Impact of Representing Model Error in a Hybrid Ensemble-Variational Data Assimilation System for Track Forecast of Tropical Cyclone Hudhud (2014)

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INTRODUCTION

Uncertainties in Numerical Weather Prediction (NWP) models are generally not well represented in ensemble based data assimilation (DA) systems. The performance of an ensemble based DA system becomes suboptimal, if the sources of error are undersampled in the forecast system (Berner et al., 2015)

We investigated the effect of two types of model error treatment schemes and their combinations in hybrid ensemble transform Kalman filter (ETKF) – three dimensional variational (3DVAR) DA system

(i) Multiphysics approach which uses different combination of cumulus, microphysics and planetary boundary layer schemes (Meng and Zhang, 2007)

(ii) Stochastic Kinetic Energy Backscatter (SKEB) scheme which perturbs horizontal wind and potential temperature tendencies, stochastically (Shutts, 2005)

(iii) A combination of both Multiphysics and SKEB scheme.

More specifically, the impact of flow-dependent ensemble error covariances in a DA system with and without explicit model error representation for the track forecast of tropical cyclone (TC), Hudhud, is explored.

SYNOPTIC OVERVIEW

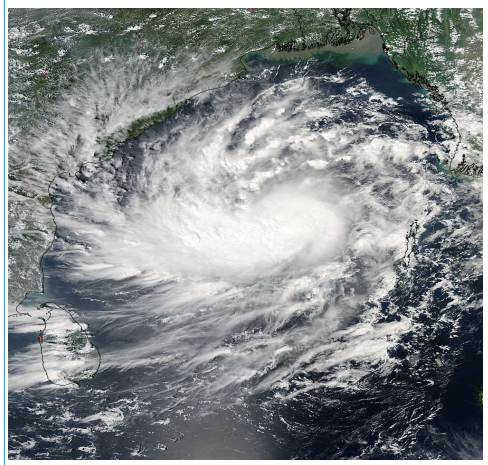

Figure 1: Hudhud cyclone as seen by MODIS Aqua Satellite

The TC considered in this study is Hudhud, which started forming as a low pressure system on October 6, 2014, over the Bay of Bengal region of North Indian Ocean.

On October 9, 2014, Hudhud was declared as a severe cyclonic storm just before it underwent rapid deepening and intensification.

Hudhud made a landfall on October 12, 2014, a few hours prior to which it attained a minimum central pressure of 950mb and a maximum wind speed of 175km/hr.

Hudhud cyclone caused extensive damages over the east coast of the Indian subcontinent

DATA ASSIMILATION SYSTEMS

(i) Three dimensional – Variational Data Assimilation System (3DVAR) (Barker et al., 2004)

(ii) Hybrid ensemble transform Kalman filter (ETKF) –3DVAR DA system. (Wang et al., 2008)

Model: Advanced Weather Research and Forecast (ARW WRF) - Version:3.6.1

Hybrid Cost function

$$J(x_1',\alpha) = \beta_1 \frac{1}{2} {x_1'}^T B^{-1} x_1' + \beta_2 \frac{1}{2} \alpha^T C^{-1} \alpha + \frac{1}{2} (y^{o'} - Hx')^T R^{-1} (y^{o'} - Hx')$$

B – 3DVAR static covariance; R – Observation error covariance; C - correlation matrix for ensemble covariance localization; x_1' - 3DVAR increment; x' - total (hybrid) increment; $y^{o'}$ - Observations; H - observation operator; β_1 - weighting coefficient for static covariance; β_2 - weighting coefficient for ensemble covariance; α - extended control variable from ensembles.

SKEBS

The SKEB scheme introduces temporally and spatially correlated random perturbations to potential temperature and a rotational component of horizontal winds.

$$\psi \quad (x,y,t) = \sum_{l=-L/2}^{L/2} \sum_{k=-K/2}^{K/2} \psi_{k,l}(t) e^{2\pi i (\frac{kx}{X} + \frac{ly}{Y})}$$

MULTIPHYSICS

The multiphysics ensembles, 40 in number, were created by the combinations shown below:

Cumulus Parameterization	Microphysics	Planetary Boundary Layer			
Kain-Fritsch	Kessler	YSU	MY	MRF	MYNN
	Lin et al				
	WSM3				
	Thompson				
Betts-Miller-Janjic	Kessler	YSU	MY	MRF	
	Lin et al				
	WSM3				
	Thompson				
Grell-Devenyi	Kessler	YSU	MY	MRF	
	Lin et al				
	WSM3				
	Thompson				

EXPERIMENTAL DESIGN

The first analysis time for all the experiments were at 00 UTC on October 8, 2014, and assimilated observations every 12 h intervals until October 9, 2014. The model was then integrated into free forecast mode, till the cyclone made the landfall.

