Evaluation of tropical wind and reference pressure measurements: Numerical experiments for observing systems[1]

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(Manuscript received January 4, 1972)

ABSTRACT

This paper describes the results of numerical simulation experiments on observing systems conducted at the National Center for Atmospheric Research (NCAR) using a six-layer 5° mesh NCAR global circulation model. The first series of experiments is aimed at evaluation of proposed wind measurements at two levels in the tropical belt (25° N–25° S) and six levels in the equatorial belt (10° S–10° N), together with vertical temperature profiles including random and systematic errors. It is shown that the tropical wind measurements are needed in the tropics where temperature data alone are not sufficient to infer winds with acceptable accuracy. The second series is performed to determine the relative importance of reference pressure located at the surface and at the 12-km level for the hydrostatic pressure calculation from vertical temperature profiles. The third series is conducted to examine the desirability of temperature versus wind observations depending on geographical latitudes and to investigate minimum requirements of global meteorological observations.

1. Introduction

This paper describes the results of numerical experiments carried out at NCAR in response to a request from the JOC (1971) concerning the planning of future observing systems of the atmosphere. The major questions investigated by these experiments are: (1) whether wind measurements obtained from the proposed geostationary satellite system coupled with vertical temperature profiles are adequate to determine the tropical wind fields to within the JOC specification of error limits, and (2) evaluation of the usefulness of reference pressure measurements for the hydrostatic pressure calculation from radiometrically derived vertical temperature profiles together with the tropical wind measurements.

We describe in Sections 2 and 3 the results of the tropical wind experiments and the reference pressure experiments. The question of the advantage of temperature or wind measurements depending on geographical latitudes is brought up by these experiments. Some experiments were conducted to investigate this and the results are described in Section 4.

Numerical experiments similar to those described in this paper have also been carried out at the Geophysical Fluid Dynamics Laboratory (GFDL), NOAA, and the Goddard Institute for Space Studies (GISS), NASA, to determine any dependency of the results on the different global circulation models. The results of these groups including NCAR were presented at the JOC meeting in Toronto, 22 October 1971. In Section 5, we compare our results with those of GISS and GFDL and point out the need for further experiments to understand the dynamical response of the atmosphere from the point of view of designing effective observing systems.

The global circulation model (GCM) used in this study is the same one used in the previous study (Williamson & Kasahara, 1971, referred to as WK in the remainder of this report). The

[1] The first version of this paper was reported in August 1971 to the Research Coordination and Planning Group on Observing Systems Simulation, Joint Organizing Committee, GARP.

[2] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Table 1. *Height at which variables are defined*

Subscript i	u_i, v_i, T_i	p_i
1	1.5 km	3 km
2	4.5 km	6 km
3	7.5 km	9 km
4	10.5 km	12 km
5	13.5 km	15 km
6	16.5 km	18 km

The surface pressure is indicated by p_s.

GCM has a grid network of six levels in the vertical plus the surface, with vertical increment of 3 km, and covers the entire globe with a horizontal increment of 5° in both longitude and latitude. The top of the model atmosphere is at a height of 18 km which corresponds approximately to the 75-mb pressure level. We will use a subscript on a variable to denote a particular level in the vertical. Table 1 lists the heights at which the east–west and north–south velocity components (u, v), temperature T, and pressure p are defined. The historical data are generated by the GCM in the same way as described in WK. Details concerning this simulation are given in Kasahara & Washington (1971).

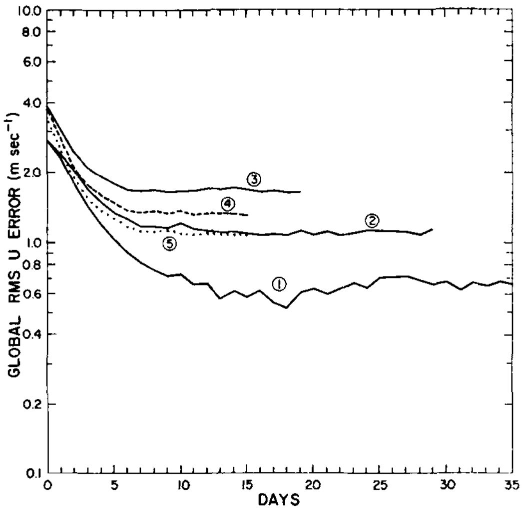

Fig. 1. Global rms zonal wind (u) error in m sec^{-1} as function of time for Exps. 1 through 5 as specified in Table 2.

2. Tropical wind experiments

The experiments concerning tropical wind measurements are summarized in Table 2. Experiments 1 and 2, which update correct surface pressure and temperature with no error and with 1°C random error, respectively, are

Table 2. *Tropical wind experiments*

Exp.	Updated variables	Error bounds	Coverage	Update interval (hours)
1	P_s	No error	Global	12
	T_1 through T_6	No error	Global	12
2	P_s	No error	Global	12
	T_1 through T_6	1°C random	Global	12
3	P_s	No error	Global	12
	T_1 through T_6	0.5°C random + 1° sin $4\lambda \sin 2\varphi$	Global	12
4	P_s	No error	Global	12
	T_1 through T_6	0.5°C random + 1° sin $4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
5	P_s	No error	Global	12
	T_1 through T_6	0.5°C random + 1° sin $4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–15° S, 15° N–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–15° S, 15° N–25° N	12
	u_1 through u_6	$\sqrt{2}/2$ m sec^{-1} random	10° S–10° N	12
	v_1 through v_6	$\sqrt{2}/2$ m sec^{-1} random	10° S–10° N	12

