Systematic differences between radiosonde instruments

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Short title: RAOB INSTRUMENT DIFFERENCES

Abstract.

Deviations of radiosonde reports' geopotential heights from the zonal mean are examined. In the summer Northern Hemisphere stratosphere, systematic differences are found between radiosonde instrument types. Persistent meridional wind anomalies, approximately constant in magnitude and fixed in location, have previously been reported in the summer stratosphere, and one such anomaly over Europe is found to be co-located with boundaries between regions in which differing types of radiosonde instruments are used. The magnitude and orientation of the radiosonde geopotential height biases are consistent with the wind anomalies. Because the overall winds tend to be light in this region and season, these wind anomalies can represent significant perturbations of the flow and must be considered when interpreting the results of trajectory and diagnostic studies.

1. Introduction

Many atmospheric research efforts require accurate wind fields. A number of institutions produce analyses on standard latitude-longitude-pressure-time grids, and these fields are used to calculate such diagnostic tools as mass fluxes and Eliassen-Palm fluxes. As computer speeds and memory sizes increase, wind fields are also increasingly used in tracing trajectories of large numbers of air parcels (see, for example *Morris et al.* [2000]). A systematic error or anomaly in the winds can have a detrimental effect on these data analysis efforts.

Bowman et al. [1998] (hereafter cited as B98) have described an anomalous meridional wind component which appears in several meteorological analyses. A persistent stationary southerly wind of about 5 m s^{-1} was seen in the Northern Hemisphere summer stratosphere between 20° and 50° E longitude during the summer months. These authors argued that such a stationary feature is inconsistent with stationary wave theory, and they suggested that the feature could be the result of systematic differences in radiosonde data and possibly a diurnal tide signal.

In this paper, radiosonde measurements of geopotential height are shown to exhibit systematic anomalies related to the instrument type and possibly the methodology used. Boundaries are apparent between geographical regions in which different instrument types are used; certain of these boundaries lie in a roughly north-south direction and thus give rise to an anomalous meridional wind via the geostrophic wind relation.

2. Data

Twice-daily global radiosonde reports were obtained from National Centers for Environmental Prediction (NCEP) from 1993 to 2000. Geopotential heights from the Northern Hemisphere for June 1 through August 31 were extracted for the 100, 70, 50, and 30 hPa pressure levels, along with the instrument type code and special processing flags that indicate which solar and infrared radiation corrections were applied and which sonde tracking technique was used.

To facilitate comparisons of radiosonde geopotential heights at different latitudes, zonal mean heights were computed from gridded meteorological analyses and then subtracted from the radiosonde measurements.

The gridded analyses used were generated by NCEP and the National Center for Atmospheric Research (NCAR). The NCEP/NCAR Reanalysis product is described in *Kalnay et al.* [1996]; the version used here consists of four-times-daily analyses on 17 pressure surfaces from 1000 hPa to 10 hPa. For each sonde profile, the reanalyzed analysis grid nearest in time to the profile was selected, the desired pressure surfaces extracted, and the zonal mean computed at each latitude. Then the zonal means $\overline{Z}$ were linearly interpolated to the sonde latitude and were subtracted from the sonde's geopotential heights at the corresponding pressure surfaces. The resulting geopotential height deviations, $Z^* = Z - \overline{Z}$, were subsequently examined for systematic differences between populations of sonde instruments.

To quantify systematic differences between geopotential height deviations, histograms were constructed from Z^* corresponding to different sonde instruments and techniques.

For large enough populations of sonde measurements (on the order of one thousand), the histograms were approximately Gaussian-shaped. The various sonde populations' mean Z^* were compared to determine if systematic differences exist. Over large enough areas, systematic differences will result from differing average meteorological conditions. The areas being compared are therefore kept small enough to reduce the effect of geophysical differences in Z^*, but large enough to ensure good statistics.

3. Results

Figure 1 shows two maps of the sonde stations over the Northern Hemisphere. In the left-hand panel, the stations are color-coded by the predominant WMO instrument type code for that station over the eight summers. For the right-hand panel, Z^* values associated with each station's predominant instrument type were averaged and plotted as color-coded symbols. Figure 1

A large-scale wavenumber one pattern in Z^* is evident, with a low over North America and a high over Asia. Two areas of particular interest are apparent: in eastern Europe a boundary between regions where different instrument types are used coincides with a gradient in Z^*. A similar boundary is seen between Japan and mainland Asia. Both of these boundaries are oriented roughly North-South, which would give rise to anomalous meridional winds via the geostrophic wind relation.

