Reanalysis dataset of the western North Pacific tropical cyclones in 2005 - 2008

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1. Introduction

Significant improvements in tropical cyclone (TC) track forecasts are witnessed in past decades (WMO 2006). But it is not the case for intensity forecasts, which may be mainly due to the lack of accuracy in TC structure and intensity analyses.

The TC intensity analyses generated by either the operational models such as GFS or WRF 3D-Var assimilation is usually much weaker than the observed when TC is strong.

In this paper, a combined tropical cyclone dynamic initialization (TCDI) and three-dimensional variational (3D-Var) assimilation method (TCDI/3DVar) was used to get more realistic analyses of TC vortex. A scheme based on the method was applied to reanalyze the TCs in the western North Pacific (WNP) and the South China Sea from 2005 through 2008. This work has been sponsored by the U.S. Office of Naval Research under Grant N000140710145 and N000140810256.

2. Methods

The TCDI/3DVar method is firstly integrating a forecast model forward from a bogus TC vortex, nudging towards the observed TC central minimum sea level pressure (CMSLP) and the three-dimensional heating field constructed with the observed precipitation and the empirical vertical profiles of heating rate. The forecast model is a hydrostatic primitive equation model with full nonlinear dynamics and physics (Wang 1999).

Once the first guess of TC vortex, i.e. the forward integration of the model is combined with first guess of environment, a 3D-Var assimilation method (Lorenc 1986) is applied to get the realistic and consistent TC analyses with the combined first guess fields.

3. Scheme

Based on the TCDI/3DVar method, a TC reanalysis scheme was developed, involving in two sets of software, the TCDI package and the Version 3.1.1 release of WRF ARW modeling system, including the WRF 3D-Var data assimilation system. They are applications of TCDI and 3D-Var methods respectively.

The reanalysis scheme is generalized as follows:

Step 1: Prepare first guess fields for WRF 3D-Var

When the observed CMSLP of TC is equal to or less than 997hPa, the TCDI package is used to generate the first guess of TC vortex. The bogus TC is constructed with the observed CMSLP by using a nonlinear balance equation (Wang 1995). The observed CMSLP as well as the TC tracks are from the Joint Typhoon Warning Center (JTWC) WNP best track data. The observed precipitation data are TRMM 3B42 3-hour rain rates, calibrations of the merged-precipitation derived from TRMM and other satellites, at a 0.25° by 0.25° spatial resolution.

The generated TC vortex is then combined with the environmental fields provided by NCEP final (FNL) operational analysis data to be the background for WRF 3D-Var. The 6 hourly FNL data from GFS are on 1°x1° horizontal grids and at 28 vertical pressure levels.

When the observed CMSLP is greater than 997hPa, only the FNL data are served as the first guess fields.

Step 2: Generate initial conditions for WRF ARW

The WRF 3D-Var system is implemented in this step. The data assimilated include in-situ observations, remotely sensed retrievals and satellite radiances, if available. The in-situ observations are SYNOP, TEMP, METAR, SHIP, BUOY, AIREP and PILOT. Retrievals assimilated include QuikSCAT sea surface winds, profiler winds, temperatures and humidities retrieved from AIRS and GPS, atmospheric motion vectors derived from geostationary satellite, SATEM thickness, etc. We directly assimilate the available satellite radiances detected by MHS boarding on NOAA-18, AMSU-A on NOAA-15, -16 and -18 as well as AMSU-B on NOAA-15, -16 and -17. For the reanalyzed TC in 2008, additional observations are assimilated, including wind profiles retrieved from the airborne 2μm Doppler lidar and observations from dropsonde deployed by the aircrafts of NOAA NRL-P3, US Airforce C-130 and DLR Falcon. All of them are field products of the THORPEX Pacific Asian Regional Campaign (T-PARC)/TCS-08 project.

Step 3: Prepare boundary conditions for WRF ARW

The lateral boundary conditions are calculated from the first guess fields created in step 1 and are updated to be consistent with the initial conditions, i.e. analyses produced by WRF 3D-Var in step 2. The lower boundary conditions are also obtained from the first guess fields.

Step 4: Forward integrate

A two-way nesting two-domain run of WRF ARW is used to obtain the final reanalyses. It is a 6-hour forward integration with hourly frequency of output. The coarse domain has 211x211 grids centered at 25°N/130°E (20°N/130°E for the TCs in 2008) at a resolution of 30km by 30km. The initial conditions and boundary conditions created above are on the coarse domain. The single nested domain is automatic vortex tracking. It has 151x151 grid points with a grid distance of 10km. Vertically, 28 η levels are defined. The main physical processes used in the run of WRF ARW are Grell 3D ensemble cumulus scheme, Lin et al. microphysics scheme, rapid radiative transfer model, Dudhia shortwave radiation sheme, Noah Land Surface Model and Yonsei University planetary boundary scheme.

