THE FGGE TROPICAL OBSERVING SYSTEM AND THE ASSIMILATION OF DATA

Paul R. Julian
National Center for Atmospheric Research

1. INTRODUCTION

This contribution will address the first two stated objectives of this Seminar, and substitute a third objective which I believe to be an important one in the tropics. Thus, the three sections of the contribution will be

i) To review the characteristics of the FGGE Tropical Observing System (TOS).

ii) To provide an up-to-date review of four-dimenstional data assimilation in the tropics, and

iii) To assess what the TOS has shown us regarding the behavior of the tropical atmosphere that is relevant for ii).

The omission of the third stated objective, the review of Observing System and Observing Systems Simulation Experiments, was suggested by the review ii), above; and the third objective substituted because I believe it to be important to a satisfactory completion of the first two. The order in which these three will be presented will be i), iii), and ii).

2. THE CHARACTERISTICS OF THE TROPICAL OBSERVING SYSTEM

The planning for FGGE that involved the establishing of observational requirements for the tropics was an especially difficult job. Not only did those responsible for the planning and requirements not know exactly how to formulate the latter, the job of how to fulfill them with the resources available looked formidable indeed. From a strict scientific viewpoint and using what was learned from GATE, it was thought that an observing system capable of resolving the transient westward moving disturbances of the tropics was needed. If that job could be accomplished, then the more energetic tropical storms as well as the planetary-scale flow components could be captured. It is well to recall that, at the time, only sketchy ideas were had concerning the role of the tropics for extended-range prediction in midlatitudes. It is also necessary to recall that an objective of the FGGE (and GARP) was to attempt to determine that role.

The requirements that were finally established are set out in Table 1 together with a very brief summary of how the actual Tropical Observing System (TOS) performed in the Intensive Observing Periods. Any evaluation of how well the TOS fulfilled the requirements would have to include the term marginal. The main deficiency is the lack of the specified vertical resolution (5 levels) on the specified horizontal scale. However, to compensate for this deficiency is the availability of single-level wind vectors, concentrated in the upper and lower troposphere, providing resolution better than that required. This Seminar has the aim of evaluating the performance of the TOS not with respect to the requirements but with respect to the goals of FGGE.

In the next subsection, a very brief review of each of the components of the TOS is given.

2.1 The Tropical Constant Level Balloon System

The TCLBS was instituted to fill a gap in the vertical coverage of the wind observation program in the tropics owing to the limited operational altitude of the Aircraft Dropwindsonde aircraft. Experience gained at NCAR during a previous constant level balloon experiment (TWERLE) provided the confidence that a similar system could be deployed in FGGE.

Table 1a: Wind Requirements - Equatorial Tropics - SOPs.

All winds to ± 2 mps.

	Horizontal Resolution	Vertical Resolution	Soundings Per Day
Stratosphere	4000 km	3 levels	1
Troposphere, Active Regions	350 km	5 levels	1
	or		
	500 km	5 levels	2
Troposphere, Inactive Regions	500 km	5 levels	1
	or		
	700 km	5 levels	2

Table 1b: Tropical Observing System Summary

Intensive Observing Periods, I, II

TWOS	60-80 wind soundings per day (TWOS-radar soundings increase this some)	[65]
ACDWS	25-110 wind soundings per day	[68]
TCLBS	4 x (100-150) wind vectors per day	[500]
WWW	125 wind soundings per day	
Cloud-drift	2250 wind vectors per day	
Aircraft	250-300 wind vectors per day	

The TCLBS, as a part of the Special Observing Systems in FGGE, consisted of 153 (and 157) platforms launched from two (three) sites within the tropics during SOP-1 (SOP-2). Because of air safety considerations the float altitude was chosen to be above commercial airspace, at 135 to 140 mb. Thus in the tropics the balloon platforms were in the upper troposphere and subject to the vicissitudes provided by convection; when floating in the extratropics the balloon platforms were in the lower stratosphere. Political and air safety considerations dictated that two cutdown systems be integrated into the TCLBS: one to destroy the platform should it be forced downward to a pressure greater than that at the top of commercial airspace (143 mb); and a second to destroy the platform were it to drift northward of an arbitrary geomagnetic lattitude. A sizeable fraction of platform loss was accounted for by these cutdown mechanisms. The platform tracking was done by the ARGOS on board the NOAA-NESS satellites, and the location and data collection system performed in a very satisfactory fashion. Level IIb data were prepared at NCAR by employing an interactive graphics system that allowed the platform file obtained from Service ARGOS to be edited (Figure 1). The position and position/velocity observations remaining were analyzed by a quantitative polynomial fit so that position and velocity could be interpreted at the standard six-hour synoptic times. Quantitative uncertainties in the wind vectors calculated by such a procedure depend on the tracking accuracy and the trajectory determination and have been found to be less than 2.0 mps (vector RMS) for 90 percent of the vectors produced. This figure is less than the uncertainty in any other wind observing system and is the direct result of the tracking accuracy and quasi-Lagrangian nature of the system.

