Assessment of the impact of satellite radiance on analysis

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Introduction

Quantifying the actual impact of each observation on forecast or analysis is important to verify the subset of the observation make the forecast better or worse.

Conventional denial method is very clear but too expensive.

Forecast sensitivity to observation (FSO) method based on adjoint sensitivity have proven to be a powerful monitoring tool (Langland and Baker, 2004; Gelaro and Zhu, 2009; Joo et al, 2012).

Unfortunately, KIAPS don't have the adjoint for the forecast model so cannot use FSO method.

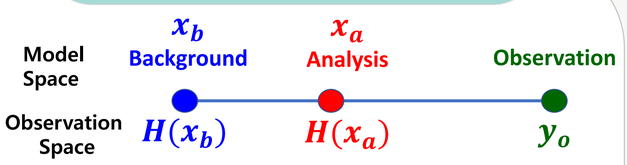
KIAPS keep up the effort to use ensemble method, i.e. EFSO (Kalany et al, 2012).

Observation sensitivity to analysis in data assimilation system has been obtained by evaluating the degrees of freedom for signal or the information content of observation (Rodgers 2000; Cardinali et al, 2004; Lupu and Gauthier, 2010).

This study introduce the simple method to get observation sensitivity of analysis to different satellite sensors and channels.

Averaged sensitivity to analysis for the subset of observation are the slope of the linear regression between 'analysis increment in observation space' and 'innovation, i.e. background departure from observation' for the given samples.

Concept of DA



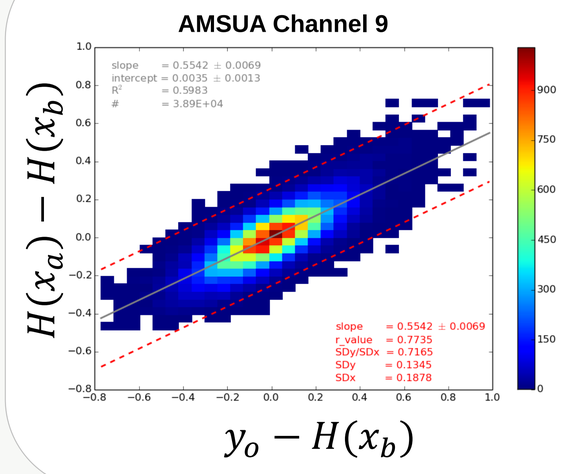
$$x_a = x_b + \mathbf{K}(y_o - H(x_b))$$

K: Kalman gain matrix, $\mathbf{BH^T(HBH^T + R)^{-1}}$
B: Background error covariance
R: Observation error covariance
H: Observation operator
H: Tangent linear of the observation operator $\quad \mathbf{H}\delta x = H(x + \delta x) - H(x)$

$$\mathbf{H}(x_a - x_b) = \mathbf{HK}(y_o - H(x_b))$$

$$H(x_a) - H(x_b) = \mathbf{HK}(y_o - H(x_b))$$

Impact of obs. (HK)



Slope ± 3SE$_{slope}$
= 0.5542 ± 0.0069

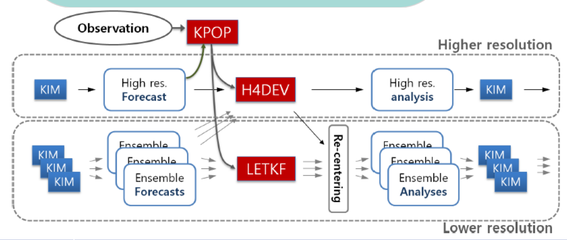
Slope means global averaged HK
: $\mathrm{HK} = \frac{\partial \mathbf{H}(\mathbf{x_a})}{\partial \mathbf{y_o}}$
: **the impact of observation on analysis**

SE$_{slope}$: standard error of slope
$= \frac{RMSE}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}} = \frac{\sqrt{1-r^2}}{\sqrt{n-1}}\frac{\sigma_y}{\sigma_x}$ where, $y = H(x_a) - H(x_b)$, $x = y_o - H(x_b)$

SE$_{ind}$: standard error of individual prediction at x_0
$= RMSE\sqrt{1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}}$

