P2.5 A STUDY OF DATA AND PRODUCTS FROM THE GOES-9 IMAGER AND SOUNDER OVER THE WESTERN PACIFIC OCEAN

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1. INTRODUCTION

Since late May 2003, the GOES-9 satellite has been operating over the western Pacific Ocean, centered over the equator at 155 degrees east longitude. Each hour, radiances from both the Imager and Sounder instruments are received and utilized to produce meteorologically-useful products. From the Imager (visible band plus four infrared bands ranging from 3.9μm to 12.0 μm), experimental Clear Sky Brightness Temperature (CSBT) data and corresponding imagery are generated. The GOES-9 Imager CSBT data are being offered to numerical modelers at the National Centers for Environmental Prediction (NCEP), and as of 7 Oct 2003 the CSBT data derived from the GOES-9 water vapor channel (6.75μm) are being assimilated operationally at the European Centre for Medium Range Weather Forecasts (ECMWF). From the Sounder (visible band plus 18 infrared bands ranging from 3.7μm to 14.7μm), several different experimental products are/can be produced: retrieved atmospheric temperature and moisture profiles and retrieved cloud parameters, various derived product images from both the retrieved profile and cloud information, as well as derived ozone imagery. In terms of sounding the atmosphere from geostationary orbit, GOES-9 provides a unique opportunity never before available over this portion of the globe.

This paper will present examples of the derived data available from the GOES-9 Imager and Sounder instruments. In addition, the quality of some of the data and products will be evaluated. For example, for the retrieved temperature and moisture profiles, gridpoint values and gradients of both guess and retrieved parameters will be compared with the same from verifying analyses. Other verifications will focus on collocated GOES-9 retrievals and radiosondes, and comparisons of GOES-9 retrievals and cloud information with in-situ data provided by the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) instrument site on Nauru Island, located in the tropical western Pacific Ocean.

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2. GOES-9 IMAGER DATA AND PRODUCTS

Radiance data from the Imager and Sounder instruments aboard the GOES-I/M series of spacecraft have been available since mid-1994 (Menzel and Purdom 1994). From the Imager data, a relatively new product has been developed—the Clear Sky Brightness Temperature (CSBT) product (Schreiner et al. 2003). This product consists of two components: a data file that contains brightness temperatures and other information for all available 11 X 17 Field of View (FOV) Imager "boxes", and single FOV images (otherwise known as cloud masks) created for selected Imager bands. Both components involve screening for clouds. Figure 1 shows a global montage of the coverage possible with the CSBT product by using GOES-9, -10 and –12. Fig. 2a shows a 10.7μm GOES-9 full disk image from 1525 UTC on 24 October 2003, while fig. 2b shows the corresponding 6.75μm CSBT single FOV image (cloud mask) from the same time. Note Typhoon Parma at approximately 31N, 160E. This same storm will be noted further in the discussions below. Full disk GOES-9 CSBT data are available hourly. As mentioned previously, the GOES-9 CSBT data, along with GOES-10 and –12, are being assimilated operationally at the ECMWF (Szyndel et al. 2003). The data are available from CIMSS in Binary Universal Form for the Representation of meteorological data (BUFR) format (WMO 1988) via anonymous ftp at:

ftp.ssec.wisc.edu:/pub/vern/csbt/gicsbt.ccyyddd.hhmm.goes09NB

Other data formats are also available.

