Satellite Data Assimilation over Antarctica : The Concordiasi Field Experiment

Aurelie Bouchard(*), Florence Rabier, Vincent Guidard, Fatima Karbou, Nadia Fourrié, Thomas Pangaud

Météo-France/CNRM-CNRS/GAME
(*)aurelie.bouchard@cnrm.meteo.fr

1 Introduction

In the framework of the International Polar year, a field experiment will take place in Antarctica during the Austral Spring 2008 and 2009 : Concordiasi.

(http ://www.cnrm.meteo.fr/concordiasi, Rabier et al., 2007)

This project is supported by the following agencies : Météo-France, CNES, IPEV, PNRA, CNRS/INSU, NSF, NCAR, Concordia consortium, University of Wyoming and Purdue University. ECMWF also contributes to the project through computer resources and support, and scientific expertise. From September 2008, additional conventional observations will be operated over Antarctica such as radiosoundings at the Concordia (DomeC :$75^o12'S$,$123^o37'E$) and Dumont d'Urville stations ($66^o40'S, 140^oE$). Moreover, 600 dropsoundings will be dropped by twelve stratospheric pressurised balloons (SPB) in 2009. Thanks to these additional in-situ observations, studies will be performed in order to improve the assimilation of infrared and microwave observations over high latitudes.

The model chosen for these studies is the meteorological model of Météo-France, ARPEGE (Courtier et al., 1994), developed in collaboration with ECMWF. It uses an advanced data assimilation system (Rabier et al., 2000) and the Variational Bias Correction method (Auligne et al., 2007) for the treatment of the radiance biases.

The first main modification in order to study polar assimilation was to change the geometry of ARPEGE. The centre of the model has been moved southward from France to DomeC. With this stretched model, the horizontal scale is less than 30km over Antarctica (see the horizontal resolution in Fig. 1).

Based on a better resolution model over Antarctica, different problems associated to the high latitudes have been studied. The problem recalled in many papers (Barker, 2005, Nordeng (WMO bulletin, 2007), McNally, 2007, Powers, 2007) is the spatial and temporal density of observations for these latitudes. Over Antarctica, there are few conventional data and mainly on the coast (see Fig. 2).

Studies have already shown the positive impact of an increase of the number of data assimilated, such as GPS radio-occultation (Wee and Kuo, 2004, à verifier). The orbitography of polar satellites allows to enhance the time sampling of observations. The use of these data is restricted due to two main problems : the estimation of the surface emissivity and the cloud detection (McNally, 2007). These two points will be seen in the following section.

