MARITIME INVERSIONS AND THE GOES SOUNDER CLOUD PRODUCT

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Abstract

The Geostationary Operational Environmental Satellite (GOES) Sounder Cloud Product (CP), in the form of the Automated Surface Observing System (ASOS) site-specific CP, has been operationally produced by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) for over five years. The derived-image format has been operationally produced by NESDIS for over one year. The hourly CP consists of cloud top pressure (hPa) and effective cloud amount (%) information for the continental United States and the surrounding area. These data are used by forecasters and observers, and by modelers to initialize numerical forecast models, and as a means of discerning cloud trends.

Recently both modelers and forecasters have noted that the height determination of the CP is erroneously high over the Eastern Pacific, especially in the region of the maritime inversion. The cloud height algorithm in use at that time (Old Method) did not perform properly in this region. It correctly defined the existence of the cloud, but incorrectly located the cloud top above the inversion rather than below the inversion, where it actually exists.

A technique developed by Mosher and Hinson (New Method) was tested and compared to the Old Method. The results show that the New Method lowers the cloud top heights to levels that are meteorologically more consistent with rawinsonde profiles along the West Coast of the United States. Biases in cloud top pressure that were about 150 hPa to 200 hPa were reduced to 10 hPa to 60 hPa when compared to rawinsonde profiles along the coast for a case study in September 2001.

A 3-D cloud analysis was generated by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) Regional Assimilation System (CRAS), using the remotely sensed product based on the Old and the New Methods. Parallel six-hour forecasts show that the cloud information based on the New Method provides more realistic results.

This New Method was implemented at the NESDIS satellite products operation facility in Washington, D.C. in May 2001.

1. Introduction

Hourly cloud top pressure and effective cloud amount based on radiance data from the Sounder instruments aboard geostationary platforms have been processed at the University of Wisconsin – Madison since 1991. Beginning in 1991, and continuing through 1994, cloud parameters were generated using radiances from the Visible Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) (Smith et al. 1981). From 1995 to the present these derived products have been produced via the Geostationary Operational Environmental Satellite (GOES) Sounder (Menzel and Purdom 1994; Schreiner et al. 2001).

During a large part of the year a strong boundary layer inversion exists over the eastern Pacific. It is most pronounced from late spring to late fall in the Northern Hemisphere. The intensity of this inversion can vary in time and distance off the West Coast of the United States. The level of the inversion is usually somewhere between 975 and 900 hPa along the West Coast. The top of the inversion undulates along the coast, but seems to be higher in southern California than in Oregon. The strength of the inversion (i.e., the difference in the temperature between the bottom and the top of the inversion) can be anywhere from 5 °C to 20 °C, although frequently it is around 10 °C to 15 °C, once again depending on the time of year and location (Palmén and Newton 1969 and Dorman et al. 2000).

As will be detailed, this type of low-level boundary inversion causes the Infrared Window Technique portion of the cloud height algorithm to incorrectly assign cloud heights by as much as 200 to 300 hPa. This problem is not unique to cloud heights from geostationary satellites. It has been observed in remotely sensed cloud heights based on High resolution Infrared Radiation Sounder (HIRS) data over the same region (Personal correspondence with Dr. Donald P. Wylie and Mr. Richard A. Frey).

The resulting incorrect cloud height poses a secondary problem. These GOES Sounder derived cloud data are used in the initialization process for numerical weather prediction models (Diak et al. 1998; Bayler et al. 2000; Kim and Benjamin 2000; and Jung et al. 2001). When these erroneously assigned data are introduced, they are ignored at best. At worst an incorrect initial cloud field may result and could wrongly influence or mislead the forecast. Forecasters and observers of the National Weather Service (NWS) have noted the misrepresented cloud heights in the past on numerous occasions (Schmit et al. 2002).

In order to determine the cloud heights over this relatively conventional data void region, a height detection technique, originally devised by Larry J. Hinson and Frederick R. Mosher (2000) at the NOAA/NWS Aviation Weather Center (AWC) in Kansas City, MO., is employed. In short, this method uses a "bottom-to-top" rather than the conventional "top-to-bottom" methodology when the IR Window Technique used. This means the profile is tested beginning with the near-surface values. The "bottom-to-top" approach is more sensitive to low-level inversions that are observed off the West Coast of the United States. The first guess used in this technique is a rawinsonde profile. Due to temporal and spatial constraints, real-time processing of the GOES Sounder product at the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (UW CIMSS) is not able to use rawinsonde profiles as an approximation of the temperature/moisture profile. In order to produce a "timely" product, a forecast of the atmospheric profile is used to describe the state of the atmosphere. This is based on an interpolation of 6- to 18-hour numerical forecasts. Replacing a rawinsonde profile with a numerical model forecast temperature/moisture profile is a compromise. Yet "timeliness," of the final product is a serious consideration when generating an operational product. A more detailed discussion of the "bottom-to-top" technique follows in Section 3.

The goal of this paper is threefold. First, to document the changes made to the GOES Sounder cloud product that is available to and utilized by forecasters and observers on an hourly basis. Second, to show how the Mosher & Hinson Technique was modified to work with an atmospheric numerical model forecast temperature profile as a first guess rather than a rawinsonde measurement to assign low-level cloud heights. Third, to demonstrate the superiority of this new technique versus the previous method. This will be done by comparison to rawinsonde observations along the West Coast of the United States and by the comparison of a numerical weather forecast using the old versus the new method.

The goals of this paper will be accomplished by providing details on the cloud height technique and the reason for the problems in the following section. Section three describes the theory involved and when the Mosher & Hinson Technique will be used. This is followed by a comparison of the results based on the two techniques (Section 4) and the results of a numerical forecast based on cloud height and amount input from the two retrieval techniques (Section 5). Finally, a summary of the results and future work are detailed in Section 6.

2. Background

Originally, the cloud product was designed to complement the Automated Surface Observing System (ASOS) (NOAA, Navy, FAA, 1992). Among the suite of instruments making up the ASOS is a laser ceilometer with a viewing limit of 12,000 ft (~3.7 km). The satellite-derived Cloud Top Pressure (CTP) and Effective Cloud Amount (ECA) provided information above the upper limit of the ASOS (Schreiner et al. 1993). A composite observation based on a 5 x 5 box of GOES Sounder fields of view (FOVs) surrounding a specific surface site location was determined. A calculation was made at each surface site throughout the continental United States, Puerto Rico, and Hawaii. Currently this site-specific technique generates an hourly product for over 17,000 locations across the CONtinental United States (CONUS).

By 1995 an additional derived cloud product from the GOES Sounder was developed and was being produced hourly at the UW-CIMSS. This new product utilized the same cloud height and amount algorithm used in the ASOS site-specific technique noted above, but exploited each FOV rather than a 5 x 5 FOV box around a collection of specific surface observation locations. Two product formats are available. First, a continuous image of cloud top pressure and effective cloud amount are generated. An example of each is shown in Fig. 1. These products are disseminated over the Advanced Weather Interactive Processing System (AWIPS). A second file consists of averaged quantities over a 3 x 3 FOV box. These include: cloud top pressure, effective cloud amount, clear and cloudy brightness temperatures for the eighteen bands of the GOES Sounder, number of cloudy FOVs within the box, and some statistical parameters related to the cloud product. A complete listing and description of the product output in addition to the processing procedures and schedule can be found in Schreiner et al. (2001).

