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ESTIMATION OF THE STRENGTH OF THE SURFACE WIND FROM 10-LEVEL MODEL FORECAST DATA

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1. Introduction

One of the important factors in forecasting the height of waves and of the swell at sea is the forecast of surface wind; additionally the forecast of swell depends on the recent past surface winds. From these wind estimates the state of the sea is calculated using empirical or theoretical relationships. Surface wind forecasts are also of some importance in the prediction of storm surges. For use in numerical schemes for forecasting waves and swell it is desirable to use surface winds derived from the 10-level model meteorological forecasts and the purpose of the work described here was to determine the most reliable method of deriving surface winds from the available forecast data.

It was known that the properties of the numerical forecasts are not constant throughout the forecast period. For example the mean square wind speed at 1000 mb decreases rapidly during the early stages of the numerical forecast, the cause being the absence of friction in the initialisation scheme for the model which leads to high initial 1000 mb winds. These are reduced by the effects of friction as the forecast proceeds. It was necessary therefore that any scheme for deriving surface wind forecasts from a sequence of both initialised and forecast fields should be formulated to remove any systematic differences between the meteorological forecast fields.

2. A comparison of various methods of surface wind estimation.

For the purposes of the present work a sequence of initialised and forecast fields from the rectangle version of the 10-level model were used covering the period 28 March 1976 to 12 April 1976. The data were used to derive surface winds using various schemes and the winds were then interpolated to the positions Ocean Weather Stations C, L, M and R. The derived surface winds were then compared with the observed surface winds obtained from the Daily Weather Report.

In the present work the strength of the surface wind was investigated although some of the schemes examined can be used to provide an estimate of the direction ofthe surface wind. A longer term project would be to examine both the wind speed and direction and to obtain vector correlations between the estimated and observed surface winds.

The simplest estimate of the surface wind can be obtained using the 1000 mb winds directly and in fig 1a the correlation between the strength of the 1000 mb wind obtained from initialised fields and the observed wind is shown. The bias towards overestimation of the surface winds can be seen and there is a low correlation between the estimated and observed winds reflecting the deficiencies in the numerical analyses. The winds are not analysed directly but are derived from the analysed height fields so that it would be expected that there would be a high correlation between the 1000 mb winds and geostrophic winds derived from pressure fields which are derived from the initialised height fields. This high correlation is shown in fig 1b and the correlation between the geostrophic wind speed and the observed wind speed is shown in fig 1c. The geostrophic winds are rather greater than the 1000 mb winds but they are rather better correlated with the observations than are the 1000 mb winds. It was decided to use the geostrophic wind in various empirical schemes for deriving the surface wind from the geostrophic wind.

It was suggested by Gordon (1952) that the ratio between the surface wind and the geostrophic wind was a constant which depends on latitude and that the angle between the two wind directions was also latitude dependent. Surface winds were calculated using the equation

$$v_s = d_G v_g$$

where v_s is the magnitude of the surface wind and v_g the magnitude of the geostrophic wind and the values of d_G for the four ship positions are given in the table:

Ship	C	L	M	R
d_G	0.64	0.60	0.58	0.68

The results obtained using this scheme are shown in fig 2(a) where it can be seen that although the magnitude of the mean difference between the derived and observed winds is reduced the correlation is lower than for the unmodified geostrophic winds. Similar conclusions were drawn from the results of a scheme of Aagaard (1969) who proposed a factor d for Ocean Weather Station M which was seasonally dependent and for which the value 0.955 was used in the present calculations. It would appear that some more complicated relationship between the geostrophic and surface winds should be used if a useful improvement in the correlation between the estimated and observed surface winds is to be obtained.

Matsumoto and Yamashita (1968) and Hasse and Wagner (1971) examined the correlation of the geostrophic wind and the observed surface winds for various locations and in various classes of stability as determined by the air sea temperature difference.

