TECHNICAL MEMORANDUM

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A standardised verification scheme for local weather forecasts

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1. INTRODUCTION

This paper is concerned with the design of verification procedures that can be used for a wide range of predictands. The requirements which were taken into account may be summarised as follows:

- procedures should be in accordance with WMO recommendations (see (1) and (2)).

- Procedures should be uniform in the sense that they should provide comparable figures for skill. This holds in particular for scores for forecasts of the same predictands at different locations.

- Procedures should provide adequate information for users. In general, users are not interested in skill scores or other sophisticated measures. A verification scheme should provide basic material that can be used for their demands as well.

- Procedures should be as simple as possible. In particular, for the verification of subjective forecasts, the forecasts should be put in a form that is readily usable for most forecasters. In this respect probability forecasts may raise some problems, but experiments have shown that forecasters quickly learn to make reliable probability forecasts (see (3)).

In the following sections, a proposal for such procedures is presented. As ECMWF is particularly interested in the verification of medium range forecasts, Section 2 is devoted to the requirements of this type of forecast. In sections 3 and 4 the parameters and forecast types to be used in a local verification scheme are discussed and defined.

In order to assess the skill of forecasts, unskilled but suitable reference forecasts have to be selected to serve as a standard of comparison. This problem is discussed in Section 5, and a reference selected.

Finally, measures of accuracy, reliability and skill are presented in Section 6. Some suggestions are also made for providing useful information to users of weather forecasts.

2. FORECASTING RANGE AND VERIFYING TIME INTERVALS

Short range weather forecasts have a fairly high resolution in time, with periods of 24 hours, 12 hours or even less. Verification of these forecasts should therefore be carried out against observations taken at specific hours. In verifying medium range forecasts (say, 4 to 7 days ahead), this approach may not be the most adequate. Forecasts for a 12 hour period on the 5th day, for example, may be adversely affected if the timing of weather developments is only 10% wrong. For such forecasts a longer verification period is proposed, extending to 3 days. Since the reliability of the forecasts varies for subsequent forecast runs, it is proposed that the forecasts are expressed in probabilities instead of the categorical statements that are generally used for short range forecasts.

Nevertheless, a short range scheme is inserted in the proposal as well, mainly based on validation periods of 12 hours. This scheme is recommended for at least the first 3 or 4 days. For 5 to 7 days ahead, however, it can be used to visualise quantitatively the deterioration of forecast quality with increasing range. Moreover, when models and methods improve, tools to assess this improvement will be required. If poor forecasts are not verified, future improvements cannot be shown.

3. PREDICTANDS AND THRESHOLDS

The proposed predictands include temperature, wind, precipitation and cloud coverage, but could be extended to other parameters such as the occurrence of fog, thunder, frost, snow, etc.

Except for precipitation forecasts, the daily forecasts refer to a night-time period (18-06 GMT) and a daytime period (06-18 GMT). For precipitation forecasts, a basic 24-hour accumulation period is considered, ranging from 00 to 24 GMT. Medium range forecasts of precipitation for 3-day accumulation periods are also valid from 00 to 24 GMT. A complete list of the predictands defined below is given in Table 1.

3.1 Temperature

Usually forecasts are made for the daily minimum and maximum temperatures. The following practice is adopted for the daily forecasts: maximum temperature in daytime and minimum temperature at night-time.

For the recommended 3-day period in the medium range, forecasts of the average temperature throughout the period can be considered to be more useful. Probability forecasts of the predictand could be made for several thresholds, e.g. much above normal, above normal, below normal, much below normal.

3.2 Wind

In wind forecasts, the wind speed is generally the main feature. Theoretically, verification of the wind vector forecast could be carried out but vector errors are not very informative for the user. Also, since vector verification is quite elaborate, the verification is restricted to wind speed in this proposal.

Users are likely to be interested mainly in the maximum wind speed reached in some period. Therefore, the verification is focused on the maximum of 3-hourly wind observations. This principle holds for daily forecasts and 3-day forecasts as well.

For the 3-day forecasts, thresholds correspond to the Beaufort scale for wind over the sea.

3.3 Precipitation

The amount of precipitation in the observations is often subject to wide variability and so direct comparison of forecast and observed values makes little sense. Therefore it is proposed that predictands are defined by means of events, each representing a certain threshold being exceeded.

