

Overview:

Proposed Infrastructure Investment:	Australian calibration and validation data for international satellite altimetry
IMOS Facility:	Satellite Remote Sensing, (Altimetry sub-facility)
Operating Institution:	University of Tasmania
Facility Leader (for this Proposal):	Dr Christopher Watson School of Geography and Environmental Studies University of Tasmania cwatson@utas.edu.au 03 6226 2489
Other(s) key people involved:	Dr John Church (CSIRO) Dr Neil White (CSIRO)
Collaborating Institutions:	CSIRO Marine and Atmospheric Research

Nature of Investment:

High precision satellite altimeter missions TOPEX/Poseidon (T/P), Jason-1 and now Jason-2 have contributed fundamental advances in our understanding of regional and global ocean circulation and its role in the Earth's climate and regional applications. Changes of the ocean surface height over various time scales can now be routinely mapped on a global and high resolution regional basis - these changes represent the most fundamental processes that essentially control all aspects of the marine environment. Ocean and atmosphere-ocean coupled models must be able to simulate these changes before model results are useful in applications such as routine ocean weather and climate forecasting. The most recent report from the House of Representatives standing committee on climate change (26 Oct 2009), emphasises the importance of data that can be used to estimate quantities such as sea level rise projections, extreme sea level events and regional variations in sea level rise, and specifically make the recommendation of increased investment from the Australian Government across these areas (Commonwealth of Australia, 2009). Satellite altimetry is undoubtedly the data stream of choice that is required for these activities.

The calibration and validation of the altimeter sensor ensemble is of paramount importance to both the Australian and the broad international user community accessing altimetry data and its derived data streams. Failure to achieve a reliable and robust calibration/validation sees the introduction of spurious offsets in sea level between different satellite missions, and an inability to distinguish between instrumental drifts/errors and real geophysical changes in ocean sea level. Calibration is therefore considered an integral part of international satellite missions, and will remain as such for the forthcoming launch of Jason-3 and subsequent missions into the future.

Australia has a large reliance on satellite altimeter data (evidenced for example in the success of projects such as BlueLink), yet is not a formal mission partner on any of the international altimetry missions. Despite any formal financial contribution at the mission level, Australian researchers have maintained access to altimetry data through continuous association with the NASA/CNES Science Working Team (SWT) and later the NASA/CNES/NOAA/EUMETSAT Ocean Surface Topography Science Team (OSTST) and specifically, through the provision of the sole absolute calibration/validation site in the Southern Hemisphere (Bass Strait). This site has been running with ad-hoc resources since the launch of TOPEX/Poseidon in 1992 (White et al., 1994, Watson et al., 2003; 2004, Watson, 2005, Haines, Bonnefond and Watson, 2009). The site is formally recognised by the NASA/CNES/NOAA/EUMETSAT mission structure as one of three key primary calibration

sites, and is viewed internationally as making a highly valuable contribution with its data contributing to the calibration constants recommended for the production of routine geophysical data. The science case for calibration was made and supported by IMOS in a previous proposal by CIs Coleman, Watson, White and Church. This previous proposal sought a small level of support for a contribution to mooring instrumentation (~\$40K). *The IMOS Blue-Water node acknowledges the importance of continuing and expanding the IMOS support to this activity, and specifically identifies this calibration task as of vital importance.* Regional IMOS nodes also require calibrated altimetry data at some level (see for example the TasIMOS node lead by Peter Thompson), and are therefore also reliant on the contribution of calibration and validation data to the international mission team.

This proposal seeks to enhance and extend the previous IMOS contribution to further develop an Australian absolute calibration data stream that provides ongoing verification and calibration of satellite altimeter data for confident use by Australian and International users. *The Australian calibration and validation data stream effectively closes the loop between the international provision of raw altimetry data, the Australian contribution of a calibration data stream and subsequent feedback into the main release validated data stream for national and international users.* The provision of these data will also make a significant and visible Australian contribution to these international satellite missions. Without IMOS support, our ability to continue to provide an ongoing calibration data stream, and maintain recognition at the highest level in these international satellite missions is limited and ad hoc. We therefore seek to develop the existing contribution, positioning IMOS as the builder of Australian capacity in an area of vital importance to the Australian and international oceanographic community.

