Radiosonde descent reports: encouraging preliminary results

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The radiosonde descent (after balloon burst) offers the possibility of an extra atmospheric profile at little or no extra cost. The Vaisala RS41 software can generate descent reports (currently in BUFR dropsonde format) and since late 2017 test data from Germany and Finland has been put on the GTS. The UK is also collecting descent reports, two months have been provided to ECMWF. The descent rate is faster than the ascent rate, especially at upper levels. Data from these three countries has been processed and compared with the ECMWF short range forecast for January and June 2018. With one caveat (temperature biases, mainly in the stratosphere) the descent data looks similar in quality to the ascent data. Surprisingly, the descent winds fit the background more closely than the ascent winds. This could be because either a) descent winds are less subject to pendulum motion or b) the filtering to remove pendulum motion is oversmoothing the descent winds. Raw wind data (from Lindenberg, Germany) shows some high frequency noise in the descent winds, but also suggests that the (time-domain) filtering needs tailoring for descent data. The steps needed before descent data can be used for operational weather forecasting will be outlined.

Background

Radiosondes ascend for up to about two hours then the balloon bursts and the radiosonde falls back down - with or without a parachute. The meteorological report generally covers just the ascent, although the radiosonde is still transmitting as it falls, and the data can still be received at the ground station until the radiosonde goes below the horizon (or behind a mountain). Unlike dropsondes (eg Hock and Franklin, 1999) normal radiosondes are designed to measure during ascent and descent measurements from them should be viewed with caution until they have been carefully assessed. The Vaisala MW41 software (used mainly with the RS41 radiosonde, but also with some RS92 radiosondes) has the option to produce a BUFR radiosonde message from the descent measurements with some processing (eg radiation correction) performed. The processing is based on that for the ascent, and has not been customised for the descent (discussed further below). The details of the Vaisala processing are not public but the GRUAN RS92 processing (Dirksen et al, 2014) has similar components.

One potentially important factor is the descent rate. During ascent the vertical motion is typically about 5 m/s, it can vary due to strong convection, or due to ice weighing down the balloon. Immediately after balloon burst the descent rate is generally large, even with a parachute, because of the low air density at upper levels, also the parachute may not open fully at first; as the density increases the fall slows, see Figure 1. The radiosondes within the UK used for this study are a) four Autosondes using 350g balloons with a small parachute within the balloon, these normally launch at 00 UTC only and reach around 26km on average and b) two manual stations, Camborne and Lerwick, they use 800g balloons (reaching around 32km) for 00 UTC and 1200g balloons (reaching around 34km) for 12 UTC, these use small external parachutes. There are also some descents from St Helena (15°S in the Atlantic) and Rothera (Antarctica) using 800g balloons without parachutes. For all of these the ascent rates are relatively constant but the descent rates show much more variability, both in the vertical and at a particular level. There are some technical problems calculating the descent rates because there are sometimes levels out of order. In the lower troposphere the mean descent rate for the Autosondes (350 g balloons) is about 4 m/s whereas the mean descent rate for Camborne/Lerwick with 1200 g balloons is about twice that - thought to be due to the weight of the balloon remains. Without a parachute (bottom right) the lower level descent rate is higher still, about 13 m/s.

Looking at data from Meisei radiosondes in southern India, without a parachute, Venkat Ratnam et al (2014) found “The descent rate initially is as high as 60 m/s and drastically decreases with increase of density to almost 10 m/s before it reaches the ground. Wild fluctuations in descent rate can be noticed, which probably can be attributed to tumbling of the radiosonde, …”

