SIMULATIONS OF THE MONTHLY MEAN ATMOSPHERE FOR FEBRUARY 1976 WITH THE GISS MODEL[1, 2]

by

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ABSTRACT

Three monthly mean simulations of the global atmosphere were computed for February 1976 with the GISS model from observed initial conditions on the first day of the month. In a replication experiment, two of these computations generated slightly different monthly mean states, apparently due to the schedule of interruptions on the computer. The root-mean-square errors of replication over the Northern Hemisphere were found to be about 2 mb, 20 m, and 1 K for sea-level pressure, 500 mb height, and 850 mb temperature, respectively. The monthly mean 500 mb forecast results for February 1976 over the Northern Hemisphere are consistent with those from earlier GISS model experiments, and again indicate some predictive skill at that level. Use of the observed monthly mean sea-surface temperature (SST) field for February 1976 in place of the climatological SST field for February resulted in slightly improved simulations over the globe and Northern Hemisphere, but not over smaller subregions.

1. Introduction

This study is a continuation of an effort to determine if a global general circulation model (GCM) initialized with data for the first day of a month can simulate realistically the mean state of the atmosphere for that month. Earlier experiments in monthly mean prediction (Spar et al., 1976; Spar, 1977) with the GCM known as the GISS[3] model (Somerville et al., 1974) have indicated that, despite the well-known decay of predictability, time-averaging of a forecast history over a month may result in some modest improvement over climatology. However, that preliminary assessment was based on only three cases: January of 1973, 1974, and 1975. In this note we present the results of still another set of monthly mean simulations with the model, for February 1976.

As in the earlier computations, the February 1976 global data set used both for initialization (00 GMT, 1 February) and verification was provided by the National Meteorological Center (NMC) from its operational analysis archive. A climatological mean February atmospheric global data set employed in part of the forecast evaluation was obtained from the National Center for Atmospheric Research (NCAR), which also furnished the

[3] The GISS model was developed at the Goddard Institute for Space Studies.

climatological mean February sea-surface temperature (SST) field (Washington and Thiel, 1970) used in two of the three separate February 1976 simulations. In the third computation, a monthly average SST field for February 1976, based on satellite scanning radiometer data provided by the National Environmental Satellite Service (NESS), replaced the climatological SST field.

The first two simulations, identified below as F1 and F2, were computed as part of a replication experiment. Run on the same IBM 360/95 computer with identical programs, boundary conditions, and initial conditions, F1 and F2 presumably differ only because of differences in the schedule of interruptions and restarts necessitated by other demands on the computer during the month-long forecast. A comparison of forecasts F1 and F2 thus provides a measure of the reproducibility of results. The third simulation, designated F3, gives some indication, when compared with F1 or F2, of the influence of ocean surface temperature variations on the predicted monthly mean atmospheric fields.

As discussed by Dickson (1976), February 1976 was characterized by unusually warm weather over most of the United States, where new February high temperature records were set at numerous locations, notably in the east and southwest. This high temperature anomaly was associated with the development during the month of a persistent, fast, flat zonal tropospheric flow pattern in middle and high latitudes over the western half of the Northern Hemisphere, accompanied by a northward shift of the strongest westerlies. Only over eastern Europe and western Asia did the hemispheric mean tropospheric circulation for the month exhibit the large amplitude short wave pattern normally associated with strong meridional thermal advection. Over North America, on the other hand, a straight westerly current of mild maritime air from the Pacific persisted for most of the month, with little southward transport of cold continental air from Canada. As a result, temperatures remained abnormally high during the month over much of North America. This monthly mean circulation pattern and the associated temperature anomaly were not in place at the beginning of the month, but developed after the first week. Thus, February 1976 is a challenging test of the ability of the model to simulate a major circulation and temperature anomaly from initial conditions in which the monthly mean pattern was not yet apparent.

2. Replication Experiment

As in our earlier forecast studies, the results of the February 1976 simulation experiments are presented below in terms of energetics, mean wind profiles, forecast error statistics, and monthly mean synoptic maps, with emphasis on the Northern Hemisphere.

In the replication experiment, the two monthly mean simulations for February 1976, designated F1 and F2, were carried out with the same program, and with identical initial and boundary conditions, on the same computer. One might therefore expect identical results from these two calculations. However, as it was not possible to carry out such a long simulation run in one continuous operation at GISS, because of other demands on the computer, the month-long forecasts were computed piecemeal, with several interruptions and restarts. The interruption schedule was indeed different for F1 and F2, and this may account for the differences between the two results. Because of the cycling schedule in the model program, and the fact that not all calculations are identical in each time step (Somerville et al., 1974), it is apparently possible for small differences to develop between two long, interrupted forecast runs. The purpose of this experiment was to determine the magnitude of these differences.

In Table 1 are shown the forecast (F1 and F2) and observed (O) global and northern hemisphere mean energetics for February 1976. P_M and K_M represent the mean

Table 1. Zonal available potential energy (P_M), zonal kinetic energy (K_M), and eddy available potential energy (P_E) and eddy kinetic energy (K_E) of standing waves only, for February 1976 over the Northern Hemisphere and the globe, integrated up to the 120 mb level for forecasts F1 and F2 and the observed (O) mean monthly atmosphere. Units: 10^5 J m^{-2}.

	Northern Hemisphere			Globe		
	F1	F2	O	F1	F2	O
P_M	58.9	58.0	49.8	42.3	41.8	35.9
K_M	8.56	8.42	7.21	6.69	6.61	5.97
P_E	2.35	2.45	3.71	1.69	1.71	2.29
K_E	1.14	1.31	2.23	0.91	1.00	1.54

zonal available potential energy and mean zonal kinetic energy, respectively, integrated up to approximately the 120 mb level (the base of the highest model layer), while P_E and K_E represent the corresponding eddy energies for the monthly mean standing waves only, all in units of 10^5 J m^{-2}. (For further details on the model energetics, see Somerville et al., 1974; Tenenbaum, 1976; Spar et al., 1976; Spar, 1977).

From Table 1 it is clear that the forecast mean energies are not identical in the two simulations. However, the differences between F1 and F2 are small relative to the "errors" of either forecast as measured against the "observed" atmosphere. The relative discrepancy between the corresponding energies of F1 and F2 is only about 10% of the error, with the maximum difference (17% of the error) in the eddy kinetic energy over the Northern Hemisphere.

As in the previous monthly mean forecasts (Spar et al., 1976; Spar, 1977), the GISS model overpredicts the zonal mean kinetic and potential energies and underpredicts the eddy energy. These results are not unexpected, as the model is known to generate Arctic winter temperatures that are too low due to its underestimate of the eddy heat transport to high latitudes. The resulting overestimate of the meridional temperature gradient produces excessive zonal available potential energy, as well as excessive westerly winds and zonal kinetic energy. The underestimate of eddy energies is characteristic of all coarse-grid GCM's. (With respect to the eddy energies, the results for February 1976 are not strictly comparable to those previously published, as the latter included the 12-hourly transient eddy energies averaged over the month, while in the present study only the eddy energies of the monthly mean state, i.e., of the standing eddies, are considered.)