- the minimum temperature in °C, as reported in the 06 GMT synop
- the maximum temperature in °C, as reported in the 18 GMT synop
- a 3-day average temperature, at least 5°C above normal
- a 3-day average temperature, at least 2°C above normal
- a 3-day average temperature, at least 2°C below normal
- a 3-day average temperature, at least 5°C below normal

- the maximum of the wind speed in knots, as reported in synops (ff) of 21 (previous day), 00, 03 and 06 GMT
- the maximum of the wind speed in knots, as reported in synops (ff) of 09, 12, 15 and 18 GMT
- a maximum wind speed in 3-hourly synops (ff) in a 3-day period (running from 21 (previous day) until 18 GMT each day) of at least 17 knots (5 Bft, 9 m/s)
- idem, at least 28 knots (7 Bft, 16 m/s)
- idem, at least 41 knots (9 Bft, 23 m/s)

- a 1-day precipitation amount of at least 0.1 mm
- a 1-day precipitation amount of at least 1 mm
- a 1-day precipitation amount of at least 5 mm
- a 3-day precipitation amount of at least 0.1 mm
- a 3-day precipitation amount of at least 1 mm
- a 3-day precipitation amount of at least 5 mm
- a 3-day precipitation amount of at least 10 mm

- the median value of cloud coverage (N) from the synop reports of 21 (previous day), 00 and 03 GMT
- the median value of cloud coverage (N) from the synop reports of 09, 12 and 15 GMT
- the sum of median day values over 3 days amounts at least 10
- the sum of median day values over 3 days amounts at least 20

Table 1: List of defined predictands

The lowest threshold is somewhat arbitrary; very low values of precipitation may be caused by fog, or even dew, and not by real precipitation. Here the value of 0.1 mm is chosen mainly for simplicity.

3.4 Cloud coverage

The verifying value of cloud coverage should be representative of either night or daytime values. Therefore, the median value of 3 contiguous observation hours is taken as the definition of the predictand. In daily forecasts the 06 and 18 GMT observations are not used.

For the forecast covering periods of three days it seems better not to mix daytime and night-time observations. Here only the daytime values are involved in the verification; these are formed by adding the 3 values for daily forecast verification.

3.5 Other elements

In this proposal, no forecasts for other events are explicitly defined. However, forecasts could be made for many meteorological phenomena, preferably in terms of probability, e.g. fog, thunderstorms, hail, snow. Generally, probability forecasts should be used for such predictands.

4. TYPES OF FORECASTS

In principle, forecasts can be of three types: probability forecasts, alternative forecasts and point estimate forecasts.

a) probability forecasts provide a probability figure for an event. Some examples of suitable events are:
   - the occurrence of precipitation
   - a temperature of more than 30°C;

b) alternative forecasts providing a categorical "yes" or "no" for an event;

c) point-estimate forecasts providing an expected value for some parameter, e.g. temperature or windspeed.

Examples of the three type of forecasts are:

Probability forecast: "The probability of frost in the night is 20%"
Alternative forecast: "There will be no frost in the night"
Point-estimate forecast: "The minimum temperature will be about + 2°C".

It should be emphasised that, theoretically, probability forecasts and alternative forecasts are defined for more than one event (see (1)). In this proposal, however, only the simple case of one event (which may occur or not occur) is involved.

Alternative forecasts and point-estimate forecasts together are called categorical forecasts. These forecasts provide no information on the reliability of the prediction that is made.

Subjective forecasts can be presented in a probabilistic form. In general, some experience is required to assess reliable probabilities subjectively, but several experiments have proved that forecasters learn quickly, if provided with sufficient feedback (see (3)). Some requirements should be mentioned here:

- the forecaster should be well aware of the climatological probability of the event that is to be forecast; even better is a conditional probability of the event under the flow pattern that is predicted;

- the forecaster should be regularly confronted with the results of probability forecasts.

Alternative forecasting incurs an important objection: the forecasts give only part of the information to a user. Probability forecasts give the probability of the occurrence of an event (or exceeding of a threshold) that may be of importance for the recipient of the forecast. Each user can compare this probability with a certain critical probability that is derived from his particular decision criterion. From this comparison the user may translate the forecast probability into a yes/no decision. In the case of alternative forecasts, this translation is made by the forecaster, whose critical probability (often given by the climatological frequency, or possibly a fixed percentage) may be quite different from the user's criterion.

