U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

September 30, 1977

W111x1/AFS

TO: Recipients of Technical Procedures Bulletin Series

FROM: Duane S. Cooley Duane S. Cooley
Chief, Technical Procedures Branch, Meteorological Services Division

SUBJECT: Technical Procedures Bulletin No. 218: THE 7L PE MODEL

This is a description of the changes which have been incorporated into the coarse-mesh 6-layer primitive equation model (6L PE) to obtain higher model spatial resolution. This modified version of the 6L PE is referred to as the 7L PE. This change in the NMC operational NWP system is the second phase of the NMC plan (see NMC Office Note 144) to improve the numerical guidance using the IBM 360/195 computer facility of NOAA. The first phase consisted of changes in the LFM system (see TPB 206). The material for this bulletin was prepared by Dr. John A. Brown of the Development Division, NMC. Model changes were incorporated and tested by Dr. John B. Hovermale, Mr. John E. Newell, Dr. John D. Stackpole, Mr. A. J. Desmarais, and members of the Systems Evaluation Branch of the Development Division. Automation Division incorporated the necessary computer changes for operational implementation. The date of implementation of this change will be announced by GENOT.

THE 7L PE MODEL

1. INTRODUCTION

Forecast improvements through numerical weather prediction can be obtained in several ways. Among these are (a) improvements in the accuracy and coverage of the observational network, (b) improvements in methods of analyzing the data into a three-dimensional, time-varying picture of the atmospheric state, and (c) improvements in the numerical accuracy and physical realism of the prediction model. This bulletin addresses the changes in operational forecast accuracy through decreasing numerical errors in the prediction model.

Forecast improvements through enhanced spatial resolution of the prediction model can be obtained with today's observational data base. NMC's Development Division has been designing, constructing, and testing various models for possible operational use on the IBM 360/195 computer facility of NOAA. A phase of this work culminated recently in a test of three models:

(1) a 2° latitude-longitude hemispheric version of Stackpole's 9-layer global model (Stackpole, 1976);

(2) a nested-grid model (NGM), developed under the direction of Dr. Norman Phillips. This model also contains nine sigma layers and a horizontal grid

consisting of a fine mesh nested in a coarser mesh on a polar stereographic projection, true at 60°N. The fine mesh (205 km grid interval at 45°N) covers a rectangular area over North America and adjacent oceans, and the coarse mesh (410 km grid interval at 45°N) extends from the fine mesh grid to the equator;

(3) the 6L PE but with LFM horizontal resolution over the entire hemisphere (190.5 km grid distance in the polar stereographic true at 60°N, or 174 km grid distance at 45°N). This model contains the pressure gradient averaging technique (Brown and Campana, 1977) and is referred to here as the HFM.

These three models were designed to run on the 360/195's, using no more than three times the computer time of the coarse-mesh 6L PE.

2. THE 6-CASE TEST

Six cases were carefully selected for meteorological examples of interest from the 6L PE standpoint. The cases were selected to illustrate 6L PE problems of such things as locked-in error, cyclogenesis, precipitation, and general problems over mountains. A seventh case was selected solely for its unusual cross-contour flow problem.

The three forecast models were run on all six cases using the operational Flattery analyses (TPB 105).

The analyses were interpolated to each forecast model grid, forecasts were made to 84 hours (except to 120 hours on two cases to test numerical stability), and then the forecasts' parameters were interpolated to the present coarse-mesh (65 x 65) 6L PE grid for output purposes.

All forecasts were evaluated both statistically and subjectively. Statistics were obtained by evaluating forecast parameters against the Flattery objective analyses and against radiosonde observations. Each forecast case was evaluated subjectively by five experienced NMC forecasters. The identification of the numerical models for the six cases was withheld from the forecasters until the entire evaluation was completed. They also did not have prior knowledge of the statistical evaluation results.

3. THE 6-CASE TEST RESULTS

The statistical and subjective evaluations are presented in Tables 1 through 8. The statistics which are presented here are for forecasts verified against radiosonde observations, except at 1000 mb the verifications are of the forecasts against the analyses.

Tables 1 and 2 are the statistical evaluations as functions of pressure and forecast hour for the three test models, the operational 6L PE, and persistence (PER). Values are for the 24-, 48-, and 84-hour forecasts and have been averaged over the six cases and over the Northern Hemisphere (Table 1) and

North America (Table 2). Table 2 contains the threat scores (Ts_p) and bias for measurable precipitation using 90 United States stations.

