Estimating the Impact of Satellite Winds for Tropical Cyclone Forecasts Using Ensemble Forecast Sensitivity Approach

Author(s)

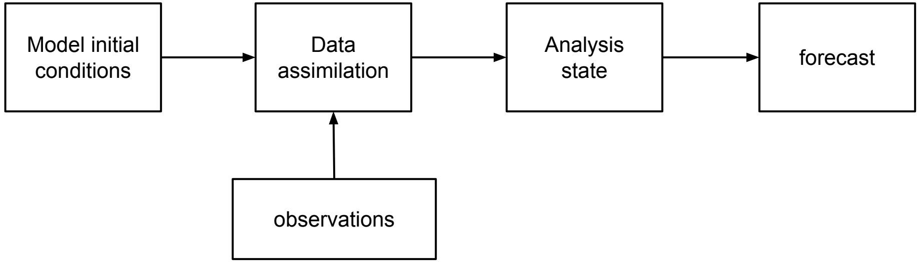
Noel Chawang[1] and G Kutty[1]

[1] Department of Earth and Space Science (ESS), Indian Institute of Space Science and Technology (IIST)

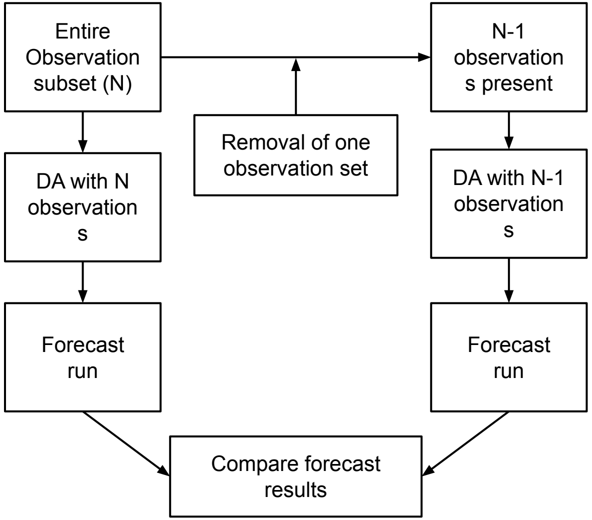
Presented By:

Noel M. Chawang
Email : chawang.noel@gmail.com

Observation impact

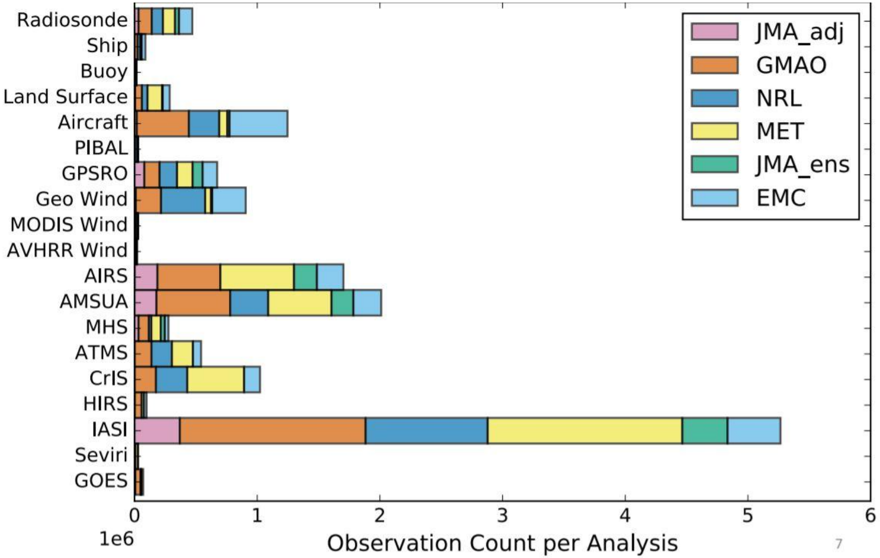


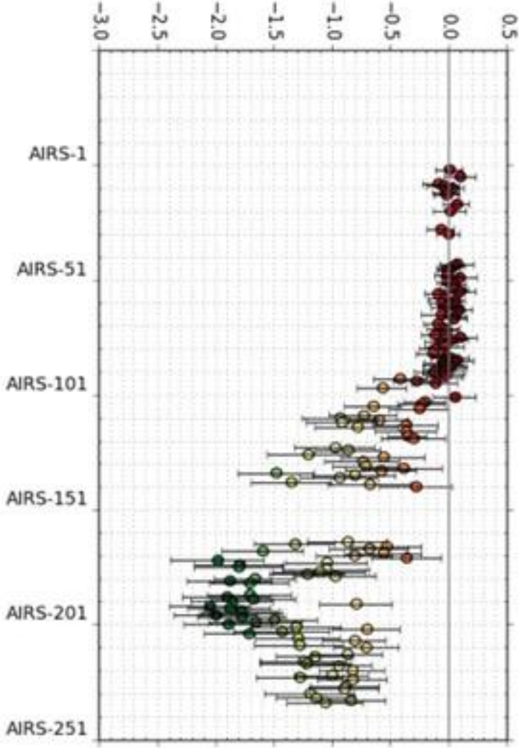
Data assimilation is how observations play a role in meteorological applications.



There are various ways of studying the observation’s impact, the **Observing System Experiments (OSEs)** is a well-known traditional method.

The problem with OSEs





The main problem that lies with OSEs are that with increasing observation system this method becomes **computationally expensive**.

AIRS no. of channels.

Rani et al. (2016)

The EFSO method

New ensemble method for observation impact

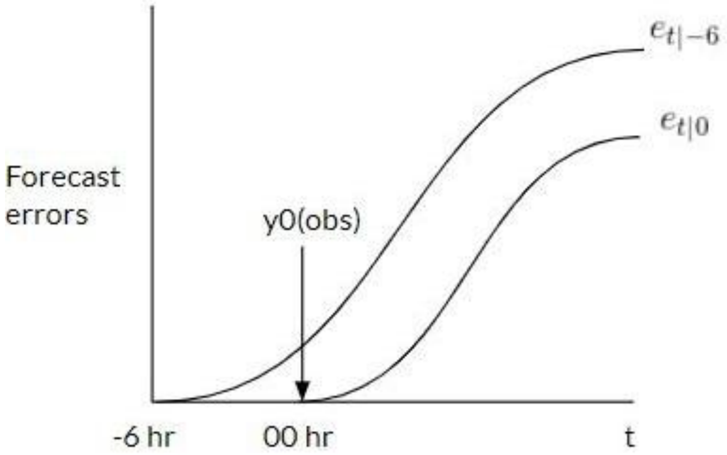
With OSEs being so computationally expensive, it brought forth a new method to study the impact observations have on the forecast. Kalnay et al (2012) following the Lui and Kalnay (2008) brought about a manner of finding out the positive or negative impact the observation through a simple formulation for **ensemble forecast sensitivity to observation (EFSO)**.

The ESFO method utilizes the ensemble perturbations as a means to estimate the observation's impact on the forecast.

$$\Delta e^2 = \frac{1}{K-1} \delta y_0^T R^{-1} Y_0^a X_{t|0}^{fT} (e_{t|0} + e_{t|-6})$$

EFSO Design

With the new EFSO method you require only **2 forecast runs**, one with assimilating the observations and one without to study the impact of all the observations that are being assimilated as long as you have the innovation vector and observation error covariance matrix.



