CENTRAL REGION TECHNICAL ATTACHMENT 95-06

ENSEMBLE PREDICTION

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1. Introduction

Terms like "ensemble prediction," "46-member MRF ensemble," "ensemble mean," "dominate cluster," etc., have appeared in some NMC discussions (available over AFOS) during the last year or so. This terminology is used most often in the narrative (PMDMRD) that accompanies the 6-to-10 day forecast, issued by the Climate Analysis Center (CAC). There has occasionally been discussion of the MRF ensemble in the PMDHMD and PMDEPD messages.

Field forecasters do not yet have access to anything from the MRF ensemble. However, work is going on to make this output available to the field. Ensemble prediction is a forecasting technique that operational forecasters will be exposed to, frequently.

The purpose of this Technical Attachment (TA) is to briefly discuss some of the basic principles of the ensemble prediction methodology, as it is now done at NMC. This prediction technique is also being employed at the ECMWF and the UKMET offices. Referenced literature will be given where additional detail can be found, as in CR TA 95-03 (Berry 1995).

2. Discussion

A. Concepts

For openers, we need to formally define an ensemble. From the point of view of statistical mechanics, an ensemble consists of a large number N (N can go to infinity) of identically constructed systems each of which is in a state that is independent of the state of the other members (Pexito and Oort 1992). In Numerical Weather Prediction (NWP), the "identically constructed systems" are the models, for any time and space-scales (Epstein 1969 and Wilks 1995).

Until now, operational ensemble prediction at NMC has been applied to medium and extended ranges (beyond day 3). However, this prediction methodology also lends itself to forecast periods shorter than day 3, and this idea is being explored at NMC (Tracton, personal communication). An example would be 12-hour forecasts for fields of static stability, when examining the likelihood of severe deep-moist convection (Tracton and Kalnay 1993).

Ensemble prediction began at NMC during December 1992. The principle rationale for adopting the ensemble approach is to provide reliable information on the nature and degree of the ever present uncertainties in NWP. Operational forecasters face these "NWP uncertainties" every shift. There is variability in the skills (as a function of time) of the operational NWP and there also exists variability in the magnitudes of the forecast uncertainties.

As done at NMC, the operational ensemble configuration involves the generation of multiple forecasts with the MRF model from a set of perturbed initial conditions (for any desired forecast field). Since these forecasts are generated from one numerical model, the NMC configuration does not quite fit the classic definition of an ensemble, given above. Therefore, the biases of the MRF model will still exist throughout the ensemble.

Put another way, the MRF ensemble is formulated from a combination of time lagging (you do this every time you compare "newer model runs" with "older ones," on AFOS, valid for the same forecast time (Livingston and Schaefer 1991)), and introducing perturbations (called "Breeding of Growing Modes") into the initial conditions (Tracton and Kalnay 1993; Toth and Kalnay 1993).

In adopting this approach, NMC explicitly recognizes those numerical model forecasts, especially after day 3, should be considered stochastic, not deterministic. There is no single solution (not deterministic), but an array of possibilities (stochastic). Ensemble prediction seeks to maximize the utility of NWP, and extract information about the future state of the atmosphere that is statistically reliable. This idea is shown schematically in Figure 1.

The screaming message to be understood from Figure 1 is the concept of forecast divergence among operational deterministic numerical forecast models, as a function of time (called "forecast divergence" for short). On the "deterministic side," the "small ellipse" surrounds "points," each representing a specific initial condition for specific deterministic NWP models (say one for the AVN, another for the MRF, one for the ECMWF, and so on; this diagram can also represent a schematic for ensemble prediction (Tracton and Kalnay 1993)). Because of observational errors, incomplete observations, differences in data assimilation cycles, etc., there will be slight differences in the initial conditions. Carr (1988) offers a concise discussion of numerical modeling errors.