The predicted (F1 and F2) mean meridional profiles of the vertically-integrated zonal wind for the nine model layers up to the 10 mb level are shown in Figure 1, together with the observed profile based on the February 1976 NMC global analyses. While the two simulations lie very close to each other, they do differ in some details. Thus, F1 indicates a mean wind maximum of 20.1 ms^{-1} at latitude 34^{o} N while F2 shows a maximum of 19.7 ms^{-1} at latitude 38^{o} N. The observed mean wind profile for the Northern Hemisphere shows that both computations seriously overpredict the maximum mean westerlies in middle latitudes, which reached only 15.1 ms^{-1} at latitude 38^{o} N, while underpredicting the westerlies in higher latitudes. In the Southern Hemisphere both forecasts of the maximum mean westerlies lie closer to

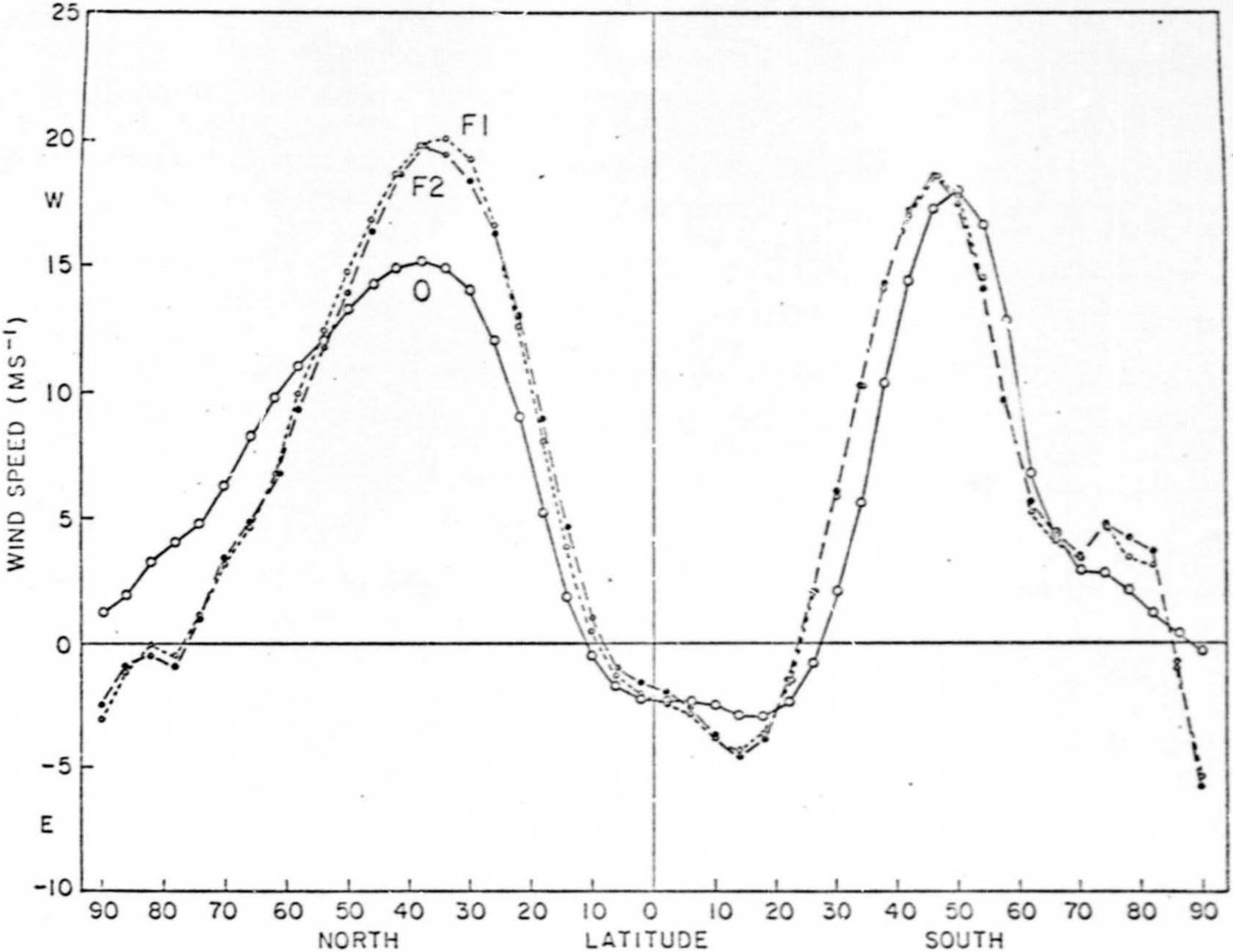

Fig. 1. Mean meridional profiles of vertically averaged mean zonal winds for February 1976. F1 and F2 represent the model simulations, and O is the observed profile.

the observed value, but both are shifted one grid length (4°) too far north.

Both the F1 and F2 simulations generate a west wind maximum at the nominal 175 mb level of the model at latitude 30° N in the mean meridional zonal wind cross-section (not shown). The location of the predicted sub-tropical jet stream is in good agreement with the observed jet, which is also at 30° N. However, the predicted wind maxima are 36.5 ms^{-1} for F1 and 35.5 ms^{-1} for F2, while the observed mean maximum is 35.1 ms^{-1}. The differences between the two simulations, as well as their deviations from the observed wind profile, are illustrated in Figure 2, which shows the three vertical profiles at latitude 30° N. Here it can be seen that forecast differences greater than 1 ms^{-1} in the monthly mean zonal winds may result purely from computational discrepancies. The observed wind profile in Figure 2 further illustrates the fact that both forecast computations overpredicted the mean westerlies at all levels, although the error at the jet stream level is quite small.

The discrepancies between forecasts F1 and F2 may also be expressed in terms of the root-mean-square (rms) differences and S1 comparison scores (Teweles and Wobus, 1954) for various fields. (For both statistics, perfect identity of fields is represented by values of zero. However, an S1 score of 20 is commonly rated as "virtually perfect" by NMC forecasters, while an S1 score greater than 70 is generally considered "worthless.") In Table 2 these statistics are shown for seven regions of the earth: (1) the globe; (2) the Northern Hemisphere; (3) the "tropics" between latitudes 22° N and 22° S; (4) an East Pacific-United States band (latitudes 30° N-54° N, longitudes 75° W-180°); (5) "North America" (latitudes 30° N-70° N, longitudes 75° W-130° W); (6) the "United States" (latitudes 30° N-54° N, longitudes 75° W-130° W); and (7) "Europe" (latitudes 34° N-86° N, longitudes 10° W-40° E). The rms differences and S1 comparison scores for F1 vs. F2 are shown in Table 2 for sea-level pressure and 500 mb height for all seven regions (with the omission of S1 scores for region 4). The rms differences of 850 mb temperatures are shown only for regions 2, 4, and 6.

Table 2 provides a provisional estimate of the minimal error in a monthly mean forecast that can be attributed to computational uncertainty alone, i.e., the error resulting purely from the inability of the computer system to replicate perfectly a monthly mean simulation from identical initial and boundary conditions. (It does not, of course, reflect that additional computationa