Red dashed lines: gray regression line ± 3SE$_{ind}$

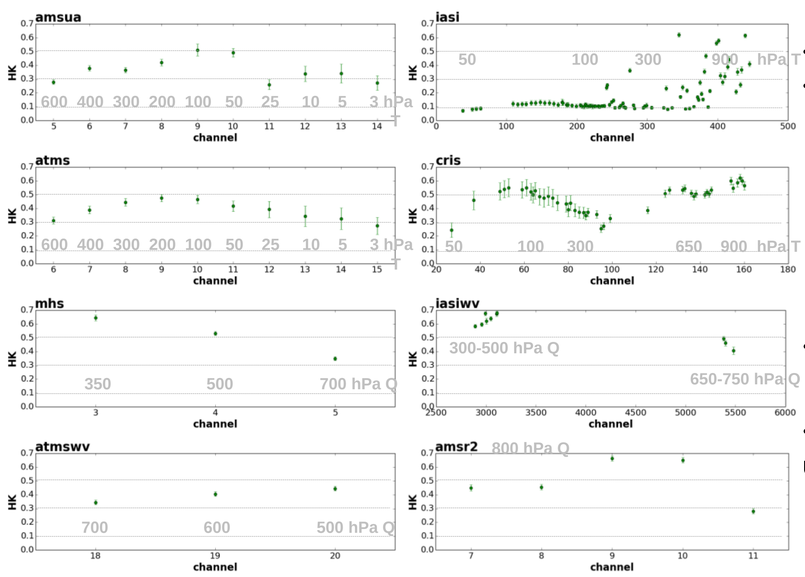
KIAPS system



Forecast model	**KIM (Korean Integrated Model) v3.4 (Aug. 2019)** - Cubed-sphere grid, ne180np3 (~25 km), 91 layer (1 Pa at the top)
H4DEV	**Hybrid 4D EnVar** - Cubed-sphere grid, ne60np4 (~50km) - Background Error covariance (B) = 0.7Static + 0.3Ensemble
LETKF	**Local Ensemble Transform Kalman Filter** - Cubed-sphere grid, ne90np3 (~50km), 50 members
KPOP	**KIAPS Package for Observation Processing** : Sonde, Surface, Aircraft, GPS-RO, AMV, ScattWind, AMSU-A, ATMS, MHS, AMSR2, SSMIS, MT-Saphir, IASI, CrIS, COMS

HK of satellite radiances

Monthly averaged HK in July 2018, vertical bar indicate the standard devaition



T sounding ch.

- AMSUA, ATMS: Large HK similar spectral trend of HK within 0.3 – 0.5 (peak at 200-50 hPa T)
- CrIS: Large HK (0.3-0.6)
- IASI: Small HK (0.1-0.6)
  upper sounding channels (50-300 hPa T)
  : Small HK (~0.1)
  : too different from CrIS, AMSUA, and ATMS
  lower sounding channels (-900 hPa T) affected by WV
  : Large HK (0.3-0.6)

Upper altitude sounding channels have larger standard deviation of HK

WV sounding ch.

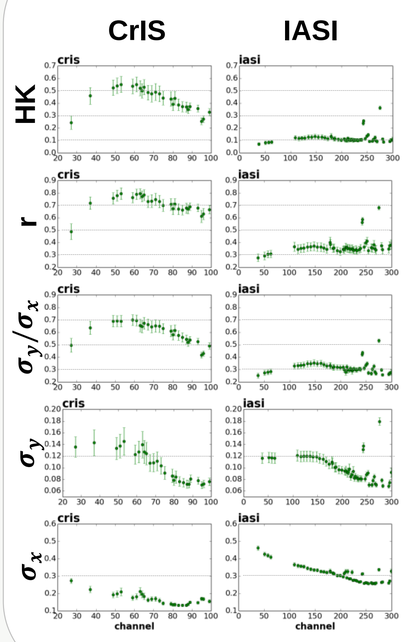
- MHS, ATMS: High HK similar spectral trend of HK within 0.3 – 0.6
- IASI: High HK (0.4-0.7)

Upper troposphere sounding channels have larger HK than lower troposphere

Imager ch.

- AMSR2: High HK (0.4-0.7)

IASI check



HK

- CrIS: ~0.5
- IASI: ~0.1, too small
- $\mathrm{HK} = \mathrm{r}(\mathrm{x},\mathrm{y})\frac{\sigma_y}{\sigma_x}$
  r(x,y): correlation btw x and y
  σ_y: stdev of y, $(H(x_a) - H(x_b))$
  σ_x: stdev of x, $(y_o - H(x_b))$

r

- **CrIS: ~0.7**
- **IASI: ~0.3, small**

σ_y/σ_x

- CrIS: ~0.7
- IASI: ~0.3, small due to σ_x
- σ_y is similar in CrIS and IASI

IASI ch 222 sample test @ 2018073000

	Ctrl	0.5 R	rm others	Out-check	Thin.
HK	0.098	0.154	0.127	0.108	0.123
r	0.332	**0.403**	**0.401**	0.312	**0.408**
$\frac{\sigma_y}{\sigma_x}$	0.293	0.357	0.317	0.345	0.302
σ_y	0.094	0.114	0.101	0.092	0.105
σ_x	0.319	0.319	0.319	0.267	0.348

- Ctrl: control, |C-B| <3 σ_0, thinning box (3deg)
- 0.5 R: experiment with half observation error of IASI
- rm others: experiment without AMSUA, MHS, RO
- Out-check: strict outlier check, |C-B| < 2σ_x
- Thin: smaller thinning box (1deg)

Summary and Conclusions

Observation impact on analysis is estimated by HK from the slope of the linear regression between $H(x_a) - H(x_b)$ and $y_o - H(x_b)$.

- **Water vapor sensitive channels have larger impact than temperature sensitive channels.**
- **Upper troposphere sounding channels have larger impact than lower troposphere sounding channels or stratosphere sounding channels.**
- **These results may be related with the magnitude of background error covariance and inflation factor of observation error covariance.**
- **Other sensors that are sensitive to temperature or humidity at similar altitude have similar HK except for IASI temperature sounding channels.**
- **The small HK in IASI is due to small r and large σ_x.**
  r : the correlation between $H(x_a) - H(x_b)$ and $y_o - H(x_b)$
  σ_x : the standard deviation of $y_o - H(x_b)$
- **Reducing observation error and thinning slightly increase r. However, the increased r of IASI is still significantly smaller than r of other sensors.**

Further Studies

- Checking whether the observation has abnormal HK
- Identifying the cause of abnormal HK
- HK retrieval for all kind of observations