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

Project Representative

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In order to pursue better understandings and predictions of high-impact phenomena in the atmosphere and ocean mainly at mid-latitudes, we conducted simulations of a typhoon and a tornado, predictability studies of precipitation in the Sahel and the Kuroshio Extension jet, and a global atmospheric data assimilation experiment with local ensemble transform Kalman filter during fiscal year 2006.

Keywords: tornadoes, soil moisture, Kuroshio Extension, predictability, data assimilation

1. Introduction

This study is a multi-year project that focuses on the predictability and process studies of high-impact phenomena in the atmosphere and ocean mainly at mid-latitudes. Some highlights from our studies during fiscal year 2006 are introduced below.

2. Simulations of Typhoon 0613 and an associated tornado

Typhoons occasionally accompany tornadoes and cause disasters due to strong winds. When the typhoon 0613 (T0613) approached the western Japan on 17 September 2006, it accompanied a severe tornado. It killed three people and caused a train accident in Kyushu. We performed two CReSS (Cloud Resolving Storm Simulator) simulations of T0613 and the associated tornado to reveal structure of clouds along the typhoon rainband and the mechanism of the tornado-genesis. The horizontal grid size is 500 m in the simulation of the typhoon, and the calculation domain is sufficiently large to simulate overall typhoon structure, including rainbands. A horizontal grid size of 75 m was used for the second simulation of a tornado within a supercell, which consists of a rainband.

The result of the second simulation shows that hook-shaped structure forms in the southernmost part of the supercell and that the intense tornado is simulated in the hook-

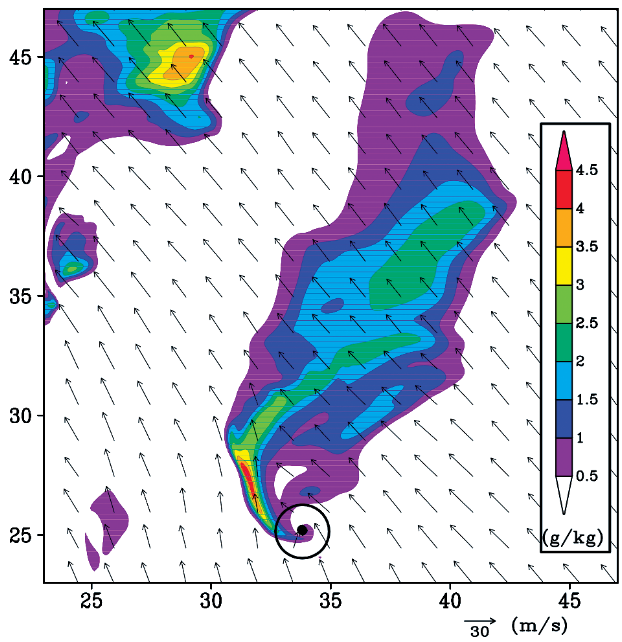

Fig. 1 Supercell cloud simulated in the experiment with a horizontal grid spacing of 75 m at 0500 UTC, 17 September 2006. Color levels indicate rain mixing ratio at 200 m in height. Arrows indicate horizontal velocity. The circle indicates that the tornado occurs in the southernmost part of the supercell. The abscissa and ordinate indicate east-west and north-south distances, respectively, in km.

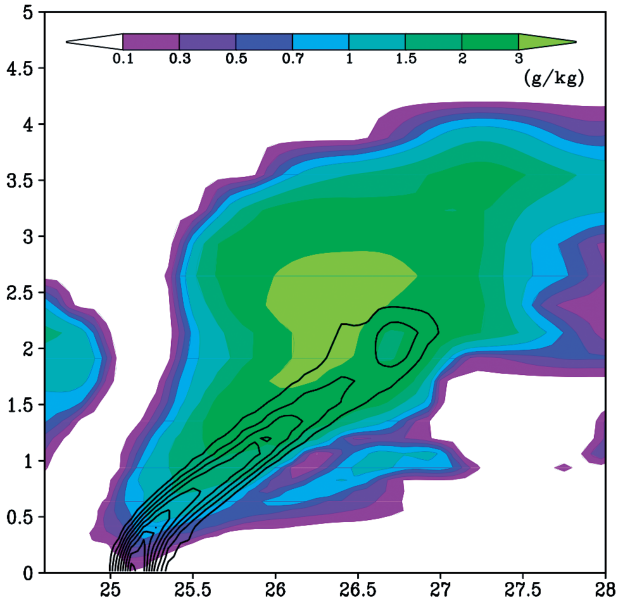

Fig. 2 Vertical cross-section of the tornado in the north-south direction. Contours are vertical vorticity drawn every 0.1 s^{-1} from 0.1 s^{-1} and color levels are cloud mixing ratio (g kg^{-1}). The abscissa and ordinate indicate north-south and vertical distances, respectively, in km.

