Resolving environmental dynamics in Port Phillip Bay, using high repeat sampling off the Spirit of Tasmania 1

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Abstract
A partnership involving a state environmental agency, a shipping line, several universities and federal infrastructure grants has developed sustained environmental observations of Port Phillip Bay and Bass Strait, in Southern Australia. The Spirit of Tasmania 1 traverses daily across Bass Strait between Devonport and Port Melbourne. EPA Victoria have instrumented the vessel with autonomous water quality sensors since 2008, and contributed the data to the Ships of Opportunity facility within the national Integrated Marine Observing System. The information has provided a high resolution window into the dynamics of Bass Strait and the adjoining Port Phillip Bay and Mersey Estuary. The data has been used to inform environmental managers and port authorities, aid fisheries research, integrate with numerical models, and investigate climate change studies. The data has highlighted Port Phillip Bay as a significantly climate modified marine system where reduced coastal discharges and higher evaporation caused elevated salinities 1.5psu higher than the adjoining ocean. This modified bay-ocean exchange processes and constrained dispersion of coastal discharges. Recently the prevailing 1998-2009 drought was broken by persistent rains that finally overturned the bay to its fresher state by the end of 2010, culminating in extensive plankton blooms. As well as catchment influences the data has picked up seasonal and weather-band intrusions from Bass Strait that can also influence biological responses in the bay. As data application is broadening, real-time delivery to the public is now being considered through the Australian Ocean Data Network web portal.

Keywords: Ships of Opportunity, climate change, blooms.

1. Introduction

In the past decade, there has been an increasing number of automated instrument packages installed on merchant vessels to frequently monitor marine conditions along repeated shiptracks. Such sampling platforms are often termed Ships Of OPportunity (SOOPs) are able to generate vast quantities of high resolution spatial data for a broad range of end users. International examples such as the FerryBox network in Europe [6] and BC Ferries Network in Western Canada [10] have proven this is a cost effective means of obtaining reliable and accurate time series measurements in relatively hostile marine environments. With recent focus on resolving climate change at both national and state levels, many monitoring programs have been challenged to deliver spatial and temporal datasets of robust indicators that are capable of resolving expected changes, whilst still able to track any management based impacts. Unattended systems on moorings and SOOPs provide the high density information that is considered essential to monitor long-term changes in the environment, and are an invaluable feed to calibrate the detailed spatial information generated by satellite imagery and modelling. This paper demonstrates the development of a SOOP in Australian coastal waters and a range of its marine applications.

2. Background

EPA Victoria has successfully operated (attended) underway marine monitoring systems on their own vessel since 1996 to map environmental condition of the Gippsland Lakes. This program has provided invaluable information to assess and predict algal blooms in that region. From this success expansion of the technique was recommended (in an external review of EPA monitoring programs) as a cost effective means of defining marine ecosystem processes in many of the unmonitored regions of the state. As part of a science investment program in 2007 EPA Victoria developed an unattended (or autonomous) sampling system for deployment on a SOOP to provide routine monitoring of Victorian marine ecosystems. As shown in Figure 1, the system resolves robust indicators (such as salinity, temperature, turbidity and plankton) and has the capacity to incorporate additional sampling instrumentation when required. After successful system trials as part of the Two Bays community engagement program [2], a variety of SOOPs operating in Victorian waters were assessed for suitability. Initially considered were the regular ferry services on the Sorrento-Queenscliff, Williamstown-Southbank and Stony Point-Cowes routes. The extensive route, reliability and frequency of Spirit of Tasmania ferries was considered an optimal choice. Regardless of weather, these vessels have coursed daily through Port Phillip Bay and Victorian coastal waters, as shown in Figure 2. A series of visits to the vessel (Spirit of Tasmania 1) and discussions with the operators (TT Line) realised the feasibility of an installation, and formulated an ongoing cooperation with TT Line technicians to ensure operations would adhere to maritime safety standards. In selection of this route, broader collaborations to support the project were possible. A collaboration was formed with the CSIRO, the Department of Primary Industry's Fisheries Research Branch, the University of Melbourne and TT Line (the operators of the 'Spirit of Tasmania I'), to support the installation and ongoing operation of the autonomous sampling system on the 'Spirit of Tasmania I'. These collaborators were attracted to this project as it provided a unique ability to regularly measure water quality at appropriate dynamic scales in the Port Phillip Bay and Bass Strait (Figure 2), where typically sampling is constrained by poor weather for both on water and airborne/satellite measurement options.

