RV *Investigator* Voyage Scientific Highlights and Summary

Voyage #:	IN2019_T03
Voyage title:	**ORCA: Using the Investigator radar as a moving reference for the Australian operational radar network.**
Mobilisation:	0800, Darwin, 22/12/2019
Depart:	0800, Darwin, 23/12/2019
Return:	0800, Henderson, 02/01/2020
Demobilisation:	0800, Henderson, 02/01/2020
Voyage Manager:	Matt Boyd
Chief Scientist:	Dr Alain Protat
Affiliation:	Bureau of Meteorology
Project name:	**Microplastic in the food chain: impact on the microbial and planktonic organisms.**
Principal Investigators:	Dr Sophie Leterme
Affiliation:	Flinders University
Project name:	**Spatial and temporal variability in the distribution and abundance of seabirds**
Principal Investigators:	Dr Eric Woehler
Affiliation:	Birdlife Australia
Project name:	**Supplementary Cloud Radar, Lidar and Aerosol Measurements**
Principal Investigators:	Dr Robyn Schofield / Dr Alain Protat
Affiliation:	University of Melbourne

Voyage Summary

Objectives and brief narrative of voyage

This transit voyage consisted of three main projects focussed around using the Investigator C-band Doppler dual-polarization weather radar (OceanPOL) and OceanRAIN ODM470 disdrometer as moving references to evaluate the calibration of selected coastal radars from the Bureau of Meteorology operational weather radar network; assessing the amount of plastics present in blue waters around Australia and identify their impact on microorganisms at the base of the oceanic food chain; and quantifying the variability in the distribution and abundance of seabirds in the marine environment around Australia and examining the relationships between physical oceanographic features and their use as seabird feeding areas. Supplementary objectives were to collect aerosol and cloud observations to provide context to the weather radar observations, and to deploy and test the Continuous Plankton Recorder (CPR). All measurements required to address the stated objectives were successfully collected in a safe manner, and the voyage was unanimously considered a great success by all the PIs.

Scientific objectives

Optimizing Radar Calibration and Attenuation Corrections (ORCA)

The aim of the Optimizing Radar Calibration and Attenuation corrections (ORCA) project is to use the Investigator C-band Doppler dual-polarization weather radar (SEAPOL) and OceanRAIN ODM470 disdrometer as moving references to (i) evaluate (and if needed improve) the calibration of selected coastal radars from the Bureau of Meteorology operational weather radar network and investigate some aspects of these calibration techniques further, and (ii) characterize the regional variability of the so-called self-consistency dual-polarization calibration relationship using disdrometer observations for use in future operational calibration techniques. Our second main aim is to develop C-band attenuation corrections for SEAPOL using unattenuated collocated S-band ground-based radar measurements from the operational radar network collected during the transit voyages.

Microplastics in the food chain: impact on the microbial and planktonic organisms.

Microplastics consist of pieces of plastic smaller than 5 mm, such as the microbeads found in domestic and personal care products. Plastic pollution of oceanic ecosystems can be observed anywhere on the planet, but microplastics create a global biological and chemical hazard due to their propensity to be ingested by marine life that is later consumed by humans. Small plastics can also adhere onto the surface of micro-organisms that are preyed upon by higher levels of the oceanic food chain such as fish. The aims of the project are (i) to assess the amount of plastics (micro through to nano in size) present in blue waters around Australia, (ii) to identify their impact on microorganisms at the base of the oceanic food chain, (iii) characterise the bacterial species associated with oceanic plastic and (iv) develop a model to understand how plastics are transported in surface and subsurface currents.

Spatial and temporal variability in the distribution and abundance of seabirds.

The project will collect data to quantify the variability in the distribution and abundance of seabirds in the marine environment around Australia. The project will examine the relationships between physical oceanographic features and their use as seabird feeding areas. The study also seeks to identify species assemblages, or associations, in the species of seabirds observed that are persistent over time. The project will use standard survey methods to ensure compatibility with existing data sets for the same species in other areas (e.g. Southern Ocean and south-eastern Australia). Observations of marine mammals will be shared with researchers to facilitate greater understanding of the role of oceanographic processes in the spatial and temporal distribution of marine mammals at sea around Australia. The project will also provide a context to current research efforts tracking seabirds and marine mammals, which are often constrained to a relatively low number of instrumented individuals relative to the population as a whole.

Supplementary Cloud Radar, Lidar and Aerosol Measurements.

The stabilized platform container with the cloud radar and lidar from BOM is to complement the weather radar observations that will be collected during the ORCA project. The cloud radar observations combined with the disdrometer and micro rain radar will be used to validate the calibration of the CSIRO weather radar (which will in turn be used as the single reference for the calibration of operational radars along the coast), derive statistical relationships between rainfall and radar observables at different frequencies, and derive self-consistent dual-polarization curves at different locations along the Australian coast, which will be used operationally to refine the operational BOM calibration procedures. Such combined use of cloud radar, disdrometer, and micro rain radar had been demonstrated during IN2018_V01 (Klepp et al. 2018; Protat et al. 2019).

We will also collect all baseline aerosol measurements available from RV Investigator to allow for investigations of how (if at all) aerosol loading and properties impact statistical relationships between radar observables and rainfall rate. While several of the instruments will have to be demobilized after IN2019_V06 in Darwin, the miniMPL, MAXDOAS, Spectronus, Tekran and uDirac instruments will continue to run with an operator, which will allow measurements of aerosol, boundary layer height, boundary layer oxidants and halocarbons to be made continuously until the AIRBOX facility is decommissioned in Fremantle.

Continuous Plankton Recorder

The CPR will be towed where possible over the longer transit sections to collect phytoplankton and zooplankton data from the West Coast. This is a poorly sampled region of Australia and the data will be a valuable resource and addition to the IMOS plankton databases. The more northern CPR sampling will occur in a similar region to the measurements of atmospheric halocarbons and DMS taken on V06. Establishing the plankton community composition from the CPR samples will increase the understanding of which plankton species are associated with high atmospheric concentrations. The data will be made publicly available through the AODN as part of the IMOS AusCPR survey.

Voyage objectives

Optimizing Radar Calibration and Attenuation Corrections (ORCA)

Recently, the Bureau has developed the SCAR (Satellite and Clutter Absolute Radar calibration) framework to monitor calibration of the operational radars (Louf et al. 2018). This approach is based on a combination of two (three) techniques for single (dual) polarization radars. The first technique, the Relative Calibration Adjustment (RCA), assumes that "ground clutter" radar echoes (buildings, topographic structures, trees, etc …) within 10km range have constant reflectivity. This technique tracks changes in calibration to better than 0.2 dB but does not provide a reference (baseline) value. The second technique (Warren et al. 2017) statistically compares collocated ground radar and spaceborne radar from the NASA Global Precipitation Measurement (GPM) mission. This technique provides an absolute calibration with an accuracy of about 1.5 dB. SCAR uses the RCA technique to detect stable periods of calibration and averages all GPM estimates of the absolute calibration, improving the accuracy to better than 1 dB. SCAR is now used semi-operationally at the Bureau but has never been evaluated against a single reference. Transit voyages along the coast with SEAPOL offer a unique opportunity to do this.

The voyage objectives are to collect Investigator C-band Doppler dual-polarization weather radar (SEAPOL), Ocean RAIN, ODM470 disdrometer, and micro rain radar (MRR-2) observations of precipitation collocated with as many radars from the BoM operational radar network located along the coast from Darwin to Fremantle. When no precipitation is present, we will make use of the SEAPOL radar data in clear air to better understand the sources of variability of ground clutter produced by land along the coast. One uncertainty in the RCA technique is that changes in ground clutter reflectivity statistics can be due to calibration changes or changes in the tilt angle of the radar beam, although this is rare and would indicate a malfunctioning of the radar. This effect has not been quantified in the literature. To study this we will request to stay on stations by periods of 10 minutes along the transit voyage and change the first tilt angle of the volumetric scan by 0.1 degree from 0.5 degree to 1.0 degree in order to measure changes in ground clutter reflectivity due to a change in tilt angle.

According to model reanalyses, the region around Broome is also a global hot spot of CAPE (convective available potential energy, which is a measure of the amount of energy in the troposphere that is available for the development of convection) - nowhere else in the world is CAPE that high according to models. We have seen this CAPE hot spot every day in the forecasts during IN2019_V06. While transiting through that region we will launch about six radiosondes (one every 1h30 to 2h) to directly measure CAPE and validate this Australian peculiarity with actual observations. The project will be led by Rob Warren (Monash University), with co-PIs Joshua Soderholm and Alain Protat from BOM.

Microplastics in the food chain: impact on the microbial and planktonic organisms.

Eight hours of ship time have been allocated for the microplastics project. Sampling sites will overlap with the ORCA radar observation sites. CTD deployments will be undertaken whilst ship is at rest with EZ-Net deployments to be undertaken once Radar and CTD operations have been complete at each site. At least three stations will be selected aiming for the regions of (Broome, Carnarvon, and Geraldton) and in tandem with ORCA project requirements. Each sampling period will take about 2.5

hours (1.5 hours for the EZ net tow (activated twice at 3 depths) at a speed of 2 knots, and 1 hour for the CTD deployment/recovery).

1.a. Sampling for enumeration and microscopy (Table 1):

1. CTD will inform of the depth of the Deep Chlorophyll Maximum (DCM)
2. 3 Niskin bottles will be triggered at each of 3 depths: subsurface (S), DCM and 20 m above the bottom (B-20) (or at the maximum depth the Niskin bottles can be triggered).
3. EZ net tows (335µm) will be undertaken at stations already planned along the route of the ship. Two nets will be triggered at the surface, at the DCM and 20 m above the bottom (or at the maximum depth the net can be triggered).

Water from the Niskin bottles will be collected, passed through a 1 µm filter (to collect all fractions of microplastics) and kept in a petri dish until analysis for assessing the abundance of small plastics.
After each net tow, the contents of the cod end from one net at each depth will be washed through a 35 µm sieve. Microplastics will be transferred to a jar and kept until analysis for assessing the abundance of microplastic and compare the collection method to the Niskin bottle sampling. Planktonic organisms will be transferred into a container filled with 95% ethanol within 15 min of the end of the tow.

