Evaluation of the impact of IASI over land using the adjoint-based sensitivity method

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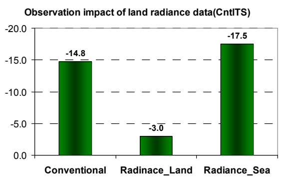
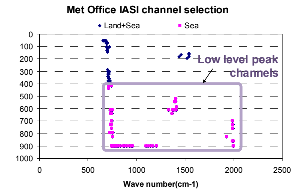
1. Motivation and purpose





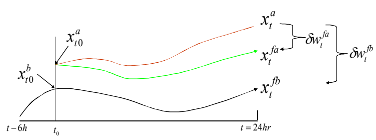
- Radiance data contributes more in reducing forecast error than conventional data but the radiance data is not effective over land because most low peaking channels are not used due to the difficulties of specifying the surface properties accurately
- A new land surface emissivity has developed to make use of the low level peaking channels over land at Met Office and it is necessary to identify which information is improving the forecast accuracy and which is not for further use and tuning of the land radiance data.
- Adjoint-based sensitivity methiod is a good tool to evaluate satellite impact because it can differentiate its impact every possible combinations(i.e. channels, location, time …)

The contribution of IASI data over land with a new surface emissivity is investigated quantitative based on the adjoint sensitivity tool for a better use of IASI data over land

2. Method

a. Observation Impact Method

Observation impact calculate an aspect of forecast error reduction due to analysis



$$\delta J = (\delta w)^T \mathbf{C}(\delta w_t^{fa} - \delta w_t^{fb}) = (\delta y^o)^T \delta \hat{y}^o$$

$$\delta w \approx \mathbf{MK}\delta y^o$$

$$\delta \hat{y}^o = \mathbf{K}^T\mathbf{M}^T\mathbf{C}(\delta w_t^{fa} - \delta w_t^{fb})$$

$\mathbf{M}$: Linear model $\mathbf{K}$: Karman Gain

δy^o: innovation $\delta \hat{y}^o$: observation sensitivity

δJ is a decrease of the global dry energy norm error(24hours) due to analysis and negative value means reduction of forecast error and better performance. (Reference : Met Office VSDP 63)

- Adjoint-based sensitivity method produces observational impacts easily aggregated by various subsets such as observation method, time, location, channels and so on.
- The method is useful to evaluate the impact of satellite radiance which contains lots of channels and depends on the observational conditions(i.e. cloud and surface properties).

b. Land Surface Spectral Emissivity (SSE)

Calculate background SSE from Atlas

Training Data Set: UCSB MODIS surface emissivity database

Select 12 leading PCs to represent SSE

$A_i^F = \sum_{j=1}^{nch} F_j(\varepsilon)\varphi_{ji}^F$, $F_j(\varepsilon)$: SSE functional Spectra φ_{ji}^F : Eigen vector

Get analysis SSE using 1dVar from background SSE

$$J = (x - x_b)^T \mathbf{B}^{-1}(x - x_b) + (y - H(x))^T \mathbf{O}^{-1}(y - H(x))$$

SSE is included as a background and retrieved with other state variables

(Reference : Zhou et al.(2010) and Ed Pavelin)

c. Experiment Design

Experiment Period: 2010.6.1.18UTC ~ 2010. 6. 7. 12UTC(6 hourly)

Name	Land Surface Spectral emissivity	Channels
Cntl	Fixed SSE(=0.98)	No low level peak channel at land
Exp1	Analysis SSE	With low level peak channels at land
Exp3	Fixed SSE(=0.98)	With low level peak channels at land
Exp4	Background SSE(=Atlas)	With low level peak channels at land
Exp5	Analysis SSE but with 0 background	With low level peak channels at land

d. The role of surface emissivity on observation impact

Simplified TOA radiance is $L = \varepsilon\tau B(T_s) + (1-\varepsilon)(1-\tau)\tau B(T) + (1-\tau)B(T)$ and for window channels($\tau \approx 1$) it approaches $L \approx \varepsilon B(T_s)$ and background TOA radiance with biased emissivity is simply $L^b = \varepsilon(1+\gamma)B(T_s^b) = (1+\gamma)L_u^b$

where, γ is an error ratio of emissivity

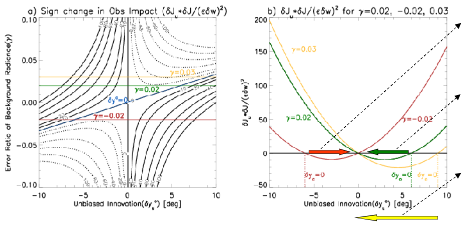
The observation impact of k^{th} satellite observation with the emissivity error becomes

$J_k = \hat{y}\delta y^o = \hat{y}(y^o - L^b)_k = \hat{y}(y^o - (1+\gamma)L_u^b)_k = \hat{y}(\delta y_u^o - \gamma L_u^b)_k = \varepsilon(1+\gamma)\delta w'(\delta y_u^o - \gamma L_u^b)_k$,where y^o:observation, δy^o : innovation, $\delta w'$: analysis sensitivity at observation position and time, and subscript u means unbiased value