An initial pilot phase during February to July 2008 provided opportunity for system enhancement and testing, formulation of quality procedures and data processing routines, and the development of data products. The observing platform became operational in September 2008 and has since provided an unbroken record, except when the vessel is taken offline for a 3 week refit every 12-18 months.

3. Methods

The configuration of the marine monitoring system was modelled on a simple robust design used by the University of British Columbia's Earth and Ocean Science Department on BC Ferries networks between 2002 and 2006. It is a compact sensor pack (400mmx 150mm x 200mm) that can be mounted horizontally or vertically in a location convenient to the vessel operator.

The sampling system was installed in the pump room on the Spirit of Tasmania 1 (Figure 1) close to the Seachest water intake (to minimise thermal heating from ship). The antenna-mounted GPS on the vessel roof supplies a digital signal via a shielded cable through the lift shaft to the system some twelve floors below in the pump room. The in-line system samples at 1Hz with a Seabird SBE45 thermo-salinograph (TSG), a Wetlabs combination fluorometer turbidity sensor (FLNTU), and a GPS stream from a 12 parallel channel Leica GPS Smart Antenna. Digital output from all the instruments are ported to an industrial fanless computer that can be set-up alongside the sensor packs in the engine room. Incoming digital data from each sensor input are managed via Labview software, and stamped by the PC clock to facilitate melding of data files.

With each daily crossing, the Spirit of Tasmania 1 samples surface waters (0-6m deep) in Port Phillip Bay shipping channel, Bass Strait and Mersey Estuary. The marine monitoring system records ten second averages of salinity, temperature, chlorophyll-a fluoresence, turbidity, and position. Travelling at ~20 knots this corresponds to sample "grabs" at every 100m along the ship track. Such high repeat sampling provides an unprecedented capability to monitor ecosystem dynamics in Port Phillip Bay.

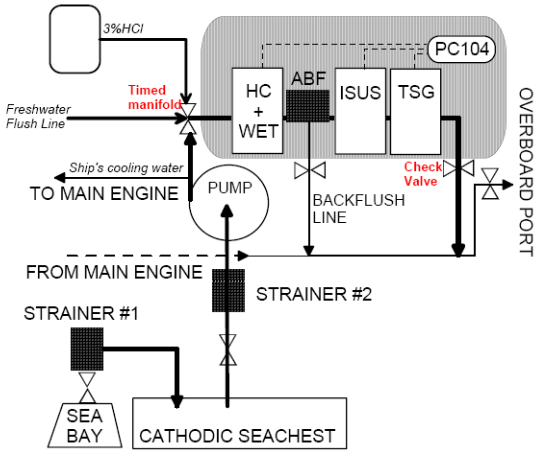

Figure 1: Set-up of the autonomous sampling system which utilises the ship's cooling water via onboard pumps (at 25-30psi) and coarse strainer. Sensors (WET-wetlabs fluorometer and turbidity sensor; TSG-themosalinograph) are arranged in-line to minimise sampling delay. Other sensors shown ISUS – a UV nitrate sensor and ABF –automatic backflushing filter, are not currently on the vessel. Twice daily freshwater flushes controlled by a timed manifold, occur while vessel is in port to assist with sensor cleaning.

To sustain the intensive data processing requirements, this project was incorporated into the national Ships of Opportunity facility within the Integrated Marine Observing System (IMOS) [7]. IMOS is a national marine monitoring framework focussed on addressing critical marine issues facing Australia, including climate change and sustainability of ecosystems.

Data for all IMOS observations is warehoused at the eMarine Information Infrastructure (eMII) facillity housed at the University of Tasmania and is freely available [3] to support other researchers and end-users. EPA and eMII have developed standardised protocols for SOOP sampling platforms to ensure all data is quality controlled and assured prior to release. These co-developments have flowed on to benefit a range of internal EPA clients. Validated data is released by EPA to the IMOS data warehouse on a 3-6 monthly basis. The data collected from the Spirit of Tasmania 1 is identified as IMOS_SOOP-TMV within the eMII database. The data is packaged as daily transect and portside files and available through the OpenDap server. [8]
The data information or "Metadata" is also provided within the fabric of each data file and within a metadata catalogue. Plots of the daily transects and shiptracks are also available as graphics files through an eMII web interface [4].

