Assimilation of advanced sounder cloudy radiances in global NWP model and retrieval of cloud parameters from IASI over Antarctica

Nadia Fourrié, Vincent GUIDARD, Florence RABIER, Tuuli PERTTULA*, Lydie LAVANANT$^+$ and Thomas PANGAUD
CNRM-GAME/GMAP, METEO FRANCE & CNRS, Toulouse, France
**FMI, Helsinki, Finland*
$^+$ *DP, METEO FRANCE, Lannion, France*

Introduction

Advanced infrared sounders, such as the Atmospheric InfraRed Sounder (AIRS) and the Infrared Atmospheric Sounding Interferometer (IASI) on board the first operational European polar-orbiting satellite Metop measure radiation in many thousands of channels. They provide atmospheric temperature and composition information at a much higher vertical resolution and accuracy that could be achieved with the previous generation of satellite instruments such as the High resolution Infrared Radiation Sounder.

Nevertheless, the main obstacle to use observation from advanced sounders is the presence of cloud, which can severely limit the information from infrared sounders. In this context, McNally (2002) previously investigated the occurrence of clouds in the sensitive areas with cloud fields from the European Centre for Medium-range Weather Forecasts model. Fourrié and Rabier (2004) also studied the presence of clouds with the AVHRR (Advanced Very High Resolution Radiometer) imager in sensitive areas during FASTEX (Joly et al, 1997). Both studies showed that there was a high correlation between the meteorologically sensitive areas and the cloud cover. Several Numerical Weather Prediction (NWP) centres have thus worked on the assimilation of cloudy radiances since a few years. In this paper we present the approach used for advanced sounders for the assimilation of cloudy radiances at Météo-France and a short study of the retrieval of clouds over Antarctica in the frame of the Concordiasi campaign

The next section presents the retrieval of the cloud parameters in the French global model ARPEGE. The description of the assimilation of AIRS and IASI cloudy radiances is done in section 3. The next section is about the Concordiasi experiment and the study of cloud retrieval over Antarctica. Finally, results are summarized and conclusions are given.

Retrieval of cloud parameters

Many NWP centres have developed assimilation schemes for cloud affected radiances of hyperspectral sounder radiances (AIRS at first, extended to IASI). All the algorithms rely on the determination of the cloud top pressure and the effective cloud amount (Heilliette et al. (2009), McNally (2009), Pangaud et al. (2009) and Pavelin et al. (2008)). These parameters are then fed to the radiative transfer model, mainly as a lower “boundary” condition, thus enabling cloudy observations in the assimilation. In our case, the cloud parameters (cloud cover and cloud top pressure) have been retrieved with the CO2-slicing method (Chahine, 1974), that is used in operations for AIRS observations to simulate cloudy observations (Pangaud et al, 2009). This method is based on radiative transfer principles (Chahine, 1974; Menzel et al., 1983; Smith and Frey, 1990) to retrieve the properties of an equivalent opaque single-layer cloud. It consists in the determination of the cloud top pressure and the effective cloud amount (which is the product of the geometrical cloud fraction and the grey body emissivity) from the observations and the clear sky simulations from the background. See Pangaud et al. (2009) and Lavanant et al. (2010) for a detailed description of the method. This technique has been adapted to IASI observations. 36 channels in the CO2 long-wave band between 657 and 861.50 cm^{-1}, which are very sensitive to clouds, are used.

Furthermore, this cloud determination scheme was also evaluated and tuned during he intercomparison of cloud products within IASI footprints by Lavanant et al. (2010). It was in good agreement with the other schemes from other centres, with close cloud top pressure and high correlations.