Six experiments were conducted:

3DVAR - utilizes the static covariances for assimilating observations
HYBRID50 - 50% weight was placed on ensemble covariances and other 50% assigned on static covariances
HYBRID100 - 100% weight placed on ensemble covariances
HYBRID-Multi – ensembles uses multiphysics configuration
HYBRID-SKEB – ensembles uses SKEB scheme
HYBRID-MultiSKEB ensembles uses multiphysics and SKEB schemes

MODEL DOMAIN

The model is configured to have two domains with 27 km and 9km horizontal resolution and 36 vertical levels.
The spatial extent of the outer domain is mostly comparable to India Meteorological Department (IMD) operational domain in WRF model simulations.

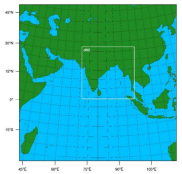

Figure 2: Model Domain

RESULTS

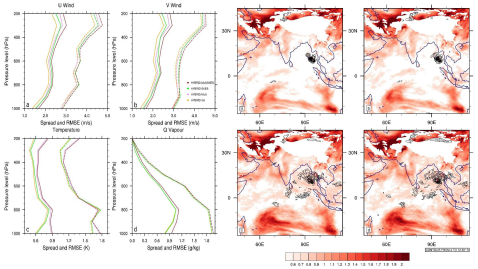

Figure 3: Spread (solid) and RMSE (dashed) with model error schemes SKEB (green), multiphysics (violet), combined SKEB and multiphysics (brown) and Hybrid100 (yellow)for variables (a) U-Wind (b) V-Wind, (c) Temperature and (d) Q Vapour

Figure 4: Geographical distribution of ensemble spread (a) HYBRID100 (b) HYBRID-SKEB (c) HYBRID-Multi (d) HYBRID-MultiSKEB for 850 hPa temperature (color) and 200 hPa wind speed (contours)

From the vertical profile of ensemble spread and RMSE, the ensemble system is found underdispersive which suggests that flow-dependent error covariances estimated from this ensemble system are possibly underestimated. SKEB scheme effectively increases ensemble spread for horizontal wind than using Multiphysics scheme.

However, for temperature and humidity Multiphysics scheme is found to be more effective than SKEB for treating underdispersive spread. The higher values of spread are mostly concentrated over the TC region. In comparison to SKEB scheme, higher ensemble spread values are seen over a larger spatial extent when multiphysics ensembles scheme is employed.

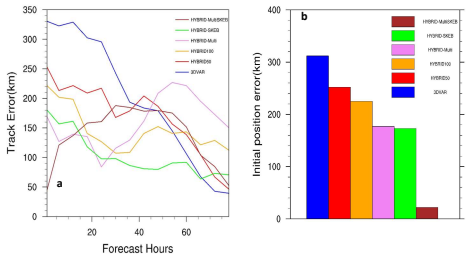

Figure 5: The track positions 3DVAR, HYBRID50, HYBRID100, HYBRIDSKEB, HYBIRDMulti and HYBRID-MultiSKEB experiments verified against the best-track data from (a) analyses valid at 00 UTC 9 October, 2014 (b) 78 h model forecast

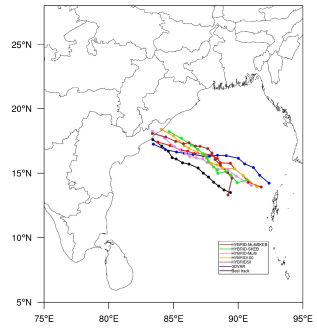

Figure 6: The 6 hourly tracks of 3DVAR, HYBRID50, HYBRID100, HYBRIDSKEB, HYBIRD-Multi and HYBRID-MultiSKEB experiments along with the best track data for 78 h of forecast

The 3DVAR analysis depicts largest error in initial TC position as compared to HYBRID analysis

The experiments which explicitly accounts for system error in HYBRID DA system shows considerable improvement in track forecast during the initial hours of the forecast

The HYRID DA system is significantly benefitted by using MultiSKEB model error scheme in simulating TC track position during the initial hours of the forecast.

CONCLUSION

Explicit model error representation is found to be beneficial in treating the underdispersive ensembles which results in substantial improvements in the track forecast of tropical cyclone initialized from a hybrid DA system.

Among all the model error treatment schemes used in this study, a combination of multiphysics and SKEB schemes has outperformed other two schemes with improved track forecast of a tropical cyclone.

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