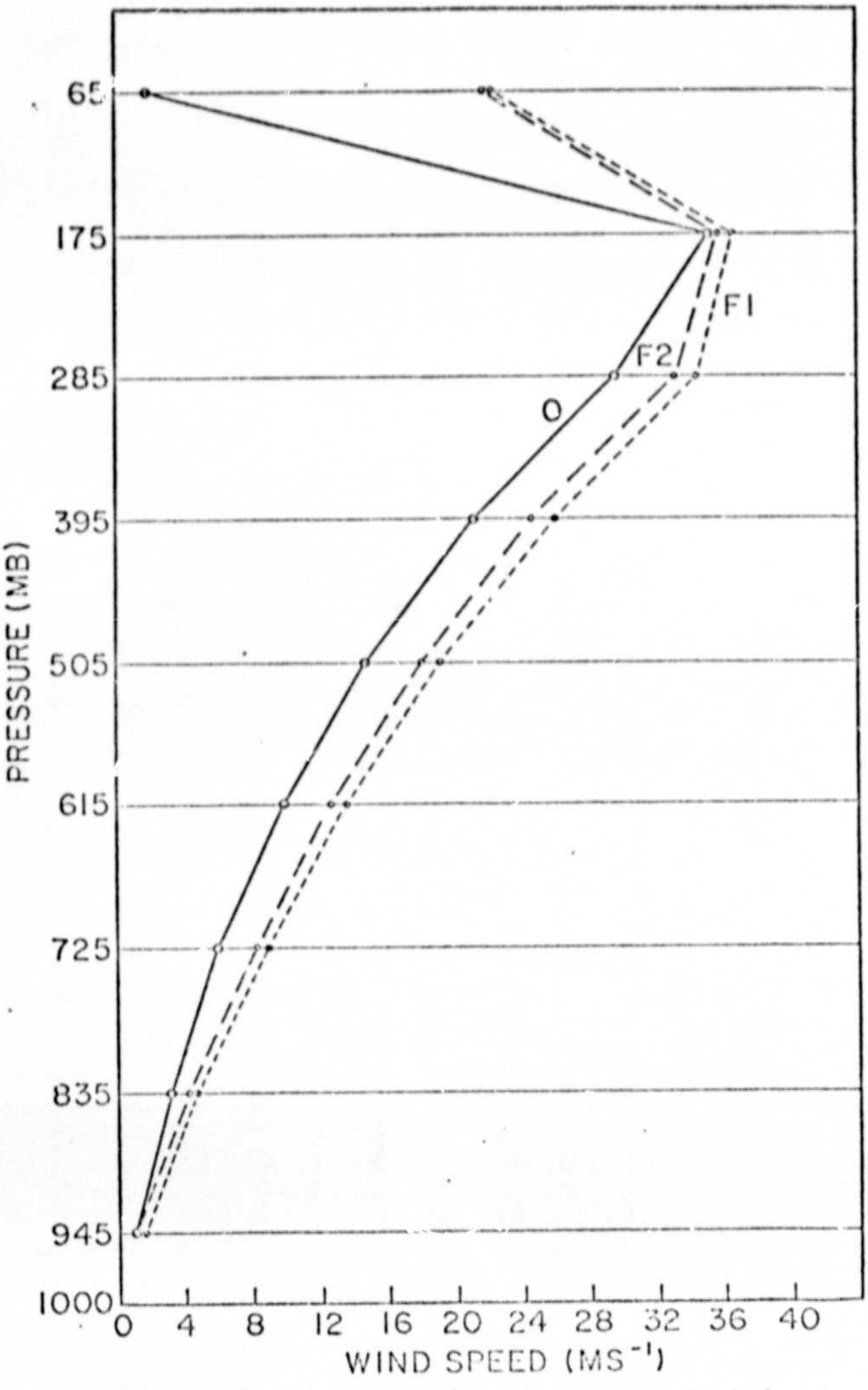

Fig. 2. Vertical profiles of mean zonal winds at latitude 30°N for February 1976. F1 and F2 denote model simulations. O is the observed profile.

Table 2. Root-mean-square (rms) differences and S1 comparison scores for February 1976 forecasts F1 vs. F2.

	Sea-level Pressure		500 mb Height		850 mb Temperature
Region	rms (mb)	S1	rms (m)	S1	rms (K)
1. Globe	1.5	38	16	21	
2. Northern Hemisphere	1.8	43	19	23	1.2
3. Tropics	0.8	37	5	33	
4. E. Pacific-U. S.	2.1		28		1.2
5. North America	2.5	51	26	20	
6. United States	2.2	48	28	16	1.4
7. Europe	2.1	43	19	25	

uncertainty associated with the existence of alternative numerical approximations.) For sea-level pressure, 500 mb height, and 850 mb temperature, these minimal rms errors are approximately 2 mb, 20 m, and 1 K for the Northern Hemisphere, while the minimal S1 scores for sea-level pressure and 500 mb height are approximately 40 and 20, respectively, over the hemisphere. For the present, these may be regarded as the irreducible errors in the monthly mean forecasts computed with the GISS model.

3. Forecast Verification Results

The forecast verification scores for F1 and F2, based on the "observed" monthly mean state for February 1976 as derived from 12-hourly operational NMC analyses, are listed in Table 3. Also shown are the scores for a "forecast" of "Climatology" (M), based on a climatological mean February data set provided by NCAR. The verification regions are the same as in Table 2.

As might have been anticipated from Table 1, the errors of the F1 and F2 simulations are similar, but not identical. Over the whole Northern Hemisphere, the differences between F1 and F2 scores are negligible. Thus, for example, the hemispheric rms errors in sea-level pressure and 850 mb temperature are the same (8.8 mb and 4.4 K) for both, and the hemispheric rms errors in 500 mb

Table 3. Root-mean-square (rms) errors and S1 skill for February 1976 forecasts F1 and F2. Also shown are the scores for forecasts of Climatology (M). (See text for details.)

A. Sea-level Pressure

Region	F1 rms (mb)	F1 S1	F2 rms (mb)	F2 S1	M rms (mb)	M S1
1. Globe	7.5	66	7.6	67	5.6	71
2. Northern Hemisphere	8.8	75	8.8	76	6.3	81
3. Tropics	5.7	58	5.8	57	2.7	71
4. E. Pacific-U. S.	5.0		4.9		4.3	
5. North America	7.3	86	7.0	84	5.4	105
6. United States	5.8	94	5.0	88	4.5	105
7. Europe	18.0	113	18.3	117	15.3	117

B. 500 mb Height

Region	F1 rms (m)	F1 S1	F2 rms (m)	F2 S1	M rms (m)	M S1
1. Globe	66	39	68	41	79	49
2. Northern Hemisphere	80	42	82	44	99	53
3. Tropics	32	59	33	58	35	68
4. E. Pacific-U. S.	101		110		90	
5. North America	119	37	125	38	97	51
6. United States	127	28	133	29	90	48
7. Europe	189	72	191	75	234	79

C. 850 mb Temperature (rms error: K)

Region	F1	F2	M
2. Northern Hemisphere	4.4	4.4	4.6
4. E. Pacific-U. S.	5.3	5.7	4.6
6. United States	6.1	6.4	5.6

height (80 and 82 m) differ only slightly. The same is also true of the S1 scores. However, over smaller regions, such as the United States, the differences between the errors of the two simulations are somewhat larger.

The rms differences and S1 comparison scores of F1 vs. F2 shown in Table 2 may now be compared with the corresponding forecast errors in Table 3. Over the Northern Hemisphere, for example, the rms difference of sea-level pressure between F1 and F2 is 1.8 mb compared with an rms forecast error of 8.8 mb, while for 500 mb heights the corresponding values are 19 m and 81 m. Thus, in both cases the rms replication error is approximately 20% of the rms simulation error. For 850 mb temperature, the replication and simulation errors over the Northern Hemisphere are 1.2 and 4.4 K, respectively, and the ratio is about 27%. Although it is certainly not trivial, the replication problem may be regarded as minor compared with the prediction problem, at least in terms of rms errors. The problem of replication appears somewhat more serious with respect to the reproduction of gradients, particularly in the case of the sea-level pressure field, where the S1 comparison score between F1 and F2 over the Northern Hemisphere is 43 compared with S1 simulation scores of about 75. At 500 mb the hemispheric S1 score for replication is also more than half the magnitude of the S1 simulation score, but in this case the value of the replication score (23) is small enough to be regarded as negligible.

The "Climatology" forecast (M) provides a standard against which the model simulations may be measured. As shown in Table 3, the model simulation for February 1976 is not consistently superior to climatology. In terms of rms error, climatology provides a better simulation of the February 1976 sea-level pressure field over both the Northern Hemisphere and the globe than does the model. On the other hand, at 500 mb the model simulation over both the hemisphere and the globe is superior to climatology in terms of both rms errors and S1 skill scores, although this positive result is not found consistently over smaller regions.

To put the simulation statistics for February 1976 into an appropriate context, they are compared in Table 4 with corresponding results from three earlier experiments with the GISS model, as reported by Spar et al. (1976) and Spar (1977). Table 4 shows the rms errors and S1 skill scores, for both the model (F) and climatology (M), of sea-level pressures and 500 mb heights, as well as rms errors of 850 mb temperatures, over the Northern Hemisphere for four months: January 1973, 1974, and 1975, and February 1976. (The February F values are

Table 4. Summary of rms errors and S1 skill scores for four GISS-model simulations of monthly mean sea-level pressure, 500 mb height, and 850 mb temperature over the Northern Hemisphere. F denotes the model simulation and M represents a "forecast" of climatology.

