Coastal Modelling 101

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Australian Water School Webinar 19th May 2021

Introduction

Coastal Modelling vs Flood Modelling

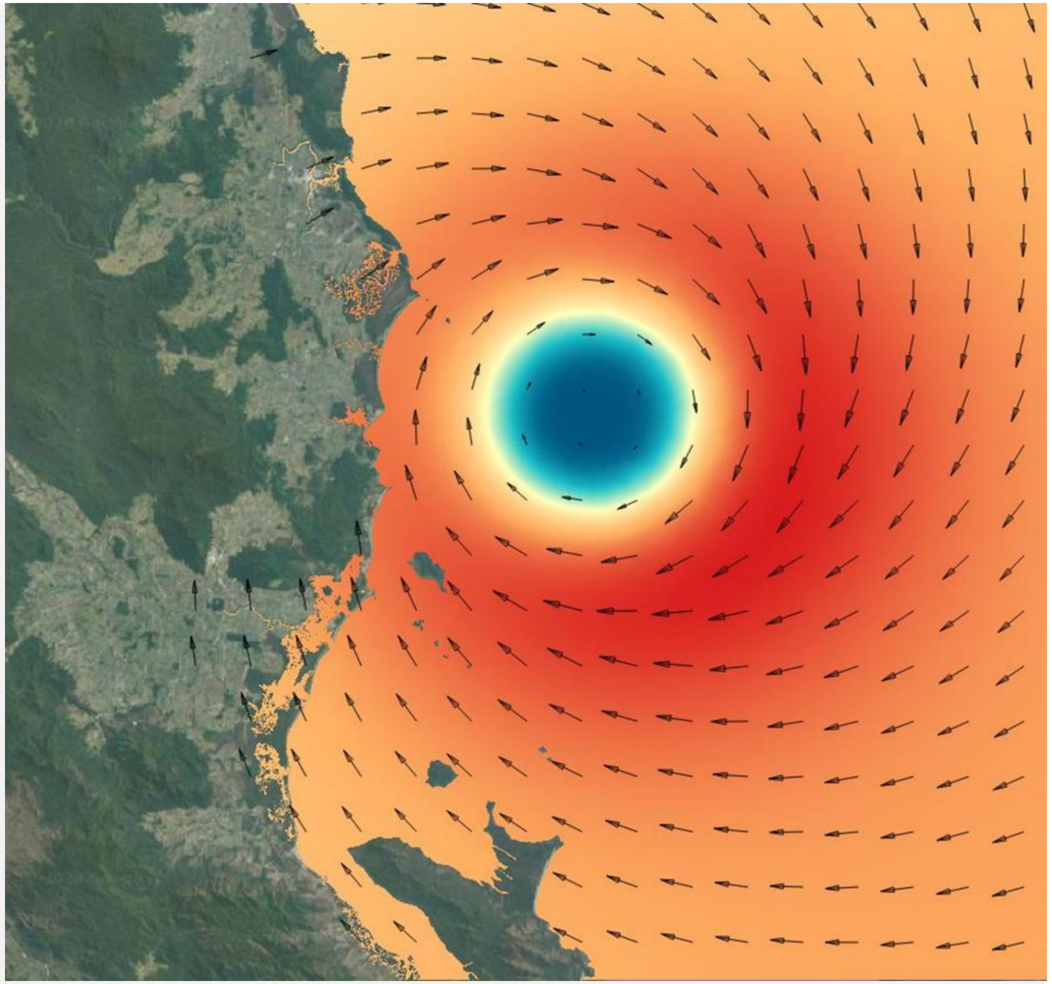
The Challenge

The Astronomical Tide

Climate, Weather and the Ocean

Spectral Wave Modelling

Review and Conclusions



Introduction

This presentation is a short ‘taster’ in coastal modelling

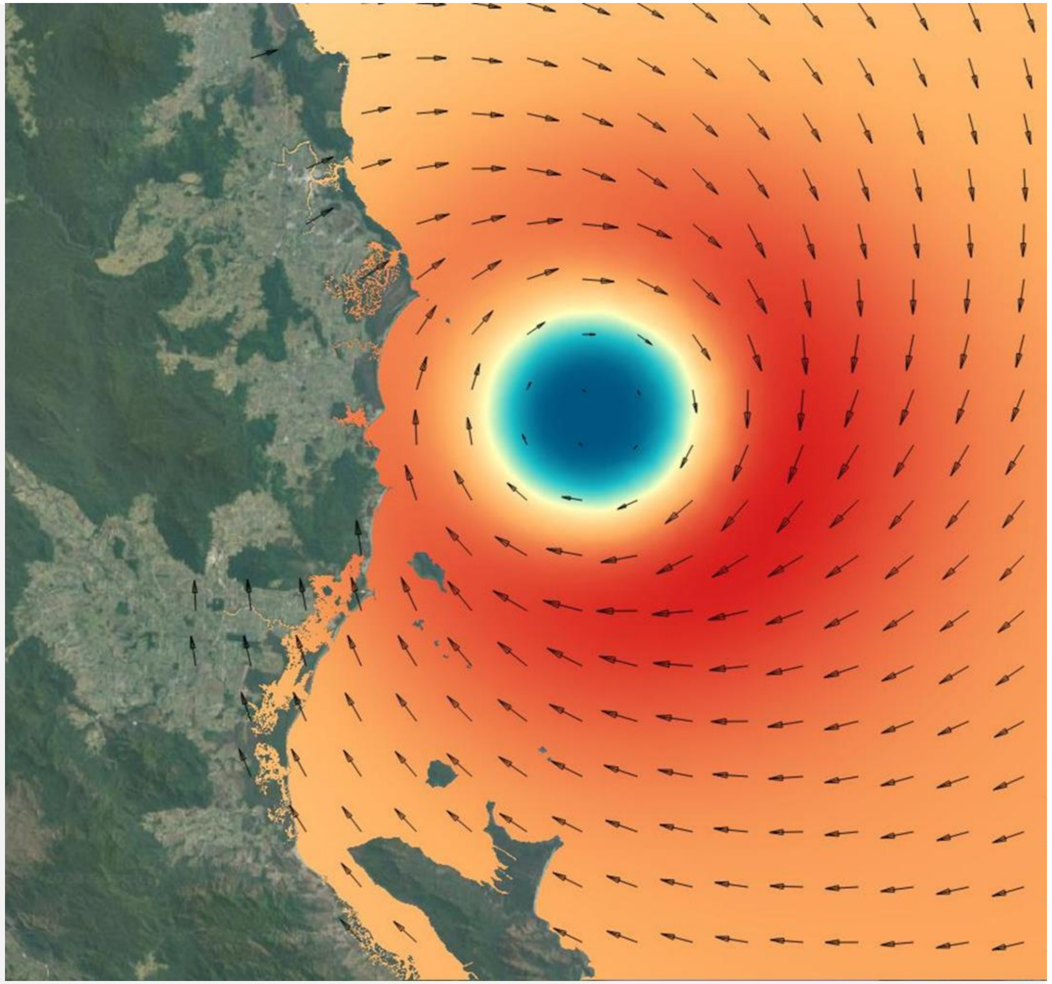
The examples developed today are from TUFLOW FV and SWAN

Aimed at new coastal modellers or with those interested in understanding more.

I’ve kept the theory to a minimum

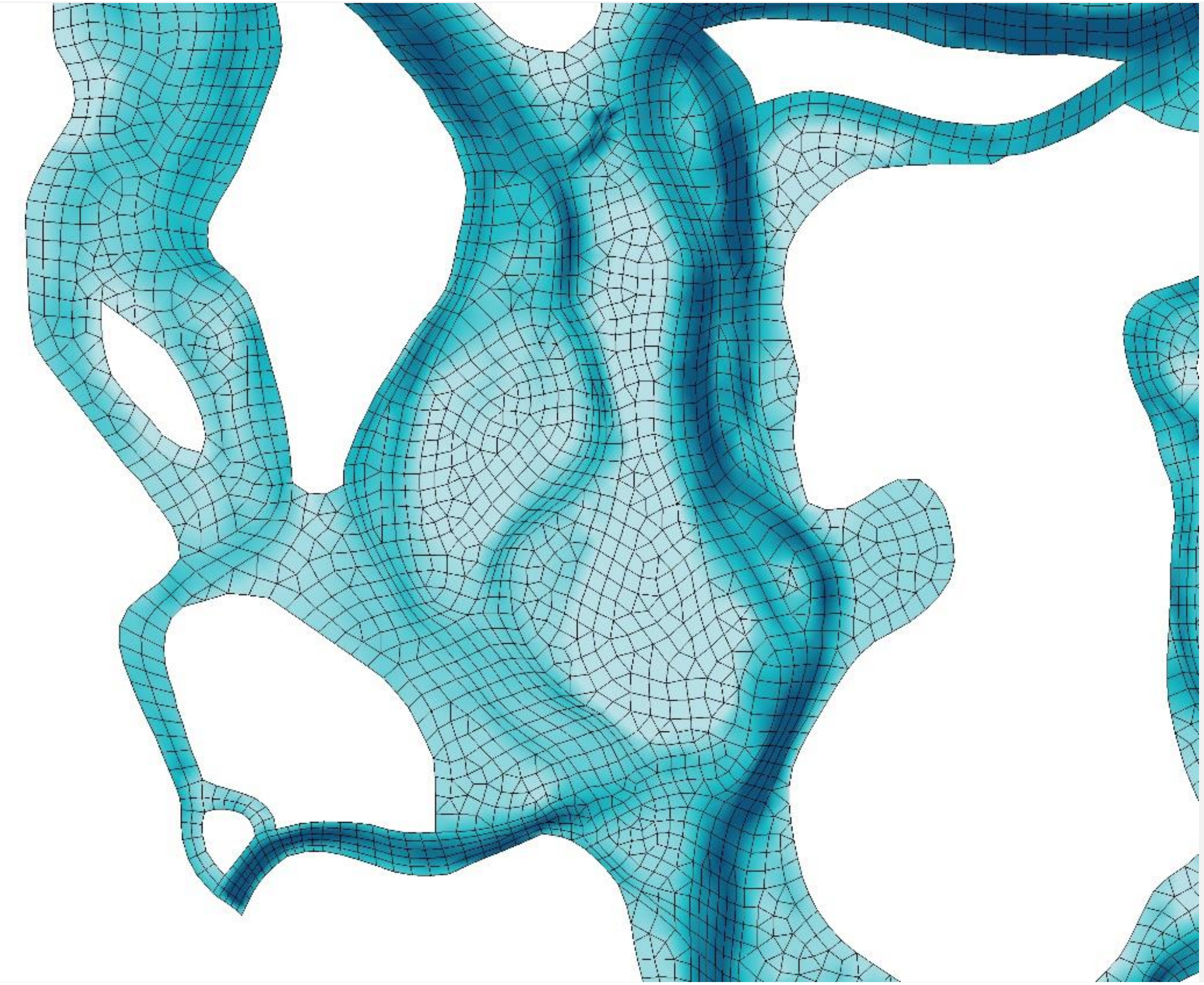
If you’d like to understand more check out ‘Astronomical Tide’ and ‘Waves’ pages of: coastalwiki.org/wiki/Main_Page

Please ask lots of question in the Q & A line.



TUFLOW FV TUFLOW’s Flexible Mesh Engine and Environmental Toolkit

- 1D, 2D & 3D (CPU or GPU) Hydrodynamics
- Advection-Dispersion/Diffusion
- Atmospheric Heat Exchange
- Sediment Transport
- Water Quality
- Particle Tracking
- Windows or Linux OS
- Spectral Wave Coupling (Single or Two-way)
- Range of Utilities, Python/MATLAB Libraries
- QGIS, SMS, GIS Mesher, SWAN GIS Tools



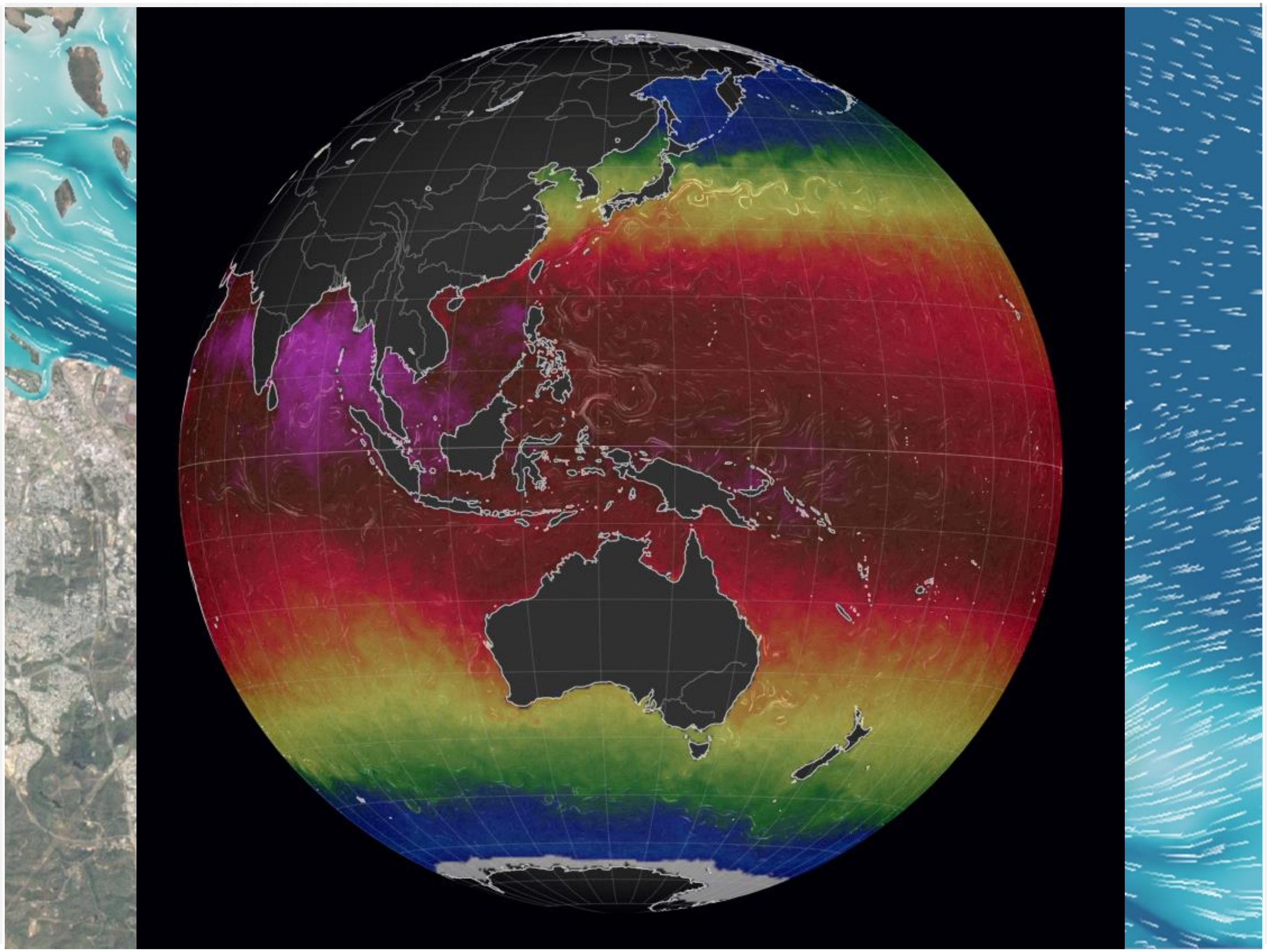
Modelling – A few definitions for this talk…

Rivers and Flood modelling – The areas of our catchments influenced primarily by rainfall and to a lesser extent groundwater

Estuaries – the region where the astronomical tide and riverine systems meet and mix

Coastal* – Seaward of the coastline 100-250km

Ocean circulation models – Global and model offshore processes



Flood and Coastal Model Interactions

Coastal processes that affect flood modelling

Tailwater (Astronomical Tide, Storm Tide, Static)

River mouth morphology

Interaction of salt and freshwater can affect flow behaviour – stratification, however for big floods this is typically reduced

River processes that affect coastal modelling

Freshwater river flows can be important in the estuary

Do flood flows affect the ocean level?

Coastal sediments and nutrients

Coastal Modelling – A few applications

Coastal and fluvial inundation

Storm tide

Tsunami

Wave overtopping

Stratified systems

Coastal protection design

Metocean and offshore design

Port development/optimisation

Marine structure analysis

Capital and operational dredging

Ship navigation and route optimisation

Morphological analysis, bed scour and deposition

Beach morphology

Contaminant or species fate

Aquaculture

Ocean outfalls and point source discharges

Ocean, lake and estuarine water quality, algal blooms, plankton etc.

