1st IMOS Bluewater Node Meeting –

Bureau of Meteorology, Melbourne, 10th August 2009

The IMOS Bluewater node met at the Bureau of Meteorology on the docklands in Melbourne on the 10th August 2009. The aim of the meeting was to bring together Australia's Bluewater and Climate community to discuss the priorities in ocean observing for the next 10 years. The outcomes will help update the IMOS Bluewater and Climate Science and Implementation plan, and feed into the planning process for the new Education Infrastructure Fund (EIF) money.

Contents

Summary of Actions:

ACTION: Update Science and Implementation plan for the Bluewater and climate Node (Ken Ridgway (CMAR) Susan Wijffels (CMAR) Bronte Tilbrooke (CMAR) Rob Harcourt (Macquarie University) Gary Brassington (BOM) Tony Worby (AAD/ACE-CRC) Moninya Roughan (UNSW) Chari Pattiarachi (UWA))

ACTION: Develop concise priority list of observations, based scientific priorities set out in updated Node Science and Implementation plan (Ken Ridgway (CMAR) Susan Wijffels (CMAR) Bronte Tilbrooke (CMAR) Rob Harcourt (Macquarie University) Gary Brassington (BOM) Tony Worby (AAD/ACE-CRC) in consultation with node members)

ACTION: work with regional nodes to develop a coherent integrated plan for observing boundary currents (Ken Ridgway)

ACTION: Identify priorities for Satellite remote sensing data, and where IMOS effort is most effective (IMOS Office to coordinate)

ACTION: Review Oceanobs whitepapers and conference outcomes to determine international priorities (Ken Ridgway (CMAR) Susan Wijffels (CMAR) Bronte Tilbrooke (CMAR) Rob Harcourt (Macquarie University) Gary Brassington (BOM) Tony Worby (AAD/ACE-CRC) in consultation with node members)

Links

- Node meeting presentations http://imos.org.au/bluewater_meetings.html
- OceanObs09 Whitepapers http://www.oceanobs09.org/blog
- Existing Science and Implementation plans http://imos.org.au/nodes.html
- EIF Funding details, including timetable and proposal templates http://imos.org.au/eif.html
- IMOS Wiki for discussing new facilities and regional collaborations http://imos.org.au/wiki/

Summary of observation requests:

Broadscale:

1. Complete and enhance Argo (in Northern Australian waters and under ice)
2. Animal borne sensors (can help Argo in both Northern Australian waters, and under ice).
3. Surface drifters – to observe variability the West Pacific Warm Pool in the Indonesian seas
4. Pilot deep ocean moorings for deep ocean monitoring beyond CLIVAR repeat hydrography lines
5. Satellite products: Improve accuracy and take better advantage of SST, Altimeters (not invested in much).

Boundary currents

Eastern/Western boundary currents – Hybrid system

6. XBT line crossing each current
7. For each current: End point mooring system, with PIES, and Glider transect
8. Moveable current meter mooring system

Indonesian throughflow

9. Combination of shelf (6 month turnaround) and bluewater (2 year) moorings in Timor-Leste waters

Tasman Outflow:

10. Mooring system (end point?) across to The South Tasman Ridge or
11. PIES from Tasmania to Antarctica

Air sea fluxes

Flux moorings

12. Bluewater flux mooring contribution to RAMA (Indian Ocean Observing System) – international activity.
13. Shelf mooring, at end of Kimberly shelf array

Ships of Opportunity

14. Equipping more ships – ie. AIMS vessels, also Southern Champion, Ocean Viking
15. Upgrade instruments on l'Astrolab.
16. Enhancing Australian Voluntary Observing Fleet (AVOF), enhancing meteorological observations (part of VOS see oceanobs papers).

Waves

Moorings

17. Waverider buoys networks assimilated into IMOS and gaps filled in
18. NRS Motion Referencing Units

Ships of Opportunity

19. X-band Radar Observations from Ships –Instruments on ships already (for detecting other ships)

Ocean Carbon

Moorings

20. *A Southern Ocean PICO CO_2 Mooring at 60°S*
21. *Shelf CO_2 Moorings at National Reference Station sites*. As part of IMOS-EIF, moorings will be deployed at Maria and Rottness or Yongala. Roll out to all National Reference station Sites.
22. Mooring sites for carbon dioxide measurements as part of GBROOS/FAIMMS Sensor network.

SOOP

23. CO_2 observations from a ship of opportunity, which travels along reef are proposed (Capricorn to York)

Large pelagic predators and birds:

24. Deploying instruments on animals, birds etc to monitor prey distributions – Rob Harcourt
25. Pelagic fish tagging and long lines – Chris Wilcox

Mid Tropic Level observations

26. Acoustics – Rudy Klosser

Phyto/zooplankton

27. Expand CPR routes ~$500k – Anthony Richardson
    a. GBR route (Gladstone to Weipa, Gulf of Carpentaria)
    b. Great Australia Bight Route (Melbourne, Adelaide to Fremantle)
    c. Tasman Sea route (Brisbane to Auckland)
    d. Indian Ocean route (Fremantle to Oman).
28. Bio-optical observations of phytoplankton and zooplankton – Peter Thompson, Martina Doblin
    a. Flow cameras on ships of opportunity,
    b. Microscopy,
    c. Multi-wavelength fluorometers,
    d. triplet sensors
29. Phytoplankton fluxes using sediment traps - Leanne Armand.
    a. Coastal: At National Reference stations, and Cofffs Harbour and Eden
    b. Bluewater, at Adélie Land (Antarctic shelf) and Heard Island

Nutrient observations -

30. Towed samplers (i.e. next to CPR)-Ed Butler

Meeting minutes

The meeting was opened by Dr Eric Schultz, co-Facility leader of the Southern Ocean Time Series (SOTS) and sub-Facility leader for the Ships of Opportunity Program, who welcomed everyone to the Bureau of Meteorology. Bluewater and Climate Node leader Ken Ridgway then welcomed the attendees to the meeting, and noted the range of disciplinary and regional interests present.