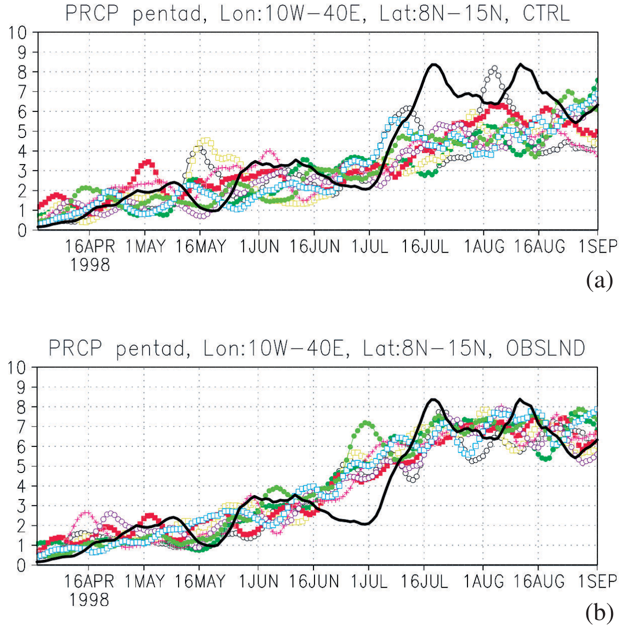

Fig. 3 Time series of eight sets of pentad precipitation (mm/day) over the Sahel Africa (10W – 40E, 8N – 15N) for CTRL (a) and SOIL (b) ensemble experiments. Black curves indicate GPCP data set.

shaped part of the supercell (Fig. 1). The horizontal diameter of the tornado is about 300 m and its maximum vorticity is larger than 0.9 s^{-1}. Pressure perturbation is about –24 hPa at the center of the tornado and maximum horizontal velocity reaches to 70 m s^{-1}. The vertical cross-section (Fig. 2) shows that the tornado extends up to a height of 2.5 km in strong upward motion. The simulation showed the detailed structures of the tornado and the supercell in the typhoon rainband.

3. Potential predictability studies

3.1 Precipitation variability associated with realistic subsurface soil moisture prescriptions

Subsurface soil moisture is known as one of the most prominent variables to have long memory in the climate system [1]. We conducted high-resolution simulations to investigate the potential predictability of precipitation variability associated with the realistic subsurface soil moisture prescription. The model we used is AFES (AGCM For the Earth Simulator) with T239 (horizontal resolution of about 50 km) spectral truncations. There are two types of ensemble experiments, named CTRL and SOIL. Both of the ensemble experiments consist of eight sets of simulations with different initial conditions and realistic boundary conditions. In CTRL experiment, the land and atmosphere interactions occur freely within the model system. Meanwhile in SOIL, a realistic subsurface soil moisture (5–400 cm depth from the land surface) is prescribed in every land surface grid cell and every time step. The realistic subsurface soil moisture dataset is produced by simulating an off-line land surface model with the GPCP (Global Precipitation Climatology Project) and other re-analyzed atmospheric forcing data [2]. It is assumed that the subsurface soil moisture is more realistic in SOIL.

Figure 3 shows time series of eight sets of pentad precipitation both for CTRL and SOIL in the Sahel (10W – 40E, 8N – 15N) from the beginning of April to the end of August. Black curves indicate the pentad GPCP. Three significant features can be found in Fig. 3. Firstly, the spread among eight ensemble members in SOIL is smaller than CTRL. Secondly, SOIL shows relatively drastic change of the onset from dry to rainy season. Thirdly, SOIL simulates similar precipitation as the GPCP in the middle of rainy season (July and August). These results suggest potential of the subsurface soil moisture to improve prediction skill of precipitation in the Sahel.