Table 3 contains the rankings for each case on a scale from 1 to 5 in order of decreasing skill. The values are averages for the 850-, 500-, and 300-mb levels.

Tables 4 and 5 contain the rankings of the average statistics for all cases for the hemisphere and North America, respectively.

Table 6 is the summary of the objective evaluation over North America from 1000 mb through 300 mb.

From this evaluation, it is evident that the HFM demonstrated a slight and consistent superiority over the NGM except at the 100-mb level. The subjective evaluation results, presented in Tables 7 and 8, also indicate a narrow but consistent margin of the HFM over the NGM. The results for precipitation forecasts are not so clear.

The results of the cross-contour flow case are presented in Figure 1 in Technical Procedures Bulletin No. 219.

The HFM was selected as the candidate for replacing the 6L PE.

4. 7L PE VS. 6L PE

It was evident from the six-case test that the HFM and the 6L PE performed poorly at the 100-mb level. This is attributable to the lack of vertical resolution in the model stratosphere. In order to improve the forecasts at 100 mb the computational cap in the HFM was eliminated and a third forecast layer was added to the stratosphere. This modified version of the HFM is referred to as the 7L PE.

The addition of the third stratospheric layer was accomplished economically by eliminating the layer of constant potential temperature (the "quiet cap" or "thetasphere") that previously perched on top of the six meteorological layers. Where the HFM had two layers between the tropopause and approximately 80 mb, the 7L PE has three layers between the tropopause and 50 mb (exactly). Experiments have shown that the extra layer, plus having the top of the model higher up, has beneficial effects upon the stratospheric region forecasts. The extra layer had no discernible effect upon the troposphere forecasts.

Another change related to the problems in the stratosphere is a modification of the vertical interpolation from the σ-surface to pressure surfaces. This amounts to assuming, in the solution for the hydrostatic equation, that temperature varies linearly with the natural logarithm of pressure, rather than assuming that potential temperature varied linearly with the Exner function, $(\pi = p/1000)^{\kappa}$. Again, this change was directed toward curing stratospheric difficulties; no differences were anticipated (on theoretical grounds) and none observed in the troposphere as a result of making the change. The principal effect of the change in the stratosphere was the substantial reduction of an apparent warm bias in the high level temperature forecasts and a corresponding bias in the geopotential heights. This bias was not in the forecast itself but one introduced by the θ-linear-with-π assumption in the σ to p coordinate transformation.

Thus the 7L PE contains four σ-layers in the troposphere (the bottom one is the 50-mb deep boundary layer) as in the coarse-mesh 6L PE. It differs from the previously operational 6L PE in the following major ways:

(1) The horizontal resolution consists of 62 grid intervals from the pole to the equator (N=62). The coarse mesh 6L PE was N=31. Thus, the new grid distance is 153 km at 30°N, 168 km at 40°N, and 180 km at 50°N. These are one-half those of the old grid. The new horizontal grid array is 129 x 129 rather than 65 x 65.

(2) A third layer has been added to the stratosphere and the computational cap has been removed. Vertical interpolation from σ to p is modified.

(3) The pressure gradient averaging technique is incorporated into the 7L PE to reduce the number of calculations required for a given forecast. Through this technique the time step increment remains 10 minutes. The pressure gradient averaging coefficient (α) and the time damping coefficient (b) as described in TPB 206 are $\alpha = 0.270$ and $b = 0.075$.

(4) Momentum mixing in the dry and moist convective adjustments is removed.

(5) The special finite differencing scheme used for the first hour of the forecast (see TPB 31 and 33) is removed and replaced with a first-forward-then-centered scheme.

(6) A light diffusion term is applied to all forecast parameters to avoid extreme gradients which cannot be properly handled by the horizontal finite differencing scheme. The 6L PE technique had been described in TPB 31 and TPB 33.

(7) Latent heat is distributed equally at the τ and $\tau+1$ time levels, rather than only at $\tau+1$.

The analysis system remains the same; the Flattery spectral technique (TPB 105). The output graphics will continue to be prepared on the 65 x 65 grid, which minimizes computer program changes without significant loss of forecast resolution.