From North Sea observations Matsumoto and Yomashita derived the equation

$$v_s = d_M v_g$$

where d depends on the air-sea temperature difference $(T_A - T_W)$, the relationship being given by

$$d_M = 0.62 - 0.02\,(T_A - T_W)$$

and it can be seen that for small air-sea temperature differences the relationship is similar to that of Gordon (1952). More complicated relationships were obtained by Hasse and Wagner who suggested that

$$v_s = d_H v_g + \alpha_H$$

Various relationships were proposed, in some of which d_H and α_H were latitude dependent and α_H was stability dependent. The most complicated form was used in the present calculations with the values of d_H and α_H in the table:

Ship	C	L	M	R
d_H	0.555	0.575	0.610	0.525
α_H for $(T_A - T_W) < -1.45$	3.0	2.9	2.65	3.2
α_H for $-1.45 \leq (T_A - T_W) < 0.75$	2.45	2.4	2.2	2.6
α_H for $0.75 \leq (T_A - T_W)$	1.5	1.45	1.35	1.6

The results obtained when these two schemes were applied to the present data are shown in Figs 2(b) and 2(c) where it can be seen that the latitude dependent effects incorporated into Hasse and Wagner's scheme are very important. The use of Hasse and Wagner's scheme gives a significant reduction in the mean difference between the estimated and observed winds compared with the use of the geostrophic estimate with only a small reduction in the correlation coefficient.

Several other methods were considered for the estimation of the surface wind from the geostrophic wind but none of those tested produced results which were better than those of Hasse and Wagner (1971). It was therefore decided to examine a method of estimating the surface wind from the 900 mb wind to determine whether this could improve the accuracy of the surface wind determination. Findlater et al (1966) described an extensive investigation of the correlation between the 900 mb wind and the observed surface winds and their relationships were used in an approximate form by Zobel and Dixon (1970) in an operational scheme for forecasting wave height. The work of Findlater et al suggested that if v_9 is the magnitude of the 900 mb wind

$$v_s = \alpha_F v_9$$

where α_F is dependent on the atmospheric stability as represented by the lapse rate and also depends on the wind speed. Zobel and Dixon assumed a lapse rate of 1.8°C per 1000 ft and incorporated the wind speed dependence of α_F on V_9 in the equation

$$\alpha_F = 1.0055 - 0.0101 V_9 + 0.000075 V_9^2$$

In their use of this equation Zobel and Dixon assumed that the 900 mb wind could be equated to the surface geostrophic wind since 900 mb wind analyses were not available but in the present work the equation has been applied to the initialised field of the 900 mb wind. The results are shown in fig 2d where it can be seen that the resultant derived surface winds are a much better estimate, both in terms of the mean difference and of the correlation coefficient than the winds derived from the initialised geostrophic winds.

It has been noted earlier that there are significant differences between the characteristics of the initialised and forecast fields so that it is desirable to examine the use of the various schemes for deriving surface winds from forecast rather than from initialised fields. A problem then arises because of the contamination of the correlation between forecast and observed surface winds which arise not from errors in the method of derivation of the surface wind but from errors in the forecast fields. It was decided therefore to examine the 12 hr forecasts produced by the Rectangle version of the 10-level model since by this stage the forecast behaviour has almost reached equilibrium but the forecast errors are not, in general, too large.

Calculations were carried out using the various schemes described earlier to calculate the surface winds from the 12 hr forecast fields and these were compared with the verifying weather ship wind observations. With forecast fields the method of Zobel and Dixon (1970) was not as successful as it was with the initialised fields, reflecting the errors of the 900 mb wind forecasts; the results are shown in fig 3(a). Compared with these results, methods based on the 1000 mb level forecast data were more successful with again the geostrophic wind at the surface being a better estimate of the forecast surface wind than the direct use of the 1000 mb wind the results being shown in figs 3(b) and 3(c). With the forecast data the best method of improving upon the geostrophic estimate was the method of Hasse and Wagner (1971) with latitude dependent constants, see fig 3(d). There was a tendency to underestimate the surface wind with this method, as there was with the same method used on initialised data, but the correlation between the forecast estimate of the surface wind speed and the observed wind speed was high. There was a tendency using all of the schemes with forecast data to predict rather lower wind speeds than were predicted from initialised fields and and this reflects the systematic differences between forecast and initialised fields. However it would appear that even with these systematic differences the forecast errors are not large compared with errors in the forecast at slightly higher levels.

