The assimilation of AIRS radiance over land at Météo -France

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Abstract

For the data void areas and with the erosion of the radiosonde coverage in some areas over land, satellite data assimilation over land is a very important issue. The problem is that most tropospheric channels of sounder instruments are very sensitive to the surface conditions, emissivity and surface temperature. Accurate knowledge of the land surface characteristics is required for NWP radiance assimilation. For that purpose, an atlas of surface spectral emissivity (SSE) climatology has been developed at Météo-France, which has 18 wavebands in the infrared spectral range and is available for each month. In order to start investigating the use of AIRS data over land, a series of four-dimensional variational (4D-Var) data assimilation and forecast experiments has been run with the French ARPEGE (Action de Recherche Petite Echelle et Grande Echelle) system, using these SSE.

Introduction

So far both the radiosonde network and the satellite observations are the most important contributors to the global observing system for atmospheric data assimilation and numerical weather prediction (NWP). However, although radiosonde observations provide measurements with very high vertical resolution, their spatial coverage can be poor. Meanwhile, satellite observations provide daily global coverage but at low vertical resolution.

The Atmospheric InfraRed Sounder (AIRS) is a spectrometer of high resolution on AQUA satellite with 2378 channels in the range of 640-2700 cm^{-1} in the infrared spectrum, which was launched on 4 may 2002. AIRS observations provided operationally global coverage with both very high vertical and horizontal resolution. It is important how to take the benefit sufficiently from the AIRS observations.

With the gradual reduction of radiosonde coverage in some areas and for the data void areas, satellite data assimilation over land becomes more important. Accurate knowledge of the land surface characteristics is required for NWP radiance assimilation. For that purpose, an atlas of surface spectral emissivity (SSE) climatology has been developed at Meteo-France, which has 18 wavebands in the infrared spectral range and is available for each month. In this study we have two targets. The first is to start investigating the assimilation of AIRS radiances over land. The second is to assess the impact of the surface characteristics, emissivity and surface temperature, on the short-range synoptic scale forecast. To reach the targets, the ARPEGE 4D-Var system has been used to perform the analysis and the forecast.

THE FOUR-DIMENSIONAL VARIATIONAL ASSIMILATION SYSTEM AND THE OBSERVATIONAL DATA

The experiments were carried out with the French ARPEGE assimilation and forecast model system. The forecast model is global and spectral. A specific feature of the model is the use of a stretched grid

in the horizontal direction to obtain an increased resolution over a geographical area of interest (Courtier and Geleyn, 1988). In the horizontal, it uses a triangular truncation T358, the grid is stretched with a factor 2.4 from 25 km over France to 150 km over New Zealand. A terrain-following pressure-based hybrid vertical coordinate with 41 levels is used. The assimilation system includes a multi-incremental 4D-Var (Courtier *et al*., 1994; Veersé and Thépaut, 1998; Rabier *et al*., 2000) with T107 and T161 truncations. The basic features are a 6-hour time window with two minimization steps, using very simplified physics in the first minimization and a more complete set of linear physics in the second (Janiskova *et al*., 1999). The configuration used in the study is taken as the operational one in 2004. It includes the assimilation of the conventional data and the satellite data. At Météo-France it includes the data as follows.

SYNOP, land stations and ship.
AIREP, Aircraft data
SATOB, Atmospheric motion winds
DRIBU, Drifing Buoys
TEMP, Radiosondes
PILOT, Balloons and profilers
SATEM, Satellite sounding data such as ATOVS, AIRS radiances
SCATT, QuikSCAT winds over the ocean

The atlas of surface spectral emissivity climatology for AIRS

(a) Land surface types and the atlas of surface spectral emissivity climatology

The emissivity spectra used in this study were taken from spectral libraries (MODIS, ASTER and JPL) compiled with the ones modelled by Snyder et al. (1998). New emissivity maps were produced separately for 18 wavebands in the infrared spectral range and for each month (Szczech-Gajewska and Rabier 2003).

