IASI Radiance Data Assimilation within KIAPS-LETKF System

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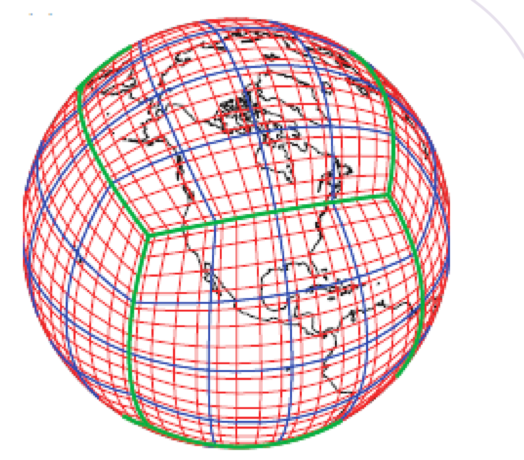
1. KIAPS-LETKF Data Assimilation System

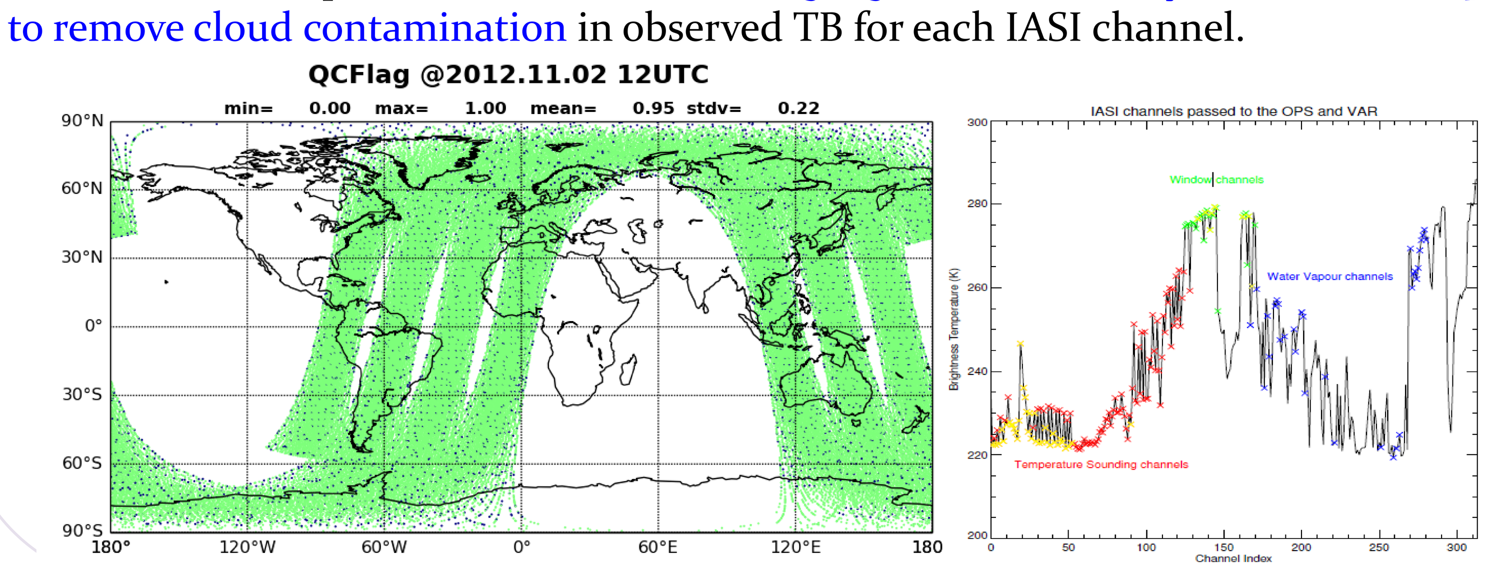


Korea Institute of Atmospheric Prediction Systems (KIAPS) has **successfully implemented Local Ensemble Transform Kalman Filter (LETKF; Hunt et al. 2007) data assimilation system to NCAR CAM-SE model** that has fully unstructured quadrilateral meshes based on the cubed-sphere grid, known as **the same grid system of KIAPS-Global Model** now developing. The KIAPS-LETKF system (Kang et al., 2013) has also adopted **most advanced data assimilation techniques** such as **an adaptive multiplicative inflation** (Miyoshi, 2011) and an estimation of **ensemble forecast sensitivity to observations** (EFSO; Kalnay et al. 2012, Ota et al. 2013).

