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PRELIMINARY NOTE ON ERRORS IN FORECAST FRONTAL POSITIONS ON 18-HOUR PREBARATICS

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PRELIMINARY NOTE ON ERRORS IN FORECAST FRONTAL POSITIONS ON 18-HOUR PREBARATICS

by C. K. M. DOUGLAS, B.A.

This preliminary note was written late in 1944.

"Prebaratics" or forecast charts of isobars and fronts have been drawn regularly in the Central Forecasting Office and circulated to out-stations in a coded form since February 1942. The word was coined by Mr. E. Gold, who had previously introduced baratics to denote coded isobars and fronts on the current chart. Prebaratics referred to an 18-hour time interval, which was extended to 24 hours on November 15, 1947.

Checking of frontal positions on the prebaratics for 0600 has been carried out since February 1944. Occasionally numerical checking is impossible owing to the introduction of new frontal structures in complex situations, and in such cases a special note is made. The large majority of fronts between 10°W. and 10°E. and between 40°N. and 63°N. have been checked at points about 300 miles apart, with numerical measurements to the nearest 10 miles, and the number of cases is now sufficient to obtain an idea of the magnitude of the errors and their predominant sign. If the movement has been over-estimated in the forecast the error is entered as positive, and if it has been under-estimated it is entered as negative. When the error does not exceed 10–15 miles it is entered as correct.

The following is a summary of results, the mean errors being of course the numerical means, taken regardless of sign.

	WARM FRONT Mean	Number of points				COLD FRONT Mean	Number of points			
	miles	+	0	−	total	miles	+	0	−	total
February ..	97	11	1	11	23	87	19	9	19	47
March ..	80	13	9	28	50	81	27	8	19	54
April ..	62	7	5	14	26	90	19	6	23	48
May ..	75	15	11	32	58	108	31	6	29	66
June ..	95	23	3	31	57	74	20	10	40	70
July ..	80	6	6	17	29	84	35	12	27	74
August ..	100	17	2	11	30	108	28	4	31	63
September ..	113	16	2	14	32	92	29	9	35	73
Whole period	84	108	39	158	305	90	208	64	223	495

	OCCLUSION Mean	Number of points				QUASI-STATIONARY Mean	Number of points	
	miles	+	0	−	total	miles	0	total
February ..	107	25	6	12	43	73	0	3
March ..	78	10	9	12	31	63	3	7
April .	85	35	11	35	81	60	1	6
May ..	80	11	5	13	29	106	1	5
June ..	74	14	7	29	50	110	1	3
July ..	63	10	8	32	50	—	0	0
August ..	64	11	2	20	33	50	0	5
September ..	107	19	1	18	38	—	0	0
Whole period	83	135	49	171	355	67	6	29

The figures show a tendency for an excess of negative errors, i.e. under-estimation of movement, which is slight for cold fronts but appreciable for the others.

The errors have been examined in conjunction with synoptic charts. The most important source of error is development in the synoptic situation leading to geostrophic winds slightly different from those expected. An error of only 5 m.p.h. in the speed throughout the 18-hour time interval leads to an error of 90 miles in the forecast position. The gradient is not always accurately known on the Atlantic, but the main cause of error is development during the period between the current and forecast charts, especially of waves and wedges. The average pressure error on the prebaratics ranges from 2½ mb. at Croydon to 5½ mb. in Iceland, but they must be higher along fronts than in other conditions.

Other sources of error arise from the arbitrary element in the position of diffuse, weak, or complex fronts, from movement in some upper layer determining the movement of the surface front, and from ageostrophic motion in the lower layers. The first two of these factors are closely related, since if there is no definite air-mass boundary low down the frontal position at sea level is likely to be taken as the same as that at 700 mb. or even higher. This happens most often at occlusions, especially in summer, but it is liable to occur also at warm or cold fronts which are weak and degenerate at sea level. A shallow cold layer is quickly warmed from below, and it gains moisture rapidly from the sea or from wet ground. It is fairly obvious that degeneracy of a front at sea level must affect the frontal position chosen by the forecaster for the current chart. So long as a real air-mass discontinuity exists at low levels it is taken as the frontal position even if the rain belt has been sheared forward by the upper wind. This is of course referred to in the descriptive part of the technical bulletins. Wherever there is a forward shear of this sort the front must always be changing its structure.

