DATA ASSIMILATION FOR THE FGGE TROPICAL OBSERVING SYSTEM

Paul R. Julian

ECMWF*

*Present affiliation:

National Center for Atmospheric Research, USA

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ABSTRACT

The Tropical Observing System of FGGE and the forecast-analysis scheme at the ECMWF are examined in concert in an effort to evaluate features which can be considered successful and those which will need some attention in the future. The evaluation considers statistics of analyses minus observations, the divergent component of the analyzed wind field, sample case studies of strong divergence-convergence, and some phenomenological illustrations including resolution of the so-called easterly waves. On the whole, the combined observation-analysis system does a qualified excellent job of resolving the divergent component of the wind field. Because of present limitations in the statistical analysis scheme and in the forecast initialization procedure, the system fails to resolve occasional strong divergence-convergence occurrences and to propagate the divergence field forward properly in time. Neither of the shortcomings is thought to be insurmountable, but both must be recognised and considered in performing observing system impact and forecast studies.

1. INTRODUCTION

In this presentation, I intend to discuss the assimilation of FGGE Tropical Observing System (TOS) data emphasizing those results of the combined analysis-observation 'system' which presently seem satisfactory and those which need attention. The presentation should divide somewhat naturally into, first, a discussion of the observations and some phenomenological features; and, second, a discussion of the ECMWF Level IIIb analysis scheme.

In the presentation, however the division will not be sharp and cross reference will be made. The Tropical Observing System for the FGGE was, of necessity, a mixture of different systems. The mixture was the best that could be achieved given the resources available, the logistical difficulties, and the requirements established by the planning groups. Various ways of assessing the performance of this mix of systems are possible. In terms of the FGGE requirements for the observation of winds in the tropics, the TOS did not strictly measure up. The main deficiency was the failure to observe at a sufficient number of levels in the vertical at the desired spatial density. Because of the inherent characteristics of the cloud motion vector, aircraft, and constant level balloon observations, the distribution of TOS reports was heavily concentrated at low levels (900-850 mb) and in the upper troposphere (250-100 mb).

However, in an important sense this characteristic may not be as deficient as it appears when evaluated in terms of the strict requirements. If we refer to present knowledge concerning the dynamically and thermodynamically important regions of the tropics (i.e. the convective ones), we conclude that these two layers are the most important one. Fig. 1, taken from the article by McBride and Gray in the July 1980 QJRMS, summarizes a large amount of wind field data in the vicinity of moderately deep convective activity. The figure presents a mean profile of divergence calculated from aggragating rawinsonde data surrounding convective systems. The latter are identified by means of satellite infrared radiometer data, and the kinematic results are appropriate to a 3.0 - 3.5 degree radius about the convection. Even for moderately-deep convection, characteristic of GATE, for example, typical divergence magnitudes are of the order of 1-2 10^{-5} sec^{-1} for the inflow (below 900 mb) and for the outflow in the upper tropical troposphere. Reference to other such results published by Gray and collaborators indicates, not surprisingly, that the mean divergence profiles increase in magnitude but with similar shape as the measure of convective activity (the cloud IR temperatures) increases. Thus, in terms of getting the primary phenomenon in the tropics right, it is fortunate that the observation density is, indeed, a maximum in these two (inflow and outflow) layers.

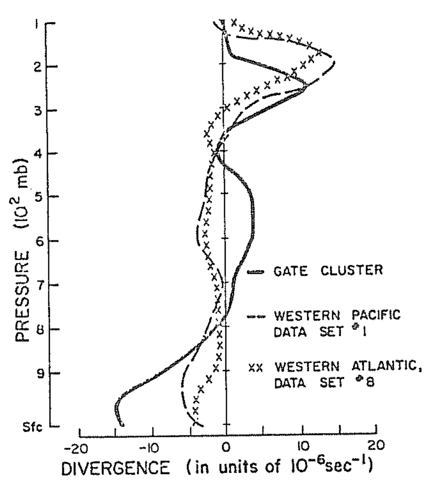

Fig. 1 Mean divergence profiles for the GATE cluster and for one of the weaker composite systems for each of the western ocean regions. (Reproduced from McBride and Gray, 1980 with permission)

In discussing the assimilation of TOS data, I will make considerable use of cloud infra-red data. The data are archived files of the 8-12 micron radiometer instrument aboard TIROS-N. They have been corrected for limb effects and represent averages over 2½ degree longitude, latitude areas. Thus, while considerably degraded in resolution, the satellite IR data are nevertheless commensurate with the ECMWF analysis-forecast scheme.

2. ANALYSIS ERROR

During Special Observing Period 1, Jan 15 - Feb 20, when all of the sub-systems of the TOS were deployed, the ECMWF statistical analysis scheme produced analyses which accommodated the various generic observing systems errors, together with the observation specific errors of the special observing systems (i.e. The Aircraft Drop-windsonde System, The Tropical Constant Level Balloon System, and The Tropical Observing Ships). The quantitative analysis errors, the rms difference of the analyzed minus the observed winds.

Table 1. Rms vector differences, ECMWF analysis minus observations. Tropics only, sample from SOP1 (metres per second).

Rms diff.	Assumed obs. error	Level (mb)
	RAWIN	
5.7	8.3	200
2.8	2.5	850
	ASDAR/AIDS aircraft	
4.5	8.3	250-200
	NESS/UWIS cloud motion vectors	
6.4	10.0	250-150
3.4	7.6	850
	METEOSAT/cloud motion vectors	
6.1	11.8	250-150
3.4	10.1	850

The analysis error, it should be noted, is less than the observation error; as, indeed, it should be in a statistical interpolation scheme. The mean component differences, or biases, were negligibly small for all observing systems except, perhaps, for the high level cloud motion vectors.

However, these statistics were computed using only those observational data which survived the data selection portion of the analysis scheme. A critical evaluation of these statistics must then include an evaluation of the data selection scheme, as well as the customary evaluation of the first guess supplied to the analysis scheme. Both of these evaluations will be attempted indirectly in what follows by means of case studies or selected examples.

3. ANALYSES OF WIND FIELD AND CONVECTIVE CLOUD SYSTEMS

February 2nd, during SOP1, was chosen as representative of a day during which all of the TOS sub-systems performed in optimum fashion. All of the aircraft dropwindsonde routes were flown, and the number and coverage of the constant level balloons was at a maximum. The ECMWF analysis for 18GMT (2 Feb) is depicted initially in terms of the stream function and velocity potential of the wind field. Figs. 2-5 show the 200 mb stream function and velocity potential and 850 mb stream function and velocity potential respectively. Figs. 6 and 7 present portions of the tropics with the divergent part of the wind field at 850 mb, bottom, and 200 mb, top, superimposed upon the cloud IR data. Cloud IR contours are in degrees Celsius.

Examination of these Figures reveals a divergence field which is related to the stream field and to organized convective activity in quite a consistent fashion. Particular note should be taken of the tropical disturbance located at 25S, 175E; the relative large amplitude ridge-trough systems in the northern sub-tropical Pacific longitudes; and the strongly longitudinal dependence of the tropical divergence field. An excellent correspondence between the location of deep convective systems and the 200 mb divergence pattern is apparent. In many cases, the correspondence can be seen for features down to 6-10 degrees of latitude (e.g. at 12S, 148E, 15S, 165W; 0, 125E). Also apparent is the fact that the relationship extends from the tropics into middle latitudes.

Examination of the velocity potential at 200 mb and at 850 mb reveals, in addition, an excellent inverse relationship in the divergent/convergent flow at the two levels.

