THE IMPACT OF NEW RF95 RADIOSONDE INTRODUCTION ON UPPER-AIR DATA QUALITY IN THE NORTH-WEST REGION OF RUSSIA

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ABSTRACT

The overall performance of geopotential measurements by Russian upper-air systems is determined by both performance of radar height measurements and performance of temperature (to much less extent - humidity) sensor of used radiosondes. Therefore, efforts aimed to improve one of the mentioned components must take into account limitations imposed on combined result by another one. The positive impact of introduction the RF95 - Russian radiosonde with Vaisala RS80 temperature and humidity sensors - onto geopotential data quality is estimated theoretically and demonstrated basing on ECMWF upper-air data quality monitoring. It is shown the apparent improvement of the upper-air geopotential data quality in the North-West Region of Russia, where RF95 was introduced since 1998. A value of using still more accurate radiosondes with existing Russian ground radars is discussed.

Recently a new RF95 radiosonde was introduced on some stations of the Russian upper-air network carrying out temperature and humidity sensors (without pressure capsule – see below) of Vaisala RS80-A radiosonde (more details in /5/). According to manufacturers specifications and results of WMO Radiosonde Intercomparison /1/ performance of RF95 sensors exceeds one of MRZ-3 – the radiosonde used on the vast majority of the Russian upper-air stations. However, a question all the time arises has it a practical impact onto performance of operational geopotential observations.

What benefit could be expected from introduction of more accurate sensors in the sense of performance of geopotential on standard pressure levels? Let's try to make at least a rough estimates. In Russian AVK system pressure is derived from virtual temperature T and humidity U, measured by a radiosonde, and height H, calculated from determined by a radar slant range D and elevation ε (details could be found in /1/).

Using linearization of equations used we derive following relationship between error of geopotential H_P at given pressure level P from errors of measured parameters:

$$\delta H_P = T_P \left(\int_{H_{P_0}}^{H_P} \frac{\delta T \mathrm{d}H}{T^2} + \int_{H_{P_0}}^{H_P} \frac{\gamma d \delta\varepsilon}{T^2} \mathrm{d}H + \int_{H_{P_0}}^{H_P} \frac{\gamma \sin\varepsilon \delta D}{T^2} \mathrm{d}H \right)$$

where d is horizontal distance and γ is temperature lapse rate.

Each error source (especially, tracking errors) is actually a stochastic process and accurate evaluation of integrals in general case is very complex task, first of all due to absence of necessary information. Nevertheless, taking into account that short-period constituents are fairly well filtered during an integration a task could be reduced to an evaluation of effect of reproducibility of each parameter upon reproducibility of geopotential in assumption of constant values of each error throughout the whole flight and neglecting the effects such as: influence of humidity upon virtual temperature[1], non-linear relationship between geometric and geopotential height, uncertainty of the radiation corrections and corrections for earth curvature and radio-wave refraction. From this we receive for the quantity under consideration the following expression:

$$\sigma\left[\Delta_P H\right] = T_P \times$$

$$\times \sqrt{\left(\int_{H_{P_0}}^{H_P} \frac{\mathrm{d}H}{T^2}\right)^2 \sigma^2\left[\Delta_s T\right] + \left(\int_{H_{P_0}}^{H_P} \frac{\gamma d}{T^2}\mathrm{d}H\right)^2 \sigma^2\left[\Delta_s \varepsilon\right] + \left(\int_{H_{P_0}}^{H_P} \frac{\gamma \sin\varepsilon}{T^2}\mathrm{d}H\right)^2 \sigma^2\left[\Delta_s D\right]}$$

As one can see a great uncertainty still remains depending from actual profiles of temperature and wind. Therefore we consider a model situation with temperature stratification according to the standard atmosphere model Cospar International Reference Atmosphere (CIRA), unvarying elevation angle (i.e. constant radial wind f_R) and permanent ascent velocity of 5.5 m/s. For characterizing measurement errors there were used the values, claimed by manufacturers for so called "sonde error" /2/. Reproducibility of temperature measurements: MRZ-3 – 0.4 °C, RS80 (RF95) – 0.2 °C below and 0.3 °C above 100 hPa, RS90/RS92 - 0.2 °C /6/, reproducibility of AVK slant range and elevation – 30 m and 0.12° (characteristics of MARL are expected to be of the same order).

Although parameterizations of CIRA allows analytical derivation of estimates in used formulation of the task it was used numerical evaluation with integration step of 1 km. Apart from resulting estimate of $\sigma[\Delta_p H]$ there were calculated relative contribution of each component into resulting variance as $R_x = \sigma^2[\Delta_p H(X)] / \sigma^2[\Delta_p H]$

Results of evaluation for the several fixed elevation angles are summarized in the Table 1 below for levels 16 and 31 km, nearly corresponding to levels 100 and 10 hPa (note, that below 100 hPa RS90 is considered to be equivalent to RS80).

First of all, at all considered situations at upper levels, with assumptions admitted, at the present state of temperature sensors performance tracking errors have negligible influence on H_P as in CIRA the temperature gradient is negative and therefore contribution of height error at upper levels has opposite sign to that at lower ones. Therefore, the gain in H_P performance is directly proportional to decrease in temperature error. So, RF95 is 60% (the contribution of parts below and above 100 hPa is about the same) better and RS90 is 100% better of MRZ-3. Of course, in real conditions at low angles radar tracking may seriously suffer from influence of surface. From other side, contribution of height error is proportional to temperature gradient and magnitudes of temperature gradients in stratosphere anyhow much more moderate than in troposphere. And uncertainty of radiation correction to MRZ-3 white-coated temperature sensor is larger than RS80 aluminized sensor has /2,7,8/ while RS90 temperature sensor radiation correction should have the least uncertainty.