The 7L PE requires about three times more computer time for the forecast than was used by the 6L PE. Thus a 24-hr forecast takes about 36 minutes. The analysis and forecast processing time, which is a substantial part of the total computer time for the OPERATIONAL cycle, will remain essentially unchanged.

5. 7L PE VS. 6L PE COMPARISONS

In Technical Procedures Bulletin No. 219 dated September 29, 1977, Figures 2 to 4 contain examples of the forecast results of the 7L PE and the 6L PE made from identical analyses. These examples were selected from 10 cases chosen for their special meteorological interest. The examples which are shown are presented to give a general idea of the differences which one can anticipate. Smaller differences were observed for the other seasons, especially summer.

Figures 5 and 6 and Table 9 are the 6-case and 10-case test results for the S1 scores as measured against analyses. S_E is the standard error of estimate.

A detailed documentation of the results of the 6-case test and the 10-case test is in preparation at NMC. NMC Office Note 159 is a detailed documentation of the case for 0000 GMT 9 January 1977, including comparisons with other NMC models as well.

The results indicate that the differences which can exist between the 7L PE and the 6L PE are similar to those which existed between the LFM (N=62) and the 6L PE. The major exceptions to this are at the 100-mb level, where the 7L PE should be superior, and in those cases where the initial analyses of the LFM and 6L PE differ significantly.

6. REFERENCES

Brown, J. A. and K. A. Campana, 1977: An economical time-differencing system for numerical weather prediction. (Submitted for publication in the J. Appl. Meteor.)

Stackpole, J. D., 1976: The National Meteorological Center 9-layer global forecast model. Proceedings of the AMS Sixth Conference on Weather Forecasting and Analysis, May 10-14, 1976, Albany, N.Y., pp. 112-116.

Table 1. Average values of objective verification statistics for all cases for four hemispheric forecast models and persistence.

NORTHERN HEMISPHERE 24/48/84 HRS

	9L HEM	NGM	HFM	6L PE	PER
S1					
850	53.2/59.9/71.9	49.7/55.5/66.9	49.4/52.7/62.0	51.9/55.7/79.6	69.2/79.5/84.7
500	45.5/49.4/64.1	44.5/46.0/62.0	43.2/44.3/57.7	47.3/47.8/75.4	60.5/71.7/78.6
300	44.6/49.9/63.3	43.9/48.0/59.4	42.1/46.9/57.2	45.9/51.7/71.2	60.1/71.7/79.7
100	66.1/65.3/73.7	66.1/63.2/68.6	67.1/66.1/70.9	68.5/68.9/80.2	56.5/66.8/79.1
RMSVE (m/s)					
850	6.7/ 7.9/ 9.0	7.1/ 8.2/ 9.7	6.3/ 7.7/ 8.5	6.8/ 8.0/ 9.2	9.4/11.5/11.7
500	8.4/11.2/13.7	8.5/10.5/13.9	7.9/10.1/13.2	8.9/11.1/14.6	14.5/19.4/19.5
300	11.9/15.4/18.4	12.3/14.9/18.9	11.2/14.5/18.2	12.9/15.8/21.0	21.2/27.6/27.4
100	7.5/ 8.7/ 9.8	8.4/10.0/12.9	9.8/10.8/12.3	10.2/11.7/13.2	8.6/12.6/13.1
RMSTE (°C)					
850	3.3/ 4.0/ 5.4	2.9/ 4.3/ 5.5	2.9/ 3.7/ 4.5	2.9/ 3.5/ 5.1	4.5/ 6.0/ 6.9
500	2.2/ 3.1/ 4.2	2.2/ 3.0/ 4.3	2.0/ 2.7/ 3.5	2.2/ 2.9/ 3.9	4.2/ 5.7/ 5.9
300	2.6/ 3.3/ 3.7	2.8/ 3.5/ 3.9	2.3/ 3.1/ 3.7	2.4/ 3.1/ 3.9	3.4/ 4.4/ 4.6
100	2.9/ 3.3/ 4.1	3.2/ 4.1/ 4.9	5.2/ 6.7/ 8.7	4.8/ 5.9/ 5.9	3.0/ 3.8/ 4.2

Table 2. Average values of objective verification statistics for all cases for four hemispheric forecast models and persistence.