3. Discussion and conclusions

The results presented here which, it must be remembered, were obtained from a very limited data sample suggest that the scheme of Zobel and Dixon (1970) for deriving the surface wind speed from the 900 mb wind speed is superior to other schemes for deriving the surface wind from the initialised fields for the Rectangle version of the 10-level model. There are however systematic differences between the characteristics of the initialised and forecast fields and the best method of deriving the surface wind from forecast fields is to modify the forecast surface geostrophic wind in the way suggested by Hasse and Wagner (1971). This formulation has been used with numerical model forecast fields in attempts to predict storm surges by Flather and Davies (1976). Some decrease in the accuracy of surface wind analyses would result however if the same formulation was used with initialised meteorological fields.

This preliminary study has concentrated on the estimation of wind speed; there is scope for investigation of the estimation of the direction of the surface wind as well as the extension of the present work to more extended periods. The maximum observed wind in the period covered by the present study was less than 50 kt and there may be appreciable errors in the schemes' prediction of stronger surface winds. The results of the present study however suggest ways of deriving a surface wind from the output of the 10-level model which would be of use pending any more detailed study.

References

Aagaard, K (1969) 'Relationship between geostrophic and surface winds at weather ship 'M''. J.Geophys.Res., 74,pp3440-3442.

Findlater, J, Harrower, T N S, Howkins, G A and Wright H L (1966) 'Surface and 900 mb wind relationships'. Sci. Paper 23. Meteorological Office, London. 41pp

Flather, R A and Davis A M (1976) 'Note on a preliminary scheme for storm surge prediction using numerical models'. Quart. J.Roy.Met.Soc.,101.pp.123-132.

Gordon, A H (1952) 'The relation between the mean vector surface wind and the mean vector pressure gradient over the oceans. Geophis. Pura et Applic.21,pp49-51.

Hasse, L and Wagner, V (1971) 'On the relationship between geostrophic and surface wind at sea'. Mon.Weath.Rev.,99,pp255-260.

Matsumoto, T and Yamashita, A (1968) 'The relationship between observed wind and geostrophic wind, or gradient wind, over the North West Pacific Ocean'. J.Met.Res.,20,Japan Met Agency, Tokyo.

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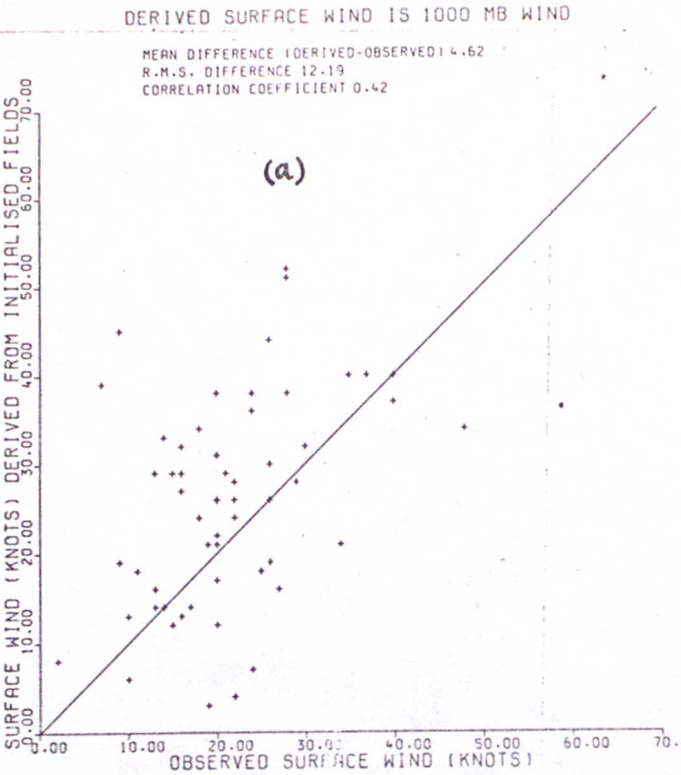
List of Figures.