The technique used to generate a cloud height or cloud top pressure and effective cloud amount at a given FOV is based on the CO_2 Absorption Technique (Chahine 1974; Smith et al. 1974; McCleese and Wilson 1976; Smith and Platt 1978; Menzel et al. 1983; Wylie and Menzel 1989; and Wylie et al. 1994) and the IR Window Technique (IRWT) depending on the height and emissivity of the cloud. (Authors note: While the cloud top product is produced in hPa, it can be converted to cloud top height. Therefore, the two terms will be used interchangeably in the article.) The references listed above for the CO_2 Absorption Technique (COAT) provide detailed explanations of the physical and mathematical principles each technique employs, therefore, only a brief description is included below.

The CO_2 absorption algorithm uses radiation measurements in four spectral bands in the CO_2 absorption band (centered at 13.4, 13.7, 14.0, and 14.4 μm) and in the infrared window at 11.0 μm with nominally 10 km resolution depending on the viewing angle. The four channels in the CO_2 absorption band differentiate cloud altitudes, and the long wave infrared window channel identifies effective cloud amount in the GOES Sounder FOV.

For the CO_2 absorption technique, a two-step process is required. First, cloud top pressure (in hPa) is derived. Once it is defined, then the effective cloud amount (in percent) is estimated.

The CO_2 absorption technique is used when the difference between the clear minus cloudy radiance at

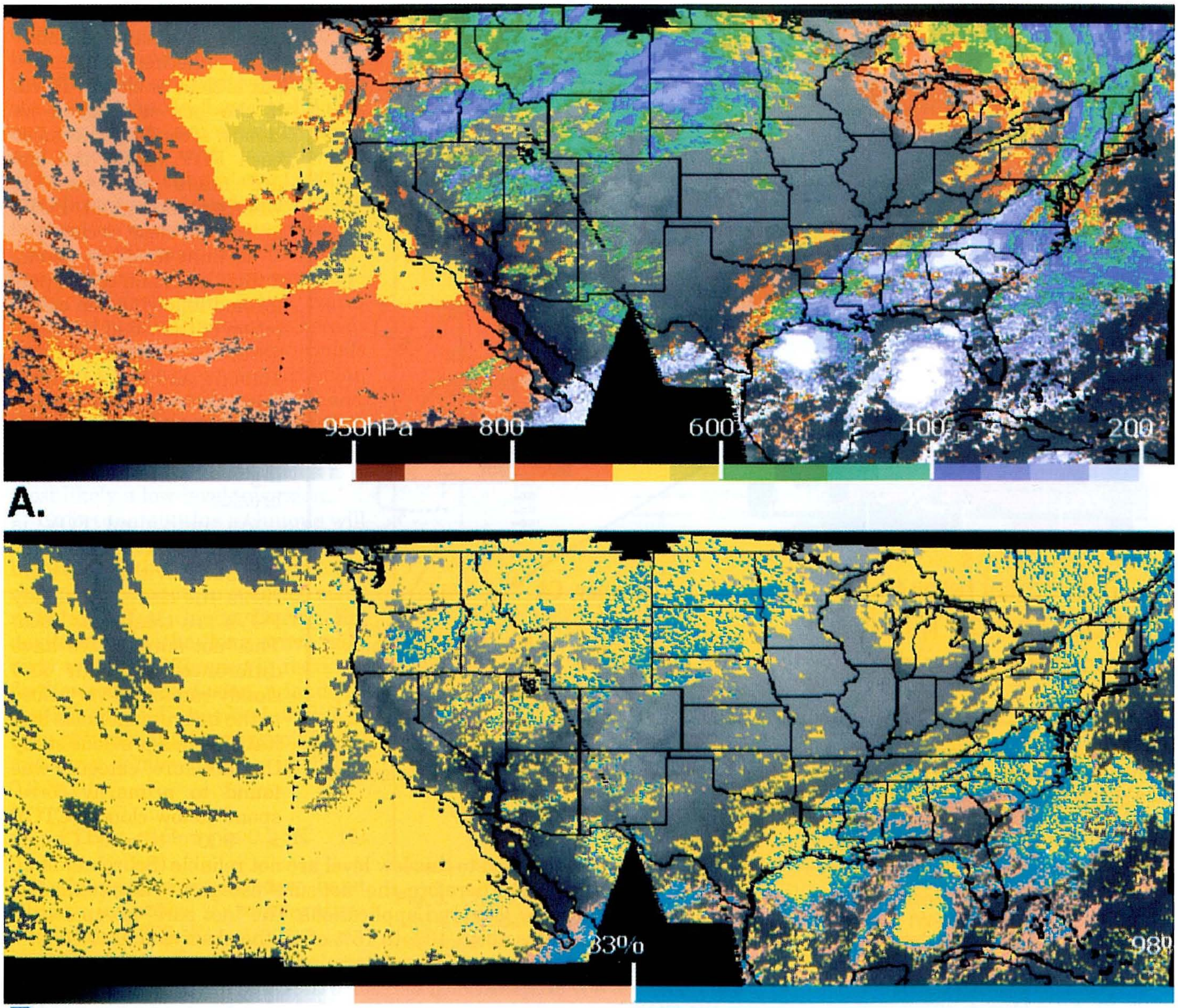

Fig. 1. A depiction at 1300 UTC 21 September 2000 of (a) cloud top pressure and (b) effective cloud amount based on radiances from four GOES Sounder sectors or areas.

each FOV is greater than or equal to two times the instrument noise level (Wylie et al. 1994). When the difference between clear and cloudy radiances is less than two times the instrument noise (this occurs for very thin transmissive, high clouds or for low warm, opaque, clouds), the infrared window channel (11.0 μm) and an in situ temperature profile ("IR Window Technique") are used to determine an opaque cloud-top pressure. Because the CO_2 absorption technique is not used in these special cases, the clouds are assumed to be non-transmissive or opaque (i.e., effective cloud amount is 1.0 or 100%).

There are two major weaknesses with the two techniques. As noted above, when the difference between the cloudy and clear radiance is small for a given FOV, the COAT fails. This occurs for very high and thin clouds or very low warm clouds. The amount of thin cirrus not detected amounts to about 10%-20% (Wylie and Wang 1997). The IRWT uses a "top-to-bottom" method when comparing the observed 11.0 μm window channel value to the in situ temperature profile. This technique fails in regions of low-level inversions, especially when the tops of the cloud deck are located below the top of the inversion. This latter atmospheric signature is quite prevalent in the eastern Pacific as is shown in Fig. 2. Also note the rawinsonde profiles along the coast and the corresponding cloud heights, as determined by the IRWT in this region.

A technique to account for this low-level inversion is the focus of this article.

