The Bureau of Meteorology

Regional coupled modelling at the Bureau (UKMO RCS)

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Motivation

Regional coupled system development

NEMO transition

- The Bureau is currently transitioning its global ocean forecasting system to the NEMO ocean model'
- Aligns us with ocean model developments at the UK Met Office, facilitated through the Momentum partnership.
- Met Office has developed a regional coupled framework realized through the Regional Coupled Suite. Additionally, a regional coupled working group, led by the Met Office, fosters collaboration and knowledge exchange.

Strategic Alignment

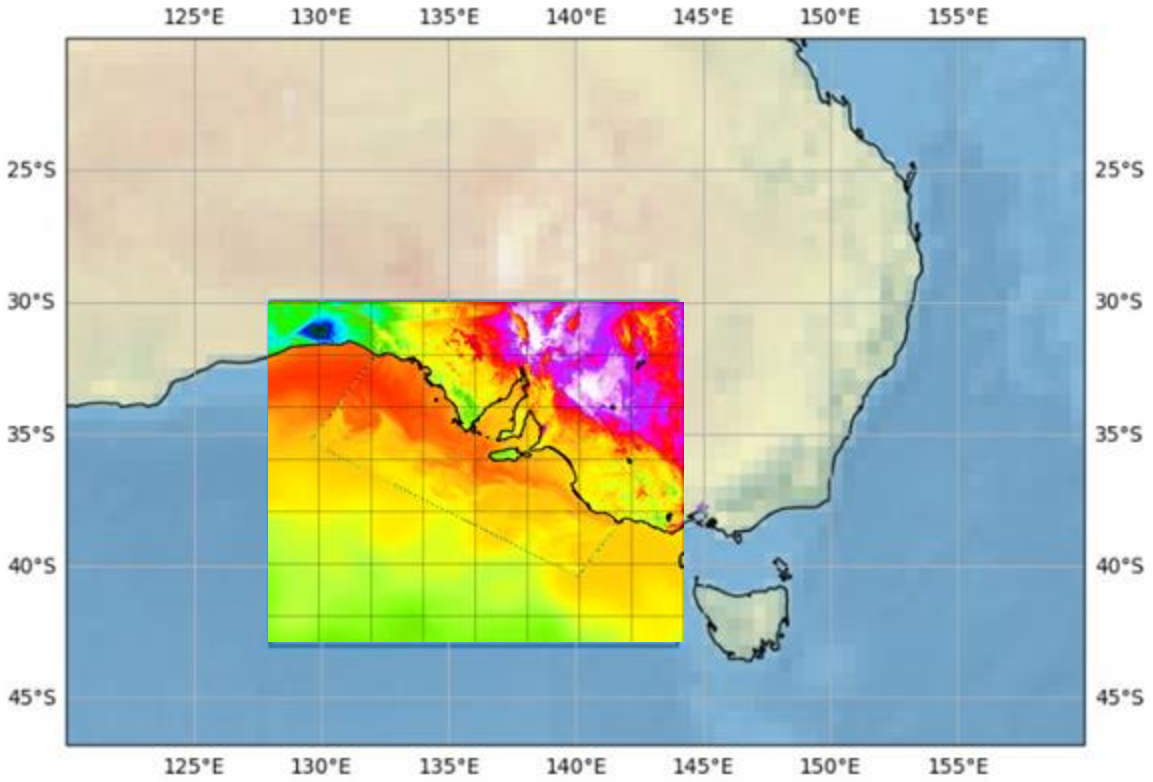
- A regional coupled capacity aligns with our strategic direction of developing coupled modelling forecasts across various time scales and spatial domains.
- Strengthening collaboration with the UK Met Office allows us to leverage existing coupled infrastructure and knowledge base.
- Engaging with other partners e.g. CCRS (Climate Change Research Section) on coupled modelling fosters collaboration within the Austral-Asian region

Atmospheric Forecast Improvement ?

- Coupled modelling may improve atmospheric forecasts by providing more realistic and dynamic lower atmospheric boundary conditions
- Improving sea surface temperature (SST) representation near the coast which may directly impact atmospheric prognostic variables

