Vertical Localization Strategies for Radiance Data Assimilation within LETKF

Ji-Sun Kang*, Hyoung-Wook Chun*, Byoung-Joo Jung*+, Juhye Kim*, and Takemasa Miyoshi#

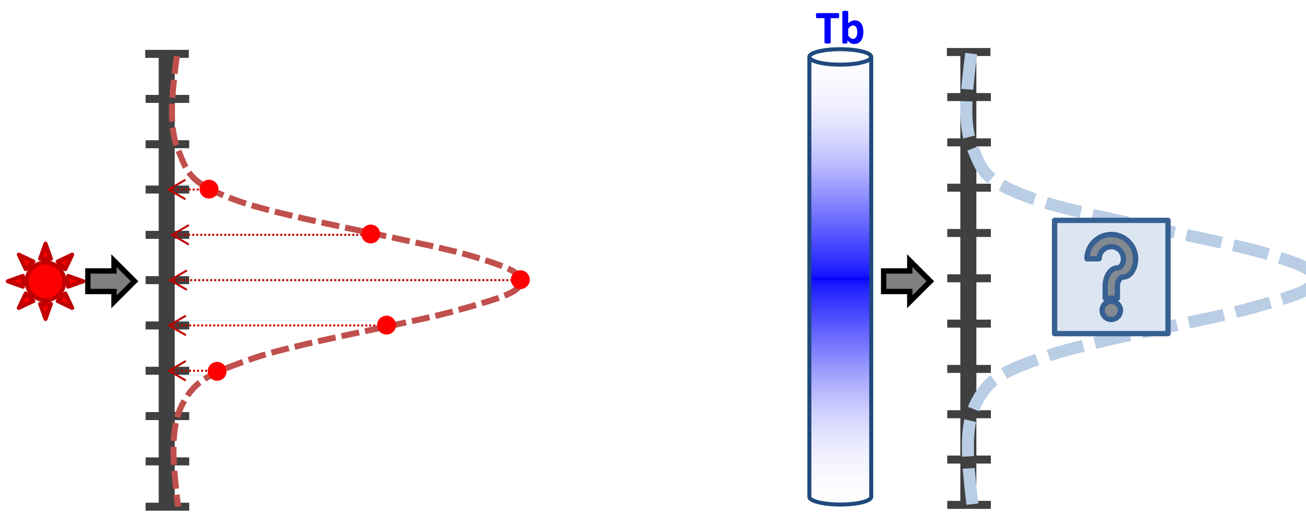
*Korea Institute of Atmospheric Prediction Systems (KIAPS, Korea), +NCAR/MMM (USA), and #RIKEN AICS (Japan)

Direct Assimilation of Radiance data within EnKF

- While radiance data have been well assimilated within variational data assimilation systems, EnKFs have not much experienced direct assimilation of radiance data.
- Main issues of direct radiance assimilation within EnKF
  - Online bias correction (e.g. Miyoshi et al. 2010)
  - Vertical localization (e.g. Houtekamer et al. 2005; Fertig et al. 2007; Miyoshi and Sato, 2007)
- **Goal** of this study is ***to see how sensitive the EnKF analysis to the vertical localization method is***, under the OSSEs with no bias of radiance data.

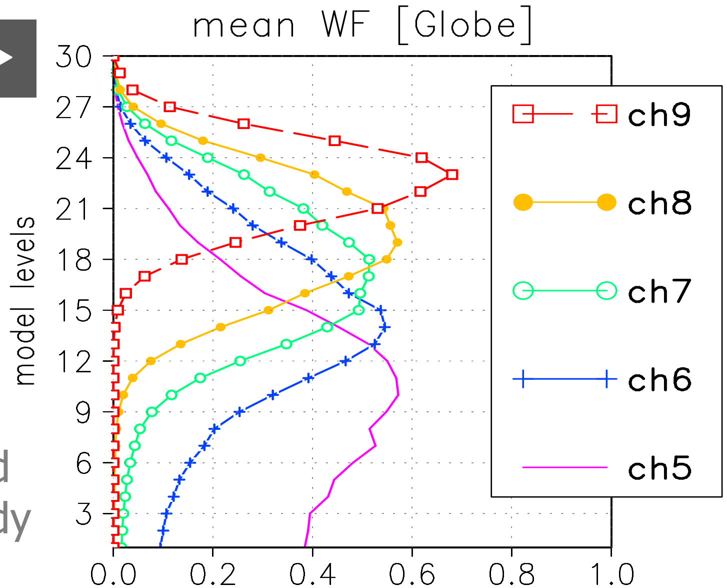
Radiance data within EnKF

- Radiance data from remote sensing represent ***column-integrated information*** of the atmosphere, ***not a pointwise value*** of the states.
- In contrast to VAR which incorporates a linearized (adjoint) model of observation operator (H), *EnKF uses only a forward model of H, and thus it is necessary to decide* ***how much analysis increment caused by the column data should be distributed to each vertical level of the model***.



