# Reduction of the Radius of Probability Circle in Typhoon Track Forecast

**Nobutaka MANNOJI**
*National Typhoon Center, Japan Meteorological Agency*

Abstract

RSMC Tokyo - Typhoon Center of the Japan Meteorological Agency (JMA) presents tropical cyclone track forecasts with probability circles* to indicate uncertainty of the forecasts. Based on the verifications of the forecasts issued from 2001 to 2003, the Typhoon Center reduced the radii of probability circles by 10% on average on 1 June 2004.

* A circular range in which a tropical cyclone is located with a probability of 70% at each forecast time.

## 1. Introduction

In consideration of the significant impact of tropical cyclone (TC) track forecasts upon disaster prevention activities as well as unavoidable error in the forecasts, most of the National Meteorological Services represent track forecast with a range of possible deviation. RSMC Tokyo - Typhoon Center (hereafter referred as Typhoon Center) adopts “probability circle” for track forecast, a circular range in which TC is located with a probability of 70% at each forecast time. Radius of probability circle is determined statistically so that the 70% of the forecasted positions will fall into the circle as shown in Fig.1. Radii of the probability circles are decreased as positional errors of forecast are decreased with technical improvements.

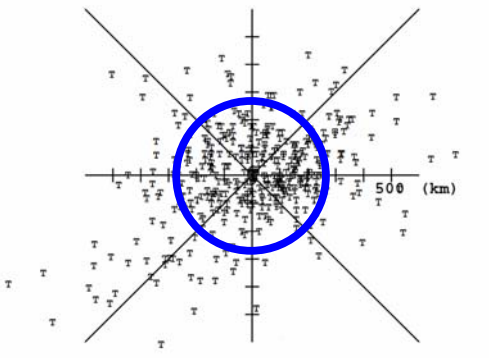


Fig.1 The forecasted positions (indicated by “T”) relative to the analyzed positions (center of the figure), and a circle into which the 70% of the TCs moved.

On 1 June 2004, the Typhoon Center reduced the size of the probability circles in TC track forecasts. Fig.2 shows a comparison of the new probability circles with old ones. Please note that as shown in the map, centers of the probability circles and lines connecting the centers are intentionally not depicted to avoid biased attention of uses on the centers of the circles.

## 2. Verification of Probability Circle

The radii of probability circles are calculated from the statistical relationship between forecast errors and TC movements such as moving speeds and directions at the forecast time for the past several years. The period for the statistics is determined in consideration of fair sampling of forecasts as well as consistency of main properties of the numerical weather prediction (NWP) model used for typhoon forecasting.

Radii of the probability circles being adopted by Typhoon Center until the revision in June 2004 were derived from the statistics for the four years from 1996 to 1999. Table 1 shows the radius of probability circle (nm) used until May 2004 in the upper row in each cell. The radius depends on the forecasted moving speed and direction as well as the forecast time. The moving speeds are divided into 6 ranges (less than 5, 5-10, 10-15, 15-20, 20-30, and more than 30 knots), and the TC movements are classified into three modes ("before recurvature", "during recurvature" and "after recurvature") depending on the forecasted moving directions.

Fig.3 shows the ratios of TCs that actually fell inside the probability circles (hitting ratios) to all TCs from 2000 to 2003. The increase in hitting ratio shown in the figure indicates some improvement in NWP model performances in the prediction of TC tracks during the period. The trend is accordingly presented in the year-year changes of the position errors in Fig.4.

Histograms of position errors of all the forecasts from 2001 to 2003 are shown in Fig.5, in which cumulative ratio (the ratio of the accumulated number of forecasts with errors less than certain distance to the total number of the forecasts) is also presented. The position error of 24 hour forecast corresponding to the cumulative ratio of 70% - 170km (90nm) as

