Dynamic Inference of Background Error Correlation between Surface Skin and Air Temperature

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Abstract

One neglected component of the background error covariance matrix used in data assimilation is the correlation between surface skin and air temperature errors. In the process of assimilating radiances which are sensitive to the surface, this correlation becomes important as it allows modification of the background temperature structure in the boundary layer in a more optimum way. In addition, surface data can influence the analysis of skin temperature through this correlation. The skin-air error correlation was inferred dynamically, that is locally and temporally, from ensembles of forecasts valid at the time of analysis. GOES-8 and GOES-10 imager channels were assimilated with and without skin-air error correlation using the MSC operational 3-Dvar analysis system. The impact of the correlation is assessed. Changes in the boundary layer temperature corrections of the order of 0.5 to 1.0 K are not uncommon.

Introduction

NWP centers now assimilate microwave and infrared radiances routinely, providing information on temperature and humidity in the atmosphere. However, most of the information used in NWP has a sensitivity covering the middle or higher troposphere, i.e. the range 200-600 hPa. Information at low levels is lacking, notably over land. Microwave emissivity over land is highly variable as it depends on soil moisture. The emissivity determination is also a problem in the infrared, but much less severe than at microwave frequencies. Due to the higher infrared emissivity, typically above 0.95, the sensitivity of the radiances in the boundary layer (first kilometer) is rather weak, while the sensitivity to surface skin temperature is high.

This paper explores the use of surface sensitive IR channels in NWP. In particular, one statistical parameter of interest is the error correlation between surface skin (hereafter T_s) and air (T_a) temperatures. This correlation is often set to zero for lack of better knowledge. In doing so, the analysis is clearly not optimum. NWP analyses are obtained from increments or changes suggested by the observations to a background estimate, which is typically a 6-h forecast. If the T_s-T_a correlation is high, significant changes to T_s inferred from IR radiances should translate into significant T_a changes in the boundary layer, even if the radiances are weakly sensitive to T_a in that region. In a similar fashion, increments to T_a obtained from surface 2-m observations will allow changes to T_s through the T_s-T_a correlation. Since the numbers of such surface observations is considerable, it is argued that the T_s-T_a correlation is very important in the determination of a T_s analysis. Examples of that impact are presented here.

The determination of the T_s-T_a error correlation represents a challenge. Here, it is determined from an ensemble of 64 6-h forecasts valid at the time of the analysis. The forecasts are taken from a recent

experiment using the ensemble Kalman filter (Houtekamer et al, 2003). The result is a correlation at the desired resolution which varies locally and is valid at the time of the analysis.