EFSO formulation

We define our errors as such; $e_{t|0} = x^f_{t|0} - x^a_t \quad e_{t|-6} = x^f_{t|-6} - x^a_t$

From langland and baker the cost function to find positive or negative impact goes as:

$$J = \Delta e^2 = (e^2_{t|0} - e^2_{t|-6}) = [e^{t|0} e_{t|0} - e^T_{t|-6} e^T_{t|-6}]$$

And with short range forecast, $(x^f_{t|0} - x^f_{t|-6}) \simeq M(x^a_0 - x^b_{0|-6})$ and we know $\delta x_0 = (x^a_0 - x^b_{0|-6}) = K\delta y_0$

Here \delta y_0 is the innovation vector. Placing them in the equations we get;

$$\begin{aligned}
\Delta e^2 &= e^T_{t|0} e_{t|0} - e^T_{t|-6} e_{t|-6} \\
&= (e_{t|0} - e_{t|-6})^T (e_{t|0} + e_{t|-6}) \\
\Delta e^2 &= [M(\overline{x}^a_0 - \overline{x}^b_{0|-6}]^T (e_{t|0} + e_{t|-6}) \\
&= [MK\delta y_0]^T (e_{t|0} + e_{t|-6})
\end{aligned}$$

Adjoint method

$$\boxed{\Delta e^2 = \delta y_0^T K^T M^T (e_{t|0} + e_{t|-6})}$$

$$K = \frac{1}{K-1} X^a_0 X^{aT}_0 H^T R^{-1} \qquad Y^a_0 = HX^a_0$$

$$MK = \frac{1}{K-1} MX^a_0 X^{aT}_0 H^T R^{-1} \approx \frac{1}{K-1} X^f_{t|0} Y^{aT}_0 R^{-1}$$

EFSO method

$$\boxed{\Delta e^2 \approx \frac{1}{K-1} \delta y_0^T R^{-1} Y^a_0 X^{fT}_{t|0} (e_{t|0} + e_{t|-6})}$$

Forecast metric

For computing the observation impact with EFSO, A suitable forecast metric should be chosen, in this study the forecast metric is KE energy.

$$KE = \frac{1}{2}\frac{1}{D}\int_D \int_{\sigma_{bottom}}^{\sigma_{top}} [u^2 + v^2]\, d\sigma\, dD$$

Here u and v are the zonal and meridional wind components computed over the horizontal domain **D** between two levels.

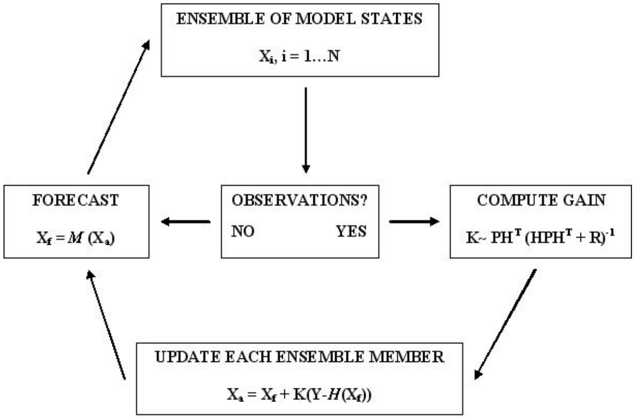
Interpreting cost function J

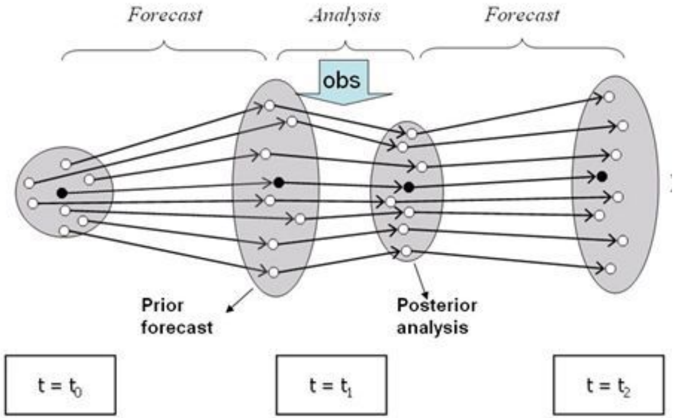
$$\begin{aligned}\Delta e^2 &= e_{t|0}^T e_{t|0} - e_{t|-6}^T e_{t|-6} \\ &= (e_{t|0} - e_{t|-6})^T (e_{t|0} + e_{t|-6})\end{aligned}$$

In the EFSO method, the idea is that if the observations have positive impact the forecast error that is computed in the run when the observations are assimilated will be lower than when observations are not assimilated. This means that **the observations have a positive impact if the cost function J (or \Delta e^2)** is negative and when **J is positive that would mean the observations have a negative impact**.

Data Assimilation - Ensemble Kalman Filter

In this study, the Ensemble Adjustment Kalman filter (EAKF) available in DART is utilized.
The ensemble kalman filter uses recursive filtering to find the optimal solution for the analysis by sampling the pdf of the forecast and analysis. It follows the updation of each ensemble member by computing the gain matrix K.





Aksoy 2003

$$X^a = X^b + K(y - H(x^b))$$

x^a : analysis state
x^b : background state
y : observations
H(x^b) : x^b on the observation space
K : Kalman gain matrix

Localization in EFSO method

Localization helps us in limiting the no. of observation taken into account and also helps in giving weights to how impactful the observation is on basis of it's distance to the gridpoint.

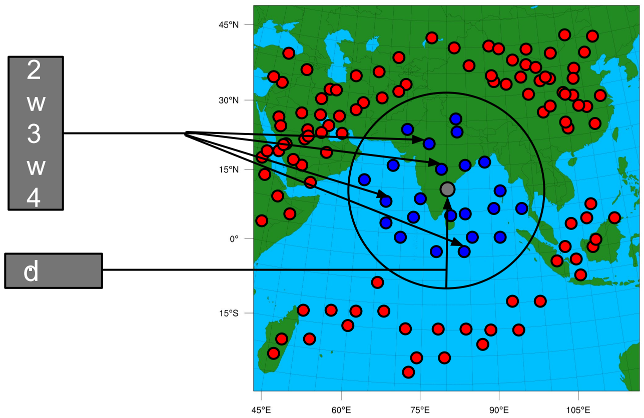
In localization, with a gaussian-type graph we shall be placing weights on the various observations it has in about a certain distance. So, say if we have a limit of 1530km (which is also chosen for this study) which will affect the the grid point, all the observation within this limit will also have a weightage to how much it can affect the gridpoint. The localization function used is the **Gaspari Cohn taper function** to remain consistent with our data assimilation system.

In the **R** matrix, we take off diagonal elements to be zero, or as to saw the observations have no correlation to each other, bringing about spurious correlations. Localization is implement to get rid of this spurious correlation that arise.