Another disadvantage is that the forecaster's judgement can hardly be reconstructed from the forecasts afterwards. This objection is of less importance, if the number of classes is small and the climatological frequencies of the classes are approximately equal.

Point-estimate forecasts have drawbacks too: they lack any indication of the reliability of the forecast concerned. In practice, however, these forecasts may at least may provide information afterwards on the mean reliability of the forecasts. For that purpose, contingency tables or frequencies of errors are useful.

In this proposal, emphasis is laid upon probability forecasts and point-estimate forecasts. However, in some cases alternative forecasting can be carried out instead of probability forecasts. If this is done, it should be kept in mind that an event should be forecast if the forecast probability of the event exceeds the climatological probability.

Probability forecasts should be given in units of 10%. This implies that the probabilities should be rounded to the next multiple of 10%. That is, a forecast value of 0 is given when the probability is estimated below 5%, 10 when between 5 and 15%, and so on up to 100.

4.1 Temperature

In daily forecasts, point-estimates of maximum and minimum temperatures should be forecast. These values should correspond to the median value of the estimated climatological probability distribution.

In 3-day forecasts, probabilities of the average daily temperature should be issued:

a)	much above normal	(5 degrees C or more)
b)	above normal (including a))	(2 degrees C or more)
c)	below normal (including d))	(2 degrees C or more)
d)	much below normal	(5 degrees C or more)

4.2 Wind speed

In daily forecasts a point-estimate value for the maximum value should be forecast, also based on the median of the estimated distribution.

In 3-day forecasts, probabilities of exceeding the following thresholds should be given:

a) 5 Bft, or $ff_{max} < 17$ Kts (9 m/s)
b) 7 Bft, or $ff_{max} < 28$ Kts (16 m/s)
c) 9 Bft, or $ff_{max} < 41$ Kts (23 m/s).

4.3 Precipitation

In daily forecasts a probability of exceeding the following thresholds should be given:

a) $RRR < .1$ mm
b) $RRR < 1$ mm
c) $RRR < 5$ mm.

In 3-day forecasts the forecasting scheme is identical, apart from the addition of a fourth threshold:

d) $RRR < 10$ mm.

4.4 Cloud coverage

In daily forecasts a point-estimate value of N is required.

In 3-day forecasts a probability of exceeding the following thresholds should be issued:

a) $N < 3$
b) $N < 7$.

5. REFERENCE FORECASTS

In order to assess the skill of forecasts, a comparison with some "unskilled" reference forecasting scheme is needed, for example climatology or persistence.

Climatological forecasting involves an estimated probability distribution that is always identical to the climatological frequency distribution. That is, probability forecasts contain climatological frequencies and point-estimate forecasts contain the median of the climatic frequency distribution. In alternative forecasting the reference is built into the definition of skill scores in a different way.

Persistence forecasting is less well-defined. In point-estimate forecasting the last-observed value is considered as the forecast value. In probability forecasting and alternative forecasting the same approach can be taken; that is, the probability of the last observed class is assumed to be 1, the probability of other classes is 0. In practice, a more sophisticated approach is often made by introducing climatological frequencies of tendencies, or (even better) conditional climatological frequencies depending on the last observed value.

For local medium range forecasts climatological reference schemes generally perform much better than persistence. Only in the case of forecasts for the range of 1 day (for temperature 2 days) are persistence forecasts the best for some predictands. For this reason climatological forecasts have been selected as the reference in this proposal. Moreover, this simplifies the verification procedures markedly, since the same reference forecast may be used for all ranges.

Note that:

(a) In the case of point-estimate forecasting a recommendable reference can be constructed by a weighted average of climatological value and persistence forecast value (see (1)). In this proposal, however, a climatological reference is quite sufficient.

(b) Climatological values can be derived from monthly statistics. However, for temperature it is important to work with meaningful figures for the season concerned, which implies the use of 5 or 10-day median (or mean) values.

6. PRESENTATION OF THE RESULTS

For users, the results should be presented in the form of tables; this procedure is considered to be the best presentation of the results.

Probability forecast verification can be presented as follows. For each possible probability (i.e. 0, 10, 20....100%) the following figures are recorded:

a) the frequency of use by the forecaster (or forecasting scheme)

b) the frequency of occurrence of the event in these cases

c) the relative frequency of occurrence (that is, the quotient of b) and a), preferably in %).

The figures c) should correspond to the forecast probabilities. An example is given in Table 2.