Assimilation of cloudy radiances

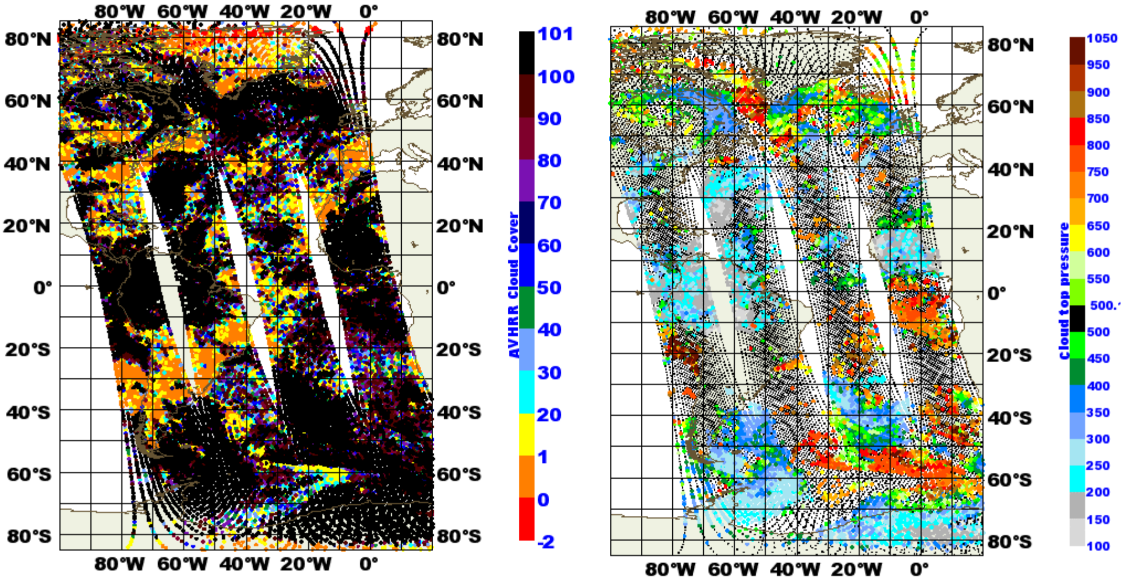

Fig. 1: AVHRR cloud cover (left panel) and cloud top pressure retrieved from IASI observations with the CO2-slicing method (right panel for the 19th of Spetember 2010 at 00 UTC. The cloud top pressure is only retrieved if the AVHRR cloud cover is 100% within the IASI pixel.

For the first trial of direct assimilation of cloudy IASI radiances using the CO2-slicing method, we tried to focus on overcast scenes. Since May 2010, the EUMETSAT agency provides users with cloud information from AVHRR within the distributed IASI level 1c datasets. This information corresponds to the percentage of cloudy AVHRR pixels within the IASI field of view. Given this information, about half of the IASI pixels contains only cloudy AVHRR pixels (see example on fig. 1, left panel). The choice was made to apply the CO2-slicing scheme when all the AVHRR pixels present in the IASI field of view are cloudy. For all other cloudy cases and clear cases, we rely on the McNally and Watts (2003) cloud detection scheme and only assimilate channels unaffected by clouds. This approach has been chosen to perform the first trial of a direct assimilation of cloudy IASI radiances. Only cloudy pixels with a cloud top pressure ranging from 650 to 900 hPa and with an effective cloud amount of 1 are assimilated this way. Moreover, only cloudy observations over open sea are used and only channels the number of which is less than 323 (upper tropospheric peaking channels), are assimilated in cloudy conditions. A set of twin experiments for the assimilation of cloudy radiances was carried out (called REF without cloudy channel assimilation and CLD with cloudy channel assimilation). Both experiments were evaluated against radiosoundings and independent analyses (from ECMWF operational model) over the 1-month time period of September 2010.