Tim Moltmann – Overview of IMOS and the way forward – Building on our strengths

IMOS director Tim Moltmann gave an overview of the IMOS program, including the process to date, and the outlined the planning process for the IMOS EIF funding. Tim emphasised that IMOS is enhancing and extending, not starting again. The Node and Facility structure will continue, with the Nodes articulating the science rationale and design of the observing system, and Facilities receiving the funding. A key to the future success of IMOS will be Integration, both regionally, and between disciplines. Tim then outlined the details of the funding and its focus. He also outlined the process to date, including the original IMOS plan, the NCRIS Roadmap, and the Federal budget.

Of the $52 million of IMOS EIF Money announced in the budget, $8 million has already been allocated. $8 million will be available for year 2010-2011, then 16 million for each of the two following years. The focus of the first $8 million was used to build on existing capability in facilities with capacity, focussing on the Southern Ocean, Northern Australian Waters, and enhancing existing IMOS activities. Full details of the plans to date, and the EIF planning timetable are available on the IMOS website www.imos.org.au/eif.html

The IMOS office has developed a draft 5 year strategy to focus the planning process for the new EIF funds. This includes the investment parameters, lessons learnt, national and international developments, and 10 strategic priorities which need to be addressed. Download the strategy at:
http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/EIF/DRAFT_IMOS_Five_Year_Strategy.pdf

Of the 10 strategic priorities, Tim identified 3 as being particularly relevant to the Bluewater node:

1. Ongoing development of a coherent and well positioned Bluewater and Climate node.
2. Impact and delivery through improving model output
3. National backbone for observing boundary currents.

The Bluewater and Climate node need to clearly articulate big questions, and how to approach them. The Science and Implementation plan needs updating to provide the vision for the next 10 years of ocean observing in the Bluewater and climate domain. Focus is also needed on the National Backbone of IMOS, which includes the National Reference Stations and Satellite Remote Sensing. In particular, an assessment is needed to determine whether the Satellite Remote Sensing facility is delivering the products that the community needs.

Discussion

In the discussion that followed, it was noted that the focus of the EIF money on Northern Australian Waters and the Southern Ocean, while a key focus of IMOS has been on the boundary currents which are at mid-latitudes.

While the 5 year strategy emphasises the impact and delivery through models, it was noted that observations are needed to monitor changes in the ocean heat and carbon budget – this has been identified in the National Framework for Climate Change Science. IMOS needs to reiterate the need for ongoing Bluewater monitoring for climate change.

The challenge of sustaining IMOS into the future, and the need for ongoing support was also identified as a big issue. Transitioning to operational oceanography is considered the ultimate goal. IMOS is a step towards that. A National Environment Information System (NEIS) is under discussion, and Ocean Observations will be a part of that. IMOS continues to invest in sustained research infrastructure, and will explore pathways to transition established observing activities to Operational.

It was also highlighted that not all the EIF money will be available for new observations, as there are costs associated with sustaining existing observations. This means that roughly 25-30% ($11-13 million) of the EIF funds can be considered money for investing in new activities. The proportion available will depend on a number of factors

1) EIF is currently not defining what proportion needs to be focussed on Northern Australian or Southern Ocean waters
2) There is the option to extend existing facilities into Northern Australia waters and the Southern Ocean.
3) There is the option too stop existing capability if it is not delivering in line with IMOS priorities.
4) There is the option to seed new activities for the future. Modest investments now could grow quite substantially in the future.

Dr Susan Wijffels – Broadscale Ocean State

Susan focused the science rational for broad scale ocean observing, and the physical measurements needed. The distribution of heat and freshwater is probably the biggest source of predictability in the climate system, and broad-scale ocean observations of temperature are needed to help close the planets energy budget. Ocean salinity changes reflect hydrological changes, and offshore large scale events such as the El Niño-Southern Oscillation drive variability in the boundary currents and on the shelf. The upcoming OceanObs09 meeting in Venice was also highlighted, which already has community whitepapers on many aspects of the ocean observing system on the OceanObs09 website.

Existing Bluewater facilities are Argo, Ships of Opportunity and the Southern Ocean Time Series. Two major gaps in the coverage of Temperature and Salinity profiles were highlighted; In the sea ice zone, and in the internal Indonesian seas, Gulf of Carpenteria, and Great Barrier Reef.

The suggestions that came in were Suggestions that came in;

1. Continue XBT Lines
2. Complete and enhance Argo (in Northern Australian waters and under ice)

3. Animal borne sensors (can help Argo in both Northern Australian waters, and under ice).
4. Surface drifters – to observe variability the West Pacific Warm Pool in the Indonesian seas
5. Pilot deep ocean moorings for deep ocean monitoring beyond CLIVAR repeat hydrography lines
6. Satellite products: Improve accuracy and take better advantage of SST, Altimeters (not invested in much).

1) Long running SOOP XBT lines are very valuable. They cross Australia's major boundary currents, and when combined with Altimeter, have been used to calculate boundary current transports. The science output from this data is ramping up as there is now a decent length (15 years) of data.

An enhancement to ships of opportunity has been proposed by Dr Chris Wilcox to instrument fishing vessel long lines with temperature/depth sensors. Chris is also developing automated tagging of large pelagics using stomach tags. These would be detectable from the AATAMS array. Such a system would provide shallow data, which is 3-4 day delayed mode. Instrumenting around 50 vessels would cost $1-1.5 million, but has the power to combine physical and biological observations

2) The Argo program has achieved its global target of 3000 floats. However, some have been grey listed as not operating well, and the core mission does not include marginal seas or under ice measurements. Hence, only 2800 floats are currently operating in the core region. Some areas are still thin on the ground, especially the Southern Ocean and the western Indian Ocean, which Argo Australia is constantly targeting with partners.