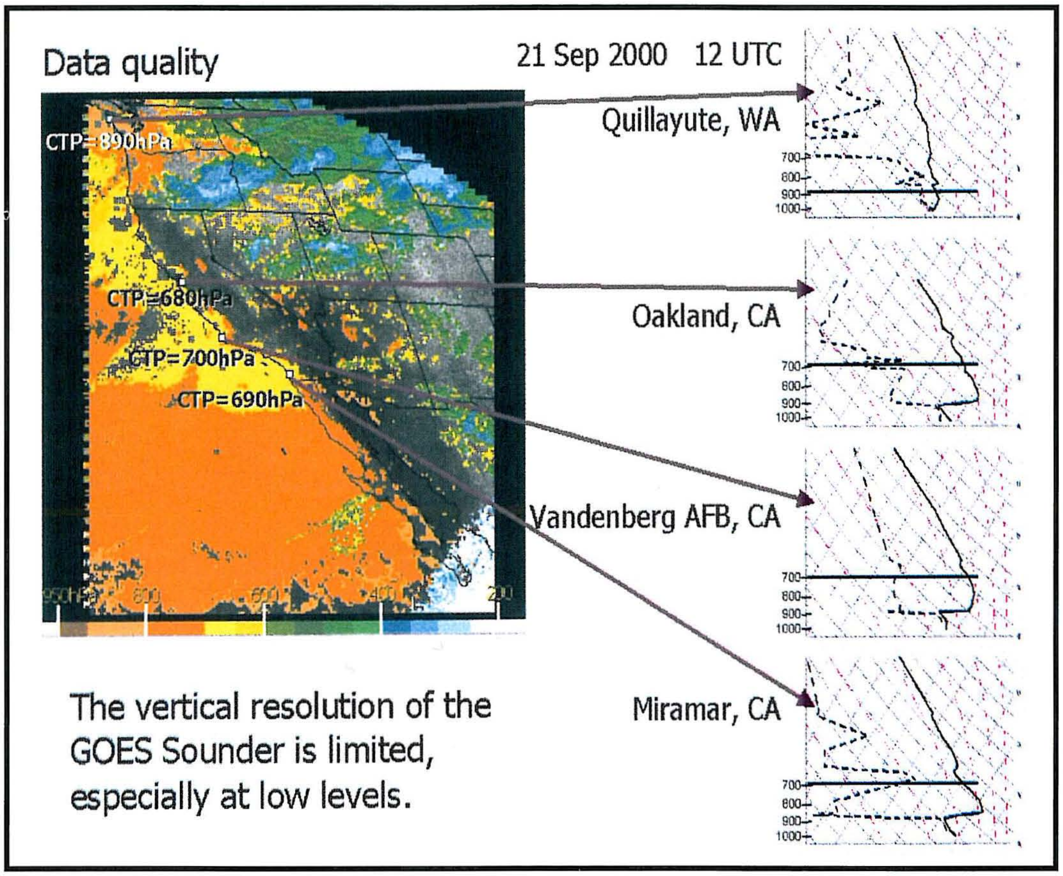

Fig. 2. GOES Sounder derived cloud top pressure for 1300 UTC 21 September 2000 using the Old Method. Also plotted are four rawinsonde profiles for locations along the west coast of the United States valid at 1200 UTC 21 September 2000.

3. Theory

The method used to determine whether a FOV is clear or cloudy is documented in Schreiner et al. (2001). A brief description is outlined below.

The infrared bands (frequencies) used from the GOES Sounder are the four "window" bands [band 6 (12.7 μm), band 7 (12.1 μm), band 8 (11.0 μm), and band 17 (3.98 μm)], a CO_2 absorption band used in detecting high, thin cirrus [band 3 (13.4 μm)], and the visible band. These bands are utilized in a series of checks for: stratus, cirrus (thin and opaque), fog, snow and inversions. After a secondary set of tests is completed, a "flag" array of nine elements corresponding to a 3 x 3 FOV box is passed along for cloud height and amount determination.

Using the GOES Sounder radiances described above, the cloud masking procedure incorporates three major steps. First, a skin temperature over land is determined from an observed surface air temperature and a simple regression model, used to account for the time difference between the surface observation and the satellite scan. Over water, the skin temperature is based on an operational sea surface temperature analysis. The cloud-masking algorithm does not use a forecast profile of temperature and moisture. Second, using this "calculated" skin temperature and a box of pre-determined size (for example 3 x 3 FOV), a series of checks are made to determine whether the entire box is clear or cloudy. Third, if the box is flagged as cloudy, secondary checks at each FOV within the box are made to determine whether individual FOVs are in fact clear or cloudy.

To limit fictitious clouds, a final inversion test is performed following the calculation of the cloud top pressure, effective cloud amount, and cloud temperature. This inversion check is sensitive to temperature inversions that occur during extreme Arctic outbreaks.

An individual FOV is flagged as clear, cloudy, or "not sure." Within this algorithm the clear and cloudy FOVs are treated as such. The "not sure" FOVs have differences in clear and cloudy radiances very close to the instrument noise limitations. In a previous study the "not sure" category was found to primarily correspond to low clouds (CTOP > 900 hPa). Clouds assigned to this low level are not reliable (Schreiner et al. 1993). Therefore, the "not sure" category is also treated as clear for cloud applications. The "not sure" group constitutes about 10% to 15% of all the observations (FOVs).

Once a FOV is determined to be cloudy, a series of tests are performed to resolve the cloud height. This is done via a series of comparisons between the long wave window (11.0 μm) band, a "dirty window" (12.1 μm), and the short wave window (3.98 μm) bands. The latter band is only used during the nighttime due to the variable effects of emissivity and solar reflectivity.

"Dirty window" refers to a specific region of the Electromagnetic Spectrum that is transparent to outgoing long wave radiation. The difference between the "dirty window" and the "long wave window" (other than the definition by wavelength) is that the former is slightly more sensitive to low-level moisture than the latter. An example where the bands differ is for a cloud-free location, which is relatively moist due to radiational cooling. The "dirty window" will appear "cooler" (i.e., lower brightness temperature) than the "long wave window."

Simulations of the characteristics of the short wave window versus the long wave window for water clouds and ice clouds are shown in Fig. 3 (left-hand side). A similar comparison is made between the "dirty window" and the long wave window in the same figure (right-hand side). Note that for optically thick or opaque clouds (optical thickness is 20) with large water droplets (droplet size of 16 µm), the long wave window is warmer (i.e., the difference is negative) than the short wave window. Low-level clouds and fog, which are optically thick, are associated with large water droplet clouds (Baum et al. 2000). The short wave minus long wave difference is never negative for ice clouds. At the same time the difference between the long wave and dirty windows for large water droplet clouds is very close to zero or slightly positive. Since low clouds and fog over the ocean, in particular, are associated with water clouds, this characteristic can be utilized to determine whether the cloud mask is indicating low or high clouds and most likely a low-level inversion.

Unfortunately, this technique will only work during the nighttime because of the sensitivity of the short wave window to reflected solar radiation off of clouds. During the daytime, only the long wave and dirty window difference is used. To further reduce confusion, a land/sea check is made. If the absolute difference between the long wave (TB_{LW}) and dirty window (TB_{DW}) is within 0.2 °K:

$$|TB_{LW} - TB_{DW}| \leq 0.2\ °K \quad (1)$$

and the long wave window band (TB_{LW}) indicates a temperature greater than 273 °K:

$$TB_{LW} \geq 273\ °K \quad (2)$$

and the comparison is over water (ocean), a low, water cloud is assumed. Figure 4 shows an example of the differences between long and short wave windows and long wave and dirty windows over the eastern Pacific for 1300 UTC 29 September 2000. Note the area over the ocean where the long wave window is warmer than the short wave window and how it closely corresponds to cloud depicted by the visible band at 1700 UTC (Fig. 6a).

The "high/low" cloud determination resolves whether a "top/down" (old method) or "bottom/up" (new method) methodology for finding a cloud top pressure via the IR Window Technique is used. The techniques will be described in the following section.

