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INTEGRATION OF GLOBAL OBSERVATIONS FOR STUDYING CLIMATE AND CLIMATE CHANGE

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1. INTRODUCTION

It is an obvious fact that the availability of accurate observations from the atmosphere, oceans and land surfaces with a suitable distribution in time and space is a necessary condition for the successful prediction of weather and climate. It is equally obvious that a successful climate research will require long-term, consistent global data sets.

Having stated this, let us consider the global observing system and its evolution in time (see summary in Table 1). It can suitably be divided into five periods.

The first covers the time up to around the second half of the 18th century. In this time period there is, with a very few exceptions, only proxy data such as sediments, ice cores, tree rings, records of drift ice, glaciers etc., historical records.

The second period covers the period say, from 1760 to 1880. It is characterized by a gradual built-up of a surface synoptic network covering the inhabited parts of the globe as well as marine observations along well-travelled routes.

The third period dates from 1880 to the end of the 2nd World War. It is characterized by a reasonably coherent surface network. Only a limited number of upper air data exist mainly from the 1930s.

The fourth period is the post-war period 1946 to 1979. During this time we have had a network of radiosonde stations covering reasonably well the Northern Hemisphere.

Finally the fifth period from 1979 is the only period where there has been a global observing network including the full depth of the atmosphere.

It is quite obvious that great caution must be exercised when we are trying to infer previous climate from the limited observation records of the past. An obvious study, namely to reduce our present network to that of past periods and through such a study try to infer the accuracy of climate fluctuations and trends still remains to be done in a systematic way.

Other problems have to do with the representativeness of stations exposed to long-term changes due to urbanisation and other local effects.

In this lecture we will mainly be concerned with the observation systems of the last 12 years. As has been demonstrated by Bengtsson and Shukla (1988), even this, in an historical perspective exceptionally good network, has serious defects due to inconsistencies in the way the observations have been assimilated in operational numerical weather prediction systems.

Table 1

Development of observing systems

Time	Characteristic observing system
< 1760	Essentially proxy data
1760-1880	Built-up of a surface synoptic system (mainly Europe and North America)
1880-1946	Basic surface synoptic system
1946-1979	+Upper air radiosonde network (mainly Northern Hemisphere)
> 1979	Comprehensive global observing system

2. LIMITATION OF CURRENTLY AVAILABLE DATASETS

Currently available gridded datasets were primarily produced by the operational NWP centres as a by-product of the daily requirement of producing initial conditions for the NWP models. Northern-hemispheric analyses of the twice daily circulation fields produced by the National Meteorological Centre (NMC) of the United States for the period 1963-1978 and global analysis produced by the NMC and ECMWF for the period 1978 to the present are examples of such datasets. A large number of useful and informative diagnostic studies of the general circulation of the atmosphere have been carried out utilizing these datasets. However, these datasets do have several deficiencies, some of which are mentioned below:

(i) Frequent changes in the forecast models

Operational NWP started about 40 years ago. Due to computational limitations the early models were extremely simple. They could only represent quasi-geostrophic motion and they had only a few vertical levels. Multi-level primitive equation models have only been in operation for some 25 years. During this evolutionary phase of NWP, models have been continuously improved to reduce forecast errors due to deficiencies in the treatment of various aspects of physical and numerical processes. This improvement is still continuing. This has had the effect that the length of useful forecasts has been extended from about a few days to at present more than a week.

The existing datasets, in particular the earlier ones, are inadequate for research to support climate modelling because of the need for accurate global fields of momentum-, energy- and water fluxes at the surface of the earth. In the past, the operational NWP models did not have a realistic treatment of the planetary boundary layer. Development of forecast models has been traditionally motivated by the ability to predict the synoptic and large-scale dynamical circulation, particularly in the extra-tropics. It is only recently that proper attention is being paid to the importance of physical processes at the air-sea and air-land interfaces. In order to produce improved datasets of surface wind stress and surface heat fluxes, it will be essential to further improve both parameterization of boundary layer processes and the assimilation of boundary layer data.

(ii) Frequent changes in data assimilation systems

Development of data assimilation techniques, particularly in the combination of conventionally derived datasets and satellite datesets, has also been a continuously evolving field of research. These changes concern better data control, more refined space interpolation and more advanced initialization. Over the years, these changes have clearly improved the initial state as well as the forecasts.