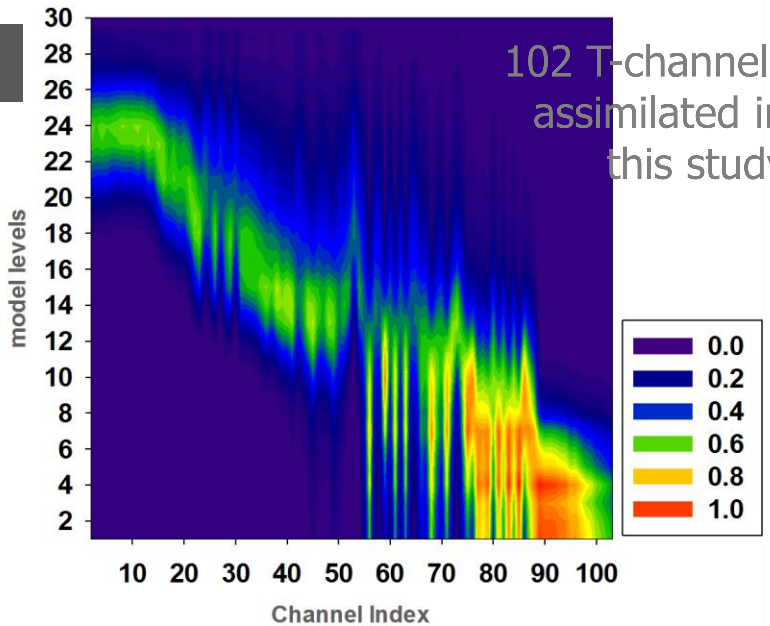
Weighting functions of AMSU-A and IASI

AMSU-A ▶



Five channels assimilated in this study

IASI ▶

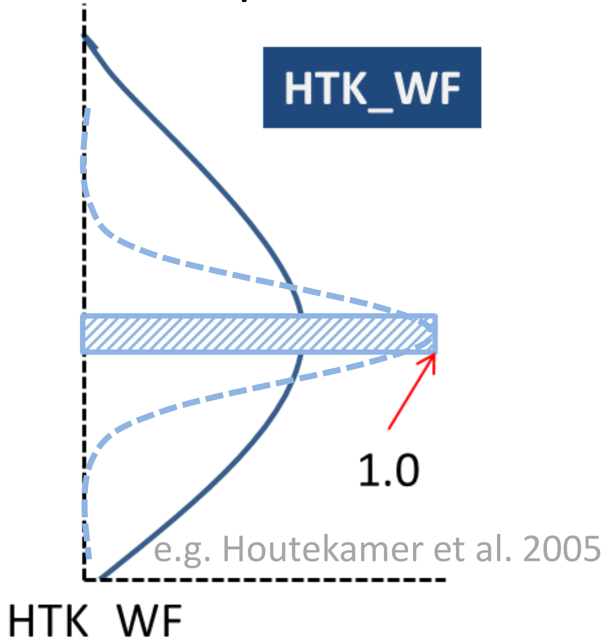


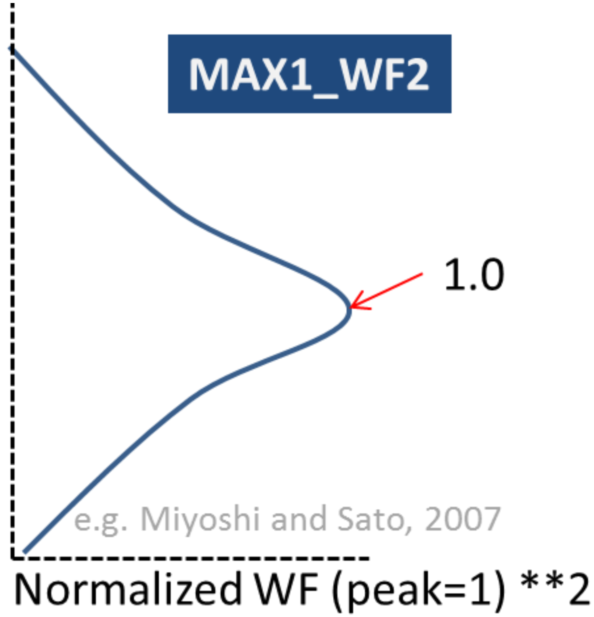
102 T-channels assimilated in this study

- **Weighting function (WF)** represents the ***sensitivity of the measured radiance for the model levels***
- WFs of AMSU-A have relatively similar shapes to Gaussian function (Miyohi and Sato, 2007).
- IASI has much more channels with various shapes and magnitudes of WFs.
  - Low-peaking channels tend to have large values and double peaks.

Previous Studies of Vertical Localization

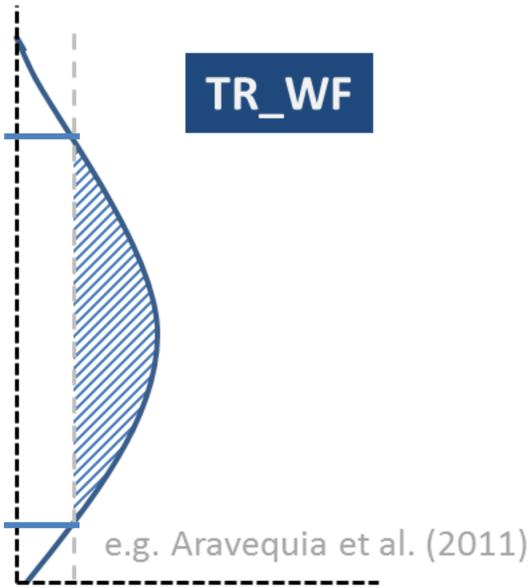
- Houtekamer et al. (2005) and Houtekamer and Mitchell (2005)
  - Consider the data as conventional data, assuming that information represents the state at the level of maximum WF in the vertical.
- Miyoshi and Sato (2007)
  - Normalize WF s.t. its maximum is equal to unity.
  - Then, use square of the normalized WF for V_Loc.