NORTH AMERICA 24/48/84 HRS

	9L HEM	NGM	HFM	6L PE	PER
S1					
1000	53.7/66.5/66.3	46.9/56.3/59.0	46.2/54.7/57.1	49.8/59.3/80.7	78.9/96.8/84.3
850	47.9/57.6/67.6	43.4/47.5/57.9	42.8/49.8/57.5	44.8/49.9/72.0	67.6/85.3/90.9
500	33.4/42.1/49.7	31.9/35.4/45.7	31.5/36.5/46.6	35.8/41.1/57.0	55.7/67.7/74.8
300	32.5/38.0/47.8	30.9/34.6/44.6	30.5/34.4/46.5	34.4/39.5/54.9	55.8/67.3/74.6
100	47.1/47.3/58.5	46.5/45.8/55.9	49.1/49.5/56.2	51.5/53.5/67.6	52.6/55.8/70.9
RMSVE (m/s)					
850	7.3/ 9.5/ 8.9	6.7/ 9.2/ 9.6	6.5/ 8.9/ 8.6	6.9/ 9.2/ 9.7	11.5/14.9/13.1
500	8.9/12.5/13.8	8.7/10.5/13.3	8.1/11.1/13.7	9.3/12.0/13.4	18.1/23.9/20.1
300	12.5/15.8/19.3	12.4/15.1/18.5	12.0/15.2/19.9	13.5/16.6/21.8	26.4/33.2/31.8
100	7.0/ 8.4/10.5	9.2/11.6/15.6	9.5/10.7/13.6	9.6/10.8/13.1	9.9/12.8/16.0
RMSTE (°C)					
850	4.1/ 4.9/ 6.4	3.4/ 5.2/ 5.7	3.3/ 4.0/ 4.5	3.2/ 4.4/ 5.6	6.4/ 8.5/ 8.4
500	2.2/ 3.3/ 4.5	2.2/ 3.3/ 5.2	2.0/ 3.0/ 4.2	2.3/ 3.2/ 4.6	4.9/ 6.7/ 7.7
300	2.9/ 3.0/ 3.8	2.8/ 3.2/ 3.9	2.5/ 2.9/ 3.7	2.6/ 2.9/ 3.3	3.7/ 4.5/ 6.5
100	2.8/ 3.4/ 4.5	3.6/ 4.7/ 4.8	5.1/ 6.3/ 8.3	4.6/ 5.2/ 6.7	3.5/ 4.4/ 5.7
Ts_p	40.4/23.7/17.2	36.2/25.3/25.9	41.1/30.9/25.0	46.7/25.1/12.0	
BIAS	80.0/109 /76.0	170 /227 /224	156 /201 /127	128 /149 /81.0	

Table 3. Case-by-case ranking of objective verification statistics for four hemispheric models and persistence average of 850-500-300 mb ranks.