These samples will be used to:

1. Count the microplastics present in the samples under a fluorescent microscope;
2. Identify the organisms that are attached onto the microplastics under Scanning Electron Microscopy (SEM);
3. Assess if microplastics are attached to zooplankton organisms under SEM;
4. Collate the data into our data set that will be used to develop an oceanographic model of plastic (micro – nano in size) distribution and movement in Australian waters.

1.b. Sampling for sequencing of communities associated to microplastics (Table 1):

Samples will be collected from the second nets triggered at each depth during the EZ-Net tow from 1a above. The samples will be used to identify the bacteria and phytoplankton attached on the microplastic surface, but also to identify the community composition of zooplankton.
The content of the cod end will be washed through a 35 µm sieve and transferred to petri dishes filled with sterile seawater for separating microplastics from zooplankton organisms:

1. Under a laminar flow, the zooplankton will be separated from the microplastics particles with sterile tweezers and placed into Eppendorf tubes containing 50 µl of Lysis buffer. The microplastics will be left in the petri dish and frozen at −20 °C until analysis. Those samples will be later sequenced for 16S (bacteria) and 18S (phytoplankton) rRNA genes.
2. The Lysis buffer will digest the exoskeleton of the zooplankton and allow for the zooplankton associated microplastics (i.e. either ingested by or attached to those organisms) to be released in the buffer. At the same time, the DNA of those zooplankton organisms will be eluted in the buffer. Samples will be kept frozen at −20 °C until analysis.

In order to understand which fraction of the ocean microbial communities are associated to microplastics, 5 L of water will be collected in triplicates using Niskin bottles triggered at the same depth as the EZ nets. The water will be concentrated into 1 L using tangential flow filtration and filtered through 0.22 and 0.45 µm Sterivex filters for 16S and 18S, sequencing, respectively.:

Table 1, Sampling Summary.

Section	Niskin bottles	EZ nets
1.a. Sampling for enumeration and microscopy	9 Niskin bottles; 3 Niskin bottles triggered at 3 depths (S, DCM, B-20)	3 nets in total; 1 net triggered at 3 depths (S, DCM, B-20)
1.b. Sampling for sequencing of communities associated to microplastics	9 Niskin bottles; 3 Niskin bottles triggered at 3 depths (S, DCM, B-20)	3 nets in total; 1 net triggered at 3 depths (S, DCM, B-20)

Spatial and temporal variability in the distribution and abundance of seabirds.

Seabird at sea data will be collected by three seabird observers according to the method described by the BIOMASS Working Party on Bird Ecology. This method has been used by Australian Antarctic Division (AAD) personnel since 1980/81 and reflects the standard protocol for obtaining seabird at sea data. Observations will be made continuously while the vessel is underway during daylight hours from the specifically designed monkey bridge on board Investigator.

Briefly, all seabirds within a 300m forward quadrant will be recorded, with details of their ages (where identifiable) and behaviours (such as feeding, sitting on water, etc). By using standard methods, the data collected on these voyages will be able to be integrated with other data sets collected adjacent with, or in overlapping areas (e.g. Australian Antarctic Division surveys 1980/81 onwards). Observations of marine mammals are also included (in the absence of dedicated marine mammal observers) using standard protocols. Observation of marine debris are also recorded.

Data will be entered in real time on laptops connected to the ships oceanographic and GPS system to automatically record abiotic and biotic data along-side seabird observational records. Standardised methods of data collection ensure continuity and compatibility with extant data for the same species elsewhere and with similar studies of other species.

Supplementary Cloud Radar, Lidar and Aerosol Measurements.

The voyage objectives are to collect continuous cloud radar, lidar, disdrometer, micro rain radar, miniMPL, MAXDOAS, Spectronus, Tekran and uDirac observations to address the scientific objectives listed above. Together with the previous voyages (IN2019_T02 and IN2019_V06), these measurements will provide a unique 2.5 months long dataset of cloud, aerosol, and precipitation along most of the Australian coastline (from Brisbane to Darwin to Perth).

Education and Training

The voyage will host two education and training programs. Two teachers will participate in the CSIRO Educator on Board (EoB) program, a professional development program for Australian STEM teachers. The voyage will also host the first students under the MNF's Indigenous Time at Sea Scholarship (ITSS). This program aims to provide opportunities for Indigenous and Torres Strait Islander tertiary students to join voyages to learn and contribute to the collaborative national marine science effort.

Results

Optimizing Radar Calibration and Attenuation Corrections (ORCA)

The first important result obtained within the ORCA project is that we have detected a mis-pointing of the OceanPOL radar using raster scans of the sun (fine-scale 0.1° resolution scanning around the expected Sun location). Our first estimate (first day of the experiment) was that OceanPOL was pointing too high by 1.8° and too clockwise by 1°, which are large biases (see Figure below).

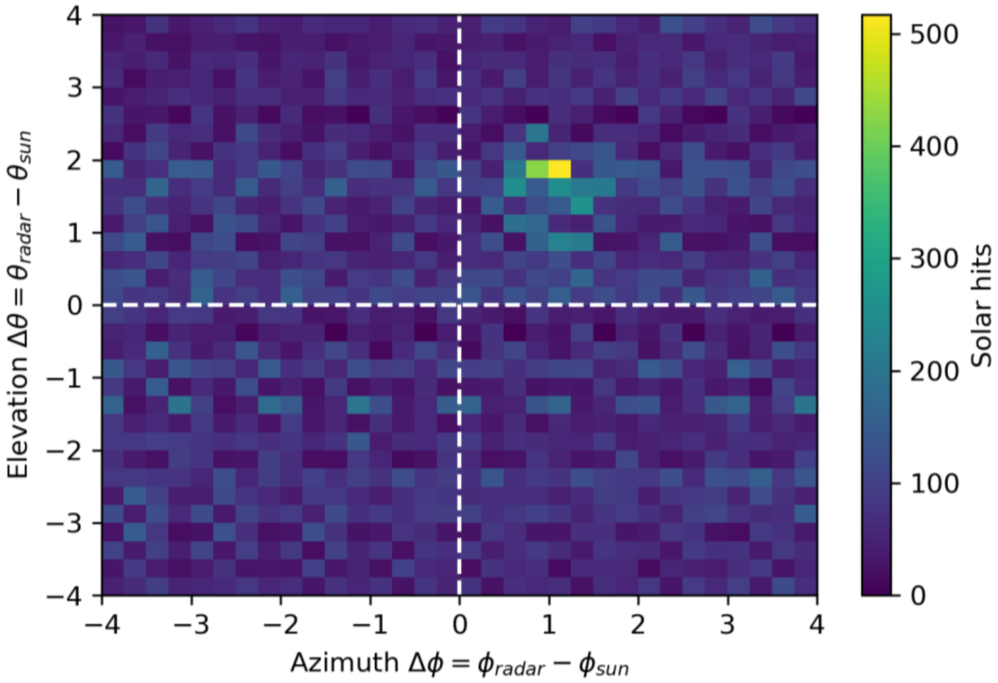


Figure 1: Azimuth and elevation bias of OceanPOL as derived from a Sun raster scan on 23/12/2019

However, by launching radiosondes we have also found that due to high moisture gradients in the lower troposphere, some of the elevation bias could be due to refraction of the radar beam downward (also known as ducting). Therefore, we have repeated this raster scan several times in different conditions. These observations will be analysed further, but seem to indicate that when ducting is minimal, the elevation bias is still about 1.3°. This will have implications when analysing OceanPOL observations from earlier campaigns, such as IN2019_V06 (YMC).

It is too early to show quantitative results on radar calibration as it has proven very difficult to work remotely on our virtual machines. However, we can report that we have collected collocated data for six out of the nine radars along the coast: Berrimah (Darwin), Broome, Port Hedland, Dampier, Learmonth, and Perth. This dataset will allow for the main objective of this project (validate our estimates of operational radar mis-calibration) to be fully addressed.

Radiosonde launches were performed regularly every 6h (except for the 00 UTC launch on 12/25, which was delayed by 3h due to other operations) between the eastern Kimberley coastline and Port Hedland (see figure below).

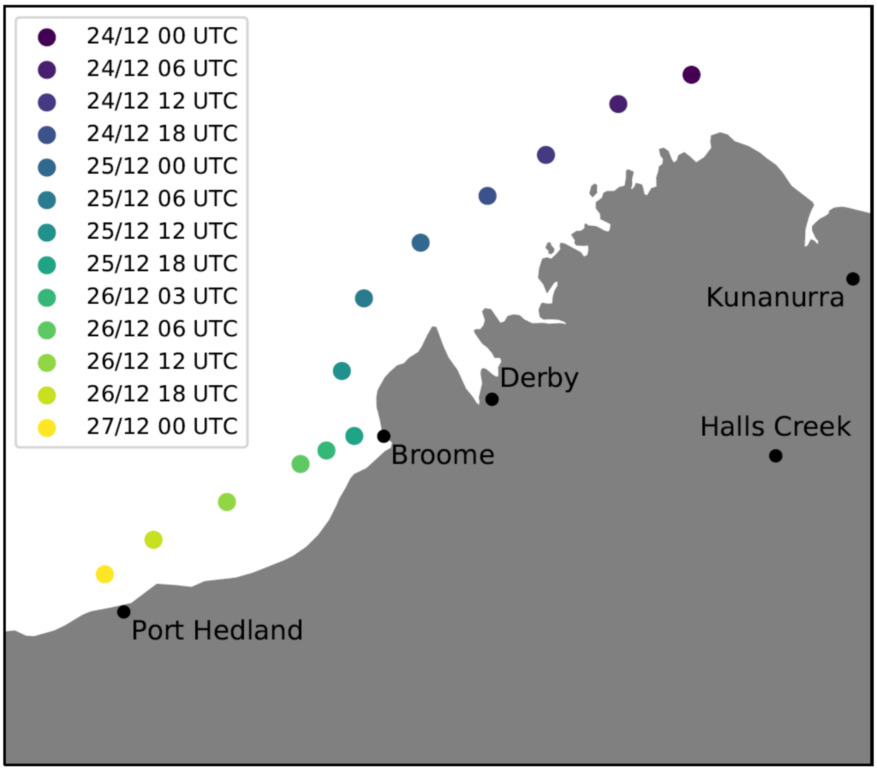


Figure 2: Location of "CAPE hot spot" radiosonde launches during the experiment. The other launches were made at each radar station.