Determination of the T_s-T_a error correlation

The T_s-T_a error correlation is obtained from that between T_s and T_a differences with respect to the ensemble mean. In fact only the correlation between T_s and T_a at the lowest predictive level (near 70 m) is calculated. Knowing that value, the correlation between T_s and T_a at other levels is readily obtained from the T_a-T_a inter-level error correlation used in the 3D-var system. Because T_s remains constant and is not perturbed over oceans in forecast ensembles, the correlation can only be derived over land by that method. Fig. 1 shows the correlation maps valid at 06 UTC and 18 UTC June 2, 2002. The resolution, rather coarse at 150 km (240 by 120 points), is the same as that used to compute analysis increments operationally in the global MSC model. The final analysis is obtained by interpolating increments at the resolution of the forecast model, which is about 100 km (400 by 200 points). In general, the T_s-T_a error correlation is high, often exceeding 0.90. It was verified that the lowest correlations tend to occur at night time (i.e. Asia at 18 UTC or America/Greenland at 06 UTC) in regions characterized by surface temperature inversions. In some sectors, the correlation is even negative.
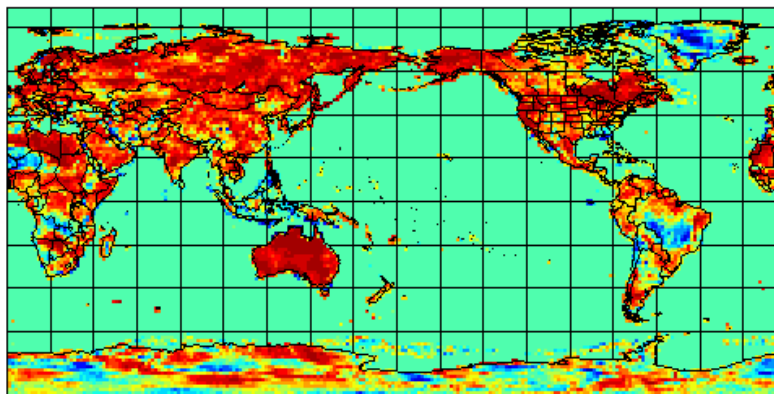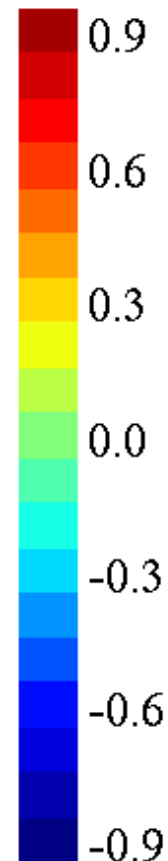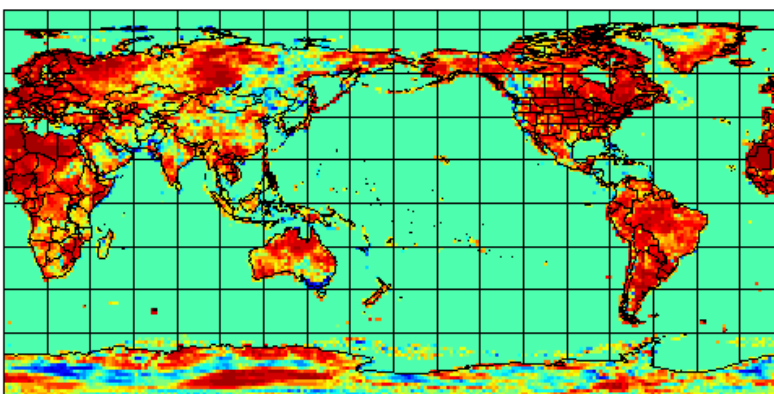

Fig. 1 T_s-T_a error correlation derived from ensemble of 6-h forecasts valid June 2 2002.

Assimilation results

GOES-8 and GOES-10 radiances from Imager 4 (IM4, 11 µ) and IM5 (12 µ) were assimilated in addition to all other data types assimilated operationally. The preparation of the radiance data is described in detail in Garand (2003). This includes the selection of the cloud free pixels, the definition of surface emissivity, and the bias correction procedure. The data cover the Americas and adjacent oceans (10 W-180 W, 60 N to 60 S). Data selected for assimilation are thinned at the resolution of 200 km, which is reasonable for the assimilation of the water vapor channel (IM3, 6.7 µ) but somewhat coarse for the mapping of T_s. Analyses were made with and without T_s-T_a error correlation presented in Fig. 1 for the corresponding two times: 06 and 18 UTC June 2 2002. Fig. 2 shows the resulting T_s analysis increments (by definition the analysis is the first guess plus the increments). The left panels, without correlation, show increments only where satellite data are assimilated. Indeed no other type of data can affect the T_s analysis with the exception of the localized influence of some TOVS microwave radiances. It is noted that increments tend to be negative at night (06 UTC) and positive in daytime (18 UTC). This result is in line with that presented in Garand (2003), i.e. there is clearly a lack of amplitude in the model T_s diurnal cycle. This tendency is largely corroborated in the analyses with correlation (right panels of Fig. 2). Through the T_s-T_a error correlation, surface data are now allowed to contribute to the T_s analysis. Again, the dominant negative increments at night and positive increments during the day give the comforting signal that both surface and satellite data tend to modify the background in the same manner. T_s increments in the range 3-5 K are not uncommon.