The figures in the table show that the predominance of negative errors is specially prominent in the case of summer occlusions. If every occlusion on the prebaratics during the period June to August had been advanced by 50 miles the positive and negative errors would have been roughly equalised, and the mean error for the period reduced from 68 to 52 miles. This tendency for summer occlusions to move faster than the air masses low down is worth keeping in mind. The 700-mb. maps should prove useful for this problem.

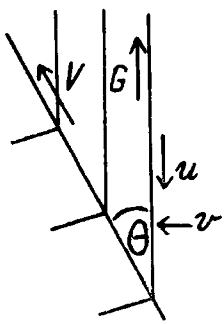
The more general problem of the influence of the upper winds on frontal motion is extremely difficult. It cannot be attacked except in relation to the structure of each individual front. It takes hours to look into all the upper air information now available for a single front, and to extract and note down the relevant facts, so that the amount of research work required for this problem is very large. Forward shear aloft is not necessarily inconsistent with a well marked front low down, even a cold front. If the cold air has subsided stability is maintained in spite of over-running aloft. Squalls descending from high up form a special category of upper cold fronts extending downwards. Squalls from above 5,000 ft. are largely limited to thunderstorms terminating hot spells in summer, but from about 4,000 ft. they are more frequent, and this may give a speed slightly faster than that of the general motion at 2,000 ft. The warm air is of course forced up and replaced by the descending air.

The errors in the forecast positions of warm fronts are due to a greater variety of causes than those of summer occlusions. The monthly distribution of signs is rather irregular, the negative excess being high in March but absent in August and September. The negative errors in March were due to deepening depressions far to northward. On the whole it pays to be bold in deepening well authenticated depressions with warm sectors, especially in the higher latitudes.

The cold front may travel faster than expected owing to the deepening of a depression or to the intensification of a wedge behind the front. Though the possibility of such developments can be foreseen there is no means of definite and accurate prediction. Owing to considerations of this type, the tendency for an excess of negative errors for all types of front cannot be wholly eliminated at present.

We have seen that some fronts have a speed faster than that of the component of geostrophic wind at right angles to them owing to a thermal wind blowing forward aloft. In such cases there is usually mixing and smoothing of the front, though in unstable conditions squalls may descend from a considerable height. Apart from such upper air effects, the motion of a front is determined by that of the cold air low down, say at 2,000 ft., and if this differs from that deduced from geostrophic motion, then the motion of the cold air is not geostrophic. This is confirmed by upper wind observations. The departures from geostrophic motion are most marked in the case of warm fronts, which move at less than the geostrophic speed, but surface friction introduces a complication, especially at fast-moving fronts over land areas. Just ahead of warm fronts the wind at 950 and 900 mb. is normally backed from the isobars and has a speed below the geostrophic, but these features are much more marked at 950 mb. (about 1,500 ft.) than at 900 mb., even when the cold air still extends above the 900 mb. level. At 950 mb. the wind may be backed 20° from the isobars and have a speed 20 m.p.h. below the geostrophic value. The soundings in the rain areas over England on October 13, 16, 17 and 20, 1944, are quite typical. Surface friction flattens a warm frontal surface near the ground and smooths the front. The amount of retardation depends on what criteria are used to fix its position. Most of the rain and most of the effect of the front on pressure travels with the air above 2,000 ft., but surface wind is much affected by the stability of the surface layers, and the full veer of wind and the rise of temperature and dew point to the warm-sector values are appreciably delayed by friction.

As a rule the ageostrophic motion of a front is from cold to warm. At a warm front it averages 10 to 15 m.p.h. but is somewhat higher over land in winter, and at a slow-moving cold front it averages about 3 m.p.h. At a fast-moving cold front (above 30 m.p.h.) it is small and difficult to detect, but it is sometimes appreciable. The above values are occasionally greatly exceeded, and if the geostrophic wind at right angles to a warm front does not exceed 15 to 20 m.p.h. it may be held up or even pushed back against the gradient. This is liable to happen when there is a very cold and strong SE. to E. current in winter, blowing at an angle with the