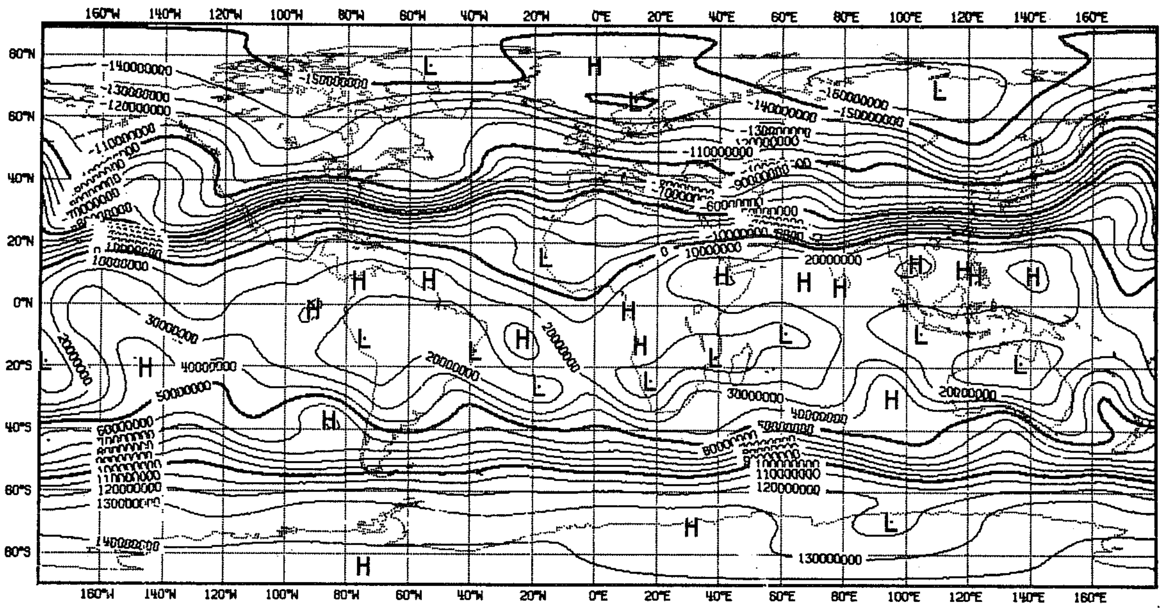

Fig. 2 Stream function, 200 mb, 18 GMT, 2 February 1979

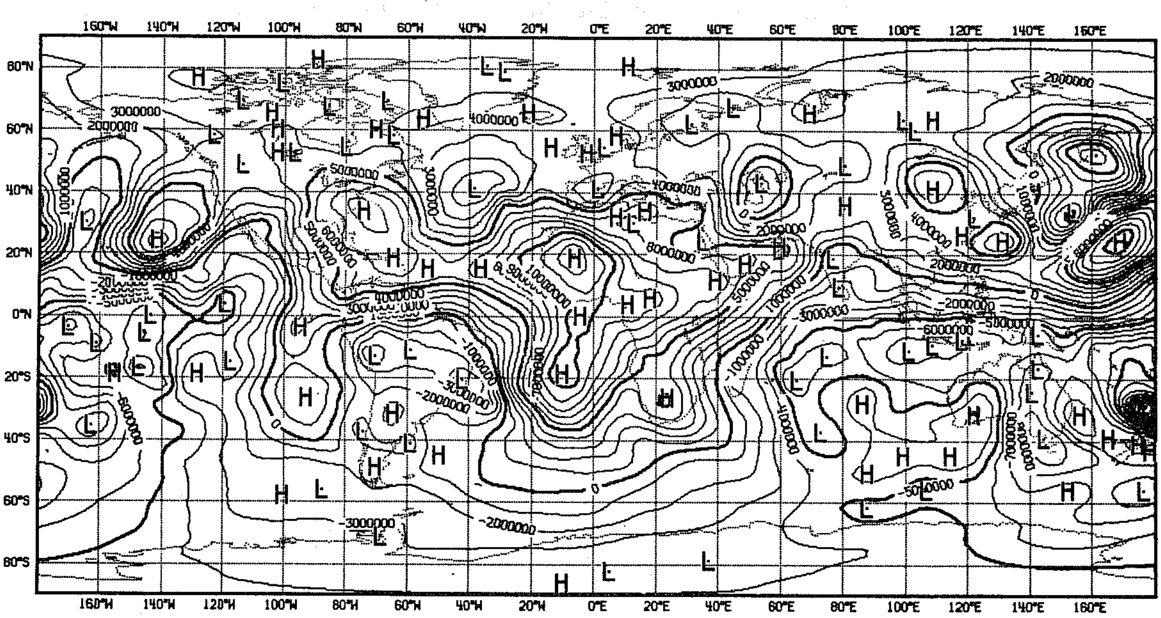

Fig. 3 Velocity potential, 200 mb, 18 GMT, 2 February 1979

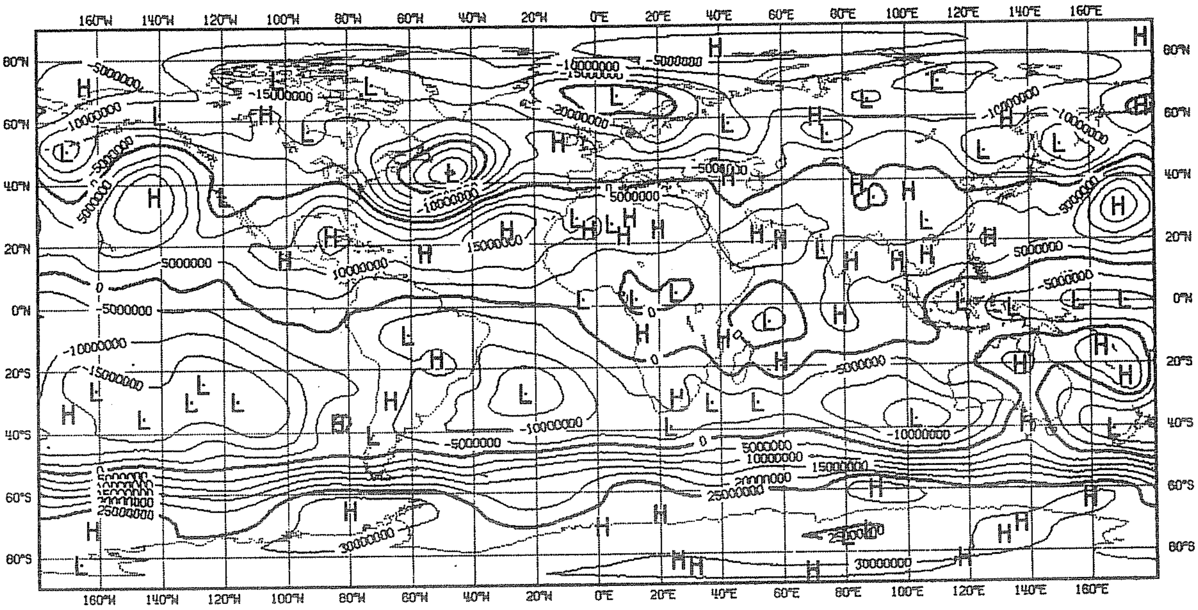

Fig. 4 Stream function, 850 mb, 18 GMT, 2 February 1979

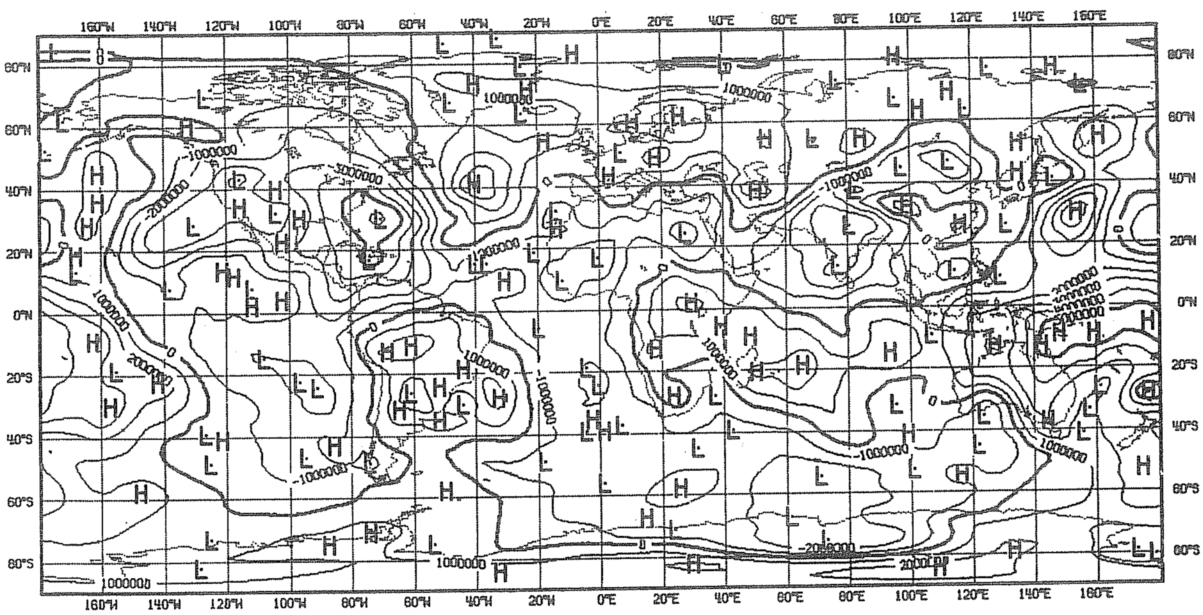

Fig. 5 Velocity potential, 850 mb, 18 GMT, 2 February 1979

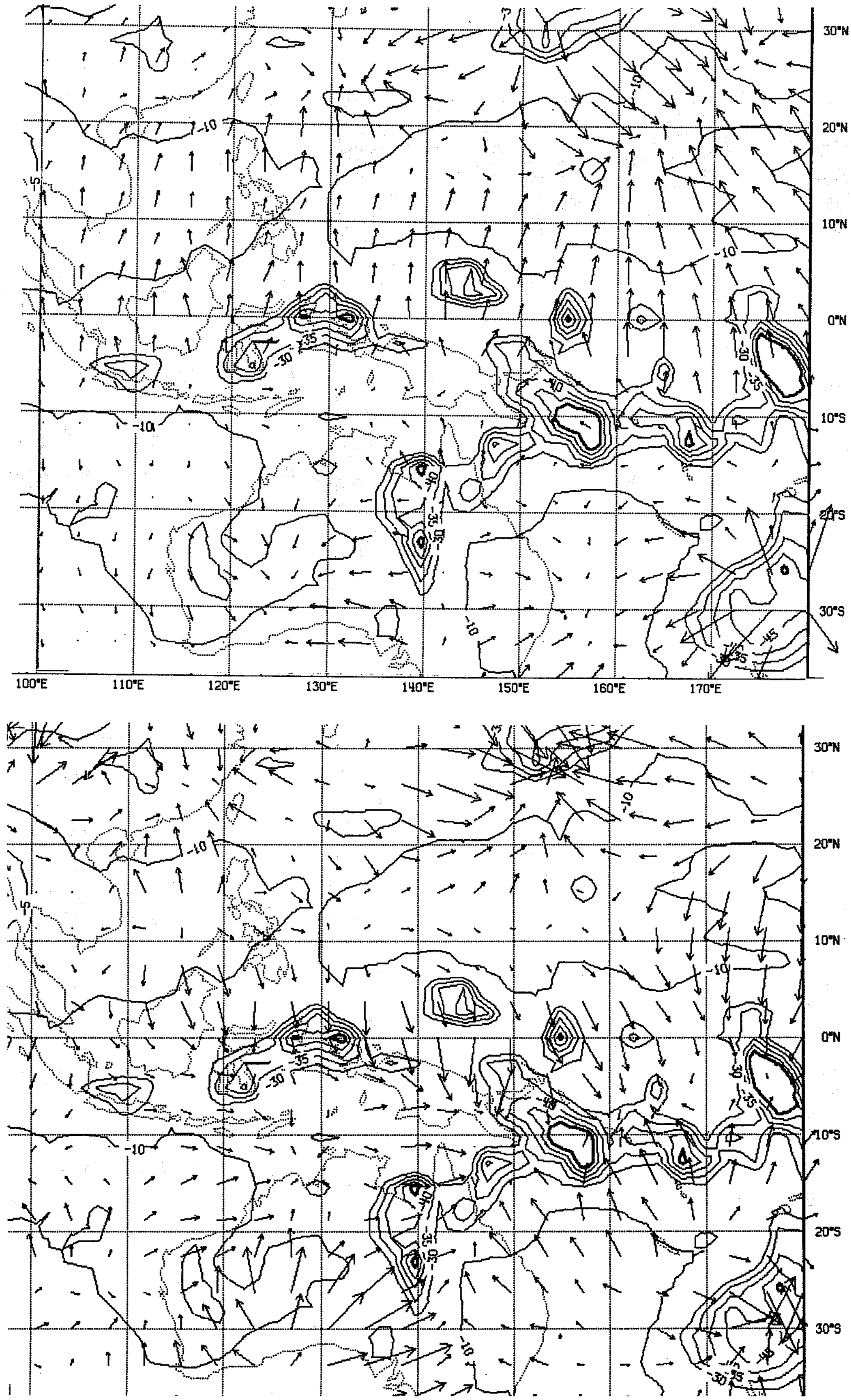

Fig. 6 The divergent portion at the 200 mb wind field, top, shown by arrows, superimposed on isopleths of IR satellite data, in degrees Celsius; 18 GMT, 2 February. Bottom portion is for the 850 mb divergent wind field.

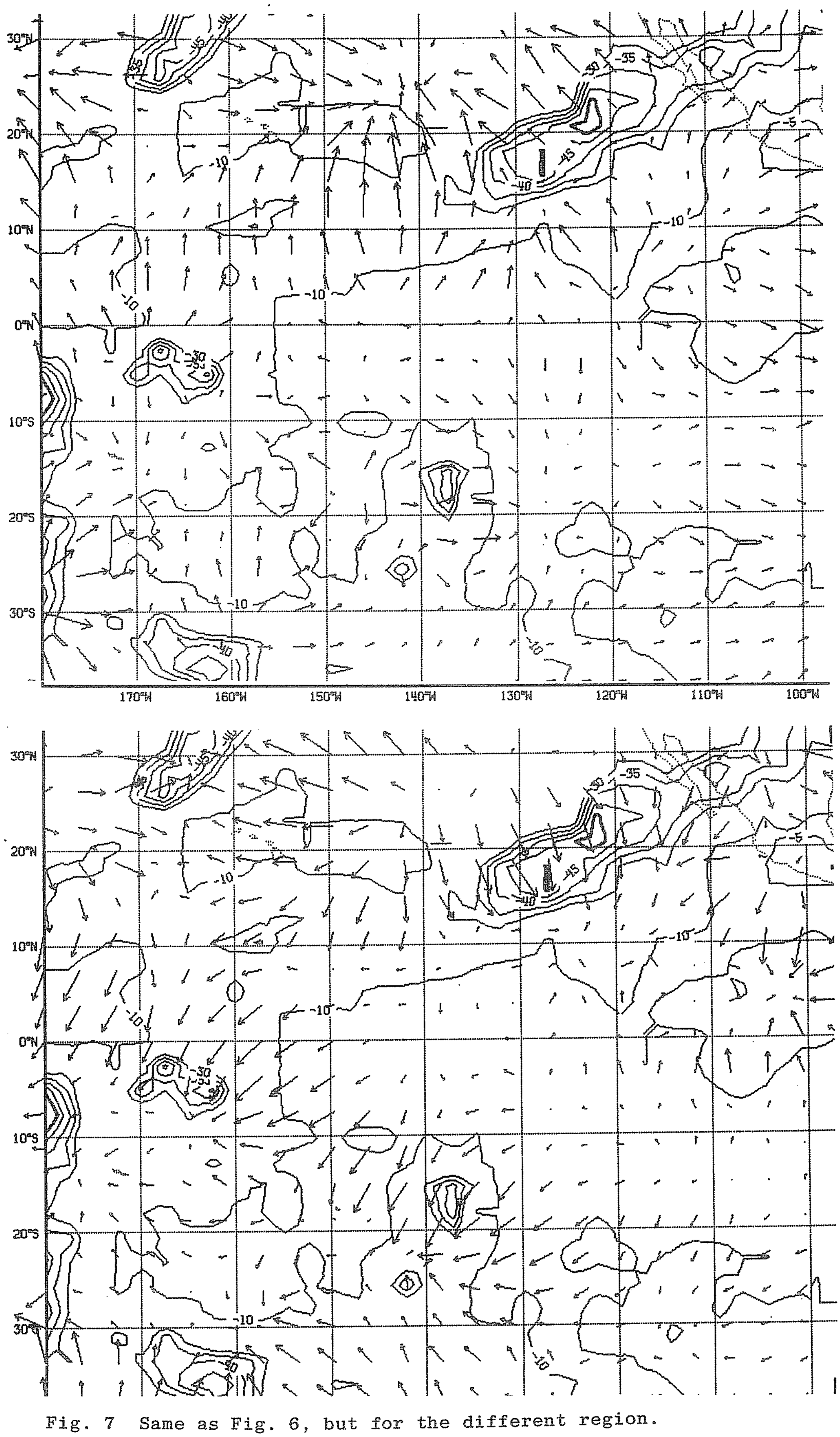

Fig. 7 Same as Fig. 6, but for the different region.

Practical space limitations prevent the presentation of a significant amount of similar illustrative material. I have detailed maps for three additional days during the early months of FGGE and the same agreement between the 850, 200 mb divergence-convergence fields and the major convective areas is apparent. To summarize, Figs. 8 and 9 illustrate the relationship on longer time scales: they are the monthly mean (Jan and Feb) velocity potential fields superimposed upon the mean cloud IR data. Remembering that the divergent wind 'blows' from low to high scalar values, one can readily see the global coherence in the two fields.

It is thus apparent that the TOS as constituted during SOP1, together with the ECMWF analysis scheme, are able to define a synoptically consistent and coherent wind field down to horizontal scales of 5-10 degrees of latitude. It is, of course, important to ascertain to what extent the detail in the divergence field is due to the data contributed by the TOS.

Meaningful data impact studies could be carried out by comparing the velocity potential fields, or the divergent part of the wind field, from analyses constructed with varying data bases. For example, the FGGE Level IIa and IIb bases, or with the present GTS operational base. Only one such comparison has so far been carried out at ECMWF: the full FGGE SOP1 observing system has been compared with a simulated GTS (operational) observing system. The qualitative results show that the GTS data base produces a divergent wind field lacking in resolution that of the FGGE TOS, but still quite well related to the large-scale convective areas. Clearly, more quantitative results with additional cases should be accomplished.

