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# Shorter contribution

## Which Australian rawinsonde stations most influence wind analyses?

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## Introduction

Since late 1994, the Australian Bureau of Meteorology Research Centre, and its successor the Centre for Australian Weather and Climate Research, have monitored the impacts of all Australian upper air observing stations upon operational wind analyses. An impact upon analysis is defined as the difference, at the location of the observation, between analyses performed with and without the entire rawinsonde (geopotentials and winds at all levels). Impact statistics, accumulated over a sufficient sampling period, can reveal which observing stations are the most influential. This information may be useful for observational network planning and assessment.

The purpose of this paper is to summarise the quarterly monitoring statistics between 1994 and 2007, with a focus on characteristic differences between the impacts, upon wind analyses, of different groups of stations. While an in-depth analysis of cause and effect is not attempted in this short contribution, several of the likely influences are mentioned.

## History of impacts

Impact calculations have been performed using analyses, at 6 h intervals, produced by the Australian Bureau of Meteorology's ('the Bureau's') global data assimilation system (GASP – Seaman et al. 1995; Bourke et al. 1995; and subsequent updates), since late 1994. 'Analysis and Prediction Quarterly Summaries' (Bureau of Meteorology 1994, and subsequent quarterly issues) from the Bureau's National Meteorological and Oceanographic Centre (NMOC) include tables of the most influential ('top ten') SYNOPs, buoys and rawinsondes during each quarter upon GASP, on the basis of root mean square impact. The rawinsonde impacts are the data base for this study.

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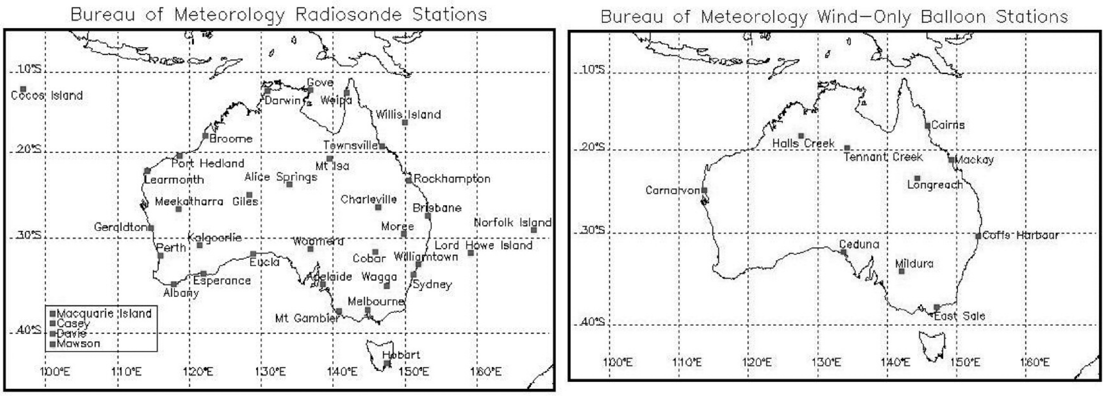
The theory and computational method underlying impact calculation are detailed in Seaman (1994). The calculations are based upon the theory of statistical interpolation (Gandin 1963). The impacts are therefore strictly only applicable to analyses performed by statistical interpolation. When impact calculations began in 1994, the GASP analyses were based upon statistical interpolation. In May 2004, the analysis component of the data assimilation was replaced by a three-dimensional variational method known as generalised statistical interpolation (GenSI – Steinle 2005; NMOC 2006). GenSI allowed a similar impact calculation, using an approximation to the observational and background error covariance matrices. Tests during a period of parallel running confirmed that impacts using GenSI were similar, although not identical, to those based upon statistical interpolation.

Both the horizontal and vertical resolutions of GASP have increased since 1994, the biggest change occurring in late 1998, with a change of model (but not observational data) resolution from horizontal triangular wave number T79 to T239, and from 19 to 29 vertical levels. At this time, the corresponding background (6 h forecast) field errors (which control the weight given to the 6 h forecasts) were substantially revised on the basis of 'observed minus background' statistics, in such a way as gave more weight than before to the 6 h forecast (and less weight to the observation) in mid-latitudes. An effect of these changes upon the calculated impacts will be mentioned in the following section, in the discussion of Table 1(d).

There have also been a number of changes since 1995, both to the Australian rawinsonde network itself, and to the observing programs (frequency of soundings) at individual stations. Figure 1 shows the upper air observing network at January 2007. The most significant changes after 1995 were as follows.

- The commencement of regular rawinsonde observations at Weipa in late 1998. The only observations prior to then were irregular with respect to frequency and height reached, and allowed few meaningful impacts to be calculated.

**Fig. 1 The Australian upper air observing network as at January 2007. (With acknowledgment to the Bureau's Observations and Engineering Branch.)**




- The replacement of a few stations by close neighbours, specifically (a) Gladstone, Queensland by Rockhampton, (b) Forrest, Western Australia by Eucla and (c) Laverton, Victoria by Melbourne Airport.
- The reconfiguration of the upper air programs at Launceston, Tasmania, and at Canberra, Australian Capital Territory, in 2003 and 2005 respectively, whereby boundary-layer profilers replaced rawinsondes.
- A substantial reduction in the 1200 UTC upper air network from early 2005, about 10 stations ceasing routine 1200 UTC soundings, although an option remained for occasional adaptive flights.