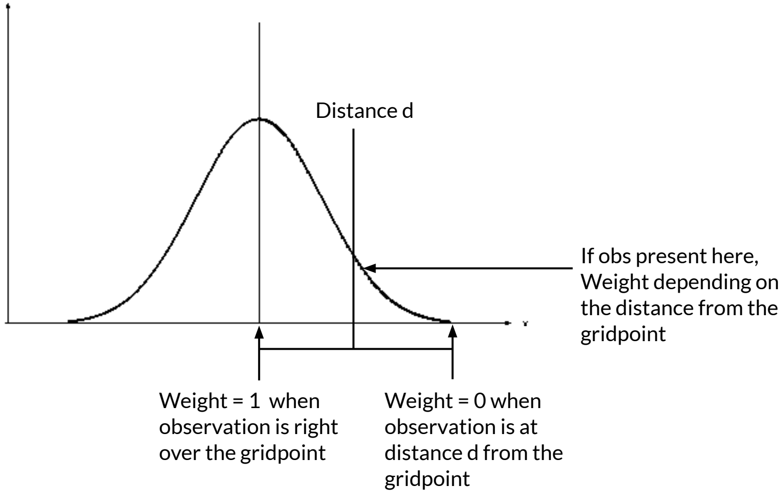
EFSO method will change and an introduction of a weight matrix **Xi** with with an element by element multiplication is to take place

$$\Delta e^2 \approx \frac{1}{K-1}(\delta y_0^T \otimes \xi) R^{-1} Y_0^a X_{t|0}^{fT}(e_{t|0} + e_{t|-6})$$

EFSO localization



●	gridpoint
●	Observation not considered
●	Observation considered



Experimental design

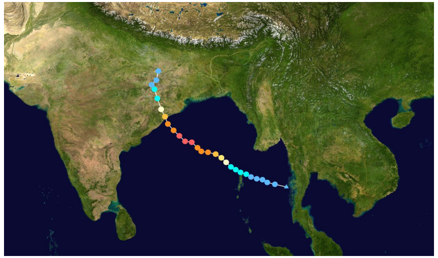
Experiment Layout

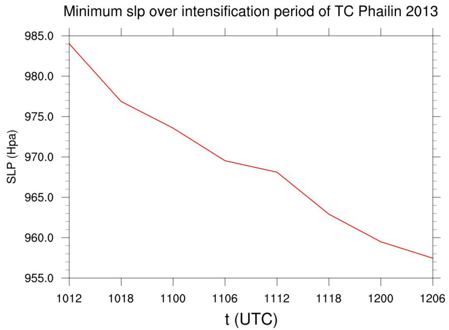
A detailed study of the **SATWIND** (Atmospheric wind vectors from geostationary satellite) observations is conducted using the EFSO method.

The SATWIND impact study is conducted over the Bay of Bengal region during intensification period of two tropical cyclones, Hudhud (2014) and Phailin (2013).

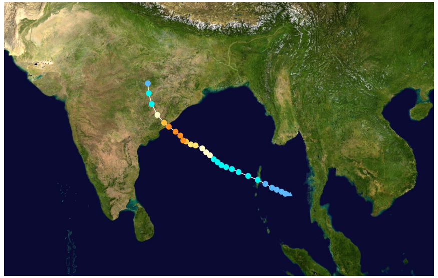
For Hudhud this is from **1200 UTC 10 October 2014 to 0600 UTC 12 October 2014**; and for TC Phailin (2013) this period starts from **1200 UTC 10 October 2013 to 0600 UTC 12 October 2013**.

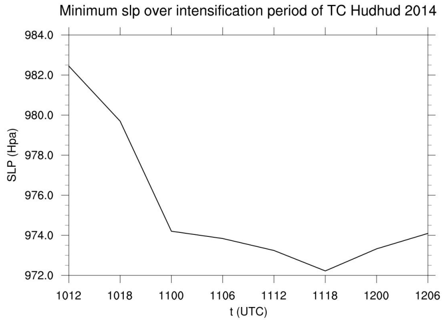
Phailin

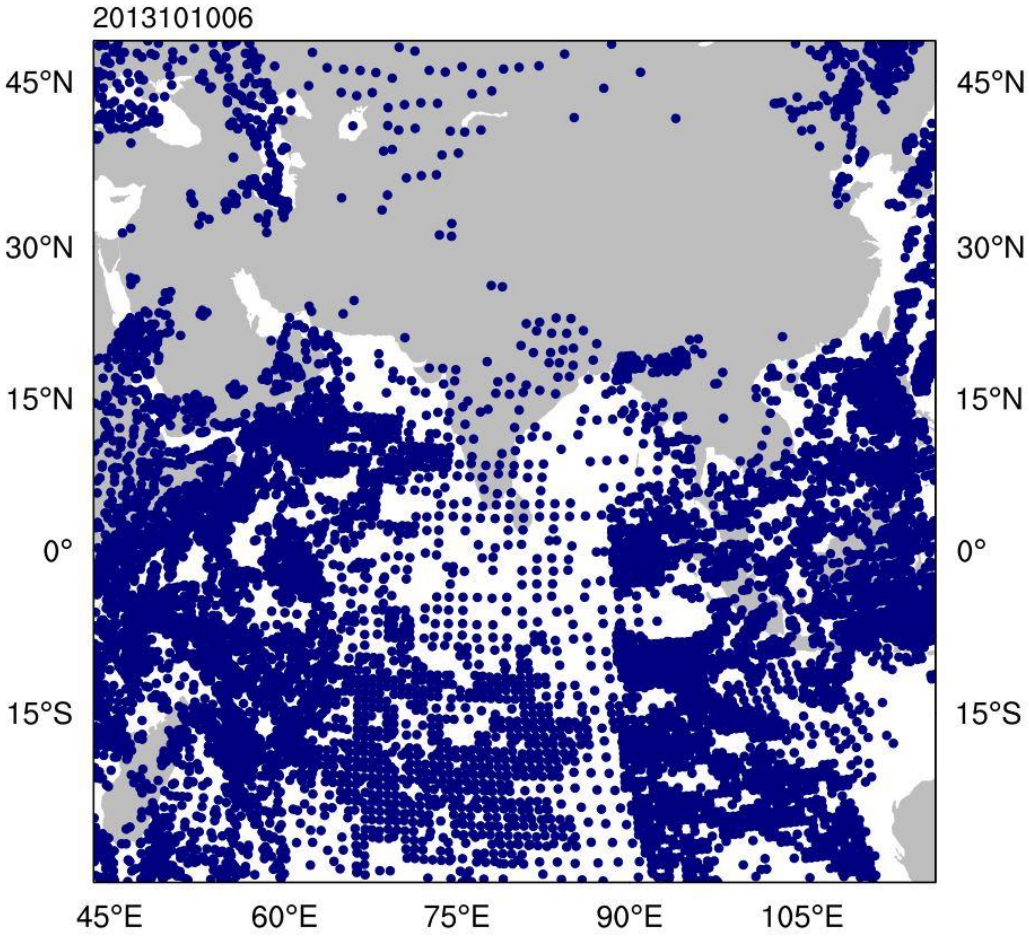




Hudhud

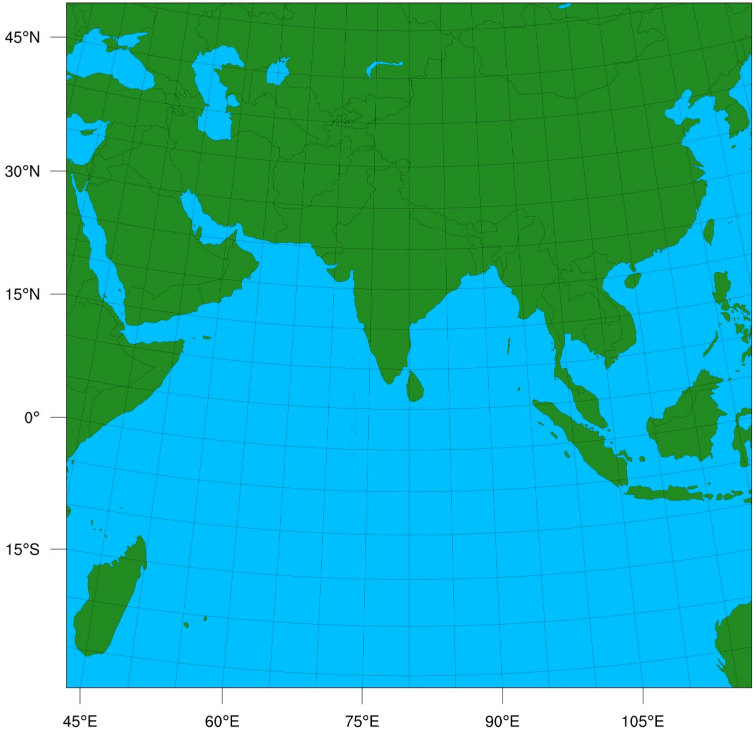






Observation spread of SATWIND that plays a role in 500hPa.