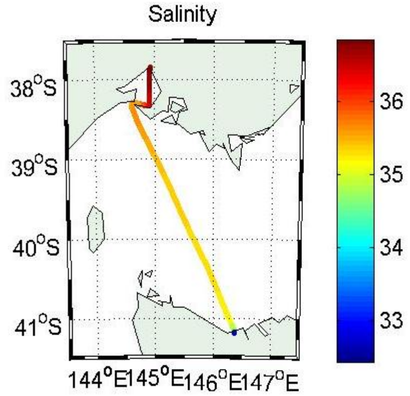

Figure 2: 13-Oct-2008 mapped salinity along the shiptrack through Port Phillip Bay and Bass Strait, in Southern Australia. An example of daily output graphics available to the public from the eMII web interface.

4. Results

The contoured sensor data is typically presented in the following section as shiptrack distance in Port Phillip Bay and Bass Strait against date. For example a six month plot represents data from ~180 Bass Strait crossings, with 10 second records representing a 100m average that accumulates to over 4400 "samples" per crossing. Apart from tidal patterns at PPB heads most weather-band and seasonal dynamics are well resolved in the dataset. The tidal information is also resolved over time as ship tracks are out of phase with the tide, so an eventual picture of tidal excursion and the spring-neap phases can be formed.

4.1 Climate and drought effects

From the beginning of sampling through to late 2010, hypersaline conditions were observed throughout PPB, as a result of prevailing drought conditions in the region. Figure 3 indicate during this period bay salinities exceeded the ocean by up to 1.5psu. This had ramifications for bay dispersion and ocean exchange [9].

4.2 Flood events and plankton blooms

The IMOS_SOOP_TMV data detects a strong low salinity signature and initial high turbidity "pulse" at the onset of a flood event in PPB (predominantly from the Yarra River). The low salinity signature prevails and extends through the bay taking several weeks to dissipate, while turbidity return to background levels in 2-3 days after the initial flood. Plankton responses are typically seen in tandem with the southward dispersion of floodwaters, similarly prevailing for several weeks. Figure 4 shows the breaking of the drought in PPB as defined in late 2010 with an overturing of bay salinity (to fresher than ocean conditions) and subsequent prolonged plankton activity.

4.3 Dredging Activity and recovery

When the prevailing turbidity signature is devoid of any coincident low salinity signature (from the Yarra River entering at the north of the bay) it indicates that dredging activity is a likely source in the north of PPB. Comparison of salinity and turbidity data during low flow periods suggest broader duration (4-5 day) elevated turbidity (5-15 NTU) could indicate dredge activity affecting some 10-15km of shiptrack in the upper bay. In contrast when accompanied with a fresh salinity signature the turbidity footprint is more confined 5-8km but often at more elevated turbidity (20-30NTU).

Dredging operations in the South Channel are not confused by any significant catchment discharge points. The observed high peaks of up to 40NTU seen in the data are well above background levels that can elevate to ~5NTU during significant storm events. For a period in October 2008, when dredging in the south channel had ceased, daily tracks were logged to measure the dredge plume footprint size (length of shiptrack above background bay turbidity) and the peak turbidity level (NTU) within this footprint.

While dredging levels of up to 40NTU occurred over a 5km track. Two days after dredging ceased this footprint quickly dispersed to 20NTU (peak) over a 10km track and by four days was at background levels associated with natural variability. Figure 5 plots this period indicating the efficiency of the dredge plume dispersal once dredge operations have ceased.

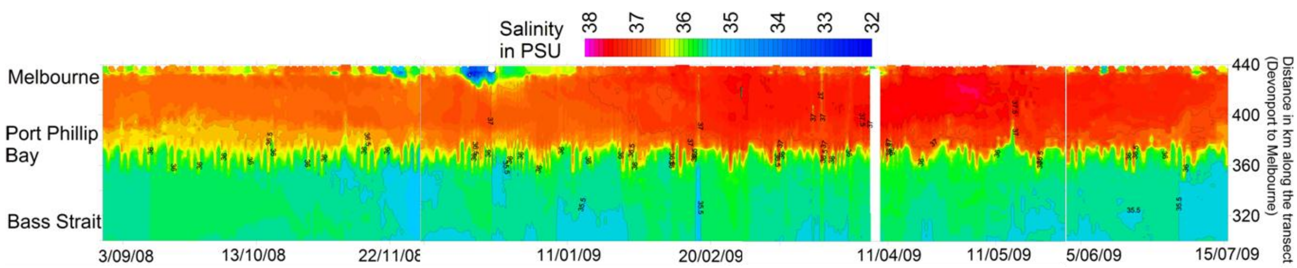

Figure 3: A prevailing hypersaline condition in PPB compared with the adjoining Bass Strait waters. While there is some seasonal variation, a strong gradient is maintained at the entrance to PPB.