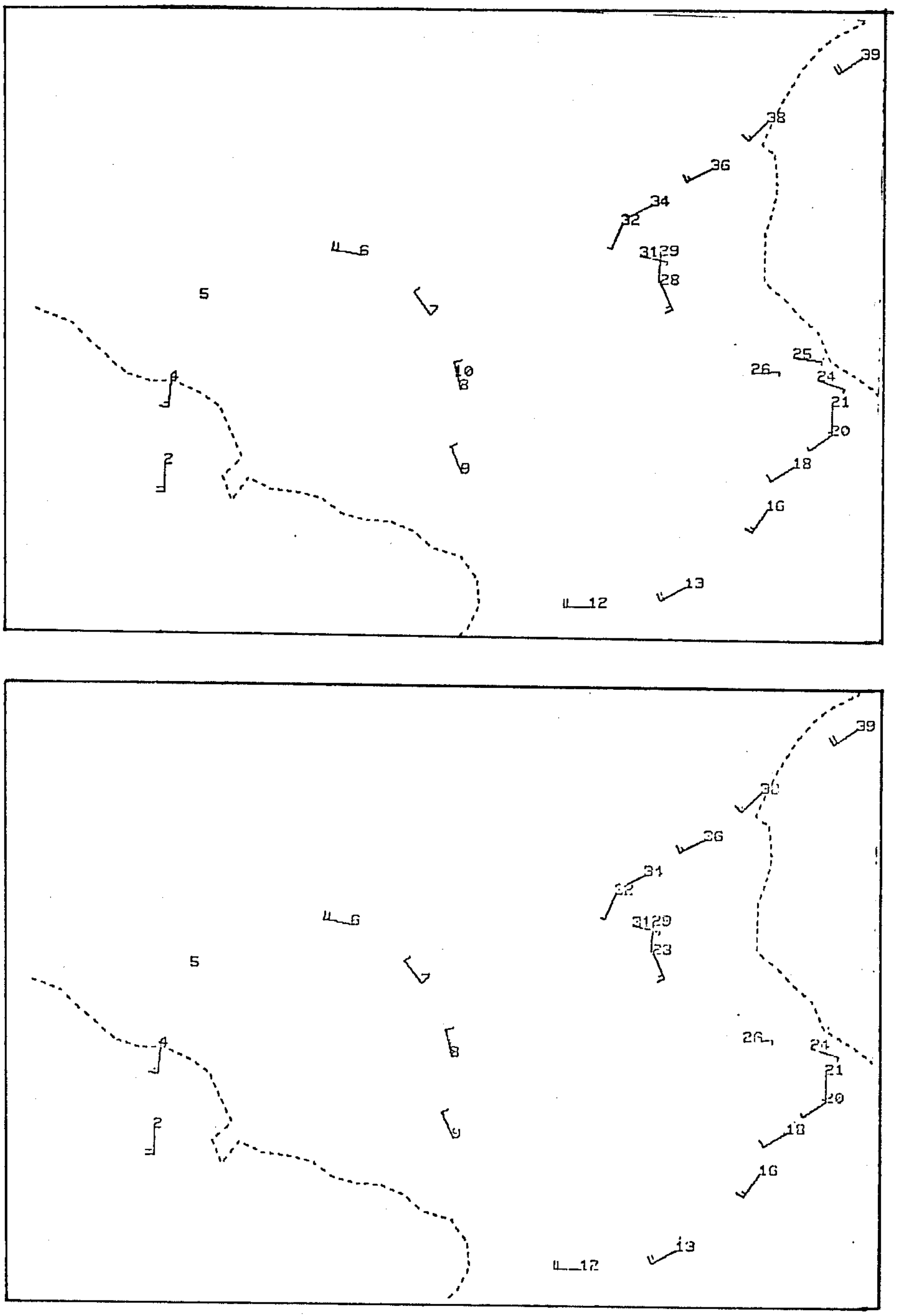

FIGURE 1. Example of interactive editing of TCLBS trajectory files. Unedited screen, above and edited, below. Numbers are serial file numbers.

