Process Studies and Seasonal Prediction Experiment Using Coupled General Circulation Model

Group Representative

Toshio Yamagata Frontier Research System for Global Change

Authors

Toshio Yamagata *1 ・ Sebastien Masson *1 ・ Jingjia Luo *1 ・ Swadhin Behera *1
Hidenori Aiki *1 ・ Satoru Shingu *1 ・ Yukio Masumoto *1 ・ Hisashi Nakamura *1
Suryachandra Rao *1 ・ Karumuri Ashok *1 ・ Hirofumi Sakuma *2 ・ Antonio Navarra *3
Silvio Gualdi *3 ・ Simona Masina *3 ・ Annalisa Cherchi *3 ・ Pascal Delecluse *4
Gurvan Madec *4 ・ Claire Levy *4 ・ Marie-Alice Foujols *4 ・ Arnaud Caubel *4
Guy Brasseur *5 ・ Erich Roeckner *5 ・ Marco Giorgetta *5 ・ Luis Kornblueh *5
Monika Esch *5

*1 Frontier Research System for Global Change

*2 Earth Simulator Center

*3 Istituto Nazionale di Geofisica e Vulcanologia (INGV)

*4 Institut Pierre Simon Laplace (IPSL)

*5 Max Planck Institute for Meteorology

In this project, a reasonably high resolution coupled GCM SINTEX-FRSGC (SINTEX-F1.0: ECHAM4.0/5 AGCM + OPA 8.2 OGCM + OASIS/PRISM Coupler) will be developed under the EU-Japan collaboration. Long model integration will be conducted to understand tropical phenomena IOD and ENSO, and their teleconnections. The coupled model also will be used in an intercomparison study with CFES to understand model biases, and in seasonal prediction experiments. Several model versions with variety of model resolutions will be tested before realization of a target resolution (SINTEX-F2.0: T255L191 ECHAM5 and 0.5˚ × 0.5˚ with 300 levels OPA). This will help us to investigate the role of model resolution in realistic simulation of global climate phenomena, intraseasonal oscillations, diurnal cycles in upper ocean, and in particular the derivative phenomena like ocean domes, eddies etc.

Keywords: SINTEX-F, IOD, ENSO, BIAS, PREDICTION

Scientific Achievements:

The first version of the coupled GCM SINTEX-FRSGC (SINTEX-F1.0: ECHAM4.0 + 2˚ × 1.5˚~0.5˚ OPA 8.2) developed under the EU-Japan collaborative framework was successfully integrated using the Earth Simulator. Results from the last 200 years of 220 years model run are analyzed. As reported in SINTEX (Gualdi et al., 2003), the SINTEX-F1 showed remarkable skill in simulating ocean-atmosphere conditions related to the IOD and ENSO: model statistics compare very well with that of the observed data available for the last 50-years. The eastern pole of the SST anomaly in the model IOD is found to intrude into the central part of the basin. Therefore, the western box (40˚–60˚E, 10˚S–10˚N) used in deriving the model dipole mode index (DMI) is slightly different from that for the observation (50˚–70˚E, 10˚S–10˚N) (Saji et al., 1999). This model bias will be investigated through intercomparison of various available CGCMs. The standard deviation of the model DMI is 0.5˚C that is slightly higher compared to the observed DMI, whereas the model Niño-3 standard deviation is 0.8˚C that is similar to the observation. As in the observation, more than 70% of IOD model events are not accompanied by ENSO events in the Pacific. Composite of pure IOD/ENSO events and partial correlation analyses of the model results confirmed the observed independent nature of the IOD in the Indian Ocean. Analysis of observed and model results showed that the subsurface equatorial long Rossby waves play a major role in strengthening SST anomalies in the central and western parts of the basin during IOD events. The SINTEX-F1 model results support the observational finding (Rao et al., 2004) that these equatorial Rossby waves are coupled to the surface wind forcing associated with

IOD rather than ENSO (Yamagata et al., 2004). The ENSO influence is only distinct in off-equatorial latitudes south of 10˚S. Through changes in atmospheric circulation and water vapor transport IOD event causes world-wide climate variability. The SINTEX-F model results confirmed the observational findings that IOD dominantly influences the East African short rains (Behera et al., 2003). The model also captured most of the observed pattern of IOD teleconnections (Fig. 1): positive IOD induces drought in Indonesia, above normal rainfall in India, Sri Lanka, Bangladesh and Vietnam, and dry as well as hot summer in Europe, Japan, Korea and East China. In the Southern Hemisphere, the positive IOD causes dry winter in Australia, and dry as well as warm conditions in Brazil (Yamagata et al., 2004).

