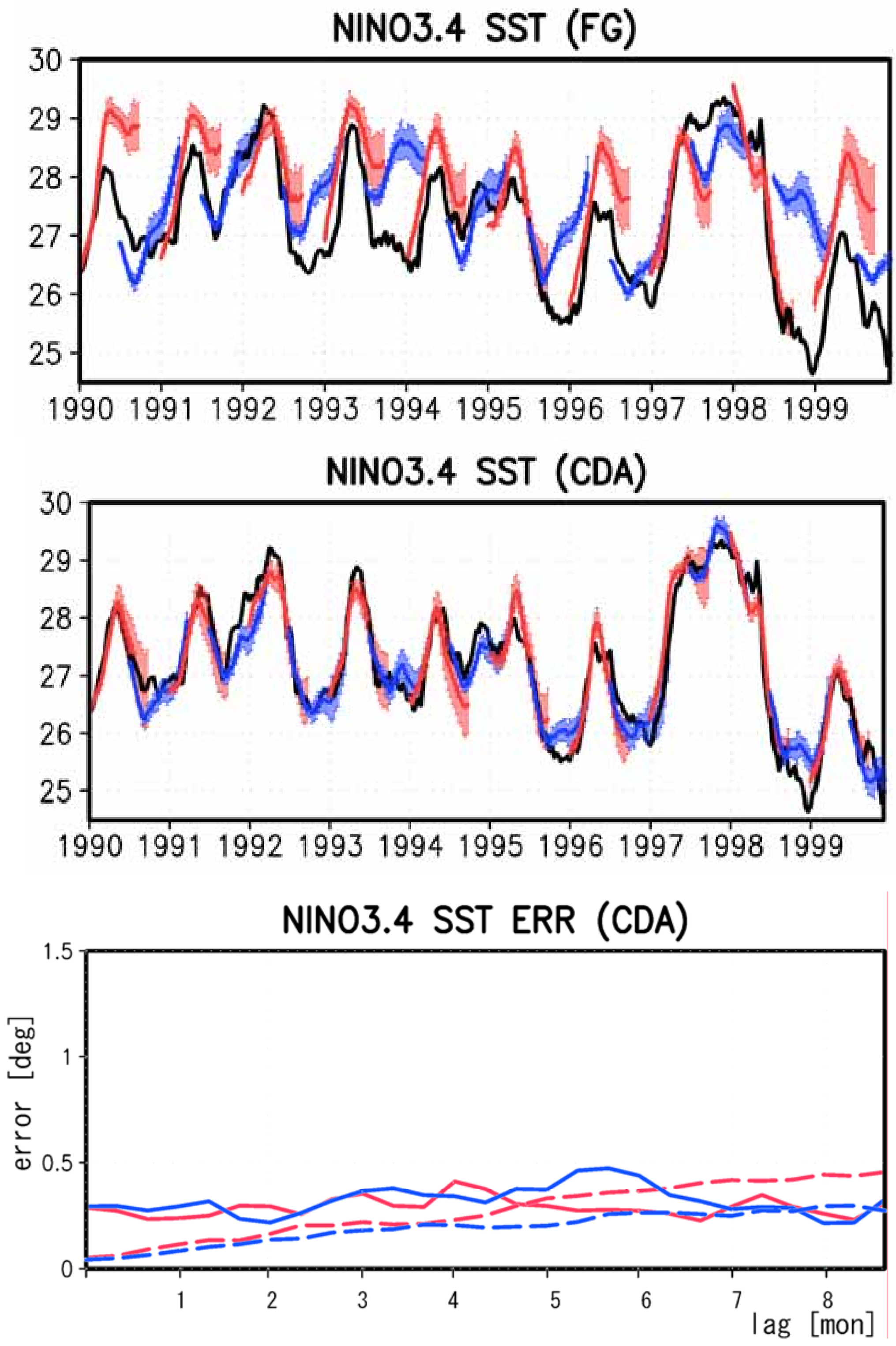

Figure 1 (a) Time change of Nino 3.4 SST for the first guess field starting from January (red) or July (blue), and observation (black curve). The error bars showing the ensemble spreads are of 1 sigma in width. The units are deg C. (b) The same as (a) but for the analysis field of the 1990s CDA experiment. (c)The averaging bahavior of error and spread of the analysis Nino 3.4 SST for assimilation windows starting from January (red), or July (blue). Solid curves show the departures of the ensemble mean from the observation, whereas dashed curves show the spreads among ensemble members.