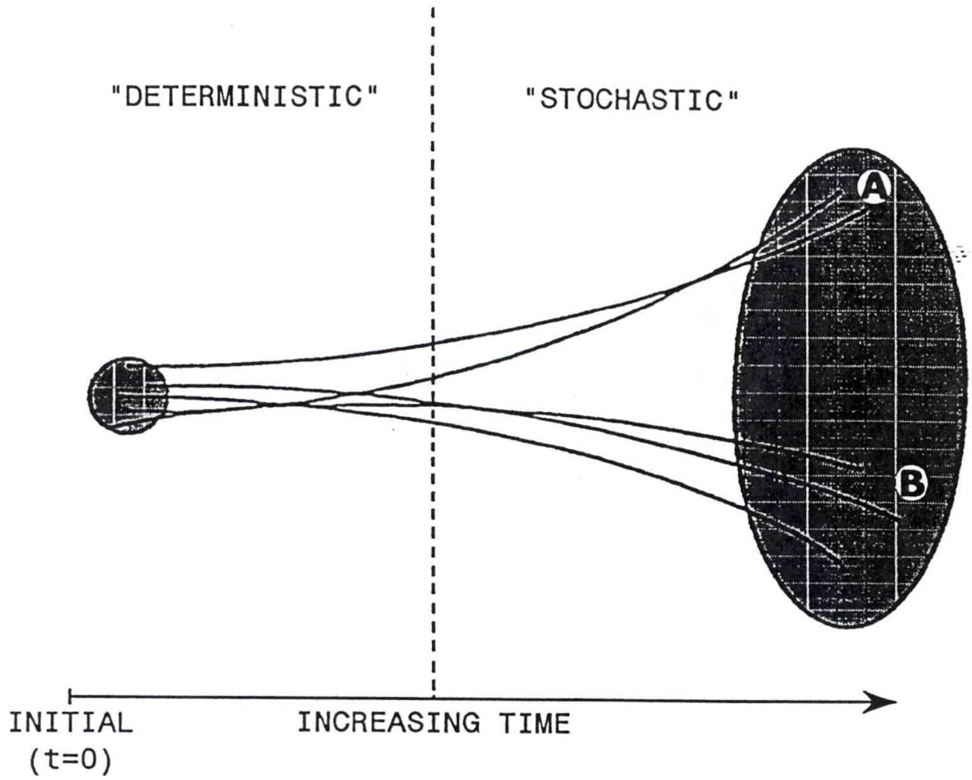

Figure 1. Schematic diagram illustrating the concept of forecast divergence. See text for details (from Tracton and Kalnay 1993).

These slight initial differences will lead to, perhaps, large differences in forecast solutions, especially after day 3, for any desired meteorological field. Put another way, the forecasts from the NWP are "close enough to each other," before about forecast day 3, such that they may be considered deterministic. Afterwards, they must be considered stochastic. Furthermore, these forecast differences are regime (or circulation pattern--say, positive verses the negative phases of the PNA) dependent, and a function of scale-interaction processes in the atmosphere. (The interested reader can refer to Lorenz 1963, 1965; O'Lenic and Livezey 1989, Palmer 1988, 1993; Zeng et al. 1993, Tracton 1990.)

These differences in forecast solutions are the forecast divergences represented in Figure 1, as we go from the "deterministic side" to the "stochastic side". Each curve represents a "trajectory" that a single model is taking to arrive at a solution for a specific valid time. On the stochastic side, it can be seen that the trajectories tend to cluster around two similar circulation states, called "A" and "B", within the larger ellipse that represents the array of possibilities.

The likelihood of verification of these clusters may be related to the number of forecasts (members) in each group (Tracton and Kalnay 1993). Concerning the latter point, the greater the number of forecasts (population) in a cluster, the more likely that cluster will verify and vice-versa.

As currently done at NMC, the MRF ensemble consists of 46 members. The graphical output, from the high resolution[1] operational MRF model that forecasters see on AFOS, is only 1 possibility out of 46. Considering, "runs from previous initial conditions can be stored" on AFOS, there are essentially 45 other possibilities that most operational forecasters, at NWS field sites across Central Region, cannot, at this time, see (including an ensemble output of the 6-to-10 day mean forecast graphics of 500-mb height and height anomalies, which are addressed in the PMDMRD AFOS messages). The forecasters are only looking at one deterministic (single solution) MRF model.

For completeness, although the ensemble configuration at NMC is derived from the MRF, theoretically, output from the operational global models of other major forecast centers, such as ECMWF and UKMET, could be incorporated into what is now a purely MRF ensemble. However, since the NMC ensemble configuration is derived solely from the MRF, characteristic biases of this model will still be present throughout the MRF ensemble configuration.

B. Operational Aspects

A major challenge of ensemble prediction is to condense the large amounts of information into a coherent user-friendly format. For instance, no operational forecaster has time to look at each member. Besides displaying each member, the size of a "postage stamp" on a single page, other ensemble products include optimally weighted ensemble averaging (Van den Dool and Rukhovets 1994), dispersion fields ("spread" charts), clustering of similar forecasts (for details, Tracton and Kalnay 1993), simple probability estimates, an envelope of storm tracks and measures of a shift in a circulation regime.