The number of additional IASI observations is quite small. A gain of 0.5 % of additional channels is obtained in the Southern Hemisphere. However, an increase of the number of assimilated data is found for other satellite sensors: +0.5% of microwave data are used in the Southern Hemisphere, +1 % of surface HIRS channels and +0.5 % of troposhperic HIRS channels are assimilated in CLD experiment. Rather neutral scores are found, which means that the assimilation of cloudy radiances on top of the clear ones does not improve drastically the forecast skill. This quite neutral impact can be explained by the fact that very few cases were added into the assimilation (around 0.2% of additional IASI data). Even though it is not statistically significant according Bootstrap test (except for humidity at 700 hPa), some improvements are observed on RMSE in the troposphere for geopotential height, temperature and humidity at the 96-hour forecast range over Europe, as shown in Figure 2.

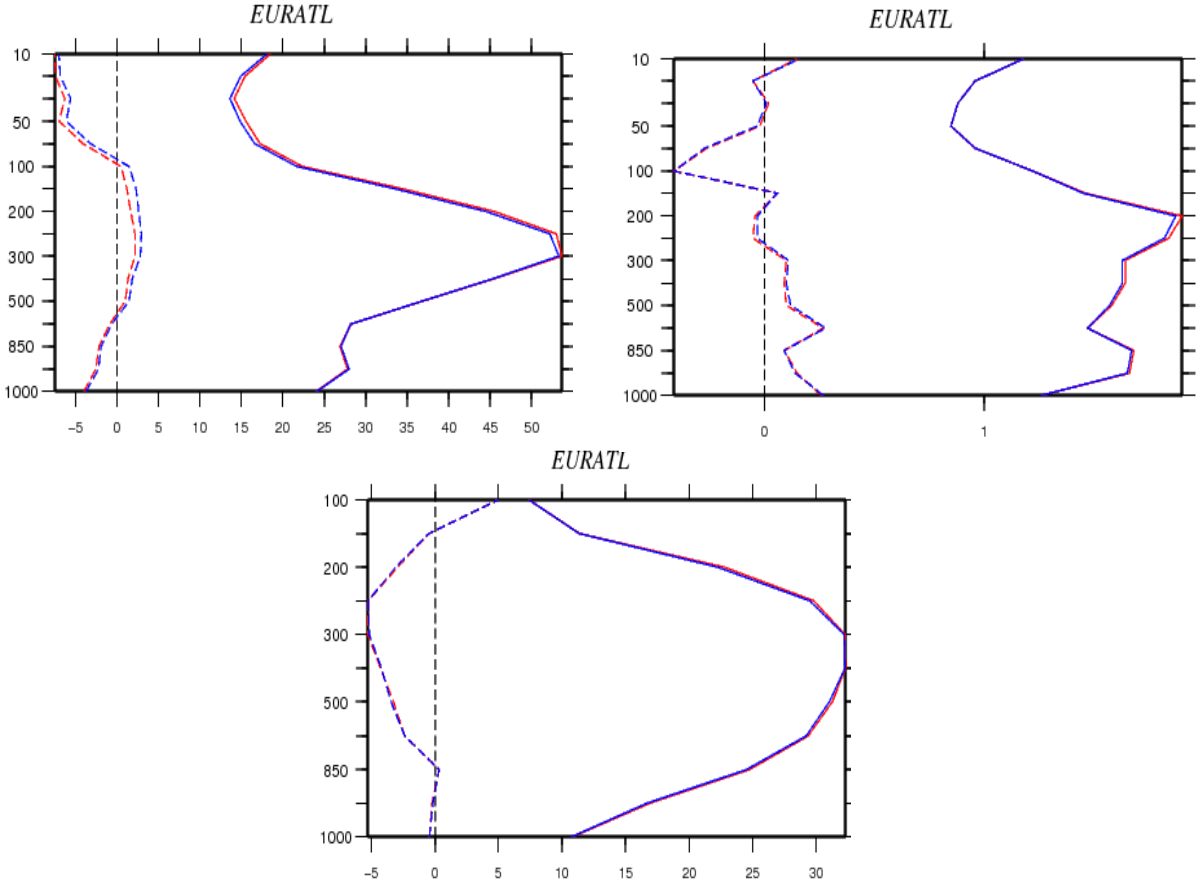

Fig. 2: 96-hour forecast root mean square error computed with respect to independent analyses for geopotential height (left top panel), temperature (right top panel) and humidity (bottom panel).

