had the call-sign 'XD' and transmitted reports at 0800, 1000, 1400, 1700 and 1900.

2. In June 1941, Nagle complained about the removal of the guard detail at Foynes and said that this detachment was required because four secret codes were being kept, one BOAC, two Air Ministry (UK) and one of their own (Irish). The codes had been given on the understanding that they would be protected.
3. The RAF had at least one meteorological unit in Northern Ireland.

Information from file EDP/36:

1. The Air Ministry (UK) used 'Syko' cipher machines at Foynes.
2. In 1942, the guard detail at Foynes was increased.

Wider reading of the archival documents indicated to Dr de Cogan that right up to 1942 there was a preoccupation in Ireland of an invasion by Germany and a great deal of consideration about the identification of key elements that should be destroyed at short notice.

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Forecast Demonstration Project Sydney 2000:
Part 1: An overview of the project and the participating systems

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This is the first of two papers describing the World Meteorological Organization (WMO)-sponsored World Weather Research Programme (WWRP) Forecast Demonstration Project (FDP), entitled Sydney 2000. The aim of the Sydney 2000 FDP was to demonstrate the predictive capabilities of short-range weather forecasting (nowcasting) tools (WMO 1998), including those either under development in research institutions, or in operational use in meteorological services around the world.

This paper presents a brief history of the WWRP and FDP Sydney 2000, a description of the participating nowcasting systems, and an overview of the FDP spanning a three-month period that included the Sydney 2000 Olympic Games. A review of the performance of the Nimrod and GANDOLF systems contributed by the Met Office and the University of Salford will follow in a second paper.

Setting the scene

The Olympic Games are extremely susceptible to disruption by the weather. With global television audiences in the billions, any decision to reschedule an Olympic event as a result of such disruption can have massive repercussions. Of paramount importance is the prevention of injury to athletes and spectators as a result of severe weather, in particular large hail and lightning. In addition, one must not forget that the performance of athletes in any one of a wide range of outdoor sports, from archery to cycling, and rowing to beach volleyball, may be highly weather-sensitive. For example, such is the sensitivity of sailing to the vagaries of the weather that sailing teams often have their own meteorologists on board.

The Sydney 2000 Olympic Games afforded an ideal opportunity to showcase the nowcasting tools developed by some of the world's leading meteorological research institutions and National Weather Services (NWSs). In addition, it provided the ideal setting in which to assess the beneficial impacts afforded by such tools.

The WWRP

In 1995 the WMO decided that a programme similar to the World Climate Research Programme (WCRP) should be established to coordinate research into a variety of weather forecast-related fields, chosen because they were both challenging scientifically and of great importance in terms of their potential human and economic impact. A Scientific Steering Committee (SSC) recommended that the WWRP integrate existing programmes concerning the development of weather forecasting techniques for all time-scales (very short, short, medium and long ranges) with the WMO's World Weather Watch and WCRP.

The WWRP mission statement is:

> "To undertake the necessary R&D [Research and Development] leading to the development and demonstration of improved and cost effective forecasting techniques, with emphasis on high impact weather, and to promote their application among member states. High impact weather is defined as weather that affects quality of life, is economically disruptive, or is life threatening, and is prominent among the concerns of the International Decade for Natural Disaster Reduction, IDNDR. High impact weather can occur in forecast ranges from the very short-range to the long-range, up to a season."

The objectives of the WWRP are:

(i) the improvement of public safety, quality of life and economic productivity;
(ii) the improvement of the understanding of atmospheric processes important for weather forecasting;
(iii) the demonstration of improvements in weather prediction, with emphasis on high-impact weather;
(iv) to facilitate integration of weather prediction research advances achieved via international and national programmes; and
(v) to encourage the utilisation of relevant advances in weather prediction systems.

The methods by which the WWRP are to achieve these aims include the promotion of technology transfer and training, research and development programmes, and FDPs.

FDPs were conceived as a means of exhibiting and formally quantifying the benefits to be derived from scientific and technological advances. As such they were required to satisfy the following selection criteria:

(i) FDPs must involve the dissemination of weather forecasts to real users in real time;
(ii) the forecasting algorithms and systems demonstrated must be suitable for transfer to member states;
(iii) the performance of the forecasting algorithms must be assessed in accordance with an internationally agreed verification strategy; and
(iv) FDPs must involve the development of training material for potential users.