	Jan. 1973		Jan. 1974		Jan. 1975		Feb. 1976	
	F	M	F	M	F	M	F	M
A. Rms errors								
Sea-level Pressure (mb)	10.0	8.7	8.6	9.2	5.3	6.6	8.8	6.3
500 mb Height (m)	72	94	80	108	62	82	81	99
850 mb Temperature (K)	4.1	4.3	4.7	5.1	4.1	4.5	4.4	4.6
B. S1 scores								
Sea-level Pressure	81	81	79	89	64	73	75	81
500 mb Height	45	55	53	60	42	52	43	53

averages of F1 and F2.) In terms of sea-level pressure, the model exhibits little or no skill relative to climatology. In two of the four months (including February 1976) the model rms errors in sea-level pressure exceed those for climatology. While the model S1 scores for sea-level pressure are all equal to or less than those for climatology, their magnitudes are generally so large (except possibly in 1975) as to indicate no skill in the reproduction of the pressure patterns. On the other hand, the model does exhibit small but consistent skill relative to climatology in its simulation of the monthly mean 500 mb height and 850 mb temperature fields.

The global forecast (top) and observed (bottom) monthly mean sea-level pressure fields for February 1976 are shown in Figure 3. Major defects in the simulation are found in the Northern Hemisphere sub-tropical highs (too weak), the Icelandic low (too far south), and the Eurasian high (too weak), as well as in the Southern Hemisphere where the sub-polar low pressure belt is underestimated. In Figure 4, showing the forecast (top) and observed (bottom) 500 mb height fields for February 1976, the simulation errors appear most serious over Europe and the eastern North Atlantic Ocean, where the model fails to reproduce a large amplitude ridge. The failure of the model to simulate adequately the anomalously

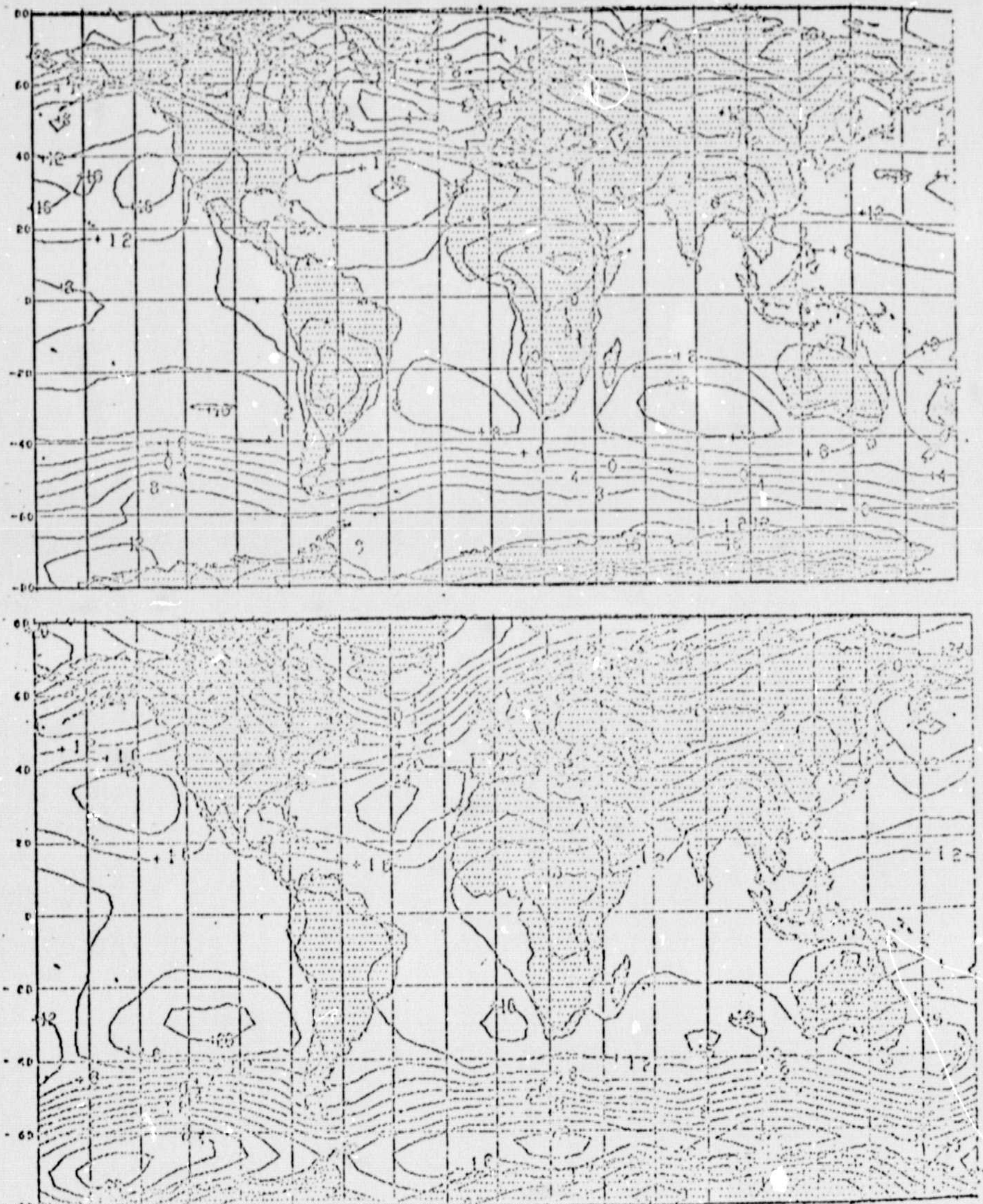

Fig. 3. Forecast (top) and observed (bottom) mean sea-level pressure fields for February 1976. 4 mb isobars.

