Retrieval of Tropical Cyclone Statistics with a High-Resolution Coupled Model and Data

S. Zhang, M. Zhao, S.-J. Lin, X. Yang and W. Anderson

Geophysical Fluid Dynamics Laboratory/NOAA

Abstract

When observations are assimilated into a high-resolution coupled model, a traditional scheme that preferably projects observations to correct large-scale background tends to filter out small-scale cyclones. Here we separately process the large-scale background and the small-scale perturbations with low-resolution observations for reconstructing historical cyclone statistics in a cyclone-permitting model. We show that by maintaining the interactions between small-scale perturbations and successively corrected large-scale background, a model can successfully retrieve the observed cyclone statistics that in return improve ocean state estimates. The improved ocean initial conditions together with the continuous interactions of cyclones and background flows are expected to reduce model forecast errors. Combined with convection-permitting cyclone initialization, the new high-resolution model initialization along with the progressively advanced coupled models should contribute significantly to the ongoing research on seamless weather-climate predictions.

Introduction

1) Incomplete understanding on physical processes and imperfect numerical implementation make high-resolution climate models biased and modeled tropical cyclone (TC) climatology and variability turn out to be significantly different from the real world.
2) One attempts to estimate the historical climatological features and variability by assimilating observations such temperature and salinity into a coupled model, including the study on simulated TC climatology.
3) Due to the filtering nature of data assimilation and the coarse resolution of observations, while the large scale model background is corrected, the small scale model perturbations such as tropical cyclones are dispersed by the data assimilation process.
4) Questions: (1) What method can one use to correct model fields without causing a significant dissipation to model self-generated TCs so that the observation-corrected model can produce realistic TC statistics? and (2) What is the impact of the corrected TC statistics on climate state estimation and the implications to climate prediction?

Methodology

1. Model: GFDL CM2.5 – ½° x ½° Atmosphere on cubic sphere and ¼° x ¼° Ocean MOM4p1
2. Data: 1999 – 2011 AVHRR gridded SSTs and NCEP/NCAR reanalysis temperature and winds as well as surface pressure.
3. Assimilation method: A simple nudging scheme to address the issues proposed in the introduction.
4. Background adjustment scheme (BGA): Before observations are applied to adjusting the model fields, the model first guess is separated as two parts – large scale background and small scale perturbations (using CT as the characteristic scale).
5. BGA results are compared to the results produced from traditional full value data assimilation (TDA) scheme.

