Understanding and Forecasting High-Impact Phenomena in the Atmosphere and Ocean

Project Representative

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In order to get insights into the predictability and mechanisms of high-impact phenomena in the atmosphere and ocean, large-scale simulations have been performed on the Earth Simulator. Attentions are paid upon mid-latitude phenomena such as the predictability of jet streams in the ocean and atmosphere and the heavy precipitation caused by a typhoon. A local ensemble Kalman filter has been developed to provide a better analysis and ensemble perturbations. Local air-sea interactions of great interest have been found in a high-resolution, global, coupled atmosphere-ocean simulation for about five years. The outcomes of this project is expected to contribute to the society through improvement of forecast skills.

Keywords: predictability, data assimilation, cloud microphysics, local atmosphere-ocean interactions

1. Introduction

There has been an increasing attention to high-impact phenomena in the atmosphere and ocean in the mid-latitudes. Those phenomena often occur along the atmospheric and oceanic jet streams and under the influence from the tropics and high-latitudes. Although several papers have pointed out possible mechanisms for the atmosphere-ocean coupling characteristic to the mid-latitudes, there is still a lack of understandings. Societal needs for the improvement of the forecast of such phenomena are enormous due to concentrated population and economic activities there. Based upon the scientific interests and societal needs, this project focuses upon the predictability and process studies of high-impact phenomena in the atmosphere and ocean in the mid-latitudes.

2. Researches on the mechanisms and predictability

2.1 Ecosystem and predictability of the Kuroshio and Oyashio extension currents

The Kuroshio and Oyashio Currents separate from the Japanese coast to form eastward currents, called the Kuroshio and Oyashio Extension currents. These extension currents are accompanied by strong temperature and salinity fronts. Variations of these fronts can induce significant anomalies in water temperature and salinity, and influence variability in the marine ecosystem and climate around Japan.

Likely due to its very high spatial resolutions, our oceanic general circulation model OFES has succeeded to represent these frontal structures and to capture their interannual/decadal variations [Nonaka et al., 2006]. This motivates us to investigate the physical influences on the marine ecosystem using a simplified four-component ecosystem model embedded in OFES [Sasai et al., 2005]. The simulated result captures a typical pattern of phytoplankton concentration at surface, which is influenced by the meso-scale eddies, fine scale fronts, and filaments (Fig. 1). The spring bloom occurs in the Oyashio region and the south of Okhotsk Sea (Fig. 1a). The distribution is consistent with the sea surface temperature (SST) distribution below 4°C. The SST field may mainly control the distribution of phytoplankton since there is enough nitrate concentration for the spring bloom (Fig. 1b and 1c).

It is expected that the Kuroshio and Oyashio extension currents can be predictable as long as a few years since the variations of the frontal structure is due to the westward propagating Rossby waves that can act as the oceanic memory. In order to test this hypothesis, we have conducted fore-

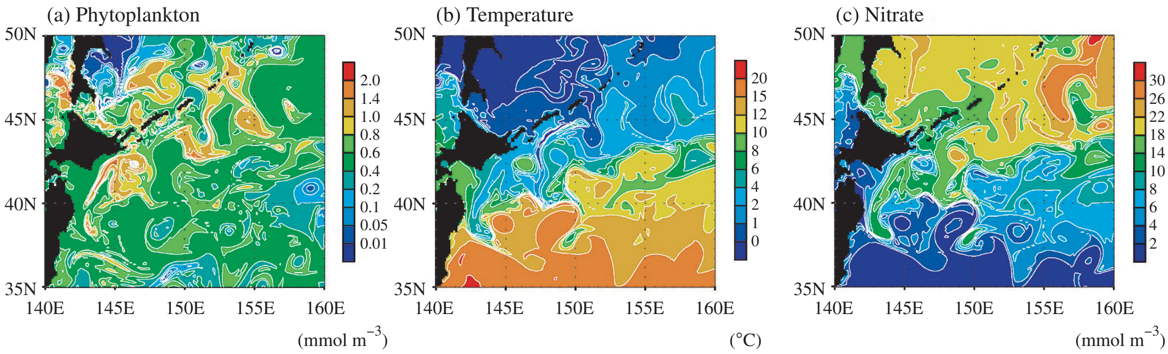

Fig. 1 The snapshots of (a) surface phytoplankton concentration [mmol m^{-3}], (b) SST [°C], (c) surface nitrate concentration [mmol m^{-3}] on April 11 in the northwestern Pacific.