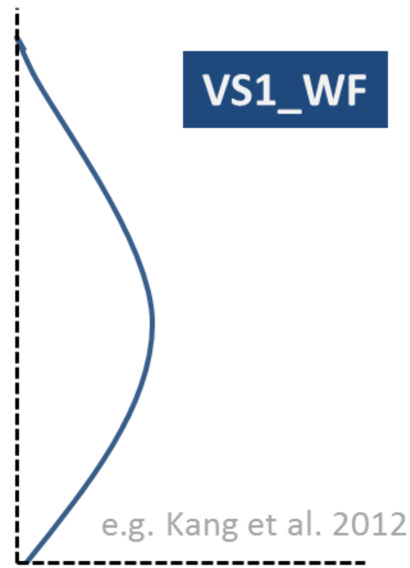


Previous Studies of Vertical Localization

- **Fertig et al. (2007) and Aravequia et al. (2011)**
  - Normalize WF s.t. its vertical sum is equal to unity.
  - Use the normalized WF for V_Loc only if WF at the level is greater than a tunable threshold. *(Aravequia et al.; WF > ε*WFmax, ε=0.8)*
- **Fertig et al. (2007) and Kang et al. (2012)**
  - Use the normalized WF whose vertical sum is equal to unity.



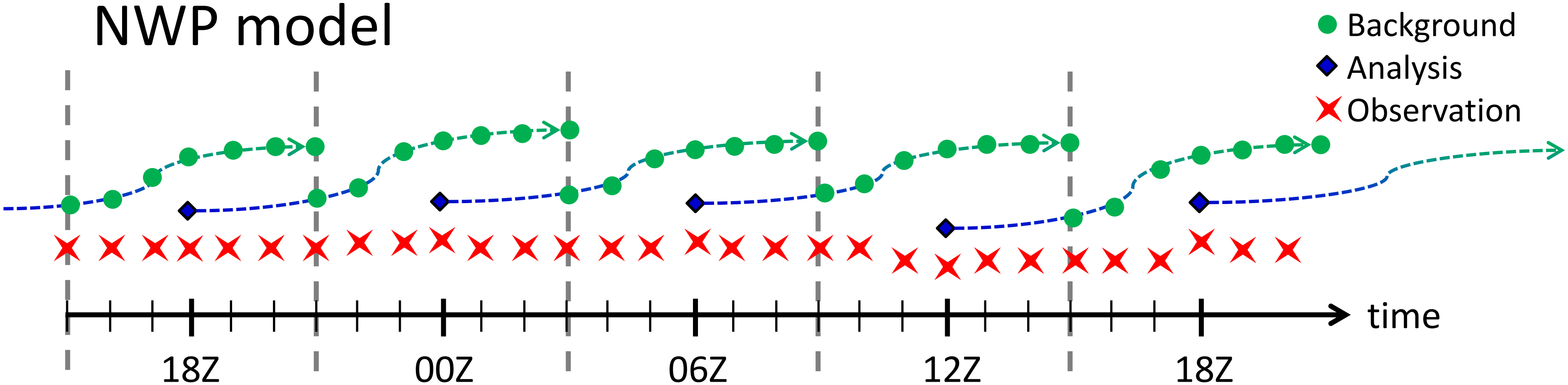
$\sum_{vertical} WF = 1$



$\sum_{vertical} WF = 1$

KIAPS-LETKF Data Assimilation System

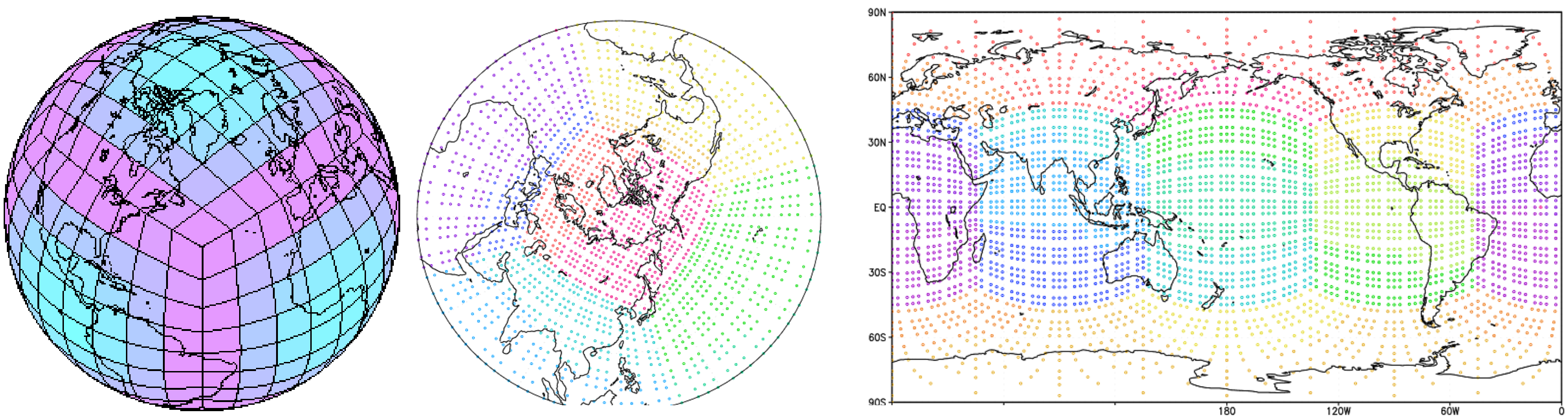
- 4D-LETKF (Hunt et al., 2007, Harlim and Hunt, 2007) for global NWP model



- Assimilation of conventional data and GPS-RO bending angle data has been examined with this system *(Kwon et al., AMT, accepted)*.
- For the radiance data assimilation, we have coupled KPOP (KIAPS Package for Observation Processing) which includes RTTOV (version 10.2).

