Circulation on the eastern Tasmanian continental shelf: The mean state and seasonal cycle

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Special acknowledgements to:
Mike Herzfeld, Mark Baird, John Andrewartha, Farhan Rizwi (CSIRO, EMS Team)
Jessica Benthuysen (AIMS)
Craig Mundy (IMAS-FAC)

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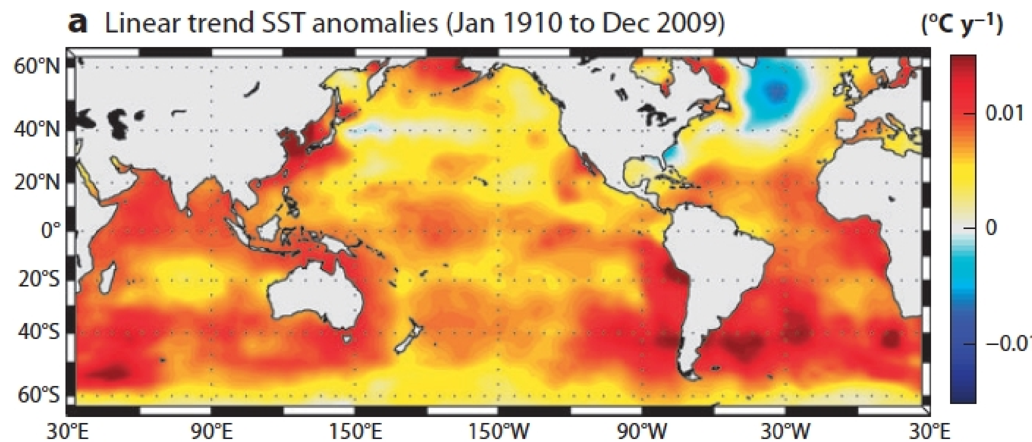
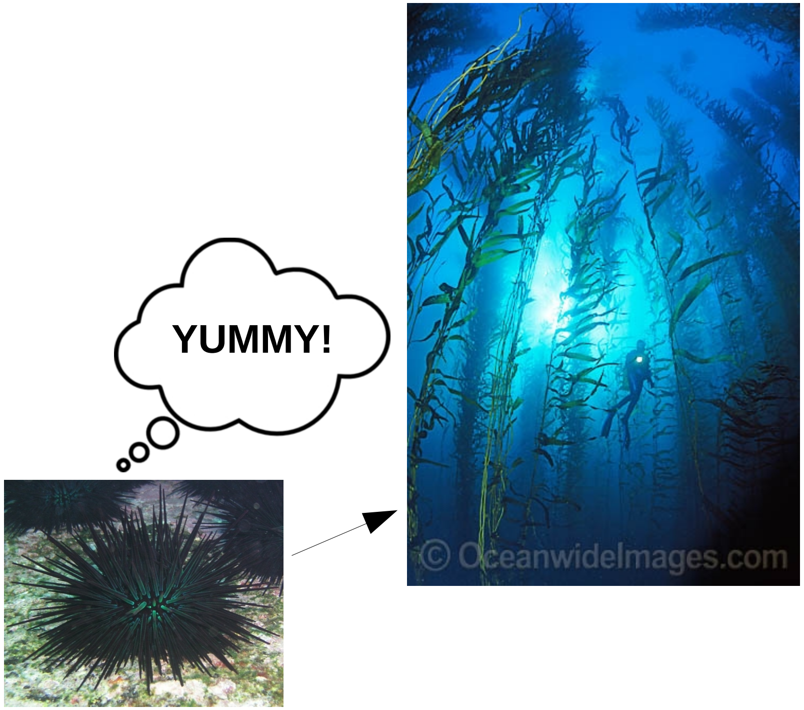
Overview

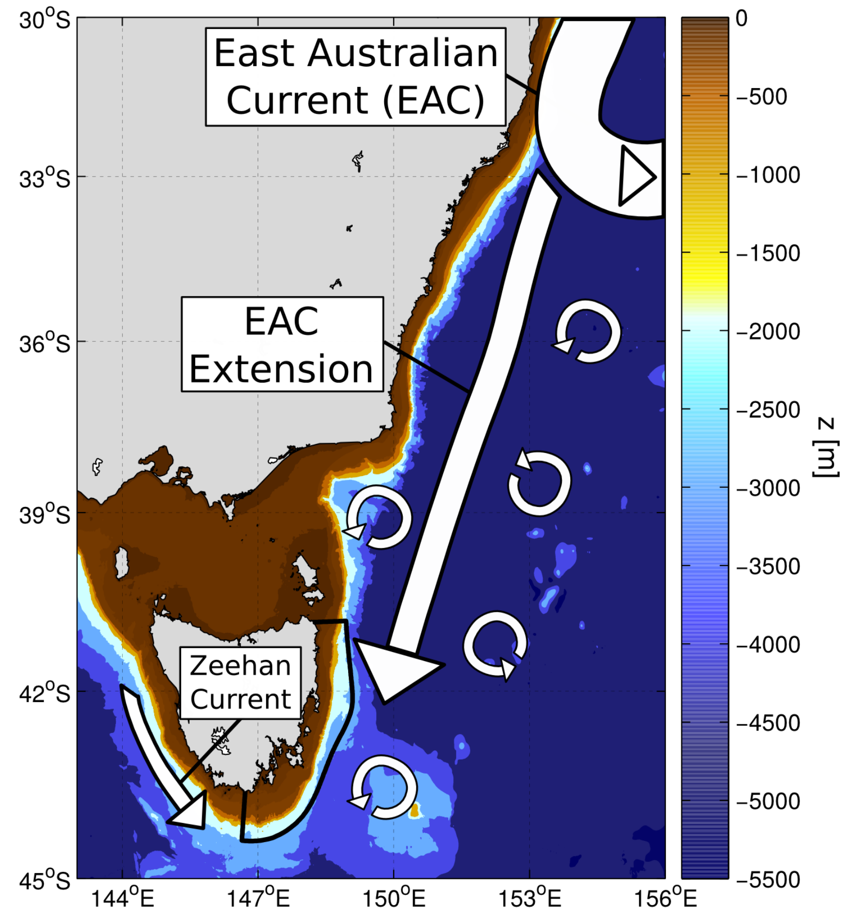
- Global marine climate is **warming**
- The SW Pacific (Tasman Sea) is a **hotspot of change**
- Impacts on **marine ecology** are already being felt
- Understanding of **historical marine climate** around Tasmania can be improved, especially near-shore
- Large-scale models and reanalysis are <u>not designed for near-shore studies</u>
- Solutions include statistical and **dynamical downscaling**
  - Existing: SETAS, D'Entrecasteaux Channel, etc...
  - We built a model for eastern Tasmania

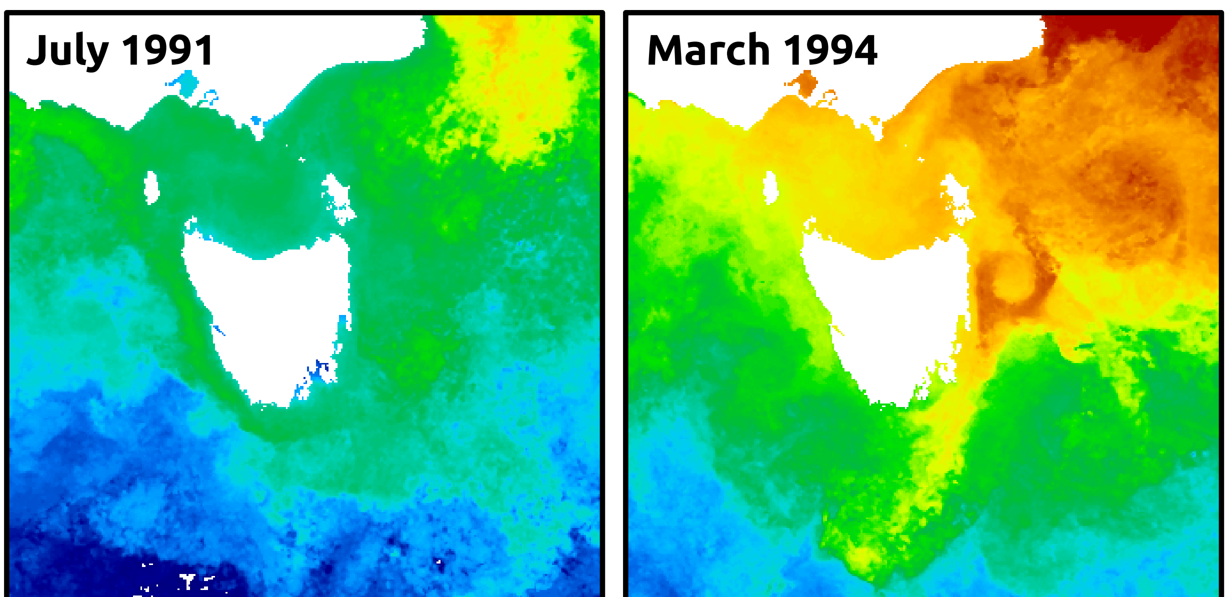




Regional Oceanography

- **East Australian Current (EAC)**, a quasi-steady western boundary current, separates from the coast ~33°S.
- The **EAC Extension** continues southward transport as far as Tasmania, but as an unsteady, eddy-rich “current”
- The **Zeehan Current**, part of a current system extending all the way to WA, runs southward and eastward along the west and south coasts of Tasmania [Cresswell 2000]





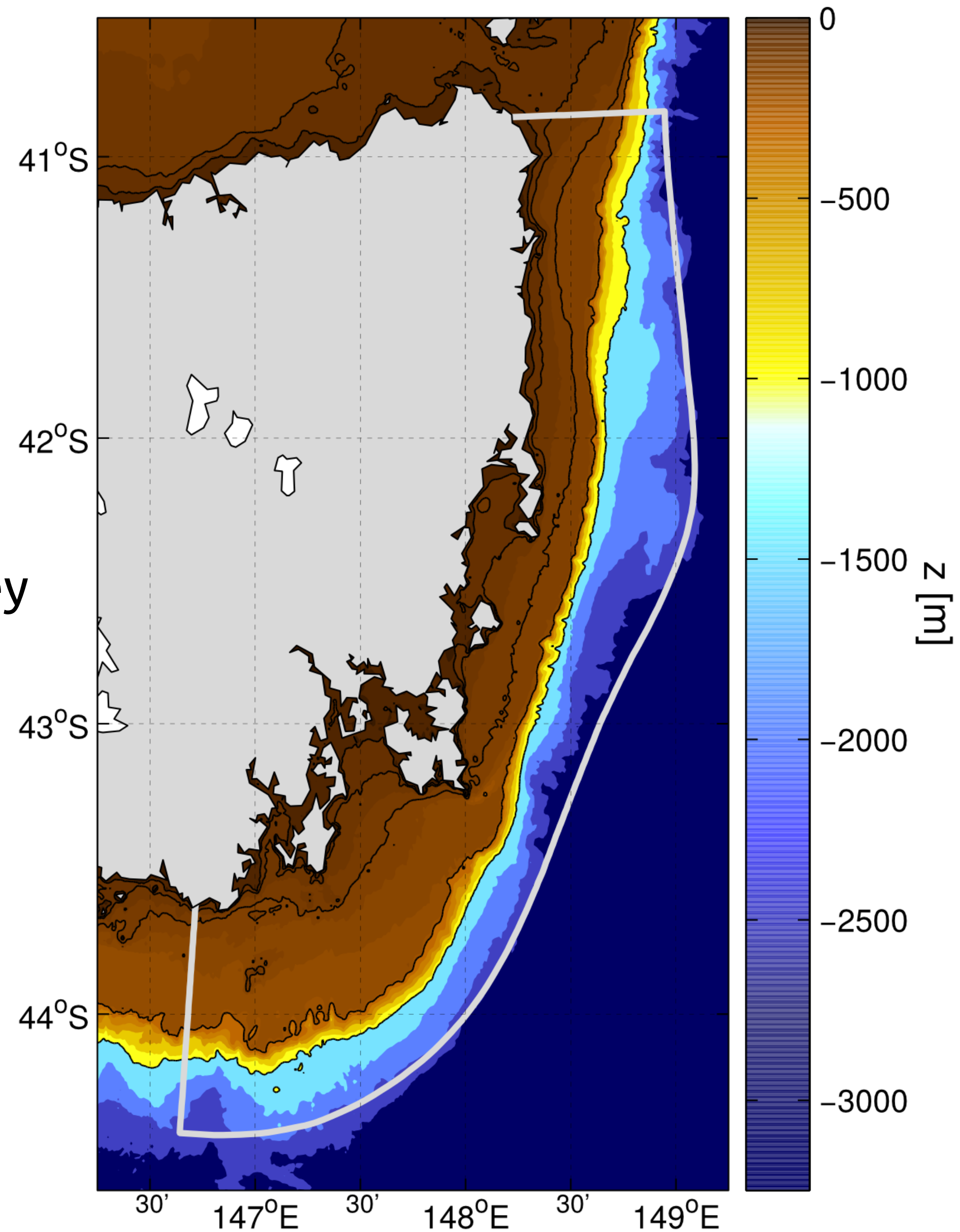
http://www.marine.csiro.au/~lband/yacht_races/yyzeecur.html

- Along the southeast coast of Tasmania, the **EAC Extension is dominant in summer** and the **Zeehan Current is dominant in winter**

Model and Grid

- We modeled the eastern Tasmania continental shelf using the **Sparse Hydrodynamic Ocean Code (SHOC)** model [Herzfeld, 2006]

- Domain: South Cape to ~Eddystone Point and seaward out to shelf break
- Bathymetry: Australian Geological Survey Organisation (AGSO) 2002 + SETAS
- Resolution: ~1.9 km resolution
- 43 *z*-levels in the vertical
- Supports tidal forcing at boundaries using CSR 4.0 tidal model