Argo Australia proposes to complete the core mission, and extend under the ice, using iridium floats programmed with ice avoidance algorithms, and ruggedized antennas to penetrate thin ice. Pilot projects should also be initiated in territorial waters, partnering with Indonesia to obtain observations of the warm pool area. This is likely to mean donating floats to Indonesian agencies for deployment. In total, Argo Australia anticipates that this amounts to a 20% increase in costs.

3) The deep ocean is currently not observed as part of IMOS. The bottom two kilometres of the ocean is starting to warm much more rapidly, with 20-30% of extra energy being captured in the global system going to the deep ocean. This has implications for sea level rise. Currently, this domain of the ocean is only captured in CLIVAR Repeat Hydrography, where transects across the ocean basins are revisited every 5-10 years.

Two approaches are being discussed for monitoring the deep ocean. Dr Bernadette Sloyan proposes deploying moorings across deep ocean choke points, where deep water has to pass through restricted passages, known as deep boundary currents. This approach is also advocated in the Southern ocean Observing System plan, where mooring arrays are proposed to capture deep outflows.
A broadscale approach is also being discussed by the international community, using long lived deep thermister moorings. The data is delivered when data pods are released which come to surface every 6 months (see Oceanobs whitepaper

4) A new Surface Drifters facility has been proposed by Dr Gary Brassington. While there has been some discussion of the use of Surface Drifters in the Indonesian Seas, Gary proposes this to be extended to deployments in the boundary currents. 8 drifters per year are currently deployed in the East Australia Current which are

provided by NOAA and deployed from the Bureau of Meteorology Australian Voluntary Observing Fleet (AVOF). These drifters are currently used to validate the Bluelink reanalysis (BRAN). A facility of 24 buoys per year is proposed to monitor the EAC and additional buoys to monitor the Leeuwin Current and other research applications.

5) There is an opportunity also to improve Satellite Remote Sensing data streams in the region. In particular, Altimeter and Sea Surface Temperature

Altimeter data is one of the most complex of remote sensing data streams, because of the number of corrections which need to be made. In particular, orbital and wave condition biases are a challenge. IMOS already contributes to the Bass Strait Jason calibration mooring. An additional mooring has been recommended in Northern Australian waters. Increase Australian engagement in remote sensing calibration/validation may leverage access to European products. A large amount of international activity is focussed on calibration and validation of SST products (i.e. the Global High Resolution Sea Surface Temperature (GHRSST) project), which is tackling issues such as skin/bulk SST differences, and diurnal cycles. Currently IMOS is targeting a small amount of funds in this area, to validate satellite SST with bulk measurements, and one ferry is taking skin measurements. However, a small amount of funding could make a big difference to our understanding of skin/bulk SST relationships by instrumenting more ships with radiometers. This may help us understand the latitude bias of different SST satellite datasets. South of 40°S, a large bias separation is seen between datasets.

Discussion

During the discussion it was noted that there are a lot of new satellites coming online not only new altimeters, but also new technology such as salinity missions. There is a need to prepare for this new generation of satellite instruments coming online, and it is important that the Australian community has the ability to access/calibrate data. IT was noted that the IMOS office is getting mixed signals from different groups on remote sensing prioirities. There is a need to articulate a clear message nationally on how IMOS should focus its efforts.

The need for Biogeochemical sensors on Argo floats was also discussed, and a Whitepaper on adding Oxygen sensors is available on the OceanObs website. However, it would cost an extra 50% to include oxygen, and there are still concerns about sensor stability and quality control. There are also likely to be issues around the United Nations Convention on the Law of the Seas (UNCLOS). Getting permission to transmit BGC data out of EEZ's might be problematic. Therefore the International Argo Steering Team are reluctant if diplomatic clearance needed for each float. Therefore, biogeochemical sensors are not a global strategy right now. A pilot study is needed and Quality Control issues need to be rectified. The meeting were assured that these issues being worked on, and measurements of Oxygen in the open ocean are extremely valuable as Oxygen is a good indicator of Carbon uptake/ventilation, and an indicator of primary production. .

The depth resolution is increasing, with a plan for half of the Argo network to ultimately be transmitting on the Iridium network, which allows data to be transmitted at 2db resolution.

Ken Ridgway – Obs of Boundary Currents and Choke Points

Boundary currents are part of the National Backbone, connecting large scale phenomena with shelf processes. Three types of boundary systems have been identified; the Western/Eastern boundary currents such as the EAC and Leeuwin Current systems, exchanges and through-flows such as the Indonesian Throughflow and Tasman Outflow, and deep circulation processes.

There is a need for IMOS to have a coherent national strategy for monitoring boundary currents, and this is highlighted in the IMOS draft 5 year strategy. Existing datastreams which contribute to observing boundary currents include:

1. XBT sections PX34 from Sydney to Wellington captures the EAC and IX1 from Fremantle to Sunda Strait, Indonesia captures the Indian Ocean South Equatorial Current and part of the Leeuwin Current
2. Ocean Gliders (however, the community are still learning how to operate these, and it is providing difficult to do repeat transects).
3. Coastal systems such as reference moorings, coastal radar and acoustic curtains (for understanding links between boundary currents and large pelagics) are useful, but integration is needed between the bluewater and coastal observations.

The current XBT line which crosses the EAC is close to the separation zone, where much of the flow separates to form the Tasman Front. Hence, only be used for calculating net transport through the Tasman Sea. XBT's also only measure the first 800m. The best place for the EAC to be measured is close to Brisbane, where it is best behaved. The Leeuwin Current is also only partially captured. Traditionally the Leeuwin current is monitored at Fremantle – as it is logistically easy, and Fremantle sea level is a useful proxy for Leeuwin Current strength. Observations of the Flinders Current, are important for understanding variations in upwelling along the South Australia coast, and the Indonesian Throughflow and the Tasman Outflow connect the Pacific to the Indian Ocean, and hence for important parts of the Global circulation. In the case of the Indonesian Throughflow, it has an important role in our climate.

Existing single approaches fail to completely capture boundary currents.

