eReefs is a collaboration between:

GREAT BARRIER REEF foundation · Australian Government Bureau of Meteorology · CSIRO · Australian Government Australian Institute of Marine Science · Queensland Government

Supported by funding from:

Caring for our Country · Queensland Government · Science and Industry Endowment Fund · bhpbilliton resourcing the future · BMA BHP Billiton Mitsubishi Alliance

Hydrodynamic Assessment.

Mike Herzfeld

April 2016

Calibration / validation strategy

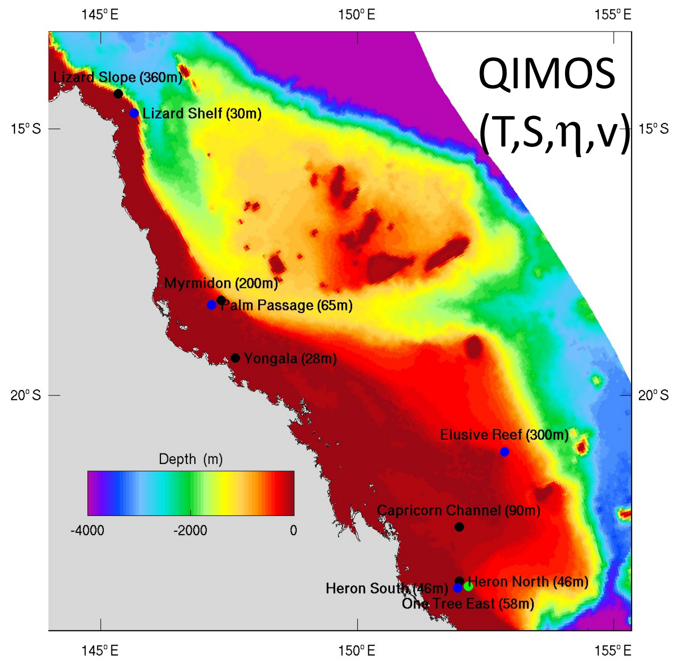
- GBR4 calibrated from Sep 2010 to June 2012 and validated from Jul 2012 to present.
- Uses:
  - Delayed mode and NRT data QIMOS data (T/S, ADCP),
  - Tide gauges,
  - Waverider buoys,
  - Satellite SST,
  - ARGO.
- Quantitative skill metrics used (RMSE, MAE, cc, bias, Willmott skill, d).

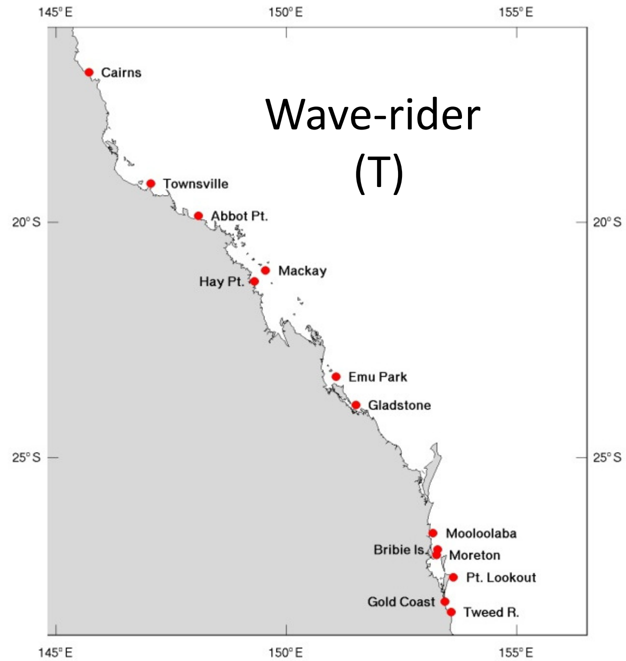
	Real-time	Temperature	Salinity	SSH	Velocity
IMOS delayed		x	x	x	x
Waverider	x	x			
Tide Gauge	x			x	
Argo	x	x	x		

Model configuration

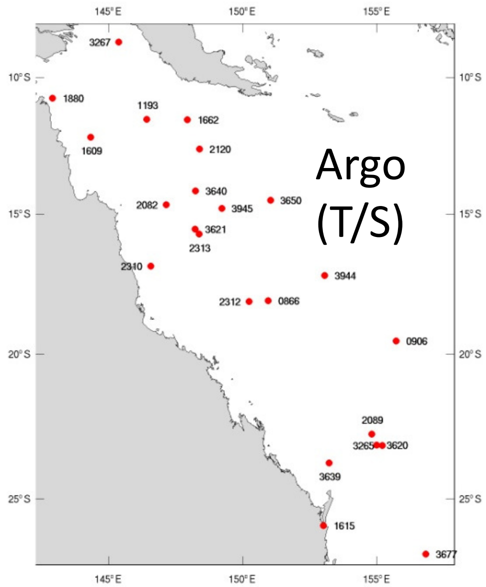
Parameter	Value
Turbulence closure	k-e
Background vertical viscosity	$1x10^{-4}$ m^2s^{-1}
Background vertical diffusivity	$1x10^{-5}$ m^2s^{-1}
Horizontal viscosity	Smagorinsky, c=0.1
Horizontal diffusivity	Smagorinsky, c=0.1
Horizontal advection	ULTIMATE QUICKEST
Time steps (3D/2D)	90 / 5 s
Bulk scheme	Kondo (1975)
Short wave attenuation	Spatially variable
Short wave transmission	Spatially variable
Short wave bottom absorption	Spatially variable
Open boundary scheme	Herzfeld & Andrewartha (2012)
Boundary relaxation timescale	Dual: 6s / default
Salinity input	Conservative: Flow dependent (Eq. 4.1)