Recently, KIAPS-LETKF system has been **upgraded**: **1) observation operator** (including spatial interpolation and nonlinear transform of variables) is **decoupled from the KIAPS-LETKF**, which allows us to easily utilize/switch an observation operator with different version or different brand. **2)** KIAPS-LETKF data assimilation system has been extended to **4D-LETKF** which considers time-evolving error covariance within assimilation window *(e.g. every hour background error covariance within 6-hour assimilation window)*. ***These two major upgrades greatly help assimilating radiance data effectively*** because KIAPS-LETKF system decoupled to observation operator does not need to be modified according to any changes of observation operator (e.g. version changes of RTTOV, or use of different observation operator such as CRTM). Also, 4D-LETKF will better reflect high resolution information in time and space that satellite data provide. Furthermore, **EFSO within KIAPS-LETKF** system can be applied to **Proactive QC** as Kalnay et al. (2012) and Ota et al.(2013) have shown.

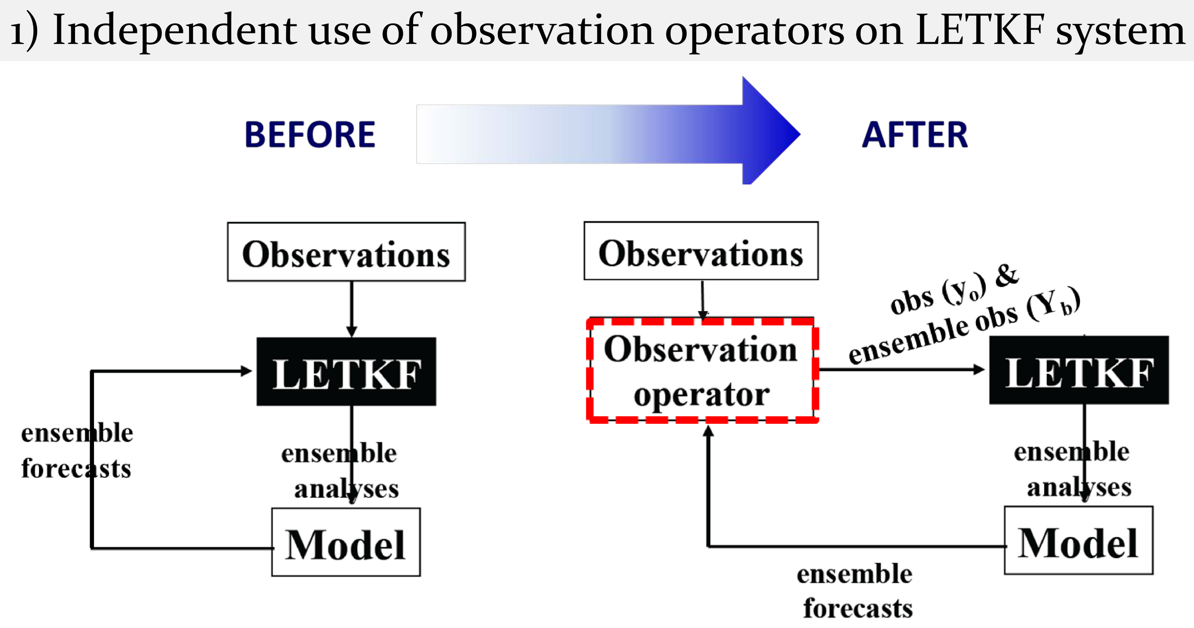
2. IASI radiance data

IASI (Infrared Atmospheric Sounding Interferometer) on board MetOp-A is an infrared Fourier transform spectrometer measuring in the spectral interval of 645-2760 cm^{-1} at a resolution of 0.5 cm^{-1}. It covers the globe twice a day, which provides lots of meteorological records (mainly temperature) in time and space. Although there are more than 8000 channels, we intend to assimilate only about 100 channels for the first test, in order to avoid inter-channel correlation and possible negative impact (e.g. Stewart et al. 2013). IASI data at KIAPS have been pre-processed by a static method of *Harris and Kelly (2001) for correcting scan and airmass biases*. Moreover, we adopt *NWP SAF cloud detecting algorithm (McNally and Watts, 2003) to remove cloud contamination* in observed TB for each IASI channel.