2.2 Aircraft Dropwindsonde System (ACDWS)

The ACDWS was the most logistically and technically complicated system deployed during FGGE. The deployment of that system aboard a fleet of aircraft of three different makes, operating from four remote bases, was a major accomplishment of the U.S. FGGE Project Office and the U.S. program. It should be pointed out that, like the Drifting Buoy System, the ACDWS hardware had received only limited testing before the Experiment. The IIb software system used to process the drops was virtually untested at the commencement of SOP-1 operations. A summary of the numbers of sorties flown, number of sondes dropped, logistic difficulties and successes may be found in The Global Weather Experiment, Final Report of U.S. Operations. A summary of the data processing and ACDWS omega windfinding may be found in Julian (1982).

In this contribution I will concentrate on two particular features of the ACDWS winds: first, the quality of the Main versus the Final IIb data sets and, second, the assimilation of the Main (Final) IIb data by the ECMWF (GFDL) IIIb schemes.

Very briefly, omega windfinding is a relatively complex process compared with radar or radio-direction finding techniques, and the assessment of quality or uncertainty, while quantitative, is more involved. Sources of uncertainty may be divided into those external to the system, mainly ascribable to various kinds of unsteadiness in the omega navigation net, and those internal to the system, mainly electronic and antenna noise. The latter may be quantified so that a minimum uncertainty or error can be attached to each wind vector. The former source of error is quite small save two important instances. One of these, the occurrence of sudden ionospheric disturbances caused by solar activity, was significant but could be (and was) easily monitored. In spite of some apprehensions about deploying a sensitive system during sunspot maximum, only 10 drops out of nearly 5000 processed had to be eliminated because of the sudden ionospheric disturbances.

The other source of external error, however, proved to be unsuspected, difficult to monitor, and much more serious on its impact on the Main Level IIb data set. Normal VLF propagation involves a standing wave mode propagating between the earth's surface and the ionosphere, and normally dissipation of the electromagnetic wave is such that received signals from a great-circle least distance path predominate at any locality-that is, the direct wave signal strength is much greater than the wave propagating through the antipodal point (e.g., Figure 2). Enough was known or predicted by waveguide theory in 1978 to stipulate that eastward daytime propagation was favored over westward propagation. As a result, the data processing algorithm used to derive the Main IIb set did not use omega signals from stations occurring at a great circle distance greater than 140°E of the drop. However, quick feedback from MONEX dropwindsonde users at Florida State University pointed to some serious problems with vectors from drops in the Indian Ocean. Subsequent examination of these drops and detailed recalculations elicited the fact that, on occasion, the eastward propagating signals instead of being dominant over 220° of arc (as above) were dominant over as much as 250°. (For the example shown in Figure 2, Hawaii propagates anomalously instead of as shown.) This longpath or anomalous propagation, as it is termed, is especially problematic because, save by recalculating the winds with and without a suspect signal, it cannot be detected uniquely by the ACDWS system itself. (This is <u>not</u> the case in the TWOS-Navaid system because of the availability in that system of direct (local) omega recorded by the ship itself.) A survey of the magnitude of the problem

FIGURE 2: True azimuthal plot of sonde-omega transmitter geometry for representative drop in the Arabian Sea. Great circle least-distance paths for all eight omega stations are shown. The circle represents the solar terminator at about 1300 LST.

Table 2: Summary of vector differences, original (Main IIb)-reprocessed (Final IIb) solutions

SOP1

Region	Total # Drops	# Reprocessed (percent)	% with vector difference 2 mps	4 mps
Arabian Sea 20-73E	309	221 (42)	56	32
Bay of Bengal 73-106E	391	103 (26)	20	10
Hawaii, central Pactific 140E - 120W	943	264 (28)	25	19
E. Pacific 120-190	303	170 (56)	42	18
W. Atlantic 90-20W	113	80 (71)	18	3
E. Atlantic 20W-20E	66	56 (85)	53	12
	2125	894 (42)	31	18

was undertaken by the ACDWS data processing group at NCAR with the results given in Table 2). A number of solutions were investigated, and ultimately all drops for the Final Level IIb were recalculated with an algorithm that uniformly eliminated certain omega stations for each of the sortie routes flown. This solution accepted maximum impact of degraded omega geometry and was necessary because of the impossiblity of detecting the anomalous propagation uniquely for each drop. Thus it should be emphasized that ECMWF IIIb, utilizing Main IIb, was assimilating less accurate data that GFDL (and GLAS) IIIb, which used the recalculated data.

