1. INTRODUCTION

In preparation for the Conference on the Results of the Global Weather Experiment, a scientific seminar on data assimilation systems and observing system experiments was organized from 3-11 September 1984 at the European Centre for Medium Range Weather Forecasts (ECMWF), Reading, UK.

The seminar had three specific objectives:

(i) to review the characteristics of the FGGE observing system,

(ii) to provide an up-to-date review of four-dimensional data assimilation; to assess results from different analysis systems eand the effects on medium range forecasts,

(iii) to review recent results from observing system and observing system simulation experiments.

The seminar was followed by a two day workshop which reviewed the new developments in data assimilation and observing system experiment studies that made the present achievements possible, and considered the outstanding problems which must be solved in order to fully achieve the FGGE goals. The workshop also made a critical assessment of the FGGE observing system. The report prepared by the ad hoc working groups on data assimilation and observing system experiments set up at the meeting summarizes the views expressed by the experts on the above problems and contains the suggestions for further research.

2. DATA ASSIMILATION SYSTEMS

2.1 CONCEPT OF DATA ASSIMILATION

The data assimilation techniques have been developed since 1970 in direct response to the need to exploit novel data from satellite and other observing systems which were deployed for the FGGE. The problems posed by these data are manifold and primarily concern the question of incorporating asynoptic and single level quantities into prediction models. In other words, the aim of the data assimilation is to adapt a forecast model to the time evolution of the atmosphere by using all information from previous and current observations, from the laws of air motion and from the statistics of atmospheric behaviour. The two essential ingredients of a data assimilation system are a forecast model and an analysis/initialization procedure. The function of the forecast model is to extrapolate the analysis from previous data to the current analysis time, whilst the analysis/initialization procedure blends the information from earlier observations, namely the forecast, with the current observations and excludes unwanted gravity waves.

2.2 INTERMITTENT AND CONTINUOUS ASSIMILATION

Two alternative strategies of data assimilation are in operational and research use, intermittent assimilation and continuous assimilation. In both strategies the technique of optimum interpolation is used to interpolate the observational data to a more or less regular grid. The interpolation is done for every model time-step in the continuous assimilation strategy, and is done once every six or twelve hours in the intermittent assimilation strategy.

The major differences between the two approaches concern the filtering properties of the interpolation procedure, and the use of initialisation algorithms.

The optimum interpolation procedure acts as a statistical scale-dependent filter of the observational data, as well as performing the necessary interpolations from randomly distributed observation points to a regular grid. The purpose of the filter is to extract meteorological information from the observations while eliminating the random noise. The sophistication and efficiency of the filter increases with the volume of data considered for the analysis of a single grid-point, and with the realism of the constraints imposed on the filter.

Most continuous assimilations use small volumes of data for a single grid-point. The strategy of continuous assimilation seeks to overcome the problem of data rejection by using the internal dynamics of the model to do the multivariate filtering of the data. By this means it frequently achieves a close fit to the data at the observation point, though there may be a noticeable level of noise in the assimilation. A compromise has to be obtained between the theoretical benefits of frequent assimilations and the shortcomings of an insufficient data coverage, which - together with inadequate knowledge of the horizontal and vertical scales represented by the datum - might have an adverse effect on the analysis.

Intermittent assimilation tends to use more data for each grid-point, and to impose more elaborate constraints on the filter. The most elaborate schemes currently use several hundred multivariate data to analyse a single grid-point. Typical constraints on the analysis are that the changes made to the forecast wind field should be locally non-divergent and approximately geostrophic in mid-latitudes. These multivariate constraints are theoretically and empirically justified, and are introduced to ensure that the resulting analysis and forecast receives the information implicit in the observation, otherwise the forecast would reject the data.

While the analysis technique is of secondary importance in data dense areas, it becomes crucial in data sparse regions. Most schemes try to evaluate the impact of an observation on its surroundings in a statistical way, both in the horizontal and in the vertical. Multivariate schemes allow an approximate incorporation of dynamical relationships between the analysed fields, thus largely avoiding the problem of data rejection by the forecast model. In cases where the atmosphere deviates from its statistical behaviour, statistical methods may lead to analysis errors. A direct fit of meteorologically relevant basis functions (e.g. Hough functions) to the data could be a possible alternative. This would also allow a proper incorporation of the tropical mass-wind coupling.