The left panel of Fig. 3 shows the T_a increments, with correlation, at 18 UTC. The changes are largely positive and in the typical range 1-3 K. The right panel shows the T_a (70 m) increment difference with-minus-without correlation. These differences can only occur in regions where GOES data are assimilated. This is an important result of this study: the magnitude of the changes is typically of a few tenths of degree, but may locally exceed 1 K. In the vertical, it can be shown that the effect of the correlation remains significant up to a typical height of 1.5 km. This shows that surface channels can contribute significantly to boundary layer profiling.

Validation

Figs. 2-3 showed that the T_s-T_a error correlation operates as expected. However, there is still a need to evaluate the impact of the correlation against independent measurements. Another analysis was done valid at 12 UTC June 2 2002. The numerous radiosonde profiles available at that time were not used in the analysis. Analyzed profiles made with and without correlation were interpolated at the radiosonde sites and compared with the observed profile. Comparisons at sites closest to largest T_a differences (i.e. Fig. 3, right but for 12 UTC) were carried out. The impact was found to be positive at most radiosonde sites. Fig 4-a presents results at Kelowna, British Columbia. The temperature profile with correlation is clearly improved. There is also a modest improvement in moisture. For that station located in the Okanagan valley, the model topography is at 1190 m while the true topography is at 430 m. This represents a problem for data assimilation based on the difference between observed (seeing topography at the scale of the satellite footprint, here near 10 km) and computed radiances. This situation will be alleviated with the next implementation of the global model at 50 km resolution in 2004. Fig. 4-b shows an example of a negative impact at Kuujjwuaq, Quebec (near Ungava Bay). It was found that the radiance causing that change was located about 200 km north of the radiosonde site. Thus the impact arises from the horizontal propagation of the observed negative (cold) increment to the warmer and wetter Kuujjwuaq site. This is a sector of air mass transition. Means to avoid such cases are not trivial, but could be in part minimized by a higher density of observations coupled with higher horizontal resolution in the analysis. An improved local estimate of the background T_s error would also help. The negative impact would have been significantly less if the radiosonde observation had been assimilated.
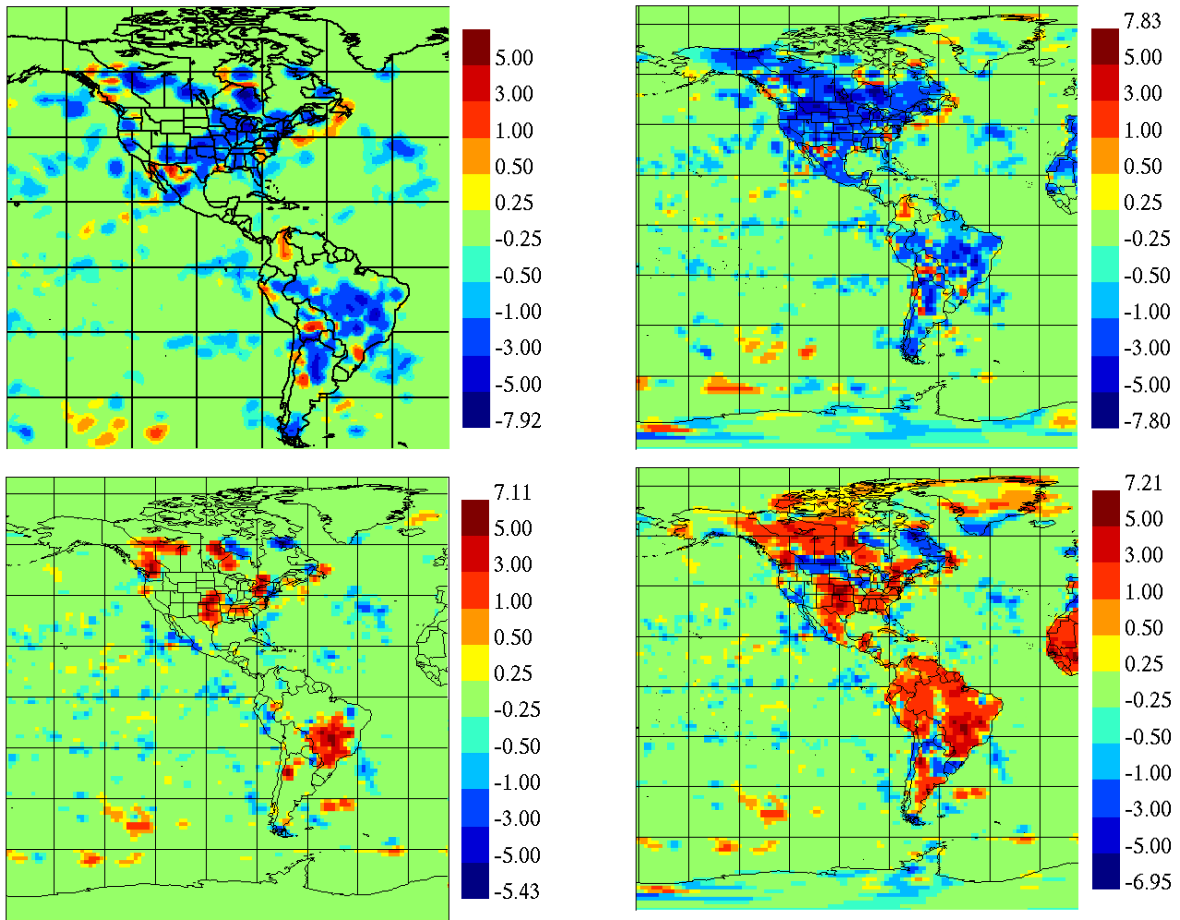
Fig.2 T_s increments at 06 UTC (top) and 18 UTC (bottom) without (left) and with (right) T_s-T_a error correlation.
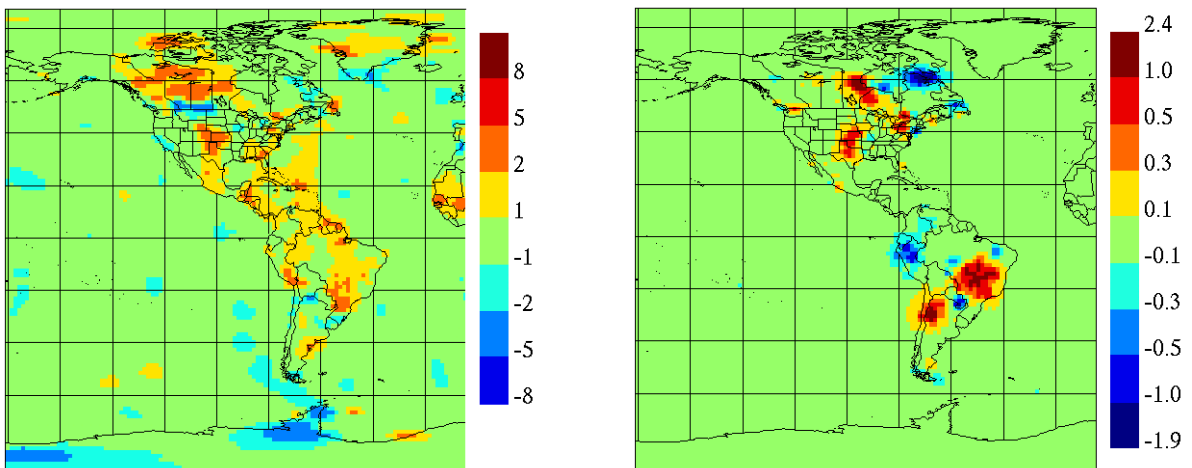

