

Monitoring a data assimilation system for the impact of observations

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The impact of an observation upon analysis is defined as the difference between the analysis using the observation and the analysis not using the observation. The statistical interpolation method of objective analysis enables the efficient computation of such observational impacts. Impact calculations provide a rigorous quantitative method of identifying the most influential observations, both upon individual analyses, and in an ensemble sense. They also enable the identification of data that, although rejected by quality control, would have had a large impact if they had been used. This report describes the computational algorithm for impact assessment, and presents examples of such assessments made within the framework of the Australian Bureau of Meteorology's global data assimilation system. The examples include the identification of the most influential southern hemisphere sea-level pressure data, a ranking of Australian upper air stations with respect to analysis impact, and the identification of important quality-control decisions.

Introduction

Most manual synoptic analysts will recall cases where a single observation has substantially changed their best prior estimate of the analysis in a particular area. Often, however, a single observation will alter the analysis only slightly from what it would have been otherwise. Numerical data assimilation systems respond in a rather similar way, and it is useful to be able to identify the most influential data. These remarks introduce the theme of this report, namely the quantitative assessment of the impacts of individual observations upon analyses produced by a numerical data assimilation system.

One application of impact information is in the area of observational resource management and network planning. For such purposes, it is often necessary to assess the benefits obtained from different observing stations. Ideally one might wish to equate the incremental benefit from a station with some measure of the corresponding incremental improvement in *forecasts*, or otherwise expressed, one might wish to assess the degradation in forecasts likely to result from the station's removal. An obvious way to assess such forecast impact is to run parallel analysis-forecast cycles, one with and the other without the benefit

of the observing station in question. However, impacts of individual observing stations are often small, and the case-to-case variation typically large, so that a large number of independent forecasts may be necessary to obtain statistically reliable results.

On the admittedly heuristic basis that stations which most influence the analysis will usually have the largest impact on forecasts, an alternative to forecast impact assessment is a corresponding analysis impact assessment. The impact of an observation upon analysis is defined here as the difference between the analysis using the observation and the analysis not using the observation. It will be shown that when objective analyses are performed by the method of statistical interpolation (Gandin 1963), analysis impact calculations require only a small amount of computation in addition to that needed for the analysis itself. Therefore, impact statistics may be computed conveniently in the course of normal data assimilation operations. The specific algorithm for impact calculation is identical to one used by Lorenc (1981), in a statistical interpolation setting, but not specifically for the purpose of calculating analysis impacts.

It is emphasised that analysis impact is a measure of *sensitivity*, and is not inherently a measure of improvement. Moreover, it is a measure that is specific to a particular system. The

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extent to which analysis impact is correlated with forecast improvement depends upon several aspects of the particular data assimilation and prediction system, including (a) quality control of data, (b) analysis methodology, and (c) prediction model initialisation. Broadly expressed, a necessary condition for analysis impacts to translate into forecast improvements is that the data be assimilated in a sensible way. Also, while analysis impact can measure the effects upon many individual analyses of leaving out an observation, it cannot measure the cumulative or compounding effects of leaving out an observing station for all time in an ongoing analysis-forecast data assimilation cycle. The latter limitation may be important when interpreting absolute, as opposed to relative impacts. Nevertheless, despite the preceding caveats, its ease of computation and its quantitative rigour make analysis impact a useful diagnostic.

In addition to applications discussed in the second paragraph of this section, impact calculations may be useful synoptically. For example, a change in the timewise continuity of analyses and, perhaps, forecasts from a numerical data assimilation system in a particular region may be ascribable to a single particularly influential datum. Impacts are also useful for identifying critical quality-control decisions. A borderline decision may be of little consequence where there is considerable data redundancy, but its impact may be substantial in other circumstances.

In following sections, the theory and method for the computation of analysis impact are set out, and specific examples of impact assessments within the framework of the Australian Bureau of Meteorology's global data assimilation system (Bourke et al. 1990; Seaman et al. 1993) are presented. These examples are drawn from the parallel testing, over several months, of the version of the system that was to be implemented operationally during 1994.