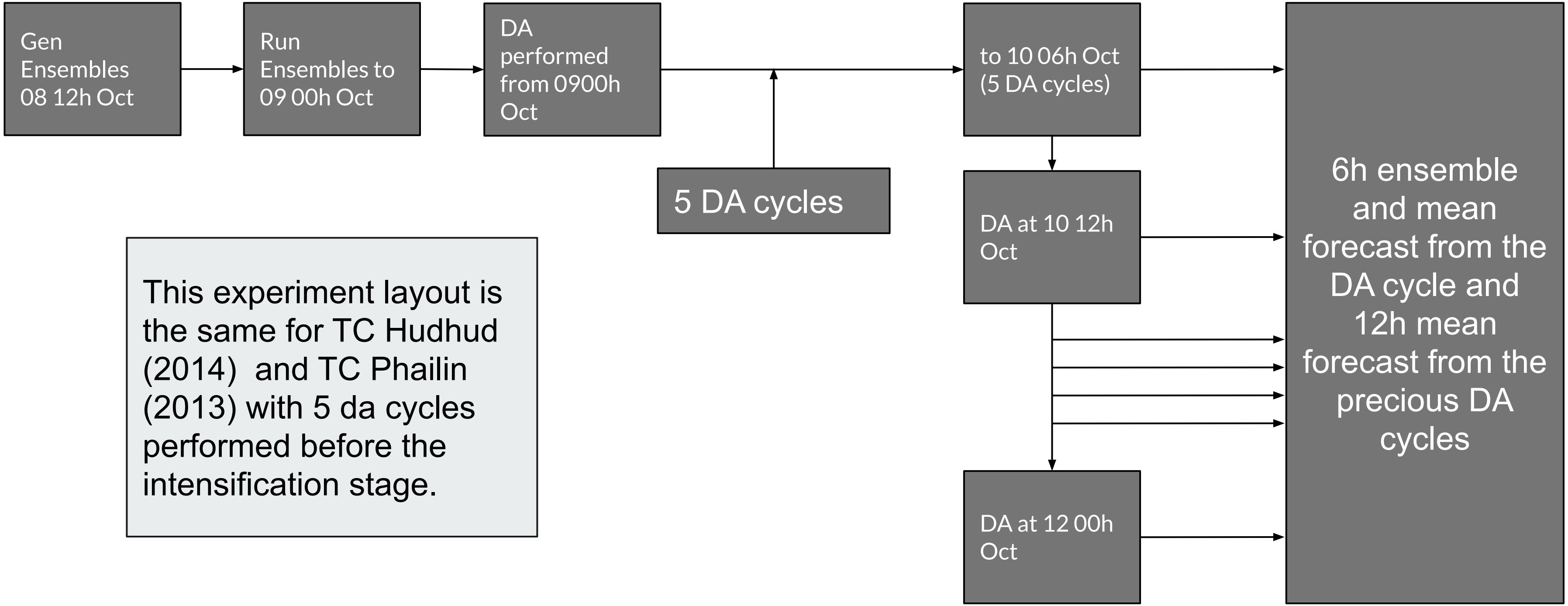
Domain and parameters



WRF model	3.8.1
Domain	(43.125E - 134.875E, 29.135S - 51.345N)
DA	Dart Lanai - Eakf
Grid size	27000m
Microphysics scheme	Option 4 : WRF Single–moment 3–class and 5–class Schemes
No. of ensembles	80

Observations assimilated	Radiosonde and dropsondes **(ADPUPA)**, surface station **(ADPSFC)**, aircraft **(AIRCFT and ACAR)**, ships and buoys **(SFCSHP)** and satellite derived wind products **(SATWIND).**
Initial conditions	NCEP Global Data Assimilation System (GDAS) final analysis (FNL)
EFSO study	SATWIND observations
Forecast metric	KE energy
Localization function	Gaspari Cohn function
Localization limit	1530km horizontally and 1.2lnp vertically
Forecast run	6h and 12h DA runs, EFSO study

Experiment layout

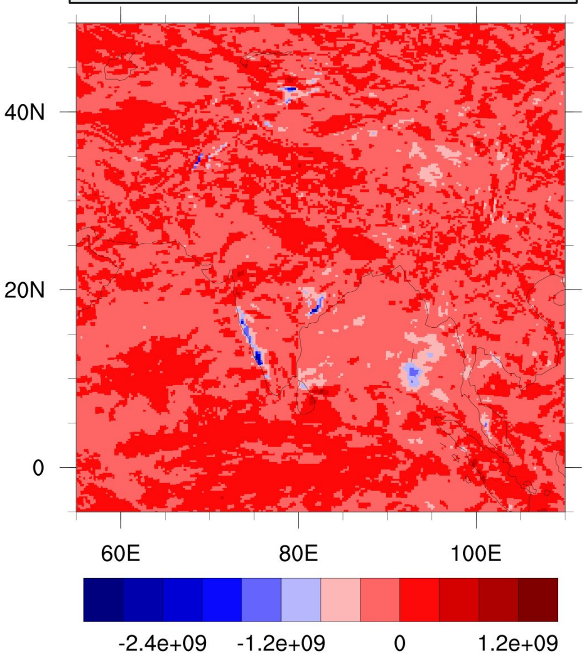


This experiment layout is the same for TC Hudhud (2014) and TC Phailin (2013) with 5 da cycles performed before the intensification stage.