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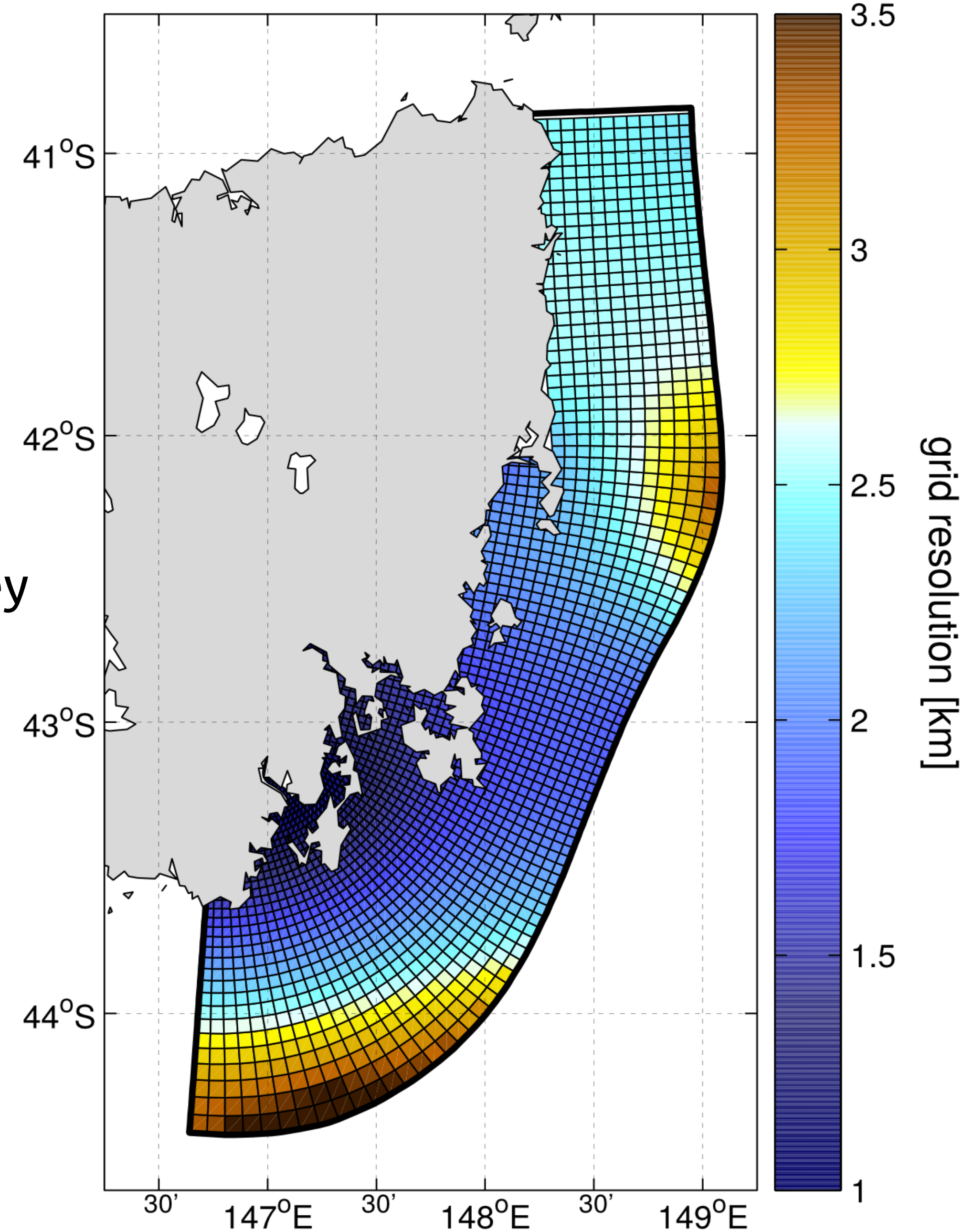

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Boundary Forcing

- Boundary conditions used the recently-developed Dirichlet boundary condition of Herzfeld and Andrewartha (2012)

Herzfeld, M. and J. R. Andrewartha (2012), A simple, stable and accurate Dirichlet open boundary condition for ocean model downscaling, Ocean Modelling, 43-44, 1-21

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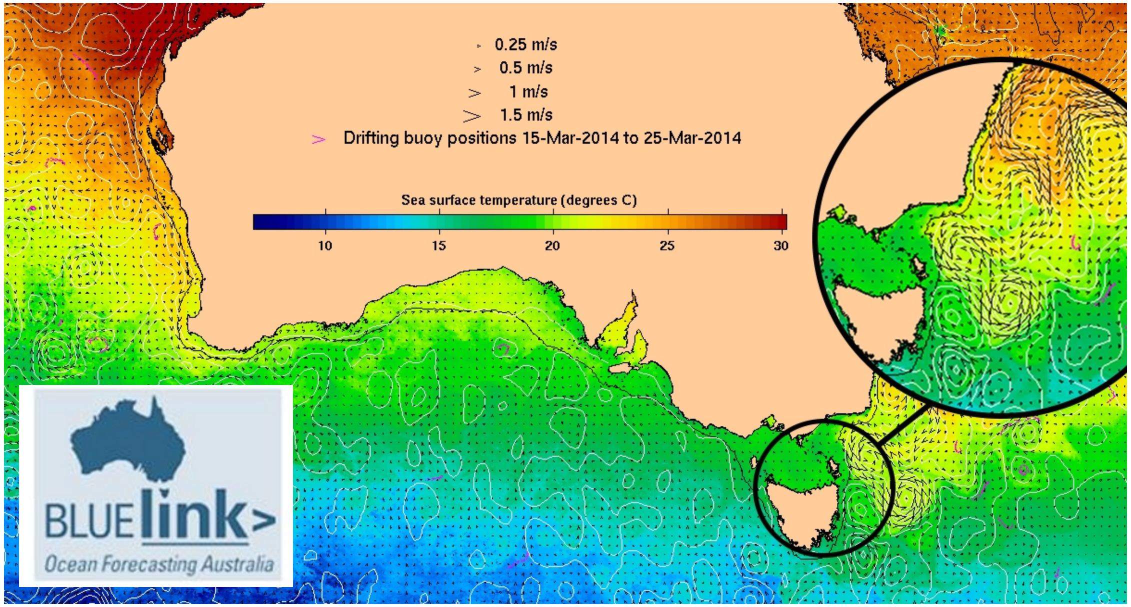

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BRAN = Bluelink ReANalysis
OceanMAPS = Bluelink Ocean Modelling, Analysis, and Prediction System

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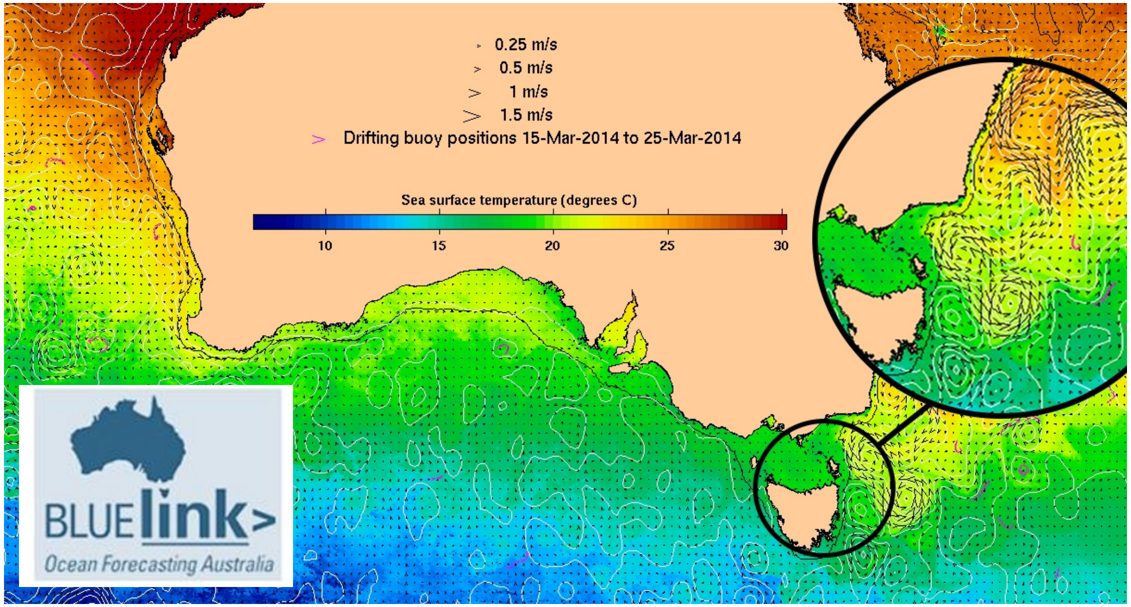
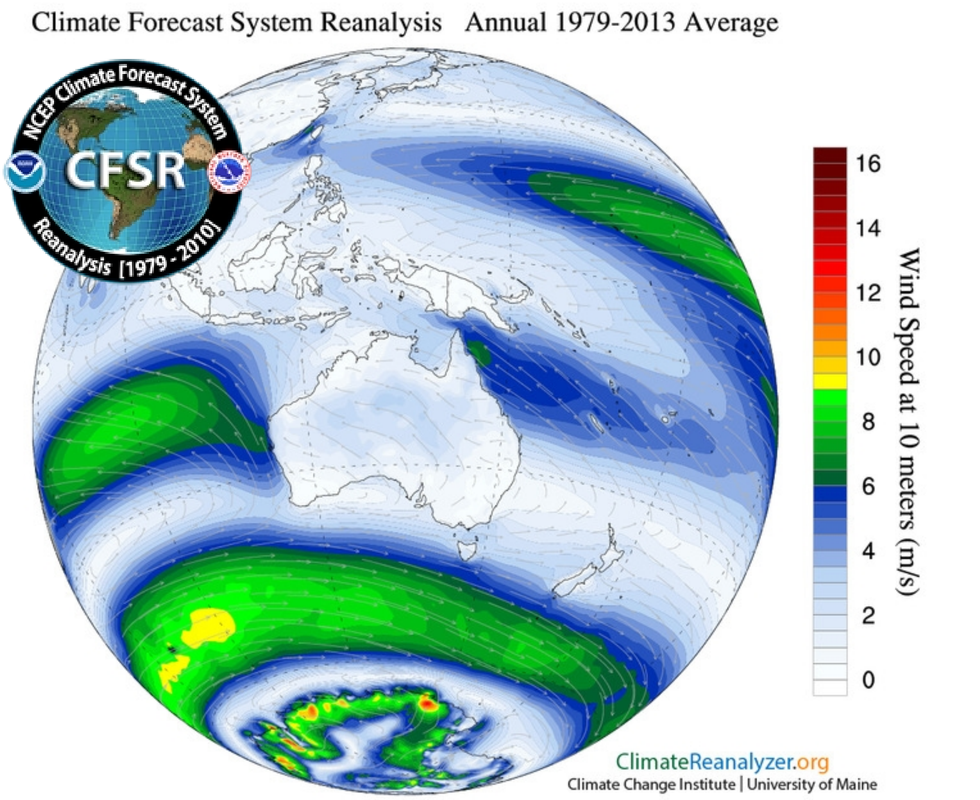
- Surface was forcing was provided from the **NCEP Climate Forecast System (CFS)** Reanalysis and Reforecast
- Coverage: 1993-2014





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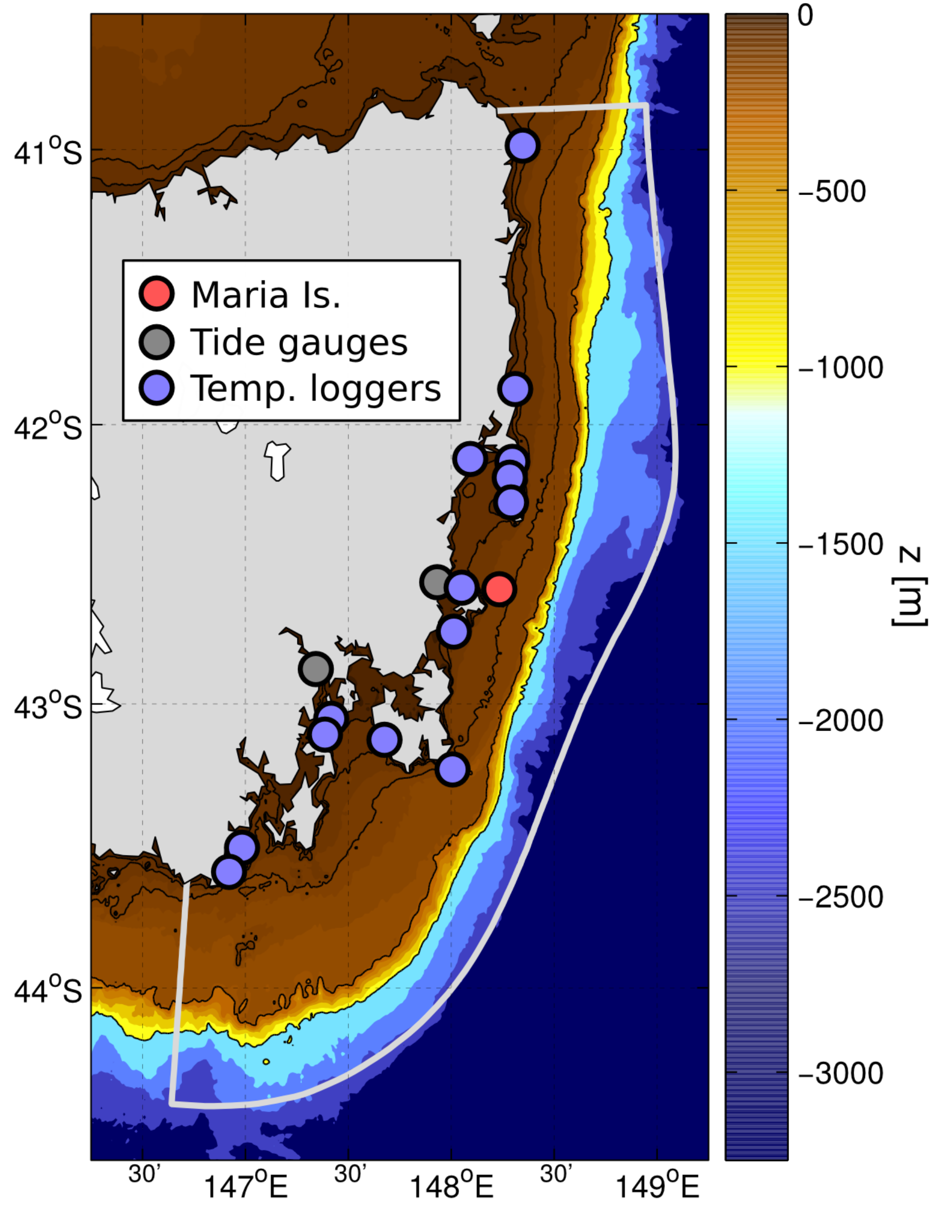
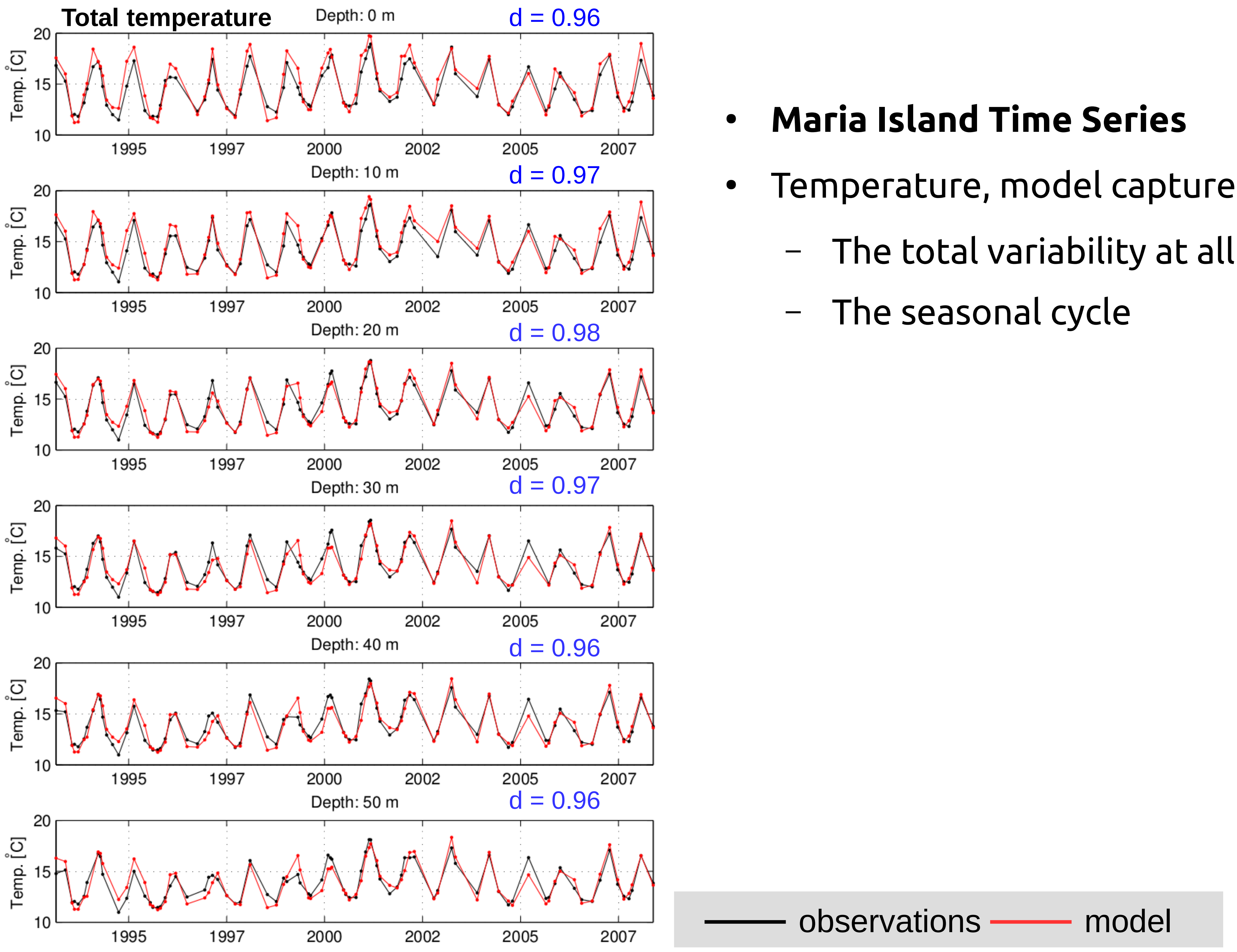
CFSR = Climate Forecast System Reanalysis
CFSv2 = Climate Forecast System version 2 (operational forecast system)