(iii) Unavailability of delayed mode data

The operational constraint of producing forecasts every day makes it necessary to impose a cut-off time for the inclusion of the incoming observations. Any data that are received after the cut-off time can not be utilized by the data assimilation system. The operational constraint can cause data gaps in those areas from which data transmission or reception is delayed. Due to telecommunication difficulties significant amount of data such as marine observations and radiosonde data from remote areas are not incorporated in the operational datasets.

3. THE GLOBAL DATA PROBLEM

Studies of atmospheric processes of significance for climate research require global observations, through the whole depth of the atmosphere, of the basic meteorological parameters: wind, temperature, and moisture. In addition, observations at ground level to define the surface boundary conditions are also required. The space and time resolution of observations might be expected to be commensurate with the resolution of the atmospheric model (i.e. 50-100 km). Fortunately this enormous requirement can be relaxed due to the strong dynamical and physical coupling between meteorological observations in space and time. This coupling means that the model can reconstitute missing data such as moisture and also through the data assimilation process fill up holes in the network. There is also considerable evidence that a realistic, high resolution dynamical model can simulate the formation and growth of small-scale weather systemss (smaller in fact than that which can be resolved by observations) even if only the relatively large-scale circulation features are explicitly described by global observations. In this respect a realistic global model can be viewed as a unique and independent observing system that can generate information at a scale finer than that of the conventional observing systems. This is possible only because the models are able to predict the short-term evolution of atmospheric circulation reasonably well. Numerical experiments have also shown that for extratropical prediction, an accurate specification of the wind and mass field in the baroclinic zones is crucial to forecast quality, while a detail analysis of the boundary layer appears to be less important. The explanation again is that the models are able to generate some of the missing information, and it also indicates that there is some redundancy among the basic meteorological parameters in the atmosphere.

The accuracy of the initial state is crucially dependent upon the data assimilation system. It is possible to estimate the accuracy of the data assimilation system by partitioning the perceived forecast error into spatially correlated prediction errors and spatially uncorrelated observation errors. The total forecast error, the difference between the model forecast and observations, consists of two parts - spatially correlated differences and spatially uncorrelated differences. The former are referred to as model-prediction error, and the latter as observation error. Detailed studies have demonstrated that for present models the estimated prediction error for height and wind over North America and Europe is about the same as the observational error for individual observations.

Compared to the situation in the mid 1970s it follows that the estimated forecast errors over North America have been halved. Assuming that there have been only modest changes in instrumental accuracy of the intervening time, it is clear that the accuracy of the forecasts must have improved substantially. Many factors may have contributed to this improvement, including higher model resolution and better analysis and initialization techniques.

4. NEED FOR A RE-ANALYSIS

Wile it is difficult to identify any significant changes in the analysed data, say from 1979 in the basic quantities wind, temperature, and moisture, one can clearly identify systematic changes in derived quantities such as vertical motion, velocity potential, energetics, heat flux, precipitation and wind stress. Examples from the ECMWF operational datasets for example it is found that the zonally averaged vertical motion for the period 1 January 1982 to 31 December 1986 have essentially doubled in strength in the tropical belt (Figure 1). This has of course nothing to do with any real change, but is simply and artefact of the forecast model and the data assimilation system used at the particular time.

One can of course ask the obvious question whether analysed datasets at all can be used for climate studies when they have such severe deficiencies. The alternative to use the observations is not very feasible due to incompleteness and to the differences in data types. The only realistic alternative is to reassimilate the data using a frozen up-to-date data assimilation system. Following an original proposal by Bengtsson and Shukla (1988) this idea has gained a lot of ground an presently two institutions, ECMWF and NMC, do plan to reassimilate data for a period of some 15 years starting in 1978/79. In the case of NMC there is an additional plan to extend the assimilation to some 35 years.

It will be of greatest importance for the climate research programme and the necessary condition for the detection of climate change to undertake this exercise as urgently and vigorously as possible.