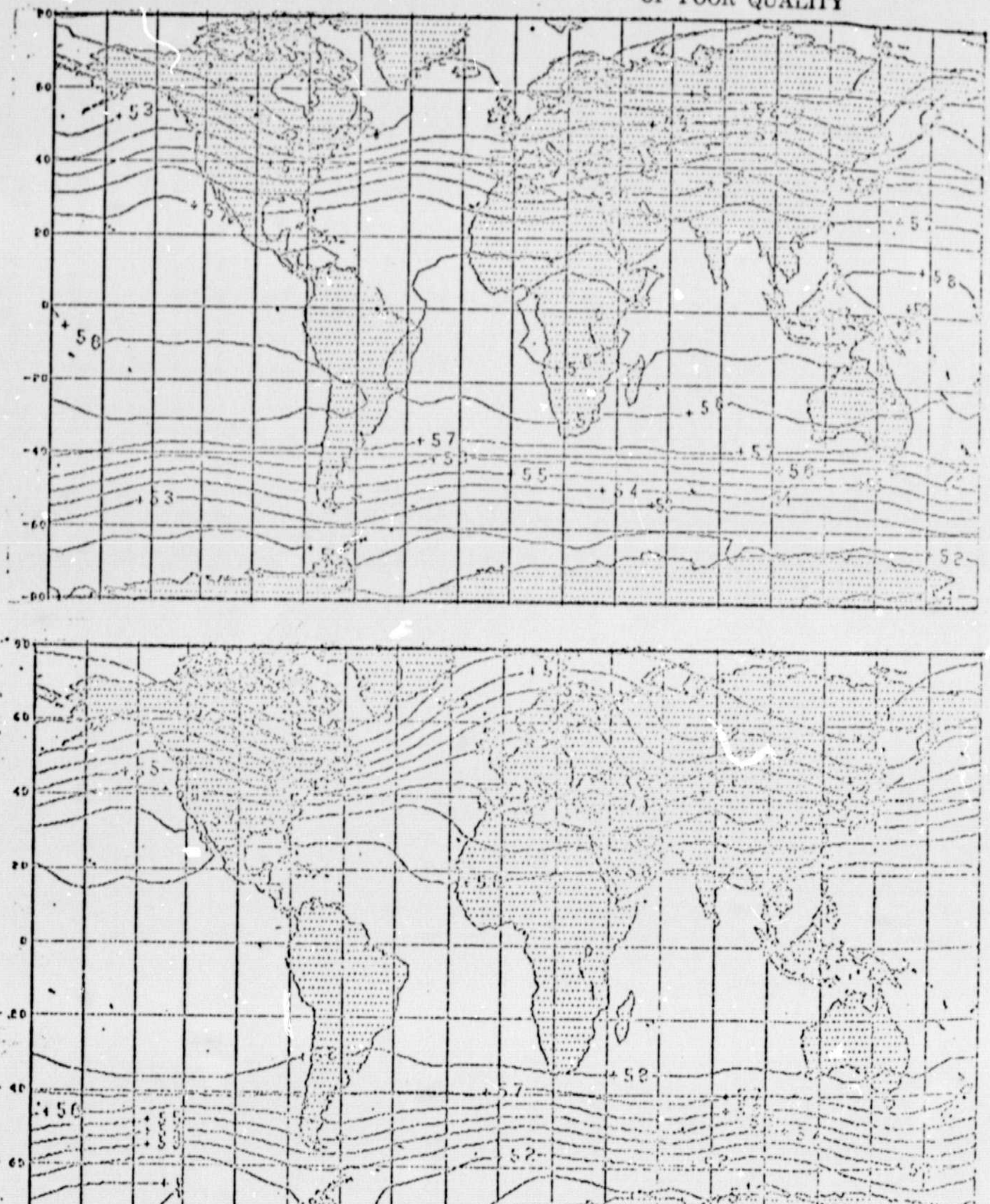

Fig. 4. Forecast (top) and observed (bottom) mean 500 mb height for February 1976. 100 M contours.

warm regime over North America in February 1976 is illustrated in Figure 5, which shows the error (forecast - observed) in the 850 mb temperature pattern over that region. Here it can be seen that negative errors as large as - 10 K are found near the Great Lakes, and errors as large as - 12 K appear over Alaska. Apparently the model is not yet capable of reproducing such a major climatic anomaly from the given initial conditions. (The large positive error over Baffinland is yet another example of a defective simulation of the temperature field.)

4. Sea-surface Temperature Anomaly Experiment (F3)

Interactions between atmosphere and ocean, and the influence of anomalous sea-surface temperatures (SST's) on the behavior of the atmosphere, especially over long periods of time, have been the subjects of innumerable studies, speculations, and publications. As part of the present investigation, a third monthly mean forecast (F3) was computed for February 1976, with observed SST's used in place of the climatological mean February values. The purpose of this experiment was to measure the influence of the SST anomaly field on the predicted monthly mean state of the atmosphere, and to determine if a foreknowledge of the global SST field would result in an

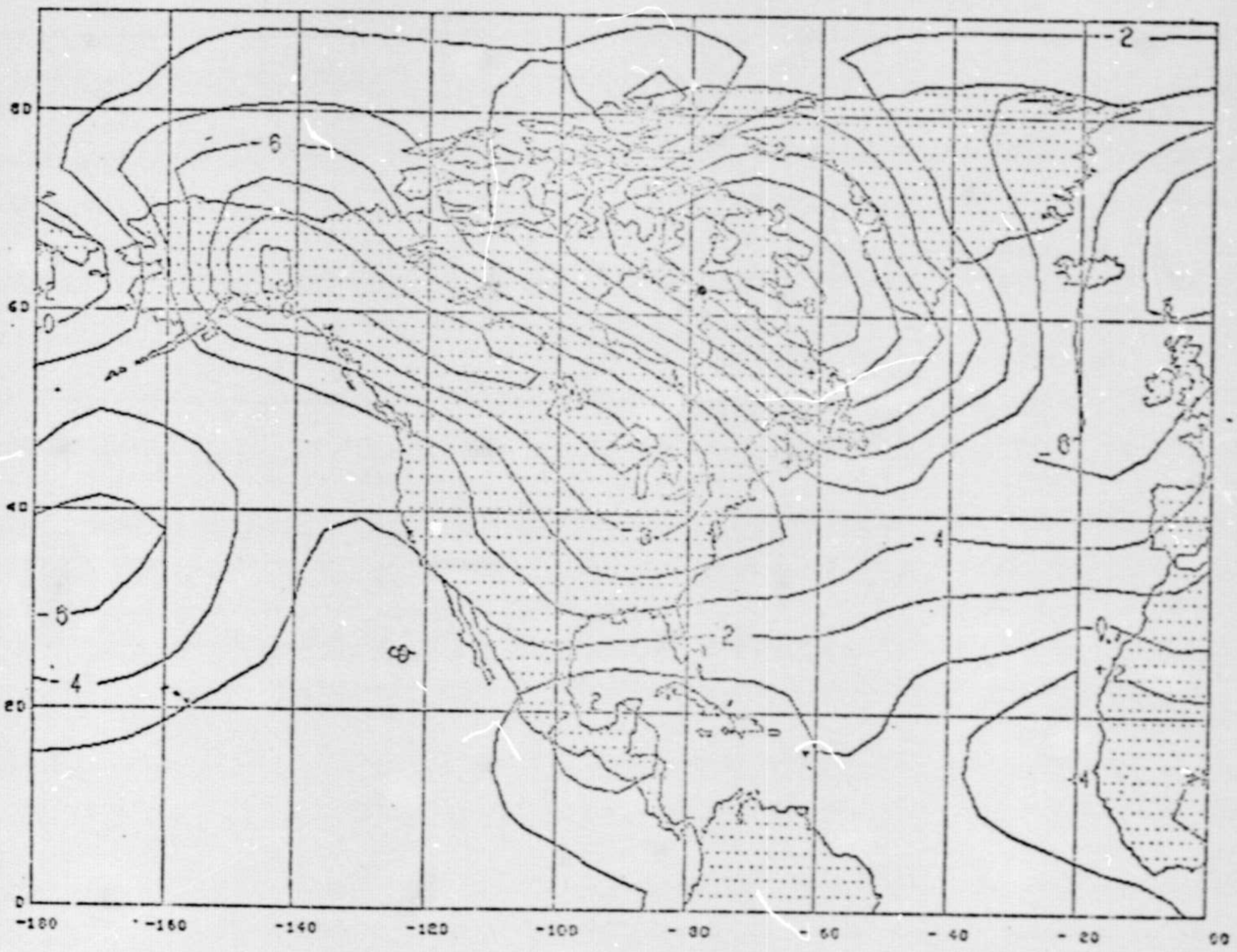

Fig. 5. Error (forecast-observed) of 850 mb temperature simulation over the northwest quadrant. 2 K isotherms.

improved simulation.

The effect of a variable ocean surface on the evolution of the atmosphere should be studied via an interactive ocean-atmosphere model; but, as such a model is not yet available in practical form, an alternative procedure is to assume that the SST field is predictable, and to use the observed sea temperatures as a surface boundary condition. The forecast designated F3 was computed on this principle.

In an earlier experiment (Spar et al., 1976), it was found that insertion of observed daily SST's during a forecast run had no detectable beneficial effect on a monthly mean simulation. The present SST anomaly experiment, F3, differs from the earlier one in that the daily observed SST's were averaged over the month, and the monthly mean observed SST field for February 1976 was then used in place of the climatological field as a fixed surface boundary condition. (The use of monthly mean SST's instead of daily updated values was expected to reduce the "noise" effects of the data.)