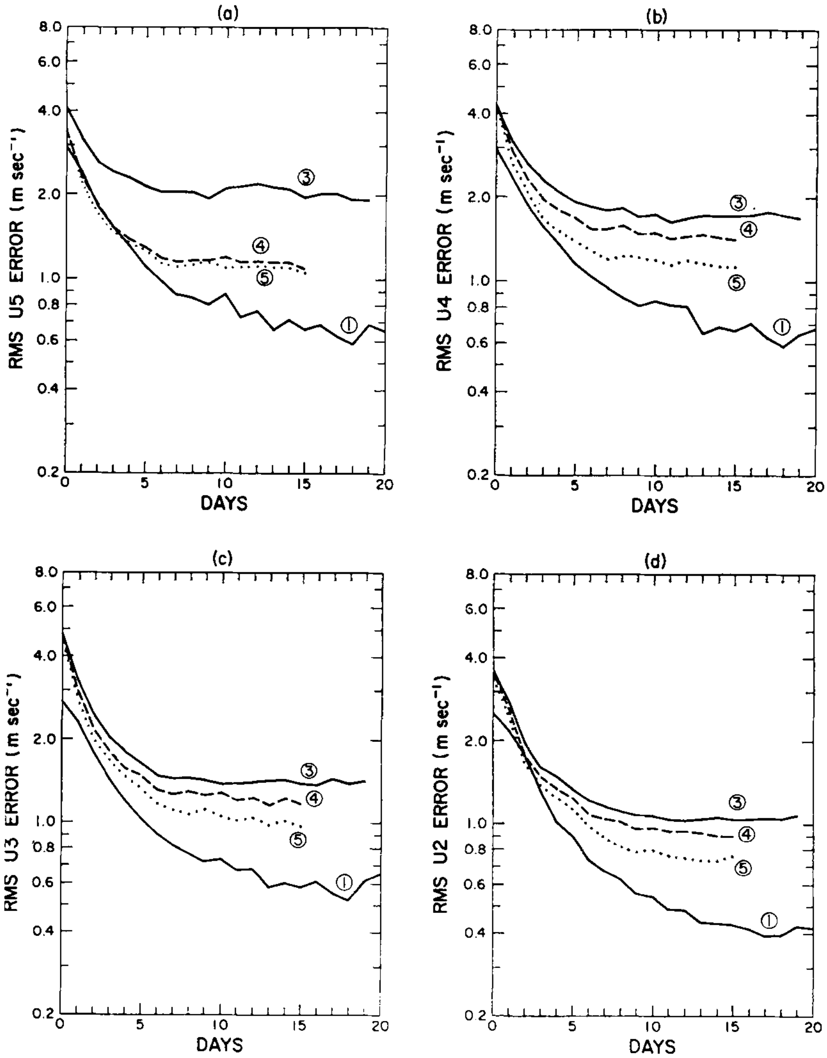

Fig. 2. (*a*) rms u_5 error, (*b*) rms u_4 error, (*c*) rms u_3 error, (*d*) rms u_2 error, all in m sec^{-1} as function of time for Exps. 1, 3, 4, and 5.

taken from WK. In this paper as in the previous, a random error will mean an error taken at random from a uniform distribution with limits of plus and minus the value specified.

In Exp. 3, correct surface pressure is updated along with temperatures with a 0.5°C random error plus a systematic error given by 1° sin $4\lambda \sin 2\varphi$, where λ and φ denote longitude and latitude, respectively. The form of the systematic error has been specified in the JOC Report (1971).

To measure the difference between two states, we use the root mean square (rms) error of a scalar quantity ψ given by

$$\mathrm{rms}(\psi) = \left[\frac{\sum_i (\psi_i - \psi_i^*)^2 \cos \varphi_i}{\sum_i \cos \varphi_i}\right]^{\frac{1}{2}} \tag{1}$$

where φ is geographical latitude and the sum is taken over some set of grid points yet to be defined. The starred and unstarred variables simply distinguish the two states. The sum can be taken over all grid points, in which case we

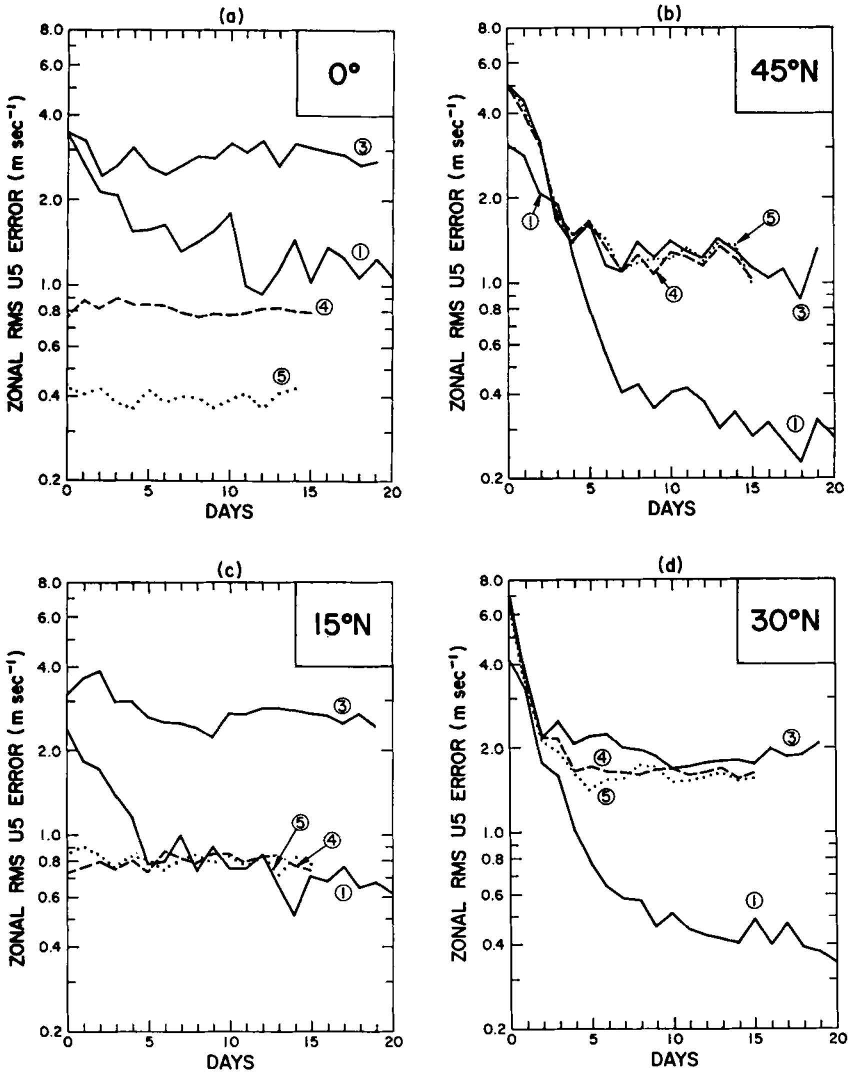

Fig. 3. Zonal rms u_5 error in m sec^{-1} at equator, 15° N, 30° N, and 45° N as labeled for Exps. 1, 3, 4, and 5.

refer to it as the *global* rms error; over all grid points at one level in the vertical, in which case we refer to it simply as the rms error; or over all points at a given latitude and height, in which case we refer to it as *zonal* rms error.

The global rms of the random plus systematic temperature errors in Exp. 3 is about 0.59°, whereas the global rms of the 1°C random temperature error of Exp. 2 is about 0.57°C. The global rms zonal wind (u) errors for Exps. 1, 2, and 3 are shown by the solid lines in Fig. 1. The different experiments are distinguished by experiment number in the figure. The lowermost curve (Exp. 1) indicates the lower limit to within which the winds can be induced by updating correct temperatures and a correct reference pressure. The asymptotic error is about 0.6 m sec^{-1}.