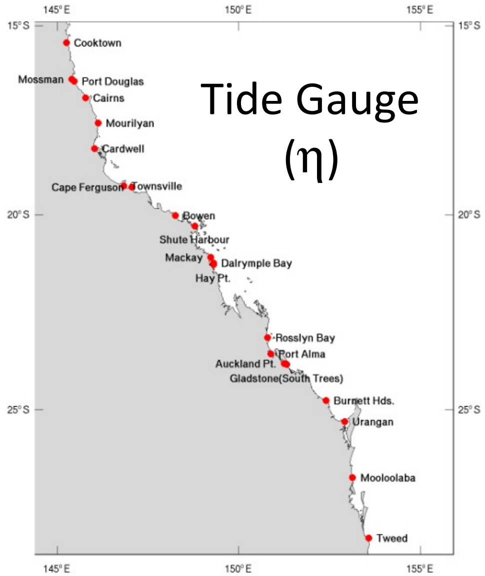
GBR Observation sites



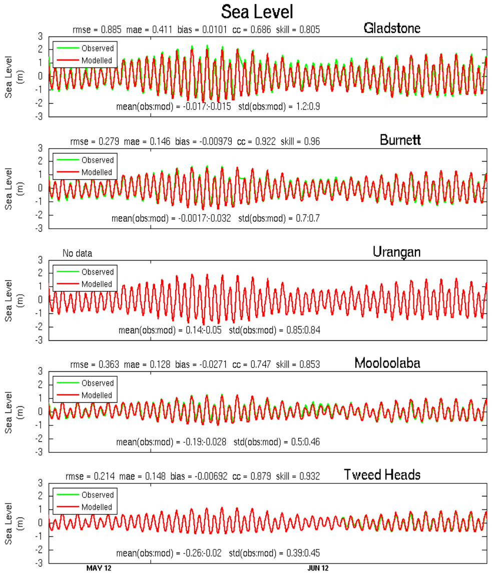


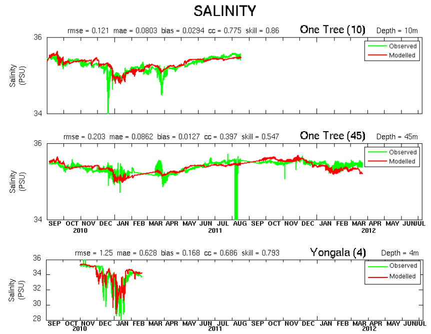
+ GHRSST

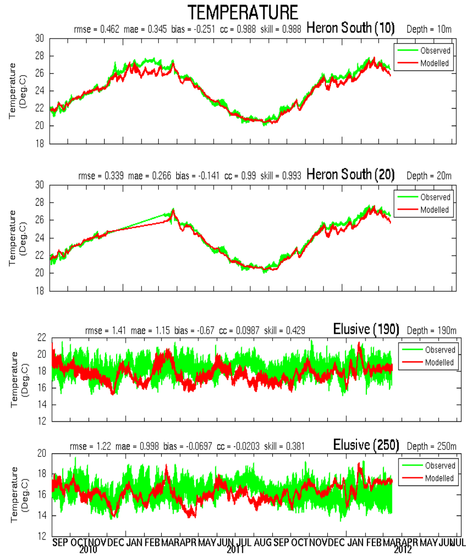


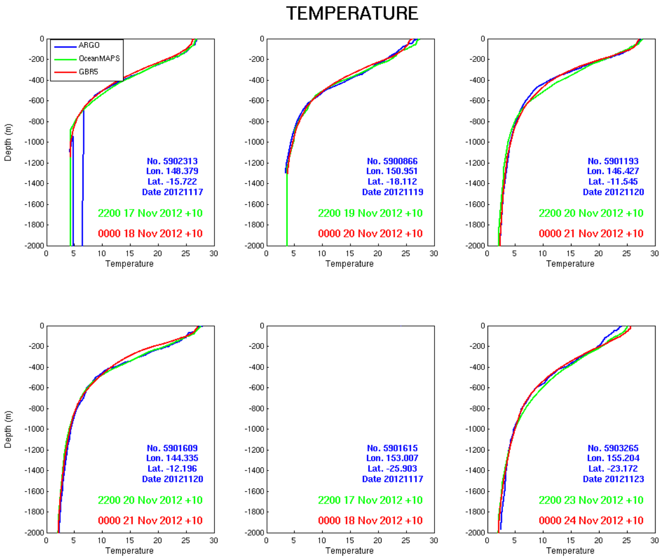


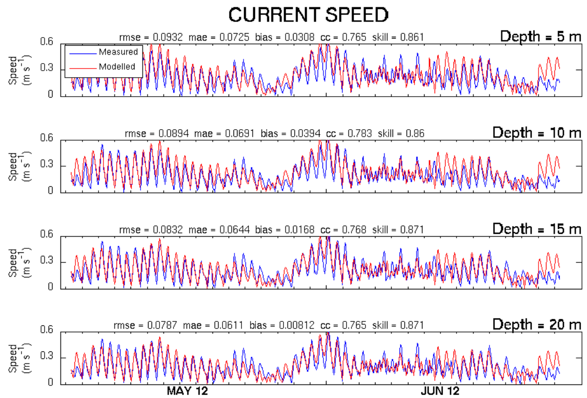
GBR4 Calibration – free running model

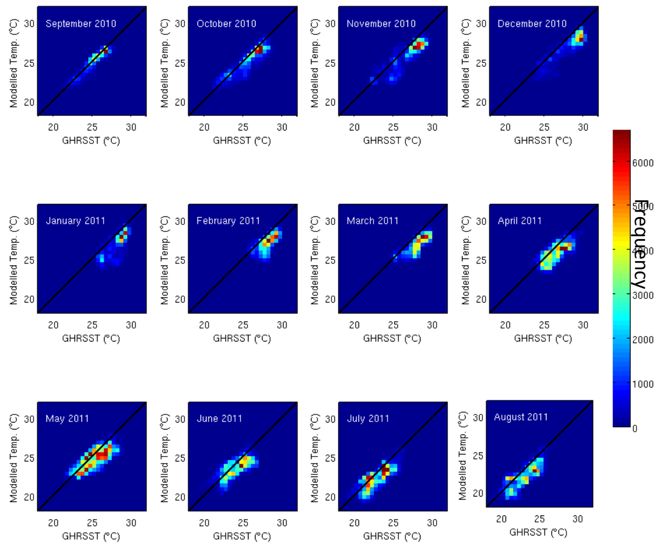




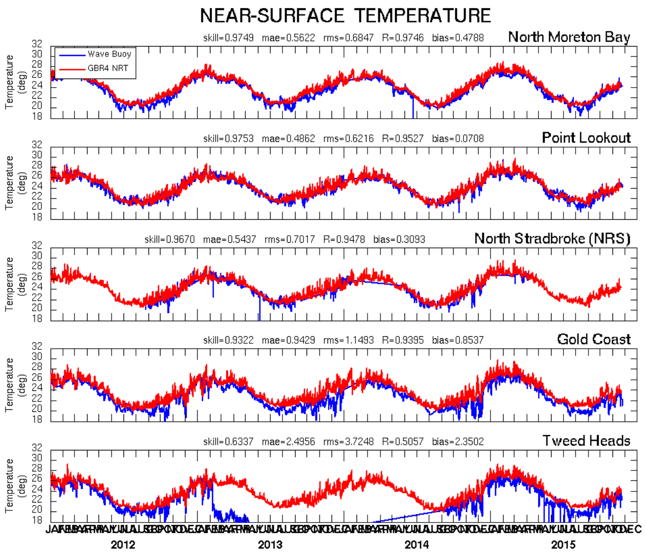


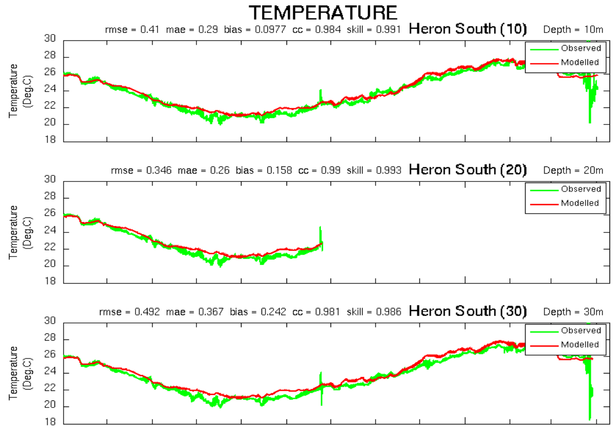


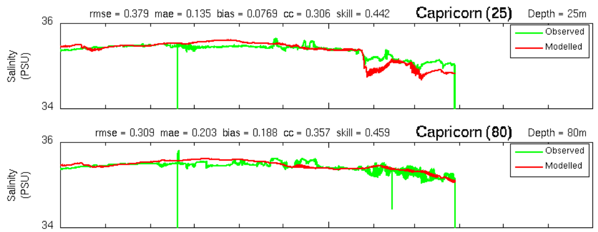


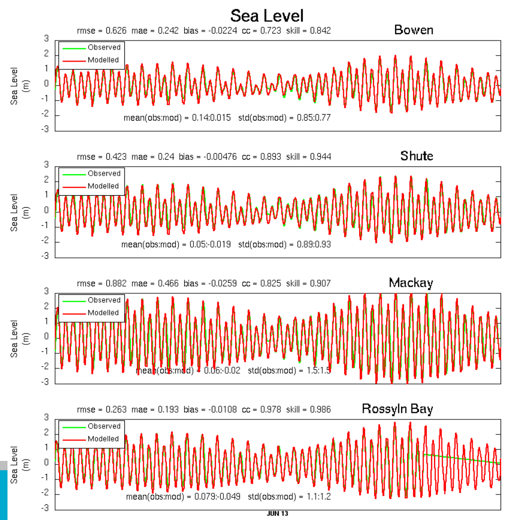


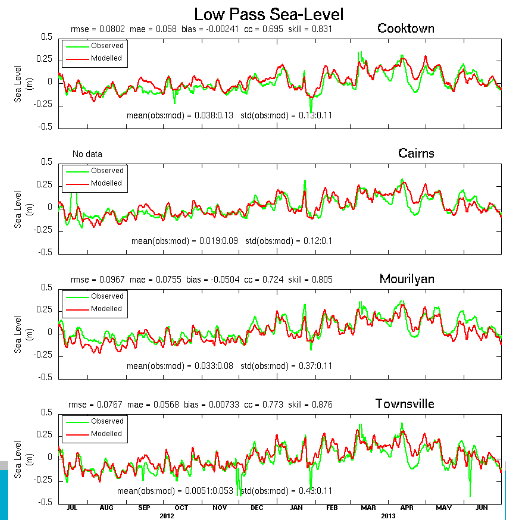
GBR4 validation











https://research.csiro.au/ereefs/models/model-outputs/gbr4/salinity-and-temperature/skill-assessment/

Mean skill across all sites

Calibration

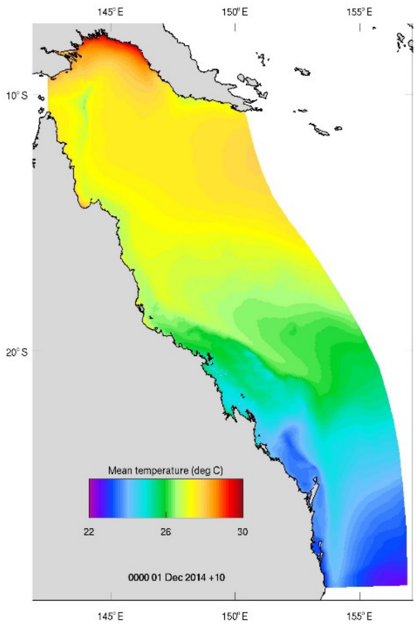
Variable	RMSE	MAE	cc	bias	skill
temp	0.76 °C	0.60 °C	0.81	-0.12 °C	0.86
salt	0.31 psu	0.20 psu	0.49	0.15 psu	0.56
η	0.48	0.21	0.83	-0.005	0.90
η_{low}	0.09	0.07	0.69	-0.002	0.81

Validation

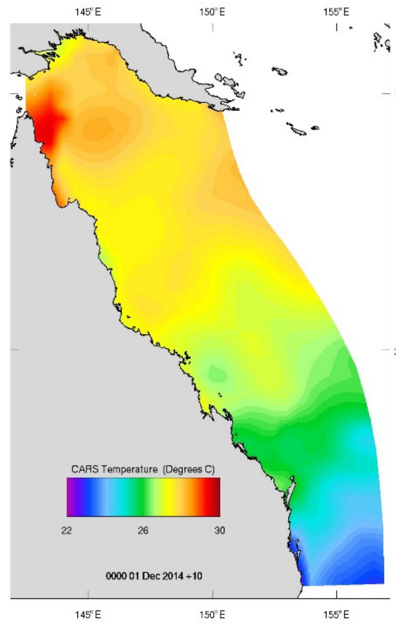
Variable	RMSE	MAE	cc	bias	skill
temp	0.90 °C	0.70 °C	0.78	-0.003 °C	0.83
salt	0.57 psu	0.19 psu	0.42	0.08 psu	0.51
η	0.45	0.20	0.85	-0.002	0.92
η_{low}	0.09	0.07	0.69	0.007	0.79