isobars. Occasionally the cold current is NE. to N. In the diagram let θ be the angle between the front and the isobars in the cold air, G the geostrophic wind, V the actual wind (say at 2,000 ft.), u and v the components of ageostrophic wind along and across the isobars shown by the arrows. The front is stationary if V is parallel with it, and is retrograde if V has a component towards it. Clearly a small value of θ is essential for retrograde motion, but 20° to 30° is quite possible. If $G = 60$ m.p.h. and $\theta = 20°$ then $G \sin\theta = 20$ m.p.h. Early in January 1940, a front was stationary for 6 hours with a value of $G \sin\theta$ as high as 28 m.p.h., and in the next 24 hours it moved slowly south-west against a geostrophic component ($G \sin\theta$) averaging 15 m.p.h. It was a very pronounced sharp front with isobars as on the diagram, so that the air at 2,000 ft. and above must have kept up with the front. Direct evidence was incomplete, but in time it will be forthcoming even in extreme cases. A stationary front with the value of $G \sin\theta$ of 20 m.p.h., mentioned above, would be less exceptional. Assuming these values of G and θ, and an equality of u and v, then if V is parallel to the front we have $u = v = 16$ m.p.h., $V = 47$ m.p.h. The motion of the front can be expressed in the form $(G - u) \sin\theta - v \cos\theta$.

Much has been written on the relation between the ageostrophic wind and the acceleration, and though the ageostrophic motion of fronts is not yet wholly understood there is no doubt that the acceleration is a very important factor. The ageostrophic motion of a front is from the cold to the warm side when the acceleration of the cold air close to the front has a component parallel to the front with the front on its left. It may be large ahead of the warm front of a deepening or rapidly moving depression. An accurate measurement of the acceleration can only be made from a trajectory based on observations, and it includes both the curvature effect and the acceleration along the trajectory. In certain conditions, notably when the trajectory of the cold air is cyclonically curved, the motion of a cold front is below the geostrophic, but pronounced cases are rare, since most intense depressions are occluded near the centre. Over the southern half of the British Isles (perhaps in the north also) the average motion of a cold front is slightly above the geostrophic value at all seasons. This excess increases southward, partly owing to the decreasing effects of curvature and partly owing to the increasing percentage of cold fronts which are in effect upper fronts.

The isallobaric gradient often gives a fair approximation to the acceleration at low levels, but it is sometimes referred to very loosely. The term " isallobaric push " is liable to be used merely because pressure is falling ahead of a front and rising behind it. Clearly this indicates a movement of the trough of low pressure, but it supplies no dynamical explanation of the ageostrophic motion of a genuine front, which requires an isallobaric gradient within the cold air near the front. If there is a line-squall the motion of the air at the squall head requires special three-dimensional treatment, but in the great majority of cases its motion is the same as that of the general motion of the air mass just behind the front. Rare but important exceptions are liable to occur when heavy rain is producing an expanding pool of cold air, and a special type of isallobaric effect accelerates the squall. On the afternoon of July 12, 1944, after temperatures up to 88°F. in the Midlands, a squall swept up from the Midlands over north-west England on a front perhaps 100 miles wide at a speed substantially greater than the observed wind at any level below 25,000 ft.

The ageostrophic motion of fronts from cold to warm tends to be greater than that deduced from the accelerations, assuming horizontal motion, the discrepancy being occasionally large. From January 26 to 30, 1940 it averaged 17 m.p.h. while the accelerations (assuming horizontal motion) only accounted on the average for 4 m.p.h. (naturally there was no appreciable isallobaric effect on the average of 5 days, but there was some acceleration along the stream-lines). If it were possible to follow the trajectory in three dimensions and calculate the true acceleration of the air mass, the discrepancy would be reduced, but it is probable that the vertical exchange of momentum by turbulence in the zone with strong thermal wind parallel to the front, i.e. associated with the front itself, also comes in. Owing to the earth's rotation this causes an ageostrophic motion from cold to warm at low levels.

The variability of the ageostrophic motion and the lack of an adequate basis for computation presents a forecasting difficulty which is occasionally serious. In certain cases the errors on the prebaratic due to this cause alone may equal the average error of 80–90 miles, and since in such cases there are often large temperature differences and heavy rain or snow and occasionally even glazed frost, they are liable to be important. On the average the errors due to this cause are smaller than the errors arising from the geostrophic wind itself. In summer the thermal wind across the front is also a large source of error.

