COMPARISON OF VERIFICATION TECHNIQUES, IS IT TIME FOR CONVERGENCE?

DR. DONALD E. HINSMAN
Senior Scientific Officer
Satellite Activities Office

WORLD METEOROLOGICAL ORGANIZATION
41 Avenue Giuseppe-Motta
PO Box 2300
CH-1211 Geneva 2, Switzerland

ABSTRACT

A review of verification techniques from the previous Workshop on Wind Extraction from Operational Meteorological Satellite Data and other sources is conducted. Characteristics of the various techniques are identified including the chosen "ground truth", graphical or tabular presentation, stratification categories and the ability to present a historical perspective.

The approved method for presenting statistical data on wind extraction at meetings of the Co-ordination Group for Meteorological Satellites (CGMS) is discussed. Based on the review of verification techniques and characteristics identified, a proposal is made towards standardizing statistical procedures for CGMS meetings.

1. BACKGROUND

Members of the Co-ordination Group for Meteorological Satellites (CGMS) have been actively involved for many years in the production of cloud track winds (CTW). New channels have become available as well as new computing power and techniques to allow extraction of more accurate wind observations. Since several members are involved, different methods have evolved in determining the error characteristics of the extracted CTWs. In most cases, the CTWs have been unique in that only one satellite operator was producing them. However, instances have occurred where two satellite operator can view the same area simultaneously but with different sensors. Another event has occurred whereby a non-satellite operator is producing CTWs. This paper investigates the various methods utilized in determining the statistical characteristics of the CTWs.

In reviewing several published papers, it was noted that varying statistical methods have been utilized. The method of presentation, either graphical or tabular, had varying degrees of applicability. This paper will first review several papers to show the wide spectrum of available statistical data while attempting to focus on those that maximize the information to the reader. After a short review of selected papers, the current CGMS standard methods will be discussed. Finally, a proposal will be presented that outlines a new hybrid for computing statistical characteristics of CTWs such that its use would maximize the information to all who evaluate them.

2. **DISCUSSION**

A REVIEW OF STATISTICAL ANALYSIS TECHNIQUES AS UTILIZED BY THE CTW COMMUNITY

To limit the scope while ensuring that a representative sample of statistical methods were evaluated, the Proceedings from the Workshop on Wind Extraction from Operational Meteorological Satellite Data 17-19 September 1991 was reviewed.

Statistical Parameters

Herman [1], in displaying error parameters in tabular form, computes average vector differences, standard deviations and root mean square error (RMS). Uchida [2] computed Mean and RMS vector difference but not standard deviations (Table 2). In Figure 7, Uchida displays graphically a time series from January 1988 through July 1991 that shows the trend over that time sequence of monthly means of vector differences between CMWs and rawinsondes. Displayed are mean satellite wind speed, vector difference (RMS) and vector difference (ABS). In Figure 8, Uchida displays a time series of speed bias for the same time period as Figure 7. He noted that in April 1990 a new height assignment table was utilized and that the speed bias has never exceeded 3 m/s since that date. Szantai and Desbois [3] employed a histogram while plotting vector differences between IR and Water Vapor in m/s. Laurent [4] estimated wind quality by computing the Root-Mean-Square (RMS) of the vector difference and the bias which he defined as the mean of the norm difference. Menzel and Merrill [5] compute RMS vector differences in m/s. Thoss [6] assesses the difference between ECMWF[A] 6 hour forecast fields and operational SATOBs for different satellites, levels and areas. In presenting Table 1, she computes vector difference RMS, speed bias and mean absolute directional difference. In Table 3, she computes speed bias as AIREPs minus SATOBs. In Figure 1, one finds density coded scatter plots of 6 hour forecast speed versus observational wind speed from different satellites. Julian [7], in computing collocations of aircraft minus SATOB (speed bias) for different satellites, noted that "aircraft navigation winds are more accurate than radiosonde produced winds." and that "aircraft winds are much more plentiful over the oceans than are radiosondes". In Figure 1 Woick [8], scatter diagrams of speed bias versus mean radiosonde speed for different time periods are shown. In his Figure 2, the different time periods with average values and regression lines are consolidated into one diagram thereby giving a time perspective for changes in speed

[A] European Centre for Medium-Range Weather Forecasts bias. Similar diagrams are also produced for vector difference RMS. While not a strict time series, Figure 2 provides a good depiction of when changes (improvements) occur. Woick [9] presented speed bias versus speed classes in a fashion similar to Julian[7] except that bar graphs are utilized. Strauss [10] presented a time series of speed bias and direction bias for different satellites. Here, he has used the ECMWF 6 hour forecast fields as the baseline. NMC Monthly Quality Monitoring Report [11] contains a section on satellite winds where speed bias and RMS have been computed. Geographical distribution of speed bias are shown in 10 degree latitude/longitude squares.

In summarizing, the eleven papers reviewed employed several different statistical parameters. However, the two most predominant were the RMS vector difference and Bias computed as a simple difference as is shown in Table 1.

Parameter	Used
Average vector difference	4
Vec diff standard deviation	1
Vec diff RMS	7
Speed difference (RMS)	1
Speed difference (ABS)	1
Speed difference (ALG)	1
Bias, mean of the norm difference	1
Bias, simple difference	6
Directional diff, mean abs	1
Directional diff	1

Table 1 Statistical parameters utilized

CGMS PROCEDURES [12]

At its Tenth Session, CGMS agreed on the need for international intercomparison of satellite winds in order to assess the homogeneity and accuracy of this product. Two forms of comparison were proposed and accepted:

a) direct intercomparison between satellite winds in the areas of overlap between adjacent satellites (Type 1);

b) intercomparison with conventional data (Type 2)

Intercomparison between adjacent satellites is achieved by all participants sending wind data on magnetic tape to the USA, where collocations are found and results computed. The comparisons with conventional data are the responsibility of each operator, but results are mailed to the USA for inclusion in a co-ordinated report.