Point-estimate forecast verification can be recorded as frequencies of errors (see Table 3). Alternatively, contingency tables can be constructed; for this purpose the predictand should be defined in classes. This approach can also be used for alternative forecasts (see Table 4).

In the annual report of ECMWF on the use and verification of products, it is impossible to display all this material. Therefore, the presentation of results should be restricted to some kernal quantities. In this section, some measures will be presented that may serve this purpose (see also (2)). Some guidelines for practical application are given in ANNEX 1.

FORECAST PROBABILITY	FREQUENCY OF FORECASTS	FREQUENCY OF OCCURRENCE	RELATIVE FREQUENCY OF OCCURRENCE
0%	7	0	0%
10%	41	2	5%
20%	67	12	18%
30%	52	18	35%
40%	31	12	39%
50%	26	15	58%
60%	46	30	65%
70%	40	26	65%
80%	33	21	64%
90%	19	14	74%
100%	3	2	67%
OVERALL	365	151	41%

Table 2: Reliability table for probability forecasts

ERROR (f/cast-obs.)	FREQUENCY OF ERROR	RELATIVE FREQUENCY OF ERROR
+6	17	5%
+5	5	1%
+4	9	2%
+3	34	9%
+2	51	14%
+1	63	17%
0	64	17%
-1	43	12%
-2	35	10%
-3	17	5%
-4	7	2%
-5	6	2%
-6	14	4%
OVERALL	365	

Table 3: Error distribution of point-estimate forecasts

(e.g. maximum temperature)

OBSERVED: / FORECAST:	YES	NO	$\sum$
YES	52 = 58%	37 = 42%	89
NO	24 = 9%	252 = 91%	276
$\sum$	76 = 21%	289 = 79%	365

Table 4: Contingency table of alternative forecasts

Percentages relate to the total amount of forecasts concerned.

6.1 Measures for probability forecasts

Notation

- N = number of forecasts
- n = subscript, referring to a certain forecast
- T = number of possible probabilities (here, T=11)
- t = subscript, referring to a certain probability
- N_t = number of forecast probabilities
- p = forecast probability of occurrence of the event
- ϕ = observation of the event (ϕ=1 if the event occurred, otherwise ϕ=0)
- c = climatological probability of the event
- f = sample frequency of the event

An overbar indicates a sample average:

$$\overline{x_n} = \frac{1}{N} * \sum_{n=1}^{N} x_n$$

Measure of accuracy: the half Brier Score BS

$$BS = \overline{(p_n - \phi_n)^2}$$

Reference accuracy:

$$BS_c = \overline{(c_n - \phi_n)^2}$$

Measure of reliability: the bias-in-the-small REL

$$REL = \frac{1}{N} * \sum_{t=0}^{T} \left(N_t * (p_t - f_t)^2\right)$$

Measure of skill: the Brier skill score SS_{BS}

$$SS_{BS} = 100 * \left(1 - \frac{BS}{BSc}\right)$$

6.2 Measures of point-estimate forecasts

Notation (see also 6.1)

e = forecast value

o = observed value

y = climatological median value

Measure of accuracy: the Mean Absolute Error MAE

$$MAE = \overline{|e_n - o_n|}$$

Reference accuracy

$$MAE_c = \overline{|y_n - o_n|}$$

Measure of reliability: the Mean Error ME

$$ME = \overline{e_n - o_n}$$

Measure of skill:

$$SS_{MAE} = 100 * \left(1 - \frac{MAE}{MAE_c} \right)$$

6.3 Measure for alternative forecasts

NB: This measure is defined here only for the 2-class predictand: the event will occur, or will not occur.

Notation (see also 6.1)

μ = forecast parameter: $\mu=1$ if the event is forecast, otherwise $\mu=0$.

Measure of accuracy: Hit rate HR

$$HR = \overline{\mu_n * \phi_n + (1 - \mu_n) * (1 - \phi_n)}$$

Measure of skill: Performance Index PI

$$PI = \overline{((2\mu_n - 1) * (\phi_n - c_n))} \; / \; \overline{(2c_n \, (1 - c_n))}$$

The denominator has a fixed value for a fixed C_n. It can be evaluated for each month or decade and afterwards averaged over the year.

The numerator can be written as the average of:

$$\left(\mu_n * \phi_n + (1-\mu_n) * (1-\phi_n)\right) - \left(\mu_n * c_n + (1-\mu_n) * (1-c_n)\right)$$

The left hand term equals 1 if $\mu_n = \phi_n$ (a hit), otherwise it equals 0.

