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TECHNICAL NOTE

Recent Assimilation and Forecast Experiments at The National Meteorological Center Using SEASAT-A Scatterometer Winds

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OPC CONTRIBUTIONS

No. 1. Burroughs, L. D., 1986: Development of Forecast Guidance for Santa Ana Conditions. National Weather Digest, Vol. 12 No. 1, 8pp.

No. 2. Richardson, W. S., D. J. Schwab, Y. Y. Chao, and D. M. Wright, 1986: Lake Erie Wave Height Forecasts Generated by Empirical and Dynamical Methods -- Comparison and Verification. Technical Note, 23pp.

No. 3. Auer, S. J., 1986: Determination of Errors in LFM Forecasts Surface Lows Over the Northwest Atlantic Ocean. Technical Note/NMC Office Note No. 313, 17pp.

No. 4. Rao, D. B., S. D. Steenrod, and B. V. Sanchez, 1987: A Method of Calculating the Total Flow from A Given Sea Surface Topography. NASA Technical Memorandum 87799., 19pp.

No. 5. Feit, D. M., 1986: Compendium of Marine Meteorological and Oceanographic Products of the Ocean Products Center. NOAA Technical Memorandum NWS NMC 68, 93pp.

No. 6. Auer, S. J., 1986: A Comparison of the LFM, Spectral, and ECMWF Numerical Model Forecasts of Deepening Oceanic Cyclones During One Cool Season. Technical Note/NMC Office Note No. 312, 20pp.

No. 7. Burroughs, L. D., 1987: Development of Open Fog Forecasting Regions. Technical Note/NMC Office Note. No. 323., 36pp.

No. 8. Yu, T. W., 1987: A Technique of Deducing Wind Direction from Satellite Measurements of Wind Speed. Monthly Weather Review, 115, 1929-1939.

No. 9. Auer, S. J., 1987: Five-Year Climatological Survey of the Gulf Stream System and Its Associated Rings. Journal of Geophysical Research, 92, 11,709-11,726.

No. 10. Chao, Y. Y., 1987: Forecasting Wave Conditions Affected by Currents and Bottom Topography. Technical Note, 11pp.

No. 11. Esteva, D. C., 1987: The Editing and Averaging of Altimeter Wave and Wind Data. Technical Note, 4pp.

No. 12. Feit, D. M., 1987: Forecasting Superstructure Icing for Alaskan Waters. National Weather Digest, 12, 5-10.

No. 13. Sanchez, B. V., D. B. Rao, S. D. Steenrod, 1987: Tidal Estimation in the Atlantic and Indian Oceans. Marine Geodesy, 10, 309-350.

No. 14. Gemmill, W.H., T.W. Yu, and D.M. Feit 1988: Performance of Techniques Used to Derive Ocean Surface Winds. Technical Note/NMC Office Note No. 330, 34pp.

No. 15. Gemmill, W.H., T.W. Yu, and D.M. Feit 1987: Performance Statistics of Techniques Used to Determine Ocean Surface Winds. Conference Preprint, Workshop Proceedings AES/CMOS 2nd Workshop of Operational Meteorology, Halifax, Nova Scotia., 234-243.

No. 16. Yu, T.W., 1988: A Method for Determining Equivalent Depths of the Atmospheric Boundary Layer Over the Oceans. Journal of Geophysical Research, 93, 3655-3661.

No. 17. Yu, T.W., 1987: Analysis of the Atmospheric Mixed Layer Heights Over the Oceans. Conference Preprint, Workshop Proceedings AES/CMOS 2nd Workshop of Operational Meteorology, Halifax, Nova Scotia, 2, 425-432.

No. 18. Feit, D. M., 1987: An Operational Forecast System for Superstructure Icing. Proceedings Fourth Conference Meteorology and Oceanography of the Coastal Zone. 4pp.

ABSTRACT

Many changes in the operational global data assimilation system of the National Meteorological Center (NMC) during the last few years are reviewed. These changes include: improved physics as well as horizontal and vertical resolution of the global forecast model, an improved quality control and data selection procedure as well as error statistics in an optimum interpolation scheme, and an improved diabatic initialization in the assimilation system. Given these improvements and in preparation for the expected availability of scatterometer vector winds from future satellite missions in the 1990's, several data assimilation and forecast experiments were conducted in the NMC's global data assimilation system using Seasat scatterometer vector winds for a two week period (September 7, 0000 UTC - September, 19 1800 UTC, 1978).

The assimilation results show that scatterometer wind data have a positive impact on height and wind analyses over the Southern Hemisphere. Two separate five-days forecasts are made with the initial conditions determined in one case by the assimilation of conventional data in the analysis cycle and in the other both conventional and seven days of scatterometer data. The forecast results show that inclusion of the scatterometer data improves short range weather forecasts, especially over the Southern Hemisphere. Results of the assimilation and forecast experiments are discussed.

1. Introduction

Scatterometer winds over the global oceans will become available operationally from various satellite missions in the 1990's. This potential availability of the scatterometer wind data gives us an impetus to revisit the question of their impact on the present day's meteorological analysis and forecast models. It is important that such assimilation and forecast experiments be conducted ahead of time to investigate all viable methods for effective use of the data on the current global data assimilation systems (GDAS).

The impact of a given type of data on a numerical weather prediction system depends on the characteristics of the assimilation system itself. That is, some systems are more amenable to improvements by the addition of one kind of data than are others. Similarly, the same system may be more responsive to the addition of data in the Southern Hemisphere than it does in the Northern Hemisphere. In general, an assimilation system contains three basic components: analysis, initialization and a prediction model. Depending upon the complexity and completeness of these components, the impact of a given type of data may be affected. The earlier impact study of scatterometer winds by Yu and McPherson (1984) was based on the NMC's GDAS system of the late 1970 (McPherson et al, 1984). The main conclusion of this study is that scatterometer winds have substantial impact in the Southern Hemisphere's low level analyses of heights and winds, but has little impact over the Northern Hemisphere. Similar conclusions have emerged from other impact studies using Seasat scatterometer winds (Atlas et. al, 1984, Duffy et. al, 1984, Baker et. al, 1984, Duffy and Atlas, 1986). Recently, Anderson et al (1991) using the ECMWF's and Ingleby and Bromley (1991) the U.K. Meteorological Office assimilation systems have more or less arrived at similar conclusions. One explanation for this is that there are less conventional data in the Southern Hemisphere, and therefore more impact was seen due to the inclusion of scatterometer winds.

During the last few years, there have been many changes in the NMC's operational GDAS. These changes include: improved physics as well as increased horizontal and vertical resolution of the global spectral forecast model, an improved quality control and data selection procedure as well as error statistics in the optimum analysis scheme, and an improved diabatic initialization in the GDAS. As a result, the forecast skills today are substantially improved compared to those a decade ago, especially in the Southern Hemisphere (Caplan and White, 1989). Given these improvements, it should be of particular interest now to conduct assimilation and forecast experiments including the scatterometer data in the current NMC's GDAS to address the impact question of the data on the overall forecast skill.

Before the impact question can be addressed, the directional ambiguity problem associated with the scatterometer wind data has to be resolved. All of the previous impact studies used different schemes to select proper wind directions. The results were undoubtedly affected by the procedures adopted for this purpose. However, this direction ambiguity problem is no longer a major difficulty in using the Seasat scatterometer wind data now. Currently there are two edited data sets available for examining the impact question: one set is produced by JPL, and the other by GLA (Atlas et al, 1987). Anderson et al (1991) report on an impact study in which two weeks of JPL scatterometer winds were assimilated into the ECMWF's GDAS. Ingleby and Bromley (1991) document results of data assimilation and forecast experiments using GLA scatterometer winds in the UK Meteorological Office's GDAS. Both studies used Seasat scatterometer winds during the period of September 7 to September 20, 1978.

This paper describes results of a recent data impact study in which the two sets of Seasat scatterometer wind data used in Anderson et al (1991) and Ingleby and Bromley (1991) have been assimilated into the NMC's operational GDAS. Figure 1 shows a schematic illustrating the design of assimilation and forecast experiments reported in this study. A brief description of NMC's operational GDAS is given in Section 2. Aspects of the GDAS particularly pertaining to the use of surface data are discussed. Moreover, where relevant, differences between the current NMC operational GDAS used in this study and that used in the previous study (Yu and McPherson, 1984, hereafter referred to as the older system) will also be discussed. Section 3 presents results of assimilation experiments using the edited JPL and GLA scatterometer vector winds, and examines the question of the impact on the analyses. Results of forecast experiments are presented in Section 4 in which the impact of scatterometer winds on the short range forecasts are addressed.

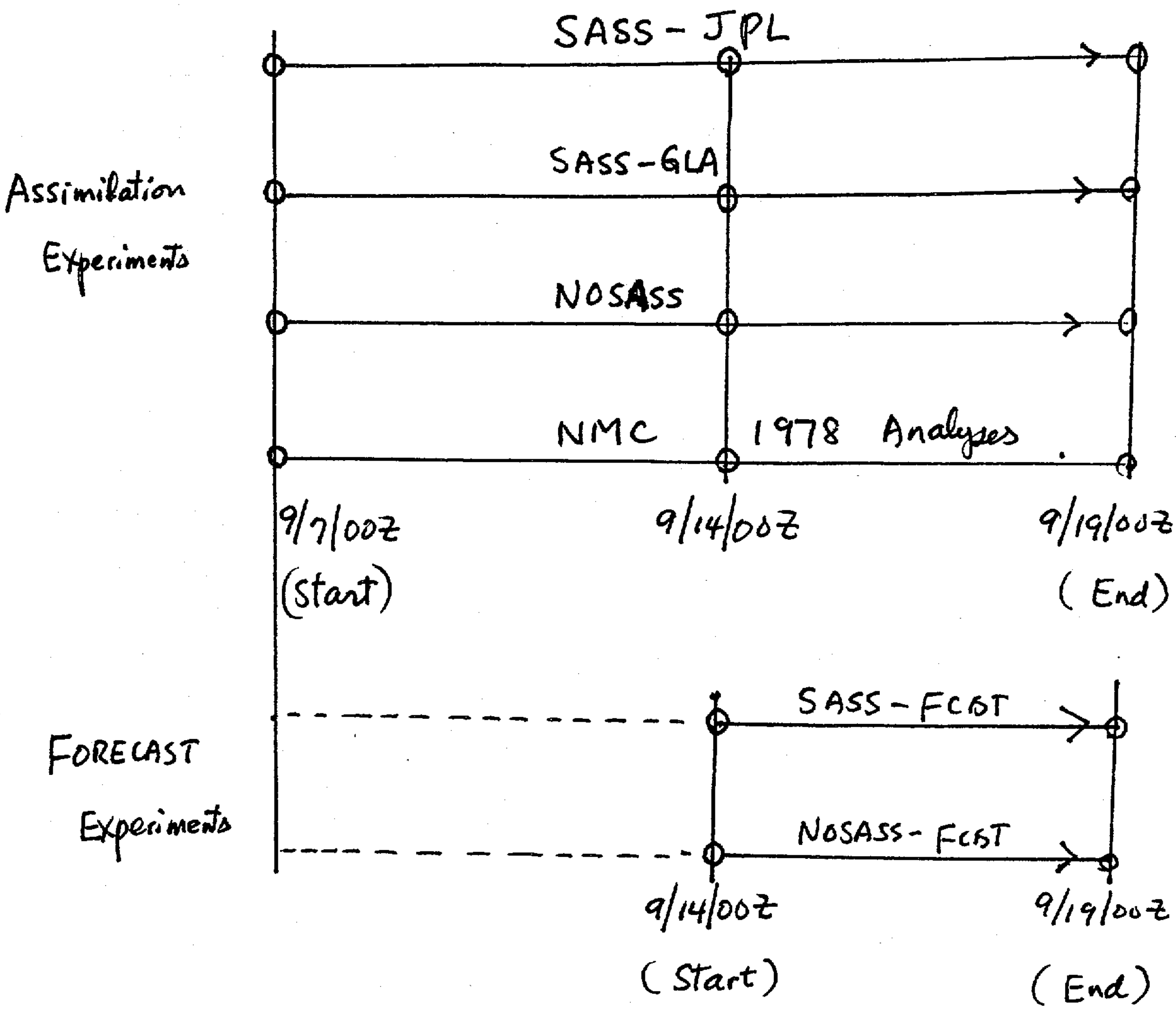


Figure 1. A schematic illustrating the design of assimilation and forecast exepriments. SASS-JPL denotes the assimilation experiment in which the JPL scatterometer data are included, SASS-GLA the GLA scatterometer winds are included, and NOSASS no scatterometer winds are included. SASS-FCST indicates that the forecast experiment uses as initial conditons the SASS-JPL analyses, and NOSASS-FCST, the forecast experiment that uses as initial conditions from the NOSASS analyses.

2. The Assimilation System

The NMC's operational GDAS consists of three major components: an objective analysis scheme, and a nonlinear normal mode initialization procedure, and a global forecast model. Details of the NMC's GDAS are discussed in Kanamitsu (1987), and therefore only a brief description will be presented here. In the NMC's GDAS, an objective analysis is performed every six hours using a six hour global spectral model forecast as a first guess, which is then updated by available observations during the six hour window. The analysis is initialized by a diabatic normal mode initialization to filter out gravity waves for the next assimilation cycle. This process is repeated four times a day at 0000, 0600, 1200 and 1800 UTC. The following gives a brief description on each of these three components.

The forecast model (Sela, 1980) uses a normalized pressure (sigma , i.e, $\sigma \equiv p / p_s$, where p is atmospheric pressure, and p_s is the pressure at the surface) system as the vertical coordinate. The model has 18 sigma layers in the vertical with six layers below 850 mb to resolve the boundary layer structure, and two layers in the stratosphere. The lowest sigma layer has a thickness of 10 mb (about 100 meters above the surface). This is a significant improvement over the older system which had 12 vertical layers with only two layers below 850 mb, and the lowest sigma layer was about 75 mb thick. This vertical structure change, which will undoubtedly lead to improvement in the first guess field of the boundary layer winds, is beneficial to the use of satellite scatterometer winds and other conventional surface observation by ships and buoys. The horizontal resolution of the model is 80 waves with a triangular truncation. This is more than twice the horizontal resolution of the older system (30 waves with rhomboidal truncation), and represents a very significant improvement in the forecast model's ability to resolve meso-alpha scale features. The prediction model includes parameterization of physical processes, such as convection, precipitation, radiation, and boundary layer physics. The physical processes included in the current forecast model (see Kanamitsui, 1987) are improved versions over those used in the older system. Most notable are the atmospheric boundary layer processes used in the model which gives much realistic low level wind and temperature forecasts (Caplan and White, 1987).