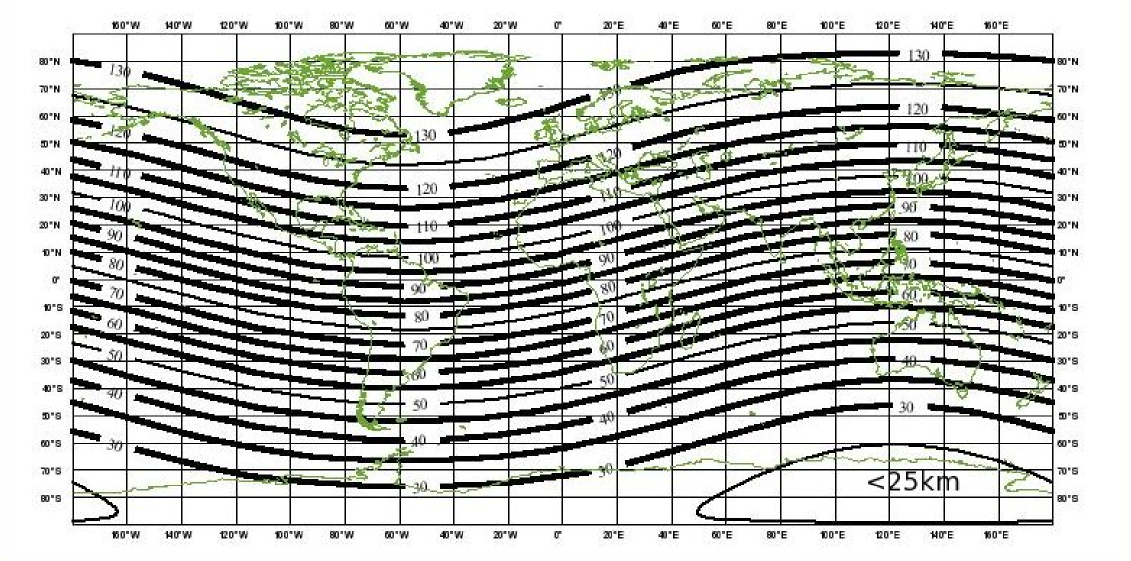

FIG. 1 – Horizontal resolution of the ARPEGE model, stretched on DomeC

2 Microwave sensors

Radiance assimilation depends on the difference in brigthness temperature between the model and the observations. In order to improve the brigthness temperature calculated by the model, a good estimation of the surface emissivity is needed. Usually, only the observations over open sea are assimilated thanks to a better estimation of emissivity over sea. Over land and mainly cold surfaces, the variability of the surface emissivity is much more complicated (Weng, 2003). For cold surfaces, the emissivity will depend on the vertical structure of the surface (presence of snow, first-year ice, multiyear ice) and of course of the physical properties of the different layers. The interaction between microwave radiation and the cold surface will vary in function of the frequency (variation of the depth penetration) (Mathew, 2007; Picard, 2007).

Karbou has developed a method, within the constraints of 4D-Var, to help the assimilation of the microwave observations over land (Karbou et al. 2006). These methods have been successfully tested at a global scale and have shown to be beneficial to our 4D-Var system. This approach is called a "dynamical approach". The emissivity derived from AMSU-A, channel 3 (50.3Ghz) and AMSU-B, channel 1 (89Ghz) are assigned to the temperature and humidity sounding channels respectively. We have compared this approach to the operational emissivity scheme (Grody, 1988 or Weng, 2001, depending on the frequency). The two approach for emissivity calculation use observations, but Karbou use also the measurement physics and the observations for each pixel in the assimilation system rather than a linear regression approach. The impact of these approximations at high latitudes is presented in Fig. 3 to 6 through the difference between the observations and the model (called "fg-departure"). Note that no bias correction has been applied to this difference.

Figures 3 and 4 show the fg-departure with the two approaches, for channel 5 (53Ghz) of AMSUA. The main difference between these figures is the decrease of the fg-departure.

