Two approaches of assimilation of cloud-affected infrared radiances

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1. Background and Purpose

- Assimilation of cloud-affected IR radiances is challenging due to strong nonlinearity, non-Gaussianity and incomplete cloud processes in NWP and Radiative Transfer Model (RTM) models.
- We are taking two approaches to assimilate those radiances:
  - 1st step: A simple cloud approach that handles radiances in single-layer, opaque and homogeneous cloud conditions
  - 2nd step: An all-sky approach that handles radiances in more general cloud conditions
- This poster presents
  - (1) Overview of simple cloud approach (Okamoto 2012) and new results by adding humidity channels of MTSAT-1R, and
  - (2) Preliminary investigation about the cloud effect on observation-minus-background (O-B) departure, modeling O-B standard deviation (SD) and its application to cloud-dependent pre-processings (Okamoto et al. 2013)

Acknowledgments

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References

- Okamoto, K., 2012: Assimilation of overcast cloudy infrared radiances of the geostationary MTSAT-1R imager. QJRMS., doi: 10.1002/qj.1994
- Okamoto, K., A. P. McNally and W. Bell, 2013: Progress towards the assimilation of all-sky infrared radiances: an evaluation of cloud effects. QJRMS., doi: 10.1002/qj.2242

2. Assimilation of simple cloud radiances

- Simple cloud: Single-layered, opaque and homogeneous cloud
  - Definition: cloud effective fraction $N_e \geq 0.8$, clear-sky rates < 5% and pixel SDs < 4.5 K
- Simple RTM : $R_i = R_i^c (1 - N_e) + R_i^o N_e$
  - R_i^c is a clear-sky radiance of channel i and R_i^o is a completely overcast radiance from a blackbody cloud at cloud top pressure P_c
  - N_e and P_c are determined so as to minimize radiance residual J from measurement R_i^m.

$$J = \Sigma_i (R_i^m - R_i)^2 = \Sigma_i \{R_i^m - R_i^c - N_e (R_i^o - R_i^c)\}^2$$

    - Two window ch (11 and 12 μm) are used to avoid as much wavelength dependence of N_e as possible
- Quality Control (QC): reject simple cloud data if $P_c < 160$ or $P_c > 650$hPa for window ch, and $P_c < 400$ hPa for humidity ch. (Fig.2.1)
- Bias correction (BC) based on VarBC applies to humidity ch (predictors: thickness $dZ_{1000\text{-}300}$, $dZ_{500\text{-}200}$, TCWV(total column water vapor), CA ("cloud effect average", see section 3) and constant term
- Cycle experiments from 20 July to 9 September 2009 are implemented.
  - JMA global data assimilation system : 4D-Var, TL319 (~60km) and 60 layers
  - Assimilating 11 and 6.3 μm ch radainces of MTSAT-1R in simple cloud conditions in addition to operational dataset shows neutral impact on forecasts. (Fig 2.2)

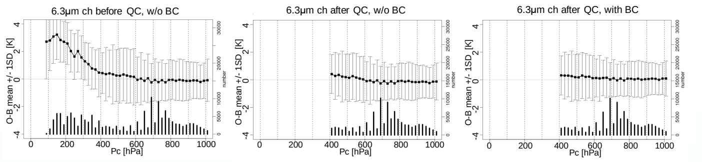

Fig.2.1 : Monthly mean value of O–B (lines with error bars ±1 SD) of brightness temperature (BT) and number (bars at bottoms) as a function of P_c at 6.3 μm ch of MTSAT-1R in simple cloud conditions over the sea

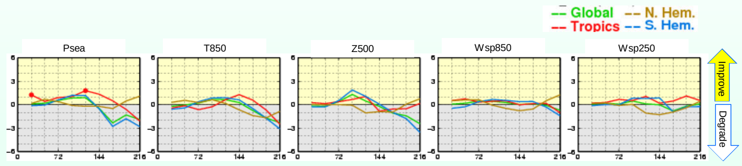

Fig.2.2 : Forecast improvement rate, defined by forecast RMSE reduction, as a function of forecast hours. Positive value indicates positive impact of cloud-affected radiances of 11 and 6.3 μm in simple cloud conditions. Dots on lines mean statistical significance.