Climatology - temperature

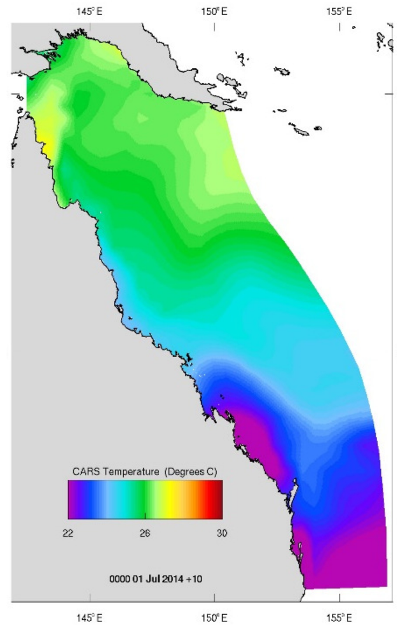
GBR4

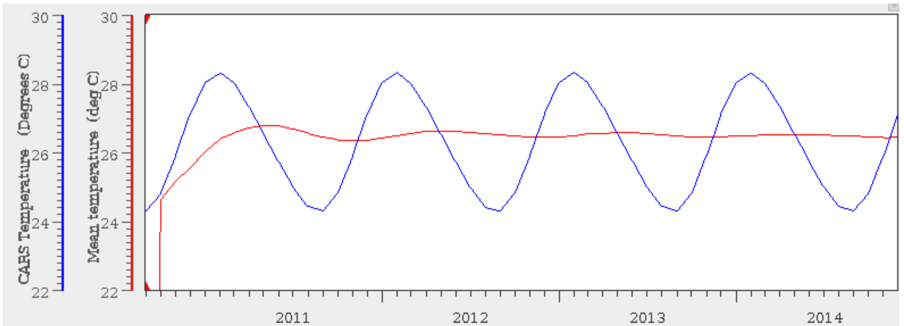


CARS summer



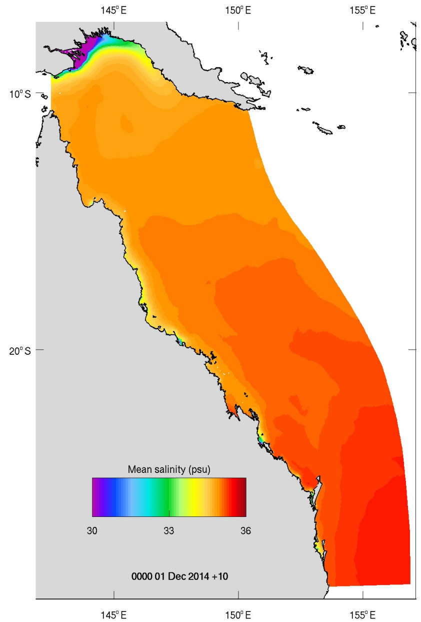
CARS winter



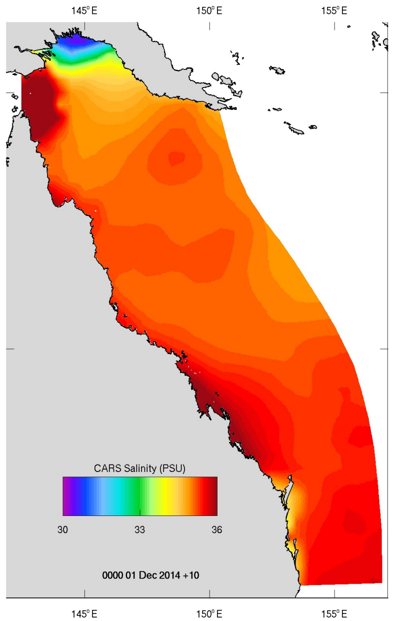


Climatology - salinity

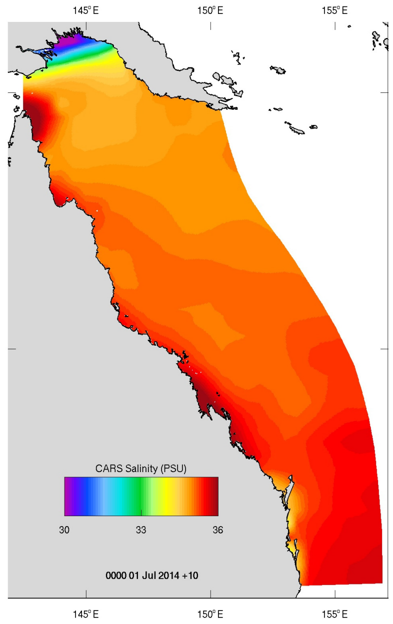
GBR4

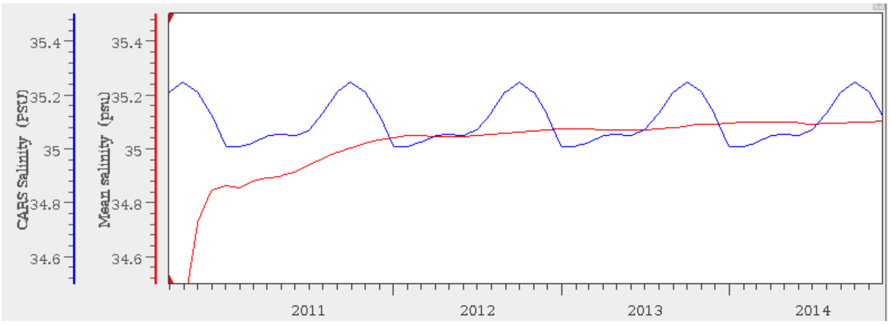


CARS summer

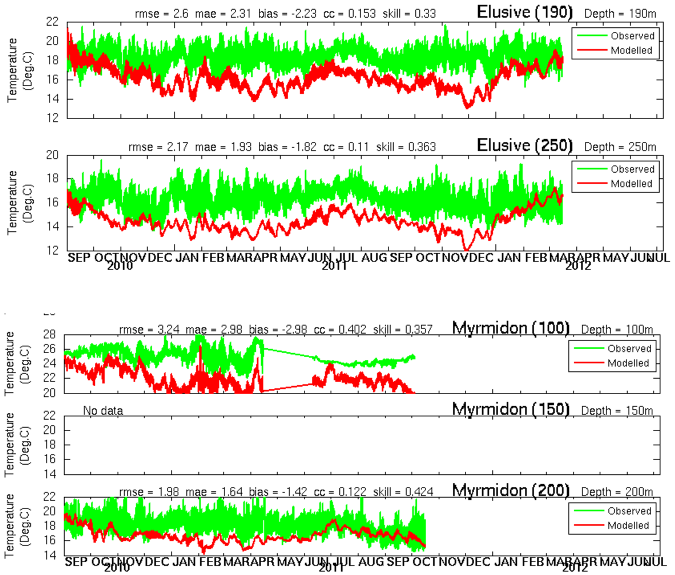


CARS winter

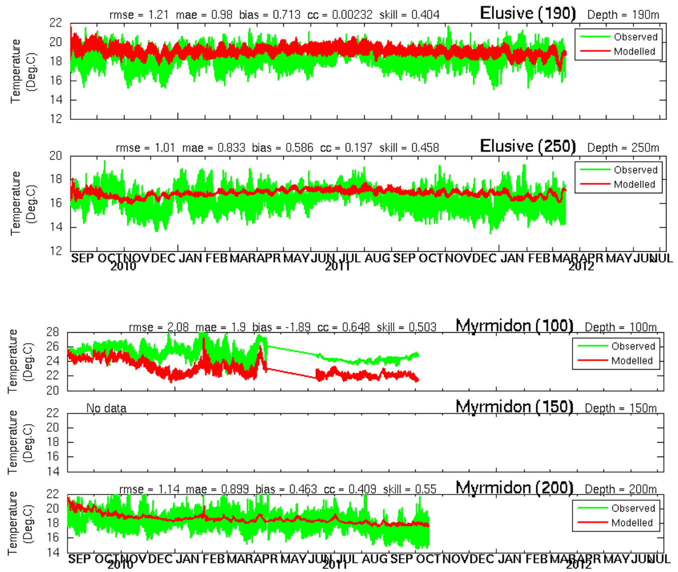




Impact of boundary forcing data

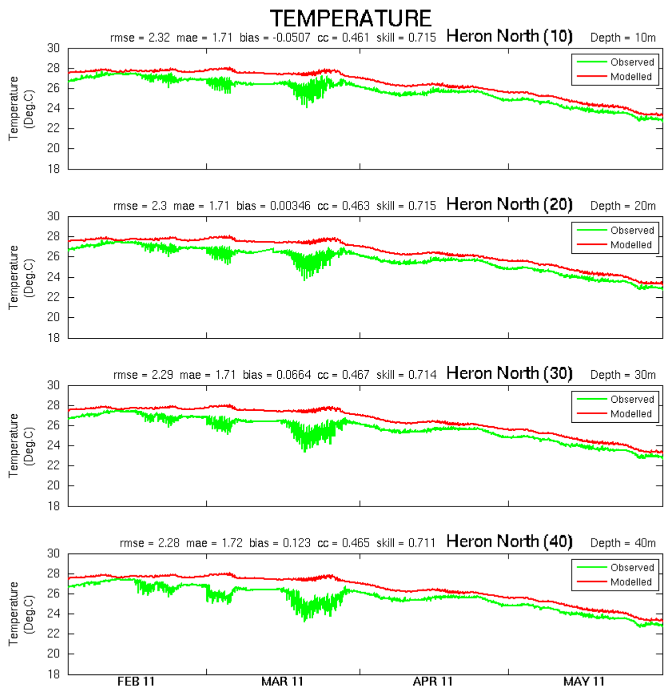


OceanMAPS

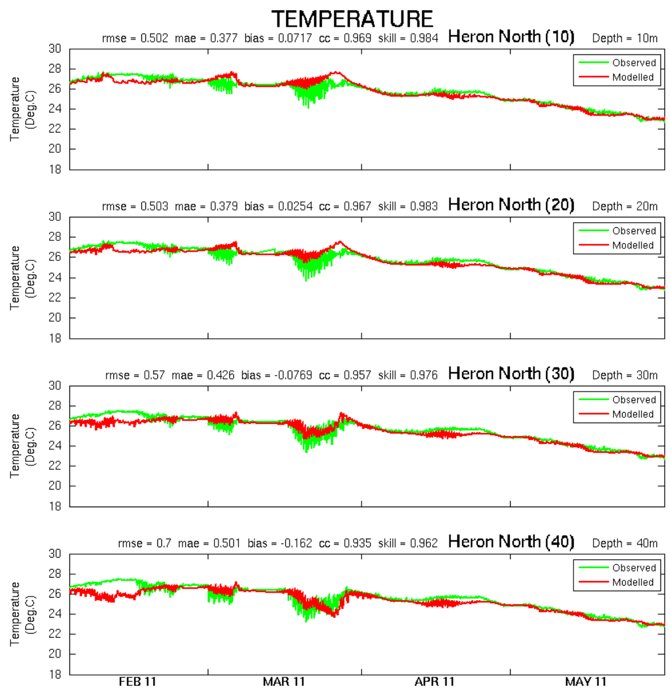


BRAN3.5

Short wave parameters