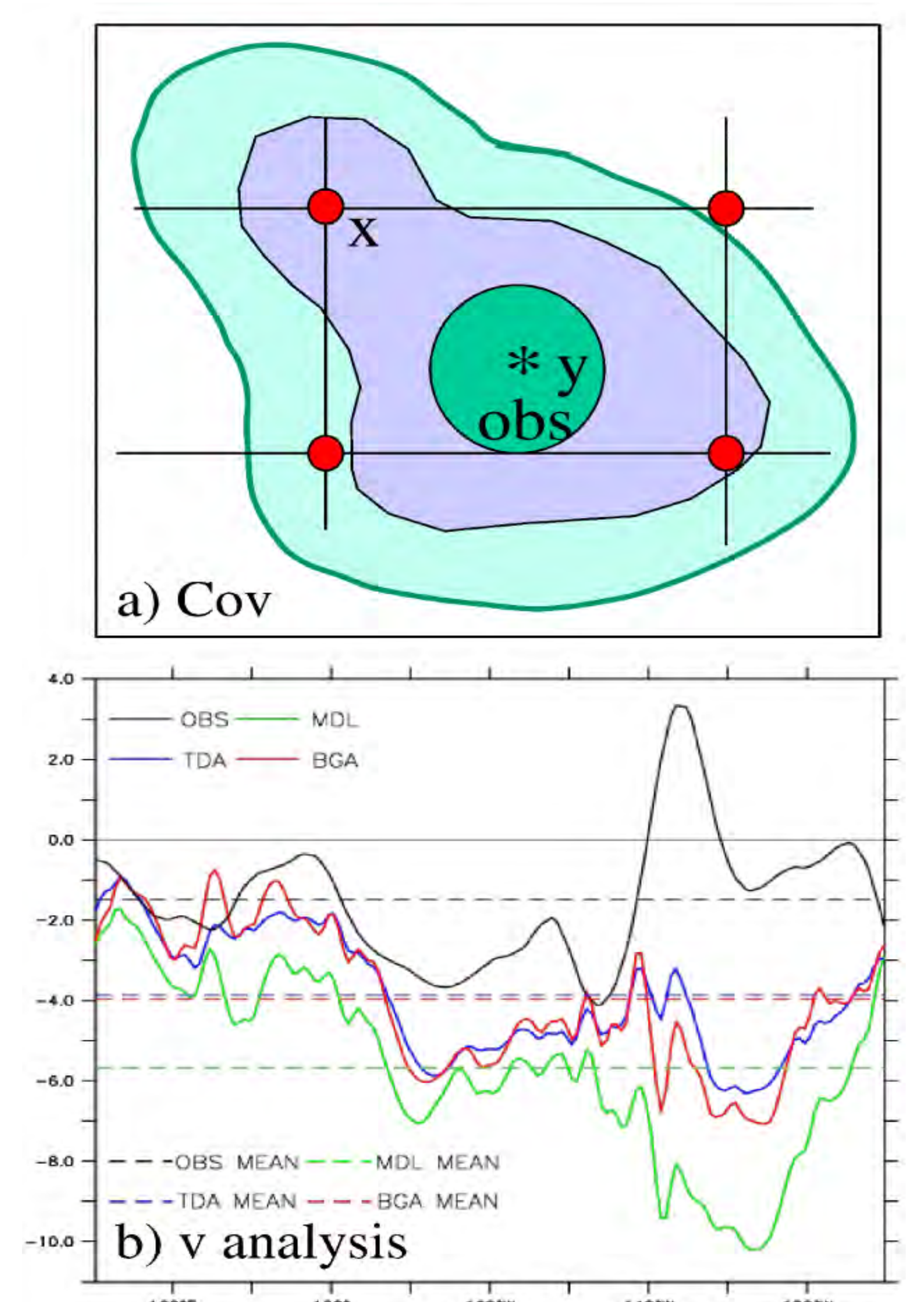

Fig. 1. The filtering of small perturbations in traditional data assimilation (TDA) and the maintenance of small perturbations in background adjustment scheme (BGA). a) The schematic of covariance (color-shaded) projecting an observational increment (computed from the observed value y and the model background) at the observational location (denoted by a black asterisk) onto the model variable x distributed on the model space (denoted by red dots). The shaded colors from green, grey to light-green schematically represent the decrease of covariance values. b) Zonal variations of v-velocities at the bottom model level along with 10°N longitudes before (green) and after the first step of traditional data assimilation (TDA, blue) and background adjustment (red) analysis. The "observations" (the NCEP/NCAR reanalysis, denoted as OBS) is plotted by a black curve in panel b.