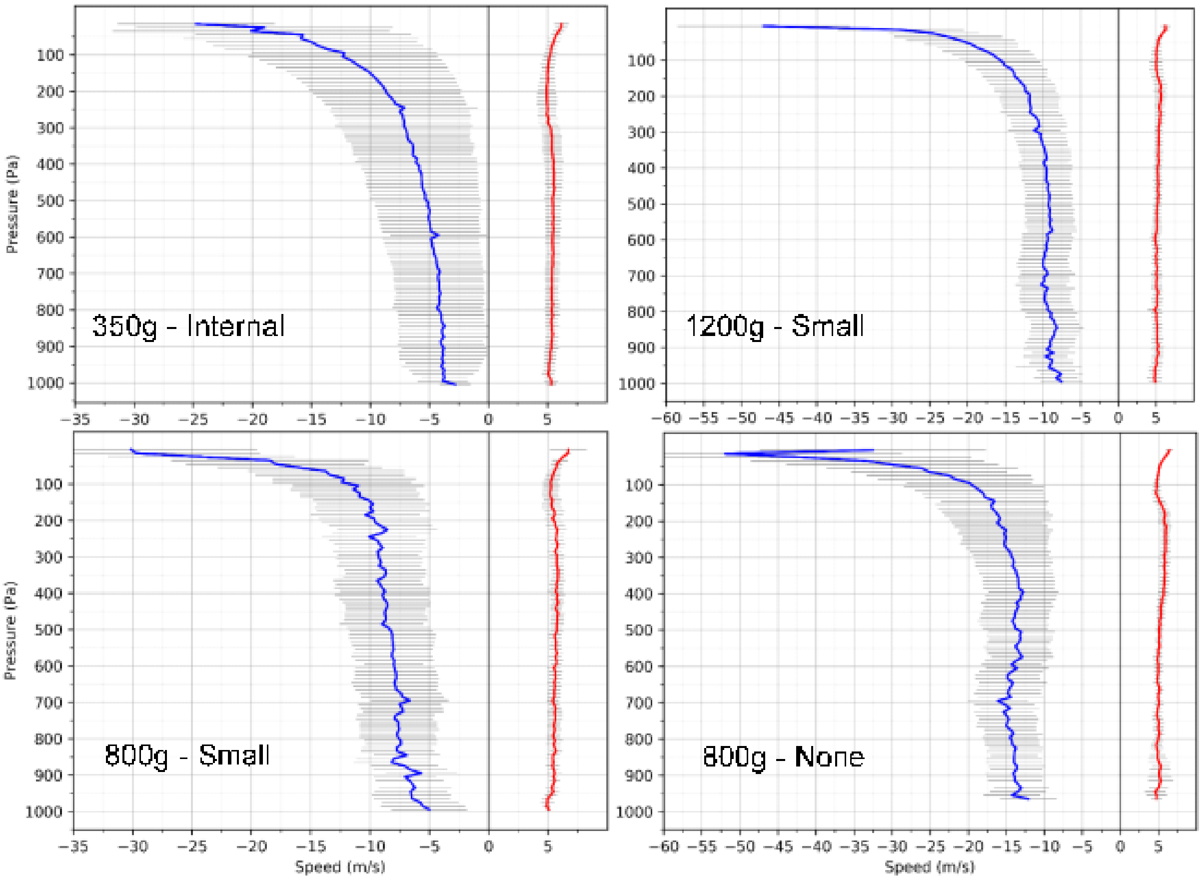

Figure 1. Ascent and descent rates for UK radiosondes, January and June 2018 combined. Thick coloured lines indicate median vertical speeds within that pressure bin, the horizontal grey bars indicate the corresponding standard deviation for the pressure bin. Red is ascent rate, blue is descent rate. Figure courtesy of Chris Wyburn-Powell.

Comparison with ECMWF background fields

On 5 June 2018 ECMWF started taking radiosonde drift into account in its NWP system - for those stations where we use the BUFR reports. This improves the rms O-B statistics by 5-10% at upper levels (Ingleby et al, 2018). A further development allowing the use of BUFR dropsonde reports (the format currently used for descent data) was used in this study. In the assimilation the ascents were split in 15 minute sections (as used operationally) and the descents into 5 minute sections; each section is treated as having the latitude, longitude and time of its lowest point.

The available descent data from Germany, Finland and the UK for January and June 2018 were processed in trial runs of the ECMWF NWP system. The German radiosondes use parachutes, the Finnish ones do not and thus have faster descent rates. Figure 2 gives an idea of the radiosonde drift in June 2018. In January 2018 (not shown) the drifts were generally further and mainly towards the East. The current descent reporting does not include a station identifier, gross statistics can be produced for latitude/longitude boxes but the lack of identifier complicates more detailed statistics. We use the degree of agreement with the ECMWF short range forecast (the background) as the main metric of observation quality. Over 95% of ascents have matching descent reports, most of the descents reach 700 hPa but the numbers available decrease below that.