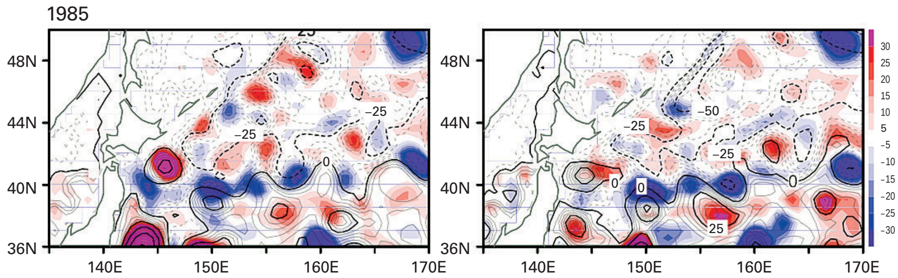

Fig. 2 SSH (contours, unit: cm) in January 1985 based in the OFES (left) hindcast integration and (right) prediction run. In the prediction run, climatological atmospheric forcing is given from January 1984 fields of the hindcast integration. Shadings show differences from the field in January 1984.

cast experiments with OFES by replacing the observed atmospheric forcing with the climatological values from some instants during the hindcast integration. Figure 2 compares predicted sea surface height (SSH) fields with those in the hindcast. Collocated SSH anomalies developed during one year (shadings) in the prediction (right) and hindcast runs (left) suggest that variations in the subarctic frontal region can be predictable at least for one year in this particular case. Further examinations of the gravest mode in the Kuroshio Extension region indicate that the gravest mode can be also predictable for about one year (not shown).

2.2 Ensemble experiments of the global atmosphere in July 2004

In order to study the predictability of atmospheric flows, ensemble experiments for a month from 1 July 2004 have been conducted using AFES at a T159L48 resolution. Figure 3 shows the anomaly correlation (AC) in terms of the geopotential height at the 200-hPa surface of the 25-member ensemble simulations using different surface boundary conditions in the northern-hemisphere mid-latitudes. The black curve represents the AC of the hindcast, where the daily analysis of the sea-surface temperature and ice are used. The red and blue lines represent the AC of the forecast and control runs, respectively. Both use the climatological boundary conditions except that the anomalies at the initial time are added and fixed in time for the forecast run. It is interesting to note that

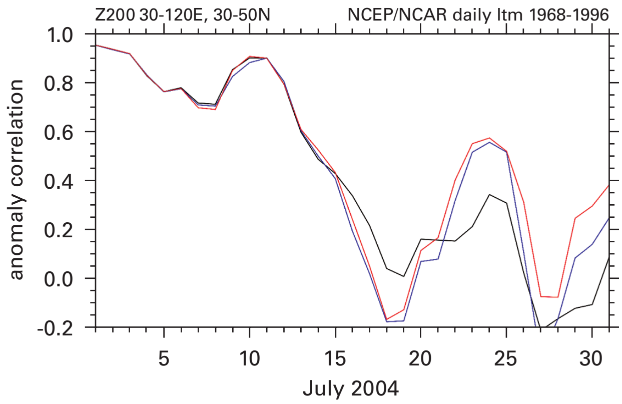

Fig. 3 Anomaly correlations of hindcast (black), forecast (red) and control (blue) ensemble experiments for July 2004 using AFES.

the time evolution of the AC of the forecast is close to that of the hindcast for the first two weeks but to that of the control in the latter half of the month. This result implies that a need for a realistic time evolution of the boundary conditions.

2.3 Mechanism of the torrential rainfalls in Kinki associated with typhoon Tokage

Precipitation is one of the primary concerns of high-impact weather events. The precipitation process of the typhoon Tokage (the 23rd typhoon in 2004) was simulated with CReSS (Cloud-Resolving Storm Simulator). The simulated precipitation is in very good accordance with the radar observation in terms of distribution and quantity. The latitude-height cross-section of condensates (Fig. 4) reveals that

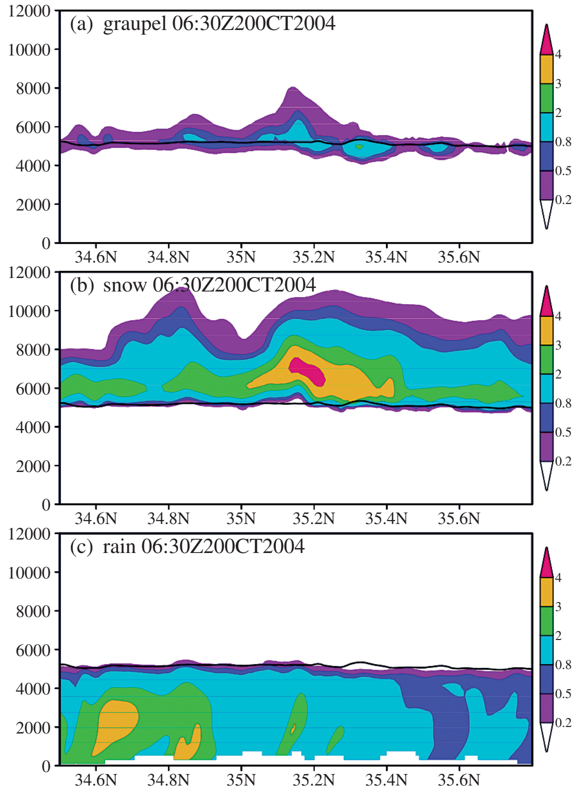

Fig. 4 Latitude-height cross-section of the distribution of (a) graupel, (b) snow, (c) rain [g kg^{-1}] in the simulation of typhoon Tokage (T0423) using CReSS.

the torrential rainfalls in Kinki area are not due to the convective origin but the chiefly the accumulation of snow in the middle troposphere.