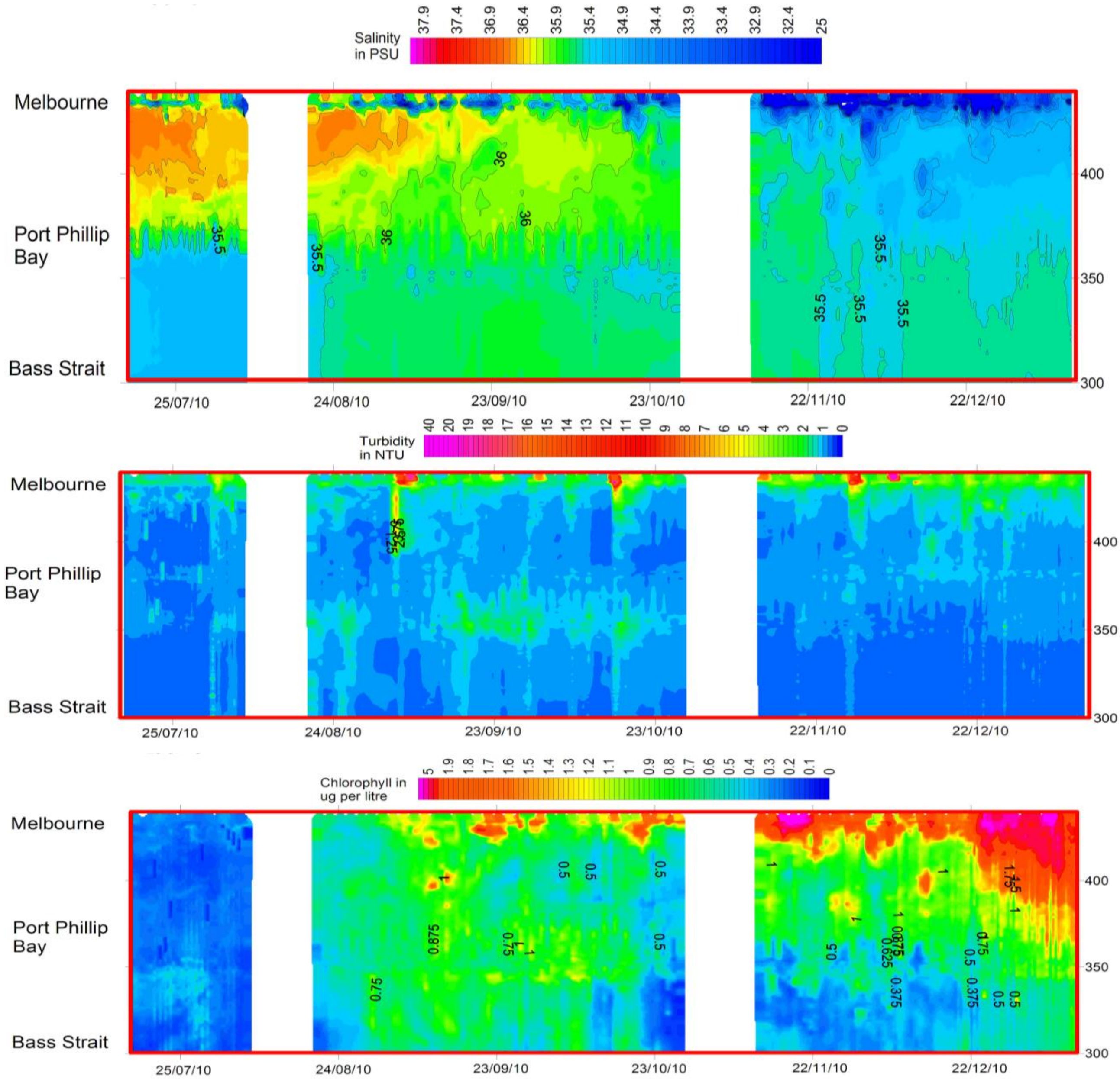

Figure 4: Break of drought conditions in PPB with overturning of bay salinity and coincident plankton bloom extension through the bay.

