

# **AN HISTORICAL VIEW OF ADAPTIVE OBSERVING STRATEGIES IN AUSTRALIA**

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## **ABSTRACT**

Variations to a routine programme of observations may be useful or necessary in some situations. Adaptive observing strategies, in which variations are made on the basis of meteorological conditions or other contingencies, come in many shapes and forms and have evolved as observing networks themselves have evolved. This paper will document a range of adaptive observing strategies of past and present, in particular aiming in each case to isolate the process and criteria used to decide on variations, and to identify the observing network capabilities that allowed the variations to be implemented.

## **Introduction**

Meteorological and related observations provide a fundamentally important base in support of the operations and services of National Meteorological and Hydrological Services. Establishing standards and methods for observations and arrangements for the international exchange of data is a key element of the purpose of WMO.

Climate applications mostly depend on consistent and homogeneous long term observing programmes.

Shorter-term forecast and warning applications, including numerical weather prediction (NWP) and manual synoptic and nowcasting activities, also benefit from consistent and homogeneous long term observing programmes. However the value of some individual pieces of information can fluctuate much more widely with the prevailing synoptic situation.

An adaptive observing strategy is one that implements variations to a routine programme of observations on the basis of meteorological conditions or other contingencies. The strategy may target additional observations to those situations of high expected value, and/or tolerate reduced observations in situations of low expected value.

## **The Context: Australian Observing Networks**

Themes and issues relevant to Australia don't all apply to other countries or regions, and don't include some of the important issues that do apply elsewhere. It is useful be aware of the Australian context in terms of observing networks and aspects of the synoptic climatology.

Australia's surface observations include a land-based component and a marine and ocean component. On land there are about 860 surface synoptic stations providing reports ranging from two or three manual synoptic observations per day through to one-minute resolution Automatic Weather Station (AWS) data incorporating a combination of manual observations and measurements from advanced sensors. In addition there are approximately 7,000 limited-purpose stations, mostly operated by volunteers who record daily rainfall and submit their readings by post at the end of each month, but also some real-time reporting and automated rainfall stations, as well as river height and some evaporation stations.

Marine and ocean observations are obtained from the Australian Voluntary Observing Fleet (AVOF) of approximately 100 ships, including about 10 ship-board AWS, as well as a regularly replenished array of drifting buoys. Upper ocean profiles are obtained from high frequency sampling by about 8 XBT-deploying ships (temperature) and the network of ARGO profiling floats (temperature and salinity) in waters surrounding Australia.

The Bureau's 50 upper air stations apply a range of technologies: 48 are balloon based while two operate boundary layer profilers (Fig. 1). The Australian weather watch radar network consists of about 60 radars, of which half are balloon-tracking radars that are used for weather surveillance between balloon flights, while a small number are configured as Doppler radars. Australia acquires satellite data by direct ground-reception from two geostationary and five polar orbit satellites.