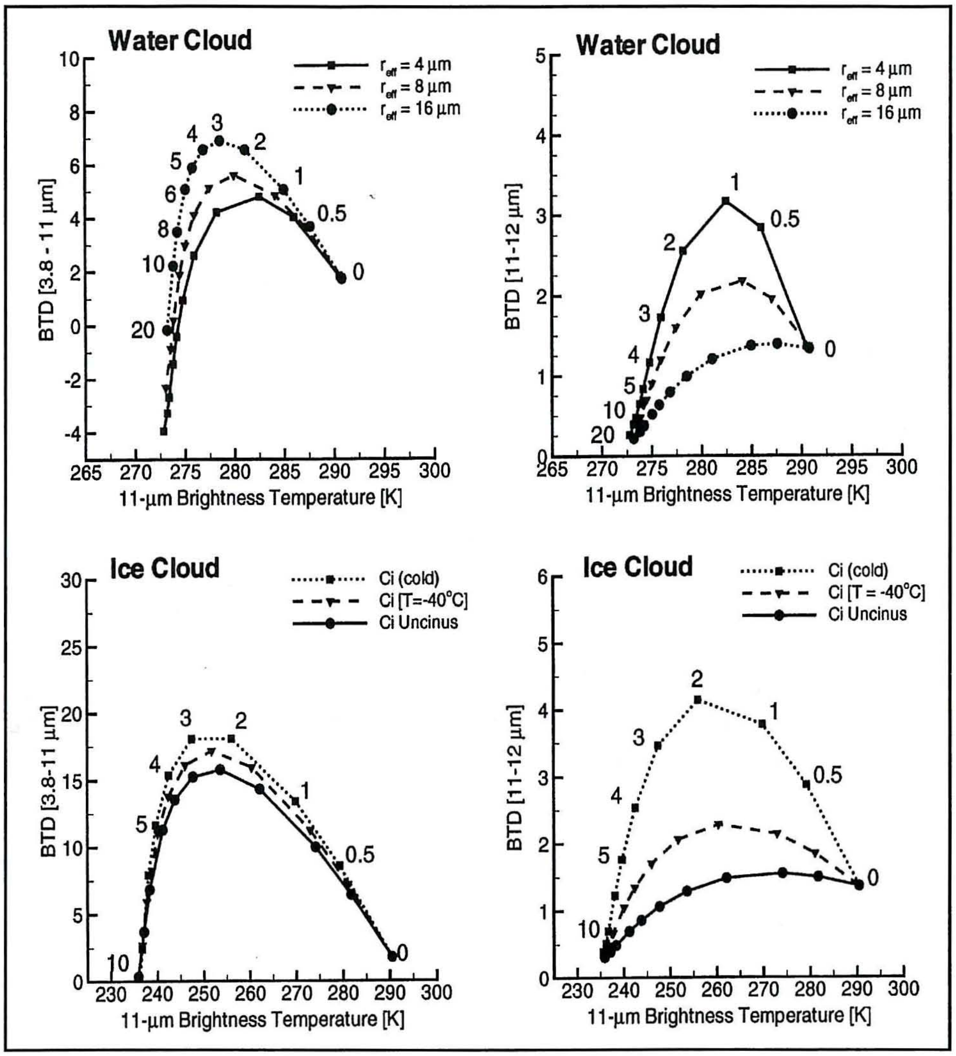

Fig. 3. Characteristics of brightness temperatures for two Infrared bands (11.0 µm and 12.0 µm) and a near-infrared band (3.8 µm) for two cloud phases (Water cloud and Ice cloud) are described. The top two figures (Water cloud) focus on three droplet effective radii of 4, 8, and 16 µm. The bottom two figures concentrate on three ambient ice cloud models. The values along the curves are optical depth, where 0.0 infers clear and 20 is opaque. Values along the abscissa are 11.0 µm brightness temperatures in degrees K. The ordinate is the difference between either the 12.0 µm or the 3.8 µm band and the 11.0 µm band in degrees K.

4. Old vs. New Method

A detailed description for determining cloud top pressure using the Old Method can be found in Schreiner et al. (1993). What follows is a brief outline. The Old Method assumes no inversions in the temperature profile. Starting at the top of the guess temperature profile, the observed long wave brightness temperature is compared to the temperature of the guess profile until a match is found. The level at which the two values agree is defined as the cloud top pressure.

The New Method compares the observed long wave brightness temperature to a guess profile, but makes no assumptions with regards to inversions. The technique begins at the bottom (actually the first level above the surface, which is 950 hPa) of the guess profile and attempts to define a cloud height based on three different approaches:

1. Using a Laplacian the New Method attempts to find the level of maximum change of dewpoint depression.

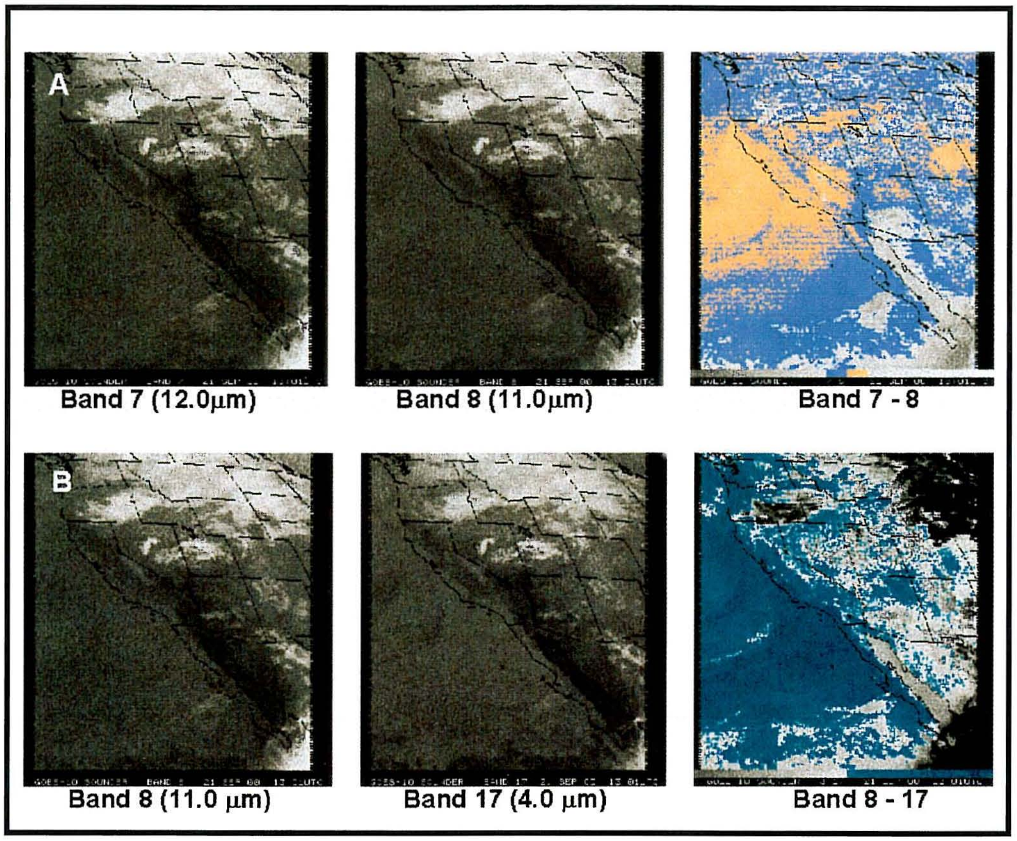

Fig. 4. (a) GOES-10 Sounder depiction of Band 7 (Dirty Window), Band 8 (Long Wave Window), and the difference between Band 7 and Band 8, respectively. The colored region represents a difference of less than 0.2 °K between the two bands. (b) Depiction of Band 8 (Long Wave Window), Band 17 (Short Wave Window), and the difference between Band 8 and Band 17, respectively. The blue region corresponds to Band 8 warmer than Band 17.

