Assimilation of cloudy infrared radiances of MTSAT-1R

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1. Background and Purpose

- Hyperspectral infrared sounders have been successfully assimilated in (limited) cloudy conditions in several NWP centres using a simple radiative transfer model (RTM; Bauer et al. 2011)
- The simple RTM models cloud effects using only two parameters of cloud top pressure (P_c) and effective fraction of cloud (N_e), which assumes
  - Single-layer cloud
  - Applicability of single N_e to different channels (i.e. Nearly constant cloud emissivity)
- Applying this approach to infrared imagers on geostationary satellites can offer the advantage of using information that is frequently measured, in spite of limitation of available channels.
- The key to this development is to select appropriate data that are well simulated by the simple RTM and background from NWP model. Thus. this study focuses on
  - Creating and characterising spatially averaged radiances (super-ob) to obtain better match of spatial representativeness between model and measurement
  - Developing quality control (QC) procedures to secure small inhomogeneity and ch-independency

Channel characteristics of the MTSAT-1R imager

Spectral channels	IR1	IR2	IR3	IR4	VIS
Wavelength [mm]	10.3~11.3	11.5~12.5	6.5~7.0	3.5~4.0	0.55~0.90
Ground resolution at nadir	4 km				1 km

2. Characteristics of MTSAT-1R super-ob radiance

- Each super-ob was constructed at model grid point by averaging infrared pixels within a circle of a predefined radius r_s.
- The frequency distribution of super-ob Brightness Temperatures (BTs) and the Standard Deviation (SD) of pixel BTs in each super-ob varies with the size of the super-ob. (Fig. 2.1; Fig.2.2)
- → An appropriate selection of the super-ob size is important for the representative scale of assimilation, especially when cloud variables from model are used.
  - For example, if the super-ob scale is smaller than the scale of the model representation, even a perfect model might fail to simulate very high or low BTs of the super-obs.
- In this study, we simply set r_s to the model resolution (30km).
  - The inconsistency between model and super-obs was small because cloud variables were extracted from super-ob themselves (see next section).

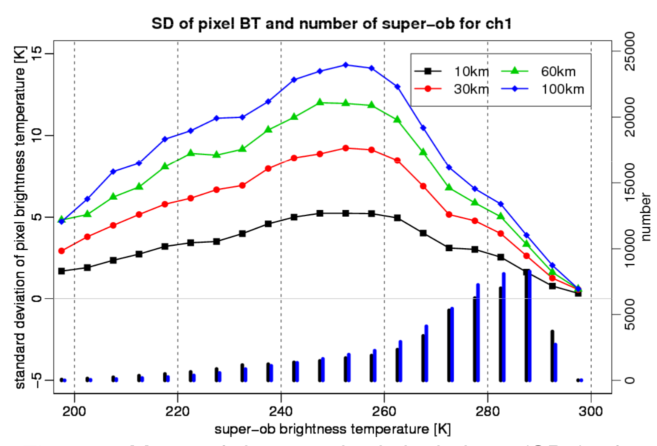

Fig.2.1: Mean of the standard deviations (SDs) of pixel brightness temperatures (BTs) for each super-ob BT bin for super-ob radii r_s = 100, 60, 30, and 10 km on 25 July 2009. The number of super-obs at each bin is also plotted for r_s = 10 and 100 km with bars (right axis).

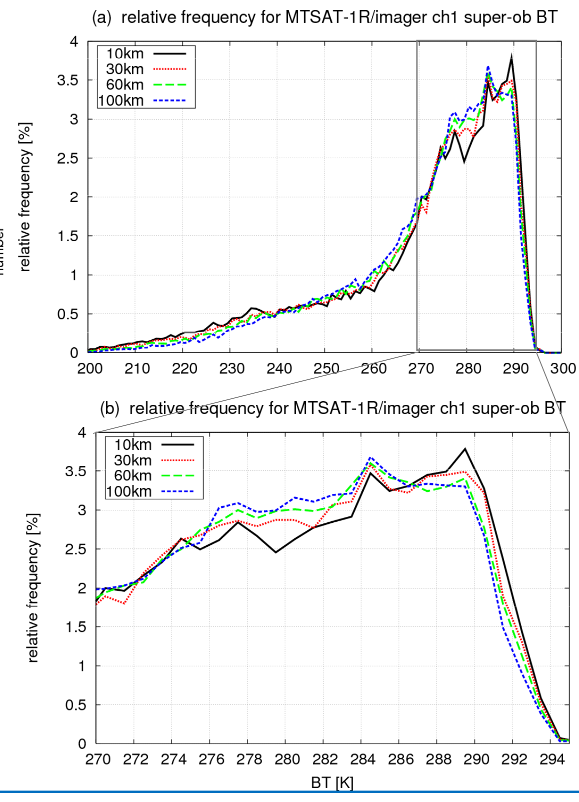

Fig.2.2: Relative frequency histograms of super-ob BTs of MTSAT-1R channel IR1 for (a) the whole BT range between 200 and 300 K and (b) a zoomed-in range from 270 to 295 K.