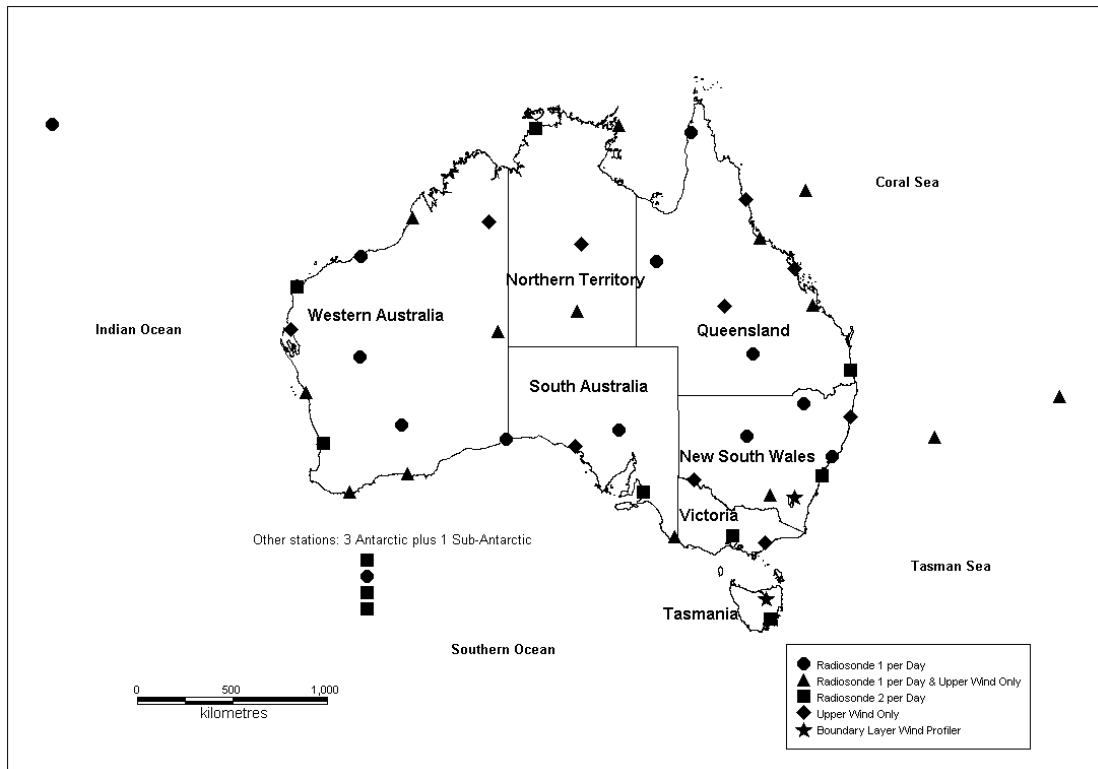


Figure 1: The distribution of Australian upper air stations, also showing the State boundaries with which the Bureau of Meteorology's seven Regions are aligned.

The relative contribution by these observing networks has changed over time as indicated in Table 1, with the increased use technology shown in the numbers listed for AWS, radars and satellite reception.

Year (as at 30 June)	Cooperative observer (manual) stations	AWS	Total surface synoptic observing stations	Weather watch Radars	Satellite reception (p = polar orbit; g geostationary)
1970	303	0	371	19	0 g / 1 p
1980	330	8	420	23	1 g / 1 to 2 p
1990	376	71	511	32	1 g / 2 p
1995	411	223	639	44	
2000	434	436	814	51	2 g / 4 p
2004	409	530	858	57	2 g / 5 p

Table 1. Historical contribution by some components of the observing system in Australia (some numbers are approximations). "Total surface synoptic observing stations" represents the combined contributions of Bureau-staffed stations, Cooperative Observer stations, plus AWS (noting an overlap at some stations where Bureau staff or Cooperative Observers combine manual observations with the AWS-compiled measurements).

The synoptic climatology of Australia reflects its size and location, spanning the tropics and sub-tropics and surrounded by large areas of ocean. Southern hemisphere summer typically produces the most threatening weather including tropical cyclones, dangerous fire weather and severe thunderstorms. Flooding is generally a greater risk in winter in the subtropics and in summer in the tropics. In winter, cold outbreaks don't reach the extremes of Europe and North America but can nevertheless cause significant disruption and dislocation, as can northwest cloud-bands and east coast lows in active years.

The size of Australia and its distance from other countries results in limited interaction with neighbours over network design and observing strategies, beyond the mutual cooperation across WMO's Region V aimed at implementing global observing networks. There is more intense interaction across the seven States within Australia on observing strategies.

## Adaptive Surface Observations

Manually prepared surface synoptic observations provided the main source of synoptic weather information for many decades until the more recent transition towards the use of AWS. Manual observations still make a contribution and, given the adaptability and wide geographic distribution of people, can be used in many adaptive roles.

The Australian Bureau of Meteorology maintains an Emergency Reporting Network in its three tropical cyclone prone Regions (Queensland, Northern Territory and Western Australia). The network consists of those observers in the routine synoptic network who are located on or near the coast, plus a larger list of observers who report only under emergency conditions (and generally have less, if any, instruments at their disposal). In the preparations before each tropical cyclone season, the network is reviewed, confirmed and upgraded, instruments are checked and observers are sent and reminded of instructions for the provision of emergency reports.