3.2 The Kuroshio Extension frontal variability

The Kuroshio Extension (KE) has recently been recognized as an important contributor to the North Pacific decadal variability. A multi-decadal (1950–2003) hindcast integration of eddy-resolving (0.1deg horizontal resolution) OFES (OGCM For the Earth Simulator) [3] provides an unprecedented opportunity to study low-frequency variability of the narrow KE jet. Here we analyzed the OFES hindcast to describe the spatio-temporal structure of the KE frontal variability and conducted the preliminary prediction experiment of the frontal variability.

The OFES hindcast captures the salient features of both the mean and interannual variance of sea surface height (SSH) compiled from multiple satellite observations (Fig. 4).

High interannual variance is concentrated within a narrow latitudinal band along the mean KE front. Figure 5 shows temporal evolution of the KE's latitudinal position and strength over the altimeter observation period as reflected in the first principal component (PC-1) of SSH zonally averaged over the KE region (142E–180E). The hindcast PC-1 tracks the observations remarkably well, and both show a full of decadal cycle.

Being a primary process for the temporal evolution of the front, the slow propagation of baroclinic Rossby waves can be a source of predictability. We perform a "prediction" run, in which the OFES is initialized with the hindcast field on 1 January 2000 and integrated forward under daily climatological atmospheric forcing. The resultant time series (blue curve in Fig. 5) closely follows the OFES hindcast as well as satellite observations for up to 9 months, including an initial decrease and the subsequent increase in PC-1. Although further ensemble experiments are necessary for a quantitative determination of useful lead time, this preliminary prediction result is consistent with Schneider and Miller [5], who use a one-dimensional Rossby wave model to predict large-scale temperature anomalies.

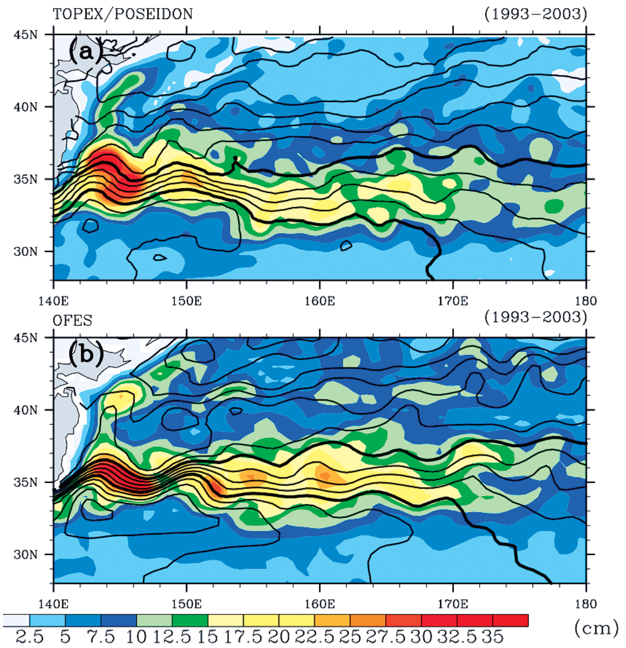

Fig. 4 (a) Standard deviation of 12-month low-pass filtered SSH observed by satellite altimeters (shade) and the mean absolute sea level (contours at 10 cm intervals; the 60 and 100 cm contours are thickened to delineate the KE frontal zone). (b) Same as (a) but for the OFES hindcast (the 30 and 70 cm contours for the mean SSH are thickened). Adapted from Taguchi et al. [4].

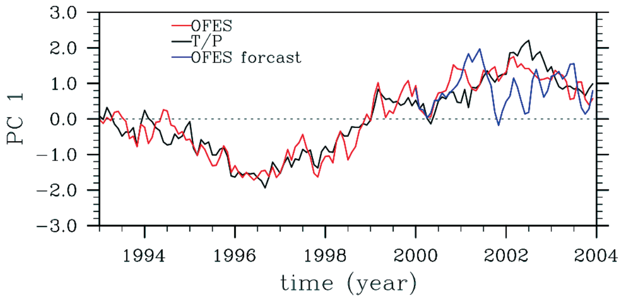

Fig. 5 OFES prediction from January 2000 (blue), obtained by regressing the zonally averaged SSH anomalies in the prediction run onto the first empirical orthogonal function of multi-decadal variations. Superimposed are PCs-1 for the OFES hindcast (red) and satellite altimeter observations (black).