CGMS-X reviewed the results achieved thus far and concluded that wind data from all three agencies (now four) were for the most part compatible. Because of the peculiar characteristics of wind derivation, interpretation of comparison statistics could be made only by taking into account the different data reduction procedures used by the different Agencies.

Annex 9 to the CGMS Consolidated Report[13] describes, in depth, particulars for the international comparison of satellite winds. Both types of comparison should be prepared and distributed semi-annually to the meteorological community. Should a bias appear in the comparisons, it will be a signal to the appropriate operating agency to investigate the cause and a caution to the users to allow for this lack of homogeny in their analysis schemes. Analysis of the statistics by each operating agency will aid in quality control of their observations and provide clues to any problems that may arise.

Type 1 Reports

Type 1 Reports will consist of a set of tables which summarize the differences of wind observations between two agencies in the areas of overlap between adjacent satellites. Comparisons are computed semi-annually during 15 - 30 January and 15 - 30 July. Each magnetic tape will include all winds derived from the common fields of view out to a distance of 60 degrees great circle arc from the satellite sub-point (SSP). The tape format will be that of the International Level II (FGGE) data as described in "Formats for the International Exchange of Level II Data Sets during the FGGE". Annex 9 contains specific criteria to select wind observations. Data will be compared: when their times of observation differ by no more than 3 hours; their location differ by no more than, 2 degrees latitude and 2 degrees longitude in the zone 25 degrees North to 25 degrees South, or 2 degrees latitude and 3 degrees longitude in the region poleward of 25 degrees and; their height fall within the following ranges of pressure:

- surface to 700 mb
- 699 mb to 400 mb
- less than 400 mb

The following statistics will be computed. Computation of speed differences will be carried out to the nearest 0.1 m/s and then rounded to the nearest integral unit for compiling into tables. Direction differences will be computed and summarized in whole degrees.

Magnitude of vector difference, m/s:

$$\Delta V = |V_i - V_j| \qquad (1)$$

Difference of speed, m/s:

$$\Delta s = s_i - s_j \qquad (2)$$

Difference of direction, degrees:

$$\Delta d = d_i - d_j \qquad (3)$$

Difference of u component, positive eastward, m/s:

$$\Delta u = u_i - u_j \quad (4)$$

Difference of v component, positive northward, m/s:

$$\Delta v = v_i - v_j \quad (5)$$

All differences, with the exception of vector magnitudes, include the sign.

Tables of percentage frequencies are assembled in the format of Figure 1. Each tabular entry represents a frequency rounded to the nearest integral percentage, thus the sum of individual entries may differ slightly from 100%. Nine tables are defined as follows:

Table	Parameter summarized	Type of frequency
1	Vector magnitude diff	Individual and cumulative
2	Speed diff	Individual
3	Speed diff	Cumulative
4	Direction diff	Individual
5	Direction diff	Cumulative
6	u-component diff	Individual
7	u-component diff	Cumulative
8	v-component diff	Individual
9	v-component diff	Cumulative

The Tables have class intervals of 2 m/s. Frequencies of differences greater than 25 m/s are summed and shown as a single entry. Tables 4 and 5 use class intervals of 20 degrees. Each table also indicates the mean of the difference computed with and without regard to sign and the Root Mean Square (RMS) of the difference, to the nearest 0.1 m/s.

Type 2 Reports

Type 2 Reports reflect the differences between satellite observed winds and independent observations called "ground truth". The table format and the rules governing their preparation will be, to the extent possible, the same as for Type 1 Reports. The method of selecting ground truth data must not vary from operating agency to operating agency and the distance and height categories must be uniform. Data for each Type 2 Report span the month of July.

Any non-satellite wind observation which the operating agency deems accurate will be a potential ground truth datum. To be used, ground truth and satellite pairs must meet the following conditions: their times of observation differ by no more than 3 hours; their location differ by no more than, 2 degrees latitude and 2 degrees longitude in the zone 25 degrees North to 25 degrees South, or 2 degrees latitude and 3 degrees longitude in the region poleward of 25 degrees and; their heights must fall within the same 500 meter layer. Vertical interpolation of rawinsondes may be used with certain restrictions. Because satellite winds are often measured in regions of significant vertical shear, interpolation of rawinsonde observations must be performed only between significant levels. Non-linear shear is common; therefore, interpolation between standard levels is unsatisfactory. Hence:

- wind observed at standard rawinsonde levels will be used only where the satellite wind is within ± 50 mb for satellite winds at pressures from the surface to 700 mb and within ± 35 mb at pressures lower than 700 mb

- winds interpolated from rawinsondes will be used as ground truth only where significant level data are available.

The equations for computing Type 2 Reports are the same as Type 1 Reports except that the "j" subscript is replaced by a "t" subscript that refers to the ground truth measurement. In a similar fashion, Tables 1 through 9 are also prepared.

Satellite Winds Comparisons, July 1 - July 31 1992

Figures 2, 3 and 4 are Tables 1 from the July 1992 wind comparison as presented to the Twenty-first session of CGMS held in Beijing, China in May 1993. The results of the July 1993 comparison will be presented at CGMS-XXII. Figure 2 is GOES/EAST minus ground truth (RAWIN). Figure 3 is METEOSAT minus ground truth (RAWIN) Figure 4 is GMS minus ground truth (RAWIN). Figure 5 is a graph of Figures 2, 3 and 4 cumulative frequency of the vector magnitude difference.