Fig. 3. Left: T_a (70 m) increments with T_s-T_a error correlation at 18 UTC. Right: difference in T_a increments with minus without correlation.
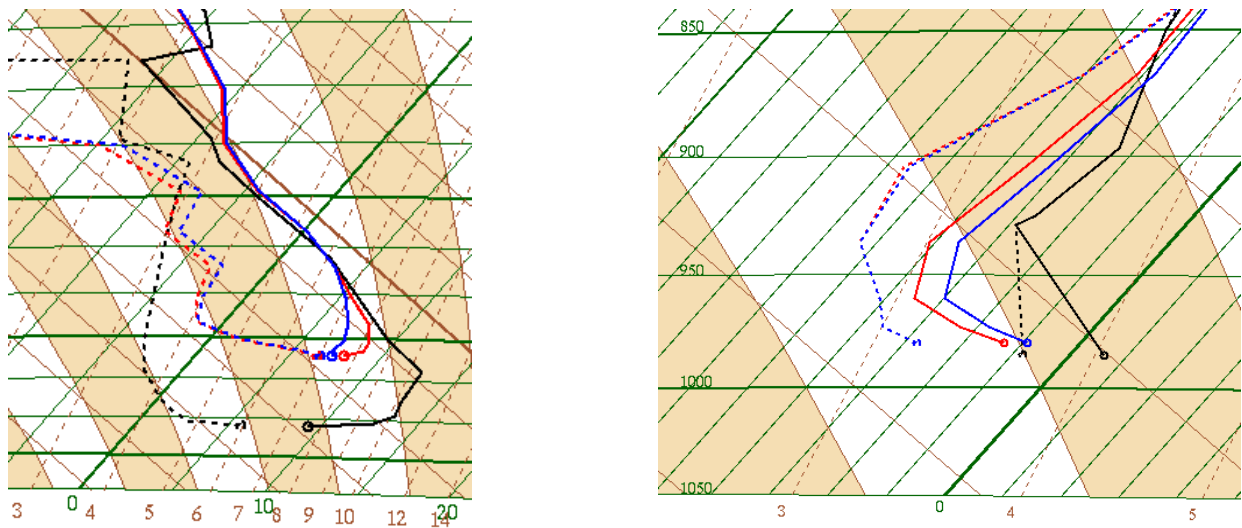
Fig. 4 Temperature (full) and dew point depression (dashed) profiles. Black: radiosonde. Red: with correlation. Blue: without correlation. Left, a) at Kelowna, B.C. Right, b) at Kuujjuaq, Que. Valid 12 UTC June 2, 2002.

Conclusion

Ensemble forecasts are used to infer the T_s-T_a background error correlation as a function of time and location. This methodology may appear at first quite expensive. However ensemble forecasts are developing rapidly at NWP centers and will soon become a routine product. One of the main reasons these ensembles are made is precisely to derive flow dependent background error covariance estimates which can then be used in NWP data assimilation. The T_s-T_a error correlation used here is just one statistical measure which can be derived from the ensembles. At first glance, this product appears realistic. The correlation tends to be generally high, with lower values, as expected, in situations of surface inversions. A remaining problem is to infer the correlation over oceans. There, a reasonable estimate can perhaps be made based on local estimates of static stability.

It was shown that the T_s-T_a background error correlation has a significant impact, in general, on both the analysis of T_s and that of T_a in the boundary layer. The impact is particularly important where infrared radiances sensitive to the surface are assimilated. The study also points to practical problems related to horizontal resolution and horizontal correlation of background errors. It is also possible to incorporate a forward operator relating T_a and T_s with surface values of temperature and humidity needed to compute radiances. This approach is currently under investigation. Even with such an operator, there will still be a need for a good estimate of the T_s-T_a error correlation.

Reference

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Houtekamer, P., H. Mitchell, G. Pellerin, M. Buehner, M. Charron, L. Spacek, and B. Hansen, 2004: Atmospheric data assimilation with the ensemble Kalman filter: Results with real observations, to appear in Mon. Weather Rev.