Theory and computational method

The following theory is similar to that presented by Lorenc (1981), but is included for completeness. When using statistical interpolation in an analysis-forecast cycle, the normalised increments f_G from a short-range (\sim six-hour) forecast at prediction model grid-points are estimated as a linear weighted sum of N observed normalised increments f_i at N data locations by

$$f_G = \sum_{i=1}^N w_i f_i \quad \dots 1$$

Here, normalisation denotes division by the pre-specified root mean square (rms) error of the short-range forecast ('prediction error'). In a

multivariate statistical interpolation scheme, both the f_G and the f_i may represent increments of more than one type of variable; commonly, increments of geopotential and wind components are analysed simultaneously. A standard least squares minimisation of ensemble error yields a system of linear equations for the weights. In vector (lower case) and matrix (upper case) notation

$$w = (P + O)^{-1} g \\ = M^{-1} g \quad \dots 2$$

where P and O are respectively the prespecified normalised covariance matrices of prediction error and of observational error for all pairs of observed data points, and g is the vector of pre-specified normalised prediction error covariances between observing points and a grid-point.

The matrix M depends upon the geographical positions of the observational data, but does not depend upon the positions of the grid-points. Therefore, if the same selection of observational data is used to interpolate to many grid-points, the matrix M needs to be inverted only once for that entire set of grid-points. Such a strategy is used in the Bureau's operational global data assimilation system. Typically, a selection of N (100 to 500) observational data is used to analyse all grid-points within a subvolume of about 1000 km horizontal dimension and spanning several model levels in the vertical (usually all model levels, for southern hemisphere subvolumes).

The relevance of the analysis strategy just described to the problem of assessing data impact is as follows. Suppose the observation whose impact is to be assessed contains n pieces of data (e.g. the geopotentials and wind components at several levels in a rawinsonde). One way of recalculating the analysis, *not* using the observation, would be simply to apply Eqns 1 and 2 again, using the $(N-n)$ remaining data. This would require the inversion of a new matrix, of dimension $(N-n)$, which is the same as M except that the n rows and columns corresponding to the withheld data are omitted. However, when n is much less than N , it is computationally advantageous not to directly invert another large matrix of dimension $(N-n)$, but rather to calculate a new matrix L from the inverse of M which is already known. As shown by Lorenc (1981, Eqn 27), when the weights corresponding to the n omitted data are constrained to be zero, a new weights vector w is given by Lg , where

$$L = M^{-1} - M^{-1} D (D^T M^{-1} D)^{-1} D^T M^{-1} \quad \dots 3$$

and D is a $(N$ by $n)$ matrix whose columns are the vectors d_k , in which the k th element is one and the other elements are zero, and k is the index (in N) of the datum to be omitted. The matrix inside the brackets in Eqn 3 is of dimension n , and D is sparse (mostly zeros), so evaluation of Eqn 3,

despite its complicated appearance, requires very much less computation than does the direct inversion of a matrix of order $(N-n)$, when n is much less than N . In fact, Lorenc (1981) did not use his counterpart to Eqn 3 to calculate data impact, but rather used it for the purpose of grid-point analysis while omitting data flagged as suspect, and (in a slightly different form) for quality control. However the computational algorithm used here is the same as Lorenc's.

A further consideration in the computation of data impact is the geographical location of the 'grid-points' at which the impact should be calculated. A comprehensive assessment of impact should probably evaluate a volume integral of impact at all prediction model grid-points within the influence of the observation. However, for application within the Bureau's global data assimilation system, it was decided to evaluate the impact only at the actual location of the observation. In other words, two evaluations, one with and the other without the observation, are made at the locations of some or all of the n data points (e.g. at a few standard levels of a rawinsonde) within the observation. A shortcoming of this procedure is that when an observation is on the edge of a data void, the maximum impact on analysis may occur at a short distance into the data void, rather than at the location of the observation itself. However, extra sophistication was not considered justified in this initial implementation.