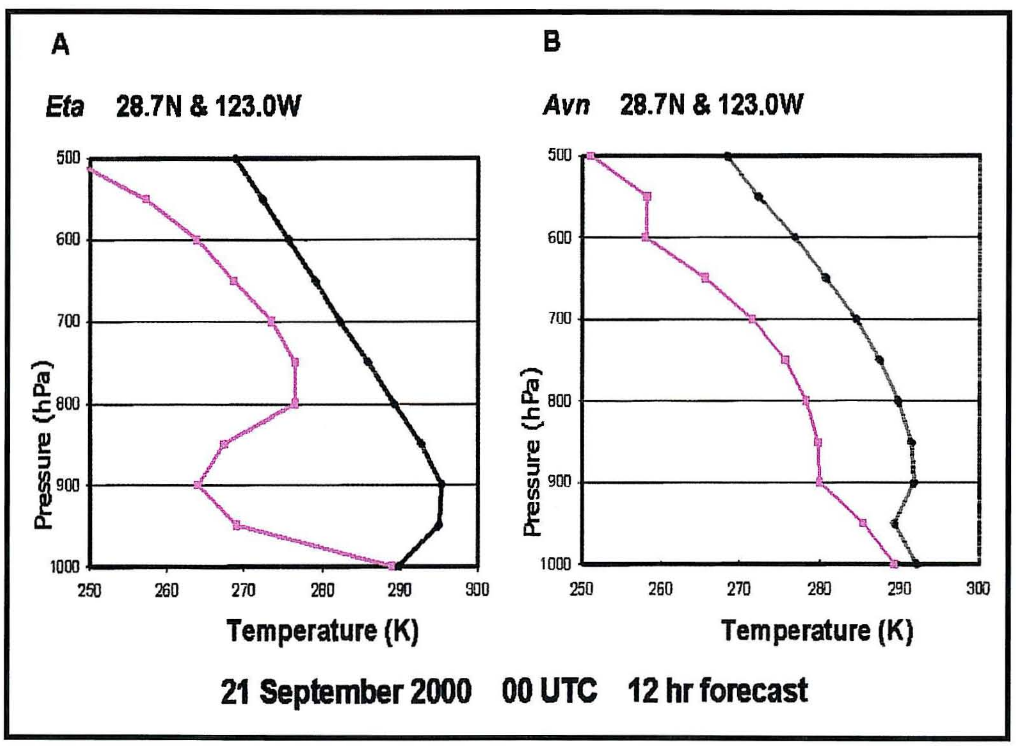

Fig. 5. Comparison of the guess profiles for the (a) Eta model and (b) the AVN model. Both are 12-h forecasts valid at 1200 UTC 21 September 2000.

2. If no well-defined level is identified (i.e., the Laplacian is not less than zero) the New Method attempts to determine the height of the temperature inversion. The level of the lowest (altitude) inversion is used as the level of the cloud top pressure.

3. If this fails the New Method reverts back to finding the first level of agreement between the long wave window observed brightness temperature and the guess profile. The difference is that this technique begins at the bottom of the profile and then works to the top.

In addition to determining either the level of maximum dewpoint change or the height of the temperature inversion, the New Method requires that the observed long wave window brightness temperature must be within some temperature threshold (currently this is set at 4.0 °K) at that particular level.

Currently, forecasts from the new Global Forecast System (GFS) are used as the atmospheric first guess profile rather than the Eta Numerical Forecast Model (Eta). When this study was being accomplished, the Aviation Numerical Forecast Model (AVN) was used. The reason for this can be seen in Fig. 5. At present, with a vertical resolution of 50 hPa, the AVN more correctly delineates the low-level inversion observed in the eastern Pacific. For the 21 September case, using the 0000 UTC 12-hour forecast for both models, a stable low layer is observed. Because the New Method starts at the first level above the surface, in the example shown in Fig. 5, it will define a cloud height of 950 hPa when using the AVN (i.e., approach #1 is satisfied). While using the Eta, a cloud top pressure of approximately

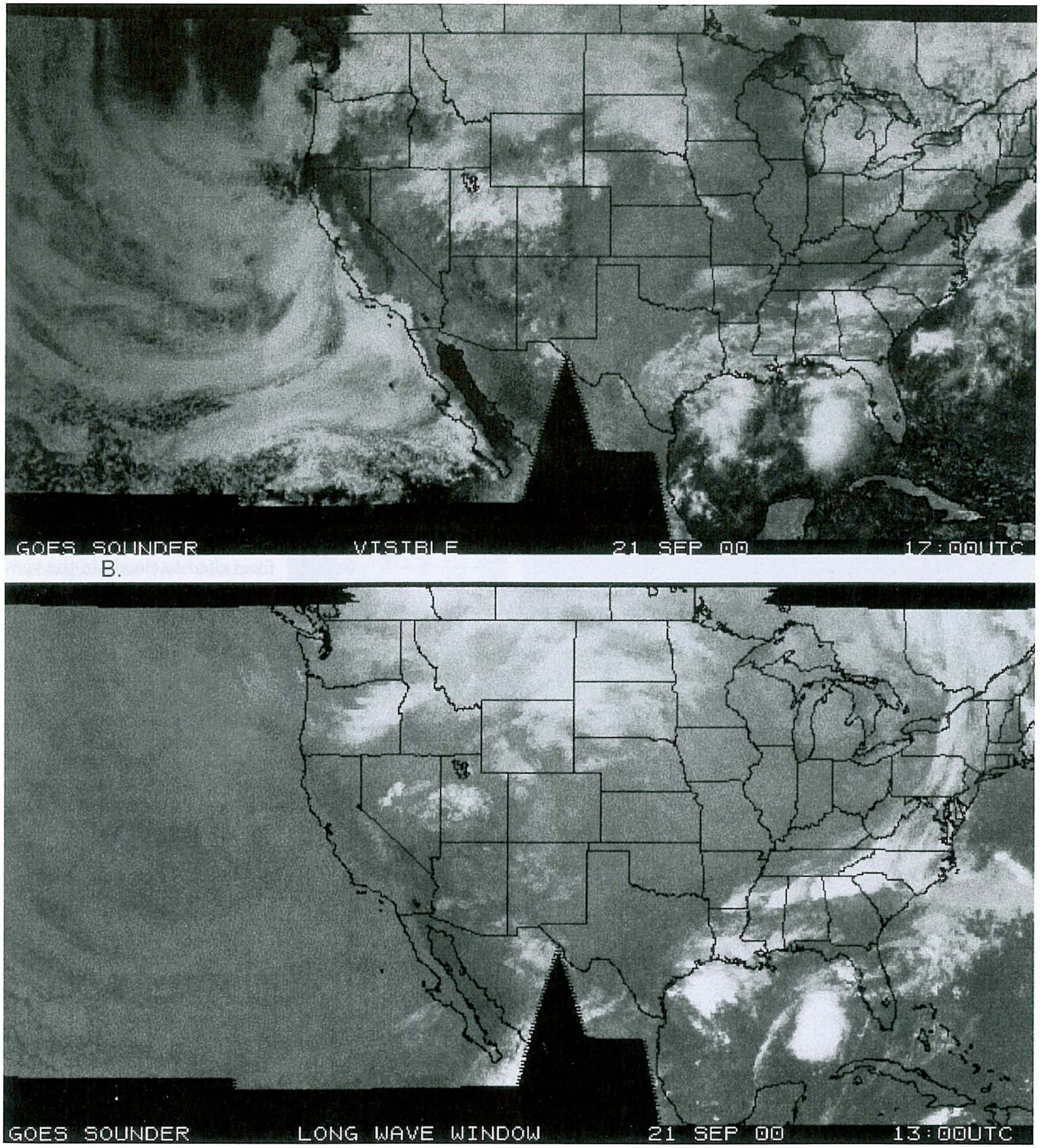

Fig. 6. A depiction of (a) the visible band at 1700 UTC and (b) the "Long Wave Window" at 1300 UTC from four sectors of the GOES Sounder on 21 September 2000.