Although the cumulative frequencies all reach 100%, the data content of Figure 5 is not readily obvious. Perhaps the satellite operators derive additional information from the rate of change of the tangent slope by class interval. It should be noted that the use of cumulative frequency for the official CGMS statistics is one that was not utilized by any of the authors at the First Wind Workshop held in Washington, DC 17-19 September 1991.

NMC produces a monthly compilation of monitoring quality. For purposed of this review, the June 1993 report was utilized. Figures 6 and 7 present the NMC Monitoring Statistics for all SATOBS in June 1993 for the 1000-701 hPa layer. Figure 6 is the RMS (labelled as MPS) of the differences from the assimilating forecast while Figure 7 is the average bias. Although the use of Marsden squares does not allow a detailed study of the difference characteristics, NMC has chosen to use a 6 hour forecast field as ground truth.

ECMWF prepares a quarterly SATOB Data Monitoring Report that has local and restricted distribution. Permission has been obtained to refer to their report. The June-August 1993 ECMWF Report14 presents several figures displaying statistical characteristics of SATOBs received at ECMWF and utilized in their forecast system. For purposes of their report, the first guess was the 6 hour forecast field produced by ECMWF. In this regard, ECMWF has chosen a method similar to NMC except that their own 6 hour forecast was utilized. Figure 8 shows the time series of the speed bias since 1988 of various satellites SATOBs minus the first guess above 400 hPa. Figure 9 displays the mean vector departures of SATOB Winds minus the first guess below 700 hPa. Finally, Figure 10 has three density plots of SATOB wind speed versus first guess wind speed for METEOSAT.

The plots readily show the bias of the observations as well as regression lines for the mean first guess and mean observation.

3. CONCLUSIONS AND RECOMMENDATIONS

The papers reviewed have indicated that there are a range of statistical parameters that one could use in viewing the accuracy of cloud track winds when compared to either other agencies' cloud track winds or to "ground truth". However, the present method of preparing CGMS Type 1 and Type 2 Reports does not appear to be in the mainstream of methods for viewing such. The value of using cumulative frequency should be reviewed. Additionally, authors writing in the area of cloud track winds and decision makers involved in their production may benefit from a more standardized method for presenting the statistical parameters.

The author recommends that CGMS consider replacing the present method for Type 1 and Type 2 Reports. As a possible alternate, a hybrid of several different presentation methods could be used. Desirable characteristics include: a time series, standardized statistical parameters, more uniform "ground truth" observations and graphical displays that show geographical distributions.

As an example, the time series (Figures 7 and 8 in Uchida[2]) or the scatter diagram (Figure 2 in Woick[8]) could be used to show time series. CGMS should give serious consideration to using aircraft winds (Julian[7]) as the primary ground truth or at least computing separate statistics for rawinsondes and aircraft winds for a restricted period of time to determine the viability of such a change. Better graphical displays of statistical information could be obtained through the use of density coded scatter plots (Figure 1 in Thoss[6]) and geographical distributions of cloud track winds minus first guess fields (Figures 1 and 2 in Strauss[10]) and NMC. Finally, root-mean-square difference should be defined and utilized as one of the standard computed parameters.

BIBLIOGRAPHIC REFERENCES

1. Herman, L.D., 1991: The Current Stage of Development of a Method of Producing Cloud Motion Vectors at High Latitudes from NOAA Satellite, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

2. Uchida, H., 1991: Height Assignment of GMS High-Level Motion Winds, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

3. Szantai, A., Desbois, M., 1991: Wind Extraction and Validation from the Water Vapor Channel of METEOSAT during the International Cirrus Experiment, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

4. Laurent, H., Wind Extraction from Multiple METEOSAT Channels, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

5. Menzel, W. P. and Merrill, R. T., The NESDIS/CIMSS Winds Algorithm: Current Status and Future Improvements, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

6. Thoss, A., Cloud Motion Winds, Validation and Impact on Numerical Weather Forecasts, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

7. Julian, P., A Comparison of Cloud Motion Vectors and Aircraft Winds, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

8. Woick, H., Verification of Cloud Motion Winds, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

9. Woick, H., Results of a METEOSAT - GOES Wind Intercomparison Campaign in August 1990, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

10. Strauss, B., Monitoring of Cloud-Motion Winds at ECMWF, PROC WORKSHOP ON WIND EXTRACTION, EUM P 10, 17-19 September 1991.

11. NMC MONTHLY QUALITY MONITORING, June 1993, US Dept. of Commerce, NOAA, National Weather Service, NMC, W/NMCx3, WWB Room 301, Washington, DC, 20233.

12. REPORT CGMS Tenth Session

13. CONSOLIDATED REPORT of CGMS ACTIVITIES, 8th Edition, April 1989.

14. ECMWF SATOB Data Monitoring Report, June - August 1993

Examples of Tables for Type 1 Reports

The three tables in this appendix do not contain actual data. Instead they represent typical differences that NESS experience has suggested might be obtained when two independent satellite systems are compared. While the table format should be followed, details such as spacing of the columns, number of tables per page, etc, are left to the reporting operating agency.