3. Development of tools for the mechanism and predictability studies

3.1 Development of a data assimilation system using an ensemble Kalman filter

Initial conditions play an important role in the short-range numerical weather prediction (NWP). To consider the uncertainties in initial conditions, we have been developing a moist singular vector method for the ensemble prediction. In addition, to improve the accuracy of initial conditions and to generate ensemble perturbations well representing actual analysis errors, a local ensemble transform Kalman filter (LETKF, Hunt 2005) has been developed and assessed with AFES at a T159L48 resolution which corresponds to about 80 km horizontal grid and 48 vertical levels. Figure 5 shows an example of analysis by the newly developed AFES-LETKF assimilating real observations adapted from the Japan Meteorological Agency (JMA)'s operational NWP system. Figure 5 indicates the analysis fields by the AFES-LETKF and JMA's operational NWP show a good agreement, which supports the AFES-LETKF system works appropriately.

3.2 Development of a high-resolution global coupled model

With our global coupled atmosphere-ocean model CFES, a coupled atmosphere-ocean simulation at the high resolutions is conducted for five and half years. The Earth Simulator enabled us to employ resolutions of T239L48 (about 50 km in the horizontal and 48 vertical levels) for the atmosphere and 0.25° (about 25 km) and 54 levels for the ocean. As far as we learned this is the highest resolution attempted as a global atmosphere-ocean coupled model with appropriate physics.

The simulation results show many interesting phenomena not existed in the lower resolution simulations, such as air-sea interactions caused by local orography (Fig. 6) and ocean surface and sub-surface response to tropical cyclones. Among other phenomena, the atmospheric fluctuations localized over the Kuroshio front (Fig. 7) attracted our attentions since it is believed to be an important process that influences the predictability of the atmosphere and ocean in the mid-latitudes.

Another interesting feature is the interactions between explosively developing extratropical cyclones near Japan and the sea-ice over the Sea of Okhotsk. Cyclones tend to be formed over the Asian continent (the northwestern Pacific Ocean) and move eastward (northeastward) when the sea-ice area is large (small). This tendency is also consistent with the observational data. This result suggests that the simulation result with CFES is quite realistic and implies a possibility of

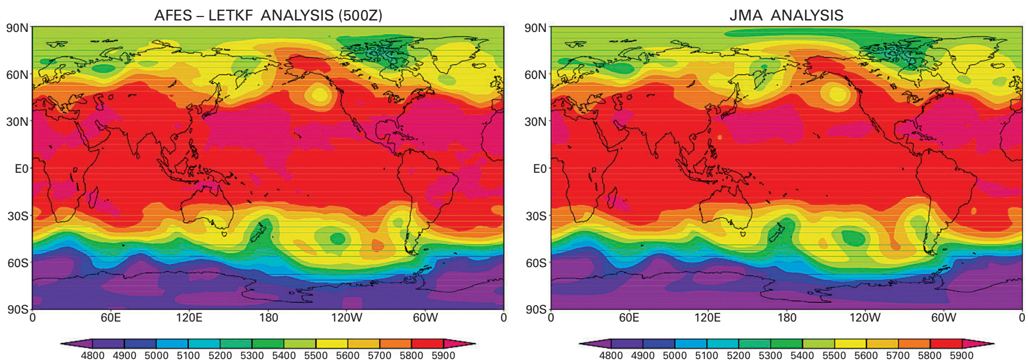

Fig. 5 500hPa height analysis fields [m] of AFES-LETKF (left panel) and JMA operational analysis (right panel) on 12Z August 16, 2004. The analysis cycle started from 00Z August 1, 2004.