During a cyclone emergency, the Senior Meteorologist in the Tropical Cyclone Warning Centre may activate relevant sections of the network by requesting stations to commence emergency observations, consisting of hourly or 3-hourly phone-in weather reports. Ideally an emergency station is not activated for more than a 12 to 24 hour period.

The Bureau also maintains a Storm Spotters network, concentrated over the eastern and southern parts of Australia where the greatest population is and also where severe thunderstorms tend to have their greatest impact. Contributors to this network are supplied with training and reference materials. Activation of reporting is self-triggered when severe thunderstorm events are observed.

The AVOF of approximately 100 ships, plus their equivalents from other countries visiting Australian waters, can and do vary their normal programme of (voluntary) observations at times. For example, forecasts and warnings transmitted to ships in surrounding high seas areas during the passage of a tropical cyclone would normally ask for 3-hourly reports rather than the typical 6-hourly reports, as follows: "REMARKS: Ships in the general area please transmit 3-hourly weather reports."

AWS, like any automatic systems, can readily provide any programme of observations they are configured to supply, for whatever periods of time required. The AWS in use at most Bureau automated sites has a range of reporting configuration options spanning: message formats (1 second, 1 minute, 10 minute, METAR/SPECI, and a full SYNOP-like format with metadata); frequency of generation of each required message type; frequency of storage (to the AWS data logger) of each required and generated message type; and frequency of transmission of each required and generated message type. It also allows for remote interrogation of the AWS, that is, polling for data. These degrees of flexibility have been used only cautiously, partly to keep the expenditure on communications services within budget, and partly because the protocols originally used to convey commands to the AWS were vulnerable, over some communications links, to corruption leaving the AWS in a disrupted non-operational state.

The most common use of this configuration flexibility has been to alter the frequency of generating and transmitting messages, generally on a seasonal basis. For example, during the dry summer period over south-eastern parts of Australia, dangerous fire weather is a common threat to the community. Those AWS that reported 3-hourly SYNOP-like messages were configured to report hourly messages for the duration of the fire season. On more isolated occasions the reporting frequency from a group of AWS has been altered for periods of several hours to several days. On occasions the frequency of logging data has been configured to a higher rate through significant events for the sake of post-event studies. In virtually all cases these decisions are made and implemented by Senior Meteorologists, in light of expected meteorological events, and other programme managers within the relevant Regional Office of the Bureau.

While an AWS can be very flexible in the time domain, the requirement is sometimes for variation to surface observations in the spatial domain. The concept of a portable or relocatable AWS has been around for a long time, though a number of implementations have been explored including tripod mounted, trailer mounted, ruggedised for deployment from military aircraft, and so on. One recent example is illustrated in Fig. 2. A relatively recent addition has been a facility to include the portable AWS in the Bureau's station dictionary and to rapidly register its latitude and longitude at its current deployment site. That enables the observations to be recognised and stored in the Bureau's standard real-time databases, from where it is available to the full range of data reporting, display and utilisation systems.



*Figure 2: Portable AWS set-up achieved collaboratively by the Australian Bureau of Meteorology with the Victorian State Country Fire Authority and the Victorian State Department of Sustainability and Environment.*

The decision to deploy a portable AWS is made by the Senior Meteorologists and other relevant managers in the Regional Office. The decision must take into account the resources required to achieve the deployment, how useful the observations are likely to be, how long the weather event and/or need to support a specific forecasting service is likely to last, and so on. However the deployments, and any forecasts provided on the basis of those observations, are often contributions within collaborative arrangements with fire management or emergency response agencies and must be made on that basis.

A typical situation is the escalation of meteorological support for fire fighting operations once the fire has survived the initial attack and grown to a size and/or difficulty likely to need a protracted period of effort. For such a campaign fire there would generally be site-specific weather forecasts to assist the safe and effective fire fighting effort.

### **Adaptive Upper Air Observations**

The Bureau's 50 upper air stations apply a range of technologies to deliver a range of observing programmes:

- 17 stations track balloons by GPS (4 are manual balloon release, the other 13 utilise Vaisala™ Autosonde© units configured for both on-site and remote-site manual flight scheduling and supervision);
- 31 stations track balloons by radar (all with on-site manual operation), one of these stations also operates a boundary layer profiler; and
- two stations operate automatically with a boundary layer wind profiler.