Results

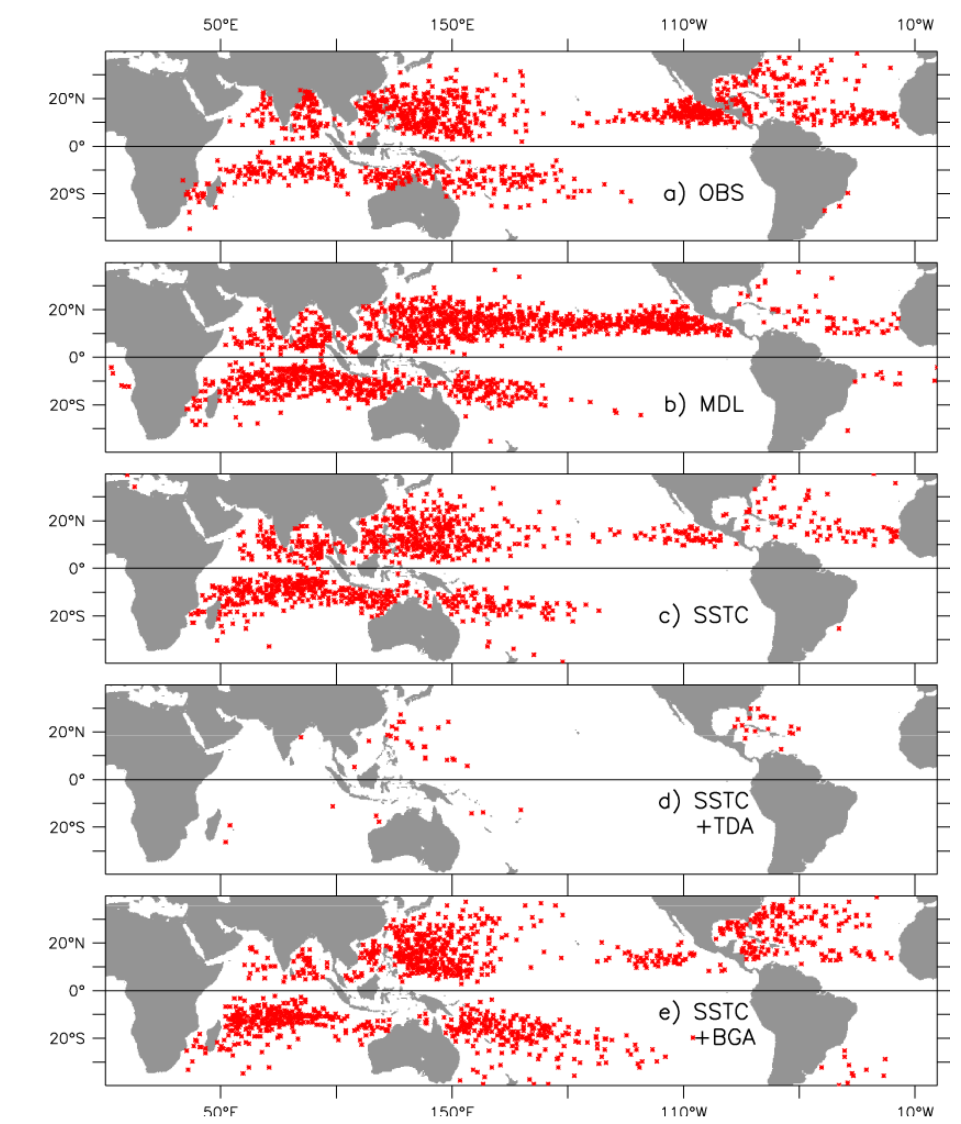

Fig. 2. Tropical cyclone (TC) genesis locations in the observations, model and 3 assimilation analyses. The spatial distribution of TCs in a) observations (OBS), b) model simulation (MDL), c) sea surface temperature constraint (SSTC), d) SSTC plus traditional atmospheric data assimilation (SSTC+TDA) and e) SSTC plus background atmospheric adjustment scheme (SSTC+BGA). The global TC records are taken from the IBTrACS (International Best Track Archive for Climate Stewardship) (Knapp et al. 2010; Kruk et al. 2010). The algorithm of detecting and tracking model storms follows the earlier work of Vitart et al. (1997) and Zhao et al. (2009).

