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IMPROVEMENTS TO THE GOES-12 IMAGER CLOUD PRODUCT

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1. INTRODUCTION

The Geostationary Operational Environmental Satellite (GOES) – 12 is the first in the series of new geostationary satellites which has a new suite of Imager bands. The previous GOES Imagers obtained information from one visible and four infrared bands (Menzel and Purdom, 1994). The new GOES-12 and beyond Imagers are similar to the previous GOES Imagers which contain one visible and four infrared bands but the new GOES Imagers have a modified water vapor band (band 3) and have replaced the 12µm band (band 5) with a 13.3 µm band (band 6) (Hillger, et al; 2003, Schmit, et al; 2001).

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The previous GOES Imagers used either the IR Window Technique (Schreiner, et al; 1993) or the IR Window-Water Vapor Intercept Technique (Nieman, et al; 1993) to determine the cloud heights. With the addition of the 13.3 µm band, it is now possible to use a CO_2 Absorption Technique (Wylie and Menzel, 1999). This CO_2 Absorption Technique also provides a more accurate calculation of the effective cloud amount than was available from previous GOES Imagers.

2. CO_2 TECHNIQUE IMPROVEMENTS

Several enhancements were made to the CO_2 absorption technique which have improved the quality of the GOES Imager cloud product. These enhancements include; a brightness temperature bias correction, a technique to interpolate the cloud top pressure between fixed forward model levels, and an improved method for determining calculated radiances.

2.1 Bias Correction

The largest change in the cloud product came from deriving the bias correction for the two channels used by the CO_2 absorption technique. These changes are consistent with Frey et al. (1999). The clear pixels, over ocean only, were determined by using the product's internal cloud mask. The temperature and moisture profiles from The National Center for Environmental Prediction's Global Forecast System forecast grids were interpolated to make the vertical sounding at each pixel's location. The Cloud Product's radiative transfer model was then used to calculate the brightness temperatures for the two bands at each clear pixel. Only the 3 hourly full disk images were used to determine the bias correction for consistency. A diurnal change in the bias was found and is shown in Fig. 1. The diurnal change seems to be greatest for band 4 (11.0µm) while the bias correction for band 6 (13.3µm) is the largest. These biases were consistent for several months. It is unclear if the diurnal variation of the bias is due to the satellite or the forecast model.

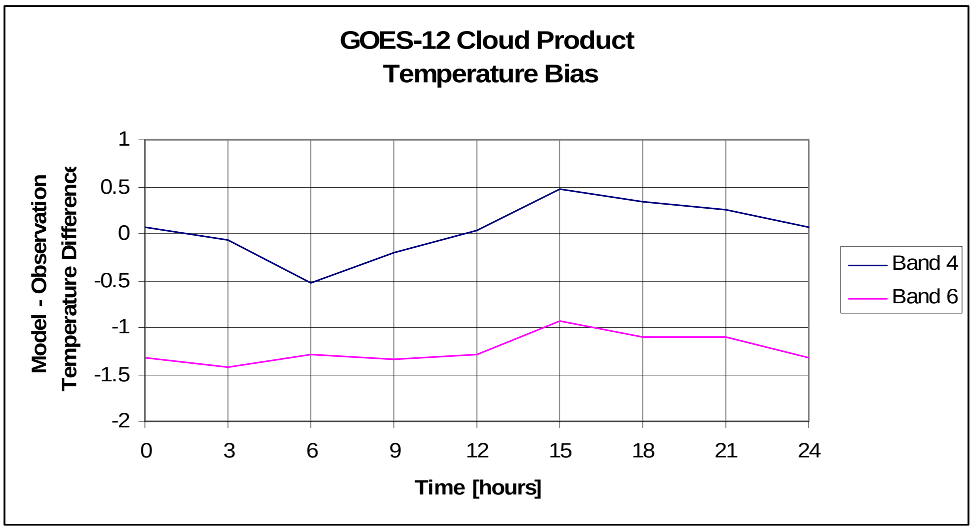

Fig. 1 A 24 hour time series of band 4 and band 6 brightness temperature bias for GOES-12 Imager.