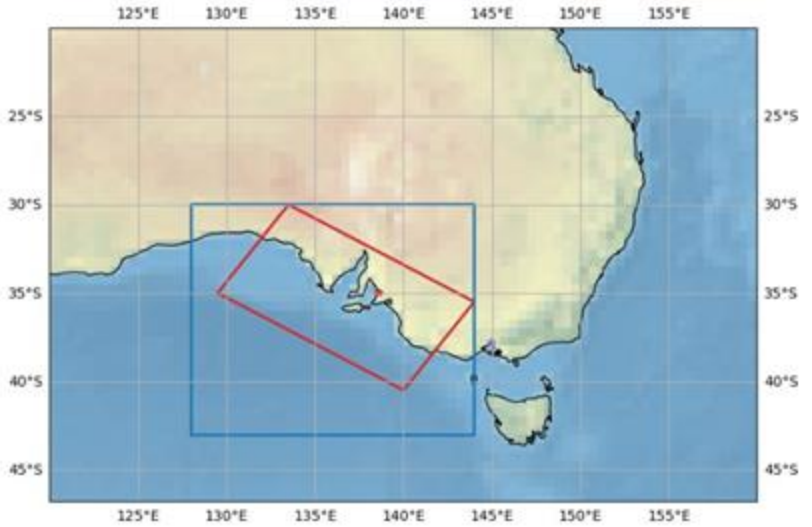
Outline

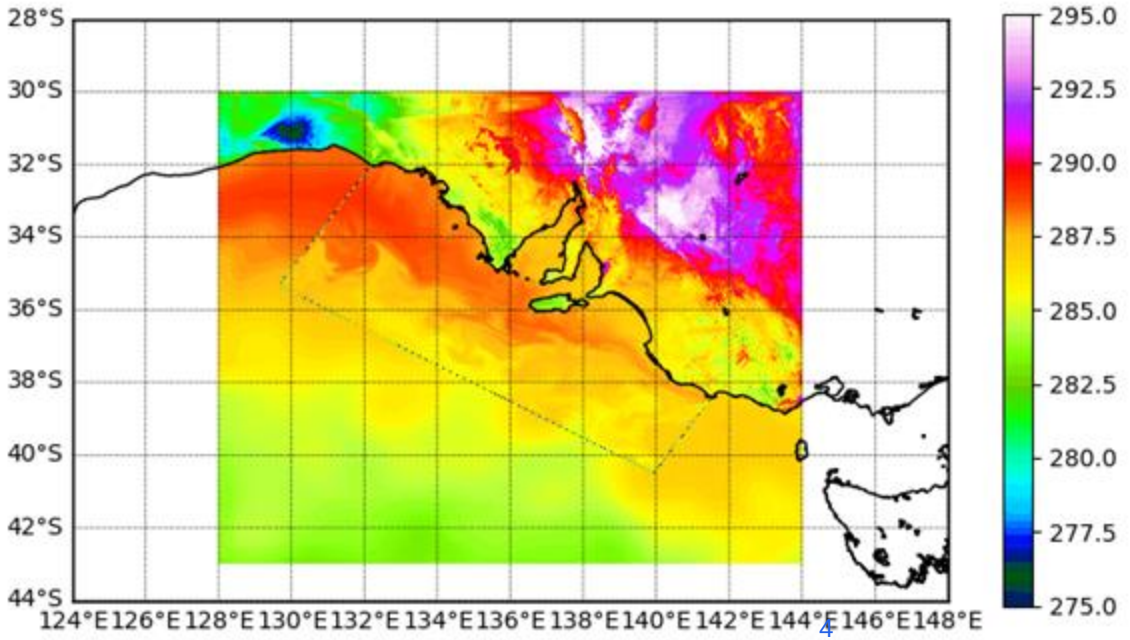
- Overview of the coupled system
- Ocean model evaluation
  - The South Australian shelf domain
  - ROMS and NEMO South Australian models
  - Comparison to observations
- Comparing coupled with un-coupled system (atmosphere)
  - e.g. boundary layer depth. T1.5m
  - Comparison to BARRA, ERA5
- Summary/ Next steps



Regional coupled system

- Coupled model utilising RCS infrastructure
  - **NEMOv4.0.4**
- Atmospheric model initial and boundary conditions from UM nesting suite
  - **UM 12.2 - RAL2M**
- Regional coupled atmosphere-ocean model over SA shelf
  - Atmosphere (1186, 964, 80) - blue
  - Ocean (439, 270, 31) - red
- 1 hour coupling time step between models:
  - Atm: heatflux, short wave, rain, evaporation, wind stress, surface pressure
  - Ocn: SST, curl
  - Coupling using bilinear interpolation
- Resources:
  - Ocean model relatively cheap (roughly 1/3 of the costs if grids are same size)
  - Atmospheric costs determined by city size models

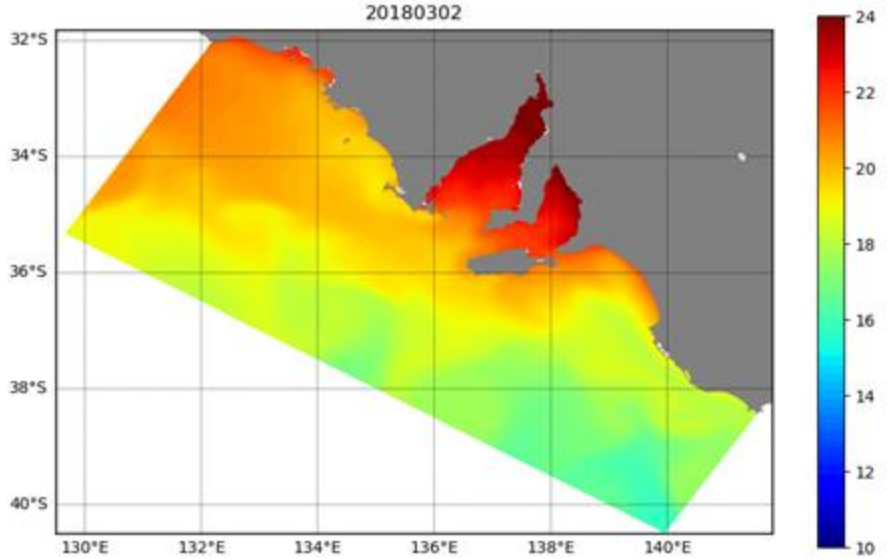




Regional ocean model

ROMS vs NEMO over the South Australian Bight

- The Bureau has been running the eSA-Marine system in research mode for about 5 years
- It has delivered 7-day ocean forecasts over the South Australian Bight
- Contains wave and ocean modelling components
  - Downscaling from OceanMAPS (10km) SAROM (2.5km) 2 Gulfs (500m) model (operated at SARDI)
  - Wave model unstructured mesh with 500m resolution along coastline
- For this comparative analysis, the ROMS and NEMO model have been run with comparable configurations
  - No data assimilation
  - Same time period: September - November 2021
  - Same atmospheric forcing: ERA5
  - Same global model forcing (BRAN2020)
- Output has been compared to available observations
- **FIRST NEMO BASED REGIONAL OCEAN MODEL**



