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An overview of the Antarctic FROST project

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A brief overview is presented of the rationale behind and the implementation of the Antarctic First Regional Observing Study of the Troposphere (FROST) project. FROST is concerned with studying the meteorology of the Antarctic during three one-month Special Observing Periods (July 1994, 16 October-15 November 1994 and January 1995) during which comprehensive datasets of *in situ* and satellite observations and model fields were assembled. These data have been used to produce high quality, hand-drawn analyses for the area south of 50°S which have subsequently been used to assess the operational analyses and forecasts produced in near real-time. The revised analyses have been digitised and are available in GRIB code format. As the FROST dataset is the most complete collection of Antarctic observations assembled since FGGY in 1979, it offers great opportunities for researchers over the coming years.

Introduction

The Antarctic has always been one of the most difficult areas for which to prepare meteorological analyses because of the lack of *in situ* data, the problems of interpreting satellite imagery and the rapidly varying orography in parts of the continent, which results in many local atmospheric phenomena. Because of the remoteness of the region from most of the heavily populated areas of the earth, the resources have never been available to improve the analyses for the area, compared with those directed towards producing good analyses for mid-latitude and tropical regions. Over the last few decades, however, there have been a number of major international projects concerned with the meteorology of the Antarctic that have advanced our knowledge of high latitude atmospheric processes. During the International Geophysical Year (IGY) of 1957-58 many new staffed research stations were established in the Antarctic allowing the production of high-quality surface and upper-air analyses, although the lack of satellite imagery at this time meant that the many mesoscale and small synoptic-scale disturbances that we now know exist at high southern latitudes were not fully resolved. Nevertheless, the density of staffed stations has not been achieved in the intervening years and the data collected at that time are still being employed in contemporary investigations (Phillpot 1991).

More recently, the First GARP Global Experiment (FGGE) of 1979 (Hollingsworth 1989) resulted in renewed interest in the meteorology of the Antarctic and the high-quality analyses that could be produced using the additional data collected during the experiment were employed in a number of studies, such as an investigation of depression activity around the continent (Physick 1981). However, since FGGE the meteorological investigations carried out in the Antarctic have been much more regional in nature

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(e.g. the Winter Weddell Sea Project of 1986 (Rabe 1987)) and there have been no continent-wide experiments that made use of the new data sources becoming available. For these reasons the Physics and Chemistry of the Atmosphere (PACA) Working Group of the Scientific Committee on Antarctic Research (SCAR) decided to organise an international experiment that would reassess our capability to analyse the surface and upper-air conditions over the Antarctic and to make reliable forecasts. In addition, we hoped that a comprehensive dataset of observations could be created for investigations into particular aspects of the Antarctic climate system, such as synoptic and mesoscale weather systems, precipitation, cloud cover and katabatic winds.

The five specific goals of FROST were to:

1. Assess our capability to utilise meteorological data over Antarctica and the surrounding sea areas in operational assimilation/forecast schemes. This work should be of benefit to the weather services which run global forecast models.
2. Assess the current state of the short (24 h) and medium-range (up to seven day) forecasts for high southern latitudes in terms of representation of hemispheric, synoptic and subsynoptic-scale systems, boundary-layer structure, local coastal and other topographically induced features. Diagnostic data produced should be of value in improving the parametrisation of high latitude processes in the models.
3. Gain insight into the hemispheric, synoptic and mesoscale atmospheric processes important in the Antarctic and over the Southern Ocean through analysis of satellite and *in situ* data and high resolution mesoscale numerical models.
4. Improve the derivation of atmospheric products from satellite data for the region.
5. Assemble comprehensive datasets of Antarctic observations for future atmospheric research.

As the resources available to the project were limited, it was not possible to consider the establishment of new stations, but great efforts were made to collect and make use of the observations made at all the existing sites and to encourage the nations operating the bases to increase the frequency of their observing programs during the experiment. In order that an enhanced observing schedule could be maintained for the duration of the experiment it was decided that the observing phase of FROST should be limited to three one-month Special Observing Periods (SOPs), followed by several years of data collation and quality control, chart re-analysis and the assessment of results.

Many groups from the weather services and the academic community are involved in FROST and Table 1 provides a breakdown of the division of work.

Table 1. Groups involved in FROST and their role in the project.