Animal migration

Salvage, rescue

Scale

	Flooding	Coastal	Ocean
Temporal Scale	Hours to days	Hours to years	Days to hundreds of years
Spatial Scale	Meters to kilometres	Meters to thousands of kilometers	Global

Processes

Rainfall is no longer the star of the show…

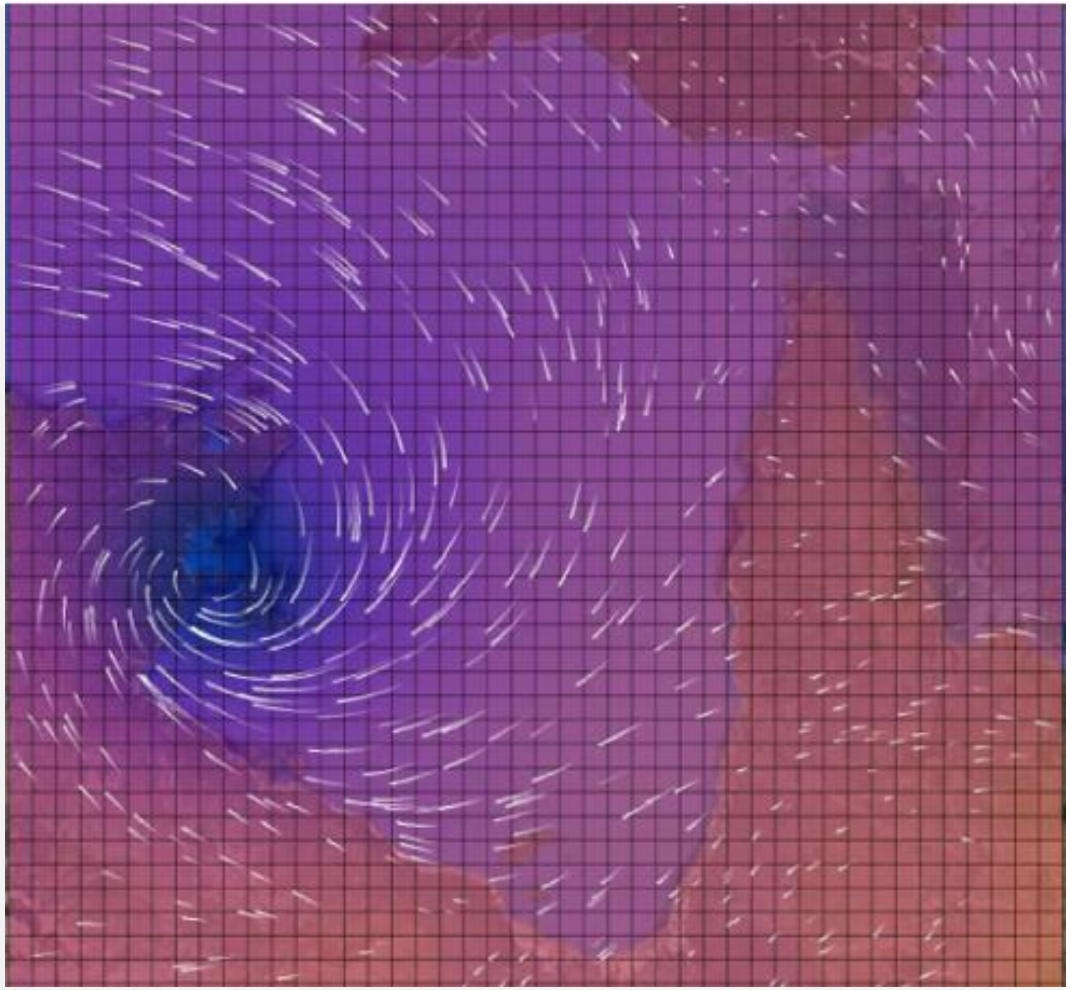
Astronomical Tides

The interaction between the atmosphere and ocean is important

Coastal model boundary conditions tend to use gridded inputs – vary in space and time

3D effects often need to be considered, salinity, temperature

Waves



The Challenge

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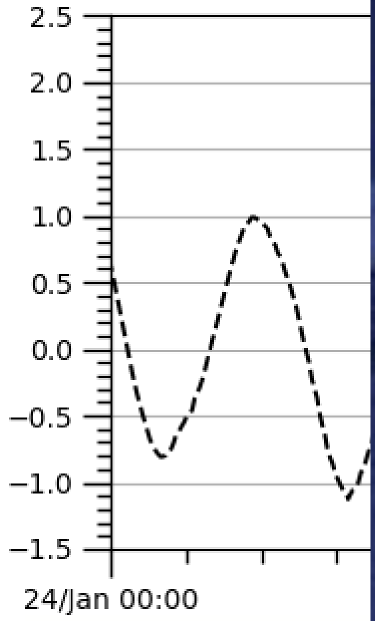
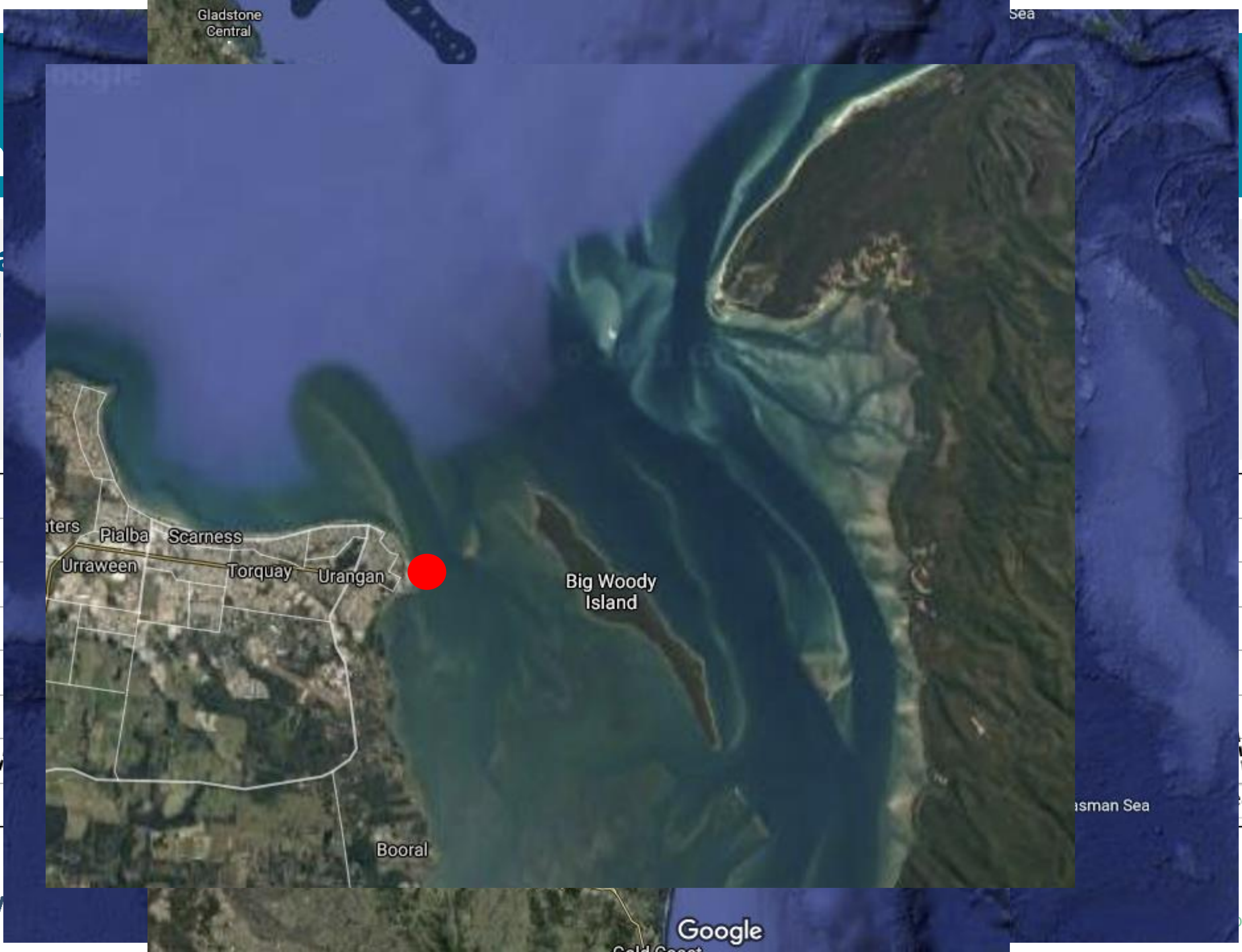
Build a coa

Urangan –





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The Steps

1. Develop the model domain

2. Run with the astronomical tide only

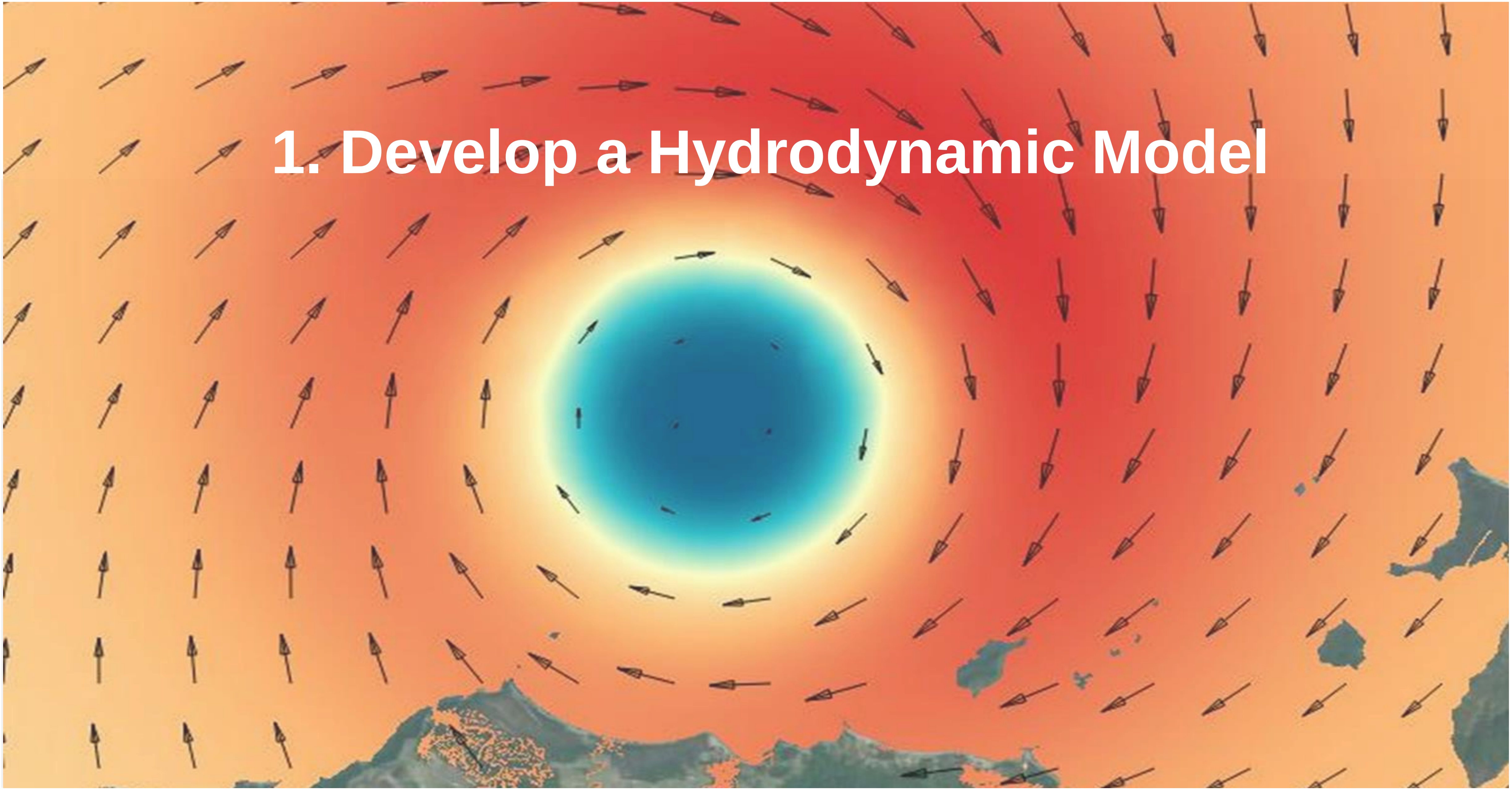
3. Run with astronomical tide + meteorological influences (Air pressure and wind)

Along the way I'll discuss:

1. The various datasets we need

2. The physical processes

1. Develop a Hydrodynamic Model



Coastal vs. Flood Models

Both types of models require similar features

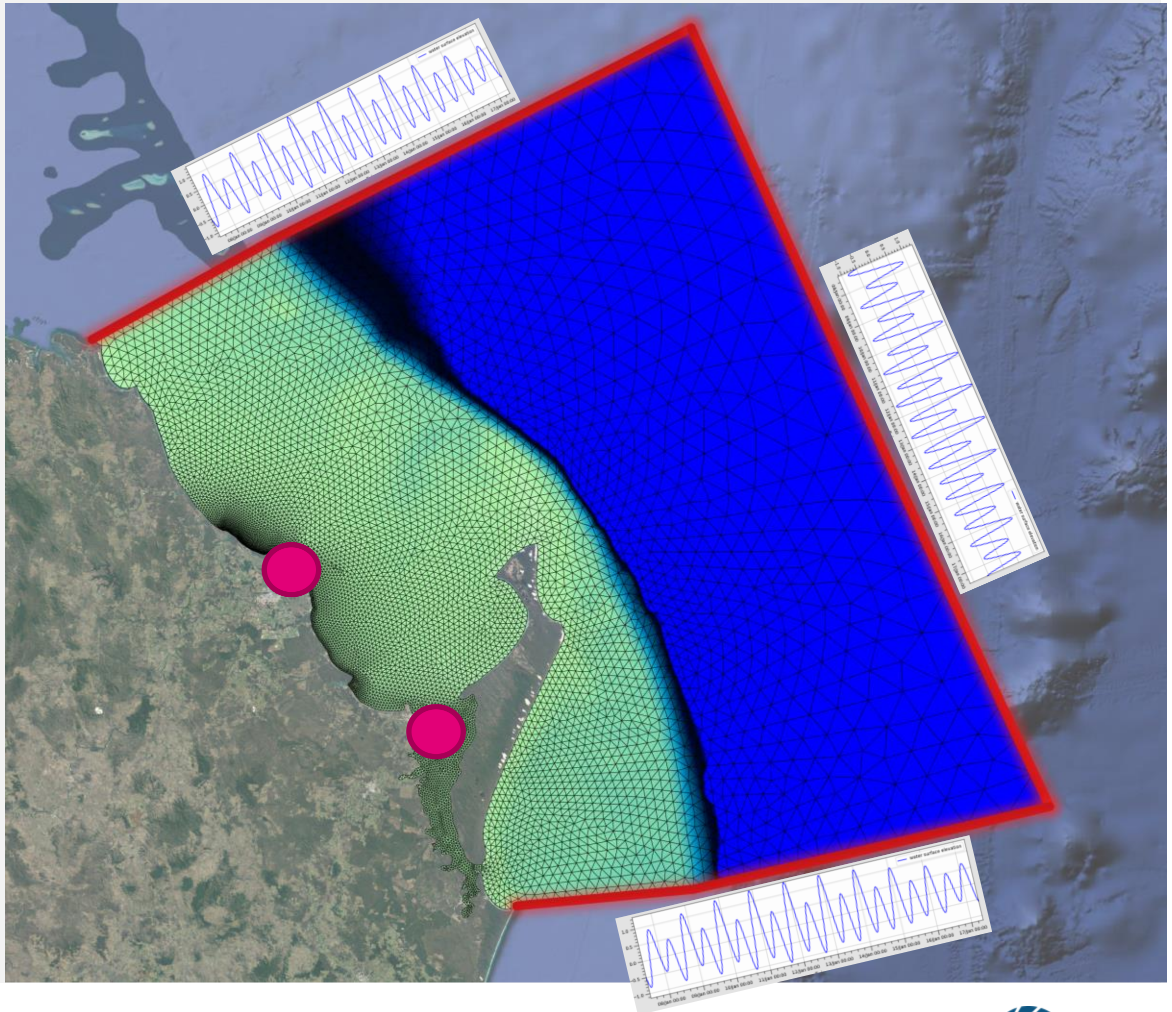
Bathymetry/Topography

Computational Grid/Mesh

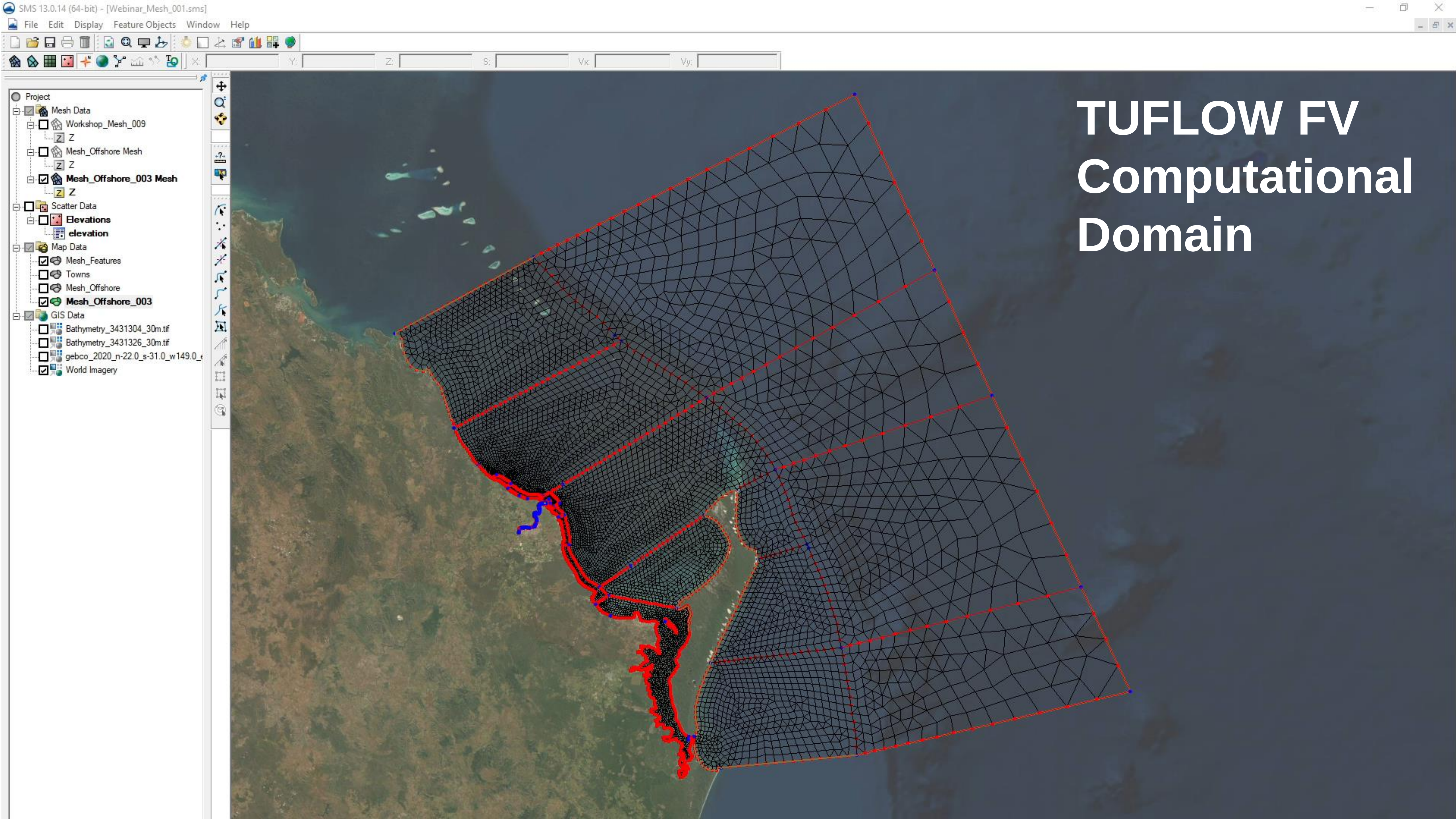
Boundary Conditions

Model Selection i.e. bed roughness, turbulence

Calibration!!!