The annual ENSO was also reproduced by the SINTEX-F1 model (Tozuka et al., 2004). Many features of the annual ENSO, such as the classical El Niño that triggers an air-sea interaction in the eastern equatorial Pacific, a westward expansion of sea surface temperature anomaly (SSTA), a westward propagation of sea surface height anomaly along 5˚N, are reproduced. However, in contrast to observation, the northward expansion of SSTA in the eastern tropical Pacific stays south of the equator. This is because the model generates unrealistically strong Rossby waves in the south-eastern tropical Pacific, which reflect at the western boundary and intrude into the eastern equatorial Pacific. Changes in the amplitude of SSTA for the annual ENSO mode is reproduced in the model, but its variance is about 20% of the observation; this is again due to the lack of northward migration of seasonal SSTA in the equatorial region and weaker coastal Kelvin waves along South America.

The evolution mechanism of the IOD and ENSO is far from fully understood. In several occasions it is found that models fail to capture the phase and amplitude of these tropical climate anomalies. Therefore, to understand the tropical ocean-atmosphere interaction, part of our study focuses on the mixed layer processes including the barrier layer (BL) in the ocean. This year, we attempted to validate model simulated BL structure with observations and previous studies. In agreement with observations, a thick BL (more than 20 m) is observed in the model: (1) in the northern part of the Bay of Bengal from July to March with a maximum extent in January-February, (2) in the south-eastern Arabian Sea in January-February and (3) offshore of Sumatra in December-January. In agreement with Masson et al. (2002), off Sumatra, the BL variability is controlled by intraseasonal and interannual variability of the Wyrtki jet. The formation mechanisms explored in previous studies are found well-simulated in the coupled model. Regarding to the potential impact of the BL on the climate, we found, in agreement with recent study of Durand et al. (2004), that in the south-eastern Arabian Sea the thickness of BL maximum lead SST maximum by about 1 month suggesting a significant impact of BL through the trapping of heat bellow the mixed layer. From December to February, vertical inversion of temperature of more than 2 degree is located in the northern part of the Bay. Regarding the interannual variability, the coupled model shows similar results in comparison with the study of Masson et al. (2004) suggesting the positive impact of equatorial shallow salinity stratification on the IOD amplitude. Our future works will add quantitative results by performing model sensitivity experiments.

Besides enhancing the understanding of variability on seasonal (e.g. annual ENSO) to interannual scales (IOD and ENSO), the model simulation results also helped in the understanding of decadal scale phenomena. For example, the

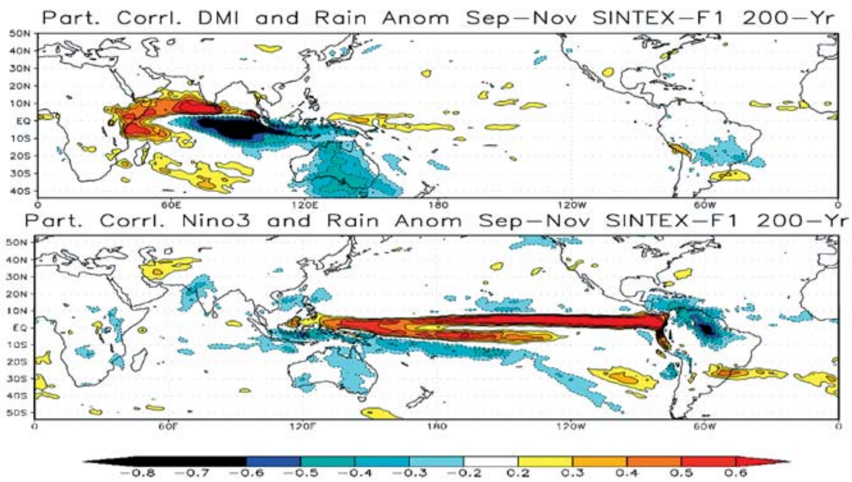

Fig. 1 Partial Correlation of model DMI with rainfall anomalies taken from Yamagata et al., (2004). The upper panel shows the partial correlation of the model DMI with the rainfall anomalies (where the Niño-3 influence is removed from the correlation) and the lower panel shows the corresponding partial correlation for the Niño-3 index (where the DMI influence is removed from the correlation). Shaded values are statistically significant at 99% level using a 2-tailed t-test.