3. GOES-9 SOUNDER DATA AND PRODUCTS

3.1 Retrievals of atmospheric temperature and moisture

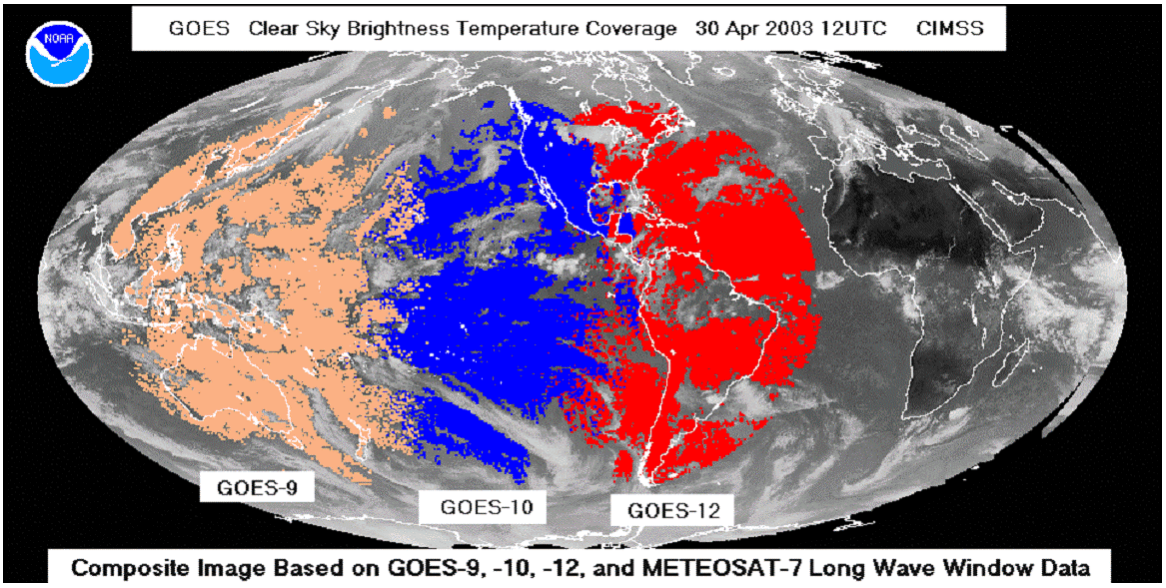


Fig. 1 Global montage of GOES-9, -10 and -12 Imager Clear Sky Brightness Temperature (CSBT), supplemented with METEOSAT-7 longwave window imagery, from 30 April 2003.

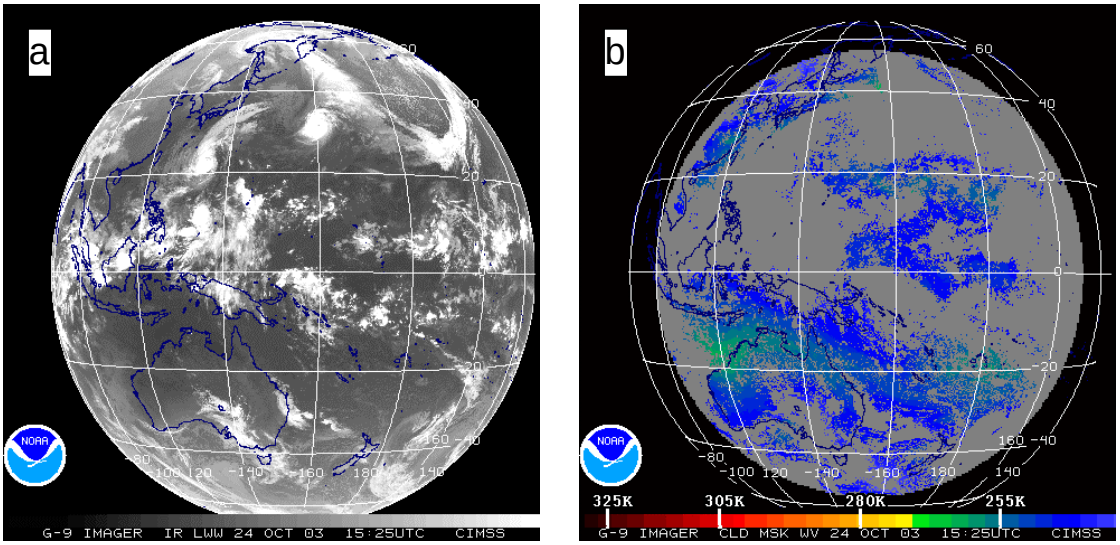


Fig. 2. (a) GOES-9 Imager 10.7µm infrared image from 1525 UTC 24 October 2003; (b) GOES-9 Imager 6.75µm CSBT cloud mask image from 1525 UTC 24 October 2003.

For the last several years, GOES retrievals of atmospheric temperature and moisture at CIMSS have been produced using a nonlinear physical retrieval algorithm (Ma et al. 1999). Briefly, this algorithm uses GOES Sounder cloud-free radiances in a number of spectral bands that have been averaged over 1-N Fields of View (FOV) to adjust initial guess vertical profiles of temperature and moisture. The averaging is done within a 3 X 3 matrix of FOVs (N≤9). Since the nominal horizontal resolution of a GOES Sounder FOV is approximately 10km at the sub-satellite point (Menzel and Purdom 1994), the nominal dimensions of the CIMSS retrievals are approximately 30 X 30 km.