Following on with these results, however, I would like to point out a rather important consideration for evaluating data impact studies evaluated from <u>forecasts</u>. That is simply that <u>present</u> initialization schemes, in particular, and model convective parameterization schemes do not preserve and carry forward in a realistic fashion the kinematic features of the tropical troposphere that the observation system specifies. More will be said on the point in M. Kanamitsu's contribution, (and reference might be made to Chen et al, 1978, and Tribbia, 1979) but perhaps simply showing the 200 mb velocity potential of the initialized wind field, 2 Feb 18GMT, (corresponding to Fig. 3) will set the stage.

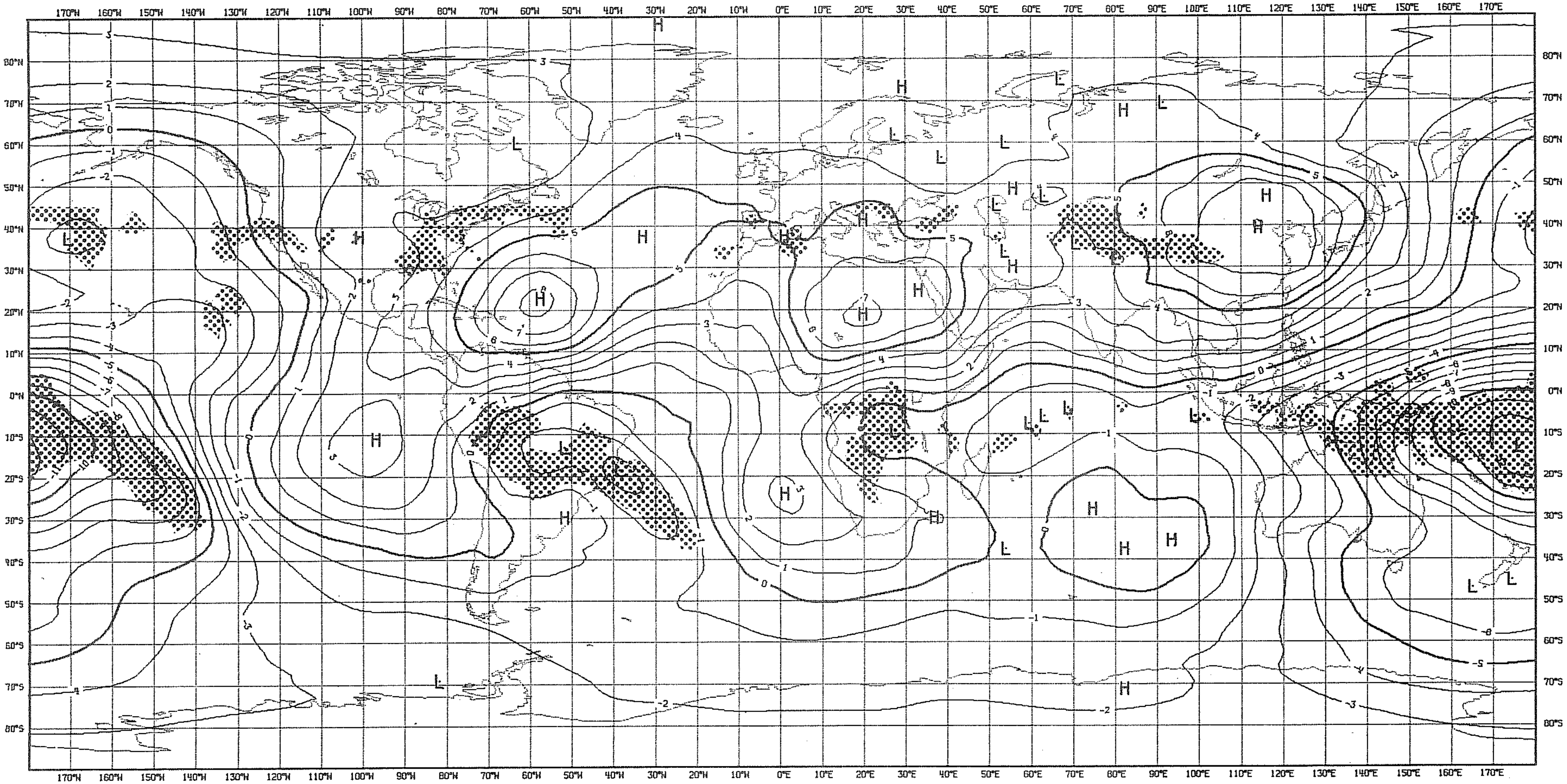

Fig. 8 January 1979 mean 200 mb velocity potential, with areas with mean satellite IR temperatures less than -30°C shaded. The IR data shown is confined to ± 45° latitude.

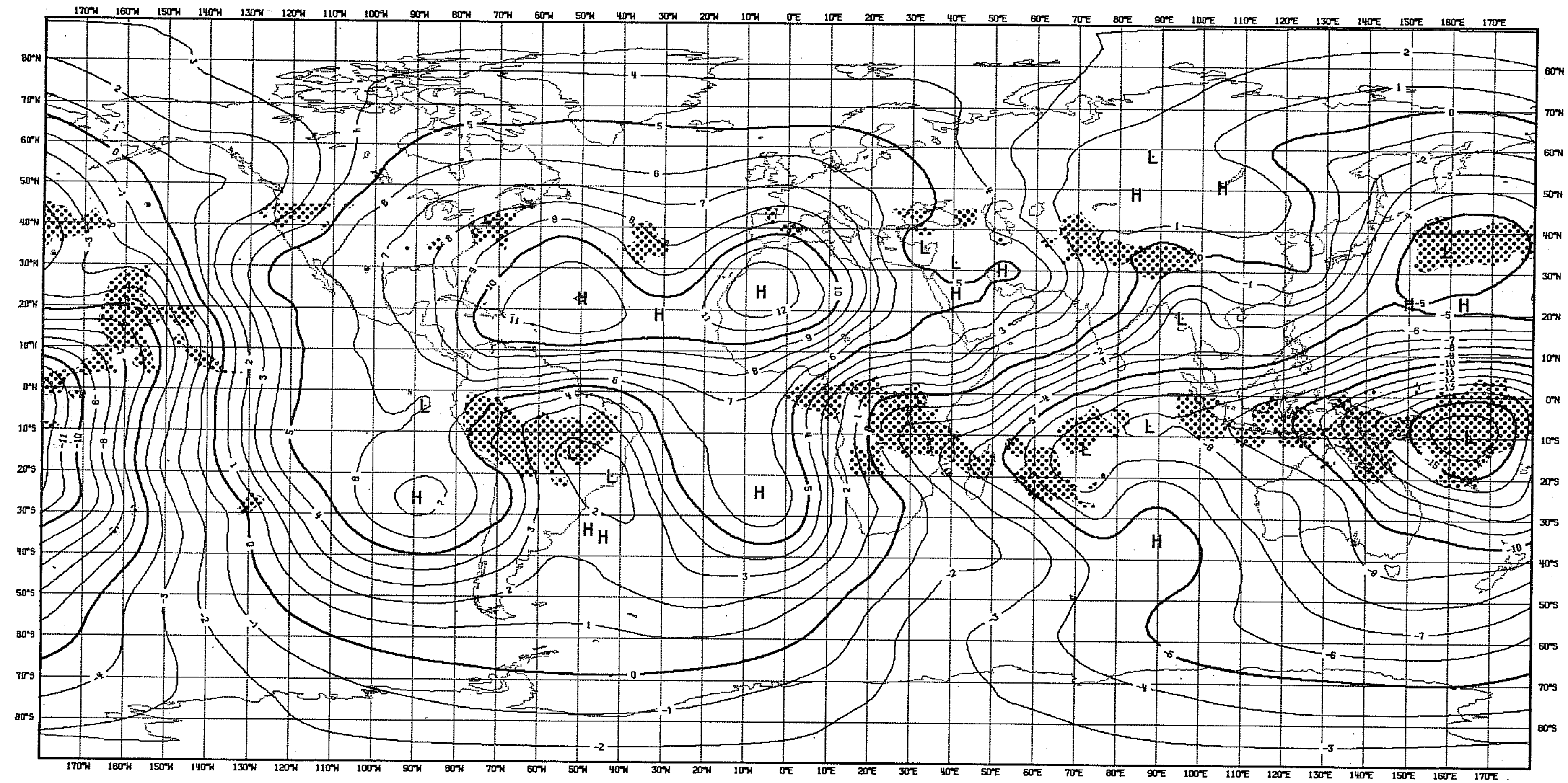

Fig. 9 Same as Fig. 8, but for February 1979.

Comparison of Figs.10 and 3 illustrate quite graphically that the present ECMWF normal mode initialization scheme drastically reduces the intensity of the divergence field and in places, e.g. over tropical South America, even changes its pattern. This property of the initialization scheme is undoubtedly due to present limitations of ignoring the model's physics. Finally, I must draw attention to the fact that in the ECMWF forecast-analysis cycle, the first guess supplied to the statistical analysis scheme is a six-hour forecast with a divergence-poor tropical region, and it is therefore primarily the observations that are recovering the realistic low latitude wind field.