The case $n = 1$ is of particular interest. It corresponds to the assessment of the impact of a single datum, such as a sea-level pressure from a drifting buoy or a ship. In this extreme case of n being much less than N , the computation in Eqn 3 is minimal. It is therefore computationally feasible to compute routinely the individual impact of every sea-level pressure report selected for use, thereby identifying those reports having the greatest impact. Examples of such computations are presented in the next section. The case of a single sea-level pressure datum may also be viewed as a least squares problem of combining two independent pieces of information, namely (a) the analysis at the location of the datum without the use of the datum, and (b) the datum itself, to obtain an improved estimate, namely the analysis using the datum. An impact result identical to that using Eqns 1 to 3 is obtained via this alternative route.

Examples

The following examples of impact assessments are some of those that have been implemented in the Bureau's global data assimilation system at the time of writing. These examples are by no means exhaustive, and other applications should come readily to mind.

Throughout this section, impacts are presented and ordered in dimensional units. It could well be argued that, before ordering, some form of normalisation is appropriate. For example, an impact of a given magnitude in the tropics may be more significant than a similar impact at higher latitude. Similarly, impacts upstream of a particular forecast area may be of special significance. The decision not to normalise was dictated by the view that the most appropriate form of normalisation is best decided by the user. The main purpose of the section is simply to convey the flavour of some of the possible applications.

The 'top ten' southern hemisphere sea-level pressure data impacts

At each analysis time, the analysis impact is calculated for every sea-level pressure datum selected for use. The magnitudes of the impacts are sorted, and the ten largest southern hemisphere impacts listed, thereby identifying the ten data that, individually, were the most influential at that particular time. Such information may sometimes reveal the causes of temporal discontinuities in the sequence of sea-level pressure analyses and, possibly, forecasts produced by the data assimilation system. A listing for a particular time is shown in Table 1. Most of the stations listed are in relatively data-sparse areas. This is usually, but by no means always the case. When the background field in a data-sparse area is in good agreement with an isolated observation, the impact of the latter will be small. Conversely, an observation in a relatively data-dense area may reveal a small-scale feature not present in the background field. On the average, however, to the extent that there is more redundancy and background fields are most reliable in data-dense areas, the impacts there should be correspondingly smaller.

Table 1. The top ten southern hemisphere sea-level pressure impacts at 1700 UTC, 22 June 1993.

Station	Latitude	Longitude	Impact (hPa)
Buoy 33021	59.5	332.7	-4.5
Young I.	66.3	162.3	4.3
Marion I.	46.9	37.9	-3.7
Macquarie I.	54.5	158.9	3.4
Grytviken	54.3	323.5	-2.9
Buoy 71552	61.0	48.7	-2.4
Port Moresby	9.4	147.2	-2.2
Buoy 33835	57.8	0.6	-2.0
Buoy 71554	57.2	49.4	2.0
Amsterdam I.	37.8	77.5	2.0

Table 2. Average numbers of southern hemisphere sea-level pressure data types at the major synoptic times, and average occurrences in the top ten most influential sea level data, based on 29 days during June 1993. PAOBs are manual bogus data.

Synoptic time Observation type	1100 UTC				2300 UTC			
	Synop	Ship	Buoy	PAOB	Synop	Ship	Buoy	PAOB
Average number per synoptic time	857	93	78	224	959	100	88	224
Average occurrences in top ten	4.17	0.34	2.58	2.90	3.52	0.38	3.07	3.03
Relative likelihood of appearing in top ten	1.00	0.76	6.81	2.66	1.00	1.03	9.48	3.70

One would expect that observing platforms deliberately deployed into data-sparse areas should figure prominently among the larger impacts. Table 2 confirms that over a period of a month, pressures from drifting buoys appeared in the top ten impacts with a frequency well out of proportion to their total numbers. Such a result indicates the importance of the drifting buoy observing system, a conclusion that will be further underlined in a later subsection.