To examine these differences more closely, station reports were collected from within 800 km of a great-circle line segment running from 70° N, 28° E, to 42° N, 19° E. This line marks the approximate boundary between major instrument types. Five instrument types dominated in this strip: 27, 28, 60, 61, and 62. (See Table 1.) Together, these make up 91% of all the Table 1 reports.

Histograms constructed from these stations' Z^* confirm that their populations have an approximately normal single mode distribution. The mean Z^* for each instrument type was computed with its uncertainties at the 99% confidence level. When computing the uncertainty, account must be taken of two factors which result from with the fact that Z^* fluctuations are associated with large-scale synoptic systems moving across the group of stations examined. First, the time series of Z^* at a given station is autocorrelated up to about five days. Second, the Z^* values from each station tend to be highly correlated with those of other nearby stations. Therefore, in estimating the uncertainties of the mean the number of degrees of freedom is conservatively estimated by counting as one report all sonde reports of a single type within the area examined, and by counting only those reports which were taken on day numbers which are evenly divisible by five. The students-t test was used to obtain the uncertainties.

Figure 2 shows the means and uncertainties for each of the instrument types as a function of pressure. Instrument types 60, 61, and 62 lie close together in a group, and types 27 and 28 are clustered in another group. The two groups are offset from each other by about 40 geopotential meters (gpm). The uncertainties at the 99% level do not overlap; the differences of the means are statistically significant. Figure 2

The analysis was repeated with the strip narrowed to 400 km. The same clustering into groups and separation between groups was observed. The smaller sample size resulted in larger uncertainties, but the separation of the means was still significant at the 50 and 30 hPa pressure levels.

To determine if the differences in Z^* might be associated with a larger-scale east-west gradient, two more tests were conducted. A new line was constructed about 400 km to the west, running from 70° N to 42° N at 9.6° E. Stations lying within 400 km to the west of this line were compared to those within 400 km to the east of the line, ignoring instrument type. The means of both populations coincided near $Z^*= 0$, consistent with the above results.

A second line was also constructed to the east, running from 70° N to 42° N at 37.4° E. Again, stations lying within 400 km to the east of this line were compared to stations within 400 km to the west, regardless of instrument type. Again the two profiles of mean Z^* were coincident near $Z^*= 40$. It seems, then, that the differences associated with the boundary between related instrument types are unlikely to be part of a larger east-west pattern.

The differences also do not appear to have varied over time. Profiles of mean Z^* were computed using data from the first two years of the eight summers, and then from the last two years. The results were consistent with each other and with the results above.

The Asian anomaly was examined next. Stations were selected within 800 km of a line running from 50° N, 140° E, to 25° N, 122° E. Instrument types 21, 22, 28, 32, and 47 were predominant, comprising 92% of all reports.

Figure 3 shows the means and uncertainties for each of these instrument types as a function of pressure. There is more of a spread between instrument types, with no tight grouping between types, but Type 32 is offset from the others by 20 to 90 gpm. Figure 3

A simple estimate of how the Z^* difference affects the meridional wind anomaly can by obtained by using the difference in the geostrophic wind relation

$$v = \frac{1}{f}\frac{\partial \Phi}{\partial x} \approx \frac{1}{f}\frac{\Delta \Phi}{\Delta x}$$

where Φ is geopotential ($g_0 Z$, with $g_0 = 9.81 \mathrm{ms}^{-2}$) and $f = 2\Omega \sin\psi$, with $\Omega = 7.292 \times 10^{-5} \mathrm{s}^{-1}$, the earth's rotational frequency, and ψ latitude. Using the European 40 gpm change in Z over 400 km near 60° N, the geostrophic relation gives a meridional wind of slightly less than 8 ms^{-1}, which is in rough agreement with the observed value for v anomaly there, $5 \mathrm{ms}^{-1}$.

