Evolution of Soliton Measurement and Modelling

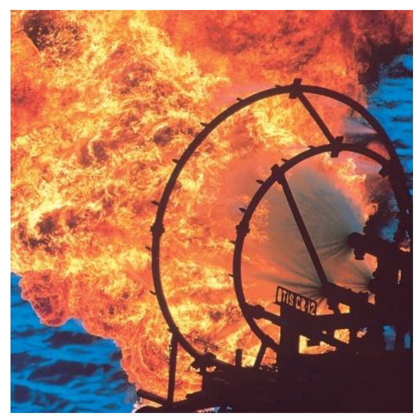
Presented by:

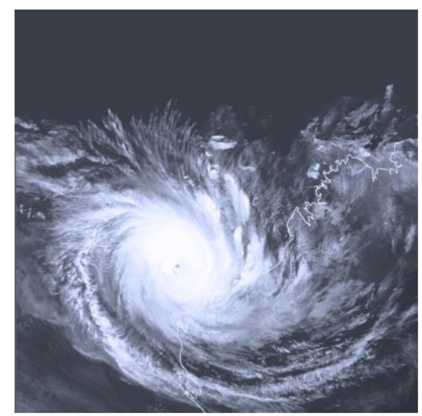
Steve Buchan

Kenji Shimizu

'With some deference to Garvey'

RPS MetOcean





14^{th} IWWHF –
Soliton Measurements & Modelling

For those who came in late ….. the previous presentation:

- Demonstrated the engineering need for soliton criteria
- Illustrated the plethora of soliton 'types' at North Rankin location
- Noted that measurements alone are insufficient
  - Can't detail spatial structure
  - Can't provide 'enough' events for reliable extreme analysis
  - Can't extrapolate to adjacent sites
- Hence the need for nonhydrostatic modelling
- Trialled MITgcm – provides the mechanism, but not (yet) with accuracy.

Presentation Structure

- Discussion of recent measurements on Outer Exmouth Plateau
- Recognition of Indonesian Archipelago as potential source for (Australian) North West Shelf internal waves
- Reconfiguration of the NWS MITgcm modelling domain to include these possible source regions
- Resulting improvements to internal solitary wave simulation
- Qualitative comparisons to North Rankin and Shelf Break measurements

Outer Exmouth Plateau Measurements

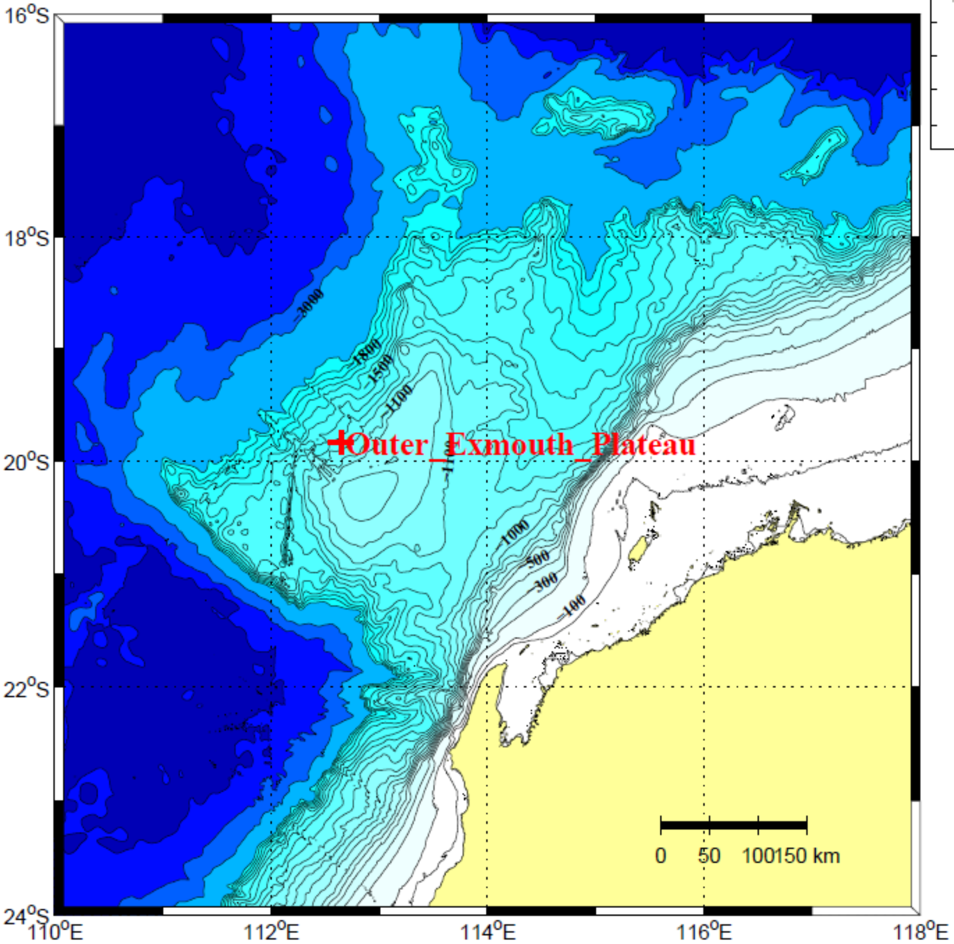
- 12 month Metocean Measurement programme to support planning for deepwater drilling operations (for Shell Australia)

- Measurements comprised
  - Meteorological (RPS buoy) measurements
  - Directional (Datawell Waverider) buoy measurements
  - Through-Water-Column current, temperature and salinity measurements

- In 1250 m of water

- The programme returned almost 100% good data.

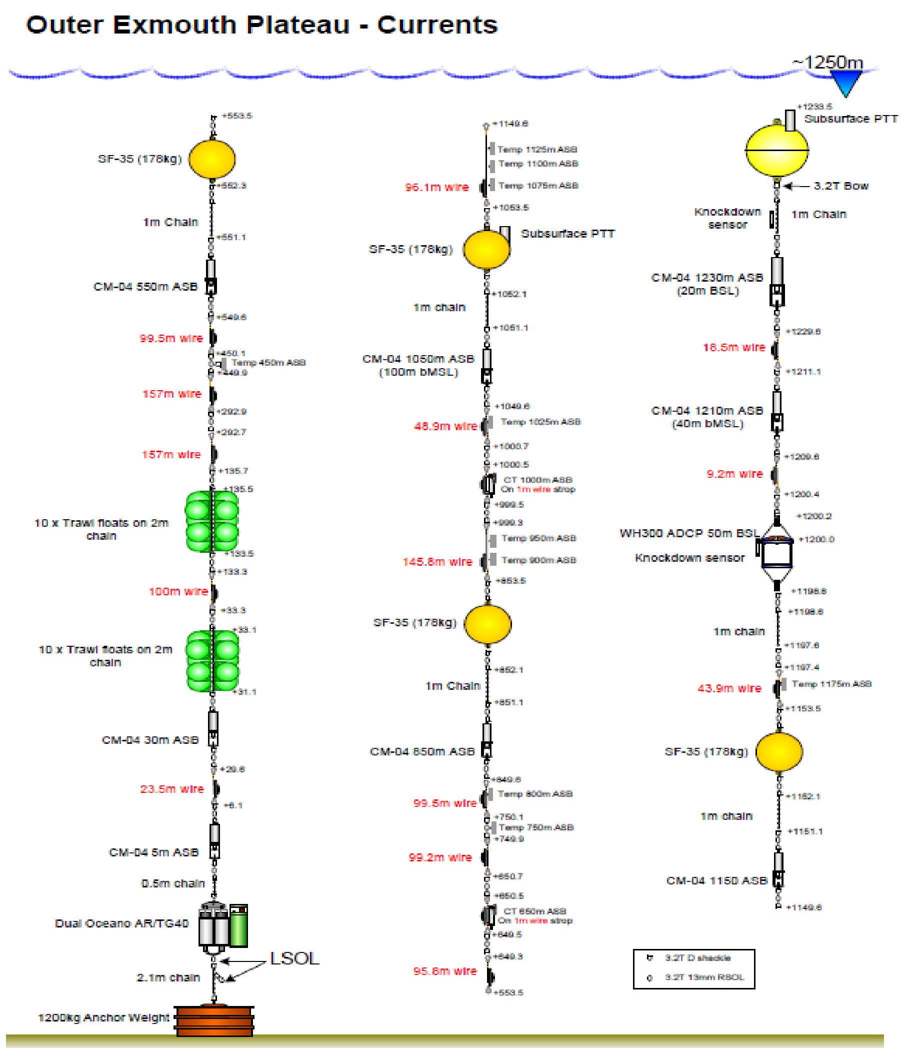
Measurement Region



- WA-489-P
- 12 Months of

Met
Wave
TWC : Current
SWT

Current Meter Mooring



Instruments comprised:

- 8 x CM04s
- 1 x 300 kHz ADCP
- 10 x temp loggers
- 2 x CT loggers
- 1 x tide gauge

in 1250 m of water.

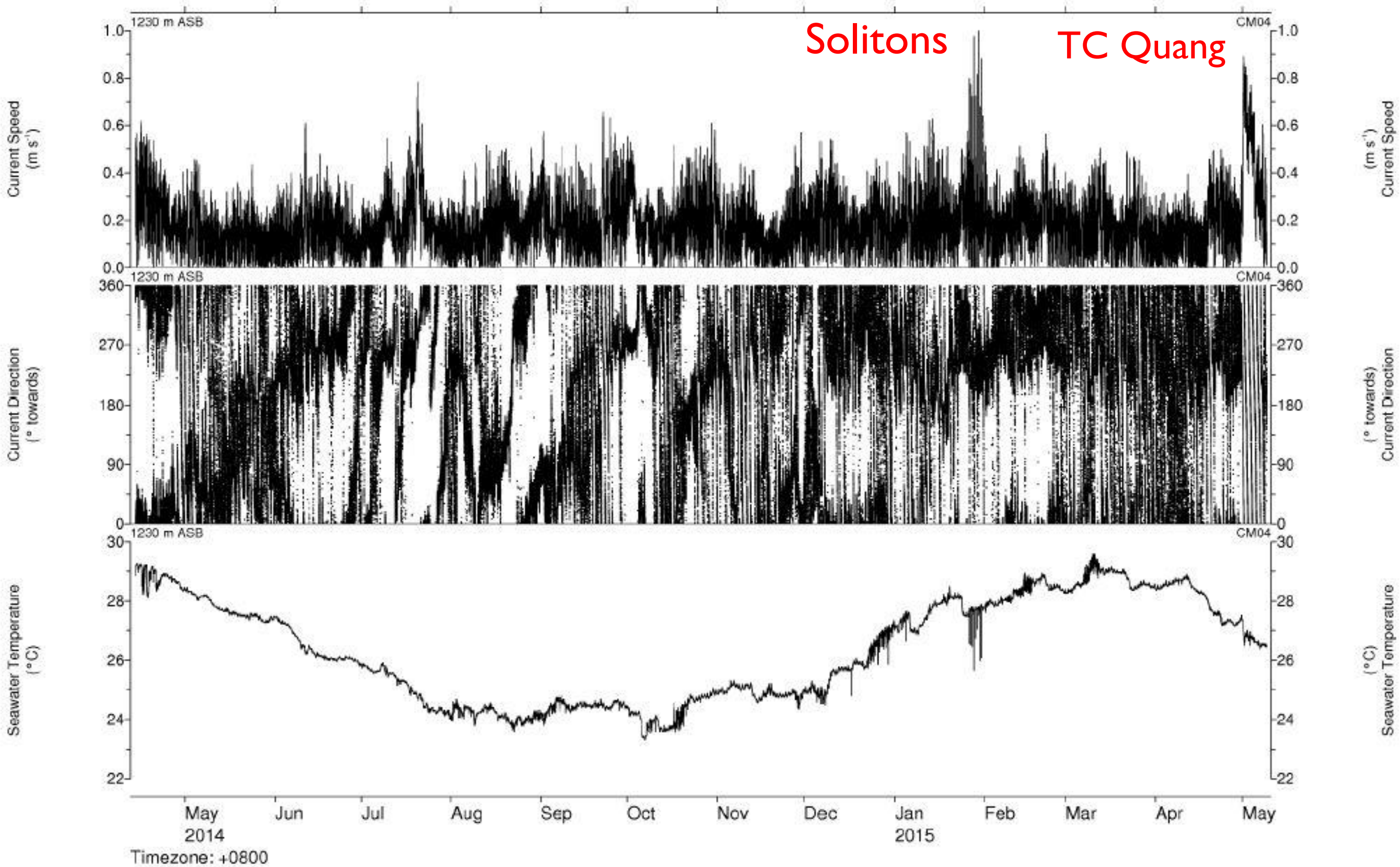
Two Events of Major Note

1. (Almost) direct hit by Tropical Cyclone Quang

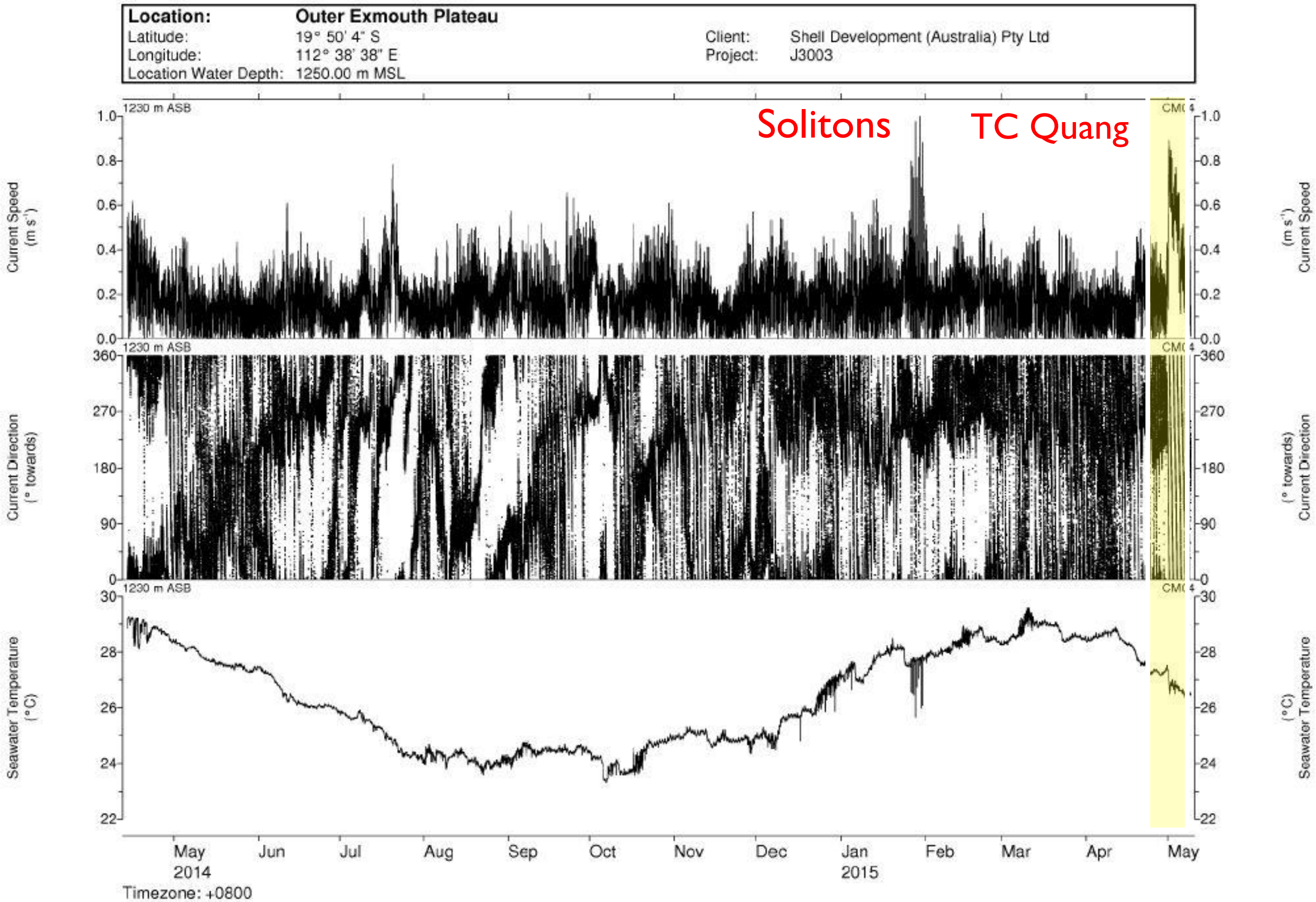
2. Extraordinary week of internal solitary wave activity.