Only two "key" products will be shown here. Again, the reader can refer to Tracton and Kalnay (1993) for additional examples of ensemble products, and including greater detail on the formulation of the two products illustrated below.

Figure 2 is an example of a "spread" chart, in this case for the 500-mb constant pressure surface for forecast day 7. What is significant about this type of representation is that it represents a real-time quantification of the spatial distribution of forecast uncertainty that operational forecasters face. Areas that are 0.8 and greater, which are shaded, are regions of high forecast uncertainty. In those uncertain areas, operational forecasters would generally have a lower confidence than "usual", in the MRF model, in this case for day 7. At times, the information shown on this type of chart will be mentioned in the NMC discussions.

Figure 3 is an example of output from an ensemble cluster (from Tracton and Kalnay 1993). In this case, this chart is for forecast day 4, for 1000-mb

[1]T126 (Triangular Truncation wave number 126; Carr (1988) gives a discussion of "Triangular Truncation") through day 7, then T62 through forecast day 16.

heights and 1000-mb to 500-mb thicknesses. At the time this chart was generated (0000 UTC 10 March 1993 initial conditions), there were just 14 members to the MRF ensemble. At the top of the Figure, "1" means "yes" and "0" means "no" with respect to whether or not a particular member was grouped into that cluster.

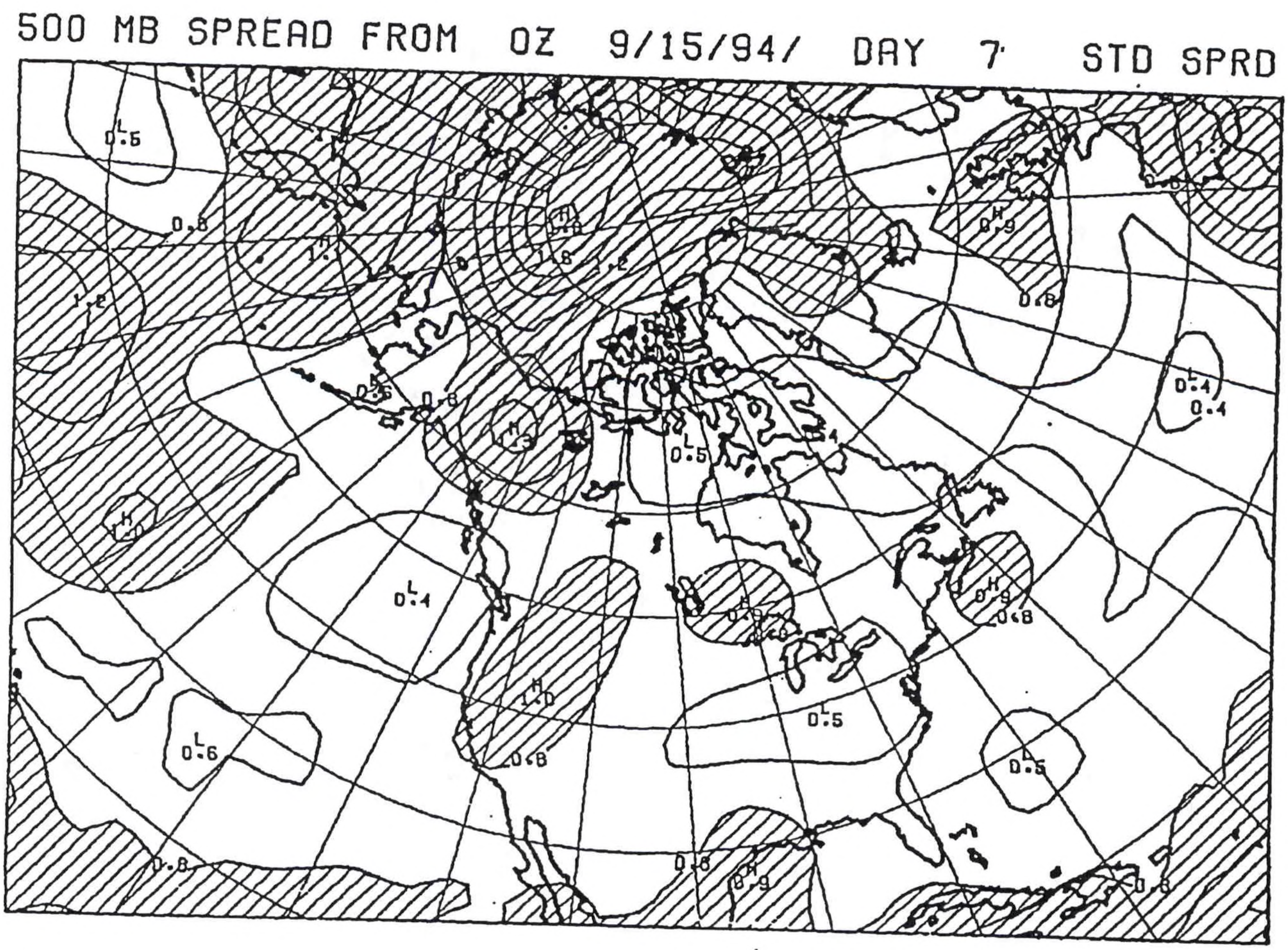

Figure 2. Graphic illustrating the concept of spread among the members of the 46-member MRF ensemble. For this case, the spread is for forecast day 7, at 500-mb. This spread gives a quantification of the real-time forecast uncertainty. Areas where spread is significant are shaded (greater than 0.8).

For the situation shown in Figure 3, 10 of the 14 members were grouped into that cluster. Suffice to say that would allow an operational forecaster to have high confidence with using this solution. As readers with good memories will immediately notice, this was a forecast for the now famous "Superstorm of 1993". It can be seen that this cluster performed quite well.