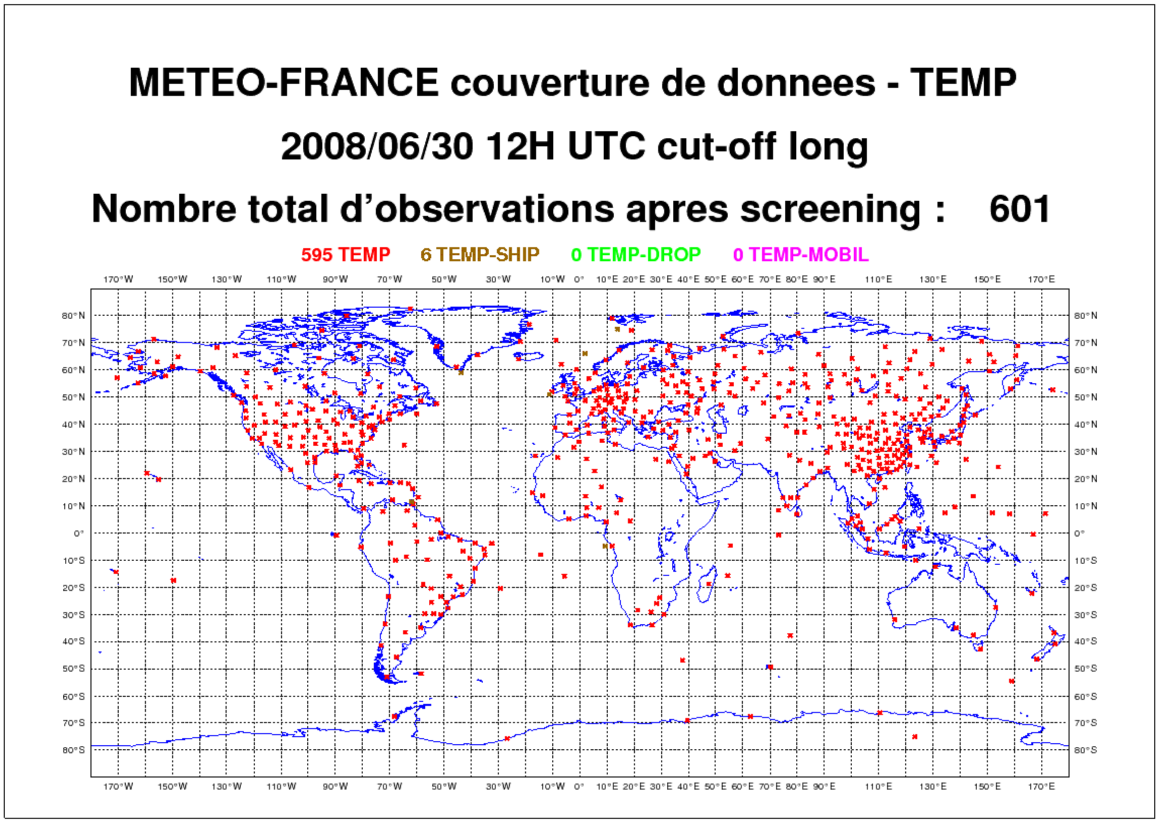

Fig. 2 – Radiosounding assimilated over Antarctica in ARPEGE

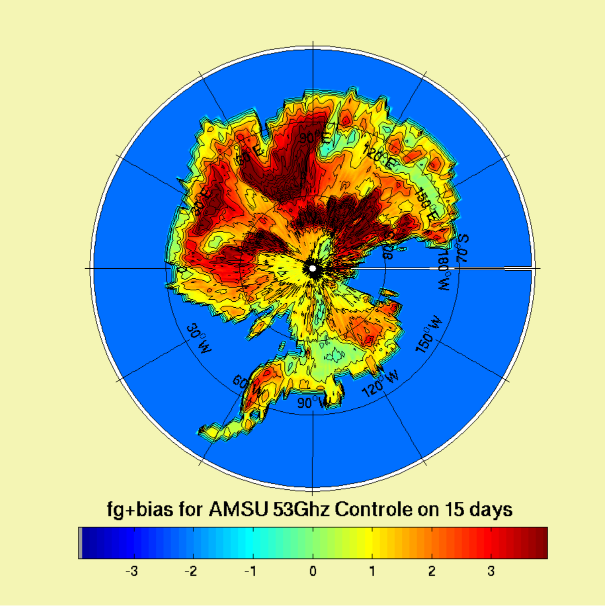

FIG. 3 – fg-departure with the operational emissivity scheme. Channel 5. AMSUA (K)

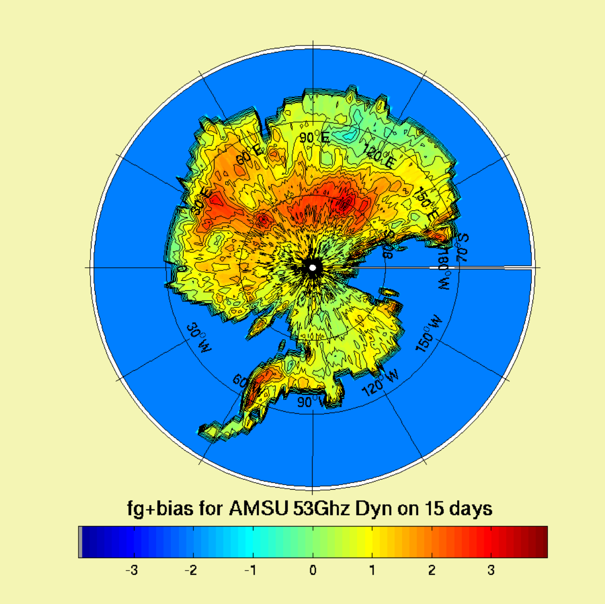

FIG. 4 – fg-departure with the dynamical approach. Channel 5. AMSUA (K)

So, the model with the dynamical approach has a better fit to the observations. As a consequence, more observations will be assimilated, in this case up to 41%. The impact can also be seen through the comparison of the histogram of the "fg-departure" (Fig. 5 and 6). The histograms have been calculated for a two-week period, over Antarctica.