Apart from the changes at Weipa, and at Launceston, discussed further in the next section, none of the above changes appeared to affect the overall relativities of station impacts very much.

## Results and discussion

When interpreting the following results, one should bear in mind the factors that may influence the relative impacts of the different stations. The most important may be (a) the geographical variation in density of the rawinsonde network itself, (b) the influence of other observing platforms (satellite-based sounding data, cloud-drift winds and aircraft winds), and (c) the presence or absence of upstream observations. Hence one would expect a larger impact from stations that are distant from other rawinsondes, and where the contribution to the wind analysis from other platforms is relatively minor. Note that satellite-based sounding data were assimilated at or above 100 hPa over land, but at all levels over sea.

The following Tables 1(a) to 1(d) focus upon frequencies of 'top ten' occurrences, or in other words, upon peak performances. The comparative impacts of Australian rawinsonde stations may be conveniently summarised by counting the number of quarters that each station was ranked in the top ten at 500 hPa, and the number of quarters it was in the top ten at 200 hPa (for a maximum possible score of 98). The 42 stations are subjectively classified into four groups of approximately equal size, and their comparative performances are shown in Tables 1(a) to 1(d). Note that a few of the 42 stations, shown in the right panel of Fig. 1, observe only upper winds (not geopotentials). Discussions of Tables 1(a) to 1(d) follow.

Table 1(a) – 'Star performers' – comprises stations that ranked in the top ten in more than 60 quarters. Except for Weipa, the stations are located in the tropical and subtropical northwest of the continent. The top performer, Giles, was in the top ten, at both levels, in nearly all quarters. The table substantially understates the influence of the Cape York Peninsula station Weipa, which had minimal opportunity to impact the analyses prior to 1999.

Table 1(b) – 'Often prominent'. These stations ranked in the top ten in 32 to 59 quarters, and are also mainly tropical stations. All except Alice Springs were more influential from 1999 onwards.

**Table 1(a). Star performers.**

| *Station* | *Top ten occurrences at* | |
|---|---|---|
| | *500 hPa* | *200 hPa* |
| Giles | 42 | 42 |
| Port Hedland | 34 | 34 |
| Learmonth | 29 | 36 |
| Broome | 38 | 26 |
| Weipa | 32 | 29 |

**Table 1(b). Often prominent.**

| *Station* | *Top ten occurrences at* | |
|---|---|---|
| | *500 hPa* | *200 hPa* |
| Tennant Creek | 36 | 23 |
| Mount Isa | 29 | 29 |
| Gove | 29 | 25 |
| Alice Springs | 29 | 22 |
| Halls Creek | 30 | 20 |
| Carnarvon | 11 | 27 |
| Darwin Airport | 16 | 16 |

**Table 1(c). Mainly 200 hPa.**

| *Station* | *Top ten occurrences at* | |
|---|---|---|
| | *500 hPa* | *200 hPa* |
| Rockhampton/Gladstone | 6 | 11 |
| Perth Airport | 0 | 12 |
| Meekatharra | 2 | 10 |
| Geraldton | 0 | 9 |
| Longreach | 1 | 7 |
| Kalgoorlie | 2 | 6 |
| Moree | 0 | 6 |

**Table 1(d). Mid-latitude.**

| *Station* | *Top ten occurrences at* | |
|---|---|---|
| | *500 hPa* | *200 hPa* |
| Albany | 15 | 20 |
| Forrest/Eucla | 12 | 15 |
| Ceduna | 15 | 9 |
| Hobart Airport | 14 | 6 |
| Esperance | 14 | 3 |
| Woomera | 5 | 6 |

**Table 1(e). Rare appearances.**

| *Station* | *Top ten occurrences at* | |
|---|---|---|
| | *500 hPa* | *200 hPa* |
| Charleville | 1 | 4 |
| Cobar | 1 | 2 |
| Brisbane Airport | 0 | 2 |
| Mount Gambier | 2 | 0 |
| Adelaide Airport | 1 | 0 |
| Cairns | 0 | 1 |
| Wagga | 1 | 0 |

Table 1(c) – 'Mainly 200 hPa' – comprises stations where top ten occurrences at 200 hPa substantially outnumbered such occurrences at 500 hPa. It is speculated that this may be associated with the location of the subtropical jet. Carnarvon, from Table 1(b) could well have been in this category too.

Table 1(d) – 'Mid-latitudes' – comprises stations that featured in the top ten mainly, but not entirely, between 1994 and 1998. See the previous discussion of the changes that took place late in 1998. The contribution of satellite-based remote sounding data to analysis of the wind field over the surrounding oceans, which will be more of a factor in mid-latitudes than in the tropics, may also be relevant to the generally lower impact of these stations relative to tropical ones, particularly post-1998. While the impacts pre-1999 correctly indicate the large influence of the Table 1(d) stations then, their impacts post-1998 more meaningfully reflect their influence in the improved assimilation configuration.