Of the 48 stations with a balloon-based programme:

- 10 (radar tracking) never use radiosondes and report wind-only, mostly at 00, 06 and 12 UTC;
- 14 (radar tracking) use a radiosonde at 00 UTC and report wind-only at other times, mostly at 06 and 12 UTC;
- 7 (radar tracking) use a radiosonde at both 00 and 12 UTC and report wind-only at 06 and 18 UTC (although one of the 7 stations routinely uses non-standard reporting times);
- 4 (GPS tracking, 3 manual and one autosonde) fly a radiosonde at both 00 and 12 UTC; and
- 13 (GPS tracking) fly a radiosonde at only 00 UTC.

Across that profile there are different opportunities, costs and benefits for implementing adaptive strategies, such as extra wind-only flights and/or radiosonde flights.

Historically there were two developments in Australia's upper air network that led to the introduction of adaptive radiosonde flights. Firstly, through the mid to late 1990s, Autosonde units were introduced at twelve (now thirteen) sites across Australia. Those sites maintained a complete programme of 00 UTC and 12 UTC radiosonde flights, however they lost the intermediate wind-only balloon flights that had previously been performed at 06 UTC and 18 UTC utilising a dual mode (weather watch and wind find) radar. To help ameliorate any impacts, a small holding of additional radiosondes was supplied to Autosonde stations to be used on an adaptive basis. As expected, those radiosondes were most consistently drawn on in the tropics

during tropical cyclone events to resume 6-hourly wind profiles. Month by month deployment of adaptive radiosondes is shown in Fig. 3.