Outer Exmouth Surface Currents

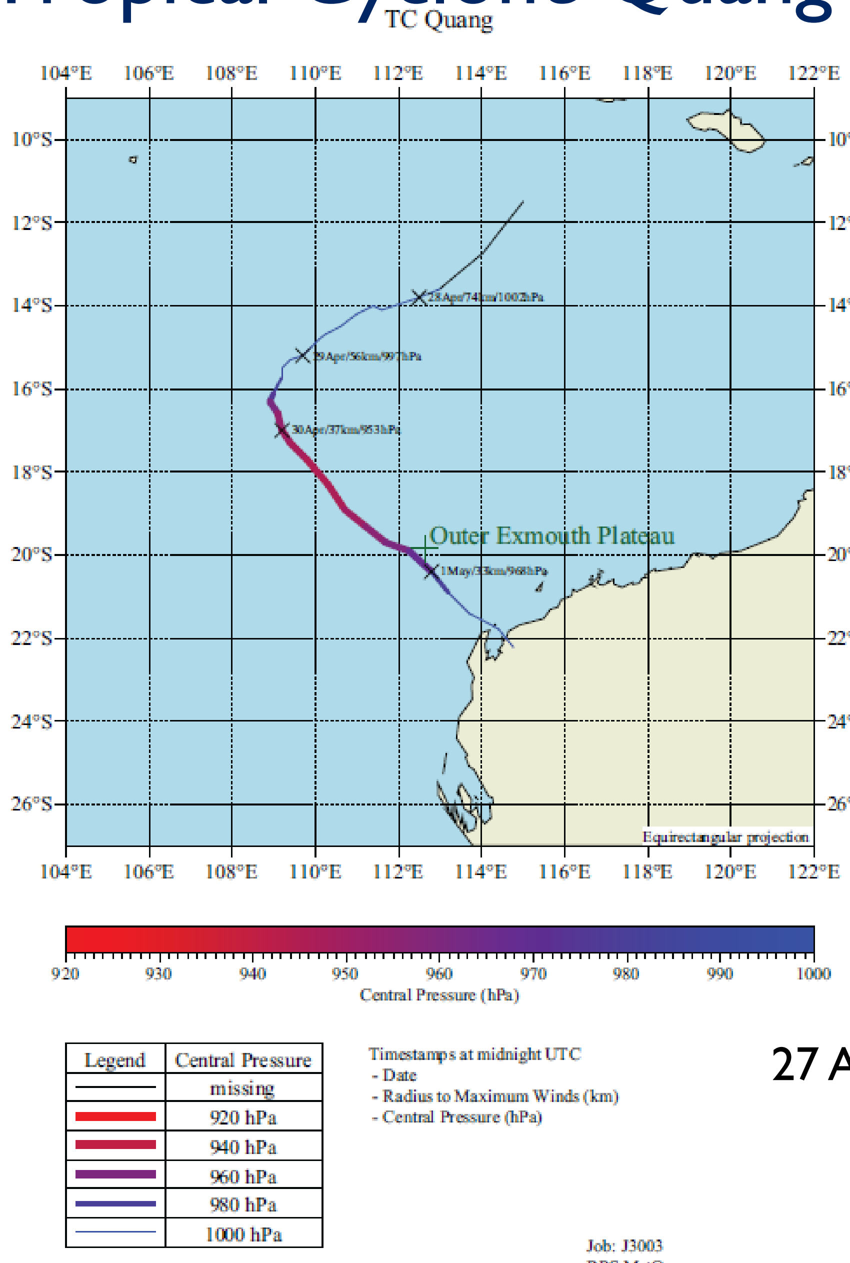
Location:	**Outer Exmouth Plateau**		
Latitude:	19° 50' 4" S	Client:	Shell Development (Australia) Pty Ltd
Longitude:	112° 38' 38" E	Project:	J3003
Location Water Depth:	1250.00 m MSL		



Exmouth Surface Currents – TC Quang

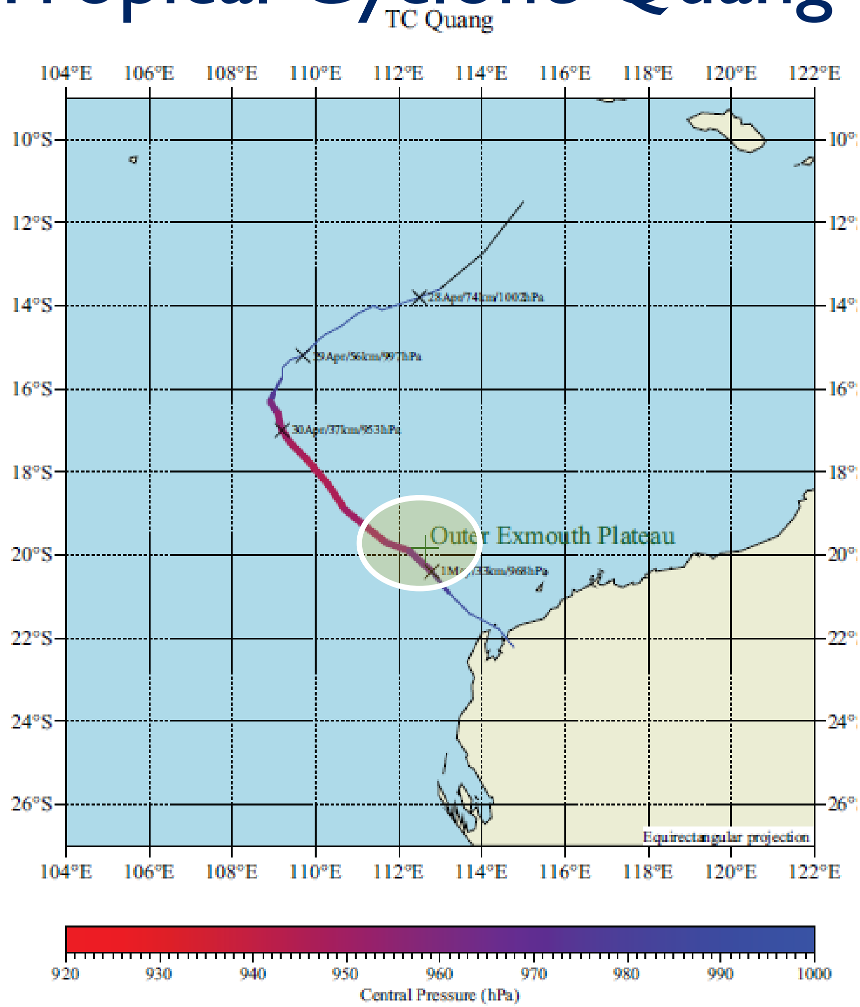


Tropical Cyclone Quang



27 April to 1 May 2015

Tropical Cyclone Quang

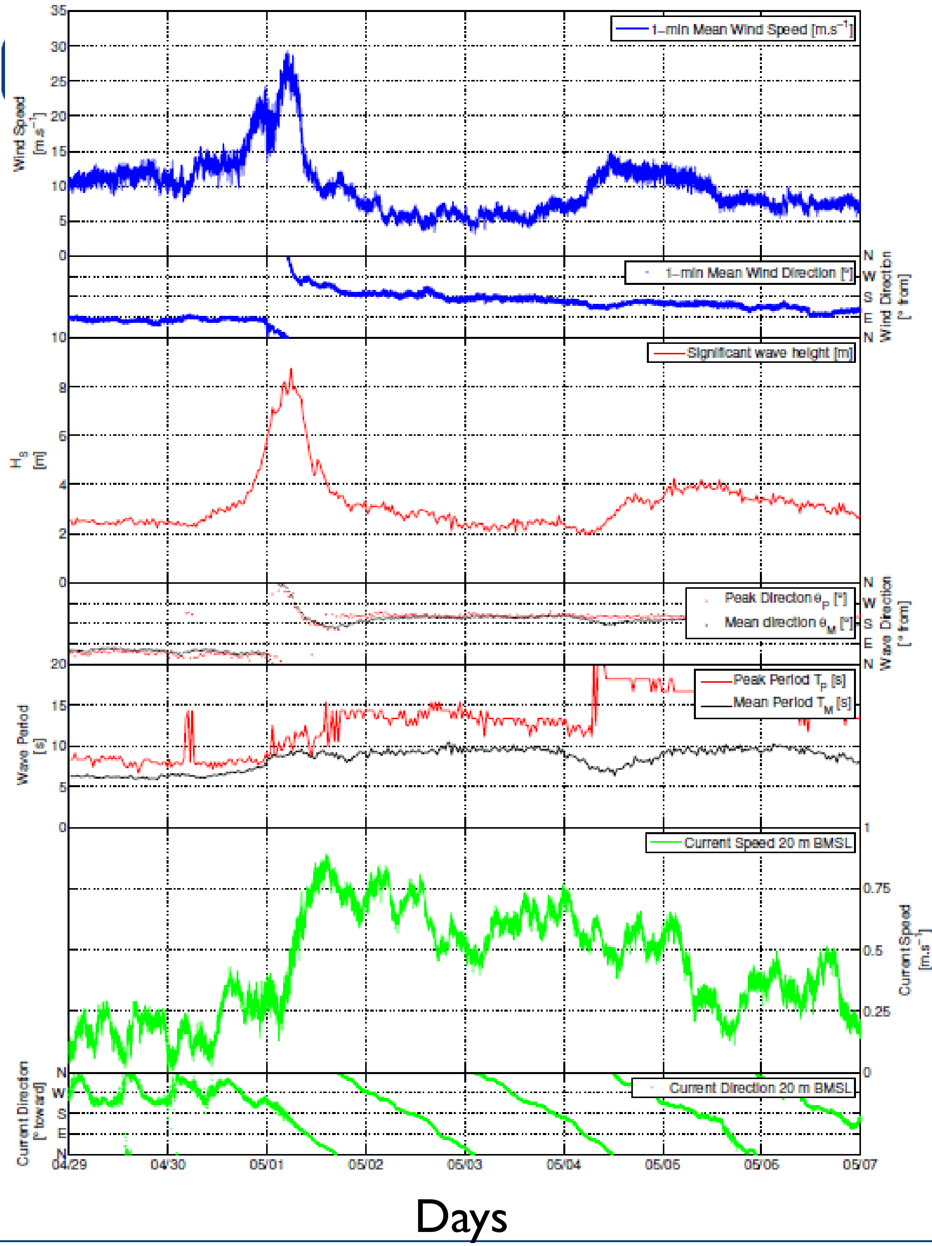


Legend	Central Pressure
(black line)	missing
(red line)	920 hPa
(crimson line)	940 hPa
(purple line)	960 hPa
(violet line)	980 hPa
(thin blue line)	1000 hPa

Timestamps at midnight UTC
- Date
- Radius to Maximum Winds (km)
- Central Pressure (hPa)