Group	*Role*
British Antarctic Survey Cambridge, UK.	The main FROST archiving centre. Also involved in assessment of the numerical analyses and forecasts.
Bureau of Meteorology Hobart, Australia.	Collection of GTS data. Automated chart plotting and archival. Taking the lead in the reanalysis exercise.
Bureau of Meteorology Research Centre Melbourne, Australia.	Involved in the assessment of the analyses and forecasts.
Byrd Polar Research Center Ohio State University USA	Assessment of the US numerical products.
Department of Earth Sciences University of Melbourne Melbourne, Australia.	Analysis of depression tracks during the SOPs.
Antarctic Cooperative Research Centre University of Tasmania Hobart, Australia.	Contributing to the reanalysis effort.
Meteorologisches Institut, University of Bonn, Bonn, Germany.	Production and analysis of meteorological products derived from passive microwave data over the ocean.

Data collection and the Special Observing Periods

The three FROST SOPs were chosen as July 1994 (during the Austral winter: SOP-1), the summer month of January 1995 (SOP-3) and a month covering the formation of the Antarctic ozone 'hole' (16 October – 15 November 1994: SOP-2). The summer and winter SOPs are the primary FROST study periods for tropospheric investigations, the spring period being included at the request of the stratospheric chemistry community.

For the three SOPs, an attempt was made to collect as many observations as possible, along with numerical analyses and forecasts and ancillary datasets. The primary source of observations from the staffed stations, ships, drifting buoys and automatic weather stations (AWSs) was the World Meteorological Organization's Global Telecommunications System (GTS), which links the national weather services and the observation collectors. Prior to the SOPs, three assessments of the Antarctic data on the GTS were carried out with observations being collected at Hobart, Australia, and Cambridge, UK. As described by Turner et al. (1996), the GTS was found to be fairly successful in transferring the Antarctic observations to the main analysis centres, although some problems were found. For these reasons, the main FROST data archive was created by merging the observations at these two nodes of the GTS. A few additional observations that were not transmitted on the GTS were obtained from contacts in the countries that operate the Antarctic stations, although the fact that the vast majority of the observations are sent out of the Antarctic in near real-time is a tribute to the dedication of the meteorological observers on the stations.

The basic dataset of synoptic observations was supplemented by AWS data and satellite imagery from national operators, passive microwave imagery from the US National Aeronautics and Space Administration (NASA), and Australian, US, British and European Centre for Medium-Range Weather Forecasts (ECMWF) analyses and forecasts from the GTS.

Turner et al. (this issue) provide a comprehensive review of the data collected during the FROST SOPs and give details of how to access the datasets.

The re-analysis exercise

In order to produce the best possible analyses for the SOPs, all the available data for these periods were used to prepare surface and upper-air charts, using the operational analyses of the UK Meteorological Office (UKMO) as a starting point. These analyses were chosen since they were based on the output of the 19-level numerical assimilation scheme, but were modified by analysts who could take account of satellite imagery. Further advantages in using these charts were that frontal positions were manually drawn and the surface wind vectors produced from the scatterometer data were plotted.

Two different approaches were taken in the re-analysis depending on the area under consideration. Over the ocean areas and flat ice shelves a conventional surface analysis could be undertaken using the *in situ* observations and satellite imagery. The satellite data in particular were found to be of great value, especially the high resolution imagery obtained for certain periods. The imagery revealed the complexity of many of the low pressure systems around the continent and greatly aided the analysis of fronts and multicentred lows. The upper-air fields were prepared by integrating the surface fields and thickness charts derived from observations from the TIROS Operational Vertical Sounder (TOVS) instruments aboard the NOAA spacecraft, communicated on the GTS in SATEM code.

Over the continent, a different approach had to be adopted since much of the surface is above 2 km in elevation and no pressure at mean sea level (PMSL) charts could be prepared. Instead, the lowest level analysed over East (West) Antarctica was at 500 (700) hPa with the SATEM thickness values being added to this base field. The 500 and 700 hPa surfaces were determined from the available AWS data using the technique of Phillpot (1991).

Further details of the re-analysis exercise can be obtained from Hutchinson et al. (forthcoming).