3. Preliminary investigation of all-sky IR radiance assimilation

- Observation data and data assimilation system
  - Data: IASI 373channels, over the sea from 1 to 15 August 2011
  - System: ECMWF IFS T511(40km) and 91 layers, 4D-Var, RTTOV10.2
- Cloud-affected radiances are well simulated even for window ch (1090) that is significantly sensitive to cloud:
  - 85 (69) % of all data over the sea satisfy |O-B| < 10 K (5K). (Fig 3.1)
  - However, systematic inconsistency still exists, for example, for the storm track region in the SH and stratocumulus regions off the west coast of the continent.

- A new parameter CA was developed to quantify the cloud effect in the radiance space.

$$\mathrm{CA} = 0.5*(|\mathrm{CB}|+|\mathrm{CO}|),\ \ \mathrm{CB}=\mathrm{B}-\mathrm{B}_{\mathrm{clr}},\ \ \mathrm{CO}=\mathrm{O}-\mathrm{B}_{\mathrm{clr}}, \tag{3.1}$$

    - CA: cloud effect average. O = observed brightness temperature (BT), B = simulated BT, $\mathrm{B}_{\mathrm{clr}}$ = clear-sky simulated BT (cloud effect turned off in RTM)
  - As CA increases, O-B SD monotonically increases. After the saturation (overcast condition) O-B SD decreases. (Figs.3.2 and 3.3)
    - The simple relation enables us to predict cloud-affected O-B SD using O, B and $\mathrm{B}_{\mathrm{clr}}$
- Normalized O-B, or (O-B)/SD, shows (Fig.3.4)
  - Non-Gaussian form with excessively sharp peak and long tails if cloud effect is ignored using constant (cloud-independent) O-B SD
  - Gaussian form if cloud-dependent (dynamic) O-B SD is used

- O-B SD predicted from CA can be applied to cloud-dependent QC and observation error assignment
- Cloud dependent QC (Fig.3.5)
  - For O-B check where the thresholds are determined by O-B SD, cloud-dependent O-B SD predicted from CA can reasonably relax the thresholds in cloudy regions, compared with when using cloud-independent constant SD → More cloud-affected data pass the QC
- Cloud-dependent observation error σ
  - Information content (IC) of cloud-affected radiance using (1) clear-sky σ, (2) cloud-independent (constant) σ, and (3) cloud-dependent (dynamic) σ is compared.
    - IC is estimated based on an optimum linear estimation theory:

$$\mathbf{A}=(\mathbf{I}-\mathbf{KH})\mathbf{B},\quad \mathbf{K}=\mathbf{BH}^{\mathrm{T}}(\mathbf{HBH}^{\mathrm{T}}+\mathbf{R})^{-1} \tag{3.2}$$

      - **A, B** and **R** are analysis, background and observation error covariance, respectively. **I** is an identity matrix. **H** is Jacobean of RTM. **K** is a Kalman gain.
      - IC at level i is defined as : $\mathrm{IC}i = 1 - \frac{\sqrt{a_i}}{\sqrt{b_i}}$, where a_i, b_i are diagonal component of **A** and **B** at level i
  - For a thin cloud case,
    - The dynamic σ is much smaller than constant σ for tropospheric ch. The clear-sky σ is the smallest of the three. (Fig. 3.6)
    - The use of cloud-dependent σ gives higher IC of temperature and humidity than the constant IC does although IC in clear-sky is the highest. IC of cloud content and fraction with cloud-dependent σ is greater than that with constant σ. (Fig. 3.7)

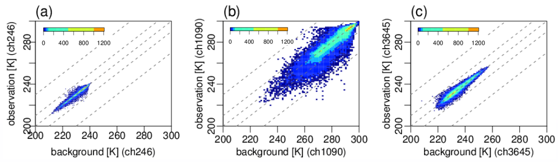

Fig.3.1: Density scatterplots of background and observation brightness temperatures (BTs) at (a) upper tropospheric temperature ch (246, 14.16μm), (b) window ch (1090, 10.9μm), and (c) upper tropospheric humidity ch (3645, 6.3μm). The data are taken from the globe over the sea from 1 to 15 August 2011. Dashed lines represent O-B = ±10 and ±30 K.

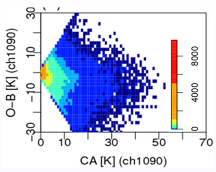

Fig.3.2: Density scatter plot of O-B at ch 1090 against the cloud effect average CA.

