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Improved use of atmospheric in situ data

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Improved use of atmospheric in situ data

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Atmospheric in situ observations from surface stations, aircraft and radiosondes are important both for direct use in the ECMWF data assimilation system and for diagnostics. Radiosonde and surface observations also help to control biases in the assimilation system. However, like other Earth system data, in situ observations can be complex to interpret and close attention to quality control, observation uncertainty and in some cases bias correction is needed to optimise their use.

This article describes a range of recent improvements in the use of atmospheric in situ observations at ECMWF. One of these has been made possible by the gradual transition in reporting such observations from alphanumeric codes (such as TEMP and SYNOP) to Binary Universal Format for the Representation of meteorological data (BUFR): extra information in BUFR enables balloon drift to be taken into account in the assimilation of radiosonde data. A change to this effect will be implemented in the next upgrade of ECMWF's Integrated Forecasting System (IFS Cycle 45r1).

Other improvements in the next IFS upgrade include better bias correction and reduced thinning of aircraft data. ECMWF has also begun to use varying uncertainty estimates for different types of radiosondes. All these changes improve the quality of ECMWF's forecasts. Further current developments include the use of solar radiation measurements from surface stations to verify predicted surface fluxes and the monitoring of radiosonde descent reports to see what use can be made of them.

Radiosondes

The change from alphanumeric to BUFR format requires significant software changes at the radiosonde stations and downstream. In return it makes it possible to report at much higher vertical resolution, providing the position at each level plus extra precision and metadata (*Ingleby et al.*, 2016). Figures 1 and 2 show how the provision of high-resolution reports has progressed, but there is still much to do. High-resolution reports were initially mainly available from Europe. In late 2015, Australian stations were added, and in the second half of 2017 most stations in the USA started sending high-resolution data. With contributions from other countries there are now some high-resolution reports from each continent. However, there are still large areas with no acceptable BUFR data. ECMWF thins the levels in the vertical (from often between 3,000 and 6,000 to about 350) before assimilation. ECMWF's use of 'significant levels' (turning points) in alphanumeric reports is not optimal (*Ingleby et al.*, 2016), so this provides an additional reason to move to high-resolution reports.

When new BUFR bulletins are received at ECMWF, the data are monitored for a while before being assimilated. Occasionally changes to the decoding software are needed to cope with new features in the messages. Sometimes data producers are notified of problems in the messages. The rolling implementation in the assimilation is needed to ensure that ECMWF is using the BUFR reports before the alphanumeric reports cease to be distributed.

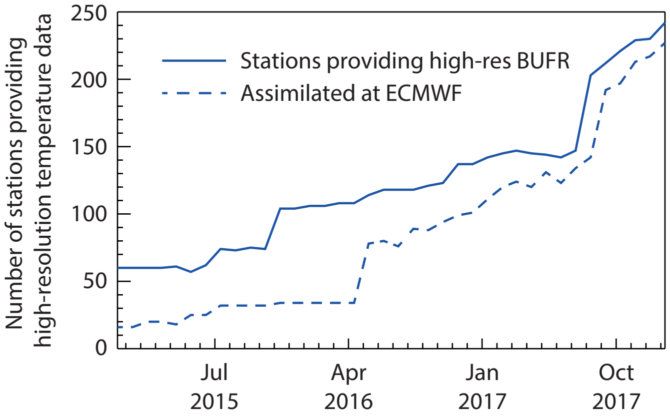

Figure 1 The number of land stations providing at least five high-resolution temperature profiles per month and the number of such stations assimilated at ECMWF. About 800 stations in total provide five or more temperature profiles per month in TEMP and/or BUFR format.