South Pacific origin of the decadal ENSO is further confirmed from the simulation results (Luo et al., 2003). The physical mechanisms responsible for the decadal ENSO-like phenomenon are quite controversial and remain as a great challenge. Recent observational studies have shown pronounced subsurface signals moving from the South Pacific to the equatorial region, probably favored by the absence of the potential vorticity barrier in the Southern Ocean. The SINTEX-F1 model reproduces realistic decadal variability involved with the South Pacific ocean-atmosphere processes. Remotely forced by the tropical warm (cold) SSTAs, a southeast-northwest tilted atmospheric cyclone (anticyclone) appears in the South Pacific. This induces the same SE-NW tilted Ekman upwelling (downwelling) along the northeastern edge of the anomalous circulation, and gives rise to cold (warm) subsurface temperature (Tsub) there. The South Pacific Tsub acts as an external thermal source to discharge/recharge the tropical ocean, thus, inducing decadal fluctuations of the ENSO-like phenomenon. The present coupled model results confirm in general the observational findings (Luo and Yamagata, 2001). Besides, the model reproduces amazingly a high lagged-correlation between the global land surface temperature and the decadal Nino3 SST.

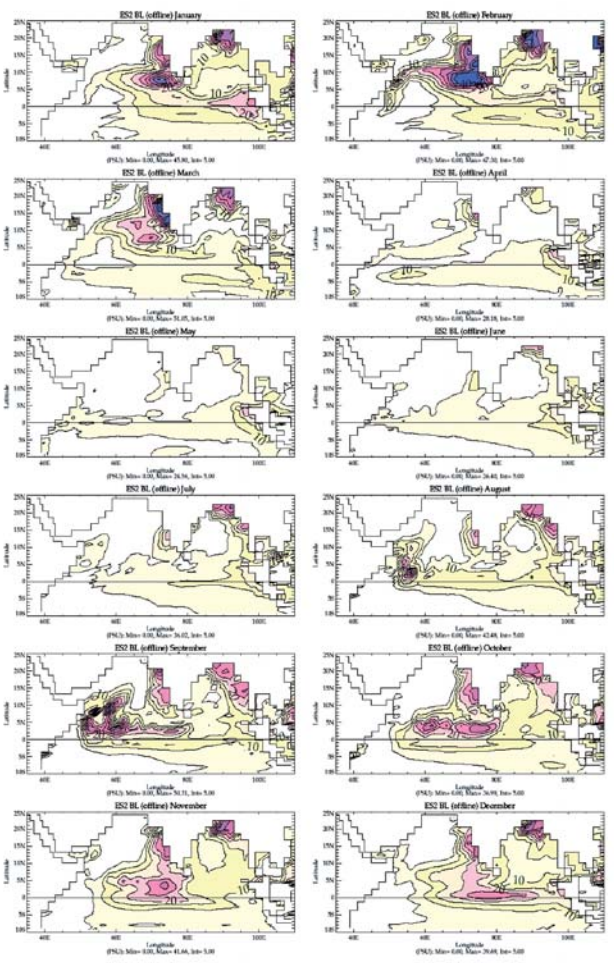

Fig. 2 Seasonal barrier layer structure in the Indian Ocean as simulated by SINTEX-F1.

Despite the model biases, this suggests a potential prediction skill of the global warming based on the ENSO-like decadal variation.

For extending our knowledge of the climate variability to the benefit of the society, we have implemented several seasonal hindcast experiments using SINTEX-F1 for the period 1982-2001 with different coupling physics for each run. The initial conditions were provided by using a simple coupled SST-nudging scheme after 11-year spinup of the CGCM. This scheme generates realistic subsurface signal and zonal wind stress along the equatorial Pacific and captures events of intraseasonal wind bursts. The CGCM gives a skillful ENSO prediction over one year lead time with the highest skill appearing in the central tropical Pacific. Especially, the strongest 1997/98 El Niño event was predicted quite well with model Nino-3 amplitude close to the observation. The spatial pattern of predicted ENSO SST anomaly in the eastern Pacific is similar to the observation with a broad meridional structure. Concerning the global precipitation changes associated with the ENSO, the model also realistically predicted, up to 9-month lead time, the rainfall anomalies in the Indo-Pacific regions, the East Asian area, the American continents and the tropical Atlantic not only for the winter (DJF) season during the peak of ENSO but also for the summer (JJA) season after the ENSO peak.