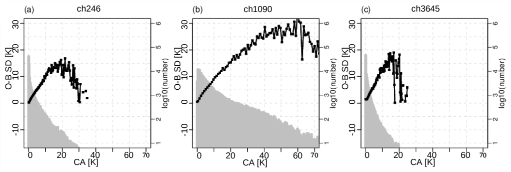

Fig.3.3: O-B SD against CA at (a) ch 246, (b) ch 1090 and (c) ch 3645. The sample number in each CA bin is shown by grey bars and right axis.

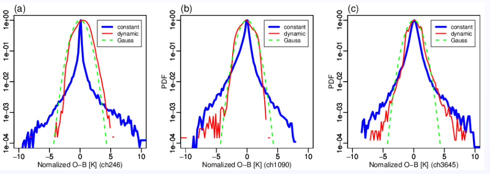

Fig.3.4: PDFs of O-B normalized by O-B SD at (a) ch 246, (b) ch 1090, and (c) ch 3645. SD is calculated from the whole sample, in which SD is constant irrespective of cloud effect (blue lines), or predicted with CA (dynamic or cloud-dependent SD, red lines). Normal Gaussian PDFs are also plotted (green line).

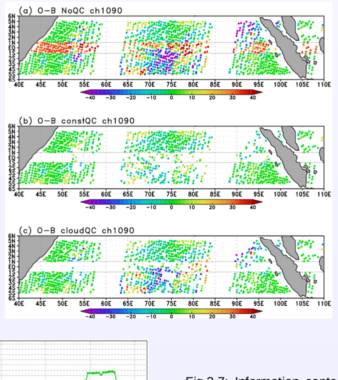

Fig. 3.5: (a) O-B at ch 1090 for analysis at 00 UTC on 1 June 2012. An artificial gross error of 30 K is given to the data in the latitudinal band between 1N and 1S (the boundary plotted with grey lines).

(b) is as (a), but after applying the constant threshold QC.

(c) is as (a), but after applying the cloud-dependent threshold QC estimated from CA.

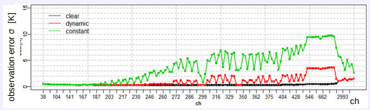

Fig.3.6: Observation errors as a function of 141 IASI channels. Clear-sky σ (black line) is calculated with RTTOV without cloud effect in clear-sky conditions. Constant σ (cloud-independent, green) is calculated from the whole samples irrespective of clouds. Dynamic σ (cloud-dependent, red) is calculated from CA in a thin cloud case.

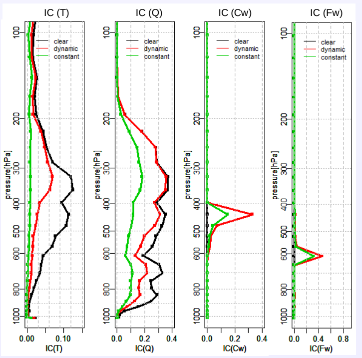

Fig.3.7: Information content (IC), for temperature (T), mixing ratio (Q), cloud water content (Cw) and cloud water fraction (Fw). IC is calculated with clear-sky σ (black lines), dynamic σ (red) and constant σ (green) for 141 IASI radiances are assimilated in a thin cloud case.

4. Summary

- Simple cloud approach
  - Cloud-affected radiances are assimilated with a simple RTM using N_e and P_c in one-layer, thick and homogeneous cloud conditions.
  - Assimilating radiances at 11 and 6.3 μm ch of MTSAT-1R shows neutral impacts due probably to very few data available passing strict QC procedures to meet the cloud condition.
  - QC and BC procedures may need to be improved. More impact can be expected from more satellites (e.g. ASR of Meteosat) and next generation geo-satellites (e.g. Himawari-8).
- All-sky approach
  - NWP and RT models well reproduce observations even in general cloudy situation while there is systematic deficiency.
  - A newly developed cloud effect parameter enables us to predict O-B SD of cloud-affected radiances.
  - All-sky radiances can be handled under the Gaussian assumption if their variability due to clouds are correctly treated, for example, using CA.
  - The predicted O-B SD can be applied to cloud-dependent QC and observation error assignment.