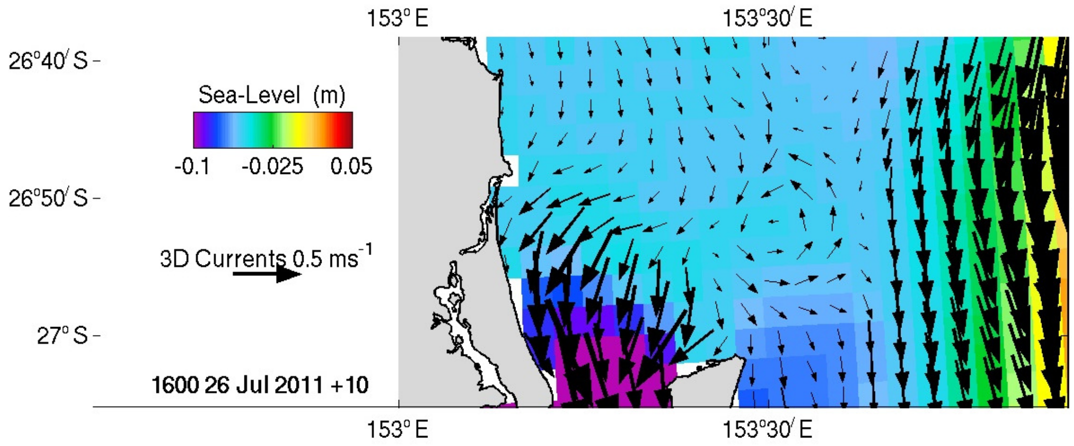


Constant parameters

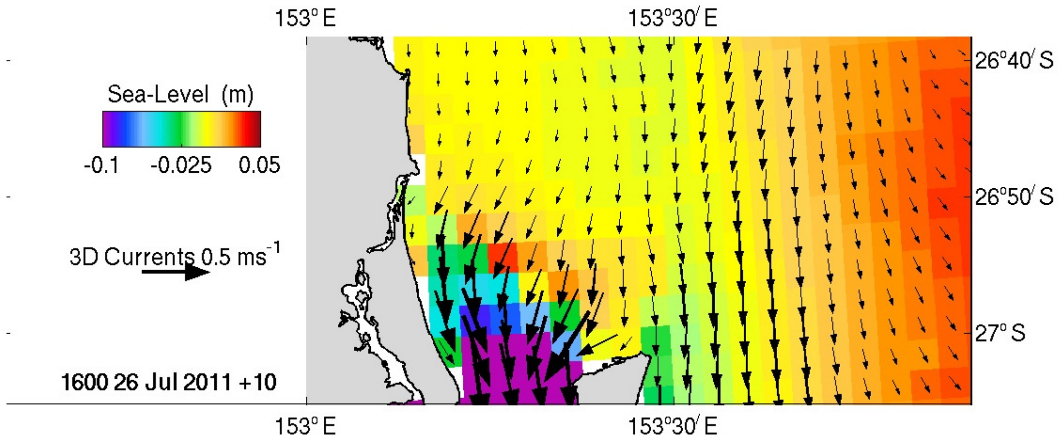


DA estimated parameters

Horizontal mixing sensitivity

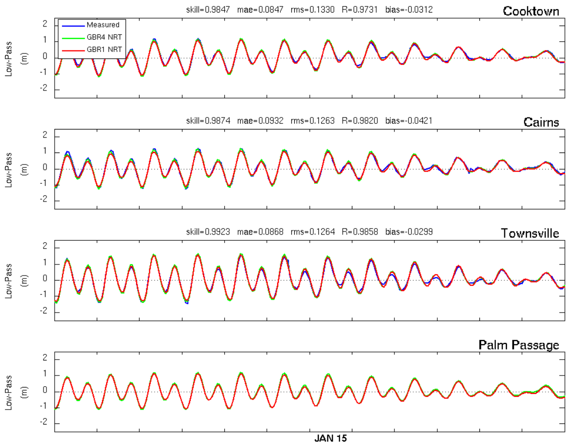


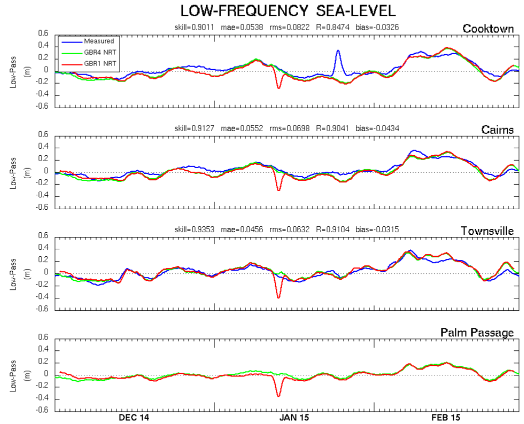
Smagorinsky mixing

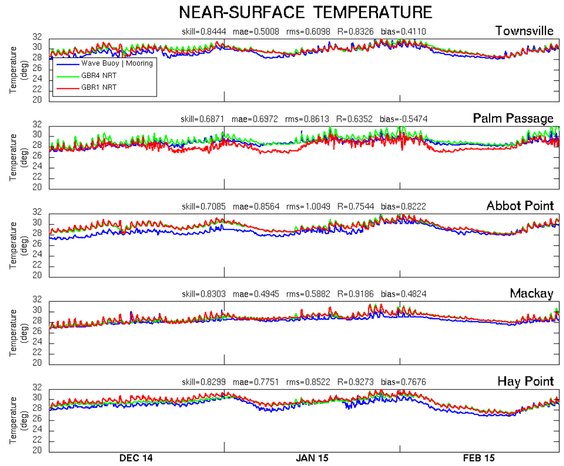


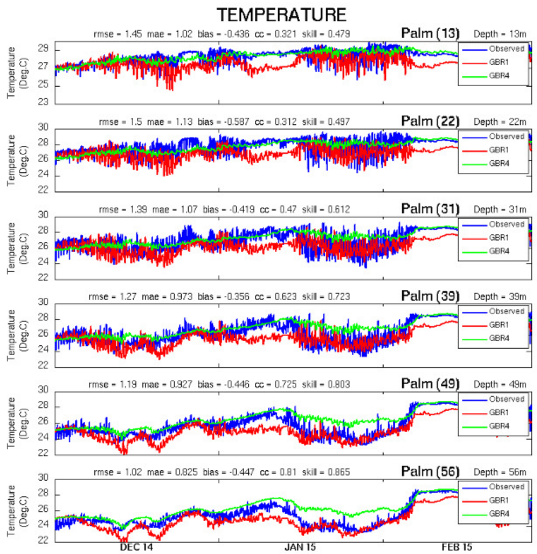
Constant mixing

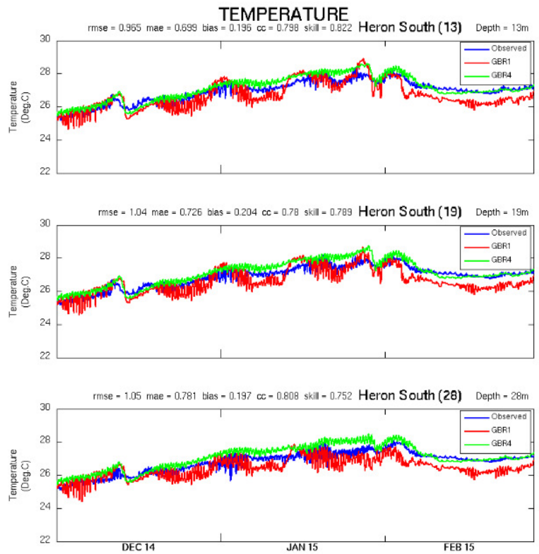
GBR1 calibration





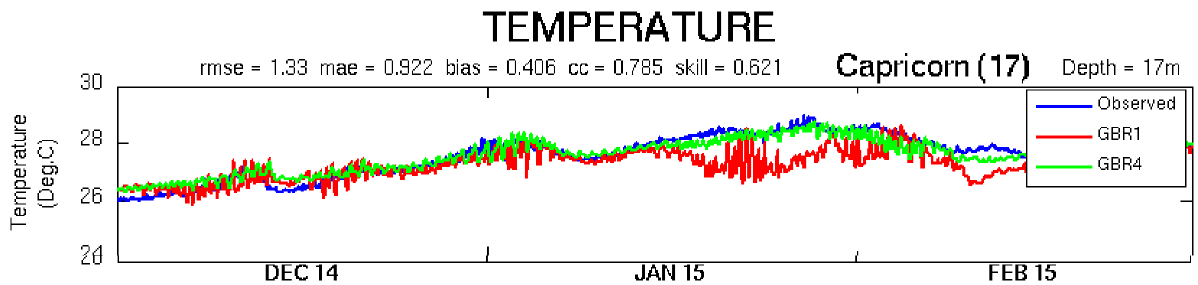


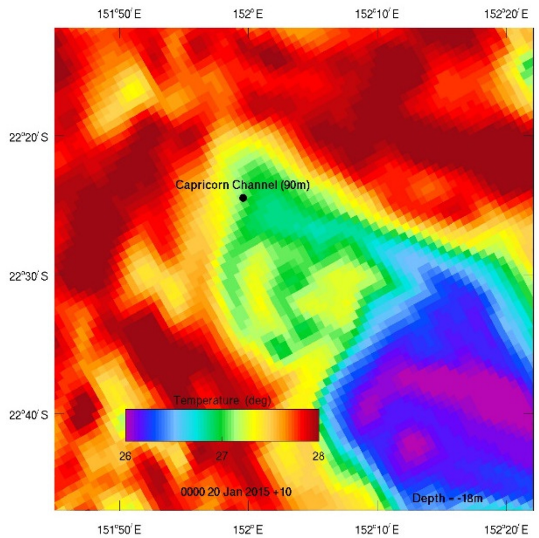




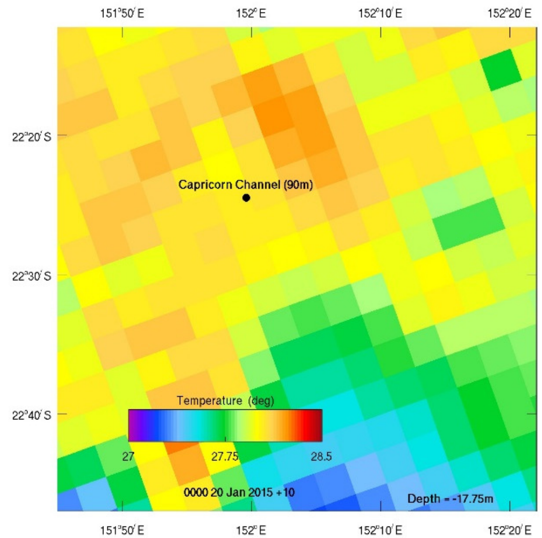
https://research.csiro.au/ereefs/models/model-outputs/gbr1/salinity-and-temperature/skill-assessment/