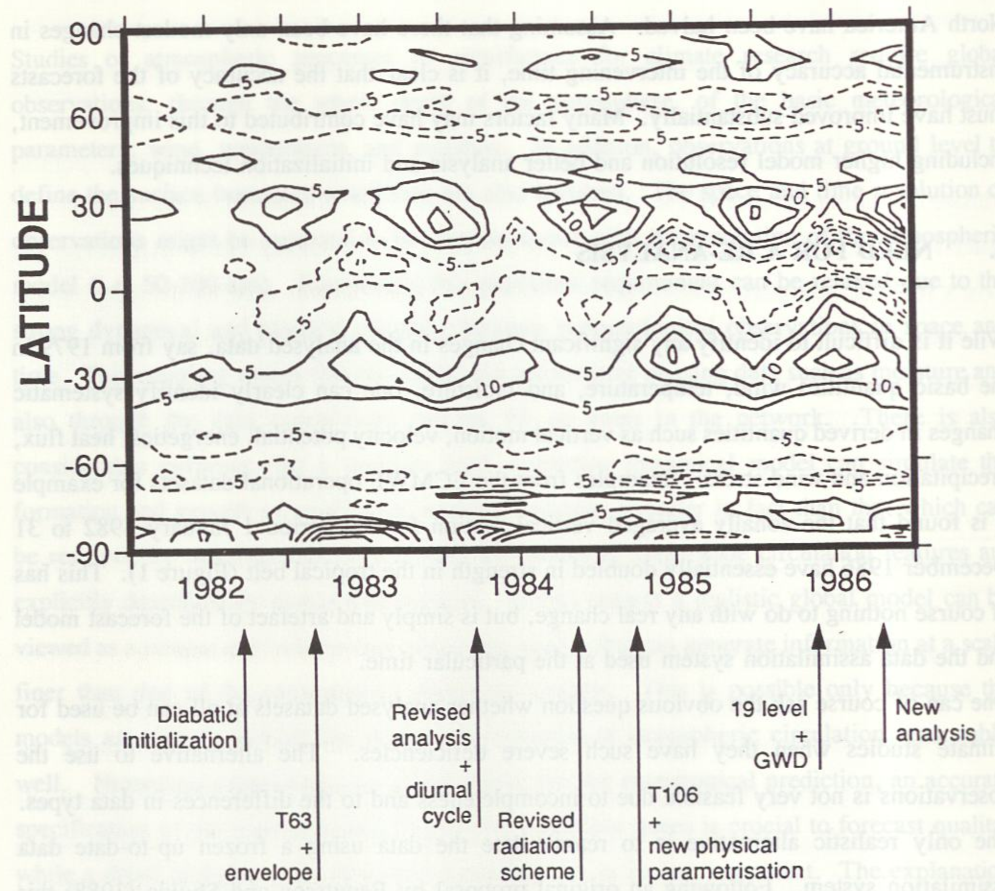

Fig. 1. Zonally averaged vertical motion (10^{-3} Pa . s^{-1}) as analyzed by the ECMWF forecast model for the period 1 January 1982 to 31 December 1986. Important model changes are indicated at the bottom. (Bengtsson and Shukla, Bull. Am. Met. Soc., Vol 69, No. 10, Oct. 1988).

RECONSTRUCTIONS OF CLIMATE FROM A.D. 1000 TO THE PRESENT

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1. INTRODUCTION

In most parts of the world our ability to characterise the climate of a region, through instrumental records of temperature and precipitation, is limited by the short period over which measurements have been made. Generally, instrumental records are less than a century in length and, in inhospitable areas such as polar and desert regions, records may only be available for a few decades. As a result, our perspective on climate variability, both spatial and temporal, is quite limited and this poses particular problems when trying to assess the impact of anthropogenic effects on the climate system. Human influences will be superimposed on any underlying 'natural' climatic variations, and it is therefore essential to understand what changes have occurred in the past. We have a general picture of how climate has changed over the last 150,000 years (through the last glacial-interglacial cycle) but only in terms of very large-scale, low frequency changes. Our understanding of climatic changes at higher frequencies -- variations on the decade to century timescale - is very poor, yet it is this timescale which is most relevent to current environmental concerns (Bradley and Jones, 1992). Contemporary climatic variations must be viewed in the context of changes which have occurred *before* global-scale anthropogenic impacts on the environment. This requires a perspective extending back many centuries, using records which can be resolved to an individual year or season. This is not an easy task, since there are few natural archives of past climatic history which provide the necessary resolution and the clarity of signal to enable climatic conditions in the past to be reconstructed. For the last 1000 years, such archives include tree rings, ice cores, historical documents, annually laminated (varved) sediments, and banded corals. As with the longest instrumental records, these natural archives are generally restricted to a few regions; ice cores are obviously limited to polar and high alpine environments and even there, only a handful of records spanning the last millennium in any detail are available. Tree ring records are limited to those areas where