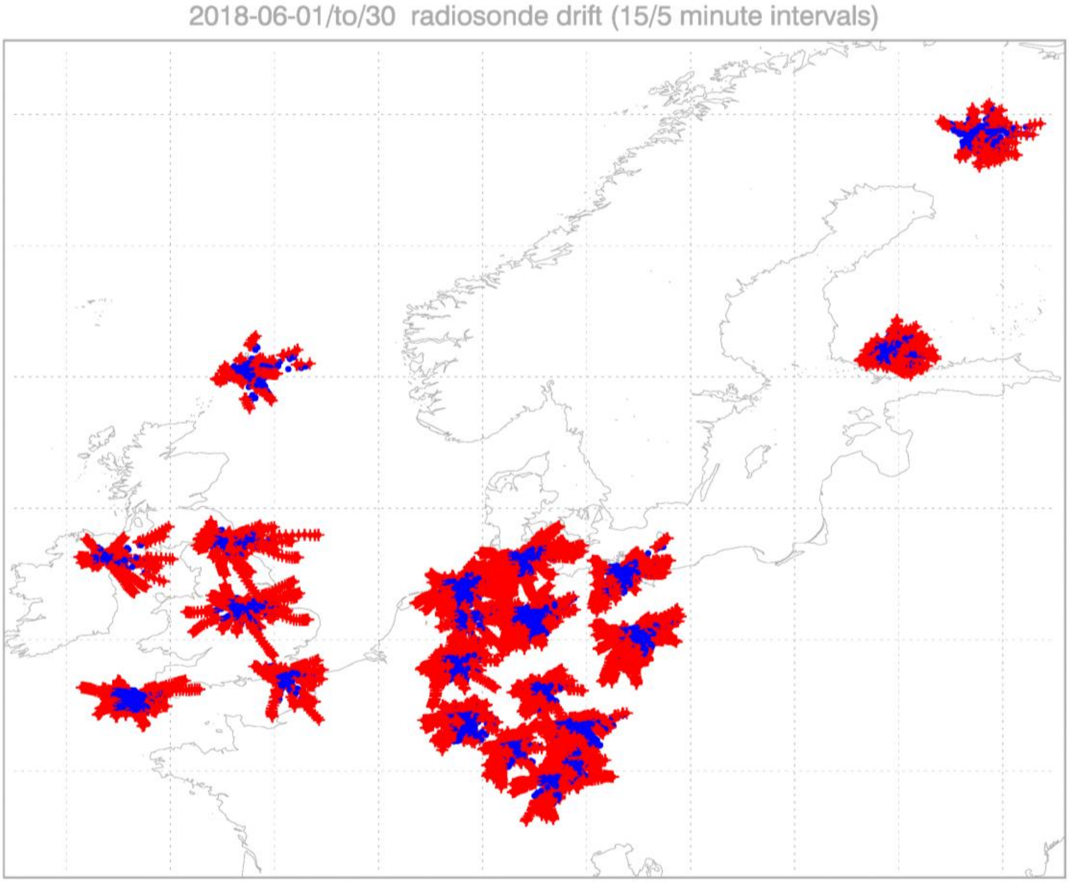

Figure 2. Radiosonde positions every 15 minutes for ascent (blue) and 5 minutes for descent (red): June 2018 showing only those radiosondes providing descent data (other radiosondes were processed as normal).

Figures 3, 4 and 5 show O-B statistics for June 2018 for the three countries (for comparison Ingleby, 2017, shows O-B statistics for different latitude bands and radiosonde types). Partly because of the larger sample size the German stations provide the smoothest O-B statistics. Mostly the descent statistics look similar to the ascent statistics with two main differences: larger temperature biases at upper levels and smaller vector wind root mean square (rms) differences, most marked at upper levels. The ECMWF background has a cold bias at lower stratospheric levels, this is the main reason for the mean O-B ascent difference at these levels. The descent temperatures are slightly warmer than the ascent reports. For the Finnish data (Fig 4) some descent bias extends into the troposphere and the descent standard deviation (SD) is slightly larger for temperature. For the UK temperature data (Fig 5) there is a slight bias in the troposphere and the SD is marginally larger for descent, these features disappear if the statistics are restricted to the central three autosondes (not shown). Thus there may be a link between descent rate and the descent temperatures being too high, but more work is needed on the details. The relative humidity (RH) descent statistics look (perhaps surprisingly) similar quality to the ascent statistics, although the background humidity is a less useful reference than background temperature and wind. The descent wind rms looks very good compared to the ascent wind - discussed in the next section. Broadly speaking the January 2018 results for Germany (Fig 6) are similar except for a reduced descent temperature bias in the stratosphere and of course the seasonal differences caused by the tropopause height and differences in synoptic variability. Statistics for St Helena (not shown) are most similar to those from Finland in terms of ascent/descent differences, the sample from Rothera is rather small.