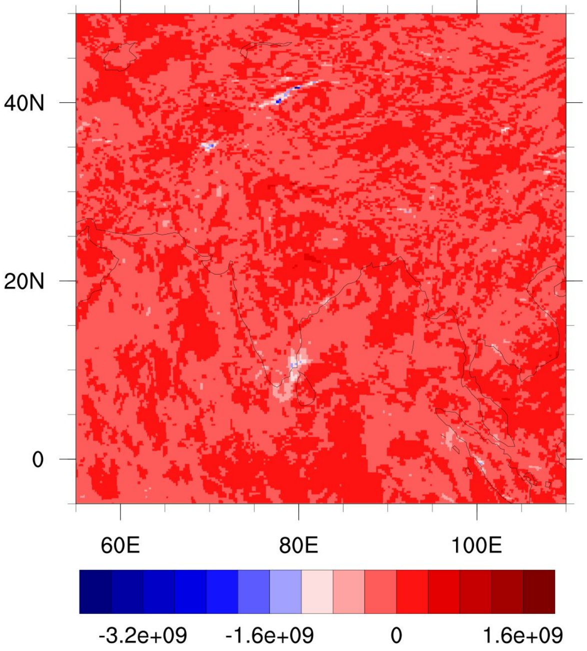
Results

No localization

Forecast metric : Meridional wind

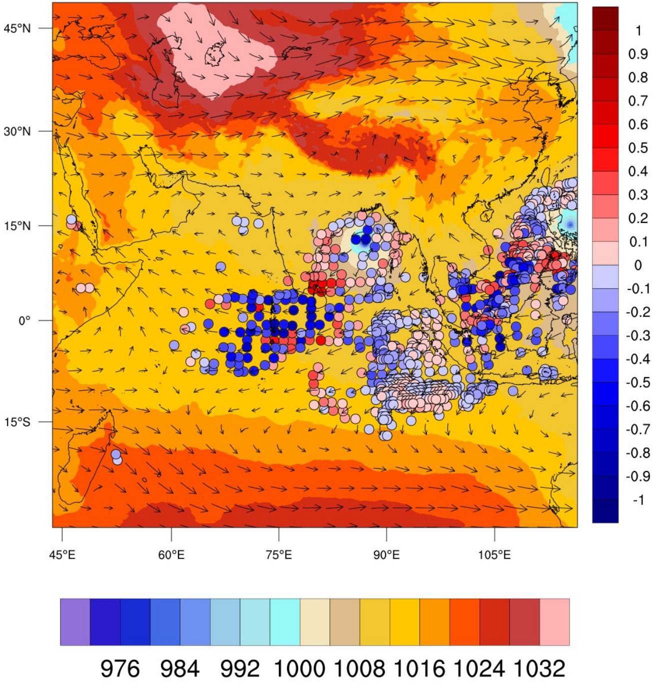


Forecast metric : zonal wind



500hpa

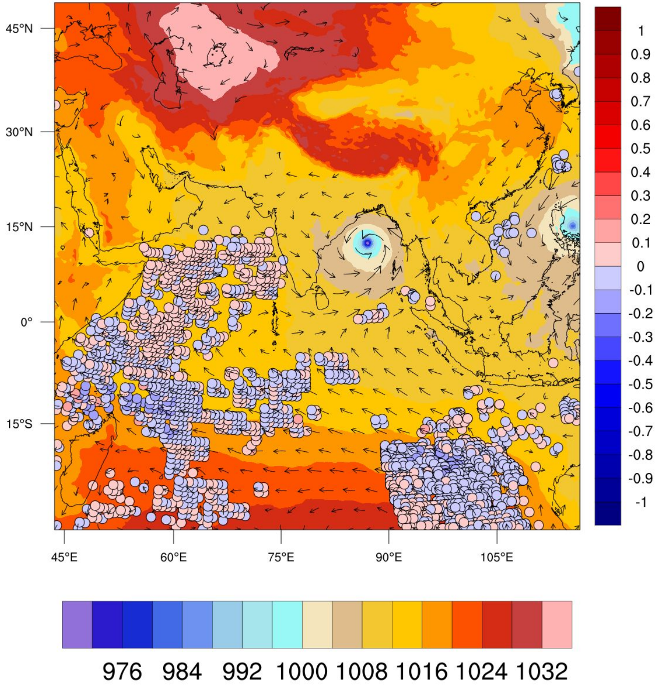
Localization performed



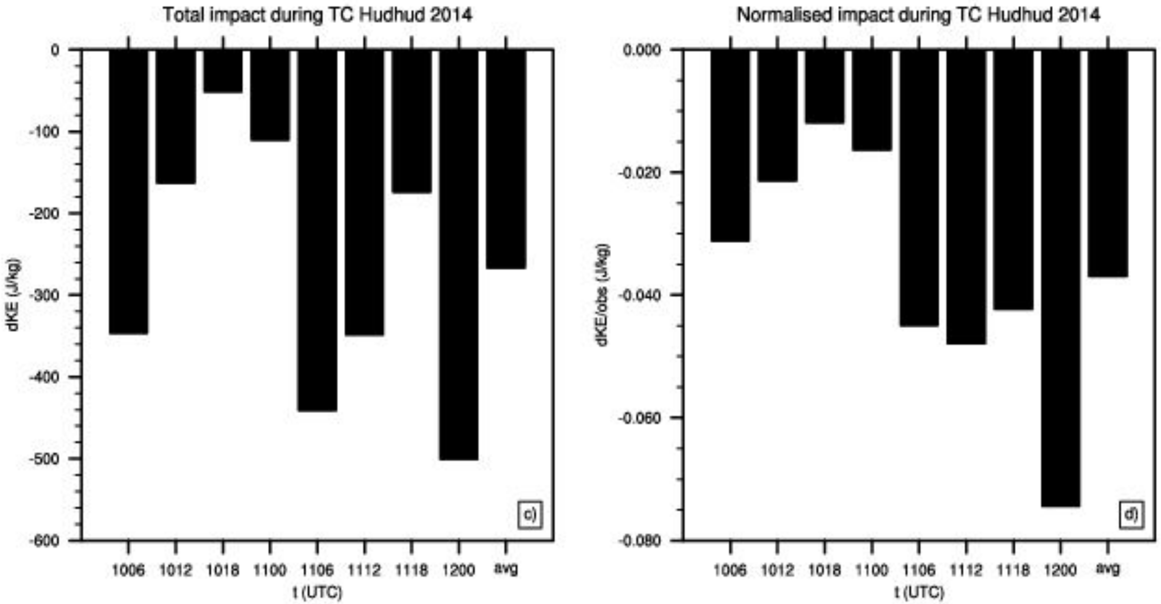
Slp overlaid with wind vectors and the spatial spread of observation impacts

