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FINDINGS FROM THE PRE-ASSIMILATION OF GOES IMAGER CHANNELS

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1. INTRODUCTION

An important advantage of geostationary satellites is the availability of full disk observations at high temporal resolution. Another advantage is the high horizontal resolution of imaging channels. At the MSC, an effort has been undertaken to directly assimilate the GOES imager channels and at the same time pave the way for the assimilation of infrared data from upcoming satellites such as AIRS, IASI and GIFTS.
In preparation for the assimilation of GOES radiances every six hours, statistics of observed (O) minus calculated (P, for predicted) model 6-h equivalent radiances were computed at that temporal scale. This paper shows the strong diurnal cycle in the (O-P) statistics for the surface channels (4 and 5) for the entire month of March 2001. This is attributed to the diurnal cycle of sea surface temperature (T_s). The amplitude of this cycle is studied from a retrieval of T_s. Surprisingly, there is also a diurnal cycle in Imager 3, a channel which does not see the surface. This is attributed to the MSC forecast model in which upper tropospheric humidity tends to be higher in daytime than at nighttime.

2. RADIANCE STATISTICS

Model equivalent radiances are computed using a radiative transfer model named MSCFAST (Garand et al.,1999). This model proved to be very accurate in a recent intercomparison of radiative transfer models (Garand et al., 2001). Statistics of (O-P) were computed from GOES-08 and GOES-10 imager channels 2-5. In the case of Imager-2, affected by the sun, only nighttime data were compiled. The GOES processing is done on 1 X 1 degree boxes since data are to be assimilated at that scale. Within each box, the processing software finds the most likely clear area using criteria such as the local variance (the original GOES pixels at ~4 km resolution were sampled at ~13 km resolution and re-mapped to 1 X 1 degree: each box contains about 8 X 8 pixels). Various tests are made to decide if the pixel is to be assimilated or rejected as cloudy. Surface emissivity was modeled as a function of wavelength and surface wind speed over oceans. Over land, it depends only on the surface type (maps available on the same 13 km grid as the re-mapped GOES images). The (O-P) statistics revealed some biases of the order of 0.5 K in surface channels and 1.5 K in the water vapor channel 3. Assuming that the model over a large number of cases has no bias, the satellite observation bias is removed using the simple relation: bias = a BT+ b where BT is the observed brightness temperature. For example, for March 2001 and GOES-08 imager 4, the bias is -0.49 K and it is removed using a =-0.00657 and b = -2.406 K. Using additional parameters such as the viewing angle or atmospheric predictors from the model first guess was judged undesirable.

Fig. 1 shows the statistics for GOES-08 and GOES-10. The plot indicates the number of cases, the bias and the standard deviation. The number of cases is larger for Imager-3 as the system accepts the observations when clouds are below the level where the humidity and temperature Jacobians become negligible (low clouds do not affect the outgoing radiance). The bias is negligible after bias correction. The peak-to-peak amplitude of the diurnal cycle is of the order of 0.6 K and is quite regular. There is a sharp minimum for 06 UTC data. This is due to the sea surface temperature cycle. A retrieval of

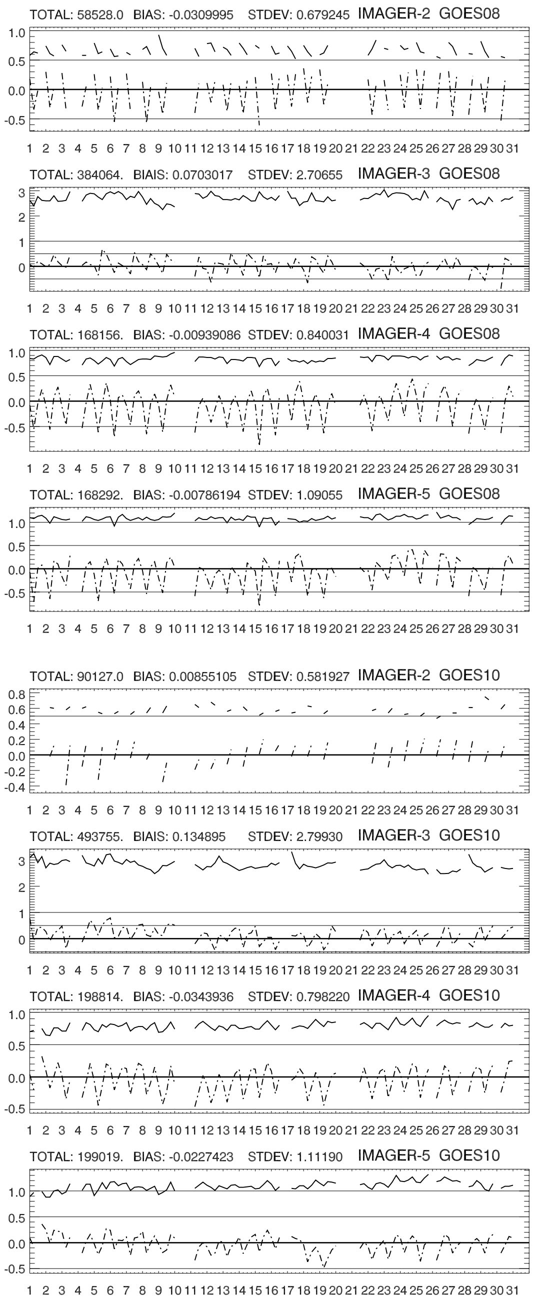

Fig. 1 Statistics of observed minus 6-h forecast calculated BT for imager channels of GOES-08 and 10 in March 2001 every six hours. Upper line is standard deviation; the mean is centered around zero. A bias correction was applied to the observations (see text). Only daytime date used for Imager 2. Number of cases, overall bias and standard deviation indicated. Data taken over oceans in clear areas for surface channels.