2.3 Tropical Wind Observing Ships (TWOS)

Two different wind measuring systems were used for the TWOS component of the TOS. One, referred to in FGGE jargon as TWOS-Navaid, employed a standard balloon-borne sonde with the omega windfinding system used to track the balloon. The principles of calculating winds are identical to the Aircraft Dropwindsonde System, although different algorithms were used. Since the sondes were launched from slow moving or stationary ships, the TWOS-Navaid system recorded local, or direct, omega signals together with sonde-retransmitted omega. This significant difference made the selection of omega signals for wind calculation much more straightforward than in the dropsonde system. The large aircraft velocities precluded using local omega for this purpose.

The ships contributed by the Soviet Union to the TOS carried a radar-tracking wind measurement system, presumably comparable to that used in GATE. Little is known about the quality of these TWOS-radar observations. Subjective comparison with wind vectors obtained by other observing systems suggests that no major difficulties occurred. The agreement in such comparisons is generally good.

3. SOME CHARACTERISTICS OF THE TROPICAL TROPOSPHERE RELEVANT TO DATA ASSIMILATION

Examination of the TOS data base and the Level IIIB assimilation of it have pointed up some characteristics that present special problems for four-dimensional data assimilation. In previous surveys of the TOS (Julian 1981a, b, c) those characteristics were best illustrated by case studies and examples. Two important characteristics are included here.

First, there is in instances wherein the TOS data density is adequate a very good agreement between the divergence/convergence indicated by the upper tropospheric wind vectors and the pattern of organized deep convection indicated by satellite infa-red imagery. Examples of the agreement have been included in the references cited above, and the relationship has been exploited by Julian (1984) to aid in the objective analysis of the tropical wind field. Although that such a relationship should exist was demonstrated by the work of e.g. Gray and collaborators (1976, 1980) from compositing techniques, it was only when the TOS data became available and the Level IIIb assimilation began that the full synoptic clarity of this relationship became apparent. The facts, that organized deep convection which occurs on scales equal to and greater than the analysis scale can be resolved by assimilation techniques, and that mid-latitude assimilation procedures were not designed to do so, have been demonstrated. The assimilation schemes must match the wind, mass, and convective thermal forcing fields in these dynamically important regions of the tropics (Wergen, 1983).

Second, the quasi-Lagrangian trajectories of the TCLBS provide us with some, possibly indirect, evidence of tropical upper tropospheric

