Use of drifter technology for scalar transport monitoring in estuaries and rivers

Authors

Richard Brown, Yanming Feng, Kabir Suara and Charles Wang
Science and Engineering Faculty, Queensland University of Technology

Helen Fairweather, Roy Sidle and Adrian McCallum
Environmental Engineering School, University of the Sunshine Coast

Michael Borgas, Marine and Atmospheric Research, CSIRO

Hubert Chanson, Civil Engineering, University of Queensland

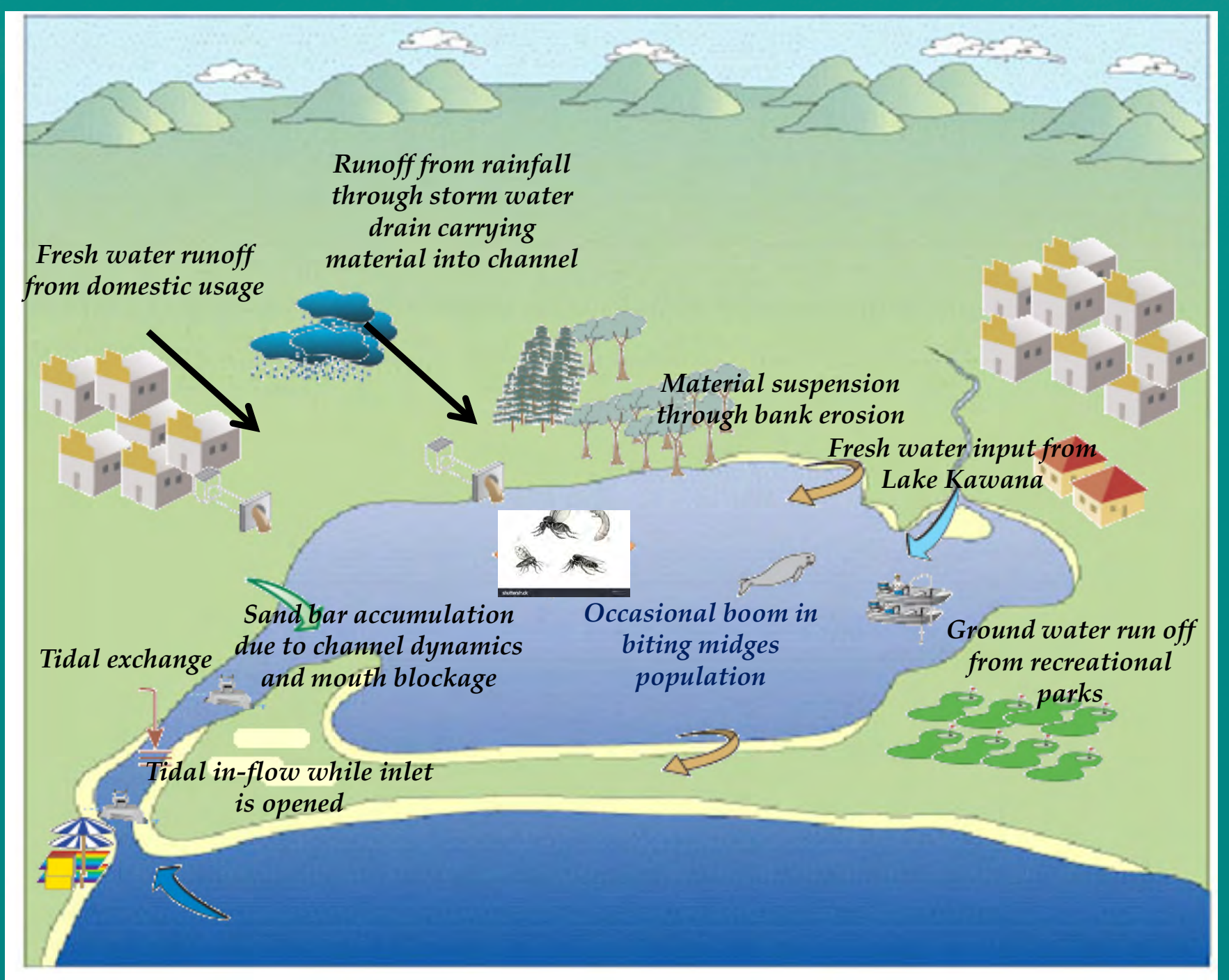
Introduction

Lagrangian field data in tidal shallow waters are rare, but valuable for the understanding of the spatio-temporal structure flow and water qualities, validation and calibration of hydrodynamic models, and advection-dispersion models for such systems. Recent improvements in GPS technology have paved the way for the development of instrumented high resolution Lagrangian drifters capable of being deployed in shallow rivers and estuaries where processes of interest occur at small temporal (100 seconds) and spatial (few metres) scales.

Purpose

The aim of this project is to develop a novel Lagrangian drifter system - Real-Time Flow Logging of Water (RTFLOW). This system is capable of monitoring river and estuarine water velocity and turbulence, dispersion coefficients, water parameters (initially temperature and salinity. Future versions capable of incorporating a wide range of sensors including dissolved oxygen, nitrates, phosphates, pH, turbidity, chlorophyll, etc.) and measuring air-water interface flux exchange.