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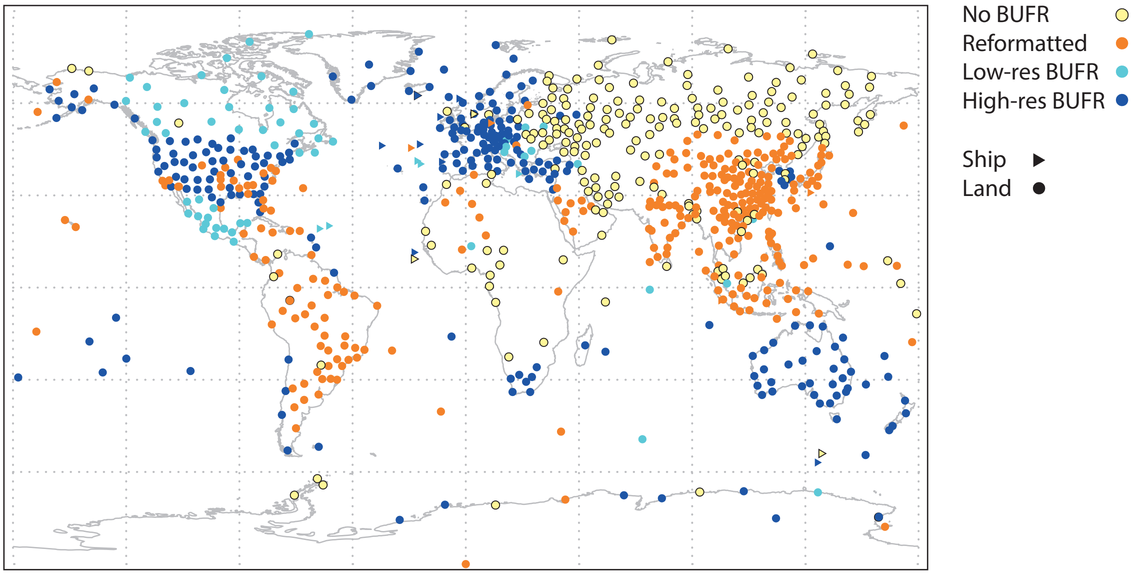
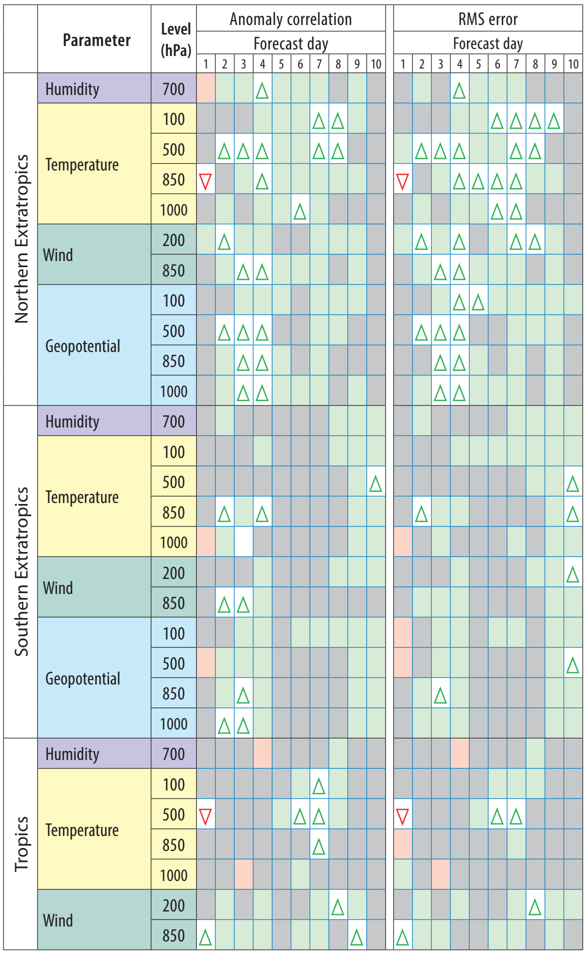


Figure 2 Radiosonde stations reporting in January 2018. Nearly a third of the 814 stations (31%) provided high-resolution reports and a further 8% provided low-resolution reports with drift positions. Reformatted TEMP reports (36%) are problematic and are not assimilated at ECMWF. In general, ECMWF uses the alphanumeric report if a BUFR report is not available or not assimilated.