The new classification of surface type was based on the Ecoclimap, a complete surface parameter global dataset (Masson, 2003). In general, areas of homogenous vegetation were represented by 215 ecosystems. They were derived by combining existing land cover maps, climate maps, normalised difference vegetation index (NDVI) inferred from observations of the Advanced Very High Resolution Radiometer (AVHRR) instrument and The Food and Agriculture Organisation (FAO) database of soil texture. Most of these ecosystems were a combination of only one of twelve vegetation types (so-called pure ecosystems) with addition to urban areas and water, which gave us full description of fourteen simplified global land cover types as Table 1.

Table 1: Fourteen land cover types

Number	The surface type	Comment
1	bare soil	
2	rocks	
3	permanent snow and ice	
4	crops type C3	omnipresent except tropical and equatorial belts, and where the corn is intensively cultivated
5	crops type C4	applied for crops C3 exceptions
6	irrigated crops	
7	natural herbaceous	temperate
8	natural herbaceous	tropics
9	wetland herbaceous or irrigated grass	
10	needleleaf trees	
11	evergreen broadleaf trees	
12	deciduous broadleaf trees	
13	urban areas	
14	Water	

The range (645-2760 cm^{-1}) of the infrared spectrum is divided into 18 wavebands with respect to their usefulness for the channel selection (informative bands). The wavebands have been chosen narrower and denser in areas with high (>0.5) transmittancy running average over 40 channels. This was done in order to follow the variability of the land cover types spectra and to validate the emissivity climatology created from emissivity maps of MODIS channel 31 and 32.

Climatological fields of surface spectral emissivity were created respectively to these wavebands. The creation was based on the global new land cover types and vegetation maps with resolution of 0.5 all over the globe (Masson, 2003) and SSE calculated for each of 14 simplified types from separate emissivity spectra of different natural and man-made materials.

AIRS is a grating spectrometer with 2378 channels at approximately 1 cm^{-1} resolutions covering the 3-15 μm spectral interval. For data transmission reasons the data volume was reduced, only one in every eighteen fields of view are used and thinned additionally by sampled 1/7 locations, and a subset of 324 channels was prepared by the NOAA AIRS Science Team. After channel selection, the total number is further reduced to 64 channels. These channels were grouped into the seventh of eighteen bands. Because of the spectral coverage of AIRS and channel selection, the wavebands 5-8, 11-14 and 16-18 were out of the AIRS range and the numbers of AIRS channel were not averaged over each waveband (Table 2).

Table 2. 64 channels in the infrared spectral range for AIRS at Meteo-France. Nr is the waveband number, band is the infrared spectral range of waveband

Nr	Band(cm^{-1})	AIRS channels used
1	645-760	333 338 362 375
2	760-805	453 475 484
3	805-885	497 528 587 672
4	885-950	787 791 843 870
9	1210-1240	1301
10	1240-1968	1329 1371 1415 1424 1449 1455 1466 1477 1500 1519 1520 1538 1545 1565 1574 1583 1593 1627 1636 1652 1669 1694 1708 1723 1740 1748 1756 1771 1777 1783 1794 1800 1806 1826 1843 1852
15	2180-2450	1865 1866 1868 1869 1872 1873 1875 1876 1877 1881 1882 1911

(b) Validation of the atlas of surface spectral emissivity climatology

In order to evaluate the impact of the SSE, preliminary validations have been performed on the differences between observed and simulated brightness temperatures (obs-guess) for different SSE over land. These were taken as the atlas of surface spectral emissivity climatology and the constant surface spectral emissivity equal to one for the period from 22 to 24 October 2004. Table 3 presents the statistic results of "good points" in the range from –2K to 2K for all of 324 channels before bias-correction over Europe and Africa. The atlas of surface spectral emissivity climatology has a positive impact on the forecasted brightness temperatures for both day and night time over Europe. The SSE improved noticeably the quality of simulated brightness temperature around local night, but it degraded significantly the quality around local noon over Africa. The results show that the impact of the SSE has some relations with local time. We think that the problem may come from the skin temperature, which is under-estimated around local noon.