The FDP Sydney 2000

The FDP proposal, submitted to the SSC in 1998 by the Bureau of Meteorology (BoM), was entitled Australia's Sydney Olympic Project (ASOP). The remit of the sanctioned FDP was threefold:

(i) to demonstrate the automated recognition, and very-short-range and short-range prediction of severe weather for the Olympic Games;
(ii) to demonstrate the value of weather radar in detecting severe-weather signatures associated with mesocyclones, downbursts and large hail; and
(iii) to demonstrate the prediction of convective storms, including their initiation,

development and movement using 'state of the art' nowcasting algorithms.

In accordance with the stated objectives of the WWRP, ASOP was also required to demonstrate added value in terms of forecast capability, and positive human and economic impacts.

The Olympic Games were held in Sydney between 15 and 30 September 2000, to coincide with Australian springtime. In general, spring weather in this part of Australia is ideal for sport. Maximum temperatures typically range between 18 and 25 °C. Conditions are relatively dry, but may be rather windy at times. There is a small risk of a thunderstorm bringing some locally heavy downpours accompanied by severe weather including large hail, strong winds and lightning.

During the Olympic period, the BoM were solely responsible for both routine and severe-weather forecast services. The FDP was run alongside these operations at the New South Wales (NSW) regional meteorological office in Sydney. Six research groups participated in the FDP, and the products produced by their various nowcasting systems were available to operational weather forecasters who had received training in their usage.

The participating systems were all nowcasting systems concerned with the production of weather forecasts with maximum lead times of six hours. This definition is based upon the premise that beyond six hours mesoscale modelling techniques should provide better forecasts than those produced by extrapolation of intensive observations. The common tool of the six participating groups is weather radar. In some cases this was used alone, whilst in others it was combined with forecasts from a mesoscale model. A review of nowcasting techniques and systems is provided by Wilson *et al.* (1998).

Of the six groups involved in the FDP, two were based in the USA, one in Canada, two in the United Kingdom and one in Australia. The National Center for Atmospheric Research (NCAR) contributed their Autonowcaster system, whilst the National Severe Storms Laboratory (NSSL) ran the latest version of their Warning Decision Support System (WDSS-II). Environment Canada ran the Canadian Radar Decision Support System (CARDS). The Nimrod system provided by the Met Office was run on the same hardware as the GANDOLF system, a developmental version of which was implemented by the University of Salford. The Bureau of Meteorology Research Centre (BMRC) ran their spectral prognosis rainfall nowcast scheme and the Thunderstorm Identification, Tracking Analysis and Nowcasting (TITAN) system.

A year before the start of the Sydney 2000 Olympic Games, FDP participants installed their systems in the NSW regional forecast office. During the following 12 months, BoM technical staff worked alongside system experts from each of the groups to ensure smooth running of the various nowcasting algorithms. Two operational trials of the systems were conducted during September 1999 and February 2000. These served several purposes. They were used to demonstrate the integrity of the data feeds provided by the BoM, to fine tune the nowcasting algorithms, and to establish a framework for relaying information from the FDP systems to the operational weather forecasters.

The FDP began in earnest on 4 September 2000. From this point onwards the systems were run operationally, and modifications to the nowcasting algorithms were disallowed. During the subsequent three months, representatives from each of the six participating groups worked on ten-hour shifts, covering the hours between 0600 and 2000 local time (LT) each day. An FDP product champion was nominated on each shift. It was the product champion's responsibility to summarise pertinent forecast information generated by the nowcasting systems, and deliver it to the BoM's severe-weather forecasters (see Fig. 1).

The final phase of the FDP involved a WMO-sponsored workshop, held at the beginning of November 2000, and hosted by the BoM in Sydney. The workshop was attended by representatives of NWSs from around the world. Emphasis was placed upon the sharing of nowcasting expertise amongst member states of the WMO. To facilitate this, the BoM has prepared a CD-ROM incorporating information on the nowcasting techniques and systems run during the FDP, training material presented by the

Fig. 1 Product champion, John Bally of the Bureau of Meteorology Research Centre (left) and Jim Wilson of the National Center for Atmospheric Research at work during the World Weather Research Programme Forecast Demonstration Project Sydney 2000, at the Bureau of Meteorology, Sydney, held from September to November 2000

system experts during the workshop, and case-study data compiled between September and November 2000.