TABLE 1 E. VECTOR MAGNITUDE GOES E - GOES W JUNE 1978

		SFC-700 MB INDIV.	SFC-700 MB CUM.	699-400 MB INDIV.	699-400 MB CUM.	LESS 400 MB INDIV.	LESS 400 MB CUM.
0	1	11	11	1	1	5	5
2	3	37	48	30	31	28	33
4	5	25	73	31	62	27	60
6	7	23	96	15	77	18	78
8	9	0	96	15	92	8	86
10	11	2	98	2	94	9	95
12	13	0	98	2	96	0	95
14	15	1	99	0	96	0	95
16	17	1	100	2	98	4	99
18	19			1	99	0	99
20	21			0	99	0	99
22	23			0	99	0	99
24	25			1	100	0	99
GTR	25					1	100

	SFC-700 MB	699-400 MB	LESS 400 MB
NUMBER	866	97	259
ALG. MEAN	4.1	5.7	5.8
ABS. MEAN	4.1	5.7	5 8
RMS	4.9	6.7	7.1

Figure 2

PERCENT FREQUENCY OF DIFFERENCES (MPS) OR (DEG)
JULY 1992
GOES
GOES/EAST MINUS GROUND TRUTH (RAWIN)

TABLE 1: VECTOR MAGNITUDE RAWIN - GOES EAST

		SFC-700 MB		699-400 MB		LESS 400 MB	
		IND	CUM	IND	CUM	IND	CUM
0	1	17	17	10	10	4	4
2	3	46	63	25	35	17	21
4	5	24	87	29	64	24	45
6	7	7	94	17	81	18	63
8	9	4	99	10	91	13	76
10	11	1	100	5	96	9	85
12	13	0	100	2	98	8	93
14	15	0	100	1	99	4	97
16	17	0	100	1	100	2	99
18	19	0	100	0	100	1	100
20	21	0	100	0	100	0	100
22	23	0	100	0	100	0	100
24	25	0	100	0	100	0	100
GTR	25+	0	100	0	100	0	100
NUMBER			71		374		1244
ABS. MEAN			3.3		5.1		6.8
RMS			3.9		6.0		7.9
AVG GOES SPEED			7.0		10.2		16.8
AVG RAWIN SPD			6.4		11.9		18.1

Figure 3

PERCENT FREQUENCY OF DIFFERENCES (MPS) OR (DEG)
JULY 1992
ESA
METEOSAT MINUS GROUND TRUTH (RAWIN)

TABLE 1E: VECTOR MAGNITUDE RAWIN - METEOSAT

		SFC-700 MB		699-400 MB		LESS 400 MB	
		IND	CUM	IND	CUM	IND	CUM
0	1	11	11	6	6	5	5
2	3	35	46	26	32	19	24
4	5	31	77	25	57	20	44
6	7	16	93	18	75	17	61
8	9	4	97	11	86	16	77
10	11	2	99	6	92	10	87
12	13	1	100	3	95	5	92
14	15	0	100	3	98	3	95
16	17	0	100	1	99	2	97
18	19	0	100	0	99	2	99
20	21	0	100	0	99	0	99
22	23	0	100	1	100	1	100
24	25	0	100	0	100	0	100
GTR	25	0	100	0	100	0	100
NUMBER			334		584		494
ALG. MEAN			4.0		5.7		6.9
ABS. MEAN			4.0		5.7		6.9
RMS			4.6		6.9		8.2
AVG MSAT SPEED			10.4		14.2		20.1
AVG RAWIN SPD			10.1		14.9		20.1

Figure 4

PERCENT FREQUENCY OF DIFFERENCES (MPS) OR (DEG)
JULY 1992
GMS
METEOSAT MINUS GROUND TRUTH (RAWIN)

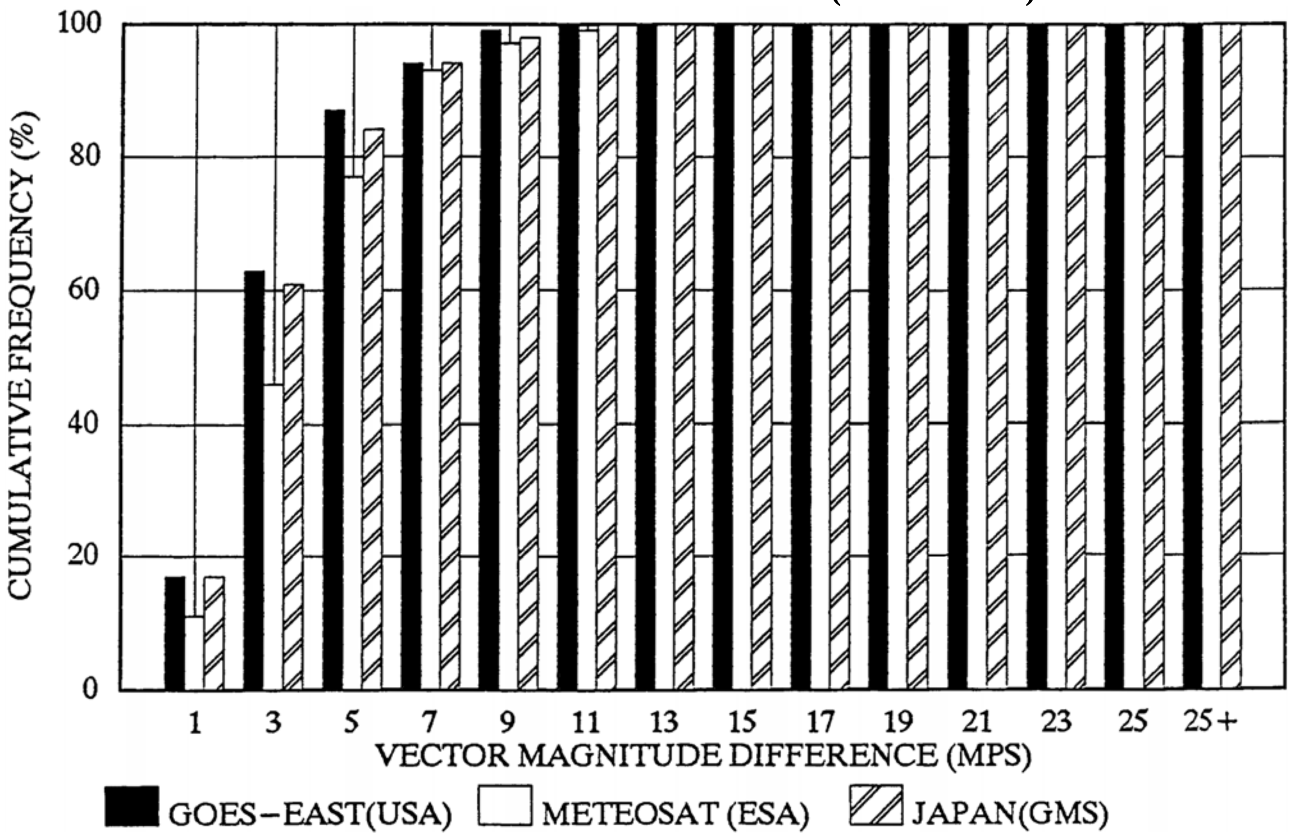
TABLE 1G: VECTOR MAGNITUDE RAWIN - JAPAN