1. XBT's – too shallow, no salinity, may not resolve spatial & temporal variability
2. Argo - and surface drifter density too sparse in narrow & swift currents
3. Gliders - too slow to fight strong currents , not deep enough
4. Current Meter mooring arrays – expensive, may miss full current width, but capture full transport
5. End point moorings - may capture mass trans., cannot resolve heat trans., expensive, require annual turn if surface moored, miss non-geostrophic parts
6. Altimetry – loss of data at endpoints, subsurface only estimated

Therefore, multiple (or hybrid) approaches are recommended, exploiting the strengths of XBT's, Argo, Gliders, Current Meter Moorings, end point moorings and Altimeter.

An OceanObs whitepaper on boundary currents (see links) identifies the optimal hybrid system as an “end point mooring system” for measuring geostrophic flow. This includes End point current meter moorings, Pressure Inverted Echosounders (PIES), and gliders.

PIES measure the time of flight of a signal up through the water column, which closely corresponds to heat content. By combining with gliders, full column can be observed, with boundaries being constrained by current meter moorings. It was proposed that such systems can be deployed around the country for each boundary current, with one “moveable” current meter array for calibration purposes.

However, this system will miss the non-geostrophic component of the flow, and research would need to be carried out to determine how wide the system needs to be. The PCM mooring array deployed to measure the EAC as part of the World Ocean Circulation Experiment was not wide enough to capture the complete flow, which meandered in and out of the array. However, results show that the EAC has a strong barotropic component.

Solution – a hybrid approach.

A nationally integrated approach to measuring boundary currents is proposed. Each boundary current should be captured at one location. Different systems require a different approach.

Eastern/Western Boundary Currents
By combining an end point mooring system with the XBT lines across each current system once (where it is “best behaved”), and gliders around the coast (1 every 5 degrees), an accurate picture of variability in the boundary currents could be developed. While ambitious, such a system is doable with existing technology. There is then potential to develop weekly boundary current indicators of transport, heat content, heat transport and freshwater anomalies.

NOTE: Since the meeting, DEWHA have identified boundary current strength as being a key indicator of ecosystem health.

Indonesian Throughflow
A Northwest shelf ITS mooring array has been proposed, which was also discussed at the Northern Australian Observing System planning meeting held on 29th July in Perth. A combination of shelf (6 month turnaround and bluewater (2 year) moorings are proposed in the Timor-Lest Waters. A suggested alternative site of the Kimberly coast would also be of interest in the Bluewater node for sampling the flow of the Leeuwin Current (useful for comparison with the two rocks line).

Tasman Outflow
Is the westward flow of water south of Tasmania towards the Indian ocean, making up the southernmost point of the northern limb of the southern hemisphere super-gyre. The South Tasman Ridge/Saddle acts as a natural choke point, so observations of the Tasman Outflow could be carried out by instrumenting a short distance. However, a long term vision would include instrumenting from Tasmania to Antarctica using PIES.

Observations of boundary currents are essential to improving models where western boundary currents, in particular are a large source of error. Ultimately, these observations can be assimilated into Bluelink, but initially will be most useful for validation. Bluelink could be used to help design the observing system. This type of Observing System experiment has already been used to help design the Indian Ocean Observing System (INDOOS), and the placement of the Coffs Harbour Radar for New South Wales IMOS

As mentioned before, this vision is ambitious, and would require significant investment. It is not something that can be tackled in one go. The long term vision needs to be articulated, and then scaled to what can be achieved in the coming years. Another limitation are human and ship resources. However, opportunities may arise due to other proposals (such as the Solomon Sea mooring activity MoorSPICE, a contribution to the Southwest Pacific Ocean Circulation and Climate Experiment, SPICE) not going ahead. The new ship also offers some opportunities for increased ship support in the future.

Discussion

In the discussion that followed, it was mentioned that choke points in northeast New Guinea act as a wave guide for ENSO, and are hence important for understanding Australian shelf processes (especially on the west and south coast). The MoorSPICE activity was going to address this, but is not going ahead (see above). However, it was suggested that perhaps this region is outside the scope of IMOS, which should focus on the EAC and Leeuwin current systems.

There is an opportunity to leverage expertise in the region also. A Scripps/NOAA group (part of the Consortium on the Ocean's role in Climate) are at the cutting edge of endpoint moorings, and are instrumenting the entrance to the Solomon Sea to observe subtropical-tropical exchanges. This is a great opportunity to partner with this group to instrument the Coral Sea/Northern EAC.

It was noted that two northwest Australia mooring arrays are being discussed, and the Bluewater node needs to decide which is the priority. One would be more focused on monitoring the ITF, and the other, the Leeuwin Current.

It was also suggested that while current transports might be needed, others might be interested in eddies and eddy shedding. However, it is not easy to separate signal from noise, so best to observe where observations are cleanest.

Lastly, it was acknowledged that as boundary current represent the link between the open ocean and shelf processes, Bluewater node and the regional nodes need to integrate boundary current observing plans.

Eric Schultz - Air Sea Interaction

Eric Schultz outlined the motivation and observing system requirements for observations of air sea fluxes and wave processes. Air sea flux estimates are needed for understanding the global energy budget on weather (1-7 day), intraseasonal, seasonal and climate (>10 year) scales. As a flux is the exchange of heat and gas between the ocean and atmosphere, observations of sea surface temperature, ocean heat content, atmospheric temperature, and gases across the interface are needed. In addition wave processes impact on energy and property transfer across the air-sea interface. Users of Air sea flux cases include numerical weather prediction, seasonal forecasting, climatology development and wave reanalysis.

Existing flux climatologies are problematic – especially in the Southern Hemisphere, where the differences between climatology products can be as big as the signal.

Existing flux observations include SOTS, SOOP, and Wave rider buoys (currently only NSW ones part of IMOS). SOOP provides a low coast option for flux observations, however, coverage is difficult to control, as the routes of the *RV Southern Surveyor* and the *RSV Aurora Australis* are seasonally dependant. SOTS provides high quality time series data at one location, but the cost may mean more than one platform of this type is too expensive. Wave rider buoys have good coverage on the east coast, and sparse in other parts of the Australian coastline.