Most profiles show extremely high surface-based CAPE, much lower values of mixed-layer CAPE, and high values of mixed-layer CIN; these features are associated with a very moist marine boundary layer capped by a deep elevated mixed layer, which appears to originate over the adjacent land surface see figure below).

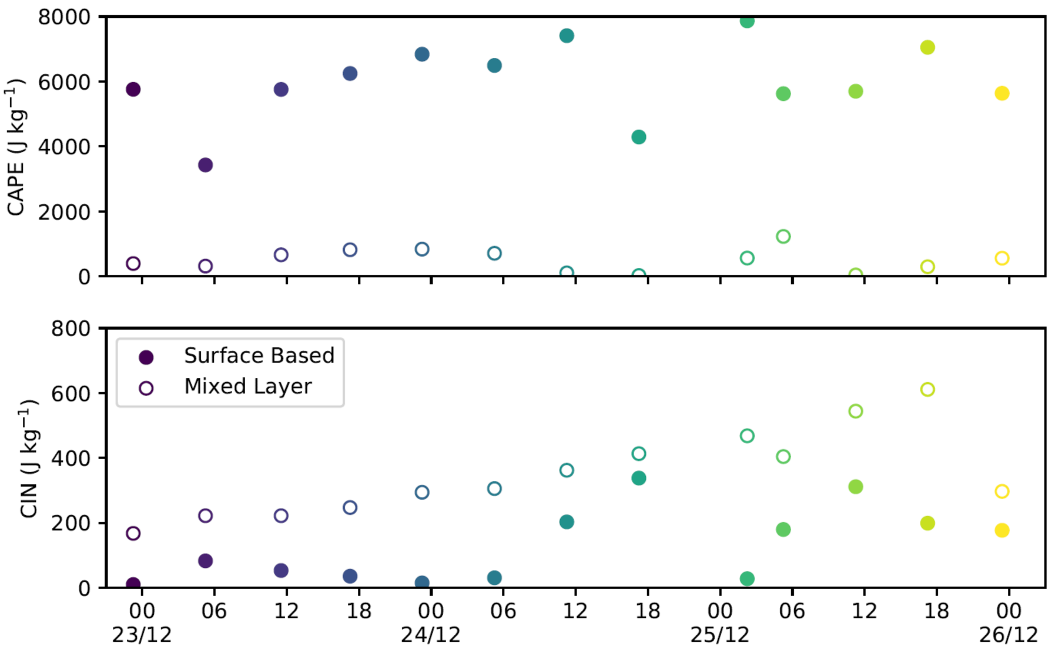


Figure 3: Convective Available Potential Energy (CAPE, upper panel) and Convective Inhibition (CIN, lower panel) measured by the radiosondes.

In general, we observed a decrease in the depth of the moist surface layer, an increase in the strength of the capping inversion, and a drying out of the free troposphere (all of which act to increase mixed-layer CIN) as the ship progressed south and west along the coastline (see below).

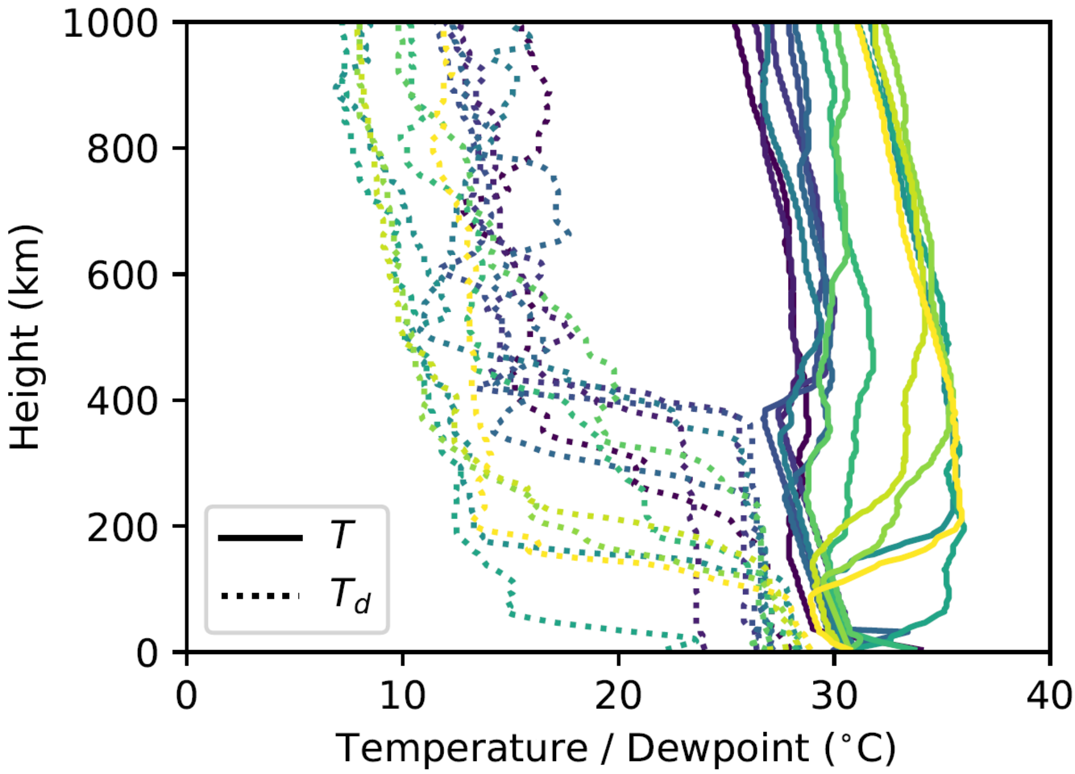


Figure 4: Temperature (solid lines) and dewpoint temperature (dotted lines) measured by the radiosondes. The colour code is the same as the previous figure (day of the month)

Future research directions with the radiosonde dataset include analysis of the origins of the different airmasses, assessment of the representation of these environments in atmospheric reanalyses (e.g. ERA-5, BARRA), and exploration of the relationship to deep convection and its offshore propagation.

Microplastics in the food chain: impact on the microbial and planktonic organisms.

The EZ Net was utilised to sample microplastics greater than 0.3 mm in size, to quantify the amount of plastic ingested by/attached to zooplankton and to determine the zooplankton community associated with each depth (surface, deep chlorophyll maximum and 10 m from the bottom) and site. The Niskin Bottle Rosette was utilised to identify the bacteria associated within the water at the time of sampling; allowing for a comparison with the bacteria present on the biofilm of the plastic, and to collect plastic fragments greater than 0.0002 mm (0.2 µm) in size.

EZ Net and Niskin Bottle Rosette samples were successfully collected from sites near Broome (18 08.585S, 121 28.078E) and Exmouth (21 29.358S, 114 31.423E). The Niskin Bottle Rosette was deployed at sites near Geraldton (27 27.816S, 113 34.244E) and Perth (30 44.460S, 114 44.856E). An EZ Net tow was attempted at the Geraldton location, however, this was aborted due to rough sea state and excess tension on the winch and cable; similar conditions were observed near Perth.

Controls were run on the vessel to determine the level of contamination from our sampling and laboratory protocols and within the operational spaces. The controls allow for a correction factor to be applied to the data by removing the contamination value from the results.

It is too early to show quantitative results for sites and depths of this project. The EZ Net samples for microplastic concentrations (> 0.3 mm) and zooplankton ingestion are currently being processed at Flinders University (for RNA extraction and SEM). The zooplankton communities have been preserved; these samples will be analysed after processing the former samples (microplastics). Bacterial samples have been preserved in RNAlater and stored in a – 80 °C freezer; RNA will be extracted from these samples at the completion of additional voyages in 2020/21. Plastic fragments > 0.2 µm are currently being isolated from the membranes they were filtered onto and prepared for Attenuated Total Reflectance Fourier-Transform Infrared Spectroscopy (ATR-FTIR), Transmission FTIR and RAMAN Spectroscopy.

This project will also use the data collected from the Acoustic Doppler Current Profiler (ADCP). These data will be utilised to develop a better understanding of the oceanic features present at the time of sampling. The information collated will be used in the development of a predictor model which utilises the weight and plastic rise velocities of collected plastic fragments in conjunction with oceanographic data; potentially allowing for the identification of aggregation points on shores around Australia.

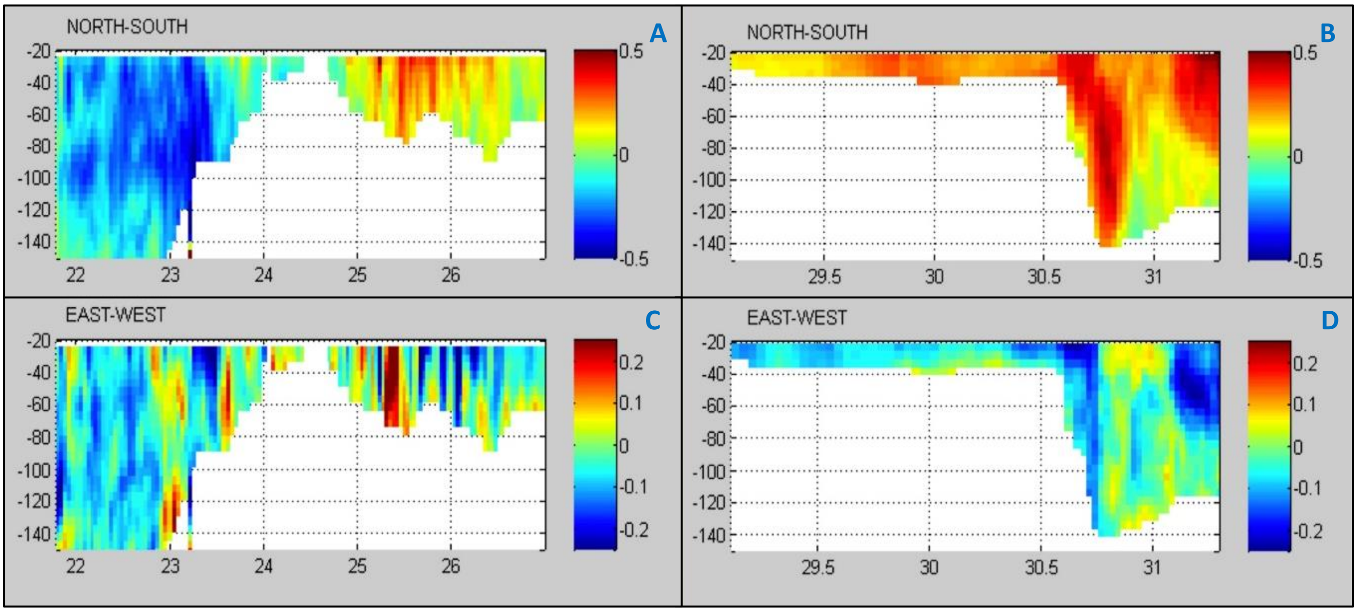


Figure 5: North-south and east-west current components colour-coded in m/s along two sections of the ship’s track south from NW Cape; north and east are red; south and west are blue. Depth is depicted in meters (m) on the y-axis with latitude (°S) on the x-axis. The ADCP data are 15-minute averages. (Credit: G. Cresswell (UWA)).

