

THE AUSTRALIAN COASTAL OCEAN RADAR NETWORK: A FACILITY OF THE INTEGRATED MARINE OBSERVING SYSTEM

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Abstract

The Australian Coastal Ocean radar Network (ACORN) is a monitoring network of HF radars which are being installed around Australia under a National Collaborative Research Infrastructure Strategy (NCRIS). It is a five-year project, at the end of which there will be five pairs of radar stations and one triplet installed and operating, enabled by the central pool of funding for the Integrated Marine Observing System (IMOS) which is a part of NCRIS, and augmented by funding from other sources. At each chosen site there is a pair (or triplet) of radar stations, mounted on the shore, which receive radar echoes from the rough sea. The two stations provide a triangulation which enables the data analysis software to extract surface currents, wave heights and directional wave spectra over the coastal ocean. The NCRIS strategy is to support research into coastal dynamics and exchange between the open ocean and the continental shelf. Research is being undertaken into the use of maps of surface currents, well resolved in time and space, in mixing of different bodies of water, physical connectivity between reefs and islands, and nowcasting and short-term forecasting of surface currents. There is potential for application of the data to management of coastal marine resources, and in marine safety areas. Real-time maps of surface currents and the prospect of short-term forecasting have the potential to reduce search areas in coastal waters and to make pollution/spill mitigation more effective. The near real-time provision of surface currents and wave height data in graphic format on a freely accessed web site has the potential to improve the community level of recreation and awareness of the maritime conditions. With the establishment of HF radar monitoring stations like those in ACORN, there is growing opportunity for researchers around the world to access data from well curated archives to carry out basic research on physical oceanography, or applications research without having direct access to the measuring facility. One of the features of IMOS is to establish such an archive which is easy to access and free to research users. This feature brings the ACORN HF radars into GEOSS for coastal processes and dynamics.

1. The Australian Coastal Ocean Radar Network (ACORN)

The core of the Australian Coastal Ocean Radar Network (ACORN) consists of three HF radar pairs and one triplet, which are being deployed at various points around the Australian coastline. ACORN includes phased array, beam-forming technology as well as the distinctly different small footprint, amplitude direction-finding technology, in order to offer maximum flexibility in site selection, and availability of a wide range of monitored parameters. Two other HF radar systems, one in the Great Barrier Reef and one in South Australia, are being acquired by funds outside the IMOS capital budget and are managed by ACORN in return for the data being delivered to the IMOS archive. The sites for the first series of deployments (three pairs and one triplet) are shown in Fig. 2 as red stars, and the yellow stars show the locations of the last two sites in the ACORN programme. The first approved installations are around Heron Island in the Capricorn and Bunker Groups on the Great Barrier Reef, west of Kangaroo Island in the Southern Ocean, and the north side of Perth in the Indian Ocean.

The data will be routed through a central laboratory for quality assurance and metadata labelling. System diagnostic data will also be sent to the central laboratory and all monitoring and maintenance will originate there. The maintenance model is a combination of caretaker casual staff at each site, with full technical competence at the central laboratory. The main advantage of this centralised model is that it will ensure that the data are archived in a consistent way. There is a need to build capacity and expertise around the country, and discussion is underway to determine the relative emphasis which should be placed on technical expertise and on applications expertise, and science. Deployment of the radars will be in support of IMOS regional nodes where there is a range of identified questions concerned with boundary currents and associated eddies and their interactions with shelf water and topography. In turn these are linked to productivity, connectivity of biological populations and phenomena such as coral bleaching