The daily SST data were provided by the National Environmental Satellite Service (NESS), and are based largely on satellite scanning radiometer measurements with quality control through use of ship observations (Brower et al., 1976). These daily fine-mesh NESS data were interpolated to the $4^{\circ} \times 5^{\circ}$ GISS grid, and averaged over the month. The deviation of the monthly mean February 1976 SST field from the climatological pattern for the month is illustrated in Figure 6, which shows the SST anomaly only over the northwest quadrant of the earth. The SST anomaly isotherms, drawn for an interval of 1° C, reveal several pools of relatively warm water, with maxima of + 3° C in the eastern Pacific and + 4° C in the western Atlantic. The global map (not shown) exhibits smaller anomalies (up to + 2° C) in the western North Pacific, and a band of positive anomalies (up to + 3° C) in the subtropical latitudes of the Southern Hemisphere.

The impact of SST anomalies on the atmospheric monthly mean simulation is indicated numerically in Table 5 for the same regions as in Tables 2 and 3, in terms of rms differences and S1 comparison scores between forecasts F3 and F2, for sea-level pressure, 500 mb height, and 850 mb temperature. Comparing Tables 5 and 2, it is apparent that the rms impact of the SST anomaly on the sea-level pressure field is considerably larger than the rms replication error over all regions. However, the impact on the sea-level pressure pattern as represented by the S1 scores is only slightly greater than the error of replication, and is therefore of questionable significance. The 500 mb data in Table 5

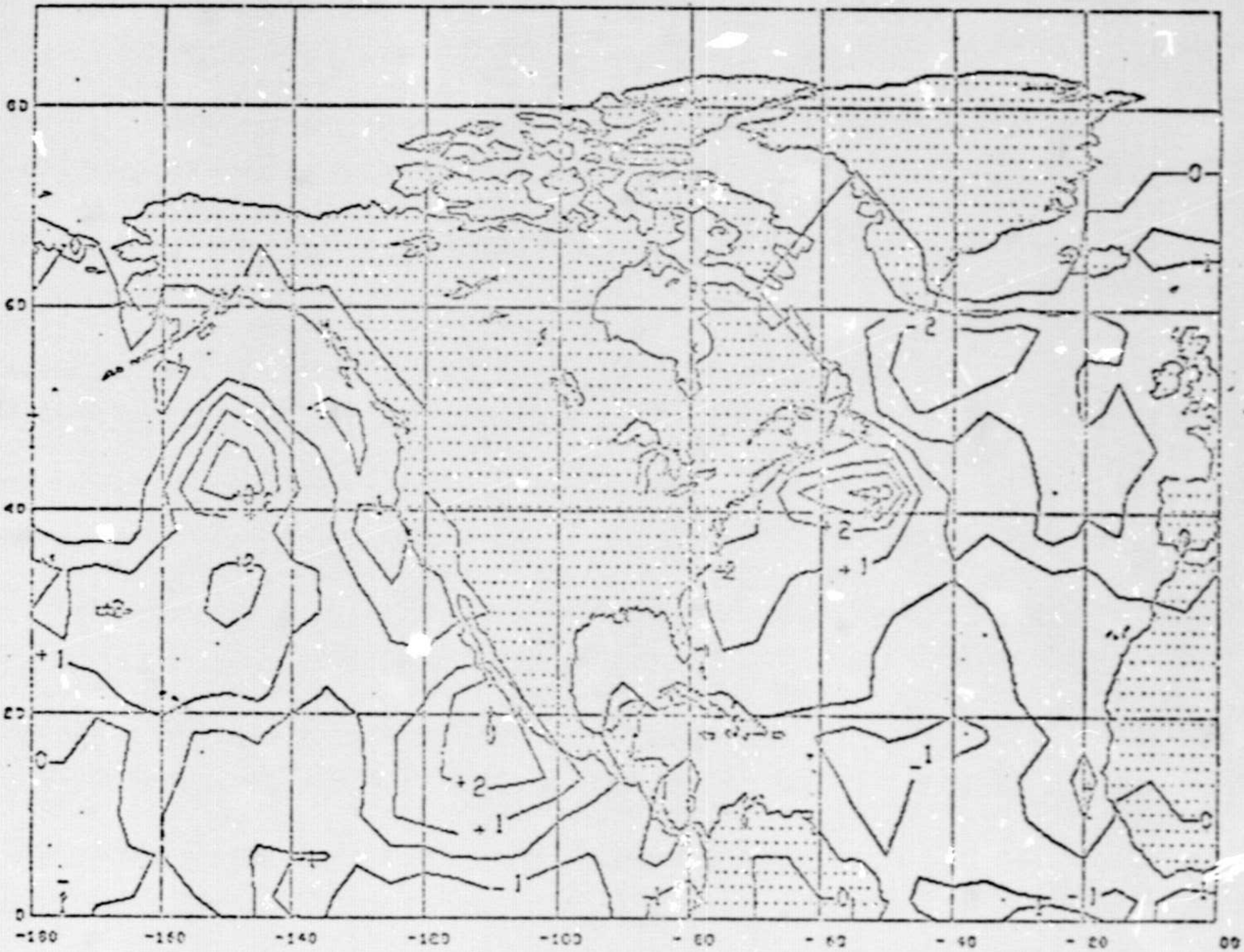

Fig. 6. Monthly mean sea-surface temperature anomaly (observed-climatology) for February 1976 over the northwest quadrant. 1°C isotherms.

Table 5. Root-mean-square (rms) differences and S1 comparison scores for February 1976 between forecasts F3 (with observed SST's) and F2 (with climatological SST's).

	Sea-level Pressure		500 mb Height		850 mb Temperature
Region	rms (mb)	S1	rms (m)	S1	rms (K)
1. Globe	4.1	47	41	28	-
2. Northern Hemisphere	3.8	49	39	26	1.6
3. Tropics	3.0	40	31	38	
4. E. Pacific-U. S.	6.2		54		1.7
5. North America	5.7	56	52	21	
6. United States	6.0	54	47	16	1.5
7. Europe	4.7	51	37	32	

similarly exhibit a relatively large rms impact (compared with the replication results in Table 2), but no significant effect on the contour pattern as represented by the S1 scores, which are about equally small in Tables 5 and 2. Modest impact is also indicated on the 850 mb temperatures by the rms differences in Table 5, which are only slightly greater than the replication errors in Table 2.

Whether or not the small impact of the SST anomalies on the atmospheric simulation was beneficial may be judged from the rms errors and S1 skill scores for forecast F3, shown in Table 6, which should be compared with the corresponding error statistics for F1 and F2 in Table 3. In general, a comparison of Tables 6 and 3 reveals that the use of "observed" SST's in place of climatological values did reduce the simulation errors over the globe and Northern Hemisphere, but not necessarily over the smaller sub-regions. When evaluated over the globe and Northern Hemisphere, all the errors of F3 shown in Table 6 are smaller than the corresponding errors for F1 and F2 shown in Table 3. Furthermore, the rms errors of 500 mb height are consistently smaller for F3 than for F1 and F2 over all regions (although the same is not true of the S1 scores). However, when one examines the sub-regions, 3 through 7, it appears that

Table 6. Root-mean-square (rms) errors and S1 skill scores for February 1976 forecast F3.

Region	Sea-level Pressure rms (mb)	Sea-level Pressure S1	500 mb Height rms (m)	500 mb Height S1	850 mb Temperature rms (K)
1. Globe	5.8	60	51	38	
2. Northern Hemisphere	7.2	72	66	41	4.3
3. Tropics	3.4	57	12	59	
4. E. Pacific-U. S.	5.7		73		5.8
5. North America	9.3	86	86	32	
6. United States	6.1	96	84	28	6.6
7. Europe	14.1	108	177	68	

the F3 simulation errors are actually worse than those for F1 and F2 in many instances, notably over the eastern Pacific and North America. This is particularly true for the sea-level pressures and 850 mb temperatures.