New methods have been developed to estimate the multivariate forecast error statistics in a substantially complete manner. The full significance of these results has still to be estimated. It is clear, however, that the forecast error statistics for wind now have a secure observational and theoretical basis.

2.3 INITIALIZATION

High frequency gravity waves (noise) which are, in principle, admitted in a primitive equation model may be excited in a forecast model due to imbalance between the inserted mass and wind field data. While forecasts beyond one day do not require an initialization, it becomes crucial in some data assimilations, where a first guess contaminated by noise impedes application of the data-checking algorithms and may lead to erroneous quality control decisions. Multivariate methods allow some control of noise generated by the insertion of data into a forecast model. However, these methods cannot incorporate the global, three-dimensional non-linear constraints required to suppress noise. Many approaches to the data initialization had been tried, including the use of the balance equation and the technique of dynamic initialization. These had only limited success and suffered from special problems in low-latitudes and near mountains. The development of non-linear normal mode initialization leads to a considerable weakening of the tropical divergent circulation. Through the use of diabatic schemes or by application of frequency filters it is possible to retain the divergent circulation. The problem of obtaining consistency between the analysed divergent circulation and the one implied by the physical parameterization schemes remains to be solved.

2.4 OBSERVATIONAL ERROR CHARACTERISTICS AND QUALITY CONTROL

The accuracy of an optimum interpolation analysis depends on reliable information about the error characteristics of all of the observations and the forecast model. Substantial errors in either of these sets of statistics will result in a degradation of the quality of the analysis. Much work has been done on the error characteristics of the special FGGE observing systems, but there are still large areas of uncertainty.

It appears, for example, that there are large variations among assimilation systems in the relative accuracies assigned to SATOB and TEMP wind data. There are similarly wide variations in the relative accuracies assigned to SATEM and TEMP thicknesses. It is clearly important that these inconsistencies be resolved by further research after allowing for the differences inherent in the assimilation methods.

Less controversial features include incorrect height assignments for some cloud-track winds, horizontally correlated errors in the SATEM data, biases in the winds and heights from some radiosonde stations, and irregularities in the reports from some buoys near the end of their useful life.

Knowledge of the bias and correlation structure of instrumental error is very helpful in three-dimensional analysis and exchange of information on these problems among analysis centres is of great value.

An essential feature of any assimilation system is an effective set of quality control algorithms, both for real-time quality control, and for longer term monitoring of the Global Observing System. It has been shown in intercomparisons of FGGE III-b analyses that quality control decisions can have a profound impact on the analyses and the ensuing forecasts.

A measure of data redundancy in a global observing system is essential for effective data checking and quality control procedures. The most sophisticated quality control schemes use all the observational data within a radius of about 1000 km, together with the background field, to make a preliminary estimate of the expected value of the observation. Observations which depart too far from this estimate are deemed to be wrong, and rejected. The effectiveness of any such test, and indeed the accuracy of the resulting analysis, depends on reliable information about the error characteristics of all the observations, and of the forecast model.

Data monitoring techniques have proved valuable in some of the FGGE analyses, and in operational work since FGGE. It would be desirable to exploit these techniques fully in any re-analysis of the FGGE data.

2.5 CRITICAL ASSESSMENT OF THE FGGE OBSERVING SYSTEM

The quality of the FGGE observing systems did not everywhere meet the observational requirements as outlined in GARP Publication Series No.11. These requirements were considered as minima to be achieved in data-sparse areas. Temperature soundings from the polar orbiting satellites, cloud wind vectors from geostationary satellites and surface pressure from drifting buoys were essential supplements to the data set provided by the conventional networks. The greatest deficiency was found in the accuracy in the upper level satellite winds which had errors considerably larger than the required level of 2-3 ms^{-1}. This is of particular concern in the tropics and for small scale weather systems where the wind field is of primary importance. The errors of the upper level winds are to a large extent due to the problem with the height assignment of the cloud pixels which can be wrong by a considerable amount. Systematic ways of correcting such errors were undertaken during the FGGE III-b data assimilations, which led to some improvements. In spite of the remaining errors, the satellite wind data were satisfactorily assimilated by the level III-b schemes and provided a realistic insight into the circulation of the tropical atmosphere. The accuracy of the satellite temperature soundings was found to be 2-3°C below 850 mb and 1.5 - 2°C above, with slightly larger errors in cloudy regions. These data were also satisfactorily assimilated and played an important role in analysing the large scale weather systems at middle and high latitudes, in particular for the southern hemisphere. When these data were excluded, the predictive skill was reduced significantly for the southern hemisphere.