27 April to 1 May 2015

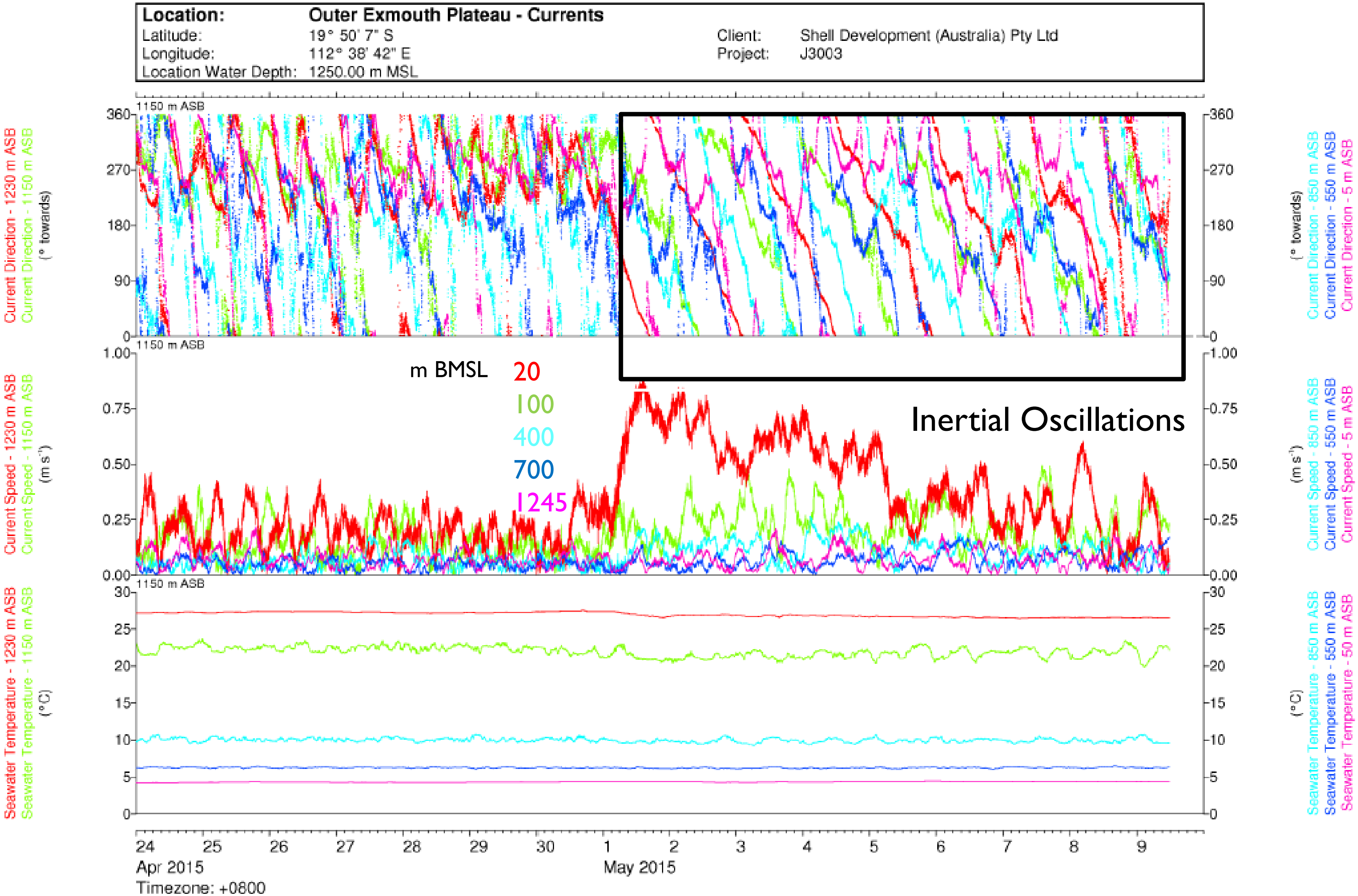
Job: J3003



Peak Wind Speed $U_{10} = 28\ m\ s^{-1}$

Peak Wave Height $H_s = 8.7\ m$

Peak Current Speed $V_s = 0.9\ m\ s^{-1}$



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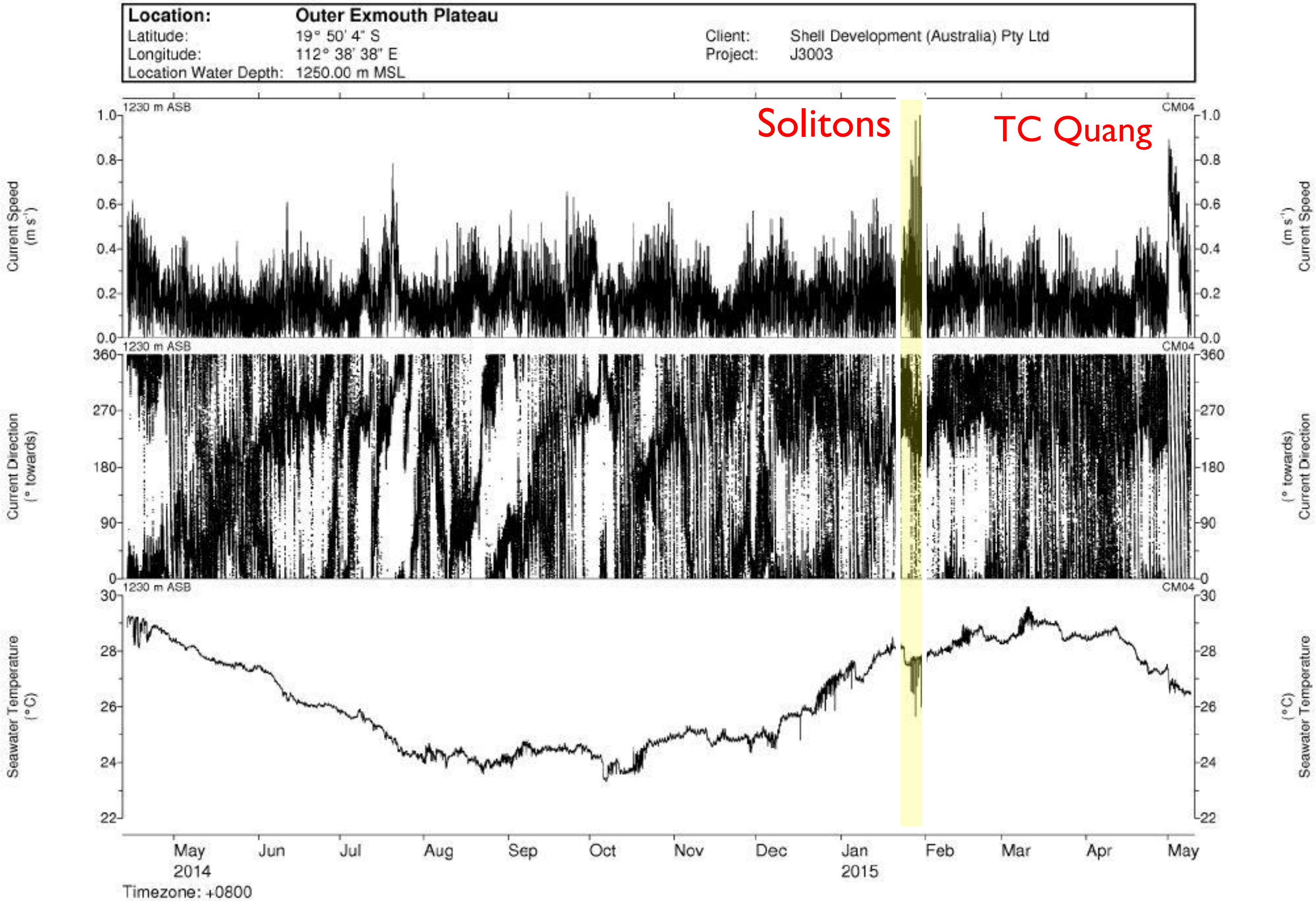
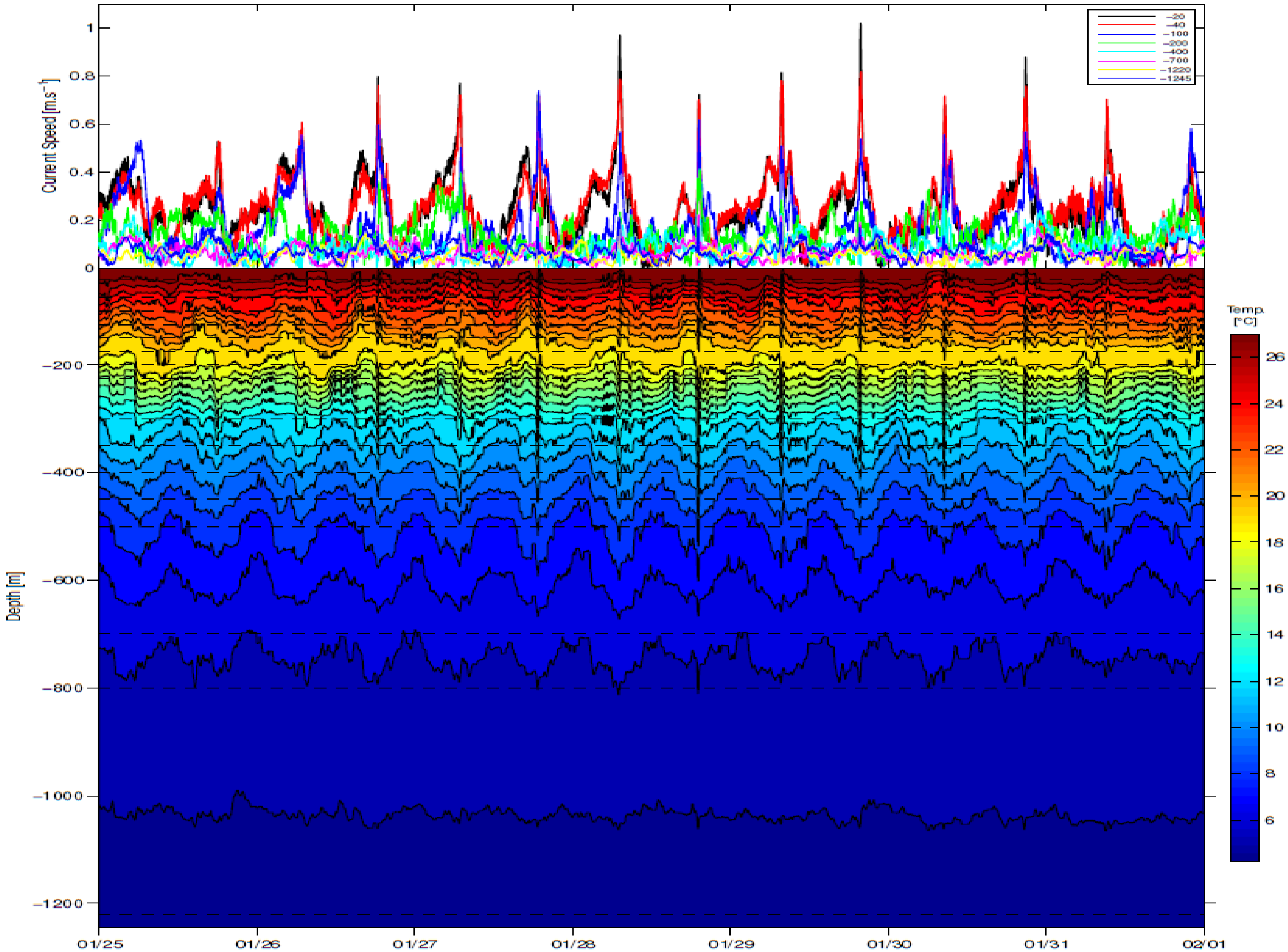
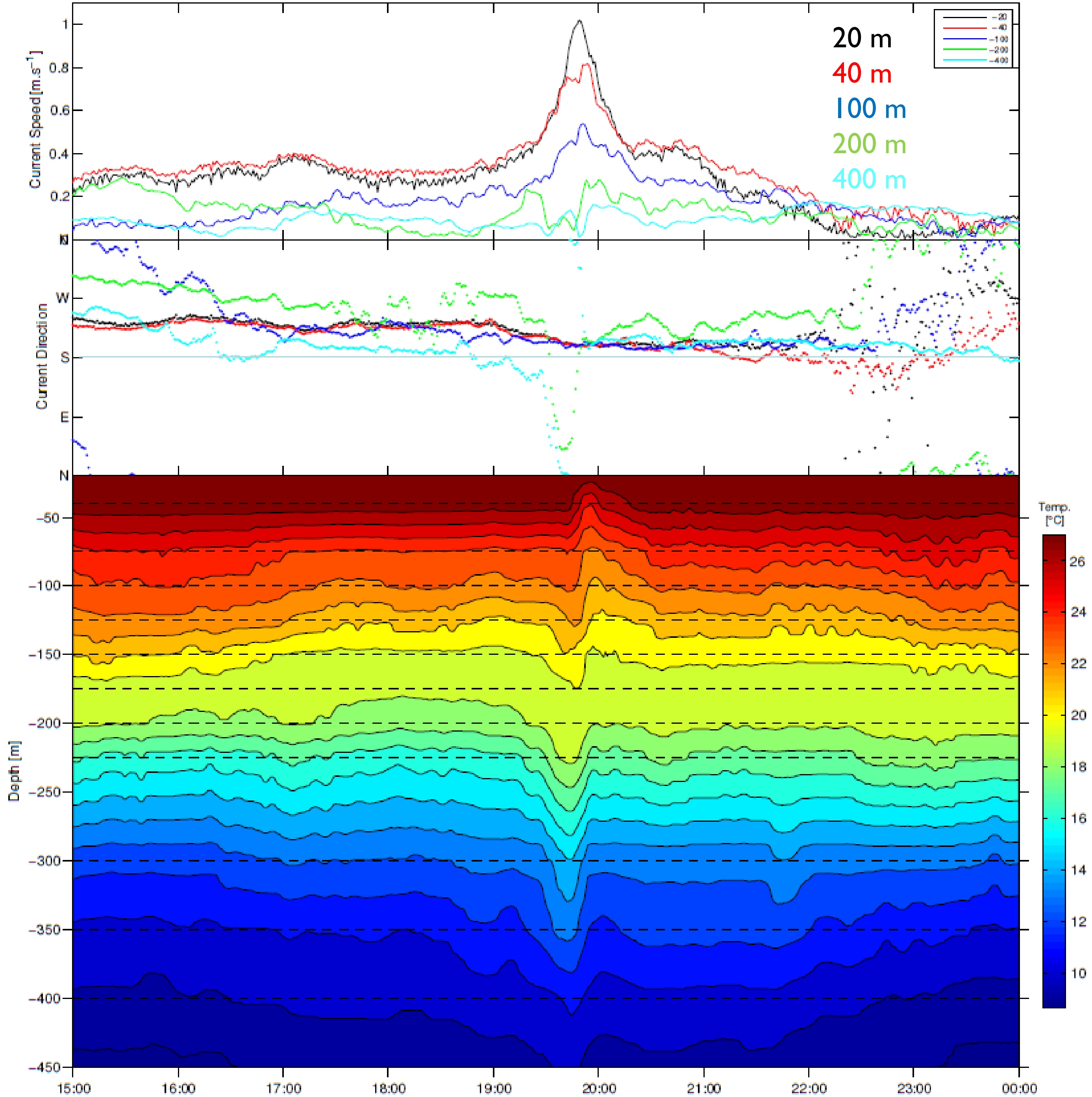
Exmouth Surface Currents – Soliton Sequence



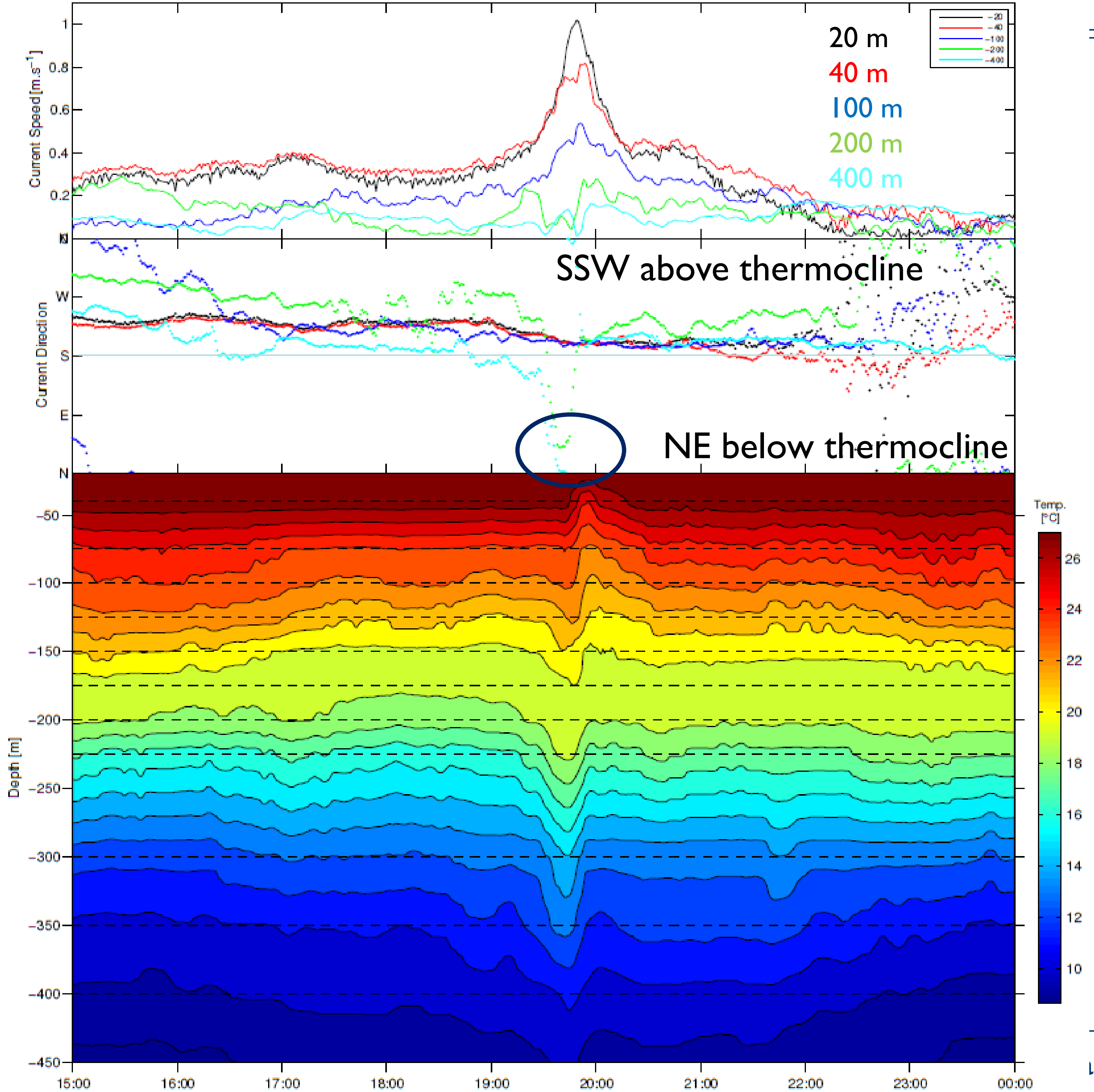
The Super Soliton Series



RPS


20 m
40 m
100 m
200 m
400 m
Current Speed [m.s-1]
Current Direction
N
W
S
E
N
Depth [m]
Temp. [°C]
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00