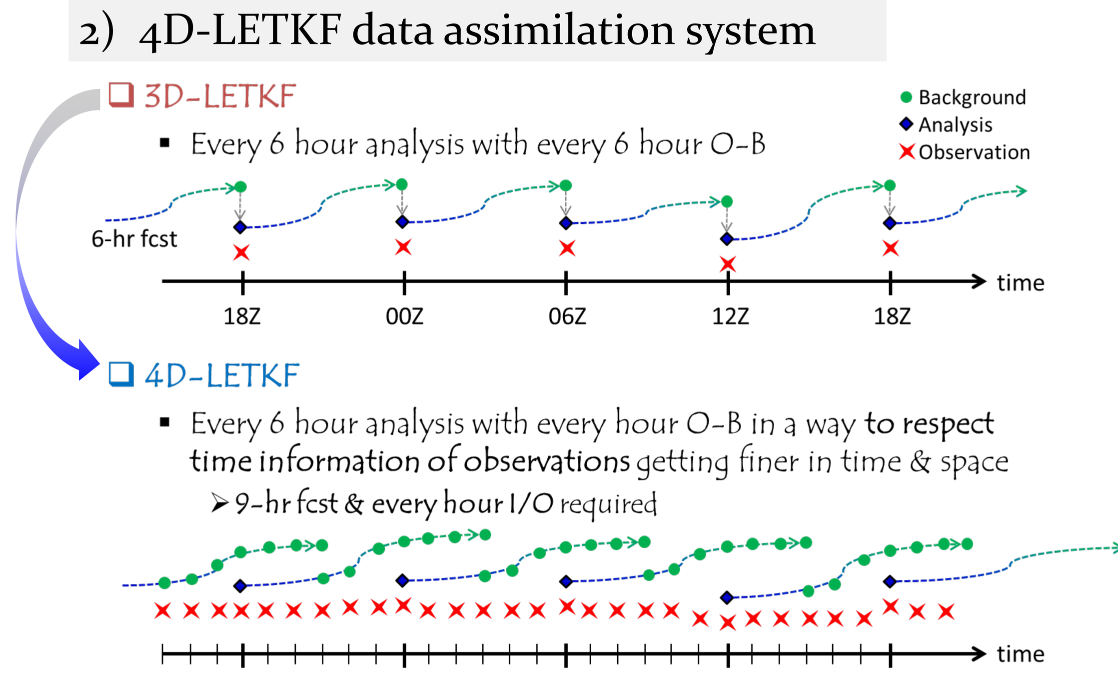
3. Strategies of assimilating IASI data into KIAPS-LETKF system

1) Independent use of observation operators on LETKF system



This work was inspired by Mr. Guo-Yuan Lien's LETKF-GFS system developed at the Univ. of Maryland. (His final defense for Ph.D is today, March 28, 2014!)

2) 4D-LETKF data assimilation system

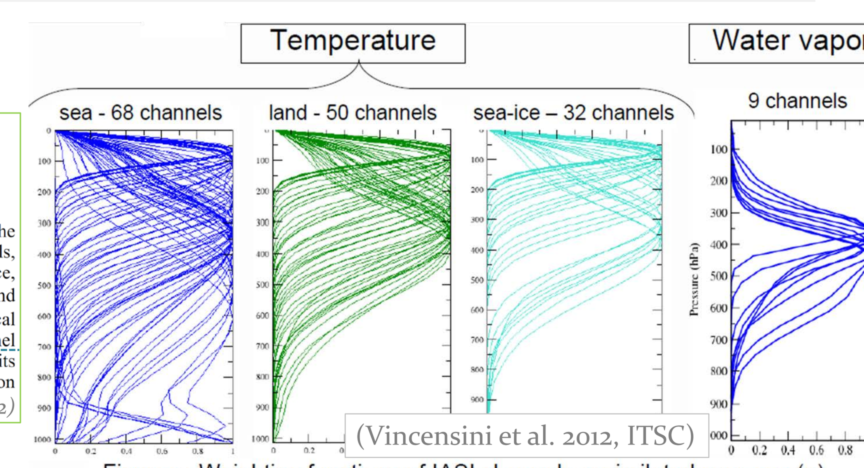


3) Vertical localization using vertical weighting function of data

After computing background radiance following the equation below,

$$y_k^b = \mathbf{H}\left(\mathbf{x}_{k,l}^b\right) = \sum_{l=1}^{nlev} a_l S\left(\mathbf{x}_{k,l}^b\right)$$

where the subscript k indicates the kth ensemble member, the subscript l indicates the lth vertical level of total $nlev$ levels, y_k^b is ensemble background radiance at the observation space, $\mathbf{H}$ is an observation operator, $\mathbf{x}_{k,l}^b$ is the kth background ensemble forecast of CO_2 concentration for the lth vertical level at the model space, a_l is the value of averaging kernel at the lth vertical level which is normalized in a way that its vertical sum is equal to unity, and S is a spatial interpolation operator. (Kang et al. 2012)



(Vincensini et al. 2012, ITSC)

how to update analysis using those O-B, i.e. which level and how much we will allow to update through DA?