In Fig. 5 and 6, the plots for the operational emissivity scheme is in light blue and the dynamical approach in dark blue. With the new approach, one can see, for all channels

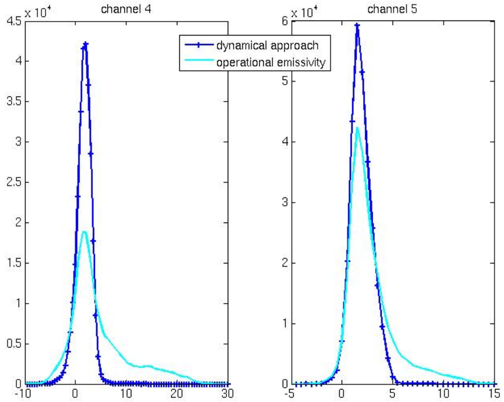

Fig. 5 – Histogram of "fg-departure" for AMSUA, channel 4 and 5 (K).

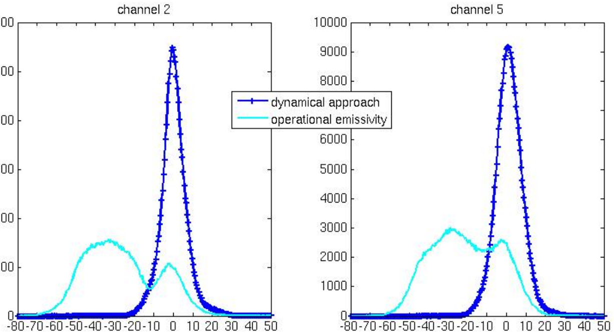

Fig. 6 – Histogram of "fg-departure" for AMSUB, channel 2 and 5 (K).

for each sensor, a histogram thinner and closest to the zero line. So, the model is closer to the observations for the dynamical approach. For example, the histogram with the operational emissivity show two peaks near -40K and 0K for the channel 2 of AMSUB (fig. 6). For the same case, with the new approach, the histogram have only one peak centred near OK, which reached more 10000 pixels. So, with this approach, most of the points are close to the observations.

Studies have also been performed over sea ice. Fig. 7 and 8 show the comparison between the operational and dynamical models for which the calculation of emissivity is based on satellite data, over sea ice. As for land studies, the difference between observations and the model is smaller in the case of the dynamical approach.

3 Infrared sensor

One aim of the campaign is the validation of IASI (Infrared Atmospheric Sounding Interferometer) sensor. As recalled before, the main problem with the estimation of the infrared emissivity over land is the cloud detection. Nowadays, in NWP, only clear radiances

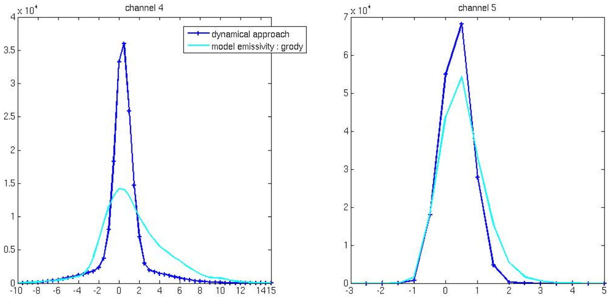

FIG. 7 – Histogram of "fg-departure" for AMSUA, channel 4 and 5, over sea ice (K)

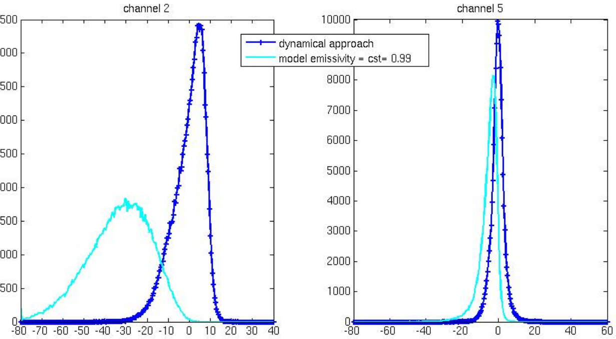

FIG. 8 – Histogram of "fg-departure" for AMSUB, channel 2 and 5, over sea ice (K)