Further Technical Developments:

Several developments of OPA have been done to prepare the next version of the coupled model. First we implemented the ORCA05 configuration with a horizontal configuration of 0.5 degree on the whole planet. Second, in order to investigate the impact of the diurnal cycle in the climate variability, we develop in collaboration with French Laboratories and the Earth Simulator a model configuration with very high vertical resolution of 300 levels with one meter resolution in the upper 150 m of the ocean. Besides the expected scientific results, this new version of the ocean model greatly improves parallelization performances essential for the high performance computing on the Earth Simulator. We are now able to use efficiently 16 nodes of the ES (with a V.op.R of 99.3% and a mean speed of 2.64 GFLOPS for each CPU)

The newer version of the AGCM ECHAM5.2 is made available to us by the Max Planck Institute for Meteorology (MPI). The model is adapted to the Earth Simulator with the collaborative effort with MPI. We are able to use now 30 nodes using this new version of the AGCM. We also plan to develop a high resolution version of the AGCM for the Earth Simulator in collaboration with the MPI researchers.

We appreciate the support extended by the Earth Simulator Center in achieving our project goals.

References

Behera, S. K., J.-J. Luo, S. Masson, T. Yamagata, P. Delecluse, S. Gualdi, and A. Navarra, Impact of the Indian Ocean Dipole on the East African short rains: A CGCM study. *CLIVAR Exchanges*, 27, 43–45, 2003b.

Durand. F, S. R. Shetye, J. Vialard, D. Shankar, S. S. C. Shenoi, C. Ethe and G. Madec, 2004: Impact of temperature inversions on SST evolution in the south-eastern Arabian Sea during the pre-summer monsoon season. *Geophys. Res. Lett.*, 31, L01305, doi: 10.1029/2003GL018906

Gualdi S., E. Guilyardi, A. Navarra, S. Masina, and P. Delecluse, 2003: The interannual variability in the tropical Indian Ocean as simulated by a CGCM. *Clim. Dyn*. 20, 567–582.

Luo, J.-J., S. Masson , S.K. Behera, P. Delecluse, S. Gualdi, and A. Navarra, and T. Yamagata, 2003: South Pacific Origin of the Decadal ENSO-like variation as reproduced by a coupled GCM, *Geophys. Res. Lett.*, 30, 2250, doi: 10.1029/2003GL018649.

Luo, J.-J., and T. Yamagata, 2001: Long-term El Niño-Southern Oscillation (ENSO)-like variation with special emphasis on the South Pacific. *J. Geophys. Res.*, 106, 22211–22227.

Masson S., P. Delecluse, J.-P. Boulanger, C. Menkes, 2002: A model study of the seasonal variability and formation mechanisms of the barrier layer in the eastern equatorial Indian Ocean. *J. Geophys. Res.*, 107, C12, 8017, doi:10.1029/2001JC000832

Masson S., J.-P. Boulanger, C. Menkes, P. Delecluse and T. Yamagata, 2004: Impact of salinity on the 1997 Indian Ocean dipole event in a numerical experiment. *J. Geophys. Res.*, 109, C02002, doi:10.1029/2003JC001807.

Rao, S. A., S. K. Behera, and T. Yamagata, 2004: Subsurface feedback on the SST variability during the Indian Ocean Dipole events. Dynamics of Atmosphere and Ocean (submitted).

Saji, N. H., B. N. Goswami, P. N. Vinayachandran, and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature* 401, 360–363.

Tozuka, T., J.-J. Luo, S. Masson , S. K. Behera, and T. Yamagata, 2004: Annual ENSO simulated in a coupled ocean-atmosphere model, *Dynamics of Atmosphere and Ocean* (submitted).

Yamagata, T., S. K. Behera, J.-J. Luo, S. Masson, M. Jury, and S. A. Rao 2004: Coupled ocean-atmosphere variability in the tropical India Ocean, *AGU monograph "Ocean-Atmosphere Interaction and Climate Variability"*, (in press).