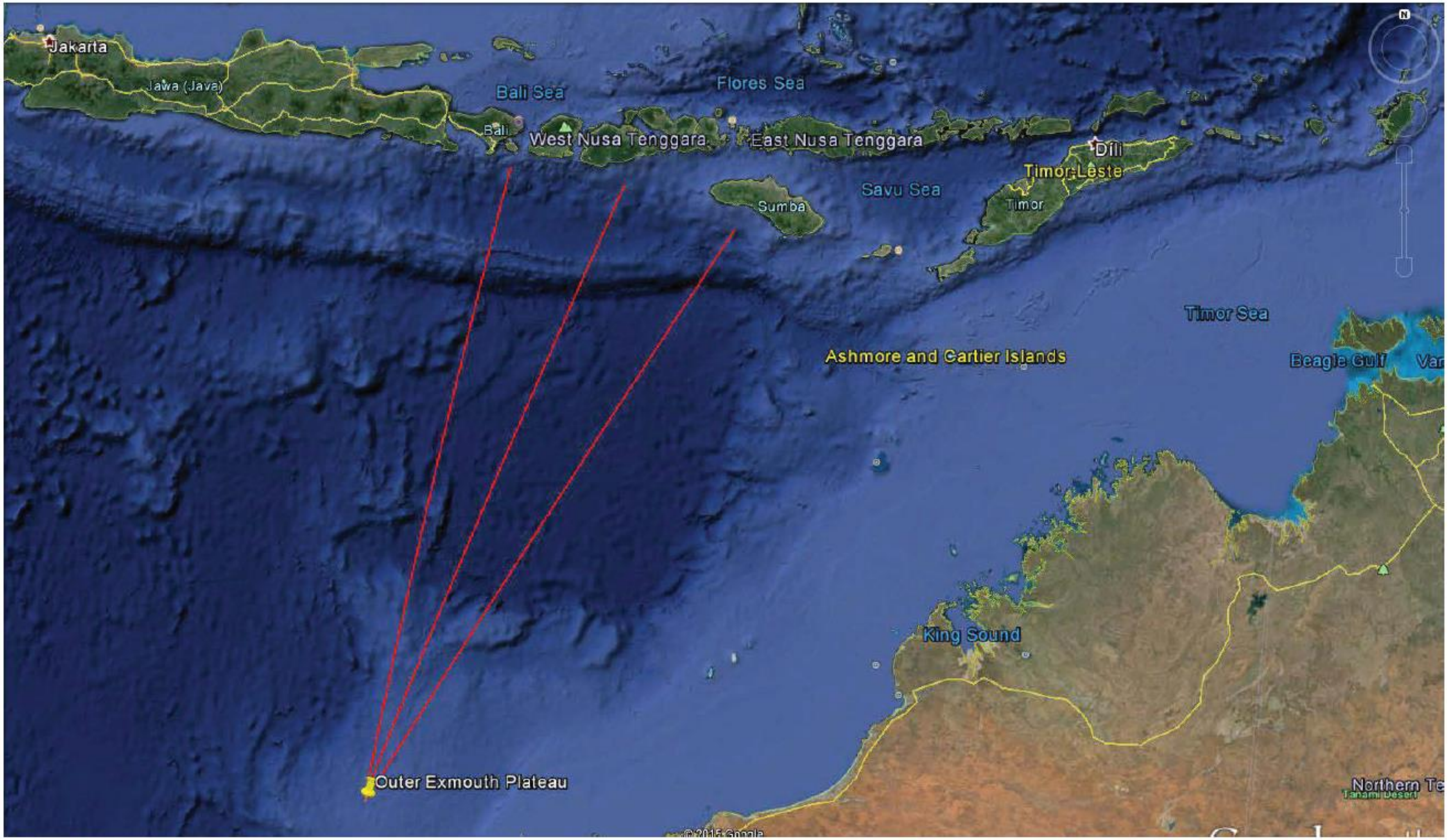
RPS


20 m
40 m
100 m
200 m
400 m
Current Speed [m.s-1]
SSW above thermocline
NE below thermocline
Current Direction
Depth [m]
Temp. [°C]
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00

Their Likely Source

- Thermal structure shows they are Vertical Mode 1 (VM1).
- Peak speeds in upper layer in the direction of propagation.
- Back-track along Great Circle Route.
- Lombok and Sape Straits (both known internal wave generation locations) bound the potential generation arc.
- Argo Data provides ‘typical’ density structure.
- Simple KdV calculations suggest a propagation speed of 2.5 m s^{-1}.
- Propagation time ~ 6 days.

RPS



Jakarta
Jawa (Java)
Bali Sea
Flores Sea
Bali
West Nusa Tenggara
East Nusa Tenggara
Dili
Timor-Leste
Savu Sea
Sumba
Timor
Timor Sea
Ashmore and Cartier Islands
Beagle Gulf
King Sound
Outer Exmouth Plateau

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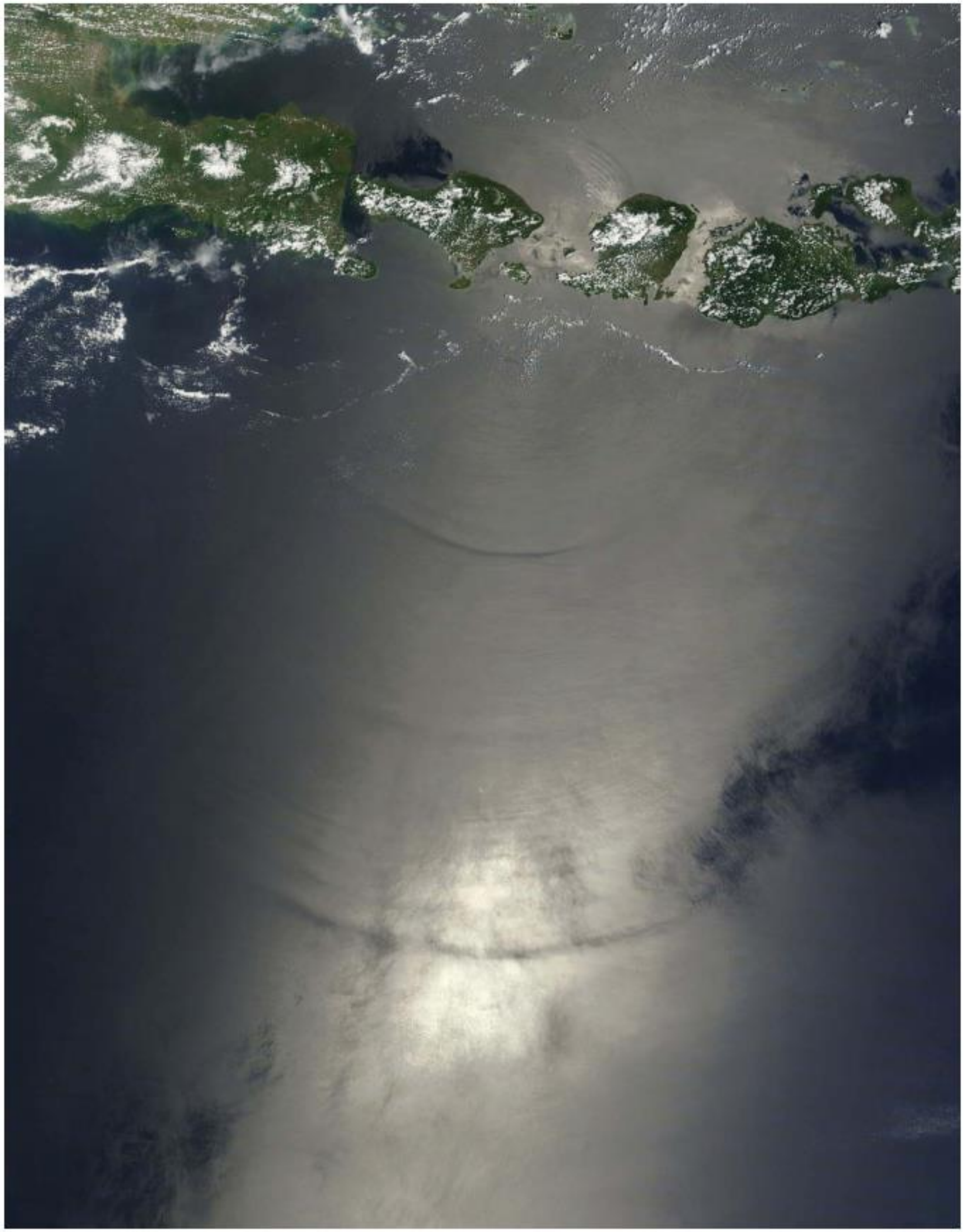


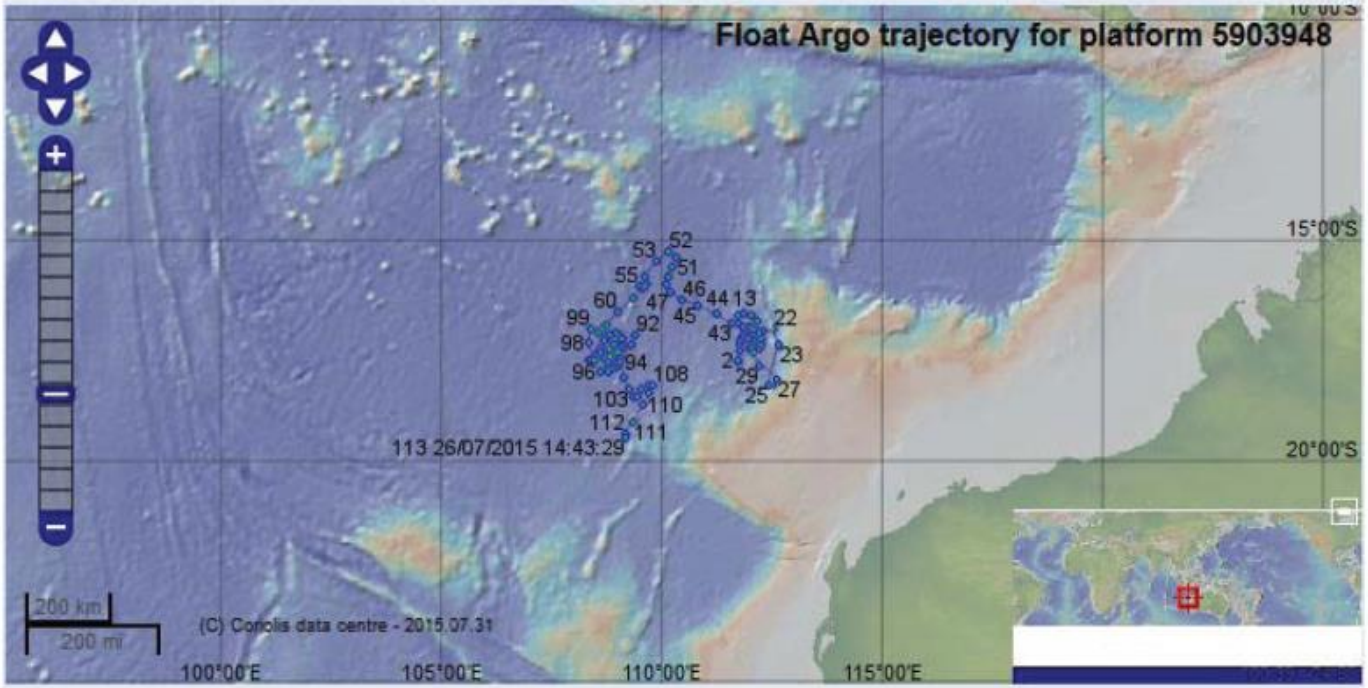
Lombok Strait

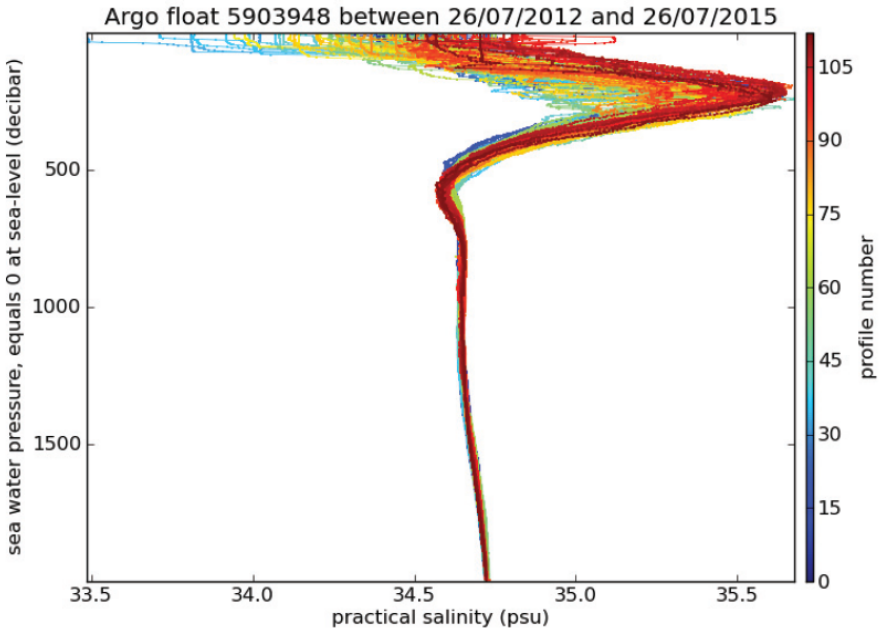
- Known area of internal wave generation.
- Shallow sills (~ 200 m)
- Strong Tidal currents in between Islands

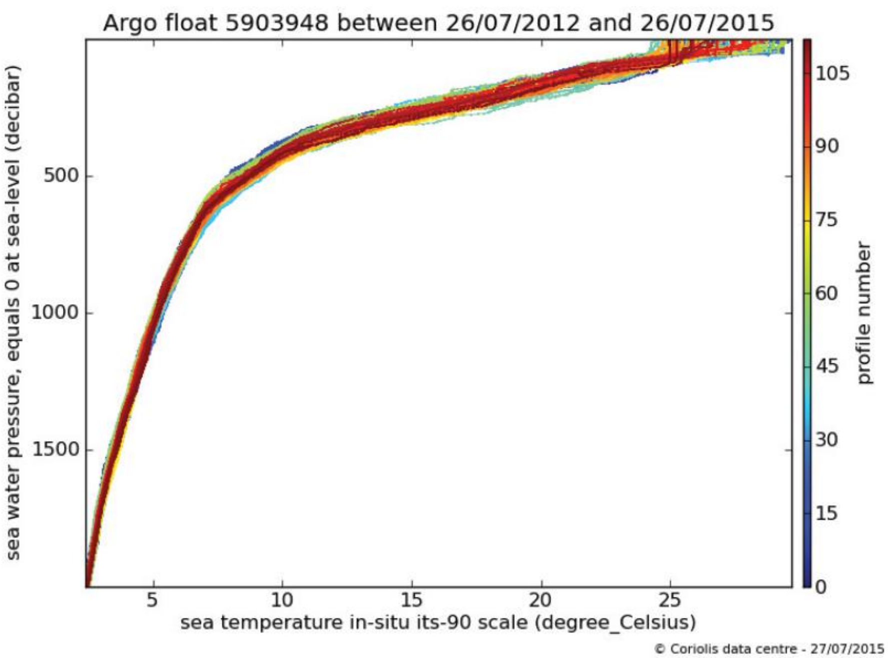
Their Likely Source

- Thermal structure shows they are Vertical Mode 1 (VM1).
- Peak speeds in upper layer in the direction of propagation.
- Back-track along Great Circle Route.
- Lombok and Sape Straits (both known internal wave generation locations) bound the potential generation arc.
- Argo Data provides 'typical' density structure.
- Simple KdV calculations suggest a propagation speed of 2.5 m s^{-1}.
- Propagation time ~ 6 days.