Issues with comparison at high resolution





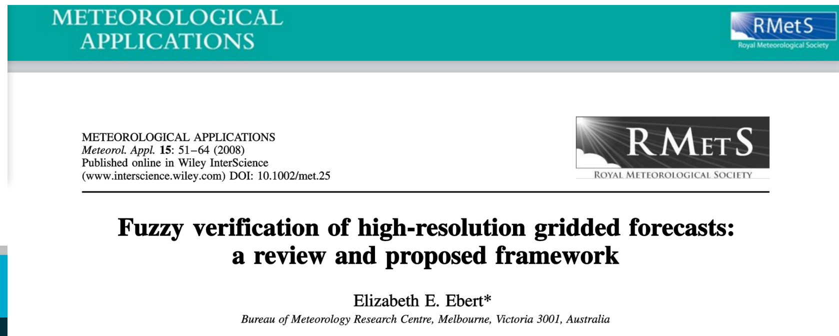
GBR1 temperature @ 18m



GBR4 temperature @ 18m

Issues with comparison at high resolution

- Traditional skill metrics are no longer indicative of true model skill as small scale features become more prevalent.
- Small offsets in position of a feature are penalized as severely as if the feature were absent.
- ‘Double penalty’ (observed-but-not-forecast and forecast-but-not-observed) more prevalent at high resolution.
- Long acknowledged in the meteorological community;
  - Neighbourhood techniques and developed to overcome the issue.
  - Look for agreement in a spatial neighbourhood of the point of interest.
  - Categorical metrics used to assess skill.



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Fuzzy verification of high-resolution gridded forecasts: a review and proposed framework

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Categorical metrics target specific skill characteristics

Table I. Characteristics of several fuzzy verification methods. A decision rule of ' – ' indicates that the method does not use neighbourhood events. The metrics are defined in the Appendix unless otherwise indicated.

Fuzzy method	Matching strategy[a]	Decision model	Quantities compared	Decision rule for event $\langle I \rangle_s$	Original metrics
Upscaling (Zepeda-Arce *et al.*, 2000; Weygandt *et al.*, 2004; Yates *et al.*, 2006)	NO-NF	Useful forecast resembles the observations when averaged to coarser scales	$\langle I_x \rangle_s, \langle I_y \rangle_s$	$\langle I \rangle_s = \begin{cases} 0 & \langle \overline{Y} \rangle_s < \text{threshold} \\ 1 & \langle \overline{Y} \rangle_s \geq \text{threshold} \end{cases}$	BIAS, TS, ETS
Minimum coverage (Damrath, 2004)	NO-NF	Useful forecast predicts the event over a minimum fraction of the region of interest	$\langle I_x \rangle_s, \langle I_y \rangle_s$	$\langle I \rangle_s = \begin{cases} 0 & \langle P \rangle_s < P_e \\ 1 & \langle P \rangle_s \geq P_e \end{cases}$	POD, FAR, ETS
Fuzzy logic (Damrath, 2004), joint probability (Ebert, 2002)	NO–NF	Useful forecast is more correct than incorrect	$\langle I_x \rangle_s, \langle I_y \rangle_s$	$\langle I \rangle_s = \langle P \rangle_s$	POD, FAR, ETS
Multi-event contingency table (Atger, 2001)	SO-NF	Useful forecast predicts at least one event close to an observed event	$I_x, \langle I_y \rangle_s$	$\langle I \rangle_s = \begin{cases} 0 & \langle P \rangle_s < P_e \\ 1 & \langle P \rangle_s \geq P_e \end{cases}$	ROC, V
Intensity-scale (Casati *et al.*, 2004)	NO-NF	Useful forecast has structure that is more accurate than a random arrangement of the observations	I_x, I_y	–	SS
Fractions skill score (Roberts and Lean, 2007)	NO-NF	Useful forecast has similar frequency of forecast events and observed events	$\langle P_x \rangle_s, \langle P_y \rangle_s$	–	FSS (refer to text)
Pragmatic (Theis *et al.*, 2005)	SO-NF	Useful forecast has a high probability of detecting events and non-events	$I_x, \langle P_y \rangle_s$	–	BS, BSS
Practically perfect hindcast (Brooks *et al.*, 1998)	SO-NF	Useful forecast resembles one that would have been issued by a forecaster given perfect knowledge of the observations beforehand	$I_x, \langle I_y \rangle_s\ I_x, \langle I_x \rangle_s$	$\langle I \rangle_s = \begin{cases} 0 & \langle P \rangle_s < \langle P \rangle_{s,\text{optimal}} \\ 1 & \langle P \rangle_s \geq \langle P \rangle_{s,\text{optimal}} \end{cases}$	TS_x, TS_y
Conditional square root of RPS (Germann and Zawadzki, 2004)	SO-NF	Useful forecast has a high probability of matching the observed value	$I_x, \langle P_y \rangle_s$	–	CSRR (refer to text)
Area-related RMSE (Rezacova *et al.*, 2007)	NO-NF	Useful forecast has a similar distribution of intensities as the observations	ordered X, ordered Y	–	RMSE

[a] NO-NF, 'neighbourhood observation-neighbourhood forecast'; SO-NF, 'single observation-neighbourhood forecast'.

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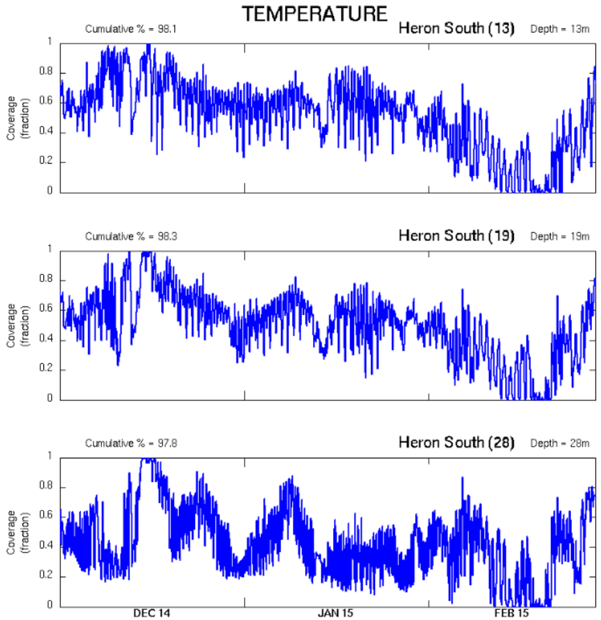
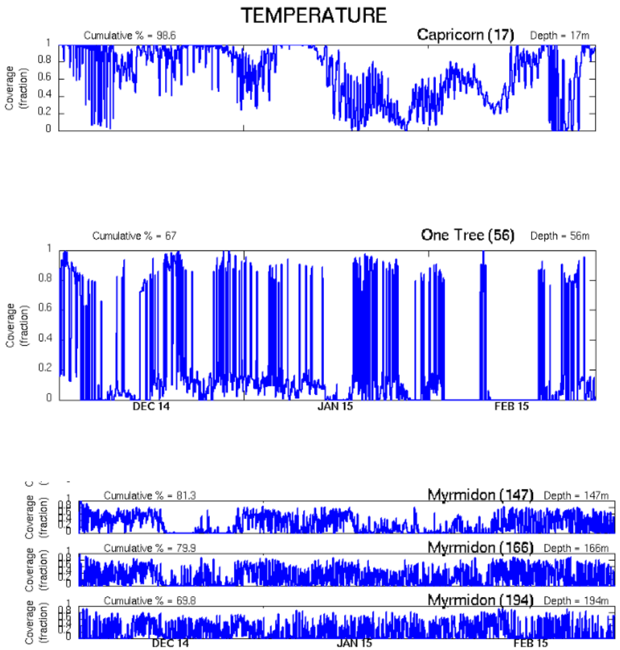
Example – Minimum coverage metric





Minimum coverage metric for temperature using a neighbourhood size of 31 km and model-observation difference threshold of 0.5°C

GBR1 skill summary - temperature

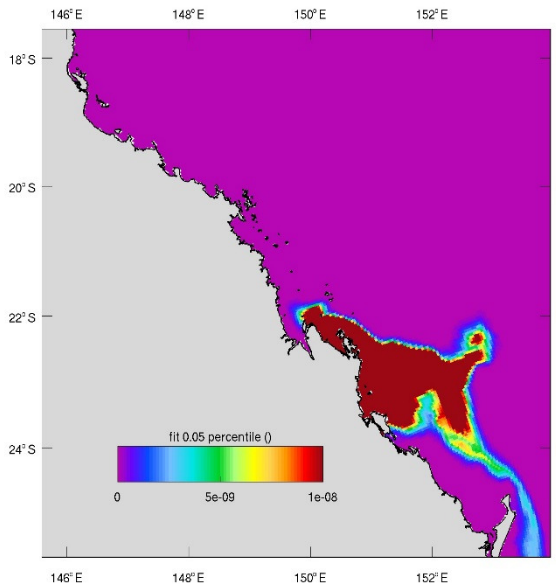
	d	RMSE	CC	Bias	MAE
GBR1 Wave-rider	0.82	0.79	0.84	0.28	0.65
GBR4 Wave-rider	0.82	0.89	0.88	0.72	0.77
GBR1 QIMOS	0.61	1.4	0.52	-0.55	1.1
GBR1 $QIMOS_{NH}$	0.9	0.48	0.91	0.24	0.28

$QIMOS_{NH}$ uses best fit neighbourhood within the decorrelation length scale (30 km)

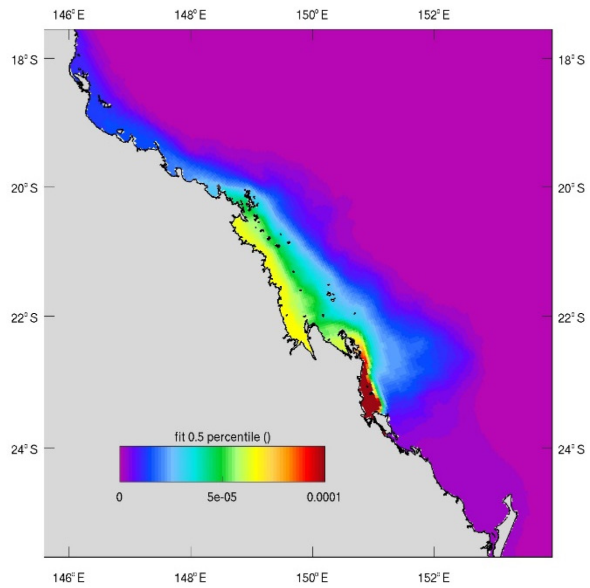
Catchment connectivity

- Input a unit flux at each river input in the domain,
- Run the model for 4 years,
- Post-process the order statistic distributions of tracer,
- Provides median spatial distribution of tracer from each catchment,
- Provides magnitude of tracer that is scalable to the input flux,
- Provides variability estimates of the distributions (e.g. 5, 95-%ile distributions).