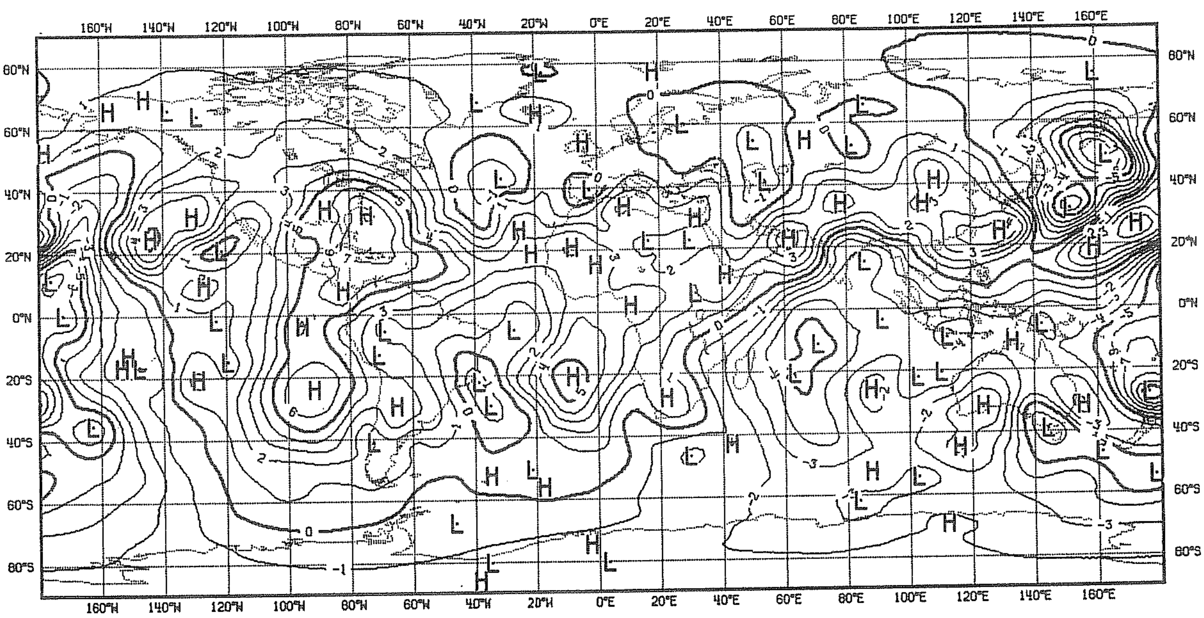

Fig. 10 The velocity potential for the 200 mb initialized wind field, 18 GMT, 2 February. This field should be compared with Fig. 3.

4. PROBLEMS FOR THE ANALYSIS SCHEME

The following material, in the nature of case studies, was selected to illustrate situations which are meteorologically important, but for which the analysis scheme has difficulty providing an adequate solution.

4.1 Case 1: 16 December 1978

Figs.11 and 12 show a portion of the central equatorial upper troposphere at 12 and 18GMT, 16 December. In Fig.11, the ECMWF 250 mb analysis is shown with arrows denoting the wind direction and dashed lines the isotach field. The observations available to the analysis scheme are plotted in more or less conventional form. (Aircraft reports have the flight identifier at the base (e.g. FM880, PA809, or AIRCF)). Fig. 12 presents the situation in the six-hour interval 15-21 GMT. Now cloud motion vectors are available, and are entered with either LD or NS at the base of the vector.

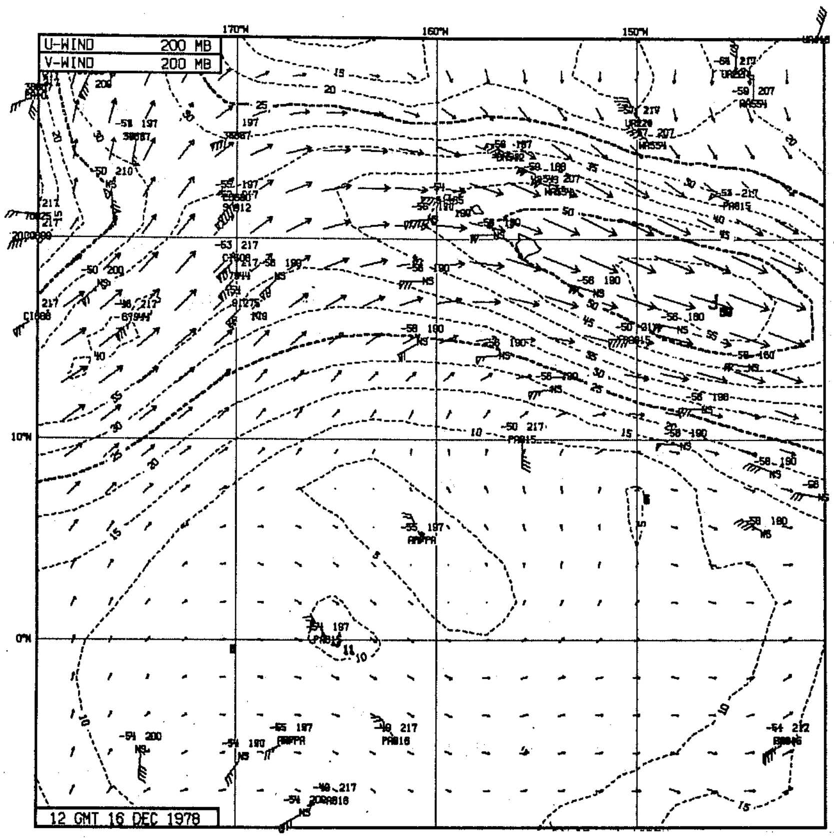

Fig. 11 The ECMWF analysis at the 200 mb wind field, 12 GMT, 16 December 1978 with observations included. The dashed lines are isotachs. See text for explanation of the data plotted.

These two Figures summarize a situation with extremely strong velocity divergence oriented along a line from 8N, 170W to 9N, 150W. The cloud motion vectors and aircraft winds are in excellent agreement and taken together with similar data from other levels and during the first six hours of 16 Dec (not shown here) provide overwhelming evidence of a very large scale and extremely strong divergence field. Examination of GOES-West imagery for this interval supports this feature, indicating massive and very deep convection in the area bounded by 0-10N, 170-160W.

The ECMWF analysis scheme made a valient attempt to cope with this situation, but because of the fact that the wind structure statistics

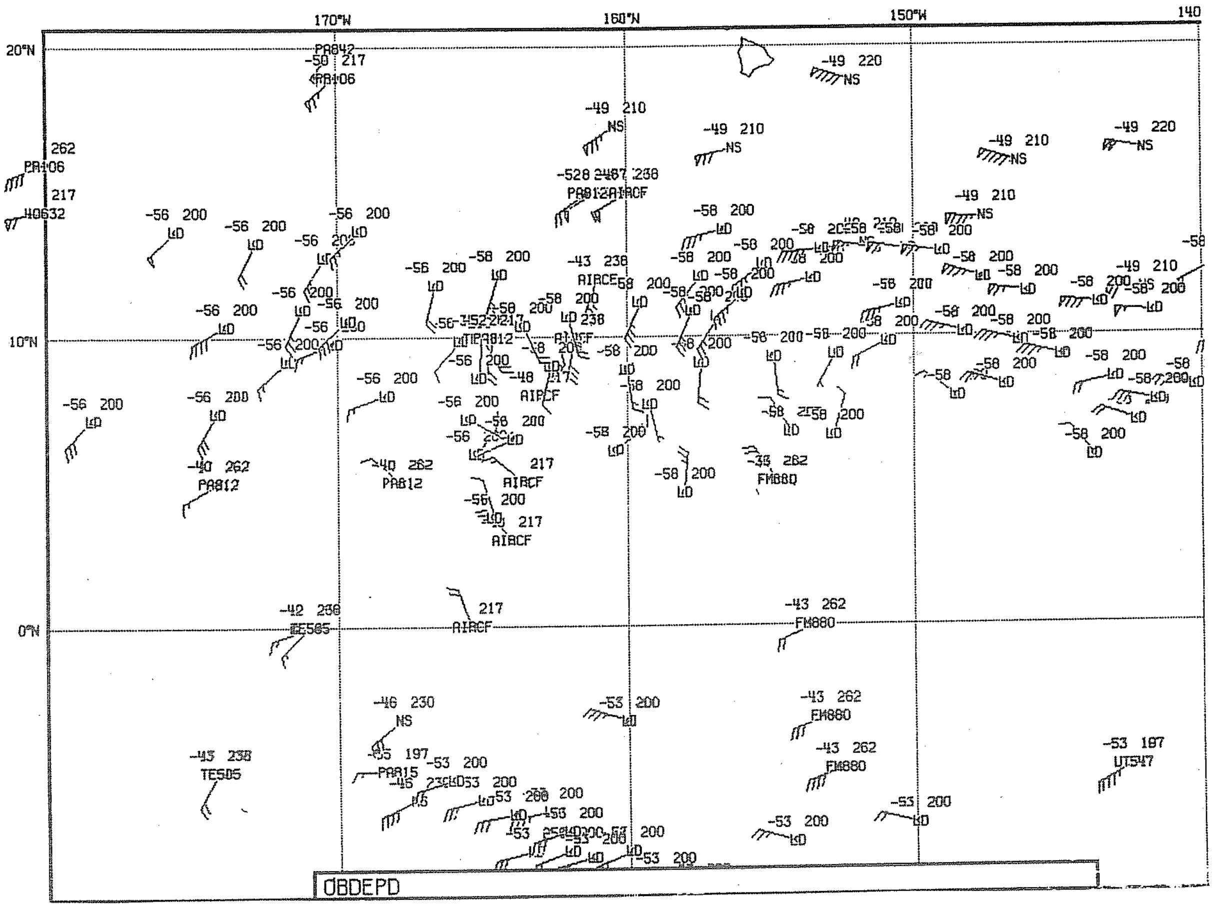

Fig. 12 A plot of the observations alone for the six-hour interval centred at 18 GMT, 16 December, immediately following Fig. 11. See text.