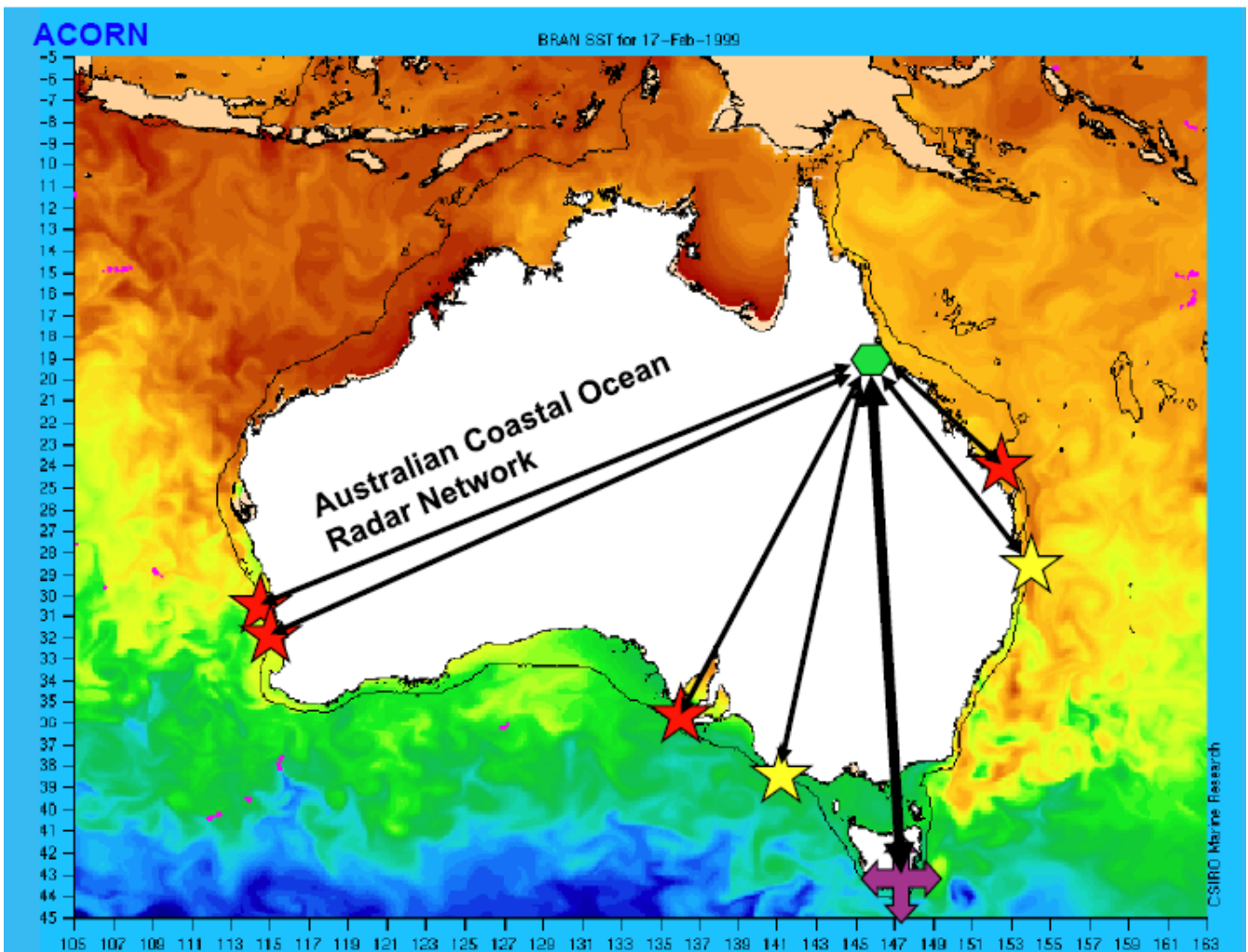


Figure 2. Initial deployments of three pairs and one triplet HF radar systems. The field sites are marked with red stars, the location of the data and maintenance laboratory is green and the IMOS archive centre has the purple cross. The yellow stars mark the positions of the final two station pairs. The background sea surface temperature map is a product from CMAR's BLUELINK computer model.

and diseases. In most cases the use of HF radars will be complemented by data from regional moorings and by the fleet of unmanned gliders. The radar network will provide a basis for applied research in wave prediction and will offer test sites for hydrodynamic modelling.

2. HF Radar: How it works

Coastal ocean surface radar is a land-based technique which uses scattering from the rough sea surface to obtain echoes which are Doppler shifted by the dynamics of the sea. It has been shown (Crombie, 1955) that the scatter is predominantly a Bragg interaction between the radio wave and the sea surface gravity wave that is propagating in the same direction and with half the wavelength of the radio wave. This Bragg interaction gives two strong first-order lines in the

echo spectrum; one from the resonant gravity wave moving radially away from the station, and one from the resonant gravity wave moving towards the station.