		SFC-700 MB		699-400 MB		LESS 400 MB	
		IND	CUM	IND	CUM	IND	CUM
0	1	17	17	0	0	5	5
2	3	44	61	0	0	19	25
4	5	23	84	0	0	24	49
6	7	9	94	0	0	19	68
8	9	4	98	0	0	14	82
10	11	1	100	0	0	6	88
12	13	0	100	0	0	4	92
14	15	0	100	0	0	4	95
16	17	0	100	0	0	1	97
18	19	0	100	0	0	1	99
20	21	0	100	0	0	1	99
22	23	0	100	0	0	0	99
24	25	0	100	0	0	0	99
GTR	25	0	100	0	0	1	100
NUMBER			1515		0		1095
ALG. MEAN			3.4		0.0		6.6
ABS. MEAN			3.4		0.0		6.6
RMS			4.1		0.0		7.9
AVG GMS SPEED			8.3		0.0		21.5
AVG RAWIN SPD			8.6		0.0		22.4

Figure 5

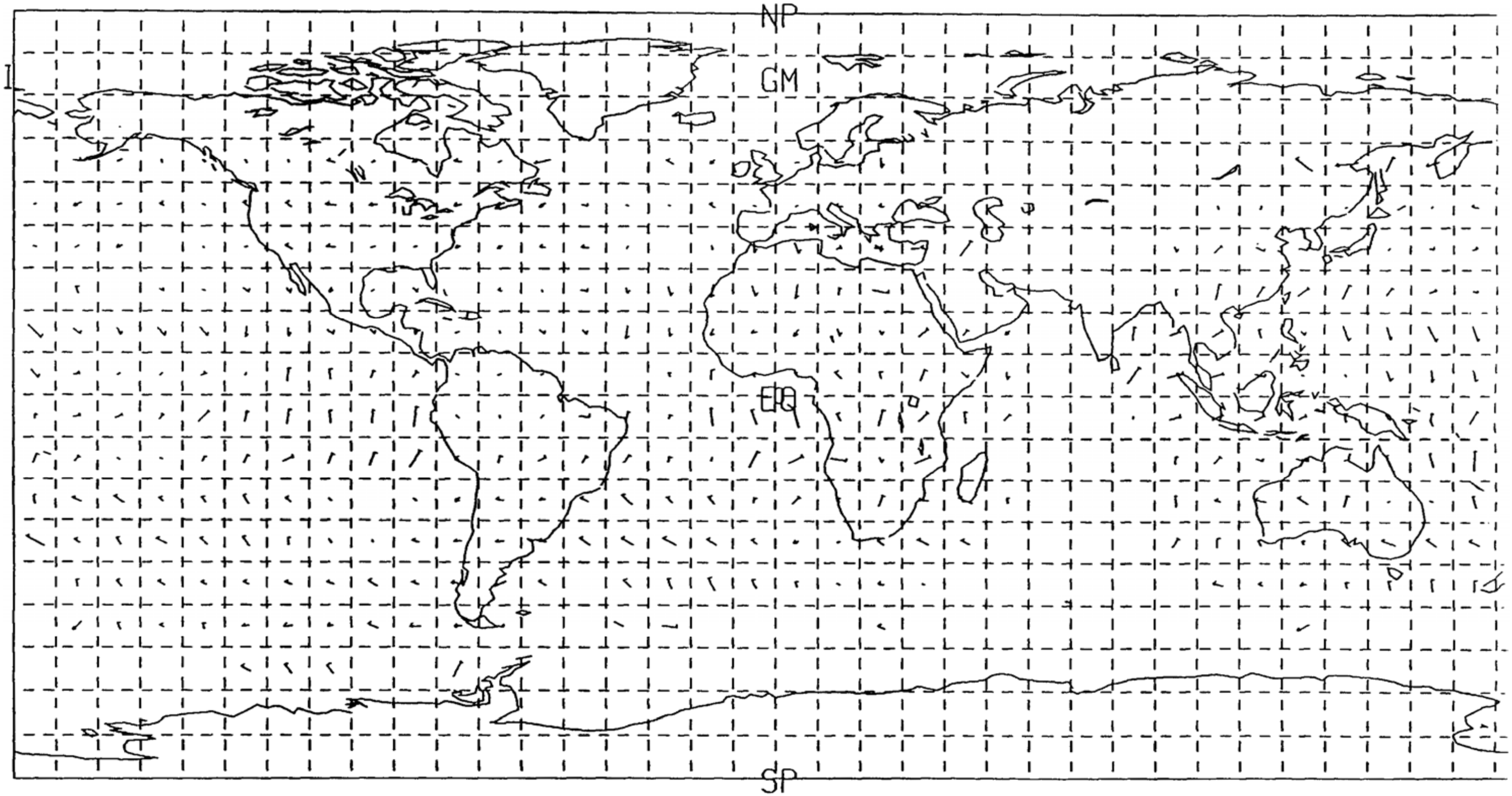
PERCENT FREQUENCY OF DIFFERENCE

SATELLITE VS. RAOB LOW LEVEL(SFC–700 MB)