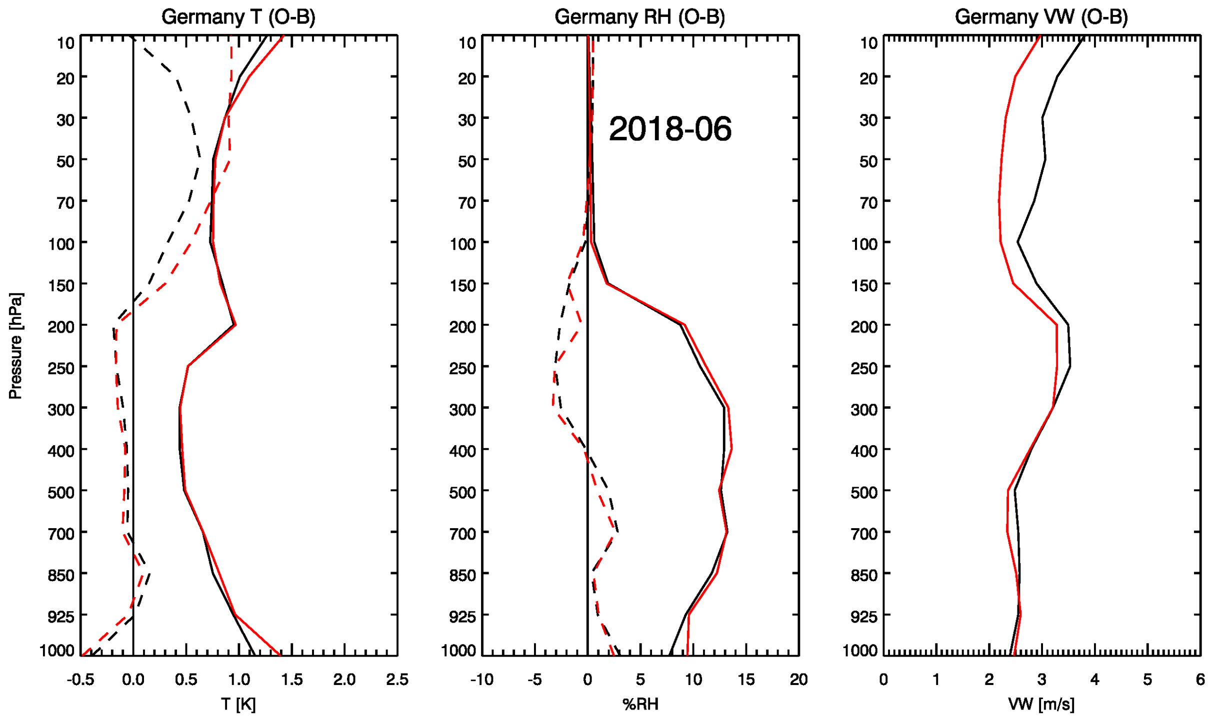

Figure 3. O-B statistics for Germany, June 2018, temperature and RH mean (dashed) and standard deviation (solid) and rms vector wind. Black - ascent, red - descent.

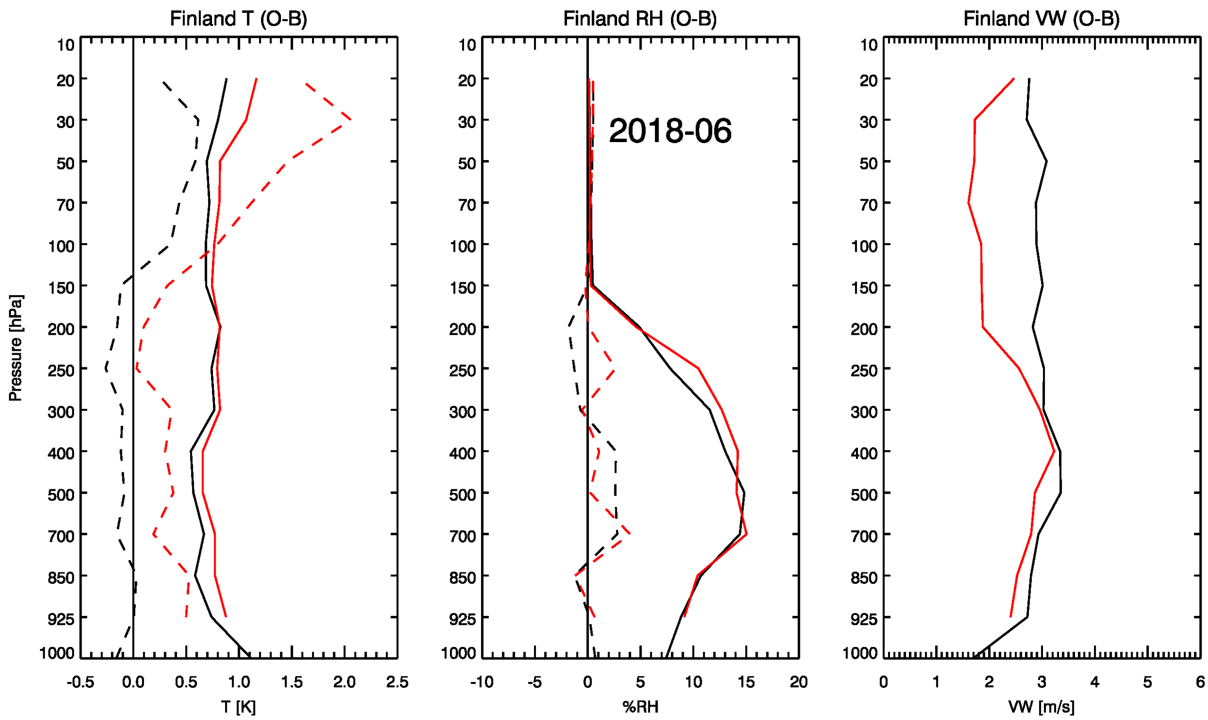

Figure 4. As figure 3 but for Finland, June 2018.