The first-order spectral lines are generally more than 30 db above the noise in the band and enable us to make very reliable and accurate measurements of surface currents and other ocean surface parameters, (Fig. 3). Barrick (1972) wrote a theoretical paper on the scatter cross-section which provides a firm background for the scattering process.

Each radar station can identify the radial distance and the azimuth of each scattering pixel over a large area to be mapped as shown in Fig. 4, where the grid points are 4 km apart for the deployment on the Great Barrier Reef (GBR).

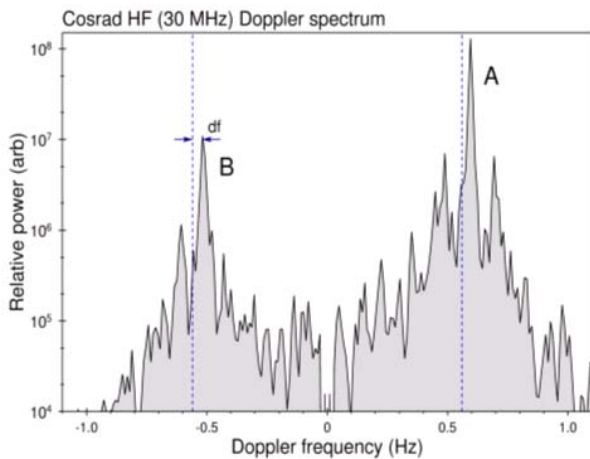


Figure 3. A typical HF radar Doppler shift spectrum of echo energy from a phased array system operating at 30 MHz. Note the sharp peaks A, B, and the >40 db difference between peak A and the noise floor.

3. HF Radars: The Sea Surface Parameters that they Produce

The main product from the HF radar is the map of surface currents. With the configuration at the GBR site we produce a map of surface currents every 10 minutes on a 4 x 4 km grid over an area of about 150 km x 150 km. One such 10-minute grab is shown in Fig. 5 for the GBR radar system. These surface current maps will be archived with quality assurance indices on each data point. Surface current components are measured as radial components along the line from the grid point to the radar station and are derived from the frequency of the first-order peaks labelled A and B in Fig. 3. Because it is based on a frequency standard, the precision of these data are generally very good. Both the phased array and the direction finding genres of HF radar produce surface currents as their prime product.

3.1 Phased Array Systems

Phased array systems determine the azimuthal angle between the station and the pixel by forming a narrow beam; the range to the pixel is set by the propagation delay for the electromagnetic wave. For the phased array systems, the two radar stations each operate for alternating periods of 5 minutes on, and 5 minutes off, out of phase so that they can use the same frequency. During each 5 minute 'on' period the radar measures the component of the surface current at each pixel projected onto the radial from the station to the pixel. At the end of

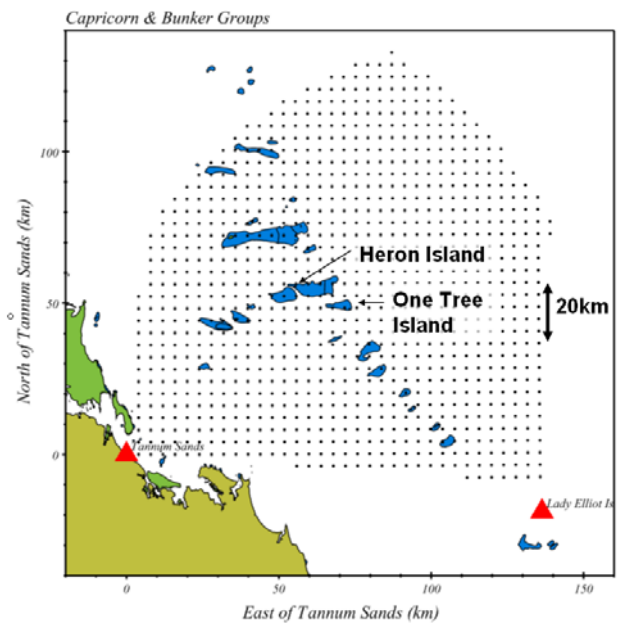


Figure 4 The configuration of the GBR coastal ocean radar with the Tannum Sands station at the bottom left and the Lady Elliot Island station on the bottom right. The dots show the grid points at which measurements are made.