Every six hours, the forward integration of the forecast model is interrupted and new observations are used to update the model's representation of the atmosphere. The updating is done by first computing the observed increments of eastward and northward components of the winds, geopotential heights, and relative humidity by subtracting the forecast values of these variables from the observed values at the observation locations. These observed increments are then interpolated onto 12 mandatory isobaric levels of the analysis grid which has an east-west resolution of approximately 450 km, and north-south resolution of 250 km. The interpolation uses a three dimensional optimum interpolation analysis scheme (Dey, 1987). The results of this statistical interpolation (called the analyzed increments) are added to the first guess fields to form the desired analyses. Following the completion of the optimum interpolation, the analysis fields are adjusted by a diabatic normal mode initialization procedure (Ballish, 1980) to control gravity waves caused by the imbalance between the mass and the winds in the analysis fields.

With the three-dimensional optimum interpolation scheme, an observation at a given pressure level not only influences the update in its own layer but also the layers above and below. The degree to which the observation affects the update above and below depends on an assumed vertical structure function. The vertical structure function used for this study is illustrated in Figure 2 (see DiMego, 1987). With this vertical structure function, surface observations typically influence the lowest two layers significantly and the next two to a lesser degree. The scatterometer winds have the most significant influence on the wind analyses at the lowest two mandatory pressure surfaces, i.e., at 1000 mb and 850 mb. Since the forecast model has six sigma levels below 850 mb, this suggests that scatterometer winds have the most influence upon the wind analyses and forecasts at these levels.

3. Assimilation Experiments

As shown in Figure 1, several assimilation experiments were conducted for about two weeks of the Seasat period starting at 0000 UTC, September 7, 1978, and ending at 1800 UTC, September 19, 1978. In one experiment NMC's operational GDAS as of February 1991 is run according to the procedure described in Section 2. Only the conventional data such as those from upper air radiosondes, surface observations, aircraft reports and satellite temperature sounding (VTPR) were used in the two weeks' assimilation. This experiment

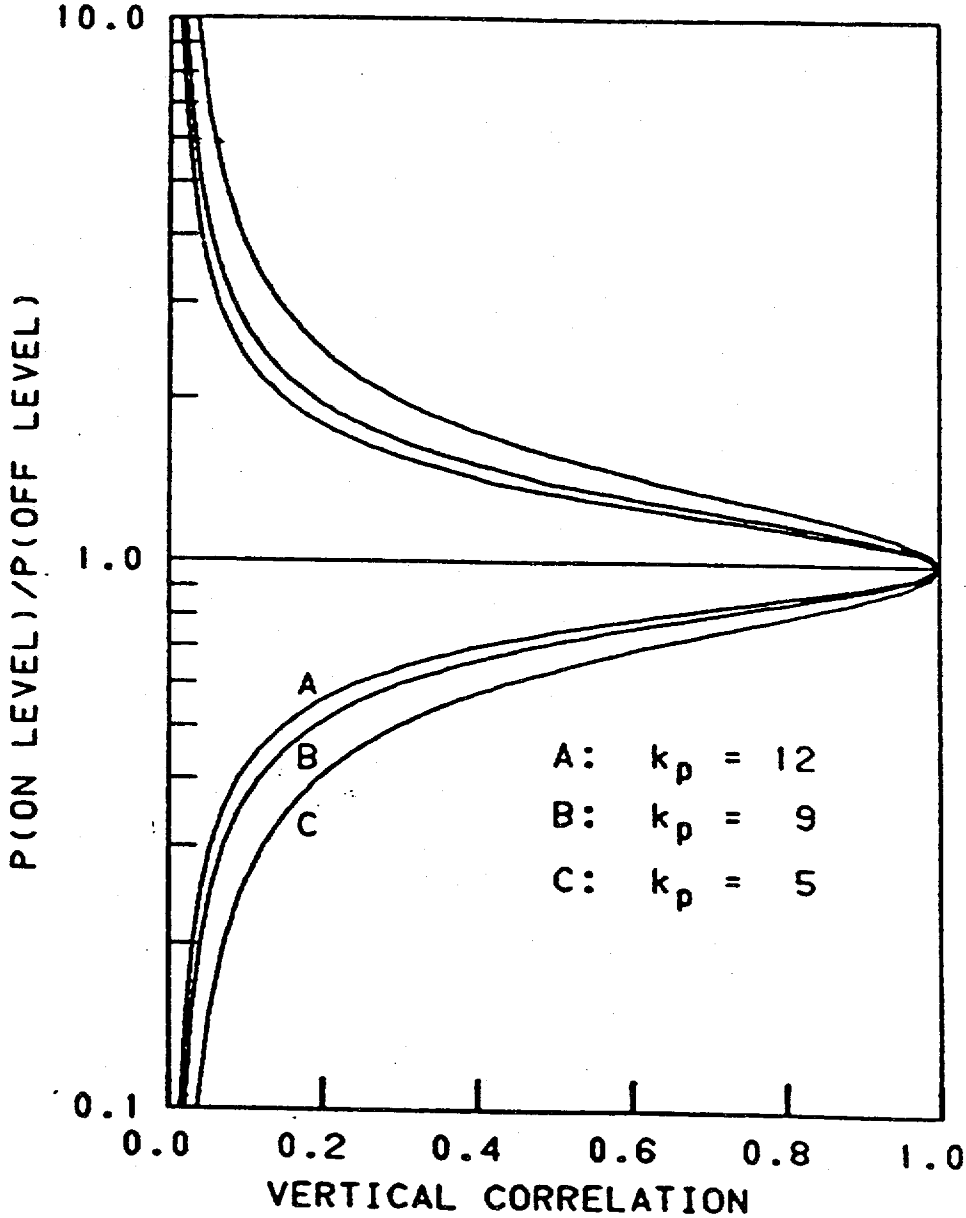


Figure 2. Vertical structure function used in the three-dimensional optimum interpolation analysis scheme (after DiMego, 1987). The curve with K_p = 5 is adopted for this study.

shall be referred to as the NOSASS run. In the other assimilation experiments where scatterometer wind data together with all the conventional data are included shall be referred to as the SASS runs.

As mentioned earlier, there are two sets of Seasat scatterometer winds available for the impact study: one from JPL, and the other from GLA. To determine the sensitivity of the assimilation system to the two data sets, two SASS assimilation experiments were carried out starting 0000 UTC September 7, 1978. After one week of assimilation, the two assimilated states do not appear to show significant differences in the height and wind analyses, indicative of the fact that the assimilation system used in this study is not sensitive to the two scatterometer wind data sets. This further suggests that any differences in the conclusions of the recent impact studies conducted among ECMWF (Anderson et al, 1991), UK Meteorological Office (Ingleby and Bromley, 1991), and the present study are not likely due to the use of these two different scatterometer wind data sets. Therefore, the following discussions are restricted to results from the SASS assimilation experiment using the JPL scatterometer wind data set and the NOSASS experiment. Moreover, where it is possible, our results will be compared with those of Anderson et (1991) and Ingleby and Bromley (1991).

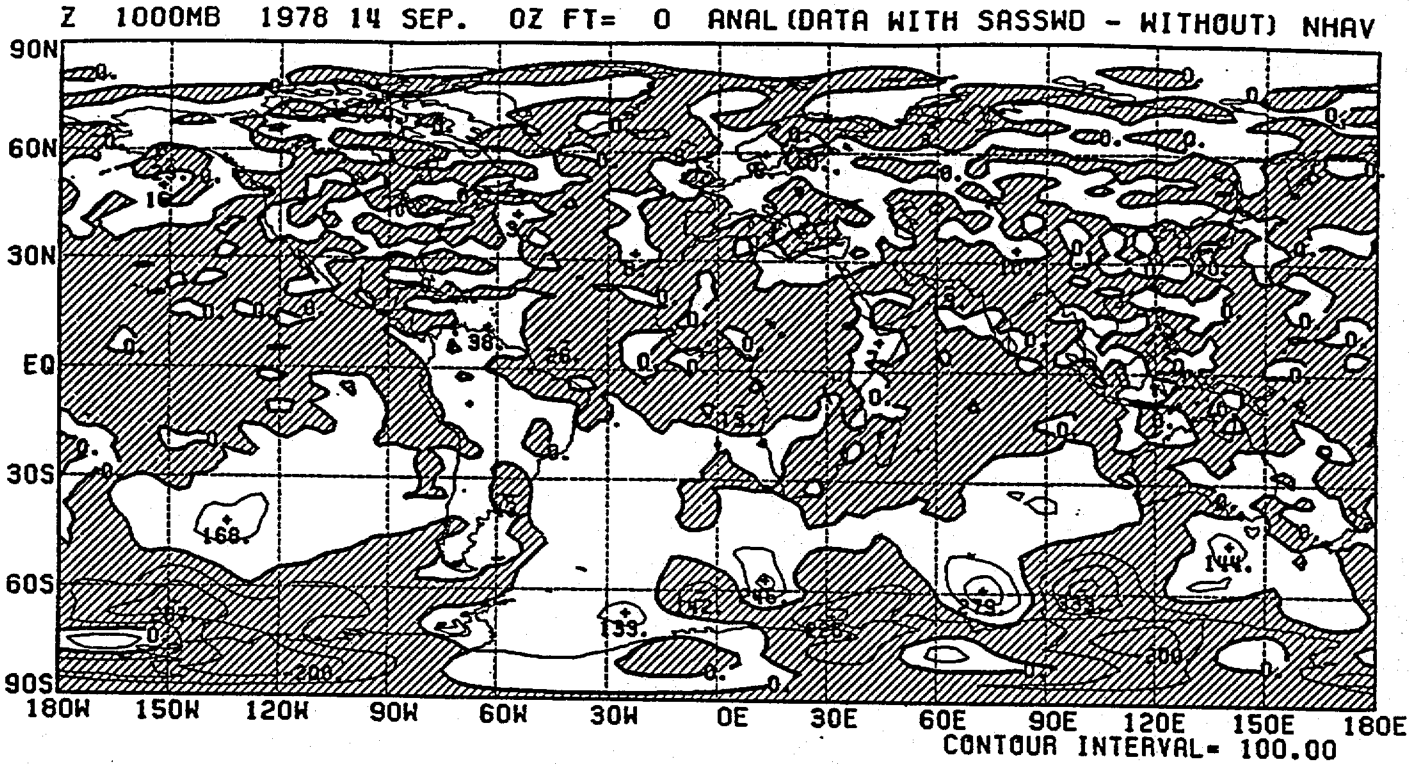
Two synoptic times are selected for comparison: the first is 0000 UTC, September 14, 1978, one week after the start of data assimilation, and the other is 0000 UTC, September 19, 1978, near the end of the assimilation period. The first synoptic period is chosen for two five-day forecasts (to be discussed later) which use the SASS and NOSASS analyses as initial conditions. The second synoptic hour is of interest because it is the verification time for the five- day forecasts. In addition to the synoptic differences for the two selected times, mean and RMS differences between SASS and NOSASS experiments are presented for the total 13 days' period (52 samples).

a. Synoptic Differences

Fig. 3 shows the differences between SASS and NOSASS analyses valid at 0000 UTC, September 14, 1978 of the 1000 mb heights (Fig. 3a) and vector winds (Fig. 3b) after seven days of assimilation. The scatterometer wind data are seen to make very little impact in the Northern Hemisphere, partially as the result of more abundant conventional data available for use to define the analyses of heights and winds at this level. Large differences occur, however, in the Southern Hemisphere where conventional data are scanty and scatterometer winds are plentiful to improve the initial analyses. The areas of these large differences occur in the extratropics of the Southern Hemisphere, which agree well with those reported in recent impact studies of Anderson et al (1991), and Ingleby and Bromley (1991).

Fig. 4 shows a synoptic example of the differences between the two analyses for an intensive extratropical storm system. The largest synoptic differences in heights exceed 330 meters at the 1000 mb (Fig. 4a). The inclusion of scatterometer wind data has contributed to the deepening of the cyclones in south western

(a)



(b)

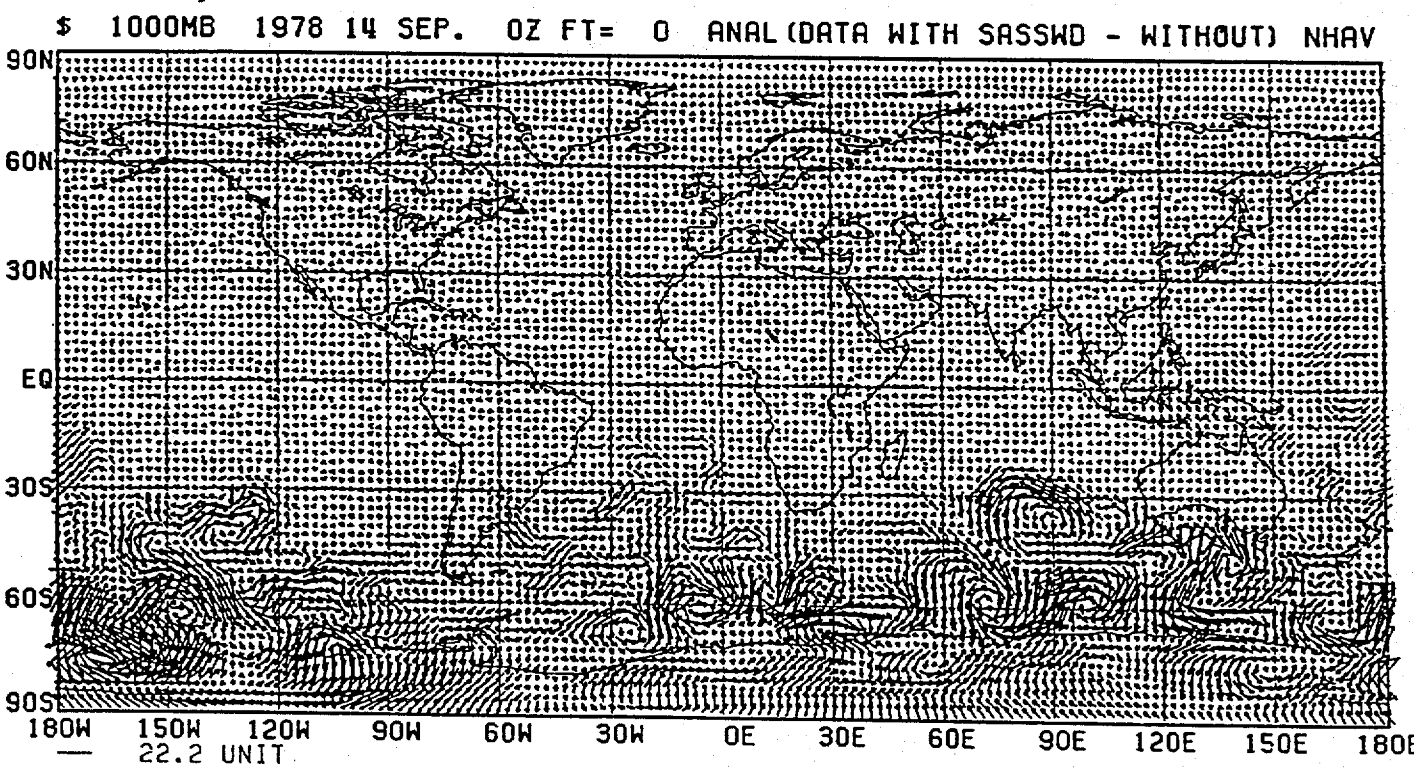


Figure 3. Differences between SASS and NOSASS analyses of (a) 1000 mb height, and (b) 1000 mb vector wind valid at 0000 UTC, September 14, 1978