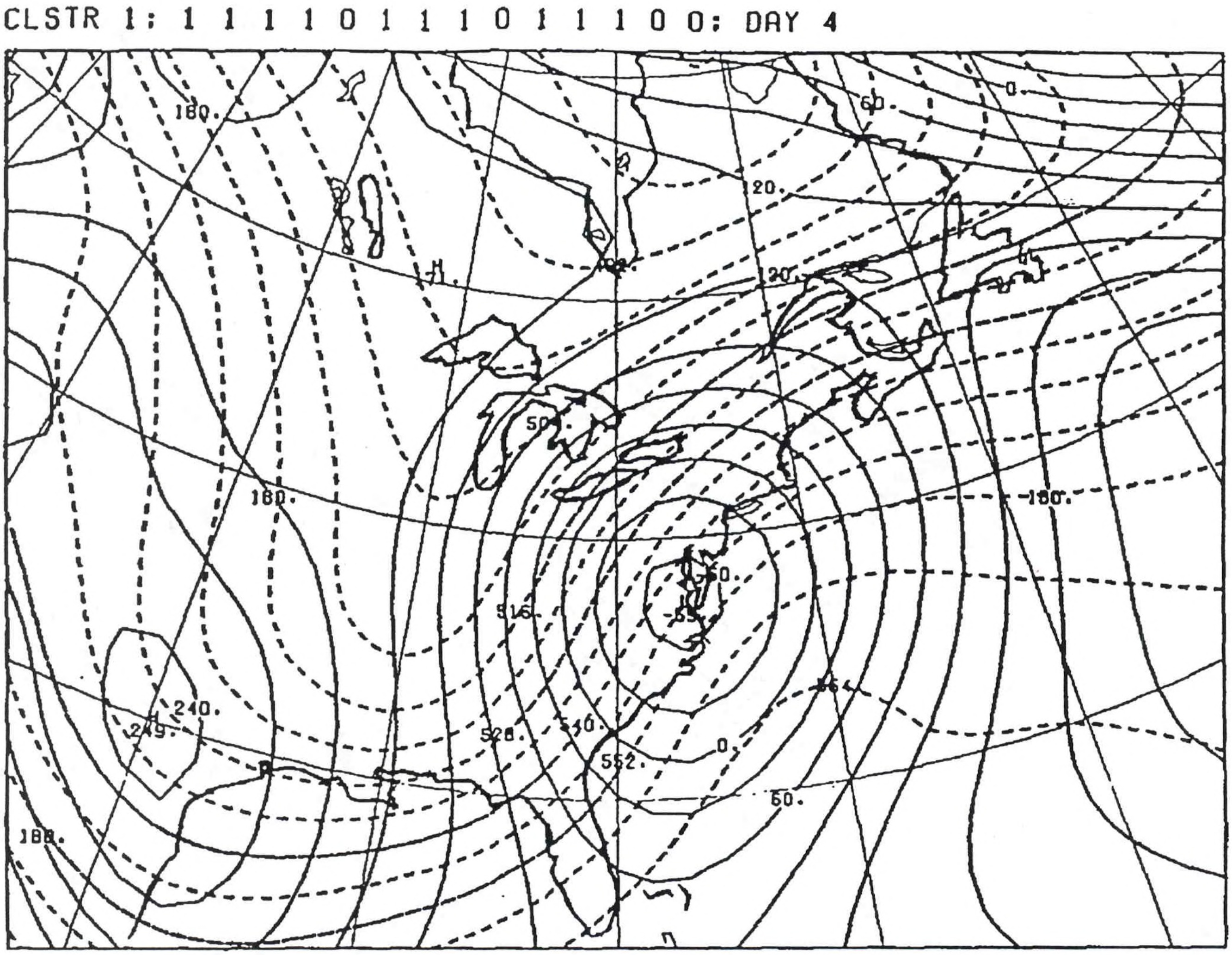

Figure 3. Example of an ensemble cluster for 1000-mb heights (solid, meters) and 1000 to 500-mb thicknesses (dashed, decameters). See text for details (from Tracton and Kalnay 1993).

3. Summary

A brief overview of the ensemble prediction methodology has just been given. A key point that again needs to be emphasized is that ensemble prediction addresses the uncertainties the operational forecasters face daily. Furthermore, ensemble prediction seeks to maximize the utility of NWP, and extract information about the future state of the atmosphere that is statistically reliable. The latter is true for any time and space scales, and for any meteorological fields.

For greater detail on what was discussed, please consult the references listed below. Work is going on to make the ensemble output available to field offices. It is hoped that this TA will give Central Region sites some “heads up” as to “what is coming”.

4. Acknowledgements

As was also true for TA 95-03, assistance was provided to me by other members of Central Region, Scientific Services Division (SSD). I want to thank Deborah White-Haynes for expertly preparing this manuscript for publication and Michael Manker for excellent graphical support. Appreciation is given to Dr. Preston Leftwich for carefully reviewing an earlier version of this manuscript. Finally, I thank Dr. Richard Livingston for encouraging and supporting me to write these types of Technical Attachments for Central Region.

5. References

Berry, E.K., 1995: The Pacific/North American Teleconnection (PNA). DOC/NOAA/NWS Central Region Technical Attachment 95-03, Kansas City, MO.

Carr, F.H., 1988: Introduction to Numerical Weather Prediction Models at the National Meteorological Center. DOC/NOAA/NWS Southern Region, Scientific Services Division, 63pp.

Epstein, E.S., 1969: A scoring system for probability forecasts of ranked categories. *J. Appl. Meteor.*, **8**, 985-987.