2.2 Interpolation

For an infinitesimal cloud thickness at one pressure level, the difference in cloud-produced radiances, $I(\lambda)$, and corresponding clear air radiances, $I_{cl}(\lambda)$, for a given field of view are written as:

$$I(\lambda) - I_{cl}(\lambda) = \text{ήἐ} \int_{Ps}^{Pc} \frac{\tau(\lambda,p)\ dB[\lambda,T(p)]\ dp}{dp}$$

Where $I(\lambda)$ is the observed radiance (from the satellite), $I_{cl}(\lambda)$ is the clear radiance at wavelength λ and calculated from the temperature and moisture profile, ήἐ is the effective cloud amount, P_s is surface pressure, P_c is cloud pressure, $\tau(\lambda,p)$ is fractional transmittance for radiation of wavelength λ emitted from the atmospheric pressure level (p) arriving at the top of the atmosphere (p=0), T(p) is the atmospheric temperature profile, $B[\lambda,T(p)]$ is the Planck radiance of wavelength λ for temperature T(p). Given a priori knowledge of the temperature and moisture profile, satellite measurements of clear and cloudy radiances at a given wavelength leave one equation and two unknowns, ήἐ and P_c.

With measurements at two wavelengths close enough together so that ἐ$_1$ approximates ἐ$_2$, the ratio of clear and cloudy sky radiance deviations in the two spectral wavelengths leaves an expression by which the cloud pressure within the field of view can be specified by:

$$1 = \frac{I(\lambda_2) - I_{cl}(\lambda_2)}{I(\lambda_1) - I_{cl}(\lambda_1)} \bullet \frac{\int_{Ps}^{Pc} \tau(\lambda_1,p)\, dB[\lambda_1,T(p)]\, dp}{\int_{Ps}^{Pc} \tau(\lambda_2,p)\, dB[\lambda_2,T(p)]\, dp}$$

The right side is calculated for a range of cloud top pressures, typically from 1000 – 100 hPa at 50 hPa intervals. The pressure where the numerator equals the denominator (equation equals one) is the cloud top pressure. Due to the 50 hPa intervals, the true cloud top pressure is seldom found. Using the intervals just above and below the actual cloud pressure (the two values closest to one), a better cloud top pressure can be obtained with a log – log interpolation. While there are plans to also interpolate for the Sounder product, currently it only reports clouds to the RTM levels.

2.3 Radiative Transfer Model

Significant changes were made to the cloud product software to accommodate a new radiative transfer model (RTM). The previous Radiative Transfer TOVS (RTTOVS) model, which as been used since the launch of GOES-8, has been replaced with the Pressure-Layer Optical Depth (PLOD) model now commonly called Pressure-layer Fast Algorithm for Atmospheric Transmittance (PFAAST) (Hannon, et al: 1996).

3. VERIFICATION

Cloud top verification is difficult. Direct measurements of cloud top are available in only limited regions and usually correspond to only a few pixels of a hemispheric satellite image. In the past Smith and Platt (1978) used rawinsonde profiles and ground based lidar, Wylie and Menzel (1989) and Frey, et al. (1999) used lidar and aircraft measurements while Schreiner, et al. (1993) used surface observations to verify CO_2 derived cloud heights. We will compare the GOES-12 Imager CO_2 derived cloud heights to lidar measurements and show improvements in cloud drift wind quality when compared to other height assignment techniques.

3.1 Cloud Phase Lidar Comparisons

During the Atlantic THORPEX Regional Campaign (ATReC) cloud top information was measured using a Cloud Physics Lidar. Comparisons of lidar measured cloud top height to the GOES-12 Imager Cloud Product along a 5 December 2003 flight track are shown in Fig. 2. A histogram of cloud top height differences, for the same flight, (Fig. 3) suggests the GOES-12 Imager Cloud Product may have a low bias compared to the lidar measurements. One would not expect an exact comparison due the pixel resolutions and the inherent measurement differences. For the example, the IR techniques will give a mean “radiative” height.