The lack of real support to calibration and validation activities was highlighted recently in the Australian strategic plan for Earth observations from space. *“Dedicated funding and involvement in mission teams and calibration/evaluation activities is generally limited and ad hoc... This is a serious problem that needs to be addressed. By doing so Australia could make a systematic contribution to a range of international public-good satellite missions”.* (AAS, ATSE, 2009)

This proposal to IMOS directly addresses this issue, providing targeted support for a calibration data stream to continue well into the future – this contribution will have a direct flow through benefit to the international community of oceanographic data users. This represents a clear shift in the support of the provision of calibration data, recognising it as a vital Australian contribution at the international level.

This extension of the existing Bass Strait site in order to support a significant and prolonged contribution to the provision of calibration data, and hence the more effective closure of the loop between international data, IMOS data and end users, will involve two complimentary and mutually beneficial data streams:

1. The maintenance and extension of the absolute bias calibration methodology applied at the primary Bass Strait calibration point by incorporating an additional two (2) calibration points situated on the same altimeter pass (Figure 1), but in different wave and meteorological environments. This has important ramifications as it allows for the provision of a more rigorous set of calibration data given orbit errors are likely to be similar on the same satellite pass. This therefore provides an ability to further calibrate well known problematic error sources such as the sea state bias (SSB), identified as a key limitation in satellite altimetry (Bonfond, Haines and Watson, 2009).
2. The provision of a bias drift calibration data stream that is complementary to the Absolute calibration at Bass Strait and will further elevate the Australian contribution to the NASA/CNES altimetry missions with minimal additional cost to IMOS. The drift calibration data are vital barometers for detecting failing sensors within the satellite sensor ensemble (such as the radiometer for example), which cannot typically be detected at the “absolute” style calibration sites. Bias drifts are highly important for the most demanding applications

such as regional sea level change and circulation studies, such as BlueLink. Without such data, spurious drifts will likely bias user data across the broad user community (including the modelling community who also rely on these data).

Part 1 requires the bulk of the resources within this request for funding to IMOS, with the request for hardware, infrastructure and personnel relating to:

- a) Four ocean moorings (bottom pressure sensor, conductivity, temperature, and depth sensors, and current metres) for repeat concurrent six and twelve-month deployments.
- b) Custom GPS buoys for the precise measurement of in-situ sea surface height.
- c) Ship time and travel costs for deployment and retrieval.
- d) Travel costs to attend NASA/CNES/NOAA/EUMETSAT science team meetings annually so as to report the Australian results and ensure their recognition internationally.
- e) 0.8 FTE for a new field/analysis assistant to be based at UTAS to physically undertake the buoy deployments, assist with the production of the data stream and its dissemination. This is capacity that does not currently exist and is vital in order to resource this data stream.
- f) 0.4 FTE for CI Watson's time, 0.3 FTE for CI White and 0.1 FTE for CI Church.

In addition, in-kind support from the IMOS and CMAR mooring equipment pool is required. There are also potentially synergies with the TasIMOS node (Peter Thompson) and mooring provisions for the SW coast of Tasmania.

Part 2 requires the provision of comparatively few IMOS resources with the ability to significantly value add and enhance the value of the overall data stream. This part provides support for the generation of the bias drift calibration data. Bias drift cannot be reliably determined from a time series of absolute bias estimates (i.e. the data stream from part 1, due to the inherent noise in that time series). Bias drift data may only be generated using a far larger network of "relative" rather than "absolute" comparison points. Practically, this can only be achieved using a subset of the global tide gauge network, including those around Australia and the Pacific Ocean, operated by the Australian National Tidal Centre (NTC). While tide gauge data are already freely available, in order to extract the relevant calibration estimates, it is vital to remove the tectonic signal at the tide gauge – for this we require tectonic velocities from GPS data collected at collocated sites with tide gauges. To date in Australia, this is undertaken irregularly and not with the specific purpose of generating an altimetry calibration data stream. CI Watson has the expertise that spans altimetry and space geodesy to complete these analyses routinely (see for example, Tregoning and Watson, 2009, King and Watson, 2009, Watson, Coleman and Handsworth, 2008, Watson et al., 2003; 2004), but is not funded to allocate the time required to undertake this task. An additional 0.3 FTE for CI Watson is requested. This represents a small fraction of the overall request, yet provides a data stream that has the potential to significantly elevate the Australian contribution to calibration and validation. The importance of Australia contributing a bias drift data stream is perhaps best evidenced through the degradation observed within the Jason-1 radiometer – these drifts incurred a spurious global trend in mean sea level approaching 40% of the magnitude of the signal.