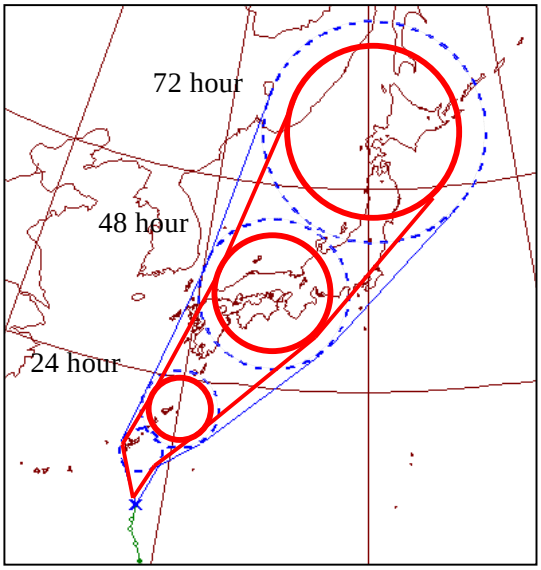


Fig.2 Comparison of the new probability circles with the old ones in the case of a track forecast of TY ETAU (T0310) issued at 12UTC 6 August 2003. The inner solid circles and outer dashed circles indicate new and old probability circles, respectively.

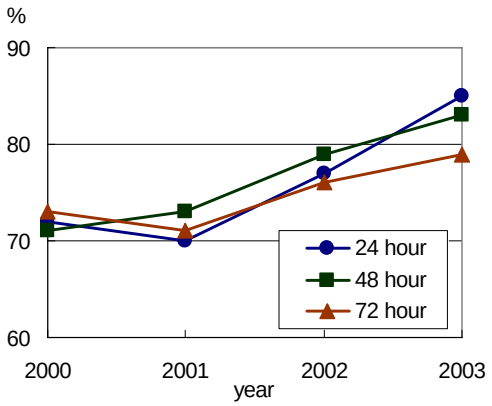


Fig.3 Ratios that a tropical cyclone actually moved into the issued probability circle (hitting ratios) of 24, 48, and 72 hour forecasts from 2000 to 2003. Vertical axis is the ratio, and horizontal axis is year.

compared to the radius of the probability circle for all the cases shown in Table 1 - 100nm suggests the significance of revision of the radius size and accordingly formed a basis to prepare a new table in June 2004.

Fig.5 also shows that the TCs that fell within 15km from the center of the probability circle are less than those that located between 15km and 30km in 24 hour forecast. However, this does not mean a tendency of TCs to deviate from the center of the probability circle. The probability density is calculated and shown in the Appendix 1. Several outliers found in the histogram are worth investigating. The results are described in the Appendix 2.

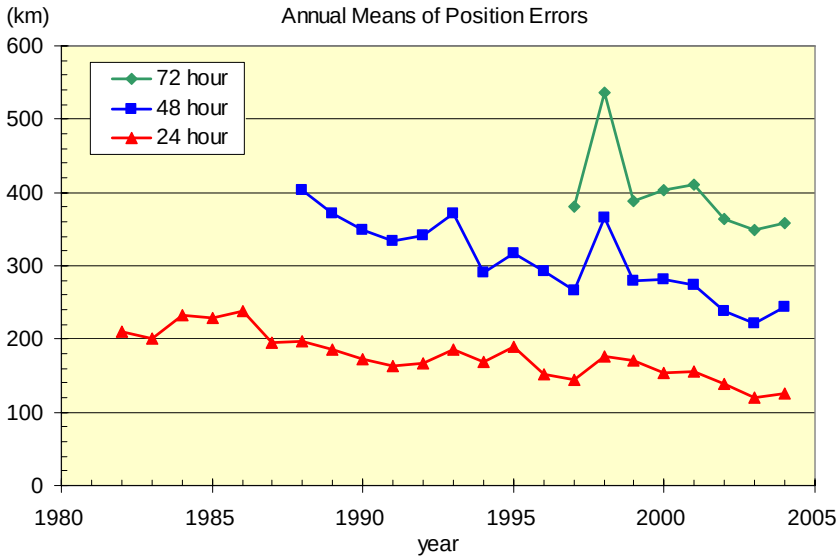


Fig.4 Annual means of position errors of 24, 48 and 72 hour forecasts from 1982 to 2004.