Video of daily averaged surface temperatures

- Model is capturing the surface circulation well
- No obvious problems with the boundaries
- From 2018-03 2018-08, daily averaged SST

Features:

- Upwelling along the Bonney Coast
- Coastal Current:
  - South Australian (Leeuwin Current) visible
- Northwestward flowing Flinders Current visible

Comparing the ocean model to observations

Available observations over the 3-months period

- Boundary and initial conditions can be created for ORCA12 a
- **Assessment of global products via EnKF-C (Sakov, 2014**
- Boundary conditions generated over 3 months period from S model available during that period)
- **Assessment on SST, subsurface temperature and subsu**
- **Note, few observation in the subsurface over this region (ARGO ~1 obs every 2-3degrees)**

TYPE	PROVIDER	INSTRUMENTS	AVG OBS per day
SST	NAVO ACSPO	AVHRR VIIRS	~10,000
Temp	BoM	Argo and others	~34.9
Salt	BoM	Argo (mainly)	~34.8

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Comparing ROMS and NEMO systems

Directly comparable model simulations NEMO (BRAN) vs ROMS (BRAN)

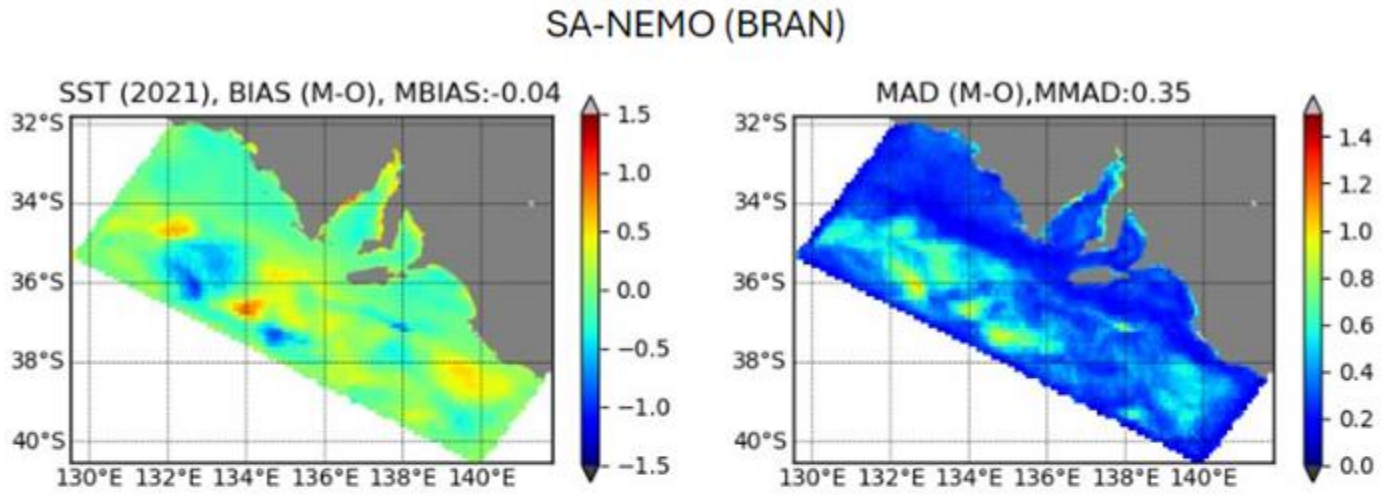
2021-09 to 2021-11

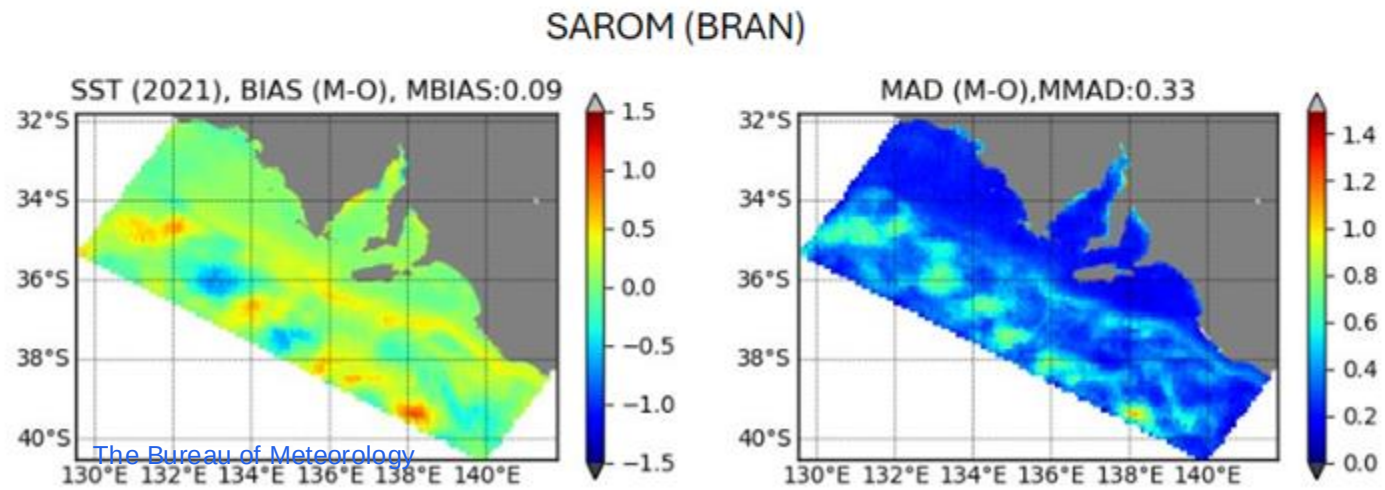
	SST			TEM			SAL		
EXP	**MAD**	**BIAS**	**#OBS**	**MAD**	**BIAS**	**#OBS**	**MAD**	**BIAS**	**#OBS**
NEMO	0.34	**0.0179**	9500	**0.556**	**0.142**	34.9	0.117	0.013	34.8
ROMS	**0.334**	-0.105	9500	0.573	0.19	32.5	**0.112**	**0.0126**	32.4