are assimilated. In the cold regions, the radiative impact of a cloud is different. A cloud can be seen warmer than the surface and so more difficult to detect. The method used is called "cloud detect", developped by McNally and Watts (2003). A pixel can be classified as "cloudy", based on a cloud test. For one pixel, all channels will be examined and classified. Clear channels above the detected cloud will be kept and assimilated. A previous study by Dahoui, 2006, has shown that the cloud detection algorithm is not so accurate for low clouds at these latitudes. Specific problems to high latitudes is the detection of the Polar Stratospheric Cloud (PSC) (McCormick, 1982). Two infrared sensors have been studied : AIRS (Atmospheric Infrared Sounder) and IASI. In order to compare the cloud detection by the model for these sensors, satellite data not assimilated in operational, have been chosen as references. In the case of the AIRS sensor, profiles along the track of this sensor have been compared to CloudSat product (Fig. 9a and b). The CloudSat (Nasa-Colorado State University - Department of Energy) mission, part of the A-Train constellation, has an on-board millimeter wavelength radar (Stephens et al., 2002). The product shown here on Fig. 9a is the radar reflectivity (2B-GEOPROF data product), the 9th january 2008 over Antarctica. Fig. 9b show the Cloud Fraction defined by the Cloud Detect method in ARPEGE, for AIRS track, the same day. 0 means clear pixel and 1 for cloudy. For one pixel, each channel is plotted. On the both figures, the abscissa axis give an information on the time along the track of the satellite. The ordinate axis indicates the range (km) for the reflectivity radar and the maximum of the weight function (hPa) for AIRS. Orography is also represented by the black curves on plots.

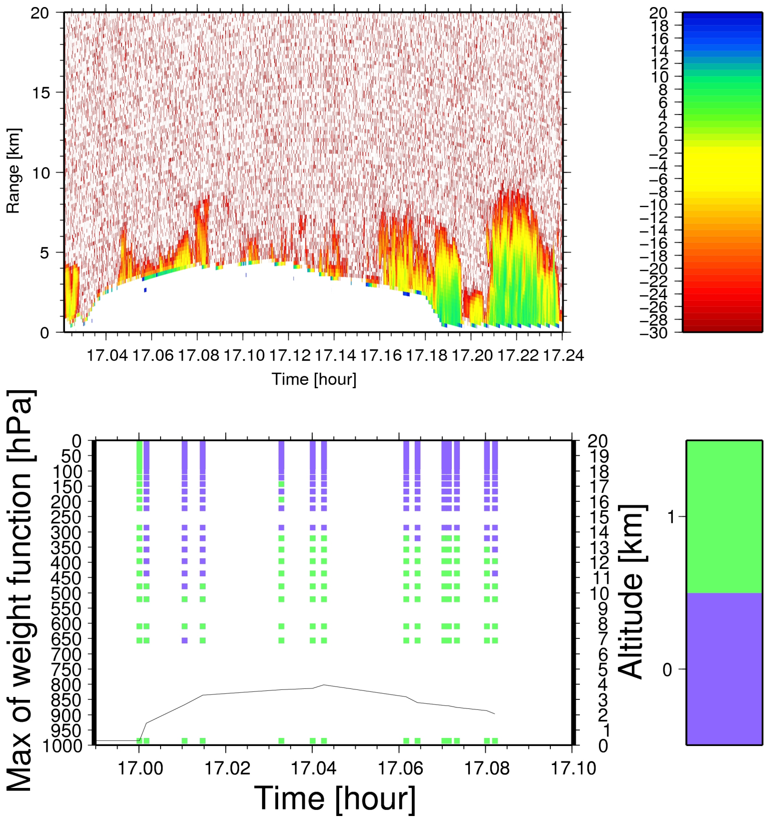

Fig. 9 – Reflectivity Radar (Z) (dBZ) from CloudSat, on the left side (9a). Cloud Fraction for AIRS/ARPEGE, on the right side (9b). The dark line on 9b indicates the orography.

The comparison of Fig. 9a and b, shows quite a good agreement between CloudSat and AIRS/ARPEGE. For example, the good detection of the presence of the cloud near the time 17.16s for CloudSat and 17.08s, for AIRS.

For the IASI sensor, the cloud fraction (0 : clear ; 1 : cloud) is compared to the MODIS cloud product (Fig 10a and b). MODIS (MODerate Resolution imaging Spectroradiometer), on Aqua, supplies informations about cloud properties (such as cloud particle phase or cloud top temperature ...) (Platnick, 2003). Cloud Top Pressure product of MODIS has been compared to cloud fraction of IASI/ARPEGE for the Channel 242. Channel 242 has a maximum of weighting fucntion at 286 hPa. This channel brings an information on the localisation of the high cloud.