More information on the assimilation of IASI cloudy observations can be found in the paper by Guidard et al. (2011) which gives an overview of the assimilation of IASI observations in the Météo France models.

The CONCORDIASI experiment

The Concordiasi experiment (Rabier et al, 2010) is a multi-disciplinary effort studying the lower stratosphere, troposphere, and land surface of Antarctica. One aim of the Concordiasi campaign was the improvement of IASI data assimilation. Concordiasi field experiments took place in Austral springs 2008, 2009 and 2010, including surface measurements and radiosoundings at the Concordia station at Dome C and radiosoundings at Dumont d'Urville and Rothera. In 2010, an innovative constellation of balloons provided a unique set of measurements covering both volume and time. The balloons drifted for several months on isopycnic surfaces in the lowermost stratosphere around 18km, circling over Antarctica in the polar vortex. Some of them were driftsonde balloons that were able to drop some sondes on demand. Co-locations of dropsondes with the MetOp satellite overpasses were dedicated to calibrate IASI data assimilation in numerical models and IASI retrieval validation. When possible, collocations with both MetOp and the A-train were favoured.

We studied the cloud detection with the CO2-slicing method and the impact of the modification of the input profile of the radiative transfer model by the dropsonde data for the cloud parameter determination. The dropsonde temperature profiles from all levels except the ground level were used as well as the dropsonde humidity profiles below 400 hPa except the ground level. Due to the time difference and distance between dropsonde and IASI sounding points, the 2 m temperature and humidity, and the skin temperature were taken from the model instead of using the dropsonde measurements.

Colocations were also performed with observations of the Caliop lidar and the CPR radar from the Aqua Train. 120 IASI observations were selected over 11 days ranging from October 3rd to November, 11th 2011. The pairs were chosen so that the distance between the IASI field of view and the dropsonde was shorter than 300 km, the time between both observations lower than 3 hours and the elevation of the surface on land areas approximately the same to obtain the most similar conditions as possible.

Among this global data set, 40 cloudy observations among the 120 colocations were detected by CPR or Caliop and only 8 observations were seen as cloudy by CPR and Caliop. As a consequence, for clear CPR/ Caliop observation, the pixel was often covered entirely by cloudy AVHRR pixels. 9 pixels over sea ice and over land have thus been selected and studied.

Result over sea ice

Figure 3 shows the cloud top pressure and the effective cloud fraction retrieved from IASI. The bottom panel highlights the location of the IASI observations and the dropsondes data. IASI cloud top pressure seems to be closer to the CPR one. Only one pixel is detected clear by all sensors. The effective cloud fraction retrieved is partial varying around 0.4, when the cloud cover from AVHRR is mainly of 100%. A problem in the surface temperature has been found and may influence the retrieval of cloud over sea ice. The modification of the input profiles with dropsondes seems to be beneficial as the retrieved cloud top pressures seem to be closer to the CPR ones.

Result over land

Figure 4 gives an indication of the orography on the Antactica. As it is shown the collocated observations are often above 2000 m. Only one cloud is seen by CPR and for that pixel the CO2slicing is not able to retrieve a cloud with IASI. In the other case the cloud top pressure found with IASI is around 400 hPa. In this case, the AVHRR found often a low fraction of cloud or no cloud. The effective cloud fraction found with IASI is about 0.4. It would be beneficial to use the imager information for the cloud detection as made in operations in order to reduce the false alarm rate. In contrast to sea ice cases, the modification of the profile with dropsonde data hardly influences the cloud retrievals.