Table 3: The percentage of "good points" in the range from –2K to 2K against the number of total points (all 324 channels) before bias-correction for the atlas of surface spectral emissivity climatology and the constant emissivity

		Europe	Africa
00UTC	climatology	62.8	57.0
	constant	62.4	53.6
12UTC	climatology	52.0	44.3
	constant	51.6	46.9

PROCESSING OF AIRS RADIANCES OVER LAND

One of the problems of using AIRS data over land is that most channels of AIRS are very sensitive to the surface emissivity. Météo-France does not use AIRS data over land for the time being. In order to use more AIRS data over land, we have performed the following work to use them more adequately.

- The surface emissivity uses the new surface spectral emissivity climatological maps which have 18 wavebands in the infrared spectral range for each month with 14 land cover types over land. Over ocean, the surface emissivity is constant with the value equal to one.
- The channel selection used over land is the same as over ocean.
- Over land, if orographic altitude is higher than 1500m, all of the channels are rejected.
- The neural network bias correction is applied for each channel over land, i.e. the bias-correction scheme is the same as over ocean.
- The observation errors over land were preliminarily analysed. The results show that the value of the observation errors over ocean can be used over land too.
- Cloud detection is the same as over ocean, i.e. NESDIS cloud detection scheme is used (Goldberg et al., 2003).

EXPERIMENTS

(a) The impact of AIRS observations over land on the accuracy of NWP

Table 4: experiments of four-dimensional variational data assimilation and forecast suite with AIRS observations

Num	Name	AIRS		SSE		T_{skin} adjusted around local noon over land
		ocean	land	ocean	land	
Exp.1	reference	used	no	constant		no
Exp.2	control	used	used	constant	climatological	no
Exp.3	emissivity	used	used	constant	constant	no
Exp.4	skin temperature	used	used	constant	climatological	adjusted

The impact of AIRS observations over land was evaluated from the results of two experiments in table 4. Exp.1 is a reference experiment of four-dimensional variational data assimilation and forecast suite with AIRS observations over ocean for the period is from 0000 UTC 22 October 2004 to 0000 UTC 6 November 2004. The SSE uses a constant emissivity equal to one over ocean. The other observations were the same as the present operational suite. Exp.2 is a control experiment of four-dimensional variational data assimilation and forecast suite with AIRS observations over both land and ocean to ensure that differences could only arise from the change in AIRS soundings over land. The SSE uses the new surface spectral emissivity climatological maps over land. The others were the same as Exp.1.

Figure 1 shows the root mean square error (RMSE) of geopotential height, temperature and wind between Exp.1 (without AIRS over land) and Exp.2 (with AIRS over land) at pressure levels by 72h. The RMSE of geopotential height in Exp.2 was less than that in Exp.1 at most pressures (Fig.1, top and mid-left panels) over the northern hemisphere (20°N-90°N), especially over northern America. The RMSE in Exp.2 was a little more than the RMSE in Exp.1 at most pressures (Fig.1, bottom-left panel) over the southern hemisphere (20°S-90°S). The patterns for temperature and wind (Fig.1, mid and right panels) are similar to geopotential height.

In order to investigate the horizontal difference distribution of the two experiments at different stage (00h,72h), the root mean square difference between Exp.2 and Exp.1 analysis and the mean