Proposals to improve flux observations over the next 5 years include:

1. Air sea fluxes
    1) Flux moorings
        - Bluewater mooring - Contribution to RAMA (Indian Ocean Observing System) – international activity.
        - Shelf mooring, at end of Kimberly shelf array
    2) Ships of Opportunity
        - Equipping more ships – ie. AIMS vessels, also Southern Champion, Ocean Viking (Both don't want position known)
        - Upgrade instruments on l'Astrolab.
    3) Enhancing Australian Voluntary Observing Fleet (AVOF), enhancing meteorological observations
        - part of VOS _ see oceanobs papers.
2. Waves
    1) Moorings
        - Waverider buoys-Most waverider buoys networks run by states. Does IMOS provide an opportunity to pull together?
        - NRS Motion Referencing Units
    2) Ships of Opportunity
        - X-band Radar Observations from Ships –Instruments on ships already (for detecting other ships)

The vision for the next 10 years includes;

3. Air sea fluxes
    1) Meteorological observations on all National Reference Stations, to give fluxes on shelf.
    2) Boost AVOF ships with Met obs. Systems.
    3) Waves at NRS (just motion sensors, or more than that?)

- Waves
    4) Filling gaps in Waverider buoy network around the coast.
    5) Radar systems which can be used to observe currents + waves at very large scale (1000's kms) (more information?)

Bronte Tilbrook – Ocean Carbon

Motivation for increasing ocean carbon measurements under IMOS was outlined, highlighting a strong international effort under the International Ocean Carbon Coordination Panel (IOCCP) to resolve carbon fluxes in the ocean to +/-0.2PgC/yr. Improved understanding of the variability of carbon uptake and storage in the oceans is needed to predict future responses to ocean changes (i.e. warming, circulation, ventilation, primary production). An emerging issue is ocean acidification, which is a product of the ocean's uptake of CO_2. This impacts the ability for organisms to form skeletons, and hence will have consequences for ecosystem functioning, including iconic systems such as the Great Barrier reef, as corals form calcite skeletons.

There are Parameters which we need to observe to understand CO2 system. These are;

- the partial pressure of carbon dioxide (pCO2),
- total carbon dioxide (CO2),
- total alkalinity (tAlk)
- pH.

No sensors are available for Argo floats yet, however, but some are available which can be deployed on moorings (pCO2). Underway systems have also been developed for use on ships, but these are not small, and require a lot of care. Hence, are only used on research ships, where scientific support is available. Currently, one is on a ship from the US (NOAA collaboration), one on the *RV Southern Surveyor*, and one on *RSV l'Astrolabe*.

There are a number of OceanObs09 papers on the topic of ocean carbon observing systems – both new sensor technology and approaches, and observing system requirements

A carbon product produced by Takahashi et al (2009) provides a gridded climatology estimate of the flux of carbon between the atmosphere and the ocean from 3.5 million observations over 40 years. However, this is heavily averaged and there is no coastal coverage in observations. There are also big gaps in data coverage in the Australian region. Acidification will have the biggest impact on shelf regions and coral reef systems. Currently there is very little understanding of both spatial and temporal variability, which might give us an insight into how systems may respond/adapt into the future.

Anticipates changes in the Australian region include, changes in carbon fluxes due to increased stratification and an enhanced EAC; Sea Ice loss and the response of wind s to Southern Annular Mode (SAM) in the Southern Ocean and subpolar waters could impact the carbon fluxes.

Gaps in our understanding include the carbon dioxide flux response to the shift in wind patterns due to the SAM. The Southern Ocean is a sink for atmospheric carbon dioxide. Under the most likely emissions scenarios, the Southern ocean will cross aragonite saturation threshold (ie. the concentration at which organisms can precipitate aragonite shells) by mid century, followed by Calcite early next century.

The *RSV Aurora Australis* provides the regional coverage to complement *RSV l'Astrolabe.* However, the equipment has been taken off and may not go back on due to crew/staffing limitations. The RSV Aurora Australis wintertime voyages are particularly valuable, as there is very little winter data in the Southern ocean.

The new opportunities for observations were highlighted;

- The Platform Instrumentation for Continuous Observations (*PICO) CO2 Mooring package* is built by NOAA, but there is the capability within Australia to deploy/manage. The mooring is a modular system, so the sensor pack can be built into a mooring design appropriate for the conditions.
- *A Southern Ocean Mooring at 60°S* would complement the SOTS flux mooring, and provide valuable winter data (winter-time out-gassing, summertime, biological drawdown). It could also be serviced by *RSV l'Astrolabe*.
- *Coastal Moorings at National Reference Station sites*. Deployment of PICO moorings at National Reference Stations is a great opportunity to benefit from the regular servicing, and enhancing coastal coverage of carbon dioxide

measurements. As part of IMOS-EIF, moorings will be deployed at Maria and Rottnest or Yongala, with the hope that they can be rolled out to all National Reference station Sites. Currently, total carbon dioxide and Alkalinity are part of the NRS sampling regime.

- Great Barrier Reef – carbon dioxide observations are extremely important, as it is already reaching marginal pH conditions for coral growth in the south. A observations from a ship of opportunity, which travels along reef are proposed (Capricorn to York). Mooring sites for carbon dioxide measurements could also be added as part of GBROOS.

Rob Harcourt – Bluewater Ecosystem monitoring.

Rob began by highlighting the seal CTD tagging activity, an enhancement to the Australian Acoustic Tagging and Monitoring program. This new activity will not only provide details of seal movements and foraging grounds in the Southern Ocean, but also temperature and salinity data while they are going about their daily business. In the Antarctic elephant seals will be used, providing valuable under-ice, and Southern Ocean data coverage. In Southern Australia, Australian Sea lions and Fur Seals will be tagged, which go to the shelf edge and back, providing data on Upwelling systems, for example. In the future there is potential for expanding this technology to observe turtle distributions and their environments in Northern Australian waters. Optical sensors are also a potential addition.