Validation Data

- In-situ time series
  - Maria Island time series **[RED]**
    - Historical temperature and salinity @ surface and 5 depths
    - Quasi-monthly, 1944 - 2008
  - Craig Mundy (IMAS-FAC, UTAS), near-bottom temperature gauges **[BLUE]**
    - Near-bottom temperature in 5-20 m water depths
    - Daily, 2005 – present-ish
  - 2 Tide gauges (Hobart, Spring Bay) **[BLACK]**
    - Sea level
    - Hourly and daily, 1985 - 2012
- Remotely sensed
  - NOAA OI SST V2: daily, $1/4^{o}$ x $1/4^{o}$ resolution maps, 1982-2014

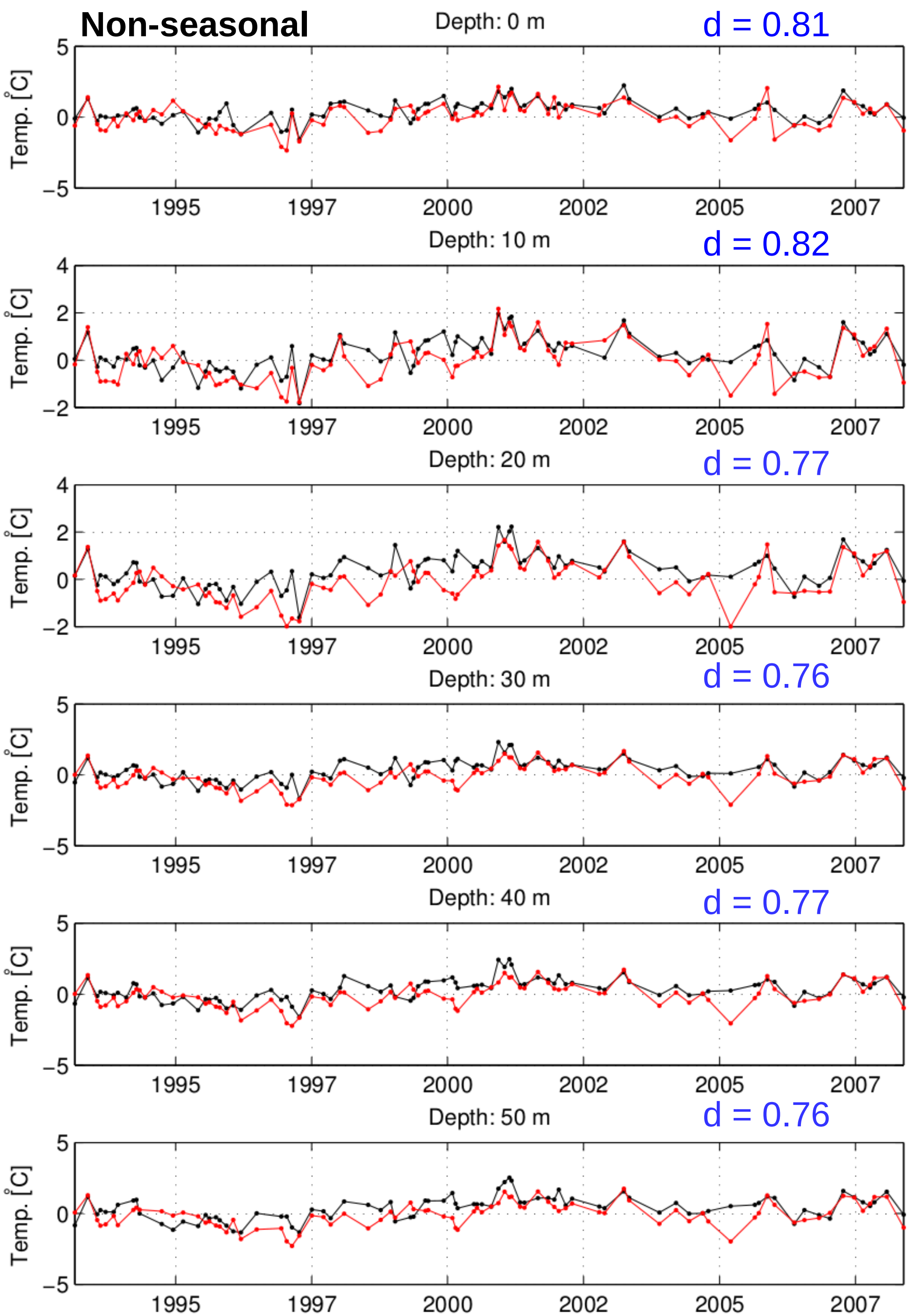


Maria Island Time Series



- **Maria Island Time Series**
- Temperature, model captures well:
  - The total variability at all depths
  - The seasonal cycle

Maria Island Time Series



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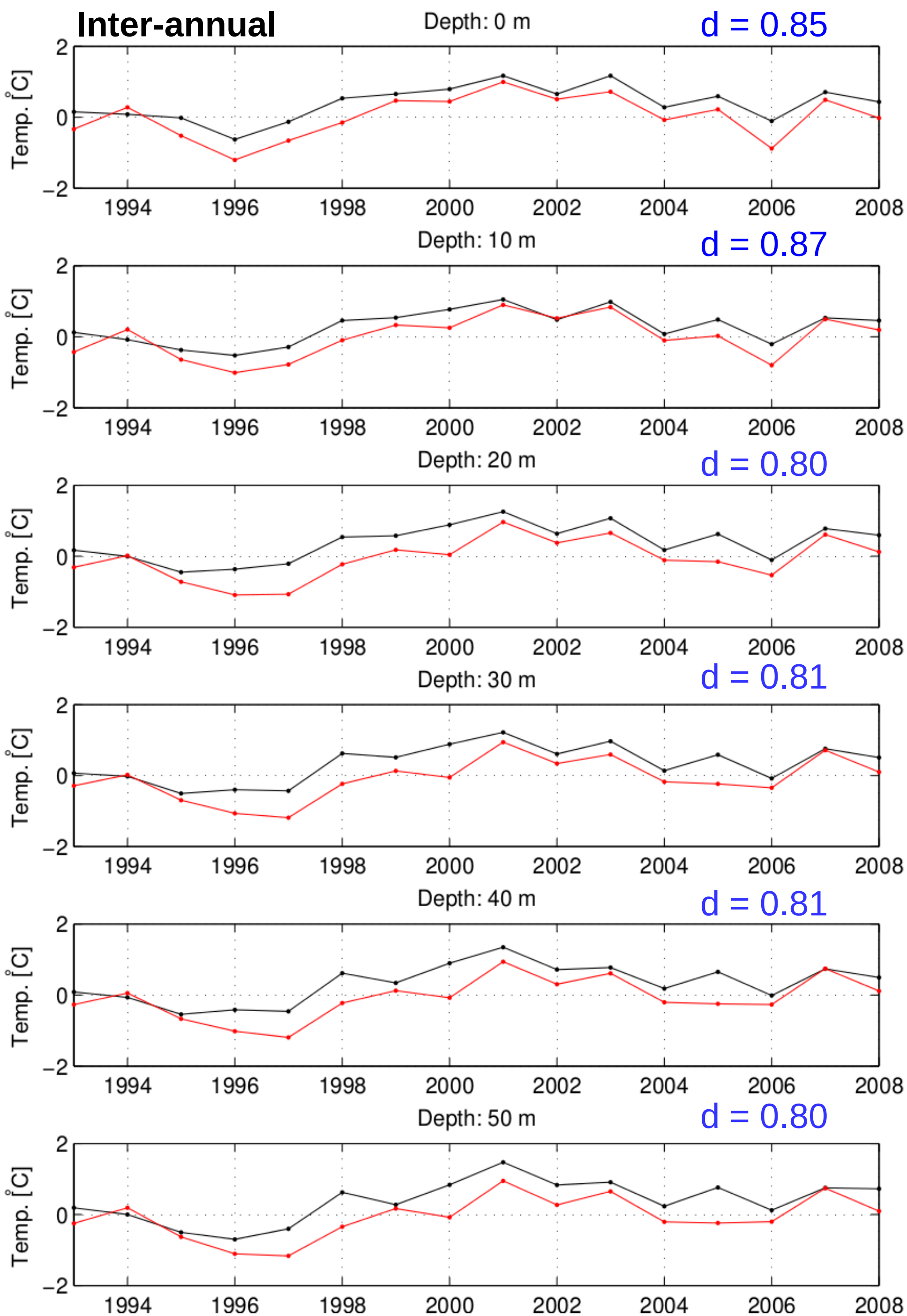
  - The seasonal cycle
  - The non-seasonal variability

observations model

Maria Island Time Series



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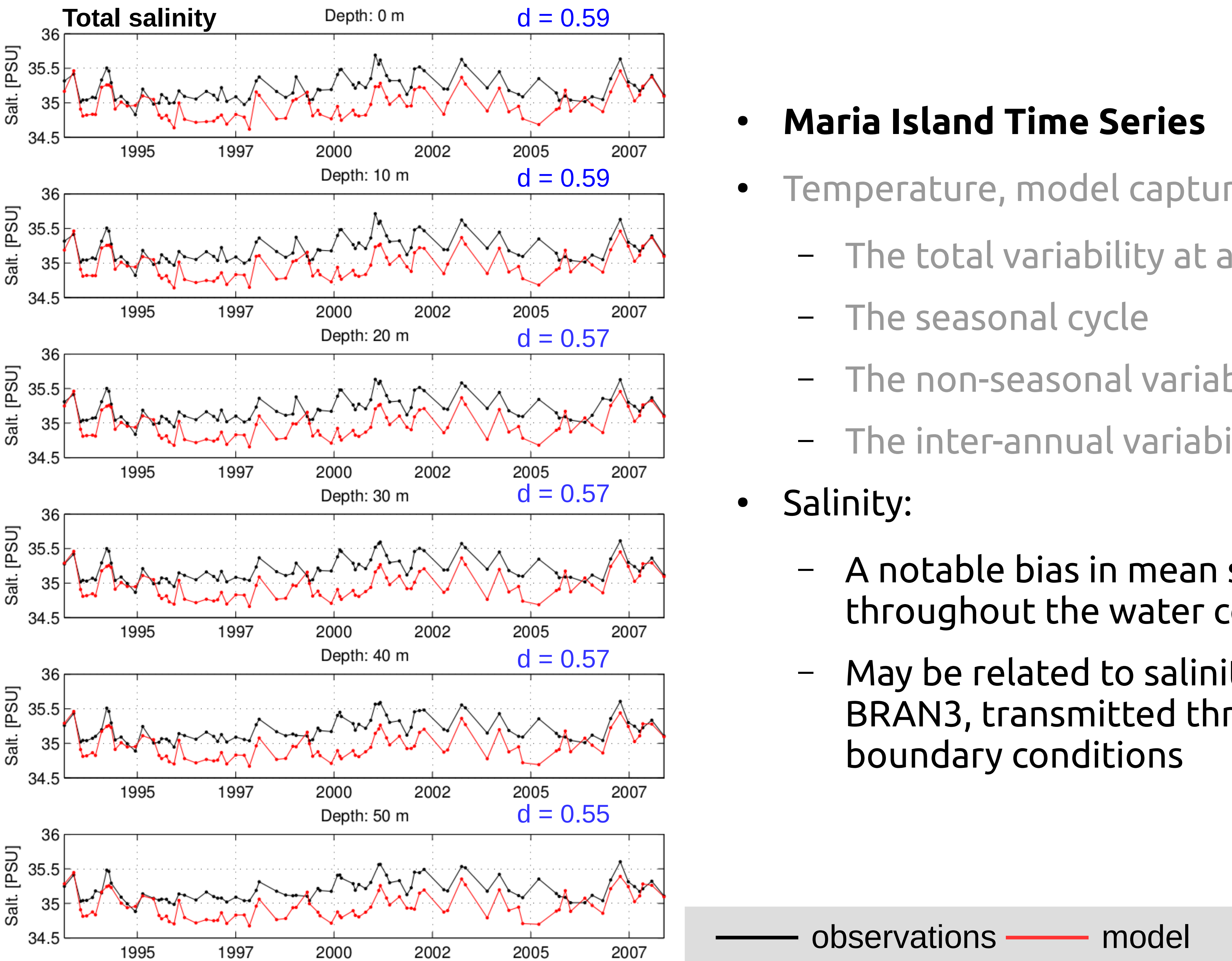
  - The inter-annual variability