Australia did not have the capability to detect this bias drift and it is vital that Australia contribute at the international level in this regard.

The funding requested represents a very modest contribution to elevate Australia's contribution to oceanographic data provision at the international level, closing the loop between international data, national feedback and the provision of an ultimately improved data stream. It is also important to note that this proposal provides one of very few IMOS projects to show a real connection between other NCRIS capabilities. In this case, GPS infrastructure part funded through the AuScope capability (total investment in GPS in the order \$15.8M) must be utilised in the generation of the bias drift calibration data stream that is required for the marine / oceanographic communities. Without the marine community and IMOS taking the lead on this, this valuable application of this data stream will not be exploited.

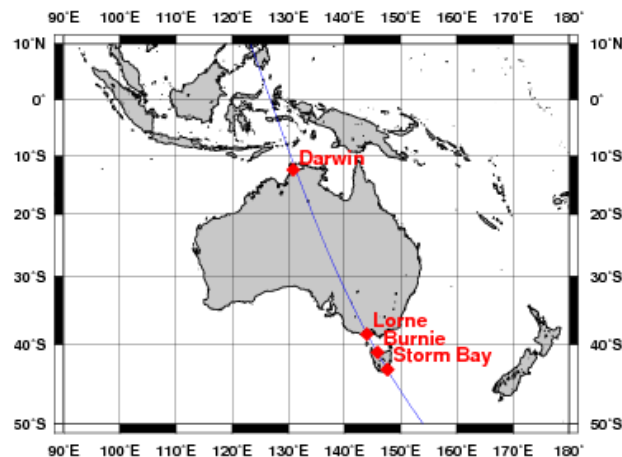


Fig 1: Altimeter Pass 088 and absolute bias sites of interest, Bass Strait (Burnie – the primary site), Storm Bay, Lorne and Darwin.

Implementation Strategy:

Summary and Objectives

The primary objective of this proposal is to enhance and extend the Australian contribution to the calibration of international oceanographic satellite missions through the provision of a multi-faceted calibration data stream. The funding requested from IMOS will provide real capacity in Australia to contribute a valuable data stream to the NASA/CNES/NOAA/EUMETSAT mission structure.

The original design principles of IMOS, including the need for linked global/coastal components and the need for strong international engagements are well reflected in the proposed outcomes. Calibration sites such as Bass Strait are considered a link between ocean/coastal applications, specifically due to their ability to assess the performance of the water vapour radiometers that are often contaminated by the land for coastal applications of altimetry (see for example Bonnefond, Haines and Watson, 2009). This proposal also provides a unique opportunity for IMOS to make a more visible contribution at the international level on these satellite missions.

The large user group of satellite altimeter data both nationally and internationally require a calibrated data product – the IMOS goals are therefore also reflected in this proposal, specifically ‘the provision of sustained ocean observations that meet the broad needs of the Australian marine and climate communities’ and ‘to provide the marine and climate research community with free and timely access to quality assured data’.

This proposal also addresses a number of the 10 strategic IMOS priorities going forward towards 2013.

1. “Impact and delivery through improving model output”: Satellite altimetry data is key to quantifying the success of ocean and ocean-atmosphere coupled models. Model output must be able to replicate the broad spatio-temporal ocean surface height signatures that are observed with high accuracy altimetry. It is therefore vital that Australia understand the performance (i.e. undertake calibration and validation) of the altimetry data stream that is vital to such a broad group of national and international users.
2. “Continuing to build institutional strengths into national capability”: The calibration of altimetry has been a shared strength between the CSIRO/UTAS institutions since the launch of the TOPEX/Poseidon mission in 1992. With the support of the funds requested in this proposal, this strength has the clear potential to be transformed into a real national capability in terms of the ongoing provision of a data stream that is vital at the national and international level.

3. “Driving down the cost per observation”: The value of this proposal is underscored by the magnitude of the satellite altimeter data user base, both nationally and internationally. This proposal represents a modest national contribution to the provision of a calibrated and validated data stream.
4. “Ensuring the data is used”: The data generated from this proposal will be provided directly to the mission teams within NASA/CNES/NOAA/EUMETSAT that directly distribute the calibrated geophysical data products.
5. “Partnering for sustained ocean observation”: This proposal seeks funds to ensure the sustained operation of the Australian calibration data stream, lifting it from a data set that has been funded in the past on an ad-hoc and limited basis.