Observing System Simulation Experiments

- Model: **NCAR CAM-SE** (Dennis et al., 2012)
  - It has *unstructured quadrilateral meshes based on the cubed-sphere grid*.
  - CAM-SE coupled with an active land surface model (CLM2, Bonan et al., 2002) and a thermodynamic only sea ice model (CICE, Hunke and Lipscomb, 2010) generates true states.
  - For the ensemble forecast, we turn off CICE.
  - Horizontal resolution is ne16np4 (~2.5 deg)
  - 30 vertical layers with 2.3 hPa top



▲ **Unstructured grid on the cubed sphere** ▲

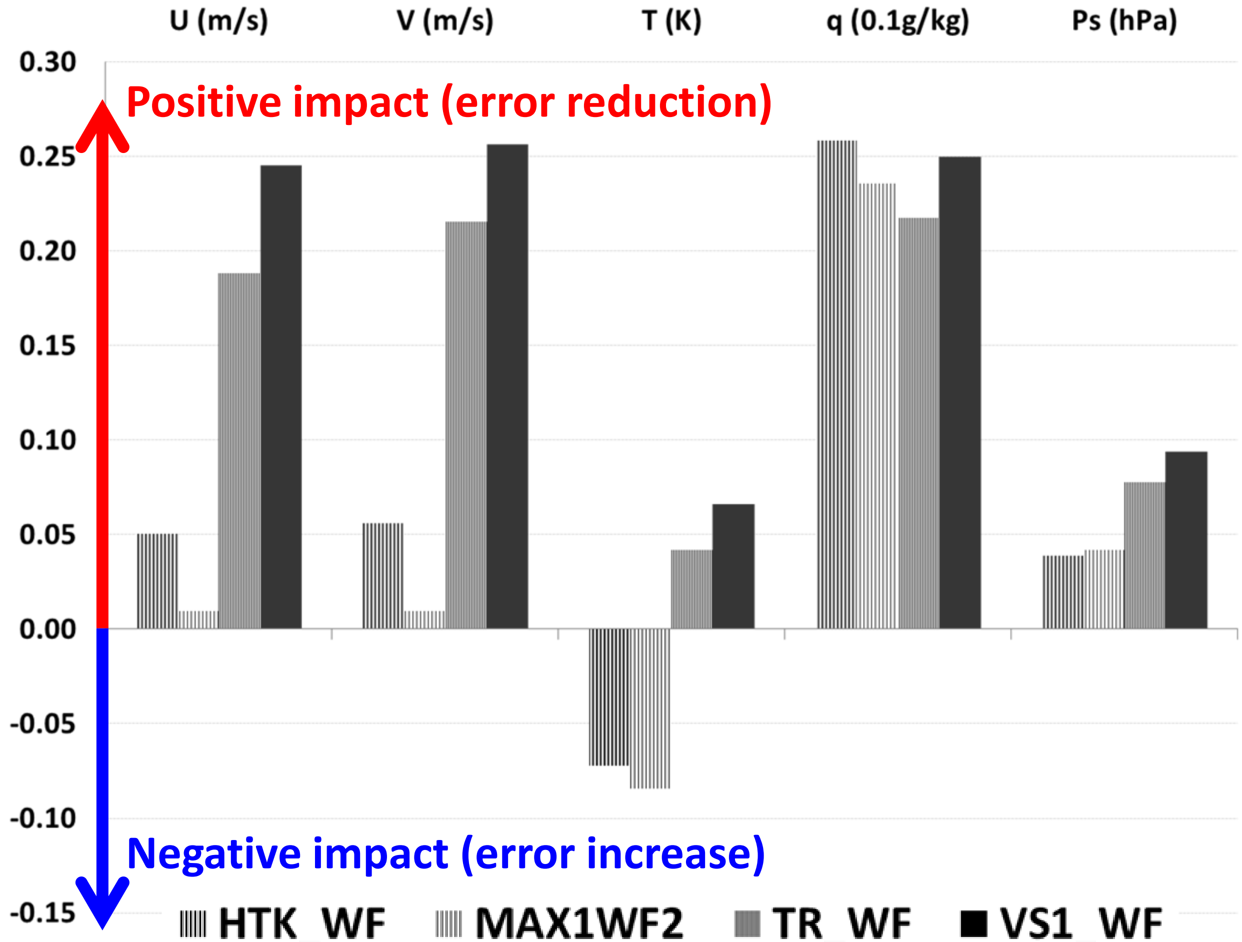
Observing System Simulation Experiments

- **4D-LETKF data assimilation for one month of Nov. 2012**
  - 30 ensembles, and adaptive multiplicative inflation (Miyoshi, 2011)
- **CNTRL_SONDE**
  - Assimilates conventional data which mimic the spatial and temporal distributions of NCEP prepbufr data.
- **EXP_AMSUA**
  - Assimilates **AMSU-A radiance data (Chs 5-9)** in addition to the conventional data used for CNTRL_SONDE.
- **EXP_IASI**
  - Assimilates **102 temperature channels of IASI radiance data** in addition to the conventional data used for CNTRL_SONDE.

