BIOPHYSICAL COUPLINGS IN SOUTH AUSTRALIAN SHELF WATERS UNDER CONDITIONS OF SUMMER UPWELLING AND WINTER DOWNWELLING: RESULTS FROM THE SOUTHERN AUSTRALIA INTEGRATED MARINE OBSERVING SYSTEM (SAIMOS)

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ABSTRACT

The Southern Australia Integrated Marine Observing System, or SAIMOS, is one of five nodes operating as part of the Australia-wide Integrated Marine Observing System (IMOS). This collaborative program is designed to observe Australia's oceans, both coastal and blue-water. Since February 2008 Physical Data has been collected for SAIMOS in both summer and winter months during 8 surveys. The data collected during summer are used to characterise the nature and dynamics of the Kangaroo Island-Eyre Peninsula upwelling system during a record upwelling event in February 2008. During this event a plume of very cool water was observed along the bottom from South of Kangaroo Island up to the Eyre Peninsula. This plume dissipated rapidly after the end of upwelling favourable winds and by March 2008 had disappeared entirely from the observations. The data are also used to study the dense high salinity outflow from Spencer Gulf observed during the winter months, and resulting from surface cooling of high salinity waters at the head of Spencer Gulf. The outflow occurs during a series of strong pulses with a period of approximately 2 weeks and duration of 1-3 days, with bottom velocities at 100 m exceeding 1 m s-1. The abundance and composition of viral, bacterial and pico- and nanoplankton communities have concurrently been investigated. In summer, the space-time dynamic of viral, bacterial and pico- and nanoplankton communities is generally driven by the plume of upwelled, cool and nutrient rich water that flows across the continental shelf, and is locally heavily influenced by the level of vertical stability of the water column. In winter, the structure of the plankton community is related to the local physical properties of the water column, i.e. dense plume of bottom waters outflowing from the Spencer Gulf, vertical stability of the water column and presence of a deep chlorophyll maximum.

1. REGIONAL SCIENCE OVERVIEW

1.1. Physical Oceanography

Along Australia's vast southern shelf, eastward propagating storms drive intense Coastal Trapped Waves (CTWs; ocean weather) that are further intensified by waves generated off Western Australia [1]. These waves can have typical velocities of 25 cm s^{-1} with annual extreme values of up to 50-90 cm s^{-1} [1]. On the shelf, water is advected back and forth along isobaths with periods of 5-20 days, although such waves can be important to cross-shelf exchange. In turn, the waves generated along the southern shelves drive CTWs within Bass Strait and on the NSW shelf [1].

At longer time scales, the west-ward Flinders Current is driven by both a bifurcation of the Tasman Outflow (Fig. 1) and the equator-ward transport of the Southern Ocean. It forms a small sister of the world's major western boundary currents and is sensitive to large scale changes in the Southern Ocean winds as well as changes in the Tasman Outflow, itself regulated by the East Australian Current and winds in the Pacific [1]. Little data exists describing the current, although it appears to be largest (5-20 cm s^{-1}) at depths of 400-600 m, and trapped to the shelf slope. As such it will be enhanced/reduced by shelf slope eddies and may be important to upwelling within the deep canyons along the shelf. In the west, it forms part of the Leeuwin Undercurrent with speeds of 20 cm s^{-1} [1].

More specifically, the Kangaroo Island-Eyre Peninsula region (Fig. 1) hosts one of Australia's iconic and distinct marine upwelling systems [2]. Both data and model indicate that upwelling originates to the south and south-east of Kangaroo Island and quite possibly is directed along the 100 m isobath to the north and north west [1,3].

In conjunction with the west-ward Flinders Current, the submarine du Couedic canyon may be important to the upwelling dynamic in the region. Recent theoretical studies demonstrate that submarine shelf-break canyons support a deep localised upwelling in situations when the ambient slope currents run opposite to coastal Kelvin wave propagation [4,5]. Previous mooring observations indicate that such conditions associated with northwest-ward flow are established during the summer months south of Kangaroo Island [6]. Consequently, canyon-upwelling events are presumably key ingredients in the upwelling dynamics as these events are particularly deep and bring nutrient-rich water from a depth range of ca. 200-400 m onto the shelf and contribute to the formation of the Kangaroo Island pool [5]. In particular, the du Couedic canyon seems to represent a focal point for the inflow of upwelled waters toward the continental shelf.