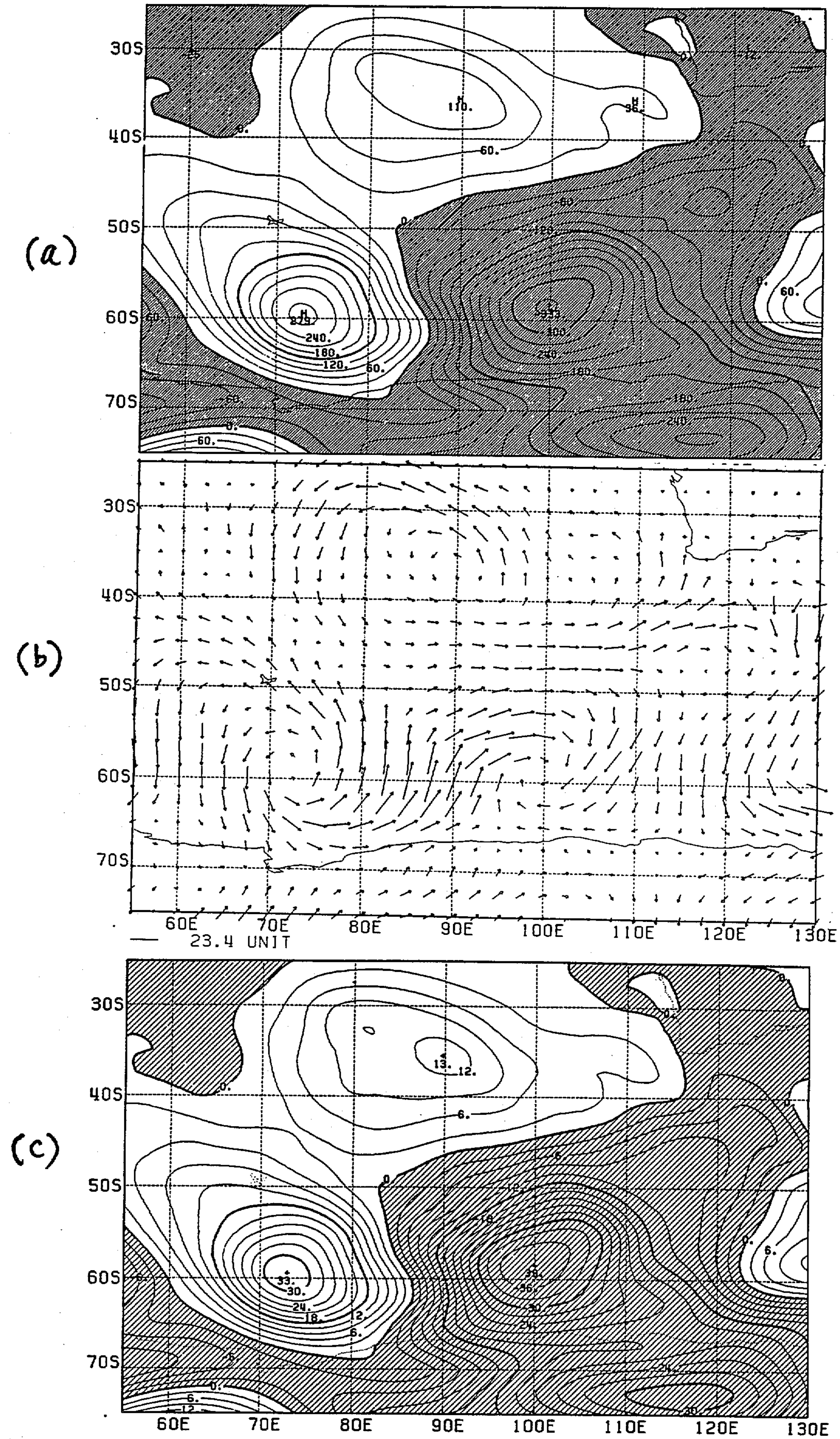


Figure 4. Differences between SASS and NOSASS analyses of (a) 1000 mb height, (b) 1000 mb vector wind, and (c) sea level pressure over a limited area of the Southern Hemisphere valid at 0000 UTc, September 14, 1978

Australia, where the vector wind differences exceed 25 m/s (Fig. 4b). These large differences in 1000 mb height and wind analyses correspond to surface pressure differences of nearly 40 mb at this region (Fig. 4c). It should be mentioned that a similar study at ECMWF by Anderson et al (1991) show that at the 1000 mb the wind changes can be as large as 20 m/sec and the heights differences can be in excess of 135 meters after a week of data assimilation.

These height and wind differences between SASS and NOSASS analyses are not confined to the boundary layer alone, but extend to higher levels, as large differences are still evident at 500 mb level (Fig. 5). However, comparing with the changes in 1000 mb height and wind analyses (Fig. 3), these differences in 500 mb between SASS and NOSASS analyses represent only less than 10 % of changes that occur at the 1000 mb level.

Table 1 shows standard deviation statistics of the fit of the first guess heights and winds to the Southern Hemisphere radiosondes valid at 0000 UTC, September 14, 1978. The statistics are stratified by 30 degree latitude bands, and the numbers inside the bracket indicate the numbers of radiosondes used in the analyses. One would expect that if the scatterometer wind data have a positive impact on the analyses, the first guess fields of the SASS experiment should give a better fit to the radiosonde observations than those of the NOSASS experiment. This is indeed the case as Table 1 shows that the Seasat scatterometer winds after seven days of assimilation have clearly had a positive impact in the Southern Hemisphere by reducing the error of the first guess. The number of radiosondes rejected in the quality control is also

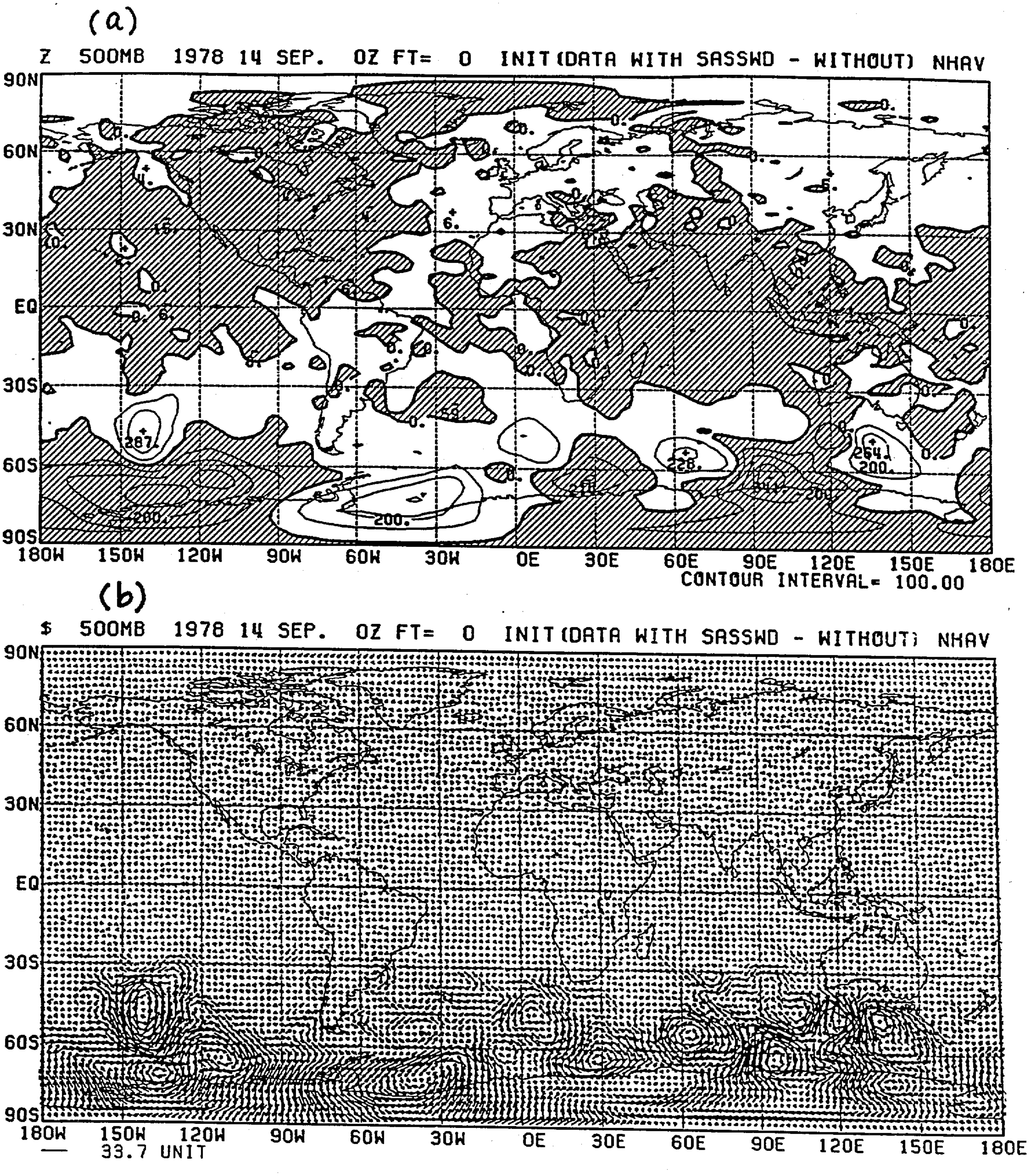


Figure 5. Same as Figure 1 except for (a) 500 mb height, and (b) 500 mb vector wind analyses

Table 1. Standard deviation of the fit of the first guess z - height (meters), u - wind (m/s), v - wind (m/s) to the Southern Hemisphere radiosonde data for the GDAS experiments (valid 9/14/00z/1978). The number inside the bracket indicates the number of radiosondes used in the analyses.

With SASS Winds

			1000 mb		700 mb	500 mb	250 mb
z	90S- 60S	(10)	47.37		48.12	63.03	86.91
	60S- 30S	(24)	20.67		21.35	40.48	56.80
	30S- 0	(31)	27.50		16.20	15.45	27.23
u	90S- 60S	(1)	0		9.73	8.79	14.53
	60S- 30S	(4)	1.71		3.93	5.23	8.84
	30S- 0	(12)	2.83		4.55	4.79	7.43
v	90S- 60S	(1)	0		7.71	8.10	13.15
	60S- 30S	(4)	2.09		4.93	6.58	13.56
	30S- 0	(12)	1.37		4.31	6.27	9.28

Without SASS Wind

			1000 mb		700 mb	500 mb	250 mb
z	90S- 60S	(7)	58.50		56.87	88.18	154.00
	60S- 30S	(24)	18.15		17.45	41.87	62.21
	30S- 0	(31)	24.19		17.51	17.97	30.01
u	90S- 60S	(1)	0		10.30	9.83	13.15
	60S- 30S	(4)	2.78		4.03	6.42	9.22
	30S- 0	(12)	2.74		4.31	5.55	8.45
v	90S- 60S	(1)	0		9.09	11.14	15.34
	60S- 30S	(4)	3.48		6.29	7.42	12.60
	30S- 0	(12)	1.66		4.20	5.68	9.30

reduced because of the better agreement with the first guess. It should be noted that the most significant improvement in the height analyses occurs at the 1000 mb level over the higher latitudes (60S-90S) - about a 10% of reduction of first guess errors by the inclusion of the scatterometer winds. At higher levels, although the magnitudes of improvements in the height analyses errors are large, they represent a smaller percentage when compared to the 1000 mb analyses. The same statement can be made regarding the wind analyses. The improvement are seen to occur all over the entire Southern hemispheric oceans, although one cannot really be certain at the 1000 mb because there are no radiosondes at that level for comparison.

As the period of data assimilation increases, and if the scatterometer data continue to have a positive impact, one would expect the areas of large differences between the SASS and NOSASS runs to maintain and propagate eastward. This is indeed the case as can be seen from the areas of large differences in height and vector winds for the 1000 mb (Fig. 6) and 500 mb levels (Fig. 7) between the SASS and NOSASS runs valid at 0000 UTC, September 19, 1978. Most of the differences are observed in the Southern Hemisphere. Note that the system near south western Australia with large differences in heights and winds shown in the previous synoptic time (0000 UTC, September 14, 1978) have been deepened by the inclusion of scatterometer wind data and moved eastward (Compare Fig. 3 with Fig. 6 for the 1000 mb level, and Fig. 5 with Fig. 7 for the 500 mb level). Note in particular that very large differences in height and wind analyses are evident near south