At 100 hPa level tracking performance (within model adopted) has more significant influence, nevertheless it starts to prevail over temperature induced error of RF95 only under extremely strong winds and even under those conditions RF95 is still worth to be used as alternative to

[1] As contribution of humidity to virtual temperature is rather small, therefore the influence of humidity errors onto geopotential accuracy is considered to be of the second order.

MRZ-3 ceteris paribus. From other side, even at quite low winds (not to speak about calm when influence of distance error increases) one could not expect two-fold gain in H_P performance from the use of RF95 – the maximum possible gain is about 80%.

RS90 sensors might be worth to use in Russian system at those stations, which should provide high quality measurement at upper levels such as GUAN stations – there are twelve such stations in Russia.

Since the mid of 80-s it's already the common practice to evaluate performance of upper-air observations by comparison of observations against short-range forecast produced by the modern numeric models, valid for the time of observations. ECMWF is appointed by WMO as leading center for upper-air data quality monitoring. Produced by ECMWF OB-FG[2] statistics is widely recognized and for example is used by WMO Rapporteur on Radiosonde Compatibility Monitoring for overview of the quality of worldwide upper-air observations.

Usually such a statistics is produced for temperature, geopotential and wind (both for polar and Cartesian presentation). Statistics of geopotential is used more often than one for temperature, as being derived for standard pressure levels it represents an integrated indicator of radiosonde and ground station performance for temperature and height (as mentioned before – in Russian upper-air systems height is measured directly).

For the demonstration here are used diagrams of ECMWF OB-FG geopotential statistics for 1998 and 2000, kindly provided by Mr. A Garcia-Mendez (ECMWF) for the evaluation of impact of RF95-NW – project, arranged according to the Agreement between Roshydromet and Finnish Meteorological Institute (FMI), of aerological programme support during 1998-2000 on upper-air sounding stations 22113-Murmansk, 22217-Kandalaksha and 26063-St. Petersburg (Voejkovo) of the North-West Region of Russia using a new radiosonde RF95. Regular sounding with RF95 only on those stations has started since 1999.

It's necessary take into account looking at OB-FG geopotential statistics that the lower is the level under consideration the more strict are requirements to performance. As measure of magnitude it may serve WMO guidelines for selection of suspected (i.e. producing useless data) stations according to root-mean-square OB-FG deviations[3]: 45, 100 and 125 m for 500, 100 and 50 hPa respectively. On other edge of ruler could be placed neighboring station 2836, which shows quite typical performance for RS80-DigiCORA sounding system representing state of the art in the modern upper-air sounding /9/. For evaluation of particular station bias and standard deviation of OB-FG are equally important because they reflect average of errors and their day-to-day variability. However, for the whole network differences between biases of stations are also essential as they make inhomogeneous presentation[4] of atmospheric processes.

From these standpoints, one can interpret from the time series of ECMWF OB-FG geopotential statistics:

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[2] As such a forecast is often used in particular as background, or first-guess, field for objective analysis of upper-air data abbreviation FG is conventionally used to denote these data. OB denotes results of observations.

[3] Practically could be estimated as square root from squares of bias and standard deviation

[4] Of course, individual scatter also reflects the extent of distortion in meteorological fields caused by observational errors

All stations under investigation showed substantial improvement especially at upper levels:

- 22113 - in 1998 the bias varied from -50 to 80 m at 50 hPa and the standard deviation reached 100 m. In 2000 the corresponding values reduced to less than 25 m at all levels.
- 22217 - in 1998 the stratospheric bias was very high, exceeding 125 m at 50 hPa, whereas it was small in the troposphere; the standard deviation remained below 50 m at all levels. In 2000 a rather noticeable positive bias still existed in the stratosphere but didn't exceed 50 m; the standard deviation also decreased from 1998 to values of less than or equal to 25 m.
- 26063 - in 1998 the bias at 00UTC varied from -25 to 40 m, while the bias at 12UTC reached even 80 m; the standard deviation was noticeable and reached almost 50 m. In 2000 the bias was less than or equal to 25 m during all months except in October, and the standard deviation was below 25 m during most months with occasional monthly extremes exceeding 25 m.

During some months in 1998 the statistics on particular levels at some stations were close to, and occasionally even exceeded, the limits for suspected stations established by WMO/CBS. In 2000 all data had acceptable quality far from such limits. As well, in some months of 1998 the absolute magnitude of systematic differences between individual stations exceeded 100 m. The examined stations were compatible in performance with the station 02836 during 2000: 22113 showed perfectly the same, while 22217 and 26063 showed a slightly inferior behavior.