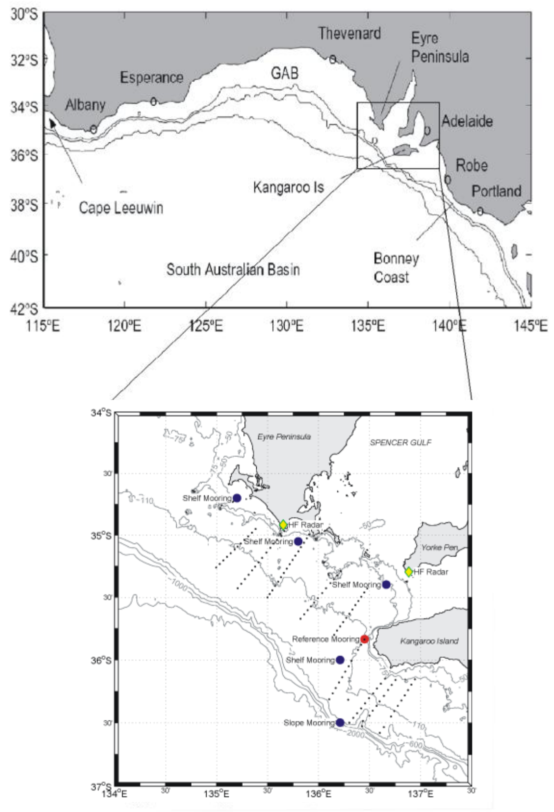

Figure 1. The Kangaroo Island-Eyre Peninsula region and synopsis of SAIMOS implementation plan. The blue dots are the locations of the shelf and slope moorings, the red dot is the reference station (included in the National Reference Station Network), the yellow/green diamonds the locations of the two arrays of HF RADAR antennae (Cape Wiles in Eyre Peninsula and Cape Spencer in York Peninsula) and the black dots are the stations were CTD profiles are taken during the seagoing work (8 cruises per year).

In winter the winds become downwelling favourable, and in association with coastal cooling, water generally becomes well mixed over the shelf down to depths of 200-300 m[1]. However, it is also known that the salty dense waters formed in the Spencer Gulf during summer can cascade as a density current following winter cooling [7]. As a consequence, the du Couedic Canyon also appears to represent a focal point for the outflow of the density current. The mean east-ward shelf currents are typically 20 cm s^{-1} during winter, 2-3 times that found in summer, with the latter flowing from east to west. Analyses of the region suggest that the mean shelf currents, upwelling and the Flinders Current are also subject to significant El Niño influences via West Australian shelf-slope currents.

1.2. Biological Oceanography

The Kangaroo Island-Eyre Peninsula region has traditionally been perceived as a region of limited biological activity due to low nutrient availability. However, recent evidence for the occurrence of coastal upwellings in summer-autumn characterised by low surface water temperatures and elevated concentrations of chlorophyll *a* [2,3] suggest, however, that during this period surface waters may be enriched with nutrients and may promote high levels of primary productivity. These upwelling events are unique as they only occur 2 to 4 times a year over periods of 3 to 10 days [1] and the upwelled waters are transported over large distances (up to 200-400 km over a period of 10 days[1]) through the wide continental shelf which supports one of Australia's largest commercial fisheries and highly diverse ecosystems, including a variety of whale, dolphin, pinniped and shark species.

2. RESEARCH CHALLENGES AND IMPLEMENTATION

The level of productivity of this ecosystem has, however, still barely been investigated and, *de facto*, poorly understood. In this context, the Southern Australia Integrated Marine Observing System combines a network of 6 instrumented moorings and an array of sampling stations (Fig. 1) together with the deployment of an HF radar array and Slocum gliders to understand the space-time dynamics of both summer upwelling and winter downwelling, ocean circulation patterns and the related dynamics of the pelagic ecosystem. In particular, it is critical to assess the lag between an upwelling event and the biological response, as well as the qualitative and quantitative nature of the food webs initiated by the upwelling. There is still much to understand about the productivity of these communities, their potential link with the microbial food web, and the bentho-pelagic and the ocean-atmosphere couplings.

3. SOUTH AUSTRALIAN PHYSICAL AND BIOLOGICAL OCEANOGRAPHY

3.1. Physical Oceanography

Since February 2008 Physical Data has been collected for SAIMOS in both summer and winter months during 8 surveys. The data collected during summer are used to characterise the nature and dynamics of the Kangaroo Island-Eyre Peninsula upwelling system during a record upwelling event in February 2008. During this event a plume of very cool water was observed along the bottom from South of Kangaroo Island to the Eyre Peninsula. This plume dissipated rapidly after the end of upwelling favourable winds and by March 2008 had disappeared entirely from the observations (Fig. 2a, b). The data are also used to study the dense high salinity outflow from Spencer Gulf observed during the winter months (Fig. 2c, d). The dense plume result from surface cooling of high salinity waters at the head of Spencer Gulf. One striking result of these observations is that the outflow occurs during a series of strong pulses with a period of approximately 2 weeks and duration of 1-3 days. During these pulses bottom velocities at 100 m can exceed 1 m s^{-1}.