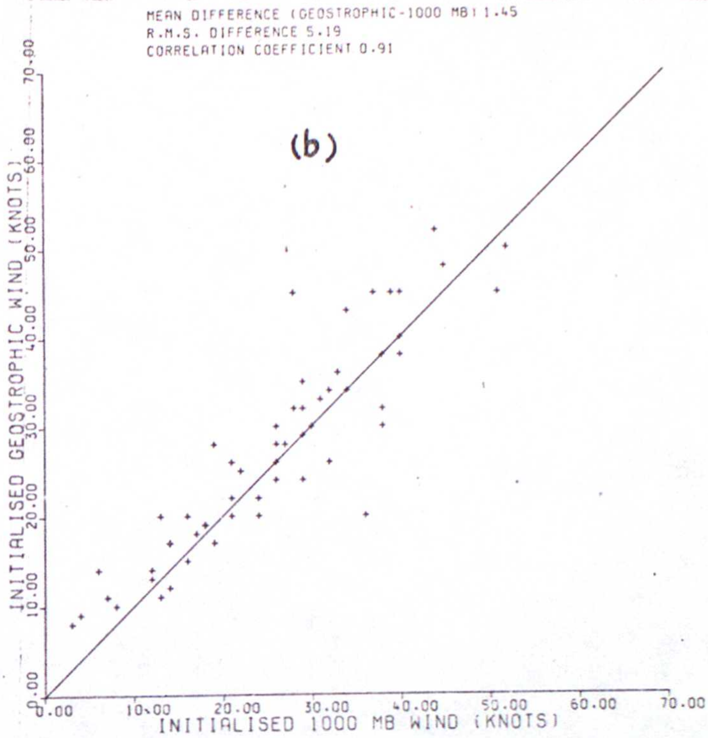
Fig 1 Diagram showing the correlation between (a) observed surface and initialised 1000 mb wind speeds; (b) initialised geostrophic and 1000 mb wind speeds; (c) observed surface and initialised geostrophic wind speeds. The mean and root mean square differences are shown together with the correlation coefficient. For reference the line of perfect correlation is shown.

Fig 2 As fig 1 except that the correlation is between the observed surface wind and that derived from initialised fields by the schemes of (a) Gordon, (b) Matsumoto and Yamashita, (c) Hasse and Wagner using latitude and stability dependent factors and (d) Zobel and Dixon.

Fig 3 As fig 2 except that the correlation is between the winds derived from 12 hr forecast fields and the verifying observed winds. The schemes used are those of (a) Zobel and Dixon, (b) the use of the 1000 mb wind, (d) the use of the geostrophic wind and (d) Hasse and Wagner.

Fig 1


DERIVED SURFACE WIND IS 1000 MB WIND
MEAN DIFFERENCE (DERIVED-OBSERVED) 4.62
R.M.S. DIFFERENCE 12.19
CORRELATION COEFFICIENT 0.42
(a)
SURFACE WIND (KNOTS) DERIVED FROM INITIALISED FIELDS
OBSERVED SURFACE WIND (KNOTS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00


MEAN DIFFERENCE (GEOSTROPHIC-1000 MB) 1.45
R.M.S. DIFFERENCE 5.19
CORRELATION COEFFICIENT 0.91
(b)
INITIALISED GEOSTROPHIC WIND (KNOTS)
INITIALISED 1000 MB WIND (KNOTS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00