## 3. Estimation of the radius

Table 1 presents the distance (nm) corresponding to cumulative ratio of 70% during 2001 through 2003 in the middle row of each ell in bold, which is an estimated radius for a new table. The number of samples is also listed in the lower row in each cell. It is found that there are some irregularities in the table. For example, tendency of radii for 72 hour forecast after recurvature according to moving speed is different between in the previous table (upper row) and in the new table. The previous radius for 5-10 knots, 260nm, is the least, while the estimated radius for 0-5 knots, 240 nm, is the least. Furthermore, the error of 24 hour forecast with the moving speed less than 15 knots seems to depend on the moving direction, rather than on the moving speed, although 24 hour forecast is not classified with moving direction in the previous table.

Considering the feature mentioned above, we decide that the cases with moving speed less than 15 knots is divided only by the moving directions but not moving speed including 24 hour forecast. As the difference between estimated radii of 15-20 knots and those of

20-30 knots is small, they are unified to one class for 15-30 knots. There is no class considering the moving direction for the moving speed more than 15 knots. Then the class of moving speed, six, is reduced to three (0-15, 15-30, 30- knots). Since the number of sample is small for the moving speed more than 30 knots, the reducing rate of 15-30 knots from the previous table to the new table is applied for the radii more than 30 knots.

The new table is shown in Table 2, which has been used operationally since June 2004. Mean hitting ratios of probability circles in 2004 were 74, 67 and 70% for 24, 48 and 72 hour forecasts, respectively, after the new table of radius of probability circle was applied. The new table can correctly represent the 70% probability. Mean radii of probability circles of issued forecasts in 2004 after using the new table and those in 2003 are listed in Table 3. The table shows that the radii of probability circle are decreased by nearly 15%. The new probability circle assists in more effective disaster prevention activities including the preparedness against TCs with more focus on the target area than before.

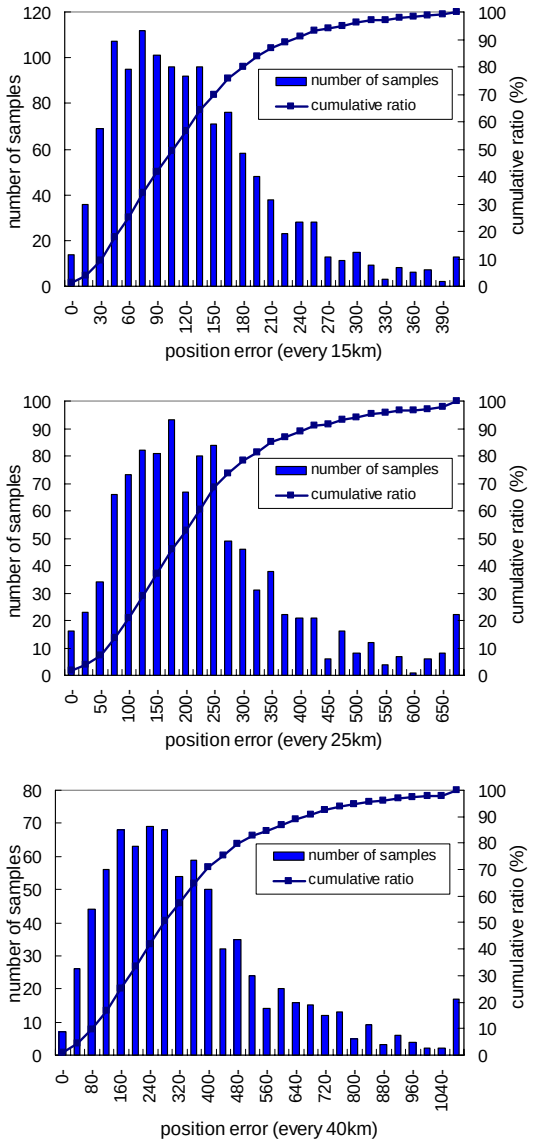


Fig.5 Histogram (bars) and cumulative ratio of position error (polygonal lines) from 2001 to 2003. 24hour forecast (top), 48 hour forecast (middle) and 72 hours forecast (bottom). Histogram is measured with left axis and cumulative ratio is measured with right axis.

## 4. Concluding remarks

The radius of the probability circle was reduced in 2004 based on the statistics from 2001 to 2003. The position errors in 2002 are evidently reduced compared with those in 2001 as shown in Fig.4. The major reason can be attributed to the introduction of the three dimensional data variational method to the global data assimilation of NWP system in autumn 2001. As is shown in the Appendix 2, the most of the outliers are in 2001. Therefore, if the statistics from 2002 to 2004 is used, the radius can be reduced a little bit.