The practical points which emerge from this discussion are the probable gains from reasonable boldness in deepening warm-sector depressions, and the possibility of an improvement in forecasting the movements of summer fronts, especially occlusions, by greater use of the 700-mb. charts. This problem is not an easy one, and the more general one of using upper winds in relation to all fronts will require prolonged research. The order of magnitude of the errors in forecasting frontal positions will probably be much the same for many years. In terms of timing the error must be of the order of 3 hours on the average for 18-hour time intervals, and fully 5 hours for 30-hour time intervals. In the case of many straightforward fronts the error is much less, and it is to some extent possible to estimate in advance whether large errors are likely or not. In a favourable case one may hope that the error in timing will not appreciably exceed one hour for an 18-hour forecast. Anything less would require good fortune as well as good judgment.

There are many difficult and complex situations in the atmosphere when accurate timing cannot be expected. When forecasts extending to 30 to 36 hours from the time of the chart are again issued to the general public, expressions such as " perhaps rain later " cannot always be avoided. Most people would rather carry an umbrella or waterproof unnecessarily than risk being soaked on the way home. Ability to pick out the more doubtful from the less doubtful cases is part of the art of forecasting.

Addendum, 1947

ERRORS IN FRONTAL POSITIONS

	WARM FRONT				COLD FRONT				OCCLUSION			
	Mean	Number of points			Mean	Number of points			Mean	Number of points		
	miles	+	0	−	miles	+	0	−	miles	+	0	−
1944												
January ..	52	16	11	17	80	22	16	26	62	1	4	10
February ..	97	11	1	11	87	19	9	19	107	25	6	12
March	80	13	9	28	81	27	8	19	78	10	9	12
April	62	7	5	14	90	19	6	23	85	35	11	35
May	75	15	11	32	108	31	6	29	80	11	5	13
June	95	23	3	31	79	20	10	40	74	14	7	29
July	80	6	6	17	84	35	12	27	63	10	8	37
August ..	100	17	2	11	108	28	4	31	64	11	2	20
September ..	113	16	2	14	92	29	9	35	107	19	1	18
October ..	90	12	6	12	104	16	10	31	95	25	5	34
November ..	89	25	6	15	61	20	8	24	90	27	5	17
December ..	119	8	0	11	108	26	2	27	84	22	4	28
Weighted mean	84	—	—	—	90	—	—	—	84	—	—	—
Total points ..	—	169	62	213	—	292	100	331	—	210	67	265
1945												
January ..	61	12	8	28	89	17	7	20	61	14	7	11
February ..	100	15	3	32	82	21	6	26	99	16	6	20
March	85	24	5	29	89	12	6	26	52	10	7	11
April	63	7	7	19	91	22	5	33	109	14	2	18
May	94	4	3	20	76	15	8	21	49	10	8	23
June	80	9	3	14	78	20	10	34	73	21	12	15
July	71	18	5	16	75	25	8	40	93	8	12	3
August ..	80	22	5	20	87	18	11	34	59	16	8	20
September ..	63	12	11	18	102	23	4	33	49	19	11	29
October ..	70	14	5	20	102	18	12	49	73	4	2	7
November ..	113	8	0	10	105	7	5	23	96	2	1	13
December ..	97	15	3	16	92	9	2	32	101	40	11	31
Weighted mean	80	—	—	—	89	—	—	—	76	—	—	—
Total points ..	—	160	58	242	—	207	84	371	—	174	87	201
1946												
January ..	71	21	2	9	100	13	6	36	94	13	1	25
February ..	97	11	1	1	87	19	9	19	107	25	6	12
March	80	13	9	28	81	27	8	19	78	31	9	12
April	62	7	5	14	90	19	6	23	85	35	11	35
May	75	15	11	32	108	31	6	29	80	11	5	13
June	93	23	3	31	74	20	10	40	74	14	7	29
July	80	6	6	17	84	35	12	27	62	10	8	32
August ..	100	17	2	11	108	28	4	31	64	11	2	20
September ..	113	16	2	14	92	29	9	35	107	19	1	18
October ..	89	10	3	14	88	14	10	35	75	11	9	32
Weighted mean	86	—	—	—	91	—	—	—	83	—	—	—
Total points ..	—	139	44	171	—	235	80	294	—	180	59	228

Quasi-stationary fronts:
- 1944, 33 points, mean 75.
- 1945, 83 points, mean 52.
- 1946, 25 points, mean 83.

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