Conclusions

Following previous studies undertaken for AIRS data, the CO2-slicing method has been adapted to IASI measurements in order to characterize clouds with a cloud top pressure and an effective cloud amount of an equivalent single-layer cloud. As this one-layer assumption is supposed to be more accurate for homogeneous overcast scenes, our first trials of cloud-affected IASI radiances use only the scenes where the sub-pixel information from the AVHRR was 100 % cloudy. This implementation leads to statistically neutral impact on forecast skill, despite a RMSE reduction for temperature and relative humidity at medium-range forecasts. The IASI cloudy radiance assimilation has been put in the 2012 e-suite. The chosen approach for the operational assimilation of cloudy radiances is quite simple but for long term, studies are done by Martinet et al. (2012) in order to develop cloudy radiance assimilation with cloud profiles for the mesoscale model AROME and to adjust into account the hydrometeor profiles in the control variable.

Concerning the cloud parameter retrieval over Antarctica, the modification of the imput profile with dropsonde profile does not bring significant impact in the cloud characterization. There is a need of cloud product for comparison with similar sensors. In fact CPR, Caliop, and IASI instruments are sensitive to different particle size and it is difficult to obtain comparison.
Antarctica is a region where problem of surface temperature in the model and high elevated orography cause difficulties for the retrieval of cloud parameters from satellite sensors, especially in the infrared wave length. In addition the presence of strong vertical gradient in the temperature field near the surface and low values of temperature prevent an easy cloud determination.

References

Chahine, M. (1974). Remote sounding of cloudy atmospheres. I, the single cloud layer. *J.Atmos. Sci*., 31 :233-243.

Fourrié N. and Rabier F. (2004). Cloud characteristics and channel selection for IASI radiances in meteorologically sensitive areas. *Quart. J. R. Met. Soc*., 130**,** 1839-1856.

Guidard V., Fourrié N., Brousseau P. and Rabier F. (2011) : Impact of IASI assimilation at global and convective scale and challenge for the assimilation of cloudy scenes. QJRMS, 137, 1975-1987. DOI:10.1002/qj.928.

Heilliette, S. et Garand, L. (2007). A practical approach for the assimilation of cloudy infrared radiances and its evaluation using AIRS simulated observations. *Atmosphere-Ocean*, 45(4):211-225.

Joly, A. Browning K. A., Bessemoulin P., Cammas J.-P., Caniaux G., Chalon J.-P., Clough S. A., Dirks R., Emanuel K. A., Eymard L., Gall R., Hewson T. D., Hildebrand P. H., Jorgensen D., Lalaurette F., Langland R. H., Lemaitre Y., Mascart P., Moore J. A., Persson P. O., Roux F., Shapiro M. A., Snyder C., Toth Z. and Wakimoto R. M. 1999. Overview of the field phase of the Fronts and Atlantic Storm-Track EXperiment (FASTEX) project. *Quart. J. R. Met. Soc.* **125** 877-946.

Lavanant L, Fourrié N, Gambacorta A, Grieco G, Heilliette S, Hilton F, Kim MJ, McNally AP, Nishihata H, Pavelin E, Rabier F. (2010). Comparison of cloud products within IASI footprints for the assimilation of cloudy radiances. 137,1988-2003. DOI:10.1002/qj.917.