TUFLOW FV Computational Domain



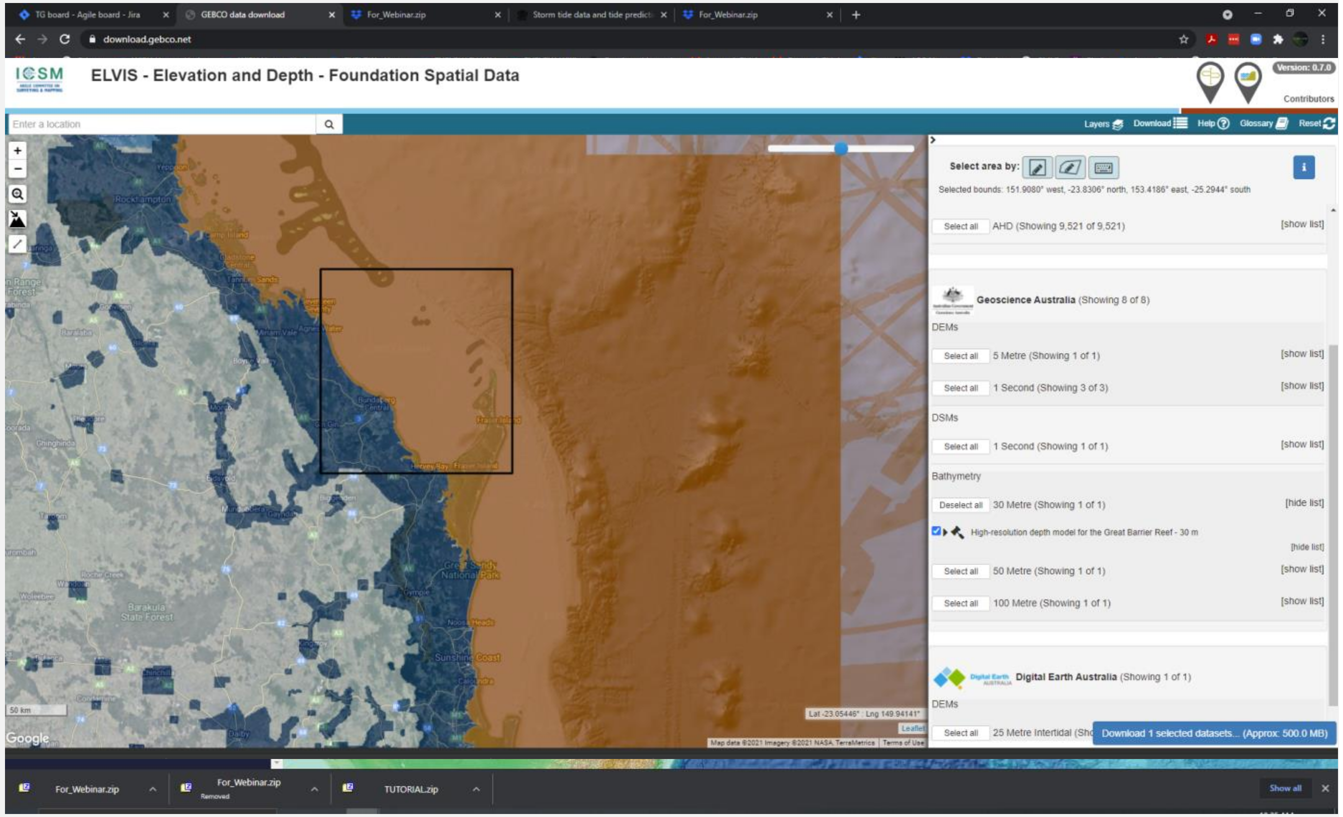
Bathymetry

Admiralty Charts (Analogue or digital)

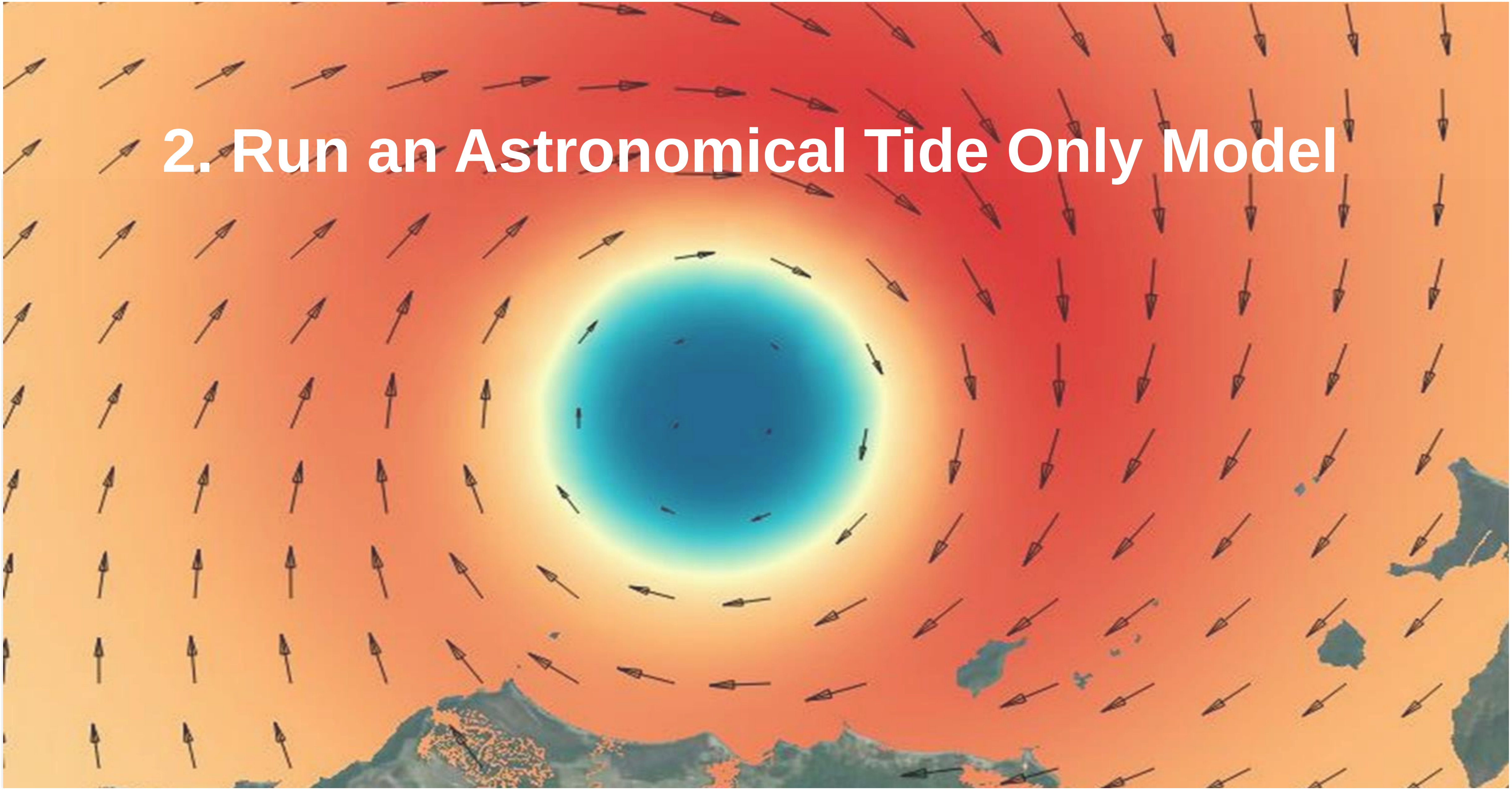
Online data services

Estuaries – Often have to source new data (survey) or derive from cross sections

Storm tide/Tsunami – LiDAR



2. Run an Astronomical Tide Only Model



Why are the Astronomical Tides Important?

Water levels and currents

Intertidal areas – mangroves, mudflats, seagrass

Coastal morphology, beaches

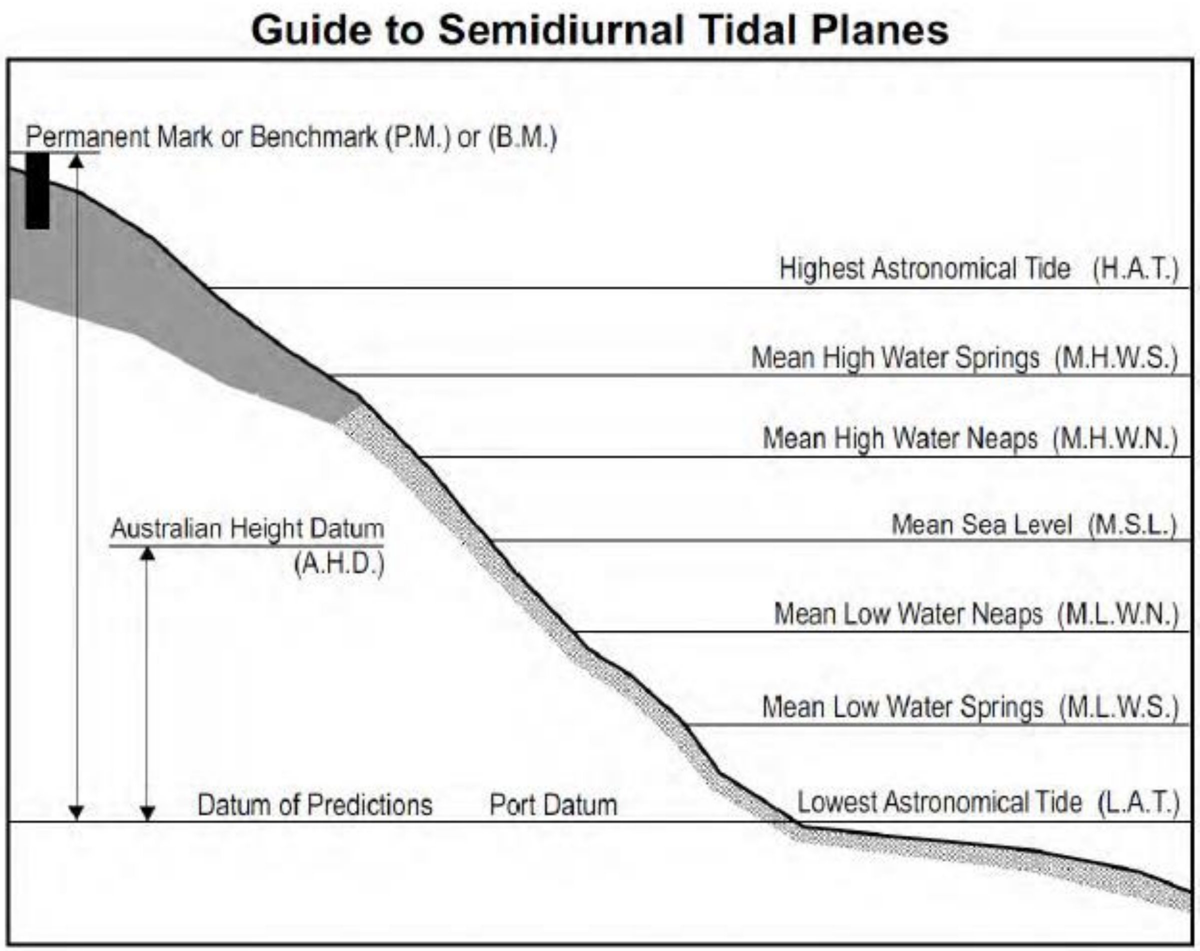
Coastal infrastructure

Navigation

Where the tides start and end for a lot of flood modellers

Height above lowest astronomical tide

Place	Latitude South	Longitude East	Time Difference HW 1 H M	LW 2 H M
Tidal Datum Epoch 1992 - 2011				
Bundaberg (Burnett Heads) cont.				
Hervey Bay -				
Point Vernon	25 15	152 48	-0 10	-0 10
Burrum Heads	25 11	152 37	+0 12	+0 30
Woodgate (Theodolite Creek)	25 04	152 33	-0 15	-0 15
Wathumba Creek (Fraser Island)	24 58	153 14	-0 12	+0 36
Elliott River Entrance	24 55	152 30	-0 09	-0 09
Burnett River (Town Reach)	24 52	152 21	+0 32	+0 57
Bargara	24 49	152 27	+0 00	+0 00
Kolan River (Booyan Bridge)	24 42	152 11	+0 23	+1 30
Baffle Creek (Winfield)	24 32	152 02	+1 05	+1 56
Lady Elliot Island	24 07	152 43	-0 21	-0 21



Astronomical Tide

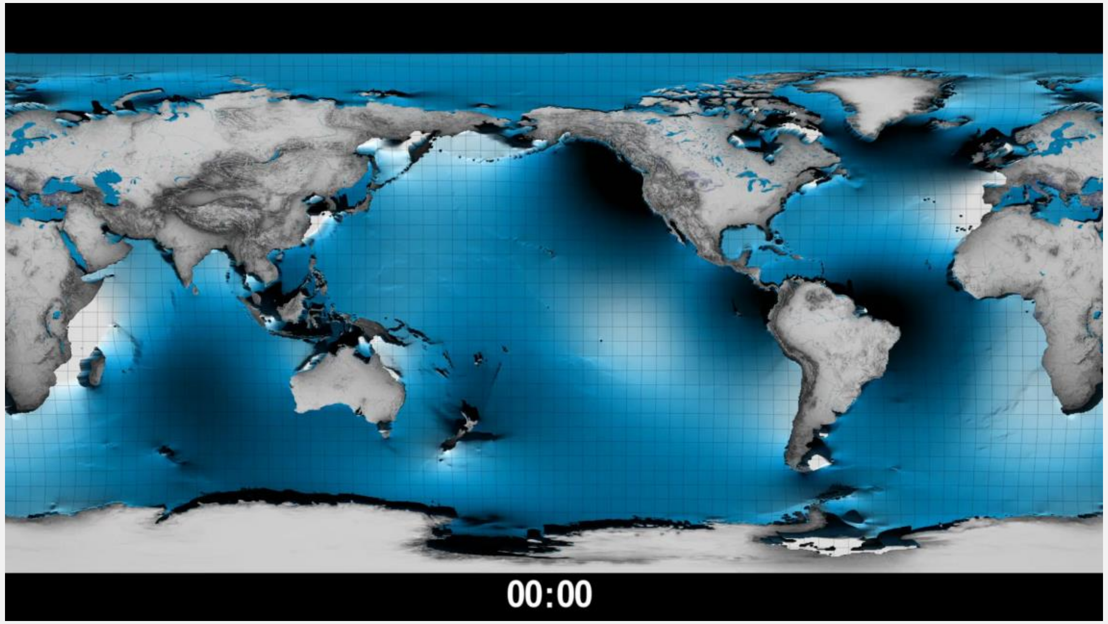
Long period waves driven by the differences in gravitational attraction at various locations on our rotating earth to the moon and sun

Time of year, changes in the moon's orbit, earth's orbit and the earth's axial tilt affect the tides

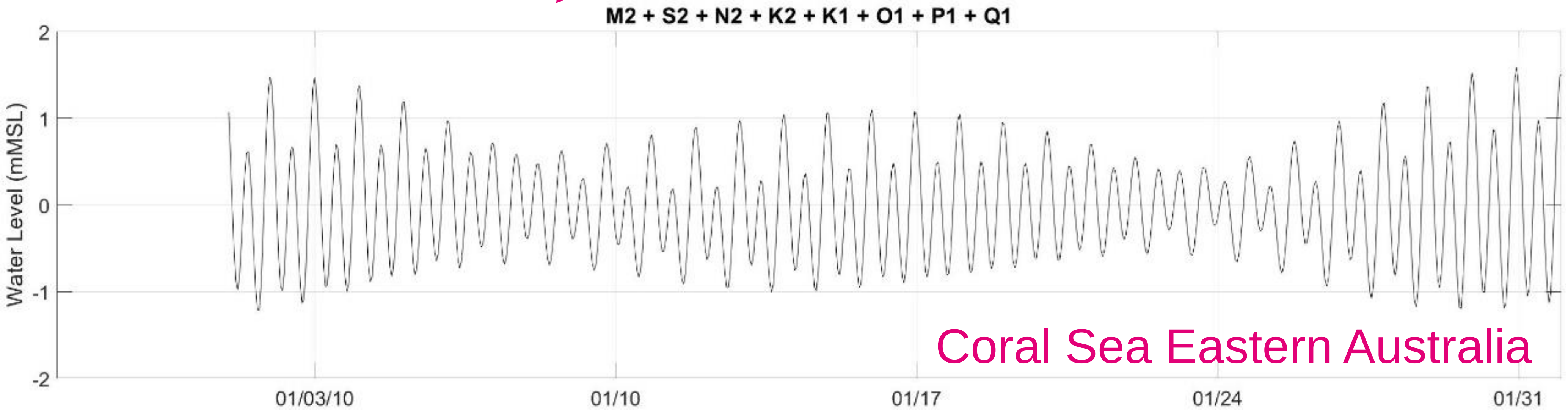
Can be broken down into a series of partial tides called tidal constituents

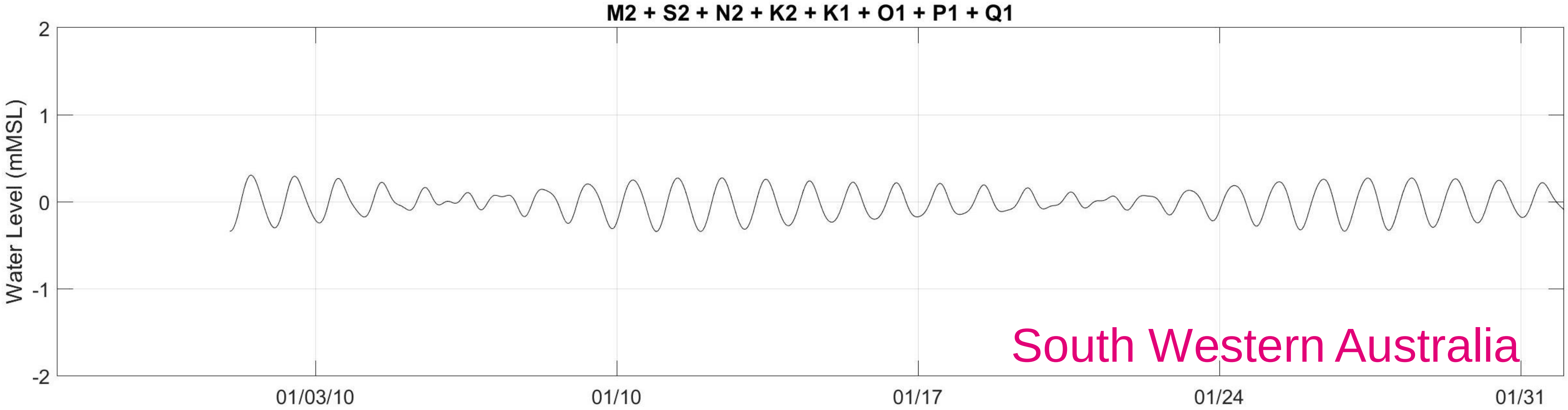
These forces are influenced by the continents, ocean bathymetry and Coriolis Force