3. Simulation of cloudy radiances and QC

- 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
  - We calculate R_i^c and R_i^o with RTTOV-9.3 (Matricardi et al., 2004; Saunders et al., 2010)
- N_e and P_c are determined so as to minimize radiance residual from measurement R_i^m, defined with J.

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

  - Channels IR1 and IR2 were chosen to avoid as much wavelength dependence of N_e as possible
- Validation of P_c with CloudSat
  - The MTSAT super-ob cloud top height well agrees with the CloudSat value when $N_e \geq 0.8$ (Fig.3.1)
  - Correlation coefficient=0.972; RMSE=1.030 km

- In this study, the super-ob radiances that meet the below criteria are called **OSR** (Overcast Super-ob Radiances) and will be assimilated after passing all QCs.
  - $N_e \geq 0.8$
  - clear-sky rates < 5% and pixel SDs < 4.5 K (Homogeneity check)

- QC: OSRs are reject if
  - P_c <160 or P_c >650hPa, because those data have ch-dependent biases (Fig.3.2)
  - over land, coast and sea ice areas
  - local zenith angle > 62.5°

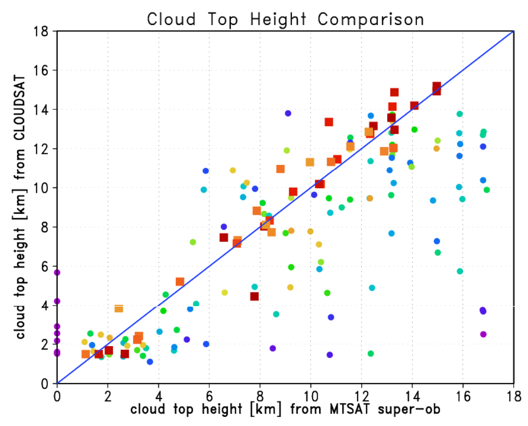

Fig.3.1: Scatter plot of cloud top height (km) from CloudSat (left axis) and MTSAT-1R super-obs (bottom). Collocation was made where the difference between the CloudSat CPR footprint and the centre of the MTSAT super-obs was less than 15 km in distance and 5 minutes in time. The collocated cloud top heights of CloudSat was averaged to super-ob size (r_s = 30km)