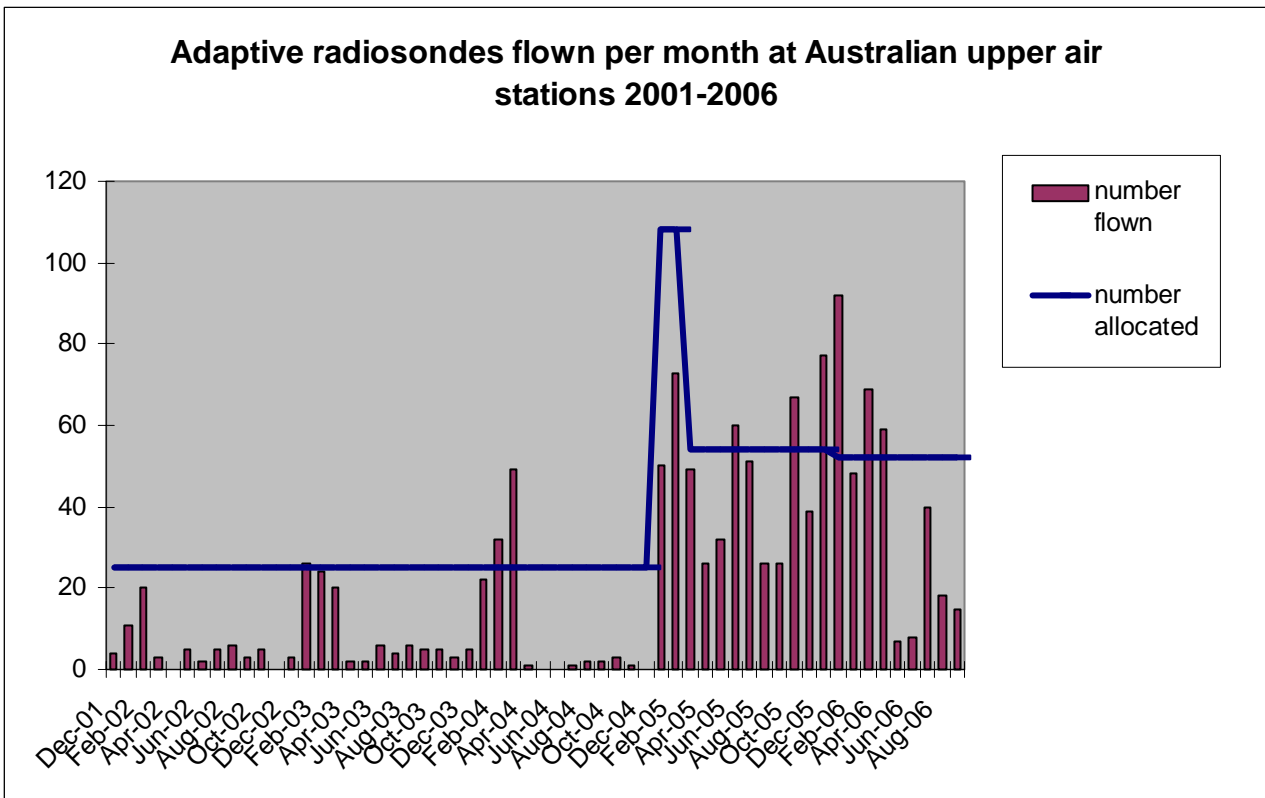


Figure 3: The number of adaptive (non-routine) radiosonde flights at Australian upper air stations each month for the period December 2001 to September 2006; also shown is the notional number of radiosondes allocated and available for adaptive operations.

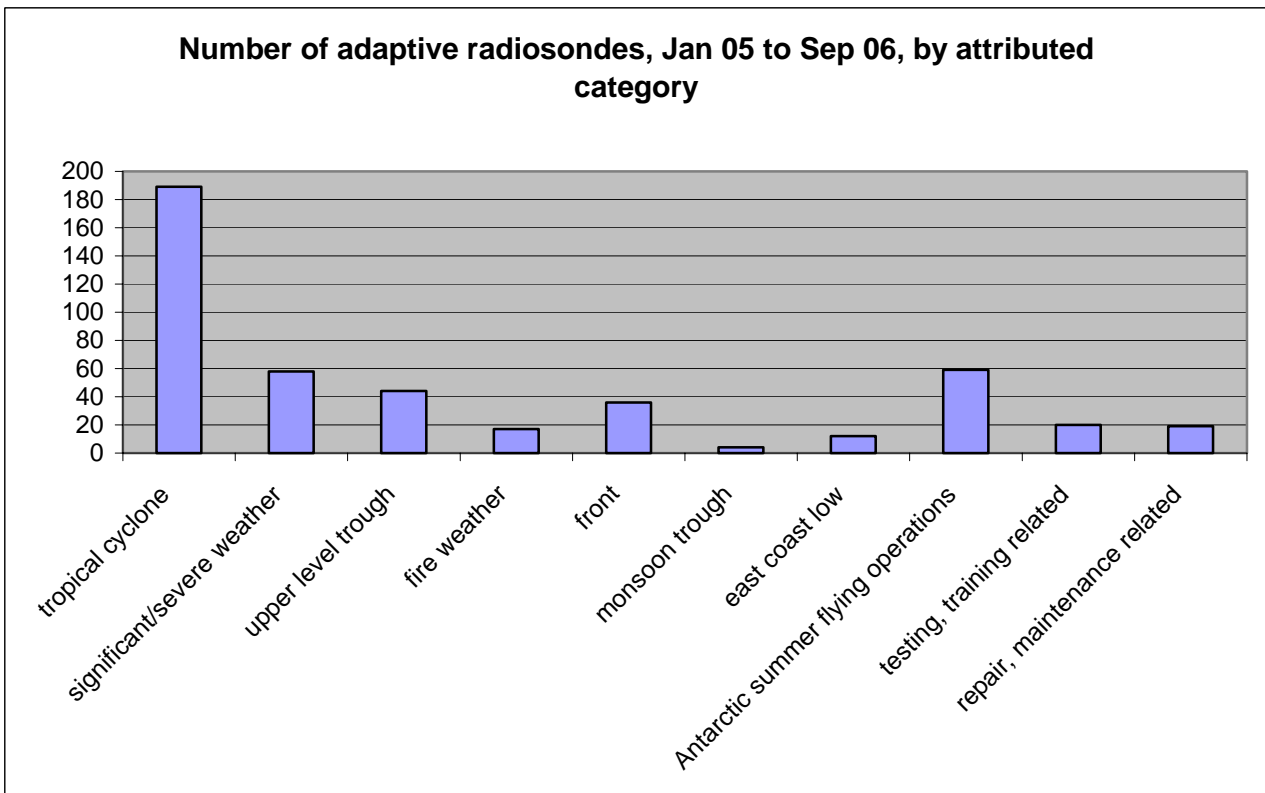


Figure 4: Attribution of adaptive radiosonde deployments during January 2005 to September 2006 to major categories. Note that only about half the adaptive deployments in this period were provided with an attribution.