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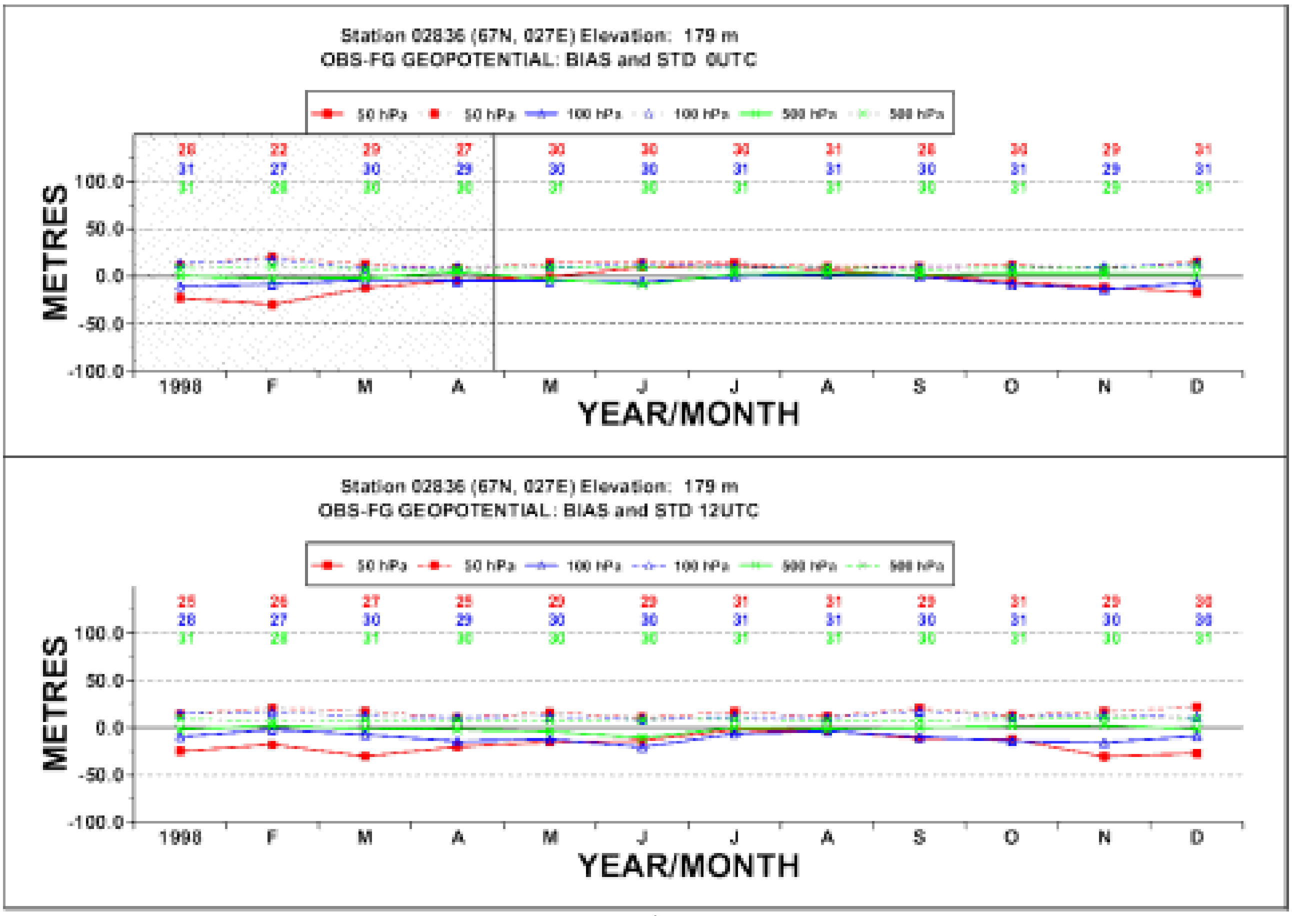
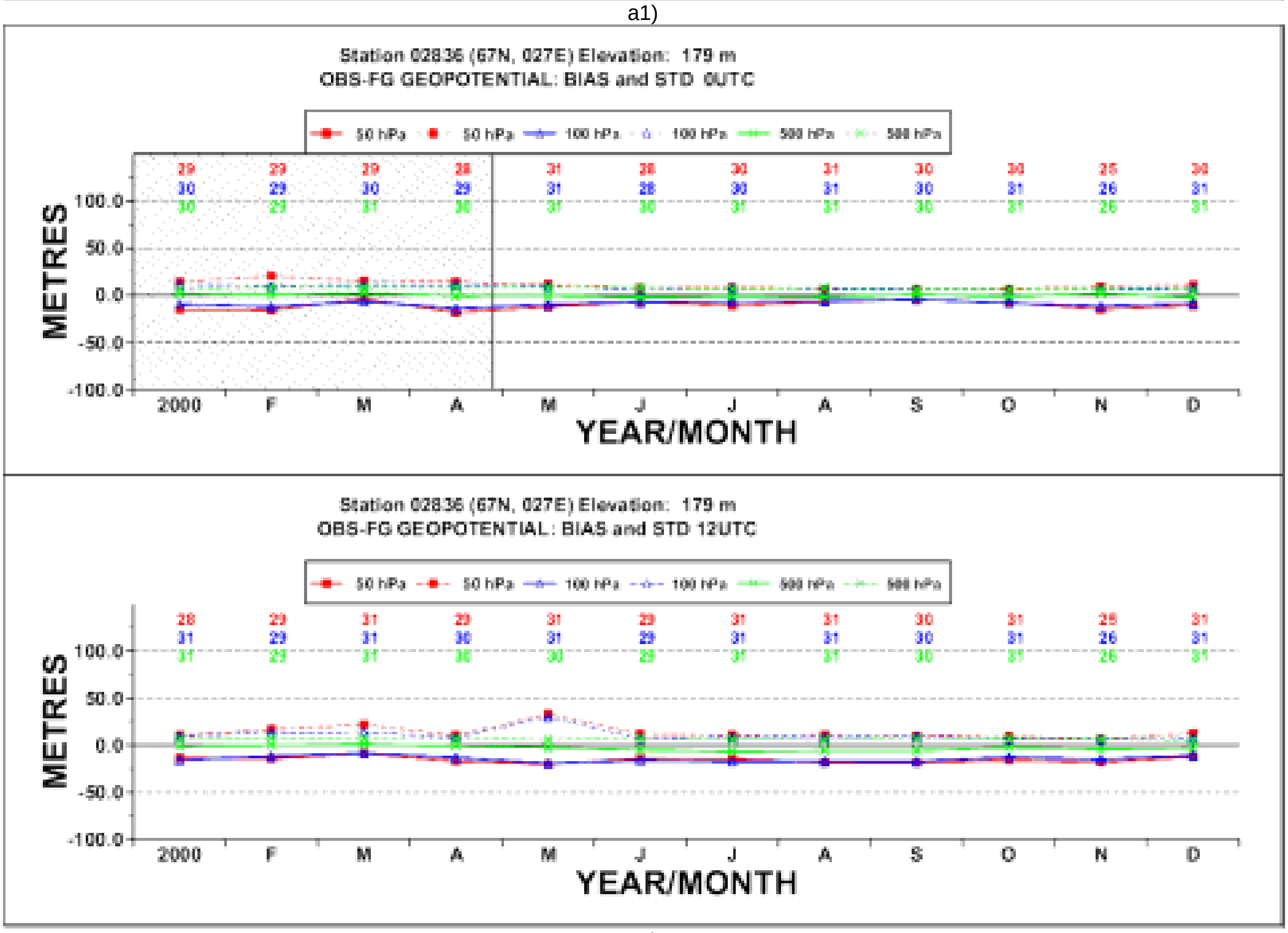
Table 1. Estimates of reproducibility of measurement of geopotential height at fixed pressure level for AVK radar with radiosondes using different temperature sensors