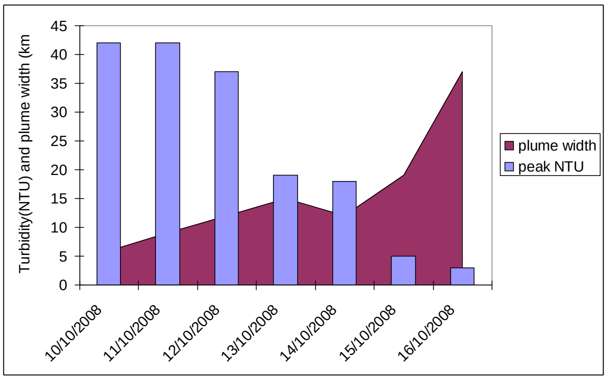

Figure 5: Dredge plume footprint size (length of shiptrack above background bay turbidity) and the peak turbidity level (NTU) within this footprint, show recovery (to background) for a period in October 2008 when dredging activity had ceased.

4.4 Improving Data interpolation

Since 1984 the monthly monitoring program has been undertaken with six sites in the bay. A baywide sampling program for the Channel Deepening Project (CDP) augmented the routine sites with an additional five. The salinity data from all 11 sites [5] is interpolated as mapped contours with and without IMOS_SOOP_TMV data in the winter example in Figure 6. Clearly there is an improved product that defines regional patterns within the bay when both data sets have been integrated, the ship data has highlighted the importance of gradients associated with entrance exchange processes. Some of the regional patterns defined by this integrated dataset may differ from the traditional spatial segments defined in State Environment Protection Policies as the bay function shifts with our changing climate.

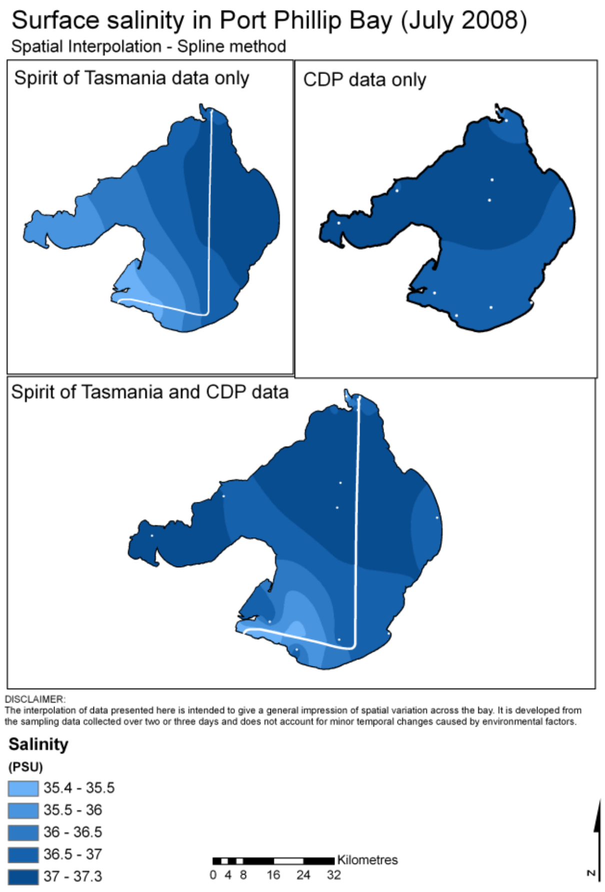

Figure 6: Salinity data from 11 monthly sites (CDP data) are interpolated to indicate spatial distributions across Port Phillip Bay. The addition of IMOS_SOOP_TMV data to this interpolation significantly improves the interpretation of regional patterns. *(CDP data source [5])*

4.5 Model Assimilation

Numerical models can be corrected (for drift) using the daily IMOS_SOOP_TMV data, in a similar fashion to how daily Sea Surface Temperature (SST) data from satellite images has been used in the Port Phillip Bay hydrodynamic model [9] for "corrective steering", otherwise known as "nudging". As it has been shown, salinities across the bay are also variable and a result scales are not represented in the model's heat equations. Assimilating daily IMOS_SOOP_TMV salinity and temperature data will be able to nudge the model toward convergence and thereby provide a more representative evaporative flux from the bay.

4.6 Satellite Image ground-truthing

Typically in-situ data is collected from routine sampling stations to build up a relationship between satellite and ground sampling. This can take a significant amount of sampling before a reliable "local" algorithm can be developed. Alternatively SOOPs provide a good opportunity to relate many in-situ data points to satellite image pixels at a regional scale. SOOP data from the Ferrybox system in Europe has been applied to ground-truth MERIS satellite data [12]. IMOS_SOOP-TMV shiptrack turbidity data is shown (Figure 7) overlaid on satellite images. It indicates sensitivity to turbid signals associated with dredging campaigns in the north of the bay (11 September 2008) and the south channel (11 October 2008). Through GIS cross-analysis the satellite pixel values can be adjusted to match the measured values from the SOOP_TMV. This calibration then enables imagery to be utilised quantitatively, combining footprint size with concentration to provide a measure of a load discharged and it's dispersal and recovery (with subsequent imagery) in the receiving marine environment.