JUL 1 - JUL 31,1992

Figure 6

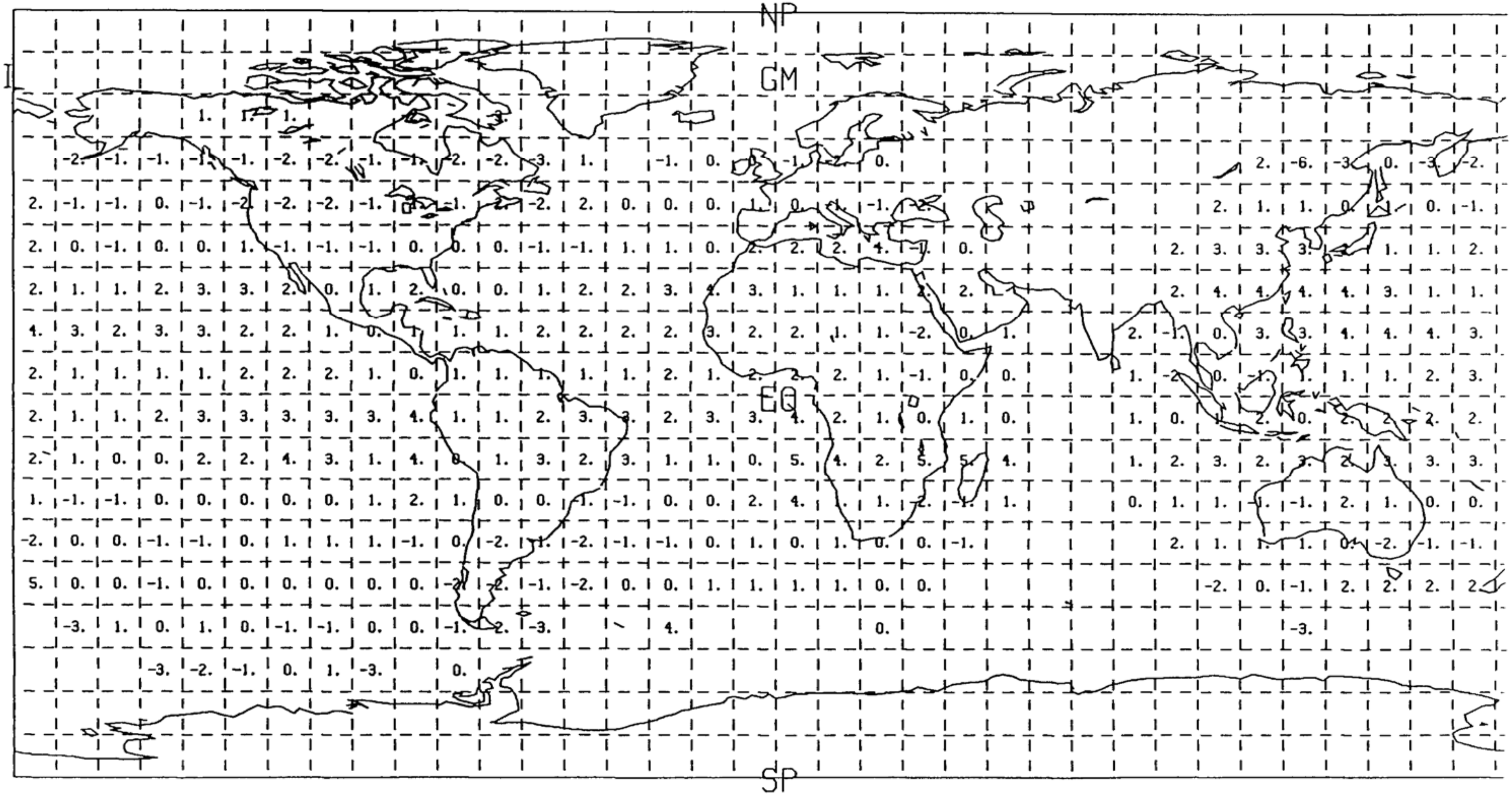


NMC MONITORING STATISTICS

ALL SATOBS , OBS–6HR FCS — 4 MPS — 8 MPS

JUN, 1993 (440-100HPA)

Figure 7



NMC MONITORING STATISTICS
SATOBS, AVE BIAS IN SPEED

JUN, 1993 (440-100HPA)