Around the Antarctica Peninsula, the comparison of the two figures shows a good agreement in the position of the cloud for high clouds. For example, the pixels, located on the Antarctica Peninsula, between 60^oS and 65^oS, where the cloud top pressure reaches 300hPa (in blue on Fig. 10a) are also seen cloudy (red pixel on Fig. 10b) by IASI/ARPEGE. Of course, this channel will be classified as clear for all clouds in the lower layer of the troposphere.

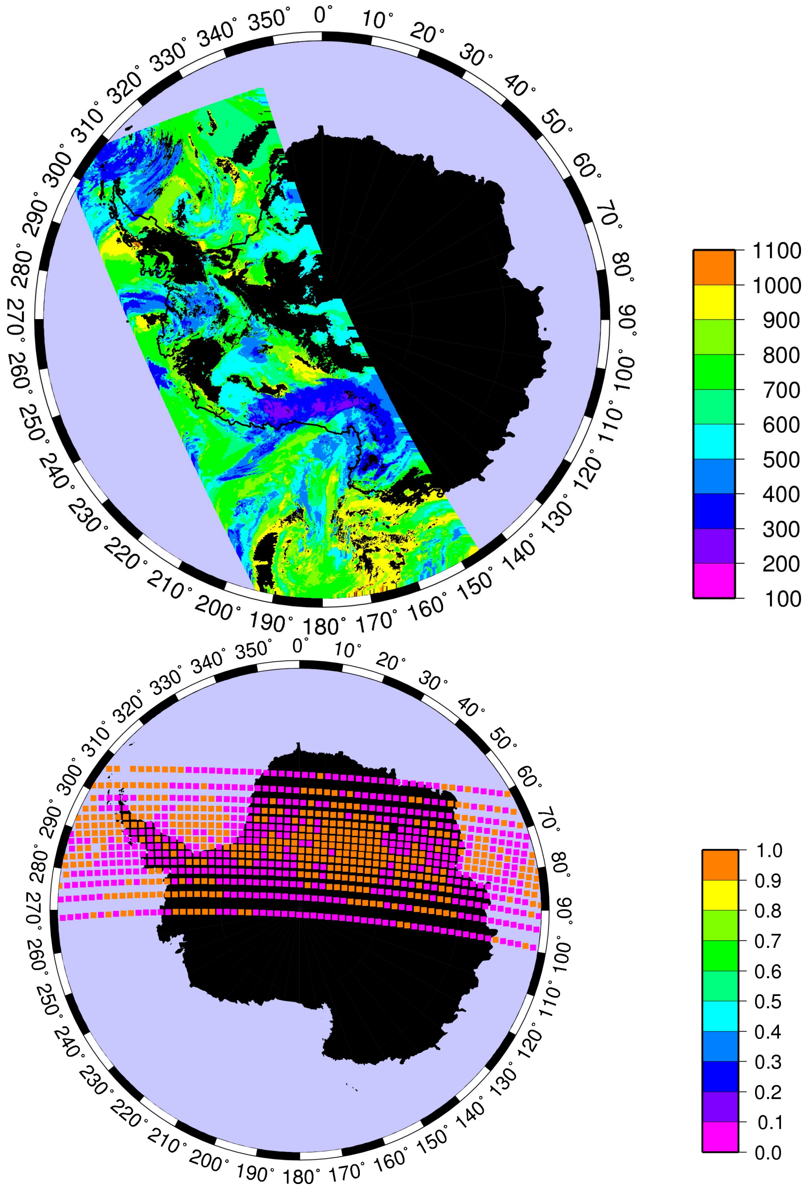

FIG. 10 – Cloud Top Pressure (hPa) for MODIS, on the left side (10a). CLoud Fraction for IASI/ARPEGE (10b), on the right side, for the channel 242. For CLoud Fraction, 0 : clear, 1 : cloudy.

4 Conclusion

These preliminay tests have shown a positive impact, at high latitudes (over sea ice and land), of the assimilation of the microwave sensors (AMSU-A/B), using the emissivity dynamical approach, developed by Karbou. In a future work, the assimilation of microwave data will be performed adjusting thresholds for these areas. Moreover, recent studies on the emissivity computation, show that using a lambertian or semi-lambertian surface rather than a specular surface could be interesting.