Some of the synoptic effects of the SST anomaly field are illustrated in Figures 7 and 8, which display the global simulations for F3 of the monthly mean sea-level pressure and 500 mb height fields respectively. Compared with Figure 3, Figure 7 shows stronger and more realistic subtropical highs, but a weaker and less realistic North Pacific low. The 500 mb simulation for F3, shown in Figure 8, appears hardly distinguishable from the forecast in Figure 4, indicating no obvious major impact of the SST anomaly. The effect of the SST anomaly on the 850 mb temperature field is illustrated in Figure 9, which shows the difference between the monthly mean 850 mb temperatures generated by F3 and by F2 (F3 - F2) over the northwest quadrant. The positive differences over Alaska and northwest Canada, when compared with the error field in Figure 5, do indicate an improvement in the temperature simulation over those areas. However, these local effects are not reflected in the regional error statistics of Table 6.

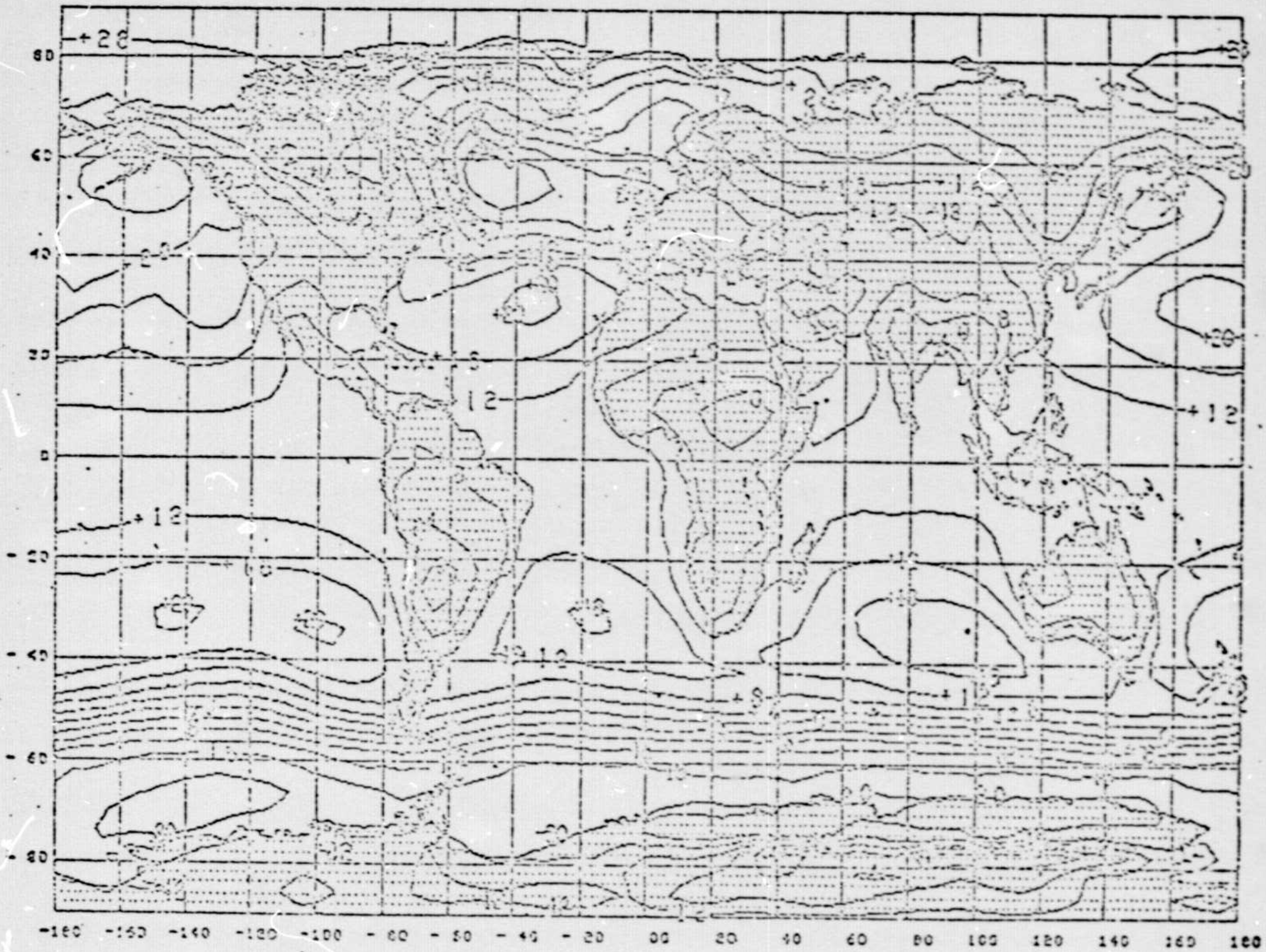

Fig. 7. Forecast monthly mean sea-level pressure field for February 1976 computed with observed SST's (F3). 4 mb isobars.

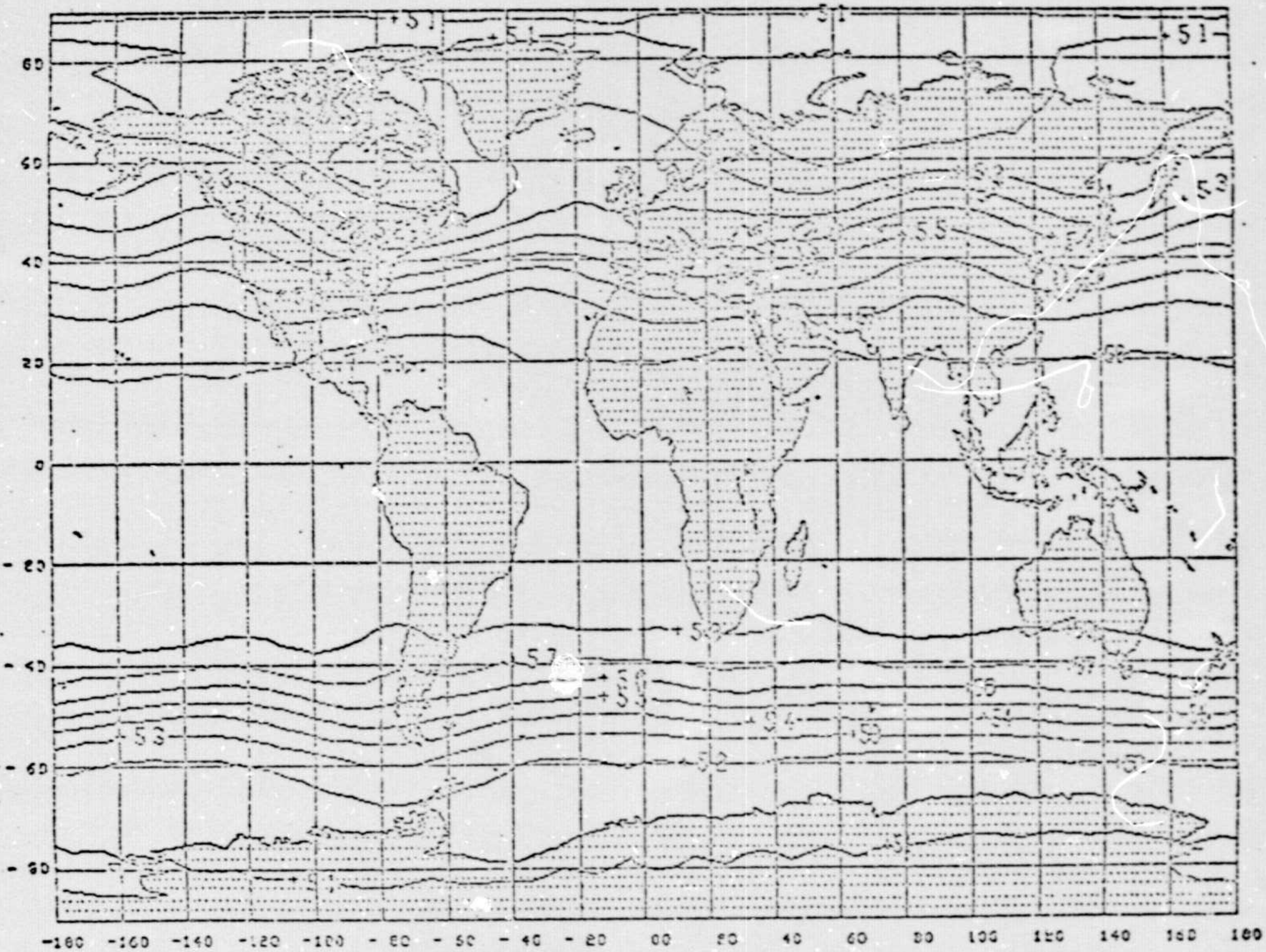

Fig. 8. Forecast monthly mean 500 mb height field for February 1976 computed with observed SST's (F3). 100 M contours.