Right is the observation impact in J/kg units

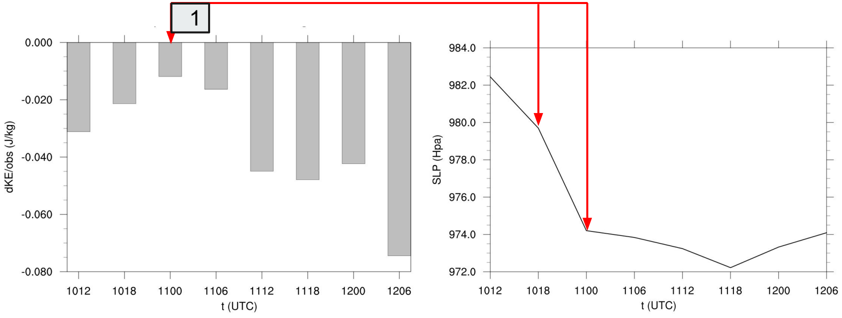
Bottom is the slp in hPa

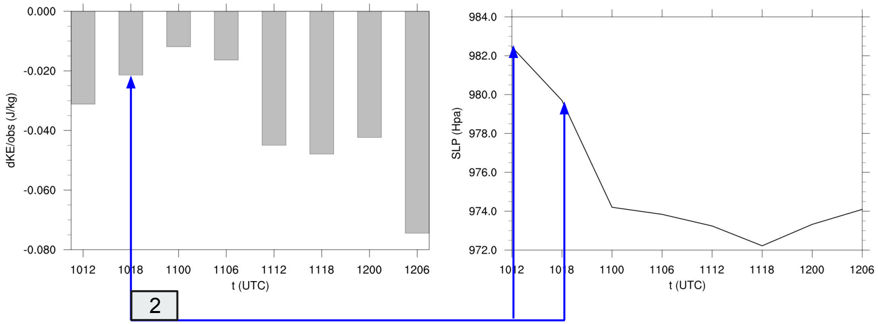


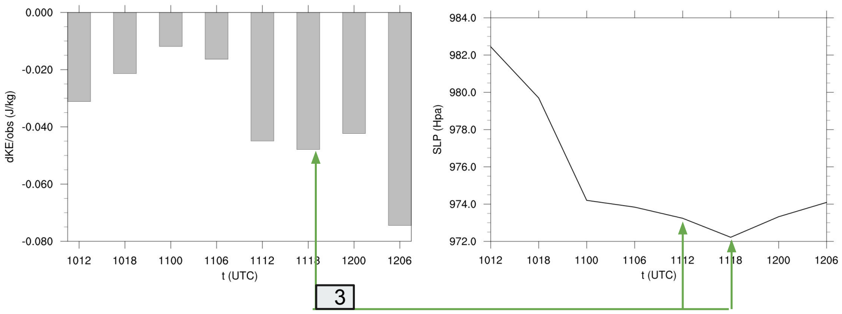
TC hudhud 6h SATWIND impact



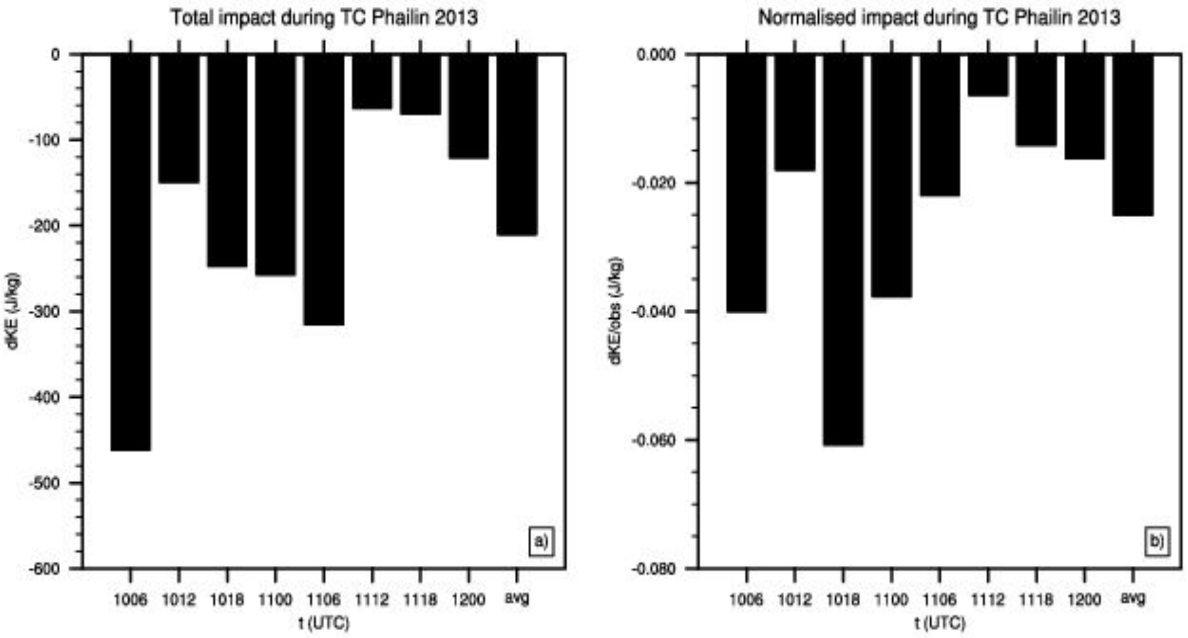
TC Hudhud 6h impact



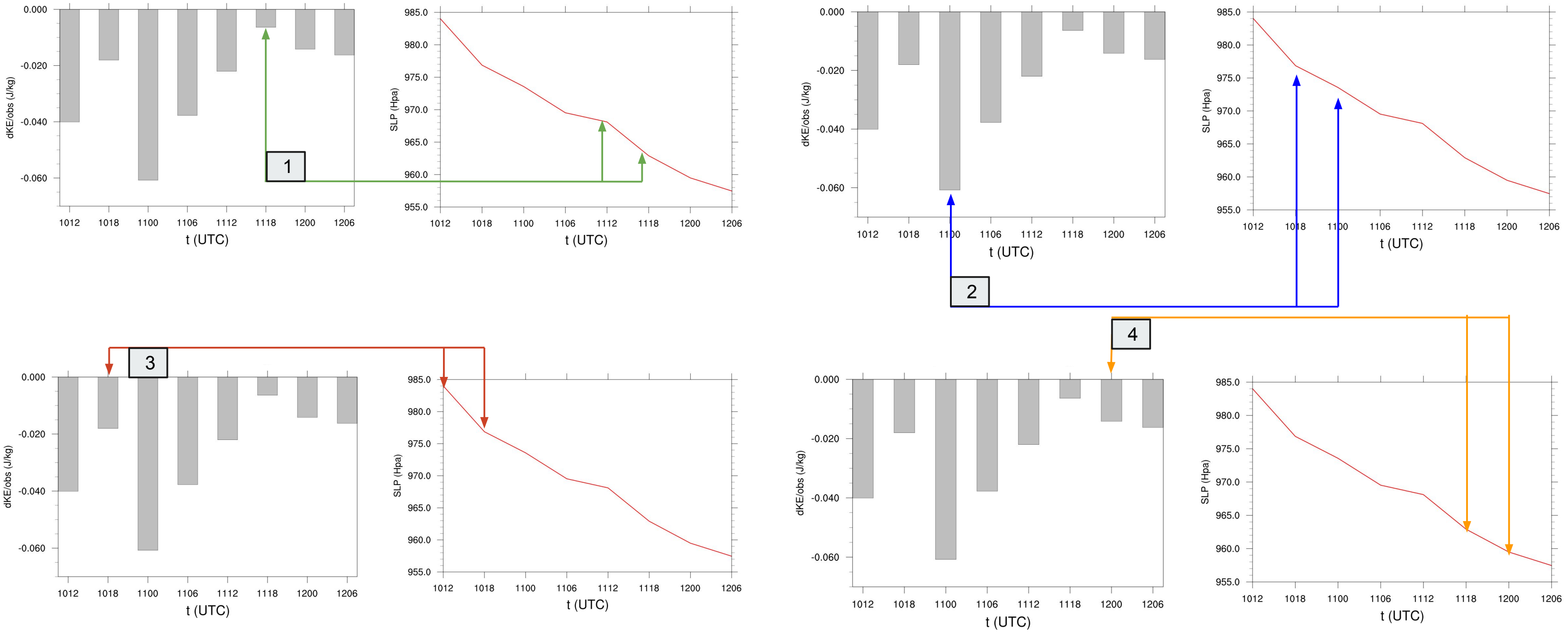




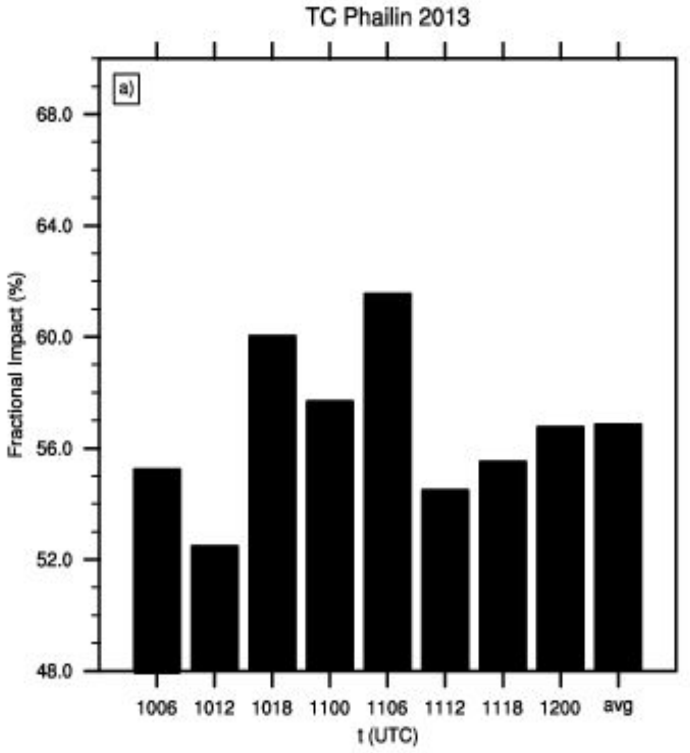