- Results suggest both regional models are performing similarly
- NEMO has slightly better statistics for surface temperature BIAS and subsurface temperature.
- **Suggesting successful first implementation of a regional NEMO ocean system, which forms the basis for the ocean component of the coupled system**

Comparing innovation stats – NEMO (BRAN) vs ROMS (BRAN)

Spatial pattern of SST bias and error





Innovations statistics over 2021-09 to 2021-11

- Overall ROMS and NEMO reveal similar spatial pattern of error and bias
- Larger bias and error over the deep ocean
- Good representation of SST over the shelf. NEMO appears to have slightly larger errors in close proximity to the coast (i.e. Spencer Gulf)
- ROMS error appear to be closer to the boundary

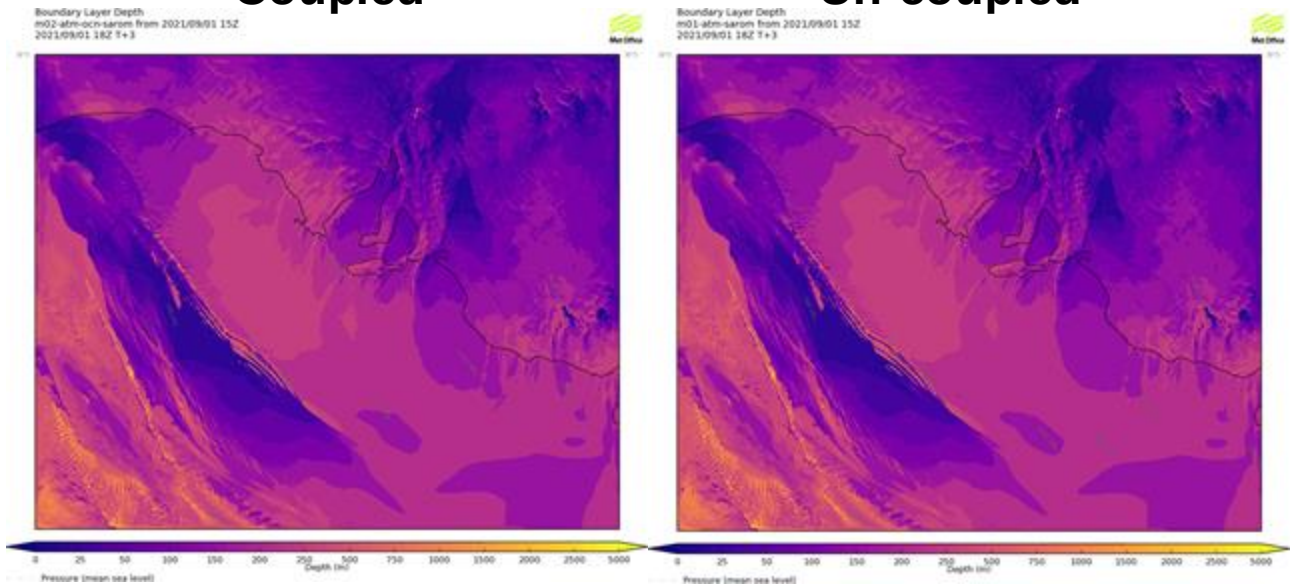
Comparing innovations statistics for sea surface temperature. NEMO (upper) and ROMS (lower) regional models against observed SST's.

Regional coupled suite - South Australian domain

First results - atmospheric model output

Boundary layer depth

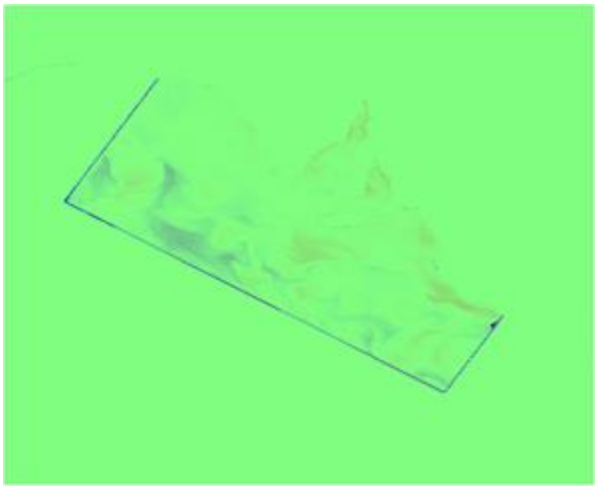
Coupled **Un-coupled**



- Left (right) Coupled (Un-coupled) simulation
- Shown are hourly output of a 5 day forecasts starting at 2021-09-01 T15Z
- The rim outlining the ocean domain is visible in the coupled model output □ needs to be addressed

Temperature difference (T 1.5m)