10 minutes the radial components of surface currents can be combined to find the vector at each position on the grid. While surface currents are generally the data of most interest, the phased array systems can also produce significant wave heights and wind directions at each grid point, and a calculation of the full directional wave spectrum at ranges of up to about half the maximum (which is 150 km).

Significant wave heights and wind directions are produced every 10 minutes on the same grid. Significant wave heights are derived from the ratio of energy in the second-order continuum surrounding peaks A and B in Fig. 3 to the energy in the adjacent first-order spectral line. The algorithm relating this ratio to the significant wave height involves empirical analysis and the use of a semi-empirical model (Graber and Heron, 1997; Heron and Heron, 1998). For this reason significant wave height data are less robust than surface current data. Wind direction is derived from the ratio of energy in the two first-order spectral lines. The algorithm to derive wind direction requires data from both radar stations and involves adoption of a model for the directional pattern of wind waves generated by the steady wind (Heron and Prytz, 2002; Heron, 2005). For wind directions errors are likely to be above 10 degrees.

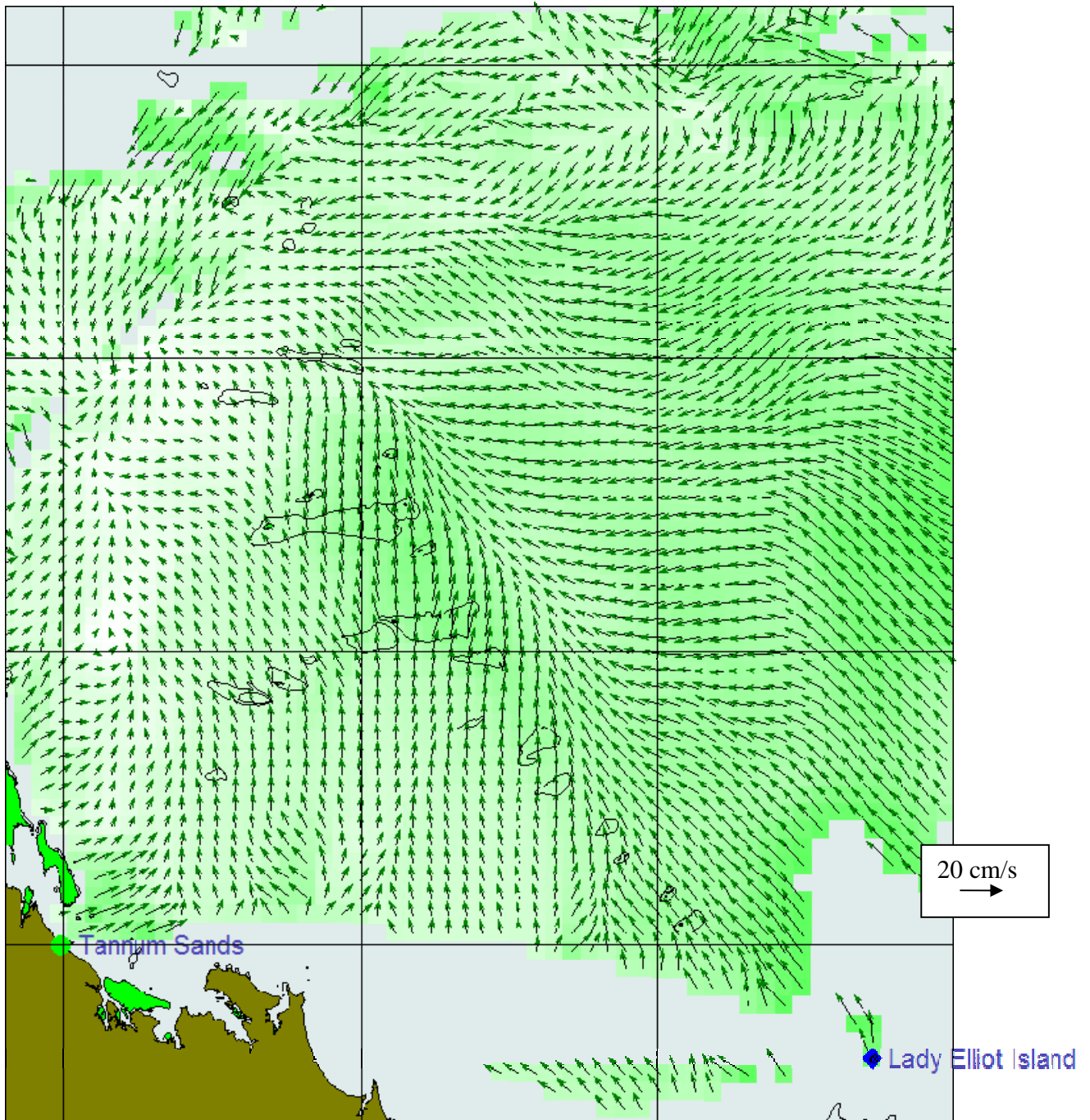


Figure 5. A 10-minute grab of surface current data from the GBR radar system. The data points are not smoothed in time or space, and are untouched data from the real-time processor. The marked grid lines are spaced 50 km apart.

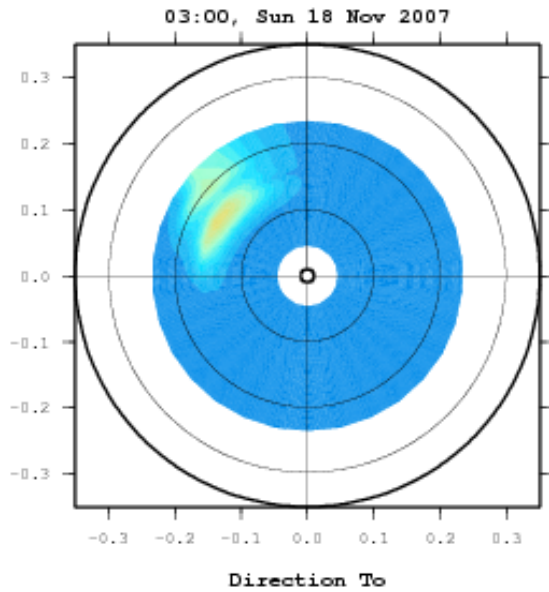


Figure 6. Directional wave spectrum obtained from a phased array radar, showing the dominant energy towards the north-west at a wave period of about 0.17 s, and a secondary peak shifted about 10 degrees to the north with a dominant wave period of about 0.2 s. Directional wave spectra are taken from a group of 4 x 4 pixels and integration over a period of 1 hour.