Identification of critical quality-control decisions

Occasionally the appearance of a station in the top ten impacts may indicate a quality-control problem. In the Bureau's global data assimilation system, clearly unreasonable data are flagged for rejection at an early stage. Then a more refined quality-control check is performed, by means of cross-validation. During cross-validation, an observed datum is compared with an estimate obtained from nearby data (if any) and the background field. See Lorenc (1981, section 3c) for details. There will inevitably be cases just within or just outside tolerance, and the former may have large analysis impacts. In Table 1, for example, all of the top ten impacts are from drifting buoys and isolated island stations with the exception of Port Moresby, a tropical station not in a particularly data-sparse area. One might suspect that station to be a borderline quality-control case, and it is discussed in more detail in a later subsection.

Similarly, impact calculations may assist in identifying data that were rejected by cross-validation, but which would have had a large impact had they been used. These cases usually comprise only a minority of cross-validation rejects, because cross-validation detects many errors in data-dense areas by means of spatial consistency, and in such areas the use or non-use of a datum is often of little consequence. The most difficult quality-control decisions are those where a datum in an otherwise data-sparse area differs substantially from the background field, in which case the datum is either very valuable, or wrong. A typical case is shown in Table 3 where, at a particular synoptic time, among the sea-level pressure rejects in the southern hemisphere only two would have had impacts of more than 2.5 hPa (the arbitrary lower limit for a large impact). Both of these data, one from Marion Island (68994) and

Table 3. The southern hemisphere sea-level pressure data (hPa) at 2300 UTC, 28 June 1993, rejected by cross validation, which had they been used would have had an impact of over 2.5 hPa.

Station	Latitude	Longitude	Observed	Impact
Marion I.	46.9	37.9	1011.9	-3.9
PAOB	67.0	205.0	983.0	17.5

Table 4. Geopotential and wind ensemble impacts at Rockhampton (WMO identifier 94374; 23.4 south, 150.5 east) during June 1993. Column headers are standard levels (hPa). Legends to rows are: NZ — number of geopotential reports, ZAV — mean geopotential impact (m), ZRMS — rms geopotential impact, ZMAX — maximum geopotential impact; NUV — number of wind reports; UAV, URMS, VAV, VRMS — statistics similar to ZAV, ZRMS but for west-east and south-north wind components ($m s^{-1}$); VCRMS — rms vector impact, VCMAX — maximum vector impact.

94374	1000.	850.	500.	200.	100.	50.
NZ	29	29	29	29	29	29
ZAV	-0.4	-0.6	-0.7	2.7	-4.0	-4.8
ZRMS	2.3	2.4	4.6	5.8	7.6	7.0
ZMAX	4.4	5.0	12.2	11.3	17.5	17.3
NUV	57	112	114	113	101	20
UAV	-1.1	-0.6	0.1	2.1	-3.5	-3.1
URMS	1.5	1.4	3.2	5.3	6.3	4.2
VAV	-0.2	0.3	0.5	-2.1	-1.0	-0.7
VRMS	1.0	1.5	3.0	5.7	5.0	2.8
VCRMS	1.8	2.1	4.4	7.8	8.1	5.0
VCMAX	3.0	4.3	11.2	24.1	24.0	8.4

the other a manual bogus observation (PAOB), are in data-sparse areas.

In cases like these, it may be difficult to 'second guess' the quality-control decisions without a careful post-analysis. Nor would time schedules usually permit a rerun in any case. Nevertheless the user should be aware of the quality-control decisions that were in fact critical, so that resultant predictions may be interpreted accordingly. Of course, should a particular station appear consistently, further investigation would be warranted.

Ranking of Australian upper air stations

The two preceding subsections dealt mainly with synoptic diagnostics of analysis impact. The ensemble characteristics of impacts over many analyses may be equally useful. As discussed in the introduction, network reductions are sometimes inevitable, and in such situations it is helpful to have quantitative assessments of the impacts of different network options.

With such applications in mind, the impact of the complete upper air report (height, if observed, and wind at all levels) is calculated at all Australian upper air stations at each analysis time (0500, 1100, 1700 and 2300 UTC). The number of data (n) selected for use from a rawinsonde is typically about 30, so the calculation in Eqn 3 requires the inversion of a matrix of that order. The computational overhead is therefore more

than for sea-level pressure data ($n = 1$) but is not excessive since such computations are performed only at about 40 stations per analysis time.