differences (Exp.1 - Exp.2) for the root mean square error of geopotential height at 500hPa were calculated over the period for forecast time 72h.
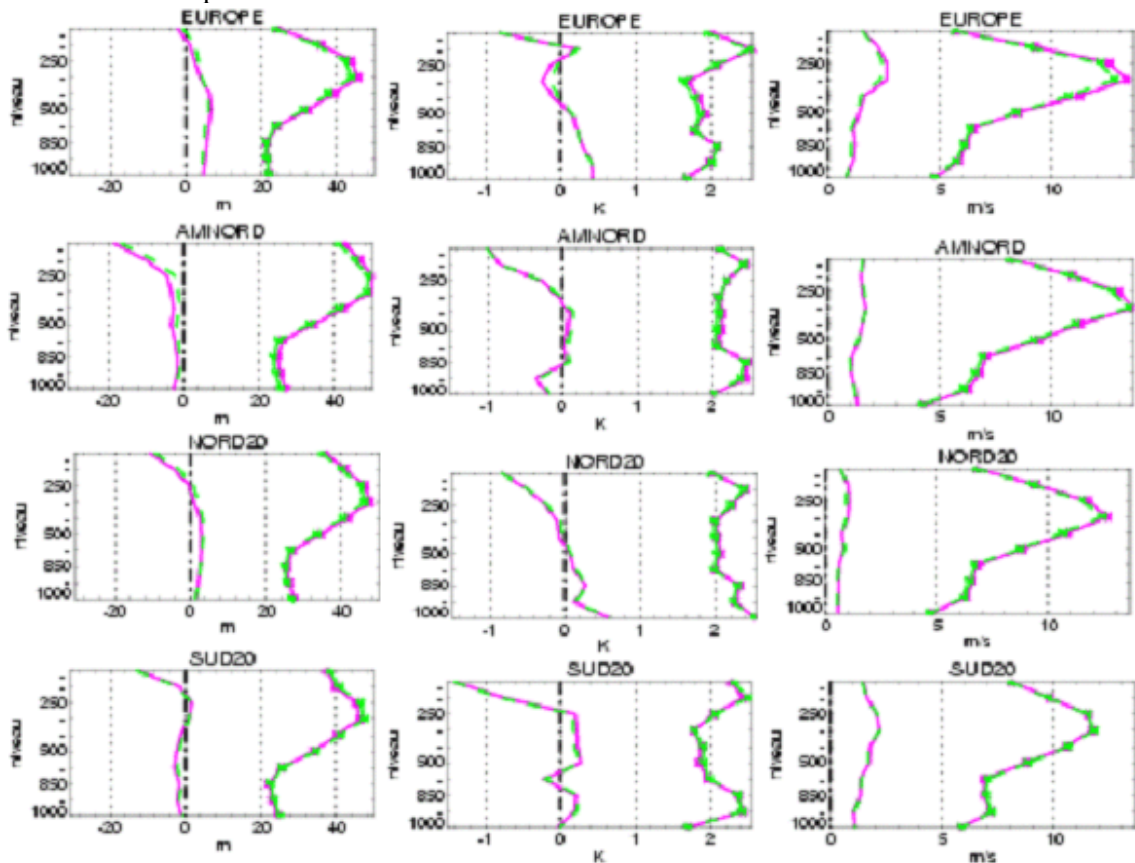

Fig.1: Root Means Square Error (RMSE) and bias of Exp.1 and Exp.2 with respect to radiosondes by 72h, left column is geopotential, middle column is temperature, right column is wind. The X axis represent RMSE and bias values, and Y axis represent the vertical pressure levels. The lines with and without stars represent RMSE and bias respectively. Exp.2 is represented in green, Exp.1 in red.
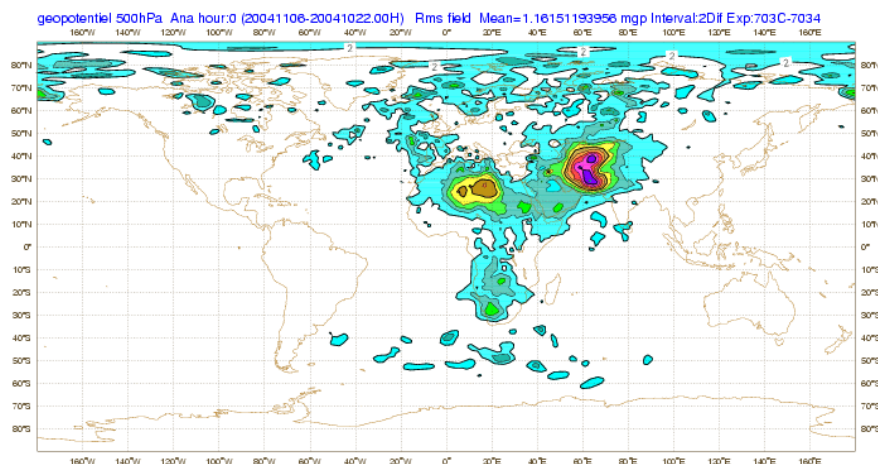

