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AN EVALUATION OF NGM LIFTED INDEX PREDICTIONS OF EXTREME INSTABILITY

Steven J. Weiss
National Severe Storms Forecast Center
Kansas City, Missouri

1. The NGM Lifted Index

The NGM lifted index is computed by lifting parcels from each of the bottom four model layers dry adiabatically to saturation, then moist adiabatically to 500 mb. The difference between the parcel temperature and the predicted 500 mb temperature is calculated, with a negative value indicating instability. The most unstable value is retained; hence, the term "Four-layer Lifted Index" (4LI). Parcels in the fourth layer are just below 850 mb when the surface pressure is 1013 mb. Note that the 4LI can reflect instability originating in warm air overlying a shallow cold layer, such as in warm frontal overrunning.

2. Forecast Data

NGM 24h and 36h forecasts of the 4LI were examined during the period from June 15, 1986 through August 31, 1986. Major additions to the NGM simulation of physical processes, including radiation parameterization, surface fluxes of heat and moisture over land, turbulent mixing, and adjustments to the cumulus parameterization scheme were implemented at 1200 GMT July 23, 1986. See Technical Procedures Bulletin 363 for details. Note that this implementation date is at the approximate midpoint of the data sample, and provides an opportunity to study the effect of the new physics package on the 4LI forecasts.

Summer outbreaks of severe thunderstorms and tornadoes tend to develop in very unstable air masses. Since widespread instability is often present during the summer, the location of extreme instability can be crucial when identifying potential severe weather threat areas. Accordingly, the 4LI forecasts over the contiguous United States were examined for conditions of extreme instability, defined as the occurrence of areas enclosed by an isopleth value of -8C. Forecast areas on the facsimile charts that were separated by a small distance (approximately 60 nm or less) were treated as one continuous area to facilitate the data analysis.

Table 1 presents a summary of the 4LI forecasts of extreme instability. A total of 69 model runs produced 120 forecast areas of extreme instability during the study period. (Model output was not available for four model runs.) There was virtually no change in the relative frequency of extreme instability forecasts after the addition of the new physics package on July 23. (Hereafter, the period from June 15 through 0000 GMT July 23 will be referred to as BP - "Before Physics," and the period beginning 1200 GMT July 23 will be AP - "After Physics").

Table 1
Summary of NGM Forecasts of Extreme Instability (EI)

	Number of EI Forecast Areas	Number of Model Runs Forecasting EI	Total Model Runs in Data Sample	% of Model Runs Forecasting EI
BP Period	55	33	73	45
AP Period	65	36	79	46
Totals	120	69	152	45

Forecasts of extreme instability occurred more frequently from model runs based upon 0000 GMT initial data, with this tendency becoming more pronounced in the AP period (Table 2). Finally, Table 3 reveals there is no significant bias toward projection times (24 or 36h) or valid times (0000 or 1200 GMT) of the forecast areas, although the percentage of forecast areas valid at 0000 GMT and at the 36h projection increased slightly in the AP period.

Table 2
Initial Data Time of NGM Forecasts of Extreme Instability (EI). Numbers in parenthesis refer to the percent of areas or model runs during the data period.

	Number of EI Forecast Areas	Number of Model Runs Forecasting EI
BP Period		
1200 GMT	22 (40)	13 (39)
0000 GMT	33 (60	20 (61)
AP Period		
1200 GMT	23 (35)	12 (33)
0000 GMT	42 (65)	24 (67)

Table 3
Forecast Projection and Valid Time of NGM Predictions of Extreme Instability Areas

	Forecast Projection		Forecast Valid Time (GMT)	
	24h	36h	1200	0000
BP Period	30	25	29	26
AP Period	33	32	29	36

3. Verification of Forecasts

To determine the accuracy of the 4LI forecasts of extreme instability, the 120 cases were compared with the NGM 4LI 00h forecast valid at the verifying times. The 00h forecast in the NGM consists of data interpolation to sigma coordinates followed by a Normal Mode Initialization to suppress noise. Additional interpolation back to pressure coordinates is then accomplished. The NGM 00h forecasts are not equivalent to an "initial analysis."