700 hPa will result (i.e., only approach #3 will be successful). When the processing software for the GOES Sounder Cloud Product is able to use higher vertical resolution guess profiles, the Eta may perform as well as the AVN in these cases. Even using the AVN forecast output as a background, the vertical resolution is still compromised when using the New Method. But when approach #1 or #2 is used the adjusted cloud top pressure shows a substantial improvement over the Old Method.

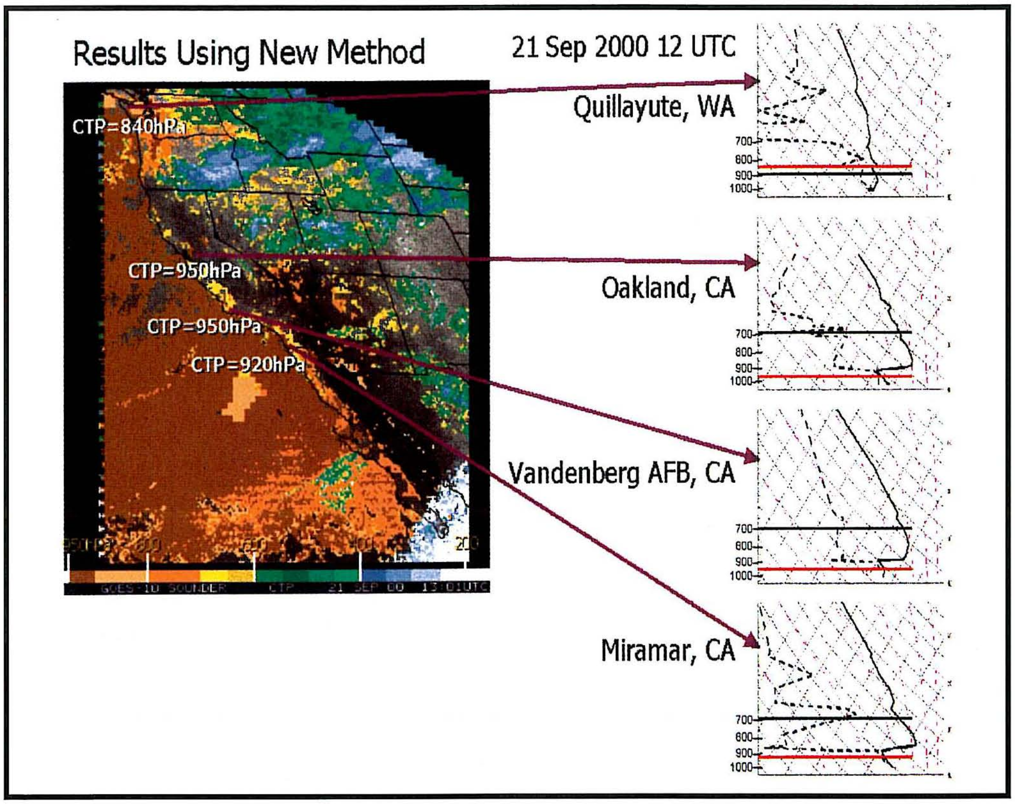

Fig. 7. Same as Fig. 2 except cloud top pressures are based on New Method and are indicated by the red horizontal lines on the rawinsonde profiles.

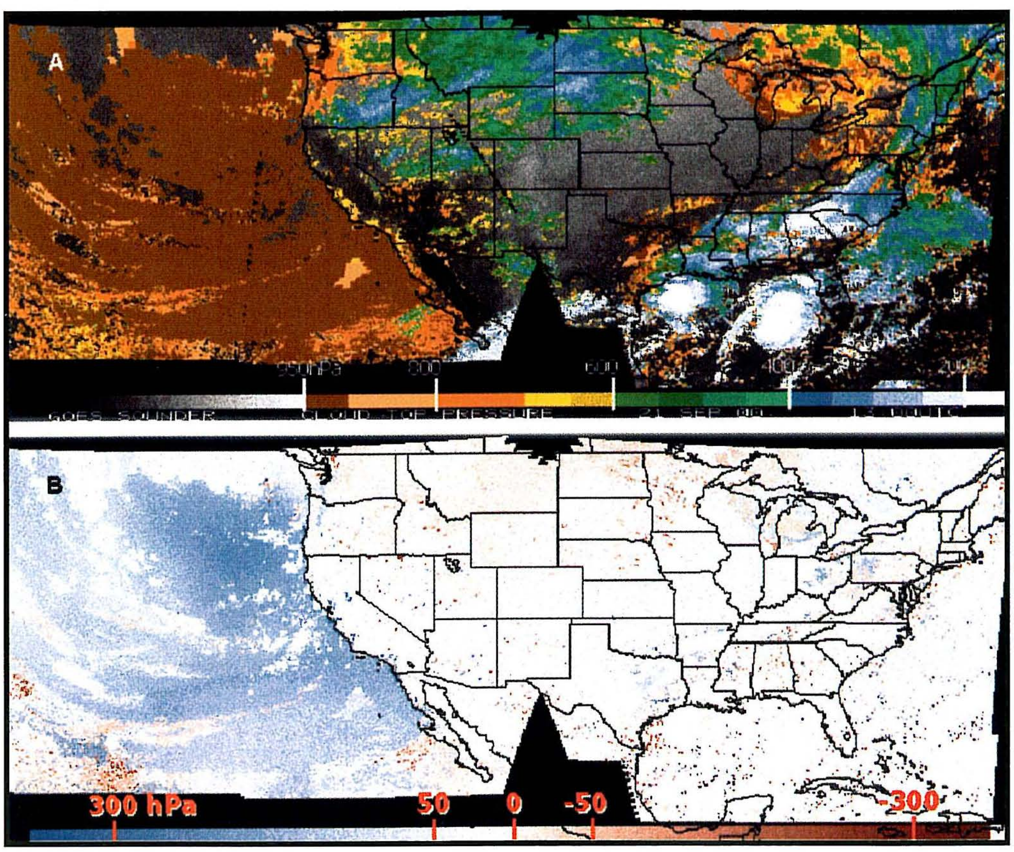

Fig. 8. (a) Four panel depiction of cloud top pressure from the GOES Sounder for 1300 UTC 21 September 2000 using the New Method and (b) a four panel depicting the difference of the New Method minus the Old Method.

5. Case Study

a. Comparison of techniques

An example of the Old Method versus the New Method is shown in this section for the 1300 UTC 21 September 2000 GOES Sounder data. A visible image (Fig. 6a; the 1700 UTC imagery is shown instead of 1300 UTC because the sun is below the horizon at the case study time) and long wave window image (Fig. 6b) from the GOES Sounder are also shown. The visible clearly shows an extensive cloud deck off the West Coast of the United States. Conversely, the long wave window composite image implies that the height of the clouds is quite low as the variation in gray shades (287 °K to 290 °K change) is minimal when going from clear to cloudy in the visible depiction compared to the long wave window image.