And thus the tides differ greatly across the globe

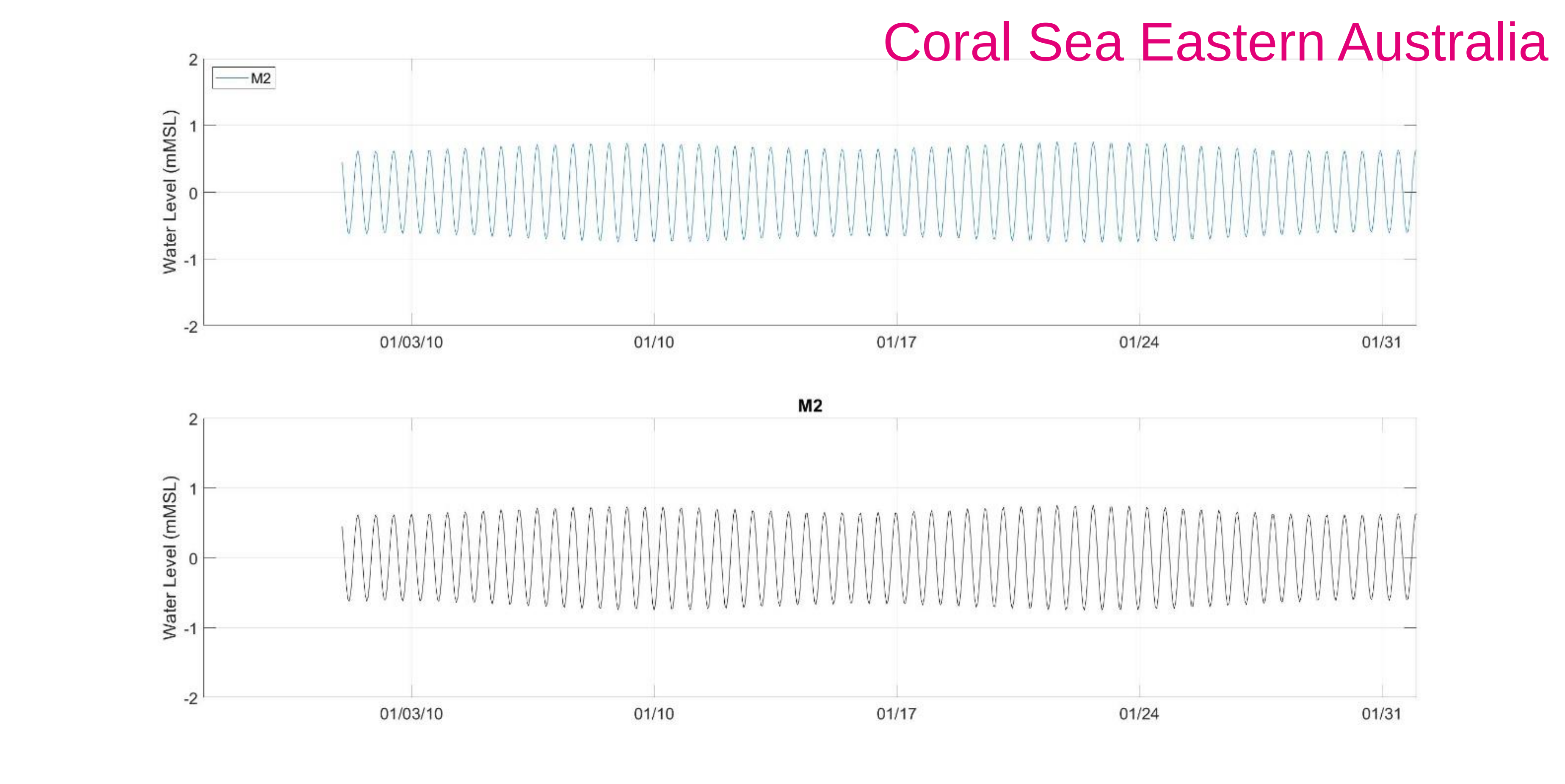


Tidal Constituents





Astronomical Tide



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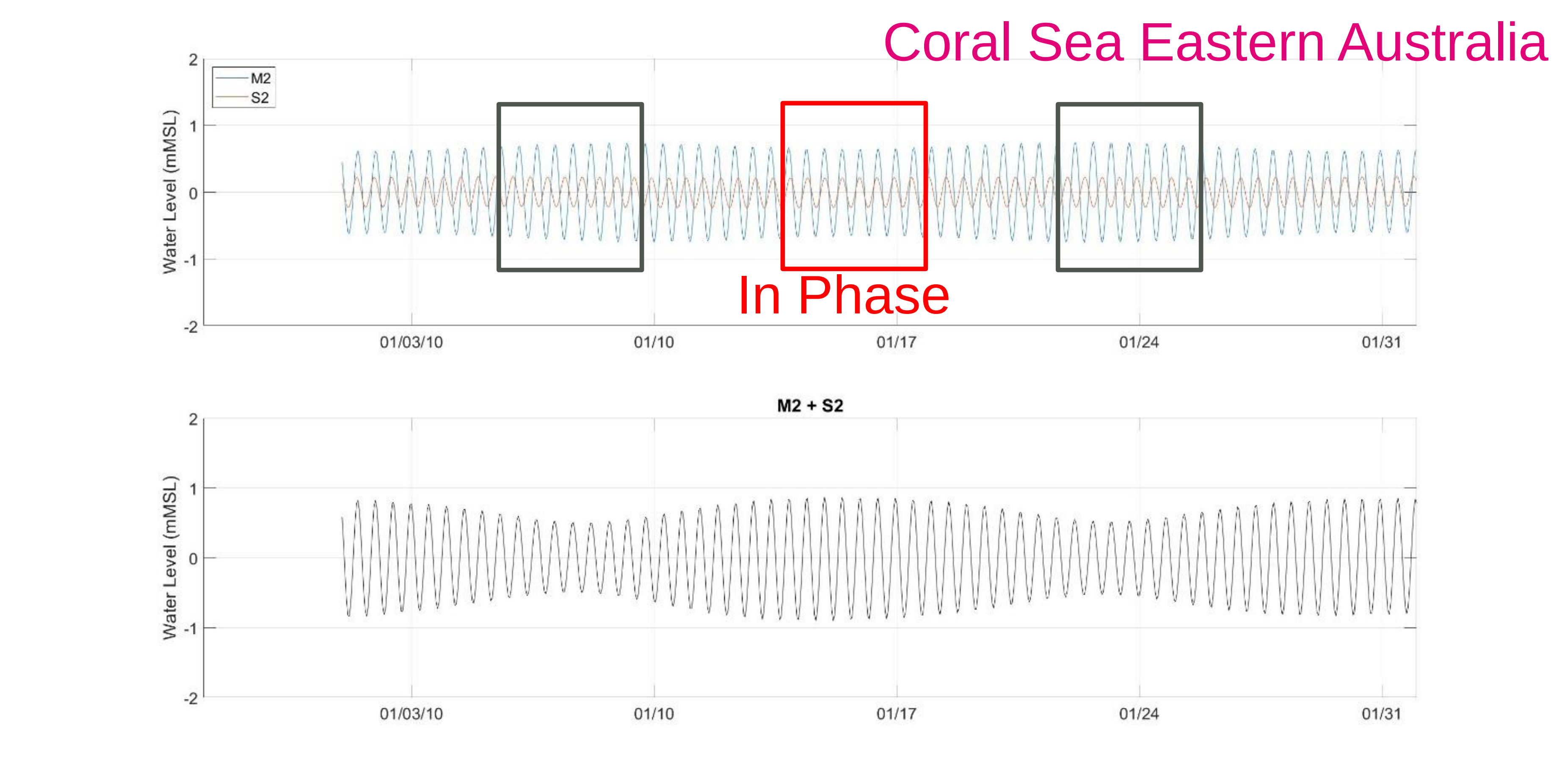
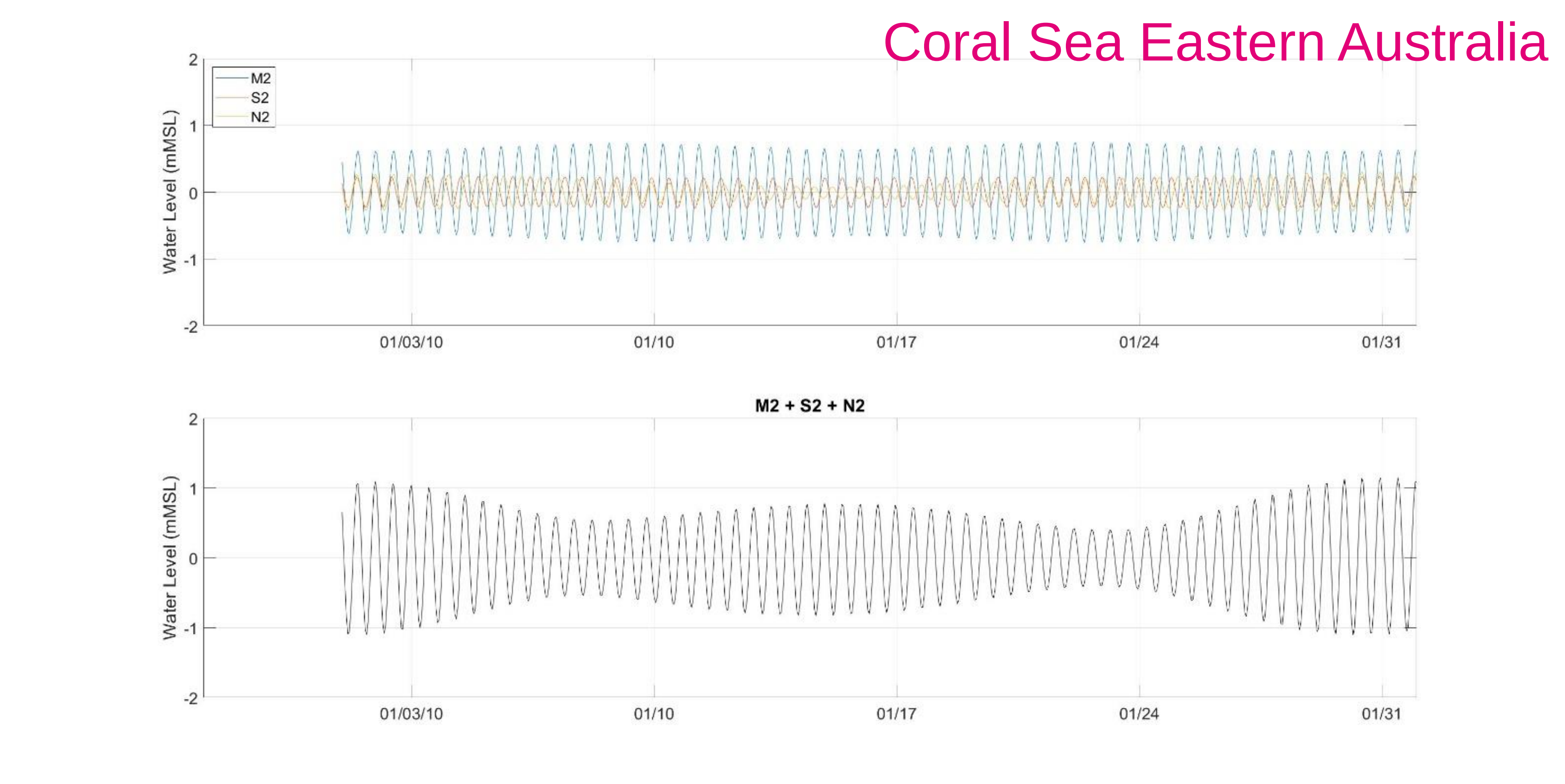
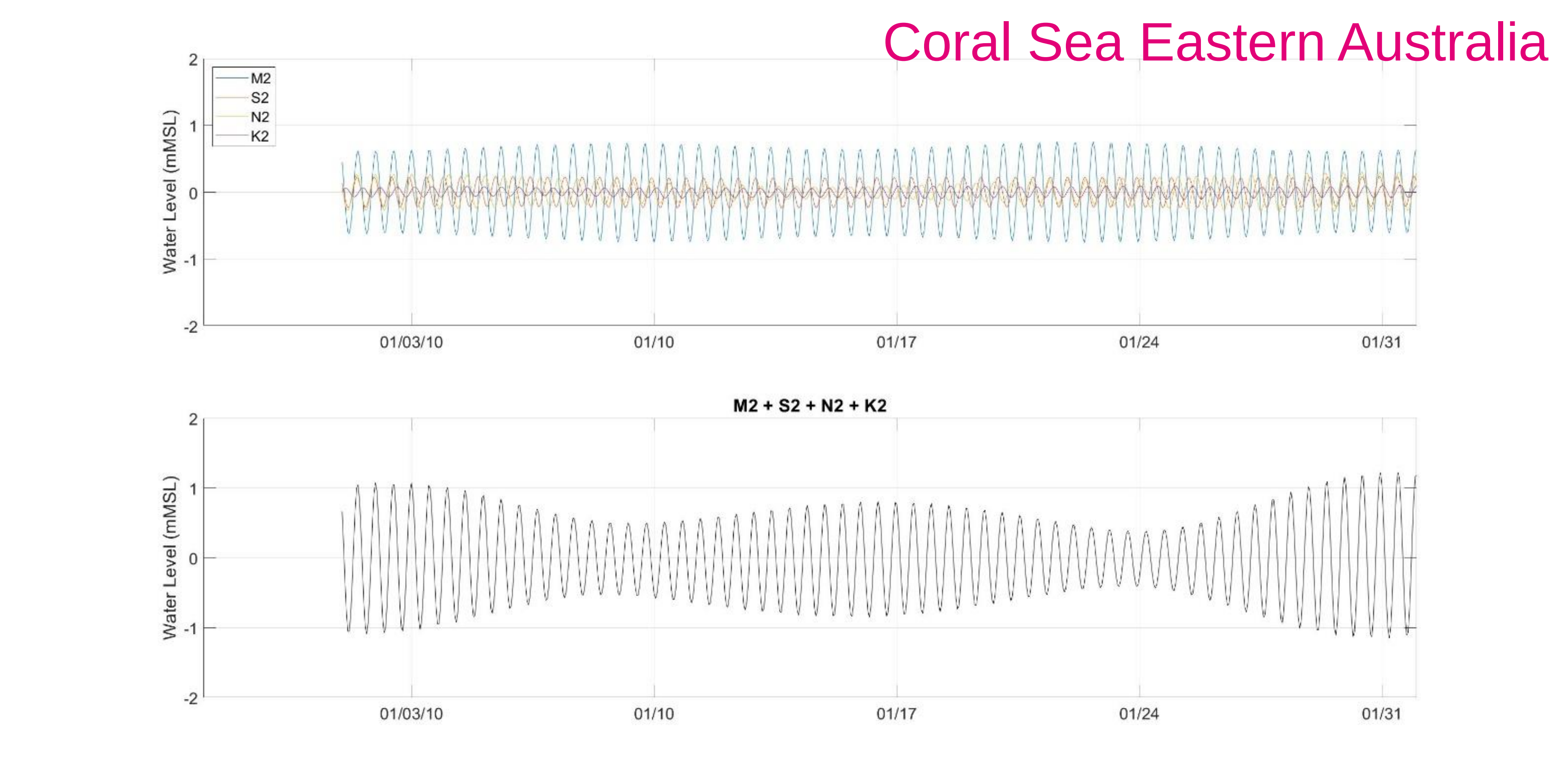
Astronomical Tide