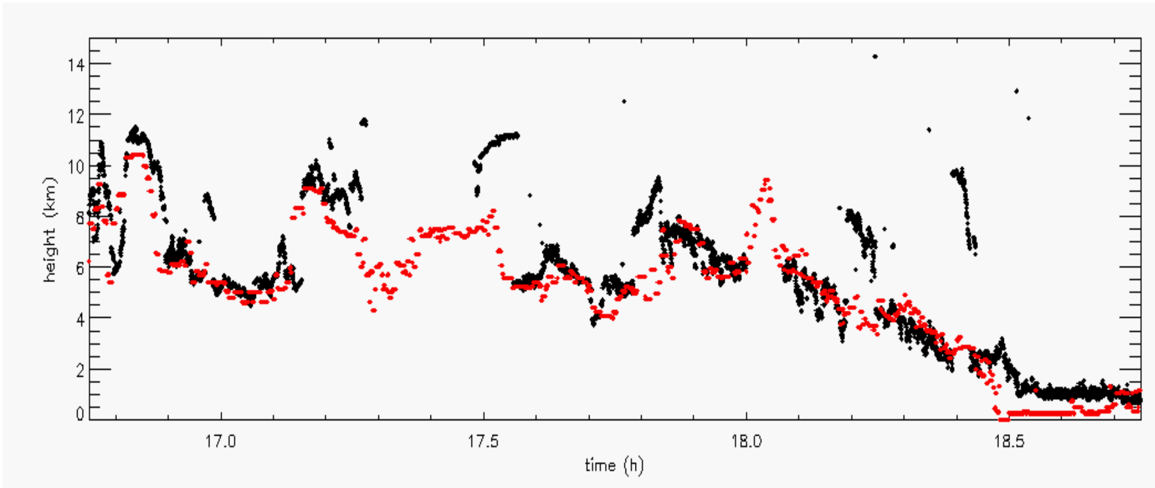

Fig. 2 ATReC cloud phase lidar cloud top (black) comparison with GOES-12 Imager Cloud Product (red) along the ER2 flight track.

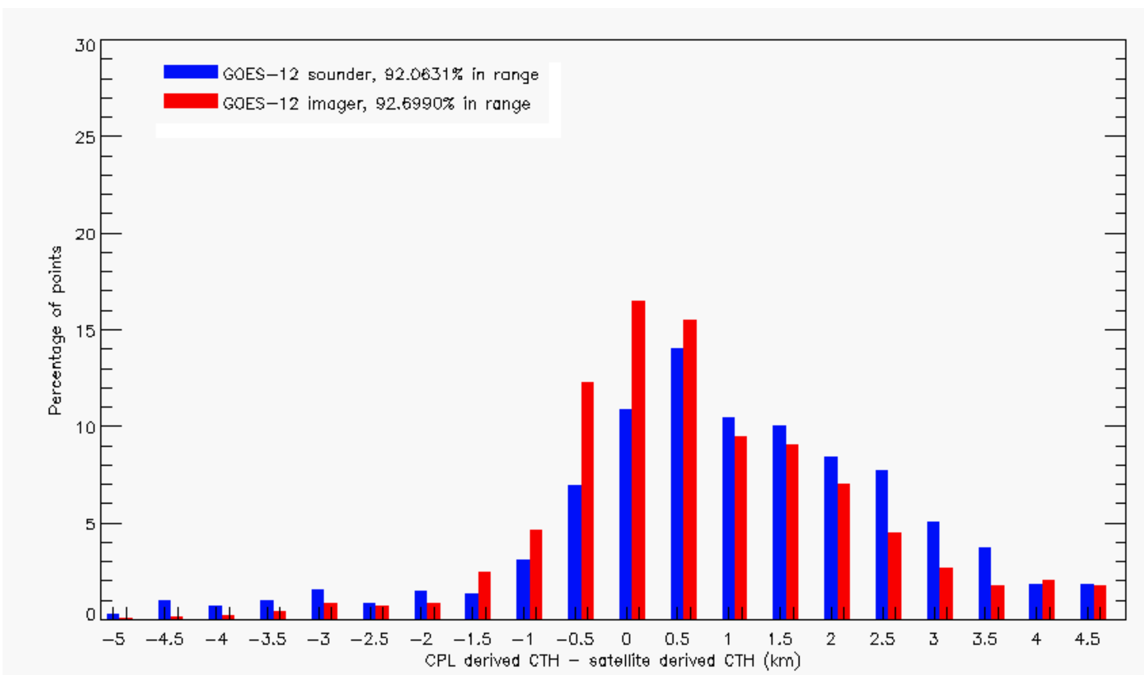

Fig. 3 Histogram of lidar measured cloud top minus GOES-12 Imager (red) and Sounder (blue) cloud top.

3.2 Cloud Drift Wind Comparisons

GOES-12 cloud-drift winds (Neiman et al, 1997) were generated and the CO_2 absorption algorithm was used to assign heights to viable cloud tracers. CO_2 heights were computed with and without application of a radiance bias correction. The cloud-drift winds were then matched in time (1 hour) and space (100km) to rawinsondes at 00Z and 12Z and comparison statistics generated. Table 1 shows the comparison statistics for GOES-12 high-level (100-400 hPa) cloud-drift winds, whose heights were assigned with CO_2 heights (with and without the bias correction), and collocated rawinsondes for the period 8-14 January 2004. A drastic reduction in the mean vector difference and speed bias occurs when the radiance bias correction is applied. In fact, the speed bias (satellite wind – rawinsonde wind) changes sign, going from negative (satellite winds slow relative to rawinsonde) to positive (satellite winds fast relative to rawinsonde). The application of the radiance bias correction had the effect of moving the CO_2 heights downward in the atmosphere on the order of 50mb.