Recent verification shows that the position errors of Tropical Storm (TS) and Strong Tropical Storm (STS) are larger than those of Typhoon (TY). The classification depending on the strength of TC may bring more proper representation of uncertainty.

The present radius is determined statistically. However, the dynamical method can be applied after the Typhoon Ensemble Prediction System (EPS) starts in 2007. The preliminary verification on the TC track forecast using the results of the EPS for medium range forecast shows that position error and spread of forecast have a correlation. The radius of the probability circle can be determined based on the spread derived from EPS in future.

Table 3. Mean radius of probability circle (km) in 2004 after the new radius of probability circle was applied and that in 2003.

| Forecast hour / year | 24 | 48 | 72 |
|---|---|---|---|
| 2003 | 189 | 332 | 502 |
| 2004 | 160 | 281 | 420 |

Table 2 Radius of probability circle (nm) used since June 2004. 24 hour forecast (top), 48 hour forecast (middle) and 72 hour forecast (bottom). Hatched area means the number of sample is smaller than 20.

24 hour forecast

| moving speed / moving direction | ≦ 15kt | 15 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|
| 180-320° | 80 | | | *80* |
| 320-10° | 90 | | | *90* |
| 10-180° | 100 | | | *100* |
| all direction | | 100 | 150 | *90* |

48 hour forecast

| moving speed / moving direction | ≦ 15kt | 15 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|
| 180-320° | 150 | | | *140* |
| 320-10° | 150 | | | *150* |
| 10-180° | 160 | | | *170* |
| all direction | | 170 | 190 | *150* |

72 hour forecast

| moving speed / moving direction | ≦ 15kt | 15 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|
| 180-320° | 220 | | | *220* |
| 320-10° | 220 | | | *220* |
| 10-180° | 290 | | | *290* |
| all direction | | 270 | 400 | *230* |

## Appendix 1 Probability Density of the Forecasted Position of TC Center

Forecast error of the center position has the normal distribution. Fig.A1 shows the histogram of the probability density calculated from the same data used for Fig.5. The probability density is defined as the number of the samples in a certain area divided by the area normalized by the area of the 70% probability circle as well as by the total number. Fig.A1 shows that the probability density is generally higher in the inner area. The probability density function assuming the normal distribution of the forecast error of the TC position, shown in Fig.A1, agrees well with the probability density calculated from actual distribution.