The nowcasting systems

The nowcasting systems on trial during the FDP can be categorised into two groups. Not surprisingly, the division runs along continental lines with the North American systems being designed to make use of the Doppler capability of radar, whilst the UK and Australian systems do not. There are fundamental differences between these two approaches. The UK systems are primarily concerned with nowcasting existing weather phenomena, with an emphasis on precipitation. By contrast, the North American systems attempt to predict the initiation of convection and associated severe weather through the identification of wind-field convergence zones in velocity data from Doppler radar.

Autonowcaster

The Autonowcaster is a multi-purpose nowcasting aid that is designed to identify areas of thunderstorm initiation, and forecast storm motion and dissipation. Its most powerful attribute is its use of Doppler wind fields, retrieved from clear-air radar returns. These are employed to identify regions of low-level convergence.

The Autonowcaster detects and extrapolates convergence lines from wind fields retrieved using single-Doppler radar data (Sun and Crook 1994). An extrapolation routine allows the system to predict where convergence is likely to occur in the near future. The system uses its knowledge of the atmospheric environment gathered from numerical weather prediction (NWP) model data and meteorological observations (*e.g.* mesonet data and sonde ascents) to compute a number of convective initiation indices. When an area of convergence is predicted to intercept regions of potential storm development, the relevant areas are flagged as initiation zones for severe weather.

Another feature of the Autonowcaster is its storm tracking and prediction algorithm. This forms part of the TITAN system (Dixon and Wiener 1993), and is the only radar-based nowcasting tool currently operational in the BoM. TITAN can extrapolate storm motion and size. A radar-reflectivity threshold can be set to limit the number of storms that are identified.

WDSS

The WDSS has been operational for several years in a number of weather centres across the USA, and has a severe-weather focus. The system ingests three-dimensional radar reflectivity and Doppler radial velocity data, surface and upper-air observations, satellite imagery and rapid update cycle NWP model data. It includes a suite of algorithms that are enhanced versions of those implemented on the WSR-88D radars in the USA (Crum and Alberty 1993).

The central algorithm is the Storm Cell Identification and Tracking algorithm (SCIT) (Johnson *et al.* 1993). The SCIT identifies convective cells from volumetric reflectivity data. The algorithm delineates only the cell centroids or cores. This allows the SCIT to disaggregate rain areas into their component cells and thus detect differential motion within a rain area. The past history of a cell can be ascertained by examining time sequences of radar volumes. Cell velocity is determined using a linear least-squares fit to a series of past centroid locations. The resultant velocity is employed to predict future positions of the cell at ten-minute intervals.

The SCIT and the other algorithms in the WDSS output the attributes of each identified cell to a SCIT table. These attributes include cell base and top heights, cell direction, speed, maximum reflectivity and the height of the maximum reflectivity. The probability of hail and severe hail (greater than 2 cm in diameter) is estimated, together with the maximum hail size (Witt *et al.* 1998).

CARDS

CARDS, developed by the Meteorological Service of Canada and known as the Unified Radar Processor in Canada, analyses radar reflectivity and Doppler velocity data to generate numerous analysis and nowcast products. The analysis products include Plan Position Indicator (PPI), Constant Altitude PPI and Velocity Azimuthal Display scans, user-defined vertical cross-sections of reflectivity, and echo top and maximum reflectivity maps. A Z–R (radar reflectivity factor–rainfall rate) relationship is used to estimate precipitation rates. Sequences of rain-rate analyses are integrated to estimate three-hourly rainfall accumulations at the earth's surface.

CARDS produces rainfall nowcasts by extrapolating observed radar echoes. During the FDP, point rain accumulation nowcasts were computed for each of the Olympic sports venues. In addition, a range of diagnostic tools provided automatic detection of severe weather. Wet microbursts were identified from vertical reflectivity profiles. A series of empirical relationships between hail size and the height of the 50 dBZ echo above the freezing level were used to estimate maximum hail size. Mesocyclones were detected from the azimuthal shear in a Doppler-derived velocity field.