System	$\sigma[\Delta_p H]$, **m**	R_T**,%**	R_D**,%**	R_ε**,%**
	H=16 km, d=12.5 km, f_R= 4.3 m/s			
AVK+MRZ	25	93%	6%	1%
AVK+RF95	14	77%	20%	4%
	H=16 km, d=37.5 km, f_R= 12.9 m/s			
AVK+MRZ	26	89%	1%	10%
AVK+RF95	15	66%	4%	29%
	H=16 km, d=62.5 km, f_R=21.5 m/s			
AVK+MRZ	28	76%	0%	23%
AVK+RF95	18	44%	1%	55%
	H=16 km, d=100 km, f_R=34.4 m/s			
AVK+MRZ	33	56%	0%	44%
AVK+RF95	25	24%	0%	76%
	H=32 km, d=25 km, f_R= 4.4 m/s			
AVK+MRZ	54.1	99.0%	1.0%	0.0%
AVK+RF95	33.7	97.4%	2.5%	0.1%
AVK+"RS90"	27.4	96.1%	3.8%	0.1%
	H=32 km, d=75 km, f_R= 13.3 m/s			
AVK+MRZ	53.9	99.5%	0.2%	0.2%
AVK+RF95	33.5	98.8%	0.6%	0.6%
AVK+"RS90"	27.2	98.2%	0.9%	0.9%
	H=32 km, d=125 km, f_R= 22.2 m/s			
AVK+MRZ	54.0	99.3%	0.1%	0.6%
AVK+RF95	33.5	98.8%	0.6%	0.6%
AVK+"RS90"	27.3	97.2%	0.4%	2.4%
	H=32 km, d=200 km, f_R= 35.5 m/s			
AVK+MRZ	54.3	98.4%	0.0%	1.6%
AVK+RF95	33.5	98.8%	0.6%	0.6%
AVK+"RS90"	27.8	93.8%	0.1%	6.0%


Station 02836 (67N, 027E) Elevation: 179 m
OBS-FG GEOPOTENTIAL: BIAS and STD 0UTC
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
100.0
50.0
0.0
-50.0
-100.0
1998
F
M
A
M
J
J
A
S
O
N
D
YEAR/MONTH
Station 02836 (67N, 027E) Elevation: 179 m
OBS-FG GEOPOTENTIAL: BIAS and STD 12UTC
YEAR/MONTH

a1)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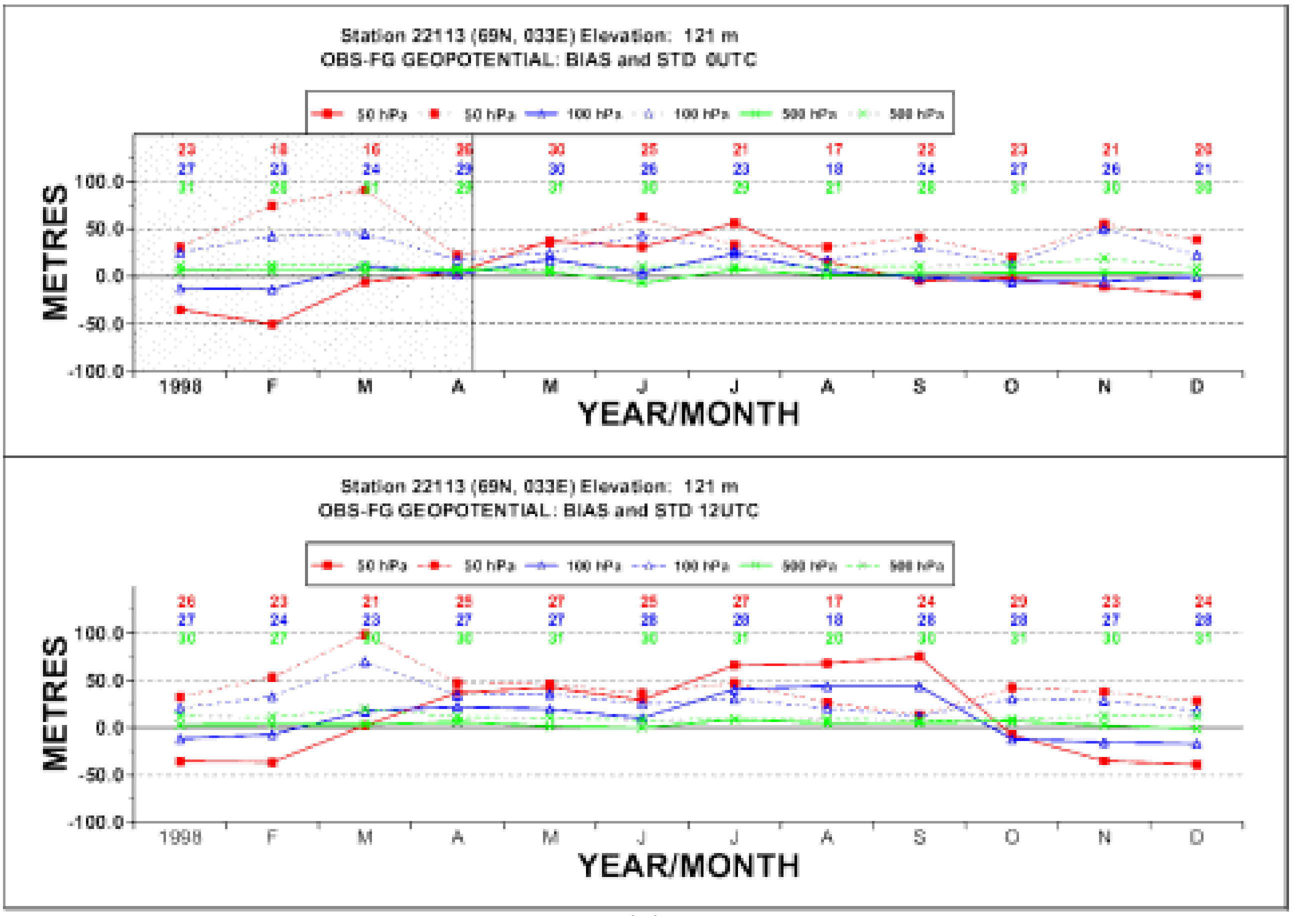
OBS-FG GEOPOTENTIAL: BIAS and STD 0UTC
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
100.0
50.0
0.0
-50.0
-100.0
2000
F
M
A
M
J
J
A
S
O
N
D
YEAR/MONTH
Station 02836 (67N, 027E) Elevation: 179 m
OBS-FG GEOPOTENTIAL: BIAS and STD 12UTC
YEAR/MONTH