The preliminary ADCP data shows a change in current direction (Figure 5) at around 25 °S. Between 22 °S and 24 °S the currents had a southward component of up to 0.5 m/s, perhaps due to a weak Leeuwin Current. From 25 °S there was a northward current component of up to 0.5 m/s, probably the Capes Current. There was considerable velocity variability with depth as can be seen in several frames from a draft time-lapse movie in Figure 6. The distribution of plastic fragments will be correlated with the ADCP data. This will provide an understanding of the sub-surface transportation of plastic fragments.

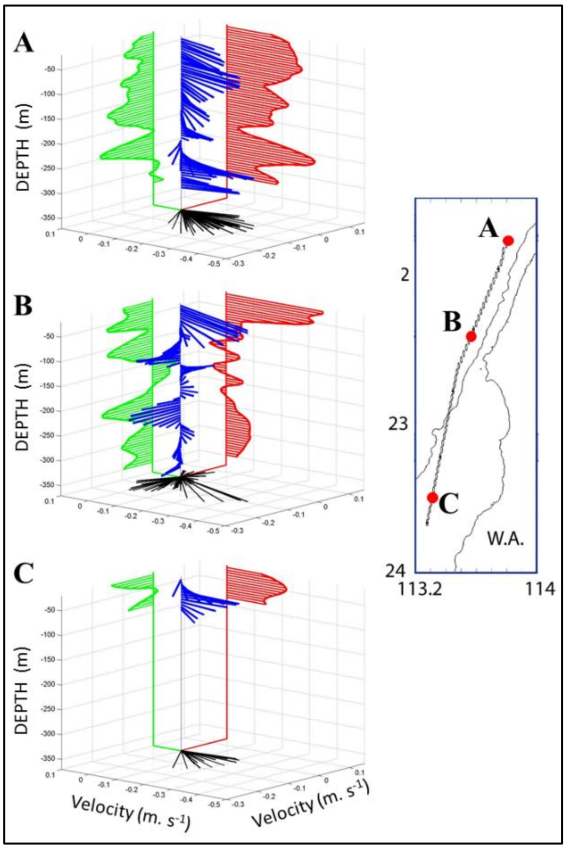


Figure 6: A 3D view of the ocean currents at several locations (cf. Figs. 5a and c). The vertical axis is depth in m. The horizontal axes are in m/s. The current vectors at 5 m intervals are shown in blue. Red and green show the southward and westward components of the currents. Black shows the vectors projected onto the (arbitrary) 130 m plane. Note that the instrument does not capture the upper 20 m and loses the lowest 15% of the water depth. (Credit: G. Cresswell (UWA)).

The samples and information collected on IN2019_T03 forms the basis of the dataset for this project, which will be supplemented by future voyages in 2020/21. These opportunities strengthen the quality of information gathered and allow the objectives of this project to be addressed.

Spatial and temporal variability in the distribution and abundance of seabirds.

Seabird and marine mammal observations were undertaken on 10 days between Darwin and Perth while the vessel was underway (Figure x). No problems were encountered, and the project was popular with crew and other researchers on board. All seabird and mammal data are currently being verified before consolidation with previous voyages' data. Numerous observations of tuna feeding events were unexpected and are currently the subject of more detailed analyses. The seabird species diversity was higher than expected, as were overall abundances.

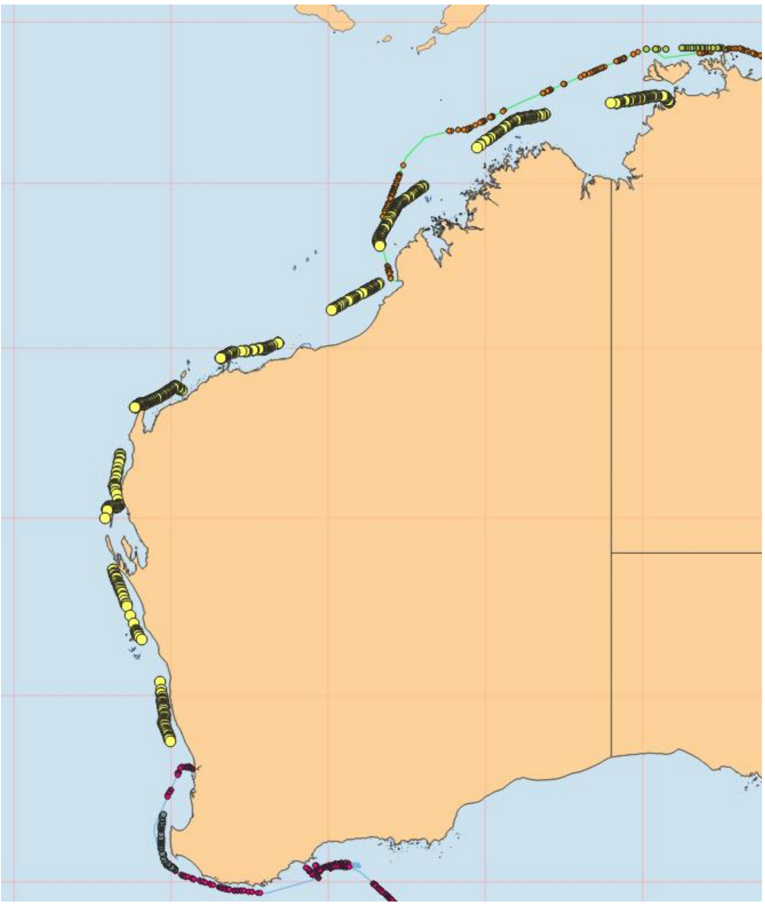


Figure 7: Data collected during IN2019_T03 (yellow symbols) Darwin – Perth. Gaps indicate night times.

Continuous Plankton Recorder

Four CPR tows were undertaken between Darwin and Perth. Issues were encountered with both the cassettes and the CPR unit itself, meaning that only 1 and a half tows sampled successfully.

Voyage Narrative

Below is a day-by-day description of activities during this transit voyage.

Sunday, 22/12

Plan is to depart Monday 23/12 at 0800. Estimated travel time to Broome is 65 hours, which means we'll arrive at **Broome on Thursday at 0100 am**. Start at 0600-0700 (not night-time).
Forecasts of convection differ: GFS says there is going to be a bit of convection, ECMWF has nothing.
We need to check that the crew is OK to do night-time EZ net as we arrive at the Broome station.
We should start launching sondes every 6 hours at 00 UTC on Tuesday (0930 Darwin LT, so prep at 0815 LT, launch time at 0845 LT). OK from the Master to launch one sonde at each station.
Morning meetings with the Master will be at 0800.
Microplastics project and Ben Arthur had an interview with Channel Nine News Darwin.

Monday, 23/12

We left port at 0800 as planned.
We did a RASTER scan of the sun with the weather radar this morning. Seems to confirm that there is a bias in elevation (about 1deg but the raster scan was centred so we may have missed the real max) and azimuth (+1deg too). We will do another one this late afternoon to work it out. We have found 1.8 deg in elevation and 1 deg in azimuth using the Bureau technique.
Stabilized platform was restarted at about 1140 am LT. We will use the profiler mode for now, then we'll test the 3D wind mode at some point during the voyage when there are lots of clouds.
Update on the Broome station: at about 10 knots we should be at Broome Thursday morning at ~0600 am LT (Darwin). If that is confirmed, then we'll stay for the radar sampling then do the microplastics sampling at first light to avoid night-time EZ net deployment.
Just tested the 3D profiler mode for the BASTA cloud radar between 0509 and 0527 UTC today on a very nice cirrus case. The first part of the cirrus is sampled using the normal wind profiler mode, so we'll be able to compare the two results. At some point during the experiment we should do this again and launch a radiosonde for comparison.
We did two more raster scans of the sun and can now confirm that OceanPOL was characterized by an elevation bias of 1.8 degrees (too high) and an azimuth bias of 1 degree (too clockwise). This bias has been corrected but will need to be accounted for when processing earlier datasets.
Microplastics team set-up the Wet Clean Laboratory and prepared for running control samples, then had a radio interview with ABC Darwin at 0800.

Tuesday, 24/12

First radiosonde was launched at 0845 LT and will be assimilated in the forecast models worldwide.
For three days we are going to launch radiosondes every 6 hours to measure for the first time the global hot spot of convective available potential energy (CAPE) found in model reanalyses.
Estimated time of arrival to the Broome station is currently Wednesday evening at 2330 LT (still Darwin time).
Microplastics team started running controls in the lab to quantify contamination levels in sampling methodology and operational space.

Wednesday, 25/12

Excellent storm today with lots of lightning. **We have a full evening and night of collocated radar observations with the Broome radar.** Unfortunately, the two weather stations on the mast stopped working early morning (Thursday) and the stabilized platform locked up in one of the extreme positions at about 22 UTC.