Coupled - Un-coupled



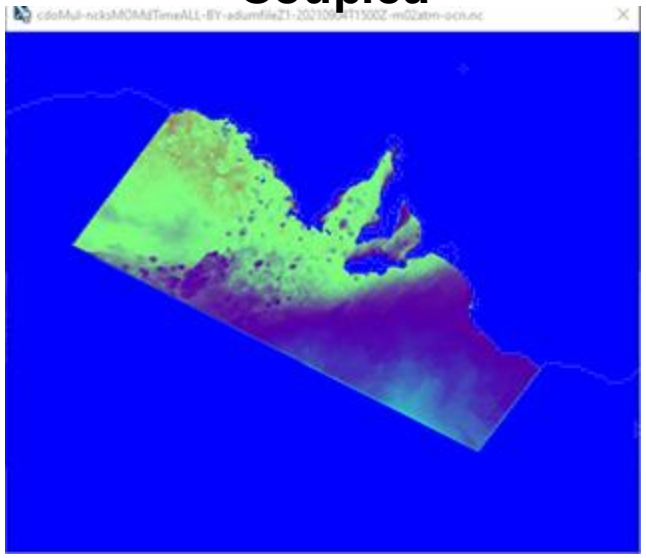
- Air temperature difference at T1.5 over a 5 day forecast.
- Larger differences over the ocean domain and along the coastal regions indicating feedback from the ocean is increasing variability in the atmosphere

NEMO domain cutout plots

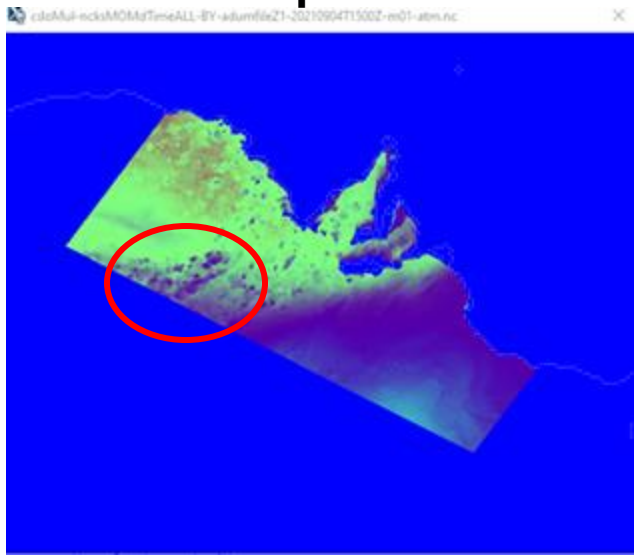
First results - atmospheric model output

Temperature (T 1.5m)