a2)


Station 22113 (69N, 033E) Elevation: 121 m
OBS-FG GEOPOTENTIAL: BIAS and STD 0UTC
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
100.0
50.0
0.0
-50.0
-100.0
1998
F
M
A
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J
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O
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D
YEAR/MONTH
Station 22113 (69N, 033E) Elevation: 121 m
OBS-FG GEOPOTENTIAL: BIAS and STD 12UTC
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
100.0
50.0
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-50.0
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1998
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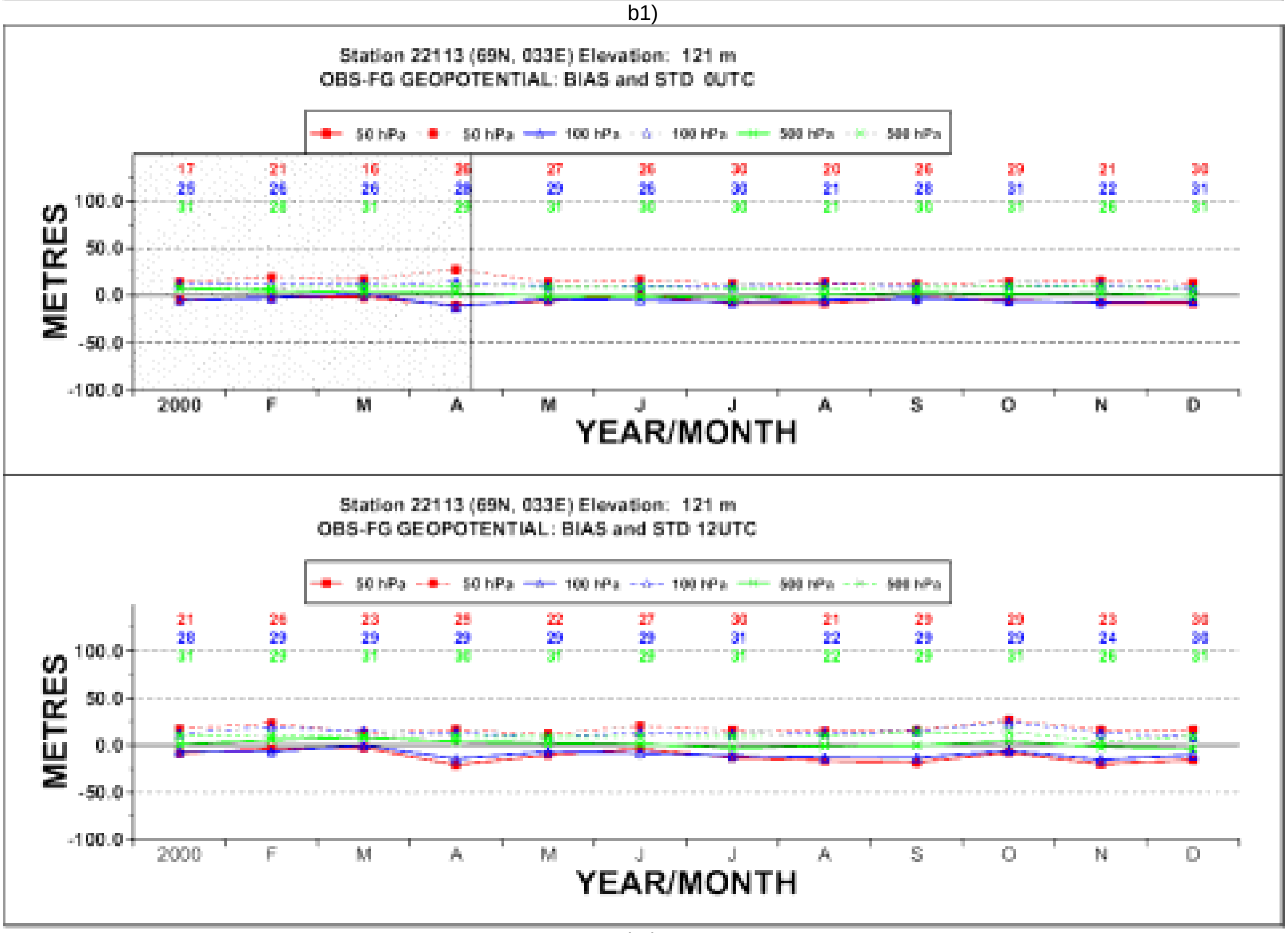
YEAR/MONTH
b1)