Lorenz, E.N., 1963: Deterministic non-periodic flow. *J. Atmos. Sci.*, **20**, 130-141.

__________, 1965: A study of the predictability of a 28-variable atmospheric model. *Tellus*, **17**, 321-333.

Livingston, R.L., and J. Schaefer, 1990: On medium-range model guidance and the 3-5-day extended forecast. *Wea. Forecasting*, **5**, 361-376.

O'Lenic, E.A., and R.E. Livezey, 1989: Relationships between systematic errors in medium range numerical forecasts and some of the principle modes of low-frequency variability of the northern hemisphere 700-mb circulation. *Mon. Wea. Rev.*, **117**, 1262-1280.

Palmer, T.N., 1988: Medium and extended range predictability and the stability of the Pacific/North American mode. *Quart. J. Roy. Meteor. Soc.*, **74**, 691-713.

__________, 1993: Extended-range atmospheric prediction and the Lorenz Model. *Bull. Amer. Meteor. Soc.*, 74, 49-65.

Pexioto, J.P., and A.H. Oort, 1992: *Physics Of Climate*. American Institute of Physics, 520pp.

Toth, Z., 1993: Preferred and unpreferred circulation types in the northern hemisphere Wintertime phase space. *J. Atmos. Sci.*, **50**, 2868-2888.

__________, and E. Kalnay, 1993: Ensemble forecasting at NMC: The generation of perturbations. *Bull. Amer. Meteor. Soc.*, 74, 2317-2330.

Tracton, M.S., 1990: Predictability and its relationship to scale interaction processes in blocking. *Mon. Wea. Rev.*, **118**, 1666-1695.

__________, and E. Kalnay, 1993: Operational ensemble prediction at the National Meteorological Center: practical aspects. *Wea. Forecasting*, **8**, 379-398.

Van den Dool, H.M., and L. Rukhovets, 1994: On the weights for an ensemble-averaged 6-10 day forecast. *Wea. Forecasting*, **9**, 457-465.

Wilks, D.S., 1995: *Statistical Methods in the Atmospheric Sciences.* Academic Press, 467pp.

Zeng, X.A., R.A. Pielke and R. Eykholt, 1993: Chaos theory and its applications to the atmosphere. *Bull. Amer. Meteor. Soc.*, 74, 631-644.