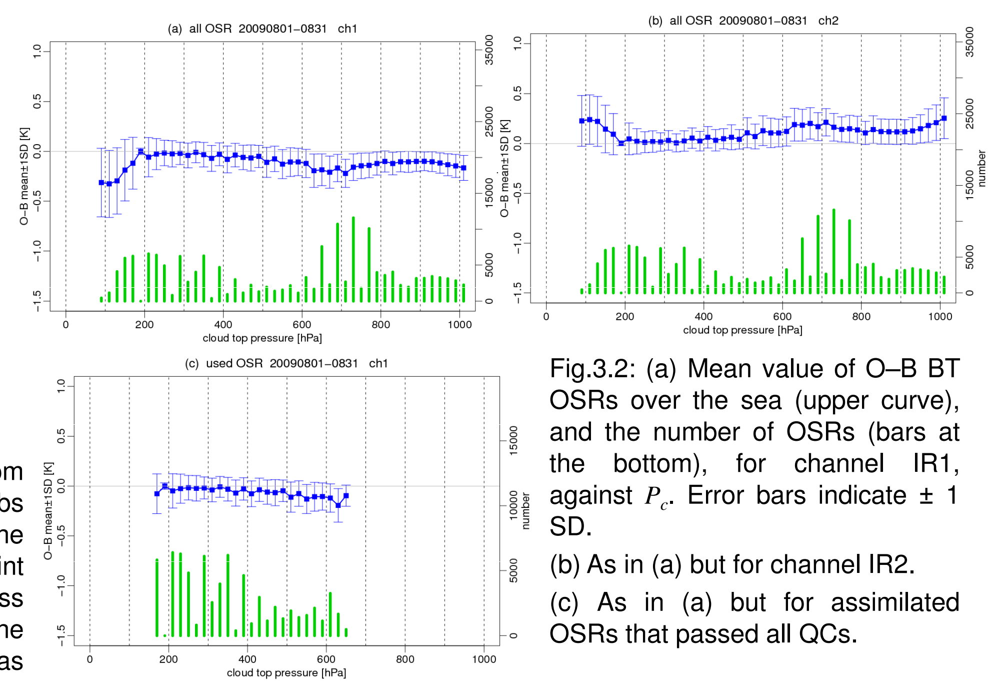

Fig.3.2: (a) Mean value of O–B BT OSRs over the sea (upper curve), and the number of OSRs (bars at the bottom), for channel IR1, against P_c. Error bars indicate ± 1 SD.

(b) As in (a) but for channel IR2.

(c) As in (a) but for assimilated OSRs that passed all QCs.

4. Assimilation of OSRs

- CNTL: a low resolution version of JMA's operational global data assimilation system as of Jul.2011
  - Model Resolution : TL319L60 (~60km)
  - Analysis : 4D-Var with inner loop T106L60 (~120km), 6-h assimilation window
  - Assimilated radiance data : ATOVS, SSMI,SSMIS,AMSRE andTMI in clear conditions and Clear Sky Radiance (CSR) of 5 geo-satellites
  - Analysis variables : temperature, vector wind, logarithm of specific humidity, surface pressure, and coefficients of VarBC. No cloud variables are analyzed.
  - 219-h forecasts made at 12 UTC
- TEST: add MTSAT-1R OSRs to CNTL
  - Assimilate IR1 only, no bias correction, observation error set to 0.2 K
  - Thin to one per 3 model grid boxes (~60x3=180km) in almost every time slot (5 out of 6 slots)
- TEST2: same as TEST but OSRs are assimilated in every second time slot (3 out of 6 slots).
- Experiment period
  - Assimilation : 20 Jul. ~ 9 Sep. 2009, Forecast : 1 ~ 31 Aug 2009

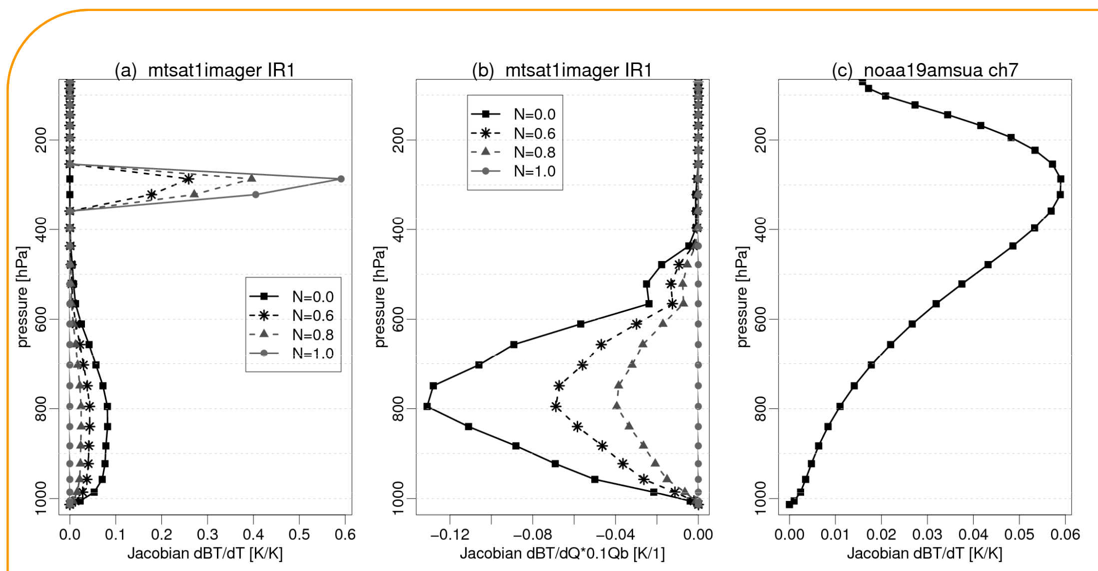

Fig.4.1: (a) Jacobian of channel IR1 BT with respect to a temperature perturbation of 1 K in the presence of a single layer of cloud at P_c=300 hPa with N_e=0.0, 0.6, 0.8 or 1.0.