Fig.2: The root mean square difference between Exp.2 and Exp.1 analysis for the root mean square error of geopotential height at 500hPa, Interval: 2.0, Unit: geopotential
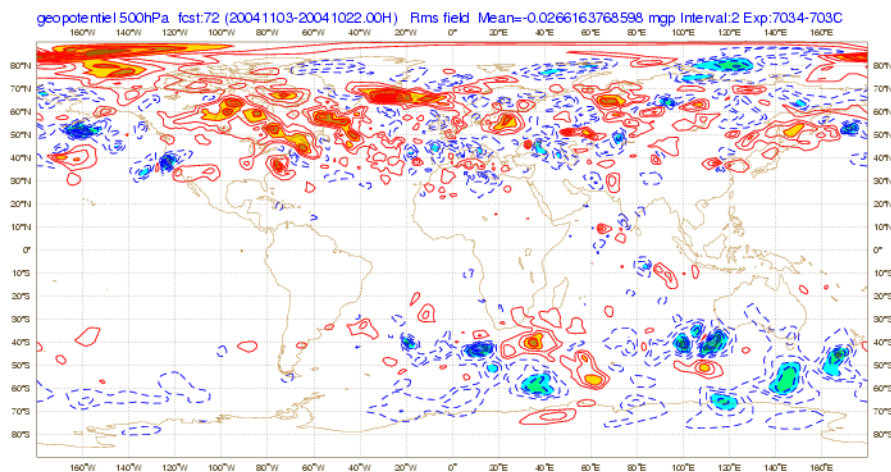
Fig.3: The differences (Exp.1 - Exp.2) of the root mean square error of
geopotential height at 500hPa at 72h forecast, the red solid line is positive, the
blue dash line is negative, Interval 2.0; Unit: geopotential

The differences between Exp.2 and Exp.1 analysis (Fig.2) are rather large over Africa, Europe, the northern part of Northern America, Northern Atlantic, Middle Asia, western part of Russia and Arctic and the region of the large difference is a triangle shape, which result from the increase of AIRS observations over land. By 72h (Fig.3), the large positive differences cover mainly over north of 30°N, the differences are small over Africa, positive and negative differences are distributed over the ocean of Southern Hemisphere and the negative values are more than the positive values over the region.

The AIRS observations over land has a major impact on the forecast performance over Europe for 9 November 2004. By 72h the forecast using no AIRS data over land missed a trough over the western part of Russia (comparing Fig.4(a) and (b)). The forecast using AIRS data over land successfully simulated the trough although it looks more shallow than the verifying analysis, the pattern in Exp.2 is closer to verifying analysis than that in Exp.1 (comparing Fig.4(a) and (c)).