Maria Island Time Series

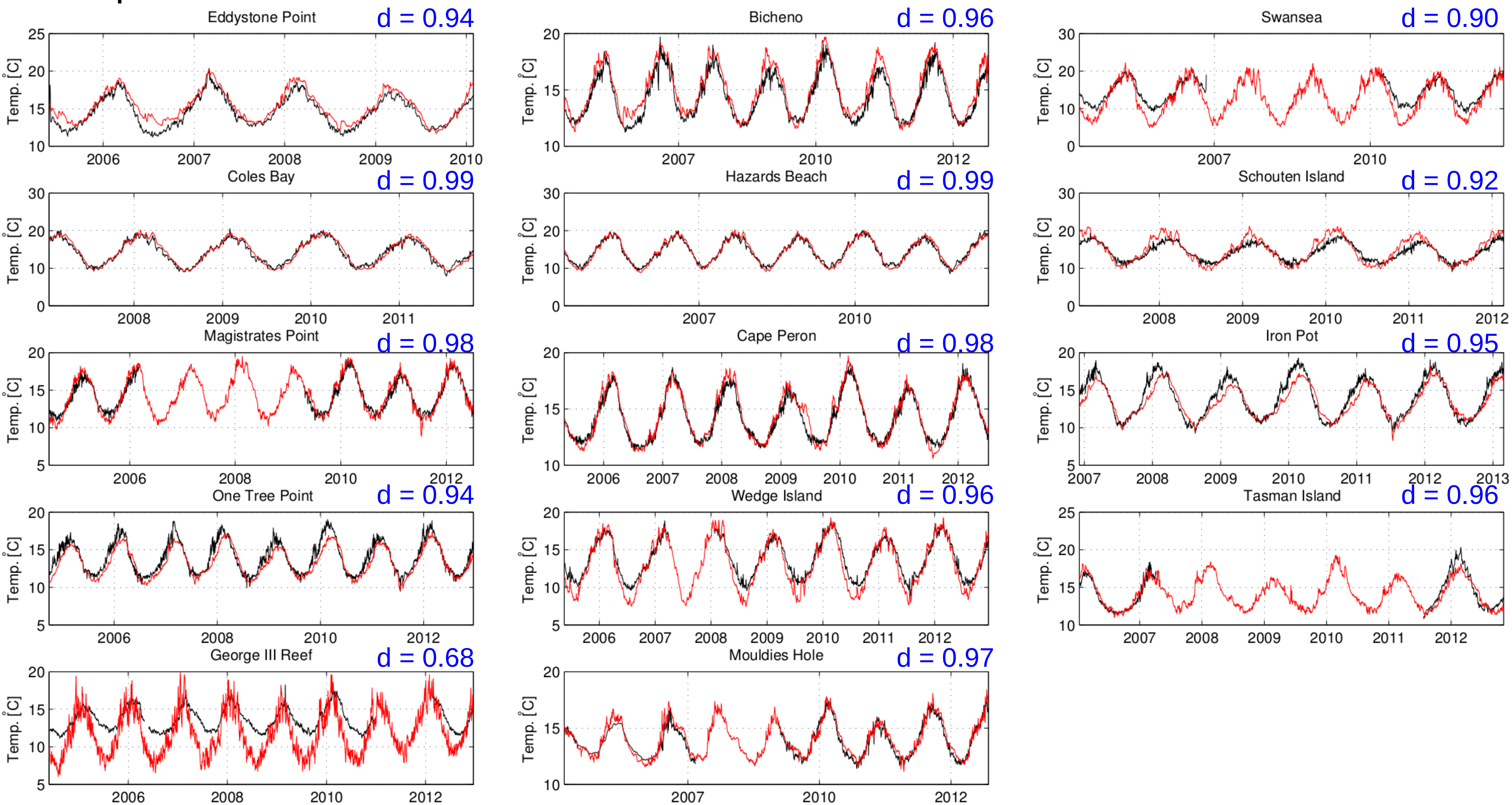


- **Maria Island Time Series**
- Temperature, model captures well:
  - The total variability at all depths
  - The seasonal cycle
  - The non-seasonal variability
  - The inter-annual variability
- Salinity:
  - A notable bias in mean salinity throughout the water column
  - May be related to salinity bias in BRAN3, transmitted through boundary conditions

Near-bottom temperatures

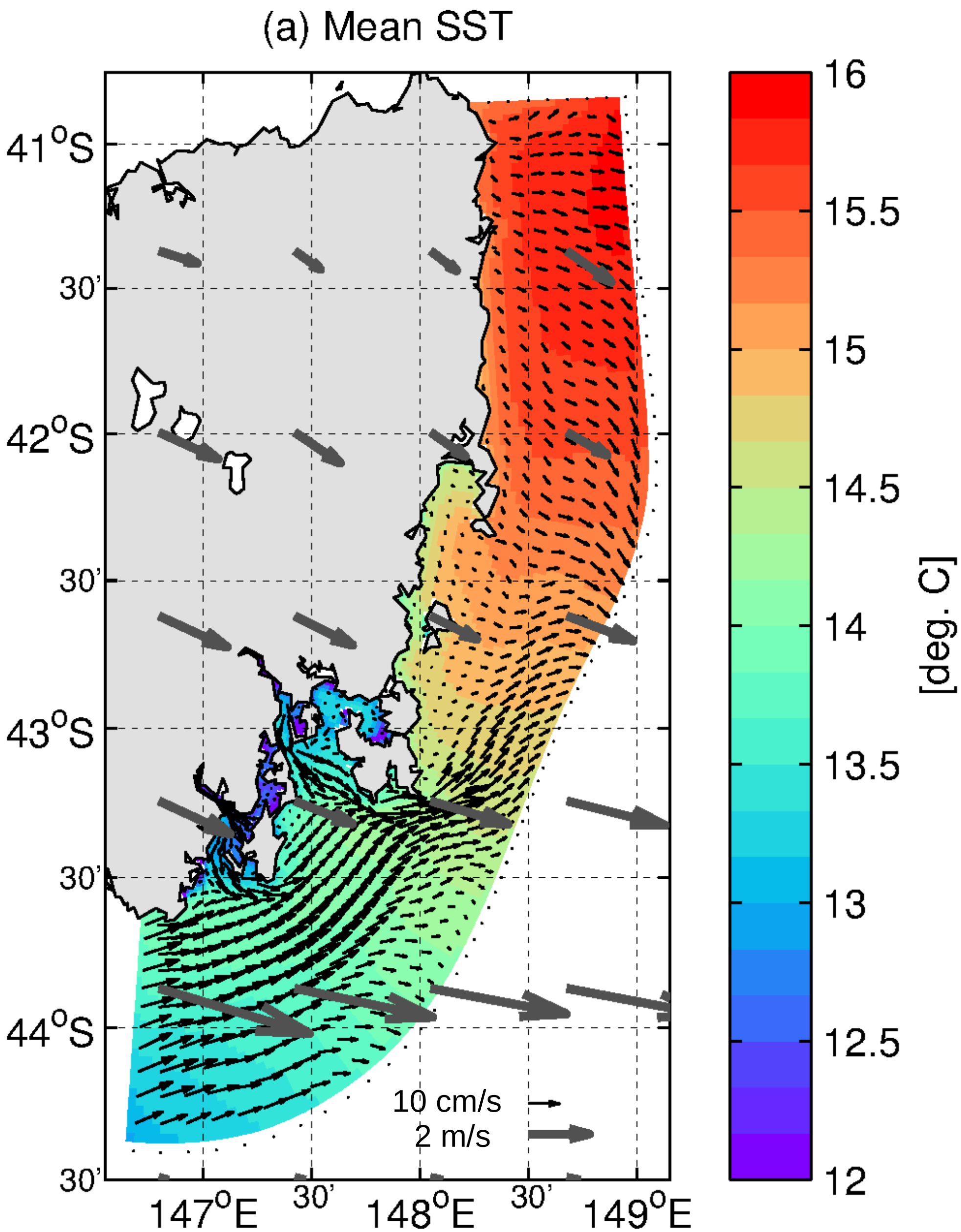
- **Near-bottom temperature loggers**
- Model captures well the total variability (incl. seasonal cycle)

Total temperature



Surface Mean State

Mean SST and Circulation



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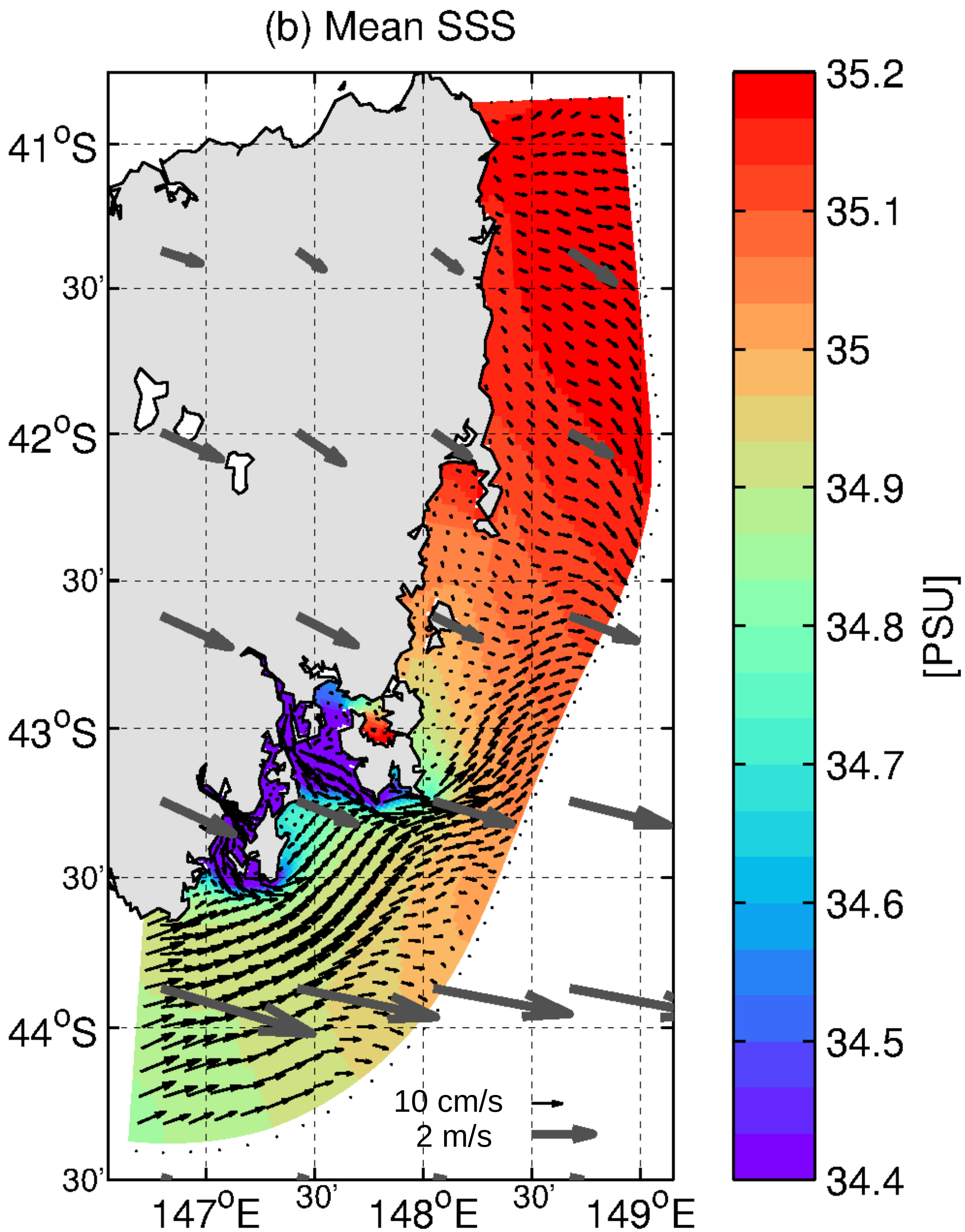
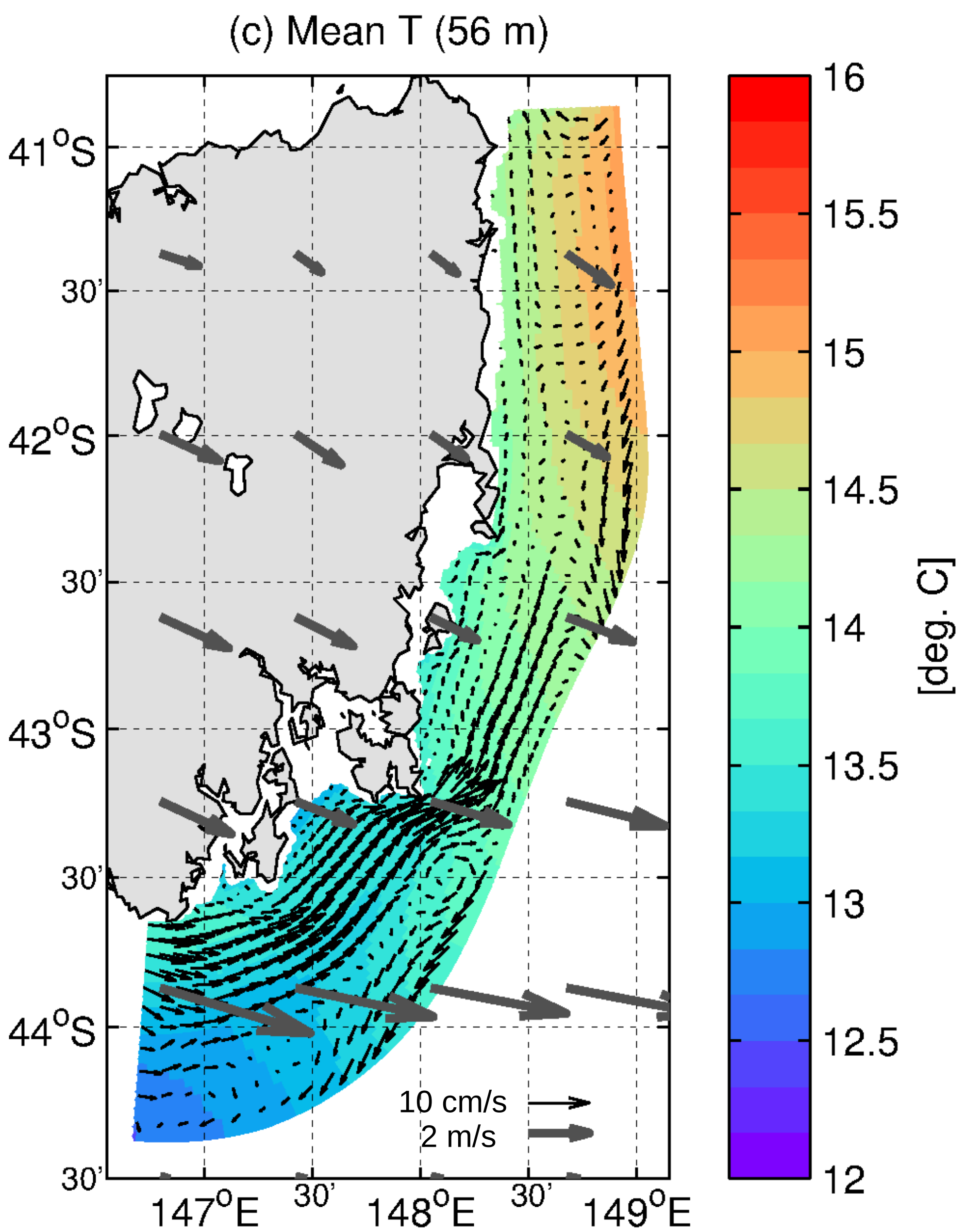
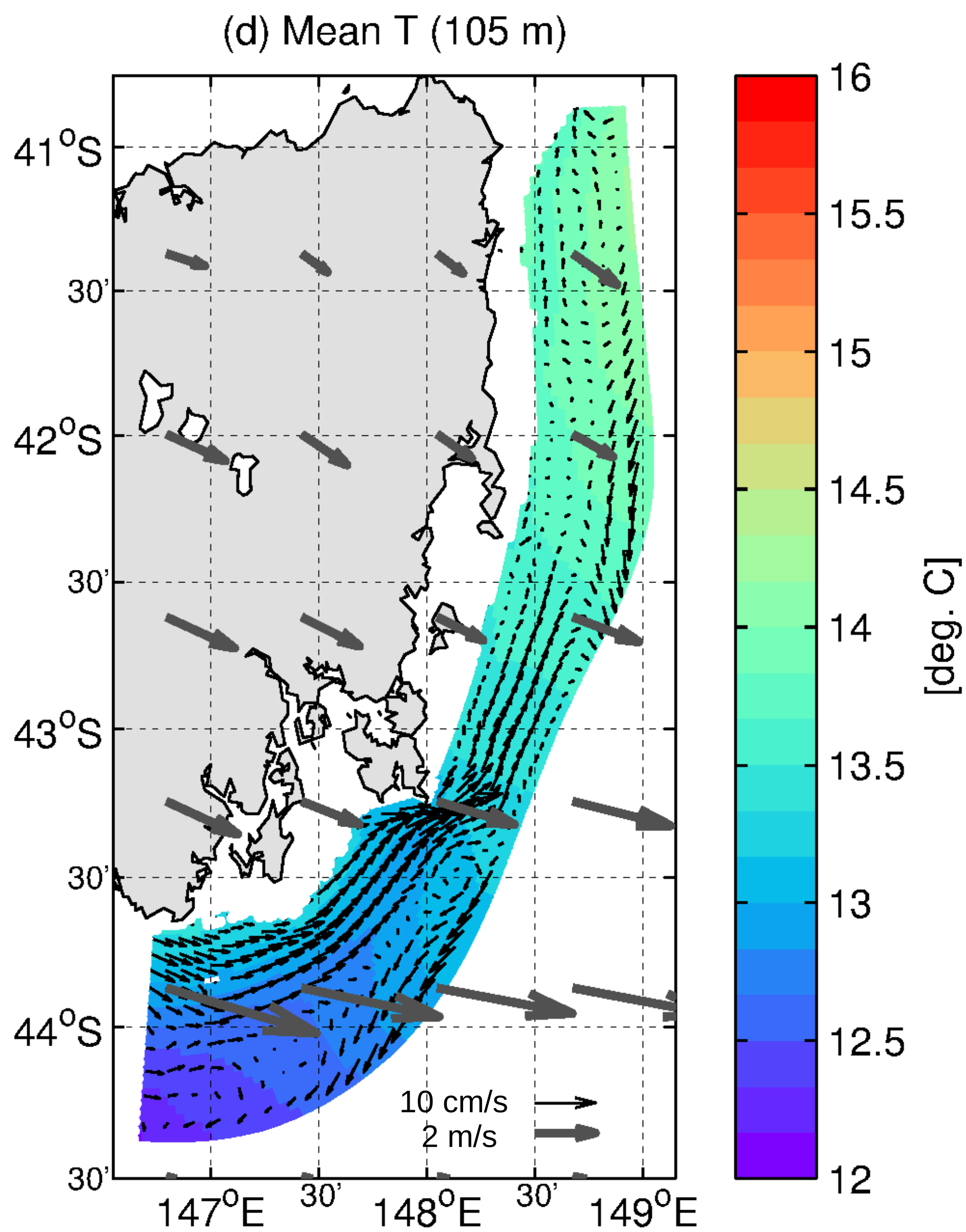