Argo Float Trajectory from 26/4/12 – 26/07/15







Lombok Strait to Outer Exmouth - rough KdV Calcs				
Trial		1	2	3
Nominal Depth (m)		1250	1500	2000
u1	$m\ s^{-1}$	1	1	1
Bearing	°	205	205	205
h1	m	150	150	150
h2	m	1100	1350	1850
rho1	$kg\ m^{-3}$	1025	1025	1025
rho2	$kg\ m^{-3}$	1030	1030	1030
C	$m\ s^{-1}$	2.51	2.54	2.57
C0	$m\ s^{-1}$	2.51	2.54	2.57
eta	m	69.47	67.50	65.29
u2	$m\ s^{-1}$	0.16	0.13	0.09
Propagation Distance	km	1300	1300	1300
Propagation Time	days	6.0	5.9	5.9

Phase Speed ~ 2.5 $m\ s^{-1}$
Propagation Time ~ 6 days

Upper Level Speed ~ 1 $m\ s^{-1}$
Lower Level Speed ~ 0.15 $m\ s^{-1}$

Their Likely Source

- Thermal structure shows they are Vertical Mode 1 (VM1).
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- Back-track along Great Circle Route.
- Lombok and Sape Straits (both known internal wave generation locations) bound the potential generation arc.
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- Simple KdV calculations suggest a propagation speed of 2.5 m s^{-1}.
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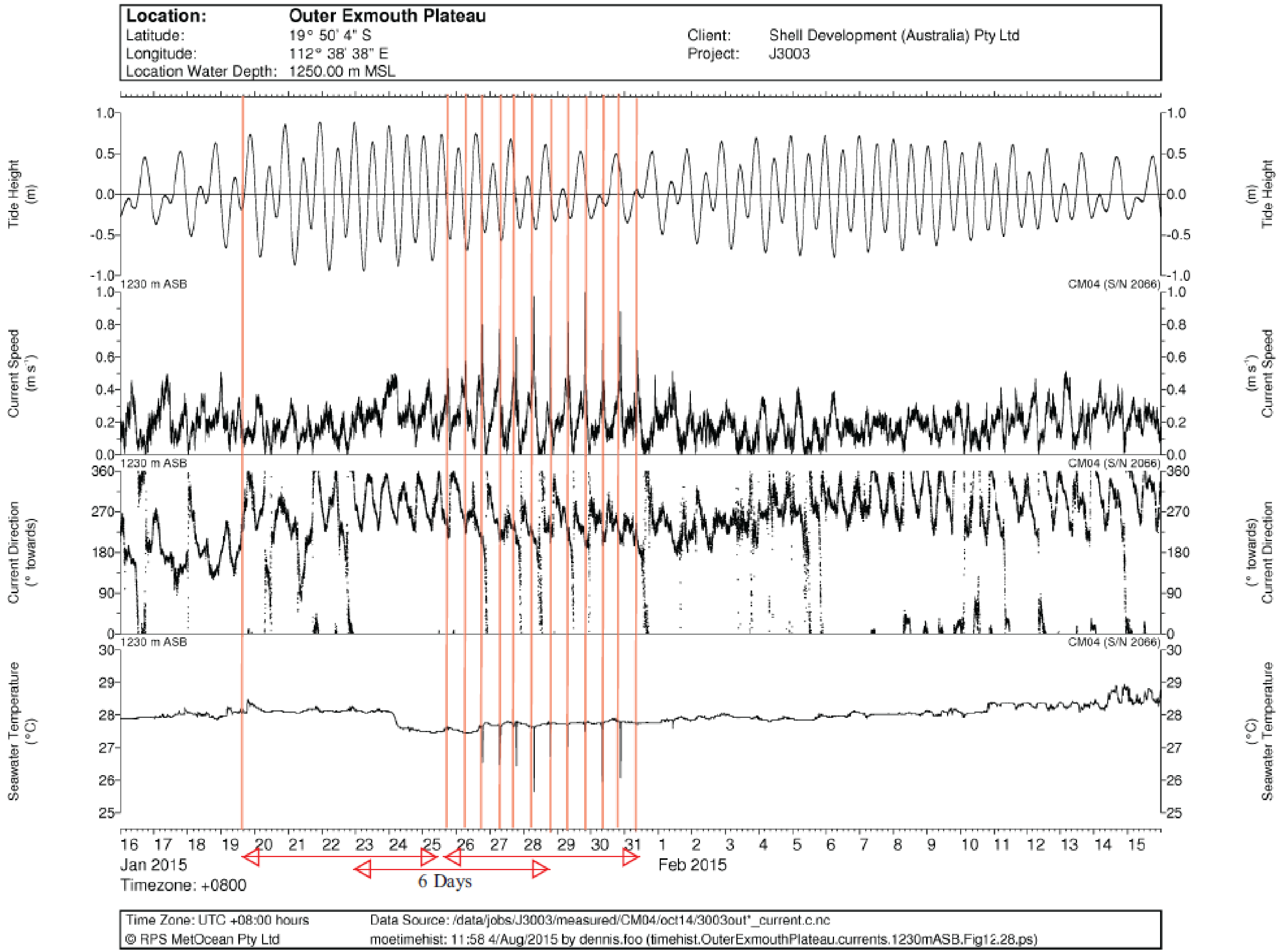


Location: Outer Exmouth Plateau
Latitude: 19° 50' 4" S
Longitude: 112° 38' 38" E
Location Water Depth: 1250.00 m MSL
Client: Shell Development (Australia) Pty Ltd
Project: J3003
Tide Height (m)
Current Speed (m s⁻¹)
Current Direction (° towards)
Seawater Temperature (°C)
1230 m ASB
CM04 (S/N 2066)
Jan 2015
Feb 2015
Timezone: +0800
6 Days
Time Zone: UTC +08:00 hours
© RPS MetOcean Pty Ltd
Data Source: /data/jobs/J3003/measured/CM04/oct14/3003out*_current.c.nc
moetimehist: 11:58 4/Aug/2015 by dennis.foo (timehist.OuterExmouthPlateau.currents.1230mASB.Fig12.28.ps)

The Upshot

Long-travelled solitons have the potential to generate higher riser loadings than tropical cyclones in deep waters off Australia's North West Shelf

We believe that we need to include Indonesian Straits in any comprehensive soliton modelling for the North West Shelf

We can establish this via running of the "adjoint" of a hydrodynamic model (we chose MITgcm).

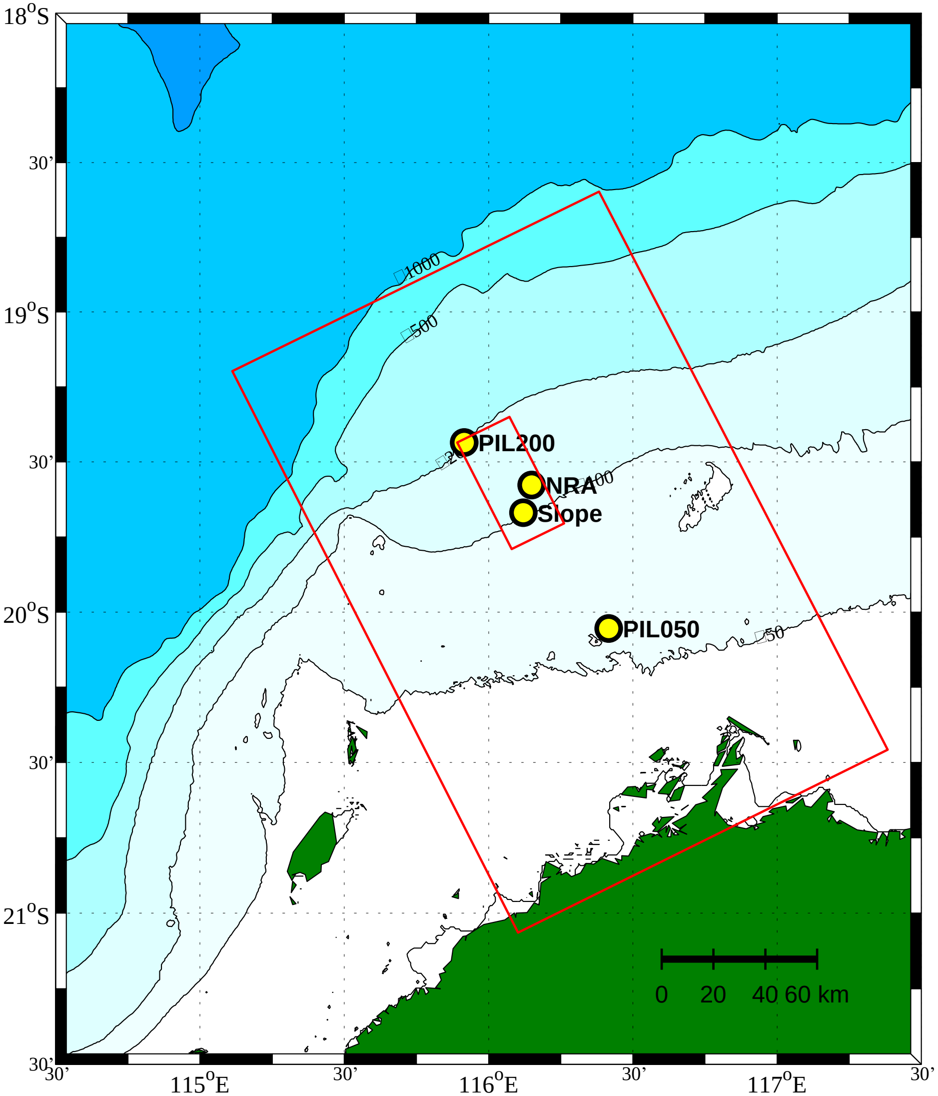
We focused on data from IMOS PIL200 location, because these data are publicly available.

Locations of Measured Data

PIL200, PIL100 and PIL50 – IMOS data in 200, 100 and 50 m depth, respectively

NRA – RPS data in 125 m depth

Slope, Break and Shelf – ARC data in 100, 80 and 78 m depth, respectively.



Adjoint MITgcm Modelling

The Adjoint of MITgcm calculates the sensitivity of a cost function to model state variables and input data.

Model State Variables and input data include

- tidal forcing
- density structure
- bathymetry (seabed slope)

The Cost Function is defined as

- the (VM1) isopycnal displacement at PIL200 location

Sensitivity can be expressed wrt vertical modes, the theory of which relates 'forcing' (of VM1) from the barotropic tide (VM0).

The Adjoint of the MITgcm Model

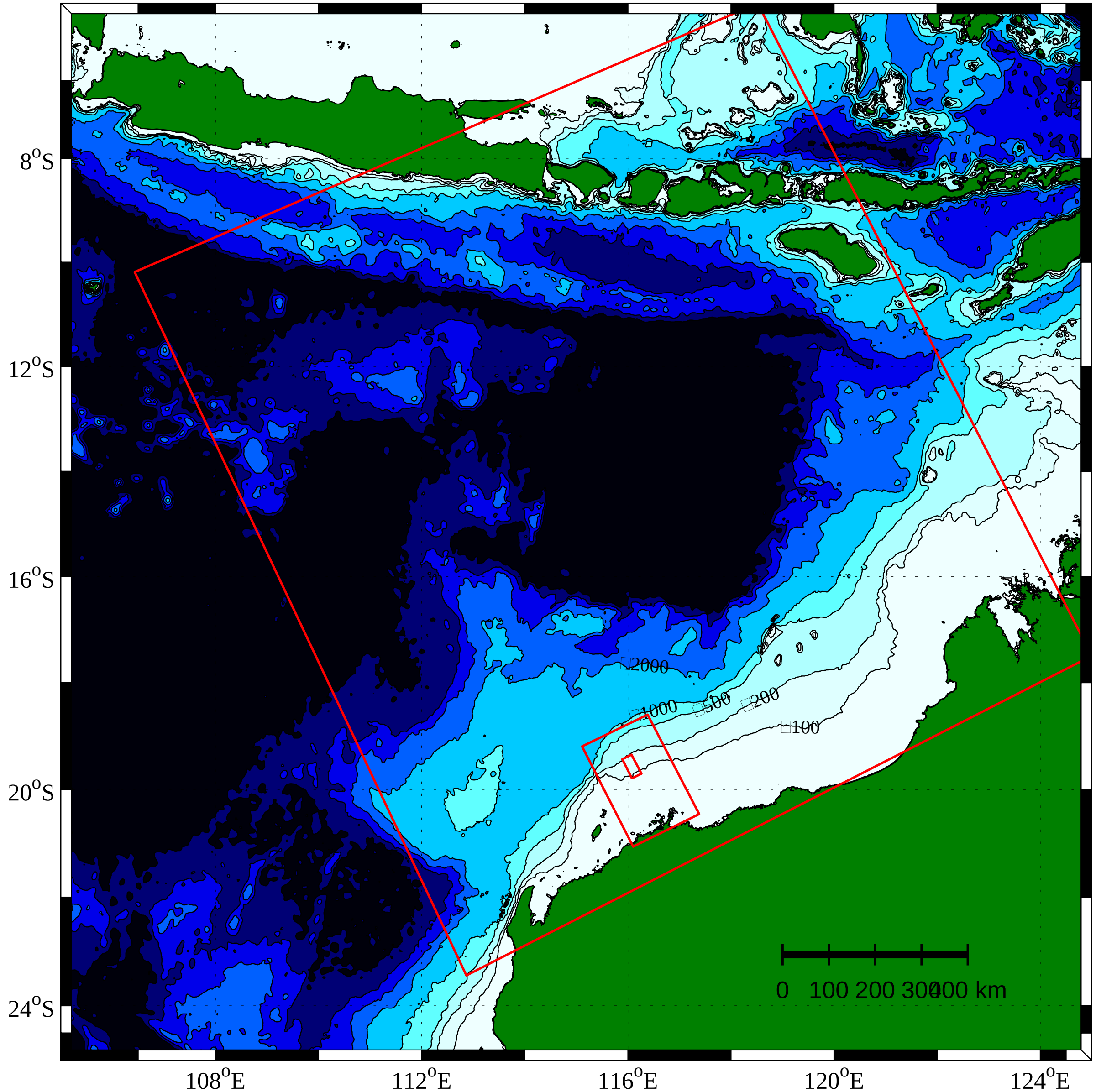
Is used to assess the sources of energy affecting internal wave motion - in this study - at PIL200 location.

The Cost Function (the only non-zero initial condition in the model domain) is set as the positive VM1 isopycnal displacement about PIL200 location.

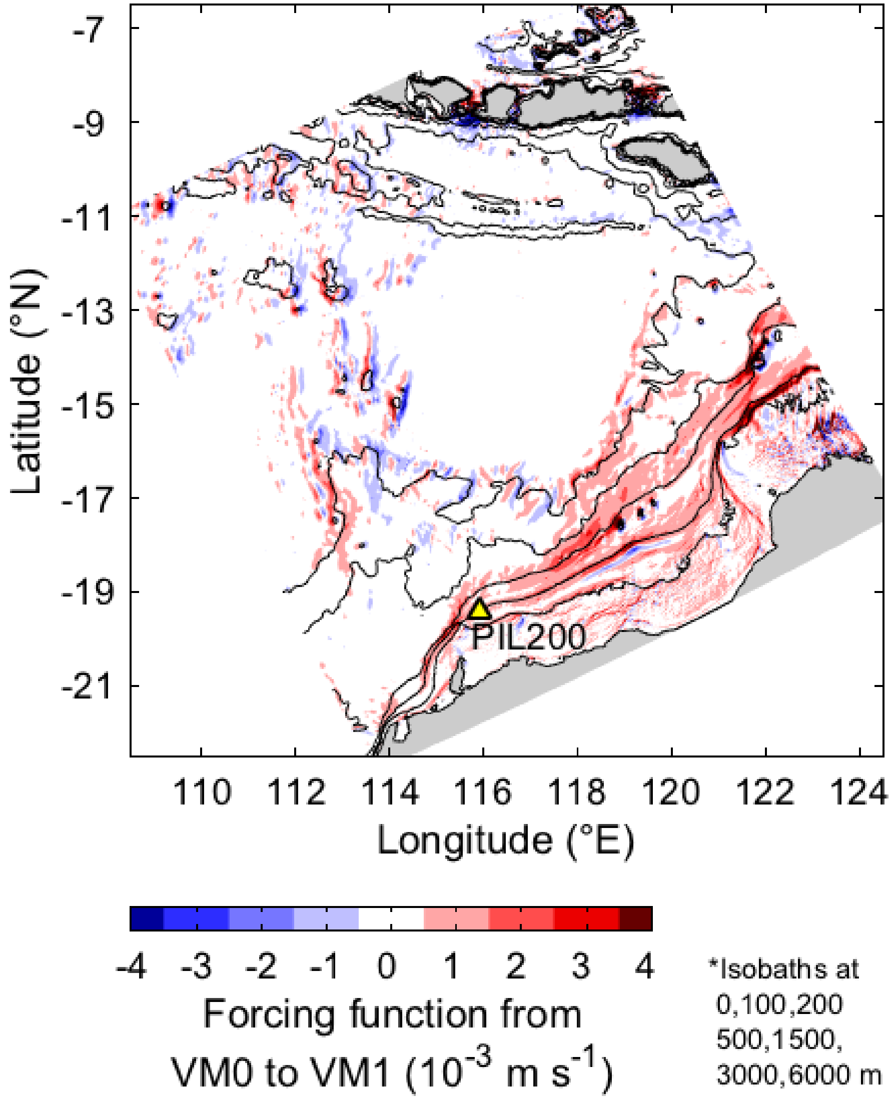
The Forcing Function is a direct computation of the efficiency of energy conversion from VM0 (barotropic) to VM1 (baroclinic) motion, given bottom slope and density structure.

The Sensitivity of the Cost Function to remote Forcing is calculated by stepping the model 'backwards' in time.