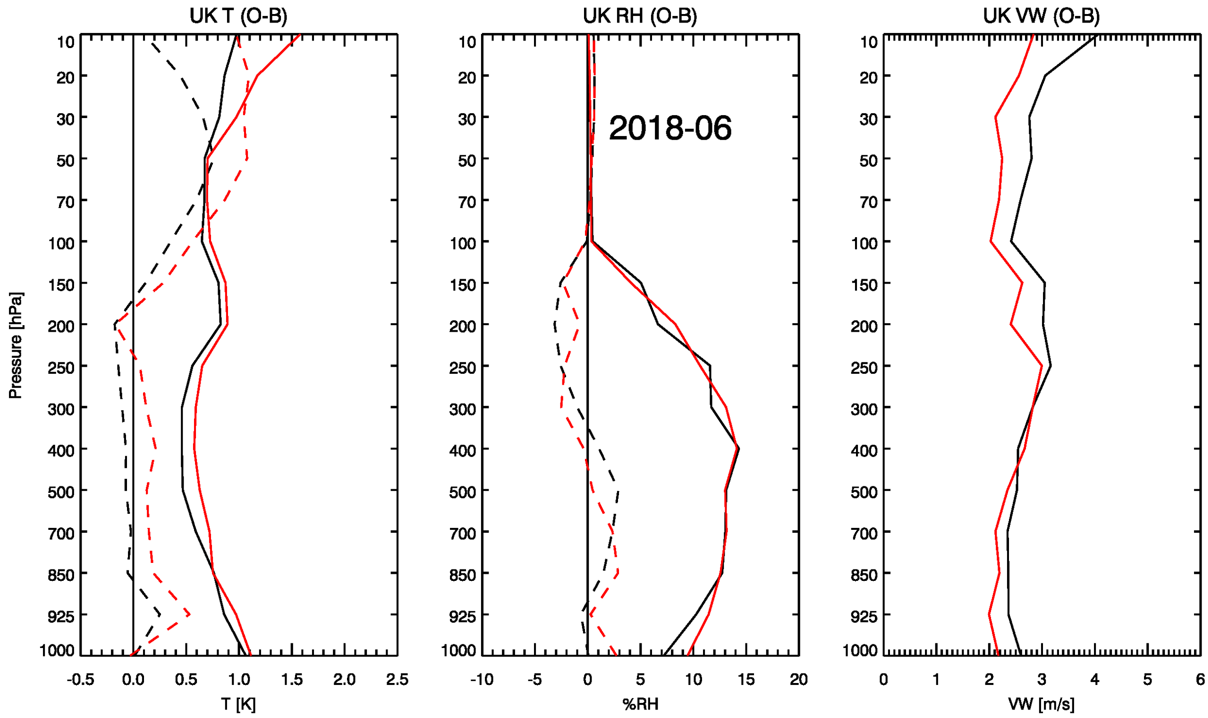

Figure 5. As figure 3 but for the UK, June 2018.

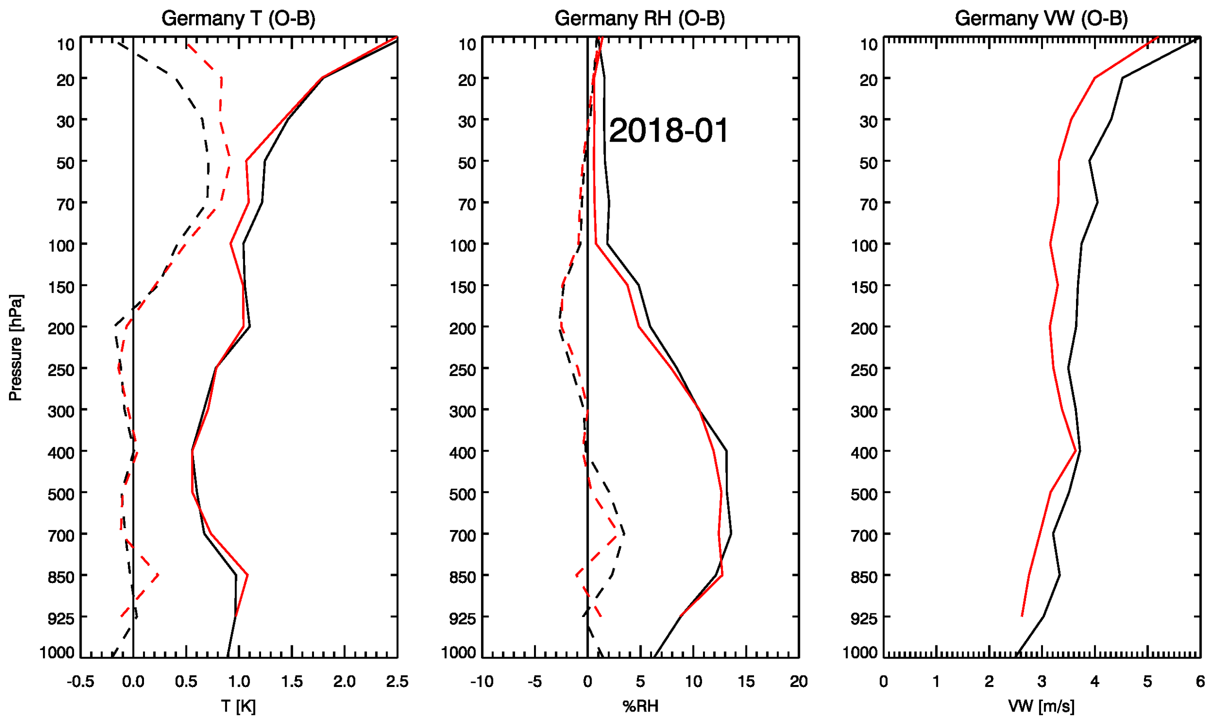

Figure 6. As figure 3 but for German stations in January 2018.