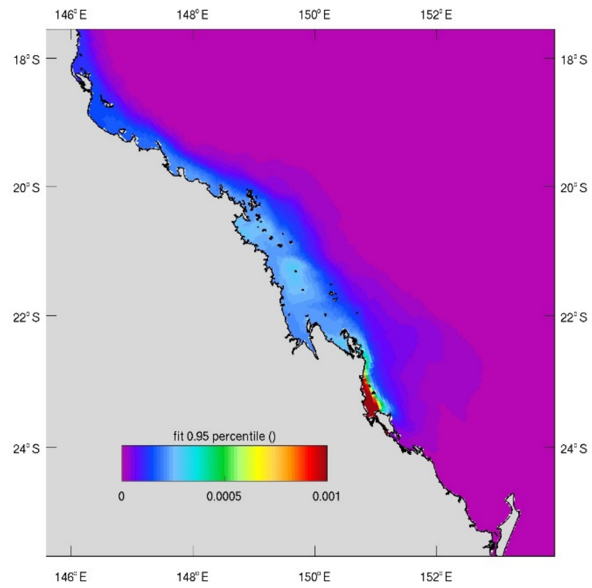
Example – Fitzroy distribution



5-%ile distribution

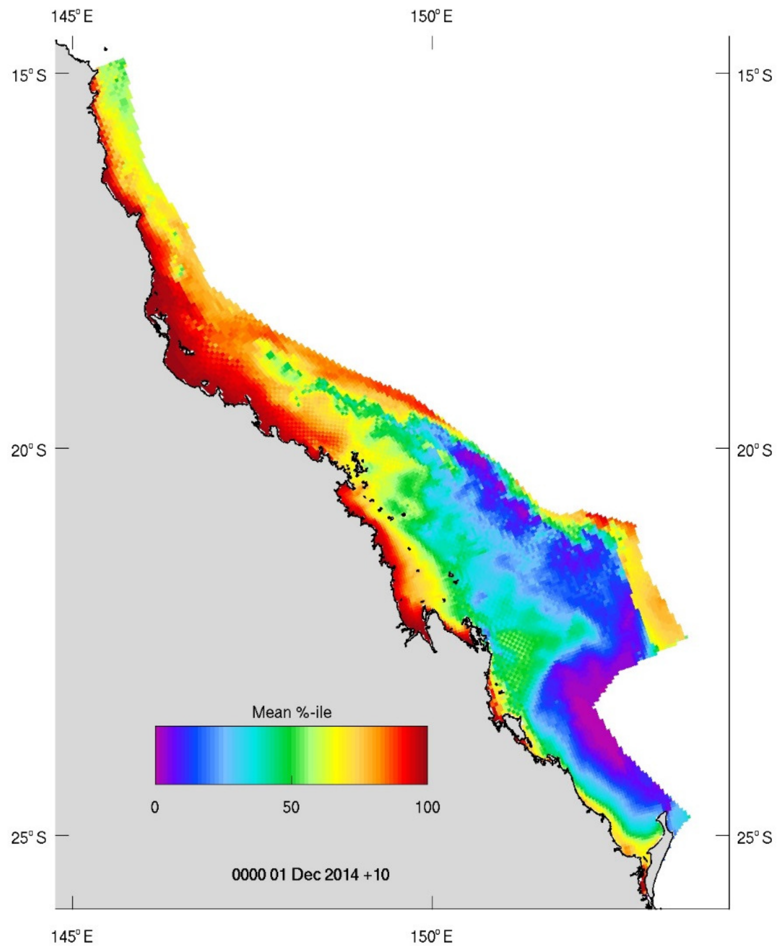


Median distribution



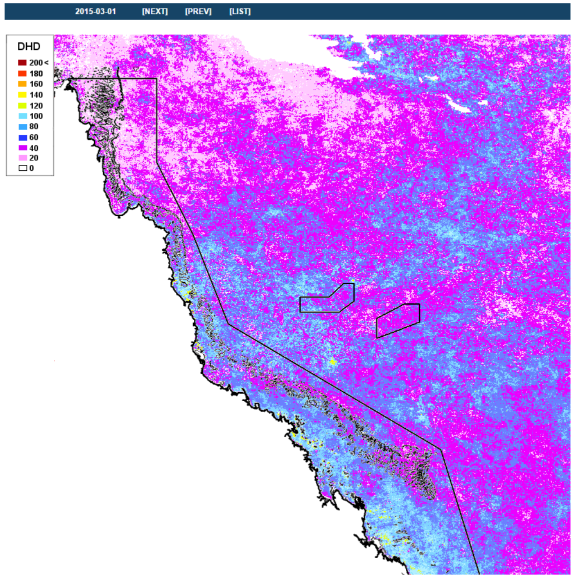
95-%ile distribution

Spatial order statistics

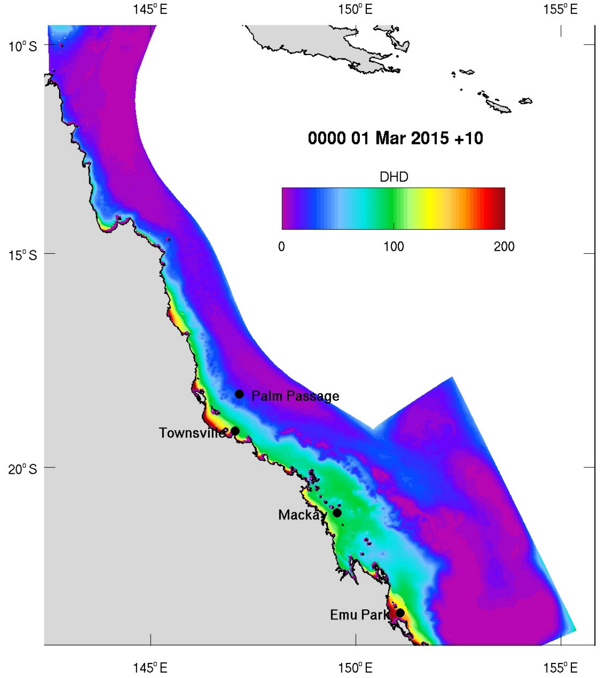


Mean temperature %-ile distribution 2010-2014

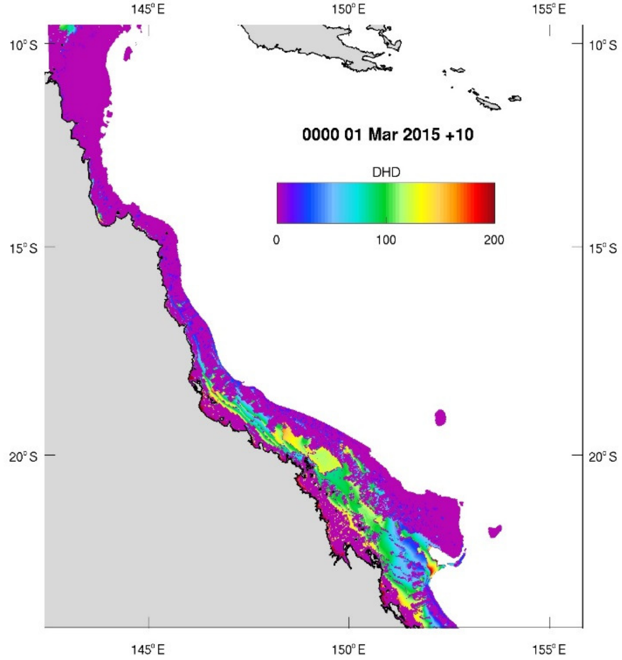
Temperature exposure



ReefTemp for 2015

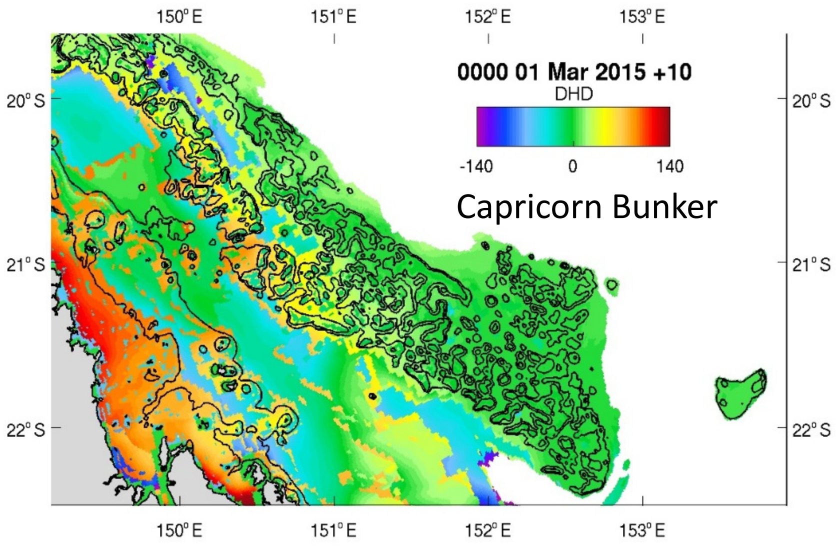


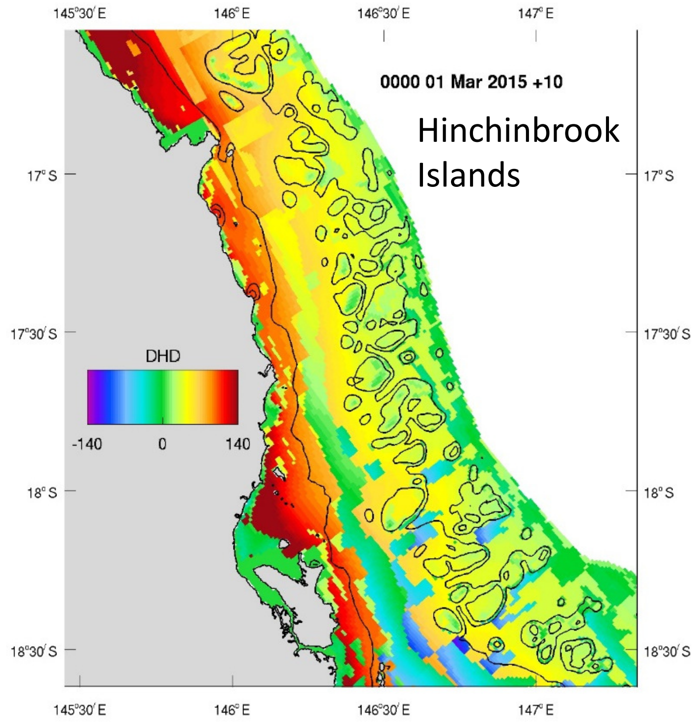
Surface GBR1 for 2015

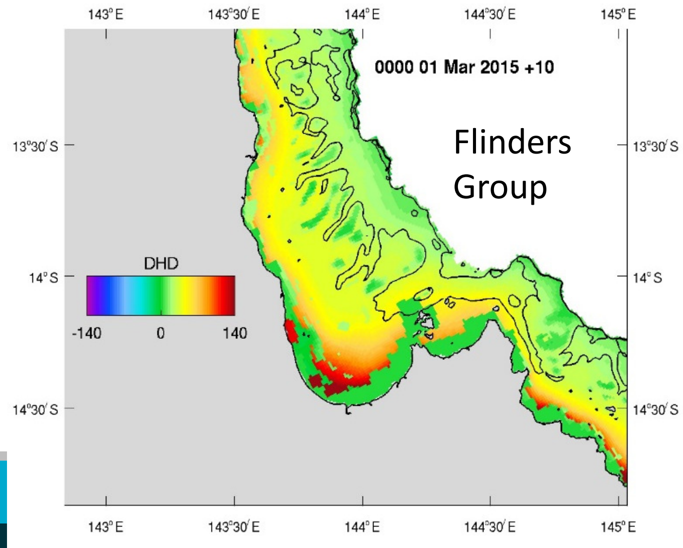


Bottom GBR1 for 2015

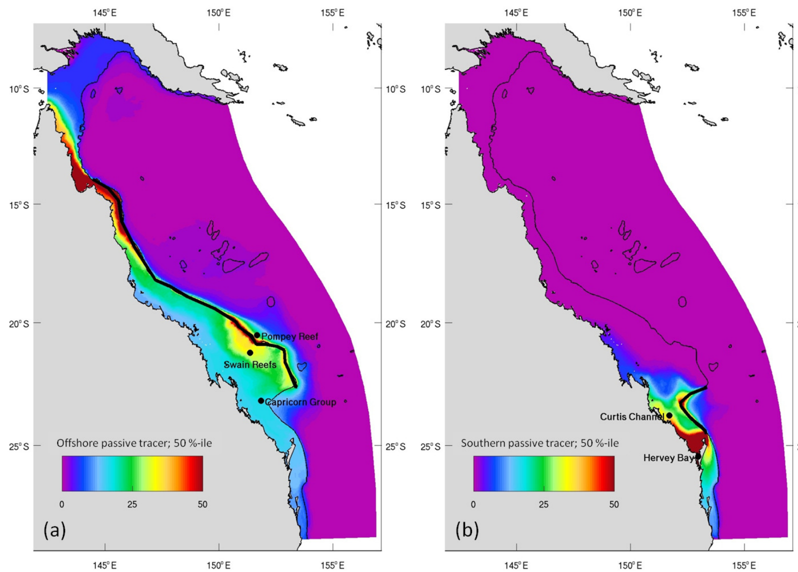
Exposure difference (top – bottom)



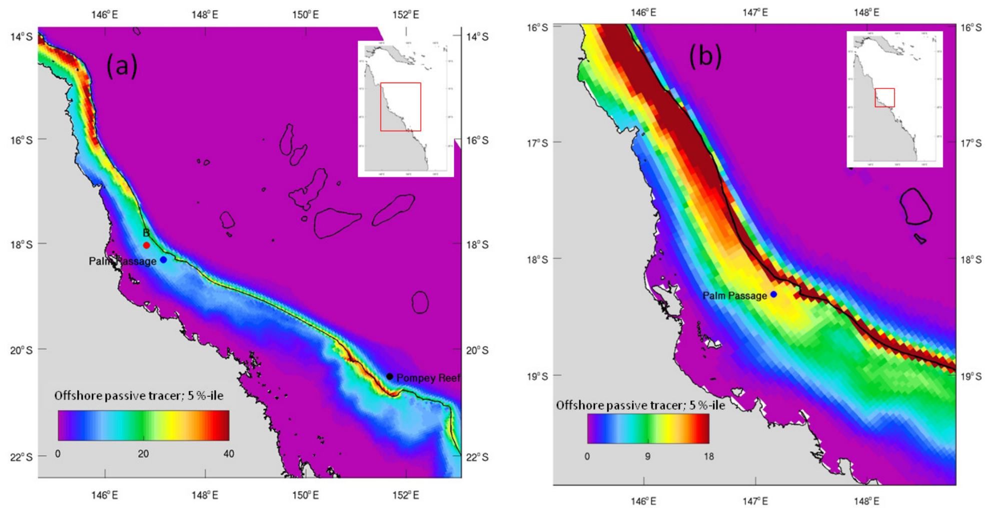




Coral Sea connections

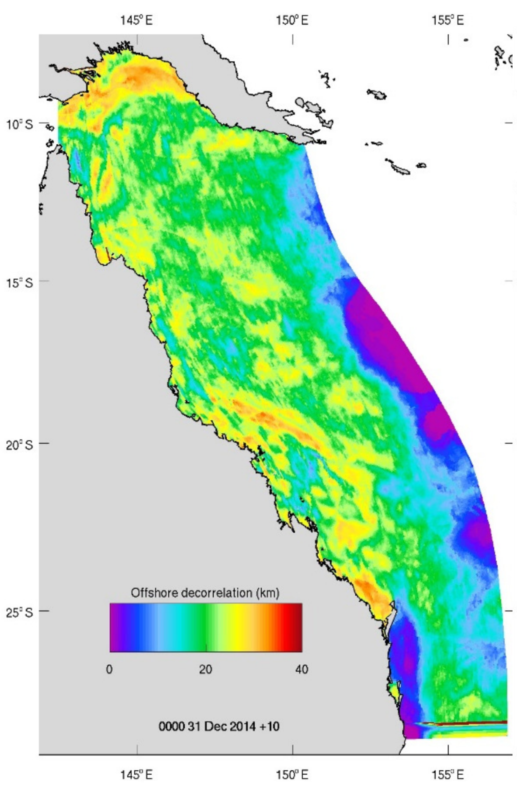