Table 4 shows an example of the ensemble impact statistics for Rockhampton (World Meteorological Organization (WMO) identifier 94374; 23.4 degrees south, 150.5 degrees east) during June 1993, for all four analysis times. The statistics correspond to the impact of removing the *complete sounding* of both height and wind, upon the height and wind at each level. While the rms vector impact (VCRMS) at subtropical jetstream level was about 8 m s^{-1} , the extreme impact was much larger (24.1 m s^{-1} at 200 hPa).

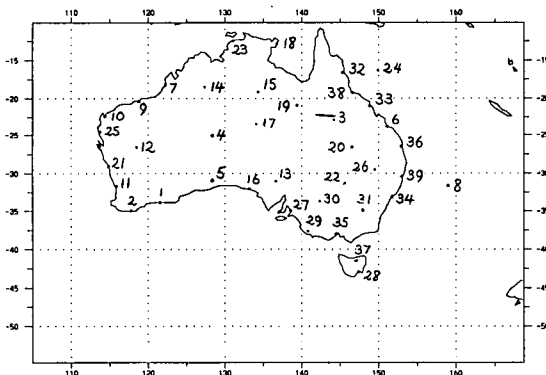
A comparison of the ensemble statistics at the location of each station enables these stations to be ranked with respect to rms analysis impact. Table 5 shows the rankings of Australian upper air

Table 5. Australian upper air stations in average rank order with respect to 500 hPa wind impact. The second column is the WMO station identifier. The impacts (m s^{-1}) and ranks are shown for individual months. See Fig. 1 for station locations. Gladstone (6) closed and was replaced by nearby Rockhampton (23.4 south, 150.5 east) before May 1993.

	Station	Aug 92	Dec 92	May 93	Average Rank
1	94638 Esperance	6.4 1	4.2 1	4.8 2	1.3
2	94802 Albany	6.2 2	4.1 2	5.1 1	1.7
3	94346 Longreach	5.1 7	3.6 9	4.0 3	6.3
4	94461 Giles	5.0 11	3.5 10	3.9 4	8.3
5	94646 Forrest	5.0 10	3.9 4	3.8 12	8.7
6	94380 Gladstone	4.5 19	3.7 6	3.9 6	10.3
7	94203 Broome	5.1 8	3.4 11	3.7 13	10.7
8	94995 Lord Howe Island	5.6 3	3.1 24	3.9 5	10.7
9	94312 Port Hedland	5.4 4	3.7 8	3.5 20	10.7
10	94302 Learmonth	4.8 12	3.3 14	3.9 8	11.3
11	94610 Perth	4.8 13	3.3 16	3.8 9	12.7
12	94430 Meekatharra	5.0 9	3.2 19	3.8 11	13.0
13	94659 Woomera	4.7 14	3.4 13	3.7 14	13.7
14	94212 Halls Creek	4.6 17	3.2 18	3.9 7	14.0
15	94238 Tennant Creek	4.7 15	3.3 15	3.6 15	15.0
16	94653 Ceduna	5.2 5	3.2 20	3.5 21	15.3
17	94326 Alice Springs	5.2 6	3.2 21	3.2 24	17.0
18	94150 Gove	3.5 31	4.0 3	3.4 22	18.7
19	94332 Mount Isa	3.9 25	3.4 12	3.5 19	18.7
20	94510 Charleville	4.6 16	2.9 25	3.5 18	19.7
21	94403 Geraldton	4.1 22	3.2 22	3.6 16	20.0
22	94711 Cobar	4.2 21	3.2 17	3.2 23	20.3
23	94120 Darwin	3.6 29	3.8 5	3.7 30	21.3
24	94299 Willis Island	3.6 28	3.6 7	2.9 29	21.3
25	94300 Carnarvon	4.1 23	2.4 33	3.8 10	22.0
26	94527 Moree	4.6 18	3.1 23	3.0 26	22.3
27	94672 Adelaide	4.4 20	2.7 30	3.1 25	25.0
28	94975 Hobart	3.3 33	2.9 26	3.6 17	25.3
29	94821 Mount Gambier	3.7 27	2.7 28	3.0 27	27.3
30	94693 Mildura	3.9 24	2.4 32	3.0 28	28.0
31	94910 Wagga Wagga	3.8 26	2.6 31	2.6 31	29.3
32	94287 Cairns	2.8 36	2.7 29	2.5 33	32.7
33	94367 Mackay	3.0 35	2.9 27	2.0 37	33.0
34	94776 Williamtown	3.4 32	2.3 34	2.4 34	33.3
35	94865 Laverton	3.5 30	2.1 37	2.1 36	34.3
36	94578 Brisbane	3.2 34	2.0 38	2.6 32	34.7
37	94968 Launceston	2.6 38	2.1 36	2.2 35	36.3
38	94294 Townsville	2.2 39	2.3 35	1.8 38	37.3
39	94791 Coffs Harbour	2.6 37	1.6 39	1.7 39	38.3