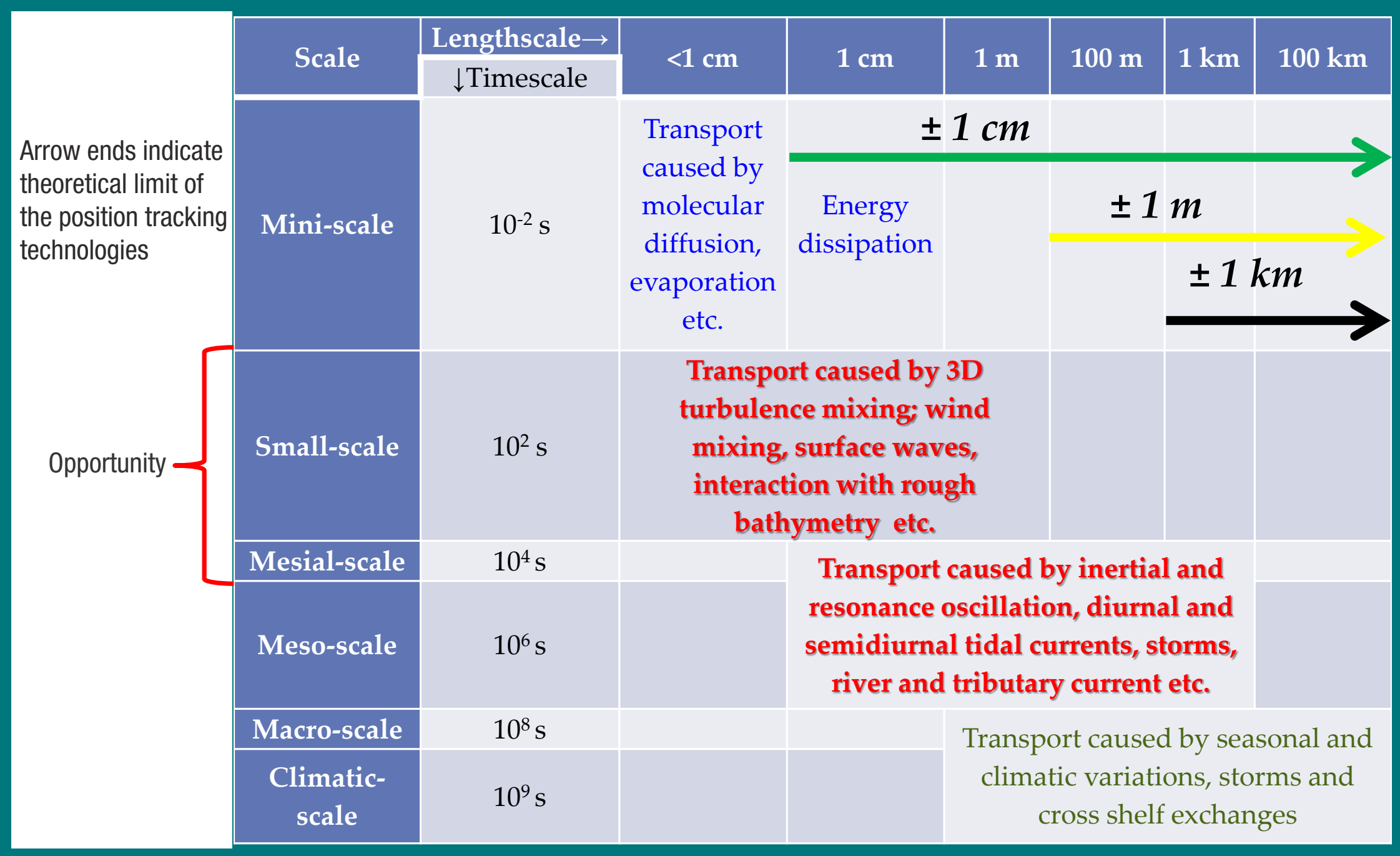
With about 50% of the global population living in coastal areas, human activities around shallow water bodies (e.g. rivers, floodplains and estuaries) have increased. These water bodies are exposed to pollution, climatic change, tidal and sub-tidal exchanges, which all influence their characteristics and thus pose dangers to their ecosystems. In order to put effective safety measures in place, monitoring of water bodies, estimates of mixing and dispersion of particles/contaminants , measurement of scalar concentration and flux exchange in Air-water interface are important.



Significance

This research will enable improved hydrodynamic models to be developed through better calibration and improved representation of their governing processes. These improved models will provide more accurate predictions of flood and tidal surge levels, pollutant transport, changes in water parameters due to spills or weather events, erosion and other environmentally important phenomena.