The results using the Old Method are shown in Fig. 1a. Tops of the low clouds off the West Coast of the United States are between 799 hPa and 600 hPa, based on the height scale along the bottom of the figure. A closer examination of the remotely derived cloud top pressures and rawinsonde profiles for four coastal sites is shown in Fig. 7. At each location the remotely sensed cloud top pressure is plotted (thick horizontal black line) over the rawinsonde profile. At least for the southern three profiles, the top of the cloud deck is between 850 hPa and 900 hPa, which is the top of the Maritime boundary layer. For Quillayute, Washington, the cloud top is probably somewhere between 850 hPa and 750 hPa. Conversely, the cloud top based GOES brightness temperatures using the Old Method for determining IR Window heights at each of the rawinsonde locations are 690 hPa, 700 hPa, 680 hPa, and 890 hPa going from the southernmost to the northernmost location, respectively. If it is assumed that the cloud top is at the top of the boundary layer (defined as the level where temperature dramatically increases with height and dewpoint dramatically decreases with height), the calculated cloud tops are between 150 hPa and 200 hPa too high.

Using the New Method, the cloud tops were reprocessed for the GOES Sounder. Figure 7 shows cloud heights resulting from the New Method and how they compare to the rawinsonde profiles at 1200 UTC 21 September 2000. Over the waters of the eastern Pacific, a dramatic change in resulting cloud top pressures has taken place. When the remotely sensed results using the New Method are compared to the inferred cloud tops from rawinsonde profiles, a dramatic improvement can be seen. Over the three southernmost rawinsonde locations, the remotely sensed cloud top pressures are within 20 hPa to 60 hPa of the inferred cloud tops based on the temperature and moisture trace at each of the three locations. At Quillayute, Washington, the New Method has determined the cloud top pressure to be slightly higher (altitude) than the Old Method, which may also be more in line with what the rawinsonde profile indicates.

Figure 8a shows the GOES Sounder cloud product over the entire satellite domain using the New Method, and Fig. 8b focuses on the difference of the New Method minus the Old Method over that same domain. By far the greatest impact of using the New Method can be seen off the West Coast of the United States. The New Method substantially decreases (altitude) the height of the cloud top pressures in this region. The difference portion of the figure infers that the change is nearly 300 hPa in some areas of the eastern Pacific, and these changes are only in the area where low clouds are present. The remainder of the GOES processing region is largely unaffected or changed no more than 20 hPa to 40 hPa.

Although remotely sensed cloud top pressures appear to verify better using the New Method along the West Coast of the United States, it is difficult to verify the cloud tops generated off the coast. One way to determine the validity of the new results is to use these data in a numerical forecast model.

b. The impact of the GOES cloud product in numerical forecast products

What follows is a brief discussion on assimilating

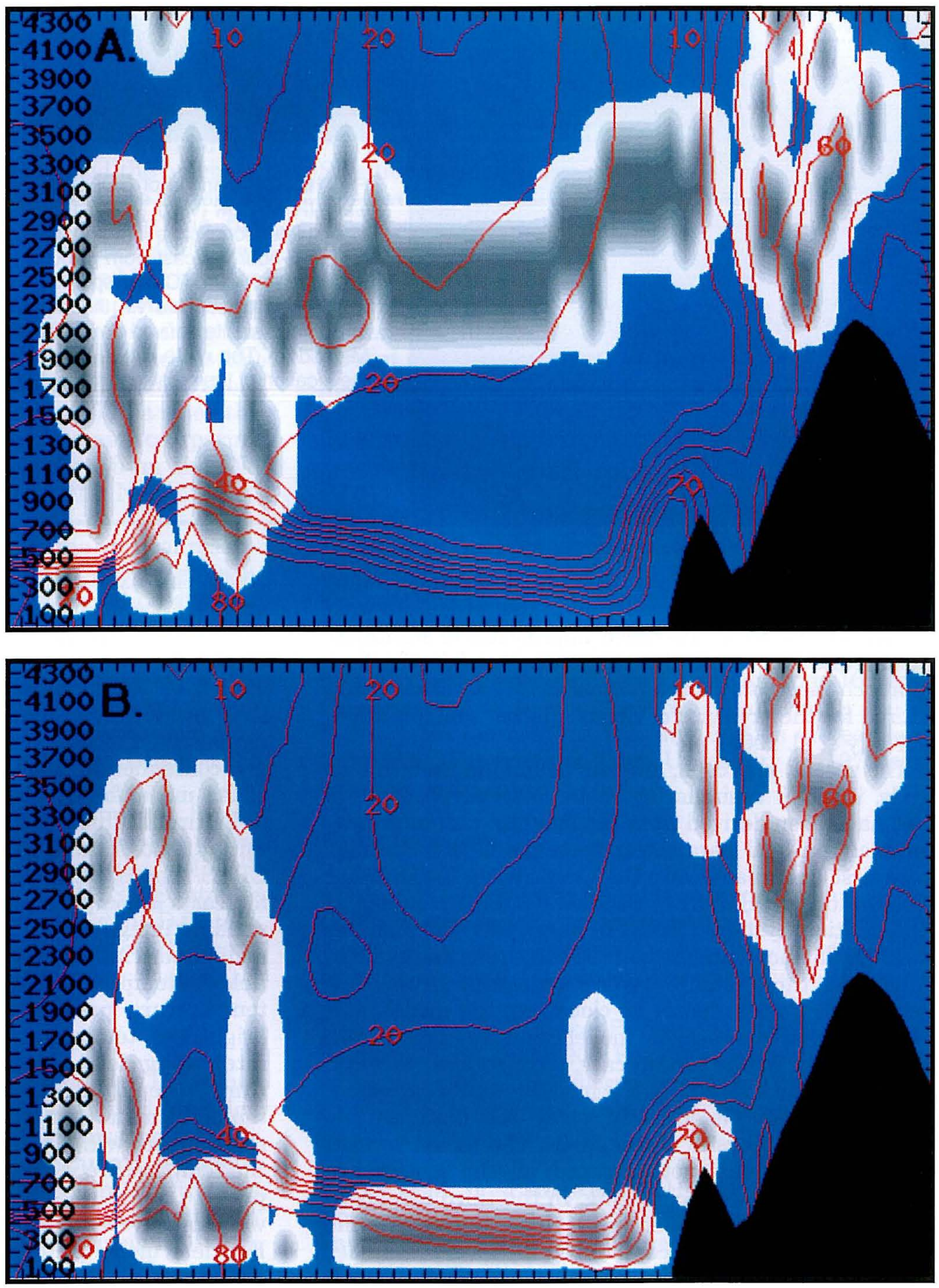

Fig. 9. Cross section of satellite derived clouds using (a) the Old Method and (b) the New Method. Relative humidity (%, red), based on the Eta 1200 UTC model is the background analysis. The vertical coordinate is height in meters. The horizontal cross section extends from 25N, 160W to 35N, 110W. The location of the cross section is shown in Fig. 10a for reference.