TC Phailin 6h SATWIND impact

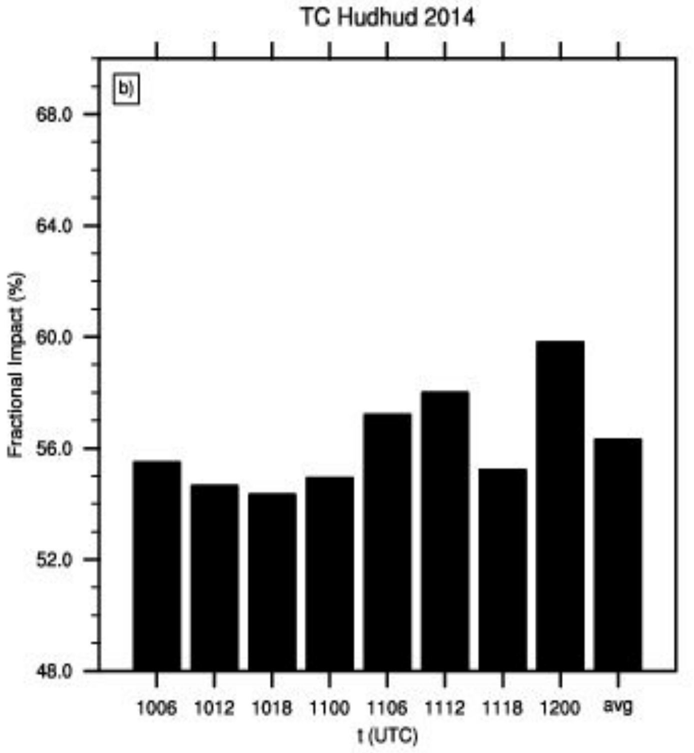


TC Phailin 6h impact



Fraction of 6h SATWIND observations showing positive impact

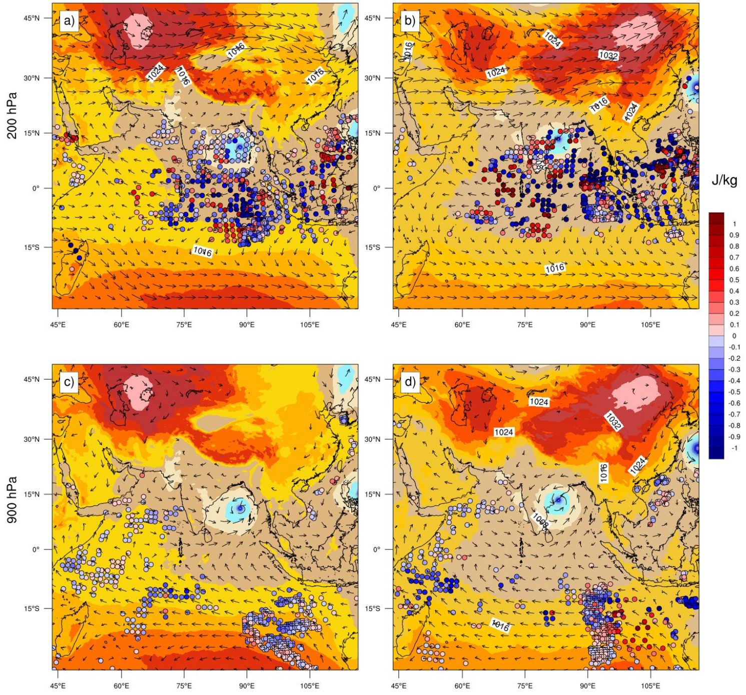




Spatial Impact plot over Max and min impact days

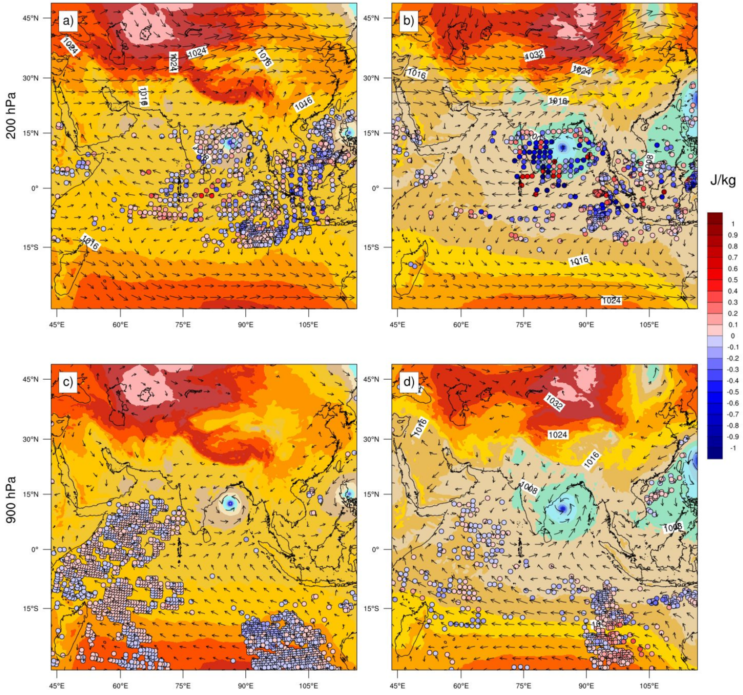
Spatial AMV impact distribution at time of max positive impact