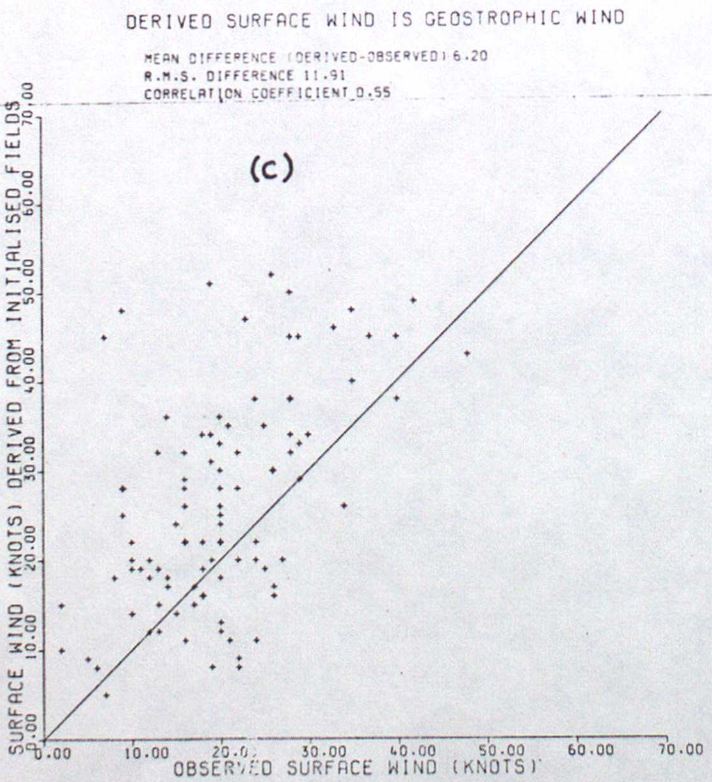

DERIVED SURFACE WIND IS GEOSTROPHIC WIND
MEAN DIFFERENCE (DERIVED-OBSERVED) 6.20
R.M.S. DIFFERENCE 11.91
CORRELATION COEFFICIENT 0.55
(c)
SURFACE WIND (KNOTS) DERIVED FROM INITIALISED FIELDS
OBSERVED SURFACE WIND (KNOTS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00