a. Forecast Assessment

A detailed verification of grid point data was beyond the scope of this study. However, it was possible to evaluate a range of predicted 4LI values based upon the contour interval on the facsimile charts. To accomplish this, each range of 4LI values was assigned a categorical designator:

CAT 1: +4 to 0
CAT 2: 0 to -4
CAT 3: -4 to -8
CAT 4: -8 to -12
CAT 5: -12 to -16

The area enclosed by the predicted -8 contour was manually transferred onto the appropriate 00h initial conditions, and a categorical verification was performed. For example, if a CAT 4 (-8 to -12) forecast area verified within the CAT 3 (-4 to -8) contour, the prediction was an overforecast of one category. (That is, $CAT_{fcst} - CAT_{verf}$ = error, with positive errors indicating an overforecast.)

Mean forecast errors are presented in Table 4. Overall, only 5% of the forecasts verified in the proper category. All six correct forecasts occurred during the AP period, and one half of these originated from 00h initial instabilities of -8 or less over the forecast area. In the other cases (95% of the sample) of predicted extreme instability, the destabilization process was overforecast, particularly during the AP period. In most instances, the errors were not simply one of either location (e.g., the forecast instability category was correct, but the location needed minor adjustment), or one of magnitude (e.g., the axis of maximum instability was correctly located, but the degree of instability was underforecast). Rather, most errors consisted of combinations of both location and magnitude.

Table 4
Mean Categorical Errors for NGM Forecasts of Extreme Instability.
Times in GMT.

	Projection Time 24h	Projection Time 36h	Valid Time 0000	Valid Time 1200	All Cases	Number of Correct Forecasts
BP Period	1.37	1.42	1.38	1.39	1.39	0
AP Period	1.61	1.84	1.67	1.79	1.72	6

Large forecast errors, defined as errors of two categories or more, were also examined. More than two thirds (71%) of all cases during the AP period qualified as large forecast errors, whereas less than 40% of the errors during the BP period were large. Further, more than 10% of the AP cases contained very large errors of three categories or more.

The ability of the NGM to predict extreme instability when it did occur was also examined. Forecasts at the 24 and 36h projections were compared to actual conditions of extreme instability that were identified on the 00h forecasts. Table 5 indicates that these conditions were usually underforecast, with larger errors occurring at the 36h projection. Smaller errors were noted for the AP period. A comparison of the mean errors listed in Tables 4 and 5 suggests that the NGM forecasts of the 4LI became more unstable (in a relative sense) during the AP period.

Table 5
Mean Categorical Errors for NGM Forecasts Valid at 00h
Conditions of Extreme Instability

	Projection Time 24h	Projection Time 36h	All Cases	Number of Correct Forecasts
BP Period	-1.50	-1.75	-1.63	1
AP Period	-1.28	-1.43	-1.36	1

b. Relationship to Forecast Precipitation

A key consideration in the introduction of the more complete physical processes in the NGM was the desire to improve warm season precipitation forecasts. The relationship between forecast precipitation and large overforecast errors of extreme instability in the 4LI predictions was examined, since the large error situations potentially have the most serious impact on the operational forecaster. The large error cases were screened for the occurrence of the following forecast parameters: (1) measurable precipitation, and (2) a printed precipitation maximum (QPF_{max}), located within or very close to the area of predicted extreme instability. The QPF_{max} were also examined for the appearance of localized excessive amounts, or "bulls-eyes", defined as quasi-circular areas of maximum precipitation consisting of two or more concentric isohyets (contour interval of 0.5 inch on the facsimile charts).

Table 6 indicates that a marked change in the model precipitation efficiency occurred in the AP period, when all large error cases were associated with measurable precipitation. Further, nearly three quarters of the large error AP cases had a QPF_{max} located within or very close to the extreme instability forecast area, and almost one third of all AP cases with large errors were associated with QPF_{max} bulls-eyes. In dramatic comparison, only a small percentage of the BP large error cases had any forecast precipitation near the predicted location of extreme instability.

Table 6
Summary of Large Categorical Forecast Errors of NGM Forecasts of Extreme Instability and Associated Forecast Precipitation. Numbers in parenthesis refer to percent of cases during period.