The southern hemisphere buoy network could not fully meet the requirements as far as the density of the network was concerned (750 - 1000 km horizontal resolution was achieved instead of 500 km originally planned). However, the buoy data played an important role in providing a reference level for the satellite temperature soundings and were, moreover, of direct value in short range weather prediction.

At present some components of the FGGE observing systems are in daily operational use and are an essential adjunct to the radiosonde and SYNOP networks.

Since FGGE there has been a gradual improvement in the accuracy of satellite wind and temperature data due to more experienced and more accurate retrieval schemes. Due to the uniqueness of the FGGE data, a further reprocessing of some of the satellite data obtained during the experiment is recommended in the case where there is clear indication that a further increase of the accuracy is possible.

2.6 EXPERIENCE FROM FGGE

The FGGE analyses are providing important input towards identifying those aspects of data assimilation in need of further study. Two techniques may be used in this regard:

1) a comparison of Level III-b data-sets;

2) forecast impact studies involving the Level III-b data-sets.

2.6.1 Comparison of Level III-b analyses

Only preliminary comparison of the principal Level III-b data sets from ECMWF and GFDL has been undertaken. However, for limited periods mid-latitude comparisons have been made (both northern and southern hemisphere) between Level III-b analyses from ECMWF, NMC Washington and the UK Meteorological Office prepared using the same set of observations. Such comparisons need to be extended to the tropics.

It should be noted that important differences exist between the data coverage, data processing and assimilation systems used to produce the GFDL and ECMWF III-b analyses. GFDL had access to more data than was available from the main FGGE Level II-b data set used by ECMWF, and GFDL used a continuous assimilation system whereas the ECMWF used the intermittent data assimilation approach.

Extra-tropics - Northern hemisphere 500 mb height analyses and the monthly mean 200 mb zonal wind show generally good large-scale agreement between GFDL and ECMWF. Despite some differences, both III-b analyses show a consistency in features over the oceans relative to analyses based on conventional data which does indicate some benefit of the FGGE extended data-set (II-b observational network).

In data sparse regions significant differences appear with the ECMWF analyses tending to have stronger zonal winds and more eddy activity in the southern hemisphere. In addition the ECMWF mean sea level pressure analyses show systematically deeper lows. Differences in the analysis method and a tendency for rejection of surface pressure in GFDL's continuous assimilation process seem responsible.

Tropics - Substantial differences between the III-b analyses occur in divergent circulations. The overall level of divergent kinetic energy in the GFDL analyses as well as in those produced at GLAS, has been shown to be much greater than ECMWF for several cases. The spectrum of divergent kinetic energy falls steeply in the ECMWF analyses, but is much flatter in those from GFDL. The global rotational kinetic energy is somewhat greater in the ECMWF and GLAS III-b analyses . Also the Hadley circulation in the GFDL analyses is consistently more intense compared with that produced from ECMWF analyses, presumably the result of GFDL allowing more model dependence in the analysis as well as using fewer modes in the initialization. The different tropical data coverage available to ECMWF and GFDL is a factor in some of the differences seen. Verification of FGGE analyses against observations is desirable; limited studies indicate that the ECMWF analyses are smoother and fit the observations more closely than those at GFDL.

Preliminary indications that the moisture is not being analyzed well in either III-b system need to be documented. Much work is still needed regarding the proper balance of physics and dynamics on the important scales of motion in the tropics.

Since FGGE, further improvements in tropical data assimilation have taken place at the ECMWF by including diabatic initialization and better structure functions. A comparison of analyses of the final FGGE II-b dataset with the latest versions of the ECMWF and GFDL assimilations systems is desirable.

