Assimilation of GOES imager channels at the MSC

L. Garand and N. Wagneur

Meteorological Service of Canada

1. Introduction

This work describes the effort made at the Meteorological Service of Canada (MSC) to assimilate GOES imager channels in NWP analyses, with the focus on surface sensitive channels. Interestingly, the direct assimilation of radiances leads to a unified land/ocean surface skin temperature \( T_s \). Currently, a SST (sea surface temperature) analysis is done daily at the MSC with no attempt to measure the diurnal cycle. Over land, no analysis is done as the forecast model starts from a LST (land surface temperature) deduced from the surface radiative balance. A LST analysis will eventually fill the gap between the model and observed fields. It is a fact that surface sensitive channels are currently underused in NWP. This work also provides a necessary preparation for the assimilation of advanced infrared (IR) sounding channels such as those from AIRS (Atmospheric Infrared Sounder).

2. Data

GOES-8 (sub-point 75° E) and GOES-10 (sub-point 135° E) were processed every 6-h for the entire month of May 2001. The basic processing on 1 x 1 degree grid has been operational since 1993 at the MSC. This processing extracts radianc e information as well as cloud parameters such as effective cloud fraction (CF) and height. For the assimilation of radiances, CF has to be below 50%. A single pixel is chosen within the 1 x 1 degree area. The location of that pixel is the same for all valid channels and is based on an Imager 4 (IM4) radiance point defined by the 5% warmest pixel from the histogram of the 1 x 1 degree area. This choice increases the probability of dealing with a cloud-free pixel. Brightness temperatures (BTs) are computed (P, for predicted) from the atmosphere defined by 6-h forecasts matching the observations (O) using the MSCFAST radiative transfer model (Garand et al., 1999). A bias correction of the BTs is made using the usual assumption that over a large ensemble of data the mean value of \( O - P \) is zero.

The bias takes the simple form (a BT + b) where a and b are fitting constants. GOES data are used up to a viewing angle of 70°. For radiative transfer calculations, surface emissivity maps were established for each channel based on land classification, the percentage of water, and the presence or not of snow. Over oceans, the emissivity varies with viewing angle and wind speed.

3. Variational assimilation

A 1D-var assimilation is done by minimizing the classical objective function (see e.g. Gauthier et al. 1999):

\[
J(X) = 0.5 \left[ (X - X_b)B^{-1}(X - X_b)^T + (H(X) - y)^T R^{-1}(H(X) - y) \right]
\]

(1)

where \( X \) is the model state of dimension \( N = 58 \) (28 T and q levels, \( T_s, P_s \)) and \( X_b \) is the 6-h forecast background state. \( B \) is the background error covariance matrix officially used at the MSC. No correlation is assumed between \( T_s \) and other variables. \( R \) is the observation error covariance matrix and has dimension \( M \times M \) channels. \( H \) is an operator, here the MSCFAST model, computing the equivalent of observations \( y \) from \( X \). The system is solved iteratively by a Gauss-Newton technique which requires the derivative:
\[ J'(X) = B^{-1}(X-X_b) + H^T(X) R^{-1}(H(X)-y) \] (2)

The second derivative leads to a local estimate of the analysis error \( \Delta \):

\[ J''(X) = A^{-1} = B^{-1} + H^T(X)R^{-1}H(X) \] (3)

Here \( H' \) represents the Jacobian of the radiative transfer model. It corresponds to \( \frac{dBT}{dX} \). \( M \) is set to 2 for IM4 (11 \( \mu \)m) and IM5 (12 \( \mu \)m), but assimilations are also done with IM2 (3.9 \( \mu \)m) and IM3 (6.7 \( \mu \)m). The change of variable \( (X-X_b) = B^{1/2}Z \) leads to a better conditioning of the background term and to a reduction in the number of iterations by a factor of 6. A whole GOES disk can be processed in less than 4 minutes on MSC's SX4 computer. The disk is processed one line at a time, which is natural since the \( B \) matrix varies with latitude. The background error associated with \( T_S \) is of the order of 0.85 K over ocean (it is maximum over strong gradient areas at 1.5 K) and is fixed to 3 K over land. The \( R \) matrix is diagonal with variances set to 50% of the total error variance found from (O - P) statistics, e.g. (0.85 K)\(^2\) for IM4 and (1.21 K)\(^2\) for IM4.

4. Results

Fig. 1 shows an example of \( T_S \) analysis for GOES-8 along with an estimate of error from \( A^{1/2}(T_S) \) derived from (3). The 1D-var analysis is smooth. Ocean/land boundaries are avoided using a map of the water percentage within 1 x 1 degree areas. On average, the analysis modifies the background by about 0.5 K over ocean. Observations indicate a 0.51 K difference in BT4 between 18 UTC and 06 UTC. This diurnal cycle should normally translate into a 0.7 K cycle in \( T_S \) (because the Jacobian \( dBT4/dT_S \) is about 0.75 K/K on average). The analysis imposes a diurnal cycle with amplitude of 0.23 K only due to the 50% weight of the background and due to the fact that the observation forcing translates not only into \( T_S \) analysis increments but also into low level \( T \) and \( q \) increments. Over land the observations have much more weight and correct the analysis on average by 6.6 K at 18 UTC and 2.4 K at 06 UTC. Thus, the background error associated to \( T_S \) should vary with local time (it is much higher in daytime). The model was found to underestimate the diurnal cycle of \( T_S \) by about a factor of 2. Increments to the background as large as 20 K are seen at 18 Z (8 K on average). The amplitude of the diurnal cycle seen by satellite reaches 30 K over mountainous regions. Ground observations of upward IR radiation were transformed into equivalent \( T_S \) at some 30 CAVE stations (many over Oklahoma and Kansas, see http://www.tanalo.larc.nasa.gov). These observations confirmed the amplitude of the diurnal cycle seen by satellite.

Collocations were made between GOES-10 and GOES-8 1D-var \( T_S \). Over oceans, there was no bias and a standard deviation as low as 0.23 K from 138,810 collocations. This agreement is well below the expected analysis error of \( \sim 0.65 \) K (Fig. 1b). Over land the agreement is 1.4 K at night, rising to 2.2 K at 18 UTC (near local noon). These numbers are likely representative of the quality of the retrievals over land. Finally, ocean collocations with drifting buoys were made. The agreement between satellite and buoys was excellent: 0.45-0.55 K within GOES-10 and 0.55-0.65 K within GOES-8 based on about 1000 collocations for each of the four synoptic times.
Fig. 1 Example of $T_s$ analysis for May 3, 2001 at 18 UTC using IM4 and IM5 radiances (top) and corresponding estimate of the error (K) based on Eq. 3 (bottom).
5. Conclusion

Work toward the assimilation of GOES imager channels in the 3-D NWP analysis has been done in the context of a 1D-var analysis. The direct assimilation allows an integrated LST/SST analysis and its cost is no more a critical issue. $T_s$ estimates have a typical accuracy of 0.50-0.8 over oceans. Over land, the error should be in the range 1.0-1.5 K at night and 1.6-2.2 K in the afternoon. Tests with the inclusion of IM2 have shown a neutral impact. There are situations where IM2 and IM4 give a conflicting direction for correcting the background; such cases should be avoided. More work is needed to understand anisotropy effects over land and how the assimilation improves the low level analyses of temperature and humidity. The effect of $T_s$-$T$ correlations also requires investigation. A paper with complete details of this work has been submitted for publication (Garand, 2002).

6. References