Scales of transport processes



Arrow ends indicate theoretical limit of the position tracking technologies

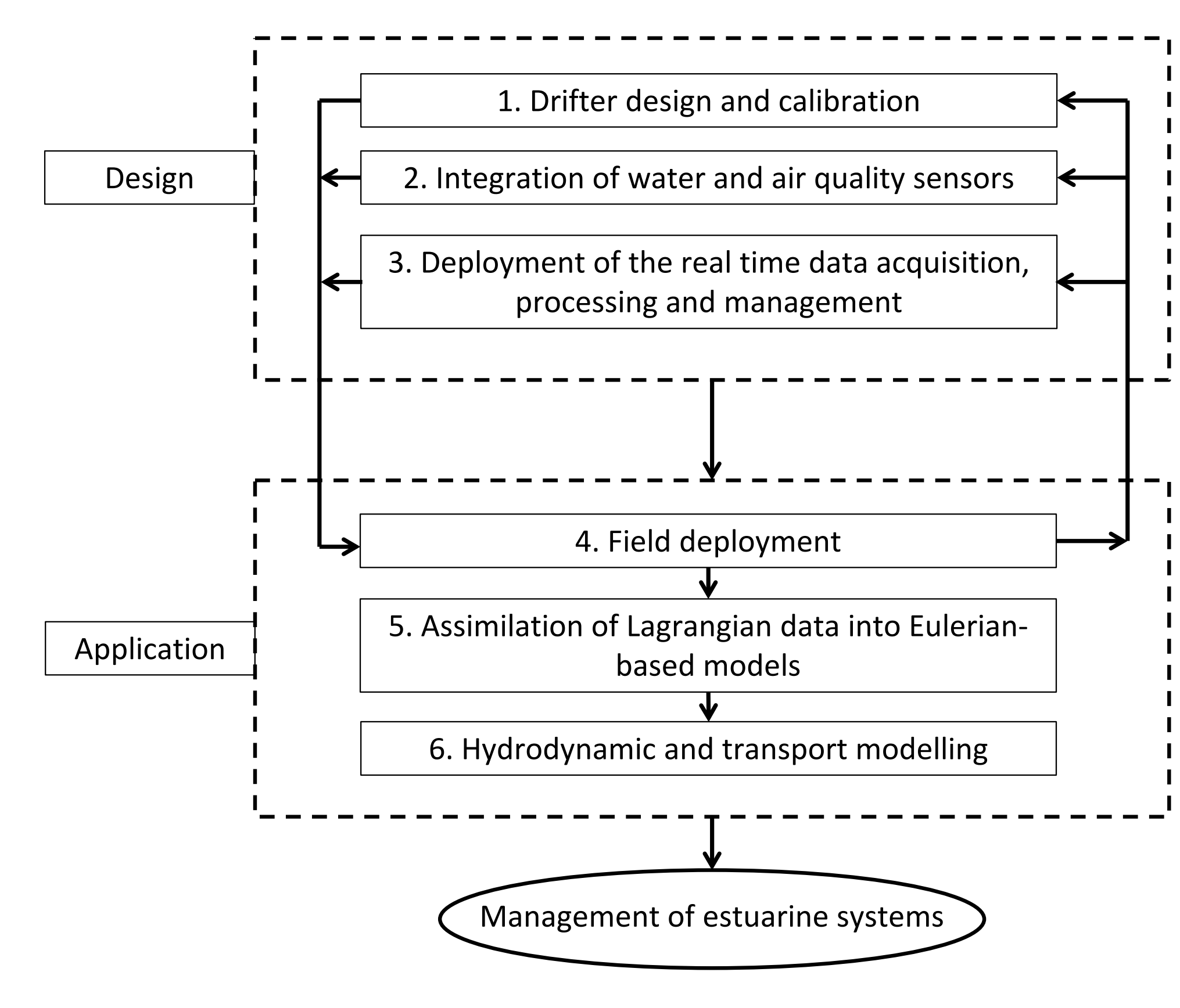
Opportunity

Scale	Lengthscale→ ↓Timescale	<1 cm	1 cm	1 m	100 m	1 km	100 km
Mini-scale	10^{-2} s	Transport caused by molecular diffusion, evaporation etc.	± 1 cm Energy dissipation		± 1 m	± 1 km	
Small-scale	10^{2} s	Transport caused by 3D turbulence mixing; wind mixing, surface waves, interaction with rough bathymetry etc.					
Mesial-scale	10^{4} s		Transport caused by inertial and resonance oscillation, diurnal and semidiurnal tidal currents, storms, river and tributary current etc.				
Meso-scale	10^{6} s						
Macro-scale	10^{8} s			Transport caused by seasonal and climatic variations, storms and cross shelf exchanges			
Climatic-scale	10^{9} s						

Timeline of technology development

Year	Tracking error	Technology	Applications	Comment	Source
1990s	O[1 km]	Acoustic	Large ocean	Still in use	Ollitrault and Rannou (2013)
1996	O[1 m]	GPS	Coast and estuary	Differential mode	George and Largier (1996)
2003	O[1 m]	GPS	Surf zone & lakes	Non-differential mode	Johnson et.al. (2003)
2003	O[1 cm]	GPS	Surf zone	Differential mode	Schmidt et al. (2003)
Now	O[1 cm]	GPS	Estuary	RTK in differential mode	RTFLow project

Conceptual model



Design

1. Drifter design and calibration
2. Integration of water and air quality sensors
3. Deployment of the real time data acquisition, processing and management

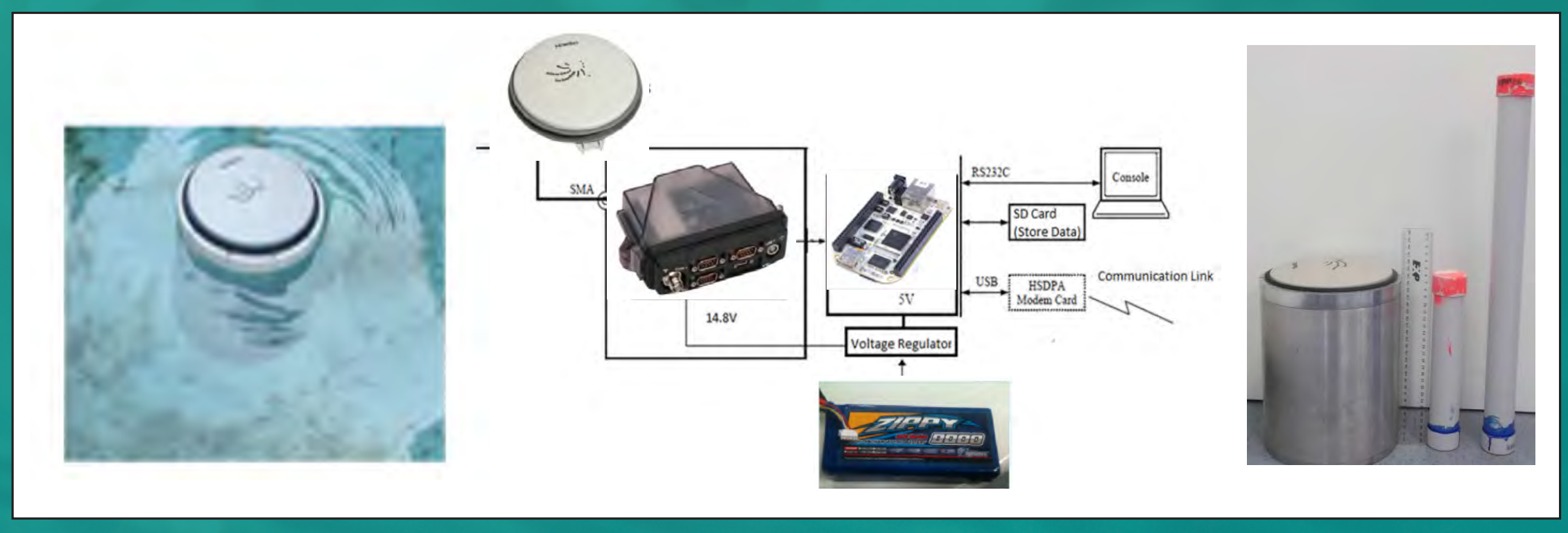
Application

4. Field deployment
5. Assimilation of Lagrangian data into Eulerian-based models
6. Hydrodynamic and transport modelling