When the temperature includes the random error as specified in Exp. 2, the global rms u error approaches an asymptote of about 1.05 m sec^{-1}. When the temperature error is systematic as in Exp. 3, but with approximately the same rms as the random error in Exp. 2, the

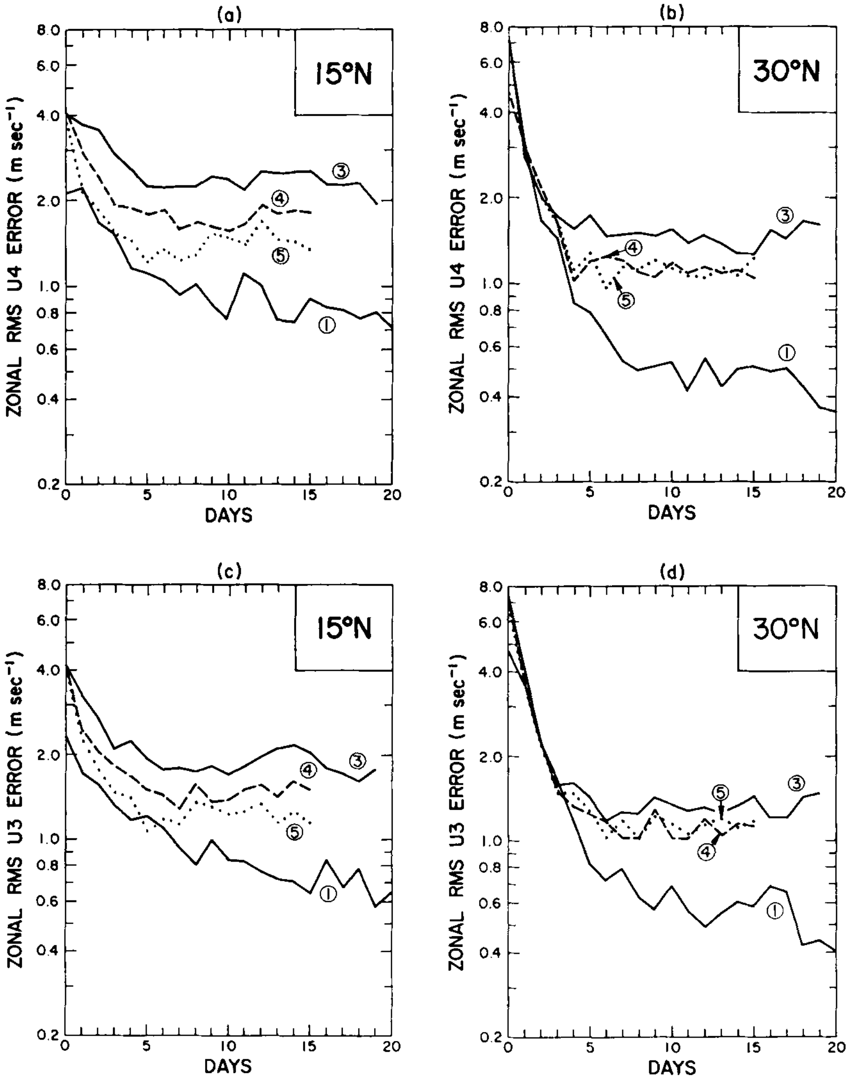

Fig. 4. Zonal rms u_4 error in m sec^{-1} at (*a*) 15° N, and (*b*) 30° N. Zonal rms u_3 error in m sec^{-1} at (*c*) 15° N, and (*d*) 30° N.

global rms u error approaches an asymptote of about 1.6 m sec^{-1}. Thus, a systematic error is more detrimental than a purely random error with the same rms value.

In Exp. 4, correct surface pressure and temperatures with the same errors as Exp. 3 are updated along with the winds at 1.5 km (u_1, v_1) and 13.5 km (u_5, v_5) in the tropical belt (25° N–25° S). These winds would correspond to winds determined from cloud movement in the lower troposphere and at 150 mb by constant level balloons. The winds are updated with a random error having a maximum vector error of 2 m sec^{-1}.

In Exp. 5, the same variables are updated as in Exp. 4 with the addition of winds in the equatorial belt (10° N–10° S) at all levels with a random error giving a maximum vector error of 1 m sec^{-1}. The global rms u error curves in Fig. 1 show that the additional wind measurements reduce the asymptotic rms u error. However, it must be remembered that the average is taken over *all* grid points, including those where the wind is updated.

Table 3. *Reference pressure experiments*

Exp.	Updated variables	Error bounds	Coverage	Update interval (hours)
6	P_4	No error	Global	12
	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
7	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
8	P_4	No error	Global	12
	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
9	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
10	P_4	No error	Global	24
	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
11	P_4	0.3 mb random	Global	24
	T_1 through T_6	0.5°C random $+1° \sin 4\lambda \sin 2\varphi$	Global	12
	u_1 and u_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12
	v_1 and v_5	$\sqrt{2}$ m sec^{-1} random	25° S–25° N	12

Fig. 2 shows the rms u_2, u_3, u_4, and u_5 errors for Exps. 1, 3, 4, and 5. We will discuss first the effect of the tropical wind measurements at two levels as shown by the difference between Exps. 3 and 4. The difference shows the improvement gained by updating the wind at two levels in the tropics. The largest improvement is at level 5 (13.5 km) where the winds are updated, but at this level the rms error is computed by averaging over updated and non-updated regions. This is not the case at levels 2, 3, and 4. The updating of winds at levels 1 and 5 improves the determination of winds at levels 2, 3, and 4 perhaps slightly better at higher levels than at lower levels.

The zonal rms u_5 errors at 0°, 15° N, 30° N, and 45° N are shown in Fig. 3 for the same cases shown in Fig. 2. Again we compare Exps. 3 and 4 first. The latitudes 0° and 15° are both in the area being updated in Exp. 4. Notice in Fig. 3*a* and *c* that in the low latitudes the zonal rms u_5 error curves of Exp. 3 show no reduction of error from the initial values of about 3 m sec^{-1}. This means that if observed temperatures contain systematic errors on the order of rms 0.6°C, then the updating of temperatures alone does not determine winds in these areas within the JOC error specification. It is clear that to determine the wind field in the low latitudes, we must make direct measurement.

The zonal rms u_5 error at 30° in Fig. 3*d* shows a slight improvement by updating winds in the tropical belt, but the zonal rms error at 45° in Fig. 3*b* shows no difference. The information added by updating two levels of winds in the tropics propagates in the vertical, but not much to the region outside the updated area in the horizontal. This conclusion is further illustrated in Fig. 4*a* and *b* showing zonal rms u_4 and u_3 errors at 15° N and 30° N. The improvements in u_4 and u_3 at 15° N (between levels being updated) are greater than the improvement in u_5 at 30° N (adjacent to the area being updated).

The results of updating equatorial winds (10° N–10° S) at all levels as in Exp. 5, in addition to the tropical winds (25° N–25° S) at two levels, are also shown in Figs. 2, 3, and 4. Fig. 2 shows the rms u error at specified heights computed over the sphere which includes the updated areas. The effects of the additional wind information are clearly seen in Figs. 3 and 4. Fig. 4 shows that there is a noticeable influence on the winds at 15° N immediately adjacent to the updated area, but almost no influence farther away at 30° N.