Updating full levels in the vertical, according to the weighting function?

Figures : Weighting functions of IASI channels assimilated over sea (a), over land (b), over sea-ice (c) for temperature and weighting functions of IASI channels assimilated over sea, land and sea-ice for water vapor (d).

Updating one level which has a peak of the weighting function?

Updating levels around the peak levels of the weighting function with Gaussian weight?

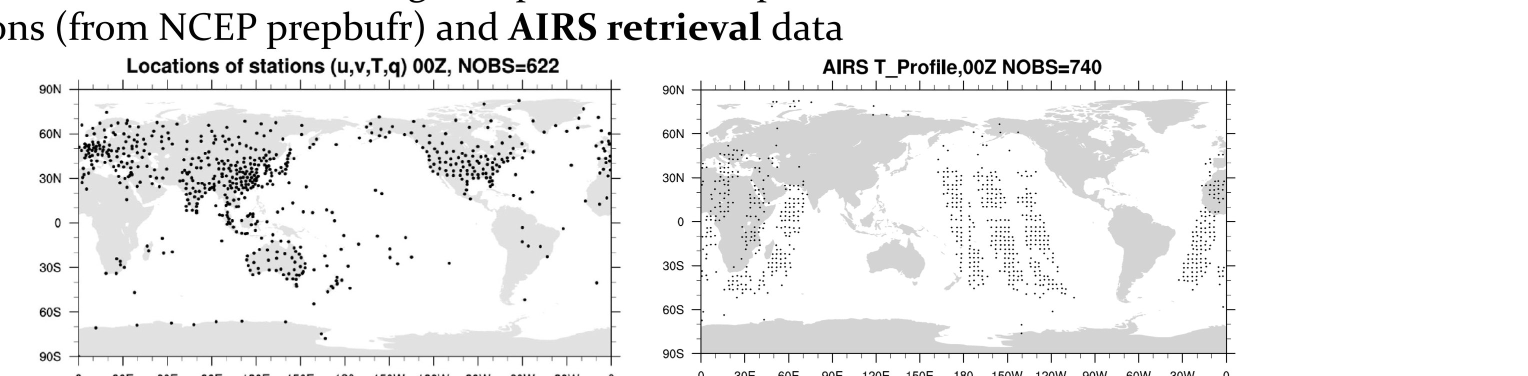
Please visit the poster **10p.08** for more discussion

(Miyoshi and Sato, 2007; Fertig et al. 2007, Miyoshi et al. 2009)

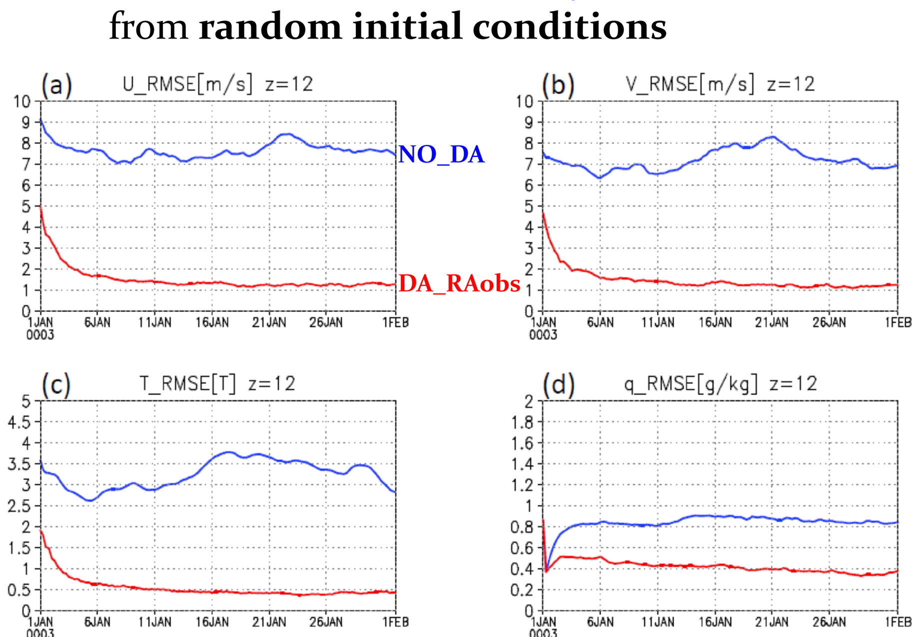
4. Preliminary Results of KIAPS-LETKF system