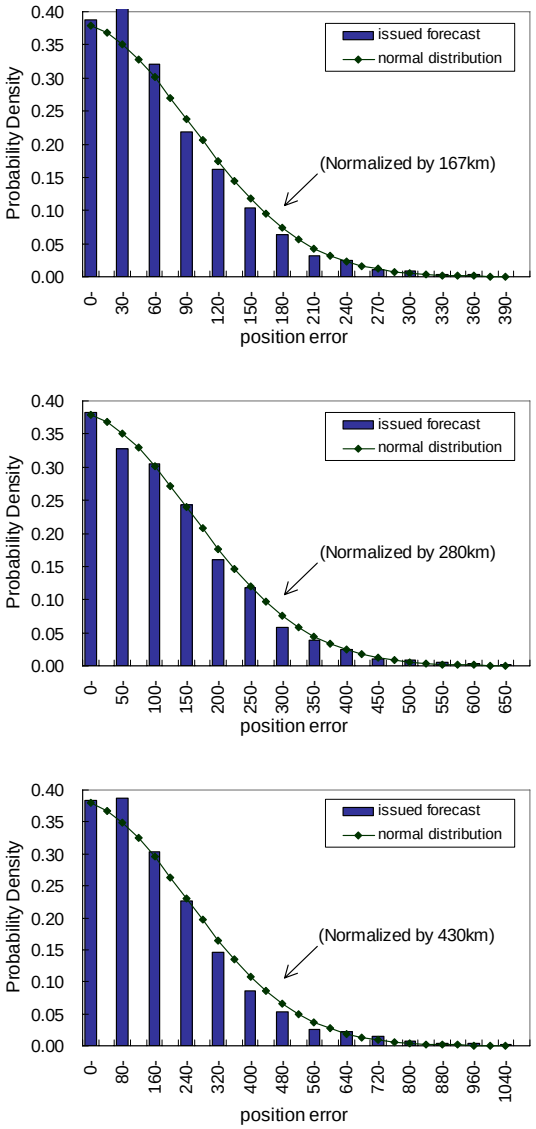


Fig.A1 Probability density of the actual track forecast error from 2001 to 2003 (bars) and probability density function assuming the normal distribution (polygonal lines). 24hour forecast (top), 48 hour forecast (middle) and 72 hours forecast (bottom).

## Appendix 2 Forecast with Relatively Large Error

There are several cases with relatively large error, which are listed in Table A1. The cases with position error of more than 675km and 1080km for 48 hour forecast and 72 hour forecast, respectively, are listed in the table. 26 cases of 10 named tropical cyclones are found. The forecasted moving direction of the most of the cases is north-westward. The features of these cases can be summarized as follows:

(a) TC was forecasted to start to recurve, although it recurved and accelerated (Fig.A2). The cases where acceleration is not adequately forecasted despite of the almost correct track (Fig.A3) are included. (8 TCs, 19 cases)

(b) TC was forecasted to move northward in the very early stage, although it moved westward (Fig.A4). (1 TC, 6 cases)

(c) TC was forecasted to be almost stationary just after it became TS in the South China Sea, although it moved north-eastward (Fig.A5). (1 TC, 1 case)

65% of the cases listed in Table A1 occurred in 2001. It suggests that the recent improvement of NWP system such as data assimilation method, physical parameterization schemes and bogussing technique reduced the large error. It is, however, still difficult to forecast TC track in a very early stage as well as acceleration after the recurvature in 2004.

Table A1 List of the 48 and 72 hour forecasts with relatively large error from 2001 to 2003.

| | Forecast time | | | | Forecast | Error | moving direction | moving speed |
|---|---|---|---|---|---|---|---|---|
| | Year | Month | Day | UTC | Hour | (km) | (degree) | (knots) |
| T0106 KONG-REY | 2001 | 7 | 25 | 12 | 72 | 1094 | 20 | 5 |
| | | 7 | 25 | 18 | 72 | 1160 | 40 | 5 |
| | | 7 | 26 | 12 | 48 | 765 | 40 | 6 |
| T0111 PABUK | 2001 | 8 | 14 | 12 | 48 | 1054 | 10 | 9 |
| | | 8 | 14 | 12 | 72 | 1469 | 360 | 13 |
| | | 8 | 14 | 18 | 48 | 884 | 10 | 10 |
| | | 8 | 14 | 18 | 72 | 1458 | 360 | 15 |
| | | 8 | 15 | 00 | 48 | 961 | 10 | 14 |
| | | 8 | 15 | 00 | 72 | 1544 | 10 | 16 |
| T0120 KROSA | 2001 | 10 | 05 | 18 | 72 | 1214 | 360 | 3 |
| | | 10 | 06 | 00 | 72 | 1448 | 10 | 3 |
| | | 10 | 07 | 00 | 48 | 697 | 30 | 11 |
| T0121 HAIYAN | 2001 | 10 | 15 | 00 | 72 | 1456 | 0 | 0 |
| | | 10 | 15 | 18 | 48 | 691 | 60 | 7 |
| | | 10 | 16 | 00 | 48 | 848 | 50 | 9 |
| T0125 FAXAI | 2001 | 12 | 22 | 18 | 72 | 1162 | 30 | 13 |
| | | 12 | 23 | 12 | 48 | 681 | 20 | 12 |
| T0203 HAGIBIS | 2002 | 5 | 18 | 00 | 72 | 1153 | 30 | 15 |
| T0221 HIGOS | 2002 | 9 | 28 | 18 | 72 | 1097 | 20 | 20 |
| | | 9 | 29 | 00 | 72 | 1105 | 20 | 20 |
| T0225 HAISHEN | 2002 | 11 | 22 | 06 | 48 | 800 | 40 | 7 |
| | | 11 | 22 | 12 | 48 | 774 | 40 | 11 |
| | | 11 | 22 | 18 | 48 | 772 | 40 | 14 |
| T0304 LINFA | 2003 | 5 | 26 | 00 | 72 | 1092 | 0 | 0 |
| T0315 CHOI-WAN | 2003 | 9 | 18 | 00 | 72 | 1278 | 330 | 3 |
| | | 9 | 18 | 12 | 72 | 1096 | 40 | 5 |