For infrared sensors, the "cloud detect" method seems to bring quite good results over cold areas. This last point indicates that the assimilation of IASI and AIRS, in the troposphere, over cold land could be possible. Of course, more tests must be done, to continue the validation of "cloud detect" over cold surfaces. Other methods such as MMR(Methode Multi-variee du Residu Mininum) (Auligne, 2007) could also be tested.

5 Reference

Auligné, T., A. P. McNally and D. Dee, 2007 : Adaptive bias correction for satellite data in a numerical weather prediction system, Q.J.R. Meteorol. Soc., 133, 631-642.

Barker D. M., 2005 : Southern High-Latitude Ensemble Data Assimilation in the Antarctic Mesoscale Prediction System, Mon. Wea. Rev., 133, 3431-3449.

Courtier P., Thépaut J. N. and Hollingsworth A., 1994 : A strategy for operationnal implementation of 4D-VAR, using an incremental approach., Q. J. R. Meteor. Soc., 120, 1367-1387.

Dahoui M., Lavanant L., Rabier F., Auligne T., 2005 : Use of MODIS imager to help deal with AIRS cloudy radiances, Q. J. R. Meteo. Soc., 131, 2559-2579.

Grody N. C., 1988 : Physical retrieval of land surface temperature using the special sensor microwave imager, J. Geo. Res., 103(D8), 8839-8848.

Karbou, F., Gérard, É. and Rabier, F., 2006 : Microwave land emissivity and skin temperature for AMSU-A and -B assimilation over land. Q. J. R. Meteorol. Soc., 132, 2333-2355

Mathew N., 2007 : Retrieval of Surface Emissivity of Sea Ice and Temperature Profiles over Sea Ice from Passive Microwave Radiometers, Berichte aus dem Institut für Umweltphysik.

McCormick, M. P., H. M. Steele, P. Hamill, W. P. Chu, and T. J. Swissler, 1982 : Polar stratospheric cloud sightings by SAM II. J. Atmos. Sci., 39, 1387???1397.

McNally T. and P. D. Watts, 2003 : A cloud detection algorithm fro high spectral resolution infrared sounders. Q. J. R. Meteorol. Soc., 129, 3411-3423.

McNally T., 2007 : The use of satellite data in Polar Regions, ECMWF, Reading, Seminar Proceedings.

Nordeng T. E., Brunet G., Caughey J., 2008 : Improvement of weather forecasts in polar region, Bulletin WMO, International Polar Year 2007-2008.

Picard G., Brucker L; Fily M., Gallee H., Krinner G., 2007, Modeling Time series of microwave brigthness temperature, submitted.

Platnick S., King M. D., Ackerman S. A., Menzel W. P., Baum B. A., Riedl and Frey R. A., 2003 : The MODIS cloud products : Algorithms and examples from Terra, IEEE Trans. on Geos. and Rem. Sens., Aqua Special, 41, 2, 459-473.

Powers J. G., 2007 : Numerical Prediction of an Antarctic Severe Wind Event with the Weather Research and Forecasting (WRF) Model, Mon.. Wea. Rev., 135, 3134-3157

Rabier, F., A. Bouchard, V. Guidard, F. Karbou, V-H. Pauch, N. Semane, C. Genthon, G. Picard, F. Vial, A. Hertzog, P. Cocquerez, D. Parsons, D. Barker, J. Powers, T. Hock, 2007 : The Concordiasi project over Antarctica during IPY. Joint EUMETSAT/AMS conference. Amsterdam, 24-28 September 2007

Stephens G. L., Vane D. G, Boain R. J., Mace G. G., SassenK., Wagn Z., Illingworth A. J., O'Connor E., Rossow W. B., Durden S. L., Miller S. D., Austin R. T., Benedetti A., Mitrescu C and the CloudSat Science Team : THE CLOUDSAT MISSION AND THE A-TRAIN. A New Dimension of Spaced-Based Observations of Clouds and Precipitation, Bulletin of Am. Meteor. Soc., 83, 12, 1771-1790.

Wee T.-K., kuo Y.-H., 2004 : Impact of a Digital Filter as a Weak Constraint in MM5 4DVAR : An Observing System Simulation Experiment, Mon. Wea. Rev.,132, 543-559.

Weng F. and Yan B., 2003 : A Microwave Snow Emissivity, Proceedings of the Thirteen International TOVS Study Conference, Canada.

Weng F., Yan B. and Grody N., 2001 : A microwave land emissivity model, J. Geo. Res., 106, D17, 20, 115-123.