Surface Mean State

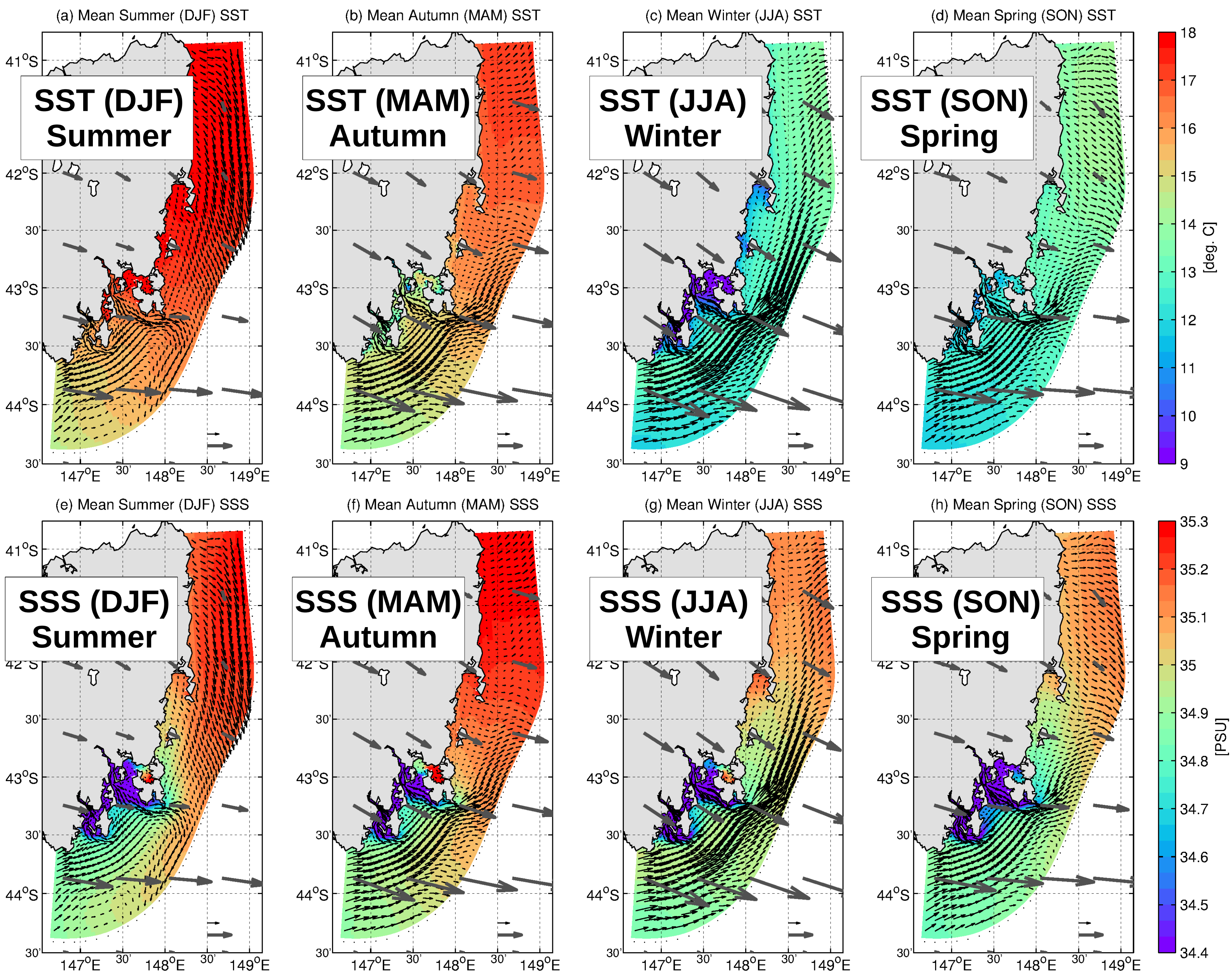
Mean T and Circulation @ 56 m



Mean S and Circulation @ 105 m



Surface Climatology



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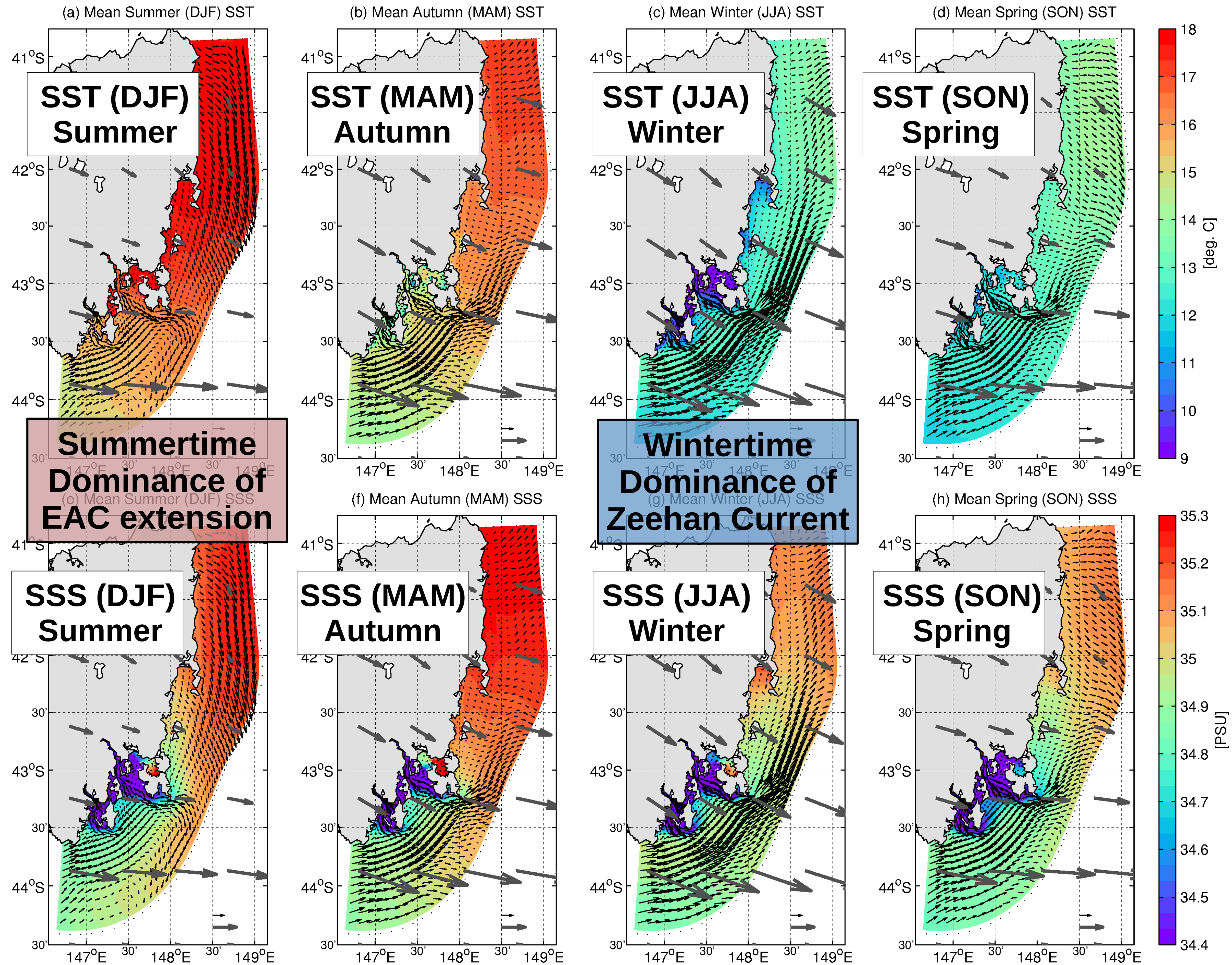
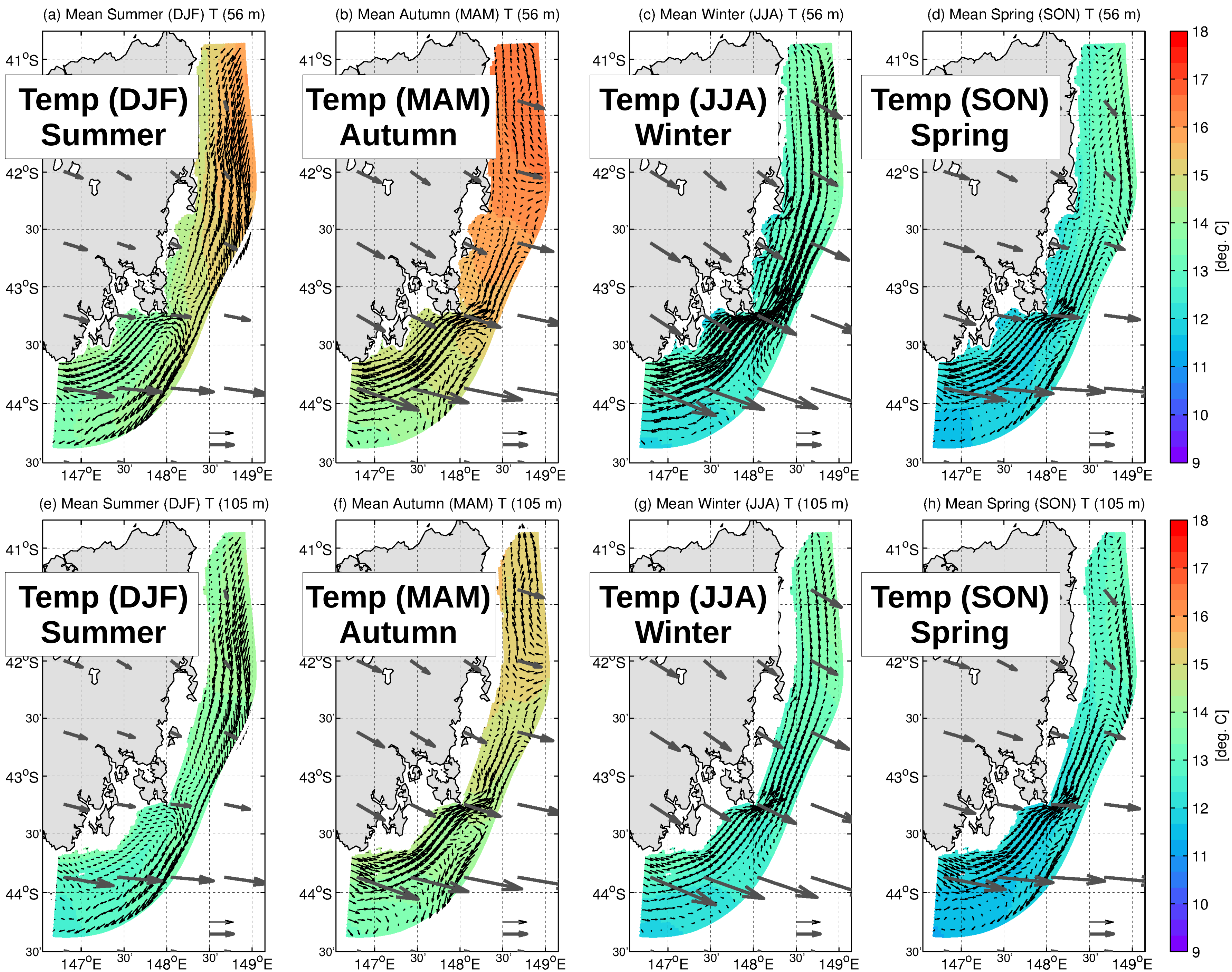