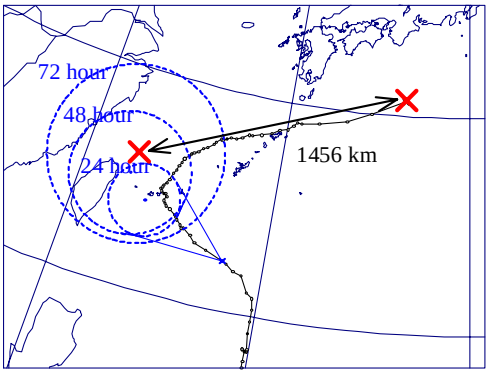


Fig.A2 Track of T0121 HAYAN with forecast at 00UTC 15 Oct. 2001. Probability circles indicate forecast, and solid line indicates analyzed typhoon track. TC was forecasted to start to recurve, although it recurved and accelerated.

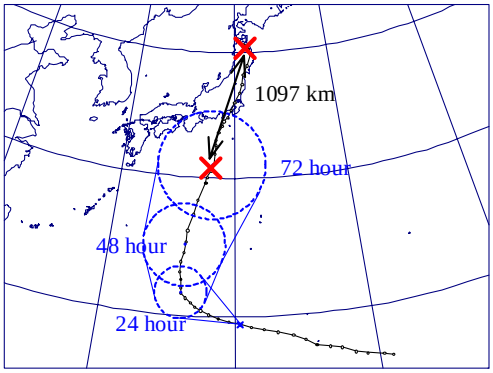


Fig.A3 Track of T0221 HIGOS with forecast at 18UTC 28 Sep. 2002. Acceleration is not adequately forecasted, although the forecasted track is almost the same as the actual one.

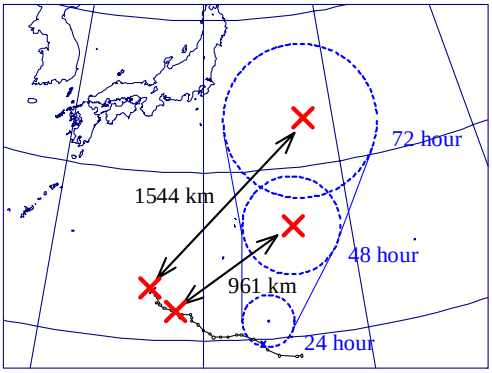


Fig.A4 Track of T0111 PABUK with forecast at 00UTC 15 Aug. 2001. TC was forecasted to move northward in the very early stage, although it moved westward.

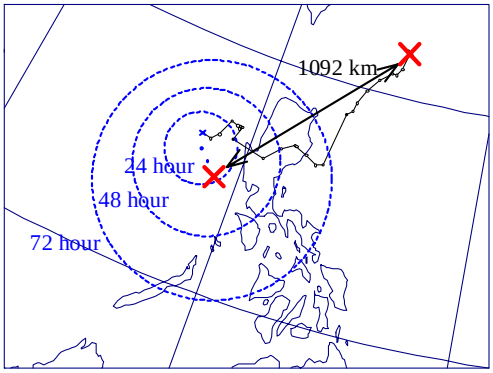


Fig.A5 Track of T0304 LINFA with forecast at 00UTC 26 May 2003. TC was forecasted to be almost stationary just after it became TS in the South China Sea, although it moved north-eastward.

Table 1 Radius of probability circle (nm) used until May 2004 (upper row in each cell), distance (nm) corresponding to cumulative ratio of 70% (middle row in bold in each cell) and number of samples in 2001-2003 (lower row in italic in each cell). 24 hour forecast (top), 48 hour forecast (middle) and 72 hour forecast (bottom). Angle of the moving direction is measured clockwise from north. Moving directions of 180°-320°, 320°-10° and 10°-180° correspond to "before recurvature", "during recurvature" and "after recurvature", respectively. Classification with moving direction was not adopted for the 24 hour forecast until May 2004. Hatched area means the number of sample is smaller than 20, and the distance of 70% cumulative ratio is not listed.