The monitoring of top predator distributions was advocated as they can provide information on spatial and temporal variability in the distribution of their prey. Zooplankton, fish and squid remain the most difficult aspect of the southern ocean ecosystem to monitor, and predator movements remain one of the most effective means of gaining basic distribution and abundance data.

Below is a summary of ecosystem proposals for the Bluewater node:

Large pelagic predators and birds:

1. Deploying instruments on animals, birds etc to monitor prey distributions – Rob Harcourt
2. Pelagic fish tagging and long lines – Chris Wilcox

Mid Tropic Level observations

3. Acoustics – Rudy Klosser

Phyto/zooplankton

4. Expand CPR routes ~$500k – Anthony Richardson
   a. GBR route (Gladstone to Weipa, Gulf of Carpentaria)
   b. Great Australia Bight Route (Melbourne, Adelaide to Fremantle)
   c. Tasman Sea route (Brisbane to Auckland)
   d. Indian Ocean route (Fremantle to Oman).
5. Bio-optical observations of phytoplankton and zooplankton – Peter Thompson, Martina Doblin
   a. Flow cameras on ships of opportunity,
   b. microscopy,
   c. multiwavelength fluorimeters,
   d. triplet sensors
6. Nutrient observations - Ed Butler
   a. Towed samplers (i.e. next to CPR)
   b. 5 years time, hope to have sensor technology developed for Argo, gliders, etc. (optical nitrogen sensors currently being tested).
7. Phytoplankton fluxes using sediment traps (Antarctic shelf) - Leanne Armand.

a. At National Reference stations
b. At Coffs Harbour and Eden
c. SOTS (Bluewater) – already in place.
d. Adélie Land (Antarctic shelf)
e. Heard Island

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Discussion –

In the discussion that followed, it was highlighted that the Seal CTD data is transmitted on the GTS (along with Argo, XBT data, etc). Providing extremely valuable data in regions that are traditionally data sparse, and some areas not covered by Argo floats (ie. on the shelf and under the ice. The Mercator ocean forecasting group are already using the data.

It was mentioned that there is concern from the animal ethics committee on the use of seals as oceanographic samplers verses using the data to understand their movements and habitats.

Gary Brassington – IMOS Bluewater and Opperational Modelling.

Gary outlined the objectives and observational requirements for operational ocean forecasting, giving an estimate of ocean properties in 3 dimensions from hours to months ahead.

Currently, the only things going into Bluelink forecasts are taken from the GTS. Real time data is essential for ocean forecasting. And the data used is written into the Bluelink contracts.

There is no reason why all delayed mode physical data shouldn't ultimately be going into the Bluelink reanalysis (BRAN). Currently, BRAN is fed by the CARS dataset (the original profiles, not the gridded version).

Satellite altimetry is essential for ocean forecasting and reanalysis. However eddy dynamics are still a significant challenge and Altimeter has large signal to noise ratio in this area (due to point rather than swath measurements). In Bluelink, eddies (vortices) can reach 4000m, but they appear to sheer at depth and join up with other features – this is a serious concern. Reasons for this may include time aliasing from the altimeter 10 day cycle, and the assimilation process, which smeers eddies from spin up.

It is thought that the Global Ocean Observing System is generally able to constrain the Mesoscale variability in the oceans. The performance of Bluelink is skilful for SST, but sea level anomaly skill is still modest and inhomogeneous. That said, the first order limits on performance are technological, as decisions on model set up, resolution and assimilation process are constrained by computational cost. However, Bluelink is comparable to the world's best practice in the Australian region.

The links between operational oceanography and IMOS were then discussed. Ultimately, all observations with a known error and bias can contribute to ocean forecasting. However impact of observations is space/time limited for Mesoscale applications (i.e. eddy tracking).

Observational needs from IMOS include:

1. Subsurface Temperature and Salinity – particularly eddy cores, fronts, mixed layer depth, thermoclines, shallow seas and shelves.
2. Ocean currents - surface, subsurface, straits, shelves
3. Air Sea Fluxes

Maintaining the highest quality global bathymetry dataset is also essential.

For data to be available for forecasts and hindcasts, realtime reporting, delivery needs to be operational/robust, and data needs to be in a conventional self describing format. Data also needs to have a known error associated with it, and automatic quality control.

In terms of the impact of data streams for analysis and forecast, bar sea surface temperature, all variables are at least under observed including sea surface height (SSH), subsurface temperature and salinity and ocean currents. Sea Surface Salinity, is particularly poor. For SSH, wide swath constellation altimetry will make a big impact.

Ultimately, IMOS and Bluelink have a mandate to understand the oceans around Australia, and closer links between the two activities need to be established. This can be built into the plans for Bluelink 3

It was highlighted that there are three ways in which IMOS and Bluelink can interact

1. Using IMOS data for model validation
2. Contribution of IMOS data to assimilation.
3. Using Bluelink to help design IMOS observing systems (Observing system simulation experiments).

Harry Hendon – Seasonal Forecasting

Outlined the key issues for seasonal forecasting in terms of processes which drive Australian rainfall, and key regions where observation are needed to be able to predict rainfall patterns.

Processes such as the Indian Ocean Dipole and the El Nino-Southern Oscillation (ENSO) were discussed in terms of their relationship with the waters around Australia, and the predictability of SST and ocean heat content. Of note, was that summer rainfall in southeast Australia was linked to La Nina and a negative Indian Ocean Dipole. However, winter rainfall in the same region was linked to the SST of northern Australian waters, not the IOD or ENSO.

However, little is known about the mechanism by which SST anomalies develop in Northern Australian waters, and the resultant changes in surface fluxes as there are few observations in the region). It was acknowledged that the planned mooring array on the northwest shelf (see boundary currents section), flux moorings and drifter observations in the Indonesian Seas, discussed as part of the Northern Australian observing system (in response to the new mandate to extend IIMOS into Northern Australian waters) would be extremely helpful in this regard.