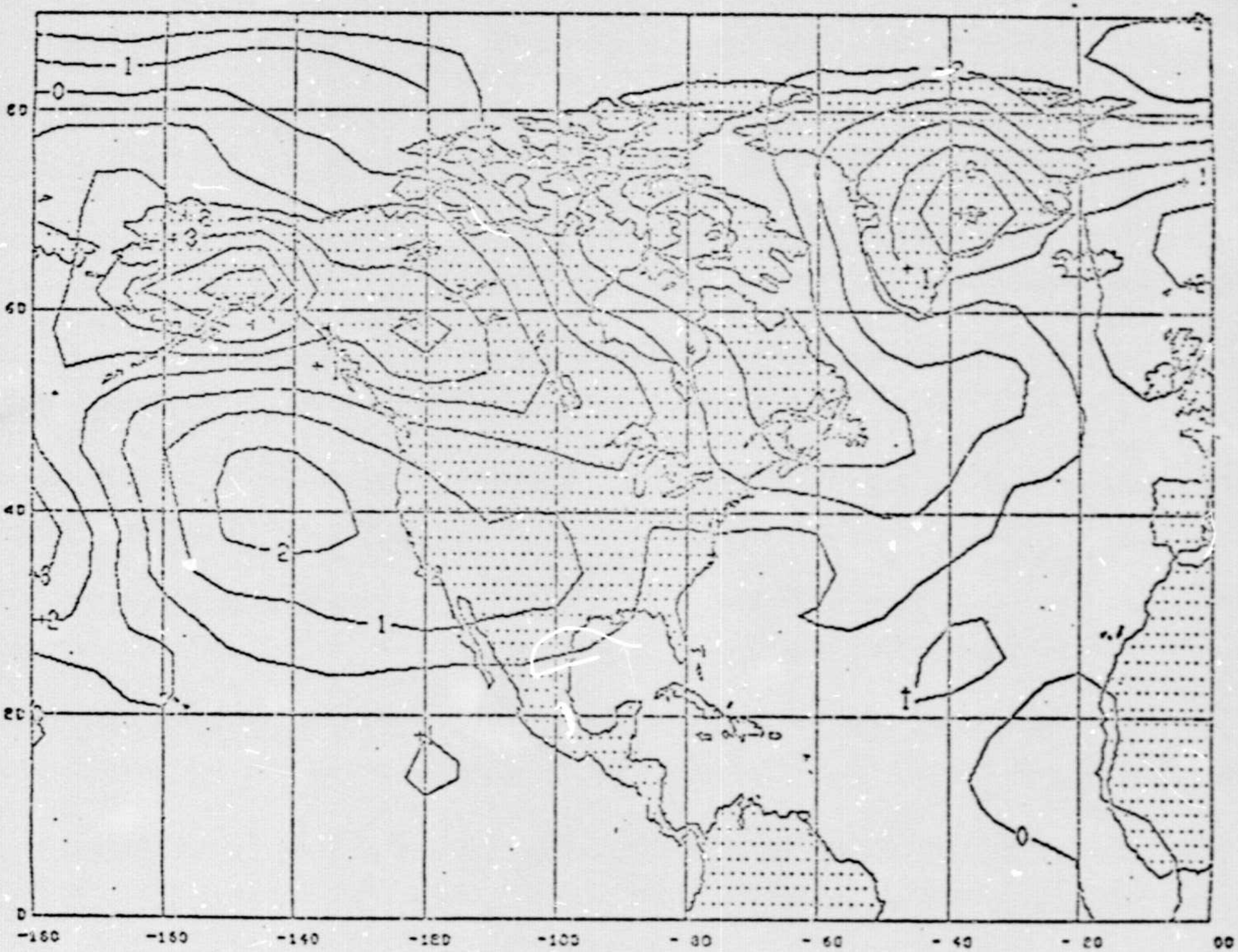

Fig. 9. Difference (F3-F2) between mean February 1976 850 mb temperatures computed, with observed (F3) and climatological (F2) monthly mean SST's. 1 K isotherms.

5. Conclusions

The results of the replication experiment indicate that small inherent uncertainties may exist in a monthly mean simulation of the atmosphere computed with a global GCM. These may be due to minor computational difficulties, such as interruptions and restarts, which may prevent the exact duplication of the chain of computations leading to the final output. In the GISS model experiment, the rms errors of replication over the Northern Hemisphere were found to be about 2 mb, 20 m, and 1 K for sea-level pressure, 500 mb height, and 850 mb temperature, respectively. In terms of S1 comparison scores, the replication errors of sea-level pressure and 500 mb height over the Northern Hemisphere were found to be about 40 and 20, respectively. These results may be viewed as provisional estimates of the computational "noise" level of the model, below which experimental "signals" cannot be reliably detected.

The replication errors are small compared with the errors generated by the model in its effort to simulate the real monthly mean atmosphere. Measured in terms of rms errors and S1 skill scores, and compared with the standard of climatology, the model simulation exhibits no skill in reproducing the monthly mean sea-level pressure field. However, the model does show some small but consistent skill relative to climatology in its simulation of the global and hemispheric fields of 500 mb height and 850 mb temperature. Unfortunately, this skill does not extend to the correct prediction of regional climatic anomalies such as the extreme warmth over North America during February 1976.

The use of observed monthly mean sea-surface temperatures (SST's) as lower boundary conditions in place of climatological values yielded ambiguous results. The impact of the SST anomalies on the monthly mean model simulations was relatively small, in general, and not consistently beneficial. While an improvement in the simulation scores over the globe and Northern Hemisphere did result from the use of observed SST's, this beneficial impact was not consistently reflected either in the regional scores or in the monthly mean synoptic maps.

Further improvements in the GISS model, as well as in the specification of surface boundary conditions (e.g., snow cover, soil moisture), are obviously desirable. Whether this will result in better monthly mean simulations remains to be seen.

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FIGURES

1. Mean meridional profiles of vertically averaged mean zonal winds for February 1976. F1 and F2 represent the model simulations, and O is the observed profile.

2. Vertical profiles of mean zonal winds at latitude 30°N for February 1976. F1 and F2 denote model simulations. O is the observed profile.

3. Forecast (top) and observed (bottom) mean sea-level pressure fields for February 1976. 4 mb isobars.

4. Forecast (top) and observed (bottom) mean 500 mb height fields for February 1976. 100 m contours.

5. Error (forecast - observed) of 850 mb temperature simulation over the northwest quadrant. 2 K isotherms.

6. Monthly mean sea-surface temperature anomaly (observed - climatology) for February 1976 over the northwest quadrant. 1° C isotherms.

7. Forecast monthly mean sea-level pressure field for February 1976 computed with observed SST's (F3). 4 mb isobars.

8. Forecast monthly mean 500 mb height field for February 1976 computed with observed SST's (F3). 100 m contours.

9. Difference (F3 - F2) between mean February 1976 850 mb temperatures computed with observed (F3) and climatological (F2) monthly mean SST's. 1 K isotherms.