Nimrod

Nimrod (Golding 1998) is the successor to FRONTIERS and has been operational at the Met Office headquarters in the United Kingdom since 1995. The system is designed to generate analyses and short-range forecasts of various meteorological variables, including rainfall. Data inputs comprise radar data from the UK weather-radar network, infrared and visible satellite imagery, surface synoptic weather reports and forecast fields from a mesoscale NWP model.

The rainfall nowcasting scheme combines object-oriented advection techniques and NWP mesoscale rainfall prediction. A short-range, extrapolation forecast of observed rain is produced by advecting precipitation 'objects' using cross-correlation vectors or wind vectors from an NWP model forecast. This extrapolation forecast is blended with an NWP rainfall forecast in such a way that greater weight is given to the NWP component at longer lead times. Precipitation products include fields of instantaneous rain rate, rain accumulation and precipitation type. Only the first two of these were available to weather forecasters at the

BoM during the FDP Sydney 2000.

GANDOLF

GANDOLF (Pierce *et al.* 2000) was developed jointly by the Met Office and the Environment Agency in an effort to improve the nowcasting of non-frontal convective rain (showers). The system employs a conceptual life-cycle model of a convective cell to simulate the growth and decay of showers in a physically realistic manner. This conceptual model is known as the Object-Oriented Model (OOM) because it makes use of object-oriented programming techniques (Hand and Conway 1995; Hand 1996).

GANDOLF produces a convective rain analysis field from a convective cell analysis. The latter identifies the developmental state of all existing convective cells using vertical reflectivity profiles derived from multi-beam or volumetric radar data. A nowcast is generated by allowing each identified cell to follow the life cycle conceptualised in the OOM, whilst the cell is advected with steering-level winds taken from a mesoscale NWP model. Rainfall rate and accumulation are the primary outputs from GANDOLF, although nowcasts of severe convective weather including large hail and peak convective gusts are also generated.

The Spectral Prognosis (S-PROG) scheme

The S-PROG scheme of the BMRC was designed to nowcast the motion of existing areas of rain over a period of one hour. Unlike the other schemes on trial in the FDP, this one relies solely upon a statistical model to predict rainfall, in contrast to the physically based approaches employed by some of the other systems described above.

A series of radar-reflectivity images are utilised to identify the recent, past motion of rain. The resultant motion vector is used to extrapolate spectral components of the rainfall field with the aid of a second-order auto-regressive model, or AR(2). The latter allows S-PROG to modify the predicted intensity of rainfall areas in accordance with the observed persistence of rainfall features with different intensities. For simplicity's sake, the AR(2) model assumes stationarity, with the result that the predicted rainfall field becomes smoother over time and tends towards the field mean rain rate.

Relationship between FDP participants and operational weather forecasters

Perhaps the most novel aspect of the Sydney 2000 FDP was the interaction between the system developers and operational weather forecasters. During the first Intensive Observation Period in September 1999, members of the severe-weather forecasting team of the BoM were introduced to the various nowcasting systems and their products, and given a series of lectures detailing the capabilities and limitations of each nowcasting algorithm. The aim was to allow forecasters to familiarise themselves with the products that would be available during the FDP.

From 4 September 2000, when the FDP commenced, until 21 November 2000 a strict operational protocol was observed. Severe-weather forecasters from the BoM were required to monitor severe weather between the hours of 0600 and 2000 LT each day. They were responsible for issuing severe-weather bulletins and site-specific meteograms for each of the Olympic venues. Existing operational, manual nowcasting procedures were heavily relied upon, at least initially. However, as time progressed, the additional guidance afforded by the FDP nowcasting systems was used with increasing regularity and confidence.

The FDP systems and participants were positioned adjacent to the severe-weather forecasting desk, and weather forecasters had routine access to selected FDP nowcasts via several interactive web pages (see Fig. 2, back cover). To avoid overloading busy forecasters with additional information, the FDP participants were required to distil the guidance from their various systems into a single, coherent text message. This entailed the nomination of a product champion, an FDP representative, to compile these text messages and liaise between FDP participants and the weather forecasters.