A closer look at winds

Figure 7 shows a matched ascent and descent profile of winds from the BUFR reports, we don't expect them to be identical because there are modest differences in position and time (the background winds, dashed, are similar but not identical. What is clear is that the descent winds are smoother than the ascent ones (which will help to give smaller O-B differences). This is generally the case although not true for all profiles. A few descent profiles show slightly suspicious 'waves' in the lower troposphere.

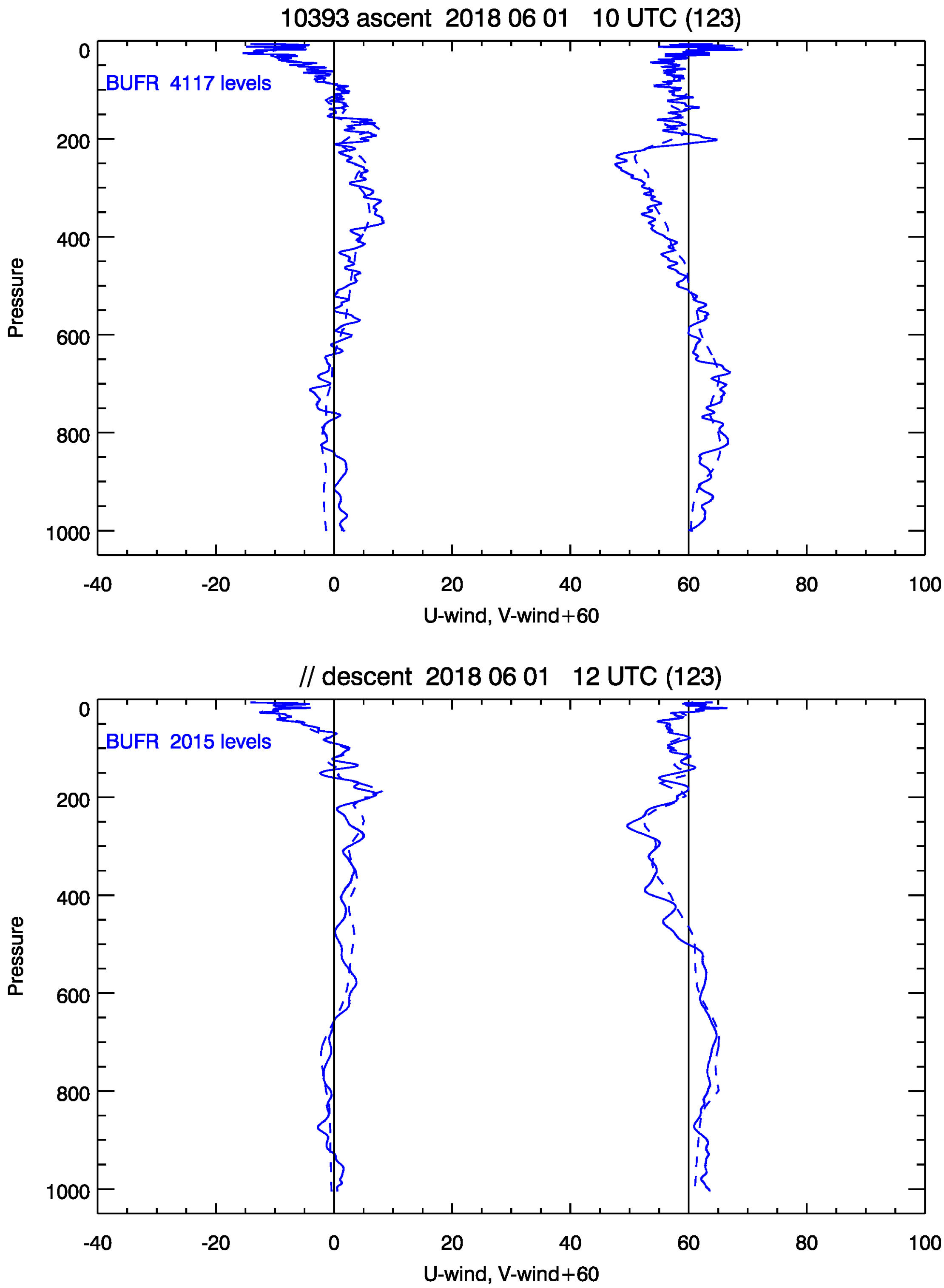

Figure 7. Ascent (top) and descent (bottom) winds, solid lines, from Lindenberg BUFR reports 12 UTC 1 June 2018 (ECMWF background dashed). 60 m/s has been added to the v component.