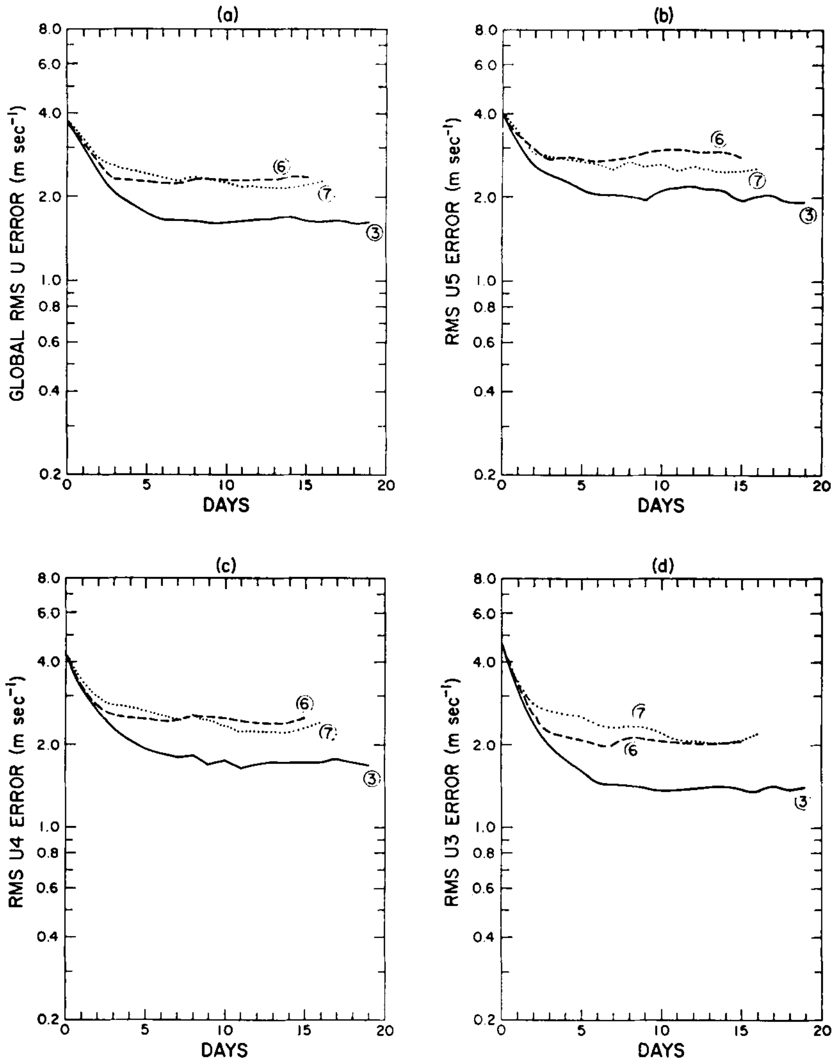

Fig. 5. Reference level Exps. 6 and 7 compared with Exp. 3. (*a*) global rms u error, (*b*) rms u_5 error, (*c*) rms u_4 error, and (*d*) rms u_3 error. All in m sec^{-1}.

3. Reference pressure experiments

The experiments listed in Table 3 combined with Exps. 3 and 4 in Table 2 are designed to examine the desirability and location of an updated reference pressure when the temperatures are updated as in the Tropical Wind Experiments. When no pressure is mentioned as in Exps. 7 and 9, the forecast value of the surface pressure is used as a reference pressure to compute the pressure at all levels from the updated temperatures.

Fig. 5 shows the global rms u error and the rms u_5, u_4, and u_3 errors for Exps. 3, 6, and 7. In all these experiments, the temperatures are updated with the random plus systematic error. In Exp. 3, surface pressure is updated; in Exp. 6, p_4 is updated; and in Exp. 7, forecast surface pressure is used instead. The surface reference pressure case produces a lower rms wind error than either of the other two cases. This result was also reported in WK where the temperatures were updated with a purely random error, but the difference there was not as great as here. The difference in the global rms u error between the

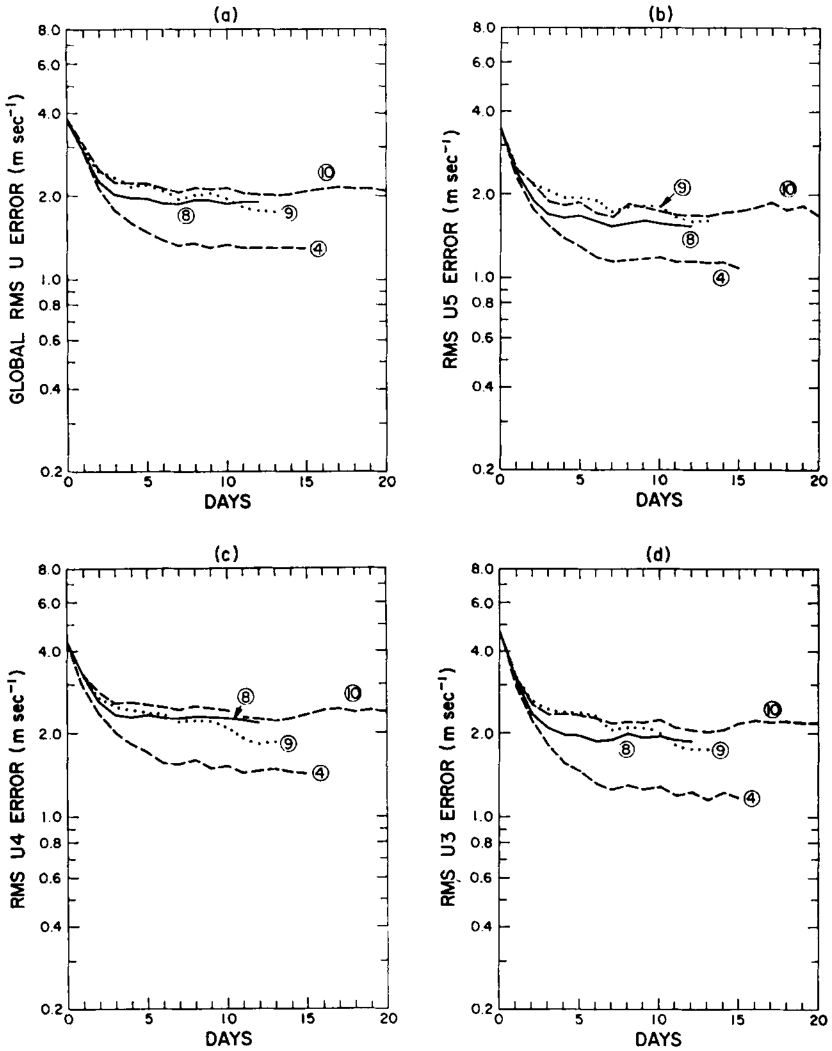

Fig. 6. Reference level Exps. 8, 9, and 10 are compared with Exp. 4. (*a*) global rms u error, (*b*) rms u_5 error, (*c*) rms u_4 error, and (*d*) rms u_3 error. All in m sec^{-1}.

case updating p_4 and the cas eupdating no reference pressure is small. This result was also found in WK. The difference between updating p_4 as reference pressure and updating no reference pressure seems to increase with height, the no-reference-pressure-case being better at higher altitudes.