1) Observing System Simulated Experiments

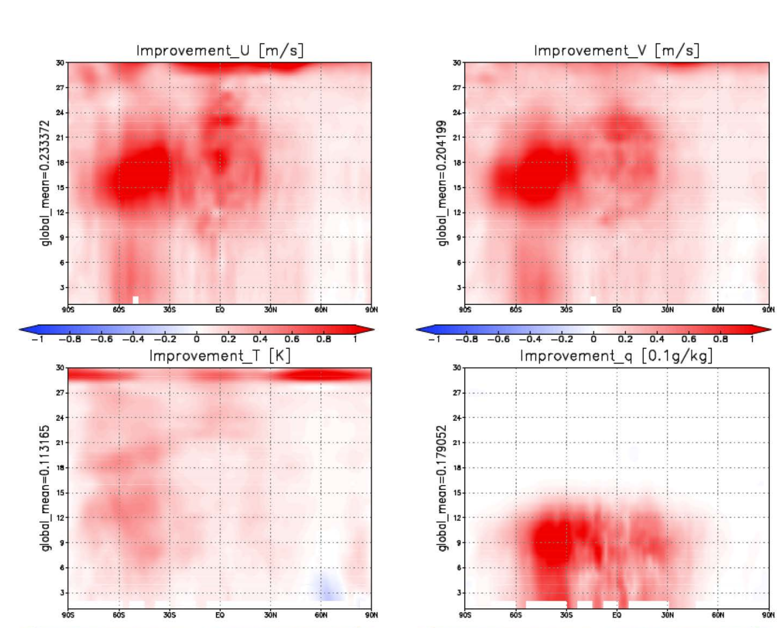
- **Nature run** (true state of the simulated experiments) from NCAR CAM-SE with ne16np4 (~2.5°) and 30 vertical levels (of top ~ 3hPa)
- **Simulated observations** following the spatial and temporal distributions of real **conventional** observations (from NCEP prepbufr) and **AIRS retrieval** data



- **Ensemble forecast with 64 members**, with the same model used for the nature run, but starting from **random initial conditions**



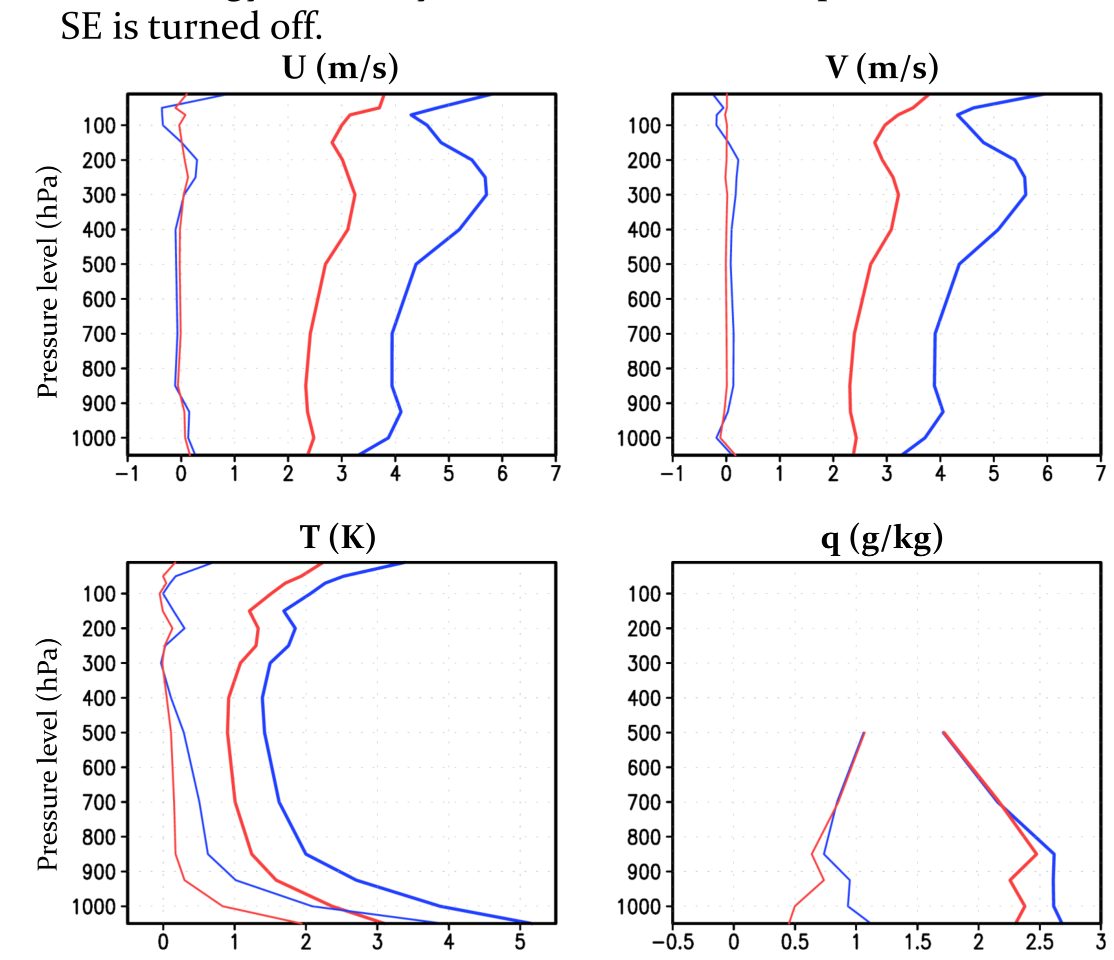
▲ Time series of RMS error resulted from the experiment with data assimilation of conventional data (red) and without data assimilation (blue)