4. Discussion

The systematic differences found in geopotential height reports between neighboring populations of radiosonde instruments are small, on the order of 50 m out of 21 000 m. The differences are slightly larger than those reported in the World Meteorological Organization's 1991 rawindsonde instrument intercomparison [*Ivanov et al.*, 1991]. Here the differences are consistently of the same sign; there, geopotential height differences between their FIN and MRZ sondes ranged between 49 and -94 m between 100 and 32 hPa.

Such differences are not uncommon. One can see comparable differences over North America in Figure 1, where different instrument types are clearly associated with different average Z^* values. In this case, however, the different instrument types are intermingled with no clear boundary separating the types, and so they give rise to no apparent wind anomalies.

What causes these differences in geopotential height? B98 showed that such anomalous wind features are not consistent with stationary wave theory. They suggested a radiosonde bias or possibly a diurnal tidal signal. Comparing sondes launched near 00 Z with those launched near 12 Z, however, shows no appreciable difference in average Z^*, which would seem to rule out a diurnal signal.

It is not surprising that small differences between instrument types might exist. Some sondes measure temperature and pressure, with geopotential height being geopotential height being derived. With others, temperature and altitude are measured, and pressure is derived [*Ivanov et al., 1991*]. An offset in geopotential height might also be affected by a difference in how radiation corrections are applied to the temperature or how the sondes are tracked in flight. Unfortunately, these procedures generally change across the same boundaries as the instrument type, making it difficult to untangle procedural differences from the instrument type. For example, most sondes to the west of the European boundary tend to have solar and infrared corrections applied automatically by the radiosonde system, while most of those to the east are marked as having only solar corrections applied automatically by the radiosonde system. Comparison is also made more difficult by the fact that relatively few sonde reports in the earlier years indicate their radiation corrections or tracking methods.

A relatively few cases were found in which European sondes had the same type of radiation corrections applied to different instrument types. The mean Z^* profiles for instrument types 27, 60, and 61 using solar corrections only are consistent with the results above: types 60 and 61 are close together near 0, and Type 27 profile is offset by 40 to 50 m. Although the reduced sample size (only 6% of all reports) makes the uncertainties much larger, these differences are still significant at the 50 hPa level. This result suggests that infrared corrections are not a factor, although differences in the way solar corrections are applied are still a possibility.

Sondes of the same instrument type but different radiation corrections were also examined. The comparisons are complicated by there being only a few sondes of a given instrument type that differ from the usual radiation corrections, and it is impossible to know how many of these were simply miscoded reports. Nevertheless, for instrument type 61, three different corrections are reported (comprising 37%, 1%, and 1% of all reports), and their mean Z^* profiles are both coincident and consistent with the above results. For instrument type 27, three different corrections were also found (comprising 4.8%, 0.9 %, and 0.8% of all reports). The set with the largest number of reports is consistent with the above results for Type 27. But those Type 27 sondes which have no radiation correction applied exhibit a mean Z^* which is not offset from the Type 60/61/62 sondes. And some Type 27 sondes (solar corrected as specified by country) exhibited an even larger offset, although their uncertainties were much larger as well. These comparisons suggest that the radiation correction for the Type 27 sondes (and presumably Type 28) may give rise to the differences with the Type 60/61/62 sondes. However, the number of reports is too small and their geographical separation too large to make definite assertions.

The tracking techniques used were examined in a similar way. The sonde reports were searched for those having the same code for tracking method. 23% of the reports indicated that the sondes were tracked automatically with auxiliary ranging. Two instrument types make up nearly all of this set: Types 27 (7% of all reports) and 62 (15%). The Z^* profiles for both of these is consistent with previous results, including the offset between two profiles.

Comparisons were also made for the same instrument type but different tracking technique. For instrument type 61, five different tracking methods were found. The two dominant tracking techniques for this instrument type (automatic with multiple VLF-Omega signals, and automatic cross-chain Loran-C, which comprised 19% and 17% of all reports, respectively) are consistent with previous results. Two other techniques (automatic with radio direction finding, with 0.7% of the reports; and automatic with auxiliary ranging, with 0.5%) had mean Z^* profiles that showed differences of 10 to -40 m from the dominant profiles, but their uncertainties were large enough that the differences are not significant at the 99% confidence level. Sondes tracked by satellite navigation (1.2% of all reports), however, showed a profile that was offset by about -30 m from the dominant two tracking techniques, and this offset is significant. (No instrument types to the east were found with multiple tracking technique codes.) These results imply that sonde tracking technique is not a major source for the European wind anomaly, but the sondes tracked by satellite navigation may exhibit a systematic offset from the others.