used with the interpolation scheme are non-divergent, the result was not realistic. In Fig. 11 the analysis produces divergence in two distinct areas, but because the non-divergent structure functions are employed on scales smaller than 6 degrees of latitude, the resolved divergence must then be distorted into the larger scales. A subjective analysis of this situation produced divergence values exceeding $8\ 10^{-5}\ sec^{-1}$ extending along the aforementioned line. The largest values of divergence found in the ECMWF analysis are of the order of $1\text{-}2\ 10^{-5}\ sec^{-1}$, with lower values indicated in some of the areas with the largest subjectively produced divergences.

4.2 Case 2: 21 January 1979

Fig. 13 is a montage showing, bottom-to-top, the 200 mb, 150 mb data and analysis, and the TIROS-N observed infra-red equivalent black-body temperatures (in minus degrees Celsius) for a region near the tropical date-line. In the lower portion, all data shown are cloud motion vectors: in the middle portion, the wind vectors having 5 digits at the base are Tropical Constant Level Balloon data. Note particularly the observation of the Balloon 519 at 9N, 180. The analysis scheme rejected this observation in the data selection phase of the analysis, and did not include it in the statistical interpolation phase. I have examined the Level I and trajectory data for this platform and found no reason to doubt the wind observation. Further, the cloud motion vectors at 180-190 mb slightly north-west of the balloon provide support and indicate that flow from the north is occurring north of 9N on a reasonably large scale. Now, examining the IR data (top), we note a very strong gradient in IR temperature along 12N (the data shown are averages over 2½ degree squares). The interpretation of these IR data is that convective clouds are present nearly everywhere south of 5-8N, with some very deep, cold clouds centered about 5N, 175E. North of 12N, however, the IR temperatures are indicative of clear, or at most low level cloudy, conditions. Thus, it appears as if the correct analysis of this situation would have involved a strong line of convergence oriented along 9N from 180 to 165E or so.

This obverse situation from the previous case is important because it indicates that the TOS is capable of resolving both significant convergence and divergence areas, whereas an observing system utilizing high-level cirrus-drift winds alone might be biased toward divergent situations.

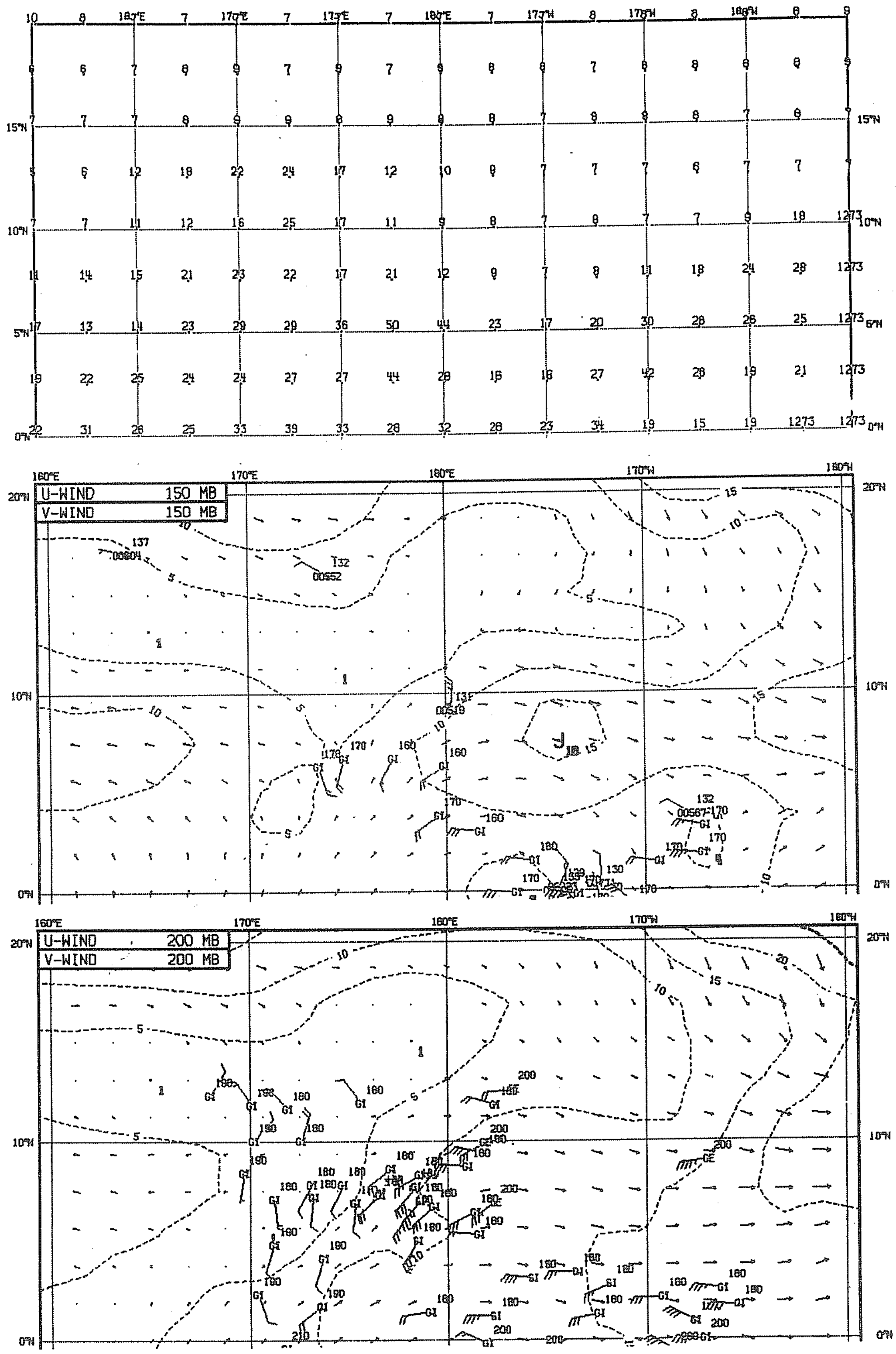

Fig. 13 Bottom-to-top ECMWF 200 mb wind field analysis with observations superimposed, same but for 150 mb, and (top) satellite equivalent block body temperatures (^{o}C, minus sign omitted) for a portion of the control equatorial Pacific, 18 GMT, 21 January 1979.

5. EASTERLY WAVES

An additional check on the performance of the observation-analysis system was made to test the ability of the system to resolve the propagating wave systems of the tropics. These systems, usually called 'easterly waves', have been studied by including cloud IR data by e.g. Chang (1970). Typical phase speeds are of the order of 5-7^{o} longitude per day; and, at least from pre-FGGE studies, preferred Northern Hemisphere geographical regions are the western Atlantic and Pacific Oceans. To investigate these systems during FGGE, longitude-time diagrams of the analyzed meridional wind component in the latitude band 5-10 N were prepared. Westward propagating disturbances were detectable on these diagrams: however, little 'easterly wave' activity was apparently present in the N.H. tropical Atlantic area during these two months. Overlays showing the TIROS-N EBB IR temperatures along 5-10 N were also prepared. Fig. 14 shows a portion of the longitude (abcissa)-time (ordinate, top to bottom) diagram for the 700 mb v-component. A sector of the Pacific from 1 to 13 January is included. A pronounced wave is apparent, commencing near the Date Line on 1 January and moving to 150E on 9 January. Southerly winds to the east and northerly winds to the west of the wave axis on the order of 4-8 metres per second. The observed phase speed is somewhat less than that typical of the western tropical Pacific.

Cloud IR data has been superimposed on the diagrams: the heavy horizontal lines indicate regions in which the IR temperature were less than -30 Celsius, and the plus signs greater than -7C. (Data from 2-3 January in the region were mostly missing). The excellent correspondence between the convective cloud location indicators and the propagating wave is evident.