Experiments 4, 8, and 9 are the same as 3, 6, and 7, respectively, with the additional updating of the tropical winds at two levels. Results of Exps. 4, 8, and 9 are shown in Fig. 6. Again updating the surface pressure (Exp. 4) produces the best wind field and there is little difference in the global rms u error between the case updating p_4 (Exp. 8) and the one updating no reference pressure (Exp. 9).

Experiment 10 compared with 8 in Fig. 6 shows that the rms error is slightly larger when p_4 is updated every 24 hrs instead of every 12 hrs. At the intervening update times, the forecast surface pressure is used as a reference pressure. Experiment 11 updates p_4 every 24 hrs with a 0.3-mb random error. The rms errors for this case are graphically indistinguishable

Table 4. *Reciprocal configuration experiments*

Exp.	Updated variables	Error bounds	Coverage	Update interval (hours)
12	P_s T_1 through T_6	No error	30° N–90° N, 30° S–90° S	12
13	u_1 through u_6 v_1 through v_6	No error	25° S–25° N	12
14	P_s T_1 through T_6	No error	30° N–90° N, 30° S–90° S	12
	u_1 through u_6 v_1 through v_6	No error	25° S–25° N	12
15	P_s T_1 through T_6	No error	25° S–25° N	12
16	u_1 through u_6 v_1 through v_6	No error	30° N–90° N, 30° S–90° S	12
17	P_s T_1 through T_6	No error	25° S–25° N	12
	u_1 through u_6 v_1 through v_6	No error	30° N–90° N, 30° S–90° S	12
18	u_1 through u_6 v_1 through v_6	No error	Global	12

from the corresponding experiment with no error (Exp. 10) and hence are not shown.

4. Reciprocal configuration experiments

To further investigate the effect of wind measurements in the tropics and the horizontal propagation of updated information, we performed an additional set of experiments listed in Table 4. In this set of experiments, the updated data are assumed to have no error, and only one type of data, either wind or temperature, is updated at any one grid point. In this section, when we refer to temperature as being updated, we mean that temperature and surface pressure are updated. Fig. 7 illustrates the configurations of observing systems for the various experiments listed in Table 4 to illustrate the reciprocal nature of the experiments.

We first consider Exps. 12–14 together with

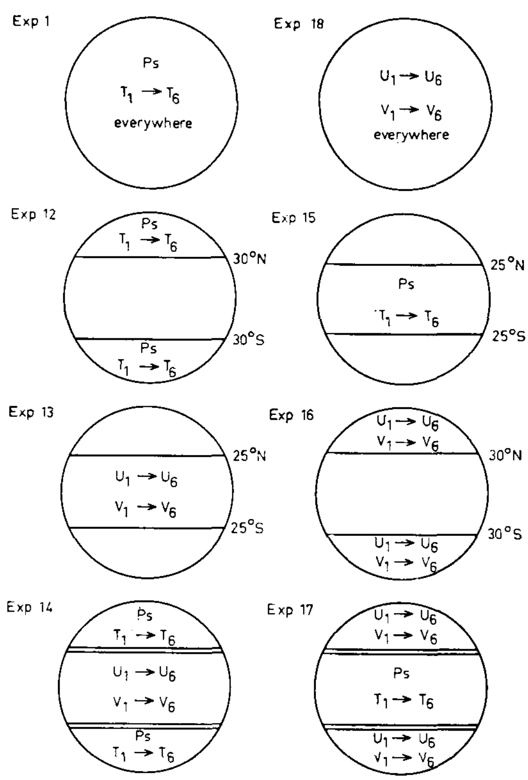

Fig. 7. Illustrative diagram for reciprocal configuration experiments 12 through 18, together with Exp. 1.

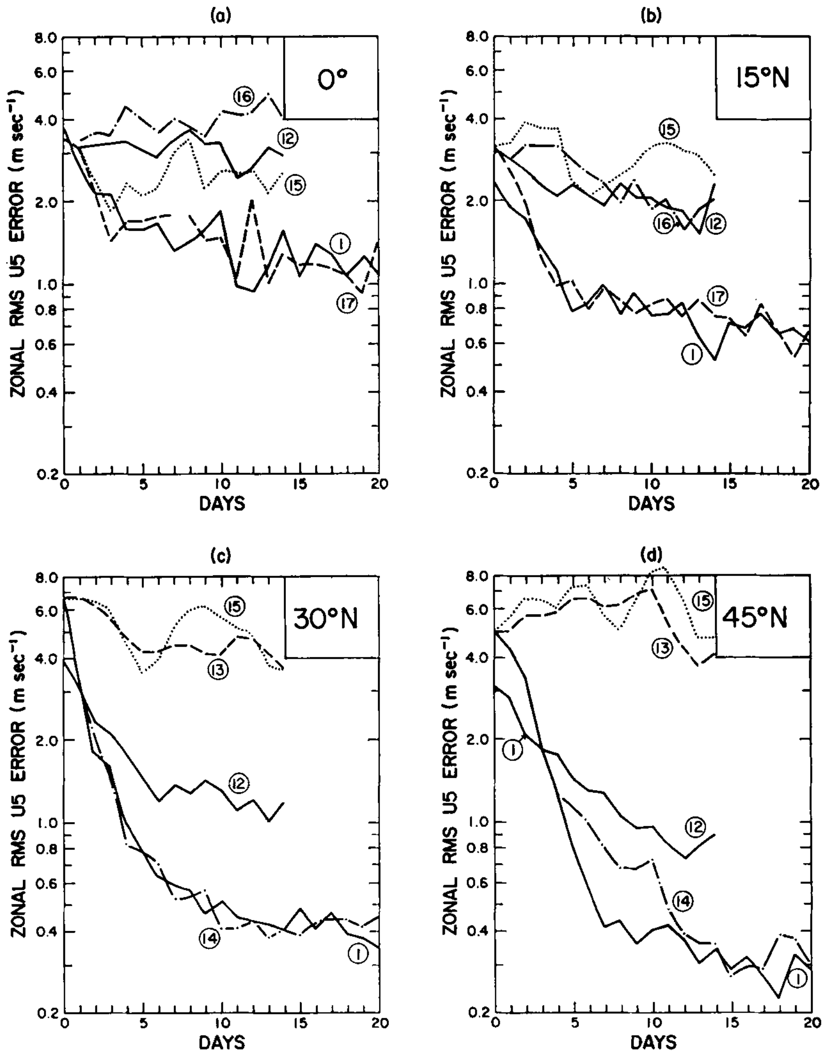

Fig. 8. Zonal rms u_5 error in m sec^{-1} at (*a*) equator, (*b*) 15° N, (*c*) 30°N, and (*d*) 45° N for reciprocal configuration experiments.