After a brief example showing the utility of GOES-9 Total Precipitable Water (TPW) Derived Product Imagery (DPI), objective evaluations of the GOES-9 retrievals will then be conducted using three different approaches. First, analyses and gradients of guess and retrieved parameters will be compared with verifying model analyses. These results will then be compared to the same for GOES-12 and –10 over the continental United States. Second, guess and retrieved parameters

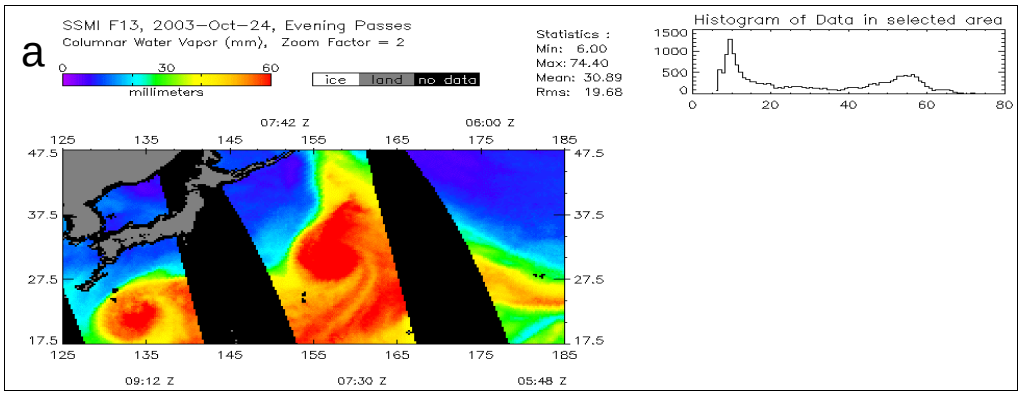
such as precipitable water and temperature will be compared with the same from verifying, collocated radiosonde data. Finally, the same types of retrieved and guess parameters will also be compared indirectly with radiometer measurements from in-situ data provided by the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) instrument site on Nauru Island, located near the GOES-9 subpoint at 0.52S, 166.91E.

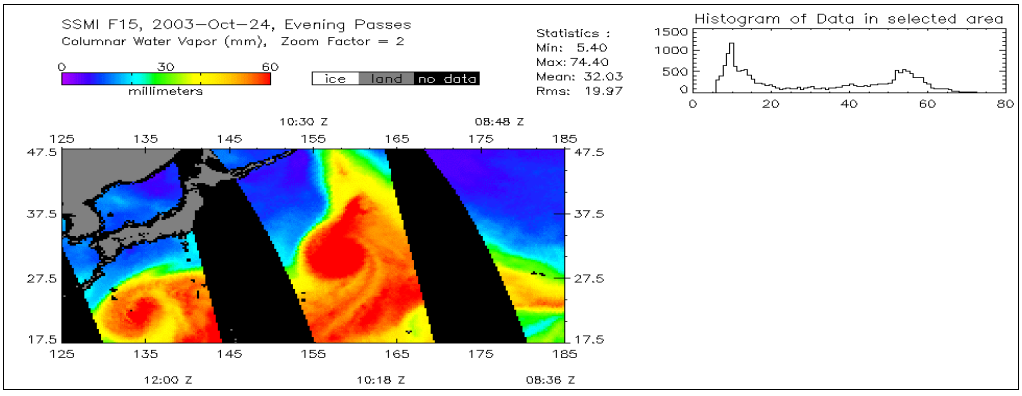
3.1.1. Typhoon Parma as seen by GOES-9 and SSM/I

Late in October 2003 a strong typhoon, named Parma, developed in the western Pacific Ocean. During the course of Parma's journey through the Pacific, her progress was closely monitored by personnel at the Joint Typhoon Warning Center (JTWC) in Pearl Harbor, Hawaii. The following text was included as part of a bulletin issued at 1500 UTC on 24 October 2003:

REMARKS: 241500Z2 POSITION NEAR 31.1N5 160.0E7. TYPHOON (TY) 21W (PARMA), LOCATED APPROXIMATELY 1265 NM WEST-NORTHWEST OF MIDWAY, HAS TRACKED EAST-NORTHEASTWARD AT 22 KNOTS OVER THE PAST 06 HOURS. THE WARNING POSITION IS BASED ON 241130Z1 INFRARED SATELLITE IMAGERY. THE WARNING INTENSITY IS BASED ON SATELLITE CURRENT INTENSITY ESTIMATES OF 127 AND 140 KNOTS. A 241023Z2 SSMI SATELLITE IMAGERY SHOWS DRY AIR IS STARTING TO BE ENTRAINED INTO THE WESTERN SIDE OF THE SYSTEM.