T_s is presented in the next section along with an evaluation of the amplitude of the T_s cycle..

3. DIURNAL CYCLE OF THE SURFACE TEMPERATURE

For surface channels, the Jacobian routine accompanying the radiative transfer model reveals that the surface temperature Jacobian dBT/dTs is of the order of 0.7 K/K (it varies from about 0.4 to 0.9 K/K). Thus, if the amplitude of the BT cycle is 0.6 K (Fig. 1), the amplitude of the T_s cycle should be about 0.85 K. T_s has been one of the first quantitative products obtained from satellite. Yet, it is only recently that attempts have been made to evaluate the T_s diurnal cycle. Most algorithms use a “split window” technique consisting in a regression using BT4 and BT5 (from imager channels 4 and 5). Yu et al (1999) estimated that over calm seas, the diurnal variation of T_s may reach 4 K. The split-window technique is very fast, but ignores or does not consider explicitly nonlinear aspects of the problem (such as the dependency on emissivity or viewing angle), which may introduce significant errors.

Here T_s is determined by a variational technique (see e.g. Garand, 2000). Such a physical method allows the determination of the surface temperature over land as well. The formulation has been presented many times: it minimizes the objective function J(X):

$$J(X) = 0.5(X-X_b)\mathbf{B}^{-1}(X-X_b)^T + 0.5(H(X)-y)^T\mathbf{O}^{-1}(H(X)-y)$$

where X is the analyzed state of the atmosphere, X_b its first guess, **B** and **O** the background and observation error covariance matrix, respectively, and T denotes the transpose. H(X) represents the radiative transfer model which computes BT from X and the y represent the BT observations. An iterative procedure finds the solution X, which requires the Jacobian H’(X). If we limit X to T_s and the BTs to channels 4 and 5, and if in addition the solution is calculated for the sum of J(X) over an ensemble of locations (instead of each location one by one), then we can obtain T_s over a full disk in less than 30 s on a large computer (SX4). If on the other hand, we let profiles of temperature and humidity vary (28 levels at MSC), the processing requires about 1100 s due to slower convergence of the Gauss-Newton iterative procedure. The solution for T_s is then in principle more optimal and differences of a few tenths of a degree from the one based on T_s alone are noted locally. For the evaluation of the diurnal cycle, we used the simpler method. Obviously, the fact that we blend information from observations sensible to the diurnal cycle with the first guess of T_s which does not resolve that cycle implies that the solution will lead to a somewhat reduced diurnal cycle compared to the one obtained from observations alone (such as from a split-window retrieval). The error associated to the background T_s was set to 1 K; that associated to BT4 was set to 0.38 K and that associated to BT5 to 0.49 K (i.e. 20 % of the total variance noted in Fig. 1). This means that the effective BT4 error associated to the background is about 0.70 K. For the month of March 2001, 62,565 cases of T_s differences (18-06 UTC) were obtained. The average difference was 0.50 K, slightly less than the expected 0.85 K difference. A map of differences was obtained. For 1 X 1 degree boxes with more than 10 cases, maxima as high as 1.5 K were noted. Another estimate of T_s was obtained by using BT4 only: inverting the radiative transfer equation, assuming the first guess temperature and humidity profile as perfect. For the same cases, an amplitude of 0.68 K was obtained. The diurnal cycle of T_s was also obtained over land. Its amplitude exceeds 30 K over regions such as the Sierra Madre (Mexico). These observations are very useful to validate the model's diurnal cycle, but such a study is beyond the scope of this paper.

4. DIURNAL CYCLE OF HUMIDITY

It is rather surprising to note a diurnal cycle for Imager 3 in Fig. 1, since this channel does not see the surface. The amplitude of the cycle is about 0.45 K. In order to evaluate if this signal is due to the model or is indeed present in the observations, we computed separately the observed and modeled BT difference (18 UTC- 06 UTC) and (12 UTC - 06 UTC) for GOES-10 over the month of March. Only cases not affected my modeled or observed clouds were retained. In addition, the corresponding modeled total (TPW) and high precipitable water (HPW, 400 hPa to top) were calculated (more than 135,0000 cases). Results are shown in table 1.

Table 1. Mean Imager 3 BT differences for GOES-10 in March 2001 between various synoptic times. Corresponding model 6-h forecast TPW and HPW differences shown. For each day, data for both times had to be available.

BT3 difference (K)

	Model	Observed
(12-06 UTC)	-0.362	-0.018
(18-06 UTC)	-0.482	0.012

Model PW difference (%)

	TPW	HPW
(12-06 UTC)	0.76	1.81
(18-06 UTC)	1.93	3.06

It can be concluded from Table 1 that there is no diurnal cycle of BT3 in the observations. The magnitude of the diurnal cycle seen in the model approaches 0.5 K and corresponds to an increase in daytime HPW of about 3 % (the mean HPW is ~0.7 mm). Model TPW (mean of ~25 mm) also increases in daytime by 1-2 %. Further analysis is required to see if this cycle is an artefact of the assimilation cycle or is really a characteristic of the model. This will be determined by verifying if the noted cycle exists in medium range forecasts (beyond day 3).

5. CONCLUSION

It is argued that time has come to produce global T_s maps at fixed hours instead of limiting ourselves to a daily product which eliminates the diurnal cycle. On average, the amplitude of this cycle approaches 1 K. Statistics of observed minus calculated radiances at high temporal resolution also reveal an amplitude of the order of 2-3 % in the model upper tropospheric humidity which does not seem to be confirmed by the satellite observations. It was also shown that a variational estimate of T_s can be obtained at a relatively modest cost, allowing studies of the large diurnal cycle over land as well.

6. REFERENCES

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