(a) (b) (c)

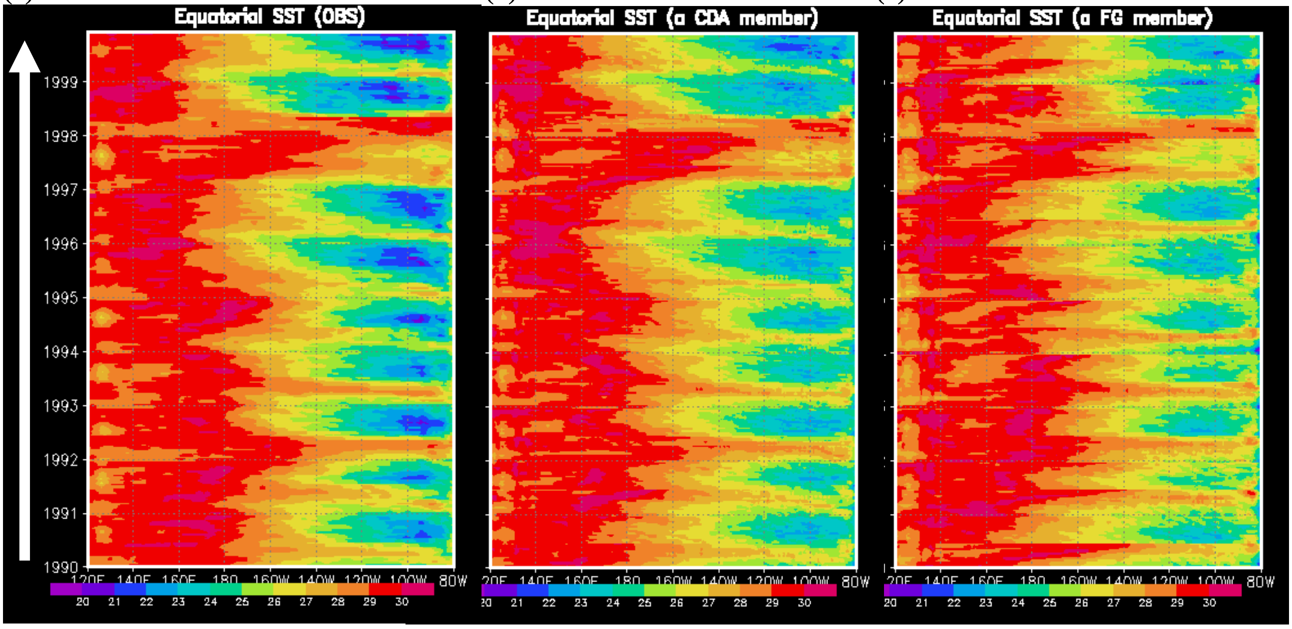

Figure 2 Hovmoeller diagrams of SST along the equator averaged between 2S-2N for the 1990s. (a) The Reynolds product, (b) the analysis field, and (c) first guess field. The units are degree C.

(a) (b) (c)