List of major activities – including major party(s) involved, duration, start, finish

This proposal involves two simultaneous components, each of which has specific activities. Two data streams will be generated, the “absolute bias” stream and the “bias drift” data stream. It is important to note that the established methodology for the absolute bias component (Watson et al., 2003; 2004, Watson, 2005) requires repeated short to medium length duration mooring deployments that are undertaken concurrently. The datum of these moorings are determined using episodic deployments of GPS buoys, then assimilation of coastal tide gauges allows the generation of a continuous calibration data stream (despite the finite mooring deployments).

The following activities are required

Activity	Description	Involvement	Start	Finish
1a	Deployment of concurrent, 6 to 12 month duration ocean mooring arrays at three locations on the ground track of altimeter pass 088. Only the Burnie mooring would be continuous and the others would be episodic deployments. The primary location remains the Bass Strait site, followed by Storm-Bay, Tasmania and a third further afield (Melville Is, Northern Territory, or Lorne, Victoria).	IMOS coastal mooring group	ASAP	Ongoing
1b	GPS buoy deployments. Two deployments lasting 48-52 hours each are required over each mooring in order to define the absolute datum of the mooring sensor. Totals six deployments.	UTAS	Cyclic – 2 deployments required per mooring deployment	Cyclic – 2 deployments required per mooring deployment
1c	Generate absolute calibration data stream and disseminate via Science Working Team.	UTAS/CSIRO	Continuous	Continuous
2a	Routine generation of bias drift calibration data stream via the regular assimilation of tide gauge / GPS and altimeter data.	UTAS/CSIRO	Continuous	Continuous

List of major equipment to be purchased / developed

Item	Description	Budget (cash)
1	Development of transportable specialised GPS buoy hardware. Requires two buoy frames, capsules and transport cases to be developed and built. Main cost for initial construction, small annual cost for maintenance (consumables, tethers, etc).	\$25K year 1 \$5K per year
2	Dedicated GPS receivers for GPS buoys (2 x Leica System 1200).	\$70K year 1
3	Accelerometer and logging hardware for GPS buoys.	\$20K
4	Ocean moorings – each require sensors SBE26+ (\$25K), SBE37 (\$11K), aquadop (\$18K), 2xORE CART (\$16K), consumables (\$7K). Much of this infrastructure is already available within IMOS and CMAR. We request funds for building the number of available sensors in the sensor pool to allow for the simultaneous deployments (i.e. replacements, repairs etc). The SBE26s are vital to this experiment and two new instruments are required.	\$50K per year plus \$28K per year for consumables

Access, pricing regimes:

This proposal is likely to be unique within IMOS in that the data stream is of vital importance to a national and international community of users, yet the provision of the specific calibration data stream is made directly to the international mission science team who then include it within the recommendations and pre-processing directives set out to the broad user community. The sole user of the calibration data streams is therefore the peak body of the satellite mission itself (the NASA/CNES/NOAA/EUMET). The broad international community of altimetry users then benefit from the calibrated geophysical data records supplied from each mission – this effectively closes the loop between raw altimetry data, a national feedback in terms of a calibration data stream, and the subsequent provision of a calibrated dataset to the broad user community.

Access and pricing is therefore highly simplified for this proposal – we will provide a formal data stream directly to the NASA/CNES/NOAA/EUMETSAT mission team on a regular basis. Major updates are provided at the time of mission science team annual meetings. Intermediate updates will be provided to the mission team three times per year or at the time of any observed anomaly, or request by the mission team.

In generating the calibration data stream we would be relying on the provision of national and international tide gauge data. This is ensured nationally by the National Tidal Centre (NTC) within BoM, and internationally through the Permanent Service for Mean Sea Level (PSMSL), and the University of Hawaii Sea Level Centre. We would also be reliant on GPS data that is publically available through Geoscience Australia and the AuScope portal.

The allocation of priorities is also simplified as this represents a self contained data stream that can be managed within the team of three CIs. The team have an existing track record in achieving timely results and contributions of value to the existing NASA/CNES/NOAA/EUMETSAT science team.