Figs. 3a-b show Special Sensor Microwave/Imager (SSM/I) images sensing Parma on 24 October 2003 at approximately 0736 UTC (from F13) and 1023 UTC (from F15), respectively. Fig. 3b is the image referenced above in the JTWC bulletin. Note the subtle influx of dryer air in Fig. 3b, compared to Fig. 3a, at approximately 32.5N, 153E. Figs. 3c-d show GOES-9 retrieved TPW DPI imagery on the same date, from 0826 UTC and 1026 UTC, respectively. The same dry air influx is not as apparent in the two GOES-9 DPI images, perhaps due to the lack of GOES-9 retrievals in the vicinity of the extensive typhoon cloud shield. Perhaps a more obvious drying signal would be seen if single FOV GOES-9 retrievals were computed, since the higher resolution (nominally 10x10 km versus 30x30 km for the 3x3 FOV retrievals) should allow more retrievals nearer to the typhoon, particularly near 32.5N, 153E. This will be attempted prior to the conference. Other situations will undoubtedly arise in the future where the superior timeliness of the GOES-9 Sounder data, compared to polar-orbiter data, will provide benefits when monitoring Pacific typhoon activity. Of course, the extensive cloud cover associated with typhoons means microwave measurements should be used, when available.





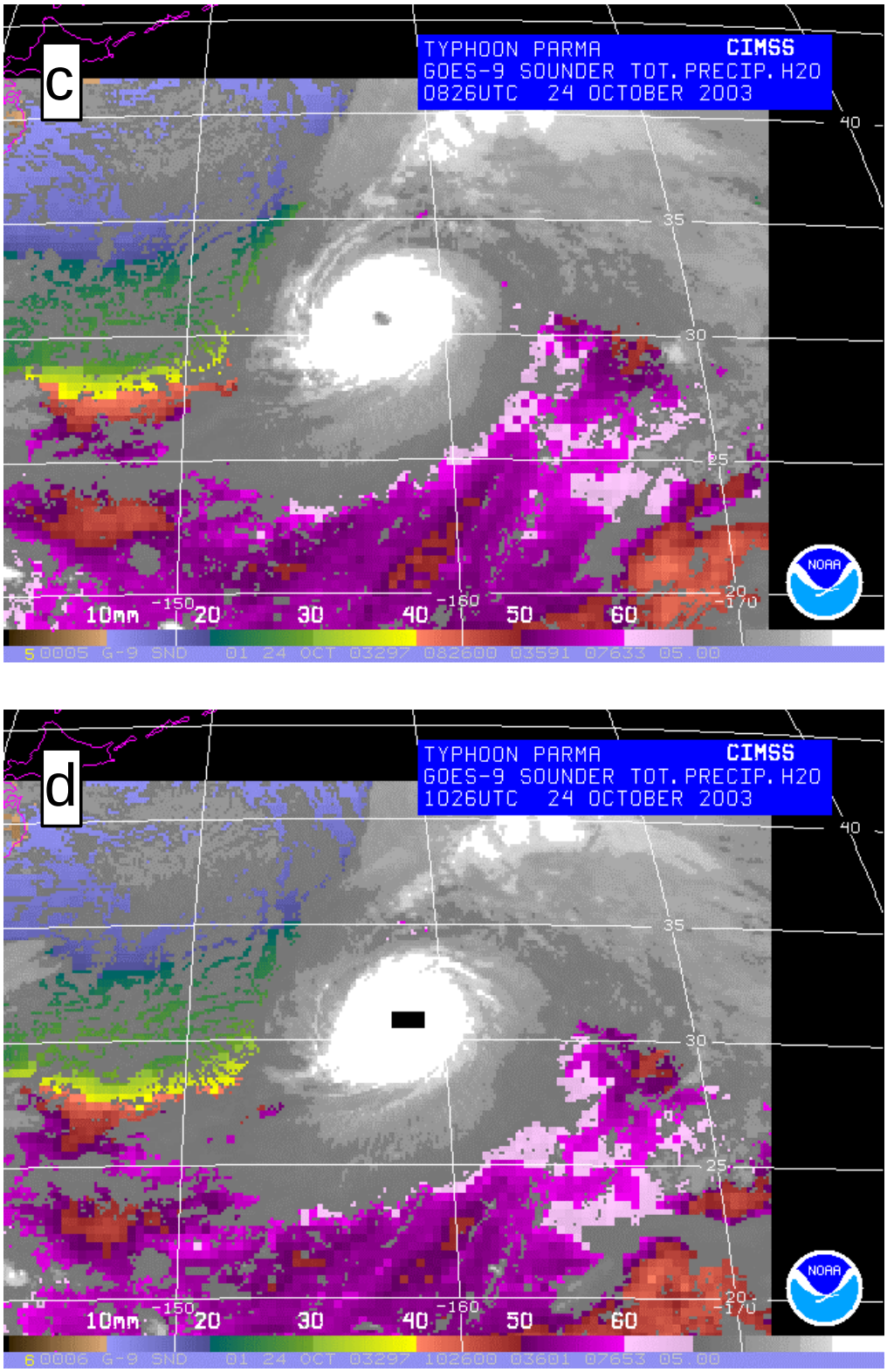


Fig. 3 (a) F13 SSM/I columnar water vapor in vicinity of Typhoon Parma approximately 0736 UTC 24 October 2003; (b) F15 SSM/I columnar water vapor near Parma approximately 1023 UTC, same date; (c) GOES-9 Sounder retrieved TPW DPI over Parma approximately 0826 UTC, same date; (d) GOES-9 Sounder retrieved TPW DPI over Parma approximately 1026 UTC, same date.

3.1.2. Comparison of guess and retrieved parameter gradients with numerical model analyses

To provide areal (as opposed to single site) verification of GOES-9 Sounder retrieved quantities, objective analyses of retrieval, guess and verifying model data are utilized. Zehr et al. (1988) noted that satellite retrievals [to that point in time] had shown more skill in detecting gradients of quantities, rather than absolute values. Hayden (1988) also examined satellite retrievals in terms of gradients. In this work, both gridpoint and gradient comparisons of GOES-9 guess and retrieval quantities with verifying model analyses are conducted.