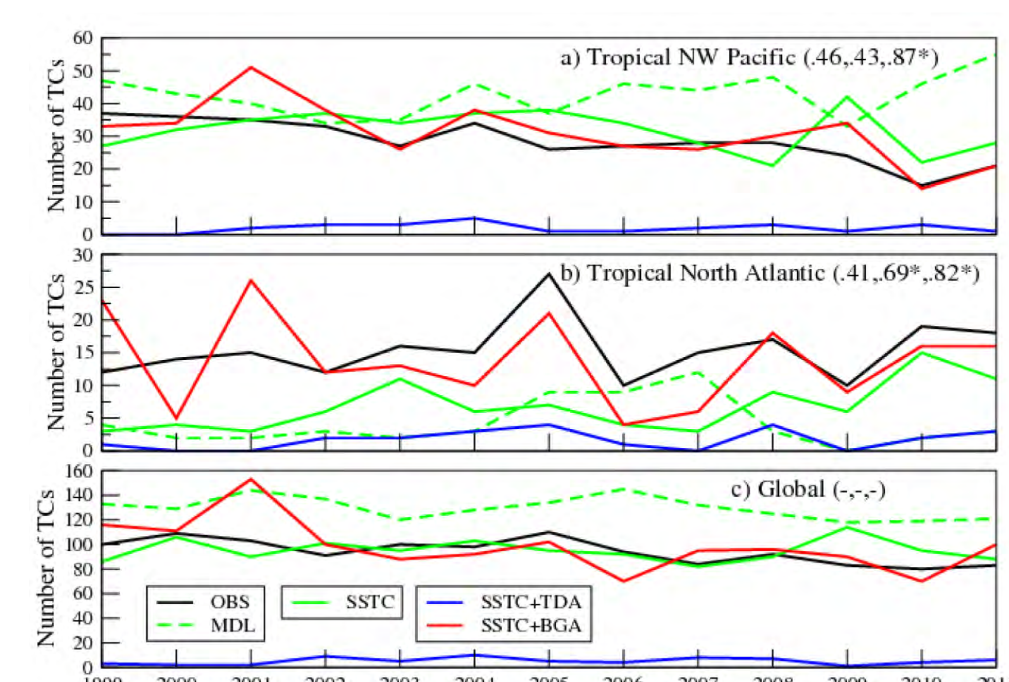

Fig. 3 The variations of tropical cyclone (TC) annual counts in two basins and global tropics. The time series of TC annual counts in the a) tropical Northwest Pacific (0-40°N, 120-180°E), b) tropical North Atlantic and c) global tropics for OBS (black), MDL (dashed-green), SSTCs (green), SSTC+TDA (blue) and SSTC+BGA (red). The three numbers by order in the parenthesis of panels a and b are the correlation coefficient between the modeled annual TC counts and the observations in experiments SSTC, SSTC+TDA and SSTC+BGA. A star indicates the correlation value with the significance above 95% confidence level. A "-" sign indicates no significant correlation existing.