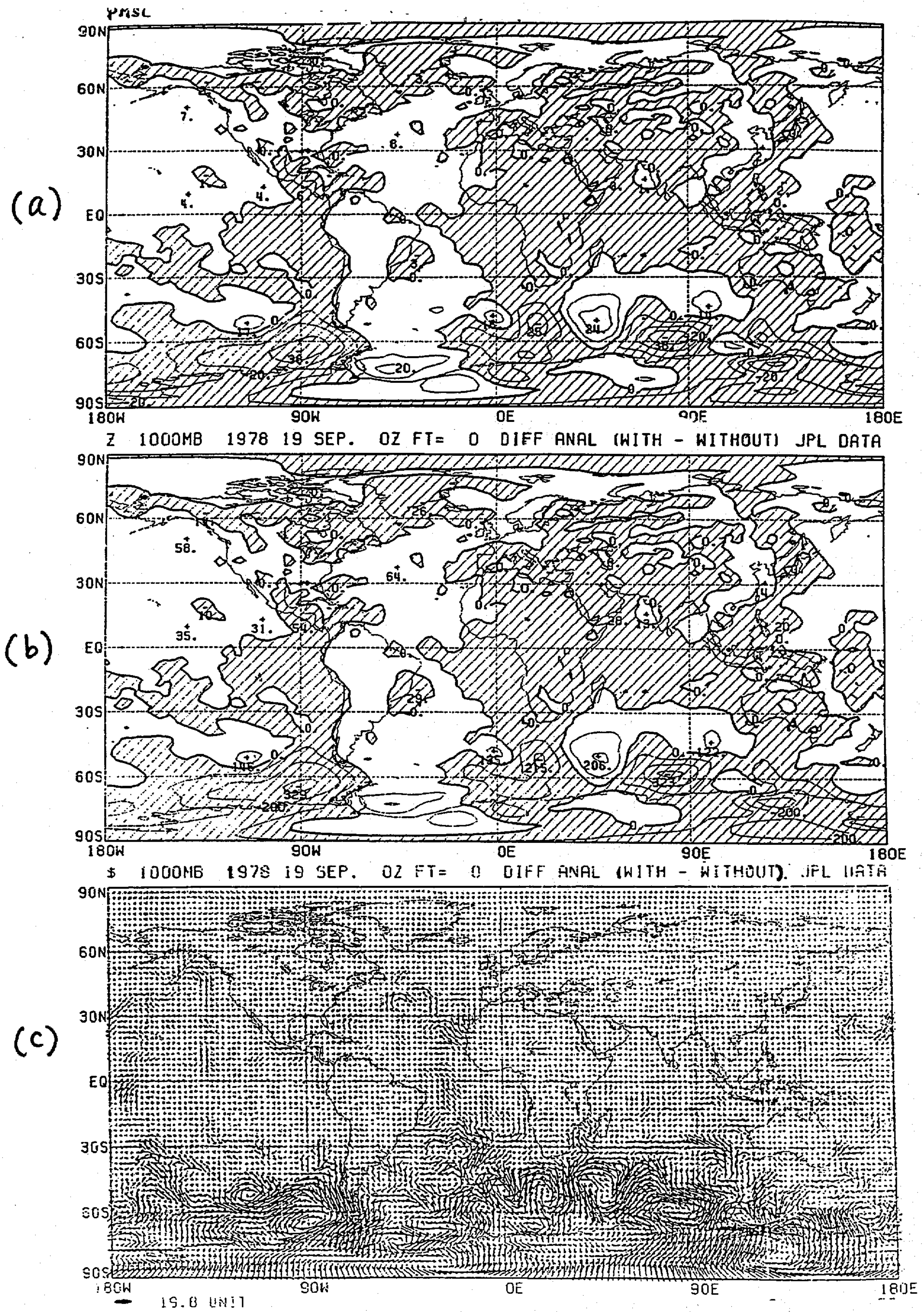
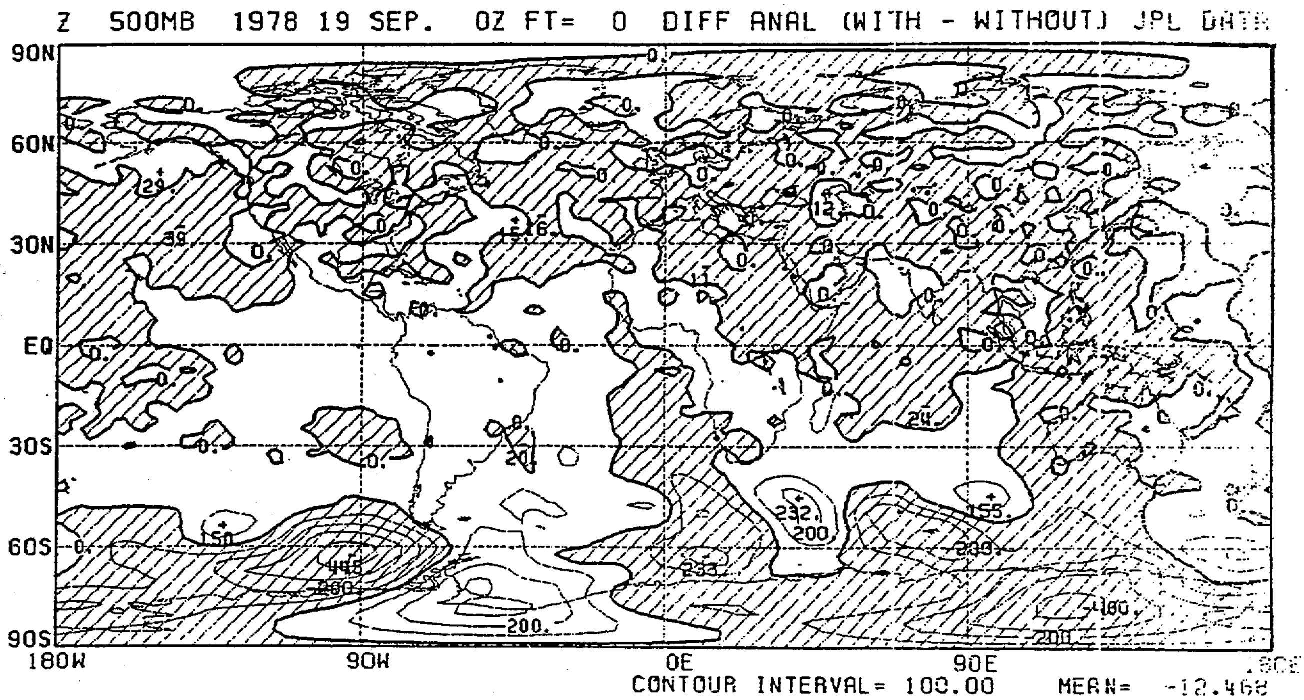


Figure 6. Differences between SASS and NOSASS analyses of (a) sea level pressure, (b) 1000 mb height, and (c) 1000 mb vector wind valid at 0000 UTC, September 19, 1978

(a)



(b)

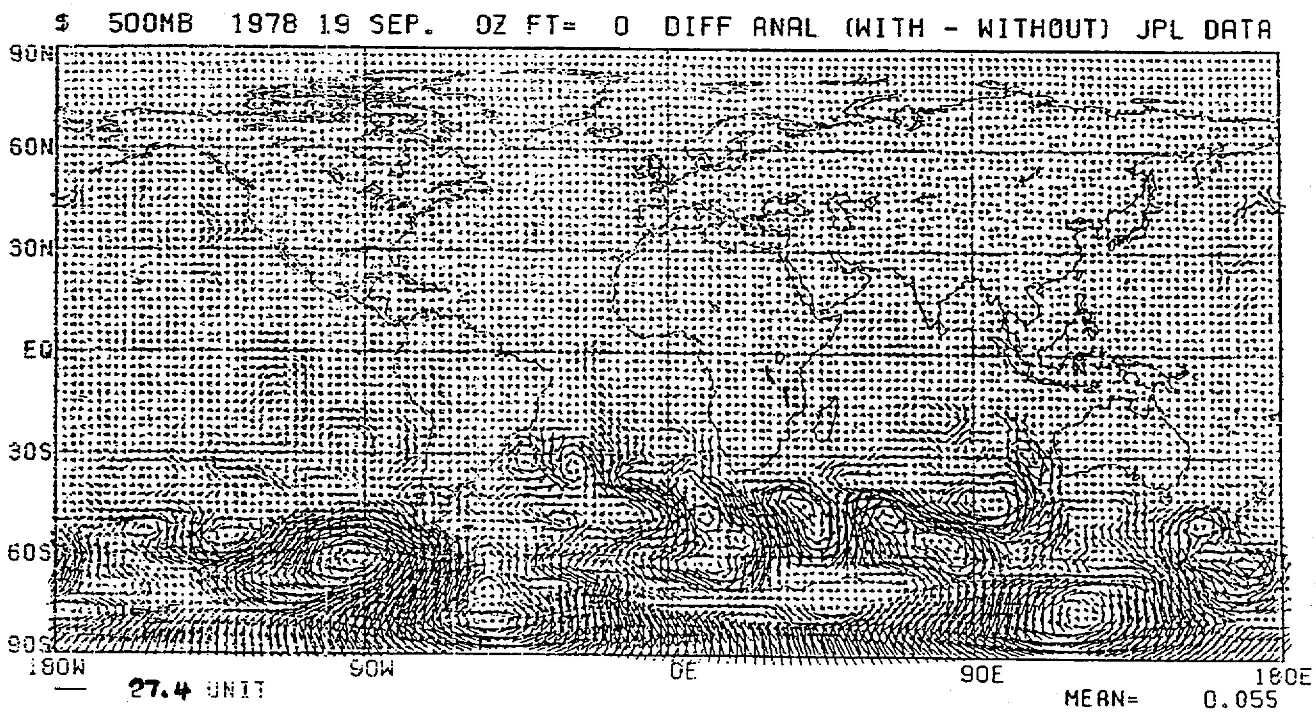


Figure 7. Same as Figure 4 except for (a) 500 mb height, and (b) 500 mb vector wind analyses

western Chile for both the 1000 mb and 500 mb levels. These two areas are important for forecast verification as will be discussed later in conjunction with five- day forecast experiments.

After nearly two weeks of data assimilation, the statistics of the fit of the first guess to the Southern Hemispheric radiosonde observations show again that SASS analyses are clearly better than NOSASS analyses at 0000 UTC, September 19, 1978 (see Table 2). Note the substantial improvement in the height and wind analyses for the SASS analyses in the mid- and high latitude regions of the Southern Hemisphere. Moreover, it is important to point out that as the assimilation period increases, the standard deviations between the first guess and radiosondes are decreased, as can be seen by comparing statistics in Table 1 and Table 2. This further affirms the conclusion that the scatterometer wind data have a positive impact on the analyses.

b. Mean and RMS Differences

This section examines the impact question based on a total of 52 analyses for the period from 0000 UTC, September 7, 1978 to 1800 UTC, September 19, 1978. Mean and RMS differences in 1000 mb heights and mean sea level pressures between the SASS and NOSASS analyses are shown respectively in Figs. 8a, 8b, and 8c. Over the Southern Hemisphere, there are two major negative mean height centers: one near south Australia with a maximum of 112 meters, and the other at the south west of Chile with a maximum of 188 meters (Fig. 8a). One can see from the mean and RMS differences shown in Figures 8a and 8b, that inclusion of scatterometer winds leads to

Table 2. Standard deviation of the fit of the first guess z - height (meters), u - wind (m/s), v - wind (m/s) to the Southern Hemisphere radiosonde data for the GDAS experiments (valid 9/19/00z/1978). The number inside the bracket indicates the number of radiosondes used in the analyses.

With SASS Winds

		1000 mb	700 mb	500 mb	250 mb
z	90S- 60S	(9) 24.08	(10) 27.43	(11) 43.76	(12) 85.12
	60S- 30S	(21) 14.23	(21) 16.79	(22) 26.18	(22) 34.52
	30S- 0	(36) 8.91	(40) 10.38	(42) 23.58	(35) 30.24
u	90S- 60S	-----	(11) 3.62	(12) 3.85	(11) 7.31
	60S- 30S	(6) 1.68	(29) 5.55	(29) 6.60	(21) 12.03
	30S- 0	(11) 3.31	(49) 4.16	(52) 3.26	(42) 6.89
v	90S- 60S	----	(11) 5.76	(12) 7.47	(11) 8.19
	60S- 30S	(6) 4.97	(28) 4.40	(29) 5.63	(21) 7.76
	30S- 0	(11) 4.48	(49) 3.51	(52) 4.06	(42) 6.40

Without SASS Wind

		1000 mb	700 mb	500 mb	250 mb
z	90S- 60S	(8) 56.39	(9) 73.58	(8) 108.76	(11) 146.46
	60S- 30S	(21) 41.98	(21) 51.69	(21) 57.23	(22) 71.53
	30S- 0	(36) 13.30	(42) 15.76	(43) 26.40	(35) 34.66
u	90S- 60S	-----	(10) 3.00	(12) 8.70	(11) 9.87
	60S- 30S	(6) 4.21	(29) 6.91	(29) 8.34	(21) 17.96
	30S- 0	(11) 4.46	(49) 3.80	(52) 4.04	(42) 6.86
v	90S- 60S	------	(10) 9.85	(12) 13.63	(11) 18.80
	60S- 30S	(6) 8.20	(27) 4.87	(29) 8.21	(21) 8.75
	30S- 0	(11) 4.33	(49) 4.32	(52) 4.28	(42) 7.35

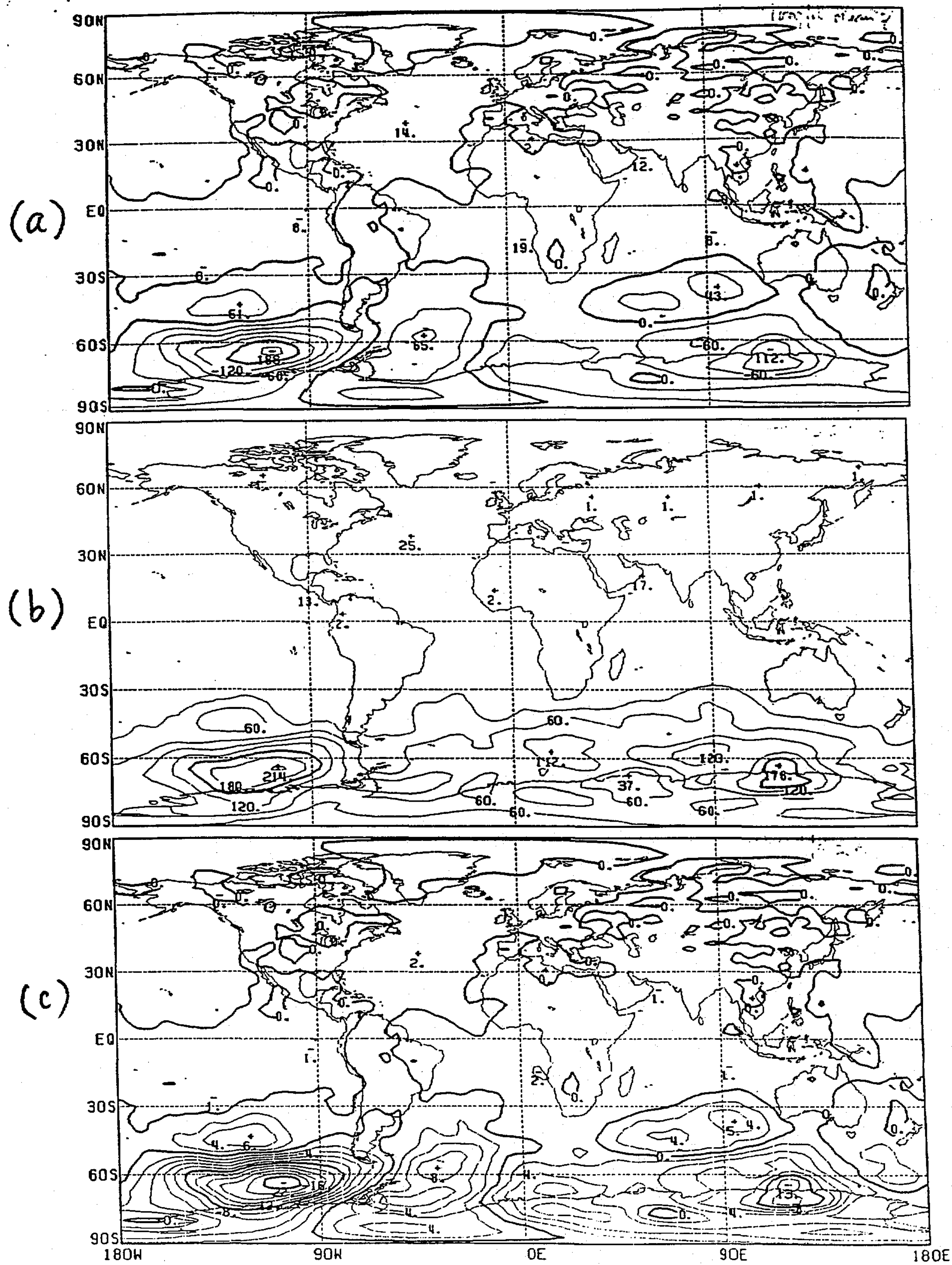


Figure 8. Differences between SASS and NOSASS analyses of (a) 1000 mb mean height, (b) 1000 mb RMS height, and (c) mean sea level pressure for the period from 0000 UTC, September 7, 1978 to 1800 UTC, September 19, 1978 (52 samples)

the intensification of the two cyclones, and the building up of two anticyclones between the two cyclones. The two anticyclones, one located near south eastern Argentina, and the other near south west Australia are not as strong and well organized as the two cyclones, however. The corresponding mean sea level pressure differences for these two major cyclonic features are respectively 13 mb and 22 mb (Fig. 8c). These results should be compared with those of Ingleby and Bromley (1991), where differences in mean sea level pressures between the SASS and NOSASS analyses are reported to be 8 mb and 14 mb respectively for the two cyclonic centers.