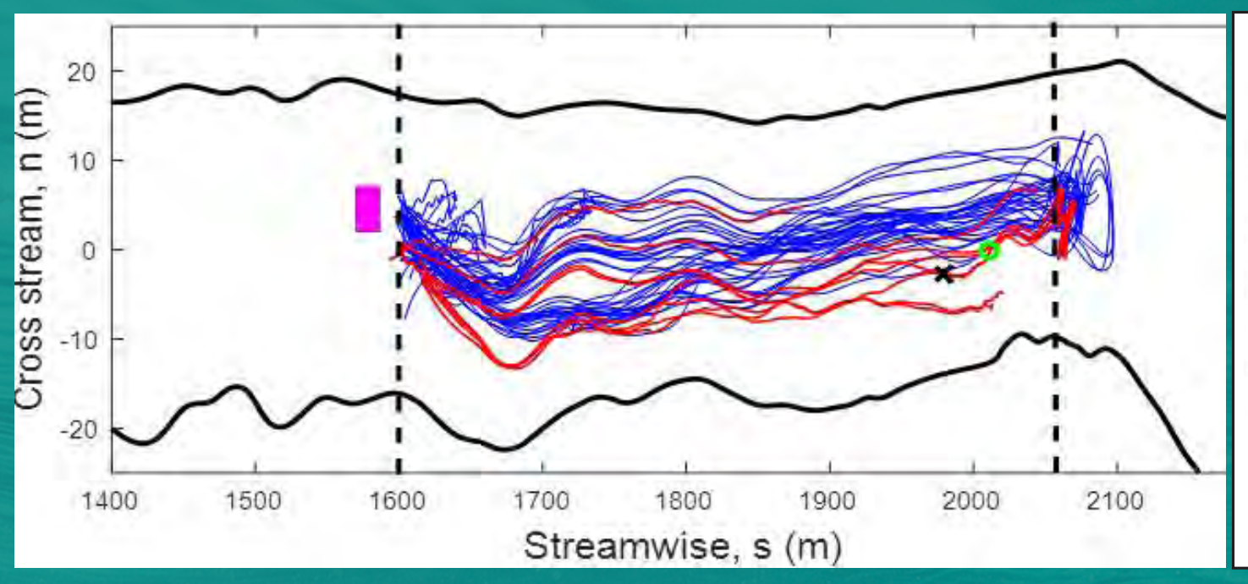
Management of estuarine systems

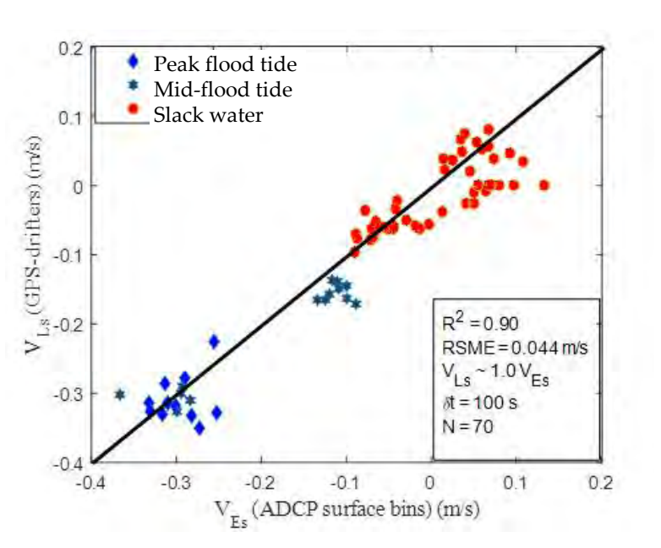
Method and materials

Drifter hull and electronics



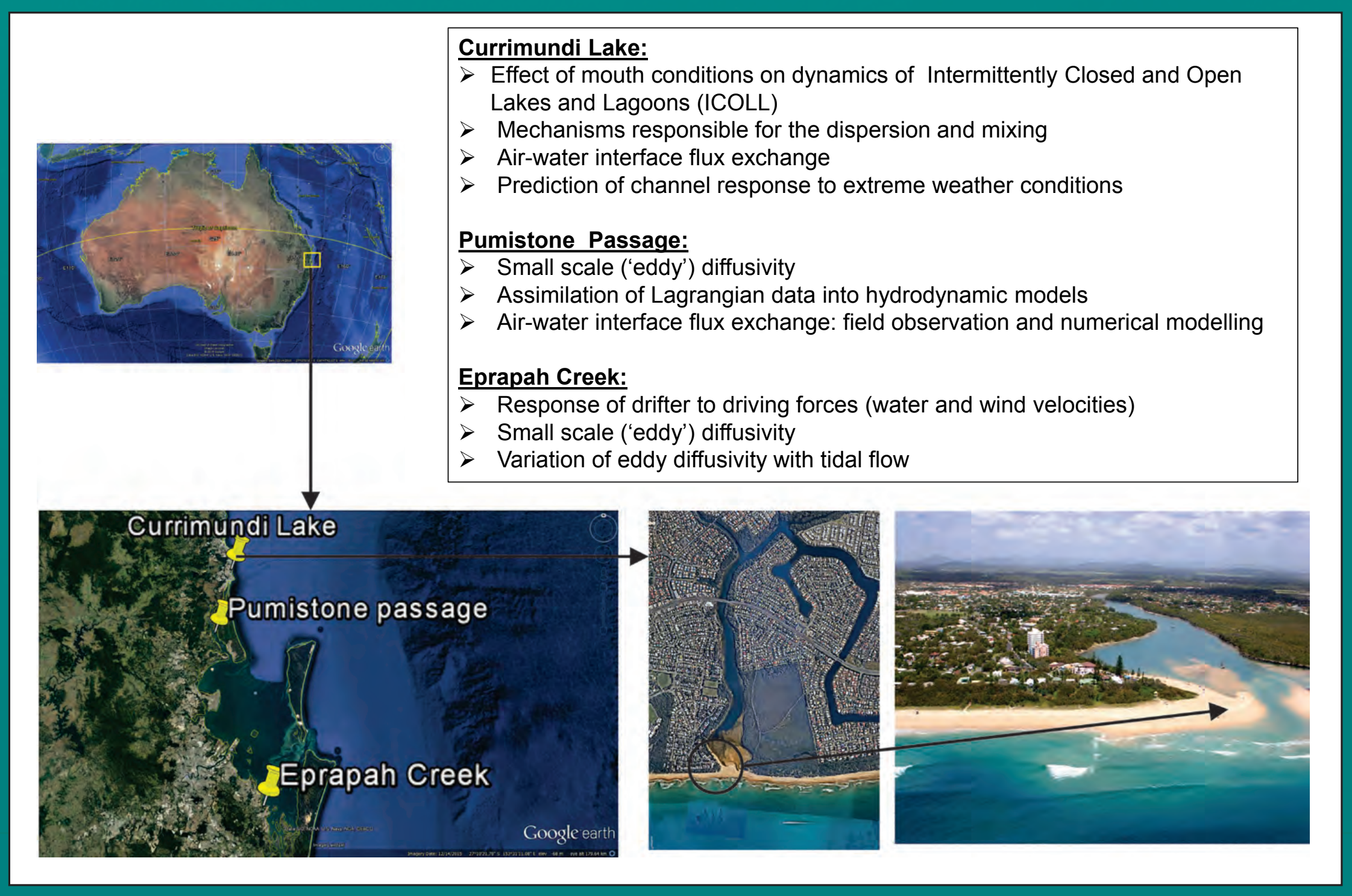
Validation of instruments





- Drifters were deployed repeatedly in a sheltered channel in the vicinity of acoustic Doppler velocimeters (ADVs), an acoustic Doppler current profiler (ADCP) and a sonic wind anemometer.
- The response of the simple designs of high and low resolution drifters to the wind and water flow in tidal shallow water was examined using qualitative correlation and coherence analyses under moderate wind conditions (0 – 4 m/s).
- Subsurface drifter motions in bounded sheltered water are affected by wind through low frequency induced wind current rather than direct wind drag when only a small portion of the drifter is not submerged.