In the scheme, each TC is reanalyzed at 00, 06, 12 and 18UTC. If the observed CMSLP at reanalysis time is equal to or larger than 1000hPa, the 0-hour WRF ARW outputs become the reanalyses. Otherwise, a strategy is used to decide which outputs of WRF ARW to be the reanalyses: For the TCs of 2008, the reanalyses are 1-hour forecasts initialized at reanalysis time. For the TCs in 2005-2007, the 1-hour forecasts initialized at 06/18UTC are always reserved as the reanalyses at initial time, while the reanalyses at 12/00UTC are the 6-hour forecasts valid at reanalysis time if the differences between the forecasted and the observed CMSLPs are less than 15hPa, otherwise the 1-hour forecasts initialized at reanalysis time.

4. Summary of reanalysis dataset

By using the scheme, 36 TCs in the western North Pacific and the South China Sea from 2005 through 2008 were reanalyzed and the reanalyses were archived in a reanalysis dataset. The followings are the summary on the dataset:

The reanalysis data are 6 hourly (00, 06, 12, 18UTC) and temporally cover the life cycles given by the JTWC best track data. However, for some TCs, the reanalysis periods may be a bit shorter than their life cycle.

The horizontal coverage is the nested domain, which is TC following, i.e. the reanalysis products are on 10km-by-10km grids with the observed TC position at corresponding reanalysis time being at the center of the domain. The data are vertically on the surface and at 21 pressure levels from 1000hPa to 100hPa.

Variables include time, latitude and longitude of grids, pressure level, surface pressure, sea level pressure, sea surface temperature, temperature at 2m, u- and v- wind component at 10m, geopotential height, temperature, relative humidity, u- , v- and z- wind component, water vapor, cloud water and rain water mixing ratio, reflectivity and max reflectivity.

One example of the reanalysis products is given in Fig. 1.

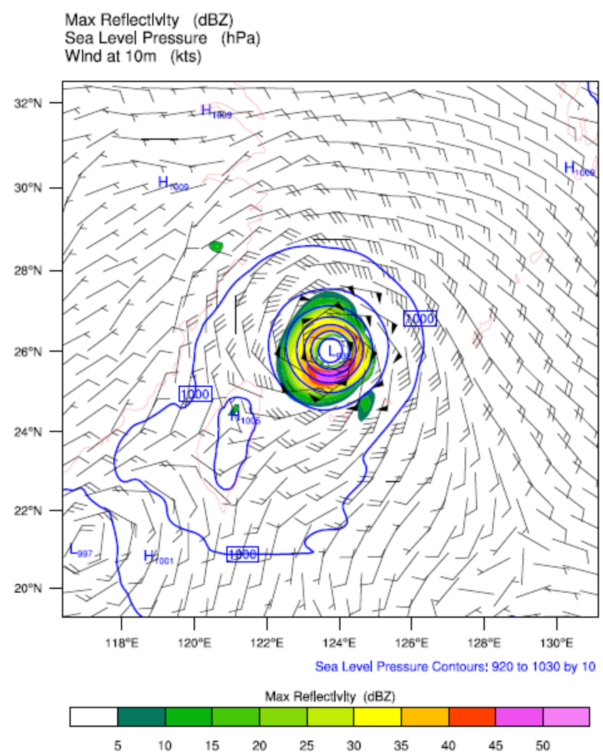

Fig. 1. Reanalyses of Saomai in Aug. 2006.

And a CMSLP comparison for Saomai in 2006 among the TCDI/3DVar reanalyses, the WRF 3D-Var analyses and the observed from

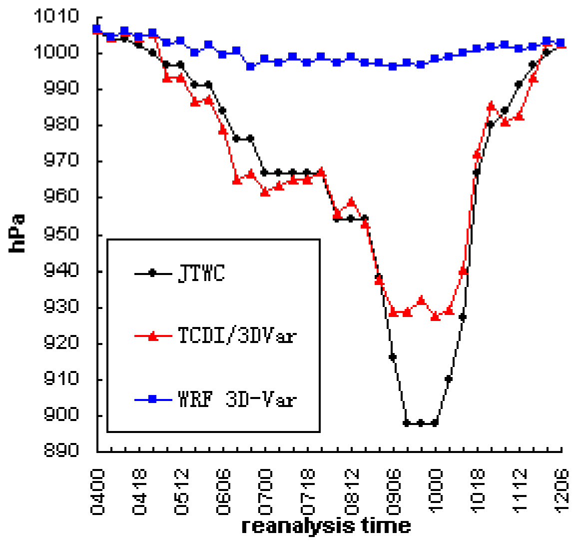

Fig. 2. CMSLP comparison for Saomai in Aug. 2006.

the JTWC best track data is given in Fig. 2. As it shows, when comparing with the observed CMSLPs, the intensity reanalyzed by the TCDI/3DVar method are much better than that created by using the 3D-Var method only, although there are still large differences as the observed CMSLPs are equal to or less than 910hPa. The awful performance of WRF 3D-Var maybe result from the first guess fields provided by the GFS FNL analyses, which can hardly represent the intensities of Saomai.

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