2.6.2 Impact on forecasts

Short to medium range - The additional FGGE observations have generally increased the range of forecast skill, notably in the southern hemisphere where some cases show an increase in useful forecast skill to 4 or 5 days. The drifting buoys and increased satellite coverage are considered to be responsible for this improvement. The impact of additional aircraft and satellite observing system in the northern hemisphere and the tropics during FGGE showed some improvement in forecasts, although not to the extent seen in the southern hemisphere.

Intercomparisons of analyses/forecasts performed by ECMWF, NMC and UK Met Office have shown a remarkable consistency among the models in responding to different analyses. Some of the large forecast errors could be traced to initial mid-latitude analysis errors, hence improvements to the analysis would result in an improved forecast.

Extended range - The improved global coverage used for the III-b analyses is important for an extended range forecast study. Recent experiments indicate that some information in the initial analysis may be retained in forecasts out to a month, at least for large scales. Some systematic differences have been seen in extended range integrations from the ECMWF and GFDL analyses. The sensitivity of extended range integrations to initial data needs to be investigated.

2.7 OUTSTANDING PROBLEMS

A detailed account of current problems in data assimilation appeared in the Proceedings of the ECMWF Workshop, 8-10 November 1982. Progress has been made in certain areas, notably:-

- the retention of diabatic circulations especially within the tropics by the incorporation of diabatic effects into initialization or the use of selective frequency filtering.

- the development of a complete optimum interpolation formalism that can fully exploit wind data.

- the statistical extraction of information on the humidity field in mid latitudes and the field of convection in the tropics from satellite cloud imagery and surface-based weather observations.

Several important problems remain outstanding, particularly affecting tropical analysis.

(a) Diabatic heating and model precipitation rates

Although the incorporation of diabatic heating into initialization can now be achieved, its proper specification remains a particular problem. For condensational heating, the most promising approach lies in the greater usage of regression methods applied to cloud information. Time and space scales need to be consistent between the specified heating, the initialization scheme and the chosen physical parameterizations if the forecast model is to satisfactorily retain the analysed heating distributions.

A related, unresolved problem concerns the slow spin-up of most assimilation/forecast systems, as evidenced by initial precipitation rates. Presently the continuous assimilation systems seem to perform better in this regard.

(b) Single level data

Real progress has been made in the extraction of useful information from single-level data but there are some difficulties which are inseparable from the nature of the data. All users have to generate vertical correlation to extrapolate the data to other levels. Examples include the barotropic and geostrophic corrections used in the assimilation of surface pressure data, and the wide variations in treatment of the use of aircraft or constant-level balloon data. Multi-level data is much more easy to analyse and assimilate. Simulation of data sparse conditions in data rich regions may be useful in estimating the necessary statistics.

(c) Analysis in mid-latitudes

In mid-latitudes further progress will require improved analysis resolution in the vertical and horizontal. Since there is no immediate prospect for obtaining comprehensive observations of the vertical wind profile, the best prospect lies in the improvement of satellite temperature data used in conjunction with accurate sea level pressure observations as well as refined statistics for the analysis of the data. The generally good state of definition of the large-scale extratropics of the northern hemisphere may be largely attributable to the good coverage provided by radiosonde observations.

In the southern hemisphere the absence of a comparable, land-based radiosonde network restricts the accuracy of the assimilating model forecasts. Here again we can look towards improved satellite temperature soundings and a buoy observational network restored to FGGE period levels as the best short-term solution to the observation problem.

(d) Tropical analysis and forecasting

It should be clearly appreciated that, from the perspective of the requirements for medium-range weather forecasting, analysis of the large-scale tropical atmospheric circulation remains seriously deficient. After FGGE, we are more clearly aware of the nature of these deficiencies. In particular, the significance of erroneous analysis of the tropical circulation for mid-latitude forecasts has been demonstrated both theoretically and practically.

(e) Data monitoring

The detection of erroneous observations without discarding observations of correct, but large, departures from the first guess still poses a significant problem. Special difficulty arises when ordinary methods for the intercomparison of data fails to detect correlated observational errors, as may happen with satellite measurements. Only careful quality checks by the data producers can eliminate this problem. It now appears possible to employ statistical summaries of forecast error to identify some systematic errors, in particular radiosonde observations. Interchange of such statistics among forecast centres is encouraged as a way of reinforcing the clear identification of these inaccurate reports.

