FOUR DIMENSIONAL DATA ASSIMILATION

Lennart Bengtsson
European Centre for Medium Range Weather Forecasts
Reading, U.K.

Numerical weather prediction can be regarded as an initial value problem whereby the governing atmospheric equations are integrated forward from fully determined initial values of the meteorological parameters. However, in spite of the considerable improvements of the observing systems in recent years, the initial values are known only incompletely and inaccurately and one of the major tasks of any forecasting centre is to determine the best possible initial state from available observations.

Prior to the satellite based observing systems the observations used to analyse the atmosphere were essentially only radiosonde measurements which provided data for pressure, temperature, wind and humidity. The radiosonde observations were and still are inadequately distributed around the earth leaving severe geographical gaps where no data are available. Furthermore, the conventional observations from the radiosonde network are point measurements which do not provide a proper sampling of the highly variable meteorological fields. The measurements cannot be representative of the true time/volume averages required by numerical models. They are also subject to significant random instrumental errors.

With the advent of the new space based quantitative observations gradually being developed from the late 1960s, numerical weather prediction was facing a new and most exciting challenge. The design and implementation of an observing system to obtain temperature and wind observations by remote measurements from space started a new era in numerical weather prediction. For the first time operational forecasts could be carried out for all parts of the world and the forecasts could be extended into the medium and long range. However, the new observations were very different in character from the previous - they were asynoptic, they represented different scales of motion and they had a complex error structure. The asynoptic character of the new observations stimulated the development of techniques to integrate the analysis process into the numerical prediction. In this way an initial state is being created by letting a model assimilate observations over a period of time instead of only using observations at a given instant in time. Past observations are hereby projected onto a future state following the trajectories of the prediction model. Consequently a more accurate initial state can be produced since we will have the advantage of significantly more data. (Fig. 1) Furthermore when the model assimilates one single atmospheric parameter only such as the wind, it will generate over a period of time, through geostrophic and hydrostatic adjustment, consistent height and temperature data. In a similar way the assimilation of height or temperature will produce wind data.

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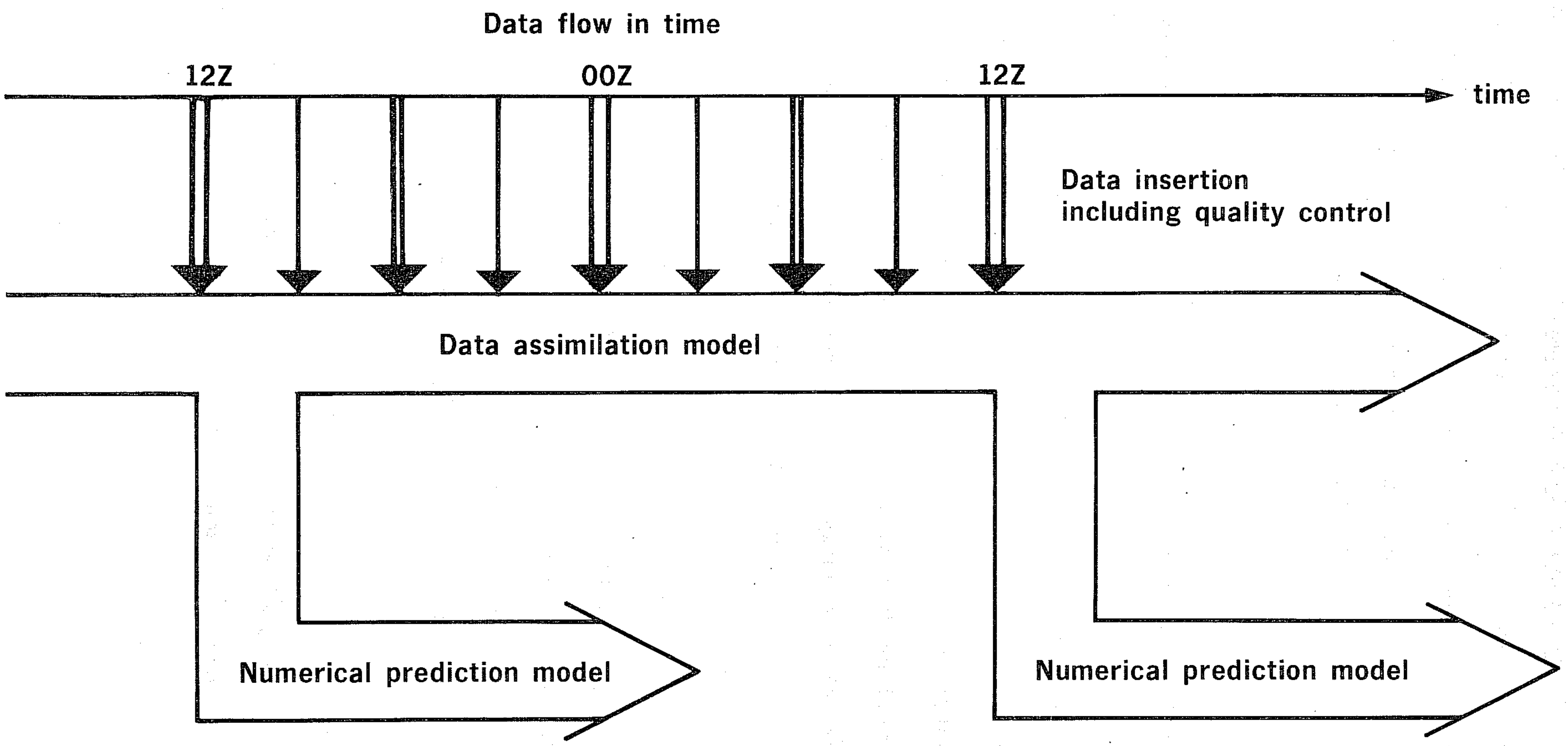