The location of the clouds along the wave axis is in agreement with synoptic studies of these disturbances, but the correspondence between 'wave' and convective cloud was not as apparent as in this instance.

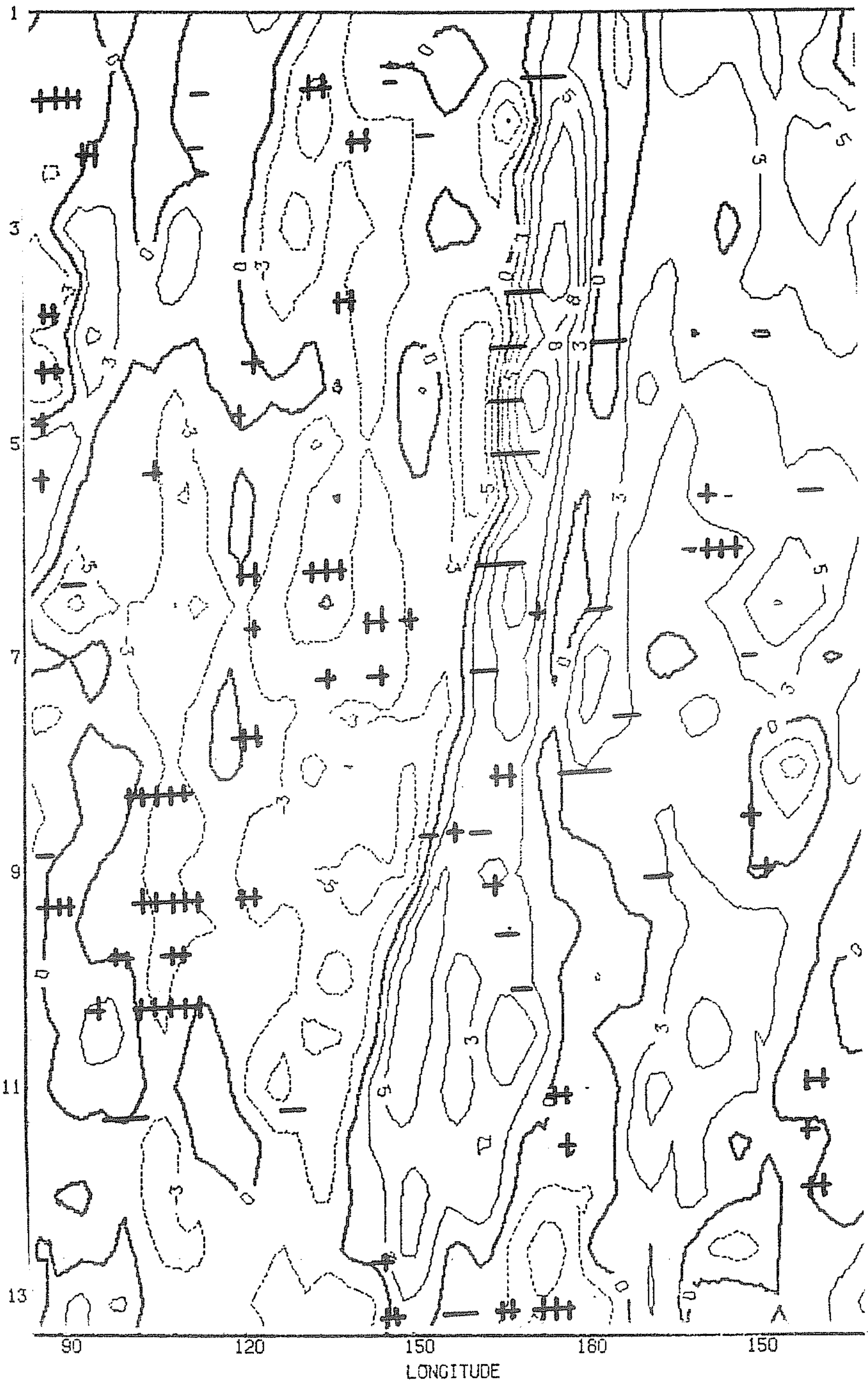

Fig. 14 Longitude time (top-to-bottom) diagram of 700 mb U-component, 5-10N, ECMWF analyses, January 1-13, 1979. The horizontal lines superimposed denote regions with satellite IR observations less than -30°C and the plus signs greater than -7°C. Most of the IR data for 2-3 January is missing.

6. INERTIAL FLOW

A phenomenological observation of interest comes from the Tropical Constant Level Balloon System. On a number of occasions balloon platform trajectories exhibited anticyclonic loops of cycloidal pattern that strongly suggested inertial behaviour. These occurrences were within 5-15 degrees of latitude (N or S). The periods and morphology of the cycloidal loops agreed very well with the theory of inertial flow in low latitudes in the presence of a time-invariant zonal pressure field. Additional searching through the trajectory data revealed cases of apparent inertial flow crossing the equator.

A sample of three such cases is given in Figs. 14 to 16. Two of these illustrate cycloidal motion, one in each hemisphere, and the other a cross equatorial trajectory - in the latter, the wavelength and period predicted by theory (Wiin-Nielsen) is, within the observational uncertainties, exactly determined.

It is important to note that typical horizontal space and time scales characteristic of this type of flow are 3-7 days and thousands of kilometers. Thus, from TOS observations, the upper tropical troposphere seems to be a region of the atmosphere with rather dichotomous behaviour. In rather restricted areas and associated with large-scale convective activity strong divergence/convergence fields and associated dynamic consequences occur. In the remainder of the tropics, the flow is at least partly inertial, reflecting the lack of convective (and other) processes and the slow (relative to mid-latitudes) adjustment of the mass and wind fields.

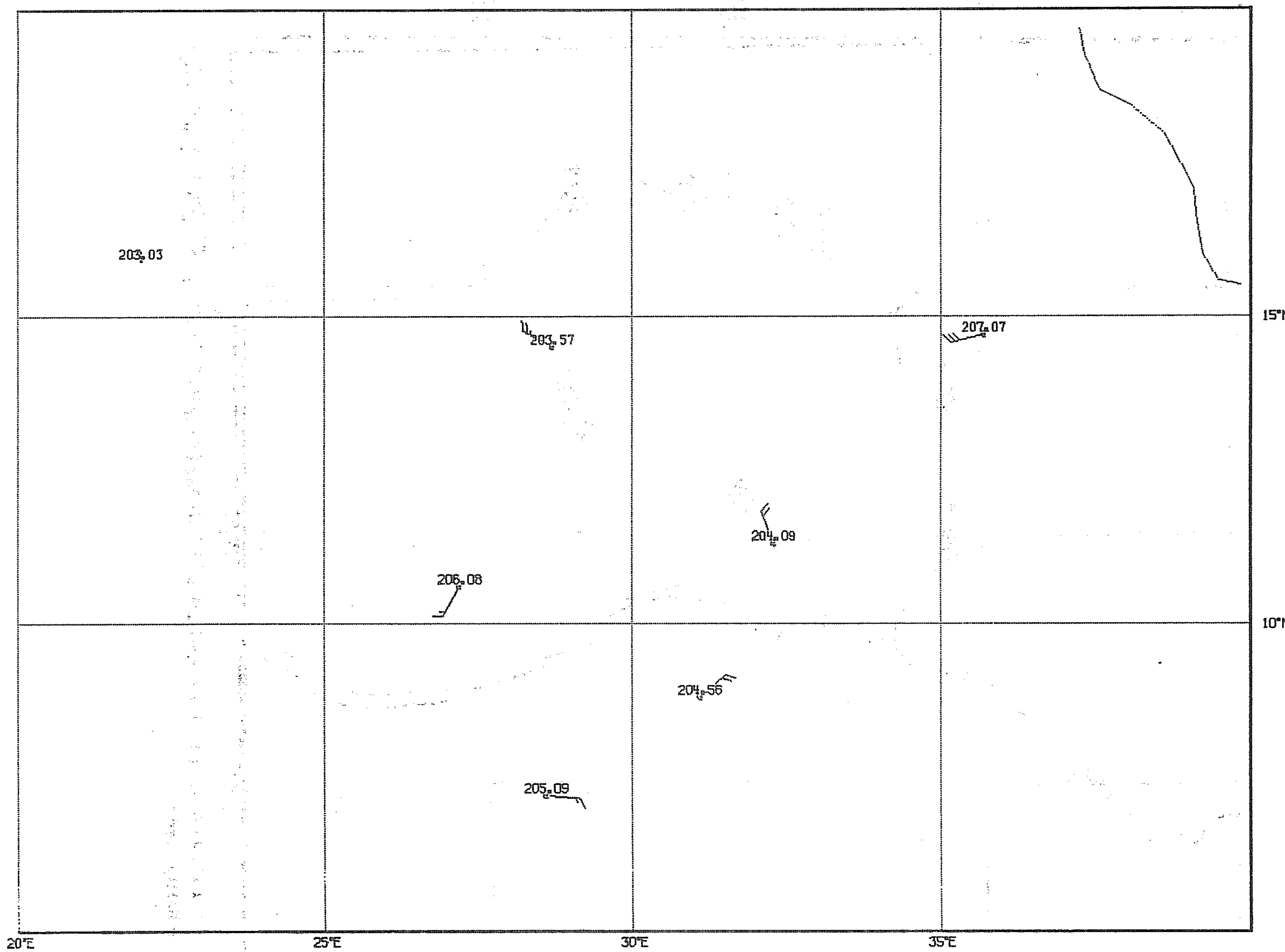

Fig. 15 A portion of the TCLBS trajectory data for balloon 621, February 3-7 1979. Winds are plotted conventionally with full barb equal to 5 metres per second. The date and time 205.09 indicates the observation was made at 09 GMT on 5 February.