Generarlly, The impact of AIRS observations over land on the quality of forecast is positive over the Northern Hemisphere, neutral over Africa, negative slightly over the Southern Hemisphere.
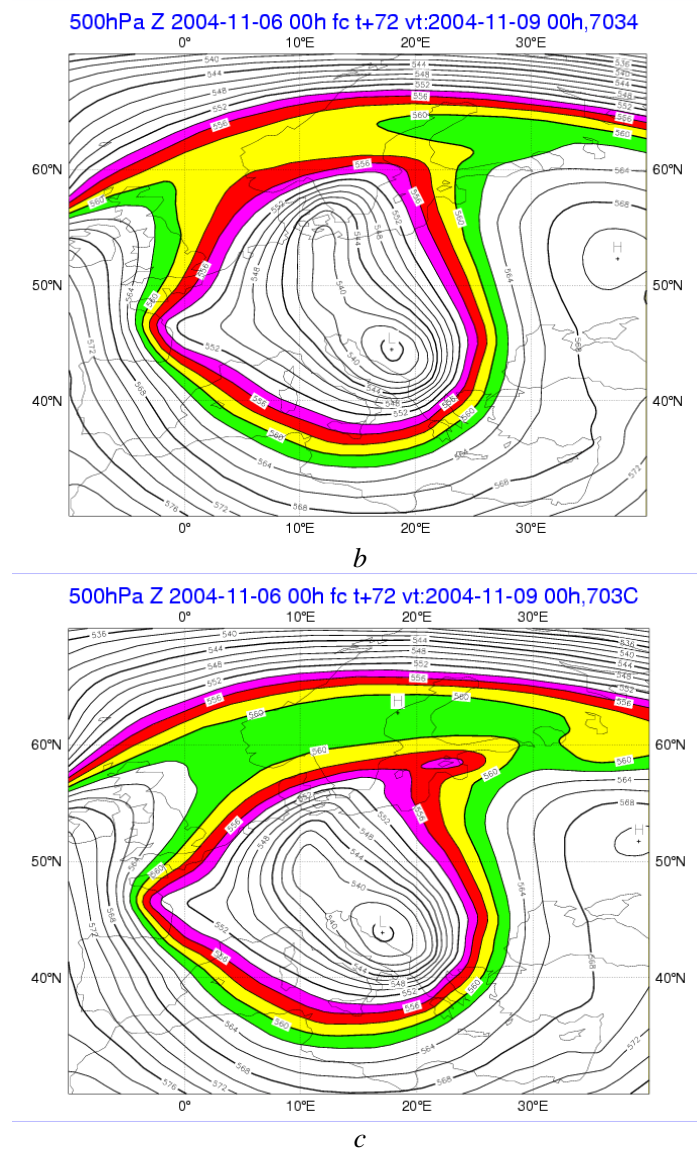

a

b

c
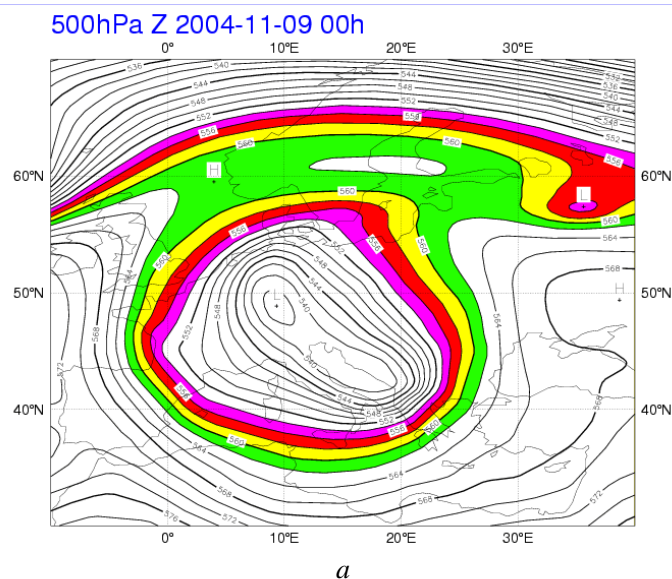
Fig.4: Geopotential at 500hPa for 9 November 2004, *a* for the verifying analysis, *b* for the forecast without AIRS data over land by 72h, *c* for the forecast with AIRS data over land by 72h.

(b) The impact of surface spectral emissivity on the accuracy of NWP

In order to investigate the impact of surface spectral emissivity over land, two experiments were evaluated in table 4, Exp.2 and Exp.3. Exp.2 has been mentioned at (a), Exp.3 is a emissivity experiment of four-dimensional variational data assimilation and forecast suite with AIRS observations over both ocean and land. SSE over land is a constant emissivity equal to 1, the others are the same as Exp.2, which can ensure that differences could only arise from the change in SSE over land comparing Exp.3 with Exp.2.