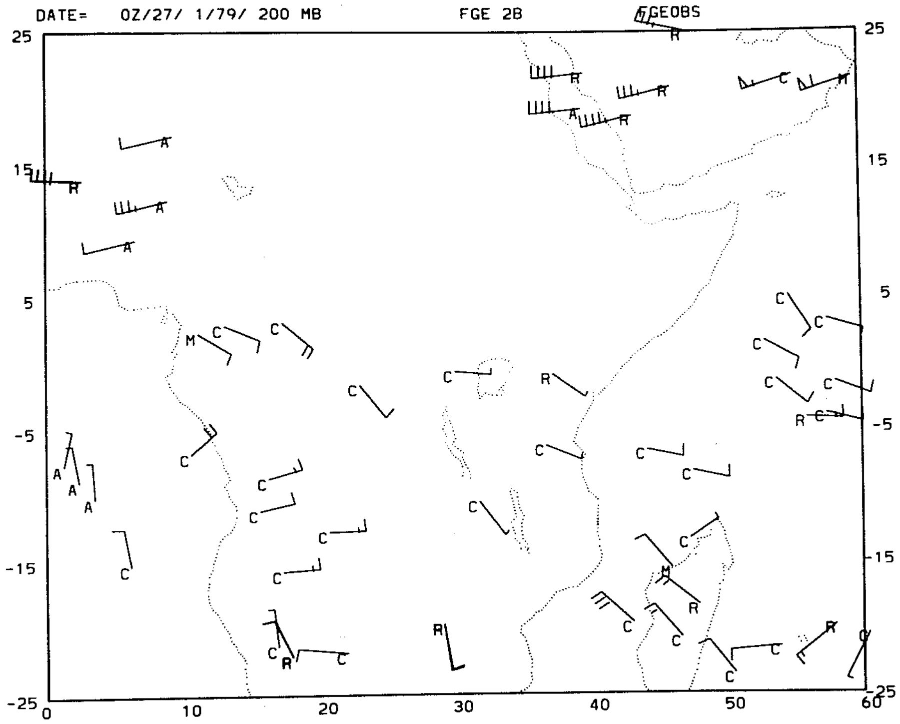

FIGURE 3: 200 mb data, 00GMT January 27.

R indicated rawin; C, satob;

M, super-ob satob; A, aircraft wind.

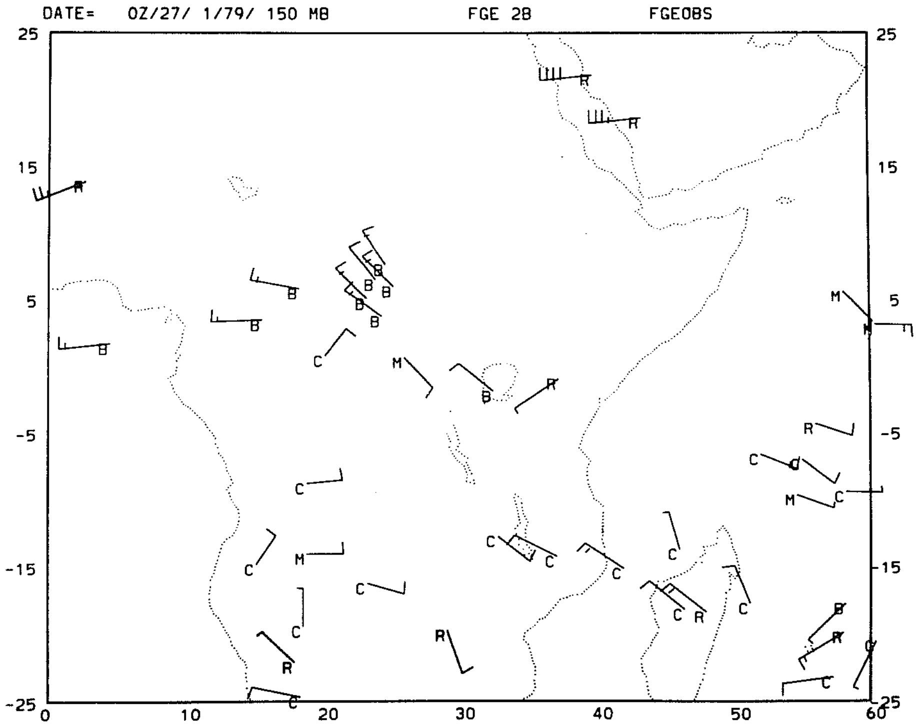

FIGURE 4: 150 mb data, 00GMT January 27.

R indicated rawin; C, satob;

M, super-ob satob; B, constant

level balloon.