A detailed report (*Ingleby*, 2017; part of a contract for Vaisala Oyj) has been produced looking at the quality of different radiosonde types, mainly by investigating how the observations compare to a 12-hour forecast known as the background within the data assimilation system. Such observation-minus-background ('O–B') statistics can be used to compare the quality of different subsets of observations. The statistics vary with latitude and height and also, particularly for temperature and upper tropospheric humidity, by radiosonde type. Until recently the ECMWF assimilation system used the same observation uncertainty estimates for all radiosonde types, but in July 2017 a change was made to vary the uncertainty estimates and also reduce the default humidity uncertainties. As shown in Figure 3, this change has had a generally positive impact on forecast scores. Unfortunately there was an error in the scaling of the temperature uncertainties, which will be corrected in the next IFS upgrade planned for later this year (IFS Cycle 45r1).

One advantage of BUFR radiosonde reports is that the position at each level can be reported. A radiosonde ascent takes about two hours and, as shown in Figure 4, during that time the radiosonde can move horizontally by 200 km or more. Only launch location is available for old-style TEMP data, so in data assimilation systems the profile has generally been treated as vertical and instantaneous. As the resolution and accuracy of data assimilation systems improve, this approximation becomes less appropriate and better treatment of the drift can improve analysis and forecast performance (*Laroche & Sarrazin*, 2013). Analogous improvements have been made to account for the slant path of satellite soundings (*Bormann*, 2017).

Processing of radiosonde drift (for stations where ECMWF is assimilating BUFR data) will become operational in IFS Cycle 45r1. For technical reasons the processing splits each profile into 15-minute intervals, and observations from each interval are treated as vertical and instantaneous. The intervals may be shortened in the future. As shown in Figure 5, the change improves stratospheric wind and temperature O–B standard deviation values by between 5 and 10% for stations reporting drift positions. In the upper troposphere, wind O–B standard deviation values are improved by several per cent. Biases are also improved, especially for wind. In the extratropics there are improvements of about 1% in 50 hPa wind root-mean-square verification against analyses for two-day forecasts. At longer range there are smaller improvements in the troposphere, which are more apparent in the southern hemisphere than in the northern hemisphere. These modest forecast improvements (not shown) were obtained when about 15% of radiosonde stations were reporting drift positions – the benefits should be greater when more stations take full advantage of the new features in BUFR (in the year since then the proportion has increased to 31%).



Symbol legend: for a given forecast step...

▲ Expt A better than expt B statistically significant with 99.7% confidence

△ Expt A better than expt B statistically significant with 95% confidence

🟩 Expt A better than expt B statistically significant with 68% confidence

⬜ difference between expt A and expt B statistically insignificant

🟥 Expt A worse than expt B statistically significant with 68% confidence

▽ Expt A worse than expt B statistically significant with 95% confidence

▼ Expt A worse than expt B statistically significant with 99.7% confidence

Figure 3 Scorecard comparing forecasts with varying observation uncertainty by radiosonde type (experiment A) with forecasts without varying observation uncertainty (experiment B) over the period July to September 2015.

