Role of Simulation in Weather Forecasting

Aman Kaura
Department of Applied Sciences
UIET, Hoshiarpur
Hoshiarpur, Punjab, India

Gurinder Singh
Department of Applied Sciences
UIET, Hoshiarpur
Hoshiarpur, Punjab, India

Abstract

In past few years computational power has increased tremendously. A number of models have been developed which have made the prediction of our climate. The basic ideas of modeling of climate were developed about a century ago. There has been remarkable progress in numerical modeling of the climate over the past 50 years. In this paper, we trace the history of climate modeling along with present day models.

Keywords: Climate Modeling, Spherical Harmonics, Gaussian grid.

I. Introduction

Computer models and simulations are used for state of the art research, testing and planning in areas ranging from the design of airplanes to the simulation of crowd movements in new sports complexes. These models represent crucial research tools and instruments for analysis. One of the most important applications of modeling and simulation technology is in the field of weather pattern simulation and forecasting. These simulations provide accurate predictions of weather forecasts based on the vast array of satellite, radar, and other data available to weather forecasters. The effects of such computer models are far-reaching. We can now predict the weather for several days in advance with a high degree of accuracy, and we are gaining great insight into the factors causing changes in our climate, and their likely timing and severity. Few years back, predicting the weather appeared to be a very cumbersome process and the data generated to be extremely unreliable. The empirical rules have been used to predict the weather forecast. The primary physical process used by the forecaster was advection, the transport of fluid characteristics and properties by the movement of the fluid itself. But the important property of advection is that it is nonlinear; the human forecaster may extrapolate trends using an assumption of constant wind, but is quite incapable of intuiting the subtleties of complex advective processes.

II. History of weather forecasting

In 1901 Cleveland Abbe proposed that the atmosphere is governed by the same principles of thermodynamics and hydrodynamics that were studied in the previous century [1]. In 1922, Lewis Fry Richardson reported the forecasting the weather numerically. Using a hydrostatic variation of Bjerknes's primitive equations, he produced by hand a 6-hour forecast for the state of the atmosphere over two points in central Europe. He calculated the change in surface pressure would be 145 millibars, a value which is not realistic. The large error was caused by an imbalance in the pressure and wind velocity fields used as the initial conditions in his analysis [2]. In the year 1954, Carl-Gustav Rossby produced the first operational forecast based on the barotropic equation [3]. In 1959, karl-heinz Hinkelmann produced the first reasonable primitive equation forecast [4]. He completed the work by removing the small oscillations from the numerical model during initialization. The work to involve sea surface temperature in model initialization began in 1972 due to its role in modulating weather in higher latitudes of the Pacific.

III. Numerical weather prediction today

A. The European centre for medium-range weather forecasts (ECMWF)

ECMWF uses the computer modeling technique of numerical weather prediction to forecast the weather from its present measured state. The centre has been spectacularly successful in fulfilling its mission, and continues to develop forecasts and other products of steadily increasing accuracy and value, maintaining its position as a world leader. The first operational forecasts were made on 1 August, 1979. ECMWF conducts a wide range of global atmospheric and marine forecasts

- Forecasts for the atmosphere out to 10 days ahead, based on a T799 (25 km) 91-level (L91) deterministic model are disseminated twice per day.
- Forecasts from the ensemble prediction system (EPS) using a T399 (50 km) L62 version of the model and an ensemble of 51 members are computed and disseminated twice per day.
- Forecasts out to one month ahead, based on ensembles using a resolution of T255 (78 km) and 62 levels are distributed once per week.
- Seasonal Forecasts out to six months ahead, based on ensembles with a T159 (125 km) L40 model are disseminated once per month.

ECMWF uses the integrated forecast system (IFS). The IFS uses a spectral representation of the meteorological fields. Each field is expanded in series of spherical harmonics. The coefficients of the harmonics provide an alternative to specifying the field values in the spatial domain. When the model equations are transformed to spectral space, they become a set of equations for the spectral coefficients. These are used to advance the coefficients in time, after which the new physical fields may be computed. The truncation of the spectral expansion, specified by the total wave number N, determines the spatial resolution. There is a computational grid, called the Gaussian grid, corresponding to this spectral truncation. A Gaussian grid is used in the earth sciences as a gridded horizontal coordinate system for scientific modeling on the sphere. The grid id rectangular with a set number of coordinates called as latitude and longitude. The grid points along each latitude i.e. the longitudes, are equally spaced. At each latitude, the distance between any two adjacent degrees of longitude is same. The centre carries out its analysis using a powerful and complex computer system. It uses an IBM High Performance Computing Facility (HPCF). Phase 3 of HPCF comprises two identical p690+ clusters. Each cluster consists of 68 computer servers, each having 32 CPUs with a clock frequency of 1.9 GHz. The peak performance is 16.5 TeraFlops for each cluster, so the complete system has a peak performance of 33 TeraFlops or 33 trillion calculations per second. It represents an increase in computer power over the intervening 50 years which is broadly in agreement with Moore's Law, an empirical rule governing growth of computers. According to this rule, chip density doubles every 18 months.

B. Ensemble forecasting

It is a numerical weather prediction method that uses an attempt to generate a representative sample of the possible future states of a dynamical system. It is a form of Monte Carlo analysis. Monte carlo methods are a class of the simulation algorithms that uses repeated random sampling method to obtain numerical results. These methods can be used to solve any problem having a probabilistic interpretation. Stochastic or ensemble forecasting is used to take into account the uncertainty. It involves multiple forecasts created with an individual forecast model by using different physical parameterizations or varying initial conditions. Another field where ensemble spread is used is a meteogram, which shows the dispersion in the forecast of one quantity for one specific location. It is common for the ensemble spread to be small to incorporate the solution which verifies, which can lead to a misdiagnosis of model uncertainty.

IV. Conclusion

Prior to the computer era, weather forecasting was a very cumbersome process. Petterssen [5] described the advances as occurring in 'small doses'. The remarkable progress in forecasting over the past years is vividly illustrated by the record of skill of the 500 hPa forecasts produced at the National Meteorological Center, now NCEP, as measured by the S1 score [6]. The skill scores, expressed as percentages of maximum possible skill, have improved steadily over the past years and each introduction of a new prediction model has resulted in further improvement. The sophistication of prediction models is closely linked to the available computer power.

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