Astronomical Tide



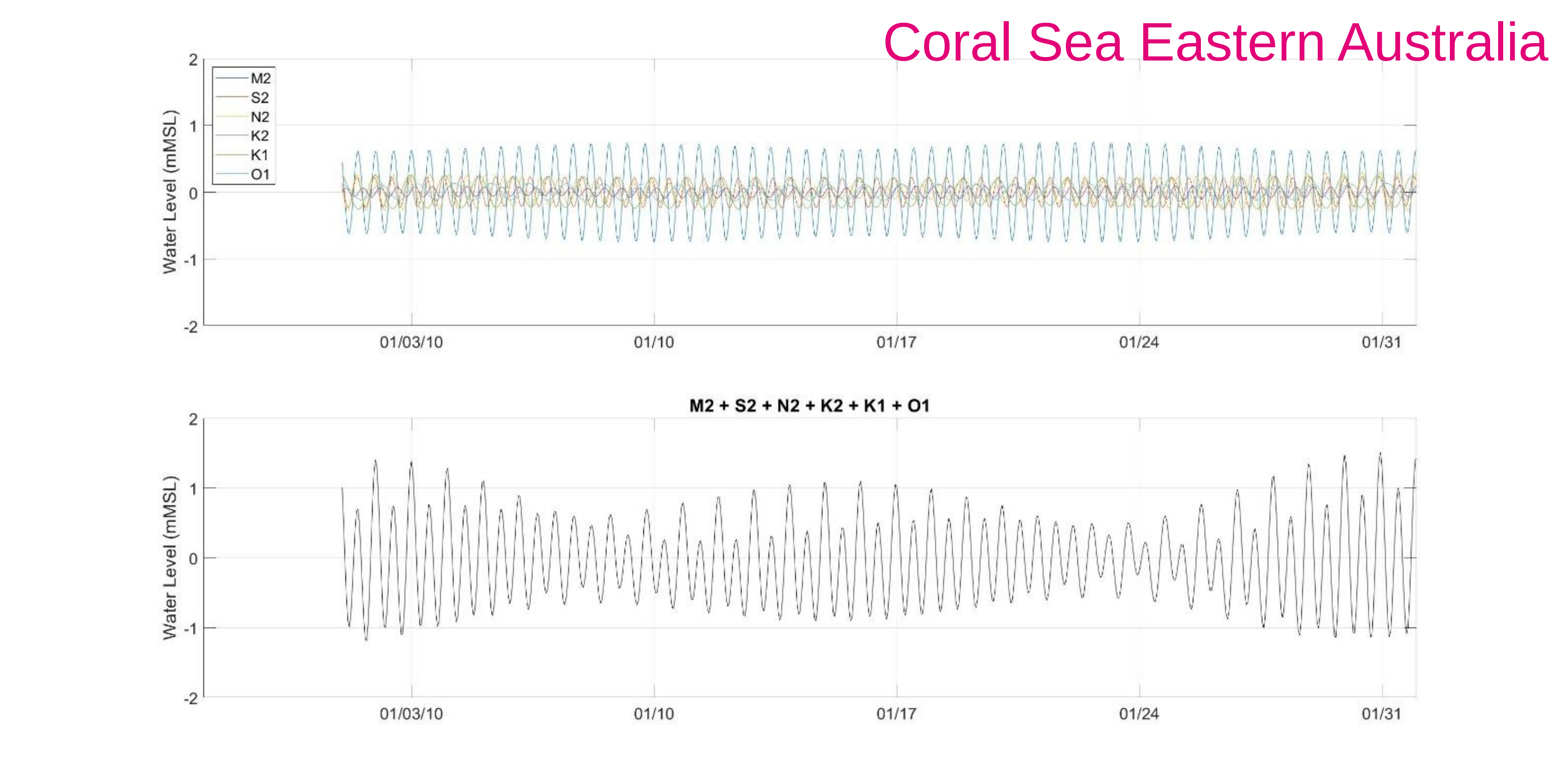
Astronomical Tide



Astronomical Tide

Coral Sea Eastern Australia

Astronomical Tide



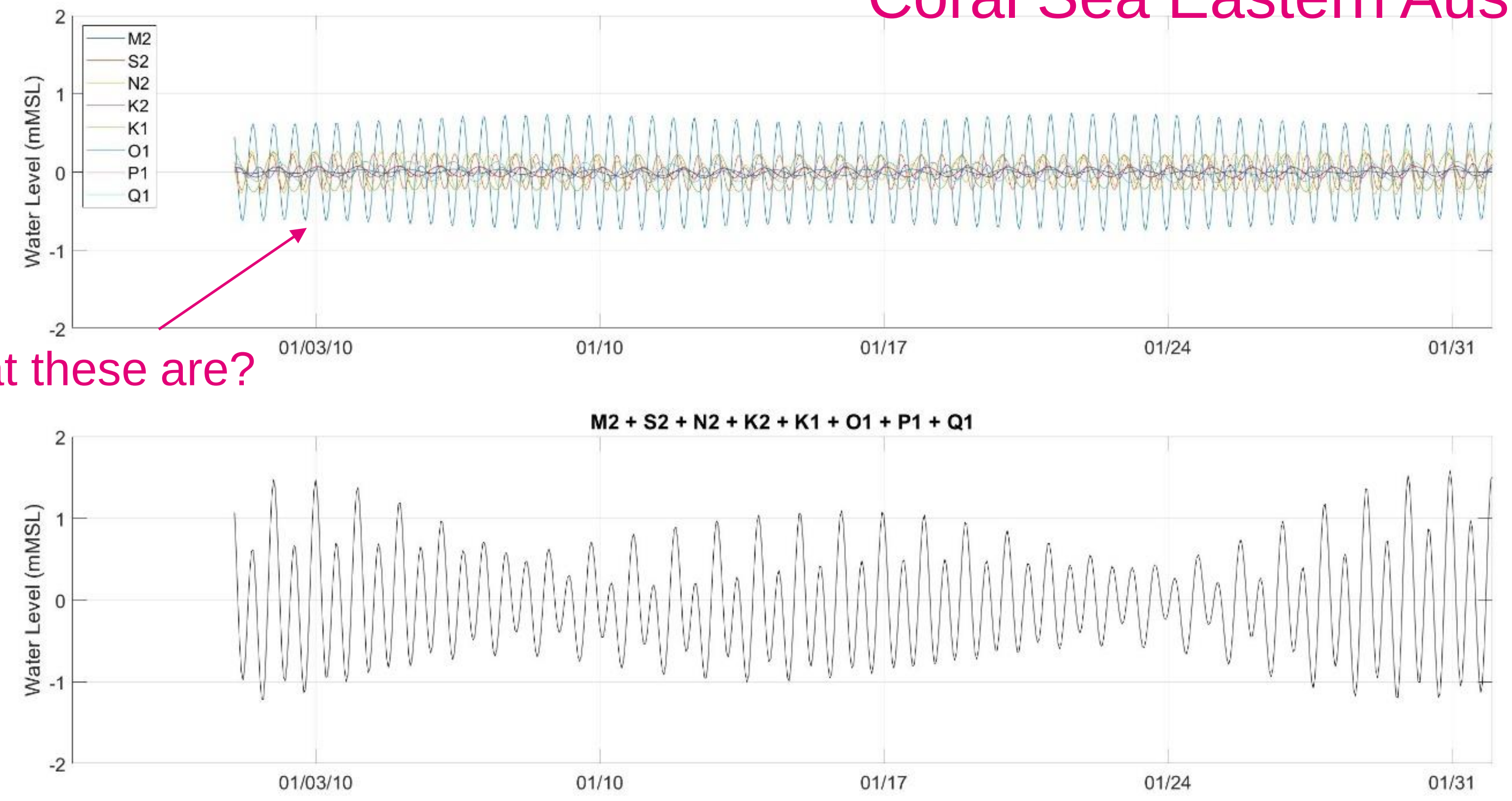
Astronomical Tide

Coral Sea Eastern Australia

Astronomical Tide

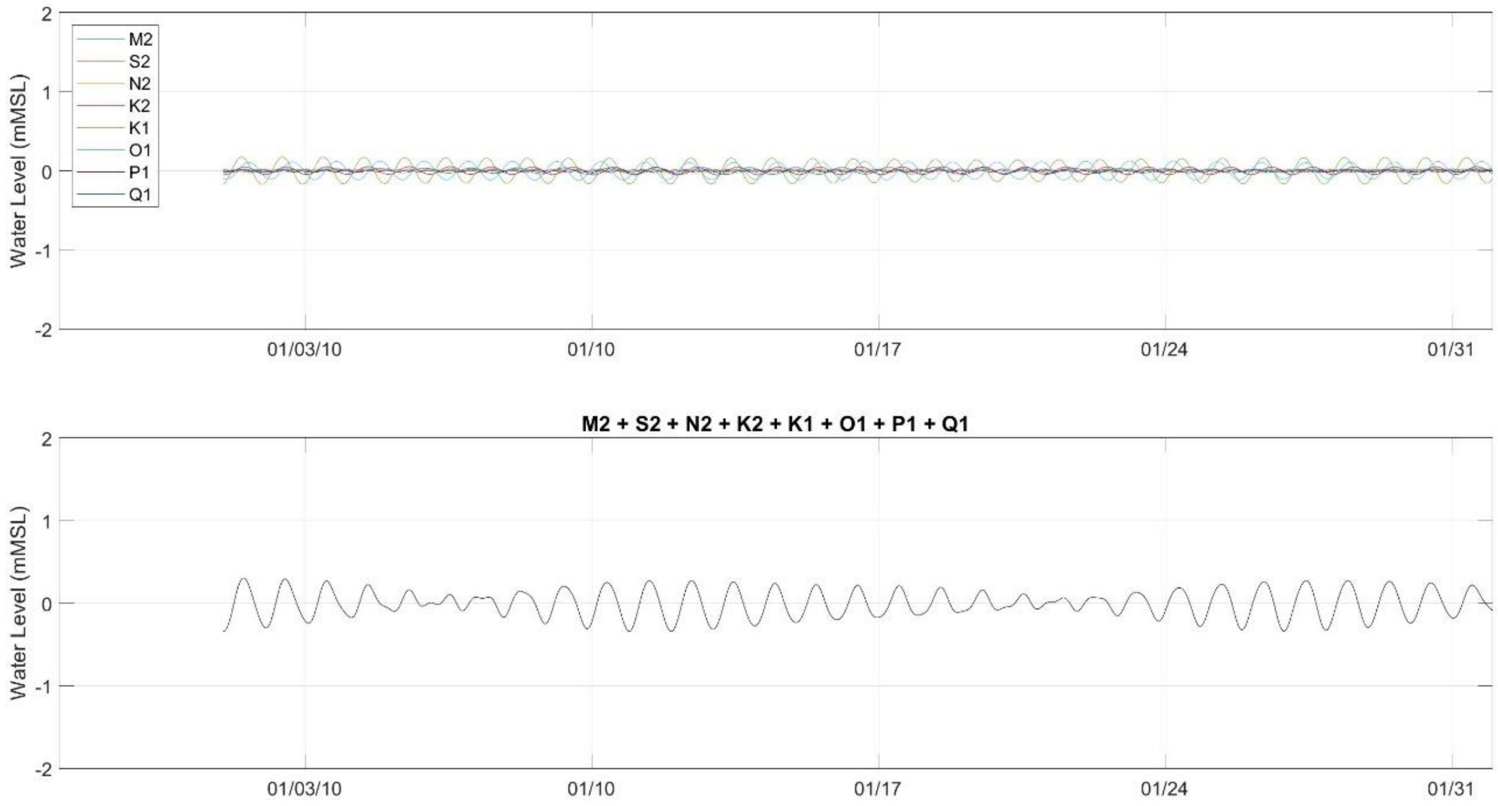
Coral Sea Eastern Australia

How do we know what these are?