The second development occurred in January 2005 when the Bureau implemented a significant reduction in the overall usage of radiosondes. That reduction was felt mostly as a reduction in radiosonde flights at 12 UTC. All the Autosonde stations (except one at Learmonth, a GUAN station) dropped back to a programme of one balloon flight per day at 00 UTC. Some other stations dropped 12 UTC radiosonde flights but were able to continue wind-only flights at 12 UTC where balloon-tracking radar remained available. To help ameliorate the worst impacts at Autosonde stations, the holding of additional radiosondes was increased to support adaptive flights, mostly at 12 UTC, at a rate of about 1 per week.

Fig. 3 shows the increased monthly deployment of adaptive radiosondes from January 2005. Fig. 4 shows the distribution across major categories to which the deployments were attributed. By far the largest application was during tropical cyclone events. As an event can extend over several days and involve a number of tropical upper air stations, many radiosondes are required for each event. For example 38 adaptive radiosondes were deployed as Severe Tropical Cyclone Larry approached and crossed the coast in March 2006 (Fig. 5). 49 adaptive radiosondes were deployed during tropical cyclone Monica the following month.

While “Antarctic summer flying operations” appears as a large category, this is seasonal in character more than adaptive to the weather situation.

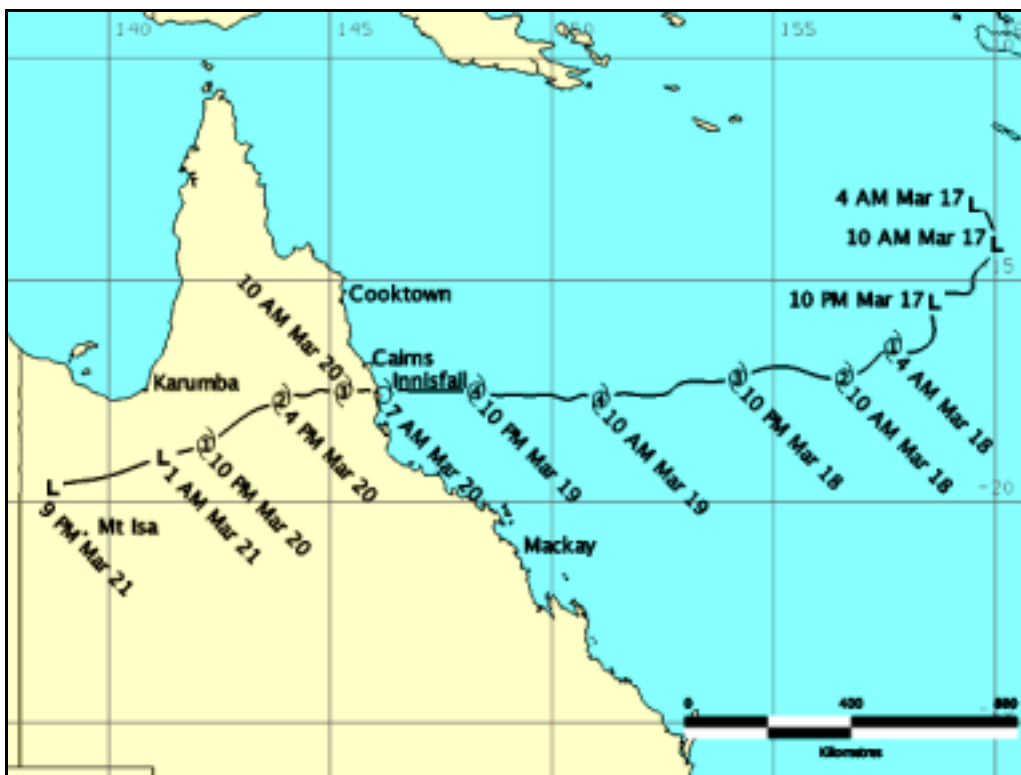


Figure 5: Severe Tropical Cyclone Larry track and intensity during March 2006.