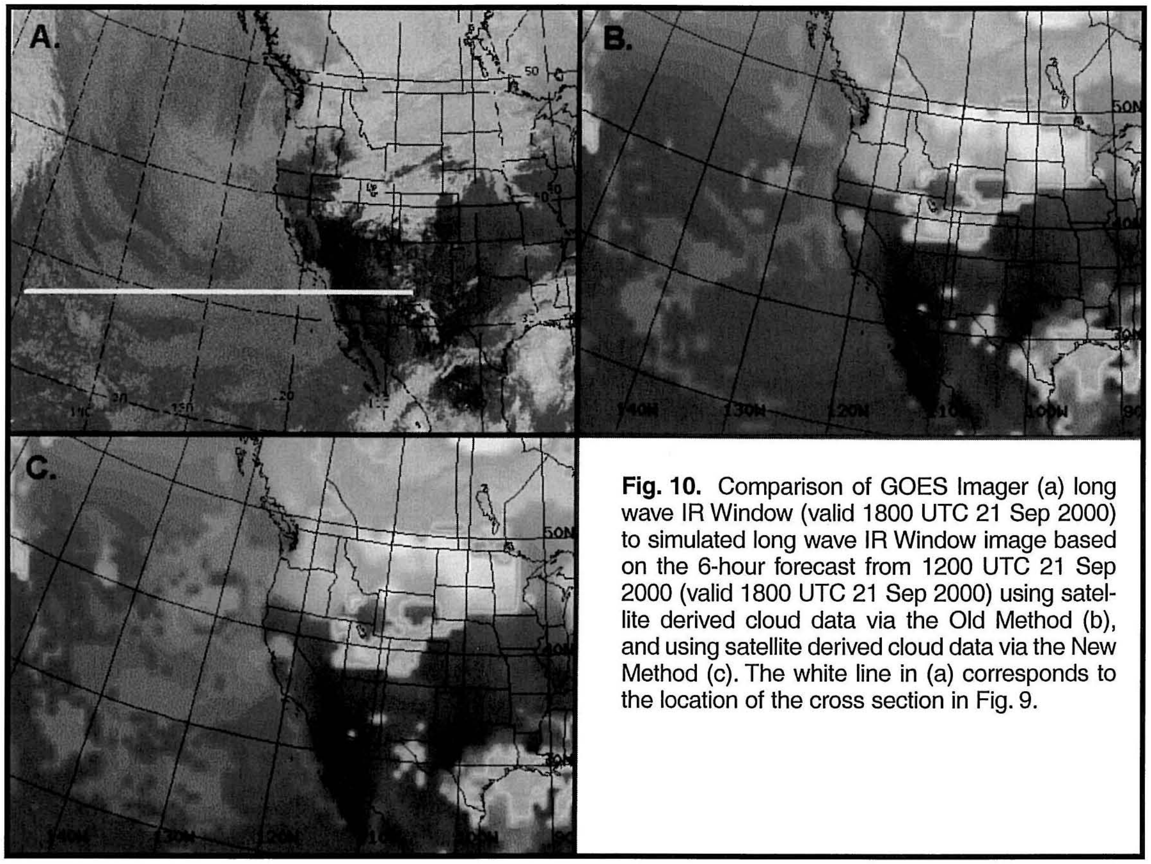

Fig. 10. Comparison of GOES Imager (a) long wave IR Window (valid 1800 UTC 21 Sep 2000) to simulated long wave IR Window image based on the 6-hour forecast from 1200 UTC 21 Sep 2000 (valid 1800 UTC 21 Sep 2000) using satellite derived cloud data via the Old Method (b), and using satellite derived cloud data via the New Method (c). The white line in (a) corresponds to the location of the cross section in Fig. 9.

satellite information into numerical models. More detailed descriptions can be found in the referenced articles within. There are two basic approaches to assimilating satellite information into numerical models. The first approach incorporates the radiances directly after being filtered for the presence of clouds (Derber and Wu 1998; McNally et al. 2000).

The second approach, and the technique used in this study, involves assimilating meteorological parameters that have been derived from the satellite radiance measurements. Cloud parameters from the GOES Sounder were first assimilated into the Cooperative Institute for Meteorological Satellite Studies (CIMSS) Regional Assimilation System (CRAS) in July 1995 (Raymond et al. 1995; Raymond and Aune 1998). In the assimilation of cloud data, three main cases are addressed. In the first case, the Sounder reports no cloud, yet the model indicates cloud. In this case, the model cloud is removed from that grid box. In the second case, the Sounder reports a sufficiently thick cloud, yet the model indicates no cloud. In this case, cloud is added in a way that is compatible with the moist physics of the model. The model vertical motion profiles are not adjusted as the clouds are assumed to be non-precipitating. In the third case, both the model and the Sounder report cloud. In this case the model moisture is modified to reflect the level of Sounder cloud (Aune 1996; Bayler et al. 2000). Synthetic IR images derived from CRAS forecasts with GOES retrieved parameters revealed improvement over those images derived without GOES satellite data, using the actual image as validation (Menzel et al. 1998). This demonstrated the improvement possible when GOES Sounder data in both clear and cloudy regions were assimilated.

For this experiment the CRAS model used the Eta 1200 UTC analysis for its background and boundary condition information. The background cloud field was set to zero. Figure 9 shows a cross section of the relative humidity (%) for the background field (red contours) and the satellite-derived clouds based on the Old Method (Fig. 9a) and the New Method (Fig. 9b) for 1200 UTC 21 September 2000. The axis along the left hand side is height in meters. Location of this cross section is shown in Fig. 10a. The major difference between the cross sections is the large area of 700 m (~ 950 hPa) clouds in Fig. 9b versus 3500 m (~ 700 hPa) clouds in Fig. 9a. It can also be seen that the lower assigned clouds (Fig. 9b) more closely agree with the background relative humidity field and are consequently more likely to be retained once the CRAS model forecast begins.

Figure 10 illustrates the effect the two different cloud initializations have on a 6-hour model forecast of the CRAS. The simulated window channel from the two forecasts is compared to an 1800 UTC GOES long wave window image on 21 September 2000 (Fig. 10a). The simulated window channel images are computed using fields of temperature, cloud-water mixing ratio and skin temperature predicted by the CRAS model. Cloudy brightness temperatures are estimated by vertically integrating cloud mass from the top of the model downward. When a threshold of .1 mm is reached, the model temperature at that level is used (based on personal correspondence with Dr. Steven A. Ackerman). In addition, the temperature is adjusted when thin cloud layers are present above the threshold level by using a mass weighted average of the temperatures at those levels. For clear model columns, the predicted viscous layer (1 cm) temperature is used. The resulting field of simulated window channel brightness temperatures tends to be warm biased because the radiative effects of water vapor are unaccounted for. Therefore, a bias correction is applied.

Figure 10b (Old Method) and 10c (New Method) depict a simulated long wave window image based on the two forecasts. Figure 10a shows that, in fact, low-level clouds extensively cover the eastern Pacific (as denoted by the extensive gray shading in that region of the image), and the forecast using cloud top information based on using the New Method (Fig. 10c) more closely resembles the actual satellite image for this time period.

6. Summary

Cloud top heights using the Old Method generate information, which incorrectly assigns cloud tops too high (altitude) over the eastern Pacific. Based on comparisons to rawinsonde profiles along the West Coast of the United States, the error is between 150 hPa and 200 hPa. A New Method employs logic to find the height of the cloud from a guess profile going from the bottom of the profile to the top of the profile rather than the top/down, which is used in the Old Method. This new technique produces cloud information, which is more meteorologically reasonable, although not perfect. When results were compared to four rawinsondes along the West Coast, cloud tops were found to be as much as 150 hPa to 200 hPa too high using the Old Method. These same errors were reduced to 10 hPa to 60 hPa when the New Method was used. Numerical forecasts comparing the results based on cloud information from the Old Method and the New Method show the New Method provides superior forecasts.

An alternative way to improve on the vertical resolution of the current product is the utilization of high spectral resolution sounder data, such as from the Advanced Baseline Sounder. With instruments of this type it may be possible to increase not only the vertical resolution, but also the horizontal resolution plus discerning multiple levels of clouds (Dittberner 2001). Unfortunately sensors of this type are not expected to be operational on a geostationary platform until the end of this decade at the earliest.

The New Method technique is being employed for the cloud product being routinely generated at the University of Wisconsin – Madison CIMSS. Implementation of the technique at the NESDIS satellite products operational facility in Washington, D.C. took place in May 2001. Access to this product can be made through the UW-CIMSS Web site (cimss.ssec.wisc.edu).

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