(f) Utilisation of existing data

A great deal of useful observational data is currently unavailable due to limitations on telecommunications capacity, or because there has not been a well articulated case for the exchange of the data. For example, high resolution temperature soundings, cloud-top brightness temperatures, and rainfall amount and intensity have been shown to be valuable in improving analyses, but the exchange of this data is not well organised. Other examples of useful data which could improve data assimilation are station pressure observations, together with accurate station height determinations. In mountainous areas, some SYNOP stations appear to have height errors of order 50m or more. The importance of representing orographic effects in forecast models is well recognised. Analysis in these areas would be much simplified if there were a single reduction procedure, or none at all.

Regular updates on the sonde types in use at all stations would be of considerable benefit to analysis centres.

3. OBSERVING SYSTEM EXPERIMENTS (OSEs)

3.1. GENERAL CONSIDERATIONS

One of the aims of the Global Weather Experiment carried out in 1979 was to provide data for the purpose of designing "an optimum composite meteorological observing system forroutine numerical weather prediction of the larger scale features of the general circulation" and the FGGE II-b data sets have provided the essential material on which to base investigations for this purpose (GARP Publication Series No.11).

Since 1979 a number of meteorological centres have carried out relevant experiments, the methodology being essentially to compare two sets of assimilations/forecasts, the first acting as a control, the second being the same as the control with the exception that it is based on a depleted or augmented observational data set. In 1982, the Working Group on Numerical Experimentation (WGNE) organised a conference at Exeter, U.K. at which the results of experiments carried out up to that time were reviewed and recommendations made about further experiments and how they should be conducted (WGNE Report No. 4).

At the present meeting it has been possible to review the results of experiments carried out since the Exeter conference and the extent to which it has proved possible to meet some of its recommendations. In preparing this section of the report, therefore, it has been convenient and useful to use the conclusions of the Exeter conference as a basis and consider how they should be altered or expanded in the light of the new evidence.

One of the recommendations of the Exeter conference was that there should be greater co-operation between centres and more co-ordination in conducting experiments and evaluating the results. There is evidence that this has been achieved and has clearly been beneficial. Thus, ECMWF, the Japanese Meteorological Agency and the UK Meteorological Office have carried out parallel experiments using the same FGGE period and these centres are actively intercomparing their results; and ECMWF, NMC (USA) and GLAS (USA) have co-operated to provide a "synthetic" observational data set on which to base observing system simulation experiments (OSSEs).

The Exeter conference also recommended that there should be an increase in the effort devoted to observing system experiments as this was seen to be essential for providing the evidence about observing systems that WMO was seeking. Unfortunately, the level of effort remains unequal to the task, and large uncertainties about how to optimize composite observing systems therefore persist.

It should be recognized that most of the experiments which have been carried out have assumed explicitly or implicitly that the purpose of the observational data sets being considered was to describe and forecast the large-scale features of the global atmosphere over several days. The conclusions are therefore limited to this context; for example, detailed forecasts for the next 24 hours require a more detailed description of atmospheric wind, temperature and humidity in the vertical than longer period, more general, forecasts.

Single level data (SLD), present data assimilation systems with difficulties which are well known. In the last few years, however, the impact of single level data on three-dimensional analyses and forecasts has been shown to be, in general, sizeable and, in particular regions, large (e.g. SATOB data in tropical latitudes, buoys in the southern hemisphere and aircraft data at most latitudes). All data assimilation systems employed to analyse the FGGE period appear to, at least partially, extract the vertically coherent portion of the information contained in SLD. Some inhomogeneities found in comparing the quantitative impact of such data in different data assimilation and forecasting systems are likely to be due to the different vertical propagation of information allowed by such systems. A degree of redundancy involving SLD systems has been shown. The inability of current data assimilation systems to extract the vertically varying portion of the information contained in SLD might also be partially responsible for such apparent redundancy. Development of data assimilation systems is therefore likely to eliminate part of this apparent redundancy by extracting more information from SLD. However, a measure of data redundancy in a global observing system is essential for effective data checking and quality control procedures.