While the CO_2 heights assigned to the cloud tracers are not validated against direct measurements of cloud top heights, the wind statistics in Table 1 can be used as a proxy to indicate that this downward placement of the cloud heights appears to be in the correct direction. These statistics indicate that a radiance bias correction should be applied in the CO_2 absorption algorithm.

Statistic	***Without* Radiance Bias Correction**	***With* Radiance Bias Correction**
Mean Vector Difference (m/s)	6.61	4.83
Normalized RMS	0.23	0.22
Sat-Raob Speed Bias (m/s)	-1.39	0.23
Speed (m/s)	26.85	26.40
Sample Size	853	853

Table 1. Comparison statistics between GOES-12 high-level (100-400 hPa) cloud-drift winds, whose heights were assigned with CO_2 heights (with and without the bias correction) and rawinsondes over the Northern Hemisphere from 8-14 January 2004.

4. SUMMARY

GOES-12 is the first in the series of new geostationary satellites which has a new suite of Imager bands. The replacement of the 12µm band with a 13.3µm CO_2 absorption band made it possible to generate an Imager cloud product using the CO_2 Absorption Technique. The addition of a bias correction, the interpolation between layers and upgrade of the RTM has improved the quality of the product.

The GOES-12 Imager cloud product has a greater geographical and temporal coverage than the Sounder cloud product as shown in Fig. 4 and 5. The substantial differences in cloud top pressure between the Imager and Sounder product over the Eastern Pacific are due to technique differences. The Sounder has more radiance bands then the Imager. In regions where marine boundary inversions are suspected, the Sounder Cloud Product algorithm uses a different technique to determine cloud height as explained in Schreiner et al, (2002). The Imager Cloud Product algorithm is not able to use this technique due to a lack of radiance information. The Northern Hemisphere sector is available every hour with full disk coverage every three hours. The imager cloud product can also be available during rapid scan episodes.

Real time GOES-12 Imager Cloud Product loops can be viewed at:

http://cimss.ssec.wisc.edu/goes/realtime/grtmain.html#imgrcld

With the recent improvements to the GOES-12 Imager cloud top product, the greater geographical coverage and more timely information than the GOES Sounder, a greater number of users may find this product beneficial. Potential users include: aviation weather, forecasters (possibly within the Interactive Forecast Preparation System), numerical weather prediction (for analysis or validation) and possibly the Volcanic Ash Advisory Center (VAAC) for determining the ash cloud heights.