However, a special case must be noted for Hobart Airport, whose influence increased from 2003 onwards, following the reconfiguration of Launceston.

Stations that rated in the top ten on five or less occasions (see Table 1(e) 'Rare appearances') were Charleville, Cobar, Brisbane Airport, Mount Gambier, Adelaide Airport, Cairns and Wagga. A bias towards the eastern third of the continent is evident.

Finally, there were no top ten appearances from the following stations: Canberra Airport, Coffs Harbour, East Sale, Launceston Airport, Mackay, Melbourne Airport, Mildura, Sydney Airport, Townsville and Williamtown. Obviously this list is strongly biased towards east coast stations, several of which are 'wind only'. An additional factor, particularly relevant to several stations in this list but also to a few stations in preceding tables, may be the use throughout the period of ascent and descent winds from aircraft. This availability will reduce the impacts of rawinsondes near major airports.

The preceding discussions may be supplemented by Table 2, which focuses upon 'average' (median) rather than 'peak' (top ten) performance. For convenience, the stations are ordered for ease of comparison with Tables 1(a) to 1(d). The table also stratifies the results with respect to the two periods 1995-1998 and 1999-2007, and with respect to the two levels, 500 and 200 hPa. This presentation underlines the points made in the earlier discussion of Table 1(a) re Weipa, the discussion of Table 1(c) re the subtropical jet influence, and the discussion of Tables 1(b) and 1(d), re the configuration change of late 1998.

The 42 stations considered above only include those located on the Australian continent and

**Table 2. Median ranks of the stations in Tables 1(a) to 1(d).**

| Table | Station | 500 hPa Median 1995-1998 | 500 hPa Median 1999-2007 | 200 hPa Median 1995-1998 | 200 hPa Median 1999-2007 |
|---|---|---|---|---|---|
| 1(a) | Giles | 7 | 7 | 6 | 5 |
| | Port Hedland | 13 | 6 | 11 | 13 |
| | Learmonth | 8 | 11 | 5 | 8 |
| | Broome | 11 | 4 | 17 | 8 |
| | Weipa | na | 2 | na | 1 |
| 1(b) | Tennant Creek | 13 | 6 | 12 | 9 |
| | Mount Isa | 19 | 5 | 16 | 8 |
| | Gove | 16 | 8 | 19 | 7 |
| | Alice Springs | 9 | 9 | 7 | 13 |
| | Halls Creek | 15 | 7 | 24 | 9 |
| | Carnarvon | 24 | 12 | 14 | 11 |
| | Darwin Airport | 27 | 9 | 22 | 9 |
| 1(c) | Rockhampton | 13 | 21 | 6 | 22 |
| | Perth Airport | 28 | 21 | 12 | 16 |
| | Meekatharra | 21 | 20 | 14 | 19 |
| | Geraldton | 26 | 21 | 14 | 18 |
| | Longreach | 18 | 15 | 15 | 16 |
| | Kalgoorlie | 18 | 26 | 9 | 25 |
| | Moree | 22 | 34 | 17 | 32 |
| 1(d) | Albany | 1 | 23 | 6 | 22 |
| | Eucla | 9 | 13 | 11 | 14 |
| | Ceduna | 5 | 19 | 12 | 21 |
| | Hobart Airport | 20 | 13 | 25 | 19 |
| | Esperance | 4 | 23 | 19 | 23 |
| | Woomera | 13 | 22 | 13 | 23 |

Tasmania. Corresponding impacts were also calculated for other rawinsonde stations run by the Bureau including, notably, Macquarie Island (54.5° south, 158.9° east). Not unexpectedly, that station consistently ranked above all the mainland stations at 500 hPa, and was in the top ten in many quarters at 200 hPa.

## Concluding remarks

Overall, the west to east, and south to north variations in impacts appear consistent with the respective factors mentioned at the start of the preceding section. The density of rawinsondes is greatest in eastern Australia, and the contribution of satellite-based sounding data to wind analysis is greater in mid-latitudes than in the tropics. Improvements to the background error specifications in 1998 may explain the changes in relativity between tropical and mid-latitude station impacts post-1998.

The methodology for calculating analysis impact was formulated in the early 1990s. Its strengths are its objectivity and ease of calculation. It can be considered as a particular case of the more comprehensive approach described by Cardinali et al. (2004). Undeniably it would be more useful to calculate similar impacts on forecasts. The latter is an area of active ongoing research, as reviewed by Rabier (2005).

As mentioned earlier, the calculated impacts on analyses strictly apply only to analyses based upon statistical interpolation. As the analysis method departs further from statistical interpolation, the resultant impacts become less valid. The current implementation of GASP will be almost its last, and its replacement will likely be based on four-dimensional variational principles. A formulation for analysis impact calculation should still be possible by application of the Cardinali et al. approach, and a period of parallel running will be necessary to verify whether the relative impacts are similar to the present ones.

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