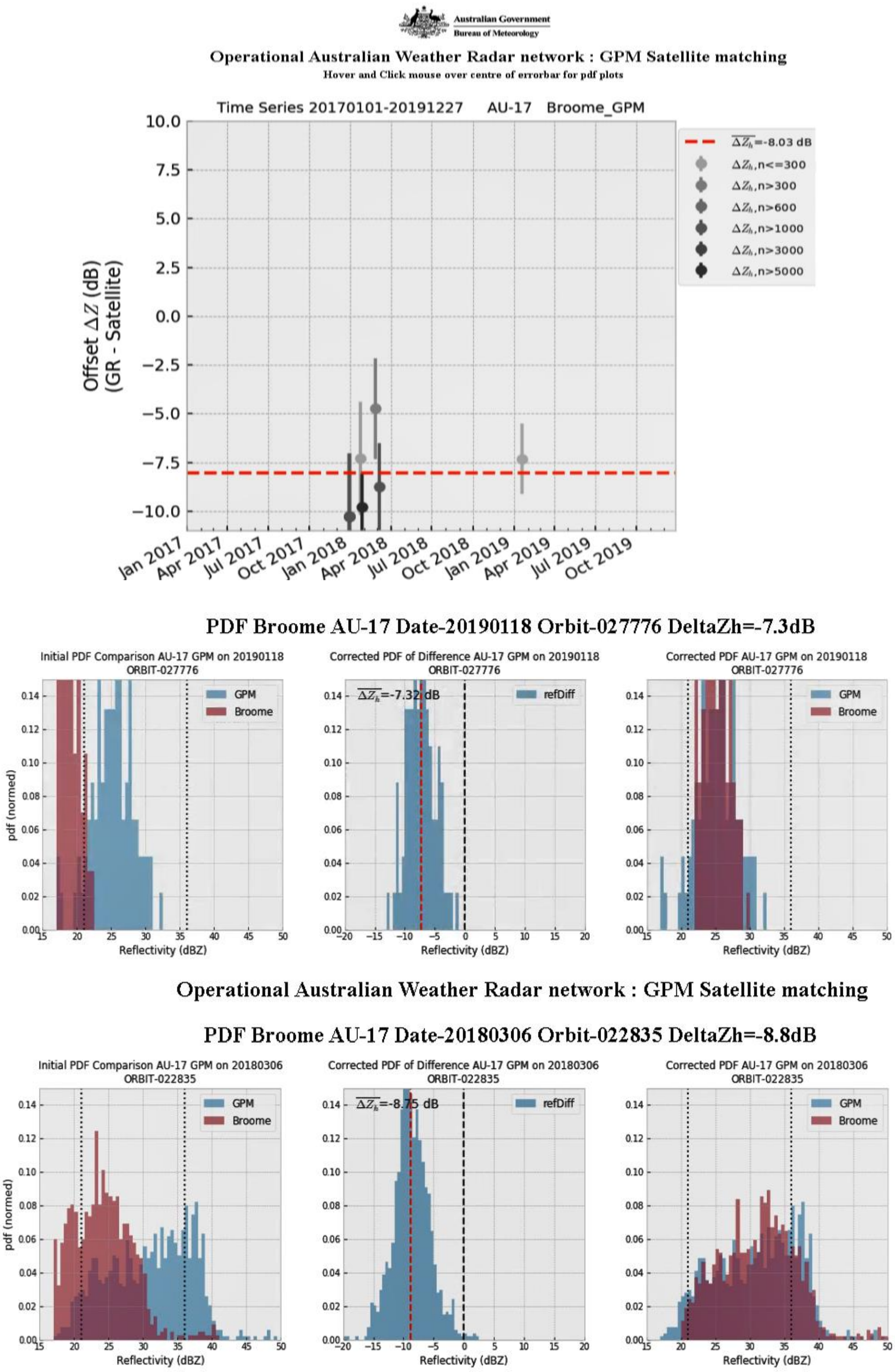


*Figure 8: Time series of comparisons between the **Broome** radar and the GPM satellite radar (top). Two examples (middle and bottom panels) of more detailed comparisons of reflectivity distributions (left), reflectivity differences (centre) and reflectivity distributions after correction of miscalibration. Latest estimate of miscalibration for this radar is -7.3 dB.*

New raster scans of the sun revealed that the azimuth and elevation pointing references have changed again, which is very surprising. Our hypothesis is that this is due to ducting of the radar beam through high humidity gradients we are measuring with the radiosondes. On Tuesday the ducting was minimal, but today it was much higher. We will keep the references from Tuesday and conduct more of these raster scans close to radiosonde times in the coming days.
Microplastics team continued running controls in the lab to quantify contamination levels in sampling methodology and operational space.

Thursday, 26/12
Radar collocated observations were conducted from 0100 till 0400 LT (Perth time). Then we moved to the first microplastics station. The first microplastics station operations lasted from about 0600 till 0900 LT. The CTD took about ½ h in 50m+ depths. The CTD was triggered at three depths, 45 m, 25 m and 5 m below the surface. Six bottles were fired at each depth and one bottle misfired. EZ Net was deployed after the CTD and took about two hours. A total of six nets were triggered for sample collection and towed for 15 minutes each. Two nets were triggered sequentially at 45 m, followed by two nets at 25 m, and then two nets 10 m below the surface. Samples from the Niskin bottles were processed in triplicates at each depth for both bacterial samples and small microplastics (> 0.2 µm). EZ net samples were placed in glass jars. For each depth one net sample was preserved with ethanol for the identification of zooplankton and one net from each depth was collected to quantify microplastics present in the waters and the ingestion of microplastics by zooplankton.
Ian McRobert has been contacted to help with resetting the stabilized platform as a reinitialization did not work. The cloud radar is stuck in the pitch=0, roll=-8 position. The weather stations are being fixed from 0830 till about 1030 by climbing on the mast. Then we'll be on our way to the Port Hedland station. Current ETA is 0400LT tomorrow morning if mast operations finish on time. Again, models disagree on what we'll have there, with GFS showing some convective activity and ECMWF nothing. Yesterday GFS was a bit more spot on but both models largely failed to forecast the storm at all.

Procedure to get the stabilized platform out of lock-up (from Ian McRobert):
Go to "System Settings" tab, change the homing method to "use actual position"
Go to "Platform control" tab, deselect "check motion range"
Now initialize. The platform will not move. It will assume that wherever it is stuck is zero in pitch and roll.
Now select manual mode. Set 0 for pitch, 8 for roll (if stuck at roll=-8). Click move. The platform should move to a safe, more central position.
Go to "System Settings" tab, change the homing method to "negative limit switch"
Go to "Platform control" tab, select "check motion range"
Click "Initialize". The platform should now be operational.

A raster scan of the sun this morning indicated an even larger (-1deg) elevation bias, so we will check with the 10:15 radiosonde if we are indeed in more severe ducting conditions.

Friday, 27/12
We arrived at the Port Hedland station at about 0500. There has been isolated convection for a while within the common sampling area of the two radars. **Two radars out of two!**

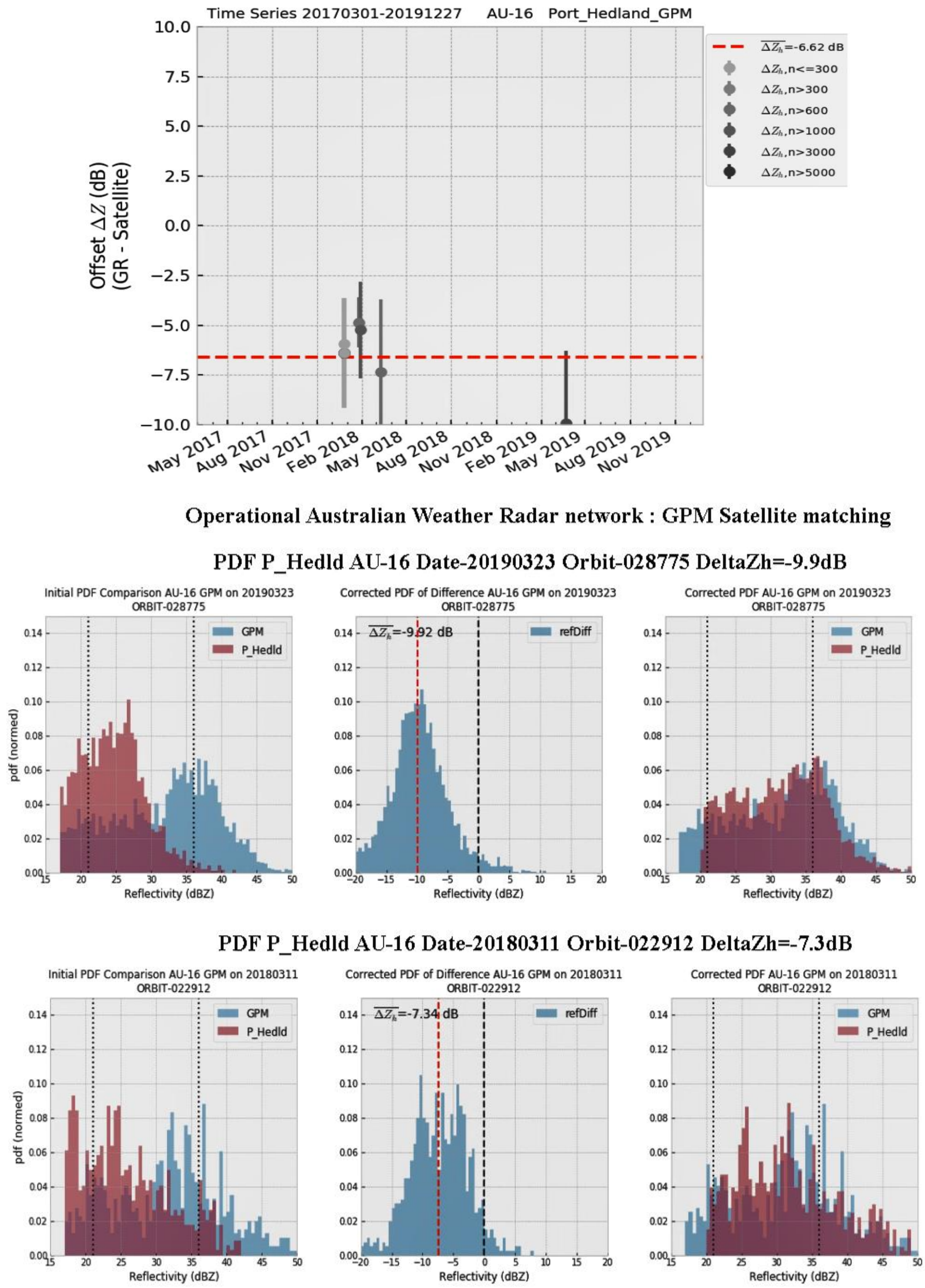


*Figure 9: Time series of comparisons between the **Port Hedland** radar and the GPM satellite radar (top). Two examples (middle and bottom panels) of more detailed comparisons of reflectivity distributions (left), reflectivity differences (centre) and reflectivity distributions after correction of miscalibration. Latest estimate of miscalibration for this radar is -10 dB.*

Decision is made to move at 0700 to follow isolated convective cells. If they survive a few hours, we will see them on the Dampier radar and that will be our third radar. These isolated cells are actually at about 150km from the Dampier radar, so we might be able to do something in case they do not survive, but they are shallow and far away. We arrived at Dampier station around 1700.