Station 22113 (69N, 033E) Elevation: 121 m
OBS-FG GEOPOTENTIAL: BIAS and STD 0UTC
50 hPa
50 hPa
100 hPa
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500 hPa
500 hPa
METRES
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-50.0
-100.0
2000
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YEAR/MONTH
Station 22113 (69N, 033E) Elevation: 121 m
OBS-FG GEOPOTENTIAL: BIAS and STD 12UTC
50 hPa
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500 hPa
METRES
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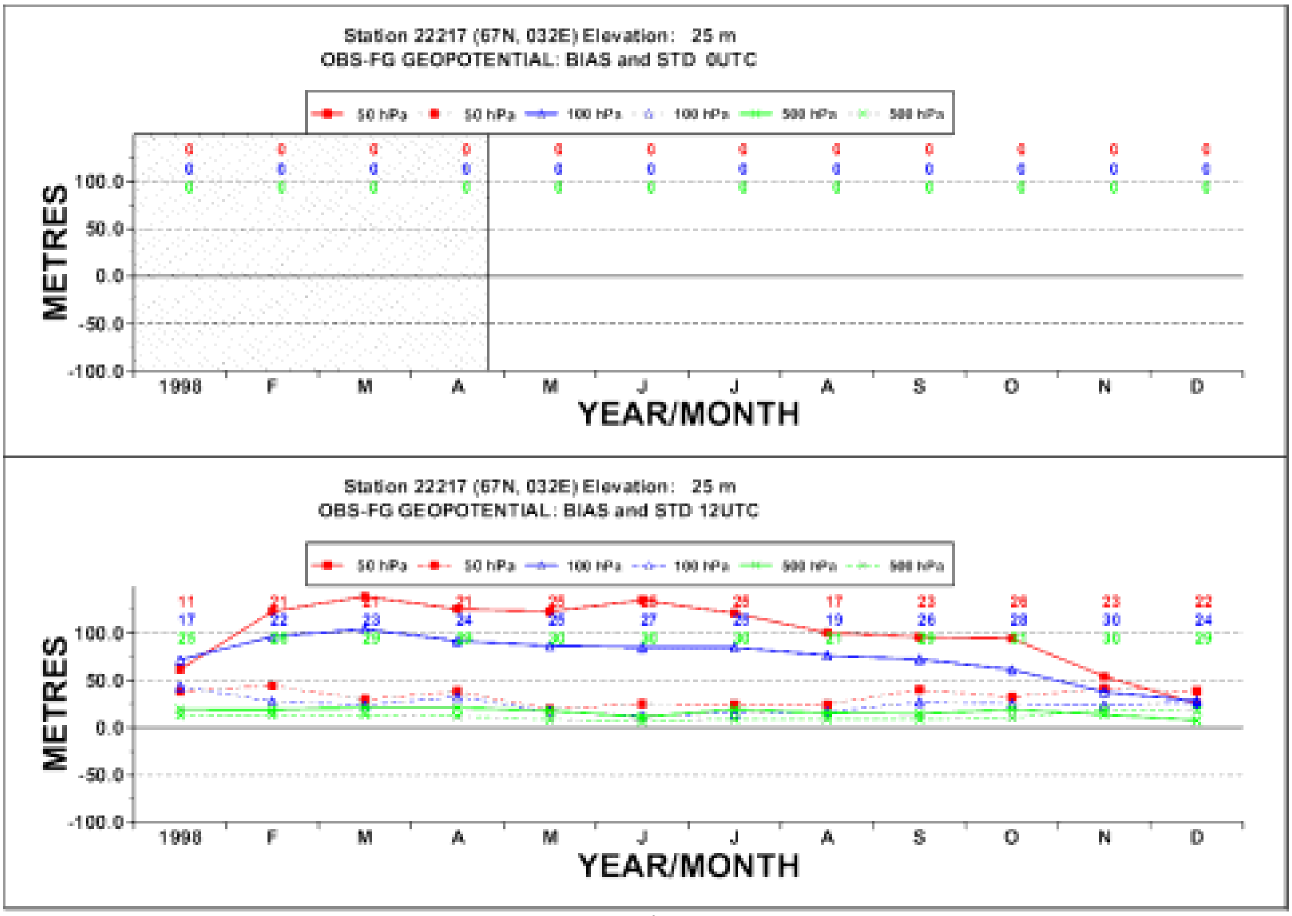
YEAR/MONTH
b2)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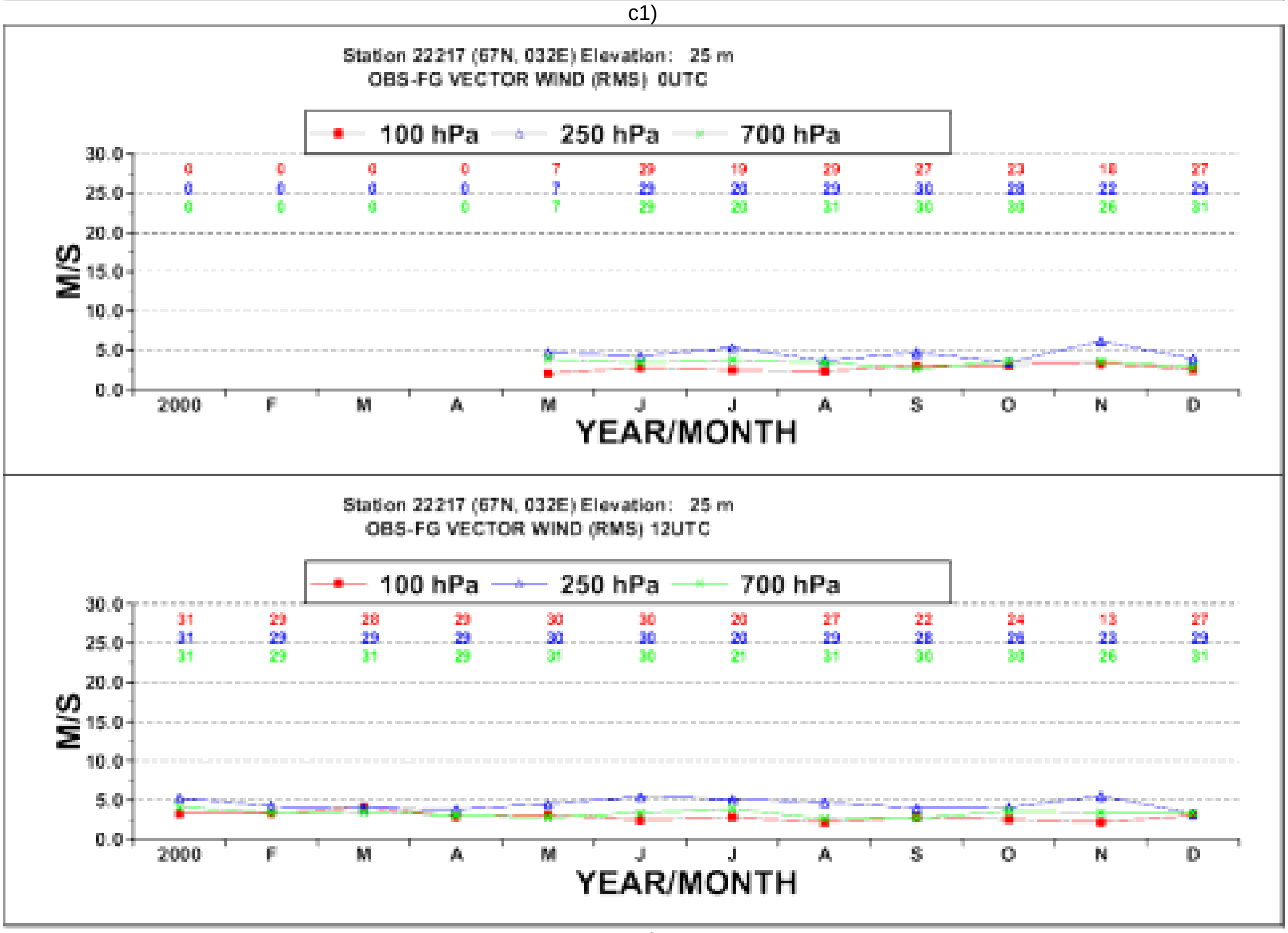
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
YEAR/MONTH
1998 F M A M J J A S O N D
Station 22217 (67N, 032E) Elevation: 25 m
OBS-FG GEOPOTENTIAL: BIAS and STD 12UTC
50 hPa
50 hPa
100 hPa
100 hPa
500 hPa
500 hPa
METRES
YEAR/MONTH
1998 F M A M J J A S O N D

