Dependence of forecast limits on the spatial resolution of the measurements used to initialize a forecast model

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Summary. A calculation of the dependence of forecast limits on the spatial resolution (that is, the effective observation density) of the meteorological data used to initialize a forecast model is demonstrated. The calculation uses the fact that the effective error-energy spectrum of meteorological measurements of a specific spatial resolution has a rapid transition from zero to 100 % of the background energy spectrum at a wavenumber corresponding to the smallest resolvable scale. For the forecast model of E. N. Lorenz (1969), doubling the data resolution by halving the smallest resolvable scale from 78 to 39 km, for example, extends the forecast limit by 1.4 h.

Abhängigkeit der Grenzen der Vorhersagbarkeit von der räumlichen Auflösung der Meßwerte, deren Ergebnisse als Anfangswerte für ein Vorhersagemodell genutzt werden

Zusammenfassung. Dargestellt wird die Berechnung der Abhängigkeit der Grenzen der Vorhersagbarkeit von der räumlichen Auflösung (d. h. der effektiven Beobachtungsdichte) der meteorologischen Meßwerte, die als Anfangswerte für ein Vorhersagemodell genutzt werden. Diese Berechnung beruht darauf, daß das effektive Fehlerspektrum der äquidistanten Messungen einen schnellen Übergang von Null bis 100 % für den kleinsten auflösbaren Maßstab hat. Für das Vorhersagemodell von E. N. Lorenz (1969) verlängert sich so zum Beispiel durch die Vergrößerung der räumlichen Auflösung der Meßwerte durch die Verkleinerung des kleinsten auflösbaren Maßstabs von 78 auf 39 km der Wettervorhersagezeitraum um 1,4 Stunden.

Because the nonlinearities in fluids couple different scales of motion, small scales will affect the future behavior of the atmosphere and ocean at even the largest scales. Lack of information about the small scales, resulting from the spatial resolution of the measurements used to initialize a forecast model, can therefore limit the predictability of that model even in the absence of other errors. The significance of unresolvable scales depends on the particular forecast model, and therefore on the application.

Calculating the dependence of forecast limits on the spatial resolution of the measurements for a given forecast model can be done by running the forecast model with initial conditions that differ only at scales unresolvable by the measurements, or by developing and running an error-growth model for the forecast model in question. Although the latter method can give more insight, developing an error-growth model can be difficult. A simplified error-growth model that gives only the evolution of error energy associated with each scale, such as that developed by

Lorenz (1969), will give an indication of the errors to be expected as a function of scale size, but cannot in general give errors for other observables such as temperature. Such a simplified error-growth model is usually sufficient for determining limits of predictability which can be defined to correspond to a particular large error energy such as 90 or 100 % of the background energy (an appropriately defined ensemble mean energy) for that spatial scale.

The appropriate initial error-energy spectrum to represent a particular spatial resolution of the measurements (neglecting measurement error) for such an error-growth model has zero error energy for resolvable scales and an error energy equal to 100 % of the background energy for unresolvable scales. Zero error energy represents perfect predictability, and an error energy equal to 100 % of the background energy represents no predictability. Here, the error-energy spectrum is defined as in Lorenz (1969), that is, it is the energy spectrum of the difference between two states of the oceanic or atmospheric system being forecast. (We can think of one state as representing the forecast and the other as representing the true state of the system.)

In the case of the forecast model analyzed by Lorenz (1969), it is possible to determine the outcome of initializing his error-growth model with an error-energy spectrum corresponding to various measurement spatial resolutions from his published results without having to perform additional error-growth simulations. This is because at each stage of his numerical error-growth experiment (called Experiment A by Lorenz, 1969), the error-energy spectrum has a rapid transition from zero to 100 % error energy (see his Fig. 2 and the accompanying discussion), and therefore approximates the error-energy spectrum corresponding to a specific spatial resolution of the measurements. Therefore, we can consider each stage in his error-growth experiment A as though it had been initialized by measurements having a specific spatial resolution. It is then straightforward to estimate forecast limits corresponding to initializing his forecast model with hypothetical measurements made at various spatial resolutions. Using values from Lorenz's Tables 1 and 3 gives the dependence of forecast limits on the spatial resolution of the measurements shown in Fig. 1.

The increase in forecast limits that results from an increase in measurement resolution can be seen, for example, by comparing the two curves labeled 78 and 39 km in Fig. 1. These curves indicate when 100 % error energy has been reached for forecasts initialized with measurements having a minimum resolvable scale of 78 and 39 km, respectively. The two curves are identical (not obvious because of the logarithmic horizontal scale) except that the 39 km curve is 1.4 h to the right of the 78 km curve; in this case increasing the measurement resolution by a factor of two has increased the forecast limit (i. e., has extended the 100 % error-energy curve) by 1.4 h. Doubling the measurement resolution (halving the smallest resolvable scale) from a high-resolution measurement extends the forecast limit by a lesser amount than doubling the measurement resolution from a low-resolution measurement.