Since about 1800, there are isolated convective cells 100-150km from OceanPOL, which are 70-120 km away from the Dampier radar. So, we will have things to compare for this radar too. **Three radars out of three!** Another raster scan of the sun has been done around 1700 and the Dampier station radiosonde has been launched at 1915. We started steaming towards the Learmonth station at 2100.

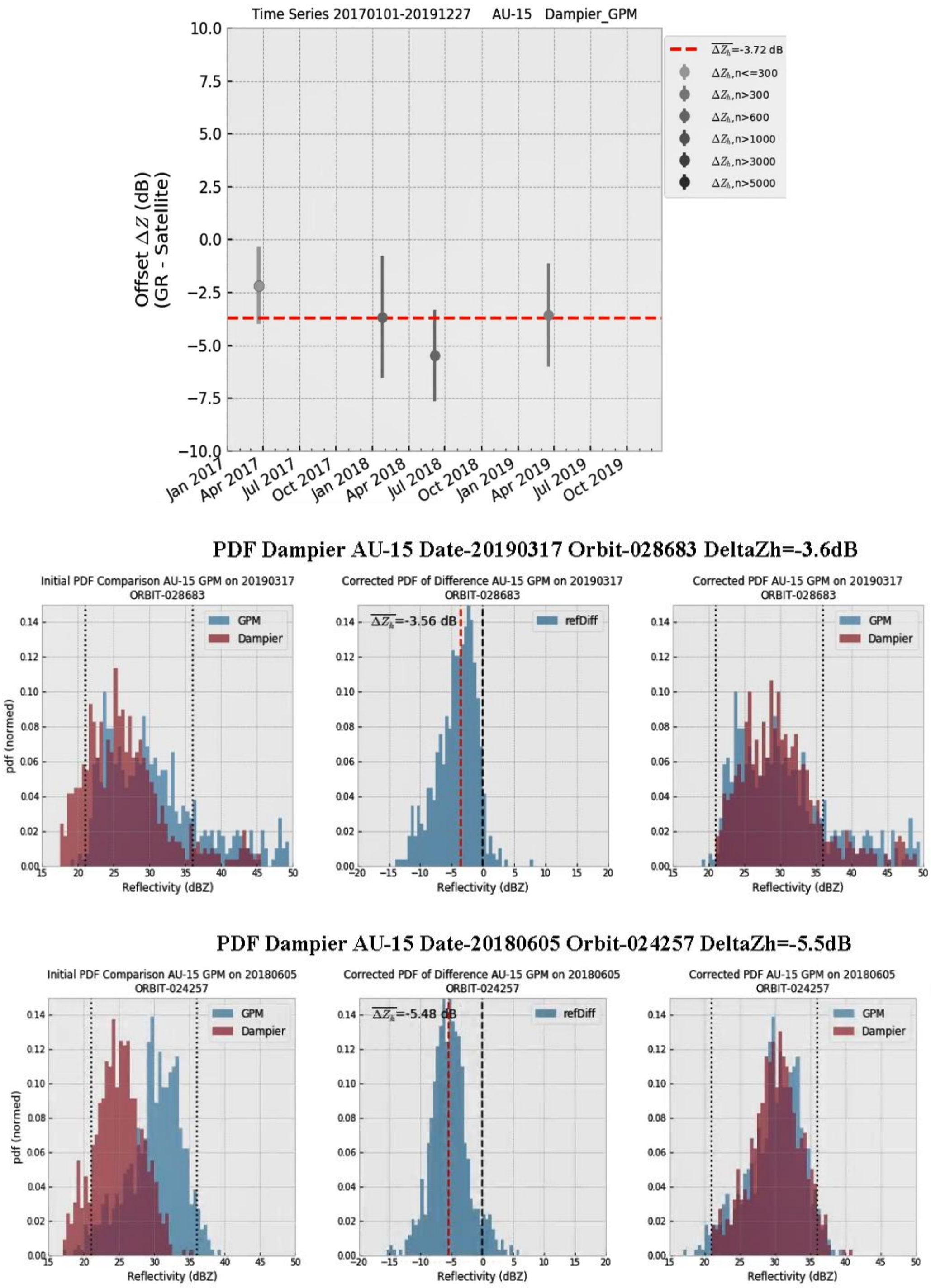


*Figure 10: Time series of comparisons between the **Dampier** radar and the GPM satellite radar (top). Two examples (middle and bottom panels) of more detailed comparisons of reflectivity distributions (left), reflectivity differences (centre) and reflectivity distributions after correction of miscalibration. Latest estimate of miscalibration for this radar is -3.6 dB.*

Microplastic and zooplankton samples were getting sorted and plastic extracted and characterised from the samples.

Saturday, 28/12:

Transiting this morning to the second microplastics site, which is north-east of Exmouth (between the Dampier and Learmonth stations). Microplastics operations should be from 110 to 1230. Then we will head to the Learmonth station. Forecast indicates there should be convective activity around Exmouth, but a bit later in the day (starting 1600-1700). We may have to stay a bit longer at the Learmonth station to get it.

Small convective cells are developing in front of the ship at 0900. This is also detected by the Learmonth radar, so we can use that to assess calibration. We should get more for this radar today but at the very least we'll have these small convective cells. They are 20km in front of our radar, and 100km northeast of the Learmonth radar.

Microplastics operations have been delayed due to a problem with the EZNET after the CTD deployment (approximately half an hour). It has resumed and was completed at 1400. We are now moving towards the Learmonth station.

The CTD took about ½ h in 90m+ depths. The CTD was triggered at three depths, 85 m, 48 m and 5 m below the surface. Eight bottles were fired at each depth to avoid miss fired bottles. EZ Net was deployed after the CTD and took about two hours. A total of six nets were triggered for sample collection and towed for 10 minutes each. Two nets were triggered sequentially at 85 m, followed by two nets at 48 m, and then two nets 10 m below the surface. Samples from the Niskin bottles were processed in triplicates at each depth for both bacterial samples and small microplastics (> 0.2 µm). EZ net samples were placed in glass jars. For each depth one net sample was preserved with ethanol for the identification of zooplankton and one net from each depth was collected to quantify microplastics present in the waters and the ingestion of microplastics by zooplankton.

This afternoon the stabilized platform got locked up again because of stronger ship motions. From now on it will be stabilized vertically to avoid that problem.

Important note: the lidar times are off by 14.5 minutes, probably since the start of YMC! (needs to be subtracted). The clock was pointing to the ntp.bom.gov.au server, which cannot be accessed from the ship … Using the ship data for the 25th of December storm, we will be able to refine that estimate. We will need to look at the earlier periods. Also, during the lidar reset the software reverted to feet for heights instead of meters.

We left the Learmonth station at 2100 after collecting some collocated data in small isolated convective cells. **Four radars out of four!**

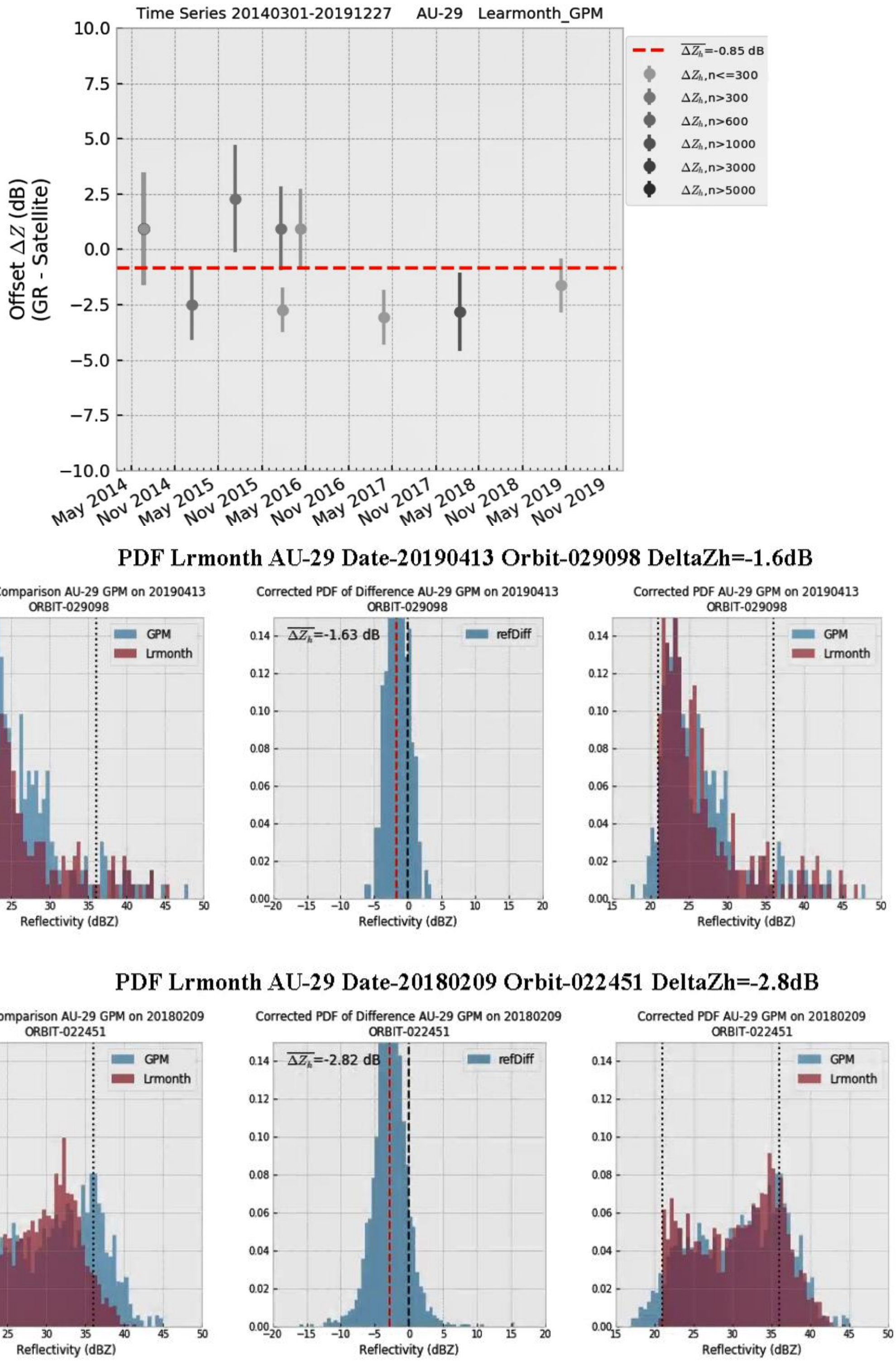


*Figure 11: Time series of comparisons between the **Learmonth** radar and the GPM satellite radar (top). Two examples (middle and bottom panels) of more detailed comparisons of reflectivity distributions (left), reflectivity differences (centre) and reflectivity distributions after correction of miscalibration. Latest estimate of miscalibration for this radar is -1.7 dB.*

Sunday, 29/12

Transiting to the Carnarvon station (ETA 1400). The forecast models indicate no convection for that day in this location. This time the forecast was right, we had no storm in the vicinity of this radar. We have only stopped from 1400 to 1500 and collected ground clutter echoes. Heading to the Geraldton station. Microplastics team continued processing samples collected from the day before.