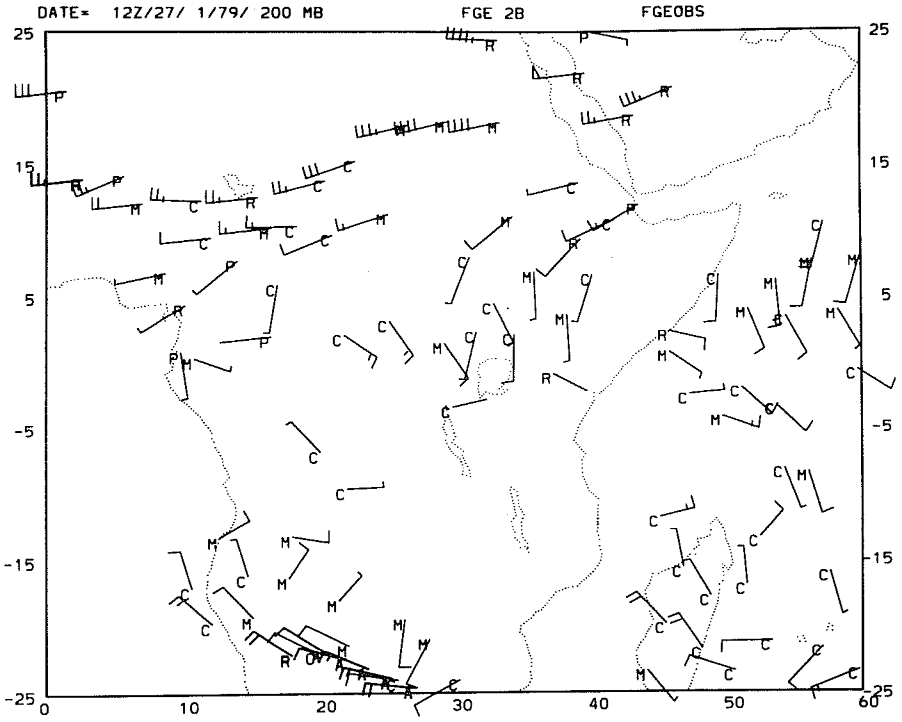

FIGURE 5: 200 mb data, 12GMT January 27.
R indicated rawin; C, satob;
M, super-ob satob; A, aircraft wind.

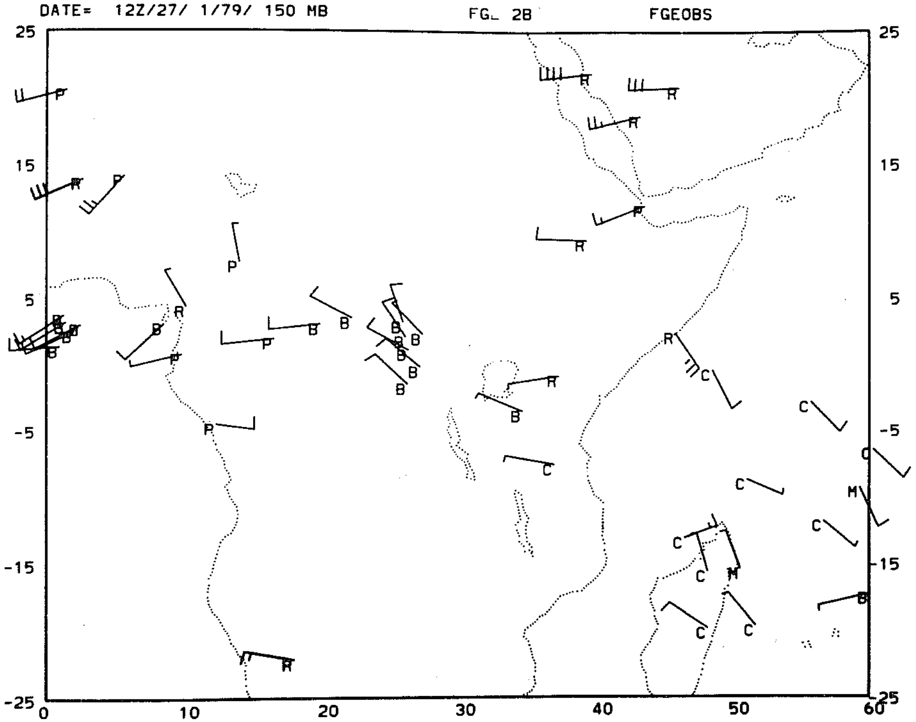

FIGURE 6: 150 mb data, 12GMT January 27.
R indicated rawin; C, satob;
M, super-ob satob; B, constant
level balloon.

behavior of some interest. Examples have shown (Julian 1981a, b, c) that some regions of large scale are characterized by motion of strongly inertial behavior. These instances occur away from areas influenced by deep convection, and a precise identification of the dynamic basis for these motions has not been made. We can, however, deduce an important consequence from these examples: since the balloon trajectories indicate that air parcels over considerable horizontal dimension, typically 1000 to 2000 km, are undergoing coherent (inertial) motion, kinematic arguments suggest that the vertical depth of these parcels must be small. If, then, some significant portion of the wind variability in the tropical upper troposphere is characterized by motions of large horizontal but small vertical scale single-level wind vectors present the analysis scheme with a serious representation problem.

One case study will be discussed here.