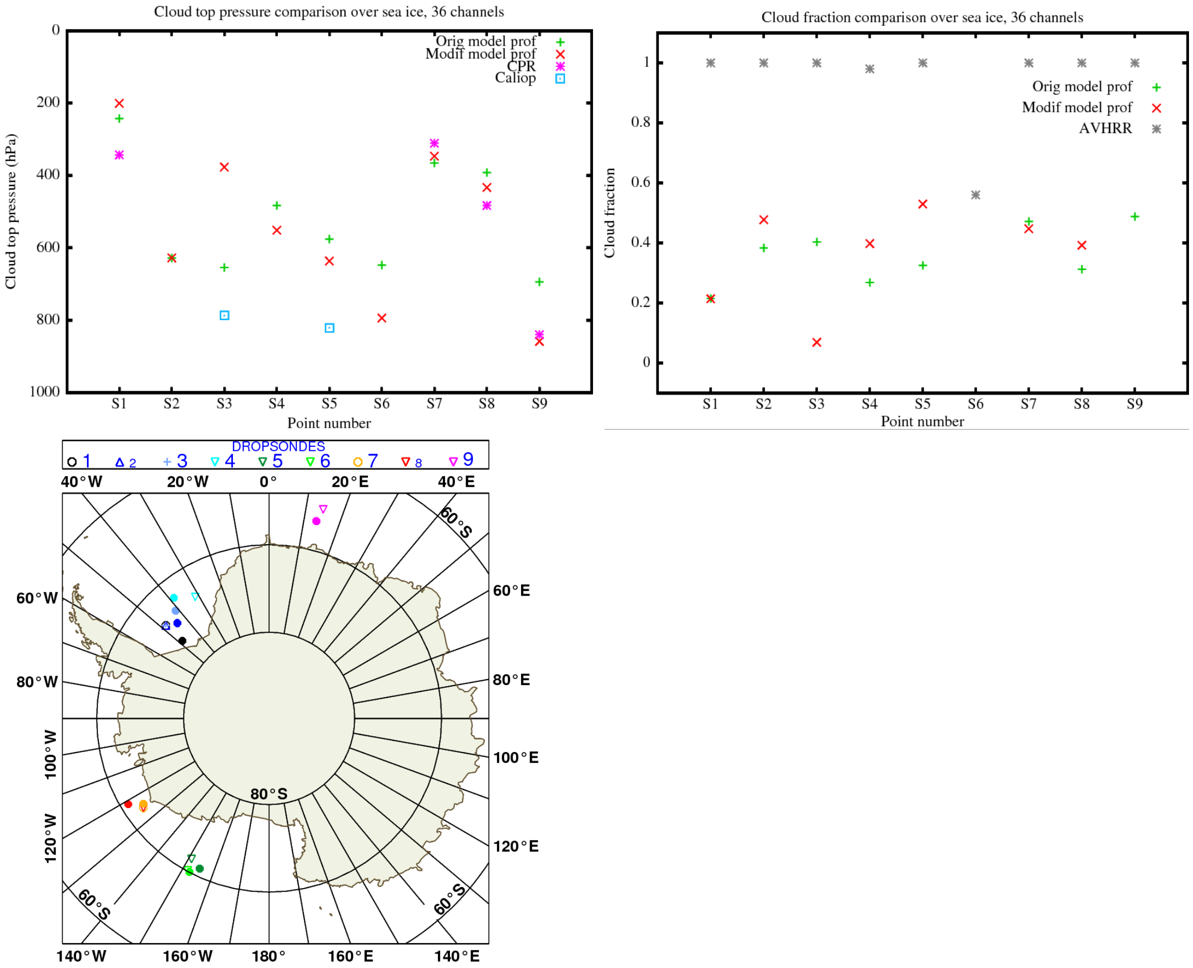

Fig. 3: Cloud top pressure (left top panel) and effective cloud fraction (right top panel) retrieved with IASI and from CPR and Caliop. Location of the dropsondes and of IASI data (bottom panel) over sea ice.