Domain of the Adjoint Model

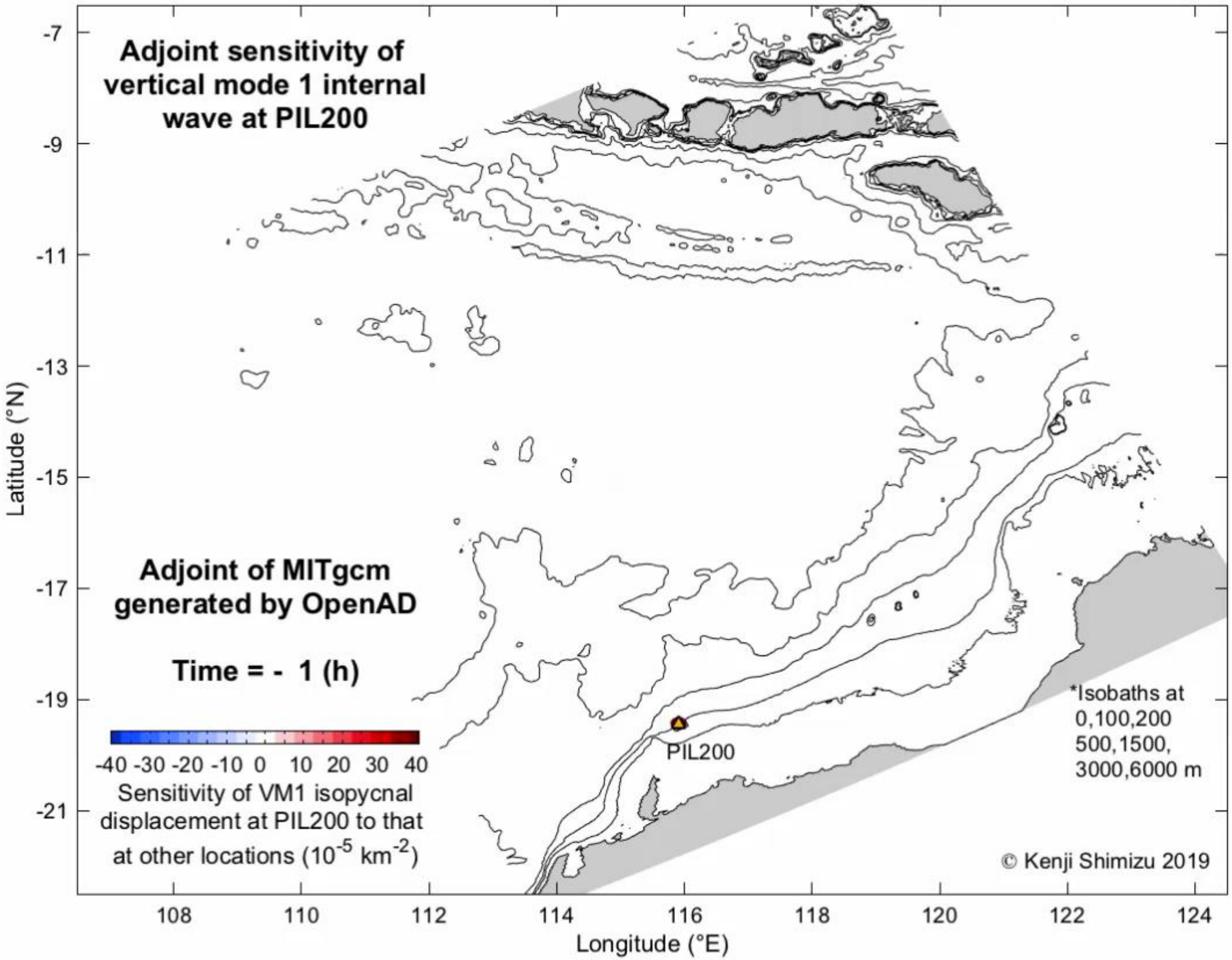


Forcing Function for M_2 Internal Tide

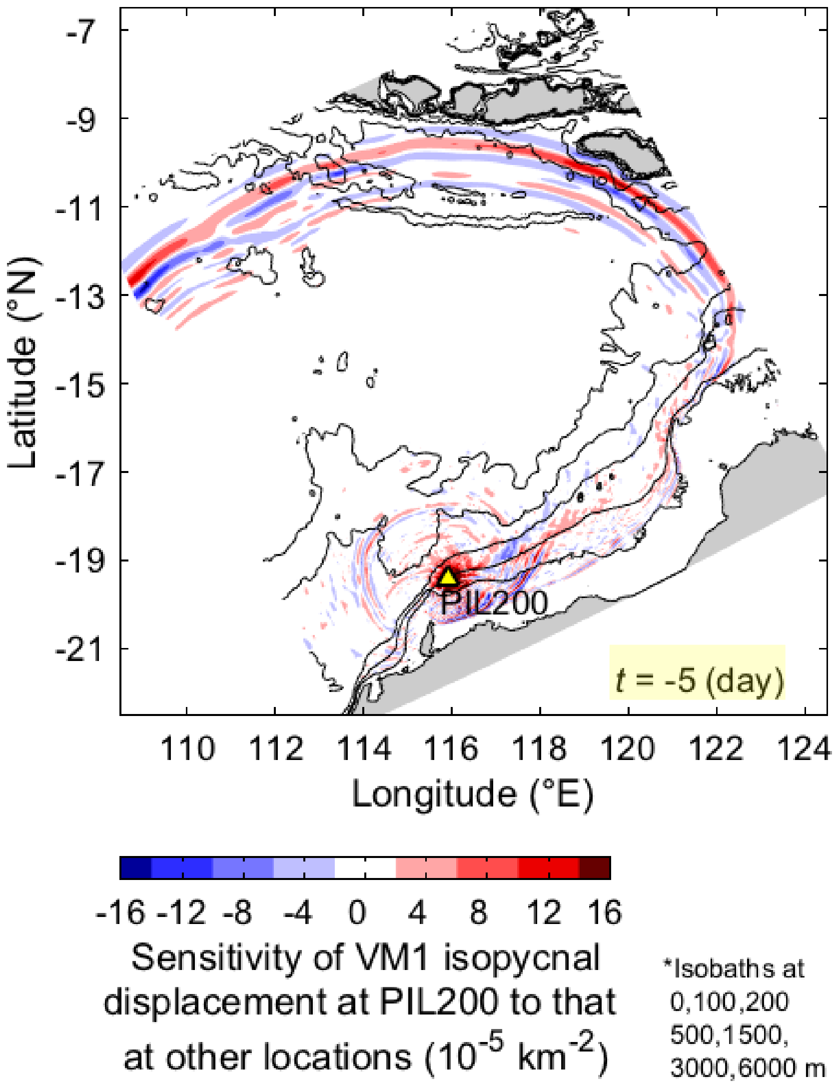


*Isobaths at 0,100,200 500,1500, 3000,6000 m

Sensitivity of PIL200 ISW - Animation



Sensitivity of ISW Vertical Displacement



*Isobaths at 0,100,200 500,1500, 3000,6000 m

Regional Contribution to ISWs at PIL200

The Source Function describes the regional contribution to VM1 M_2 tide at PIL200 location.

In time domain (for time lag τ), it is the convolution of the Sensitivity and the Forcing Function.

In the frequency domain, at a given frequency ω (in this case the tidal M_2 frequency), it is the product of the Fourier transform of the Sensitivity and the Forcing Function.

Frequency Response Analysis

In time domain

$$\eta(t) = \int_A \int_0^\infty s(\vec{x}, t-\tau) f(\vec{x}, \tau) d\tau \, d\vec{x}$$

VM1 isopycnal displacement at PIL200

Sensitivity of η to VM1 internal wave at other locations

Forcing from barotropic tides (VM0) to VM1

In frequency domain (applying the convolution theorem in Fourier Theory)

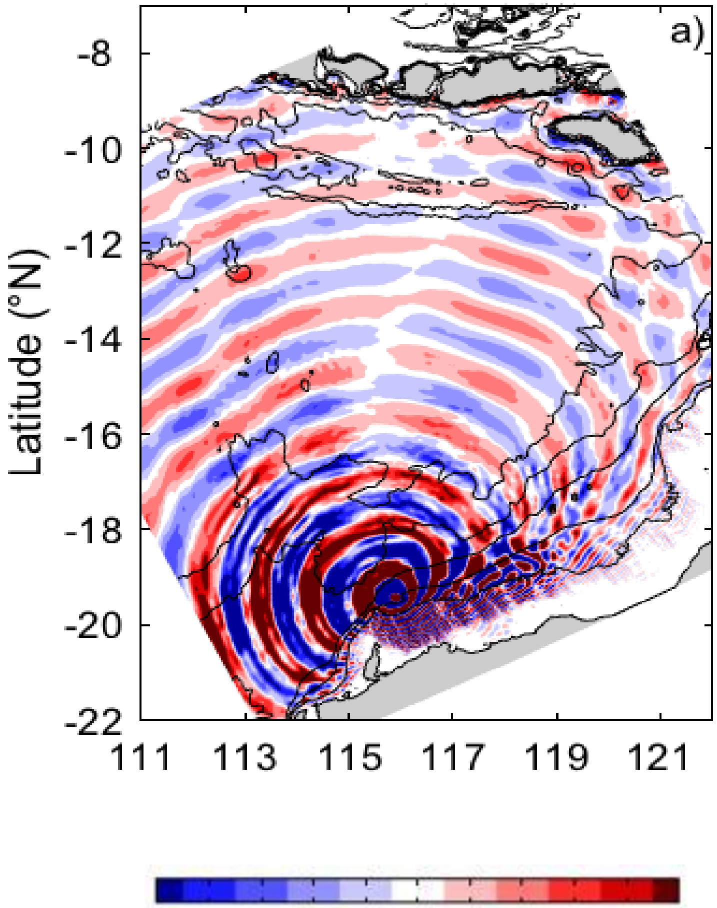
$$\mathrm{H}(\omega) = \int_A S(\vec{x}, \omega) F(\vec{x}, \omega) \, d\vec{x}$$

M_2 amplitude of VM1 isopycnal displacement

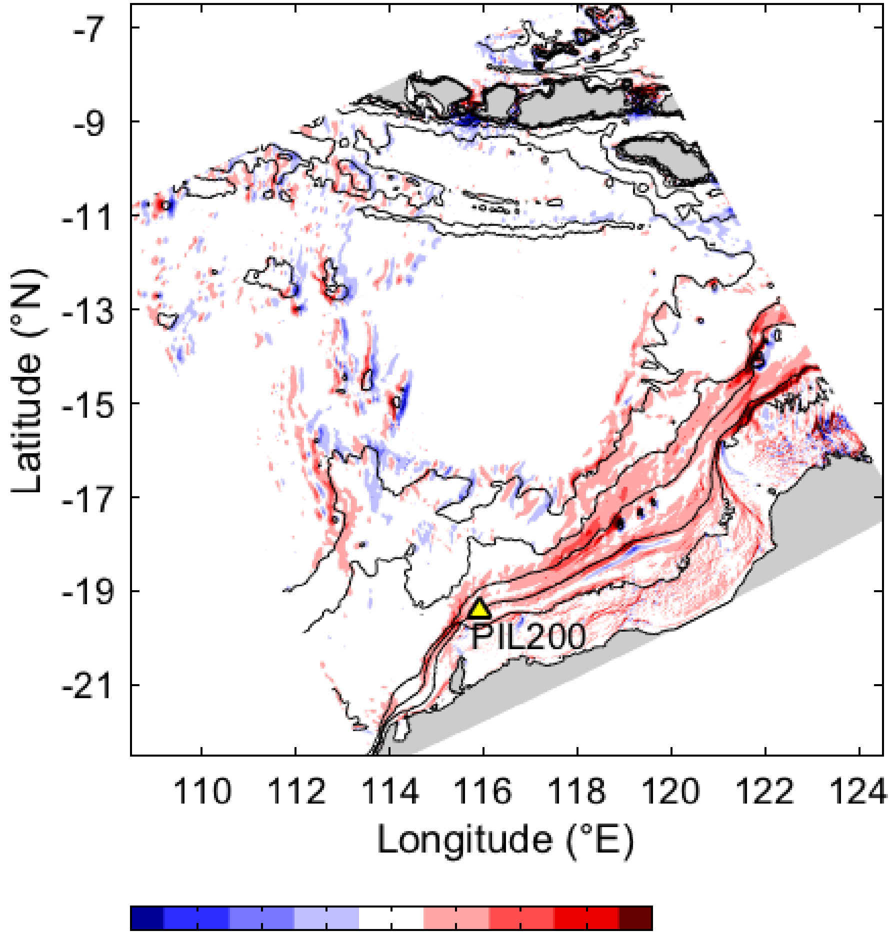
Fourier transform of sensitivity

Forcing to VM1 at M_2 frequency

Sensitivity x Forcing function for PIL200



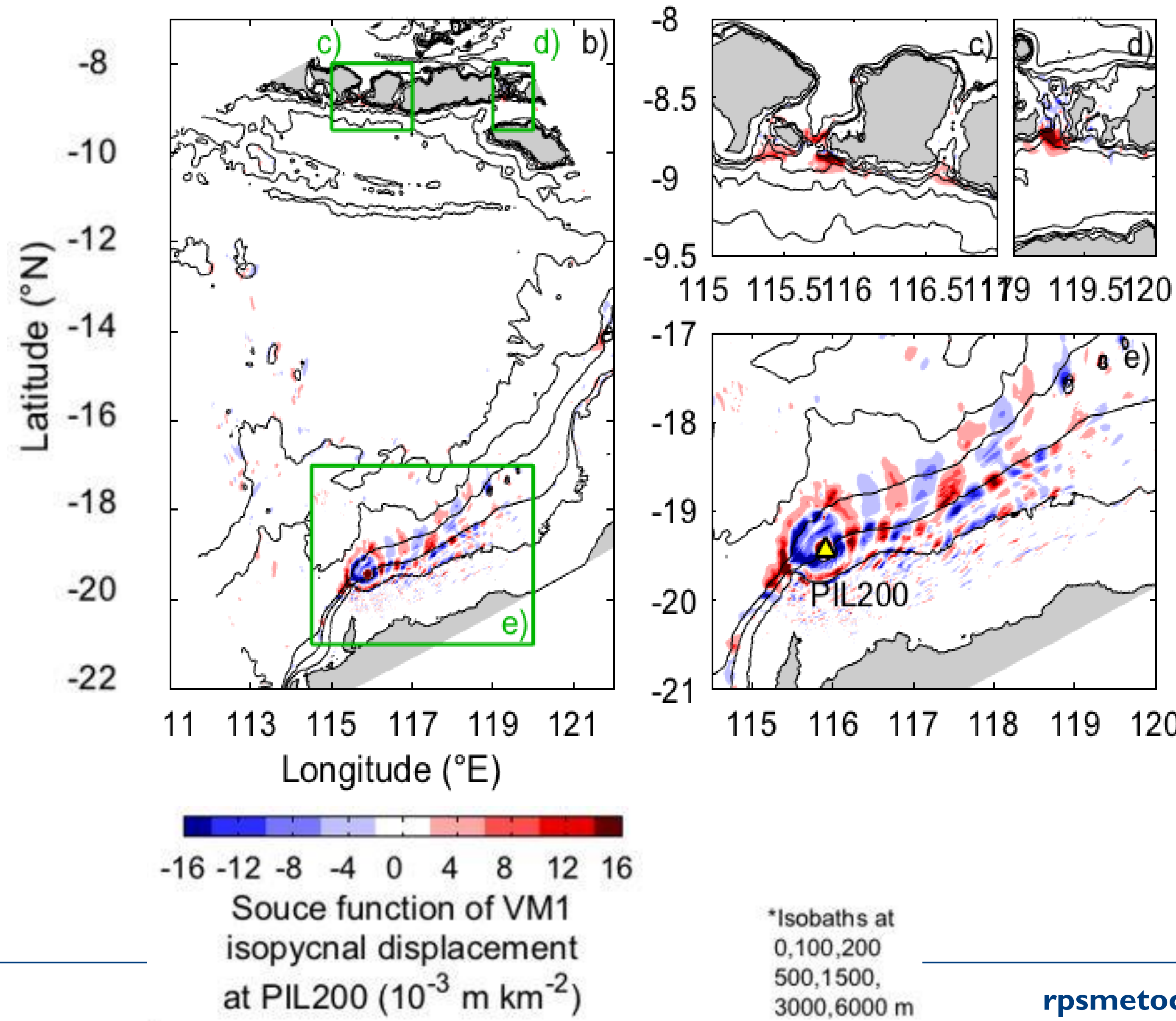
Fourier-transformed sensitivity of VM1 isopycnal displacement at PIL200 to that at other locations (10^{-4} s km^{-2})



Forcing function from VM0 to VM1 (10^{-3} m s^{-1})

*Isobaths at 0,100,200 500,1500, 3000,6000 m

Source Function for ISWs at PIL200



*Isobaths at
0,100,200
500,1500,
3000,6000 m

Spatial Integration of the Source Function

The Source Function can be integrated over any horizontal domain to establish the relative contribution of that domain to the Cost Function (the VM1 M_2 tide) at PIL200 location.

