Assimilating clear-sky radiance of SSMIS humidity sounding channels in the JMA global NWP system with newly developed cloud detection algorithm

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Abstract

A physically-based cloud detection algorithm was developed for the clear-sky assimilation of humidity sounding channels of the Special Sensor Microwave Imager/Sounder (SSMIS), which is a microwave radiometer with 24 channels covering wide range of microwave frequency. The algorithm utilizes multiple-channel feature of SSMIS and classifies cloud-affected data into three categories based on hydrometeor types (i.e., cloud liquid particles, snow crystals and ice crystals). The newly developed cloud detection algorithm can detect thick cloud (eg. cumulus, stratocumulus) which are difficult to detect with the traditional algorithm. The algorithm was implemented into JMA's global NWP system and the impact of assimilating SSMIS humidity sounding channel data was assessed in observing system experiments. The experiment results show that positive impact on water vapor analysis field globally, and on temperature and geopotential height forecast field at the southern hemisphere.

1. Introduction

Satellite microwave radiance observations at 183 GHz contain atmospheric humidity, cloud and precipitation information. They are one of the most important observations to improve and maintain the accuracy of operational numerical weather prediction. In this context, the Japan Meteorological Agency (JMA) utilizes clear-sky radiance data from the MHS on the NOAA -18, NOAA-19, MetOp -A and MetOp-B satellites, the SAPHIR on the Megha-Tropiques satellite, and the GMI on the GPM core satellite in its global data assimilation system.

Since the observations are affected by cloud liquid water emission and freezing particle scattering in cloudy situations, it is crucial to discriminate the cloud and precipitation affected data for the clear-sky assimilation of microwave humidity sounding channels, However, traditional cloud detection approaches using a single microwave window channel are not available for SSMIS onboard DMSP F-17 because its 150 GHz window channel is not working at the time of this study. Therefore, a new physically-based cloud detection algorithm was developed for the clear-sky assimilation of SSMIS humidity sounding channels. In this study, SSMIS data calibrated with the Unified Preprocessor Package (UPP) (Bell et al. 2008) were employed. Assimilating SSMIS UPP humidity sounding channels into the system helps to fill gaps among other humidity sounding data coverage as shown in Fig. 1. This paper documented the newly developed cloud detection algorithm and the impact of assimilating SSMIS UPP humidity sounding channel data.

2. Cloud detection algorithm

In this study, we developed a cloud detection algorithm which classifies cloud-affected microwave radiance into three types based on hydrometeor types (i.e., cloud liquid particles, snow crystals and ice crystals). Each cloud type is determined by using various physically based approaches. Fig. 2(a) shows threshold for detecting "Cloud liquid particles" type data. Detection of "Cloud liquid particles" type data is based on the cloud liquid water (CLW) derived from "cloud amount" (Geer and Bauer, 2011) defined as

$$cloud\ amount = 1 - Tb37Vobs - Tb37HobsTb37Vclr - Tb37Hclr$$

where $Tb37Vobs$ and $Tb37Hobs$ are the observed brightness temperature at 37GHz at vertical and horizontal polarizations respectively. When the derived CLW is more than 100 (g/kg), the data are classified as"cloud liquid particles" affected.

Fig. 2(b) shows threshold for detecting "Snow crystal" type data. "Snow crystal" type data is defined by a scattering based technique so-called Polarization-corrected Temperature (PCT) approach (Spencer et al.1986), with coefficients targeting mid-latitude adopted from Liu et al.(1998), which can be written as

$$PCT = 1.5 \times dTb(91V) - 0.5 \times dTb(91H)$$

where $dTb(91V)$ and $dTb(91H)$ are the difference between observed and calculated clear-sky radiance at 91 GHz at vertical and horizontal polarizations respectively. When the calculated PCT is less than -3K or $dTb(91V)$ is less than -5K, the data are classified as "snow crystal" affected. Weather conditions associated with snow crystal are also often associated with melting layer, which increases brightness temperature at 91 GHz due to CLW emission. In the algorithm, those data with relatively small scattering signal but has large emission signal are considered as melting layer affected. When $dTb(91V)$ is less than -0K and $dTb(37H)$ is more than 1.5K, the data are also classified as "snow crystal" affected.

"Ice crystal" type data are detected by another scattering based technique so-called scattering index (Ferraro et al., 2000), which is also used in traditional cloud detection approaches. MHS cloud detection algorithm utilized two window channels (i.e.150GHz and 90GHz), However, due to malfunction of 150 GHz onboard F17, 183±6.6 GHz (sensitive to lower troposphere) is selected as a high frequency channel in SSMIS cloud detection algorithm. This channel was chosen because it has the best correlation with 150GHz among 3 sounding channels. Fig. 2(c) shows threshold for detecting "Ice crystal" type data, which can be written as

$$Scattering\ Index = dTb(183 \pm 6.6) - dTb(91V)$$

When the calculated scattering index is less than -10K, the data are classified as “ice crystal” affected.

Fig. 3 shows a result which those quality controls were applied. Thick cloud areas are not detected as “ice crystal” type which is equivalent of those areas detected as cloud area by MHS cloud detection algorithm. The new algorithm detects these areas as “cloud water liquid” or “snow crystal” types, which allow the algorithm to reduce overlooking of cloud affected data mainly at relatively thick cloud.