Currently the predictability for SST in Predictive Ocean Atmosphere Model for Australia (POAMA) shows skill even out to 9 months in the Equatorial Pacific, but by 3 months there is no skill in predicting the SST northwest of Australia. There is better skill in Heat content, mostly due to teleconnection from Pacific due to tight coupling with thermocline this is different in the Indian ocean, as the deep thermocline means that variations in thermocline depth have little effect on SST.

The relationship between the Madden-Julienne Oscillation (MJO), Monsoons and Cyclone activity off Northwest Australia was also briefly discussed. The MJO is a prominent mode of variability in Australian summer monsoon and modulates TC activity to the north west and north east of Australia. The need for more observations of the diurnal cycle of surface temperature and fluxes was highlighted. A further reinforcement of the discussed observing plans for Northern Australia, especially the potential new drifter facility.

Tony Worby – Cryosphere observations.

The existing observations in the Southern Ocean, along with the international planning activities were summarised. Existing observations include repeat hydrography lines, underway measurements from research vessels, Argo floats, and the Southern Ocean timeseries. On an international scale, the Southern Ocean Observing System (SOOS) planning process and the new International Geosphere Biosphere Program (IGBP) Integrated Analyses of Circumpolar Climate Interactions and Ecosystem Dynamics in the Southern Ocean program (ICED) have put effort into identifying gaps and providing strong justification for observations in the Southern Ocean and marine cryosphere.

The Southern Ocean is experiencing many changes in relation to climate change. These include sea ice coverage, ice shelf collapses, and ice mass changes, as well as freshening of the deep southern ocean. The current Bluewater and Climate Science and Implementation plan identifies the extended Australian shelf domain, including the Antarctic shelf and the importance of the cryosphere, yet there are very few observations in the region. Key questions in this domain focus on the ice ocean processes and circulation under ice shelves. Argo floats with ice capability and the seals with CTD tags will contribute significantly in this area. In an existing project on the Amery Ice shelf, observations involve drilling holes in shelf and deploying instruments. Fast ice and pack ice observing systems were also accounted for. Sea ice drift can be monitored using GPS buoys, with a meteorological sensor pack also included.

The Southern Ocean sentinel program has been set up, sponsored by the Department of Environment Water Heritage and the Arts (DEWHA), the World Wildlife Fund (WWF), and the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) to provide information on the impacts of climate change in the Southern Ocean. Methods are being developed to identify indicator species which can be monitored as early indicators of ecosystem changes. It is hoped that an active long term field program, focussing on these indicators

There are three key questions for which IMOS may be able to support observing programs;

1. What is the long-term signal of biomass in key productive areas in the Southern Indian Ocean?
2. What are the seasonal dynamics of biota in Antarctica and Kerguelen Plateau?
3. Are the locations of centres of foraging activity of marine mammals and birds stable in the long term?

For the 2nd priority, repeat acoustic transects and underway sampling along 40, 60 and 80E, coordinated internationally, from 45S to the continent are recommended, combined with moored arrays on and off the shelf. For the 3rd priority, Repeated monitoring through tagging is recommended, targeting predators with different behaviours.

Phytoplankton observations were highlighted as a priority. They form the base of the marine food web and are sensitive indicators of environmental changes such as Ocean circulation and sea ice / melt water extent.

1. How do the productivity, species composition and size spectrum of SO phytoplankton communities related to oceanography, seasonality and climate change?
2. Can we identify and parameterise typical phytoplankton communities in relation to seasonality and oceanography as a basis for modelling?

An expansion of the Ships of Opportunity Program (SOOP) Continuous Plankton Recorder (CPR) network is advocated.

Existing capabilities within the Australian Antarctic Division (AAD) programs were also highlighted as potential in kind support. These included airborne imaging platforms on boat a helicopter and fixed wing aircraft, for mapping skin surface temperature, elevation (using Lidar), snow thickness (using radar), and taking areal photos. Potential partners at state level have been identified for coastal applications

An enhancement of the AUV capability is also advocated, to understand bottom topography, grounding line of ice shelves, under ice sea life. In particular, a larger AUV for more remote locations was recommended (ie. 100km range, 3000 depth with under ice capabilities).

From a data management point of view, the capabilities of the Australian Antarctic Data Centre were highlighted; AADC hosts, or contributes to, international observation databases that can be “harvested” into the purview of IMOS for integration purposes. The AAD would partner with eMII to develop additional capability focussed on biological data.

IMOS was seen has a significant opportunity to enhance Australia’s observational capability in the Southern Ocean and marine cryosphere consistent with IMOS strategic plan and national priorities. A strategic national approach needs to be developed to for physical, biological and Biogeochemical monitoring in the Southern Ocean and marine cryosphere in line with international priorities (SOOS, ICED). Many observation programs highlighted are cost effective and involve readily deployable systems that will provide sustained observations

It was also suggested that co-investment from AAD and ACE CRC partners would be considerable and international partners and data users clearly identifiable. However discussion was clearly needed around an appropriate management structure for Southern Ocean observations within IMOS.

DISCUSSION SESSON

Enhancing Biology

During the round-up discussion at the end of the day, the emerging biological priorities were discussed. There was a concern that there was a focus in the presentations that the surface productivity was a proxy for subsurface. Sea surface chlorophyll doesn't seem to be a good predictor of abundance/aggregations of tagged pelagic animals however; it is useful for other things, especially on the shelf.

Some opportunities were highlighted for sub surface observations, such as using acoustics to observe deep scattering layers from fishing boats as ships of opportunity. However, it is not clear what IMOS can contribute bar information infrastructure as the instrument infrastructure is already in place. Ecological models of ecosystem dynamics need mid trophic levels in same place and time as phytoplankton and top predators, so there is a need for biologists to come together to set priorities and integrated plans.

The IMOS wiki forum was advocated as a way for groups to come together to discuss priorities. For instance, there is a forum on national coastal time series to determine priorities at coastal sites. Sediment traps are being advocated, although there Issues with depth of NRS sites. This would mean that a temporal picture of phytoplankton could be developed, and related to physical observations at the same site.