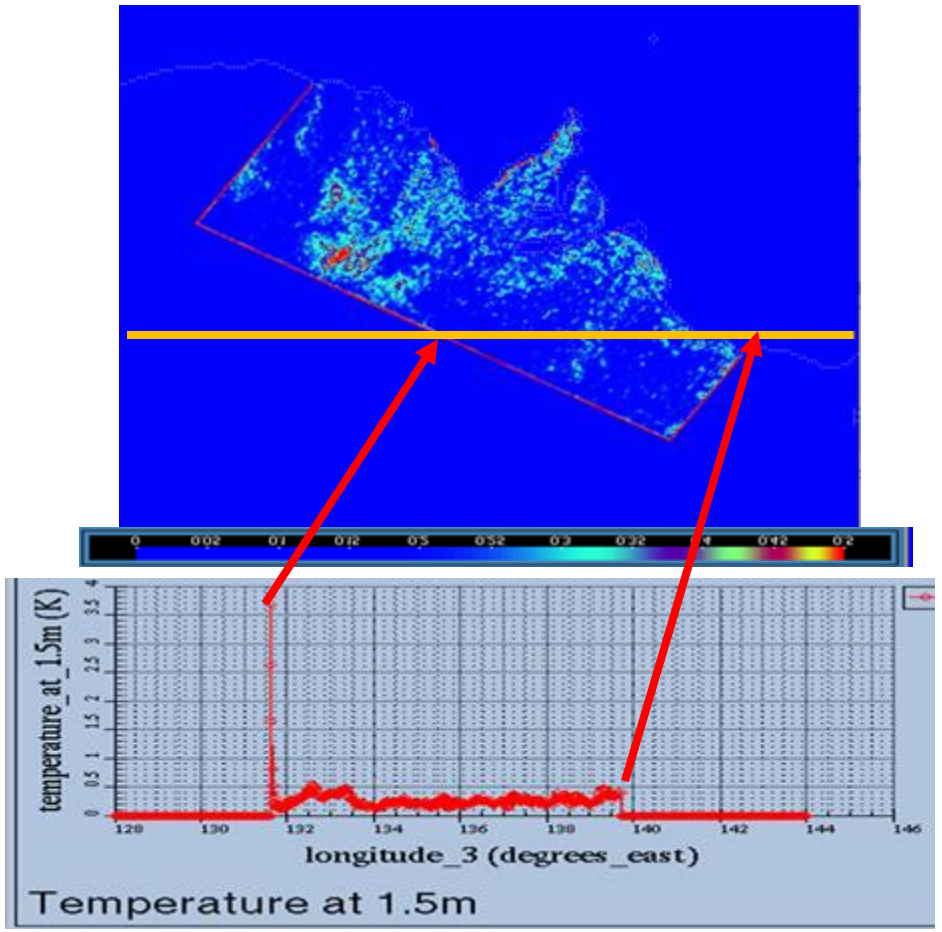
Coupled



Un-coupled

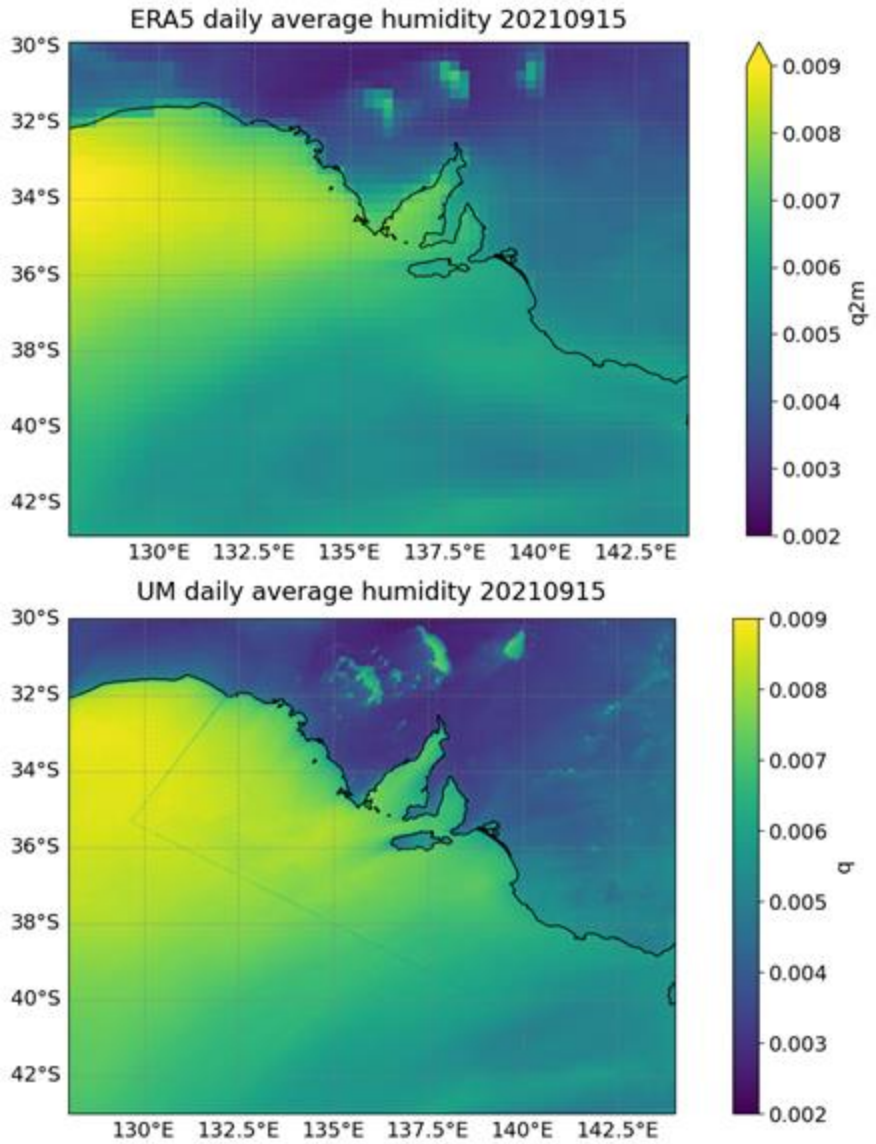


Temperature difference (T 1.5m)
Coupled - Un-coupled

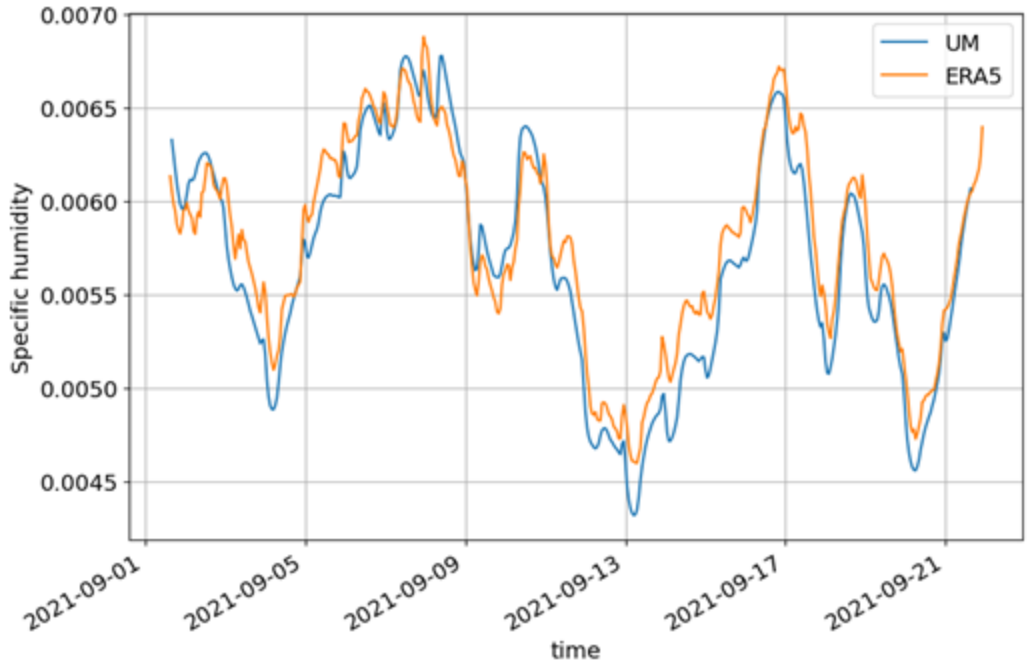


- Difference of indicated area. Possible explanation might be related to SST boundary.
- Higher SST in ocean model compared to lower SST boundary when uncoupled
  - Possible changes in heating lower atmosphere
- This effect might be also observed in the boundary layer and in convection
- To the right: cross-section indicates how different the atmospheric solution is over region of coupling