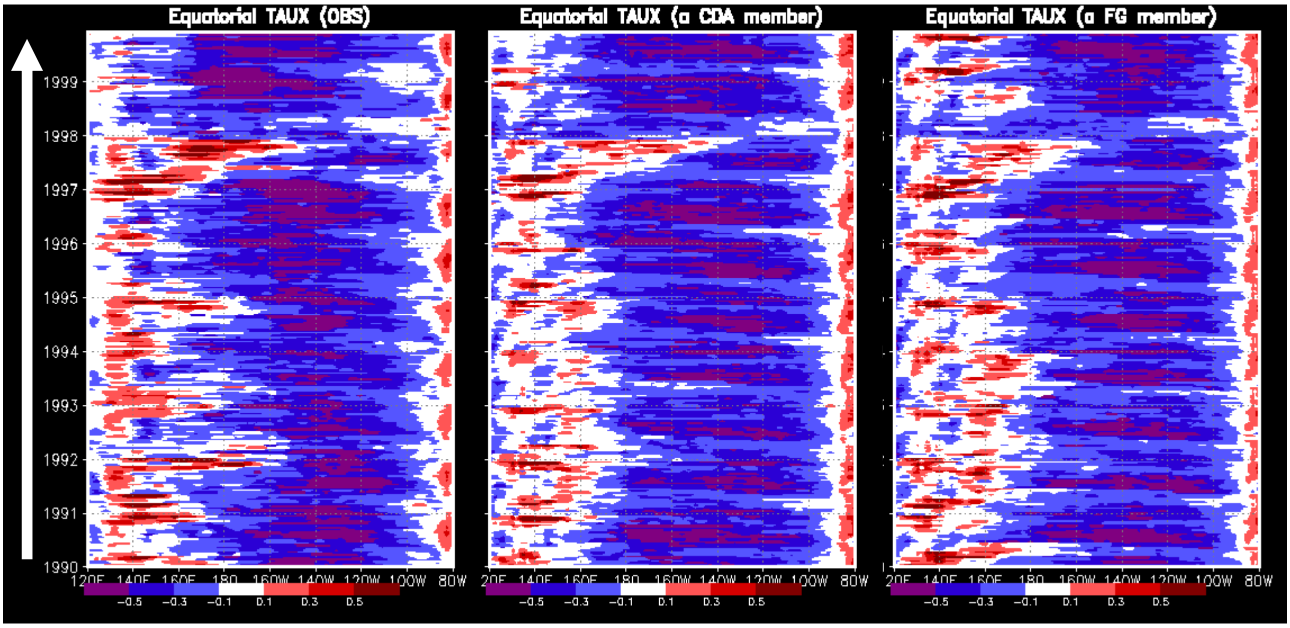

Figure 3 Hovmoeller diagrams of zonal wind stress along the equator averaged between 2S-2N for the 1990s. (a) NCEP2 product, (b) the analysis field, and (c) The first guess field. The units are dyn/cm^2.

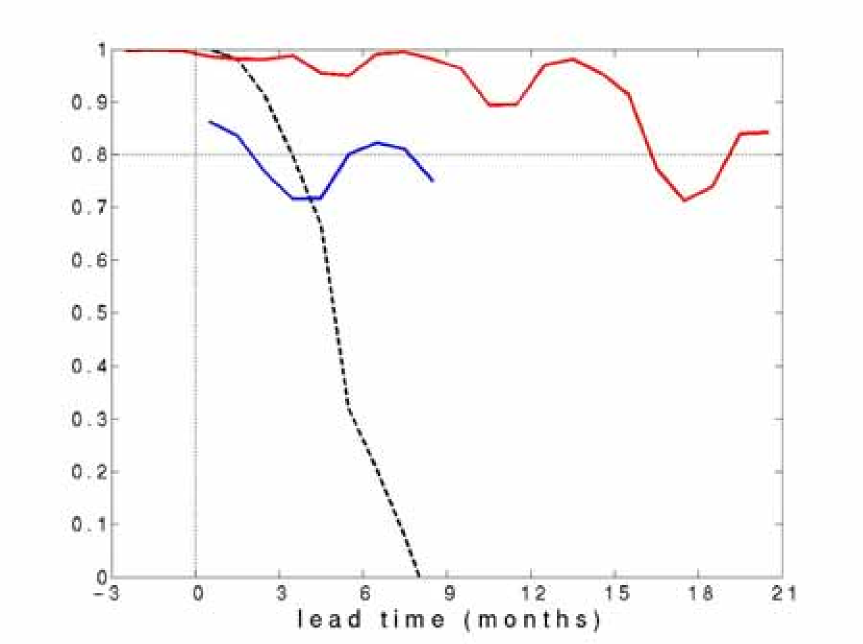

Figure 4　NINO3.4 SST anomaly correlation coefficient for preliminary prediction experiment. Red line: prediction from optimized oceanic initial conditions and with climatological bulk adjustment factors [Mochizuki *et al.*, 2007]　by CDA, blue line: prediction from oceanic initial condition by IAU and dashed line: persistence experiment. The statistics are from 6 cases of ensemble runs which start from October and April of 1996 to 1998, each with 11 different atmospheric initial conditions.

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