- The field validation of both high resolution and low resolution drifters with surface measured velocity from ADCP is good ($R^2 > 0.9$; RSME = 0.04 m/s) in the streamwise direction.

Case studies



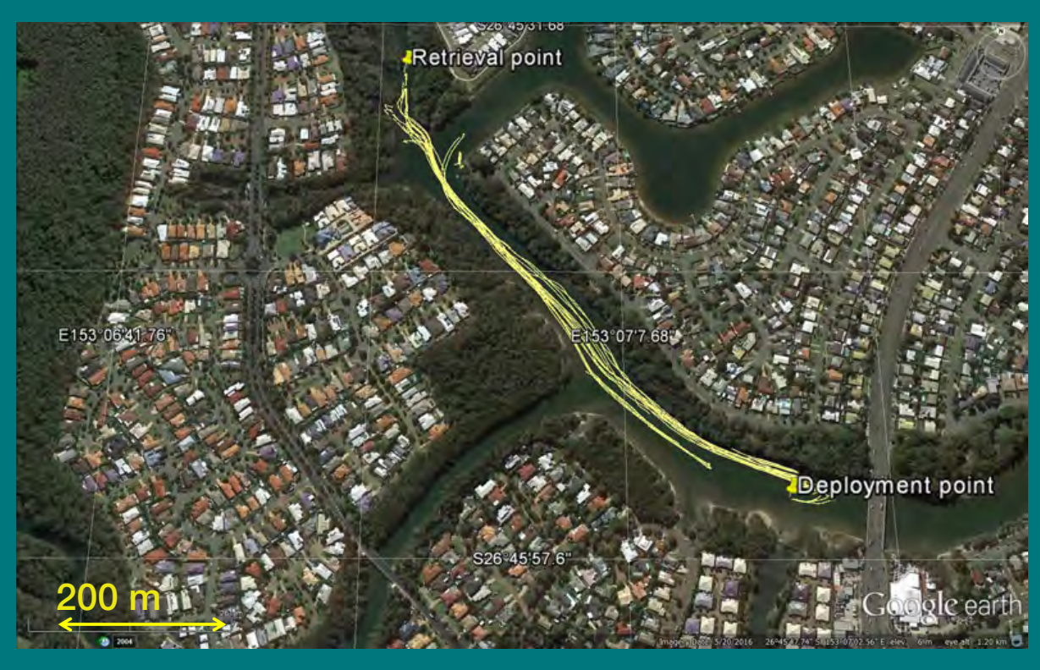
Currimundi Lake:
- Effect of mouth conditions on dynamics of Intermittently Closed and Open Lakes and Lagoons (ICOLL)
- Mechanisms responsible for the dispersion and mixing
- Air-water interface flux exchange
- Prediction of channel response to extreme weather conditions

Pumistone Passage:
- Small scale ('eddy') diffusivity
- Assimilation of Lagrangian data into hydrodynamic models
- Air-water interface flux exchange: field observation and numerical modelling

Eprapah Creek:
- Response of drifter to driving forces (water and wind velocities)
- Small scale ('eddy') diffusivity
- Variation of eddy diffusivity with tidal flow