Directional wave spectra are produced for a reduced spatial grid and at hourly intervals. This is because we need to average over space and time to improve the signal-to-noise ratio in the Doppler spectra before the

directional wave spectra are calculated (Wyatt et al., 2006; Wyatt et al., 2008). A typical directional wave spectrum produced from the GBR radar system is shown in Fig. 6.

3.2 Direction Finding Systems

Direction finding systems determine the azimuthal direction of the pixel by comparing amplitude and phase signals on crossed loop receive antennas. The direction-finding calculation is done on Doppler shift spectra for a specified range intervals which include echoes from all azimuths. This means that the spectra (like that in Fig. 3) are spread and second-order echoes from one direction are swamped by the first-order echoes from other directions. Consequently, parameter extraction using second-order echoes is not possible on a routine basis. Directional wave spectra at the location of each radar station are produced by analysing the full azimuthal spread of first-order echo amplitudes, and wind directions are derived across the grid points by taking the ratio of the positive and negative Bragg echoes.

The benefit of the direction finding systems is that they have a more compact antenna system and this is an over-riding advantage in some locations. These systems can operate on the same allocated frequency and each station runs continuously. Spectra are stored every 15 minutes and a weighted running average gives radial components of current vectors every 30 minutes.

Table 1. Parameters and their archive levels for a phased array system. The storage is given per day for a two-station site. Storage space for the Level 3 products is not given because this will vary according to the access tools which are provided at the archive exit.