The 1000 mb mean and RMS wind speed differences between the SASS and NOSASS analyses are shown in Fig. 9a and Fig. 9b. A positive mean difference of about 10 m/s and a RMS of about 18 m/s in wind speeds at 1000 mb are observed over the two cyclonic areas of the Southern Hemisphere. This positive mean wind speed difference indicates that the 1000 mb wind speeds from the SASS experiment are stronger than those from the NOSASS experiment. Two well-organized large scale cyclonic circulations are clearly depicted in the mean differences of the 1000 mb vector winds (Fig. 9c). Also, an anticyclonic circulation of lesser intensity is located in south eastern Argentina.

Figs. 10 and 11 show the mean and RMS differences of height and wind at 500 mb. The large impact of the scatterometer winds is still felt at this level. Although these differences in heights and winds are larger than those at the 1000 mb level (Figs. 8 and 9), they represent a much smaller percentage of changes with respect to the mean values of height and winds at the 500 mb level than those

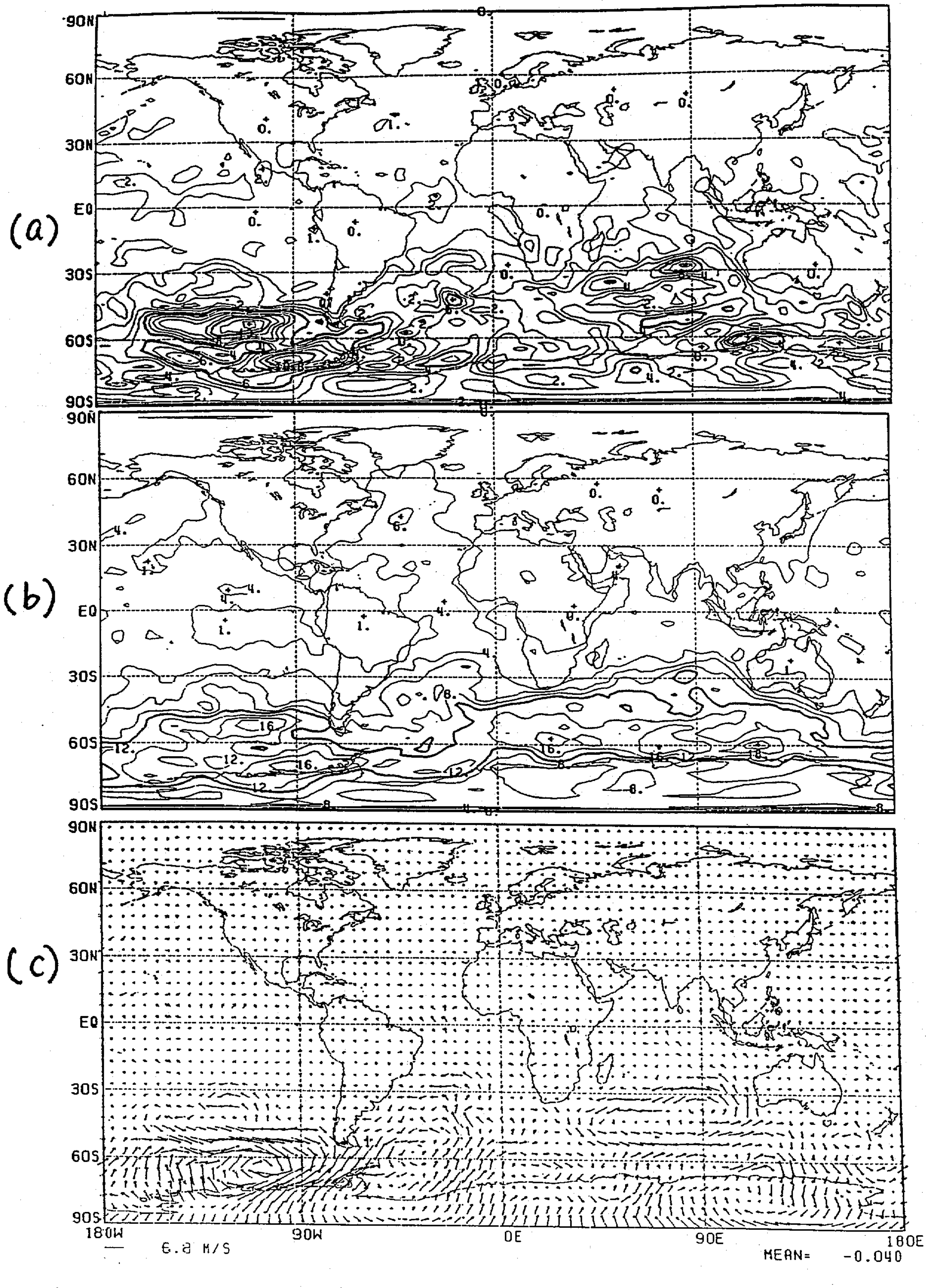
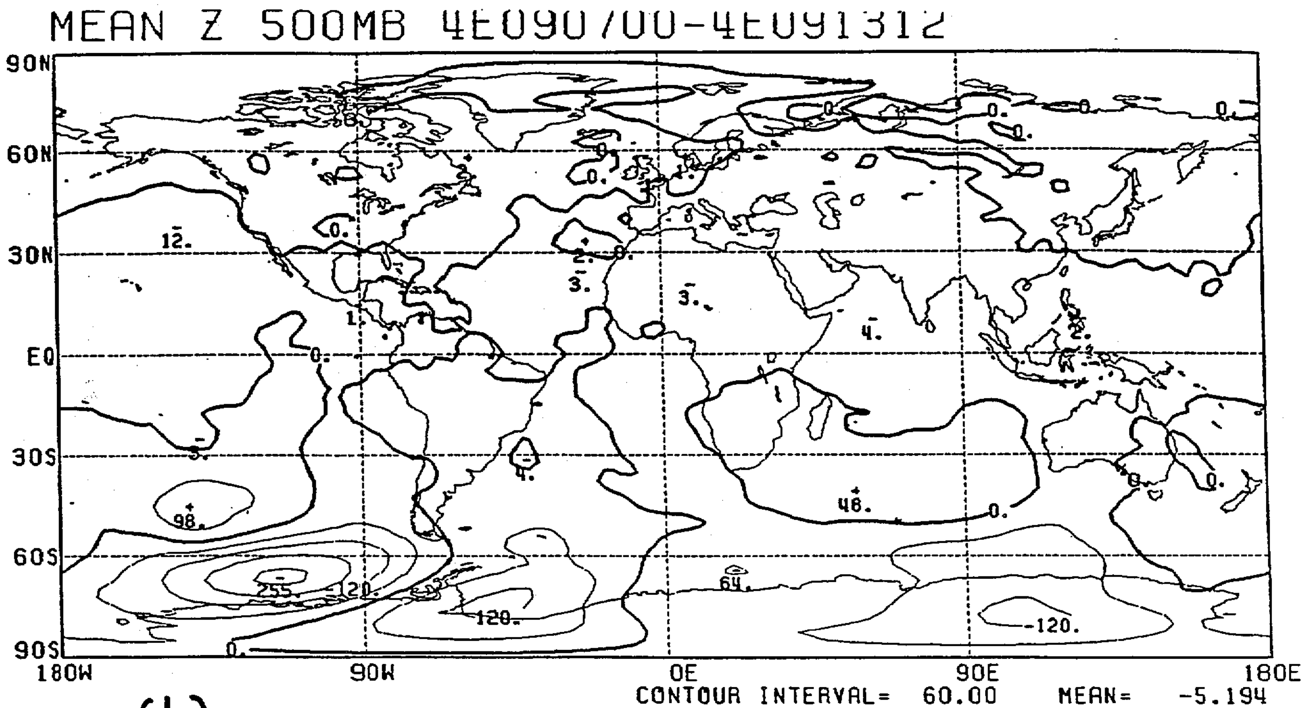


Figure 9. Same as Figure 6 except for (a) 1000 mb mean wind speed, (b) 1000 mb RMS wind speed, and (c) 1000 mb mean vector wind analyses

(a)



(b)

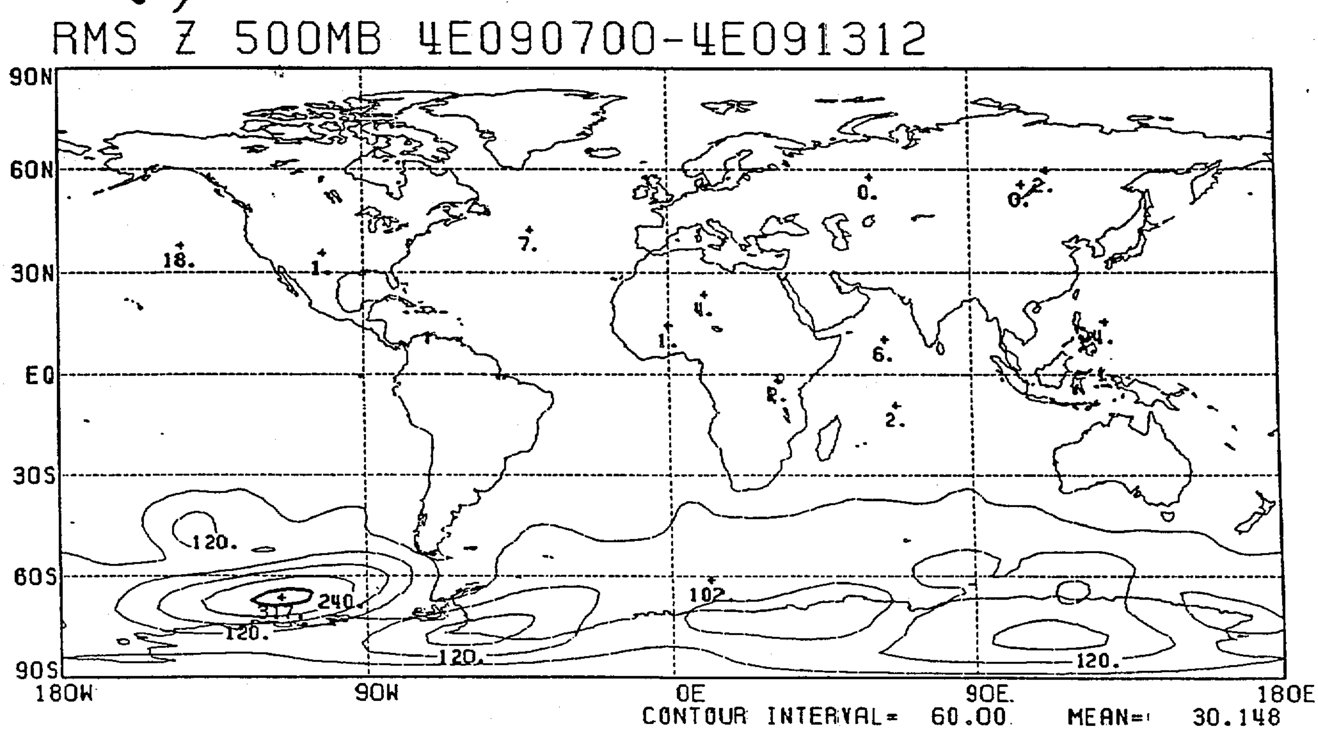


Figure 10. Same as Figure 6 except for (a) 500 mb mean height, (b) 500 mb RMS height analyses