Eprapah Creek experiment

Drifter trajectories from case study sites



Data analysis

$$v_i(t) = V_i(t) - \overline{V_i}(t)$$

$$\overline{V_i}(t) = \frac{1}{\Delta T}\int_t^{t+\Delta T} V_i(t)\,dt$$

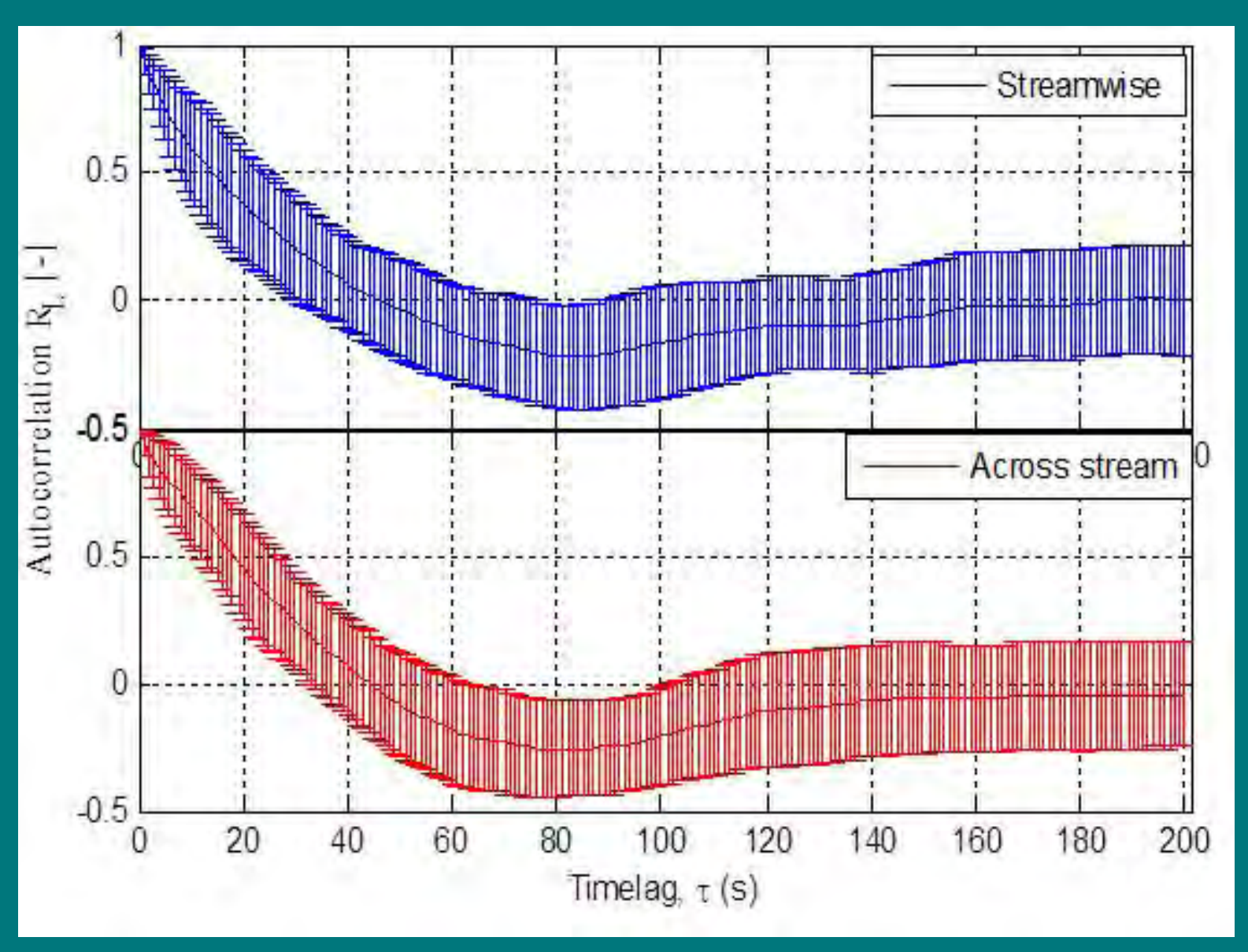
$$\left\langle v_i^2 \right\rangle_L = \frac{1}{T}\int_0^T v_i^2(t)\,dt$$

$$R_L(\tau) = \frac{\int_0^T (v_i(t)v_i(t+\tau))\,dt}{\left\langle v_i^2 \right\rangle_L}$$