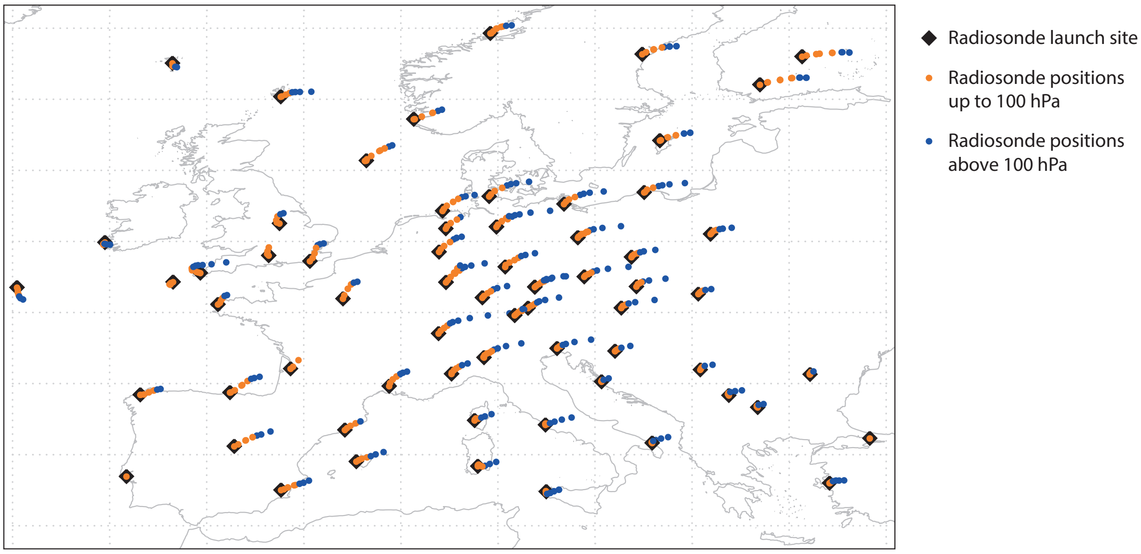


Figure 4 Radiosonde drift over Europe in the 12 UTC analysis on 21 November 2016. Only BUFR reports are shown. A few of these were reformatted and do not include drift positions. Positions are shown every 15 minutes.

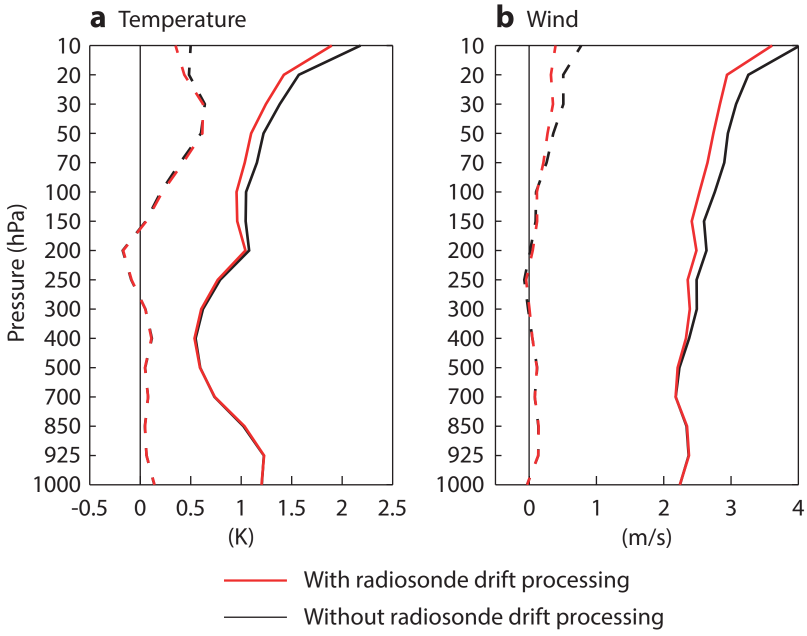


Figure 5 Standard deviation (solid lines) and mean (dashed lines) radiosonde observation-minus-background (O–B) statistics for European stations with and without drift processing for (a) temperature and (b) zonal (east–west) wind, for November 2016 to February 2017. Meridional (north–south) wind has similar statistics to zonal wind, and results for Australia plus New Zealand are broadly similar but with slightly less improvement in the standard deviation.

Over the last two years there have also been changes to radiosonde humidity conversions to improve consistency between assimilated radiosonde data and model fields in the upper troposphere (*Ingleby*, 2017). In addition, a relaxation of the quality control has been introduced to reduce rejections of radiosonde temperature and wind data in the stratosphere.