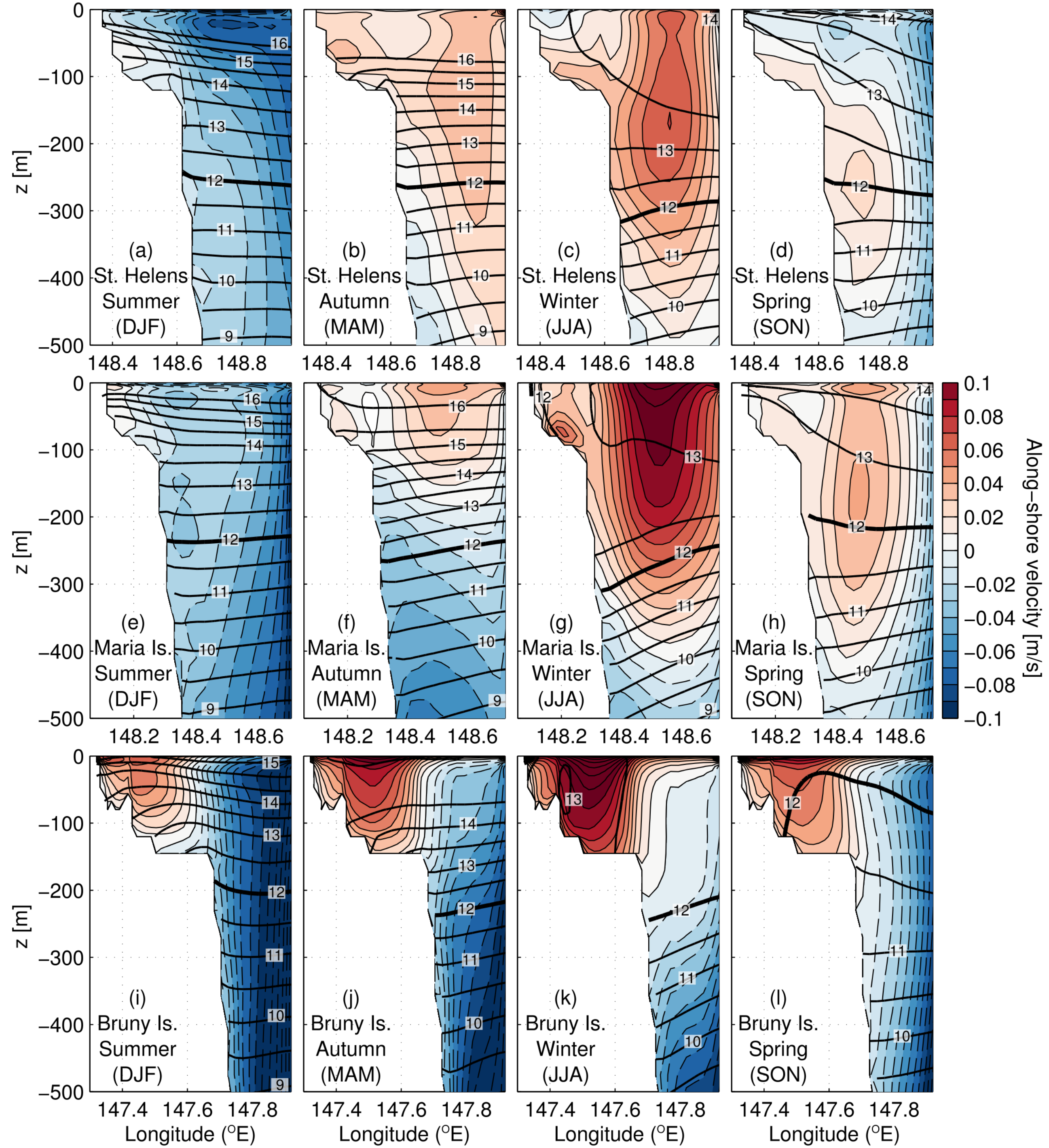
Subsurface Climatology



Cross-shelf Structure

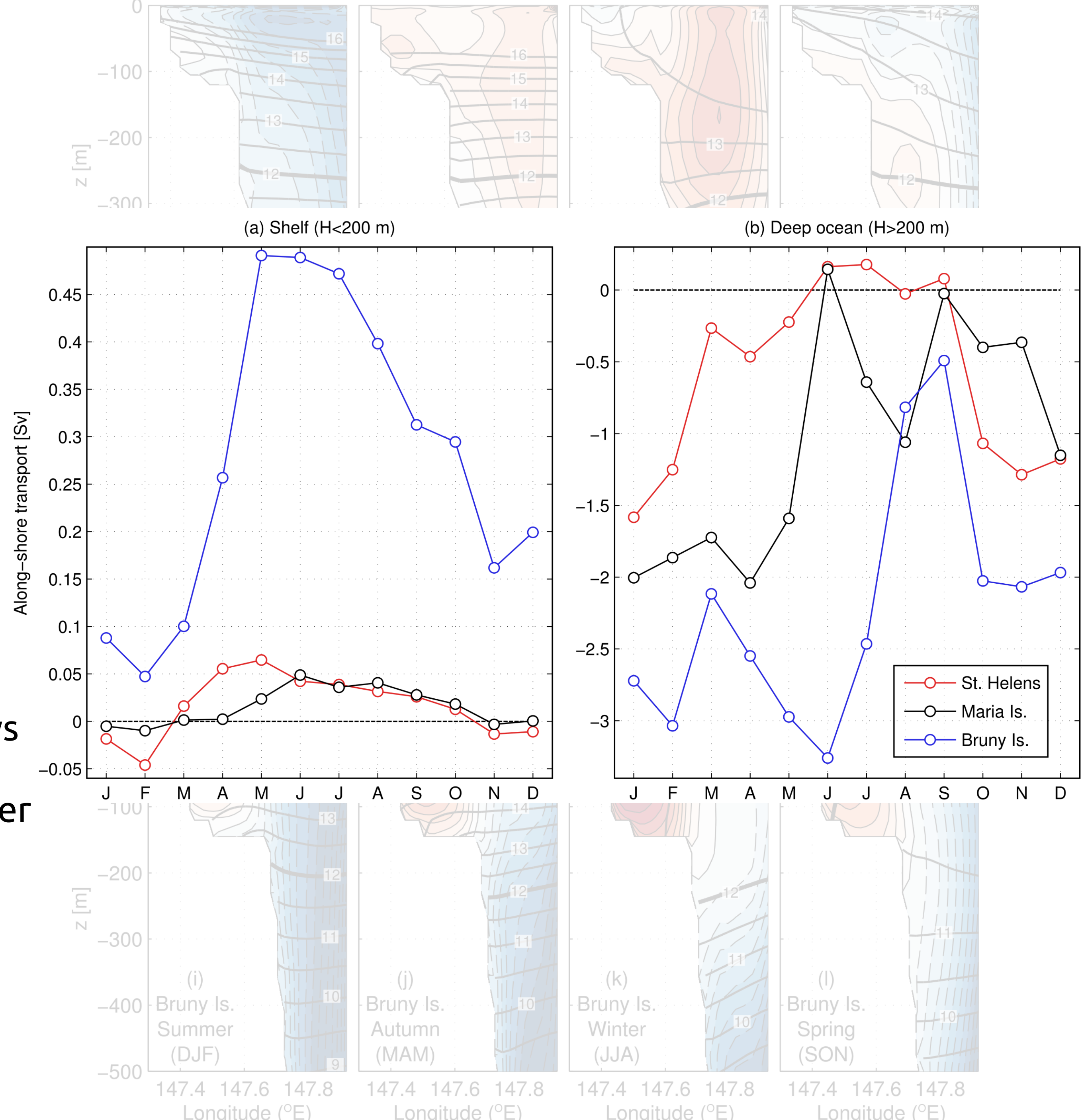
- **Sections across shelf showing temperature (colours) and along-shelf currents (contours)**

- Seasonal alternation of Zeehan Current / EAC Extension, width depth-dependent and cross-shelf structure.



Cross-shelf Structure

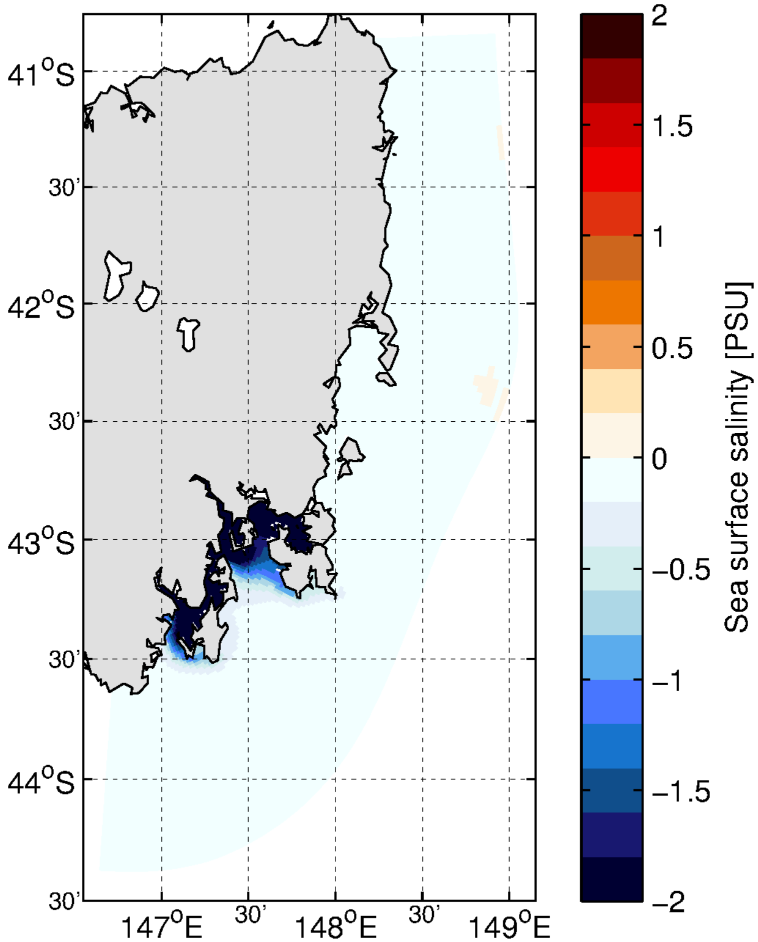
- **Sections across shelf showing temperature (colours) and along-shelf currents (contours)**
- Seasonal alternation of Zeehan Current / EAC Extension, width depth-dependent and cross-shelf structure.
- Transport over shelf is always northward off Bruny Is., northward outside of Summer elsewhere



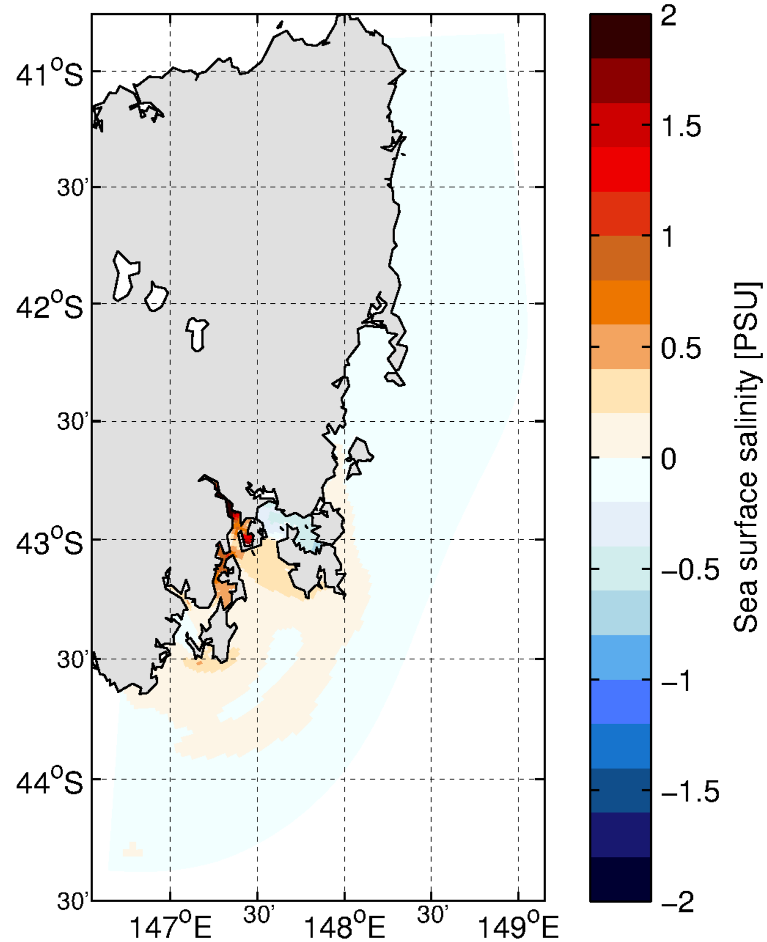
Roles of tides and rivers

- **<u>Role of the rivers</u>** (*R/NT – NR/NT*):
  - Reduced salinity in Derwent and Huon estuaries
  - Estuary mouths warm while rivers cool
- **<u>Tidal interactions</u>** (*R/T – R/NT*):
  - Tide-River interactions can be significant in and around river estuaries, Note: <u>Frederick Henry Bay and Norfolk Bay</u>

(c) Mean SSS Difference: R/NT – NR/NT



(d) Mean SSS Difference: R/T – R/NT



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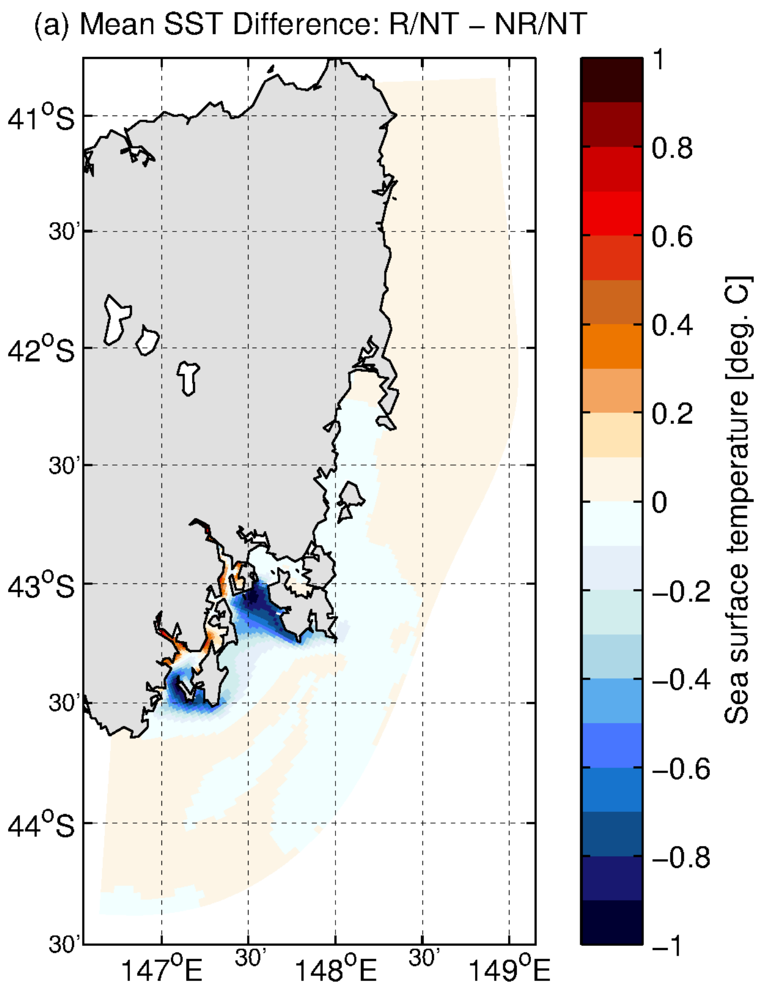
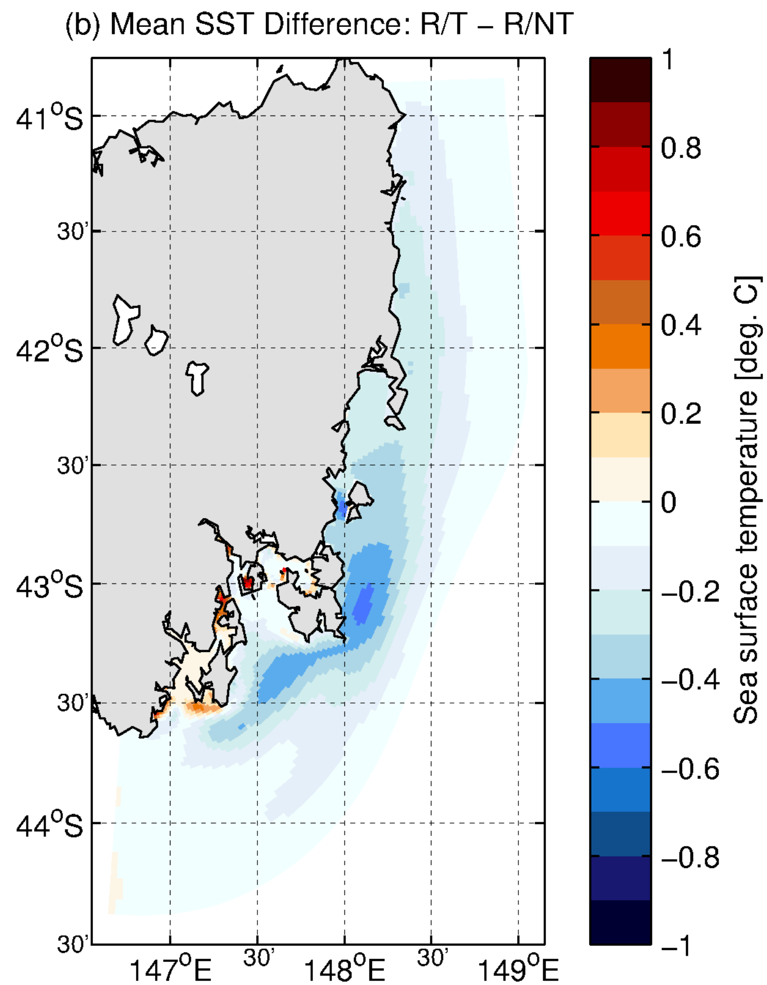