Monday, 30/12

Today the team focussed on packing up instruments. We arrived at Geraldton station at 2200. We only stayed 1 hour to collect ground clutter returns as they are no storms around. Next step: Perth.
Arrived at next microplastics site at 1200 LT. The CTD took about ½ h in 70m+ depths. The CTD was triggered at three depths, 62 m, 40 m and 5 m below the surface. Eight bottles were fired at each depth to avoid miss fired bottles.
EZ Net was deployed and two nets triggered at 62 m. The deployment was aborted due to sea state and excess tension on the winch and cable.

Tuesday, 31/12

Most instruments are now packed up and will be transferred tomorrow to the AIRBOX or put on pallets. We should be arriving near Rottnest Island at 2200.
Niskin bottle samples were processed. A fourth microplastics site was sampled. The CTD took about 45 min in 180m+ depths. The CTD was triggered at three depths, 170 m, 55 m and 5 m below the surface. Eight bottles were fired at each depth to avoid miss fired bottles.
EZ Net were not deployed as the conditions were similar to the previous day.

Wednesday, 01/01

Bunkering today. There is a little chance that we'll get some light precipitation overnight near Perth, which would give us one more radar to compare with.
The last of the Niskin bottle samples were processed and the microplastics team packed up laboratory.

Thursday, 02/01

Last minute victory for the radar team, there are small isolated convective cells over ocean and land this morning while we are waiting to get off the ship. We will therefore be able to compare OceanPOL with the Perth radar too.

ITSS Student interview with radio national, and microplastics/ITSS/Flinders University with ABC Radio Perth.

Microplastics team completed final laboratory checks and packing of samples.

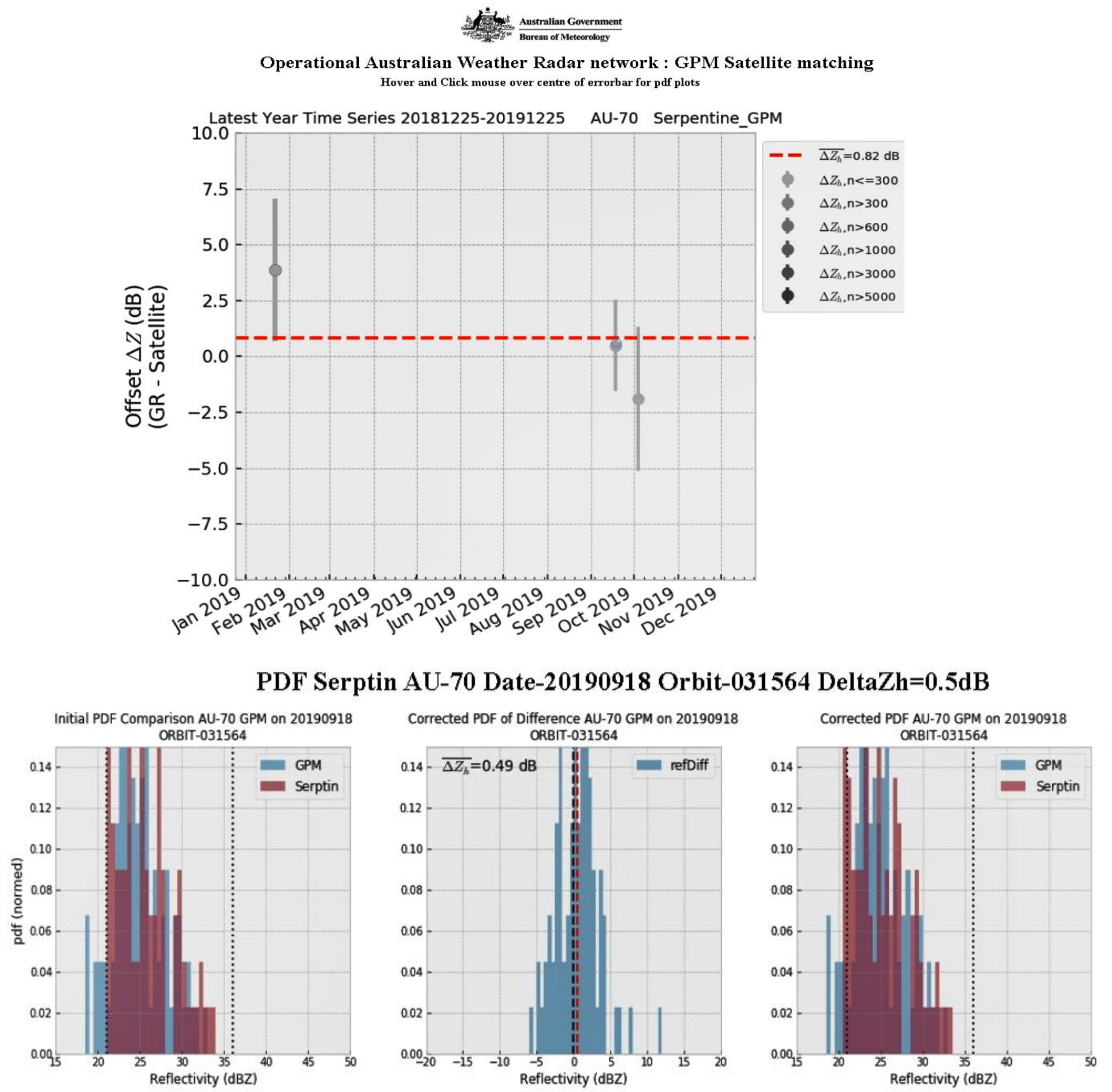


*Figure 12: Time series of comparisons between the **Learmonth** radar and the GPM satellite radar (top). Most recent example (bottom panel) of more detailed comparisons of reflectivity distributions (left), reflectivity differences (centre) and reflectivity distributions after correction of miscalibration. Latest estimate of miscalibration for this radar is 0.5 dB.*

Summary

The dataset collected during this very successful voyage will allow for the operational tools developed by the Bureau to monitor the radar calibration to be validated using one single source of reference, the OceanPOL weather radar on RV Investigator, which was the main objective of the ORCA project. Six out of the nine radars along the coast did measure precipitation as the same time as OceanPOL, which is a high rate of success given the low frequency of occurrence of precipitation along this coast. Issues have been identified with the pointing of the radar, which will need to be corrected and will impact the analysis of earlier deployments. We have also been able to confirm for the first time with radiosonde observations that the hot spot of Convective Available Potential Energy (CAPE, an indication of the potential for the atmosphere to develop deep convection) found in reanalyses was real and characterized by an unusually high moisture layer in the lowest levels of the atmosphere and a very dry layer just above.

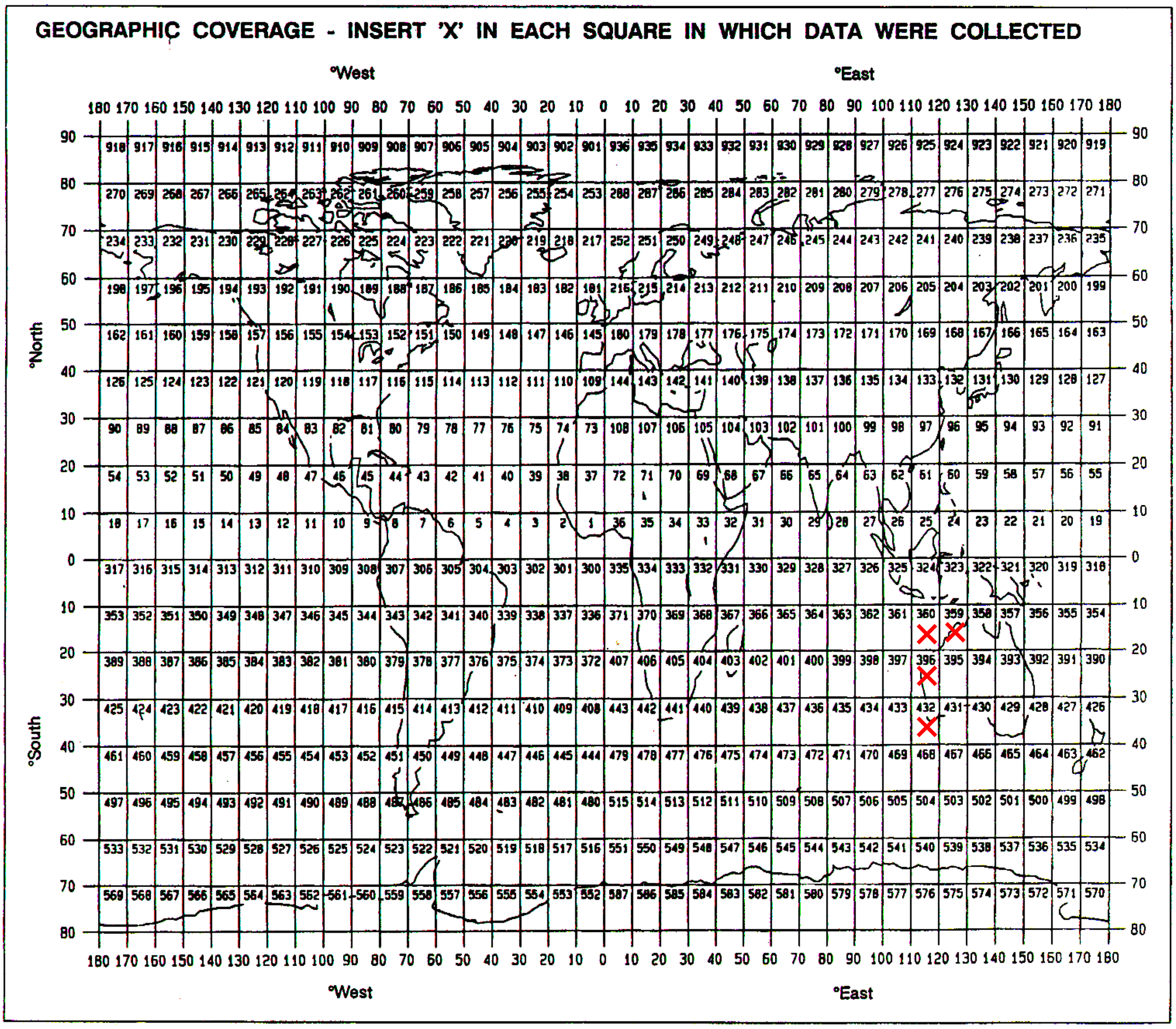
Scientific objectives of the microplastics team were met and the process allowed for the fine tuning for opportunistic sampling on future voyages. The team should have further results within the next two months.