$$T_L = \int_0^\infty R_L(\tau)\,d\tau$$

$$L_L = \left(\left\langle v_i^2 \right\rangle_L\right)^{1/2} * T_L$$

$$K = 2\left\langle v_i^2 \right\rangle_L \int_0^\infty R_L(\tau)\,d\tau$$



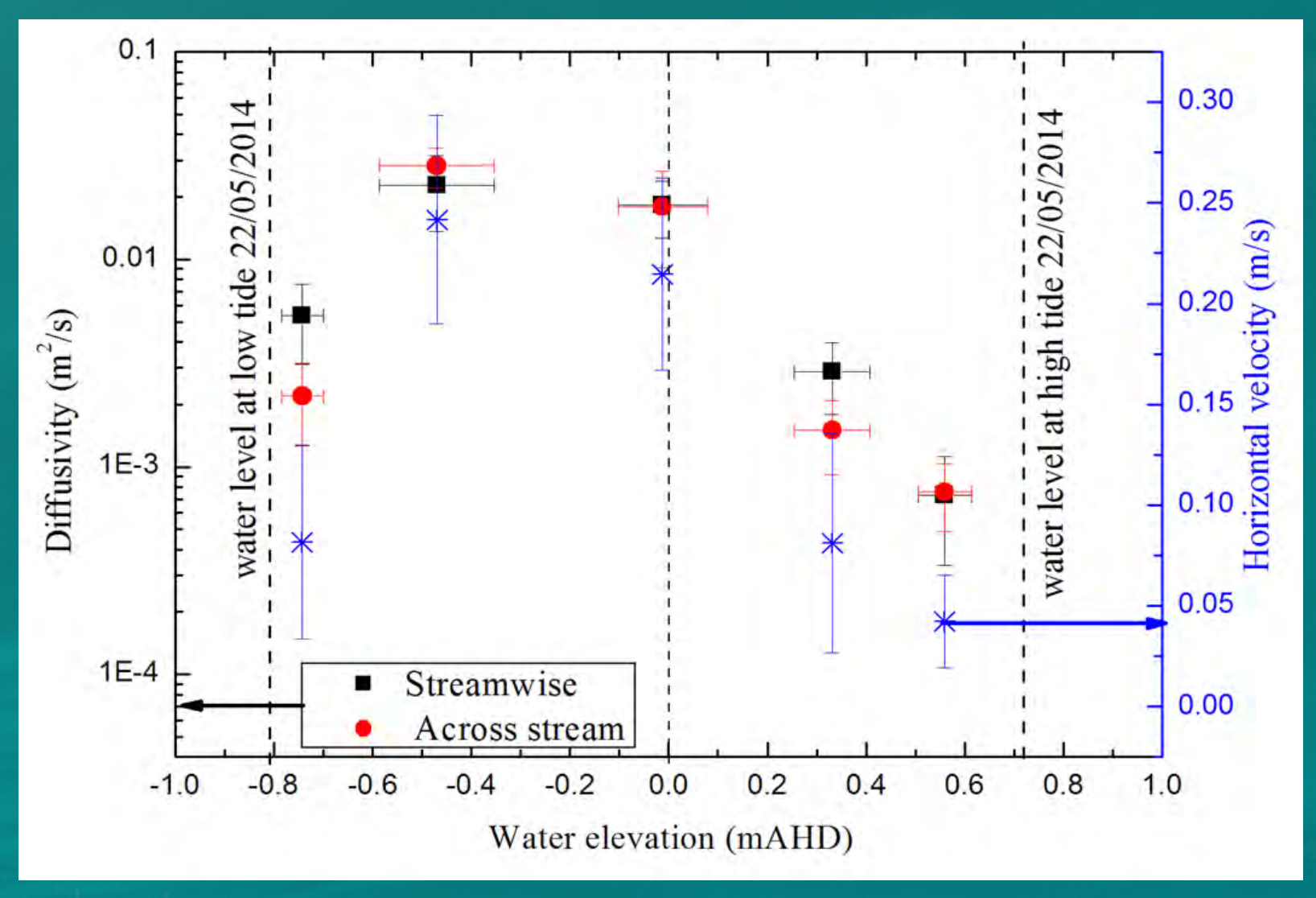
v_i = residual velocity, V = instantaneous velocity from the drifter, over bar signifies mean, t = time, Subscript 'i' = Streamwise and Across stream directions, τ = timelag, R_L = autocorrelation function, T_L = Lagrangian integral time scale, L_L = Lagrangian integral length scale, K = eddy diffusivity

Variable interval time averaging (VITA) for $\overline{V_i}(t)$; window size, ΔT= 200 s every 1 s.

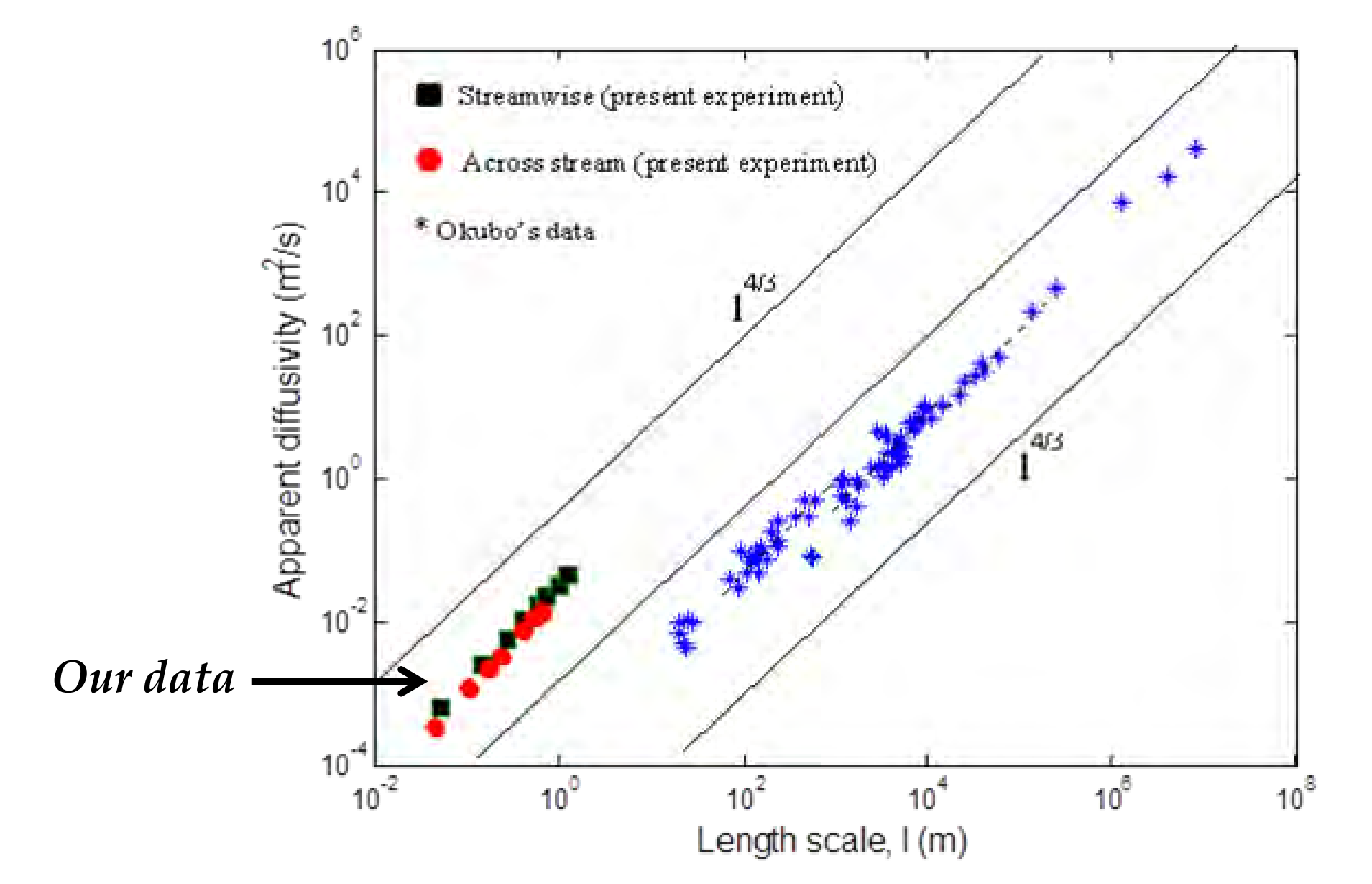
This equation suggests asymptotic behaviour of K(t) after decorrelation time. In practice, this behaviour may or may not occur. Time of first zero crossing was adopted for upper integral limit.