The observation impact with and without emissivity bias are multiplied to see when the sign of observation impact is changed due to the bias

$$\delta J_u \delta J = (\varepsilon\delta w')^2(1+\gamma)(\delta y_u^o - \gamma L_u^b)\delta y_u^o \Rightarrow \frac{\delta J_u \delta J}{(\varepsilon\delta w')^2} = (1+\gamma)(\delta y_u^o - \gamma L_u^b)\delta y_u^o$$

assume $L_u^b = 300K$ $-10 \le \delta y_u^o \le 10$ $-0.1 \le \gamma \le 0.1$



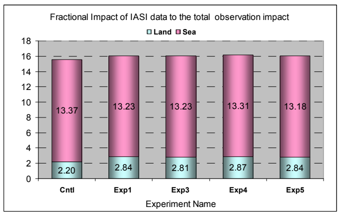
For negative emissivity bias, $\delta J_u \delta J$ is negative when innovation is positive

For positive emissivity bias, $\delta J_u \delta J$ is negative when innovation is negative

Increased bias expands the region of innovation which shows negative value of $\delta J_u \delta J$

3. Results

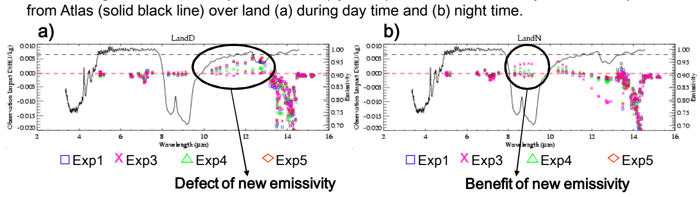
a. Fractional contribution of IASI impact



- Surface IASI channels over land has a positive impact on short-range NWP forecasts.
- The impact of IASI data over land in Exp3 is comparable to other experiments.
  - ✓ The overall impact of new SSE on forecast error reduction is not clearly shown.
  - ✓ The additional channels contribute in reducing the forecast error regardless of the SSE.
  - ✓ Emissivity from Atlas shows stronger positive impact than that of 1dvar retrieval.

b. Spectroscopic characteristics of observation impact

Time averaged observation impact over land (symbols) and surface emissivity of sand sample from Atlas (solid black line) over land (a) during day time and (b) night time.

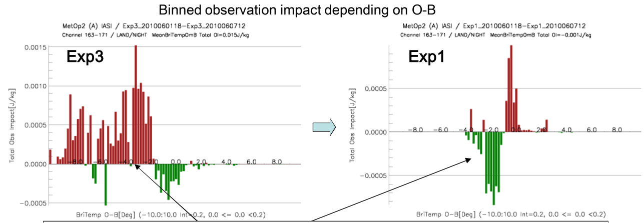


- The new emissivity has a good observation impact from 8 to 10um where the emissivity at sand sample is low and it is more significant at night observation.
- But in the high emissivity window region(10-13um), the observation impact is reduced compared to the fixed one(Exp3) and even worse, the assimilation of daytime observation increases forecast error (It is better not to use this data!).
- The effect of new emissivity becomes stronger with the 1DVAR analysis of emissivity.

c. Benefit of the new emissivity

Observation impact during night time for low emissivity region over land(8-10um)

Binned observation impact depending on O-B

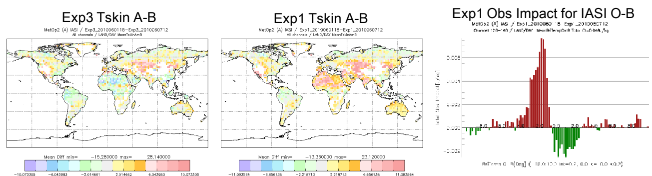


Positive emissivity in Exp3 induces wrong observation impact at the negative innovation area and it is improved with the correct emissivity in Exp1

- The fixed emissivity which has a large positive bias over land makes the background brightness temperature warm biased and the data with negative innovation degrade the model performance at Exp3
- The new emissivity improves the bias problem with a better specification of land emissivity and the degrading impact by a negative innovation is disappeared in Exp1
  - ✓ It seems like that the calculated brightness temperature get cold bias in Exp1 contrast to Exp3

d. Defect of the new emissivity

Tskin and observation impact at day time at 10-13um



- Tskin analysis is warmer in Exp1 over the deserts due to the emissivity is reduced in 8-10um
  - ✓ As long as the new emissivity is correct, the background Tskin has a strong cold bias over desert
- The high Tskin is kept because it is decoupled from the NWP cycle at MetOffice.
  - ✓ The negative innovation of 10-13um caused by persistent cold bias opposes positive analysis increment which was compensated by high emissivity in 8-10um in Exp3
- The better emissivity in 8-10um invokes Tskin problem and results in bad observation impact in 10-13 um indirectly.

4. Summary and plan

- The impact of IASI data over land with a new emissivity is evaluated using an adjoint-based observation impact method.
- The benefit of the land IASI data is shown largely in the spectroscopic region where the fixed emissivity error of sand sample is large (8-10 um and < 5um).
  - ✓The benefit is more significant for the night time observation and it is considered that the large emissivity bias is compensated by the cold bias of skin temperature of model background.
- The IASI land data with new emissivity shows negative observation impact at the window region(10-13um).
  - ✓ The better specification of emissivity in 8-10um in Exp1 invokes a problem related to the cold bias of the background skin temperature
  - ✓ The persistent cold bias induces negative innovation at 10-13um and it opposes positive analysis increment resulting negative observation impact.
- The better use of IASI land data with a background temperature bias, it is needed to apply quality control process depending on the innovation for window channels.
- The observation impact and forecast scores will be evaluated with a new quality control for the window channels over land

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