(b) As in (a) but with respect to a perturbation of 10% of background humidity (ppmv).

(c) As in (a) but for AMSU-A channel 7 in clear conditions

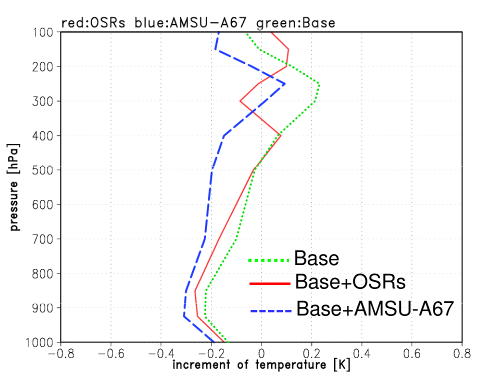

Fig.4.2: Vertical profile of the temperature increment in non-cycle assimilation experiments at 0600 UTC on 25 July 2009. The Base run assimilated no satellite data. The increments were averaged over the area within the box 141°E–144°E and 48°S–52°S.

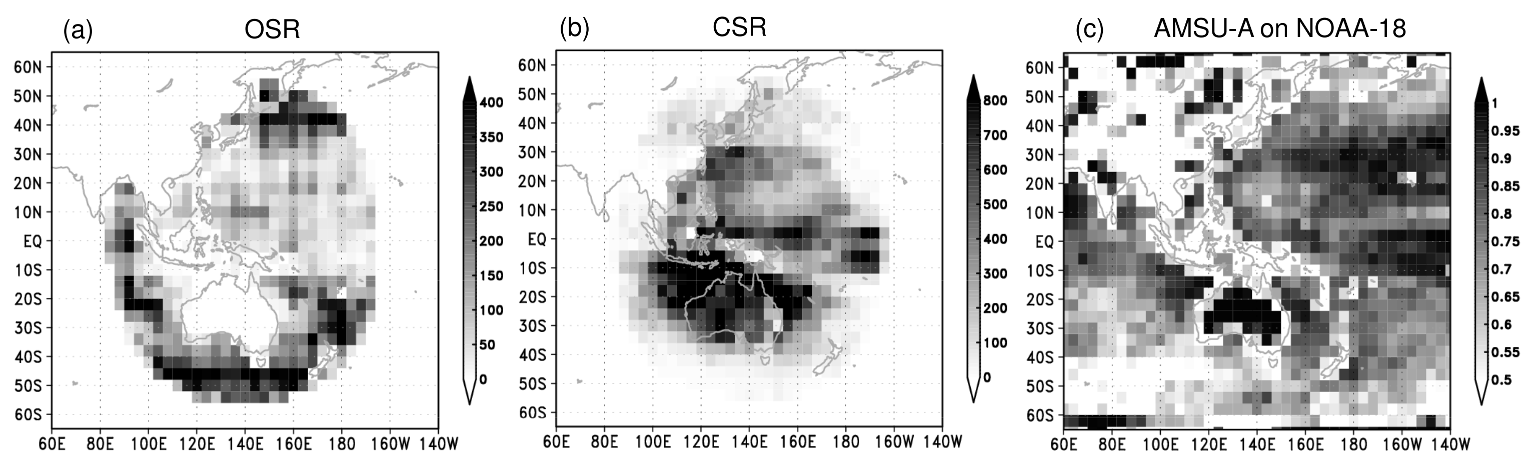

Fig.4.3: Total number of assimilated data counts in 4° × 4° grid boxes for (a) OSRs and (b) CSR from MTSAT-1R, and (c) ratio of assimilated data to all data for AMSU-A channel 6 on NOAA18 in August 2009 in the TEST run.

5.1. Results and Summary

- In order to make use of cloudy infrared radiances from geostationary satellites, we have created OSRs and assimilated them in the presence of single-layer cloud.
- QC is crucial to meet the assumption of the simple single-layer cloud RTM, including homogeneity and ch-indepenency of cloud parameters.
- Advantages of OSRs from geostationary satellites are expected to include
  (1) Having temperature information that is highly vertically resolved at the cloud top (Figs.4.1; Fig.4.2),
  (2) Availability in cloudy regions (complementary to CSR and , to some extent , MW-sounders) (Fig.4.3), and
  (3) Frequent measurements
  We confirmed (1) and (2) but have hardly found clear evidence of (3) so far.
- Assimilation of OSRs improved the forecast skill of upper tropospheric temperature and lower tropospheric wind (Fig.4.4), although the impact was small and neutral for most geophysical variables