	Level 3	Level 2	Level 1	Level 0
Surface Currents	1 hour averages; maps, movies	10 min; speed & Direction 26 MB/day	10 min; radial components to each station. 52 MB/day	
Significant wave height	1 hour averages; maps, movies		10 min; Ratio of second-order to first-order energy for each station 52 MB/day	
Wind Direction	1 hour averages; maps, movies	10 min; scalar values at grid points 26 MB/day	10 min; Ratio of energy in the two first-order lines for each station. 26 MB/day	
Dominant wave period	1 hour averages; maps, movies		10 min; scalar values at grid points for each station 26 MB/day	
Raw Time Series				Phase & quadrature at each receive antenna for each station. 3GB/day

Table 2. Parameters and their archive levels for a direction finding system. The storage is given per day for a two-station site. Storage space for the Level 3 products is not given because this will vary according to the access tools which are provided at the archive exit.

	Level 3	Level 2	Level 1	Level 0
Surface Currents	1 hour averages; maps, movies	30 min; speed & Direction 8 MB/day	30 min; radial components to each station. 17 MB/day	
Wind Direction	1 hour averages; maps, movies	30 min; scalar values at grid points 8 MB/day	30 min; Ratio of energy in the two first-order lines for each station. 8 MB/day	
Significant Wave Height	1 hour averages	30 min; near to each station 100 KB/day		
Raw Time Series				Cross spectra for pairs of receive antennas for each station. 3GB/day

4. ACORN Data Archive

We have identified four levels for archiving data from the ACORN network of HF ocean radars. Level 0 is raw data in proprietary format consisting of time series of in-phase and quadrature amplitudes of base-band signals at each of the receive antennas. These data are for re-processing or technology development research and are very large files which will be deeply archived and available only on request. The influence of fetch on the response of surface current to wind, studied by HF ocean surface radar. At the other end of the scale are Level 3 data which are smoothed visualisations of hourly values of the parameters with access tools to extract movie loops and a high standard of graphical presentation. The levels of data archive are described in Table 1.

Each data value comes with a quality index which is defined in the metadata. Metadata are included in each file. The format being followed is netCDF in order to make data discovery possible. There are numerous netCDF conventions that one can follow and the one we use is compatible with the metadata standard defined by ISO19115 and the AODC Marine Community Profile based on that standard. It is impractical to manually enter metadata records into the archive for each of our files; these are produced every 10 min per station, with at least 3 files per 10 min interval. Our files thus needed to be in a format that allows the relevant metadata to be harvested automatically when the files are uploaded to the archive.

5. Potential Research and Operational Applications

Obviously the users who will benefit most from the archived data from the ACORN HF radars are those who

are investigating coastal ocean dynamics in the areas covered by the radars. These are mostly operational maritime applications like pollution drift, search and rescue, and coastal management. There are some areas of research which, while carried out in the area covered by the radar, have wider applications in areas not covered by the HF radar. These are mostly calibration investigations like evaluating parameterisations of small scale effects in hydrodynamic modelling, evaluating algorithms for analysing satellite data on the continental shelf, and validating numerical models.

This last category is significant because it offers an opportunity for collaborative research which might involve researchers from any community in the world, and deliver research outcomes which are of global value.

There are some fundamental questions that can be addressed by using HF radar data when no other technology will be as useful. One of these, for example, is in measuring and evaluating Stokes Drift as an integral part of the surface current. Mao and Heron (2008) have shown that HF radar can separately measure the Stokes wave-driven current and the wind-stress effect which produces and Ekman current. Arduin et al., 2008 carried out a more comprehensive study but more work needs to be done to validate the parameterisation of air-sea coupling into the circulation models.

6. Conclusion

The Australian Coastal Ocean Radar Network is being established as a development of research infrastructure in Australian coastal waters. The sites have been

chosen because of research challenges in those areas, and generally they are associated with the deployment of other equipment like acoustic current profilers and wave measuring buoys. The data are archived centrally in a way that is easily accessed and essentially free for research use. Some research and operational applications are restricted to the specific sites of the deployments, but there are many research challenges of a more general nature which can be addressed using these data, but which apply globally to other locations. Some of the potential research is of a fundamental nature and not connected with any specific measuring site.

With large data archives like this, and other IOOS archives, there are increasing opportunities for researchers to participate in research projects without the need to own expensive equipment items.

Acknowledgements

Figure 2 is a typical output product from the BLUElink Operational Model. This work is supported by the Australian Research Council with grant LE0560892. It is a product of the Australian Coastal Ocean Radar Network, the Integrated Marine Observing System, and the Australian National Collaborative Research Infrastructure Strategy.

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