Specific humidity 20-day forecast comparing to ERA5



- ERA5 specific humidity computed from dewpoint temperature
- Spatial pattern of daily average from 2021-09-15 similar between UM (bottom right) outputs from coupled run and ERA5 (top right)
- Timeseries of 1.5m specific humidity from coupled run vs ERA5 specific humidity shows good agreement (below)



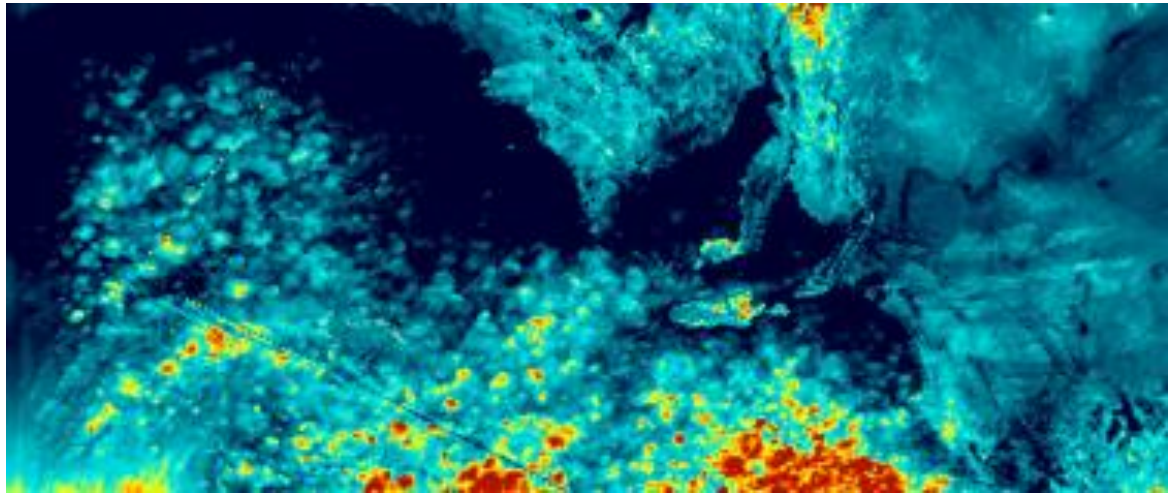
Regional coupled suite - South Australian domain

Comparison with Reanalysis (BARRA)

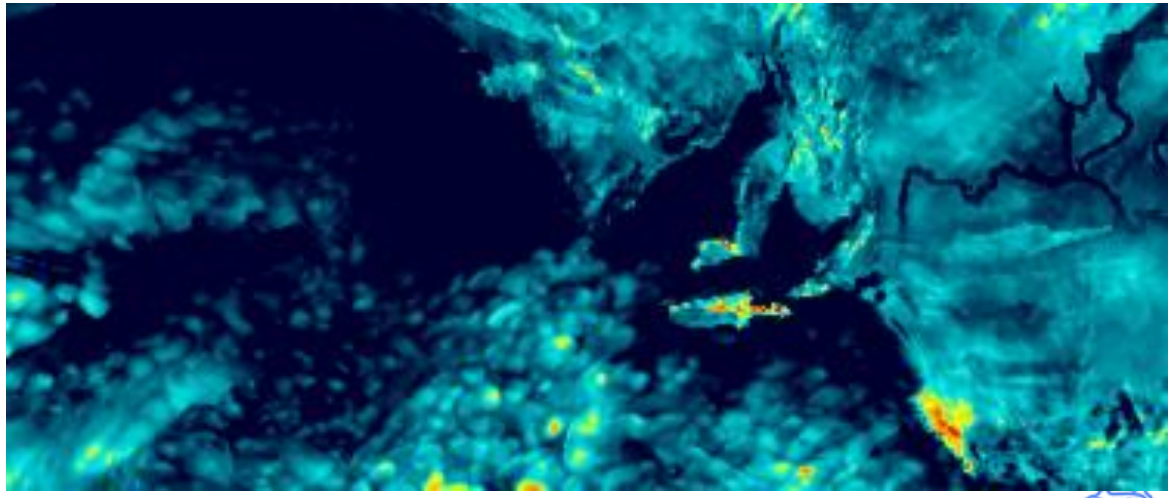
(right) Normalized 20day (2021 Sep1:20) avgT1.5m diurnal 1hr circulation for (top) RCS CPL and (bottom) BARRA-C2 reanalysis