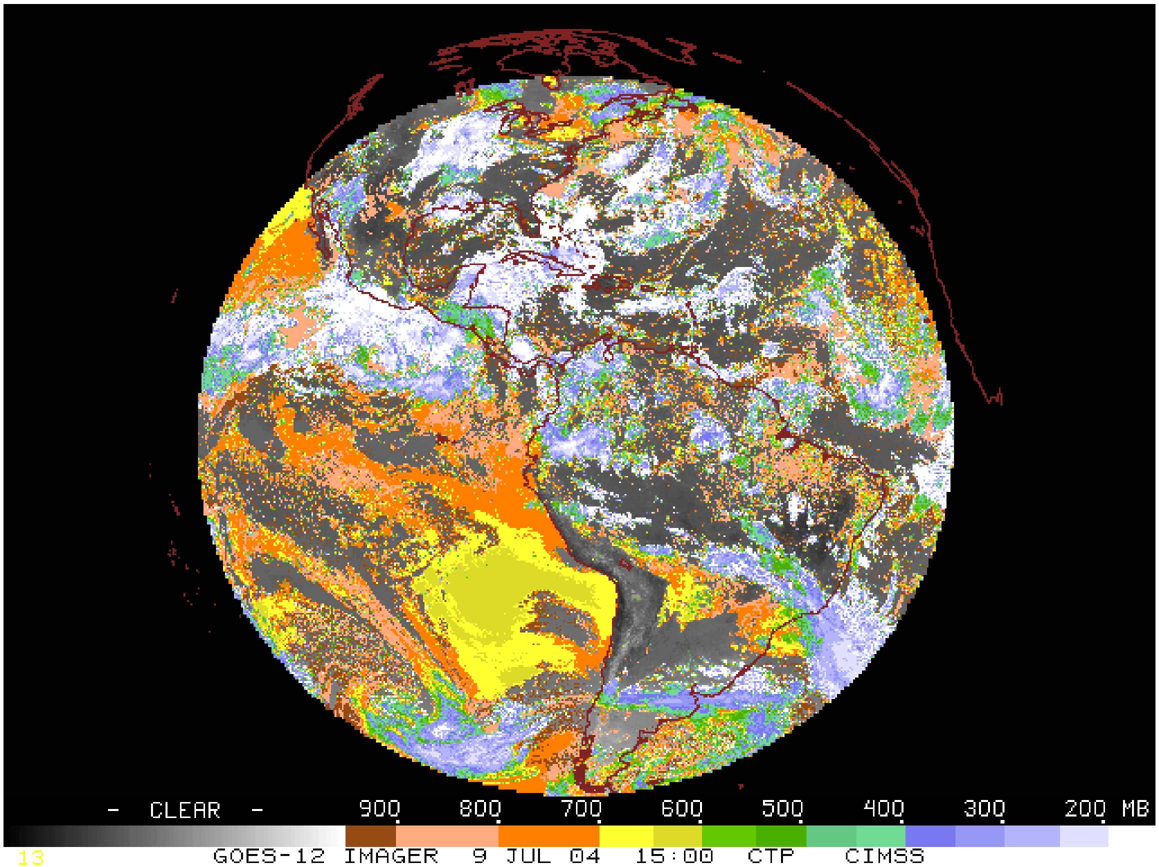

Fig. 4. Sample GOES Imager CTP DPI.

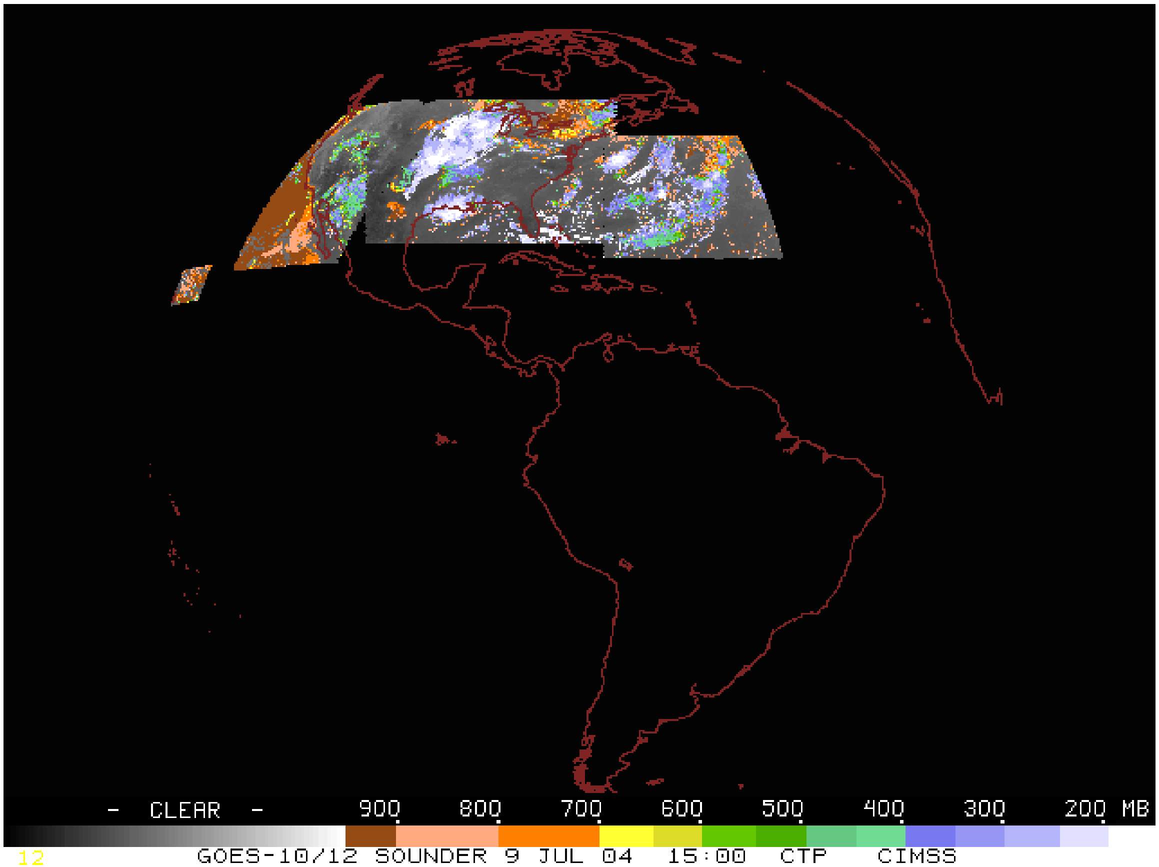

Fig. 5. Sample GOES Sounder CTP DPI.

4. ACKNOWLEGDEMENTS

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