Fig 2

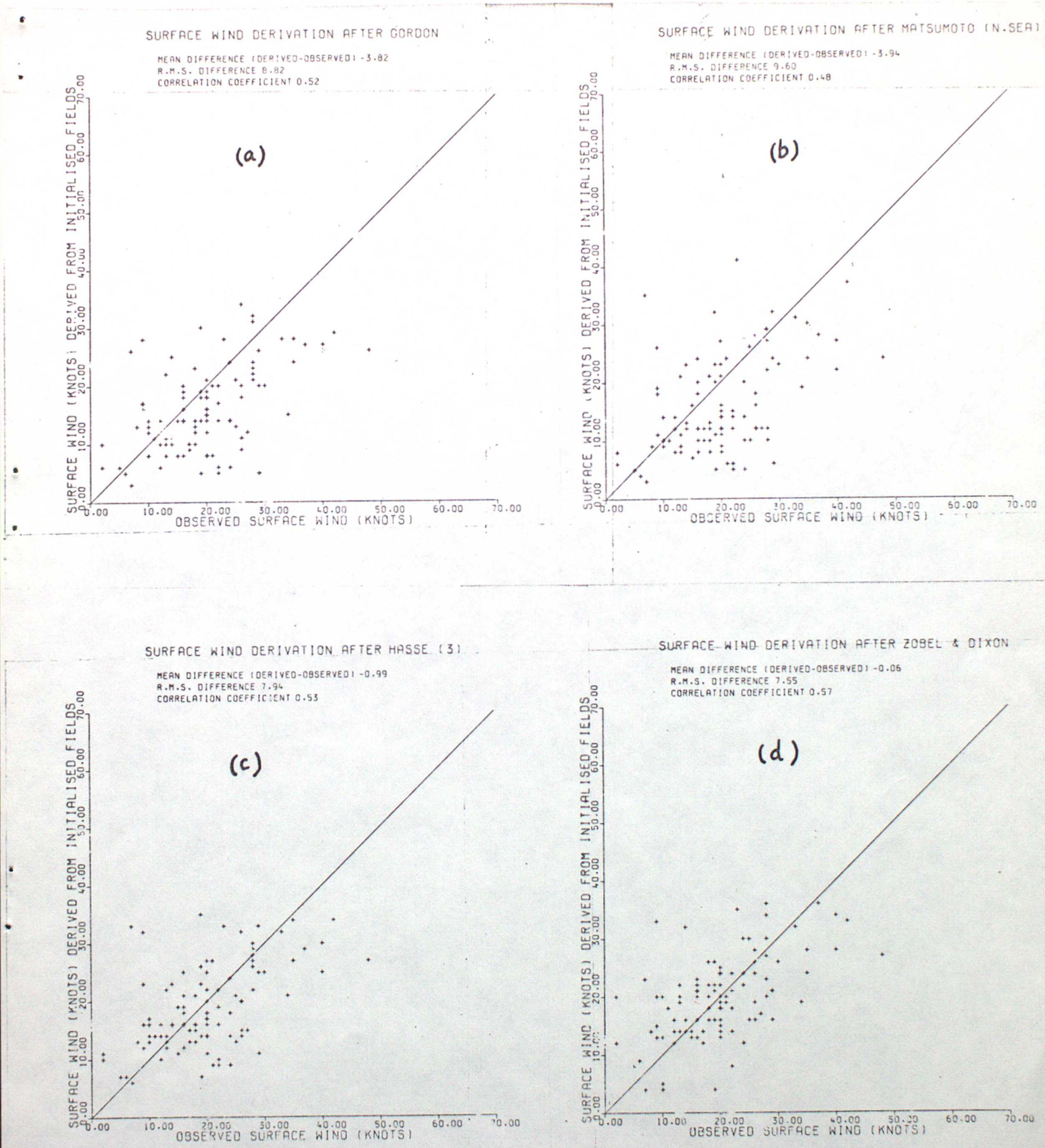
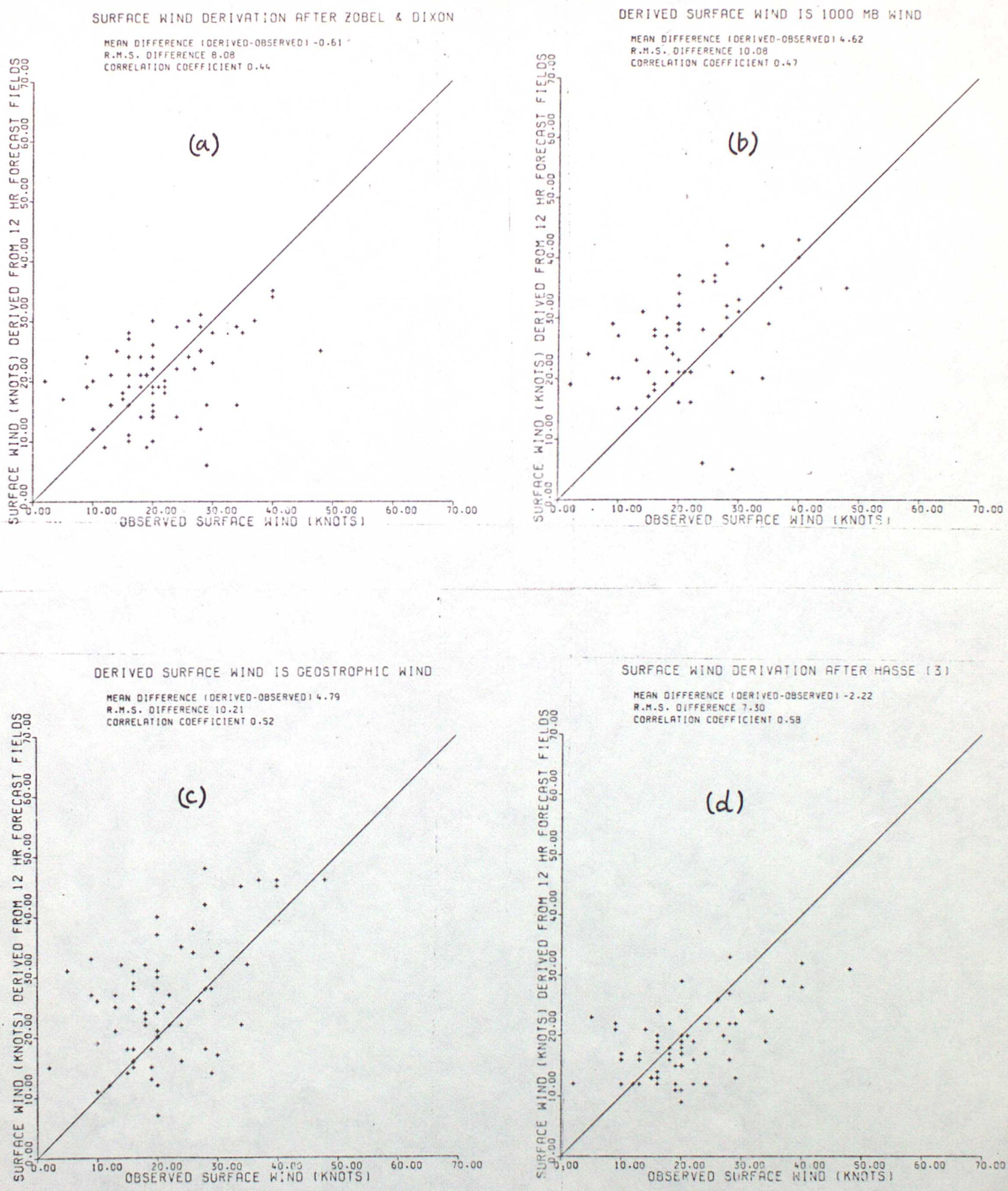