Raw data for a different case are shown in Figure 8. There is clearly some high frequency noise, presumably pendulum motion, in the ascent winds. There is also some noise (pendulum or other motion) in the upper part of the descent but this is reduced after 7000 seconds. This is not atypical (of the ~40 raw profiles examined) but some profiles show much larger amplitude noise in the ascent or descent. There are also some lower frequency, presumably realistic, waves visible in Figure 8.

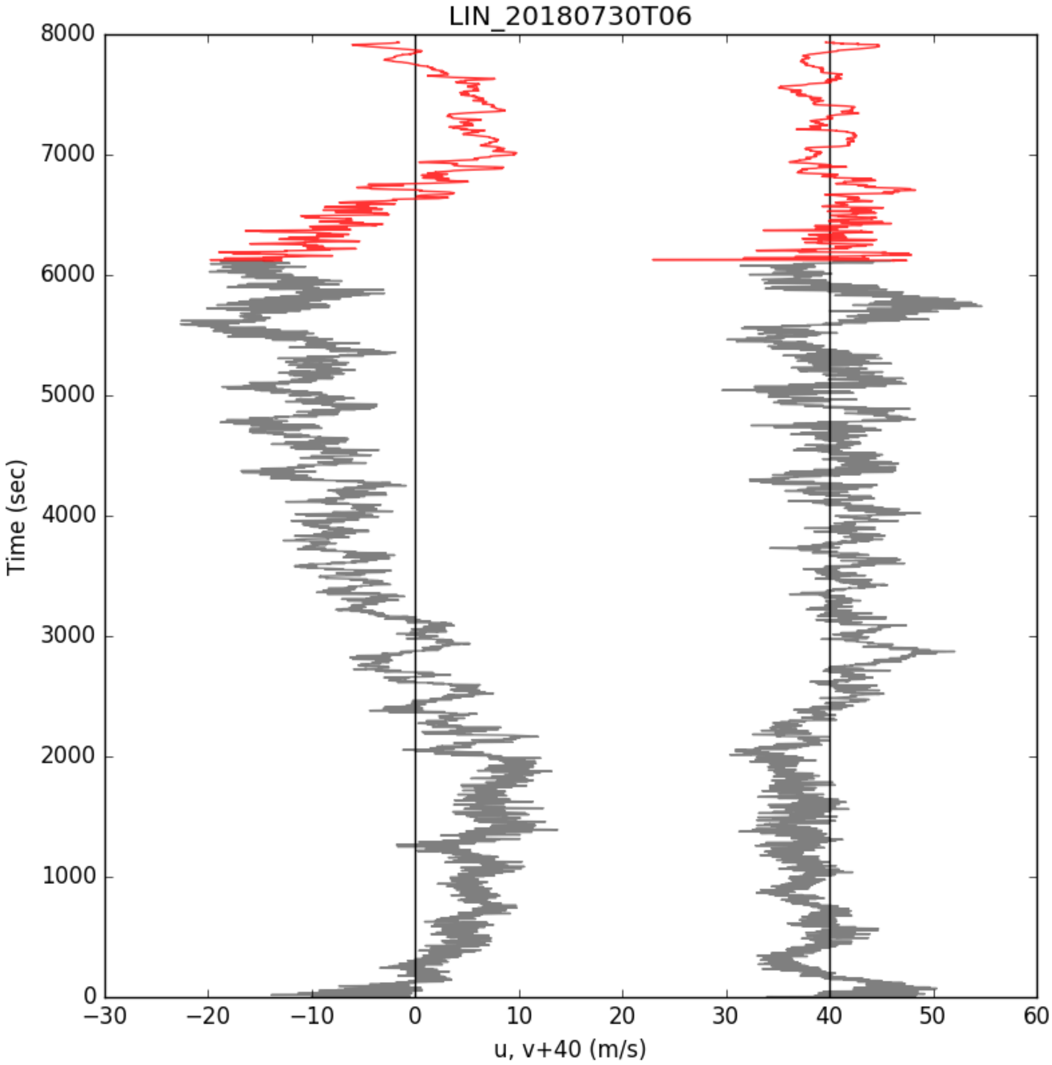

Figure 8. Raw one second GPS winds from a Lindenberg ascent (grey) and descent (red) plotted against time - different case to figure 6. Data courtesy of Michael Sommer.