NORTHERN HEMISPHERE 24/48/84 HRS

850-300 MB	9L HEM	NGM	HFM	6L PE	PER
CASE 1	0000 GMT April 18, 1975				
S1	4.0/4.0/3.3	2.0/2.0/2.3	1.3/1.0/1.0	2.3/3.0/3.3	5.0/5.0/5.0
RMSVE	3.0/3.0/2.0	3.3/1.7/2.7	1.0/3.0/1.0	2.7/2.0/4.0	5.0/5.0/5.0
RMSTE	3.7/3.0/3.7	3.0/2.7/3.0	1.0/1.0/1.3	1.7/1.7/1.7	5.0/5.0/5.0
CASE 2	0000 GMT August 23, 1975				
S1	3.0/3.0/3.0	2.3/3.3/2.0	1.3/1.0/1.0	3.0/2.7/4.3	5.0/5.0/4.7
RMSVE	2.7/2.3/1.3	2.0/3.3/2.3	1.3/1.0/2.3	3.0/3.0/4.0	5.0/5.0/5.0
RMSTE	3.7/3.0/1.0	2.7/3.3/3.7	1.0/1.3/2.0	2.0/2.0/4.3	5.0/5.0/4.0
CASE 3	0000 GMT November 24, 1976				
S1	4.0/3.7/ -	2.0/1.3/ -	1.7/3.3/ -	2.0/3.3/ -	5.0/5.0/ -
RMSVE	2.0/2.3/ -	3.3/1.7/ -	1.0/1.0/ -	3.0/3.7/ -	5.0/5.0/ -
RMSTE	2.7/3.3/ -	2.3/3.3/ -	1.3/1.0/ -	2.3/2.3/ -	5.0/5.0/ -
CASE 4	1200 GMT December 8, 1976.				
S1	2.0/4.0/ -	2.0/2.0/ -	1.3/1.0/ -	2.3/3.0/ -	5.0/5.0/ -
RMSVE	1.7/2.7/ -	3.3/3.0/ -	1.0/1.3/ -	3.7/2.7/ -	5.0/5.0/ -
RMSTE	2.0/2.3/ -	3.3/3.7/ -	1.7/1.7/ -	1.3/1.7/ -	5.0/5.0/ -
CASE 5	0000 GMT January 9, 1977				
S1	3.0/3.0/3.0	2.0/1.3/2.0	1.0/1.7/1.0	-	-
RMSVE	2.3/1.0/2.7	2.7/2.7/2.3	1.0/1.3/1.0	-	-
RMSTE	2.7/2.0/2.0	2.0/1.7/2.7	1.0/1.7/1.3	-	-
CASE 6	1200 GMT February 21, 1977				
S1	3.0/3.3/2.0	1.3/2.0/1.7	1.7/1.3/2.0	4.0/2.7/ -	5.0/5.0/4.0
RMSVE	2.0/2.3/1.7	2.0/2.3/3.0	1.3/1.0/1.3	3.7/3.7/ -	5.0/5.0/5.0
RMSTE	3.7/2.3/2.3	2.3/4.0/2.3	1.7/1.3/1.0	1.7/1.7/ -	5.0/5.0/4.0

Table 4. Ranking of average values of objective statistics for all cases for four hemispheric forecast models and persistence.

NORTHERN HEMISPHERE 24/48/84 HRS

	9L HEM	NGM	HFM	6L PE	PER
S1					
850	4/4/3	2/2/2	1/1/1	3/3/4	5/5/5
500	3/4/3	2/2/2	1/1/1	4/3/4	5/5/5
300	3/3/3	2/2/2	1/1/1	4/4/4	5/5/5
100	1/2/3	1/1/1	4/3/2	5/5/5	3/4/4
RMSVE					
850	2/2/2	4/4/4	1/1/1	3/3/3	5/5/5
500	2/4/2	3/2/3	1/1/1	4/3/4	5/5/5
300	2/3/2	3/2/3	1/1/1	4/4/4	5/5/5
100	1/1/1	2/2/3	4/3/2	5/4/5	3/5/4
RMSTE					
850	4/3/3	1/4/4	1/2/1	1/1/2	5/5/5
500	2/4/3	2/3/4	1/1/1	2/2/2	5/5/5
300	3/3/1	4/4/3	1/1/1	2/1/3	5/5/5
100	1/1/1	3/3/3	5/5/5	4/4/4	2/2/2

Table 5. Ranking of average values of objective statistics for all cases for four hemispheric forecast models and persistence.

NORTH AMERICA 24/48/84 HRS

	9L HEM	NGM	HFM	6L PE	PER
S1					
1000	4/4/3	2/2/2	1/1/1	3/3/4	5/5/5
850	4/4/3	2/1/2	1/2/1	3/3/4	5/5/5
500	3/4/3	2/1/1	1/2/2	4/3/4	5/5/5
300	3/3/3	2/2/1	1/1/2	4/4/4	5/5/5
100	2/2/3	1/1/1	3/3/2	4/4/4	5/5/5
RMSVE					
850	4/4/2	2/2/3	1/1/1	3/2/4	5/5/5
500	3/4/4	2/1/1	1/2/3	4/3/2	5/5/5
300	3/3/2	2/1/1	1/2/3	4/4/4	5/5/5
100	1/1/1	2/4/4	3/2/3	4/3/2	5/5/5
RMSTE					
850	4/3/4	3/4/3	2/1/1	1/2/2	5/5/5
500	2/3/2	2/3/4	1/1/1	4/2/3	5/5/5
300	4/3/3	3/4/4	1/1/2	2/1/1	5/5/5
100	1/1/1	3/3/2	5/5/5	4/4/4	2/2/3

Table 6. Objective Evaluation. Average of ranks of statistics, all cases, all times.