Dropsondes (dropped from aircraft) are available intermittently, often in the vicinity of tropical cyclones (TCs). Typically they improve TC analyses and forecasts, but there are cases where they are badly handled and degrade the TC analysis. The quality control and weighting of dropsonde data was recently made more robust (*Bonavita et al.*, 2017). Particularly for profiles near the eye-wall of a storm, taking into account the location of the dropsonde at each level may be very important. Test high-resolution BUFR files from US dropsondes with position information at each level have been obtained and impact experiments will be run in the coming months.

Aircraft

Aircraft observations are very valuable for global NWP. However, the temperature values are typically biased by between 0.2 and 0.5°C, depending on the aircraft. In November 2011, ECMWF implemented a variational bias correction scheme similar to the one applied to satellite soundings. It uses the aircraft tail identifier as a predictor for bias for all observations from each modern-style AMDAR (Aircraft Meteorological Data Relay) report. But it is not applied to the smaller number (5 to 10% of the total) of old-style voice reports (AIREPs), where it is not possible to identify the aircraft.

A new version of the bias correction scheme has been developed for all aircraft data types and will become operational in IFS Cycle 45r1. The new version takes account of the fact that ascent, descent and cruise aircraft temperature biases vary slightly. It does this by including three aircraft-specific bias predictors (cruise, ascent and descent) rather than just one. Three methods to represent the flight phase in the variational bias correction scheme have been tested. The first uses *dp/dt* (pressure change) computed from successive aircraft measurements, the second uses *dz/dt* (height change) computed from successive aircraft measurements, and the third method uses the cruise/ascent/descent status provided with the AMDAR aircraft measurement to set a fixed ascent/descent rate. The best results are obtained when *dz/dt* is used, which is as one would expect, so this method was selected.

The new version of the scheme has also been used to show that it is beneficial to perform a bulk bias correction of the old-style AIREP temperature observations, because the biases are fairly uniform. The old-style AIREP observations are concentrated in the North Atlantic flight routes between Europe and the USA, where they account for up to 50% of cruise level aircraft reports. Figure 6 shows how the bulk bias correction of old-style AIREP results in up to 0.5°C mean cooling of the analysis and forecasts at 200 hPa, near cruise level. The bias correction of old-style AIREP temperature observations has been applied to the new ERA5 reanalysis, leading to improvements compared to ERA-Interim in the North Atlantic region.

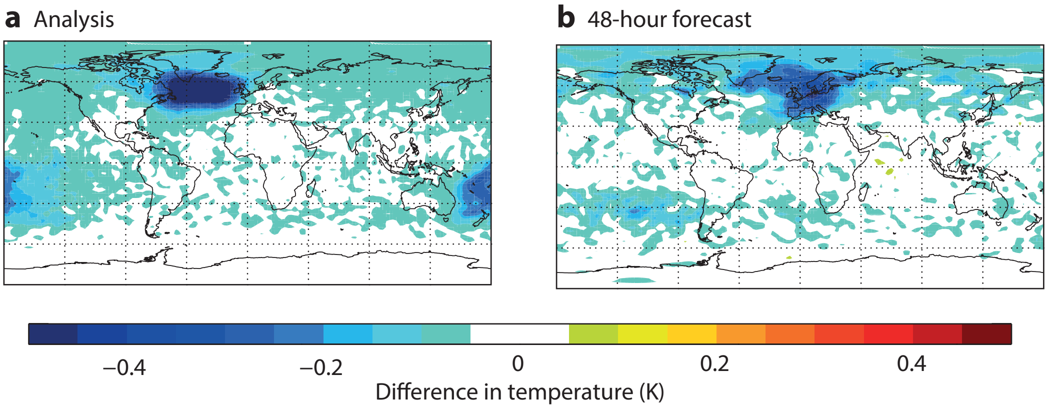


Figure 6 Mean differences in temperature at 200 hPa averaged over 50 days in June–July–August 2016 using the new and the old bias correction scheme ('new' minus 'old') for (a) the temperature analysis at 200 hPa and (b) 48-hour forecasts at 200 hPa. Blue shading means the new bias correction cools the analysed/predicted atmosphere.