Vaisala apply a digital filter to the winds before producing the meteorological (BUFR) reports - in order to remove pendulum motion and for smoothing in general, the same time filter is applied both to ascent and descent data (A Lilja and H Jauhiainen, pers. comm. 2018). It is possible that the stratospheric Finnish winds (Figure 4) have a particularly close fit to the background because of oversmoothing due to a fast descent there (without parachute). The fundamental question is how much of the variability in the raw data (such as Fig 8) is measurement noise and how much is due to real atmospheric motion? There is no clear answer to this question. (With an experimental two balloon set up Kräuchi et al, 2016, reported much less pendulum motion in ascent winds.) Radiosonde winds have been subject to much less investigation than radiosonde temperatures and humidities, partly because climate studies tend to focus on the latter, partly perhaps because winds were seen as a 'solved problem'. Also intercomparisons with multiple radiosondes on one rig (eg Nash et al, 2011) may have different pendulum motion to operational radiosondes. GPS radiosonde winds appear to be very good quality on the whole (and largely bias free) and this also appears to be true of the descent winds, but how best to filter out noise deserves more attention.

Discussion - steps towards operational and future use

One practical step is for descent data to use the newly approved BUFR sequence (309056) tailored for descent data (including the station identifier). Vaisala are planning make this available with a software release in 2019. There are also some issues with levels out of order that will hopefully also be addressed. Some have asked if the ascent and descent should be reported together - from NWP the answer is clearly no, partly on the grounds of timeliness and we may well want to apply some differences in processing and quality control to the descent data.

As discussed in the previous section it seems that the filter applied to the wind data should vary with the ascent/descent rate, the timescale for this is unclear. There also appears to be some descent rate dependence to (stratospheric) temperature biases. One approach, in an NWP system, would be to reject upper level descent temperatures (this would be easy to do based on pressure, more difficult based on descent rate) and the data loss would be fairly minor because the upper part of the descent is close in space and time to the ascent. Some fast falling radiosondes, particularly without parachutes, have a slight warm bias in the troposphere and marginally worse SDs there: this is worth further investigation (how constant in time is the bias?) and a decision on how to treat these data. Is there any need to reject wind data for a short time immediately after balloon burst? NWP centres may want to apply slightly different 'observation errors' to descent data. Over the next year or two Vaisala will reduce the weight of the RS41 by changing the outer casing, this "soft and light" version has the potential to affect the descent rate and hence the descent data. It might be best to wait for this transition and re-assess the data before operational use of descent data. There has been some experimental evaluation of Meisei descent data (Venkat Ratnam et al, 2014, also JMA, pers. comm.) but there is no move towards regular usage of such data that we are aware of.

There are longer term questions about the interface between radiosonde measurements (both ascent and descent) and NWP. Some in situ data (a temperature measurement in a Stevenson screen for example) are just reported 'as is'. However quite a lot of processing applies between raw radiosonde measurements and the reports sent on the GTS: temperature spike removal, radiation corrections, humidity time lag corrections, pendulum motion filtering for winds. (Many NWP centres perform some bias correction, on top of the 'radiation correction' performed at source, which is a bit unsatisfactory.) An alternative model would be for NWP centres to do some or all of these - one reason being that filtering can introduce error correlations between two points that were previously uncorrelated. For example an NWP system could estimate the effect of humidity time lag when 'interpolating' from model fields to radiosonde profiles and take account of this (via its adjoint) in the assimilation system (suggested by J Eyre, pers. comm. 2018). In principle this is a better way to use the measured data, but whether the effort of changing the processing and reporting systems is worthwhile isn't clear. For winds it may not be necessary to remove the 'noise' (provided that it averages to zero), NWP centres could superob/average the data perhaps onto model layers (this is effectively what the Met Office assimilation system does, see Ingleby and Edwards, 2015, supplemental material). Clearly this also requires a change of mindset and (unlike much satellite data) there would be the question: what should the forecasters see? One possible answer would be for both raw data and processed data to be provided, and in some ways this would be 'the best of both worlds'.

Summary

Two months of descent reports from three European countries have been processed within the ECMWF NWP system (without being assimilated). The fit to the ECMWF background is generally good and similar to that of the ascent data - except for a temperature bias in the stratosphere, and a smaller bias in the troposphere for rapidly descending radiosondes. Some of the radiosondes, notably the German ones and the UK autosondes show no ascent/descent bias in the troposphere. The descent winds show a closer fit to the background than the ascent winds, this surprising result may be due to oversmoothing of the descent winds, the filtering of both ascent and descent winds should be examined. For NWP the winds are as important, or more so, than the temperatures, but they tend to receive less attention. In the longer term the interface to NWP could be rethought - with NWP using a raw version of the measurements. In the relatively short term it should be possible to make fairly minor changes and assimilate much of the descent data with (hopefully) positive impact and at minimal cost.

Acknowledgements

Chris Wyburn-Powell (a summer student at the Met Office) provided valuable input. At ECMWF Tomas Kral and Ioannis Mallas helped in processing the data. DWD and FMI provided the German and Finnish data via the GTS. Hannu Jauhiainen and Aki Lilja of Vaisala provided useful information as did Michael Sommer and Christoph von Rohden of DWD. At a meeting in April 2018 Alexander Cress (DWD) and Alexis Doerenbecher (MeteoFrance) showed early results that were comparable with the ECMWF ones.

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