24 hour forecast

| moving direction \ moving speed | | ≦ 5kt | 5 < V ≦ 10kt | 10 < V ≦ 15kt | 15 < V ≦ 20kt | 20 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|---|---|---|---|
| 180°-320° | 1996-99 rad. | | | | | | | |
| | 2001-03 70% | **85** | **85** | **78** | **99** | | | **82** |
| | No. sample | *85* | *296* | *181* | *36* | *2* | *0* | *600* |
| 320°-10° | 1996-99 rad. | | | | | | | |
| | 2001-03 70% | **98** | **77** | **92** | | | | **87** |
| | No. sample | *79* | *165* | *76* | *5* | *2* | *0* | *327* |
| 10°-180° | 1996-99 rad. | | | | | | | |
| | 2001-03 70% | **99** | **87** | **95** | **103** | **105** | | **99** |
| | No. sample | *66* | *96* | *74* | *52* | *51* | *9* | *348* |
| all direction | 1996-99 rad. | 90 | 100 | 110 | 100 | 110 | 150 | 100 |
| | 2001-03 70% | **95** | **84** | **85** | **103** | **105** | | **90** |
| | No. sample | *230* | *557* | *331* | *93* | *55* | *9* | *1275* |

48 hour forecast

| moving direction \ moving speed | | ≦ 5kt | 5 < V ≦ 10kt | 10 < V ≦ 15kt | 15 < V ≦ 20kt | 20 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|---|---|---|---|
| 180°-320° | 1996-99 rad. | 200 | 170 | 160 | | | | |
| | 2001-03 70% | **152** | **148** | **141** | | | | **144** |
| | No. sampl e | *88* | *244* | *147* | *8* | *0* | *0* | *487* |
| 320°-10° | 1996-99 rad. | 150 | 140 | 180 | | | | |
| | 2001-03 70% | **149** | **145** | **148** | | | | **148** |
| | No. sampl e | *74* | *140* | *38* | *4* | *0* | *0* | *256* |
| 10°-180° | 1996-99 rad. | 220 | 200 | 210 | | | | |
| | 2001-03 70% | **146** | **201** | **150** | **175** | **161** | | **171** |
| | No. sampl e | *45* | *74* | *68* | *47* | *36* | *4* | *274* |
| all direction | 1996-99 rad. | 180 | 170 | 180 | 220 | 240 | 250 | 180 |
| | 2001-03 70% | **150** | **154** | **144** | **171** | **161** | | **151** |
| | No. sample | *207* | *458* | *253* | *59* | *36* | *4* | *1017* |

72 hour forecast

| moving direction \ moving speed | | ≦ 5kt | 5 < V ≦ 10kt | 10 < V ≦ 15kt | 15 < V ≦ 20kt | 20 < V ≦ 30kt | 30kt < V | all moving speed |
|---|---|---|---|---|---|---|---|---|
| 180°-320° | 1996-99 rad. | 250 | 240 | 220 | | | | |
| | 2001-03 70% | **242** | **214** | **220** | | | | **222** |
| | No. sampl e | *81* | *183* | *113* | *8* | *1* | *0* | *386* |
| 320°-10° | 1996-99 rad. | 240 | 240 | 200 | | | | |
| | 2001-03 70% | **257** | **205** | **200** | | | | **219** |
| | No. sampl e | *51* | *111* | *29* | *1* | *0* | *0* | *192* |
| 10°-180° | 1996-99 rad. | 350 | 260 | 300 | | | | |
| | 2001-03 70% | **240** | **285** | **290** | **266** | **228** | | **285** |
| | No. sampl e | *26* | *71* | *63* | *32* | *22* | *1* | *215* |
| all direction | 1996-99 rad. | 290 | 250 | 250 | 325 | 350 | 500 | 260 |
| | 2001-03 70% | **244** | **222** | **241** | **265** | **228** | | **232** |
| | No. sample | *158* | *365* | *205* | *41* | *23* | *1* | *793* |