The right hand term represents the climatological frequency of the forecast event. So the numerator may be written as:

$$num = \overline{h_n} - \overline{g_n}$$

where: $h_n = 1$ if $\mu_n = \phi_n$, otherwise $h_n = 0$

$g_n = c_n$ if $\mu_n = 1$, otherwise $g_n = 1 - c_n$

$\overline{h_n}$ = HR, the hit rate.

REFERENCES

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WMO PSMP Report No. 15, Geneva, Switzerland

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Monthly Weather Review, Vol. 112, 413-423 pp.

ANNEX 1

Guidelines for practical applications

In this Annex, examples are given of the (manual) collection and processing of verification data.

A centre is assumed to carry out a verification scheme, containing the recommended set of forecasts.

- Temperature (min and max) for 2 to 4 days ahead: direct model output (DMO) from the 00 and 12 GMT prognoses, post-processed product (PPP) forecasts from a statistical model and end products (EP) as issued to users. Further, a 4-6 day average temperature forecast is made, both DMO (alternative forecasts) and EP (probability forecasts).

- Wind speed forecast for 2 to 4 days ahead: DMO and EP.

- Precipitation forecasts for 2 to 4 days ahead, containing probabilities of exceeding the thresholds of 0.1 mm and 5 mm respectively: DMO (alternative forecasts instead of probabilities), PPP (supposed to be available only for the threshold of 0.1 mm) and EP. Furthermore, a 4-6 day accumulated precipitation amount in the same way, with thresholds 1 and 10 mm. PPP is supposed not to be available.

The forecasts are assumed to be made for the central station, except for the wind forecasts, which are made for a coastal station.

The forecasts are supposed to be issued the day after the ECMWF-run; that is, the forecast for the 2nd day is based on the ECMWF 3-day forecast.

In the forms for the daily collection of data, the date refers to the verifying date.

The line "CLIMATOLOGY" contains climatological median values and frequencies that can be filled out in advance. In this example, monthly climate figures are assumed to be used; for temperature, however, 10-day or 5-day median values are preferable. This problem can be dealt with by forecasting temperature anomalies instead of absolute values.

N.B. If climatological median values are not available, then there is no objection to using mean values instead. A rounding of these values to integers will not affect the results seriously.

The other lines have to be filled in from day to day by the forecasters. For reference, the time of preparation is recorded at the right.

In the case of probability forecasts and alternative forecasts, the observation is denoted by 1 if the threshold was exceeded, otherwise by 0. The alternative forecasts are represented by 1 (yes) and 0 (no) respectively.

At the end of each month the results should be processed. For each predictand a table should be constructed as shown in Tables 1.1, 1.2 or 1.3.

In Table 1.1 an example is given of a monthly processing of probability forecasts. For each day and for each forecast the difference between forecast probability and observed value (1 or 0) should be squared and written in this monthly table. Then, in column N_t, the forecast value should be marked. If the observed value is 1, it should also be marked in column $\sum\phi_t$. The rows N and $\sum D$ should be added to the results of the other months in order to get annual figures. The same holds for the scores in the lower part of the table. The latter are to be used for the calculation of the reliability.

In Table 1.2 the results of point-estimate types of forecast are to be recorded. For each day and each forecast the difference E between forecast value and observed value should be recorded, as should both E and $|E|$. Further, in the lower part of the table, the errors should be marked (this procedure provides very useful information for users; for the calculation of the final figures it is not necessary, however).

The rows N, $\sum E$, and $\sum |E|$ should be added to the results of the other months.

Table 1.3 provides an example of the processing of alternative forecast verification data. For each day and each forecast the forecast should be verified as a hit (h=1) or not (h=0). Then the climatological probability of the forecast event (or non-event) should be subtracted. After addition of the appropriate columns, a hit rate and a performance index can be calculated.

N.B. The denomimator of the PI-formula can be calculated once; see the bottom of the table.

The rows N, $\sum h$, and $\sum X$ should be added to the results of the other months, in order to get annual results.