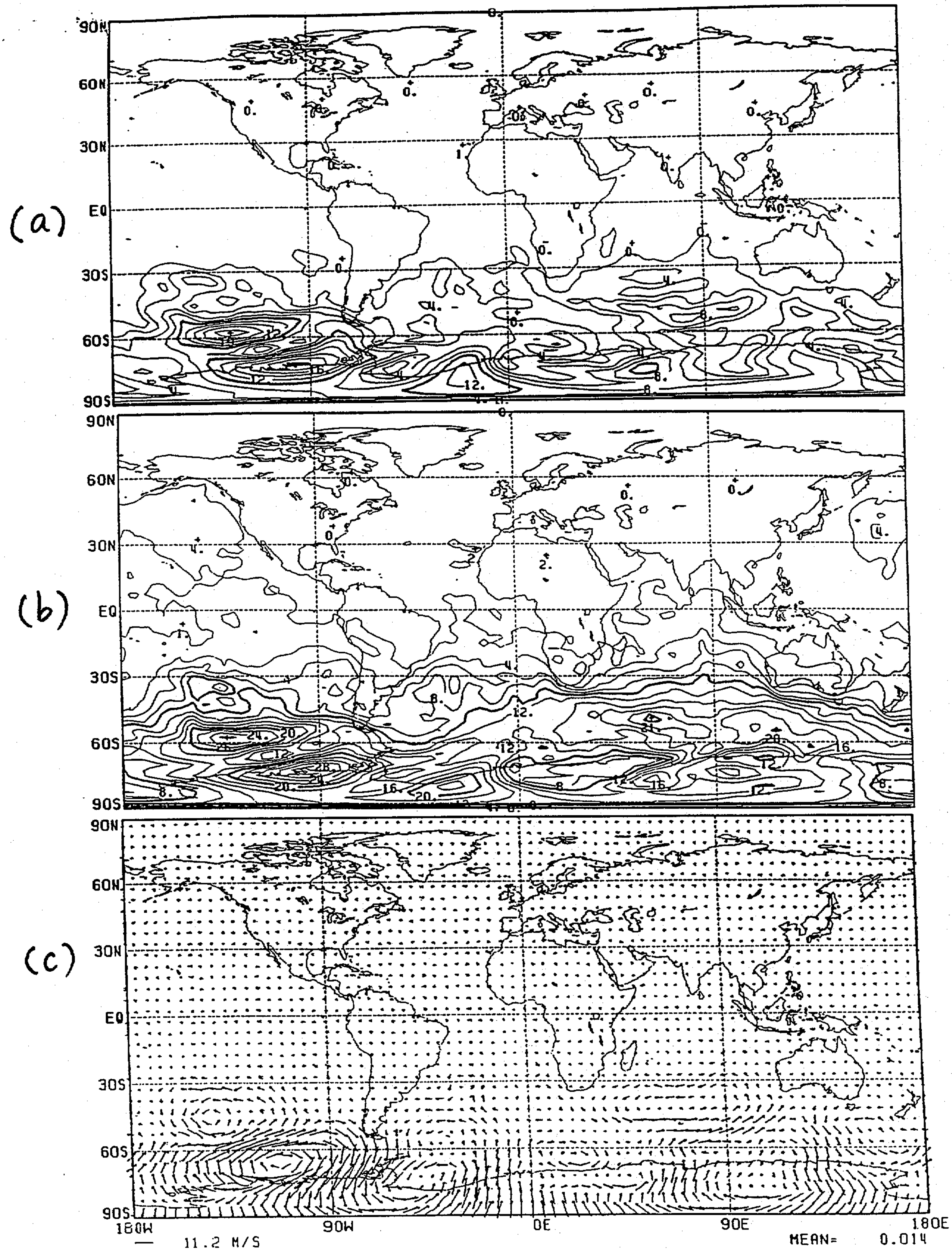


Figure 11. Same as Figure 6 except for (a) 500 mb mean wind speed, (b) 500 mb RMS wind speed, and (c) 500 mb vecotr wind analyses

at the 1000 mb level. The most striking feature is the dominant cyclonic center located just west of the Antarctic Peninsula with maximum mean and RMS height differences of 255 meters and 317 meters respectively (Figs. 10a and 10b). The accompanying mean and RMS wind speed differences are 19 m/s and 28 m/s (Figs. 11a and 11b), with a well defined cyclonic circulation (Fig. 11c). It should be mentioned that Ingleby and Bromley (1991) reported a 12 m/sec RMS vector wind difference between the SASS and NOSASS analyses at 700 mb (based on 16 analyses), with a corresponding maximum 14 mb mean sea level pressure difference near the region west of the Antarctic Peninsula.

4. Forecast Experiments

The results of the data assimilation experiments discussed above suggest that forecasts made with the SASS analyses should be an improvement in the Southern Hemisphere over the forecasts from the NOSASS analyses. The following discussions are based on results of two five- day forecast experiments in which the 0000 UTC, September 14, 1978 SASS analyses and NOSASS analyses (after 7 days of data assimilation) were used as the initial conditions. The forecast model used for the forecast experiments is identical to the model used for data assimilation previously discussed in Section 2. The results show that over all there are no significant differences in the Northern Hemisphere between the SASS and NOSASS forecasts, except for the QE-II storm case in which the SASS 48 hour forecasts are slightly better than the NOSASS forecasts in defining the center pressure intensity. These results will be discussed in a separate report later. In the following discussions, only results over the Southern Hemisphere will be presented.

The evaluation procedure consists of comparing forecasts with verifying analyses and with radiosonde observations. Specifically, the forecast sea level pressures are first verified subjectively with the SASS and NOSASS analyses, as well as the NMC's 1978 analyses. Anomaly correlations are then calculated between the forecasts and verifying analyses at 850 mb and 500 mb. Finally, errors in height and wind forecasts are evaluated at radiosonde locations in 30 degree latitude bands over several levels of the atmosphere.

a. Sea Level Pressures

The initial conditions of SASS and NOSASS sea level pressure analyses over the Southern Hemisphere for 0000 UTC, September 14, 1978 are shown in Figs. 12a and 12b. These initial conditions are the analyses after seven days of data assimilation, and are discussed earlier in Section 3. It should be remembered that the most striking features of the differences start from the southern tip of Chile and extend southward to the Antarctic region with a distinctly different flow pattern and a large sea level pressure difference between the two analyses. These features are of special significance to forecast verifications.

The 48-hour sea level pressure forecasts over the Southern Hemisphere for the SASS and NOSASS experiments are shown in Figs. 13a and 13b, and the 96-hour forecasts in Figs. 14a and 14b. The

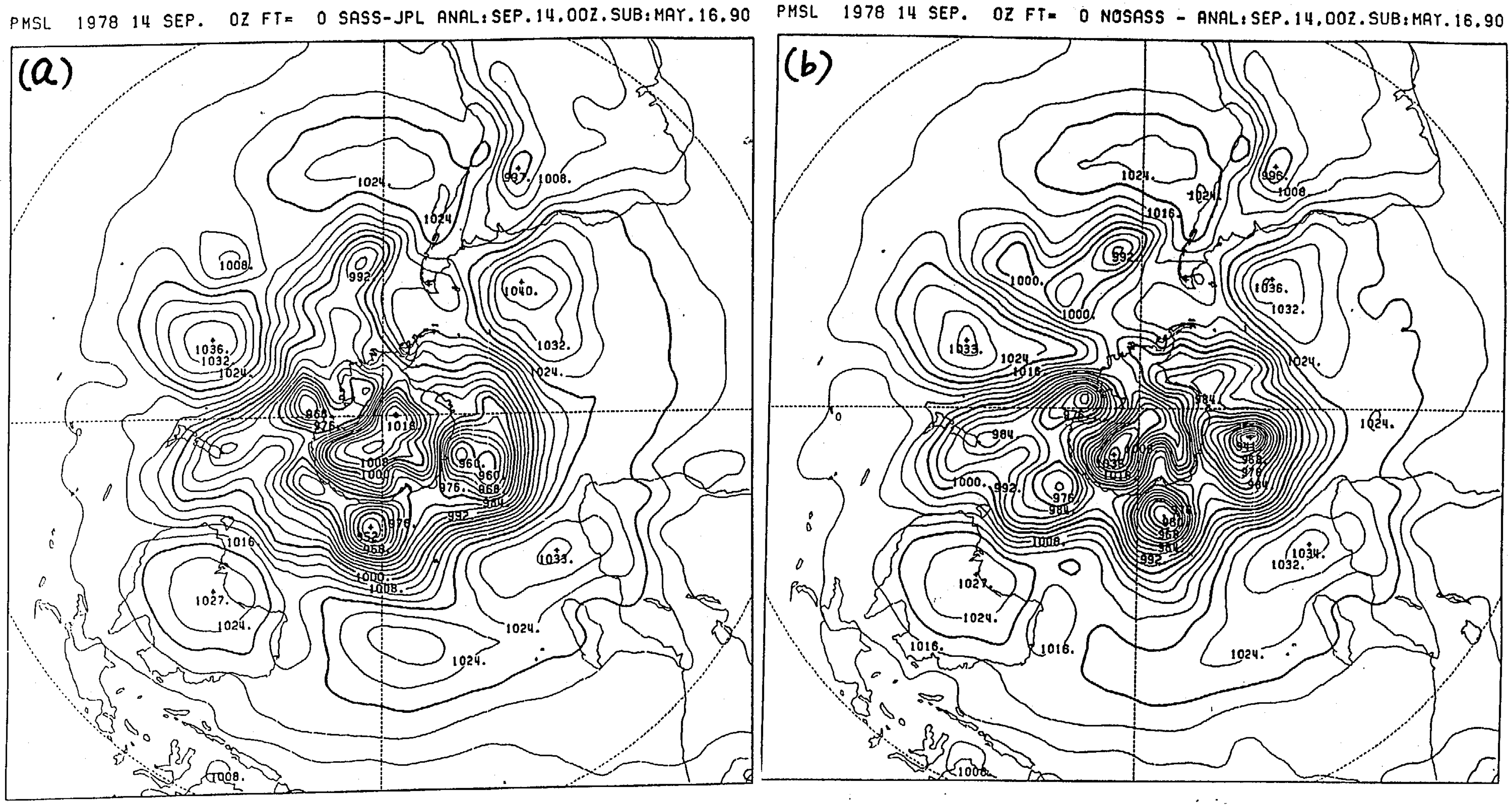


Figure 12. Initial analyses of Southern Hemispheric sea level pressure for (a) SASS, and (b) NOSASS forecast experiments valid at 0000 UTC, September 14, 1978

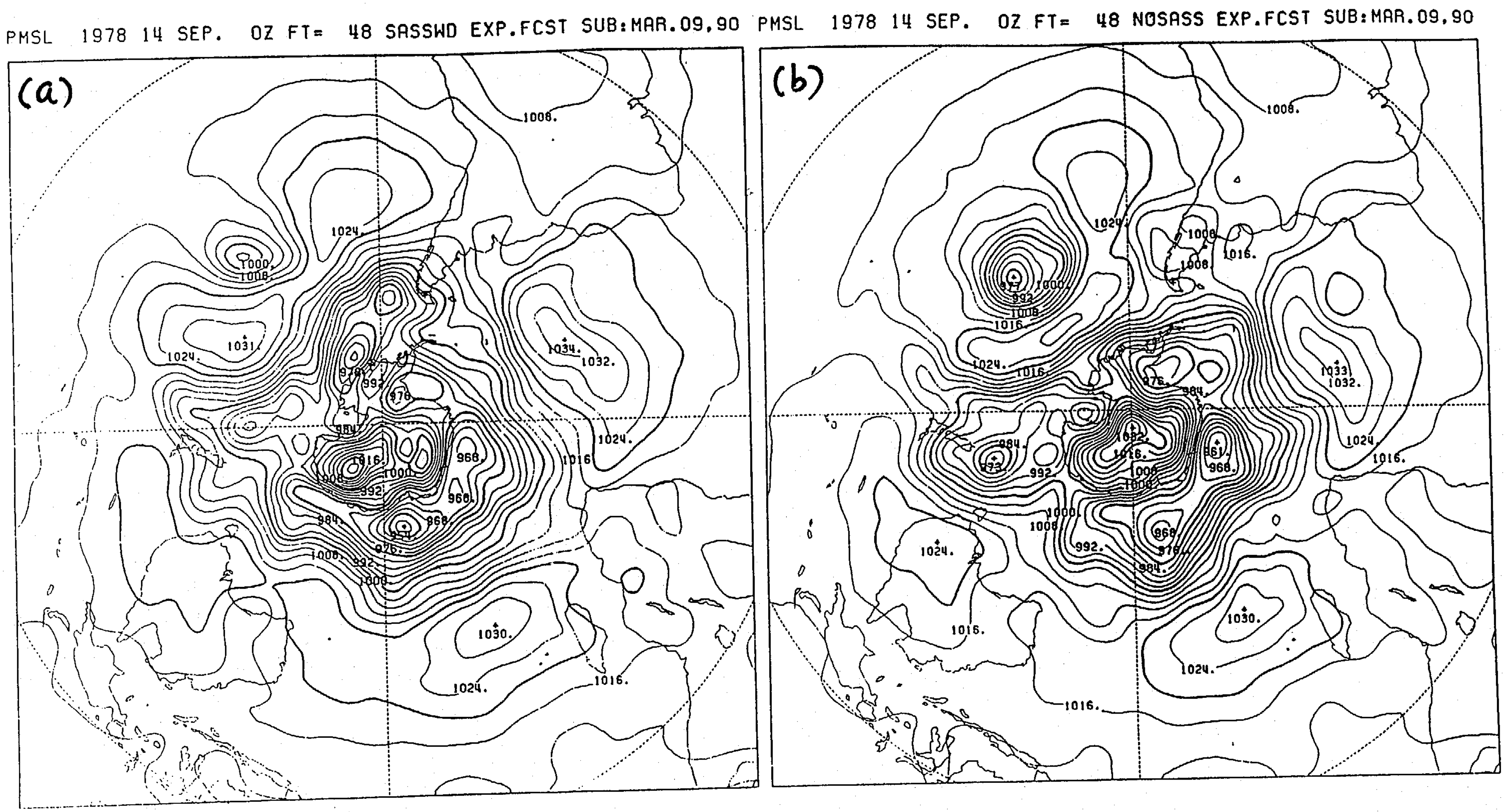


Figure 13. Forty-eight hour forecasts of Southern Hemispheric pressures for (a) SASS, and (b) NOSASS forecast experiments valid at 0000 UTC, September 16, 1978

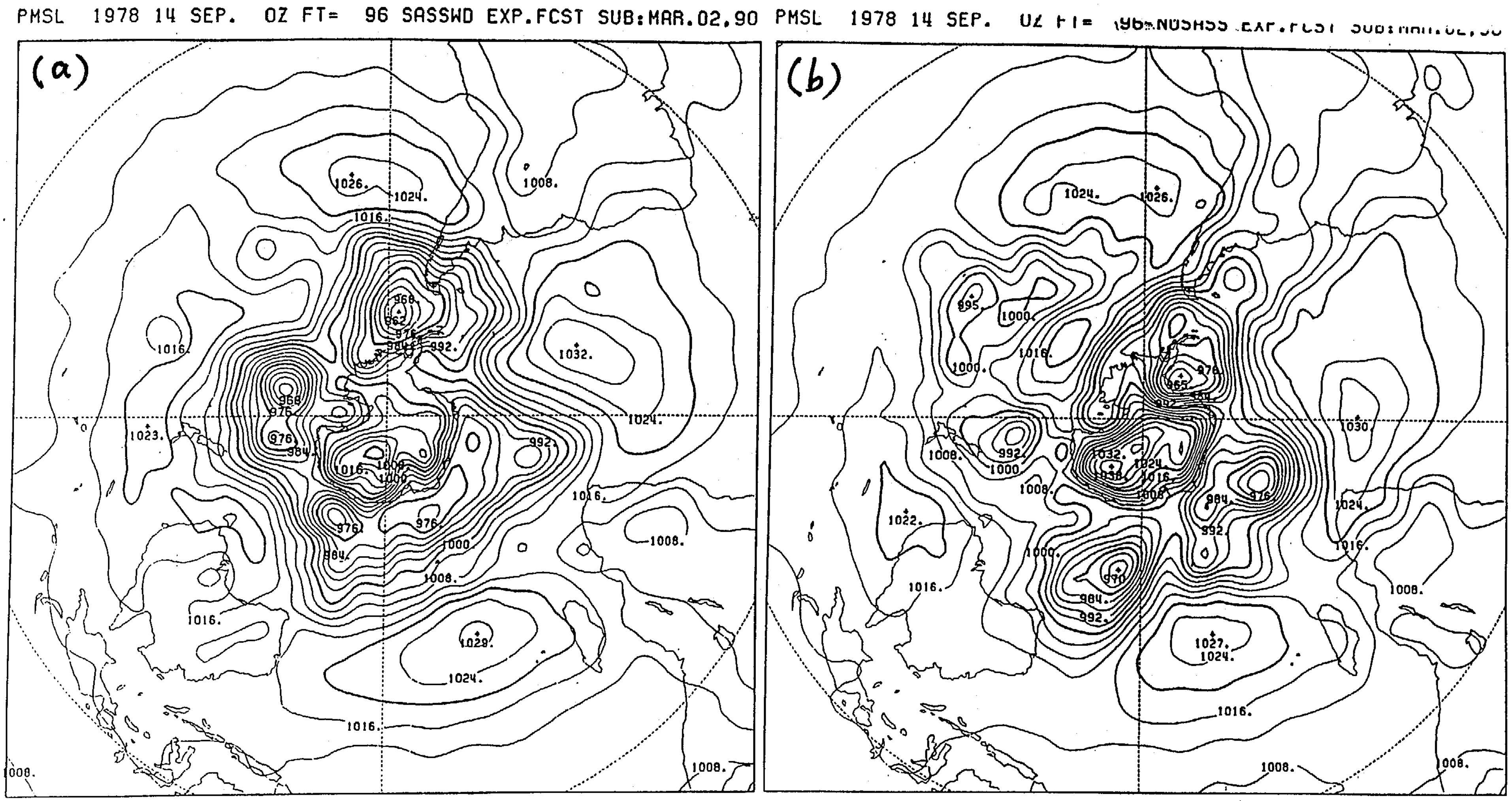


Figure 14. Ninety-six hour forecasts of Southern Hemispheric sea level pressures for (a) SASS, and (b) NOSASS forecast experiments valid at 0000 UTC, September 18, 1978