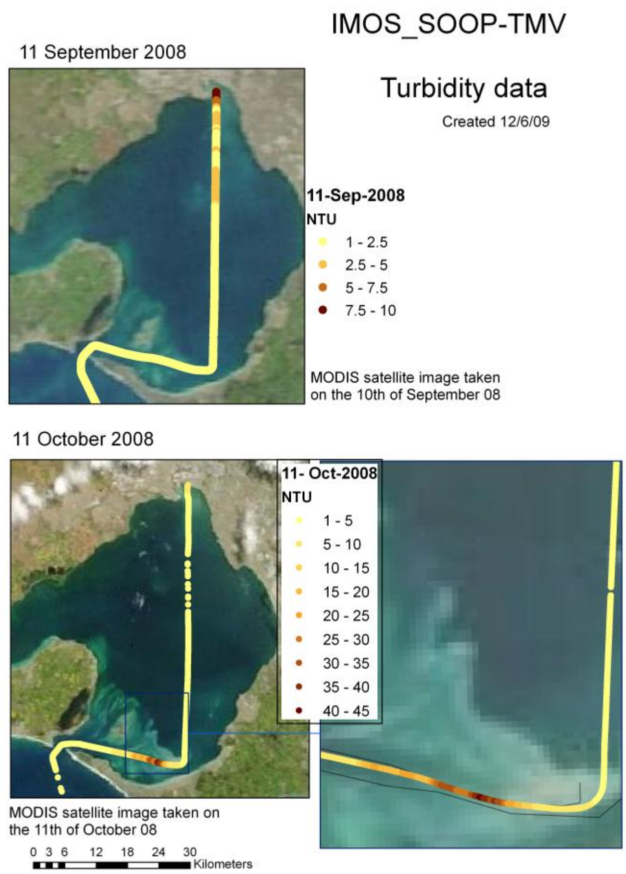

Figure 7: IMOS_SOOP-TMV shiptrack overlaid on MERIS satellite images on 11 September 2008 and 11 October 2008 relate to respective dredging operations in the north of the bay and the South Channel.

5. Discussion

The development and operations of, and data from the autonomous sampling system on the Spirit of Tasmania 1 have been incorporated into stakeholder programs.

The dataset has provided a reliable measure of background salinity (and its seasonal variations) in Bass Strait that have supported assessment of open coast developments in the region. Project based investigations using dedicated moorings are typically constrained by weather, cost and scope to deliver long term measure of Bass Strait conditions.

A complete overhaul of an aging underway sampling system used on Gippsland Lakes was possible with learnings from the proven system on the Spirit of Tasmania 1. The system was updated with improved sensor technology, reduced sample delays, increased spatial and temporal resolution, standardized post-processing and data packaging routines.

The data is being applied to a number of research studies including Snapper larval behaviour and seagrass resilience, while also value-adding to monitoring efforts on bay water quality and related impact assessments.

As data application is broadening, there is interest in delivering this information stream real-time to the public through a web portal operated by the Australian Ocean Data Network (AODN). Currently the AODN provides this real-time service for data streams from CSIRO research vessels [11], through their oceans data portal[1]. As well as advantages for public engagement, real-time delivery will provide an improved watch on operational status (minimising data loss) and an all-weather account of environmental condition.

6. Acknowledgements

While the EPA Victoria continues to manage the autonomous system and the quality of its data stream, the ongoing operations are sustained through stakeholder engagement. Currently support for regular maintenance is provided through Melbourne University related research, courtesy of Mick Keough, Greg Jenkins and Stephen Swearer. Routine calibration samples are analysied by partners at the Department of Primary Industry's Fisheries research Branch Laboratories, courtesy of Andy Longmore. In Tasmania, routine data processing and packaging is undertaken by the IMOS eMII group (led by Roger Proctor), and CSIRO Marine laboratories provide sensor calibrations. Onboard support of infrastructure (hydraulics and power) to the sampling system is provided by the TT Line engineers and electricians onboard the Spirit of Tasmania 1. TT Line management have provided continued support to the project since its inception.

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