▲ Vertical cross-section of zonal mean for improvement (red)/degradation(blue), due to **adding AIRS data** from the experiment assimilating only conventional data

2) Assimilation of real data

- The same model used for OSSEs has been also used for the real data experiment
  - NCAR CAM-SE with ne16np4 (~2.5°) and 30 vertical levels (of top ~ 3hPa)
- Surface pressure and radiosonde data from NCEP prepbufr are assimilated (Nov. 1 ~ Dec. 7, 2014)
  - When assimilating surface pressure data, we use only what has height difference less than 100 m between observation and the model background.
  - For q data, we only assimilate data over lower troposphere.
- Climatology of Hadley Center sea surface temperature (SST) has been used and a sea-ice component of CAM-SE is turned off.



▲ Mean RMS difference (thick contours) and bias (thin contours) of analysis (red)/ background(blue) from the assimilated observations

- The results are from the KIAPS-LETKF system which is decoupled from observation operator
  - For the conventional data, the observation operator just needs spatial interpolation from the model space into the observation space.
- Results clearly shows better fit of analysis to the observations than the background field in terms of both RMS difference and bias.
- We think that this is very encouraging performance, with relatively coarse resolution model assimilating only sonde and surface data.
- *Now, we are running 4D-LETKF system with the same kind of observation data, but having hourly records.*
  - Preliminary results from 4D-LETKF system also look reasonable!

5. Summary and Discussion

We have implemented Local Ensemble Transform Kalman Filter (KIAPS-LETKF) Data Assimilation System applicable to KIAPS Global Model (KIAPS-GM) now developing. Before a release of KIAPS-GM, we have examined the KIAPS-LETKF system with NCAR CAM-SE model that has the same coordinate structure as KIAPS-GM. For assimilating radiance data of IASI effectively, *KIAPS-LETKF data assimilation systems has been upgraded mainly in two ways*: **1) by decoupling an observation operator from the LETKF system** so that we can easily use any version or any brand of observation operator for data assimilation, and **2) by extending to 4D-LETKF** considering temporal evolution of error covariance within an assimilation window. Also, the system has equipped with other advanced techniques such as ***adaptive multiplicative inflation method, estimation of ensemble forecast sensitivity to observation***, etc. With these advanced techniques, we have examined the current system of KIAPS-LETKF with various **Observing System Simulation Experiments (OSSEs) and experiments with real data**. Results from the experiments done so far have illustrated **very reasonable performance** of analysis with various experimental setting such as different observation datasets, different strategies of inflation factors, and so on. In the OSSEs, we could directly compare our ensemble forecast and analysis to the true state, and thus they have proved our LETKF data assimilation system well implemented. Assimilating real data, we could confirm that the analysis tends to approach the assimilated observations in terms of both RMS difference and bias. We plan to develop more verification tools for KIAPS-LETKF system. *Now, work on the direct radiance data assimilation of IASI in addition to AMSU-A is in progress, with research on the vertical localization method and online bias correction within KIAPS-LETKF system.*