Astronomical Tide

Western Australia



2. Run an Astronomical Tide Only Model

Model setup

One month simulation January 2013

Source and apply astronomical tide boundaries

Calibrate to tidal predictions at Bundaberg and Urangan

Tide Data

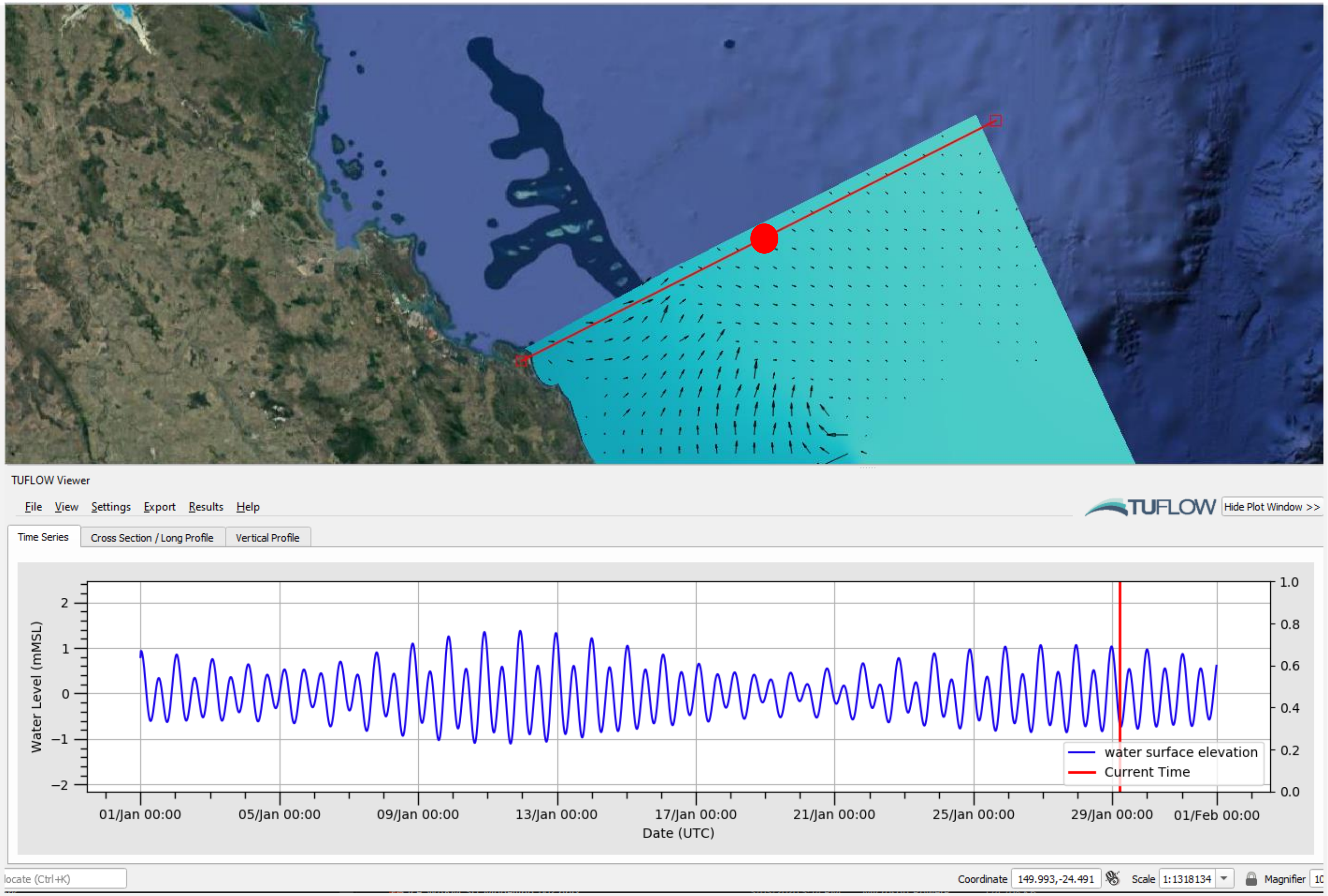
Water level point predictions

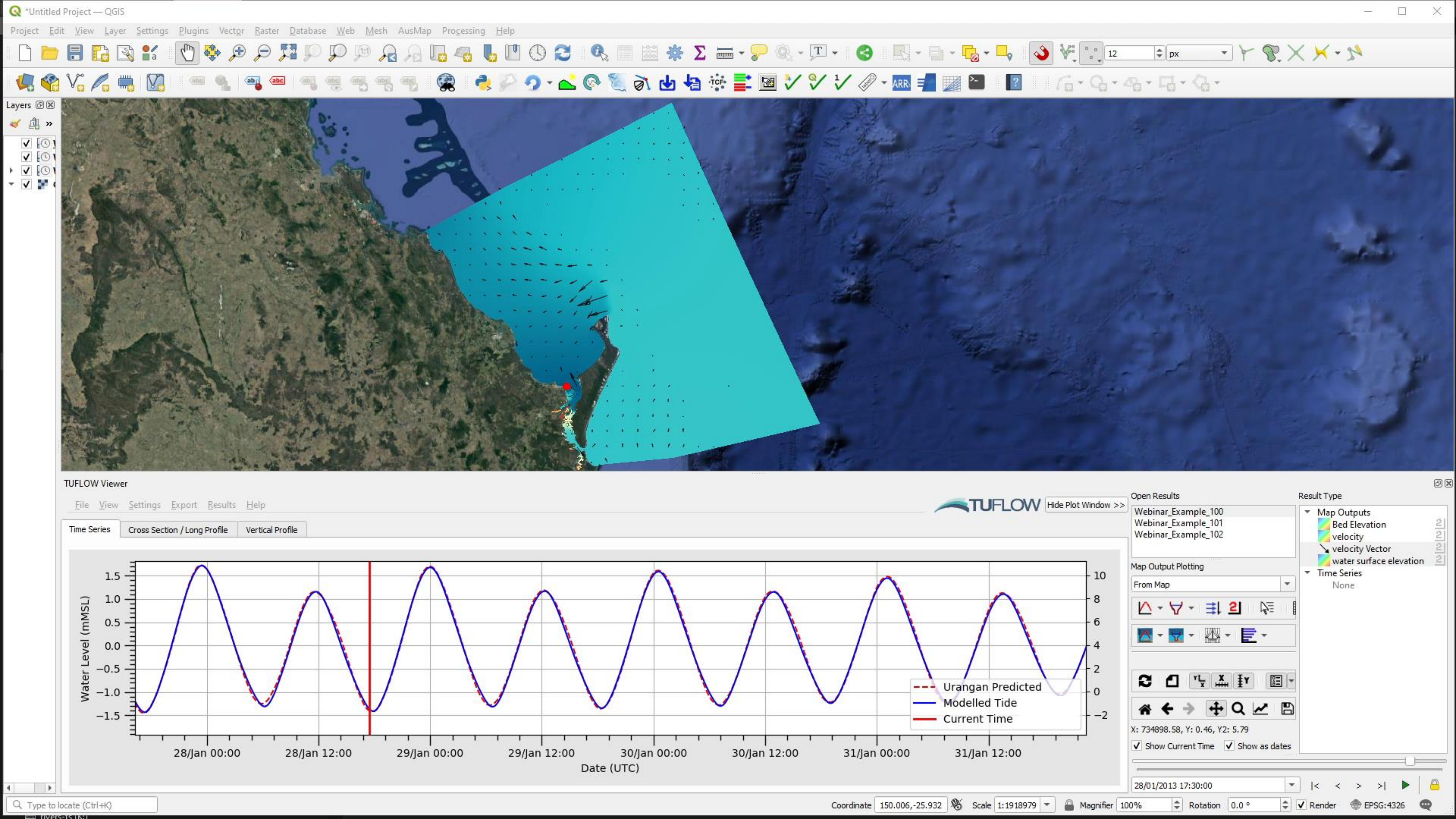
Gridded tidal predictions

https://www.esr.org/research/polar-tide-models/tmd-software/

https://pypi.org/project/pyTMD/

We have tools to assist with using these

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File View Settings Export Results Help
TUFLOW
Hide Plot Window >>
Time Series
Cross Section / Long Profile
Vertical Profile
Water Level (mMSL)
Date (UTC)
28/Jan 00:00
28/Jan 12:00
29/Jan 00:00
29/Jan 12:00
30/Jan 00:00
30/Jan 12:00
31/Jan 00:00
31/Jan 12:00
Urangan Predicted
Modelled Tide
Current Time
Open Results
Webinar_Example_100
Webinar_Example_101
Webinar_Example_102
Map Output Plotting
From Map
X: 734898.58, Y: 0.46, Y2: 5.79
Show Current Time
Show as dates
Result Type
Map Outputs
Bed Elevation
velocity
velocity Vector
water surface elevation
Time Series
None
28/01/2013 17:30:00
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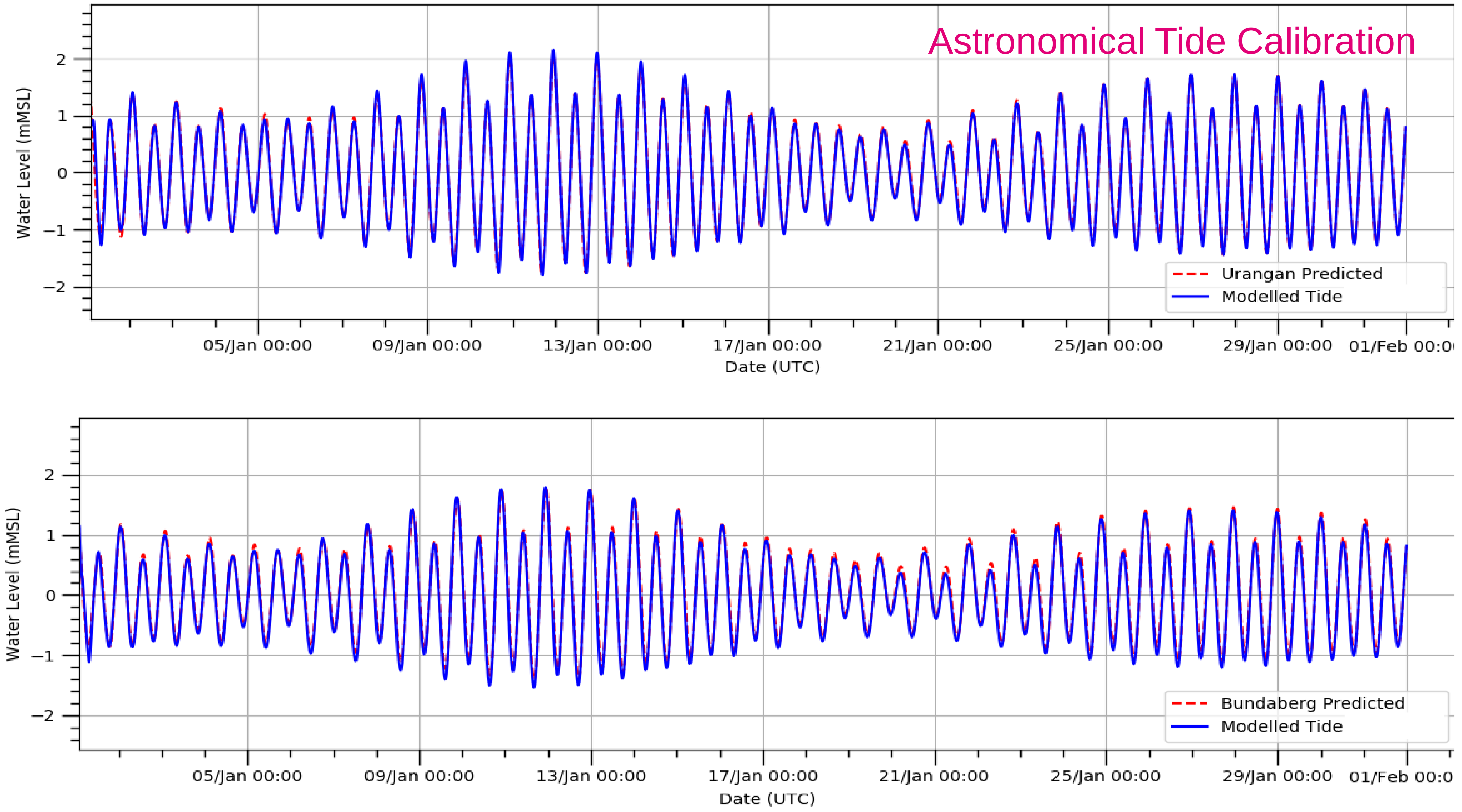
Coordinate 150.006,-25.932
Scale 1:1918979
Magnifier 100%
Rotation 0.0 °
Render
EPSG:4326

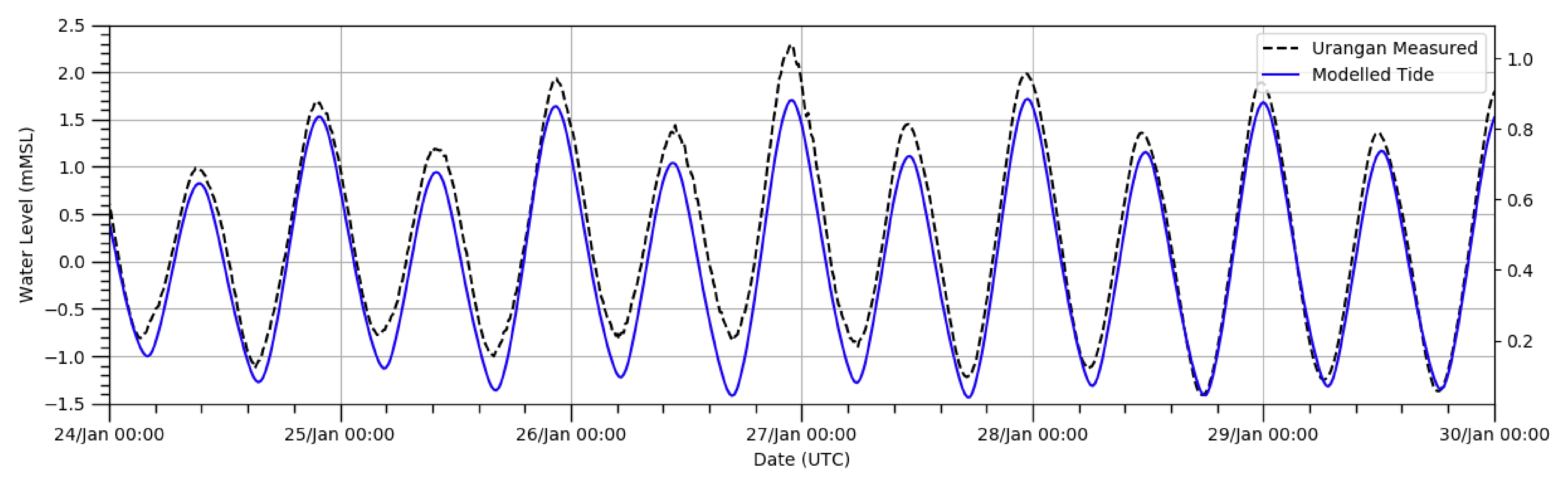


Astronomical Tide Calibration
Water Level (mMSL)
2
1
0
−1
−2
Urangan Predicted
Modelled Tide
05/Jan 00:00
09/Jan 00:00
13/Jan 00:00
17/Jan 00:00
21/Jan 00:00
25/Jan 00:00
29/Jan 00:00
01/Feb 00:00
Date (UTC)
Water Level (mMSL)
2
1
0
−1
−2
Bundaberg Predicted
Modelled Tide
05/Jan 00:00
09/Jan 00:00
13/Jan 00:00
17/Jan 00:00
21/Jan 00:00
25/Jan 00:00
29/Jan 00:00
01/Feb 00:00
Date (UTC)

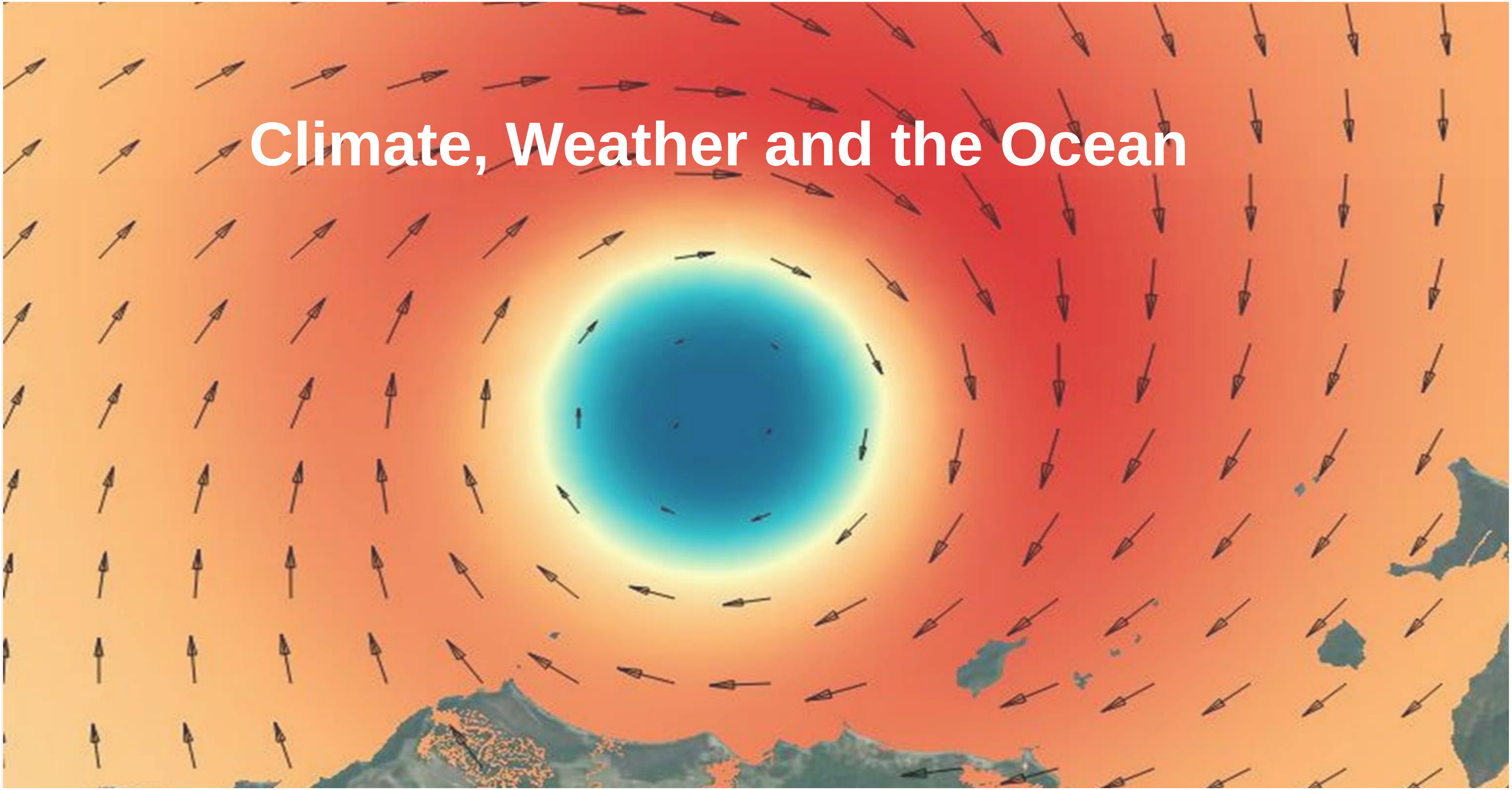
The Challenge

Build a coastal hydrodynamic model to match the observed water level

Urangan – 24th -30th January 2013



Climate, Weather and the Ocean



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Climate, Weather and the Ocean

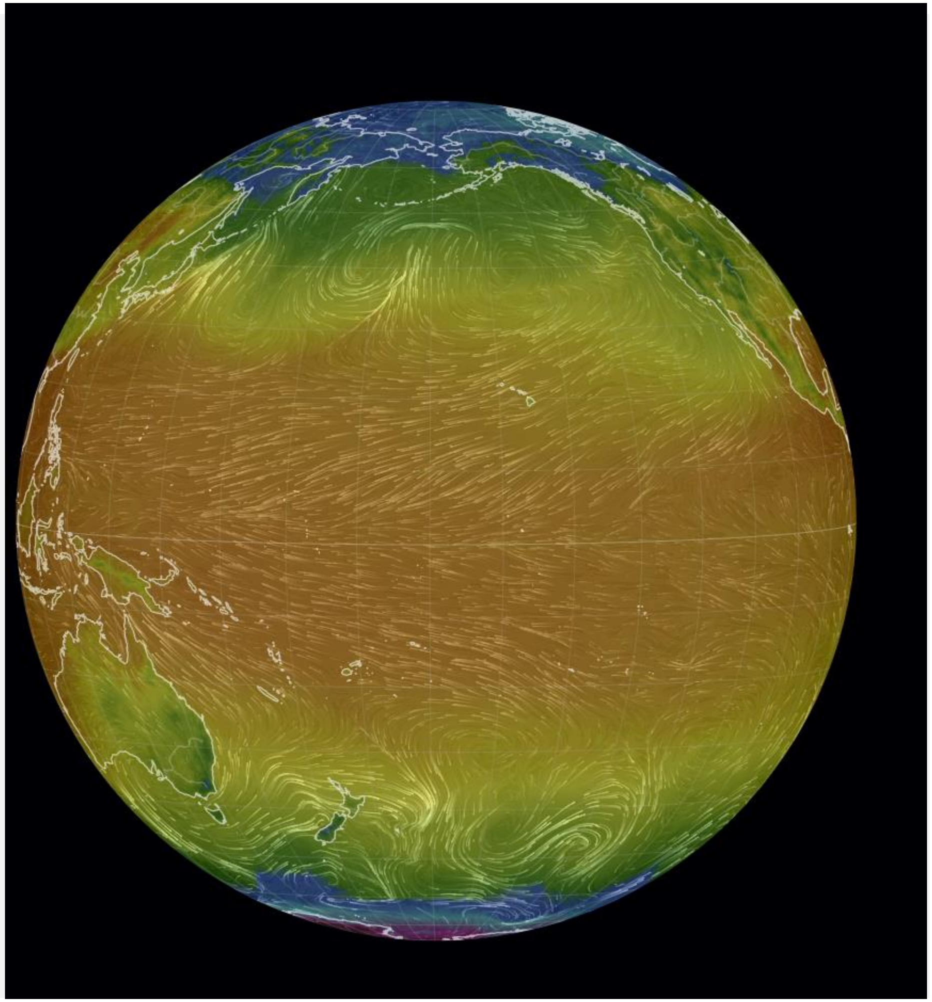
Ocean and atmosphere are intimately coupled

Differential heating of the earth

Redistribution of heat drives atmospheric circulation

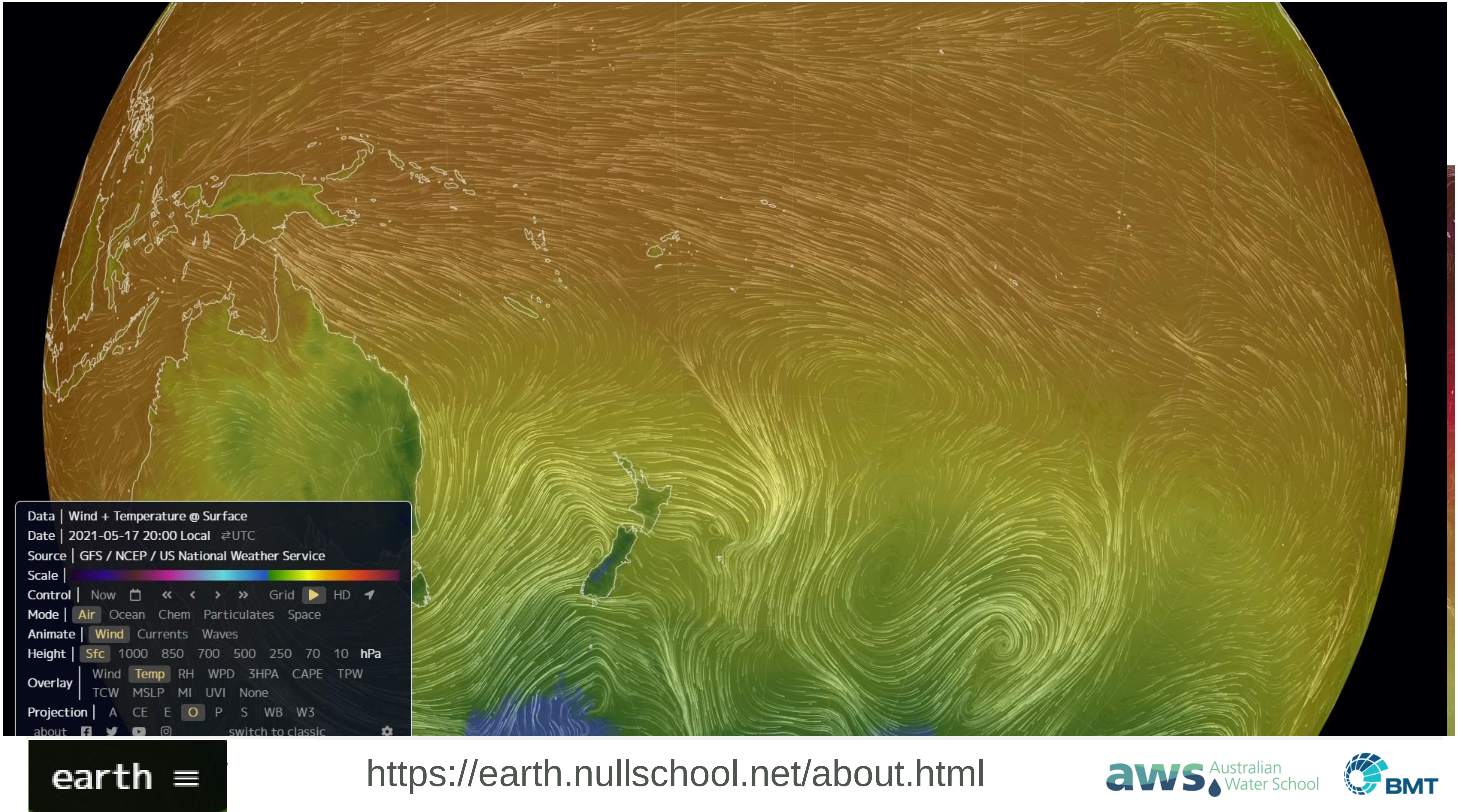
This in turn 'pushes' the ocean around affecting ocean circulation

Storms are embedded as weather events in these larger climate and oceanic processes



earth ≡

https://earth.nullschool.net/about.html



https://earth.nullschool.net/about.html

How do we model the weather, climate, ocean anomalies?

So how do we allow for these effects… Well we are lucky in 2021

Meteorological (NOAA/NCEP ECMWF BoM)

Mean sea level pressure and wind speed

Air temperature, relative humidity, short and longwave radiation, cloud cover, precipitation (For 3D modelling not covered today)

Ocean (HYCOM BRAN2020 Copernicus)

Wind waves

Salinity, temperature, currents, mean sea surface anomalies (3D modelling, not covered today)

ERA5 hourly data on single levels from 1979 to present

- Unable to get the status of this dataset, submission of requests has been disabled. Please refresh this page and try again.