The interactive capabilities of the FDP web pages allowed a two-way interaction between the two groups. Thus, operational weather forecasters could request advice on the interpretation of FDP products, and FDP personnel could post regular updates to their text message summaries. The final decision as to whether the guidance afforded by a particular product should be used in the compilation of a severe-weather bulletin or nowcast rested solely with BoM staff. The role of the FDP was to attempt to add value to the products issued by the BoM.

Figure 2 shows an example of the FDP interactive web pages available to weather forecasters at the BoM. These comprise panels summarising the outputs from the various nowcasting systems. The 12 panels shown include WDSS storm tracks and an SCIT table, TITAN storm tracks, Autonowcaster winds and precipitation nowcasts, Nimrod, GANDOLF and S-PROG rainfall nowcasts, and two CARDS severe-weather detection panels (point rain accumulation nowcasts, mesocyclone, microburst and hail detections colour-coded for severity, overlaid on TITAN 35 dBZ cell tracks). Also shown are a raw radar reflectivity image, a precipitation type product produced by the BMRC's multi-parameter radar, C-POL, and a panel reserved for the FDP text message guidance.

Associated with each of the panels was a more detailed interactive product. In most cases this was an animated nowcast loop. A weather forecaster interested in a specific algorithm could click on the relevant panel to access this additional information.

Verification

Verification is seen as an essential component of all FDPs. Verification of the Sydney 2000 FDP will be overseen by a subcommittee of the SSC. It is the responsibility of this subcommittee to define what constitutes best practice. The verification, yet to be completed, is to be based upon field- and venue-specific products produced by the various systems. Performance will be measured using a range of quantitative and qualitative statistics agreed upon before the start of the FDP.

Common observation and forecast datasets have been created for ready intercomparison of the nowcasting systems. The verification of nowcasting products from the Sydney 2000 FDP will focus on a set of case-studies comprising data from days when severe weather was observed in the vicinity of Sydney. These case-studies include examples of severe storm initiation and development, the passage of frontal rainbands with embedded convection, and wind shifts associated with sea-breeze fronts.

The results of this verification exercise will be presented in the form of a report to the SSC and will be reviewed at a final workshop. Some case-study material and verification statistics for the Nimrod and GANDOLF systems will be presented in Part 2 of this paper.

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Forty-one UK snow patches last until winter 2000/01

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The number of snow patches that survive until winter fluctuates from year to year. Here we give a fourth annual summary, following Watson *et al.* (2000). Also, we describe surviving patches on Aonach Beag near Ben Nevis and Geal-charn near Ben Alder (Fig. 1), in sites which to our knowledge have not been published hitherto.

The winter of 1999/2000

Frequent Atlantic gales led to severe blowing snow. December was cold, with good snow at Scottish ski areas. A thaw in early January removed most of it, but deep wreaths remained at high altitude. Snow in early February renewed cover and heavy precipitation caused big snowfalls high up. A very mild first week of March ended Glenshee skiing (D. Patterson, personal communication). On 16 March, A. Watson (AW) noted that snow covered only 5% of the 922 m Meall Odhar there and 0% on 19 March, but higher beds remained filled. April had heavy precipitation, at high altitude almost all of it as snow.

North winds on 26/27 May brought drifts to 950 m and heavy snow showers until 30 May. Aberdeen had 22 mm of rain on 27 May, so we estimate a 30 cm snowfall. Snow on 9 July brought 10 cm with drifts to 1070 m on the north Cairngorms, and snow fell the next day.

About the end of April (I. Murray, personal communication), a rockfall on Lochnagar exposed fresh rock that is still visible with the naked eye 17 km away near Ballater. It swept the cliff-foot snow away (Fig. 2).

Patches in May–August on Ben Wyvis

Snow at the lowest site monitored on Meall na Speireig (Pottie 1995) lasted until 15 May, the mean date for 1973–2000. Snow at all eight higher monitored sites outlasted the mean 1973–2000 disappearance dates. Patches of southerly aspect outlasted their means by 6–18 days, and those of easterly aspect by 21–33 days. Snow at Coire nan Laogh finally melted on 20 August, outlasted only in 1979, 1993 and 1994 since records began in 1973.