Although the allocation of adaptive radiosondes was provided to specific stations, Regional managers have found that some spread of these radiosondes to all upper air stations has best enabled them to address the requirements.

As with surface observations, the requirement for variations to the upper air programme sometimes relates to the location rather than time of observations and that has led to implementation of a portable balloon release and tracking capability. There have notionally been a number of emergency response applications, however it has been the collection of on-site observations during going-fires that has retained the most active support and usage. The trailer shown in Figure 2 includes a theodolite, 20 gram balloons and items for helium gas filling. This adaptive strategy is fairly manually intensive.

A number of aircraft-based adaptive upper air programmes have been proposed and/or trialled over a period of time. A Cold Fronts Reconnaissance programme was conducted over southeast Australia during 1991 – 1993 in which local airlines were contracted to fly staff to areas south of South Australia and west of

Tasmania to locate, measure and track approaching summertime cold fronts. The Severe Weather Program was interested to learn whether this would lead to increased accuracy of forecasts and warnings, particularly related to fire weather conditions.

Internal Bureau documentation records that the project showed that the acquisition of meteorological data from the vicinity of cold fronts over marine areas is both feasible and beneficial to understanding the phenomenon. However the flights had a lack of impact on weather forecasts. The assumption that observing weather systems offshore would improve forecasts over land was not really borne out. Subsequent research using mesoscale NWP has more clearly revealed and explained the significant potential for structural change and acceleration once the cold front arrives on the coast – providing further support for the conclusions of the project.

Another proposed aircraft-based adaptive upper air programme was based on the small (approximately 3m wing span and 13kg weight) unmanned aeronautical vehicle known as “Aerosonde”. After a number of trials and demonstrations, the last trial period in early 2000 produced inconclusive results and an ongoing programme has not been established.

One aircraft-based adaptive strategy that is now a reality is the software adjustment of reporting rates and locations from AMDAR aircraft. This is primarily a data optimisation scheme that allows reports to be collected from a fleet of aircraft without paying for large quantities of overlapping and redundant data. However it provides a more general capability to vary the reporting of observations according to the prevailing weather, as well as from en-route areas that otherwise would have very few observations.

### **Adaptive Weather Surveillance by Radar**

The Australian weather watch radar network consists of about 60 radars. Half of these are balloon-tracking radars that are used for weather surveillance between balloon flights. Five radars are currently used to provide Doppler velocity data operationally, with a further three Doppler radars to become operational in the coming two years.

Historically, weather surveillance was conducted as a very manual task by the on-site radar operator. A combination of PPI scans and RHI soundings were used to derive a text message (the radar report RAREP) then later a hand drawn map showing areas of low, medium and high reflectivity as well as the height of significant cloud tops. Messages/maps were prepared and sent at specified times and also whenever significant echoes needed to be conveyed. The level of effort devoted to radar surveillance was inherently adaptive to the prevailing weather and supported intensive radar based applications such as aerodrome terminal area thunderstorm service and terminal area severe turbulence nowcasting and also cyclone tracking.

The next evolution of technology brought radar dialup access and data display software onto a PC in the parent forecasting office. The forecaster using the radar data could decide and immediately implement a more frequent dialup to the radar and modification to the scheduled balloon programme. In long periods of inactive weather the frequency of radar access for weather watch purposes could be reduced. A significant tension existed between the desire for data and the cost of communication services.

The Australian radar network now has some radars from which a two-dimensional composite-PPI image is routinely obtained, then full volumetric scans are obtained during periods of active weather. However the days of adaptive strategies to weather surveillance are almost over as there emerges an over-riding need for consistency and standardisation. This need is driven by two factors: the first is the very wide visibility and usage of radar images in the community, who have grown to expect and depend on an image from all radars every 10 minutes. The second factor is the evolution that has seen manual surveillance now joined by a range of automatic and quantitative applications of radar data.

### **Adaptive Weather Satellite Observations**

Australia acquires satellite data both for manual weather surveillance and as input to automatic and quantitative applications, most importantly NWP assimilation. Direct ground-reception is maintained for data from two geostationary and five polar orbit satellites. Access is also obtained to about twice that quantity of data from other ground-reception sources.