In the periods chosen for an OSE, the observing systems being tested may or may not provide data from areas that were crucial in determining how the atmospheric state would change. Also, an impact of considerable importance in a limited area may not be reflected in measures of impact which are averaged over an entire hemisphere or more. Thus the investigation of particularly sensitive situations of atmospheric development has become a valuable supplement to the more usual attempts to reach a statistically significant indication of global impact. These case studies have demonstrated the unique importance of different types of observations and their coverage in different atmospheric situations.

The OSEs presented at the Exeter conference or carried out between 1982 and 1984 do not adequately test the impact of the tropical observing systems. Special efforts are required to improve the ability of forecast systems to simulate and predict the tropical atmosphere, and to carry out some tropical OSEs.

Application of OSE (and OSSE) results to the general design of the Global Observing System (GOS) must consider the methodologies and assumptions adopted in conducting the experiment as well as the characteristics of the available data sets. Based on some OSE results one might conclude that a specific system would have little value in the GOS, whereas under conditions different from those examined by the OSE the opposite might be true. The inherent overall value to the GOS of the observing systems evaluated, therefore, may not be represented properly by the results of the OSEs. For these reasons, the results of OSEs should be used only as one part of the input to the design of the GOS. Nevertheless, they can provide important guidance to planners, which can be obtained in no other way.

3.2 SPECIFIC OBSERVING SYSTEMS

3.2.1 Satellites

The results from observing system experiments have demonstrated that atmospheric soundings by means of remote sensing satellites in polar orbit are an essential element of the global observing system. The observations are uniform, global in extent, and can be made available on a reliable daily basis and give information through the depth of the atmosphere. Therefore they have the capability of indicating the global atmospheric state to an extent unrivalled by any other individual system.

It has been further shown that winds derived from geostationary satellite cloud images (SATOB) make a major contribution to analyses in the tropics. Their importance for tropical forecasts is expected to increase with the continuing refinement of numerical weather prediction methods at low latitudes. Individual occasions where SATOB data have contributed positively to middle and high latitude forecasts have been demonstrated. Since 1979, the methods for SATOB data derivation have improved and thus increased the benefit of these data so that SATOBs now have a more generally positive impact on forecasts.

The communications capability of satellites and platform location capability of certain polar orbiting satellites are important in the rapid and accurate collection of in situ data (e.g. drifting buoys, ASDAR). They have the potential to speed up the collection of conventional observations and so to improve numerical forecasts.

In order of priority, the requirements for satellite observations for global macroscale analyses and prediction are:

(i) Daily polar satellite sounding data for the entire globe on a continuous basis; inclusion of data collection/location capability to support drifting buoys.

(ii) Network of geostationary satellites for derivation of winds from cloud displacements; inclusion of data collection capability to improve the timeliness and accuracy of in situ observations as received by forecast centres.

3.2.2 Surface-based observations

To achieve a reliable and comprehensive data base for global analysis and prediction, satellites must be supplemented by other systems which provide additional and complementary information. Of particular importance is a good rawinsonde network which, in addition to acting as a calibration reference for satellite observations, provides at least in continental areas, three-dimensional mass, wind and moisture information, free of horizontally correlated biases and with good vertical resolution in the boundary layer and in the lower troposphere. The network of surface observations and aircraft reports which fills in essential details about atmospheric systems near the surface and at jet stream level is also of paramount importance.

In most data assimilation systems, surface pressure observations provide reference level data which enable satellite soundings to be used more effectively. In FGGE, the southern hemisphere drifting buoys were the primary source of these data. The FGGE southern hemisphere drifting buoy system has provided a positive impact on the accuracy of the analyses and forecasts in the southern hemisphere. An OSSE has shown that the addition of buoys in the present data gaps of the northern hemisphere would improve the surface network significantly.

3.2.3 Aircraft observations

Since disturbances at jet stream levels are often important for synoptic developments throughout the troposphere, aircraft observations are a useful source of information which can by themselves produce a good analysis at these levels. Where other data are also present, the aircraft observations still have a positive impact and improve the definition of the upper flow. The quality of ASDAR reports during FGGE indicates the advantage of an automated aircraft reporting system in eliminating time and position errors. Depending upon the analysis method, aircraft observations may also provide information on the main three-dimensional features of well-developed systems in otherwise data void areas. This positive impact of aircraft observations also extends into the forecast.