The seabird program was highly successful in obtaining data for a remote area of Australia’s EEZ. The species diversity was higher than expected and analyses will commence once the data have been verified.

Marsden Squares

Move a **red “x”** into squares in which data was collected

× ×



Moorings, bottom mounted gear and drifting systems

Item No	PI See page above	APPROXIMATE POSITION						DATA TYPE enter code(s) from list on last page	DESCRIPTION
		LATITUDE			LONGITUDE				Identify, as appropriate, the nature of the instrumentation the parameters (to be) measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any identifiers given to the site.
		deg	min	N/S	deg	min	E/W		
1	Sophie Leterme	18	08	S	121	28	E	H10, H09, D71, B02, B08, B09, B11, B13,	CTD, Flurometer, NIskin Bottles and EZ net deployed. Water and plankton samples collected for microplastics, zooplankton and bacterial samples.
2	Sophie Leterme	21	23	S	114	44	E	H10, H09, D71,	CTD, Flurometer, NIskin Bottles deployed, no data collected.
3	Sophie Leterme	21	29	S	114	31	E	H10, H09, D71, B02, B08, B09, B11, B13,	CTD, Flurometer, NIskin Bottles and EZ net deployed. Water and plankton samples collected for microplastics, zooplankton and bacterial samples.
4	Sophie Leterme	27	27	S	113	34	E	H10, H09, D71, B02, B08, B09, B11, B13,	CTD, Flurometer, NIskin Bottles and EZ net deployed. Water and plankton samples collected for microplastics, zooplankton and bacterial samples. EZ Net operations were stopped after the bottom tow.
5	Sophie Leterme	30	44	S	114	44	E	H10, H09, D71,	CTD, Flurometer, NIskin Bottles deployed, water samples for small microplastics and bacteria collected.
									Please continue on separate sheet if necessary

Summary of Measurements and samples taken

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
1	Alain Protat	16	Radiosonde launches	M01	Balloon launches : Vertical profiles of the basic atmospheric state (pressure, temperature, humidity and winds)
2	Alain Protat	11	days	M01	95 GHz BASTA Cloud radar (SPC): vertical profiles of cloud reflectivity and Doppler velocity at 3s resolution and variable vertical resolution (from 12.5 to 100m). A special 5 profile mode has been implemented to measure vertical profiles of the 3D winds during this voyage.
3	Alain Protat	11	days	M01	RMAN-511 Lidar (SPC): vertical profiles of cloud and aerosol backscatter (the lidar did not work during Leg 1, but was successfully restarted for Leg 2).
4	Alain Protat / Luis Ackermann	11	days	M01	24 GHz Micro rain radar (MRR) (deck 5): vertical profiles of radar reflectivity and Doppler velocity.
5	Alain Protat / Luis Ackermann	11	days	M01	Parsivel 2 disdrometer (deck 5): drop size distribution and rainfall rate.
6	Alain Protat / MNF	11	days	M01	ODM470 disdrometer (mast): drop size distribution and rainfall rate.
7	Robyn Schofield / Zoran Ristovski / Branka Miljevic	11	days	M01	AIRBOX: several instruments to characterize aerosol properties.
8	Robyn Schofield	8	days	M01	Sea-state cameras: 1Hz images of sea state from two sychronised cameras during daylight
9	Robyn Schofield	11	days	M01	Eddy flux package: 10Hz temperature, relative humidity and 3 D wind vectors
10	Robyn Schofield	8	days	M01	MAXDOAS: Multiple axis spectra at several angles between 0deg and 90deg on two

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
					spectrometers. UV:295-450nm and VIS: 430-565nm. Boundary layer profiles of aerosol, O3, NO2, HCHO, BrO and IO possible.
11	Robyn Schofield	8	days	M01	miniMPL: ANSI Class II eye-safe pulsed laser beam at 532nm, continuous relative backscatter and depolarization profiles up to 10 km height.
12	Damien Callahan	9	days	M01	u-Dirac: Gas chromatograph measuring Halocarbon concentration (ppt)
13	Robyn Schofield	9	days	M01	Tekran: Mercury concentration in ambient air (TGM – ng/m^3)
14	Robyn Schofield	10	days	M01	Spectronus: In-situ continuous measurement of CO2, CH4, CO, N2O, δ13C in CO2, δD-H2O, δ18O in H2O
15	Woehler	10	Days	B25 + B26	Observations of seabirds and marine mammals during daylight hours. Approximately 5800 individuals recorded from 30 taxa. All data are geo-referenced and will be lodged with GBIF following processing and verification.
16	Sophie Leterme	3	months	H10, H09, D71, B02, B08, B09, B11, B13,	Microplastics will be extracted from plankton samples. The communities growing on this plastic will be imaged using SEM. The polymer type will be identified with a combination of ATR-FTIR, Transmission FTIR and RAMAN Spectroscopy. Small microplastics will be extracted from the membranes and where possible characterised under a microscope. These will then be identified using combination of ATR-FTIR, Transmission FTIR and RAMAN Spectroscopy.

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
17	Sophie Leterme	2	years	H10, H09, D71, B02, B08, B09, B11, B13,	Zooplankton community identification. Bacterial RNA extraction from water and biofilm. ADCP data will be utilised over the two years and paired with the growing dataset to develop a predictor model.

Curation report

All data collected from this voyage with user-supplied equipment will be inserted in the CSIRO Marlin database within 12 months after collection.

Track Chart

Blue markers are conventional radars and yellow markers are Doppler radars from the Bureau operational radar network.

Appendix A - CSR/ROSCOP Parameter CodeS

	METEOROLOGY
M01	Upper air observations
M02	Incident radiation
M05	Occasional standard measurements
M06	Routine standard measurements
M71	Atmospheric chemistry
M90	Other meteorological measurements

	PHYSICAL OCEANOGRAPHY
H71	Surface measurements underway (T,S)
H13	Bathythermograph
H09	Water bottle stations
H10	CTD stations
H11	Subsurface measurements underway (T,S)
H72	Thermistor chain
H16	Transparency (eg transmissometer)
H17	Optics (eg underwater light levels)
H73	Geochemical tracers (eg freons)
D01	Current meters
D71	Current profiler (eg ADCP)
D03	Currents measured from ship drift
D04	GEK
D05	Surface drifters/drifting buoys

	MARINE BIOLOGY/FISHERIES
B01	Primary productivity
B02	Phytoplankton pigments (eg chlorophyll, fluorescence)
B71	Particulate organic matter (inc POC, PON)
B06	Dissolved organic matter (inc DOC)
B72	Biochemical measurements (eg lipids, amino acids)
B73	Sediment traps
B08	Phytoplankton
B09	Zooplankton
B03	Seston
B10	Neuston
B11	Nekton
B13	Eggs & larvae
B07	Pelagic bacteria/micro-organisms
B16	Benthic bacteria/micro-organisms
B17	Phytobenthos
B18	Zoobenthos
B25	Birds
B26	Mammals & reptiles
B14	Pelagic fish
B19	Demersal fish
B20	Molluscs
B21	Crustaceans

D06	Neutrally buoyant floats
D09	Sea level (incl. Bottom pressure & inverted echosounder)
D72	Instrumented wave measurements
D90	Other physical oceanographic measurements

	CHEMICAL OCEANOGRAPHY
H21	Oxygen
H74	Carbon dioxide
H33	Other dissolved gases
H22	Phosphate
H23	Total - P
H24	Nitrate
H25	Nitrite
H75	Total - N
H76	Ammonia
H26	Silicate
H27	Alkalinity
H28	PH
H30	Trace elements
H31	Radioactivity
H32	Isotopes
H90	Other chemical oceanographic measurements

B28	Acoustic reflection on marine organisms
B37	Taggings
B64	Gear research
B65	Exploratory fishing
B90	Other biological/fisheries measurements

	MARINE GEOLOGY/GEOPHYSICS
G01	Dredge
G02	Grab
G03	Core - rock
G04	Core - soft bottom
G08	Bottom photography
G71	In-situ seafloor measurement/sampling
G72	Geophysical measurements made at depth
G73	Single-beam echosounding
G74	Multi-beam echosounding
G24	Long/short range side scan sonar
G75	Single channel seismic reflection
G76	Multichannel seismic reflection
G26	Seismic refraction
G27	Gravity measurements
G28	Magnetic measurements
G90	Other geological/geophysical measurements

	MARINE CONTAMINANTS/POLLUTION
P01	Suspended matter
P02	Trace metals
P03	Petroleum residues
P04	Chlorinated hydrocarbons
P05	Other dissolved substances
P12	Bottom deposits
P13	Contaminants in organisms
P90	Other contaminant measurements