Since November 2017, almost all the aircraft that provide old-style AIREPs have provided AMDARs as well (but not exactly at the same positions or using the same identifier, making thinning difficult to handle). With the tail identifier available, we can now bias-correct these aircraft data like other AMDARs. This has had a similar effect on 200 hPa temperatures to that shown in Figure 6. With the availability of the data in AMDAR format and because the operational analysis is not yet able to bias-correct the old-style AIREP temperature data, it was decided to stop assimilating the uncorrected AIREP temperatures from 10 January 2018.

As part of the IFS Cycle 45r1 upgrade of aircraft data assimilation, aircraft observations will be rejected very close to airports (lowest 30 hPa) due to large biases in such locations, which are particularly big for temperatures over runway tarmac. Data thinning will also be reduced by a factor of two to 35 km horizontally and 7.5 hPa vertically, to be more in line with the forecast and analysis resolution upgrade introduced in March 2016. Figure 7 shows that the reduced thinning results in 10 to 20% more aircraft data being used at around 850 hPa and at or near cruise level.

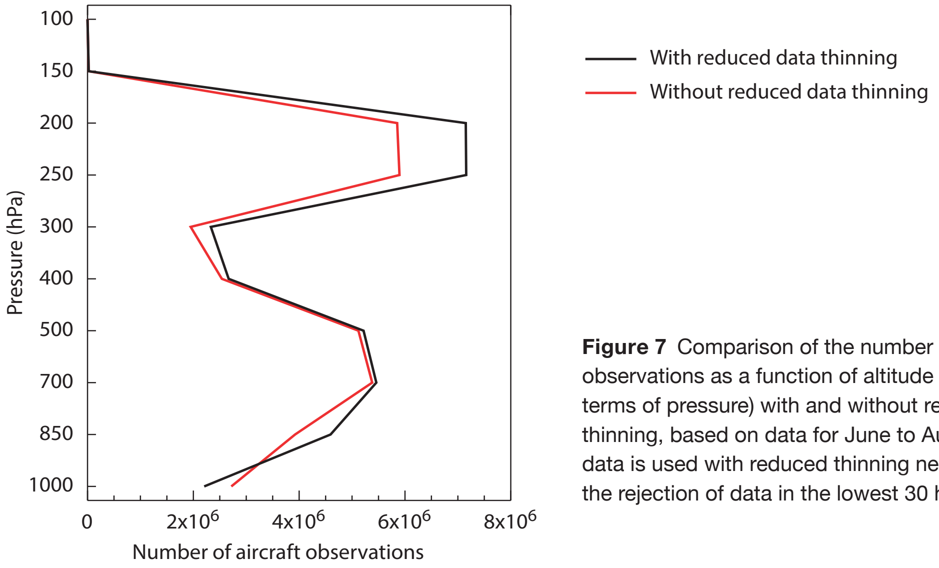


Figure 7 Comparison of the number of aircraft observations as a function of altitude (expressed in terms of pressure) with and without reduced observation thinning, based on data for June to August 2016. Less data is used with reduced thinning near the surface due to the rejection of data in the lowest 30 hPa.

The total effect of the improved bias correction and thinning of the aircraft data improves the analysis and forecasts. As shown in Figure 8, the changes reduce the standard deviation O–B values for not just aircraft and radiosonde temperature observations, but also GPS-RO bending angle data. The bending angle is related to temperature, and also to humidity at lower levels. There is also a reduction of about 0.1 K in radiosonde temperature O–B biases at 100–300 hPa (not shown).

In recent months wind errors for certain aircraft have been noted over the North Atlantic and some of these have been placed on a reject list. We understand that these are B787 aircraft and have contacted the data providers (in the USA) to try to resolve the problem in the longer term.