Median distributions due to offshore and southern tracer curtain releases

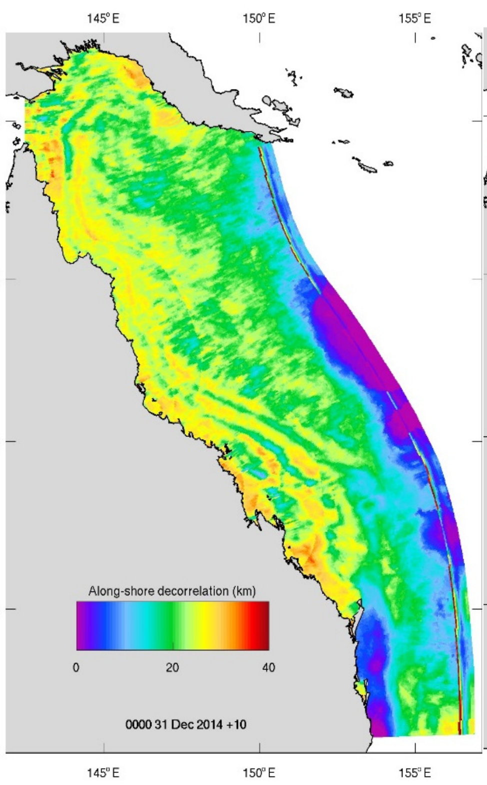


5 percentile distributions due to offshore tracer curtain releases

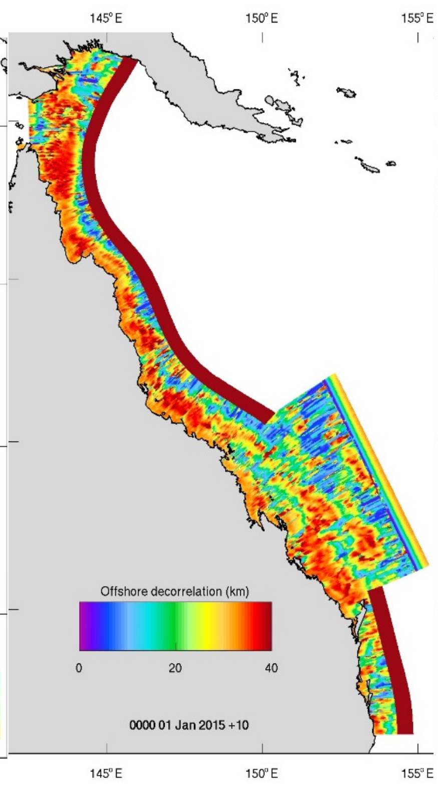
Decorrelation length scales



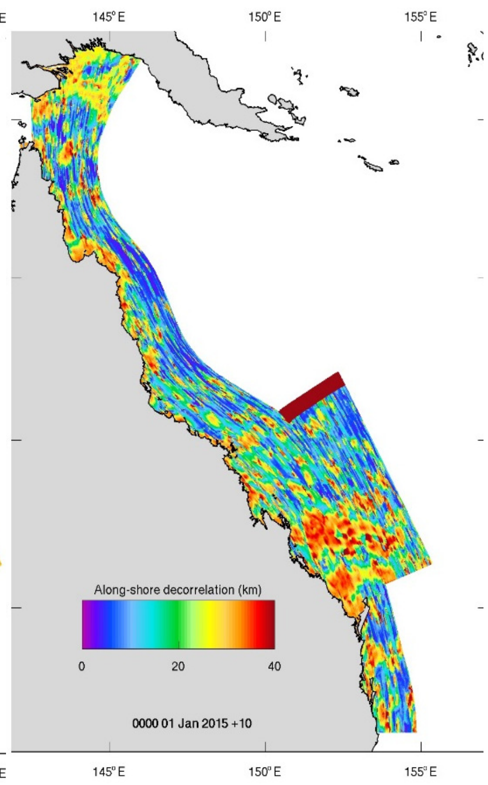
GBR4 offshore



GBR4 alongshore



GBR1 offshore



GBR1 alongshore

Submesoscale coherent vortices

- Small scale features characterized by:
  - Strong horizontal density gradients,
  - Strong vertical velocity and vorticity,
  - Horizontal scales of 10s metres to 10s kms
  - Lifetimes of hours to days.
  - Not in geostrophic or hydrostatic balance
  - Good overview in *http://carthe.org/tutorials_pdf/2013_10/McWilliams_Jim_Oceanic_Phenomena_and_Dynamics_at_the_Submesoscale.pdf*