Summary and Future Work

- **ETAS** model compares well against observed coastal sea level, historical Maria Island time series, near-bottom temperature at a number of sites, and remotely-sensed SST across the shelf
- **Seasonal alternation** between dominance of Zeehan Current in Winter (JJA) and EAC Extension in Summer (DJF) and cross-shelf structure
- Roles of rivers, tides, and climate modes:
  - **Rivers** freshen and cool estuary waters
  - **Tides** can interact with the rivers in a complex way
  - **Climate modes (SAM, Tasman Blocking)** play a role in modulating near-shore marine climate through precipitation (and thus river inputs), surface air temperature and wind forcing
- **Future work**: relative role of surface and boundary forcing, interaction between off-shore eddies and the shelf, influence of ENSO, interannual variability, quantifying EAC vs. ZC dominance, marine heatwaves

Acknowledgements: Mike Herzfeld, John Andrewartha, Mike Baird, Farhan Rizwi (CSIRO), Jessica Benthuysen (AIMS), Craig Mundy (IMAS-FAC). Australian Research Council Super Science Fellowship and Centre of Excellence for Climate System Science

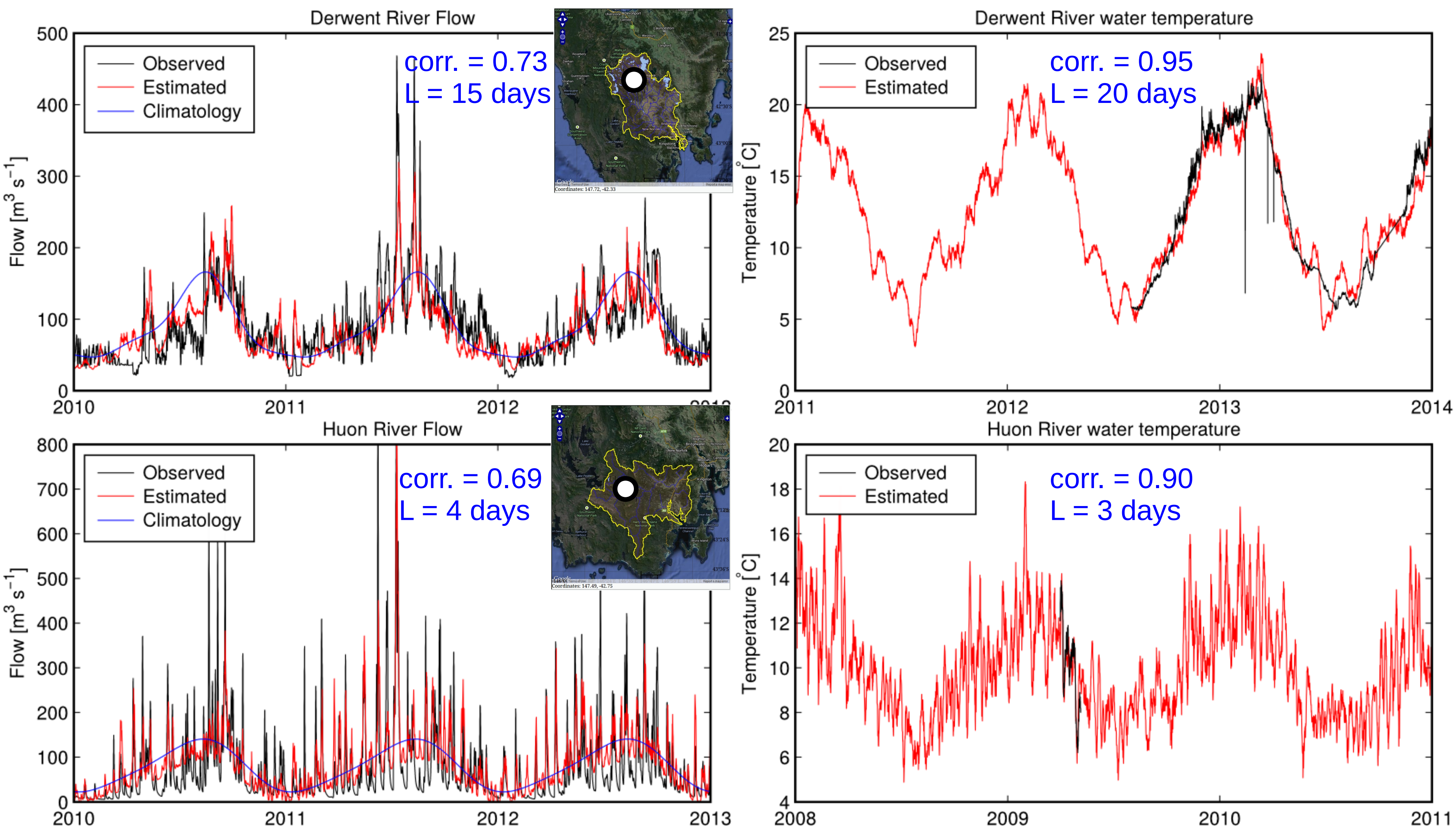
Extra Slides…

Model Parameters

- Time steps
  - 3D: 60s (CFL: 72.8)
  - 2D: 3.75s (CFL: 4.2s)
- Horizontal mixing scheme
  - Smagorinsky (c=0.1) for diffusivity
  - Viscosity = 370 m^2/s for avg. grid size (~1.9 km)
  - Scaled over domain based on changing grid size
- Vertical mixing scheme
  - k-epsilon (Burchard et al. 1998)
  - Background diffusivity and viscosity = 10^{-5} m^2/s
- Bottom friction using drag law

River Input

- River input (flow rate and water temperature) required for Derwent River and Huon River
- River inputs predicted from precipitation and air temperature using a lag-regression model and then reconstructed over 1993-2014



River Input

- We also require river input (flow rate and water temperature) for the two major rivers in SE Tasmania: Derwent River and Huon River

- We have observed records of flow (m^3/s) and water temp for both rivers, but records very short and very recent (Nov/2009 -late/2013; shorter for temp) and we require these quantities over the entire 1993-2013 period

- Therefore, we modeled river flow (F) using precipitation (P) over the river catchments (from CFSR/CFSv2) as a predictor in a multiple lag-regression model:

$$\log(F_t) = \alpha + \sum_{l=0}^{L} \beta_l \log(P_{t-l})$$

  And a similar model (without log-transforms) to estimate river temperature from local air temperature

- A two-fold cross-validation was performed to determine which value of L provided the best fit

- Given a satisfactory fit, we used historical precipitation and air temperature from CFSR/CFSv2 to reconstruct river flow and temperature over the entire 1993-2013 period

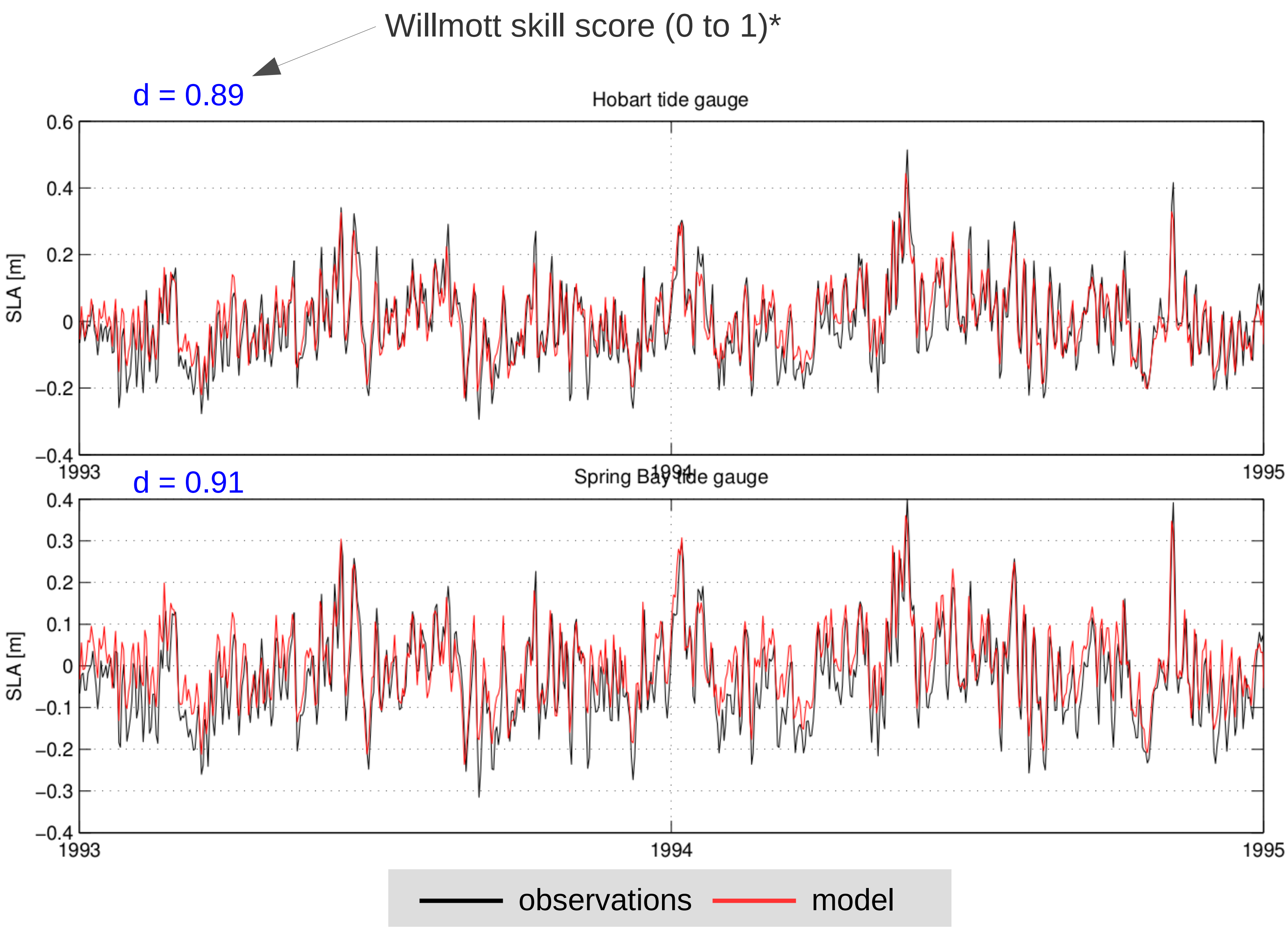
Hindcast Simulations

- Spin-up: model was spun up for 3 years using normal year forcing*, initialized from Bluelink on 1/1/1993
- Historical hindcast: model was then forced by realistic forcing over the 1993-2014 period
- Four runs were performed for all combinations
  - **with and without tidal forcing (T and NT)**, and
  - **with and without river inputs (R and NR)**
  - The **base run for validation** was with river input and no-tides (R/NT)

* NYF: climatological seasonal cycle, subseasonal variability from 1995, mean of 1993; following *Large and Yeager (2004)*; rivers are climatological only

Tide Gauges

- Model captures well sea level at Hobart and Spring Bay tide gauges

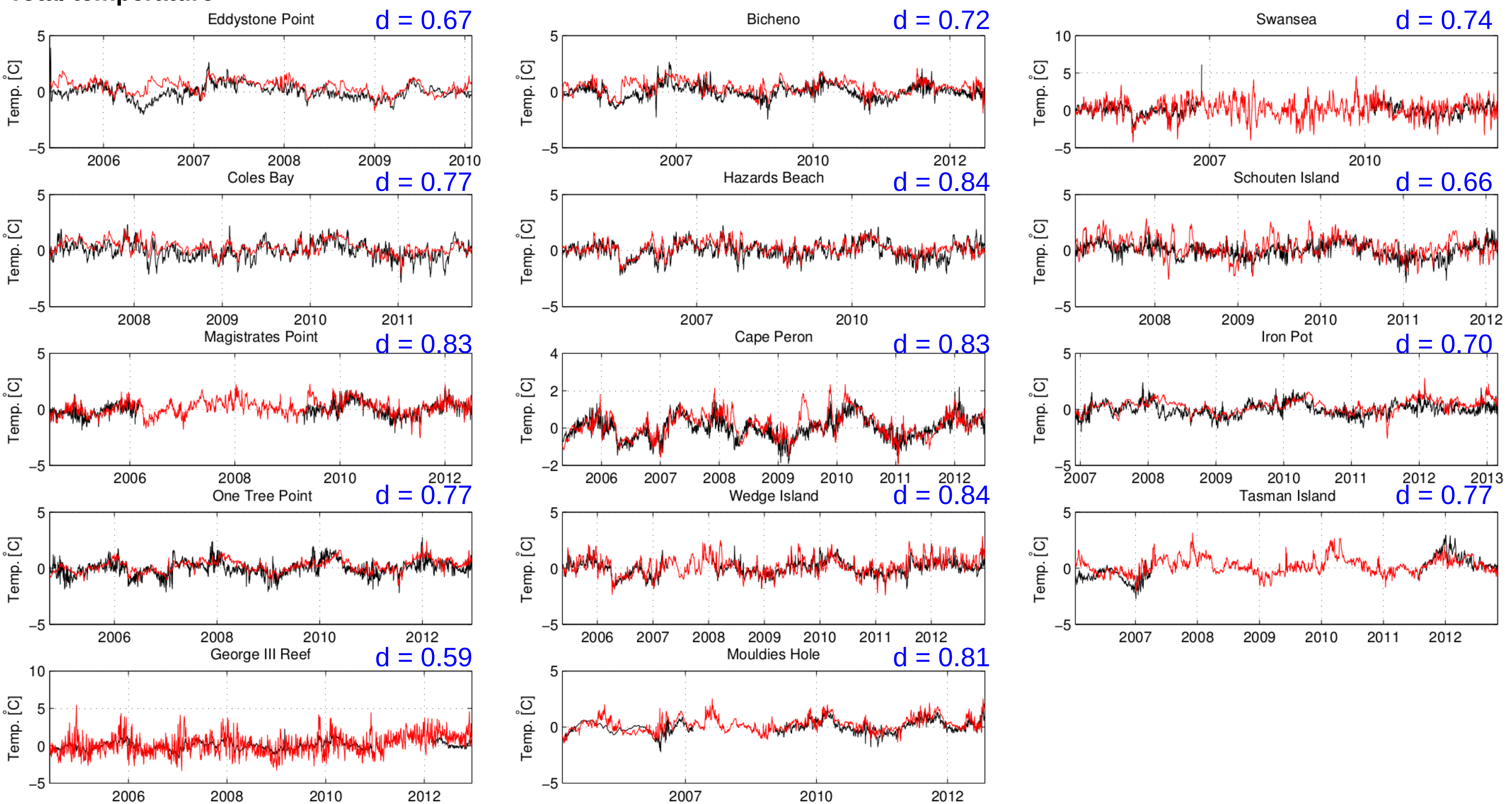


* Willmott, C.J. (1982) On the validation of models, *Physical Geography*, 2(2), 184-194