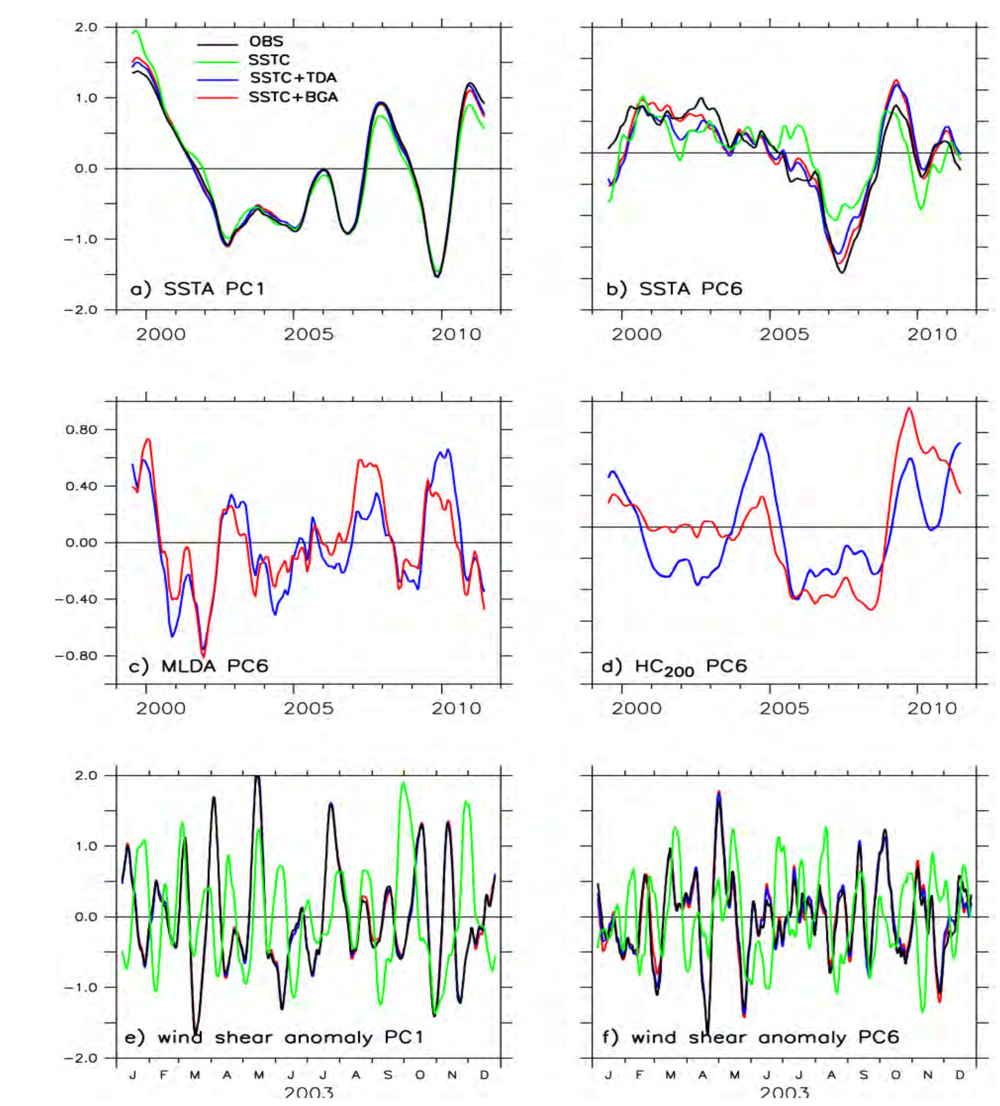

Fig. 4. Principle Component (PC) signals of anomalies of the sea surface temperature (SSTA), ocean mixing layer depth (MLDA), upper ocean (200 m) heat content (HC_{200}) (1999-2011) and atmosphere wind shear (January 2003-December 2003) in the observations, model and 3 assimilation analyses. The timae series of normalized ae) PC1 and bcdf) PC6 indices of monthly SST anomalies (panels a and b), monthly anomalies of ocean mixing layer depth (panel c), upper ocean heat content (panel d) and 6-hourly wind shear $[(u_{250}-u_{850})^2+(v_{250}-v_{850})^2]^{1/2}$ anomalies (panels e and f) in the tropical Pacific domain (120°E-80°W, 20°S-20°N) in the assimilation experiments of SSTC (green), SSTC+TDA (blue) and SSTC+BGA (red). In all panels, the corresponding observational (AVHRR SST and NCEP/NCAR reanalysis wind shear) indices are plotted by black lines. For visualization, all ocean (atmosphere) indices are performed a 12-month (10-day) running smooth. The EOF1 and EOF6 explain about 53% and 2% for the variance of SSTA, 11.7% and 3.1% for MLDA, 32.3% and 2.1% for HC_{200}, and 10.5% and 3.5% for wind shear anomalies.

Key Message

1. A high-resolution model can successfully retrieve the observed tropical cyclone (TC) statistics by the successively-corrected background interacting with small scale perturbations.
2. Corrected TC statistics improve ocean state estimates with better surface fluxes and enhanced mixing.
3. The improved ocean initial conditions together with the continuous interactions of TCs and background flows are expected to reduce model forecast errors.
4. Combining correct TC statistics with convection-permitting cyclone initialization opens a door for seamless weather-climate predictions.