Overview | Download data | Quality assessment | Documentation

Clear all

Product type

- [x] Reanalysis
- [ ] Ensemble members
- [ ] Ensemble mean
- [ ] Ensemble spread

Select all Clear all

Variable

▾ Popular

- [x] 10m u-component of wind
- [x] 10m v-component of wind
- [ ] 2m dewpoint temperature
- [ ] 2m temperature
- [x] Mean sea level pressure
- [ ] Mean wave direction
- [ ] Mean wave period
- [ ] Sea surface temperature
- [ ] Significant height of combined wind waves and swell
- [ ] Surface pressure
- [ ] Total precipitation

Select all Clear all

▸ Temperature and pressure
▸ Wind
▸ Mean rates
▸ Radiation and heat

Contact

copernicus-support@ecmwf.int

Licence

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Publication date

2018-06-14

References

Citation

DOI: 10.24381/cds.adbb2d47

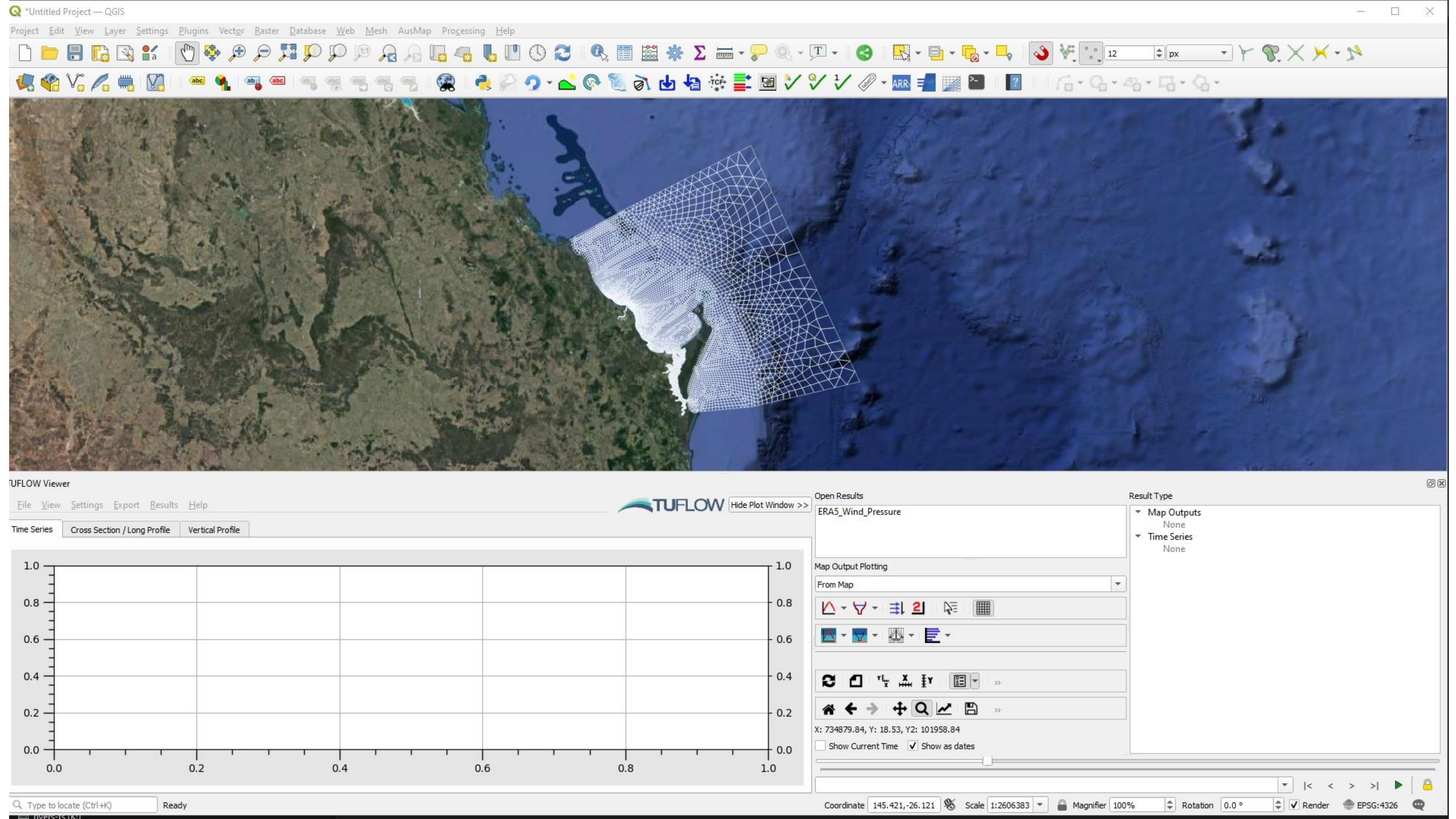
Related data

ERA5 hourly data on pressure levels from 1950 to 1978 (preliminary version)

ERA5 hourly data on pressure levels from 1979 to present

ERA5 hourly data on single levels from 1950 to 1978 (preliminary version)

ERA5 monthly averaged data on pressure levels from 1950 to 1978 (preliminary version)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Time Series
Cross Section / Long Profile
Vertical Profile
Open Results
ERA5_Wind_Pressure
Map Output Plotting
From Map
Result Type
Map Outputs
None
Time Series
None
X: 734879.84, Y: 18.53, Y2: 101958.84
Show Current Time
Show as dates
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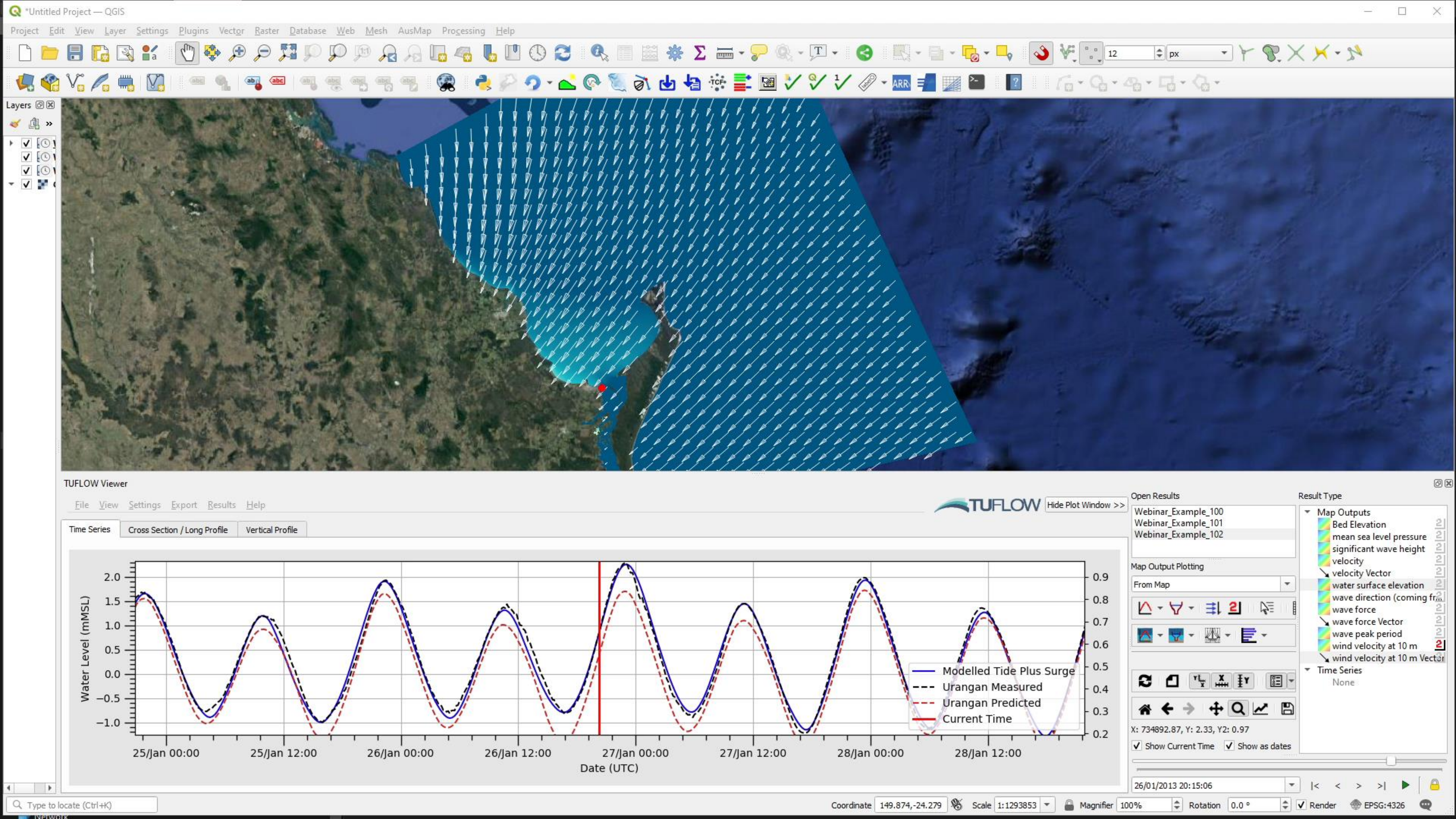
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28/Jan 12:00
Modelled Tide Plus Surge
Urangan Measured
Urangan Predicted
Current Time
Open Results
Webinar_Example_100
Webinar_Example_101
Webinar_Example_102
Map Output Plotting
From Map
X: 734892.87, Y: 2.33, Y2: 0.97
Show Current Time
Show as dates
26/01/2013 20:15:06
Result Type
Map Outputs
Bed Elevation
mean sea level pressure
significant wave height
velocity
velocity Vector
water surface elevation
wave direction (coming fr
wave force
wave force Vector
wave peak period
wind velocity at 10 m
wind velocity at 10 m Vector
Time Series
None
Type to locate (Ctrl+K)
Coordinate 149.874,-24.279
Scale 1:1293853
Magnifier 100%
Rotation 0.0 °
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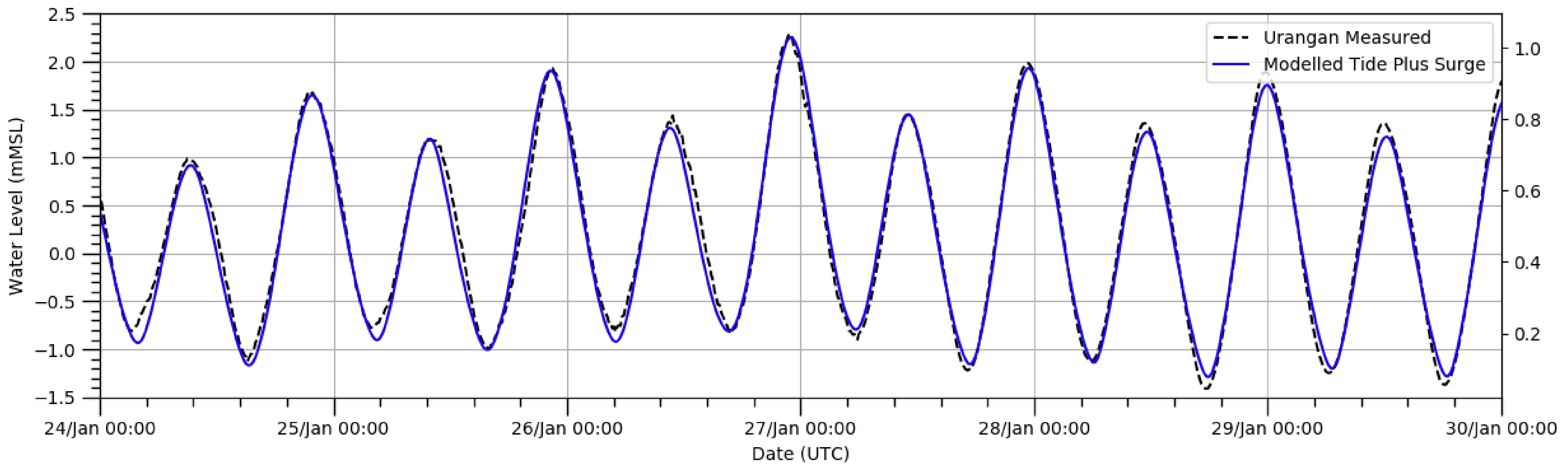
The Challenge

Build a coastal hydrodynamic model to match the observed water level

Urangan – 24th -30th January 2013 ✓



Discussion

Passage of a storm created a storm tide at Urangan

Good astronomical tide calibration

Modelling of astronomical tides only was not enough to reproduce observed water levels

Inclusion of gridded wind and pressure data required

Extending the Challenge

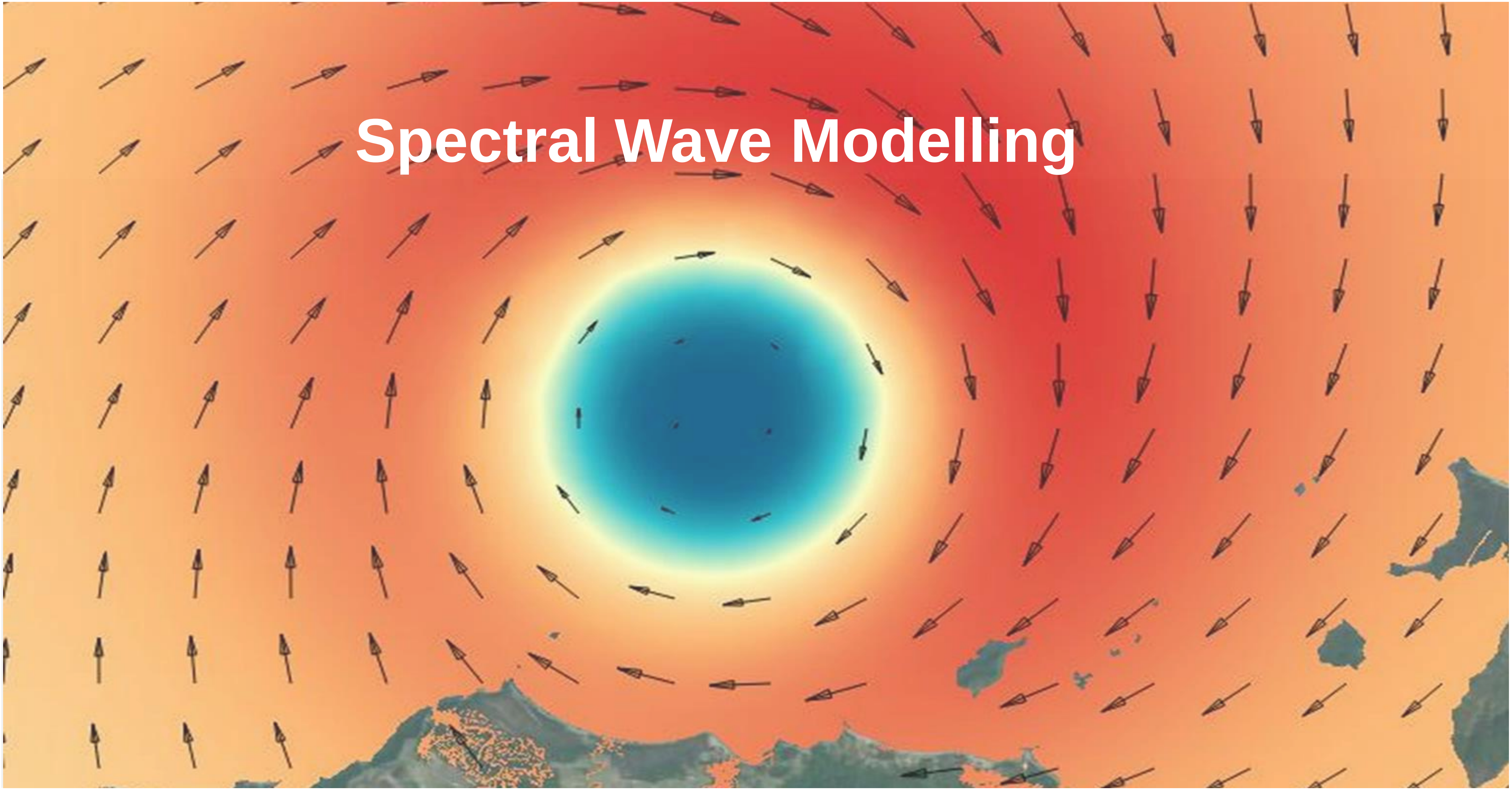
During the storm a fishing boat capsized and sank

An investigation needs to be completed to estimate the wave conditions at the wreck site at the peak of the event

Significant wave height and peak wave period

To answer these questions we need to shift our thinking from currents and water levels to wind waves

Spectral Wave Modelling



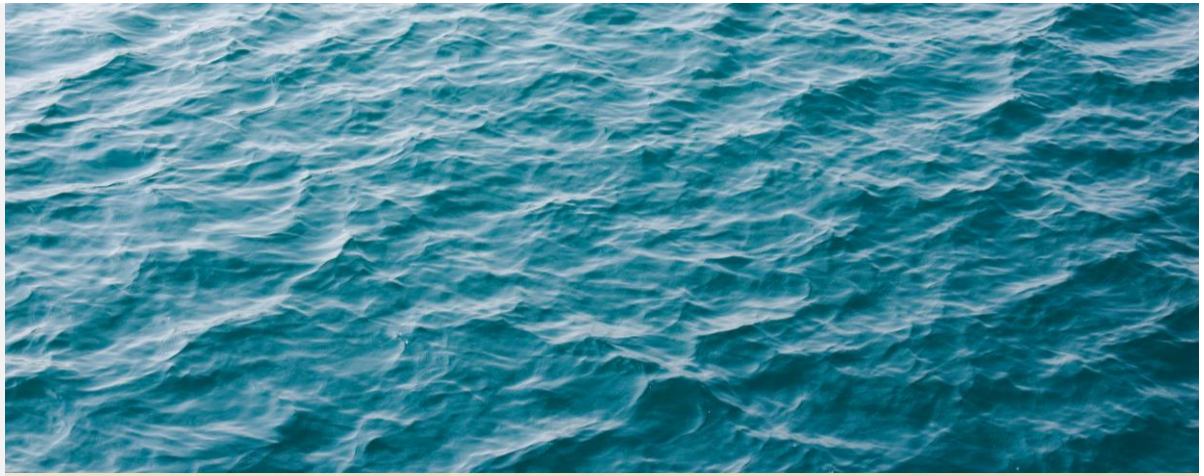
Wind Waves

Sea is a complex combination of waves with different directions, heights and speeds

Generated by shear and resonance by the wind

The longer and harder the wind blows over a given fetch the larger the waves grow until equilibrium

Sea waves and swell waves



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Why are Ocean Waves Important?