instrument	# of data points per analysis step	Observation errors (K) of brightness temperature
AMSU-A	~ 120,000	0.42, 0.3, 0.35, 0.39, 0.4 K for Chs 5-9
IASI	~ 50,000	1.0K for lower & upper level peak chs 0.7071 K for mid-level peak chs

EXP_AMSUA vs. CTRL_SONDE

- **Analysis RMS error reduction due to additional AMSU-A data,** compared to CNTRL_SONDE
  – Averaged for the last two weeks of one month DA



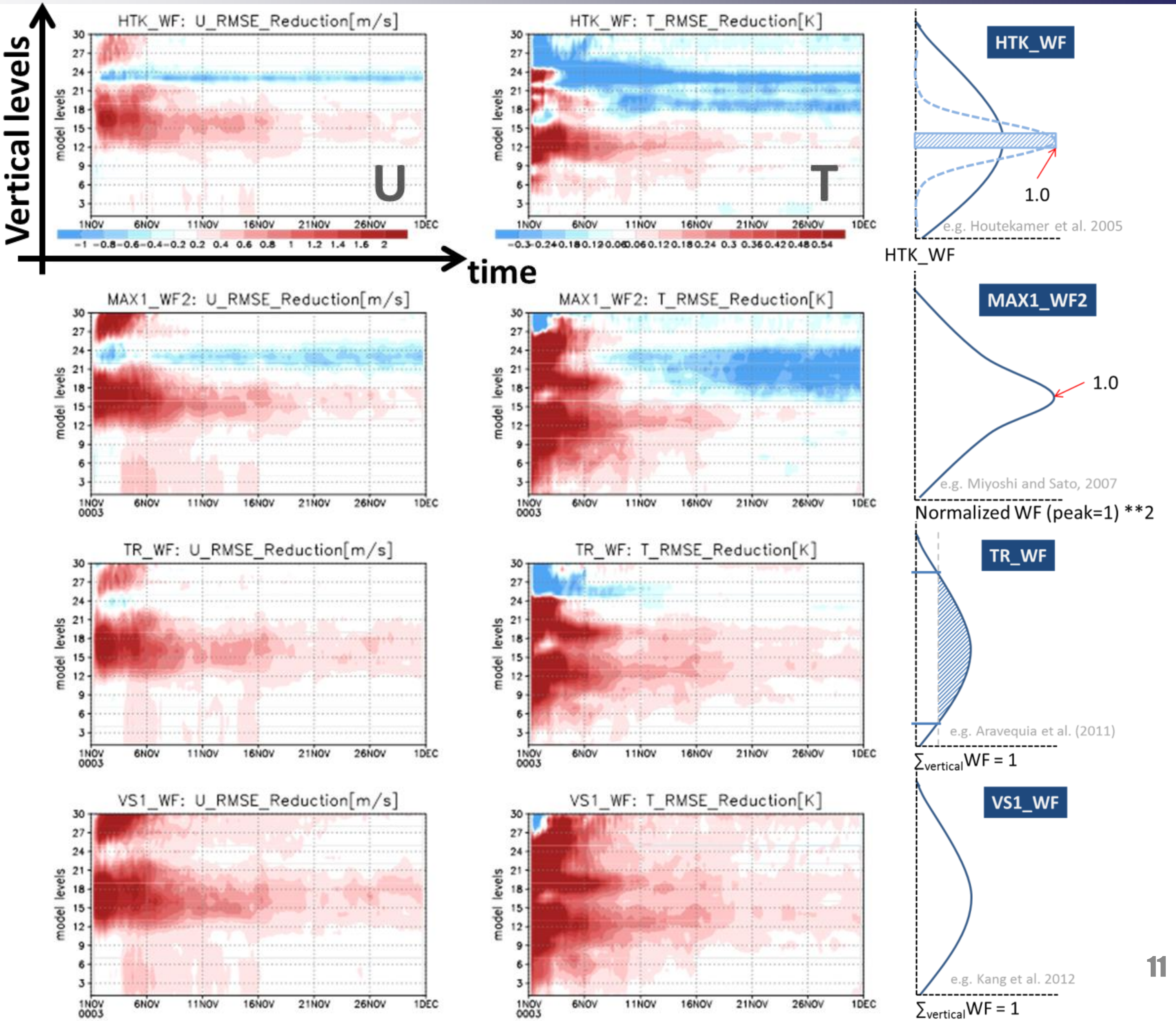
6-hr forecast RMS error reduction due to AMSU-A