corresponding verifying analyses from the SASS and NOSASS assimilation are shown in Figs. 15 and 16. Comparison of the 48-hour forecasts with the verifying analyses shows, in general, that the SASS forecasts are in better agreement with the SASS analyses than the NOSASS analyses (comparing Fig. 13a with Figs. 15a and 15b). Similarly, NOSASS forecasts are in better agreement with the NOSASS analyses than the SASS analyses for the 48-hours forecast verification (comparing Fig. 13b with Figs. 15a and 15b). Because the SASS analyses are superior to the NOSASS analyses as has been established previously in Section 3, one may conclude that the SASS forecasts are better than the NOSASS forecasts. The same conclusions apply to the 96-hour forecasts (Figs. 14 and 16). Note that the large differences between the SASS and NOSASS forecasts of sea level pressures and their associated flow patterns extend from south western Chile to the Antarctic region of the oceans in the 48 and 96 hour forecasts. These areas correspond to those where the most striking differences exist in the two initial analyses.

The NMC's 1978 sea level pressure analyses are used to further assess the two forecasts. These analyses (Fig. 17a for 0000 UTC, September 16, 1978, and Fig. 17b for 0000 UTC, September 18, 1978) were generated by NMC's operational GDAS in 1978 (McPherson, et al, 1979), and used the same global data set as the NOSASS experiment. Therefore, differences between the assimilated analyses from the present NOSASS experiment and the NMC's 1978 analyses are due to the recent changes in the NMC's operational GDAS. Although there is generally good agreement in the gross synoptic features, detailed comparison reveals substantial differences in the sea level

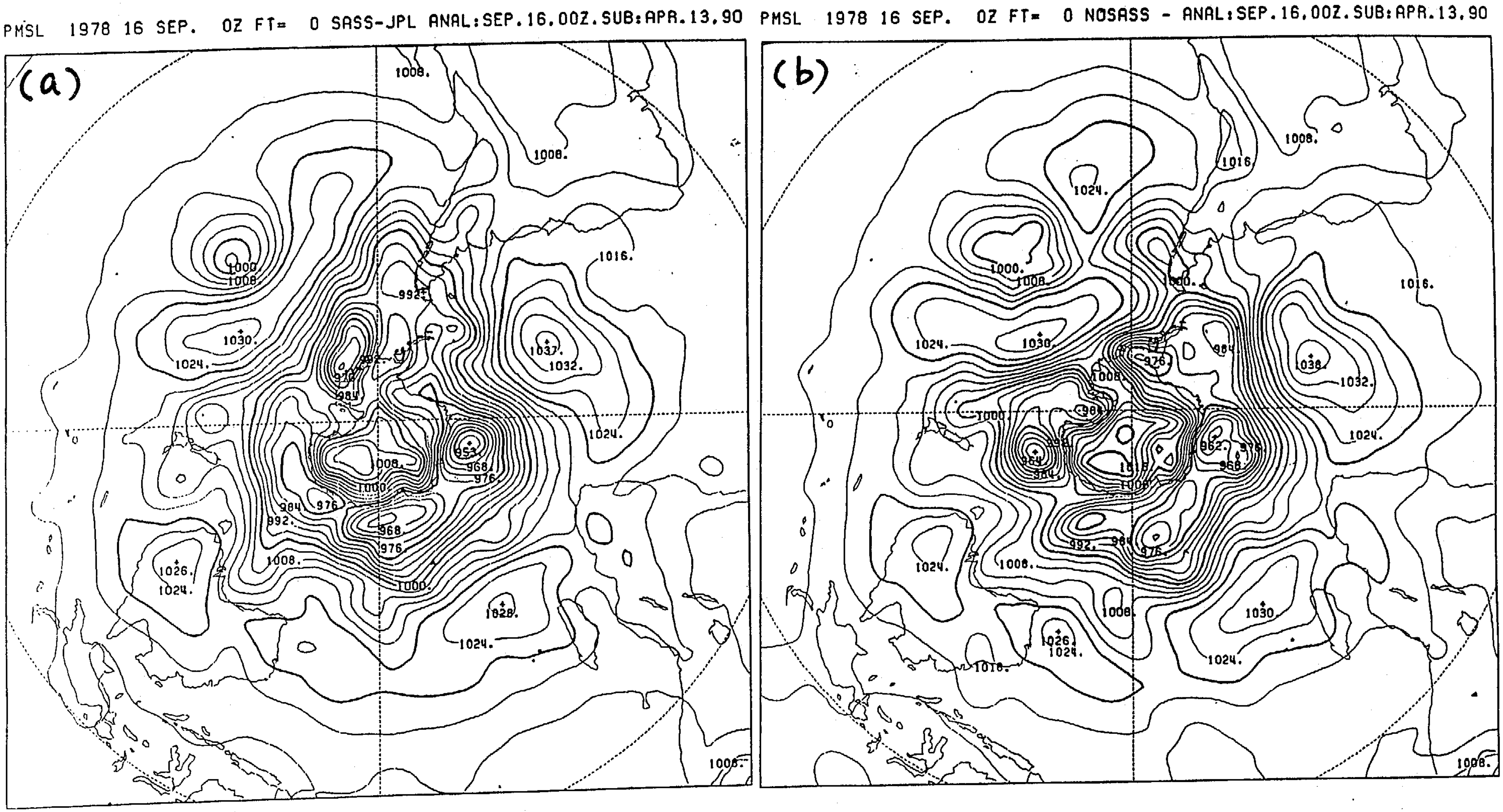


Figure 15. Verifying analyses of Southern Hemispheric sea level pressures based on (a) SASS, and (b) NOSASS analyses valid at 0000 UTC, September 16, 1978

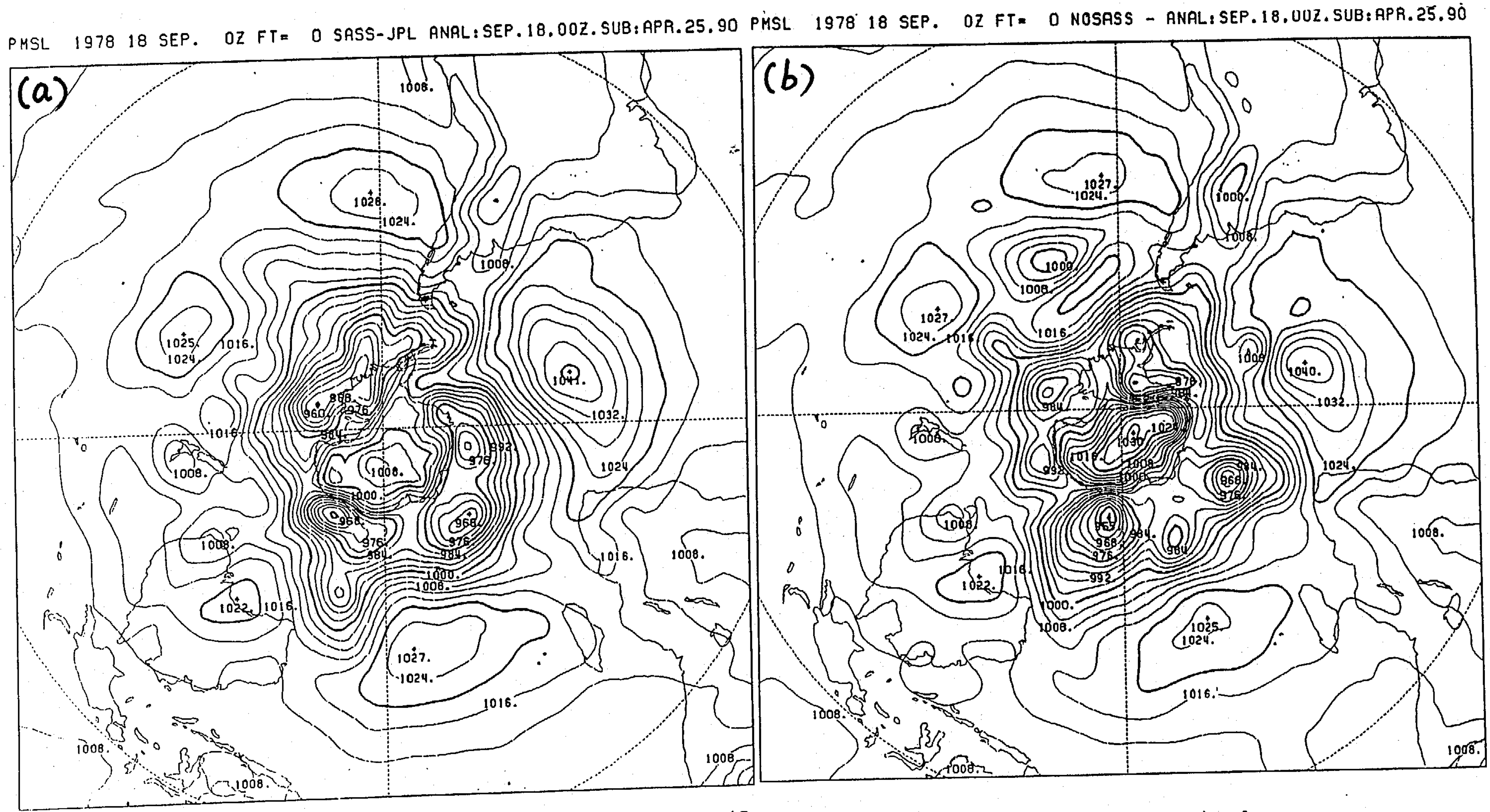


Figure 16. Same as Figure 15 except valid at 0000 UTC, September 18, 1978

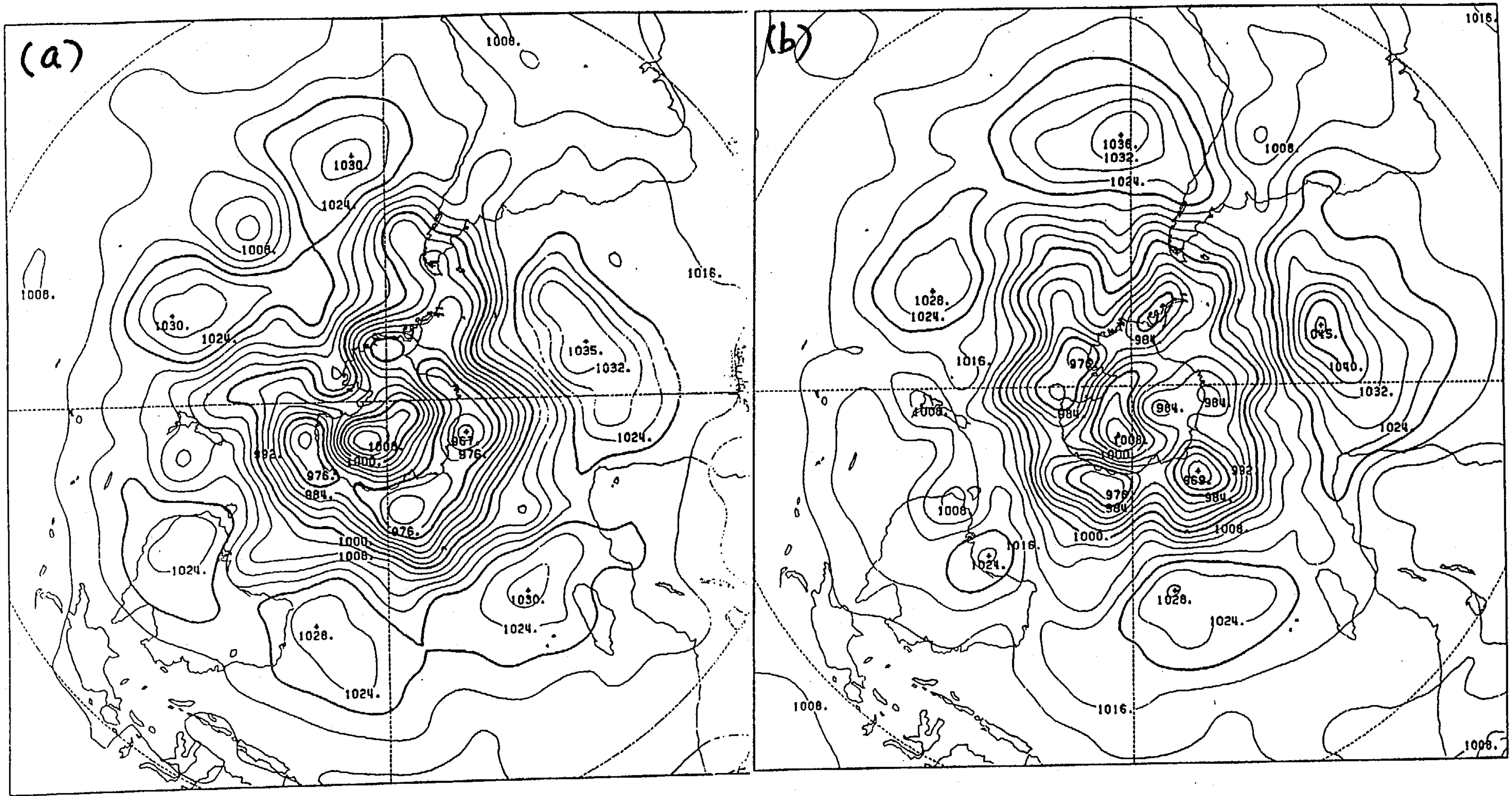


Figure 17. Verifying analyses of Southern Hemispheric sea level pressures for (a) 0000 UTC, September 16, 1978, and (b) 0000 UTC, September 18, 1978 based on the 1978 NMC analyses

pressures between the NOSASS assimilated analyses and NMC's 1978 analyses (comparing Fig. 15b with Fig. 17a, and Fig. 16b with Fig. 17b).

b. Anomaly Correlations

The anomaly correlation is another standard that may be used to quantitatively assess the accuracy of forecasts. It measures the degree of similarity between a forecast and some referenced analysis in which the climatological values are subtracted from the forecasts and analyses. Three verifying analyses are used for computing anomaly correlations: SASS, NOSASS and NMC's 1978 analyses. Note that anomaly correlations are calculated between 20 to 80 degree latitudes for Northern and Southern Hemispheres.