stations (see Fig. 1 for locations) with respect to impact upon 500 hPa wind, for all four analysis times combined, during three months in different seasons. The predominance of higher rankings (smaller numbers) in the western half of the continent is obvious. There is a large measure of consistency between months, although there are interesting differences too, such as the three tropical stations Darwin (94120), Gove (94150) and Willis Island (94299) which are much more highly ranked in December than in the other two months. The stations Nowra (34.9 degrees south, 150.5 degrees east) and Sydney (33.9 degrees south, 151.2 degrees east) are not included in the Table, because their infrequent and/or asymptotic reporting times would invalidate comparison with most other stations. The rankings of stations cannot be explained solely in terms of the spatial distribution of the conventional upper air network itself; it is also necessary to consider the average distributions of other observing platforms. For example, the frequent availability of aircraft winds at many levels in the vicinity of major airports provides some data redundancy at those locations.

Fig. 1 A location map of the Australian upper air stations in Table 5. The plotted numbers at station locations correspond to the rank order of station impact (first column of Table 5), a smaller number corresponding to a larger impact. Note that Gladstone (6) closed before May 1993 and was replaced by nearby Rockhampton (23.4 degrees south, 150.5 degrees east).



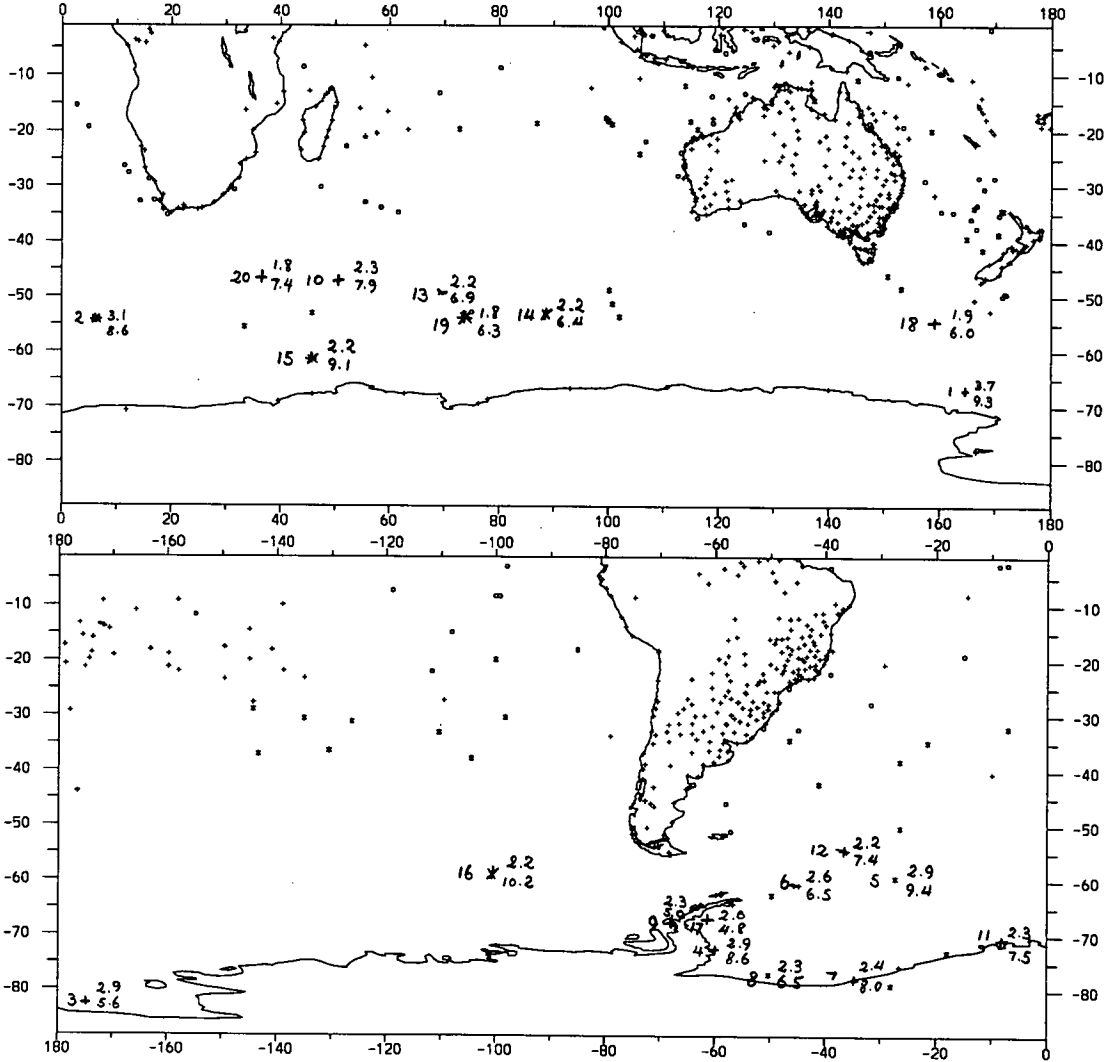
The west-east bias in impacts evident in Fig. 1 warrants careful interpretation, in view of the fact that in December 1992 and May 1993 (but not in August 1992) the upper wind observing program at Western Australian stations was reduced by the omission of most 0500 UTC wind soundings. Table 5 indicates that the general west-east bias in impacts evident in Fig. 1 was present in all three months. However, an analysis of impacts at each synoptic time (not shown) suggests that following

the 0500 UTC network reductions, the west-east bias at 1100 UTC was more marked than that shown in Fig. 1. A comparison of impacts in August 1992 (pre-reduction) and August 1993 (post-reduction) also tends to support some influence of the 0500 UTC network reductions. In August 1992, eight of the top ten ensemble impacts at 500 hPa, and five of the top ten at 200 hPa, were in