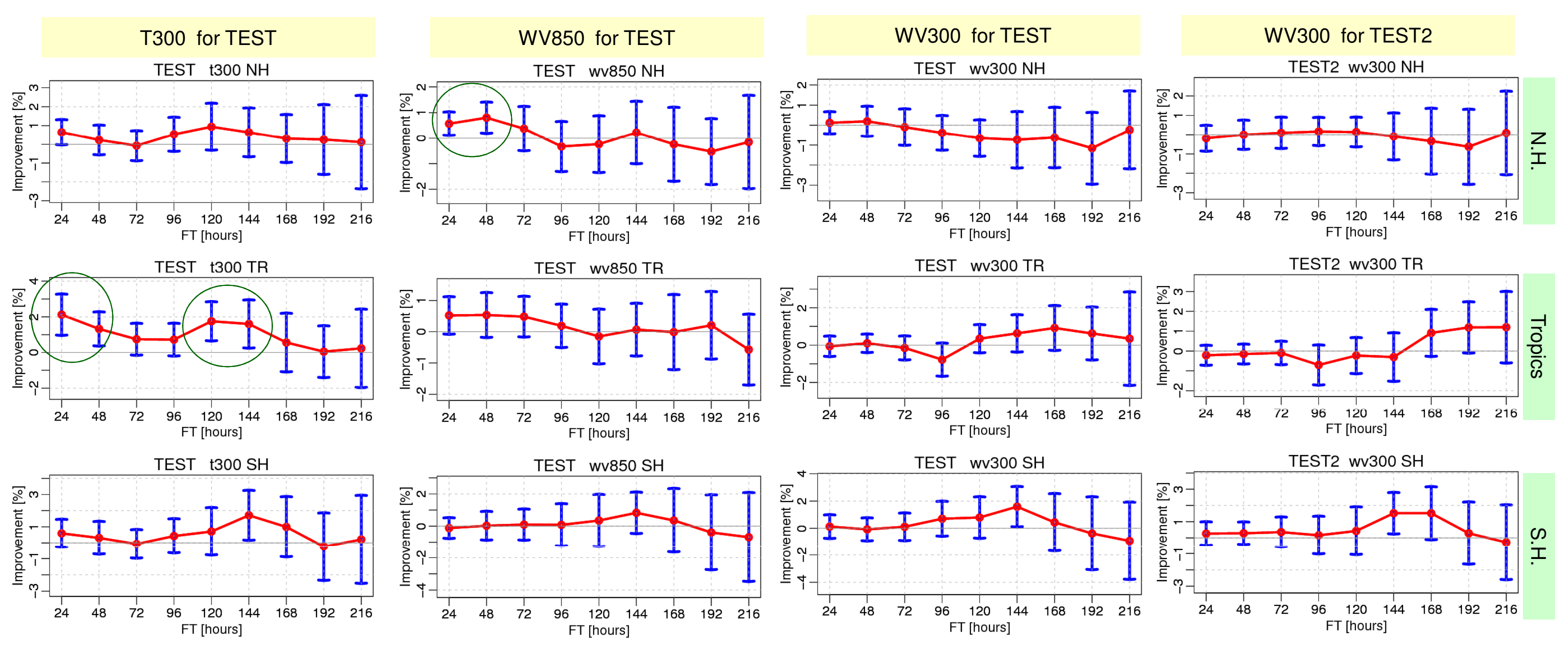

Fig.4.4: Forecast improvement of the temperature at 300 hPa (1st column from the left), wind speed at 850 hPa (2nd column) and at 300 hPa (3rd column), as a function of forecast hours. The improvement is defined by TEST RMSEs minus CNTL RMSEs normalized by CNTL RMSEs. Vertical error bars indicate the statistical confidence (t-test) at the 95% level. The 4th column shows forecast improvement of wind speed at 300 hPa for TEST2.

5.2. Discussions and Plans

- More data (i.e. more channels and less limited P_c) should be assimilated by applying bias correction to decrease inconsistency between channels
- Estimated cloud parameters estimated might be adjusted excessively so that errors in model and measurements are cancelled out. Analyzing those parameters in 4D-Var probably can alleviate this overfitting problem.
- Applying this approach in regional data assimilation systems would be more beneficial than in global assimilation systems as the systems are more frequently updated and operate with shorter cut-off time.
- Investigation on assimilating radiances in more general cloudy conditions such as multi-layer clouds is underway.