HTK_WF

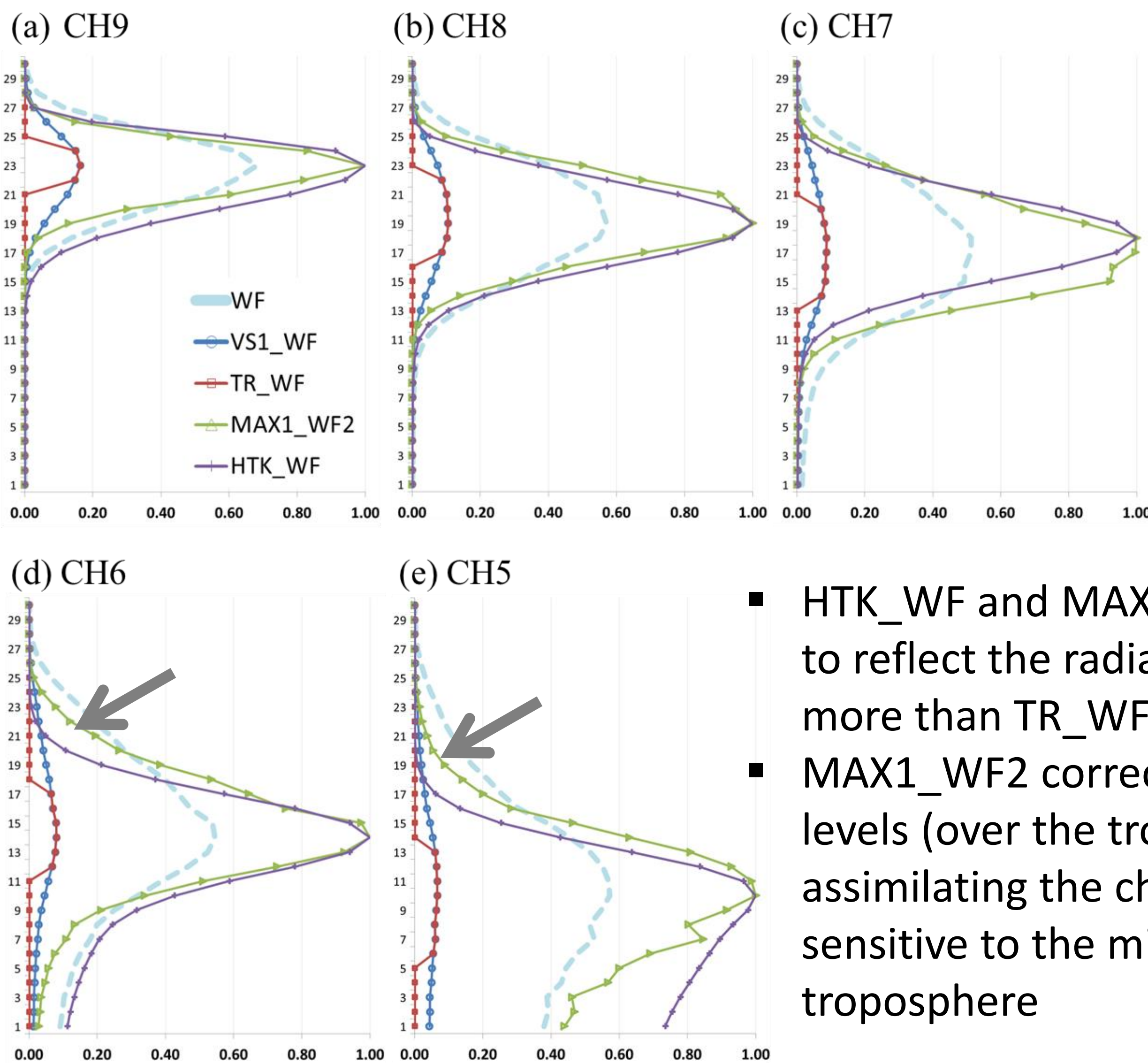
MAX1_WF2

TR_WF

VS1_WF



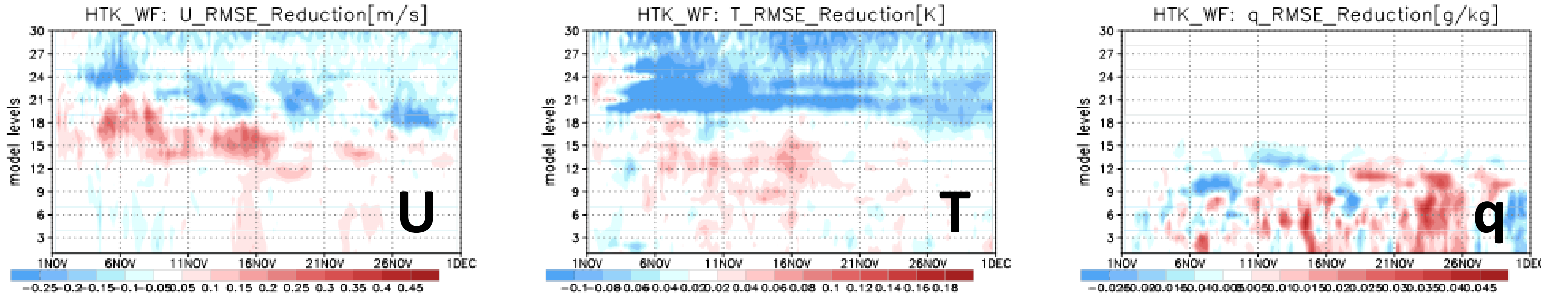
Different V_Loc [EXP_AMSUA]