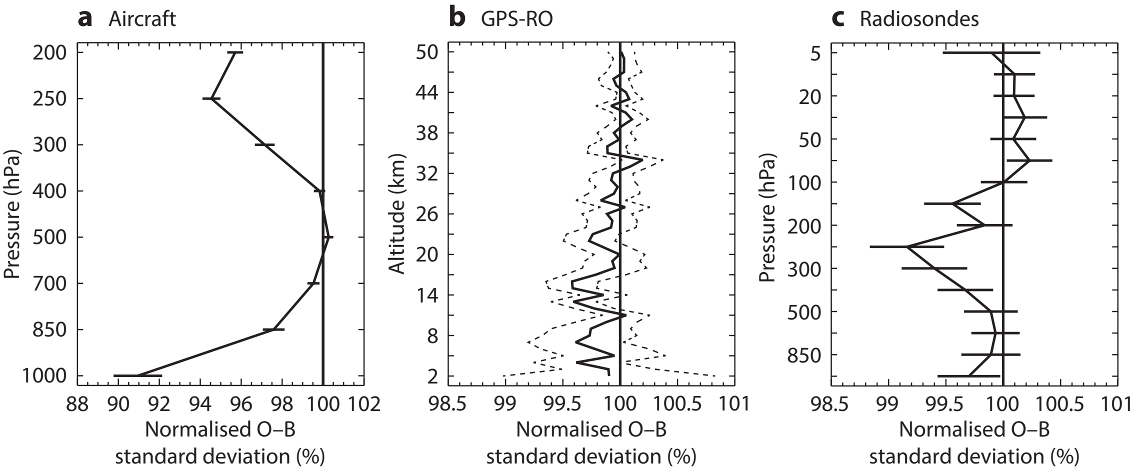


Figure 8 Normalised observation-minus-background (O–B) standard deviation for (a) temperature data from aircraft, (b) normalised bending angle for GPS-RO and (c) temperature data from radiosondes when improved bias correction and thinning of aircraft data is applied. Sections of the lines that lie to the left of the 100% mark denote improved O–B statistics. Horizontal bars and dotted lines represent 95% confidence intervals.

Surface

Interest in solar radiation measurements is increasing, partly because of the growth in photovoltaic electricity generation. Radiation measurements are also useful for validating predicted surface radiation fluxes, which are strongly affected by cloud forecasts. For many years NWP centres have performed verification of cloud forecast skill against surface station data based on SYNOP observations of total cloud cover and, where available, low, medium, and high cloud cover. However, cloud cover is not a particularly well-defined quantity, especially for cirrus clouds. More recently ECMWF has verified predicted surface radiation fluxes using data from Baseline Surface Radiation Network (BSRN) stations. These are comprehensively equipped but much less numerous than SYNOP stations, and they can take months to provide data. Over 600 SYNOP stations, mainly from Europe, now report hourly solar radiation measurements in real time (Figure 9). Smaller numbers report diffuse solar and longwave measurements. Work is under way to add these to the verification of predicted solar radiation. As can be seen in Figure 9, the network of SYNOP stations reporting radiation measurements is much denser in some parts of Europe than in others, and there are no reports at all from a number of areas. Where countries are making radiation measurements at SYNOP stations, we would urge them to add them to the real-time reports.

ECMWF applies surface pressure bias correction to a small proportion of stations (about 6%). The corrections are updated every 12 hours and sometimes they change too rapidly, usually during the passage of a storm. Work is under way to avoid rapidly changing corrections that do not represent observation biases.

In July 2016, ECMWF started assimilating surface pressure and some wind data from BUFR buoy reports before most alphanumeric reports ceased in November 2016.