The results in Fig. 1 give the forecast limits only of Lorenz's (1969) two-dimensional barotropic forecasting model, and may not accurately represent the forecast limits of the atmosphere. Evidence exists (e. g., Holloway and West 1984) that the time scales of error growth in other forecast models may differ from those of the forecast model analyzed by Lorenz (1969). For example, Litherland and Holloway (1984) show that inclusion of horizontal anisotropy or differential rotation can slow error
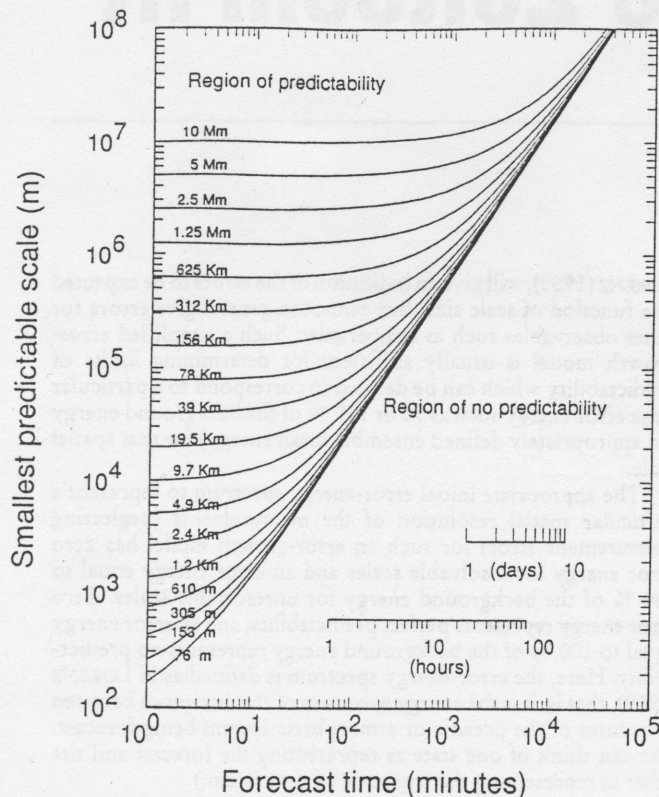
Fig. 1. Predictability limit (100 % error-energy curve) for different spatial resolutions of the meteorological data used to initialize the forecast model. Each curve is the predictability limit for the spatial resolution corresponding to the smallest scale resolvable by the measurements used to initialize the forecast model. Comparing the different curves shows the dependence of predictability limit on the spatial resolutions of the meteorological data used to initialize the forecast model.

Abb. 1. Die Grenze der Wettervorhersagemöglichkeit (100 %-Fehlerenergiekurve) für verschiedene räumliche Auflösungen von Meßwerten. Die Kurven geben die Grenzen der Wettervorhersagemöglichkeit für die angegebenen kleinsten auflösbaren Maßstäbe wieder. Der Vergleich der verschiedenen Kurven zeigt die Abhängigkeit der Vorhersagegrenzen von der räumlichen Auflösung der meteorologischen Daten, die für das Vorhersagemodell genutzt werden.

growth and thereby increase predictability in two-dimensional forecast models. Some high-resolution, limited-area forecast models also appear to give different results, such as when there is strong dynamical forcing of small scales by much larger scales (ERRICO and BAUMHEFNER 1987).

The dependence of forecast limits on the spatial resolution of the measurements could be calculated for other forecast models by developing their corresponding error-growth models. Such calculations could influence the design of future operational meteorological observation systems. The difficulty of developing error-growth models is apparent from the work of LORENZ (1969); it would be even greater for more sophisticated forecast models. For example, the background energy spectrum could depend on height and horizontal location. Also, it would be necessary to consider the vertical spatial resolution of the measurements in addition to the horizontal spatial resolution, as well as the spatial variability of measurement resolution. These are only a few of the difficulties involved. However, we see no reason why, in principle, the appropriate error-growth models could not be developed.

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Über den Probenahmefehler der Varianz in konvektiven Feldern

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Zusammenfassung. Am Beispiel eines einfachen Modells wird gezeigt, daß die Stichproben-Varianzen physikalischer Meßgrößen in konvektiven Feldern eine systematische Abweichung von den Ensemble-Varianzen aufweisen, die nicht von der Anzahl der Messungen, sondern nur von der Struktur des Feldes abhängt. Durch entsprechende Korrekturen kann aus einer Stichproben-Varianz ein erwartungstreuer Schätzer für die Ensemble-Varianz gewonnen und so die Meßgenauigkeit turbulenter Flüsse gesteigert werden.

On the error of random measured variances in convective fields

Summary. A simple statistical model of a convective field exemplarly shows a systematic deviation between random measured variances and corresponding ensemble variances. This difference only depends on the field structure but not on the number of measurements. A suitable correction makes a spot check variance an ideal estimate of the ensemble variance and thus leads to an improved accuracy in airborne flux measurements.

In einer Abschätzung der statistischen Unsicherheit bei der flugzeuggestützten Messung flächiger Varianzen und Kovarianzen merken LENSCHOW und STANKOV (1986) an, daß — da ja das