The objective analysis technique used is based on the Barnes analysis technique (Hibbard and Wylie 1985; Barnes 1964). To force the guess and retrieved analyses to most closely reflect the input data, extrapolation into data-void regions within the grids is not allowed, and the retrieval and guess data are only allowed to influence the minimum possible number of gridpoints, given the latitudinal/longitudinal resolutions of the grids. The emphasis is on achieving the most accurate analyses possible, at the expense of a potentially noisy contoured display.

Unfortunately, at the time of writing, the objective evaluations are in progress. Display of the results must be deferred until the conference.

3.1.3. Comparison of guess and retrieved parameters with collocated radiosondes

Table 1 shows retrieval versus radiosonde bulk statistics for the CIMSS GOES-9 retrievals and their associated first guesses for the period 7 September 2003 – 4 November 2003. The GOES-9 Sounder scanning strategy consists of three regions located over the western Pacific Ocean (NOAA 2003). Furthermore, the region scanned at 00 UTC and 12 UTC is the most northerly of the three Sounder regions, and the only major landmass included is Japan, supplemented with a few islands. Consequently, the number of retrieval/radiosonde matchups is considerably fewer than typical CONtinental US (CONUS) GOES-12 or –10 retrieval/radiosonde matchup exercises. The collocation dataset has been constructed by requiring that each retrieval be collocated within 50km of a nearby radiosonde. The number of collocation matches (N) is 85. In fact, it was found that all of the matches lie near Guam. We will be investigating the lack of Japanese retrieval/radiosonde matchups prior to the conference.

Table 1. GOES-9 retrieval versus radiosonde bulk statistics. The period over which the statistics are computed is 07 September 2003 -> 04 November 2003. Maximum collocation distance is 50 kilometers. Minimum clear FOVs is 4. WV1 is a layer from approximately 1000-900hPa; WV2 extends from approximately 900-700hPa; WV3 extends from approximately 700-300hPa.