Phailin (18h 10102013) **hudhud (00h 12102014)**

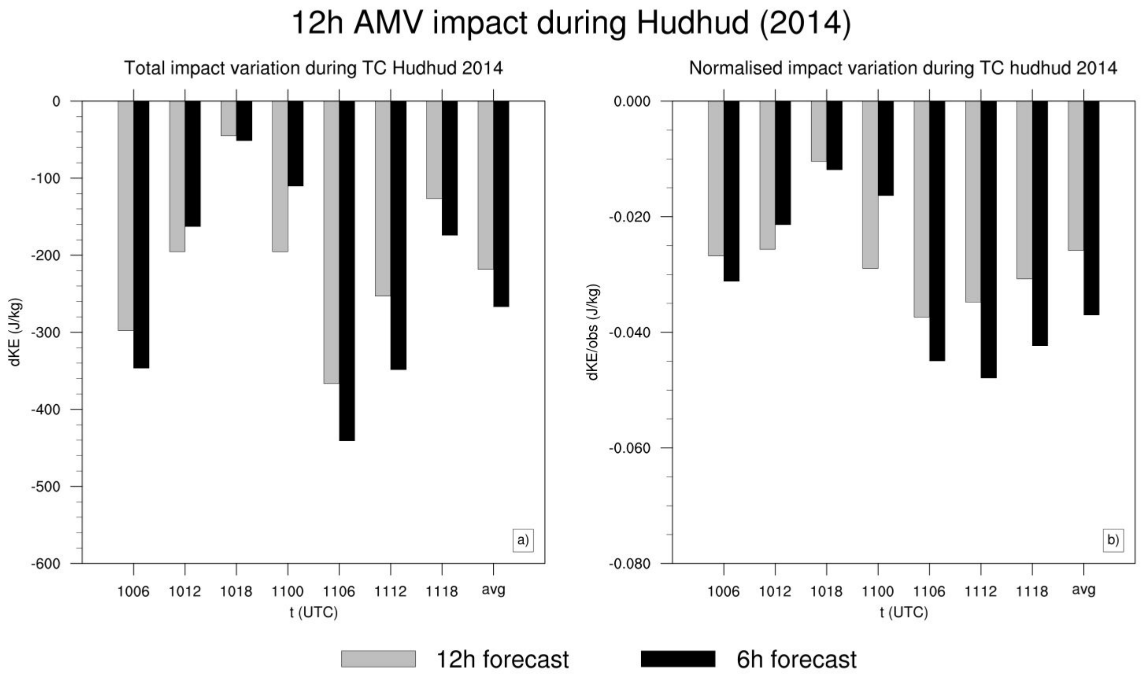


Spatial AMV impact distribution at time of min positive impact

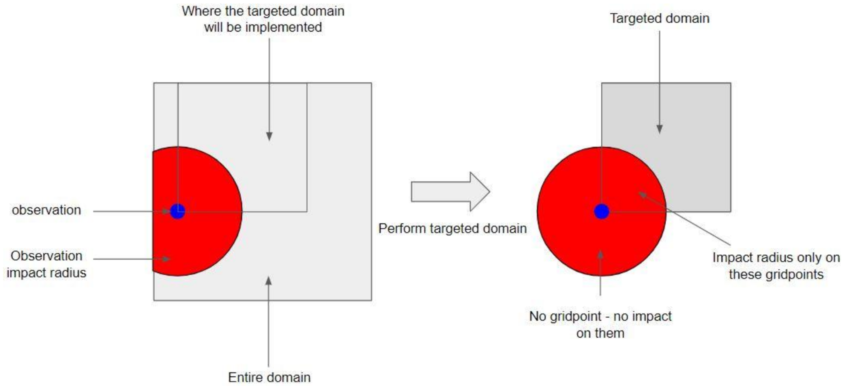
Phailin (12h 11102013) **hudhud (18h 10102014)**

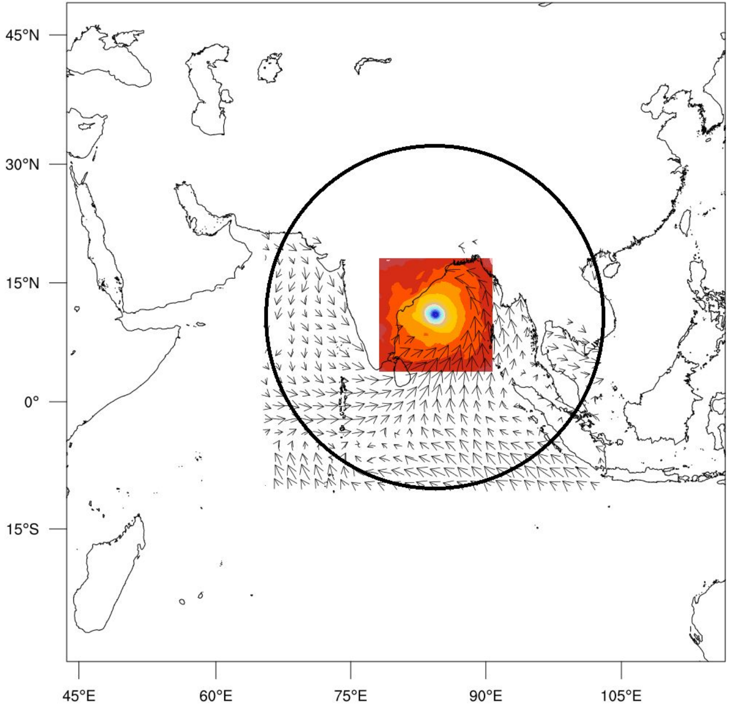


Increased forecast lead time SATWIND impact

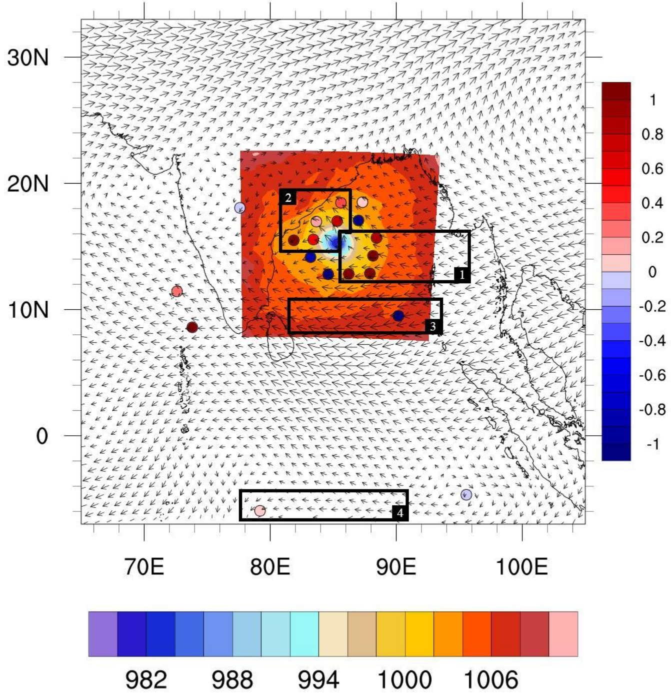


Targeted domain

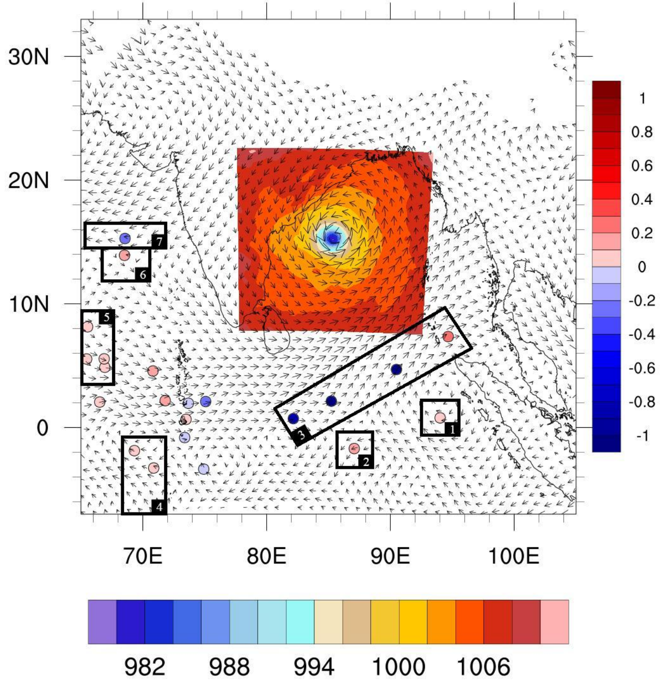




Spatial plot of observation impacts over 150 -50 Hpa



Spatial plot of observation impacts over 850 -750 Hpa



Faster computation

Conclusions

The detailed study of the SATWIND observations revealed a lot to us, contrary to our expectation, only a **little over half the observations in fact have a positive impact**.

During the intensification of the tropical cyclone, it is **not only the intensity** of the tropical cyclone that plays a factor on the impact of the observations, **but mainly the intensification** of the the tropical cyclone that plays a major role on the observation impact. At points where there is rapid intensification, the already chaotic and dynamically unstable weather event of a TC, makes the observations show low positive or a negative impact altogether.

We also see how the forecast length plays a role in the impact of SATWIND observations, with the **decrease of SATWIND impact** with **increase in forecast length**.

Add to all of this, the **targeted domain study** shows that the **position of the observation in a flow** also plays a major factor in the impact of the observation. With observations present in the **upstream region of a straight flow showing more positive impact** and observations present at **downstream regions of the flow showing low positive or negative impact altogether.**

Thankyou