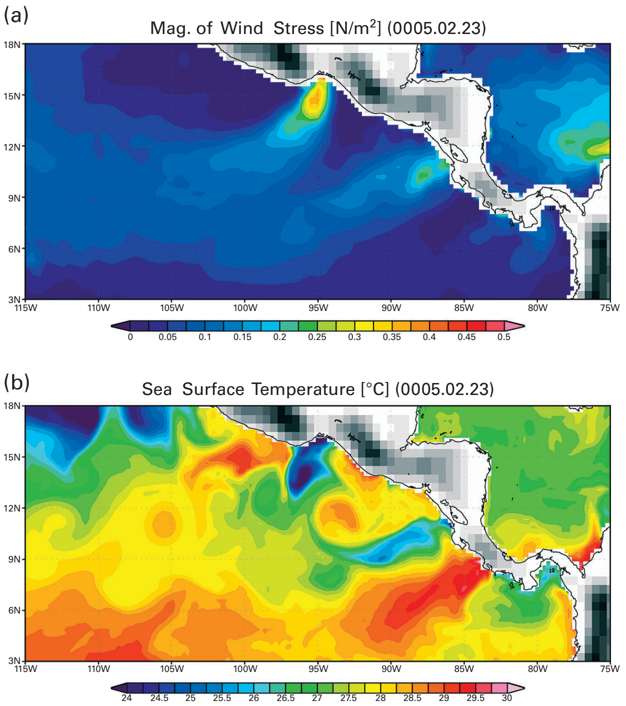

Fig. 6 Daily mean (a) magnitude of wind stress [N m^{-2}] and (b) sea surface temperature [°C] in February 23 of the model 5th year. Gray shades denote model topography.

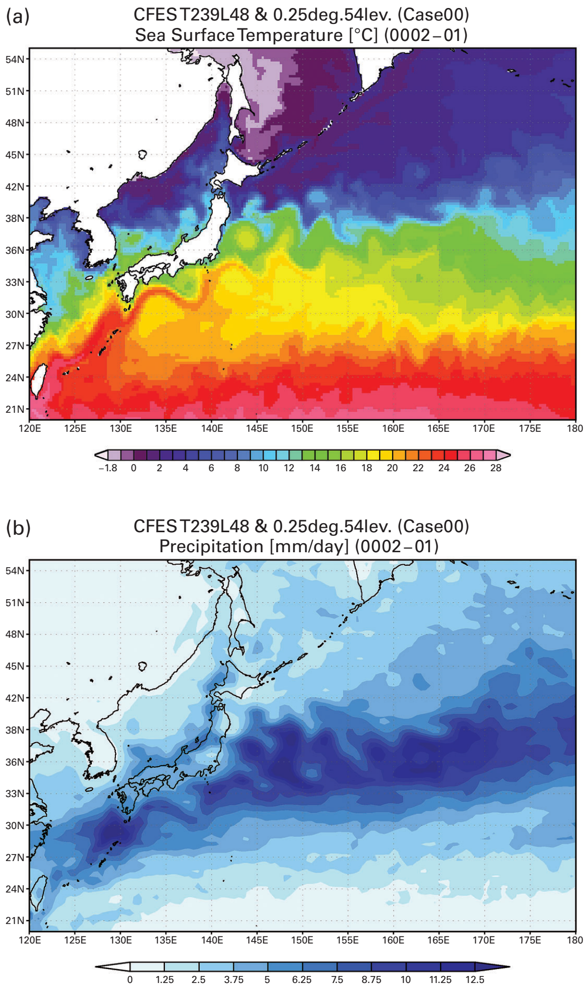

Fig. 7 Monthly mean (a) sea surface temperature [°C] and (b) precipitation rate [mm day^{-1}] in January.

seasonal predictions not only of the average fields but also of the statistics of the activity of cyclones with CFES in terms of the sea-ice area as accumulated effects of the cyclones.

4. Future works

The above outcomes motivate us to conduct further research and development. Ensemble experiments using AFES will be continued to address seasonal predictions in other seasons than the boreal summer, e.g., the boreal winter of 2005-2006 in particular. An experimental reanalysis will be performed with AFES-LETKF. CReSS will be nested within AFES to construct the AFES-CReSS hybrid system, where AFES and CReSS are responsible for the global flow and convections, respectively. The predictability of eddies and phytoplankton concentration in the Kuroshio and Oyashio extensions will be investigated with OFES and CFES by implementing the marine ecosystem model in CFES. These further studies will contribute to a better understanding of the mechanisms of the high-impact phenomena in the atmosphere and ocean, which is essential to improve their forecast skills.

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大気・海洋顕著現象の理解と予測

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大気海洋に発生する顕著な現象の予測可能性とメカニズムに関する知見を得るために、地球シミュレータ上で大規模シミュレーションを実行した。特に、大気・海洋の中緯度ジェットストリームの予測可能性や台風の上陸のような中緯度の現象に着目している。解析値とアンサンブル擾乱を改善するために、局所アンサンブル・カルマン・フィルタを開発した。約5年間の高解像度全球大気海洋結合シミュレーションには、興味深い局所的な大気海洋相互作用が見られた。このプロジェクトの成果は、予測スキルの向上を通じて社会に貢献するものと期待される。

キーワード：予測可能性, データ同化, 雲微物理, 局所大気海洋相互作用