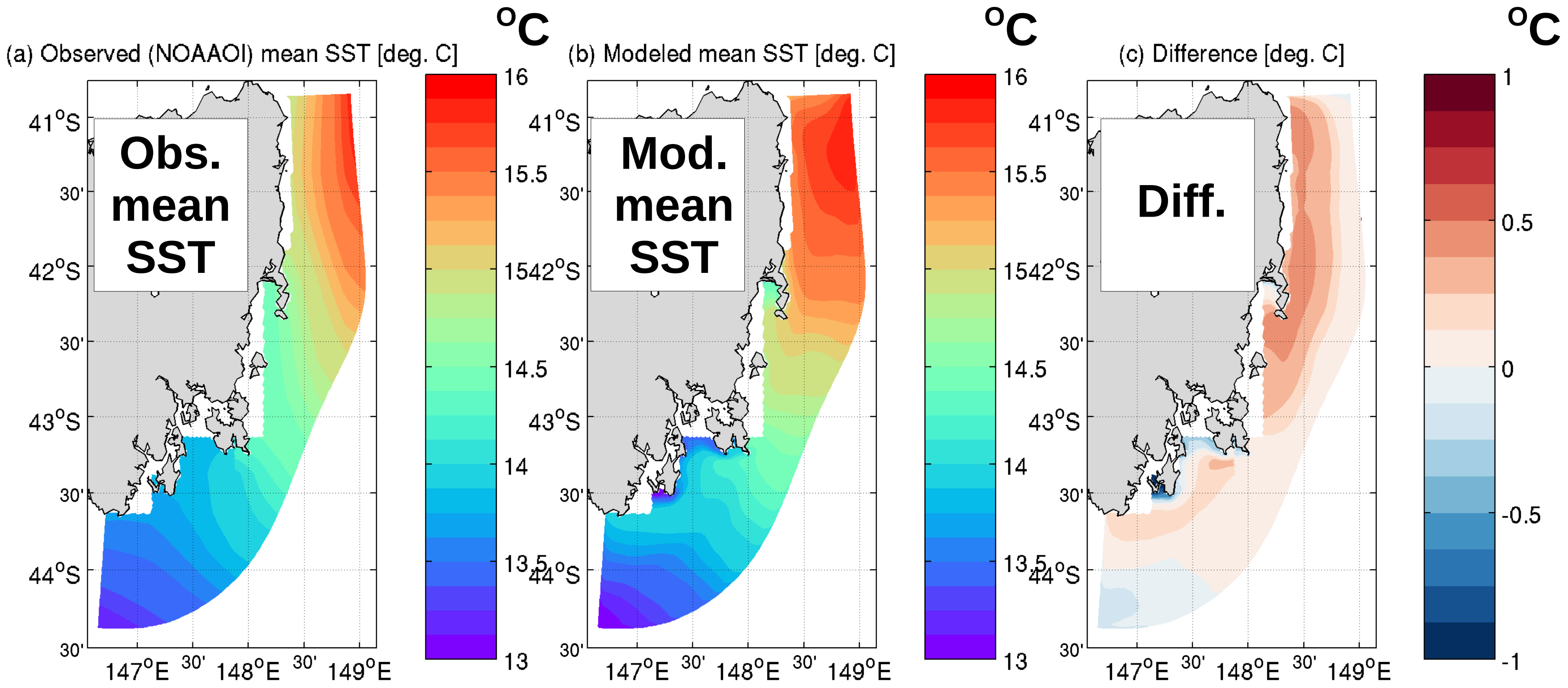
Near-bottom temperatures

- **Near-bottom temperature loggers**
- Model captures well the total variability (incl. seasonal cycle) and non-seasonal signal

Total temperature

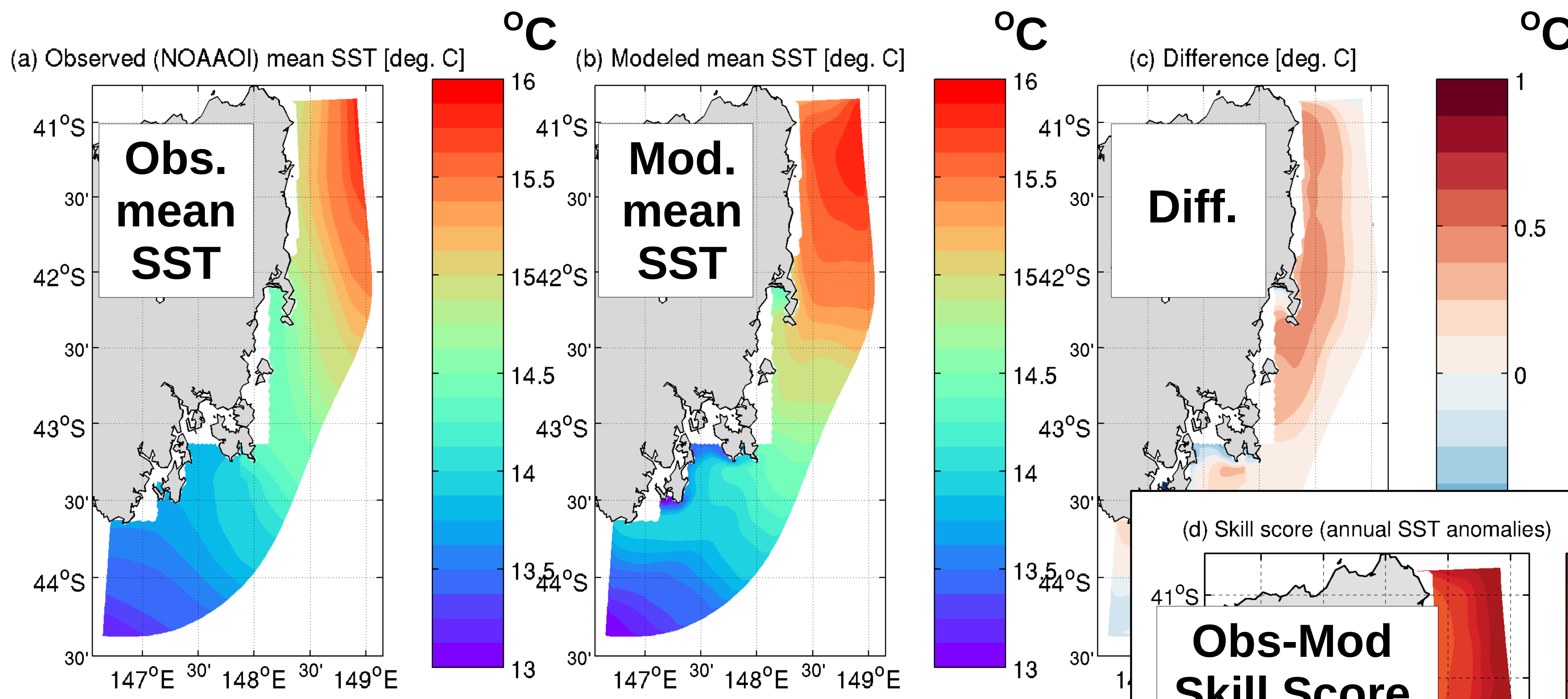


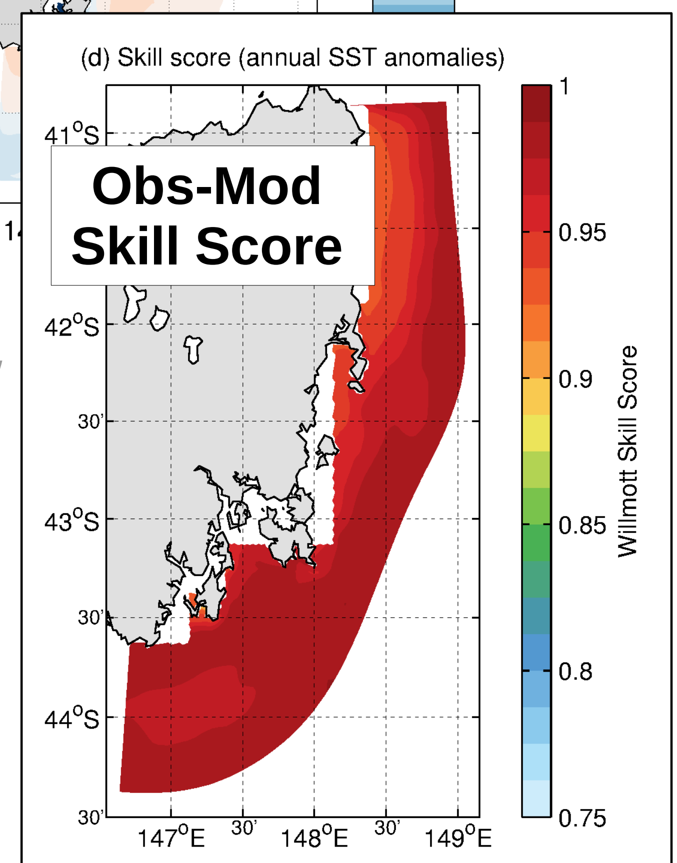
Remotely-sensed SST



- Model captures well mean SST remotely-sensed by AVHRR (gridded NOAA OI V2 product)
- A slight near-shore warm bias (0.5°C) in the northern 2/3 of the domain.

Remotely-sensed SST





- Model captures well mean SST remotely-sensed by AVHRR (gridded NOAA OI V2 product)
- A slight near-shore warm bias (0.5°C) in the northern 2/3 of the domain.
- Remotely sensed SST variations are also well captured with skill generally >0.9

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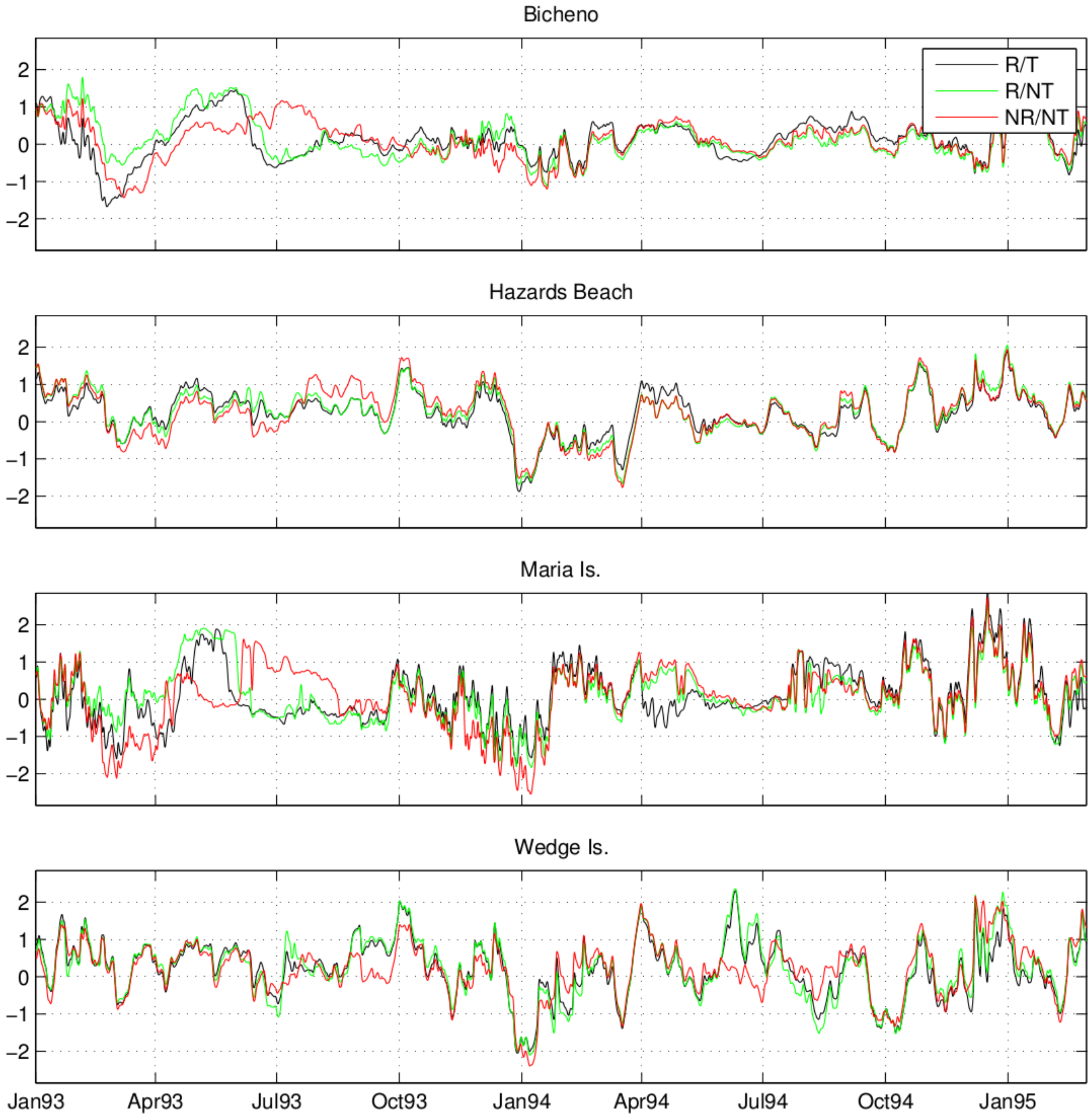
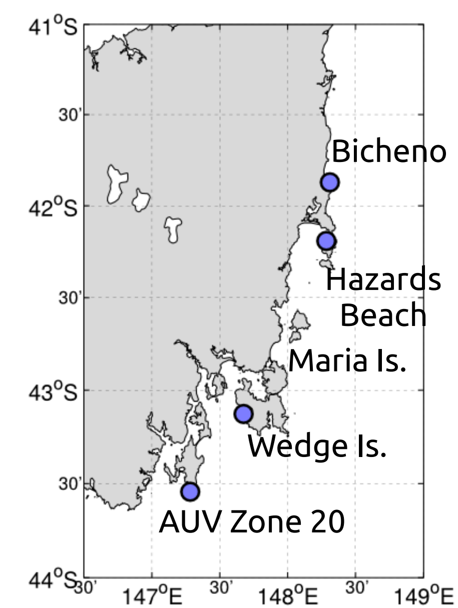
Roles of tides and rivers

UTAS



- Difference between black and green curves (tides and no-tides, <u>with rivers</u>) that cannot be explained by the difference between the blue and red curves (tides and no-tides, <u>without rivers</u>) indicates a **tide-river interaction**



Roles of tides and rivers

- RMS differences showing influence of **rivers (left)** and **tides (right)** on the ***variability*** of temperature