Governance

Performance indicators associated with this proposed infrastructure development include:

1. Level of completeness in the absolute calibration data stream from the three calibration points on Pass088 of Jason-2.
2. Latency (on top of the lag in acquisition of altimeter and tide gauge data) in the production of the calibration data stream (both absolute and relative streams).
3. Noise level in the absolute bias and bias drift data stream measured against that achieved historically by other international providers.
4. Inclusion of the absolute calibration estimates within the NASA/CNES/NOAA/EUMETSAT science team calibration reports.
5. Ability for the Australian data stream to detect anomalous data from the altimeter spacecraft, as measured against the NASA/CNES/NOAA/EUMETSAT calibration providers.

The deployment of instrumentation in a marine environment is always accompanied by some level of risk. For this infrastructure development, the deployments are based on sound and well tested techniques which are typically considered high probability for success and low risk. These are summarised below:

1. Fouling of ocean based moorings (very low risk, high impact). This will be mitigated by adopting sufficiently short deployment periods to prevent the accumulation of growth. The use of three sites also provides redundancy that has never before been achieved in any Australian contribution.
2. Failure of GPS buoys (very low risk, low impact). The GPS units are well tested and unlikely to fail. Two buoys are deployed at each mooring location in order to provide redundancy and quality assurance.
3. Failure of tide gauges (very low risk, medium impact). The tide gauges used form part of the National baseline array, and are therefore expected to be maintained on a regular basis with few if any interruptions to the supply of data. The impact on the bias drift calibration scheme is very low as the number of tide gauges used for this stream is very high and hence the method is highly redundant.
4. Failure of altimeters (very low risk). Impact, this is one of the reasons for why calibration is absolutely vital. If a break in the altimetry stream occurs due to a spacecraft related failure, calibration data (both absolute and relative) is fundamentally vital. For this reason no impact is stated as the risk drives the need for this data infrastructure investment.
5. Loss of coastal Moorings (low risk, medium impact). There is a low level of risk that a mooring(s) may be lost (for example, due to being snagged by an anchor or net). This risk is minimised as none of the deployment regions are within active fishing grounds, and the appropriate level of notification is provided by following the guidelines of the relevant Marine and Safety authority. Given the multiple deployments and six monthly cycle, sufficient redundancy is built in to ensure a calibration data stream can still be produced.

Budget (see over):

Facility budget proforma for IMOS EIF Call for Proposals 2010-2013

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		2009/10	2010/11	2011/12	2012/13	Total
NCRIS/EIF Funding (see Note 1 for dates)		(NCRIS)	(NCRIS)	(EIF)	(EIF)	(NCRIS+EIF)
Capital	Buoys x2 (frames/capsules)	25	0	0	0	25
	GPS receivers x2 (for buoys)	70	0	0	0	70
	Accelerometers x2 (for buoys)	20	0	0	0	20
	Buoy consumables	0	5	5	5	15
	Mooring equipment	50	0	50	50	150
	Mooring consumables	0	28	28	28	84
Salaries	UTAS:					
	CI Watson 0.7 FTE Level C1/2/3		77	82	89	248
	New field person 0.8 FTE Level A6/7/8		64	69	75	208
	CSIRO (FTE provided, \$ aggregated)					
	CI Church CSOF8 FTE:		0.1	0.1	0.1	
	CI White CSOF6 FTE:	(See Note 1)	0.3	0.3	0.3	
	Mooring staff CSOF4		0.2	0.2	0.2	
	Mooring staff CSOF3		0.2	0.2	0.2	
	Mooring staff CSOF4		0.1	0.1	0.1	
	Mooring staff CSOF6		0.1	0.1	0.1	
	CSIRO Totals:		122	128	135	385
Operating	Mooring freight		5	5	5	15
	Buoy freight		5	5	5	15
	Mooring related travel		10	10	10	30
	Buoy related travel		15	15	15	45
	NASA/CNES/NOAA/EUMETSAT science team travel (See Note 1)		8	8	8	24
	National dissemination of calval		4	4	4	12
	Mooring deployments		40	40	40	120
	Buoy deployments		30	30	30	90
	NCRIS/EIF Funding Total Ex-GST	165	413	480	498	1,556
	GST	17	41	48	50	156
	NCRIS/EIF Funding Total	182	454	528	548	1,711
Cash Co-investment		2009/10	2010/11	2011/12	2012/13	Total
						0
	Cash Co-investment Total	0	0	0	0	0
In-kind Co-investment		2009/10	2010/11	2011/12	2012/13	Total
UTAS	GPS receivers (for land) - Note 2		105	105	105	315
UTAS	High performance computing		50	50	50	150
UTAS	CI Watson 0.7 FTE Level C1/2/3		71	76	82	228
UTAS	New field person 0.8 FTE Level A6/7/8 (See Note 1)		59	64	69	192
CSIRO	CI Church / White + Mooring staff		113	119	125	357
CSIRO	Moorings from the CMAR equip pool - Note 3		110	110	110	330
	In-kind Co-investment Total	0	508	524	540	1,572
	TOTAL Resources	182	961	1,051	1,088	3,283