	Cases with Measurable Precipitation	Cases with QPF_{max}	Cases with QPF_{max} Bulls-eye
BP Period	4 (19)	3 (14)	2 (10)
AP Period	46 (100)	33 (72)	14 (30)

The distribution of forecast QPF_{max} and precipitation bulls-eye amounts (Table 7) reveals that nearly three quarters of the QPF_{max} amounts associated with large forecast errors of extreme instability during the AP period consisted of 12h accumulations of at least 1.0 inch, and that the majority of bulls-eye cases accumulated at least 2.0 inches of rain.

Table 7
Distribution of NGM Forecasts of 12h Accumulated Precipitation for Large Error Cases During the AP Period

12h Accumulated Precipitation (in)	Number of Cases with QPF_{max}	Number of Cases with Bulls-eyes
<0.50	2	0
0.50-0.99	7	0
1.00-1.49	10	3
1.50-1.99	6	3
>=2.00	8	8

Finally, all QPF_{max} bulls-eye cases that were virtually coincident with the extreme instability forecast area were associated with large overforecasts of instability.

4. Discussion

The data analysis indicates that the NGM model has difficulty in forecasting conditions of extreme instability during the warm season. The 24 and 36h projections of extreme instability typically overforecast the degree of instability, and this tendency has become more pronounced since the implementation of the revised physics package on July 23, 1986. A thorough analysis of the problem can only be accomplished by sensitivity tests on the model and are beyond the intent of this study. However, sufficient documentation of the NGM physical processes is available to allow speculation on possible causes of the increase in the extreme instability forecast errors.

It is well known that an air column can destabilize by several basic processes:

1. Cooling and/or drying of the upper layers.

2. Heating and/or moistening of the lower layers.

Any combination of 1 and 2 acting in concert will act to further decrease the stability of the column. Accordingly, it is possible to infer changes in stability by identifying possible thermodynamic effects of the physical processes simulated in the NGM. On September 10, 1986, NMC corrected a problem with the vertical mixing of heat and moisture that occurs rather infrequently. When the error occurred it apparently affected only a small number of grid points, thus contributing to a localized large error in the 4LI calculation. However, the appearance of large overforecasts of extreme instability has continued after the computational correction was implemented. Thus, it is hypothesized that other aspects of the revised physics package have also contributed to the instability forecast errors.

5. Summary

NGM forecasts of airmass stability during the warm season were examined for the period from June 15 through August 31, 1986. To aid operational forecasters, the following conclusions may be helpful when utilizing NGM predictions of extreme instability (defined as areas enclosed by the -8 4LI isopleth):

a. Predictions of extreme instability were nearly always overforecast.

b. The magnitude of the overforecast errors increased after the revised physics package was implemented in July 1986 (the AP period). Nearly three quarters of the AP predictions overforecast the instability by 8°C or more.

c. When conditions of extreme instability actually occurred, the NGM tended to underforecast the instability.

d. The magnitude of the underforecast errors diminished during the AP period. Approximately one third of the AP predictions underforecast the instability by 8°C or more.

e. Unlike the BP period, when a dry bias was evident, forecasts of extreme instability during the AP period were usually accompanied by forecasts of measurable precipitation.

f. Large overforecast errors during the AP period were often coincident with forecast precipitation maxima, and were occasionally associated with precipitation bulls-eyes.

g. Forecasts of extreme instability that were coincident with a precipitation bulls-eye were always associated with large overforecasting errors.

In summary, the NGM has a very high False Alarm Ratio and a very low Probability of Detection when conditions of extreme instability during the warm season are considered. It is hypothesized that some aspects of the NGM simulation of physical processes, notably the revised Kuo convective parameterization algorithm, have contributed to the instability forecast errors by increasing the amount of low level heating in the model atmosphere. (Note that in a related study, discussed in Central Region Technical Attachment 86-23, Hirt documented several cases of spurious low level cyclonic development by the NGM which was apparently related to model generated precipitation bulls-eyes.) Additional research is necessary to examine other characteristics of the NGM 4LI predictions, such as identification of possible systematic errors, geographic biases, and accuracy of stability tendencies.