Figure 8

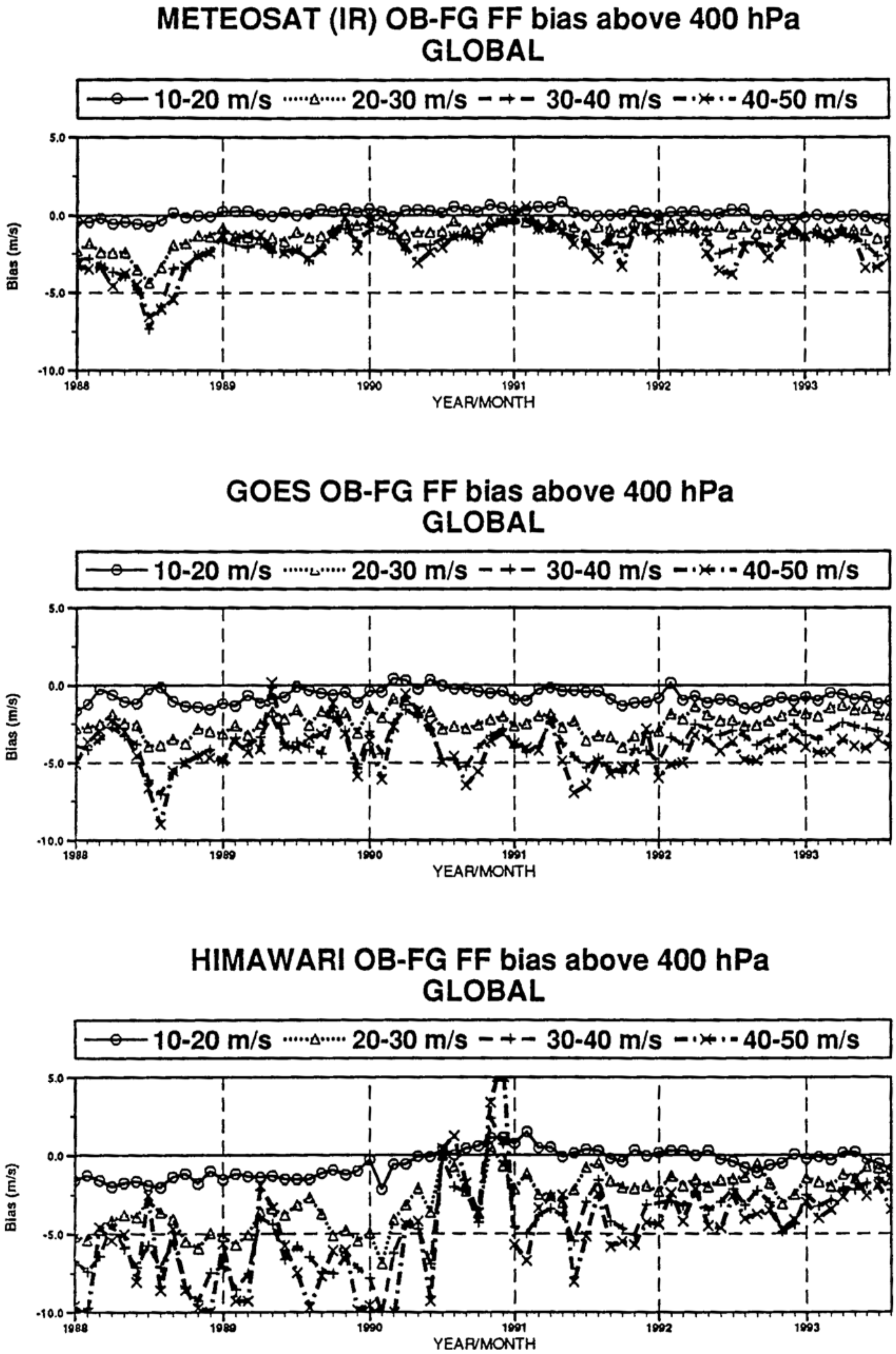


FIGURE 1

Figure 9

ECMWF Monitoring Statistics: JUN - AUG 1993
SATOB Winds: BELOW 700hPa
Observation-FG