3. Assimilation experiment

In order to assess the impacts of SSMIS UPP data assimilation in JMA’s global NWP system, an observing system experiment (OSE) covering the one-month periods of August 2015 was conducted. The results showed improved model first-guess (FG) fits to existing MHS and SAPHIR observations, which are sensitive to atmospheric moisture, indicating consistent improvement in the quality of the model FG water vapor field (figure not shown). Fig. 4 shows the changes of RMSE, which indicates positive impact on skill in forecasting the geopotential height field over the Southern Hemisphere.

4. Conclusion

A physically-based cloud detection algorithm was developed. The algorithm uses SSMIS multiple channels to determine cloud types and implemented in the JMA global NWP system to screen out the cloud affected SSMIS humidity sounding channel’s data. The impacts of assimilating those data were assessed. The algorithm was effective for the screening of cloud-affected data. The result demonstrates that the new algorithm could reduce overlooking of cloud affected data mainly at relatively thick cloud area. OSE result showed that the use of SSMIS UPP data improved the FG water vapor field and geopotential height forecasting skill for the Southern Hemisphere in the experiment.

References

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Figures

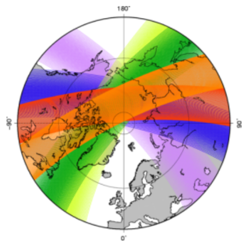


Figure1. An example of microwave humidity sounder data coverage (2015/08/01). DMSP F-17/F-18 data fill the data gap between METOP-A/B and NOAA-18/19

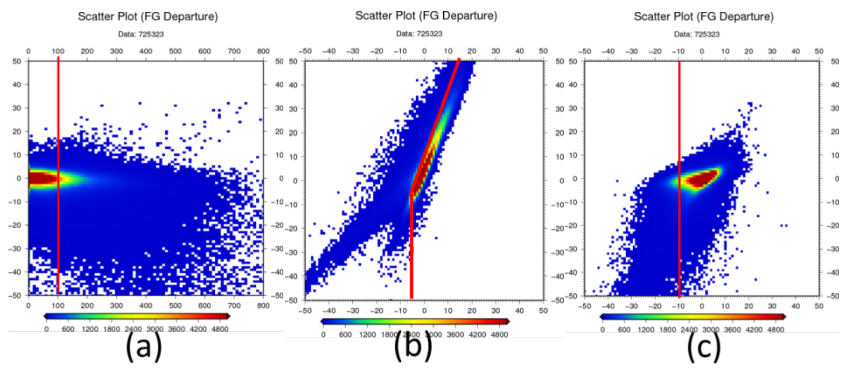
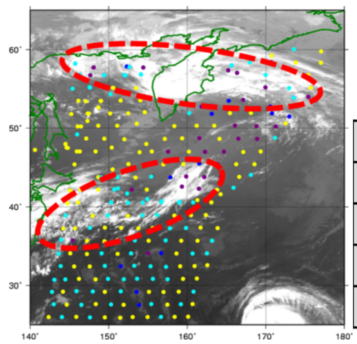


Figure2. Thresholds for detecting (a) CLW, (b) Snow crystal, (c) Ice crystal. Red lines indicate thresholds. X and Y axis of each figure denotes CLW and $dTb(183\pm6.6)$, $dTb91V$ and $dTb(91H)$, and $dTb183\pm6.6 - dTb(91V)$ and $dTb183\pm6.6$ respectively.



	ICE Crystal	Snow Crystal	CLW
Purple	✓	✓ or –	
Light Blue	–	✓	✓ or –
Dark Blue	–		✓
Yellow	–		

Figure3. Result of cloud type classification (2015/9/6 0630JST). Definition of each dot is as shown in the table. "✓" denotes "Identify as cloud" and "—" denotes "Identify as clear-sky".

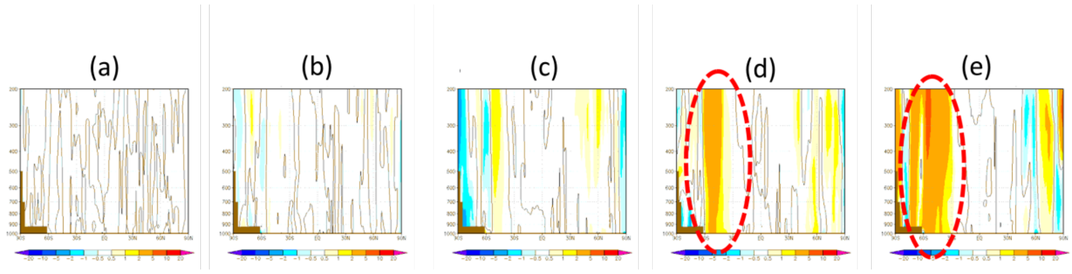


Figure4. : Latitude-Altitude cross section of changes in RMSE of Z500 [m] for (a) 24-hour forecast, (b) 48-hour forecast, (c) 72-hour forecast, (d) 96-hour forecast, (e) 120-hour forecast. Here RMSE of Z500 is defined as RMSE (CNTL)-RMSE (TEST). Orange shade indicates improvement.