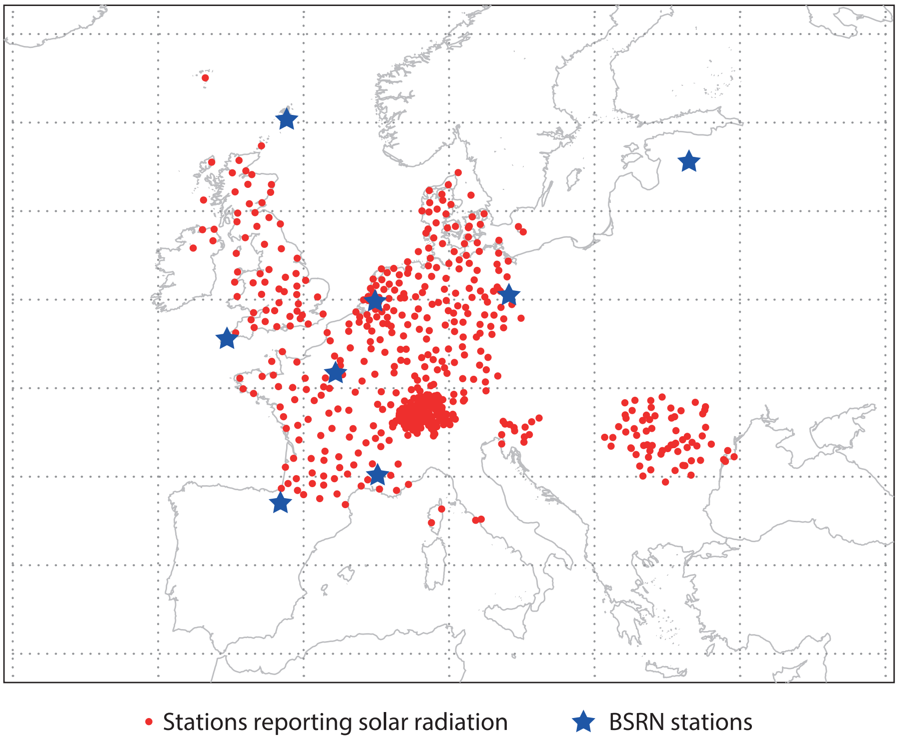


Figure 9 Map of SYNOP stations reporting solar radiation in November 2017, showing the 556 stations located in Europe. There are another 53 stations elsewhere. Also shown are the eight European Baseline Surface Radiation Network (BSRN) stations used in the verification of predicted surface radiation fluxes.

Ongoing work

The WMO has announced the replacement of five-digit station identifiers with more complex WMO Integrated Global Observing System (WIGOS) station identifiers. In the short term this means that many software systems will need to change. In the longer term it should enable ECMWF to use reports from many more surface stations – some run by weather services, some run by other agencies. In addition, work is still under way to process new BUFR templates (such as that for dropsonde data). As previously reported in this Newsletter (*Prates & Richardson*, 2016), ECMWF is taking part in a WMO data quality monitoring pilot project concentrating on surface and radiosonde data to support the future implementation of a WIGOS Data Quality Monitoring System (WDQMS).

Vaisala RS92 is still the most used type of radiosonde worldwide, but that is changing rapidly as Vaisala withdraws the RS92 in favour of the newer RS41. The ECMWF radiosonde temperature/humidity bias correction currently uses RS92 as a reference. It will soon start to use an average of RS92 and RS41 data and will switch off the humidity bias correction for RS41 radiosondes. In a separate development, test ‘radiosonde descent’ reports are being received from several stations. These contain data after balloon burst and are more variable in quality than ascent profiles. However, since there is very little additional cost, they are of interest. ECMWF will start to monitor these reports before deciding whether or not to use the data, and whether any extra processing or checks are needed.

For EUMETNET we performed a study of the impact of pressure data from drifting buoy reports on NWP and also the effect of the report density. A paper on this has been accepted by the journal *Atmospheric Science Letters*. ECMWF is also providing input to an international team considering radiosonde reporting including a) recommendations for target height and b) whether to allow more flexibility in reporting times (traditionally 00 and 12 UTC).

In situ reports are varied and valuable. To make the best use of them, work to introduce new reports and variables is needed, as is ongoing monitoring of operational data. As this article illustrates, progress is being made on many fronts. Among recent advances, the ability to account for radiosonde drift stands out as a particularly significant development since it addresses a long-standing approximation in the processing of atmospheric in situ observations.

Further reading

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