Western Australia, South Australia and the Northern Territory. In August 1993, all of the top ten ensemble impacts at 500 hPa, and nine of the ten at 200 hPa, were in the above areas. While these results may be of doubtful statistical significance, they at least suggest that the 0500 UTC wind network reductions may have accentuated a pre-existing west-east bias in upper air observing station impact. A similar effect may have arisen from the absence of Western Australian 1100 UTC radiosonde geopotentials (except Perth) in December 1992 and May 1993, but this aspect was not investigated.

Ensemble impacts of sea-level pressure data

The disproportionate frequency of buoys in the day-to-day top ten sea-level pressure impacts, mentioned previously, may be explained by the deliberate deployment of many buoys into known data-sparse areas. Land-based sea-level pressure data from individual stations located in what would otherwise be data-sparse areas are of similar value to buoys, but in contrast to buoys a large proportion of land-based pressure data is in already well-observed areas. Figure 2 shows a geographical plot of a typical 1100 UTC network of land, ship and drifting buoy data reporting sea-level pressure, upon which is superimposed the 20 sea-level pressure observing platforms (out of a total of about 1200 at the major synoptic times) that had the greatest rms impacts upon southern hemisphere sea-level pressure analyses during June 1993. Thirteen of the 20 are land-based platforms in data-sparse areas, and seven are drifting buoys. Because of uncertainties in pressure reduction procedures, only platforms below 800 m elevation were included in sea-level pressure impact calculations. This criterion excludes from consideration other potentially valuable pressure data such as automatic stations on the Antarctic plateau. For similar reasons, those stations whose elevations differ from the model topography by more than about 500 m were also excluded. With these provisos, nearly all of the twenty most valuable stations during the month are located in the otherwise data-sparse and synoptically active areas of the circumpolar trough and mid-latitude cyclonic belt. The particular impact of data in these areas was noted by Guymer and Le Marshall (1980) during the Global Weather Experiment of 1979. The platform with the greatest rms sea-level pressure impact during June 1993 was the automatic weather station at