Results are illustrated in the following table.

Sources of M_2 Internal Tide at PIL200

VM1 M2 tide at PIL200

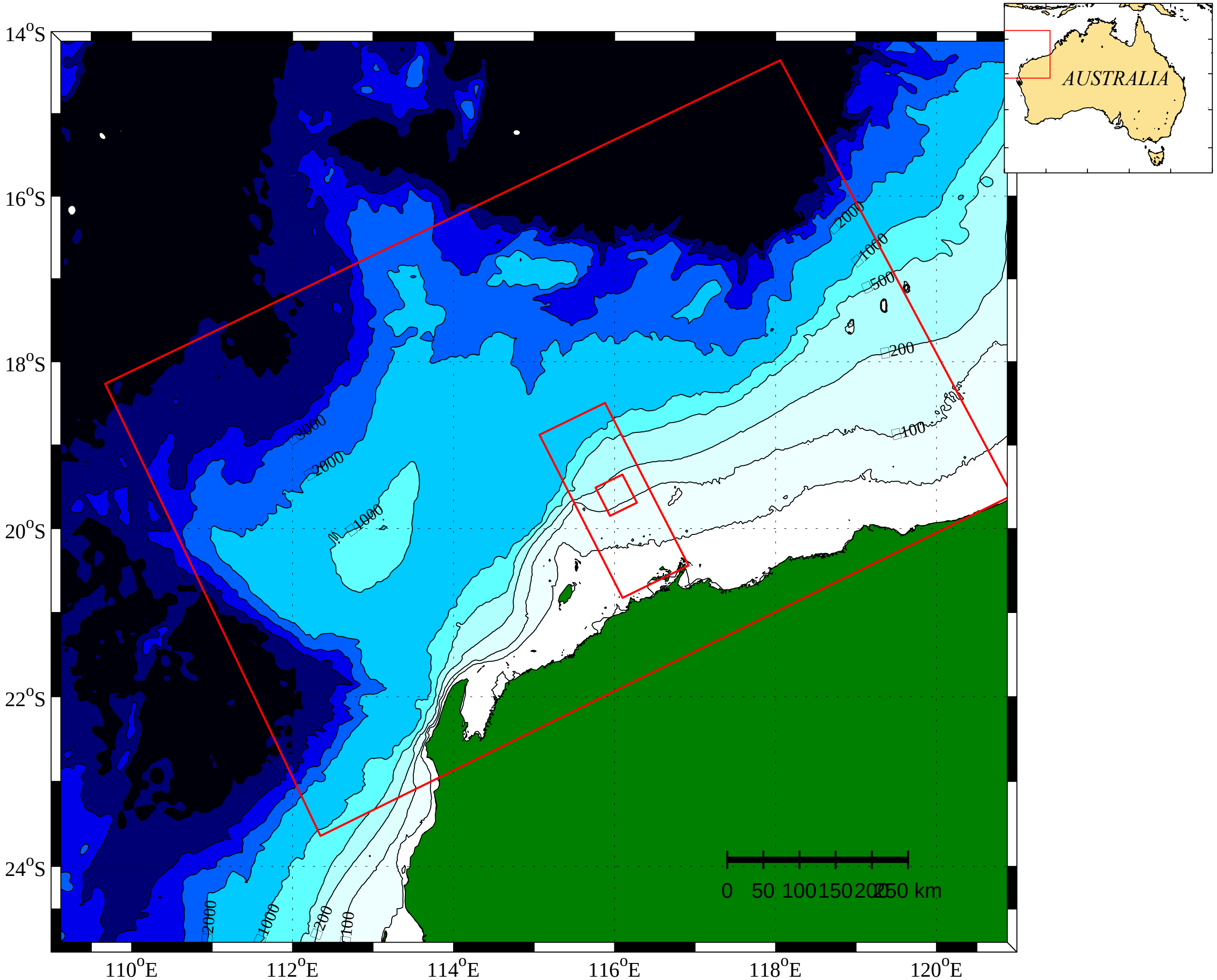
Region	Contribution (m)
Australian North West Shelf (<1500 m deep)	
Lower North West Shelf (west of ~120 °E)	-6 + 18 i
Upper North West Shelf (east of ~120 °E)	-1 - 1 i
Subtotal	-7 + 17 i
Indonesian region (<1500 m deep)	
Lombok & Bali Straits	7 + 3 i
Sape Strait	3 + 2 i
Alas Strait	1 - 0 i
Other	0 - 0 i
Subtotal	11 + 5 i
Deep open ocean (>1500 m deep)	-2 - 2 i
Total	2 + 20 i

Results of Adjoint MITgcm Modelling

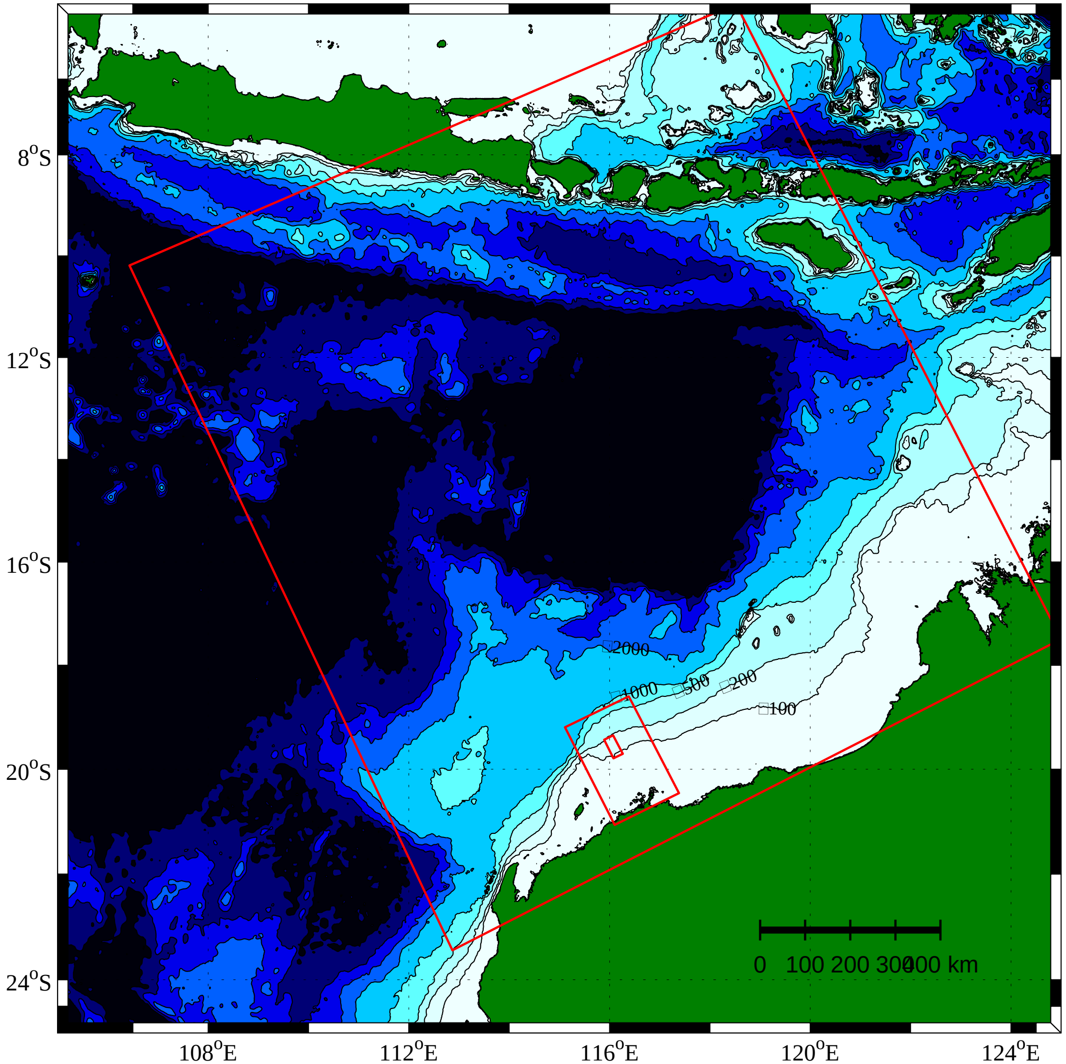
We have established that the Indonesian Straits are a significant source of internal tidal energy propagating to Australia's North West Shelf.

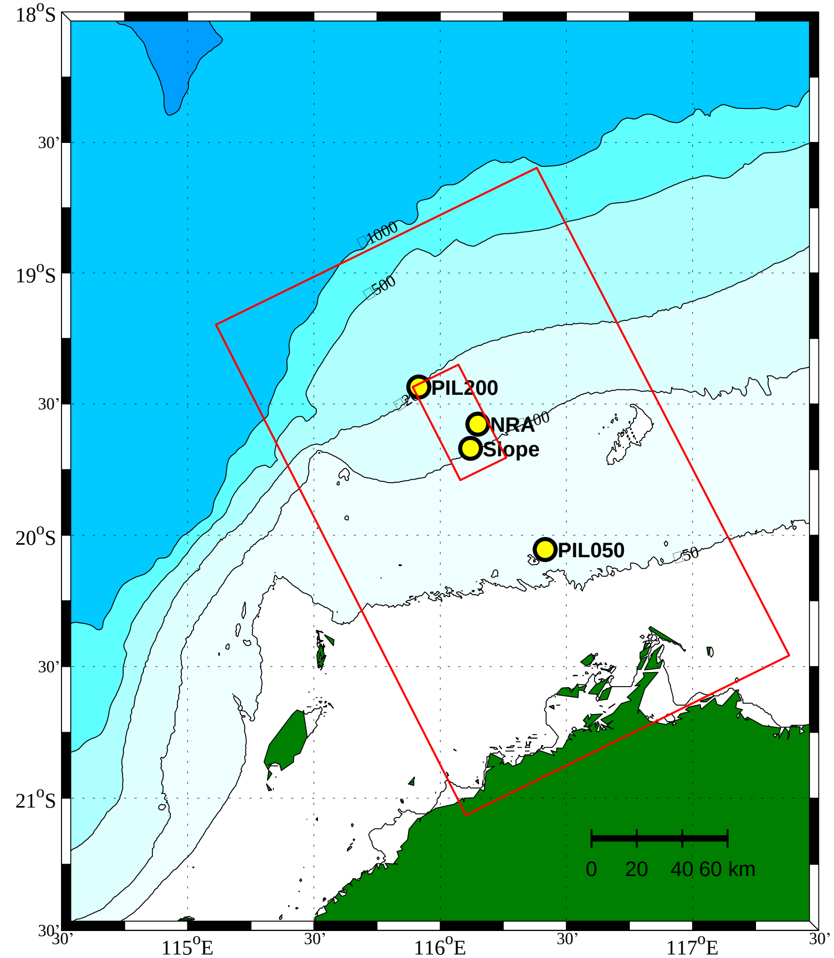
Any modelling of Internal Solitary Waves on the North West Shelf will require inclusion of these source regions in the model domain.