NOTES:

- Given the date of this submission (Nov 2009), the budget has been prepared with only capital purchases starting in 2009/10 (in order to have the bulk of the equipment ready for use/deployment in 2010/11. The salaries start in 10/11 coinciding with the first buoy/mooring deployments.
- This is a confirmed contribution and consists of a pool of GPS receivers that can be allocated for use as base stations during the deployment of the GPS buoys that will be funded from IMOS cash.
- This is a provisional number but is based on previous use of the CMAR mooring pool equipment. We propose to purchase additional equip (see mooring equipment item) that will further add to the pool

References

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- Bonnefond, P., Haines, B., and Watson, C.S. (2009), In situ Absolute Calibration and Validation - A link from open-ocean to coastal altimetry, in *Coastal Altimetry*, edited by S. Vignudelli, et al., Springer. In Press.
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Appendix - Resume of the leader of the proposed infrastructure investment

Resume – Dr Christopher Watson

Précis

My interests have an emphasis on ‘environmental geodesy’ – the use of space geodetic tools such as GNSS, satellite altimetry and space gravity applied to global climate change and sea level studies, crustal strain and seismic deformation, and surface expression of hydrologic loading. My PhD work developed an improved in-situ calibration technique for the TOPEX/Poseidon and Jason-1 satellite altimeters, and I have further developed this work as part of contributions to the NASA/CNES/NOAA Ocean Surface Topography Science Team (OSTST). With an Antarctic ice focus, I am involved in the Calibration, Validation and Retrieval Team (CVRT) on the European Space Agency (ESA) CryoSat-II mission.

Recent research has focused on error modelling within space geodetic analyses, particularly the influence of different strategies surrounding atmospheric mapping functions, a priori zenith hydrostatic delays, atmospheric loading, and mis-modelling periodic geophysical signals such as the Solid Earth and atmospheric pressure tides. Recent work has also investigated the surface expression of hydrologic loads on the crust, comparing GRACE gravity fields convolved for deformation with observed deformation from GPS analyses. I also have an interest in historical sea level studies and have worked on a novel GPS buoy calibration technique for Australian Antarctic tide gauges, and computed sea level change estimates since Mawson’s 1911-14 AAE expedition to Macquarie Island.

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Education

1999: B.Surv (Hons 1A) Surveying and Spatial Information Science, University of Tasmania. Thesis: “A Contribution to Absolute Sea Level in Tasmania”.
2005: PhD, Geodesy, University of Tasmania. Thesis: “Satellite Altimeter Calibration and Validation Using GPS Buoy Technology”.

Professional Appointments

2005 current Research/Lecturer Level B, School of Geography and Environmental Studies, University of Tasmania.
03/08-05/08: Visiting Research Fellow, Newcastle University, United Kingdom.

Research Review and Administration

ARC: Reviewer for Australian Research Council (ARC) Discovery and Linkage Projects (2008 –).
NCRIS: Science Advisory and Review Committee for the National Collaborative Research Infrastructure (NCRIS) Capability 5.13: Structure and Evolution of the Australian Continent, AuScope (2008 –).
Journals: Regular manuscript reviews for *Journal of Geophysical Research*, *Geophysical Research Letters*, *Journal of Geodesy*, *Marine Geodesy*, *Journal of Spatial Science*, *Journal of Surveying Engineering*, International Association of Geodesy Symposia.

Awards / Fellowships / Membership etc

2008: Visiting research fellowship, Newcastle University.

2004: Australian Young Scientist of the Year Award. Presented by the British Council of Australia and the Australian newspaper in recognition of generalist science writing ability.

2001: CSIRO Postgraduate Award – PhD Supplementary Scholarship.

2001: Australian Postgraduate Award, Tasmanian University Scholarship (1994-1999).