1000 - 300 mb

Statistic	9L HEM	NGM	HFM	6L PE	PER
S1	3.05	1.87	1.58	3.20	4.86
RMSVE	2.23	2.34	1.46	3.51	4.82
RMSTE	2.65	2.83	1.46	2.34	4.77
PRECIP (Ts_p and Bias Combined)	2.37	2.91	2.35	2.24	

Table 7. Subjective evaluation of relative ranking of four NMC hemispheric models for six selected forecast cases.

CASE 1 00Z, 18 APRIL 1975

JUROR	MODEL 9LH	NGM	HFM	6LP
HKS	4	2	1	3
JOC	4	2	1	3
HEB	3	2	1	4
RMM	4	3	1	2
DAO	3	2	1	4

CASE 2 00Z, 23 AUGUST 1975

JUROR	9LH	HGM	HFM	6LP
HKS	3.5	2	1	3.5
JOC	4	2	1	3
HEB	4	2	1	3
RMM	4	3	1	2
DAO	4	2	1	3

CASE 3 00Z, 24 NOVEMBER 1976

JUROR	9LH	NGM	HFM	6LP
HKS	4	3	1	2
JOC	4	3	2	1
HEB	3	4	1.5	1.5
RMM	3.5	3.5	1	2
DAO	3.5	3.5	1	2

CASE 4 12Z, 8 DECEMBER 1976

JUROR	9LH	NGM	HFM	6LP
HKS	3	2	1	4
JOC	4	2	1	3
HEB	4	2	1	3
RMM	4	2	1	3
DAO	4	2	1	3

CASE 5 00Z, 9 JANUARY 1977

JUROR	9LH	NGM	HFM	6LP
HKS	4	1	2	3
JOC	4	2	1	3
HEB	4	3	1	2
RMM	4	2	1	3
DAO	4	3	1	2

CASE 6 12Z, FEBRUARY 1977

JUROR	9LH	NGM	HFM	6LP
HKS	4	2	1	3
JOC	4	1	2	3
HEB	3	2	1	4
RMM	4	2	1	3
DAO	4	2	1	3

Table 8. Subjective evaluation. Average of relative ranking of four NMC hemispheric models for all cases, all times, all categories.

JUROR	9L HEM	NGM	HFM	6L PE
HKS	3.8	2.0	1.1	3.7
JOC	4.0	2.0	1.3	3.2
HEB	3.5	2.5	1.1	3.5
RMM	3.9	2.6	1.0	3.0
DAO	3.8	2.4	1.0	3.4
Mean	3.8	2.3	1.1	3.1
	AVERAGE OF RELATIVE RANKING PRECIPITATION ONLY			
HKS	2.8	3.2	2.7	2.7
JOC	2.3	2.9	2.2	1.8
HEB	2.8	2.4	2.3	2.2
RMM	2.3	2.3	2.8	2.7
DAO	1.7	2.8	2.8	2.8
Mean	2.4	2.7	2.6	2.4

Table 9. S1 scores (6-case and 10-case tests) for North America and Europe.

MEAN (STANDARD DEVIATION)

		24-HR	48-HR	72-,84-HR
		(N=30)	(N=32)	(N=14)
1000 mb	6L PE	47.8 (6.6)	61.8 (8.7)	74.5 (9.4)
	7L PE	42.5 (6.8)	54.9 (7.2)	68.0 (9.0)
	DIFF.	+5.3 (4.1)	+6.8 (6.3)	+6.5 (7.8)
		(N=30)	(N=32)	(N=16)
500 mb	6L PE	32.9 (5.1)	43.6 (7.2)	55.4 (10.4)
	7L PE	29.6 (5.1)	38.9 (7.4)	48.8 (7.8)
	DIFF.	+3.4 (2.6)	+4.7 (3.7)	+6.6 (6.8)
		(N=32)	(N=34)	(N=18)
200 mb	6L PE	28.6 (4.8)	39.2 (6.9)	50.8 (8.9)
	7L PE	26.1 (5.5)	34.3 (8.0)	43.8 (9.3)
	DIFF.	+2.5 (2.3)	+4.9 (3.7)	+7.0 (4.3)