5. Conclusions

Comparison of deviations of radiosonde geopotential heights from zonal mean values shows small but significant systematic differences between sonde instrument types over a relatively small geographical area. Because the boundary between areas over which the different instrument types predominate have a roughly north-south orientation, they result in a sharp east-west gradient in geopotential height that gives rise to an anomalous meridional wind that is the about the same magnitude as a wind anomaly reported by B98 in several meteorological analyses products. These differences may be related to how the solar radiation correction is applied, but no evidence for a diurnal tidal signal is seen.

A similar region of Z^* differences is seen between Japan and mainland Asia, although with more diversity of instrument types and offsets. These differences are coincident with persistent high meridional winds in several analyses of the summer Northern Hemisphere stratosphere (but not reported in B98). B98 does point out a second region of anomalous meridional wind near 180°longitude, and Figure 1 does show differences in Z^* in sonde reports between North America and eastern Asia. However, this analysis cannot address whether these are related.

A persistent meridional wind anomaly has important implications for trajectory and transport studies. Because zonal winds tend to be small in the summer stratosphere (typically less than $15 ms^{-1}$), a stationary and persistent $5 ms^{-1}$ meridional wind anomaly implies a significant perturbation of the flow through the region. A Lagrangian parcel moving with a typical zonal flow of around $10 ms^{-1}$ and encountering a $5 ms^{-1}$ southerly anomaly over 200 km can have its trajectory deflected as much as 100 km towards the North. Such calculations for the Northern summer stratosphere should therefore be approached with great caution.

Acknowledgments. This research was supported by NASA's Atmospheric Chemistry Modeling and Analysis Program and the Upper Atmosphere Research Program.

The author is also grateful to Paul Newman and Steve Pawson for helpful discussions.

References

Bowman, K. P., K. Hoppel, and R. Swinbank, Stationary anomalies in stratospheric meteorological data sets, *Geophys. Res. Lett.*, *25*, 2429–2432, 1998.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Met. Soc.*, *77*, 437–471, 1996.

Morris, G. A., J. F. Gleason, J. Ziemke, M. R. Schoeberl, Trajectory mapping: a tool for validation of trace gas observations, *J. Geophys. Res.*, *105*, 17875–17894, 2000.

Ivanov, A., A. Kats, S. Kurnosenko, N. Nash, and Z. Zaitseva, Instruments and Observing Methods Report No. 40: WMO International Radiosonde Comparison Phase III, *WMO/TD-No. 451*,, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1991.

World Meteorological Organization, Manual on Codes Volume 1 Part A: Alphanumeric Codes, *WMO No. 306., Supplement No. 7A*, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1994.

Swinbank, R., and A. O'Neil, A stratosphere-troposphere data assimilation system, *Mon. Wea. Rev.*, *122*, 686–702, 1994.

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Received September 30, 2001

Submitted for publication in *GRL*, 2001.

Figure 1. Map of raob instrument types (left) and geopotential height deviations (right). The size (area) of each symbol is proportional to the number of measurements at that station.

Figure 2. (a) Map of locations of sondes examined in Europe. Sondes were selected within 800 km of the line marked; the color of the dots indicates the type of sonde used most at that location. (b) Profiles of mean Z^* for the most prevalent sonde instrument types shown on the map. Uncertainties of the mean (at the 99% confidence level) are shown as cross-hatching. Each profile is labeled with its instrument type ID.

Figure 3. Same as Fig. 2, except for Asian sondes.

Table 1. Instrument Type Codes[a]

Code	Description
21	VIZ/Jun Yang Mark I microsonde (South Korea)
22	Meisei RS2-80 (Japan)
27	AVK-MRX (Russian Federation)
28	Meteorit Marz2-1 (Russian Federation)
32	Shanghai Radio (China)
47	Meisei RS2-91 (Japan)
60	Vaisala RS80/MicroCora (Finland)
61	Vaisala RS80/DigiCora or Marwin (Finland)
62	Vaisala RS80/PCCora (Finland)

[a]From the WMO *Manual on Codes*, [1994]