2000: Tasmanian Young Scientist of the Year Award. Presented in recognition of honours research by the National Australia Day Council.

Member of the European Geophysical Union (EGU)

Member of the American Geophysical Union (AGU)

Member of the International Association of Geodesy (IAG)

Member of the Australian Surveying and Spatial Sciences Institute (SSSI)

Teaching / Research Supervision

Full unit coordination, lecturing, tutorials and practical supervision roles in the Bachelor of Surveying and Spatial Science degree program, University of Tasmania (July 2004 –)

- Second year units in surveying and analysis of observations (least squares estimation theory)
- Third year units in surveying, geodesy and undergraduate research, research design.
- Outstanding mean student evaluation scores (consistently ~4.5 on a 5 point rating).
- Actively involved in unit and course design within the University.
- Research supervision at the Honours, Masters and PhD level

Research Grants

2008: **ARC Discovery**: Environmental Geodesy: Variations of Sea Level and Water Storage in the Australian Region (\$1.16M over 5 years). CIs Dr Tregoning (ANU), Prof Coleman (UTAS), Dr Watson (UTAS), Prof Featherstone (Curtin), Dr Kuhn (Curtin), Dr Awange (Curtin) and Prof Rizos (UNSW)

2008: **NCRIS/AuScope**. Active role in bid for Geospatial Framework funding (\$16.9M; Co-Invested \$49.4M). Lead CI on SLR Equipment Trial, French Transportable Laser Ranging System (FTLRS) in Burnie, Tasmania (\$280K for SLR component). CIs Dr Watson (UTAS), Dr Tregoning (ANU), Prof Coleman (UTAS)

2008: **NCRIS/IMOS**: Calibration and Validation of Satellite Altimeters in the Australian region. (\$40.2K). CIs: Dr Watson (UTAS), Prof Coleman (UTAS), Dr White (CSIRO), Dr Church (CSIRO).

2008: **ESA**: In-situ Validation of CryoSat-II: An Australian Contribution in East Antarctica. In-kind support only, membership of the Calibration, Validation and Retrieval Team (CVRT), CIs: Dr Watson (UTAS), Dr Tregoning (ANU), Prof Coleman (UTAS).

2006: **CRCSI**: Geodetic GPS Time Series Analysis - Improving the Height Component of Geoscience Australia's Regional CORS Network. (\$10K). CI: Dr Watson (UTAS).

2005: **UTAS IRGS**: Absolute Sea Level Change in the Australian and Antarctic Region. (\$11.3K). CI: Dr Watson (UTAS).

Refereed Publications

King, M and **Watson, C.S.**, (2009), Long GPS coordinate time series: multipath and geometry effects, *Journal of Geophysical Research*, In Press doi:10.1029/2009JB006543.

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Conference Presentations, Invited Seminars, Outreach Publications

2009: Data Archaeology: Twentieth century constraints on sea level and land level change at Macquarie Island, Invited presentation of the memorial Don Wallace Lecture, Permanent Committee for Tides and Mean Sea Level (PCTMSL), Launceston, Tasmania. October 8, 2009.

2009: Environmental Geodesy, Invited oral presentation. Surveying and Spatial Science Institute (SSSI) – Tasmanian Division Annual Congress. St Helens, Tasmania, July 2009.

2009: **Watson, C.S.**, White, N., Burgette, R., Zhang, J. Coleman, R., Tregoning, P. and Church, J. (2009). In-situ Calibration at the Bass Strait Site, Australia, Ocean Surface Topography Science Team Meeting, Seattle, June 2009.