Concern was expressed regarding the ability to gather sustained high quality biological data, as there is a large signal to noise ratio in data that is returned in acoustic data for example. It was questioned whether the Quality control of acoustic data could be automated. However, the physics community still spend a lot of money and time on quality control. While this is automated for real time data release, for delayed mode, staff are needed to ensure climate record quality. In addition, it was strongly recommended that groups planning work should talk directly with the technical teams to ensure that they have the capability to undertake the work.

The challenges of designing biological observing systems were highlighted, where the sheer numbers of parameters prohibit sustained observations of everything, everywhere. Hence, a choice needs to be made between focussing on a few places with a broader suite of measurements, or more platforms with a smaller suite of observations. Some felt that a strategic approach would be to monitor top predators to identify feeding grounds (i.e. areas of high productivity), and then develop an observing plan for other trophic levels, while others were strongly in favour of focussing on smaller regions and measuring them well.

The capability to provide sustained observations of aspects of the pelagic ecosystem was also questioned. Biomass data is useful for contribution to modes, and can be measured relatively easy using acoustics – but species cannot be characterised routinely at this stage. It may be more effective to focus resources on quantifying phytoplankton and zooplankton, where there is established capability, and also top predators, which are easy to monitor. In terms of plankton, the CPR team can envision routes all around Australia. Flow cameras would also be a useful tool.

It was suggested that the most cost efficient pathway to a biological time series is through sediment cores, coral records, then using sediment traps calibrate the cores. Modern observations are needed to calibrate the proxy/historical observations. Therefore IMOS could focus on parameters which are valuable for reducing uncertainty in proxies. For instance, there is a close relationship between phytoplankton abundance and species assemblages and SST. However, some felt that it was more effective to use variability in modern time to understand the response the system to variations as proxies rare, and big uncertainties are usually involved.

A workshop on ocean biology observatories is being held prior to OceanObs09, in Italy "..to bring together biologists, the observing community, and the technology community to develop ocean biology observatories that could address the challenges of observing ocean life and its response to global change." The outcomes of this meeting could be extremely valuable IMOS in setting priorities for pelagic biological observations.

ACTION: Review Oceanobs whitepapers and conference outcomes to determine international priorities (Ken Ridgway (CMAR) Susan Wijffels (CMAR) Bronte Tilbrooke (CMAR) Rob Harcourt (Macquarie University) Gary Brassington (BOM) Tony Worby (AAD/ACE-CRC) in consultation with node members)

Integration with regional nodes.

Opportunities to integrate with the regional nodes were also discussed. Lidar observations were discussed at the NSWIMOS node meeting. A proposal is being led by Ian Turner. Wave measurements, shelf sediment traps at National Reference stations, and enhanced glider and mooring lines have also been discussed as part of the NSWIMOS plans.

When designing boundary current observing systems, there is a clear need to integrate with coastal observations – especially coastal moorings and radar systems There is also an opportunity to utilise existing platforms to drive down costs.

A focussed intense monitoring activity was suggested, by forming a transect across Brisbane the shelf to the deep water. To get the cross shelf processes and ecosystem linkages. Brisbane was a suggested location, as it is where the EAC is best behaved, is identified as a biogeographic boundary, and is an important region for Tuna fisheries.

Bluewater and regional node plans cannot be separated when discussing Boundary currents. The approach needs to be integrated in the science and implementation plans. Currently, the science and implementation plans are quite uneven in their content.

ACTION: work with regional nodes to develop a coherent integrated plan for observing boundary currents (Ken Ridgway)

Linking across disciplines

Opportunities to link across disciplines on one platform were highlighted. Current examples include the National Reference Stations and the SOOP platforms on *RSV l'Astrolabe*. Environments need to be identified for multidisciplinary studies, to improve understanding of surface/subsurface productivity relationships, and time lags between changes in the system, i.e. the time lag for higher trophic levels to respond to physical conditions. Specific sites representing different environments/systems can could be identified to look at links between physics, chemistry and biology.

However, the key questions that the country needs answered i.e. are not covering all disciplines at once. Bar key climate variables, it was questioned whether the Bluewater node effectively cover ecosystem observations and climate observations. There is also a clear directive to build on existing facilities, as IMOS is not starting from scratch. Monitoring key climate variables will remain core business for the

Bluewater and Climate Node. Big unknowns in IPCC assessments remain. These include sea ice zone dynamics and feedbacks, and the biological responses to changes in ice cover.

Sustaining observations

Sustaining observations into the long term will be a key challenge for IMOS. It is important that existing strengths and plans are built upon.

Satellite Remote sensing was an area where it is considered that a lot of impact could be made for a small investment; as the data is provided for free. Investment is needed to process the data, but once code is written for the task, costs are minimal. Calibration with in situ observatons is also needed

ACTION: Identify priorities for Satellite remote sensing data, and where IMOS effort is most effective (IMOS Office)

Way forward

It was suggested that a smaller group, are identified to update the existing Science and Implementation plan. The questions highlighted at the meeting need to be streamlined and prioritised, and focus the climate system monitoring, and integration across biology and physics. The Bluewater and coastal nodes need to agree on the key questions, what observations are needed to address them, and who would use the data. An integrated activity is being developed in the Northern Australian waters, through WAIMOS, Q-IMOS and the Northern Territory. Similar integrated plans will need to be discussed in other regions.

ACTION: Update Science and Implementation plan for the Bluewater and climate Node (Presenters)

The writing group was identified as
Ken Ridgway (CMAR)
Susan Wijffels (CMAR)
Bronte Tilbrooke (CMAR
Rob Harcourt (Macquarie University)
Gary Brassington (BOM)
Tony Worby (AAD/ACE-CRC)
+1 representative from each regional node

ACTION: Develop concise priority list of observations, based scientific priorities set out in node science and implementation plan (Bluwater node members)