Results

Eddy diffusivity and tidal inflow velocity



- The distribution of diffusivity with the water elevation measured by the drifters and averaged in time is shown above. The estimated diffusivity varied between 0.001 – 0.02 m^2/s during a 4.5-hour experiment indicating that constant value of diffusivity used in advection-diffusion modelling of estuaries is untrue.
- Peak diffusivity was observed at the early part of the flood which corresponds to the peak horizontal mean velocity. This suggests the diffusivity in models can be scaled by the mean horizontal flow velocity.
- The small scale (eddy) diffusivity exhibited strong dependence ($R^2 > 0.9$) on the horizontal velocity.



For comparison and to examine the similarity between the scaling of small scale mixing parameters in Eprapah Creek and existing bodies of theory, the plot of the apparent diffusivity against the length scale of diffusion are presented. These are presented alongside Okubo's dye experiments ocean diagram data. Okubo's data were obtained from the dye tracer diffusion experiments covering the time scale in the range of 2 hours - 1 month and length scale 30 m - 100 km. Despite the difference in geometry, physics of the systems, approach and method of estimates, it is clearly observed that the diffusivities scale locally by 4/3 Richardson power law.

Our data clearly extend Ocean dispersion diagram to smaller scale for small water bodies.

Conclusion

- A new design for drifters with the capability of studying flow and air/water quality parameters in tidal shallow waters is evolving.
- Validation of drifter measurement in shallow tidal water showed good correlation with acoustic measurements next to the surface.
- Eddy diffusivities increase by two orders of magnitude in periods less than a tidal cycle as against constant values used in hydrodynamic models.
- Eddy diffusivity showed strong dependence (R^2> 0.9) on the mean horizontal velocity.
- Eddy diffusivity scales with integral length to the power of 4/3 similar to Richardson's. Therefore, "small scale" eddy diffusivity can be parameterised using the classic scaling.
- "Small scale" eddy diffusivity from drifter measurements in shallow tidal water extends ocean diffusion diagram.

References

Brown, R. J., & Chanson, H. (2012). Suspended sediment properties and suspended sediment flux estimates in an inundated urban environment during a major flood event. Water Resources Research, 48(11). doi:10.1029/2012WR012381

George, R., & Largier, J. L. (1996). Description and performance of finescale drifters for coastal and estuarine studies. Journal of Atmospheric and Oceanic Technology, 13(6), 1322-1326. doi:10.1175/1520-0426(1996)013<1322:DAPOFD>2.0.CO;2

Johnson, D., Stocker, R., Head, R., Imberger, J., & Pattiaratchi, C. (2003). A compact, low-cost GPS drifter for use in the oceanic nearshore zone, lakes, and estuaries. Journal of atmospheric and oceanic technology, 20(12), 1880-1884. doi:10.1175/1520-0426(2003)020<1880:ACLGDF>2.0.CO;2

Okubo, A. (1971). Oceanic diffusion diagrams. Deep Sea Research and Oceanographic Abstracts, 18(8), 789-802. doi:10.1016/0011-7471(71)90046-5

Ollitrault, M., & Rannou, J.-P. (2013). ANDRO: An Argo-based deep displacement dataset. Journal of Atmospheric and Oceanic Technology, 30(4), 759-788. doi:10.1175/JTECH-D-12-00073.1

Ozcoast (2016), Australian Online Coastal Information, http://www.ozcoasts.gov.au/conceptual_mods/index.jsp

Schmidt, W., Woodward, B., Millikan, K., Guza, R., Raubenheimer, B., & Elgar, S. (2003). A GPS-Tracked Surf Zone Drifter. Journal of Atmospheric and Oceanic Technology, 20(7), 1069-1075. doi:10.1175/1460.1

Suara, K. A., Brown, R. J., & Borgas, M. (2016). Eddy diffusivity: a single dispersion analysis of high resolution drifters in a tidal shallow estuary. Environmental Fluid Mechanics, 1-21. doi:10.1007/s10652-016-9458-z

Suara, K. A., Brown, R. J., Wang, C., Borgas, M., & Feng, Y. (2015). Estimate of Lagrangian integral scales in shallow tidal water using high resolution GPS-tracked drifters. In 36th IAHR World Congress.

Suara, K.A., Ketterer, T., Fairweather, H., McCallum, A., Vanaki, Sh. M., Allan, C., & Brown, R. (2016) Cluster dispersion of low Cost GPS-Tracked Drifters in a Shallow Water. In 10th Australasian Heat & Mass Transfer Conference, 14 - 15th, July 2016, Brisbane.

Suara, K. A., Wang, C., Feng, Y., Brown, R. J., Chanson, H., & Borgas, M. (2015). High Resolution GNSS-Tracked Drifter for Studying Surface Dispersion in Shallow Water. Journal of Atmospheric and Oceanic Technology, 32(3), 579-590. doi:10.1175/JTECH-D-14-00127.1

Taylor, G. I. (1954). The Dispersion of Matter in Turbulent Flow through a Pipe. Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 223(1155), 446-468. doi:10.1098/rspa.1954.0130

Acknowledgements

The project is supported through Australia Research Council Linkage grant LP150101172 and Sunshine Coast Council.

Thanks to Queensland Department of Natural Resources and Mines, Australia for providing access to SunPOZ network for reference station data used for RTK post processing of the high resolution GPS-tracked drifter.