Fig. 1 Principal outline of four-dimensional data assimilation. Observations are inserted into the data assimilation model (identical to the prediction model) as they become available. The data assimilation may provide at any given time, a complete initial state. In principal, therefore, a forecast can be started at any time.

The so-called four-dimensional data assimilation has been used in operational numerical weather prediction long before FGGE albeit in a simple form. An initial state for a numerical prediction was produced by letting a forecast from a previous observational time constitute a first guess which then was corrected or updated by the latest observations, e.g. Bergthorsson and Döös (1955).

The data assimilation systems used prior to FGGE had a large number of shortcomings and a large part of the forecasting deficiencies were rooted in an imperfect assimilation of available data. (Bengtsson 1975).
During recent years the development of the Global Atmospheric Research Programme (GARP) and the increasing availability of non-synoptic remote observations from satellite platforms have fostered a growing interest in meteorological data analysis and triggered very significant advances towards developing effective and optimized data assimilation methods.

There are essentially four principal problems which must be considered in any practical data assimilation system. Firstly, the observations must be carefully evaluated to identify and remove erroneous data. Incorrect data, in particular in data sparse areas, can have a detrimental effect on the analysis and significantly reduce the quality of the forecasts.

Secondly, since the observations seldom occur at the exact locations represented by the grid points of a particular model, a 3-dimensional interpolation process is required to project the data on the grid of the model.

Thirdly, the best initial state is obtained by merging the new observations with the information from past observations carried forward by the model. The system must be designed in such a way that the individual weight given to the new data and to the grid point data can vary as a function of the accuracy of the data, the accuracy of the model including the accuracy of past data inserted in the area or downstream the area. In order to avoid an extremely long and detrimental adjustment process special measures must be taken for a consistent correction of the other dependent parameters of the model.

Fourthly, the insertion of new observations in a data assimilation model will generate an unrealistically high level of gravity wave noise. Although this noise presumably has little effect, if any, on forecasts beyond a day or two, it has a detrimental effect on the data assimilation and hence indirectly reduces the quality of the forecast. Ways must therefore be found to eliminate gravity wave noise before new data have to be inserted without changing the meteorologically significant modes.

It is clear that there is a long way to go before we can be fully satisfied with the assimilation of data, distributed irregularly in time and space, into a numerical model. Nevertheless, there has been substantial progress during the last ten years. Today, several operational centra, as is demonstrated in this volume, are able to successfully utilize the non-synoptic data from satellite platforms and from aircraft. This has been possible due to the implementation of new methodologies such as 3-dimensional multi-variate analysis and non-linear normal mode initialization, essentially developed over the last ten years. The Global Atmospheric Research Programme and the Global weather Experiments in particular have acted as a focal point for the research and development in four-dimensional data assimilation. The existence of the real data, the means of processing such data and the intense international co-operation within GARP has in a most efficient way challenged and stimulated the researchers to successful and practical results.

Many problems remain to be solved. Single level data are not yet properly assimilated due to problems with the vertical extrapolation of the information. Initialization of atmospheric processes controlled by diabatic processes which are so common in the Tropics are not yet satisfactorily solved, although promising results have been achieved recently. Finally, there is the fundamental problem how to merge new data with the information of a high resolution model which carries detailed information about such features as fronts and other intense small scale features in its first guess. Very sophisticated and refined insertion methods are indeed required in order not to destroy the information which the model has extracted and mostly correctly developed from past data.

References

Bengtsson, L., 1975: 4-dimensional assimilation of meteorological observations. GARP Publication Series No.15, WMO-ICSU, Geneva, 77pp.

Bergthorsson, P. and B.R.Döös, 1955: Numerical weather map analysis. Tellus, 7, 329-340.