VERIFICATION OF FORECASTS FOR DAY 2, 3, 4

VERIFICATION DAY:

DATE: | 86 | 11 | 23 | (year, month, day)

PREDICTAND:		TN	TX	FD	R0	R5	DAY OF ISSUE
STATION:		05371	05371	05371	05371	05371	
CLIMATOLOGY:		- 4	7	18	.42	.09	
DAY 4	DMO	- 4	8	10	1	1	19/11
	PPP	- 6	6	-	.70	-	
	EP	- 7	7	14	.60	.30	
DAY 3	DMO	- 5	6	9	0	0	20/11
	PPP	- 9	5	-	.40	-	
	EP	- 9	5	15	.40	.10	
Day 2	DMO	- 8	4	8	0	0	21/11
	PPP	-10	3	-	.50	-	
	EP	-11	4	12	.30	.10	
OBSERVATION		-10	4	11	1	0	

VERIFICATION OF FORECASTS FOR DAY 4 THROUGH 6

VERIFICATION PERIOD:

DATES:				THROUGH			
	86	11	21		86	11	23

PREDICTAND:	TA	TB	R1	R9	DAY OF ISSUE
STATION:	05371	05371	05371	05371	
CLIMATOLOGY	.21	.22	.53	.18	
DMO	0	0	1	0	17/11
PPP	-	-	-	-	
EP	.10	.40	.40	.20	
OBSERVATION	0	1	0	0	

OBSERVED VALUES		
1st day	- 0.6	-
2nd day	- 1.9	0.3
3rd day	- 3.2	0.2
total	- 5.7	0.5
average	- 1.9	

norm. + 1

TABLE 1.1:

MONTH: NOV 1986 PROBABILITY FORECAST VERIFICATION

PREDICTAND: R0 STATION: 05371

TABLE OF $D = (p-\phi)^2$

DAY	CLIM	PPP-4	EP-4	PPP-3	EP-3	PPP-2	EP-2
1 2							
22 23 24	.34	.09	.16	.36	.36	.25	.49
30							
N	30	28	28	29	30	29	30
$\sum D$	7.54	6.32	6.15	5.77	6.23	5.57	4.62
BS	0.25	0.23	0.22	0.20	0.21	0.19	0.15

p_t	N_t	$\sum\phi_t$	N_t	$\sum\phi_t$	N_t	$\sum\phi_t$	N_t	$\sum\phi_t$	N_t	$\sum\phi_t$	N_t	$\sum\phi_t$
0			I		etc.							
10			III	I								
20			III	II								
30			III									
40			IIII	I								
50			IIIII									
60			III	II								
70			III	III								
80			II	I								
90			I	I								
100												

TABLE 1.2:

MONTH: NOV 1986 POINT-ESTIMATE FORECAST VERIFICATION

PREDICTAND: TN STATION: 05315

TABLE OF E = (e-o)

DAY	CLIM	DMO-4	PPP-4	EP-4	DMO-3	PPP-3	EP-3	DMO-2	PPP-2	EP-2
1 2										
22 23 24	+6	+6	+4	+3	+5	+1	+1	+2	0	-1
30										

N	30	28	28	29	30	29	30
$\sum E$	-34.3	+45	+32	+23	+ 4	+18	+ 7
ME	- 1.1	+ 1.6	+ 1.1	+ 0.8	+0.1	+0.6	+ 0.2
$\sum \lvert E \rvert$	93.6	92	86	71	59	64	45
MAE	3.1	3.3	3.1	2.4	2.0	2.2	1.5

Frequency of errors:

+4	I	II	etc.
+4	I	III	
+3		IIIII III	
+2	III	I	
+1	I	II	
0	IIIII	IIIII IIII	
-1	III	II	
-2	II	III	
-3	III		
-4	IIII		
-4	IIIII II		

TABLE 1.3:

MONTH: NOV 1986 ALTERNATIVE FORECAST VERIFICATION

PREDICTAND: R0 STATION: 05371

TABLE OF X = h-g

DAY	DMO-4	DMO-3	DMO-2
1	- =	- =	- =
2	- =	- =	- =
22	- =	- =	- =
23	1- .42 = +.58	0- .58 = -.58	0- .58 = -.58
24	- =	- =	- =
29	- =	- =	- =
30	- =	- =	- =
N	28	30	30
$\sum h$	19	21	23
HR	.68	.70	.77
$\sum x$	5.76	6.58	7.23
$\bar{x}$	.21	.22	.24
$PI = \frac{\bar{x}}{2c_n(1-c_c)}$	.63	.66	.72

c_n = .21

$2c_n(1-c_n)$ = .3318