Exp. 1. In Exp. 1, temperatures are updated everywhere. In Exp. 12, temperatures are updated outside the tropical band 25° S to 25° N, whereas in Exp. 13 winds are updated only in the tropical band. In Exp. 14, winds are updated in the tropical band and temperatures are updated outside the tropical band. The reason for choosing the latitude zone 30° S to 30° N as the tropical band is to make the area of the tropical band half the area of the sphere. However, the grid points on the 30° parallels belong to the polar caps and those on the 25° parallels belong to the tropical band as we have defined them. The zonal rms u_5 errors from these experiments are shown in Fig. 8 at 0°, 15° N, 30° N, and 45° N. The zonal rms T_5 errors for the same latitudes are shown in Fig. 9.

We first note in Fig. 8*c* and *d* that the zonal rms u_5 errors at 30° and 45° are almost identical for Exps. 1 and 14. In these two cases, one and only one of the two fields, temperature and wind, is updated at each grid point. Except for the surface level, both cases update the same amount of historical data which is half the total counting wind velocity and temperature each as one piece of information. (As far as the total amount of information used, Exp. 1 uses a little more since Exp. 1 updates the surface pressure in the tropical band as well, whereas Exp. 14 does not. The effect of the additional amount of information is probably minor.) When one of the two fields is not updated at every grid point, the asymptotic errors are greater than those produced by updating at every grid point. Comparison of Exps. 12 and 14 in Fig. 8*c* and *d* shows that the addition of wind data in the tropical band helps to determine the wind field outside the tropical band if temperature data also exist outside the tropical band. However, comparison of Exps. 13 and 14 illustrates that the wind data alone in the tropical band *do not determine the wind field outside the* tropical band. Similarly, comparison of Exps. 1 and 12 shows that the temperature data alone outside the tropical band do not help to determine the wind field in the tropical band. It must be remembered that the temperatures in Exp. 1 do not contain errors and that when there are errors in the temperatures, even the use of temperature everywhere is not sufficient to determine the wind field in the tropics as pointed out in Section 2.

Experiments 15–17 are complementary to Exps. 12–14, as seen from Fig. 7. For example, Exp. 15 updates surface pressure and temperature only in the tropical belt, whereas Exp. 12 updates the same quantities in the domain complementary to the tropical belt. Experiment 18 updates winds over the entire grid which is the reciprocal to Exp. 1 updating temperature and surface pressure everywhere.

The results of Exps. 15–18 are also shown in Figs. 8 and 9. As seen from Fig. 9*c* and *d*, Exp. 17 in which temperatures are updated in the *tropics and winds in the polar caps has about* the same asymptotic rms T_5 error at 30° N and 45° N as Exp. 18 in which winds are updated everywhere. However, updating winds outside the tropics alone as in Exp. 16 does not reduce very much the temperature error in the polar caps. As expected, updating temperatures in the tropics alone as in Exp. 15 does not help to determine the temperature field outside the tropics as seen from Fig. 9*c* and *d*, nor the wind field outside the tropics as seen from Fig. 8*c* and *d*. Similarly, updating winds alone in the tropical band as in Exp. 13 does not help to determine the temperature field or the wind field outside the tropics.

Comparison of Exps. 1 *and* 17 *in Fig. 8a and b* shows that the use of wind instead of temperature outside the tropical band (Exp. 17) results in about the same asymptotic rms u_5 error at 0° and 15° N as Exp. 1 in which temperatures are updated everywhere. Comparison between Exps. 14 and 18 in Fig. 9*a* and *b* shows that the use of temperatures instead of winds outside the tropical band (Exp. 14) results in even better reduction in the asymptotic rms T_5 error at 0° and 15° N than Exp. 18 in which winds are updated everywhere. This indicates that the configuration of the observing system of Exp. 14 is advantageous over that of Exps. 18, 17, or even Exp. 1.

As far as the determination of wind in the tropics, it is interesting to compare Exp. 15 (temperatures updated in the tropics only) and Exp. 16 (winds updated in the polar caps only) *shown in Fig. 8a and b. At the equator,* Exp. 15 gives a smaller asymptotic rms u_5 error than Exp. 16, whereas at 15° N this situation is reversed. This implies that winds in the mid-latitudes are influencing the determination of winds in the tropics more than the temperature field in the tropics is influencing the determination of wind in the tropics, except for a narrow equatorial belt.

Concerning the determination of temperature in the tropics, we shall compare the results of Exp. 16 with those of Exps. 12 and 13 seen in Fig. 9*a* and *b*. The asymptotic rms T_5 errors of Exp. 12 at 0° and 15° N are lower than those of Exp. 16. This implies that temperatures in the mid-latitudes are influencing the determination of temperature in the tropics more than are the winds in the mid-latitudes. The behavior of rms T_5 error of Exp. 13 seen in Fig. 9*a* and *b* may also be worthwhile to note. Updating of winds in the tropical band has helped to infer temperatures in the tropics at the beginning of updating, but this induction of temperatures in *the tropical band is soon overwhelmed by the* lack of supporting information from the higher latitudes. Eventually, the rms T_5 error of Exp. 13 exceeded the asymptotic value of Exp. 12.

5. Concluding remarks

We first summarize the major conclusions derived from the present experiments and then