Collocated Retrieval/RAOB Data	BIAS	SD	Average Guess or Retrieval Value	Average RAOB Value	CC	N
TPW (Guess) vs TPW (RAOB) (mm)	-1.79	3.46	53.42	55.21	0.685	85
TPW (Retrieval) vs TPW (RAOB)	1.68	2.78	56.89	55.21	0.825	85
WV1 (Guess) vs WV1 (RAOB)	-2.25	1.17	16.79	19.04	0.193	85
WV1 (Retrieval) vs WV1 (RAOB)	-0.40	0.91	18.64	19.04	0.519	85
WV2 (Guess) vs WV2 (RAOB)	-0.68	2.16	23.09	23.76	0.349	85
WV2 (Retrieval) vs WV2 (RAOB)	1.23	1.99	24.99	23.76	0.519	85
WV3 (Guess) vs WV3 (RAOB)	1.04	2.03	13.28	12.24	0.763	85
WV3 (Retrieval) vs WV3 (RAOB)	0.80	1.67	13.04	12.24	0.863	85
850T (Guess) vs 850T (RAOB) (K)	-0.42	0.35	291.62	292.04	0.784	85
850T (Retrieval) vs 850T (RAOB)	-0.58	0.39	291.46	292.04	0.737	85
850TD (Guess) vs 850TD (RAOB)	-0.76	1.55	288.23	288.99	0.064	85
850TD (Retrieval) vs 850TD (RAOB)	0.31	1.38	289.30	288.99	0.344	85
700T (Guess) vs 700T (RAOB)	-0.91	1.24	282.94	283.85	-0.295	85
700T (Retrieval) vs 700T (RAOB)	-1.18	1.22	282.67	283.85	-0.208	85
700TD (Guess) vs 700TD (RAOB)	2.07	3.52	278.06	275.99	0.216	85
700TD (Retrieval) vs 700TD (RAOB)	3.58	3.47	279.57	275.99	0.274	85
500T (Guess) vs 500T (RAOB)	0.51	0.88	268.75	268.25	0.013	85
500T (Retrieval) vs 500T (RAOB)	0.22	0.88	268.46	268.25	-0.049	85
500TD (Guess) vs 500TD (RAOB)	1.44	4.20	259.07	257.62	0.629	85
500TD (Retrieval) vs 500TD (RAOB)	-0.70	4.09	256.93	257.62	0.664	85

Looking first at the moisture collocation data, note that the standard deviations with collocated radiosondes decrease from the guess to the retrievals for TPW, WV1, WV2 and WV3. In addition, the correlation coefficient is higher for the retrieval/radiosonde data than the guess/radiosonde data for all four parameters. In terms of biases, a dry bias of –1.79mm in the guess TPW is over-moistened to 1.68mm. For the three component layers analyzed, a dry bias of –2.25mm in the guess WV1 is corrected to –0.40mm, and a moist bias of 1.04mm in the guess WV3 is dried to 0.80mm. However, the same over-compensation can be seen again for WV2, where a guess bias of –0.68mm is moistened to 1.23mm

Looking next at the temperature and dewpoint collocation statistics at 850hPa, 700hPa and 500hPa, the standard deviations decrease slightly in most cases between the guess and retrieval. The only increase is for the 850hPa temperature collocations, which increase from 0.35K for the guess to 0.39K for the retrievals. Moistening of the 850hPa dewpoints (a bias increase from –0.76K to 0.31K), and drying of the 500hPa dewpoints (a bias decrease from 1.44K to –0.70K) probably reflects similar tendencies seen above for WV2 and WV3, respectively. Furthermore, note how the 850hPa guess and retrieved temperature biases only change by –0.16K (-0.42K to –0.58K), whereas the 850hPa guess and retrieved dewpoint biases change by 1.07K (from –0.76K to 0.31K). The same tendency to change the guess dewpoint more than the guess temperature can also be seen at both 700hPa and 500hPa. Ma et al. (1999) showed that the nonlinear retrieval algorithm makes a larger adjustment to the guess moisture profile than the guess temperature profile. These bulk statistics will be updated immediately prior to the conference to reflect the latest results.

3.1.4. Comparison of guess and retrieved parameters with in-situ radiometer data

Site-specific moisture comparisons are also made between collocated GOES-9 retrievals and radiometer data acquired at the Nauru Island U. S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) site (DOE 2003). This is also work in progress, and presentation will be deferred until the conference.

3.2 Retrievals of cloud parameters

Retrievals of cloud parameters such as cloudtop pressure and effective cloud amount have been produced routinely from the GOES-I/M series of Sounder instruments for several years (Menzel et al. 1998). The same type of information is also available from GOES-9 over the western Pacific Ocean. Figs. 4a-b show the cloudtop pressure and effective cloud amount DPI determined from the GOES-9 Sounder at approximately 1426 UTC on 24 Oct 2003. Note the very high cloudtops over Typhoon Parma, and the lower effective cloud amount in the eye of Parma. To objectively verify the quality of the GOES-9 cloud information, comparisons with data from the DOE Nauru Island ARM site are slated for presentation at the conference.