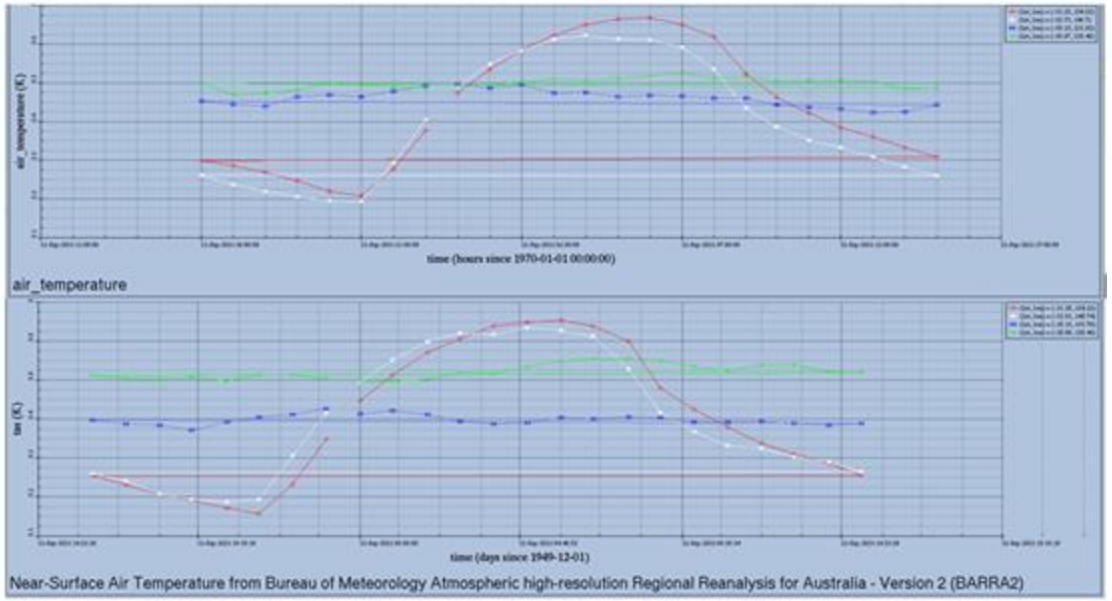
(below) 5 gridpoint time series for (top) RCS CPL and (bottom) BARRA-C2 reanalysis

Temperature (T1.5m) Coupled



Temperature (T1.5m) BARRA-C2





RCS - Comparing with reanalysis (BARRA)

RMS errors of surface temperature (T 1.5m)

Coupled | **Un-coupled** | **RMS difference Coupled - Un-coupled**

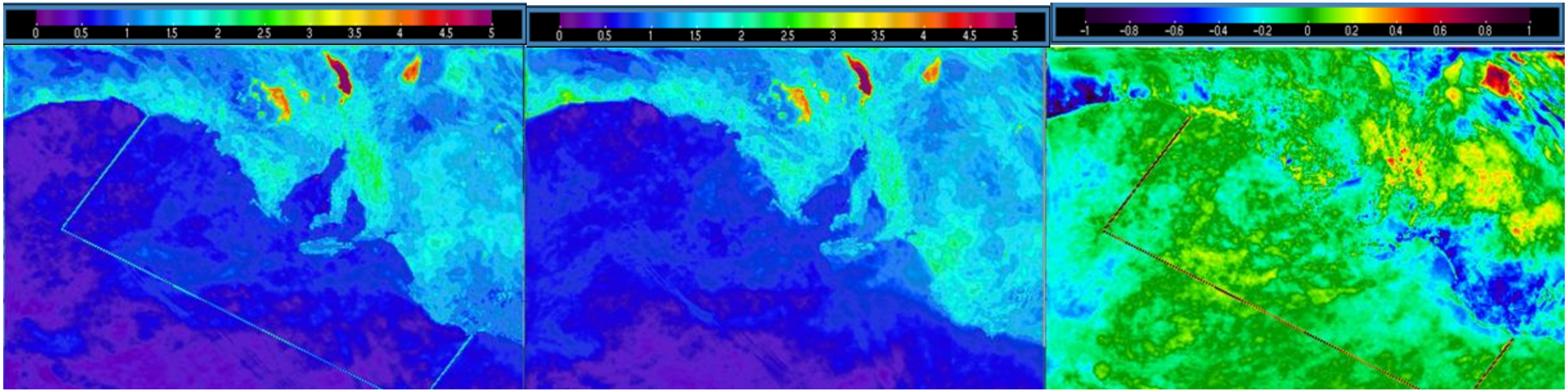


Figure: 5 day T1.5m average model-BARRA-C2 rms errors (left, middle). Right: RMS difference. Negative (positive) values suggest RMS error of the coupled simulation is smaller (larger).

- RMS error difference exist and are related to the coupling.

Summary

Work package

1. Configuration and development of a standalone regional ocean system based on the NEMO ocean code.
2. Porting and subsequent utilisation of the Regional Coupled Suite developed at the UK Met Office to the NCI HPC
3. Integrate an existing UM City type atmospheric model and ocean configuration with the Regional Coupled Suite

Results

- The standalone ocean system developed over this FY based on NEMO closely matches an existing regional model configuration based on the ROMS ocean model.
- The Bureau now has the capacity to develop regional ocean systems that may be similar in performance than those already developed
- The porting and running of the coupled modelling infrastructure was largely a technical piece of work, which has been successfully accomplished.
- Numerous experiments with the coupled system have been performed. The coupled system has been run out for 20 days with no obvious problems and all evidence suggests the coupling between the ocean and atmosphere was successful

Next stage

NEMO

- Development of a better bathymetry
  - Community tools to edit the bathymetry/mask/coastline?
- Refinement of Vertical coordinate system
  - Further work on hybrid z-s coordinate
  - Multiple envelopes

Coupled Model

- Further evaluation of the system (i.e. impact on ocean)
- Ocean initialisation/ restart suboptimal atm
  - Automatically update ocean restart procedure for consecutive 5-day forecast
- Remove the halo area model domain
- Push back site files and test cases to UKMO repository
- Improve HPC performance by redistributing NEMO and XIOS processes to UM and Flume server.
- Towards a tropical cyclone test case over the NW Shelf
- Wave coupling
- Ocean DA ? Atmospheric DA ?