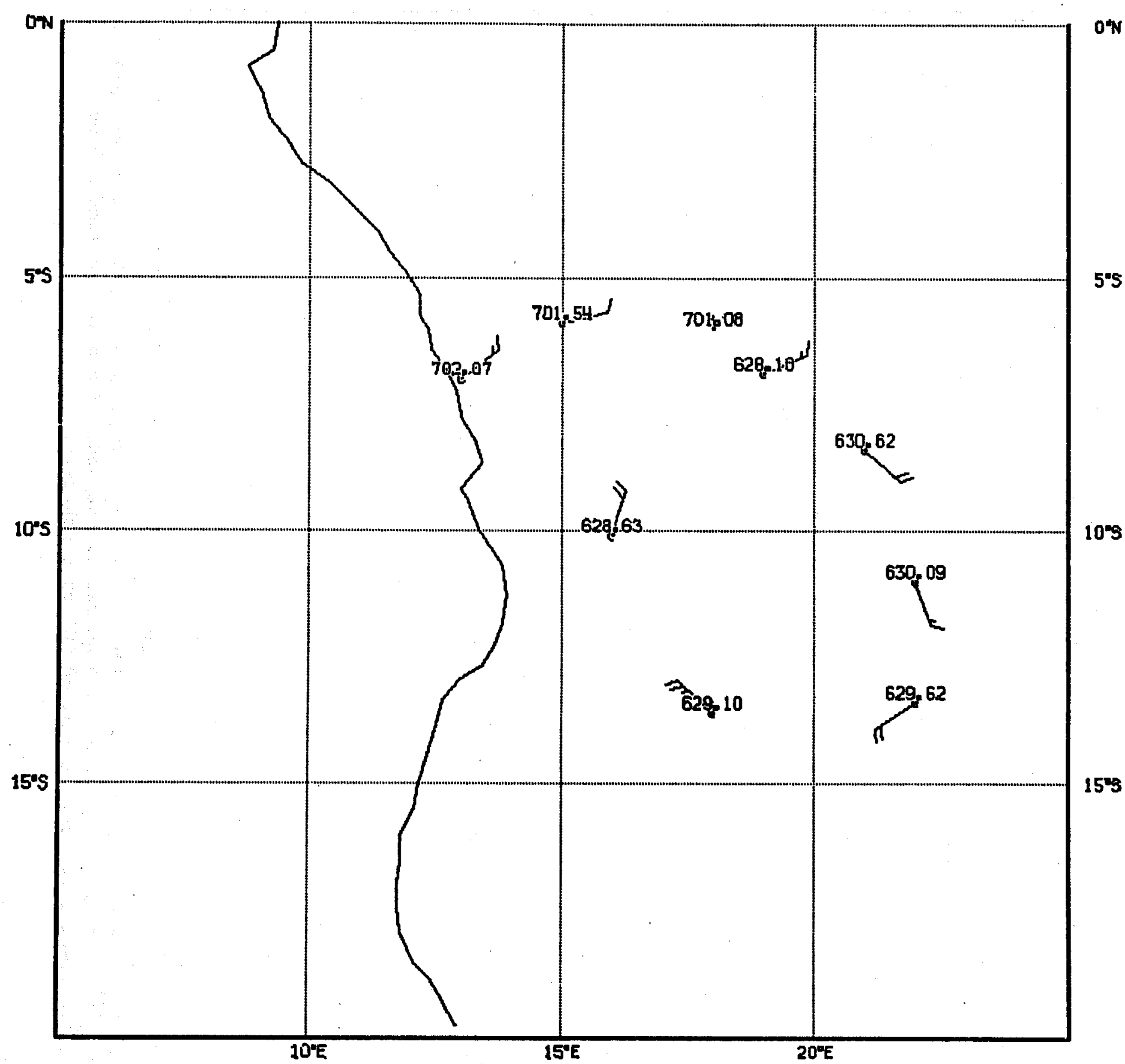

Fig. 16 A similar diagram to Fig. 15 but for balloon platform 533 in the southern hemisphere.

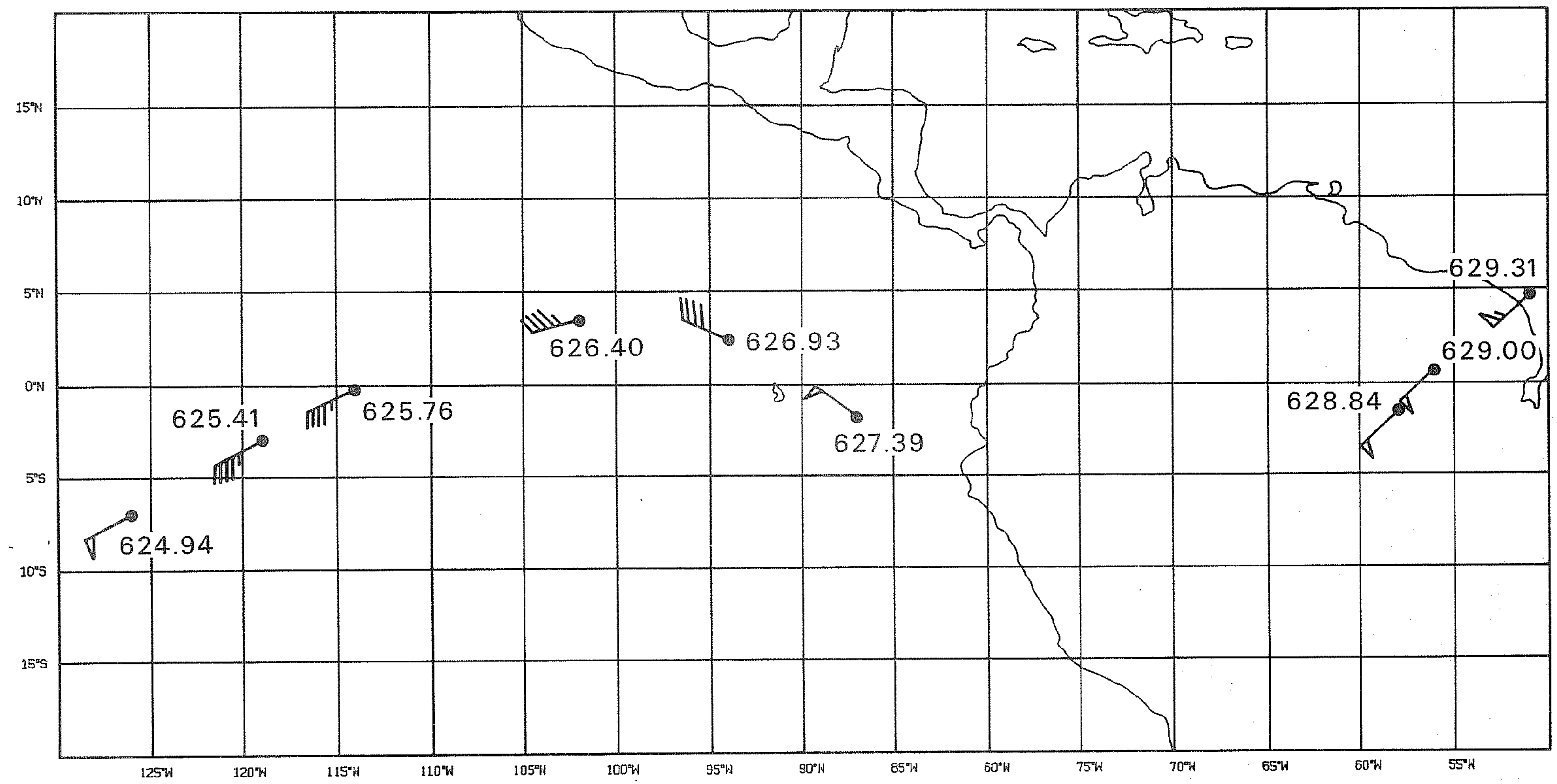

Fig. 17 A portion of the cross equatorial trajectory for balloon 667 from 24 June to 29 June 1979. Data are missing from most of the latter half of 27 and the early part of 28 June.

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