4. Assimilation of atmospheric observations using the local ensemble transform Kalman filter

A data assimilation system using an ensemble Kalman filter (AFES-LETKF) was developed and tested fiscal year 2005. In the AFES-LETKF system, AFES generates ensemble first-guess values of the global atmospheric state, and the local ensemble transform Kalman filter (LETKF) developed by the Japan Meteorological Agency assimilates the atmospheric observations to produce the analyzed fields. Following the successful one-month tests [6], an experimental reanalysis has been conducted from 12 UTC, 1 May 2005 to obtain 40-member analysis dataset of more than 19 months. Real observations including surface-pressure, radiosonde and aircraft reports and satellite-based winds were assimilated using the LETKF generalized to four dimensions (4D-LETKF). We named this dataset ALERA (AFES-LETKF experimental reanalysis).

The dataset was verified against Climate Data Assimillation System (CDAS), the extension of the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis [7] toward the present. Although ALERA is disadvantageous in the stratosphere and high latitudes in the southern hemisphere due to the lack of the satellite radiance data, its ensemble mean is very close to the CDAS fields [6].

The ensemble spread of ALERA is an estimate of the analysis error. Such a flow-dependent error has not been available in the traditional reanalysis datasets. Examination of the structure and time evolution of the ensemble spread is expected to provide us new insights into the mechanisms and predictability of atmospheric phenomena. For example, the ensemble spread of the lower tropospheric winds seems to be large in convectively active regions such as the cloud bands surrounding a typhoon (Fig. 6).

We made ALERA available for research by the end of fiscal year 2006. We believe that ALERA encourages the predictability studies. Our future plans include another reanalysis using an improved AFES-LETKF, ensemble forecast experiments from ALERA, observing system experiments (OSE).

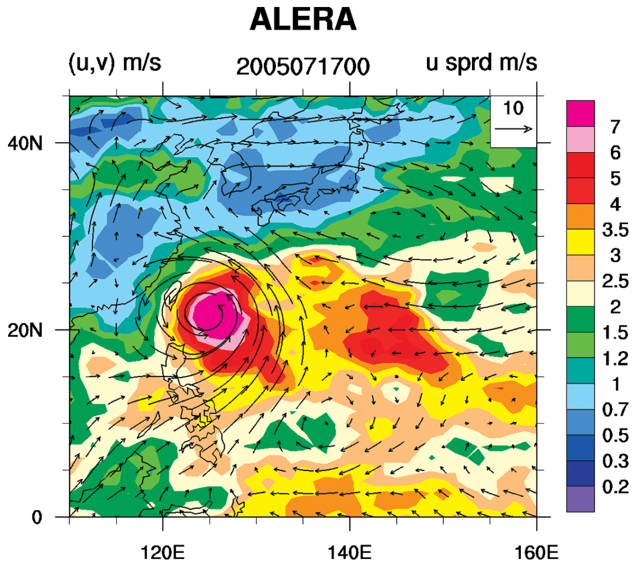

Fig. 6 The ensemble mean winds (m s^{-1}, vectors) and ensemble spread of the zonal wind (m s^{-1}, colour shades) at the 850-hPa surface at 0 UTC 17 July 2005 in ALERA.

5. Concluding remarks

Besides the reported above, we significantly upgraded our global coupled model, CFES. Future plans include further process studies of tornado-genesis with CReSS, predictability studies of the environment that is suitable for tornado-genesis with AFES, and upgraded atmospheric data assimilation, ALERA 2. We also plan long-integrations with CFES for better understanding of climate variability at mid-latitudes. These further studies shall contribute to not only scientific community but also public society in general through improvement in forecast skills.

Acknowledgement

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大気・海洋顕著現象の理解と予測

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主に中緯度の大気・海洋顕著現象のより良い理解とより良い予測のために、2006年度に行なった研究から次の四つを紹介する。1）台風とそれに伴う竜巻のシミュレーション。2）アフリカ、サヘルの降雨の季節予測可能性への土壌水分量の効果。3）黒潮続流域のジェットの予測可能性。4）局所アンサンブル変換カルマン・フィルタを用いた全球大気のデータ同化実験。

キーワード：竜巻, 土壌水分, 黒潮続流, 予測可能性, データ同化