Distribute energy

Upper ocean mixing

Structural design

Navigation

Sediment transport and coastal morphology

Recreation

https://www.abc.net.au/news/2021-04-12/port-fairy-big-surf-damage-sea-level-rise/100063670

Estimating Wave Conditions

Build a spectral wave model

Model the evolution of wave energy

Wave dissipation, wave generation, wave interactions, wave setup and much more.

'Coastal wave model' SWAN – Delft University of Technology http://swanmodel.sourceforge.net/

'Offshore wave models' WAVEWATCH III, WAM

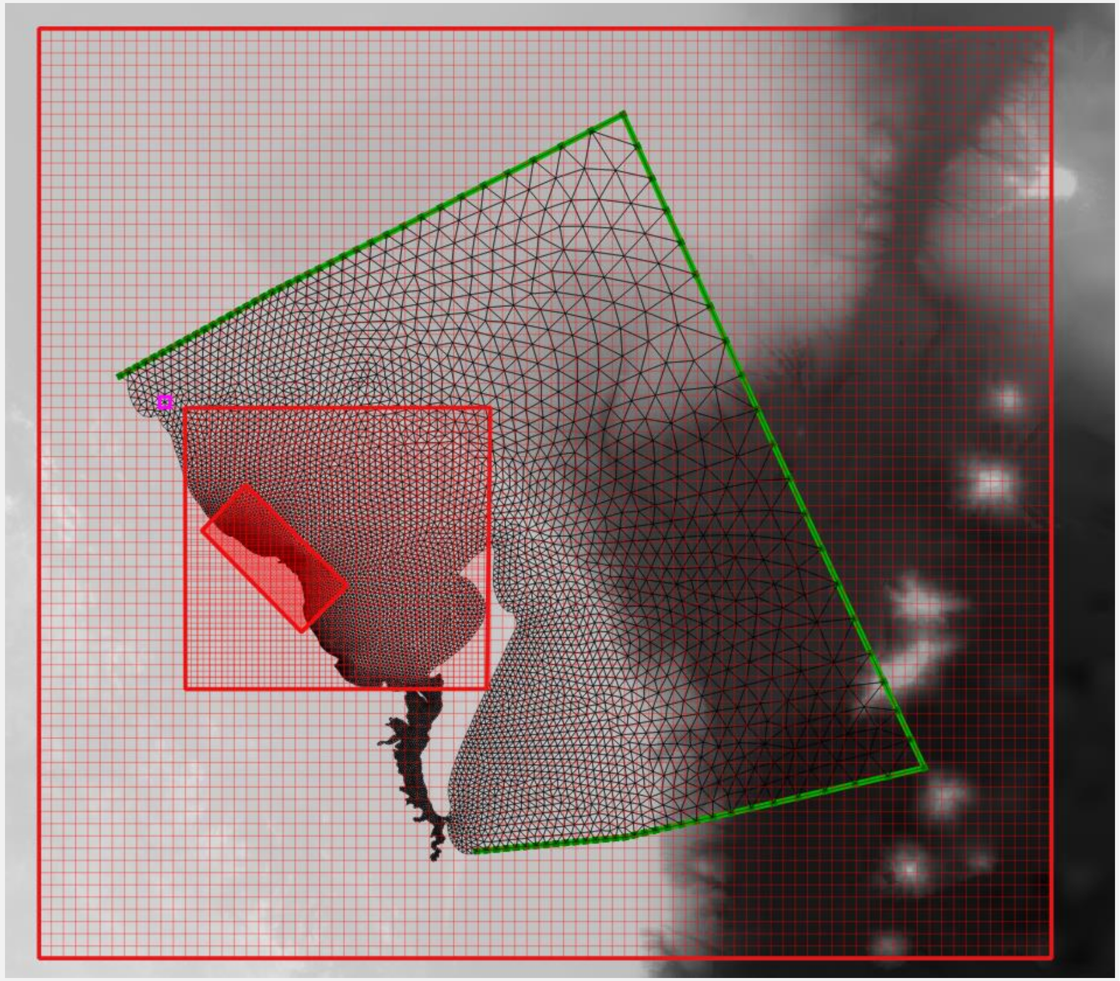
SWAN GIS Tools

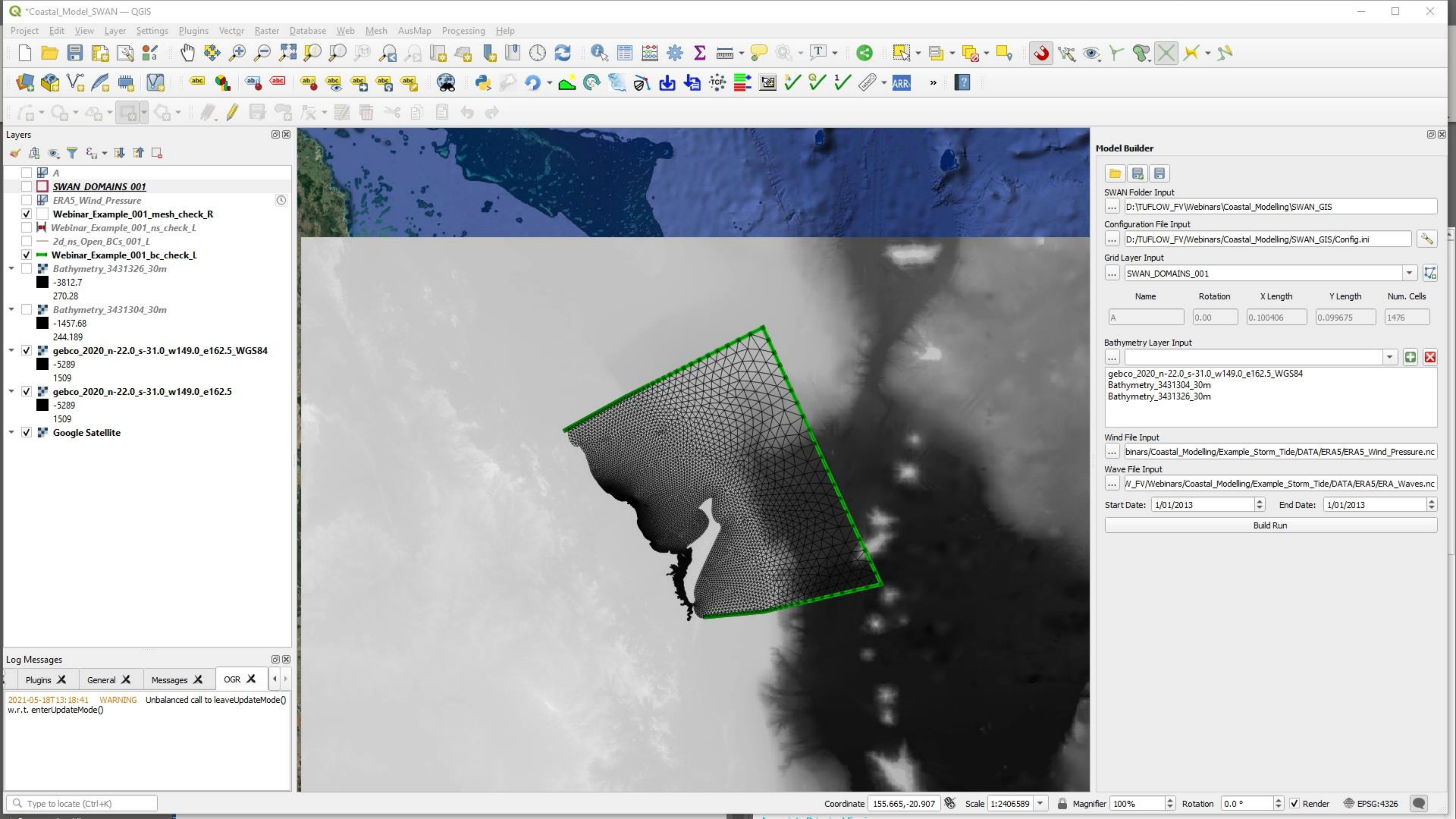
SWAN GIS Tools (Free with TUFLOW QGIS Plugin)

Not a wave model – Developed by TUFLOW to help you build SWAN wave model domains and input files with GIS

Builds .swn control files, wave spectra, nesting (where relevant), bathymetry, wind files.

Released soon. Contact support@tuflow.com if you would like to try it out.





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1509
gebco_2020_n-22.0_s-31.0_w149.0_e162.5
-5289
1509
Google Satellite
Log Messages
Plugins
General
Messages
OGR
2021-05-18T13:18:41 WARNING Unbalanced call to leaveUpdateMode() w.r.t. enterUpdateMode()
Type to locate (Ctrl+K)
Model Builder
SWAN Folder Input
D:\TUFLOW_FV\Webinars\Coastal_Modelling\SWAN_GIS
Configuration File Input
D:/TUFLOW_FV/Webinars/Coastal_Modelling/SWAN_GIS/Config.ini
Grid Layer Input
SWAN_DOMAINS_001
Name
Rotation
X Length
Y Length
Num. Cells
A
0.00
0.100406
0.099675
1476
Bathymetry Layer Input
gebco_2020_n-22.0_s-31.0_w149.0_e162.5_WGS84
Bathymetry_3431304_30m
Bathymetry_3431326_30m
Wind File Input
binars/Coastal_Modelling/Example_Storm_Tide/DATA/ERA5/ERA5_Wind_Pressure.nc
Wave File Input
V_FV/Webinars/Coastal_Modelling/Example_Storm_Tide/DATA/ERA5/ERA_Waves.nc
Start Date: 1/01/2013
End Date: 1/01/2013
Build Run
Coordinate 155.665,-20.907
Scale 1:2406589
Magnifier 100%
Rotation 0.0 °
Render
EPSG:4326

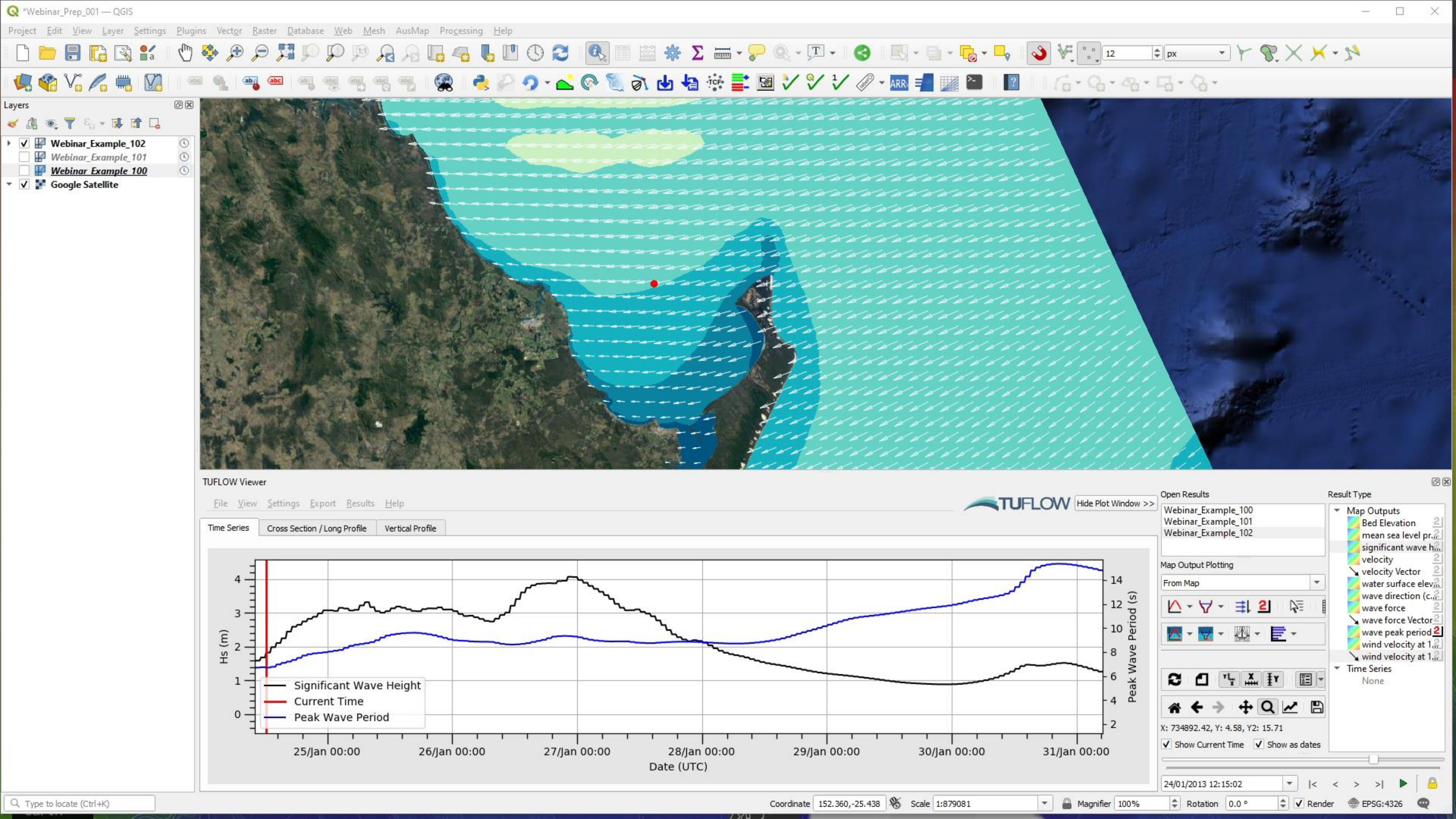
Spectral Wave Model Outputs

To address our brief we need to report:

1. Significant wave height (average of the highest 1/3 of waves)

2. Peak wave period (the time between successive wave crests)

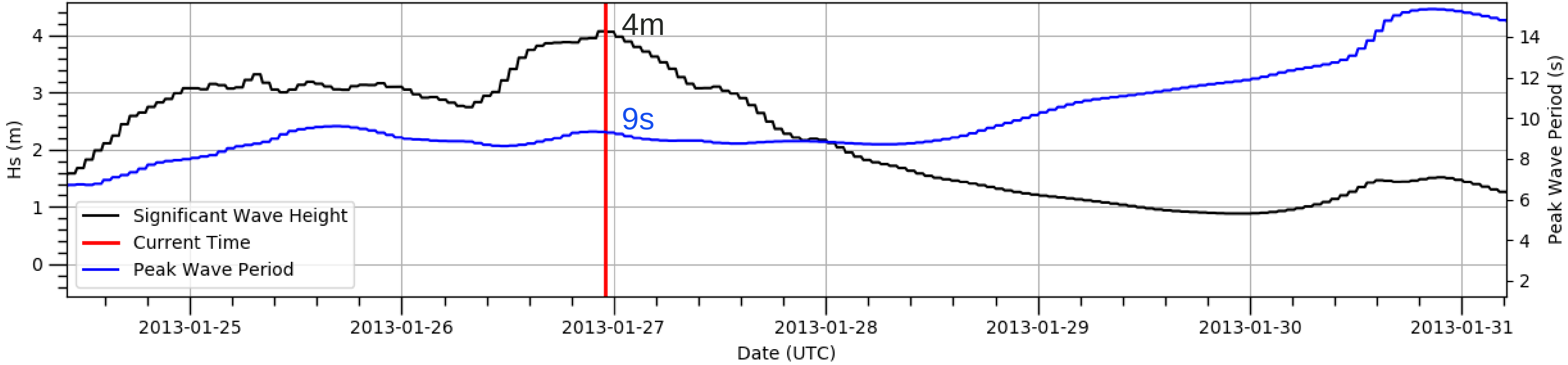
These are output directly by SWAN along with many other optional outputs


*Webinar_Prep_001 — QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh AusMap Processing Help
Layers
Webinar_Example_102
Webinar_Example_101
Webinar_Example_100
Google Satellite
TUFLOW Viewer
File View Settings Export Results Help
TUFLOW
Hide Plot Window >>
Time Series
Cross Section / Long Profile
Vertical Profile
Hs (m)
Peak Wave Period (s)
Significant Wave Height
Current Time
Peak Wave Period
25/Jan 00:00
26/Jan 00:00
27/Jan 00:00
28/Jan 00:00
29/Jan 00:00
30/Jan 00:00
31/Jan 00:00
Date (UTC)
Open Results
Webinar_Example_100
Webinar_Example_101
Webinar_Example_102
Map Output Plotting
From Map
X: 734892.42, Y: 4.58, Y2: 15.71
Show Current Time
Show as dates
24/01/2013 12:15:02
Result Type
Map Outputs
Bed Elevation
mean sea level pr...
significant wave h...
velocity
velocity Vector
water surface elev...
wave direction (c...
wave force
wave force Vector
wave peak period
wind velocity at 1...
wind velocity at 1...
Time Series
None
Type to locate (Ctrl+K)
Coordinate 152.360,-25.438
Scale 1:879081
Magnifier 100%
Rotation 0.0 °
Render
EPSG:4326

Results

We are interested in significant wave height (average of the highest 1/3 of waves)

Peak wave period (the time between successive wave crests)



Integrating Wave and Hydrodynamic Models

Wave model outputs can be applied to TUFLOW FV to affect currents and water levels

Can be used as inputs to TUFLOW FV's sediment transport module

Can also be run together in coupled mode with TUFLOW FV

https://awschool.com.au/resources/webinar-2d-and-3d-sediment-transport-and-morphological-modelling/

Review and Conclusions

Conclusions

Flood and ocean models aren’t too different

The scale and the processes that we need to include are different (noting we didn’t go 3D today)

Water levels and currents due to the astronomical tides vary across the globe in time and space

The ocean and the atmosphere are intricately coupled to each other

Water levels at the coast often exceed the predicted astronomical tide (due to ‘tidal residuals’)

Ocean wind waves are an important process to consider

Conclusions

Models help us to extend our knowledge away from measurements and also allow scenarios and designs to be tested

Calibration

There are great models out there, however ultimately it's how we use them…

Thank you!!!

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