3.3 Estimates of total atmospheric ozone

Estimates of GOES-9 total column ozone (Li et al. 2001) from 2003 are not ready for release at this time, but sample imagery will be produced for presentation at the AMS conference.

4. SUMMARY

Since late May 2003, GOES-9 has been in operational use over the western Pacific ocean at 155 degrees east longitude. This paper presents a number of examples of products currently being produced experimentally from GOES-9 Imager and Sounder data. From the GOES-9 Imager, full disk CSBT data are produced hourly. This information is currently being made available to personnel at NCEP, and since 7 October 2003 the 6.75μm CSBT data has been assimilated on an hourly basis at the ECMWF in the United Kingdom.

From the GOES-9 Sounder, several different experimental products are/can be produced: retrieved atmospheric temperature and moisture profiles and retrieved cloud parameters, various derived product imagery from both the retrieved profile and cloud information, as well as derived ozone imagery. Like the Imager, all Sounder products are available on an hourly basis.

The potential utility of derived TPW imagery from the GOES-9 Sounder retrievals is examined, in the context of Typhoon Parma on 24 October 2003. At the conference, we will be presenting objective gridpoint and gradient evaluations of several parameters related to retrieved atmospheric temperature and moisture profile data. We have also examined GOES-9 Sounder retrieval quality objectively by comparison with collocated radiosondes, and we will be presenting other indirect comparisons with in-situ data over Nauru Island at the conference.

We also show two different types of derived Sounder cloud imagery in this paper, and will present objective verification of at least some of these data at the AMS conference by again using in-situ data over Nauru Island. Finally, a presentation of GOES-9 derived total atmospheric ozone imagery is also planned for the conference.