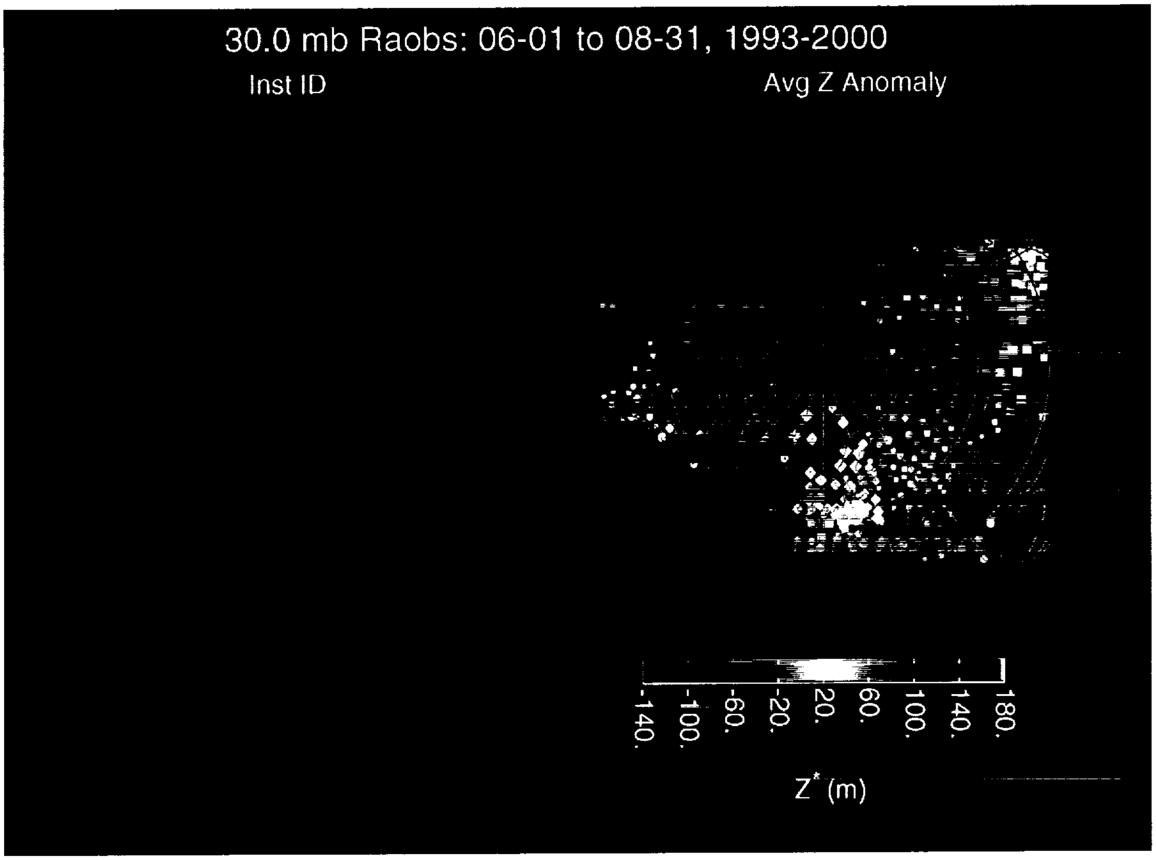
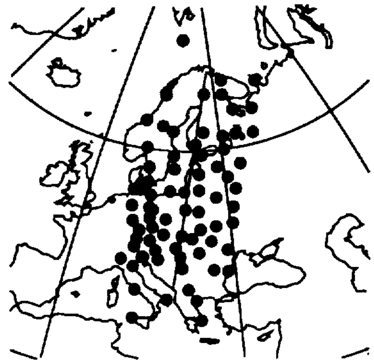
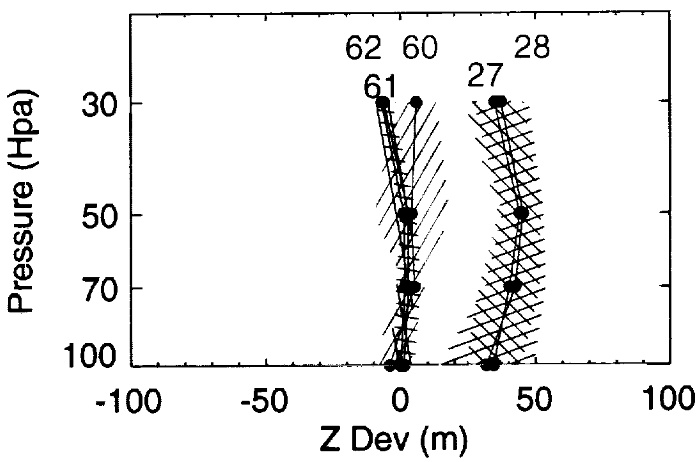