Table 5 shows that impacts of both AIRS and new SSE over land are positive over the northern hemisphere, The impact of using AIRS over land with new SSE compared with no data over land is strong and increases with altitude. The impact of using AIRS with new SSE over land compared to AIRS with a constant emissivity is slightly positive and decreases with altitude.

Table 5: The differences between experiments for the root mean square error of geopotential height at 500hPa by forecast 72h over the northern hemisphere . The values in the left column is the difference between Exp.1 and Exp.2, the values in the right column is the difference between Exp.3 and Exp.2. Positive values mean that Exp.2 improves the quality of forecast

	The impact of AIRS observations over land	The impact of surface spectral emissivity
300hPa	0.63	0.10
500hPa	0.41	0.14
850hPa	0.26	0.15

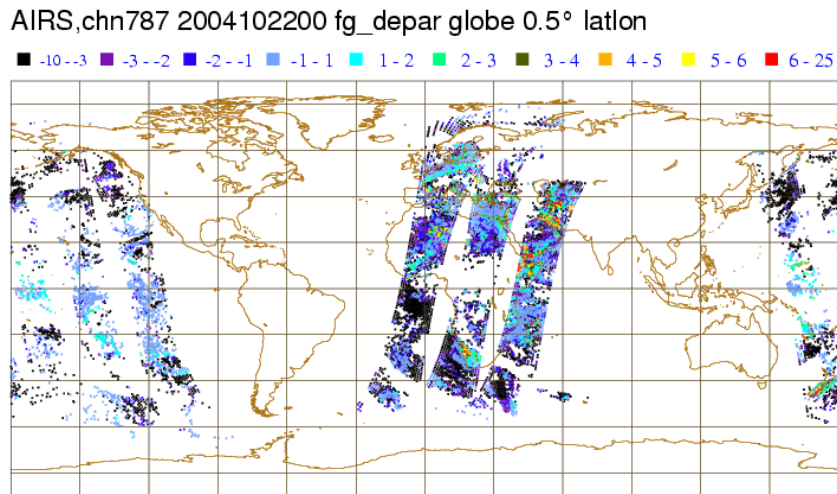## (c) The impact of the skin temperature on the accuracy of NWP

In above section, we mentioned that the skin temperature may be under-estimated at 12 UTC over Europe and Africa. We also analyzed the values of obs-guess globally at different time (00, 06, 12, 18 UTC) 22 October 2004, and found that the big biases appear around local noon (Fig.5, figures at 06,18UTC not shown). These results possibly revealed that the skin temperature has some problems around local noon. In order to prove this supposition, a new experiment was run as table 4. Exp.4 is a skin temperature experiment of four-dimensional variational data assimilation and forecast suite with AIRS observations over both ocean and land. Over land the skin temperature T_{skin} was adjusted around local noon, the others are the same as Exp.2.

T_{skin}^{new} is the skin temperature after adjusted

$$T_{skin}^{new} = T_{skin}^{old} + \Delta T \times \sin\left(\frac{t - t_1}{t_2 - t_1} \times \pi\right)$$

Where T_{skin}^{old} is the skin temperature before adjusted, ΔT is the maximum bias of the skin temperature (in this study, ΔT =2.5K), t_1 and t_2 are initial time and finished time of local mid-day respectively. We supposed that the biases of the skin temperature appeared during local mid-day (10:00-14:00) and the biases reached their maximum at noon (13:00).

Comparing Exp.4 (the skin temperature adjusted) with Exp.2 (the skin temperature not adjusted), the impact of the skin temperature adjusted is neutral on the forecast quality over globe (figure not shown). But it does not mean that the experiment of assimilation and forecast is not sensitive to the skin temperature. Fig.6 shows time series of RMSE and bias for geopotential height between Exp.2 and Exp.4 at 850hPa with time being by 72h. The forecast performance in Exp.4 is different from that in Exp.2 for different skin temperature. Generally Exp.4 improves the forecast performance during the first half period but degrades the results later over Europe.