3.3 FUTURE STUDIES

(a) Priority areas for the use of FGGE data sets

As the level IIb data set is to be improved (e.g. more ships, retrieved SATEMs), it would be useful to rerun some observing system experiments with the improved data set. Moreover, until now, the tropical observing systems have not been adequately evaluated, partly at least because numerical assimilation/forecast systems perform relatively poorly in tropical regions. Special efforts are required to improve the ability of forecast models to simulate and predict the tropical atmosphere, and to carry out some tropical OSEs.

There is also a need for some evaluations taking into account the differences between the FGGE and the present operational data sets. For example, it is likely that the results of OSEs on the southern hemisphere are very dependent on the presence/absence of the large number of buoys which were available during FGGE. So the determination of the future composite observing systems requires also some experiments run related to the present operational context rather than to the FGGE configuration.

(b) Observing system simulation experiments

Realistic OSSEs provide the only a priori quantitative assessment of the potential impact of future observing systems on the accuracy of analyses and forecasts. The methodology which has been developed, whereby two different general circulation models are used, seems promising. One model is integrated to provide the 'nature' or 'truth' from which a set of 'artificial' or pseudo-observations is produced. A second model is then used to assimilate the pseudo-observations. Either the 'nature' model or the assimilating model can then be used to generate forecasts from initial conditions which utilize or do not utilize pseudo-observations from the observing system to be evaluated. This affords the opportunity to evaluate an upper limit of data impact on forecast quality that is unaffected by forecasting model errors.

Preliminary results with this system indicate a realistic simulation of the FGGE observing system in the southern hemisphere with a significant impact of the simulated FGGE observing system consistent with the impact obtained for the real FGGE data. Simulated vertical wind profiles, as might be obtained with a Windsat system, extend the forecast skill significantly beyond that obtained with the FGGE system. The methodology is promising and should be applied to the evaluation of other possible observing systems.

(c) Operational WWW system evaluations

The concept of Operational WWW System Evaluations (OWSEs) to test composite observing systems in limited regions of the globe and the intent to create the redundancy necessary for this purpose has been accepted by WMO. Evaluation exercises involving observing system experiments need to be carefully planned and executed to derive the maximum information about the effectiveness of possible mixes of observing systems.

(d) Observational requirements for short-range forecasts

Most of the results available at the present time has been obtained from global large-scale OSEs, so they concern the "global data set" only. In recent years the application of numerical prediction models to short or very short-range forecasting have improved greatly and evaluations are needed also to define the observational requirements. In that context, some experiments to test the impact of high resolution satellite soundings on such forecasts are needed.

(e) Baseline rawinsonde networks

A carefully selected set of rawinsonde stations providing upper air data of high quality is required on a global basis. This "baseline" network should be well distributed in the several climatic regimes (tropics and extratropics) and focus on the ocean areas. The data from such a baseline network is needed:

- for long-term calibration and quality control of quantitatively derived satellite data,
- for use in the operational retrievals of SATEMS,
- to provide routine reference data as a control for data assimilation techniques.

To be of most value, the characteristics of the data from this baseline network must be well documented, of consistent high quality and compatible with data assimilation techniques used at the major centres. A substantial part of these data must also be co-ordinated in time and location with satellite passages. The number and location of the stations in the baseline rawinsonde network should be the subject of numerical evaluations.

4. INTERNATIONAL CO-ORDINATION OF RESEARCH ACTIVITIES

Co-ordination of GARP research activities in relation to data assimilation and observing systems impact studies among the national research groups has been undertaken by the JSC Working Group on Numerical Experimentation (WGNE). Due to the gradual transition from GARP to WCRP activities, the WGNE is now turning its attention to the numerical simulation of climate and modelling studies associated with development of the physical basis of climate prediction on time scales from a few weeks to decades.

Meanwhile, the WMO Commission on Atmospheric Sciences (CAS), in the framework of its activities on weather prediction research, is beginning to pay attention to the exploitation of FGGE results in particular with generating benefits for national forecasting services. Following the recommendation of the Ninth Congress, a Steering Group on Numerical Experimentation was established by CAS with the task of promoting and co-ordinating weather forecasting research based on data from FGGE and other GARP experiments. The Workshop pointed out that international co-ordination should be maintained through the WMO programmes to continue providing support for the current and future research activity relevant to FGGE.