Figure 18 shows the results of anamoly correlations for the SASS and NOSASS forecasts based on SASS (Fig.18a), NOSASS (Fig. 18b), and NMC's 1978 (Fig. 18c) analyses at 850 mb and 500 mb levels. Over the Northern Hemisphere, the anomaly correlations based on the three analyses show that both the SASS and NOSASS forecasts are very comparable at 850 mb. The SASS forecasts, however, are slightly better than the NOSASS forecasts, especially at the 500 mb level.

Over the Southern Hemisphere, the anomaly correlations show that SASS forecasts are superior to NOSASS forecasts when compared to SASS analyses. On the other hand, when compared to the NOSASS analyses, NOSASS forecasts are better than the SASS forecasts. Since the SASS analyses are better than the NOSASS analyses, it is

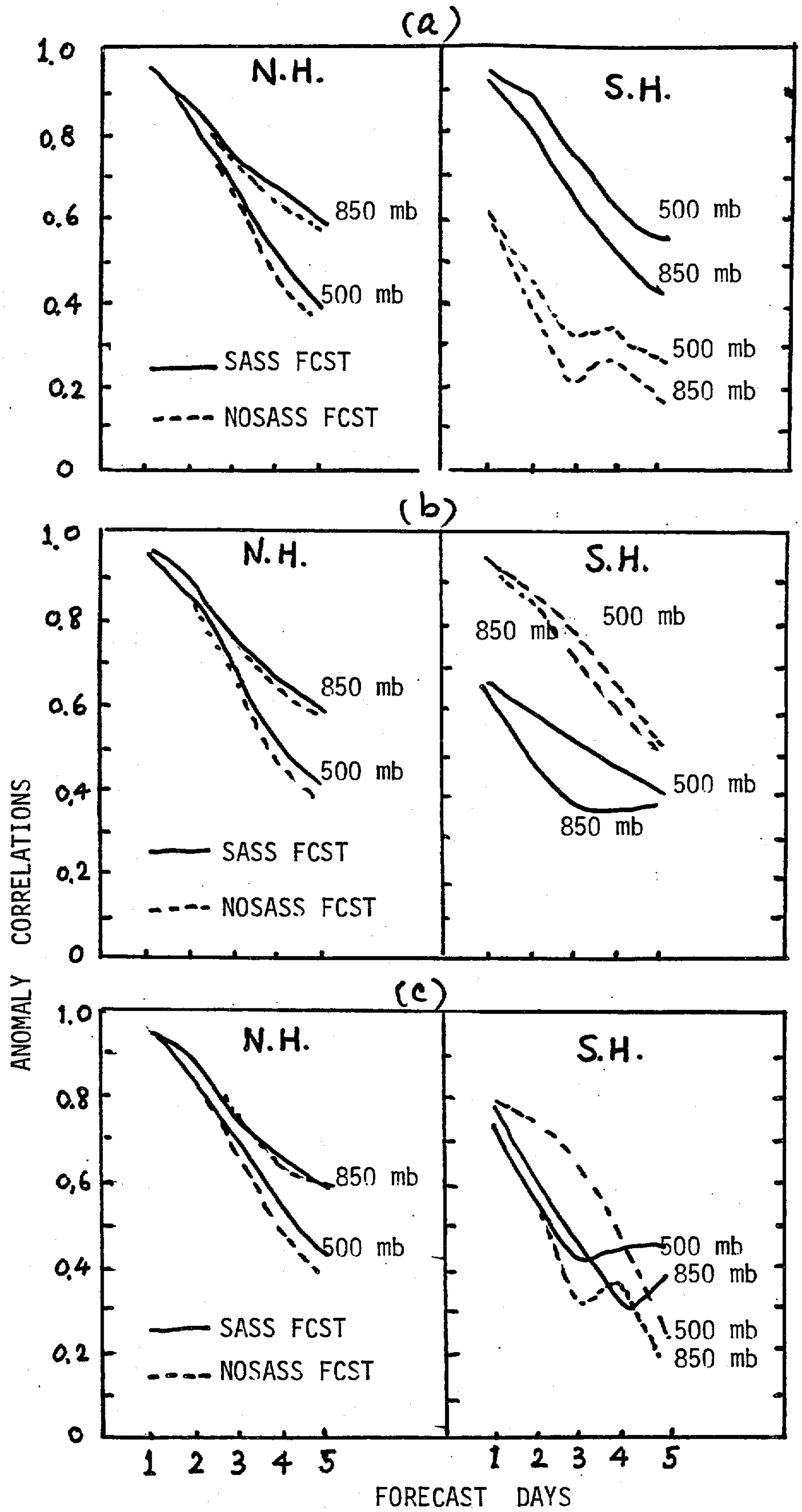


Figure 18. Height anomaly correlations at 850 mb and 500 mb over the Northern Hemisphere (left panel) and the Southern Hemisphere (right panel) for the SASS-FCST (solid lines) and NOSASS-FCST (dashed lines) based on three different verifying analyses; (a) SASS analyses, (b) NOSASS analyses, and (c) 1978 NMC analyses. SASS-FCST and NOSAS-FCST denote the same meanings as indicated in Figure 1.

thus concluded that the SASS forecasts are better than the NOSASS forecasts. This conclusion is certainly consistent with the previous results based on the comparison of sea level pressure forecasts between the two forecasts. Furthermore, based on NMC's 1978 analyses, the values of anamoly correlations (Fig. 18c) also show that SASS forecasts are slightly better than the NOSASS forecasts.

c. Radiosonde Statistics

The forecast verifications discussed thus far are computed on a regular grid. In this section, verifications will be computed at radiosonde locations over the Southern Hemisphere. In general, based on statistics of the forecast height and wind errors when compared with radiosondes, SASS forecasts are superior to the NOSASS forecasts throughout the five- days forecast period. Table 3 shows the root mean squared differences (RMSD) of heights and winds between radiosonde observations and 48 hour forecasts from SASS and NOSASS forecast experiments. In general, the SASS height and wind forecasts are in better agreement with the radiosonde observations from 1000 mb to 250 mb over most of the latitude bands. Between 1000 mb and 850 mb the improvement in the SASS forecasts are particularly evident. It should be pointed out that Ingleby and Bromley (1991) also found a slight improvement in the 24- hour SASS forecast when compared with radiosonde observations over the Southern Hemisphere.

Comparison of 96 hour forecasts with radiosonde observations shows even more conclusively that the SASS forecasts are superior

Table 3. Root mean squared difference (RMSD) in z - height (meters), u - wind (m/s), v - wind (m/s) between 48 hour forecasts and radiosonde observations. The number inside the bracket indicates the number of radiosondes used in the calculation of the statistics.

SASS Wind Forecast		1000 mb	850 mb	500 mb	250 mb
z	90S- 60S	---	(7) 94.8	(10) 300.0	----
	60S- 30S	(5) 29.1	(23) 33.8	(23) 83.4	(13) 77.3
	30S- 0	(10) 13.6	(38) 16.3	(37) 26.4	(34) 54.9
u	90S- 60S	----	(7) 7.46	(10) 10.63	----
	60S- 30S	(5) 4.64	(23) 7.17	(23) 13.13	(13) 19.36
	30S- 0	(10) 4.95	(38) 4.26	(37) 6.44	(34) 6.68
v	90S- 60S	-----	(7) 12.22	(10) 12.48	-----
	60S- 30S	(5) 2.69	(23) 7.94	(23) 10.90	(13) 10.44
	30S- 0	(10) 3.42	(38) 4.41	(37) 7.41	(34) 15.33

Control Forecast		1000 mb	850 mb	500 mb	250 mb
z	90S- 60S	------	(7) 120.0	(10) 330.3	----
	60S- 30S	(5) 44.5	(23) 76.2	(23) 136.2	(13) 99.9
	30S- 0	(10) 20.4	(38) 21.2	(37) 38.6	(34) 60.9
u	90S- 60S	------	(7) 12.0	(10) 15.85	----
	60S- 30S	(5) 6.74	(23) 7.86	(23) 14.87	(13) 18.11
	30S- 0	(10) 5.37	(38) 4.07	(37) 7.39	(34) 6.82
v	90S- 60S	------	(7) 9.98	(10) 13.16	-----
	60S- 30S	(5) 6.68	(23) 10.36	(23) 13.65	(13) 10.52
	30S- 0	(10) 3.18	(38) 5.31	(37) 7.03	(34) 14.50

Table 4. Root mean squared difference (RMSD) in z - height (meters), u - wind (m/s), v - wind (m/s) between 96 hour forecasts and radiosonde observations. The number inside the bracket indicates the number of radiosondes used in the calculation of the statistics.

SASS Wind Forecast

		1000 mb	850 mb	500 mb	250 mb
z	90S- 60S	---	(7) 64.1	(9) 99.2	----
	60S- 30S	(5) 69.5	(24) 68.5	(22) 107.1	(10) 95.9
	30S- 0	(12) 33.8	(42) 24.8	(44) 48.8	(42) 78.6
u	90S- 60S	----	(7) 9.25	(9) 10.03	----
	60S- 30S	(5) 5.24	(24) 8.46	(22) 11.96	(10) 18.90
	30S- 0	(12) 6.26	(42) 6.30	(44) 9.34	(42) 12.50
v	90S- 60S	-----	(7) 8.82	(9) 9.02	-----
	60S- 30S	(5) 3.39	(24) 7.50	(22) 11.98	(10) 13.29
	30S- 0	(12) 5.98	(42) 4.69	(44) 7.90	(42) 11.35

Control Forecast

		1000 mb	850 mb	500 mb	250 mb
z	90S- 60S	------	(7) 153.7	(9) 199.8	----
	60S- 30S	(5) 57.7	(24) 76.2	(22) 123.0	(10) 153.8
	30S- 0	(12) 49.1	(42) 31.3	(44) 54.3	(42) 88.9
u	90S- 60S	------	(7) 4.39	(9) 11.98	----
	60S- 30S	(5) 4.86	(24) 9.49	(22) 15.32	(10) 19.18
	30S- 0	(12) 5.51	(42) 7.90	(44) 11.93	(42) 13.67
v	90S- 60S	------	(7) 10.03	(9) 7.60	-----
	60S- 30S	(5) 6.73	(24) 8.50	(22) 12.72	(10) 18.04
	30S- 0	(12) 7.66	(42) 5.58	(44) 9.54	(42) 14.00

with much smaller RMSD errors at all levels and over all of the southern latitudes (Table 4). Results from Tables 3 and 4 clearly show that the impact of the scatterometer wind data on the forecasts extends from the sea surface to deep layers in the atmosphere, and has improved short range weather forecasts.

5. Summary and Conclusions

Several assimilation and forecast experiments have been conducted to investigate the impact of 1978 Seasat scatterometer wind data, on the present NMC's numerical weather forecast system. The scatterometer wind data were assimilated every six hours using the NMC's operational GDAS for a two- week period. The impact of the data on the synoptic analyses was assessed in terms of differences between the SASS (including scatterometer winds) and NOSASS (without scatterometer winds) assimilation for two selected synoptic times, 0000 UTC, September 14, and 0000 UTC, September 19, 1978. The impact of the data on the analyses of the mean state of the atmosphere was evaluated using the total 52 analyses from the two weeks period to calculate the mean and RMS differences between the two assimilation experiments. To address the impact of data on the short range weather forecasts, two five-day forecasts were made using as initial conditions the SASS and NOSASS analyses valid at 0000 UTC, September, 14, 1978. The forecasts were compared with verifying analyses from the SASS and NOSASS analyses, the NMC's 1978 analyses, and with radiosonde observations.

Results of the assimilation experiments show that inclusion of the Seasat scatterometer winds has a very large impact in the analyses of wind and height fields over the Southern Hemisphere, with little impact in the Northern Hemisphere. Based on the total 52 analyses, large mean and RMS differences of winds (greater than 15 m/s) and heights (greater than 200 meters) in the lower troposphere are found over the Southern Hemisphere. Similarly, differences for the two selected synoptic periods show that inclusion of the scatterometer winds produced an increase in the wind speeds by more than 25 m/sec in the 1000 mb winds, and to an intensification of the surface cyclones by more than 300 meters in 1000 mb heights (or greater than 35 mb in central pressures) accompanied by clearly defined cyclonic circulations. These large values of the differences are in the Southern Hemisphere and are in association with the areas of mid-latitude storm tracks. Comparison of the first guess fields from the SASS and NOSASS assimilation with radiosonde observations for the two selected periods shows that the scatterometer data clearly have a positive impact on the analyses by reducing the first guess errors of the model 6 hourly forecasts.

Results of forecasts out to five days show that scatterometer winds have little overall impact in the Northern Hemisphere, except for the QE-II storm case in which the SASS forecasts are slightly better in forecasting the intensity of the center pressures within the 48 hours of forecast period. These results are to be discussed in a separate report.

Over the Southern Hemisphere, there are large differences the between the SASS and NOSASS forecasts. The verification of 24-hour, 48- hour and 96- hour forecasts against SASS analyses and NOSASS analyses show that: the SASS forecasts compare better with the SASS analyses than the NOSASS analyses; On the other hand, the NOSASS forecasts are in better agreement with the NOSASS analyses than the SASS analyses. Since the SASS analyses are better than the NOSASS analyses, it is concluded that the SASS forecasts are superior to the NOSASS forecasts. The verification of forecasts up to 96 hours against the 1978 NMC analyses also suggests that the SASS forecasts are slightly better than the NOSASS forecasts. Results from the Comparison of the forecasts with the radiosonde observations are more conclusive; it clearly shows that the SASS forecasts are superior to the NOSASS forecasts, with much smaller errors in heights and winds from 1000 mb to 250 mb for the SASS forecasts up to 96 hour over the Southern Hemisphere.

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