c1)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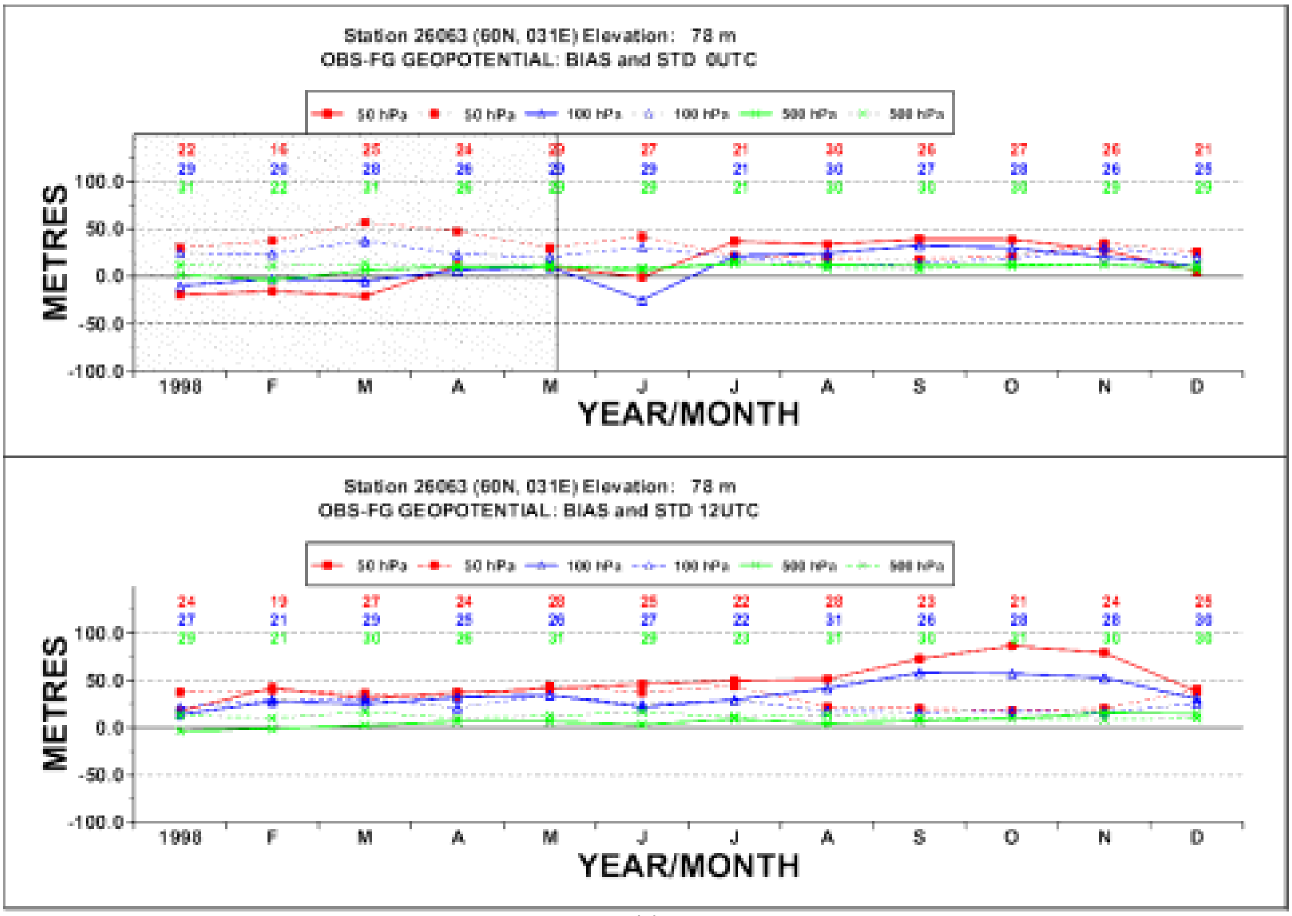
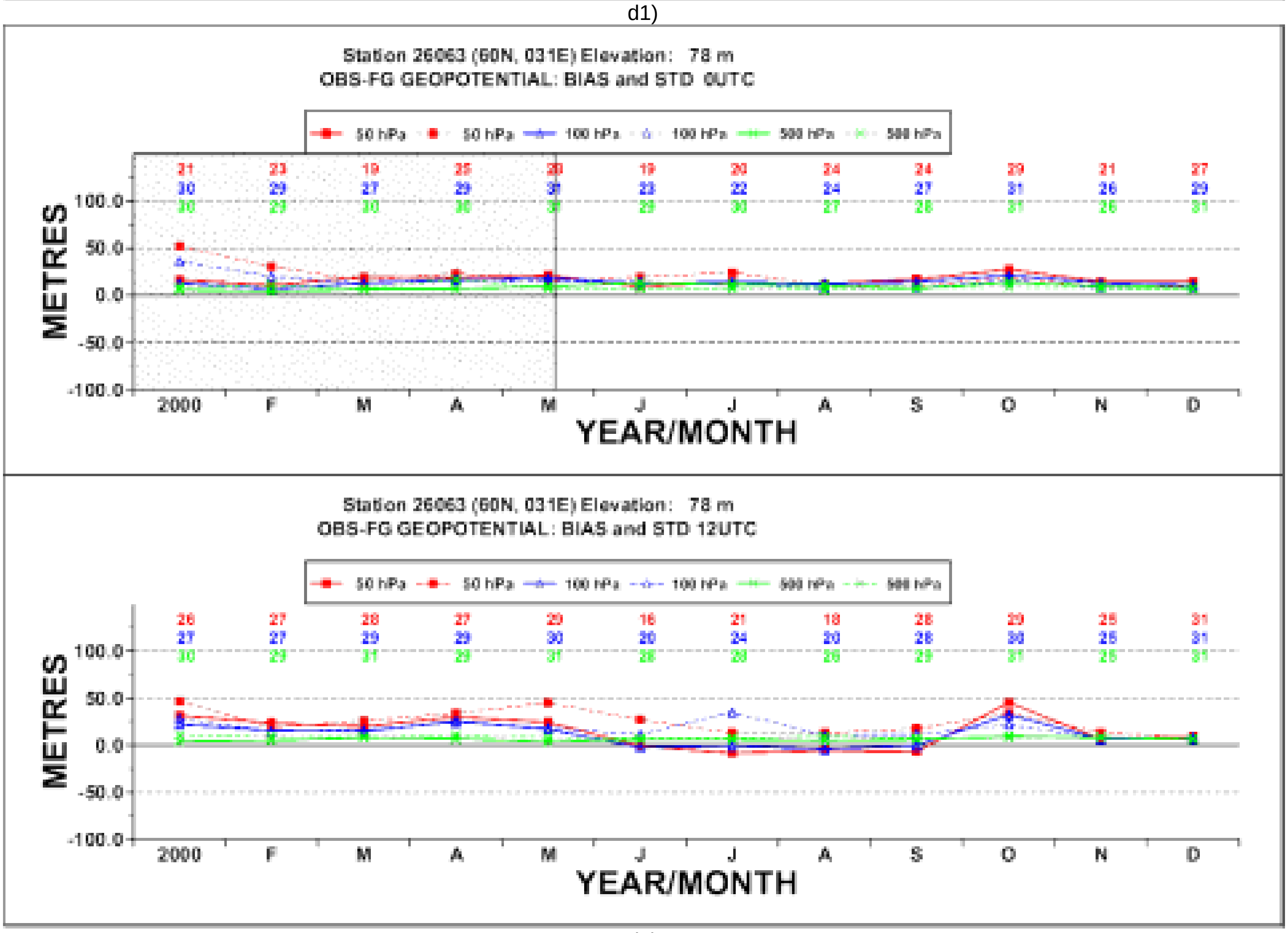
100 hPa
250 hPa
700 hPa
M/S
YEAR/MONTH
2000 F M A M J J A S O N D
Station 22217 (67N, 032E) Elevation: 25 m
OBS-FG VECTOR WIND (RMS) 12UTC
100 hPa
250 hPa
700 hPa
M/S
YEAR/MONTH
2000 F M A M J J A S O N D

c2)



d1)



d2)

Figure1. ECMWF geopotential statistics for stations 2836 (a), 22113 (b), 22217 (c) and 26063 (d) for 1998 (1) and 2000 (2).