Fig. 2 The largest 20 southern hemisphere rms sea-level pressure impacts during June 1993, superimposed upon a typical 1100 UTC network of synops, ships and buoys. The number to the left of each location is the impact ranking, the upper number to the right is the rms impact (hPa), and the lower number to the right is the extreme impact. A (+) denotes a synop (* denotes a buoy and (o) denotes a ship.



Young Island (66.3 degrees south, 162.3 degrees east). That station also had the greatest or second greatest rms impact in the other months in which impact calculations have been made, namely August and December 1992, and May 1993. Another automatic weather station, Lettau (82.6 degrees south, 174.3 degrees west), was ranked third during June 1993. However, earlier remarks about the need for normalisation are of obvious relevance when considering the results of this subsection.

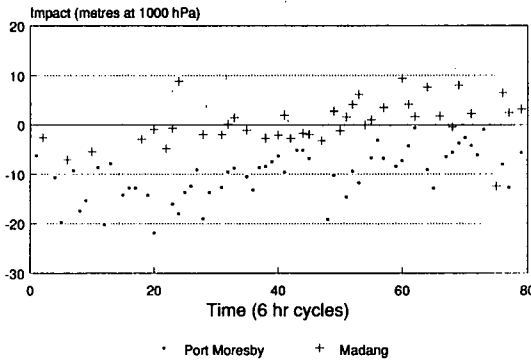
Ensemble impact statistics and quality control

It has already been discussed how day-to-day impacts can highlight critical quality-control

decisions from a synoptic standpoint. Similarly, ensemble statistics of analysis impact can detect systematic biases, which may be due either to the observation or to the background field. In this respect, impact statistics fulfil a similar role to 'observed minus background' statistics, which have been routinely accumulated from the Bureau's global assimilation system for some years (Seaman and Steinle 1992). A comprehensive account of the utility of 'observed minus background' statistics is given by Hollingsworth et al. (1986).

An obvious example of bias from ensemble impact statistics is shown by the time series of sea-level pressure impacts at Port Moresby, Papua

Fig. 3 Time series of analysis impacts of 1000 hPa geopotential (m) at Port Moresby and Madang for 20 days in August 1992.



New Guinea (9.4 degrees south, 147.2 degrees east) during June 1993 (Fig. 3, dotted series). The station Madang (5.2 degrees south, 145.8 degrees east), on the northern coastline of Papua New Guinea, shows no such bias (crossed series). Synoptic analysts confirm that it is often difficult to 'draw to' the Port Moresby pressure without introducing a small-scale perturbation into a manual analysis. There is no reason to suspect any instrumental or observational problem, and a likely explanation is that the observed pressure is simply unrepresentative on the scale of the global assimilation system, due to the local topography.

Summary

Observational data impact, defined as the difference between analyses using and not using the data in question, is efficiently calculated within the framework of statistical interpolation as currently implemented in the Bureau's global data assimilation system. The theory underlying the impact calculations has been set out, and several practical applications of both synoptic and ensemble impacts have been presented. These include:

- the identification of influential observations, to aid the interpretation of numerical forecast output;

- the identification of critical quality-control decisions for a similar purpose;
- the ranking of Australian upper air stations, in terms of their ensemble impacts on analysis, as an aid to network planning; and
- the confirmation of the disproportionately influential role of the drifting buoy network, as an argument for its continuance and extension.

Diagnostics of the types described in the paper had at the time of writing been produced during several months of parallel real-time running in 1992 and 1993, and were expected to be operationally implemented during 1994.

Acknowledgments

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