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Submesoscale, Coherent Vortices in the Ocean

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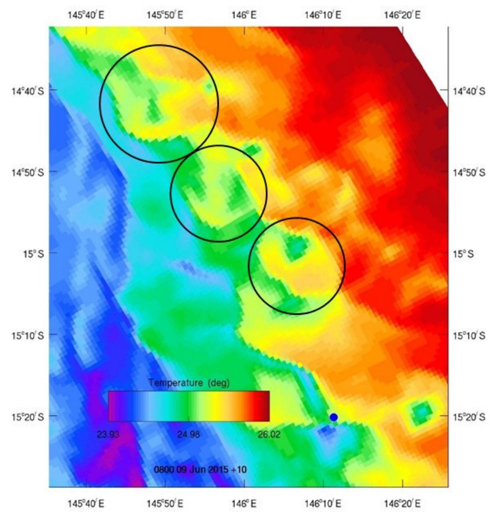
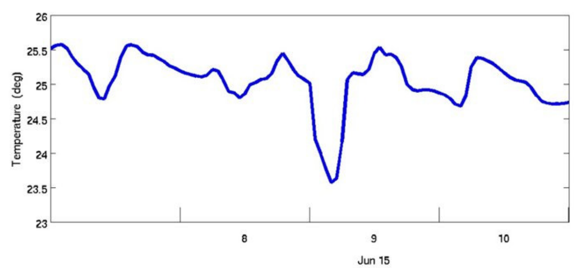
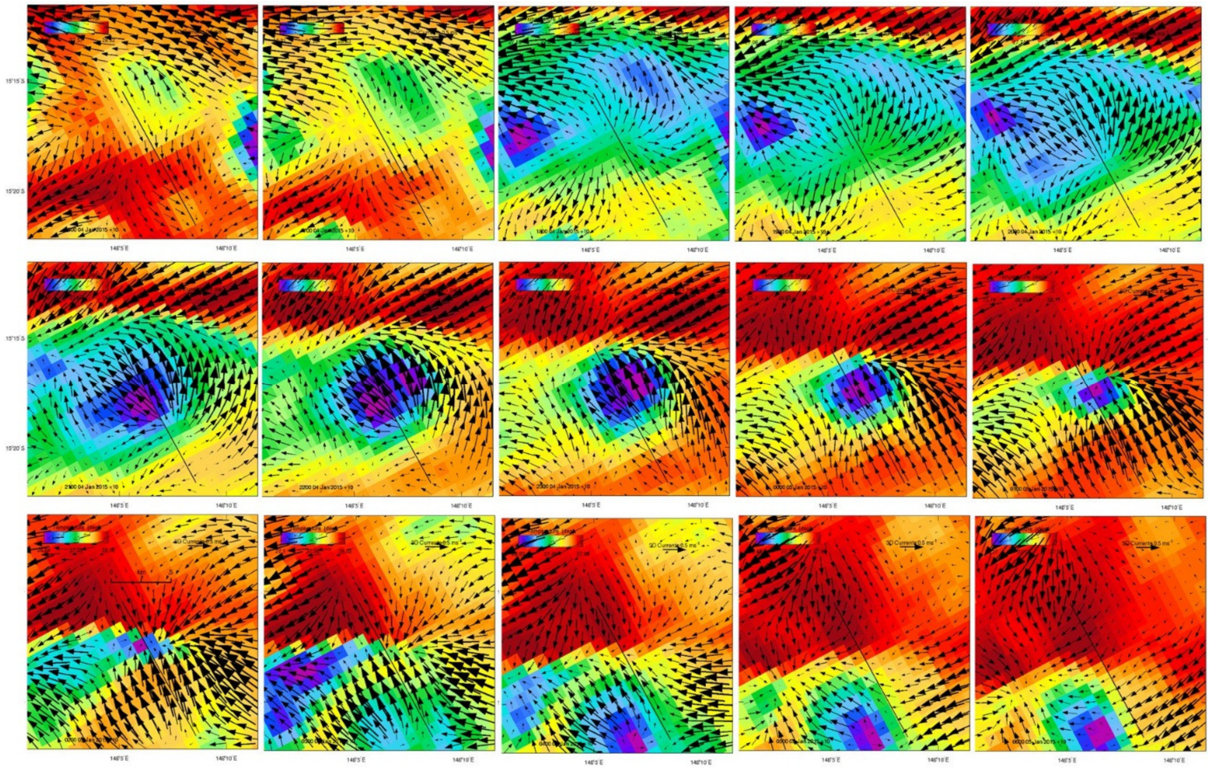
- Observed in the mean flow in GBR1 at the edge of the EAC.

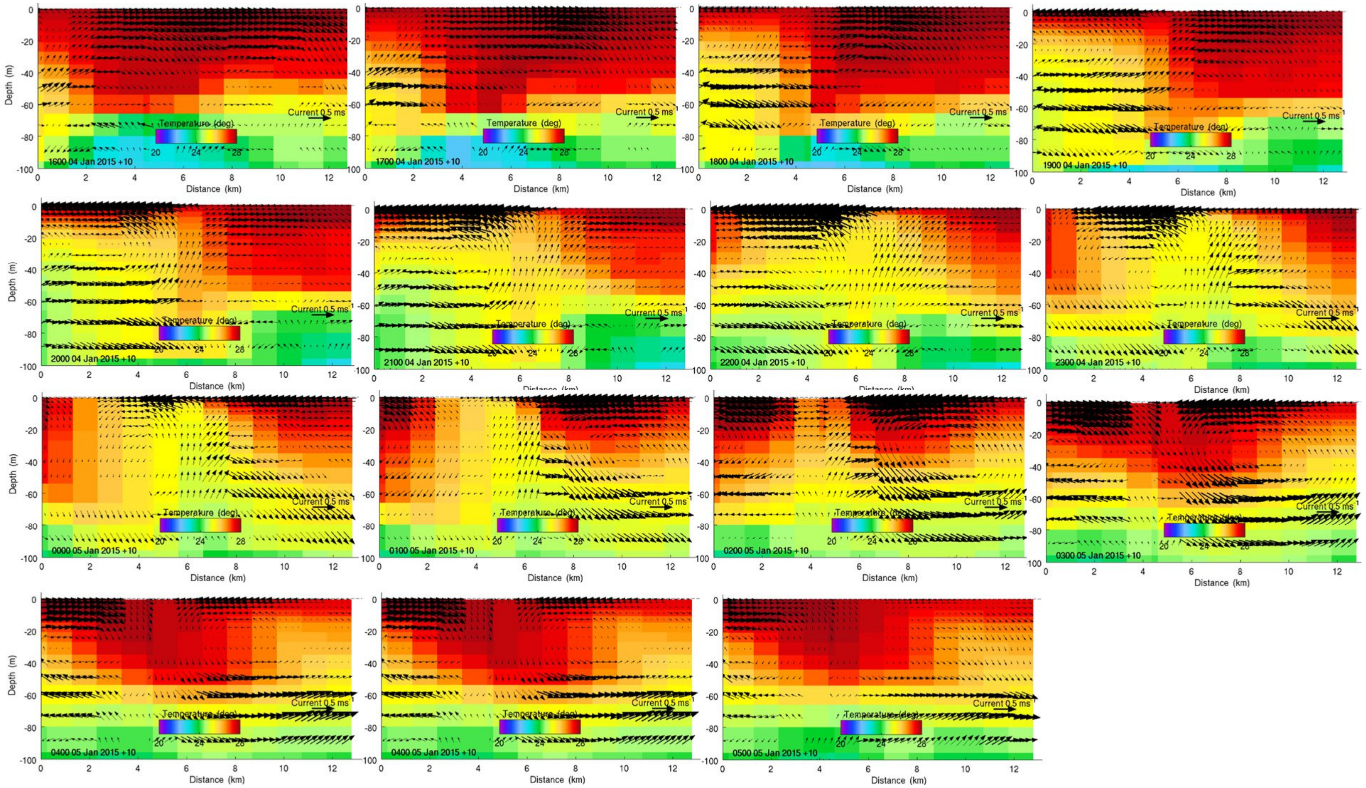




Evolution of a SCV in GBR1



Evolution in cross section



Conclusions

- GBR4 is fit for purpose to investigate broad scale phenomena, and use as a nesting vehicle for GBR1 or RECOM.
- GBR1 is fit for purpose to investigate regional phenomena (e.g. catchment or reef connectivity) and use as a nesting vehicle for RECOM.
- Neither model has sufficient resolution to study individual reefs or catchments – RECOM is appropriate for this.
- These models assist with placing supplementary information in context (e.g. observations) and should not be used in isolation (i.e. should continue to be benchmarked against observation).
- These models provide new insight into the state of the GBR and its dynamical interactions that may be leveraged to improve on-going initiatives (e.g. targeted observation design).
- The model is not perfect or static, and should evolve with availability of observations and process understanding.

Thank you

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