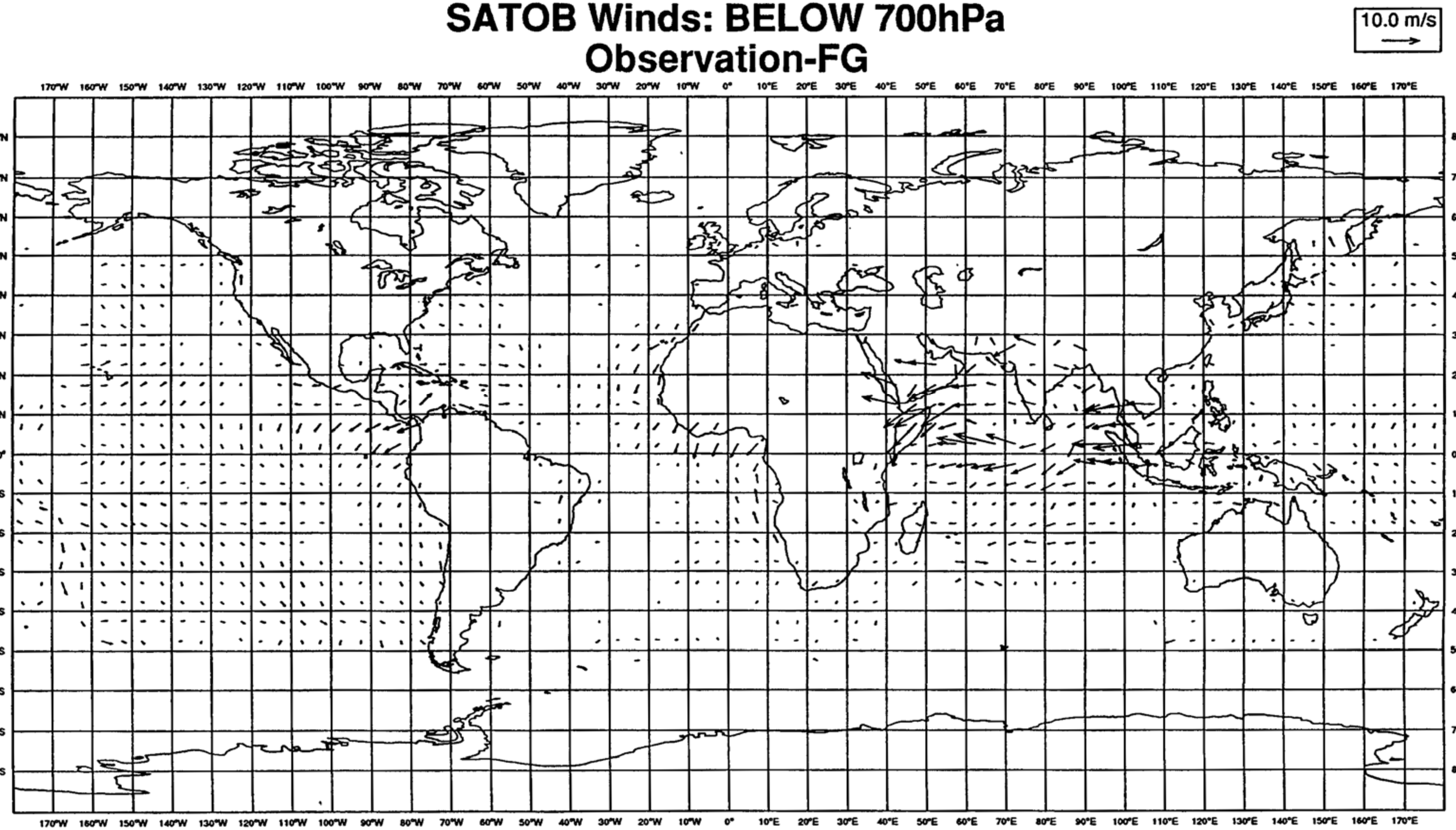
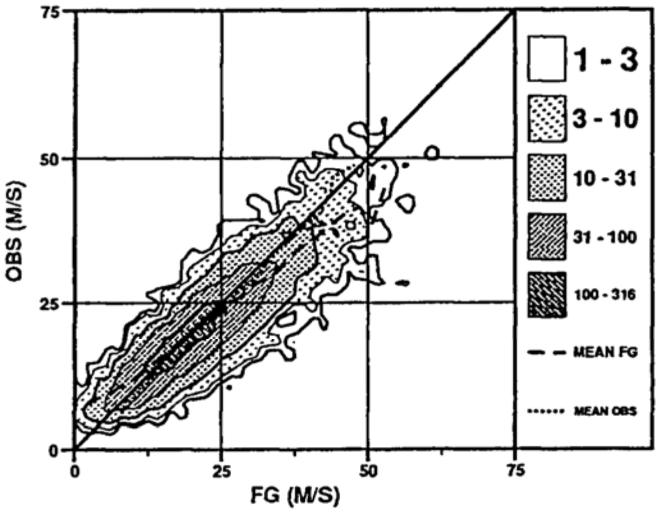


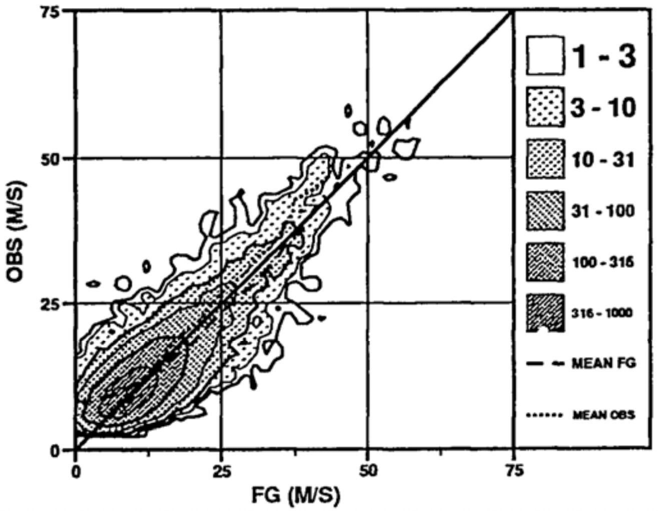
Figure 10

SATOB METEOSAT IR
ABOVE 400hPa
AREA: 20N - 90N
JUN - AUG 1993
WINDSPEED



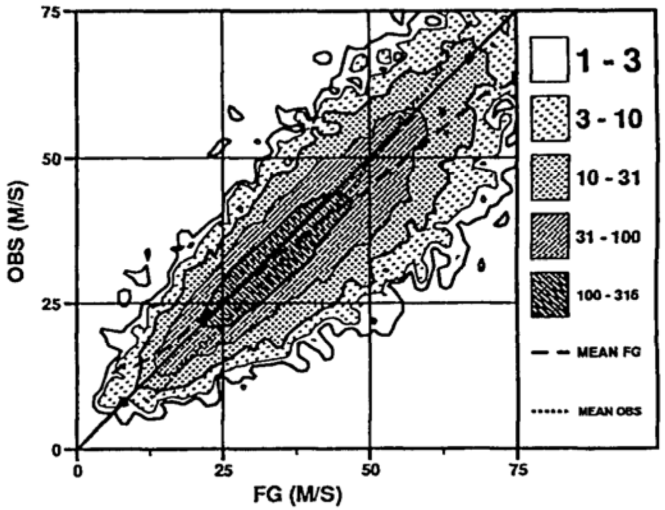
NO. OF OBS: 6631 BIAS: -1.0 STD: 4.5

SATOB METEOSAT IR
ABOVE 400hPa
AREA: 20S - 20N
JUN - AUG 1993
WINDSPEED



NO. OF OBS: 15156 BIAS: 0.2 STD: 4.1

SATOB METEOSAT IR
ABOVE 400hPa
AREA: 90S - 20S
JUN - AUG 1993
WINDSPEED



NO. OF OBS: 18726 BIAS: -2.2 STD: 6.8

FIGURE 9