In brief, from the physical perspective, highlights include:

- the detailed field survey of the extreme upwelling event in February 2008
- the identification of the origin of the summertime upwelled waters to be to the west of de Coudic Canyon, likely the Murray Canyon.
- the identification of sub-mesoscale intrusions of hot salty water on the shelf and of unknown origin (possibly baroclinicity).
- the identification of a 20-30 m deep wintertime Spencer Gulf outflow using glider data and its quasi-periodicity.

3.2. Biological Oceanography

Populations of viruses, bacteria and picophytoplankton were identified and enumerated using flow cytometry. Depending on both sampling date and location, 2 to 4 populations of viruses, 2 to 8 populations of heterotrophic bacteria, and up to 2 populations of *Synechococcus* sp., *Prochlorococus* sp. and 3 populations of eukaryotic cells were identified. Note that among the viral populations we identified both bacteriophages and phytoplankton phages. In summer, the space-time dynamic of viral, bacterial and picophytoplankton communities is generally driven by the plume of upwelled, cool and nutrient rich water that flows across the continental shelf. Their abundance is locally influenced by the level of vertical stability of the water column in both winter and summer. In particular, the abundance of the different populations of picophytoplankton communities identified is positively correlated with the potential energy E_p of the water column until a critical value above which this correlation becomes negative. The critical E_p values are specific to *Synechococcus* sp., *Prochlorococus* sp. and the different populations of eukaryotic cells. This suggests a group-specific optimal stratification level. In winter, the qualitative and quantitative nature of the plankton community is related to the local physical properties of the water column, which include the presence of a dense plume of bottom waters outflowing from the Spencer Gulf, the vertical stability of the water column and the presence of a deep chlorophyll maximum (DCM).

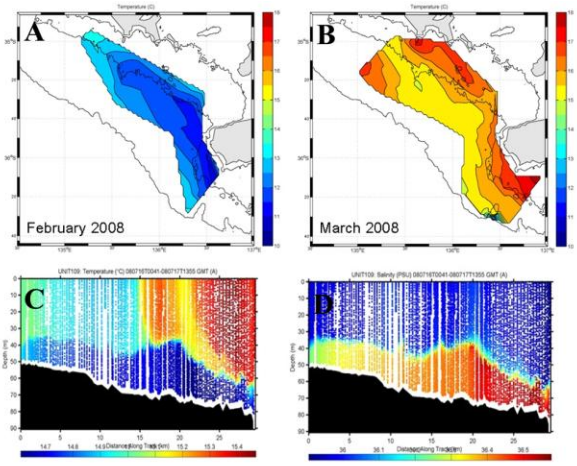

Figure 2. Illustration of the transient nature of the plume of bottom cold water flowing along the continental shelf during the 2008 upwelling event (a) which vanished one month later (b), and the temperature (c) and salinity (d) signatures of the dense and salty bottom water mass flowing out of the Spencer gulf in winter.

In March 2009, the abundance and diversity of phytoplankton communities started to be investigated at the six stations shown in Fig. 1 for sub-surface waters (15 m from the surface), the DCM and bottom waters (10 m from the bottom). Dinoflagellates and diatoms respectively accounted for 70 to 80% and from 20 to 30% of phytoplankton cell abundances. Dinoflagellates are dominated principally by the genera *Gymnodinium sp.*, *Cochlodinium* sp., *Gyrodinium* sp. et *Gonyaulax* sp.. Diatoms are mainly dominated by *Thalassiosira* sp. while *Chaetoceros* sp., *Navicula* sp. and *Pseudonitzschia* sp. are also regularly observed. The maximum abundance has consistently been found at the DCM, and the species diversity, assessed through the Pielou diversity index (R), was similar at the six stations investigated. Specifically, the spatial distribution of the genera *Gymnodinium* sp. and *Thalassiosira* sp. seems to be mainly driven by temperature and salinity.

4. CONCLUSION AND PERSPECTIVES

The strategy of SAIMOS for 2009-2013 builds on the success of the fully interdisciplinary surveys implemented at the scale of South Australian shelf waters from January 2008. More specifically, we want to increase our effort in terms of physical observations through an increase in the number of moorings so as to better monitor the shelf/slope currents and maintain four moorings continuously (instead of two). The biological focus will grow from the identification of the spatial and temporal species of phytoplankton (viruses/bacteria) to include primary and secondary productivity. This will be done in a cost effective manner by loading more instruments on existing moorings.

5. REFERENCES

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