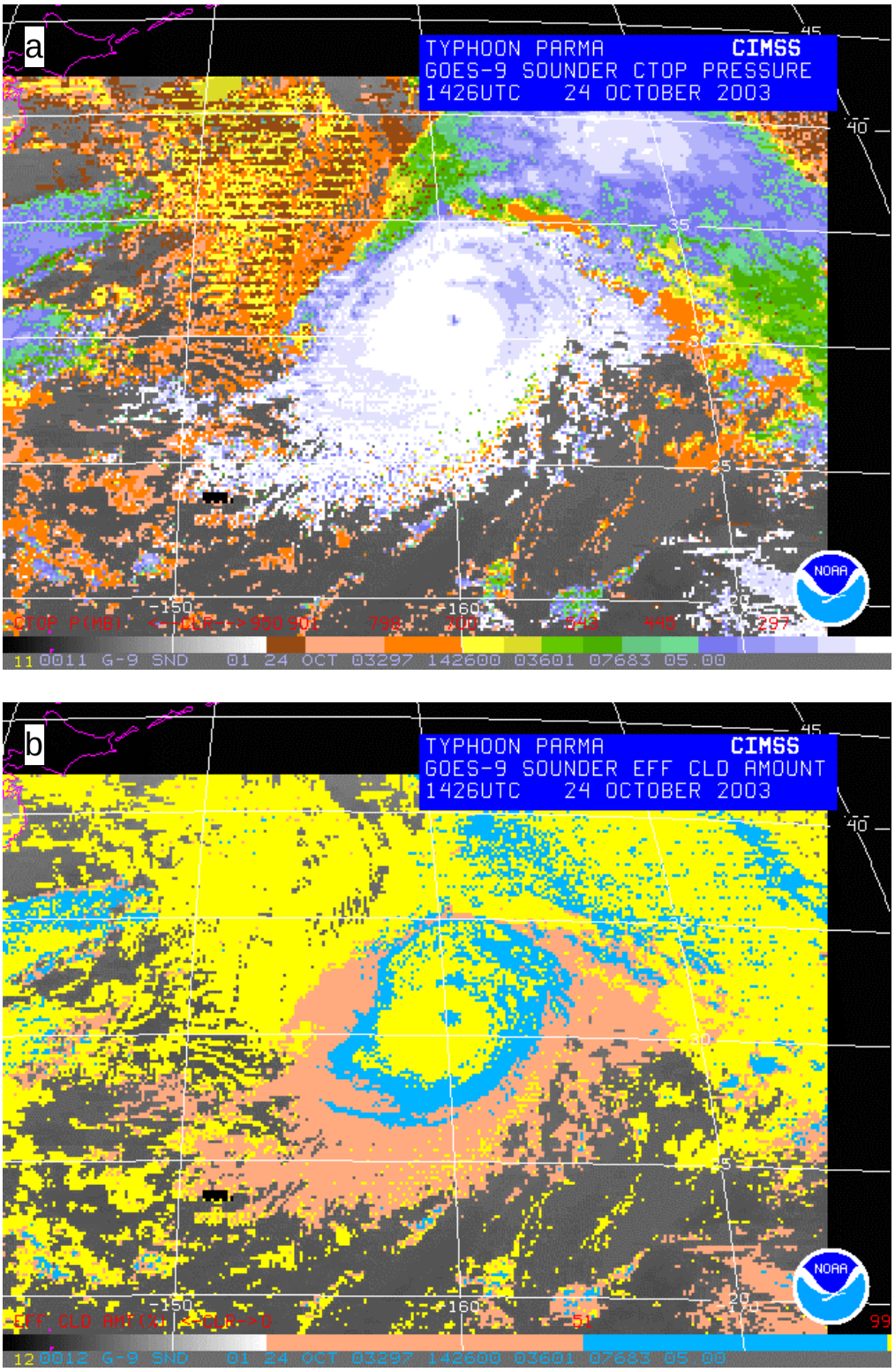


Fig. 4. (a) GOES-9 Sounder cloudtop pressure DPI showing Parma at 1426 UTC 24 October 2003; (b) GOES-9 Sounder effective cloud amount DPI from 1426 UTC 24 October 2003.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Barnes, S. L., 1964: A technique for maximizing details in numerical weather map analysis. *J. Appl. Meteor*., **3**, 396-409.

DOE, cited 2003: Available online at http://www.arm.gov/docs/sites/twp/twp.html.

Hayden, C. M., 1988: GOES-VAS simultaneous temperature-moisture retrieval algorithm. *J. Appl. Meteor.*, **27,** 705-733.

Hibbard, W. and D. Wylie, 1985: An efficient method of interpolating observations to uniformly spaced grids. Preprints, *2nd Conf. on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology,* Los Angeles, CA, Amer. Meteor. Soc., 144-147.

Ma, X. L., T. J. Schmit, and W. L. Smith, 1999: A nonlinear physical retrieval algorithm—its application to the GOES-8/9 Sounder. *J. Appl. Meteor.*, **38**, 501-513.

Li, J., C. C. Schmidt, J. P. Nelson, T. J. Schmit, and W. P. Menzel, 2001: Estimation of total atmospheric ozone from GOES sounder radiances with high temporal resolution. *J. Atmos. Oceanic Technol.*, **18**, 157-168.

Menzel, W. P., and J. F. W. Purdom, 1994: Introducing GOES-I: The first of a new generation of geostationary operational environmental satellites. *Bull. Amer. Meteor. Soc.*, **75**, 757-781.

Menzel, W. P., F. C. Holt, T. J. Schmit, R. M. Aune, A. J. Schreiner, G. S. Wade, and D. G. Gray, 1998: Application of GOES-8/9 soundings to weather forecasting and nowcasting. *Bull. Amer. Meteor. Soc.,* **79**, 2059-2077.

NOAA, cited 2003: Available online at http://www.ssd.noaa.gov/PS/SATS/GOES/NINE/sounder.html.

Schreiner, A. J.,T. J. Schmit, C. Kopken, X. Su, C. Holland, and J. A. Jung, 2003: Introducing the GOES Imager clear-sky brightness temperature (CSBT) product. Preprints, *12th Conf. On Satellite Meteorology and Oceanography*, Long Beach, CA, Amer. Meteor. Soc.

Szyndel, M., J.-N. Thepaut, and G. Kelly, 2003: Developments in the assimilation of geostationary radiances at ECMWF. EUMETSAT/ECMWF Fellowship Programme, 1st Year Report, 25 pp.

WMO, 1988**.** World Meteorological Organization Manual on Codes*,* Publication 306, Volume 1, Part B, Supplement No. 3.

Zehr, R. M., J. F. W. Purdom, J. F. Weaver, and R. N. Green, 1988: Use of VAS data to diagnose the mesoscale environment of convective storms. *Wea. Forecasting,* **3**, 33-49.