For many years the Bureau relied on the Geostationary Meteorological Satellite of the Japan Meteorological Agency as its primary source of weather observations from satellite. The ability to obtain variations to the programme of satellite observations arose from the high level cooperative working relationship under an

MOU with JMA. During the 1980's the standard frequency of provision of satellite images was 3-hourly. However an arrangement was in place allowing provision of hourly images during emergencies, for limited durations.

### **Network Capabilities**

The ability to operate and gain advantages from adaptive observing strategies relies on the capacity to *implement* variations to the routine programme of observations. Drawing on the above experiences, some themes can be noted.

The capacity to implement variations is much greater in the temporal than the spatial domain. To increase or decrease the time frequency of observations from an existing station is most often a question of how the incremental cost and effort compares to the expected value of the observations data. Costs might become prohibitive when aggregated over a number of adaptive deployments, whether that be for consumables, communications services, contractor payments, staff salaries and overtime, and so on.

To obtain observations from arbitrary spatial locations is generally more challenging and expensive, in terms of staff time and effort and/or the support and operation of specialised equipment and platforms. Hence such approaches have been operationally less prevalent. The need for, and value of, spatially targeted observations includes two distinct considerations: firstly is the need to observe significant weather systems where and as they develop (including tropical cyclones, cold fronts, severe thunderstorms); and secondly is the need to observe weather conditions at or approaching a vulnerable site (such as a site of active fire fighting operations).

Variations to manual observing programmes face different issues to variations to automatic programmes. Human observers are enormously flexible and adaptable in terms of the information and comments they can report and interpreting the need to submit a report, however they must eat, sleep and be protected from hazards. Conversely an automatic system can only report within the parameters of its design and configuration, but can operate at remote and exposed locations and continuously report at the frequency required.

The ability to communicate a weather report from the observation site to a forecast office or data processing system can also be a significant factor, both in terms of feasibility and cost.

### **Decision Process and Criteria**

The ability to operate and gain advantages from adaptive observing strategies also relies on the capacity to make timely *decisions* about variations to the routine programme of observations. Again, some themes can be identified in the experiences described above.

Adaptive deployment decisions are generally made by the Senior Meteorologist on duty in the Regional Office of the Bureau of Meteorology, in association with any relevant Regional programme managers. This works well because that is the person who is most familiar with the weather situation including current NWP outputs and associated uncertainty, and most depends on the information obtained to frame forecasts and warnings and to deliver services.

Part of the supporting framework is to have guidelines on the general policy and scope for adaptive deployments, together with some degree of resource envelope helping to set the expected rate of deployment. That might for example be the size of the additional holding of radiosondes, or the field staff overtime budget.

Similarly, an adaptive decision on whether to tolerate reduced observations can be made in light of the weather situation as well as the staff overtime budget (in the case of temporary staff absence within a manual observing programme) or the call-out and travel budget (in the case of equipment failure).

The decision process could be characterised as either "subjective" or "objective" in nature, however it is unavoidable that some contribution by both will be required to maintain a more complete "expert" decision process into the future. The historical experiences described in this paper are based on a largely subjective assessment and decision process.

There is a growing international body of work aiming to identify sensitive areas in NWP systems and hence provide objective guidance on where and when to target or prioritise observations for maximum impact on the NWP system. Such objective criteria are not available operationally in Australia at present. Bureau NWP



assimilation experts advise that there is no currently available objective basis for targeting adaptive radiosondes to have impact on Australian NWP systems. Similarly, there is not a currently available objective basis to demonstrate value of adaptive radiosondes through impact on Australian NWP systems. For this reason the National Meteorological and Oceanographic Centre (NMOC) – the Bureau’s national centre for operational NWP – has so far not taken the opportunity to request any adaptive radiosonde deployments.

More generally, the assessment of value and impact of adaptive observations needs to be aligned with the criteria used to deploy them. At a fundamental level, in these historical examples, the staff who utilise the observations provide evidence of value when they continue to invest time and effort in maintaining the capability and in contributing to the process of deciding and deploying adaptive observations (or, conversely, provide evidence of lack of value when the capability falls into disuse).