3.1 Case Study, January 27, 200-150 mb

This example was chosen because it includes many of the problems encountered in assimilating wind data in the tropics. A sequence of 150 mb data plots indicates a group of TCLBS platforms moving from Central Africa (1800 GMT, January 26) to Lake Victoria (24 hours later). Wind data from conventional rawin systems (150 mb) agree with the TCLBS vectors (130 mb). However at 1200 GMT, January 27, cloud motion vectors from 200 to 150 mb and the 200 mb winds from the rawin at Nairobi, specify flow from nearly the opposite direction (Figures 3-6). Intersystem and intrasystem agreement is good, and any analysis system, objective or subjective, is faced with the problem of accommodating all the data--there appears to be no valid reason to reject any of them. A check of satellite imagery in this case can suggest if large-scale deep convection is involved in the situation. The infrared TIROS-N imagery for passes on January 27 show moderately deep convection (equivalent black-body temperatures in the range 230°K) in the vicinity of Lakes Nyasa and Tanganyika, but, quantitatively, these infrared fluxes are neither characteristic of convection reaching the tropopause (ebbs about 210°K) nor are they very widespread. Thus a possible solution to the situation is that flow at 250 to 200 mb is associated with this convection, but that the northwest flow above 200 mb is not. The resulting vertical shear is then strong with nearly a 180° direction change between 200 and 150 mb. Madden and Zipser, (1970) found 24 percent of soundings taken in the Line Island Experiment had 150 mb vertical shears exceeding 15 m/s km^{-1}. A synoptic analyst interested in depicting what is actually going on in the tropical upper troposphere would then, presumably, require that no datum in this situation be rejected and that the respective analyses at 200 and 150 mb be faithful to the data.

Owing to the IIb data editing and the low vector uncertainties, which enter a data assimilation system as observation error, the TCLBS data should be accommodated with a relatively high degree of accuracy by the IIIb analyses. (A sample of the ECMWF IIIb fit to the IIb TCLBS gives, for the tropics, an RMS difference of 3.5 mps.) The principal problem encountered in assimilating the TCLBS data in the ECMWF scheme was that of accounting for the vertical variation in the forecast (guess) minus observation wind components and the vertical extent of the local optimum interpolation analysis volume.

The major data competitor in the tropical upper troposphere was cirrus-drift satellite winds, which have a much larger uncertainty: since these were nearly always in the same vertical slab the TCLBS vectors, the optimum interpolation scheme melded the vectors in the analysis volume together, but with relative weights favoring the TCLBS. Strong vertical shears in the tropical upper troposphere are real, and data selection criteria and broad vertical structure functions in the optimum interpolation simply cannot cope with these situations.

The ECMWF IIIb objective analysis of this case was what might be expected from these considerations: the 150 mb analysis indicated flow from the northwest, whilst the 200 mb analysis throughout much of the region showed very weak or calm winds. The proper construction of the analysis to be presented to a numerical forecast model, however, may require a different solution than either the subjective one or the objective one just described. If the analysis is to represent a flow field close to the slow manifold of the forecast model then it seems likely that yet a third solution to the situation would be required. Present knowledge apparently does not provide much guidance here, although the contributions by Heckley (1983) and Cats and Wergen (1983) are major steps forward.

4. SUMMARY

This evaluation of the TOS and data assimilation in the tropics has put forward the following:

a) The overall performance of the Tropical Observing System can be assessed in statistical terms by reference to FGGE Operations Report (WMO), (1980); the Global Weather Experiment Newsletters; Julian (1982); and papers presented at the First National Workshop on the Global Weather Experiment (1984). [See references for complete listing.]

b) The TOS cannot be said to have met the requirements established for FGGE: however, in many respects it did produce a data set which was, at once, satisfactorily complimentary, especially revealing and definitive of the upper and lower troposphere, and revealing of important distinctions between convectively active and quiescent regions.

c) Present (Main IIIb) assimilation suites are deemed deficient in the tropics in some regards because they were not specifically designed to assimlate in optimum fashion the information that the TOS had captured. Specifically, what seems to be needed is:

- i) to distinguish convectively-forced regions from the remainder of the tropics and apply appropriate (different) analysis techniques to each.
- ii) to assimilate large numbers of single-level wind observations so that the proper specification of model modes is achieved (Heckley, 1983).
- iii) to produce the proper analysis of the temperature and mass fields so that consistency between them and the wind and thermal forcing fields is achieved (Cats and Wergen, 1983).

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