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- 2008: Watson, C.S., White, N., Coleman, R., Zhang, J., Tregoning, P. and Church, J. (2008). In-situ Calibration Results from Bass Strait, Ocean Surface Topography Science Team Meeting, Nice, November 2008.
- 2008: Zhang, J., Tregoning, P., Watson C.S., Pierron, F., and Coleman R., (2008). Bass Strait In-Situ Calibration Site: Trials of The French Transportable Laser Ranging System (FTLRS), Ocean Surface Topography Science Team Meeting, Nice, November 2008.
- 2008: Sea level change at Macquarie Island since Sir Douglas Mawson's 1911-14 AAE expedition, seminars at Proudman Oceanographic laboratory (POL) and Newcastle University, United Kingdom. May 2008.
- 2008: Watson, C.S., (2008). Data Archaeology: Sea level change at Macquarie Island since Sir Douglas Mawson's 1911-14 AAE expedition, European Geophysical Union, Vienna, Austria. April 2008.
- 2008: Testut L., Coleman, R., Pouvreau, N., Watson, C.S., Wöppelmann, G. and Hunter, J. (2008). Historical sea level trends in the Southern Ocean from tide gauges. William Smith Meeting: Observations and Causes of Sea-Level Changes on Millennial to Decadal Timescales, 1-2 Sept. 2008, London. UK.
- 2008: Testut L., Coleman, R., Broisma, H., Watson, C.S., Handsworth, R. and Calzas, M. (2008). Estimating long term sea level trends in East Antarctica. Joint SCAR-IASC Open Science Conference, 8-11 July 2008, St. Petersburg.
- 2007: Improving the atmospheric pressure tide model for application in geodesy, International Union of Geodesy and Geophysics (IUGG) General Assembly, Perugia, Italy, 2-13th July 2007. Published Abstract and Oral Presentation. (Authors Watson, C.S., P. Tregoning, and L. Millet).
- 2006: Filling the information void: Absolute sea level change in the Southern Ocean at Macquarie Island, Seminar presented to the Geophysics group, University of Otago, New Zealand. September 6, 2006.
- 2006: Updated results from the Bass Strait calibration site, Ocean Surface Topography Science Team (OSTST) meeting, Venice, Italy. 16-18 March, 2006. Accepted for oral and poster presentation. (Authors: Watson, C., N. White, R. Coleman, and J. Church).
- 2006: Tide gauge calibration at Macquarie Island using GPS buoy techniques, European Geophysical Union Annual Scientific Convention, Vienna, Austria. 2-7 April, 2006. Published Abstract and Oral Presentation. (Authors Watson, C., R. Coleman, and R. Handsworth).
- 2005: Watson, C. (2005). Flowerpots Go Overboard for Climate Change, Australasian Science, 26(4) pp29-30.
- 2005: The Impact of Solid Earth Tide Models on GPS Time Series Analysis, Dynamic Planet 2005: Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic Tools, IAG/IAPSO/IABO Joint Assembly, Cairns, Australia. August 22-26, 2005. Published Abstract and Oral Presentation. (Authors Watson, C., P. Tregoning and R. Coleman).
- 2005: Measuring Sea Level at Macquarie Island – How hard can it be?, Invited oral presentation. Spatial Science Institute (SSI) – Tasmanian Division Annual Congress. St Helens, Tasmania, July 2005.
- 2004: Science Communication, Invited seminar presented to the Minerals Tertiary Education Council (MTEC), Hobart, Tasmania. November 30, 2004.
- 2004: Southern Ocean and Antarctic Sea Level: Trials and Tribulations of Measuring Sea Level in a Hostile Environment, Invited presentation of the memorial Don Wallace Lecture, Permanent Committee for Tides and Mean Sea Level (PCTMSL), Hobart, Tasmania. October 28, 2004.
- 2003: In-Situ Calibration In Bass Strait, Australia NASA/CNES Jason-1 Science Working Team (SWT) meeting, Arles, France, November 18-22, 2003. Accepted for oral and poster presentation. (Authors: Watson, C., N. White, R. Coleman, and J. Church).
- 2003: Calibration of TOPEX/Poseidon and Jason-1 Altimeters using GPS, Seminar presented at the Geomatics Department, School of Civil Engineering and Geosciences, University of Newcastle, Newcastle Upon Tyne, UK. November 10, 2003.
- 2002: In-Situ Calibration Activities in Bass Strait, Australia NASA/CNES Jason-1 Science Working Team (SWT) meeting, New Orleans, USA. October 21-23, 2002. Accepted for oral and poster presentation. (Authors: Watson, C., N. White, R. Coleman, and J. Church).
- 2002: In-Situ Calibration Activities in Bass Strait, Australia NASA/CNES Jason-1 Science Working Team (SWT) meeting, Biarritz, France. June 10-12, 2002. Accepted for oral and poster presentation. (Authors: Watson, C., N. White, R. Coleman, and J. Church).

2002: Ocean waves from GPS: Calibration of TOPEX/Poseidon and Jason-1 Altimeters using GPS. Invited oral presentation. Institute of Surveyors Australia (ISA) – Tasmanian Division Annual Congress. Hobart. June 2002.

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