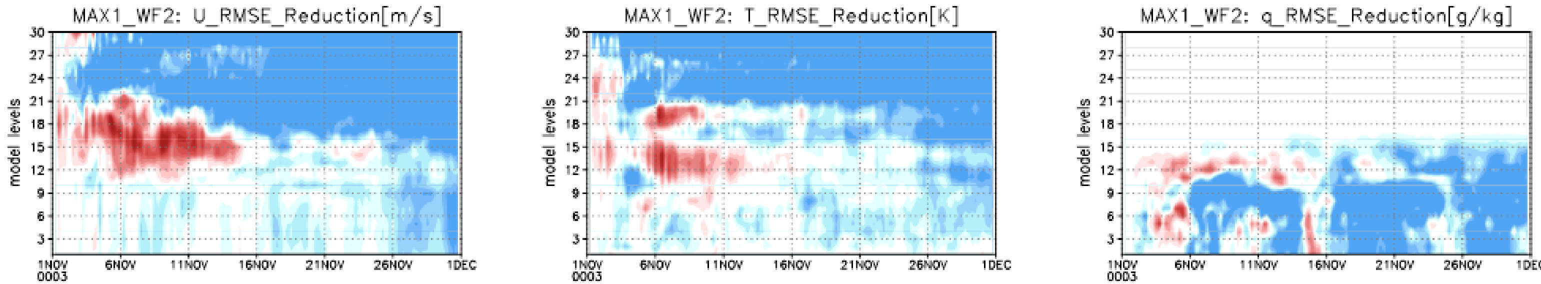
- HTK_WF and MAX1_WF2 tend to reflect the radiance data more than TR_WF and VS1_WF.
- MAX1_WF2 corrects upper levels (over the tropopause) by assimilating the channels sensitive to the mid-troposphere