(a)
SURFACE WIND DERIVATION AFTER GORDON
MEAN DIFFERENCE (DERIVED-OBSERVED) -3.82
R.M.S. DIFFERENCE 8.82
CORRELATION COEFFICIENT 0.52
SURFACE WIND (KNOTS) DERIVED FROM INITIALISED FIELDS
OBSERVED SURFACE WIND (KNOTS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
(b)
SURFACE WIND DERIVATION AFTER MATSUMOTO (N.SEA)
MEAN DIFFERENCE (DERIVED-OBSERVED) -3.94
R.M.S. DIFFERENCE 9.60
CORRELATION COEFFICIENT 0.48
(c)
SURFACE WIND DERIVATION AFTER HASSE (3)
MEAN DIFFERENCE (DERIVED-OBSERVED) -0.99
R.M.S. DIFFERENCE 7.94
CORRELATION COEFFICIENT 0.53
(d)
SURFACE WIND DERIVATION AFTER ZOBEL & DIXON
MEAN DIFFERENCE (DERIVED-OBSERVED) -0.06
R.M.S. DIFFERENCE 7.55
CORRELATION COEFFICIENT 0.57

Fig 3


SURFACE WIND DERIVATION AFTER ZOBEL & DIXON
MEAN DIFFERENCE (DERIVED-OBSERVED) -0.61
R.M.S. DIFFERENCE 8.08
CORRELATION COEFFICIENT 0.44
(a)
SURFACE WIND (KNOTS) DERIVED FROM 12 HR FORECAST FIELDS
OBSERVED SURFACE WIND (KNOTS)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
DERIVED SURFACE WIND IS 1000 MB WIND
MEAN DIFFERENCE (DERIVED-OBSERVED) 4.62
R.M.S. DIFFERENCE 10.08
CORRELATION COEFFICIENT 0.47
(b)
DERIVED SURFACE WIND IS GEOSTROPHIC WIND
MEAN DIFFERENCE (DERIVED-OBSERVED) 4.79
R.M.S. DIFFERENCE 10.21
CORRELATION COEFFICIENT 0.52
(c)
SURFACE WIND DERIVATION AFTER HASSE (3)
MEAN DIFFERENCE (DERIVED-OBSERVED) -2.22
R.M.S. DIFFERENCE 7.30
CORRELATION COEFFICIENT 0.58
(d)