30.0 mb Raobs: 06-01 to 08-31, 1993-2000
Inst ID
Avg Z Anomaly
-140.
-100.
-60.
-20.
20.
60.
100.
140.
180.
Z* (m)

Figure 1



(a)



(b)

Figure 2

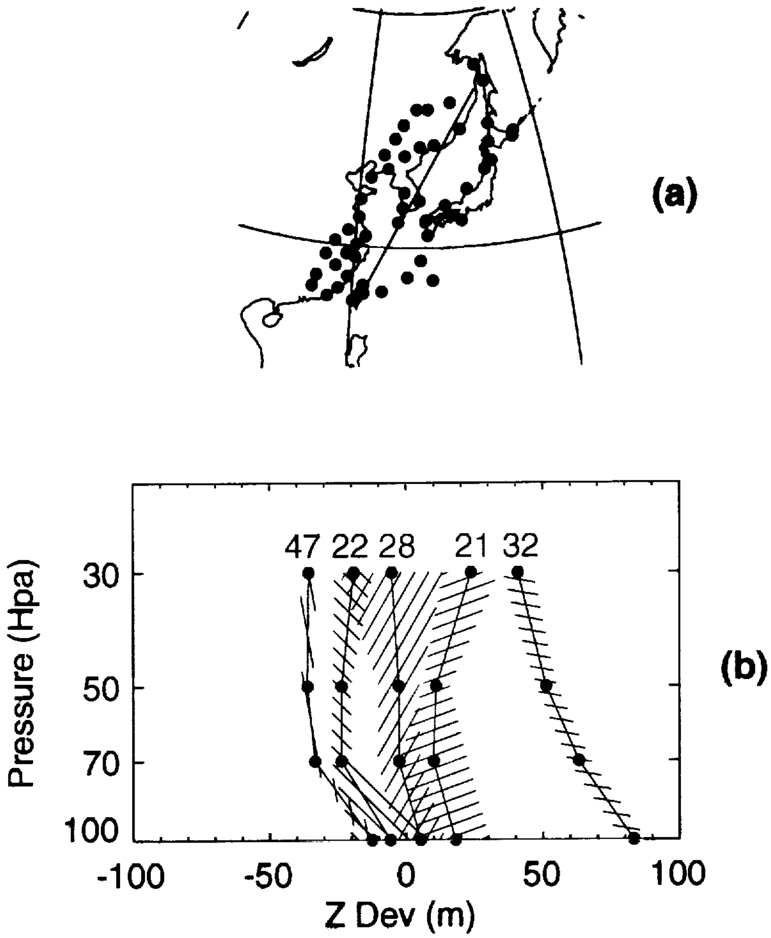


Figure 3

Popular summary of:

Systematic differences between radiosonde instruments

Balloon-borne transmitters called "radiosondes" are launched twice a day around the world to obtain operational meteorological data. We have performed a statistical analysis of these measurements at several pressure levels in the stratosphere, and we find that a small but systematic difference exists in the geopotential height reported by different models of radiosonde over Europe. (Different national meteorological services use different models of radiosondes.) This bias may come from differences in measurement technique used, including possibly a correction which is applied for solar radiation. A roughly north-south boundary is found between areas in which different radiosonde models are used, and this results in a sharp east-west difference in geopotential height. The equations of motion imply that this difference would give rise to an anomalous wind feature. An anomalous feature has been found previously in the winds of several three-dimensional gridded meteorological data sets, which are constructed using the radiosonde data. The anomaly consists of a wind towards the North at 50 hPa pressure (about 20 km in altitude) that remains in one place over eastern Europe during the summer season (June through August), year after year. Although it is weak (only about 5 m/s), it is large enough in comparison with the background winds to affect various calculations, such as tracing parcel trajectories. Thus, the anomalous wind feature appears to be caused by a problem with the radiosonde measurements.