Assessment of the analyses and forecasts

Intercomparison of the analyses and forecasts produced by the major weather services is one of the most important components of FROST, since this part of the project has the potential to help the services improve their operational assimilation and forecasting systems. A number of different techniques are being used to examine the numerical products. Mean surface and upper-air data from the different forecast centres for the SOP months are being compared via difference fields and zonal cross-sections. When major discrepancies are discovered, the origins of the differences are being investigated via difference fields for individual days and the available *in situ* data. Determining what 'truth' is in any particular situation is difficult, but satellite imagery does provide a good indication of the locations of the major depressions and frontal bands via their cloud signatures. Most of the above work is concerned with the oceanic areas around the continent where there is a reasonable amount of validation data. Over the continent itself the lack of ground truth and the limited value of satellite imagery makes validation much more difficult. The intercomparison of FROST analyses is discussed by Turner et al. (Forthcoming).

Research opportunities

The wide variety of data in the FROST archive offers many opportunities for those concerned with fundamental research into the meteorology of the Antarctic or the production of operational analyses and forecasts. Areas of research that are particularly appropriate are:

1. Observing system studies based on the use of the full, merged dataset of FROST observations. These investigations could consider the value of particular forms of data or the degradation that would occur if certain stations were closed. As some stations made twice-daily, rather than once-daily radiosonde ascents during the SOPs, the value of these two modes of operation could be examined. Such investigations would involve the re-running of assimilation schemes, but considering the cost of operating the meteorological programs in the Antarctic these studies would allow quantification of the value of the data collected.
2. Case studies of selected meso or synoptic-scale weather systems. The fact that so many diverse observational datasets have been brought together for FROST offers the chance to carry out detailed investigations of particular events using an unprecedented set of data.
3. Studies of the retrieval of geophysical parameters from raw satellite observations. Deriving products, such as cloud amounts or atmospheric soundings, from satellite data is a major challenge in the Antarctic because of the high orography and the ice and snow on the surface. However, the lack of *in situ* data over the continent makes it even more important to be able to produce high-quality geophysical parameters from satellite data for use in research or operational activities. The FROST dataset includes a large amount of raw satellite data along with many *in situ* observations for validation.
4. Investigations into the links between atmospheric flow and sea ice extent and concentration. Since we have a very good knowledge of the atmospheric conditions for the SOPs it would be possible to gain a great deal of insight into its effects on the sea ice zone.
5. Studies of the synoptic and mesoscale flow over the continent. The series of detailed analyses for the interior of the continent provide a consistent and reliable source of information on weather systems on the plateau. When used with the high resolution satellite imagery, these data could provide valuable information on disturbances in this little-studied region.

Progress to date

At the time of writing (October 1997) most of the data collection for FROST has been completed. Some drifting buoy data are still to arrive, but we do not expect to receive any further conventional synoptic observations. The assimilation of the synoptic data from Hobart and Cambridge into a merged dataset has been completed for the two main SOPs, with the raw data for the spring 1994 SOP available for anyone interested in this period. Good progress has been made in collecting the numerical analyses for the SOPs, although some of the forecasts are still to be obtained.

The re-analysis of the charts for the SOPs has proved a major undertaking, although the whole of SOP-1 has been re-analysed and the second re-analysis of the special week of 22-28 July 1994 using high resolution satellite imagery has also been completed. The re-analysed charts for the special week of SOP-1 have now been digitised and are available for use in computer-compatible form. It is hoped to make these digitised charts available soon on CD-ROM and via the FROST World Wide Web page (http://www.nerc-bas.ac.uk/public/icd/FROST/). Work is currently underway on the re-analysis of the special week selected in SOP-3 (19-26 January 1995) and it is hoped to have these charts finished by the end of August 1997. There are no plans to re-analyse the charts for SOP-2.

The assessment of the analyses has progressed well with both the hand-drawn and numerical products being considered. Major discrepancies have been studied in detail with the data used by specific assimilation schemes being examined. Some forecast errors were included in Turner et al. (1996) but the much more detailed intercomparisons of individual forecast runs have only just started.

Similarly, the work on case studies is at an early stage, although the first results of the investigations into Antarctic weather systems using the many forms of data that are available for the SOPs are beginning to appear in the literature (e.g. Lieder and Heinemann, forthcoming).

Considering the limited manpower available to FROST it is felt that a great deal has been achieved in terms of data collection, production of analyses and assessment of operational analyses and forecasts. It is hoped that scientists involved in Antarctic meteorology and allied subjects will continue to make use of the assembled data in the years to come.

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