AIRS,chn787 2004102200 fg_depar globe 0.5° latlon

a

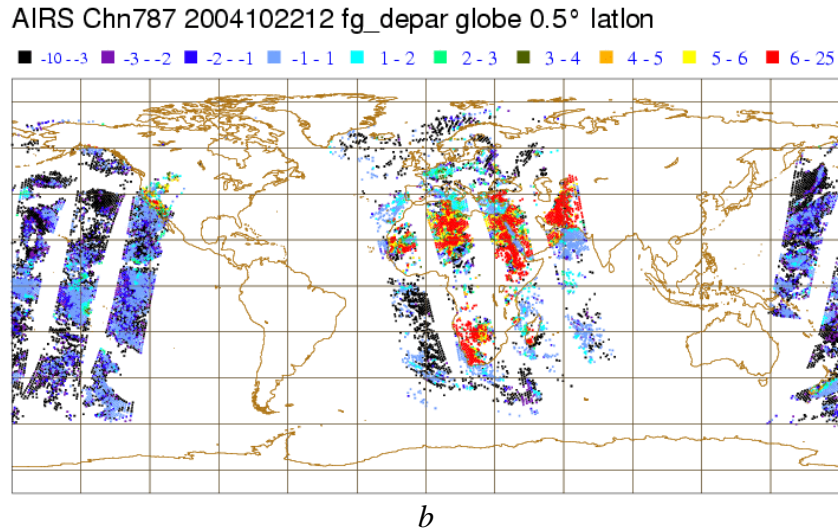AIRS Chn787 2004102212 fg_depar globe 0.5° latlon

b

Fig.5: The differences between observed and first guess brightness temperatures (obs-guess) for channel 787. *a* for 00UTC, *b* for 12UTC 22 October 2004.
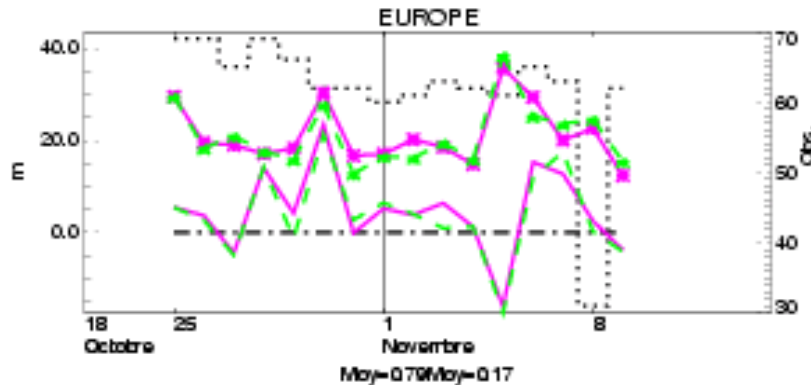

Fig.6: Time series of RMSE and bias for geopotential height between Exp.2 (the skin temperature not adjusted) and Exp.4 (the skin temperature adjusted) at 850hPa being by 72h. The Y axis represents RMSE and bias values, and the X axis represents date. The line with stars represent RMSE, the line without stars represent bias, Exp.4 is represented in green, Exp.2 in red.

CONCLUSIONS

In order to investigate the possibility of use of AIRS radiances over land, we have performed four experiments with the ARPEGE 4D-Var system at Meteo-France (Table 4). The general conclusions for the study are as follows.

- The assimilation of AIRS radiances over land has some positive impact on the forecast quality over Northern Hemisphere, even though the scheme is very preliminary.
- The experiments of assimilation and forecast, using AIRS radiances over land, are sensitive to both surface spectral emissivity and the skin temperature. The assimilation of AIRS radiances with the atlas of surface spectral emissivity climatology is better than that with a constant emissivity equal to one over land. The skin temperature in the operational suite could have a problem of under-estimation around local noon.

The preliminary results from assimilation of AIRS radiances over land are encouraging. We think that there is still some space to improve the use of AIRS radiances over land. We will study this issue further.

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