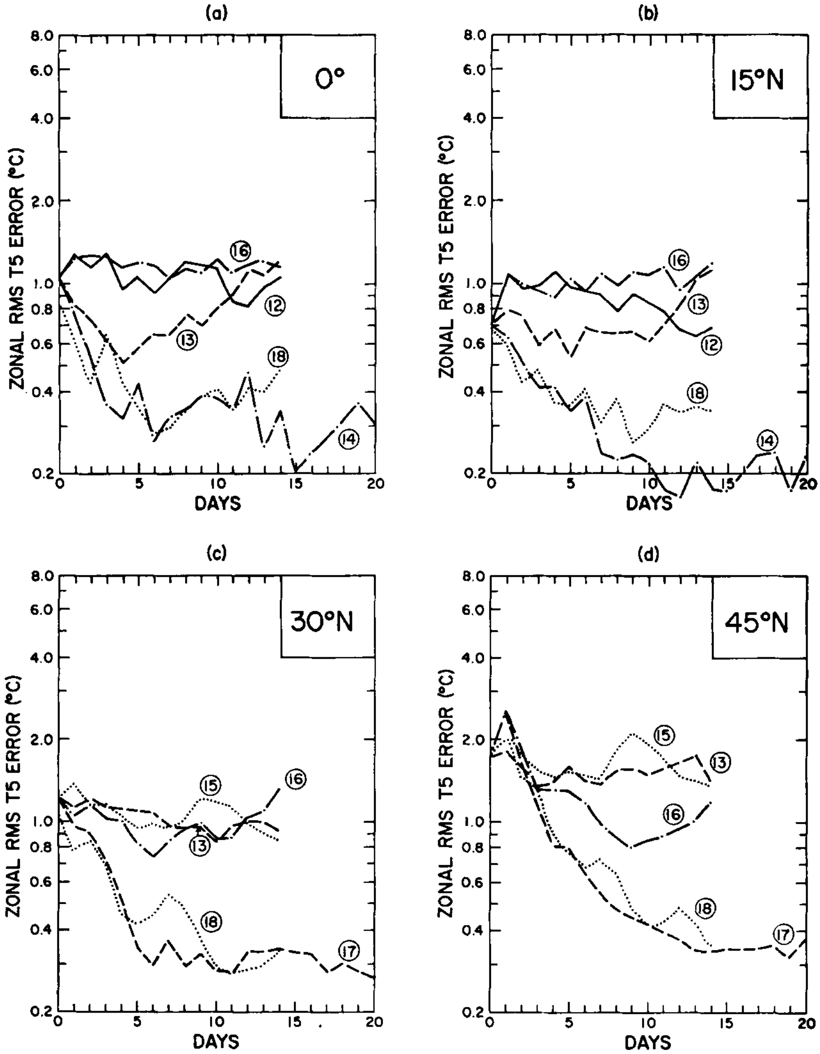

Fig. 9. Zonal rms T_5 error in °C at (*a*) equator, (*b*) 15° N, (*c*) 30° N, and (*d*) 45° N.

compare our results with those of GISS conducted by Jastrow and Halem (Jastrow, 1971) and those of GFDL (Gordon et al., 1971) which were presented together with our results at the JOC meeting in Toronto, 22 October 1971.

A systematic temperature error results in a higher asymptotic rms wind error than a purely random temperature error even though the rms values of systematic and random temperature errors are approximately the same. For the global rms of the random plus systematic temperature errors of about 0.6°C, the asymptotic zonal rms u_5 error in the tropics is on the order of 3 m sec^{-1}, whereas in the mid-latitudes it is less than 2 m sec^{-1}. Therefore, to reduce the wind error in the tropics to less than 2 m sec^{-1} rms, we need direct wind measurements. To ensure the accuracy of the wind determination in the mid-latitudes, effort should be made to reduce systematic errors in the temperature measurements. These general conclusions are consistent with those derived from the experiments at GFDL and GISS.

The information added by updating two levels of winds in the tropical belt propagates vertically to some extent, but the tropical wind information propagates very little horizontally to the mid-latitudes. The results of GISS using a two-layer model developed by Arakawa and Mintz at UCLA also show that no significant improvement occurs outside the zone of direct data insertion in the tropics. On the other hand, the results of GFDL using a nine-level model with Kurihara-type grid indicate that improved adjustment of winds also takes place in the extratropics when tropical winds are updated at two levels. The different results of GFDL, GISS, and NCAR may indicate the degree of model dependence in simulation experiments. However, as discussed in Section 4, the results of reciprocal configuration experiments demonstrate that the tropics are shielded in one direction only in the sense that information in the tropics barely gets out of the tropics, but information in the mid-latitudes can penetrate into the tropics except for a narrow equatorial belt. The results of additional experiments at GISS and NCAR also illustrate that mid-latitude information can penetrate into the tropics. The GISS experiment updated temperatures everywhere and winds in the latitude belt of 30° N to 50° N. The winds in the tropics were improved by this updated mid-latitude information. The two additional experiments performed at NCAR similar to the GISS experiments are not listed in our tables. In both experiments, temperatures were updated with the same random-plus-systematic error used in the other experiments reported in this paper. In the first experiment, winds were updated at two levels (1.5 and 13.5 km) in the band 30° N to 50° N with a $\sqrt{2}$ m sec^{-1} random error in each component. In the second, winds were updated at all levels from 30° N to 50° N with the same error. The first case resulted in no information propagation into the tropics. In the second case, information did propagate into the tropics in agreement with the GISS experiment where wind was updated at all (both) levels of their model.

It is known from the work of Mak (1969) and Bennet & Young (1969) that planetary waves in mid-latitudes can propagate into the tropics, although there are conditions which have to be met as discussed by Charney (1969) and Dickinson (1970). On the other hand, it has been shown by Rosenthal (1965), Matsuno (1966), Lindzen (1967), and others that low-frequency planetary-scale motions in the tropics are trapped horizontally (although they can propagate vertically) and, therefore, information added to most of the Rossby modes will be confined near the area of updating.

The trapping nature of equatorial planetary waves may also explain why a wall at the equator in a hemispherical model has a relatively slow influence on mid-latitude flows up to about one week (Baumhefner, 1971*a*, *b*). As indicated by Matsuno (1966), it may be possible that the inertia-gravity waves of long periods propagate through the equatorial duct. It is extremely interesting to investigate the nature of coupling between the tropics and the mid-latitudes using direct wind measurements in the tropics as proposed for GARP.

The experiments in Section 4 revealed additional useful information concerning a minimum requirement in observing systems. The preferred minimum requirement seems to be the configuration of Exp. 14 in which winds are observed in the tropics and temperatures outside the tropics. This combination of wind and temperature observations is better than the combination in Exp. 17 and the single observing systems of Exp. 1 or Exp. 18. If the total number of observations of wind and temperature is less than this minimum requirement, the large-scale description of the atmosphere will be seriously impaired. Therefore, the observing system of wind at least at two levels in the tropical belt (25° N–25° S) and at all levels in the equatorial belt (10° N–10° S), together with infrared temperature observations over the globe, is almost the minimum requirement.

As far as the desirability of reference pressure observation, the use of correct surface pressure seems to produce a better determination of the wind field than the use of correct 12-km reference pressure or the use of predicted surface pressure as the reference. We cannot think of any obvious reason why the surface is better than 12 km for the reference pressure, except that the structure of synoptic-scale baroclinic waves in the atmosphere is relatively shallow and the maximum amplitude of waves is found at the surface level.

As a word of caution in interpreting the results of simulation experiments, we should remark that these experiments were conducted in an idealized condition, namely the simulated atmospheric data were obtained from the same model as that used for the prediction. As pointed out by Morel et al. (1971), a "rejection phenomenon" might occur when data simulated with a different model or real data are used for updating experiments. The question of model dependence on simulation experiments should be investigated further.