6-hr forecast error reduction due to IASI

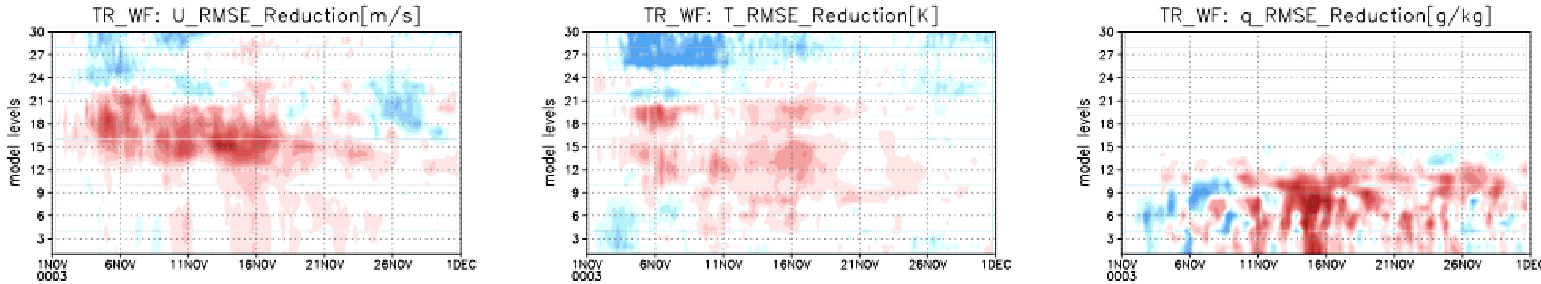
HTK_WF



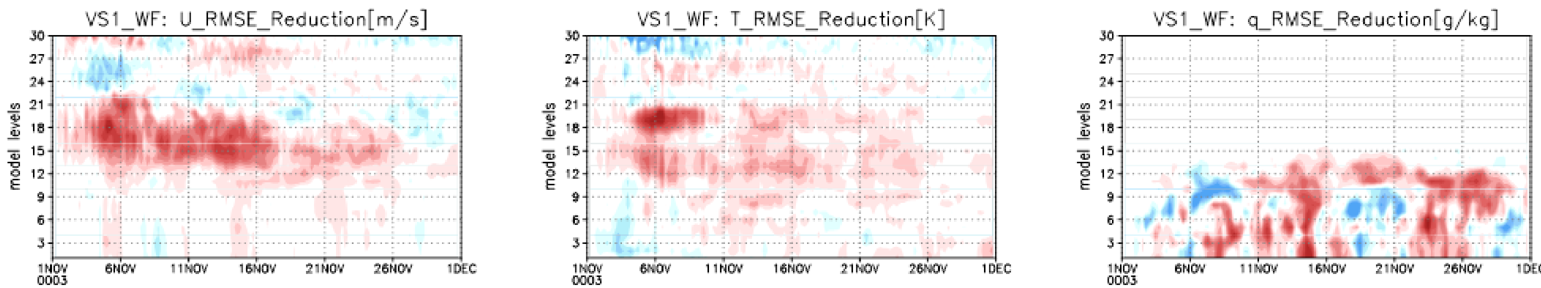
MAX1_WF2



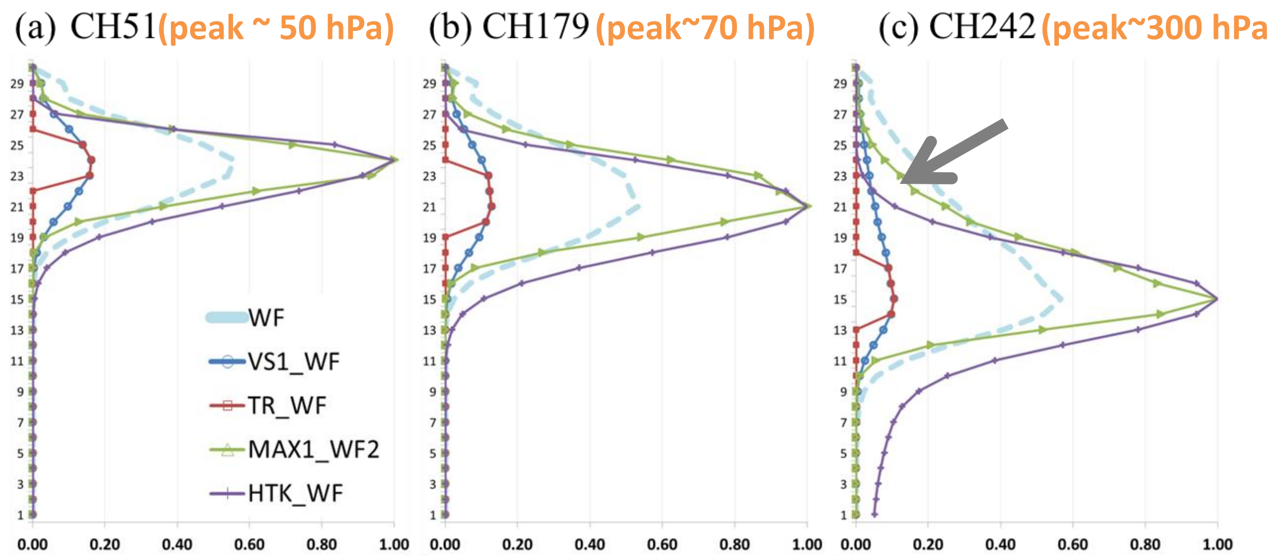
TR_WF

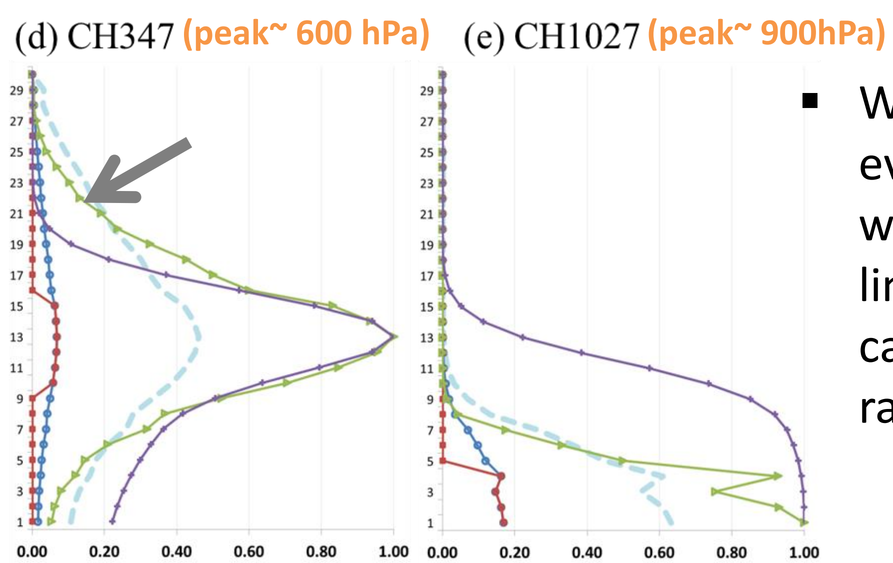


VS1_WF



Different V_Loc [EXP_IASI]





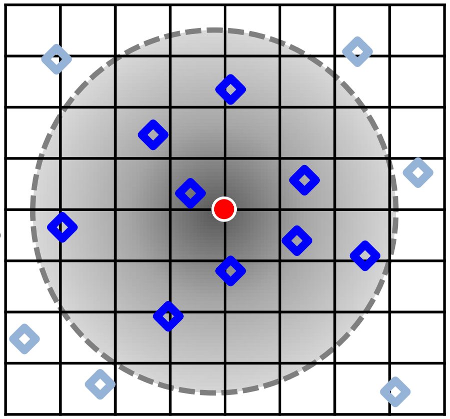
- We could not see any serious evidence of sampling errors with VS1_WF. Rather, TR_WF limits meaningful updates that can be extracted from the radiance data.

Summary and Discussion

- **Result of radiance data assimilation is sensitive to the choice of vertical localization functions.**
- HTK_WF and MAX1_WF2 tend to over-fit the analysis to the radiance data, and hence they show worse results than TR_WF and VS1_WF.
  - HTK_WF and MAX1_WF could not have positive impact of IASI data on the forecast and analysis.
- With neither distortion of WF shapes nor overuse of the data in the V_Loc (VS1_WF), we could have the best result of the radiance data assimilation with AMSU-A and IASI.
  - ***However, why the vertical sum of V_Loc should be unity?***

  ➔ **EFSR (Hotta et al.) or adaptive observation error estimation (Li et al., 2009)** can be applied to decide what should be optimal sum of V_Loc.

Impact of different V_Loc methods



- Spatial localization in LETKF
  - Analysis considers local observations within a prescribed radius centered at the analysis point.
  - Closer observations gives more increments with a Gaussian function.

$$R_{loc} = R_{diag} / e^{-\frac{1}{2}\left(\frac{D_h^2}{\sigma_h^2} + \frac{D_v^2}{\sigma_v^2}\right)}$$ ← HTK_WF

- Localization for the radiance data

$$R_{loc} = R_{diag} \Big/ \left[\left(\frac{WF(k)}{WF_{max}} \right)^2 * e^{-\frac{1}{2}\left(\frac{D_h^2}{\sigma_h^2}\right)} \right]$$ ← MAX1_WF2

$$R_{loc} = R_{diag} \Big/ \left[\left(\frac{WF(k)}{\sum_{k=1}^{nlev} WF(k)} \right) * e^{-\frac{1}{2}\left(\frac{D_h^2}{\sigma_h^2}\right)} \right]$$ ← TR_WF, VS1_WF

→ *only if* $WF(k) > \varepsilon * WF_{max}$