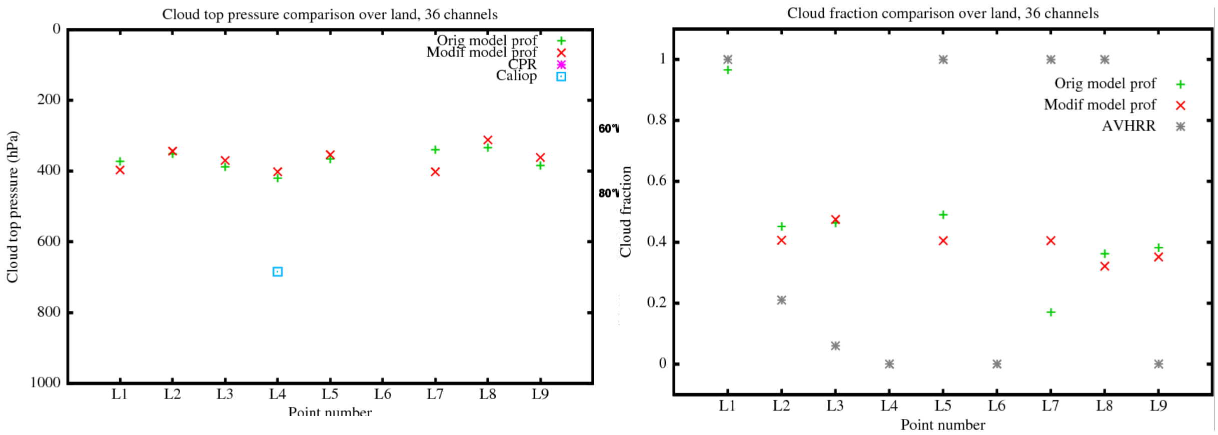

Fig. 4: Cloud top pressure (left top panel) and effective cloud fraction (right top panel) retrieved with IASI and from CPR and Caliop. Location of the dropsondes and of IASI data (bottom panel) over Antarctica continent.

Martinet P, Fourrié N, Guidard V, Rabier F, Montmerle T and Brunel P. (2012): New developments for the use of microphysical variables for the assimilation of IASI radiances in convective scale models. Quart.J.Roy.Meteor.Soc, in press.

McNally, A. P. (2002). A note on the occurrence of cloud in meteorologically sensitive areas and the implications for advanced infrared sounders. *Quart. J. R. Met. Soc*. 128, 2551-2556.

McNally, A. P. (2009). The direct assimilation of cloud-affected infrared satellites radiances for numer ical weather prediction. *Q. J. R. Met. Soc*., 135 :1214-1229.

McNally, A. and Watts, P. (2003). A cloud detection algorithm for high spectral resolution infrared sounders. *Q. J. R. Met. Soc*., 129 :3411-3423.

Menzel, W., Smith, T., et Stewart, T. (1983). Improved cloud motion wind vector and altitude assignment using VAS. *J. appl. Meteorol*, 22 :377-384.

Pangaud T., Fourrié N., Guidard V., Dahoui M. and Rabier F. (2009) : Assimilation of AIRS radiances affected by mid to low-level clouds, *Monthly Weather Review*, 4276-4292 (17) DOI: 10.1175/2009MWR3020.1.

Pavelin E, English S, Eyre J. (2008). The assimilation of cloud-affected infrared satellite radiances for numerical weather prediction. *Quart. J. Roy. Meteor. Soc*. 134: 737-749.

Rabier F., E. Brun, A. Doerenbecher, S. Guedj, V. Guidard, F. Karbou, V.-H. Peuch, L. El Amraoui, D. Puech, C. Genthon, G. Picard, M. Town, A. Hertzog, F. Vial, P. Cocquerez, S. A. Cohn, T. Hock, J. Fox, H.Cole, D. Parsons, J. Powers, K. Romberg, J. VanAndel, T. Deshler, J. Mercer, J. S. Haase, L. Avallone, L. Kalnajs, C. R. Mechoso, A. Tangborn, A. Pellegrini, Y. Frenot, J.-N. Thépaut, A. McNally, G. Balsamo, and P. Steinle. (2010), “The Concordiasi project in Antarctica,” *Bull. Amer. Meteorol. Soc*., vol. 91, no. 1, pp. 69–86, Jan. 2010.

Smith W L, Frey R. (1990). On Cloud Altitude Determinations from High Resolution Interferometer Sounder (HIS) Observations. *Journ. Appl. Meteor*. 29: 658-662.