Acknowledgements

We thank the many members of the NCAR Computing Facility for programming and operation of the Control Data Corporation 6600. We acknowledge especially Gloria Williamson, David Kennison, Kenneth Hansen, and Judith Slater for running the general circulation model (GCM) and making the modifications of the GCM code for the present experiments. Ann Lundberg typed the manuscript.

The final version of this paper was completed while Akira Kasahara was visiting Meteorologiska Institutionen, Stockholm University (MISU), Sweden, during the academic year 1971–1972. Kasahara thanks Dr B. Bolin, MISU, for his hospitality, as well as Dr J. Firor, NCAR, for his encouragement.

APPENDIX

Additional reference presssure experiment

To investigate the usefulness of surface pressure measurements taken over land only, we performed an additional experiment in conjunction with this report. Fig. 1 A compares the results of this experiment with two earlier ones. The solid curves in the figure are from the experiment updating surface pressure everywhere with no error and temperature with the random plus systematic error specified. The dotted lines are from the experiment updating temperatures everywhere with the random plus systematic error. The forecast surface pressure was used for the reference pressure in this experiment. The results of the experiment updating temperatures with the same errors as the other two experiments and surface pressure over land as defined in the NCAR GCM are shown by the dashed lines. The forecast surface pressure is used for the reference pressure over the oceans.

As seen in the figure, in the northern hemisphere the differences in the zonal rms u_5 errors between the cases in which surface pressure is updated everywhere and in which it is updated just over land are small. However, in the southern hemisphere, the zonal rms u_5 error from updating surface pressure over land is about midway between the errors produced by updating surface pressure everywhere and by updating no reference pressure. The differences between these three cases decrease approaching the equator. The zonal rms u_5 errors for these experiments are very close to each other at 15° N or S with the three curves intersecting each other repeatedly (not shown). These results agree with expectations since most of the land area is in the northern hemisphere.

Thus, a system of buoys over the extratropical oceans capable of measuring surface pressure would provide useful information for updating in the NCAR GCM. However, the observations of surface pressure over land only are sufficient for updating in the tropics and northern hemisphere when compared to observations of surface pressure everywhere.

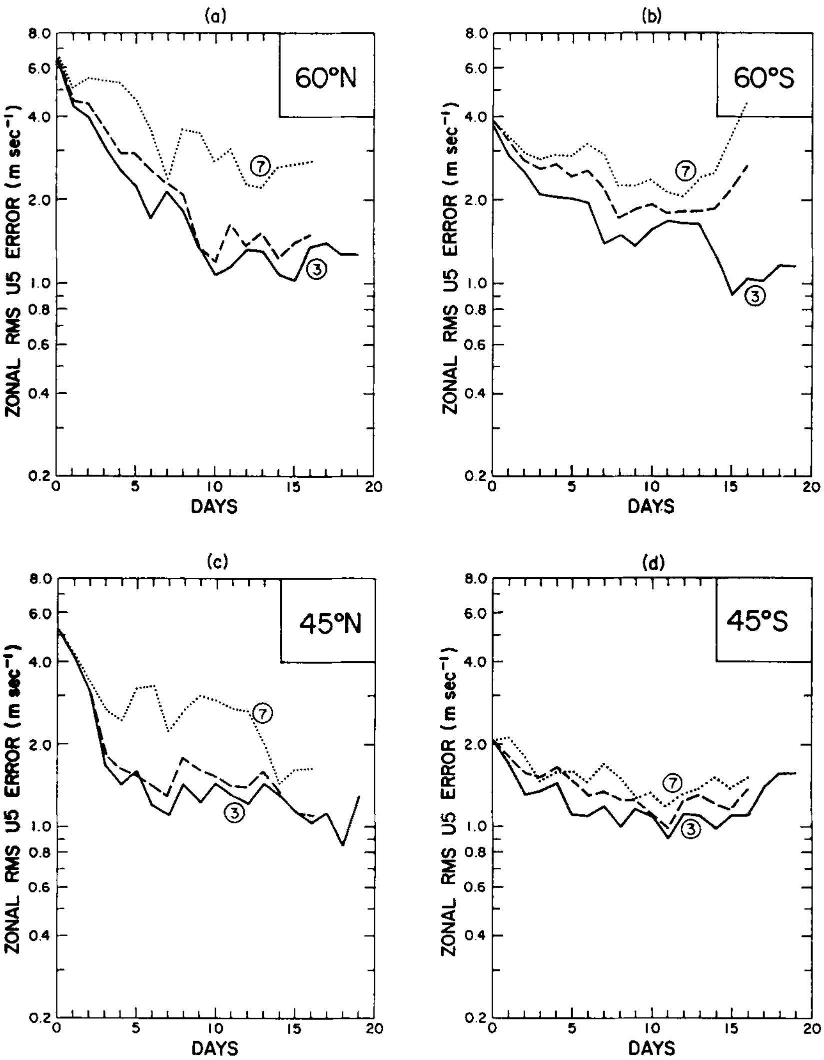

Fig. 1A. Additional reference pressure experiment.

Line code	Updated variables	Error bounds	Coverage	Update interval (hours)
	P_s	No error	Global	12
—— (3)	T_1 through T_6	0.5° random $+ 1°\ \sin 4\lambda \sin 2\varphi$	Global	12
· · · · (7)	T_1 through T_6	0.5°C random $+ 1°\ \sin 4\lambda \sin 2\varphi$	Global	12
	P_s	No error	Over land	12
- - - - -	T_1 through T_6	0.5°C random $+ 1°\ \sin 4\lambda \sin 2\varphi$	Global	12

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ОЦЕНКА ВАЖНОСТИ ИЗМЕРЕНИЙ ВЕТРА В ТРОПИКАХ И ДАВЛЕНИЯ: ЧИСЛЕННЫЕ ЭКСПЕРИМЕНТЫ ДЛЯ СИСТЕМ НАБЛЮДЕНИЙ

Статья описывает результаты экспериментов по численному моделированию систем наблюдений, проведенных в Национальном центре атмосферных исследований (США) с помощью шестиуровенной модели глобальной циркуляции с шагом 5°. Первая серия экспериментов имела целью оценку важности измерений ветра на двух уровнях в тропическом поясе (25° с. ш.–25° ю. ш.) и на шести уровнях в экваториальном поясе (10° ю. ш.–10° с. ш.), а также измерений температурного профиля, включающих случайные и систематические ошибки. Показано, что измерения ветра нужны в тропиках там, где одних температурных данных недостаточно для получения ветра с приемлемой точностью. Вторая серия проделана с целью определить относительное значение измерений давления на поверхности земли и на уровне 12 км для вычисления давления в гидростатическом приближении по вертикальному профилю температуры. Третья серия проделана для проверки желательности наблюдений температуры вместо наблюдений ветра в зависимости от географической широты и для определения минимальных требований к глобальным метеорологическим наблюдениям.