Original (2015) Model Grid

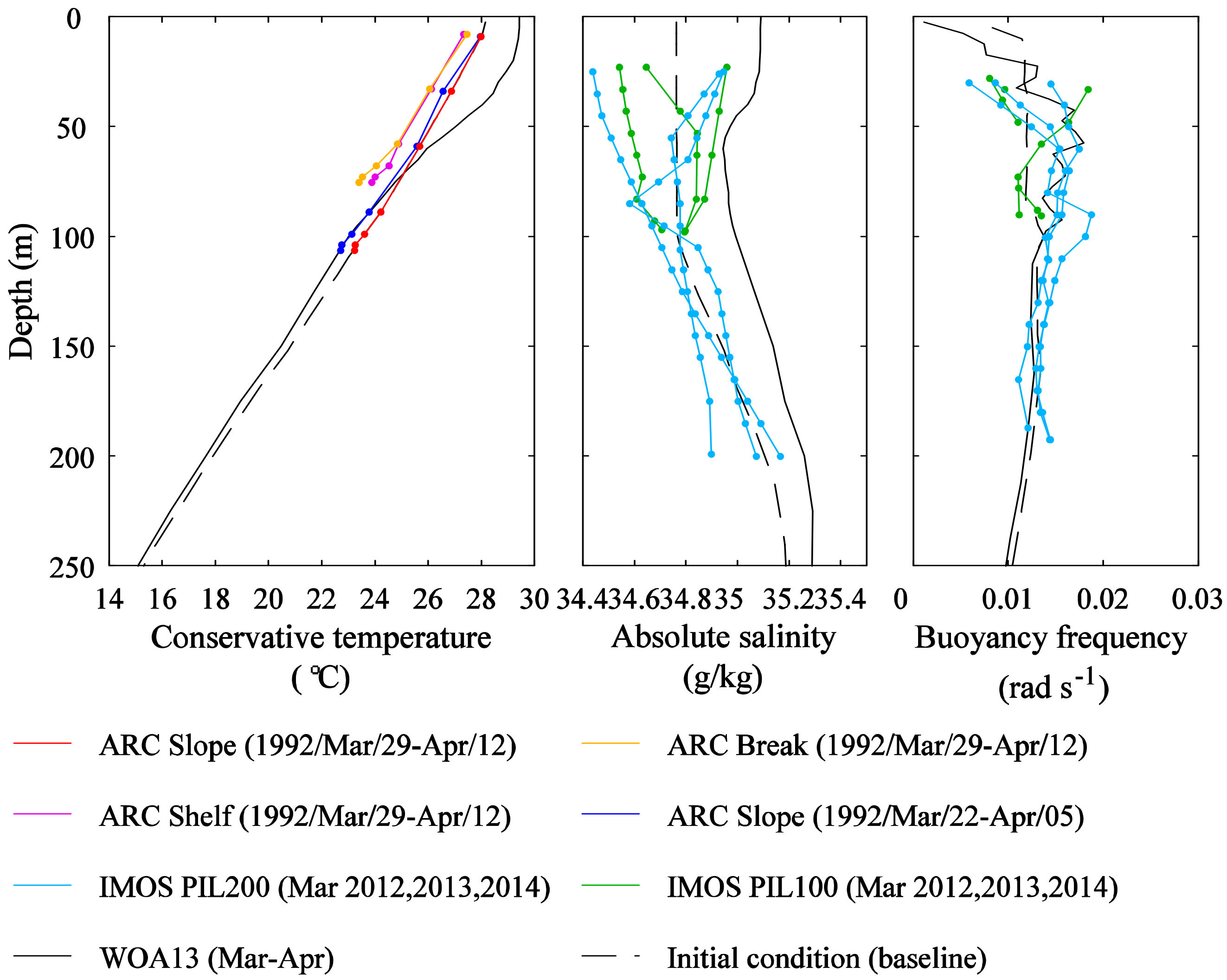


Revised Model Grid



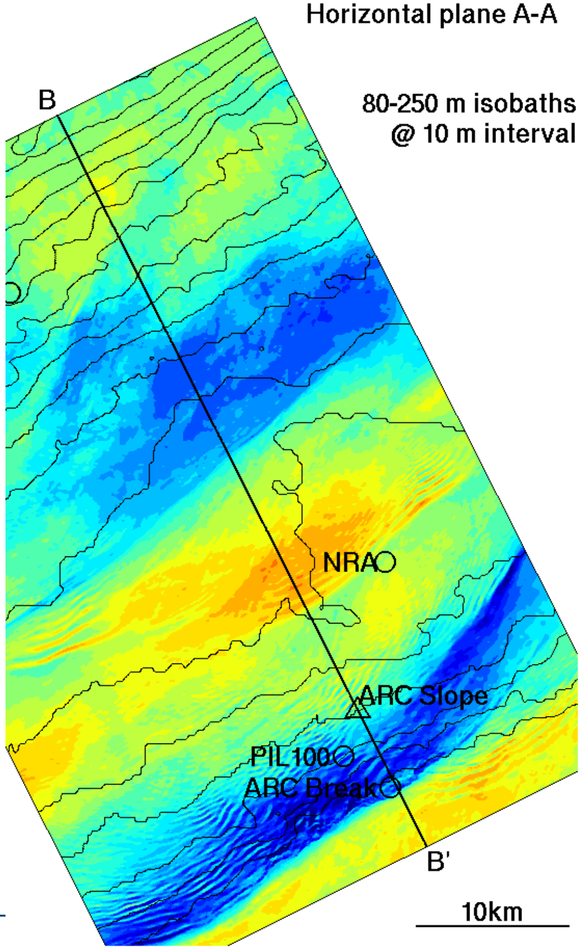


Stratification

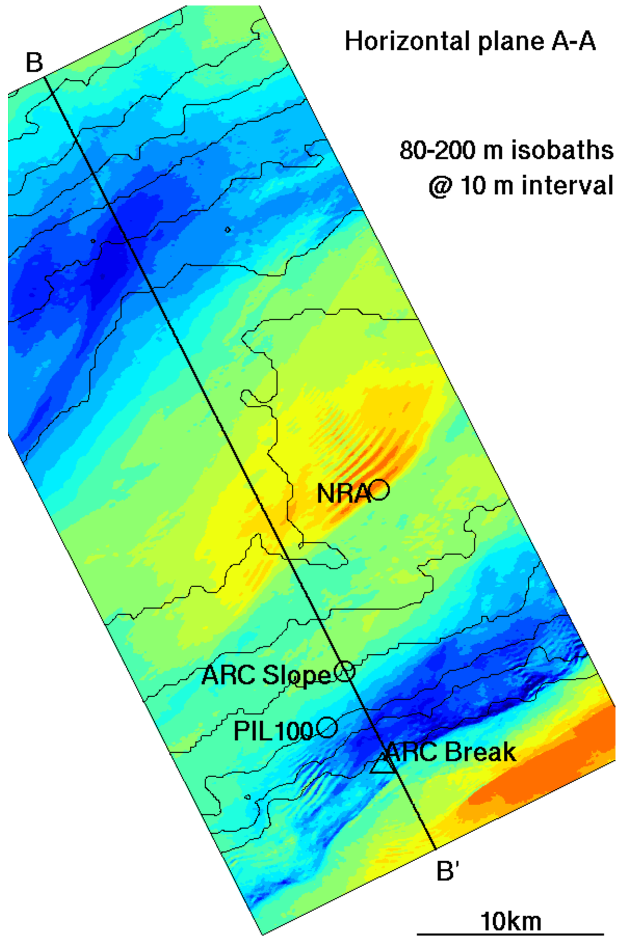


Comparison of Configurations

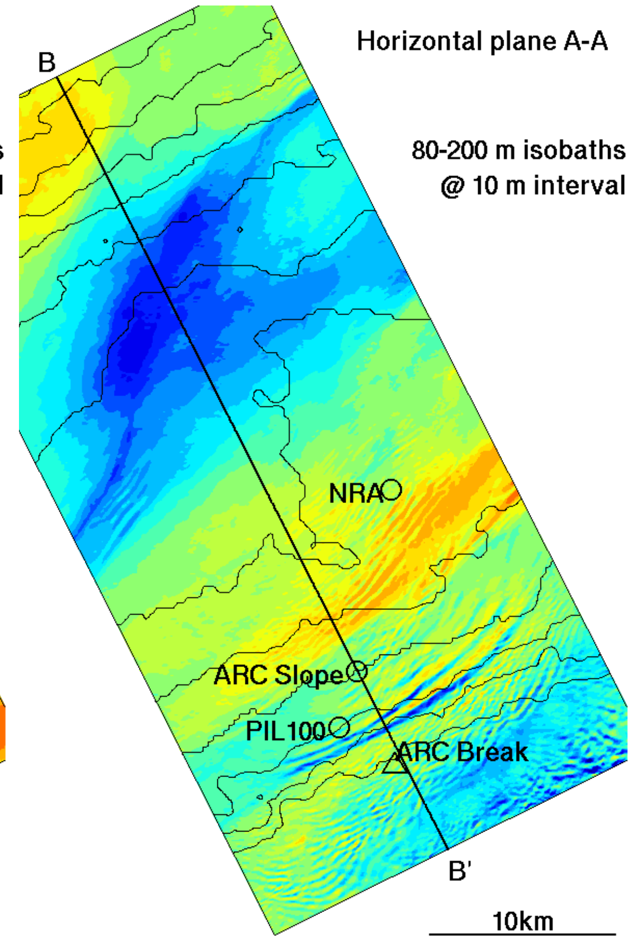
Initial grid



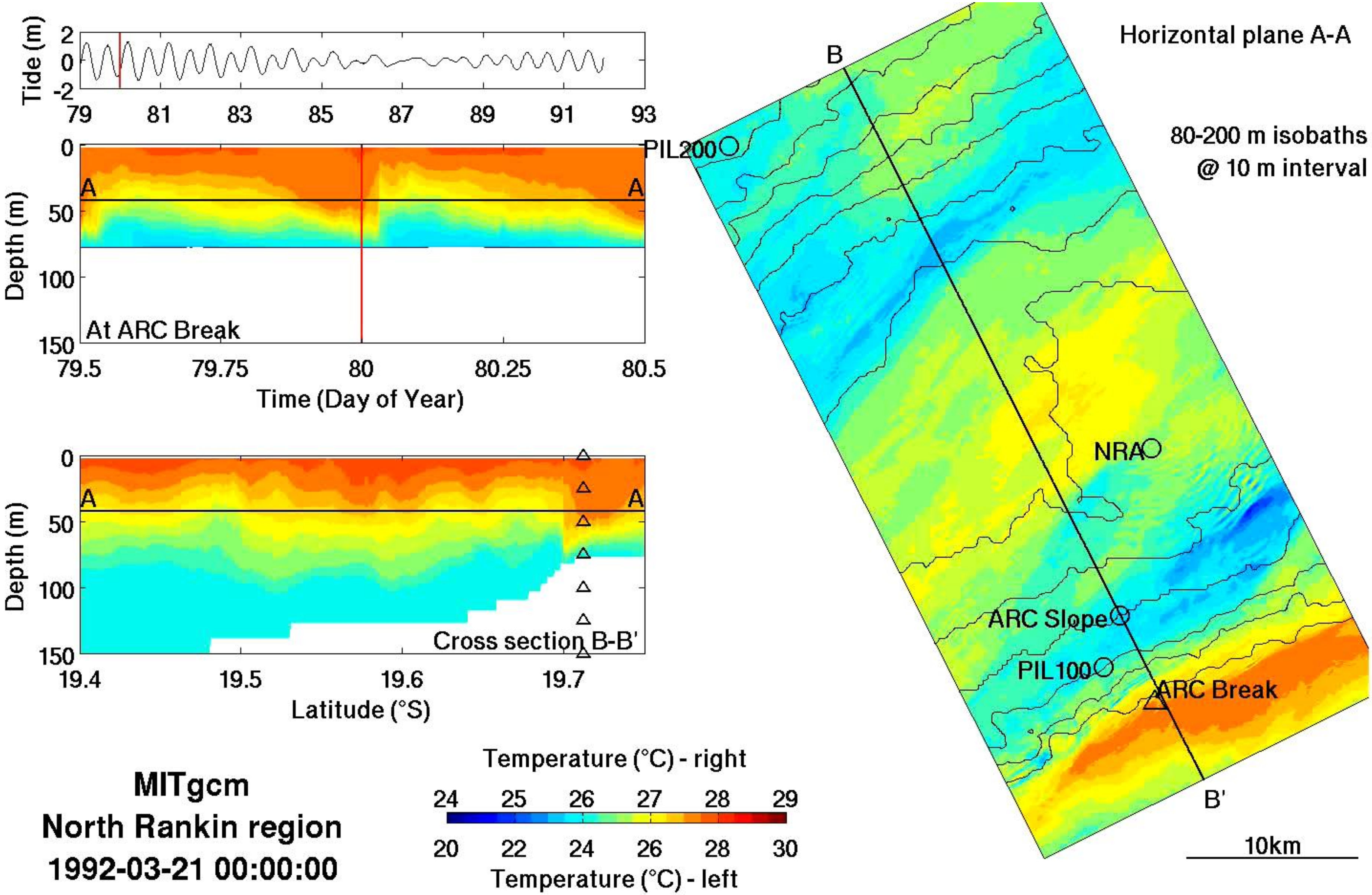
Revised grid
Initial T/S



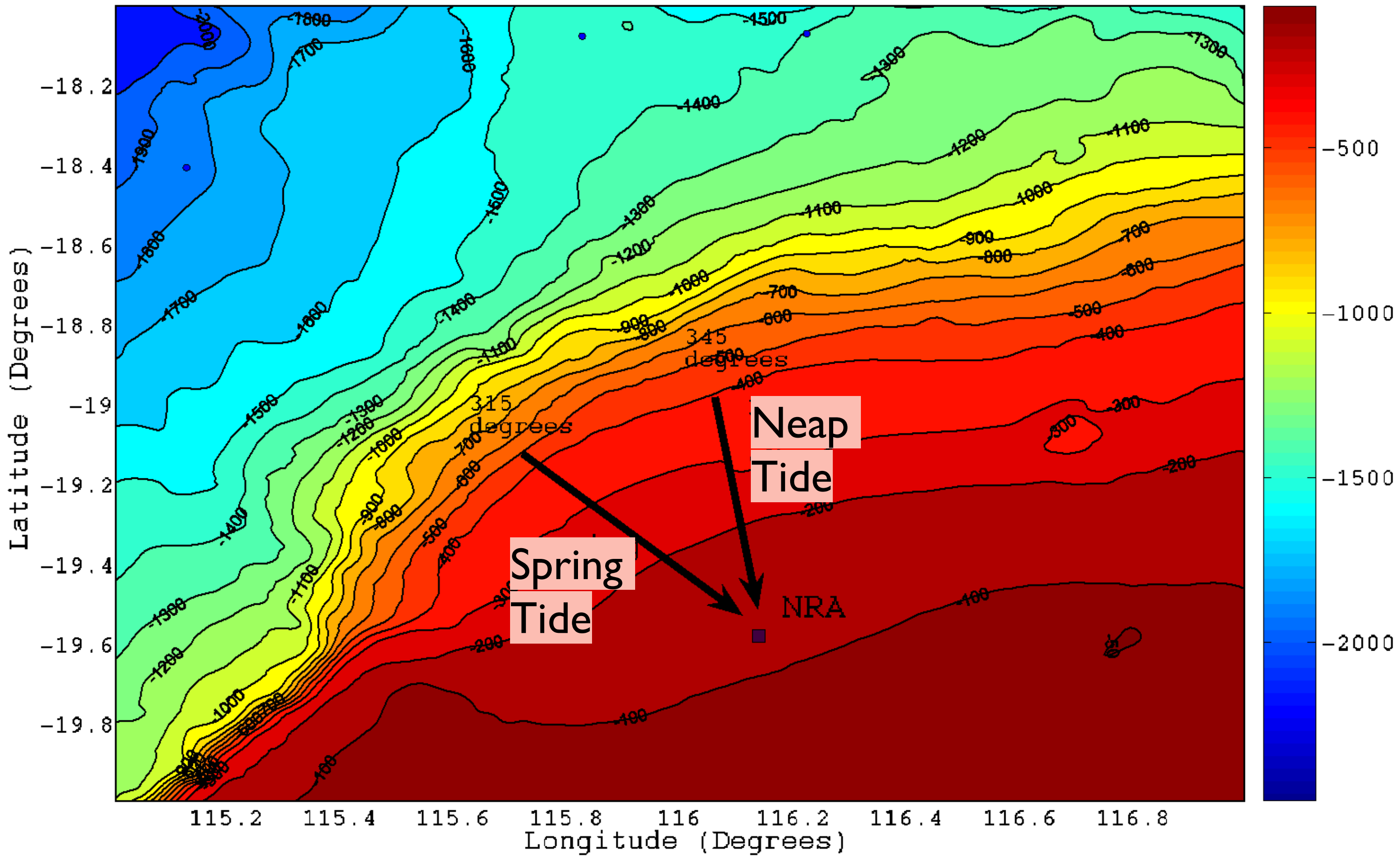
Revised grid
Revised T/S



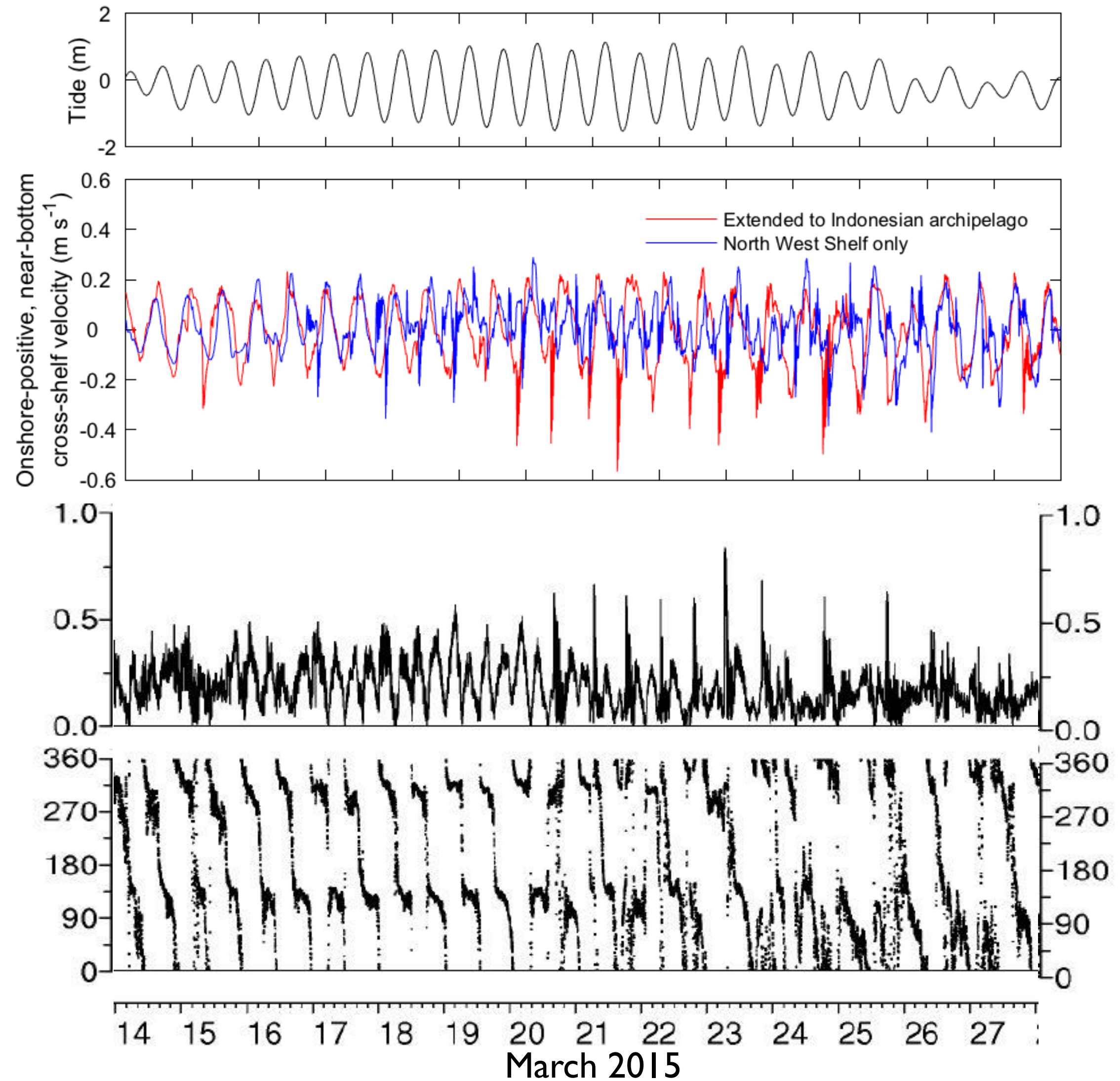
ARC Measurements – Model Animation



NRA Solitons - van Gastel et al. 2009



(Rough) Comparison with Measurements



What we have learned

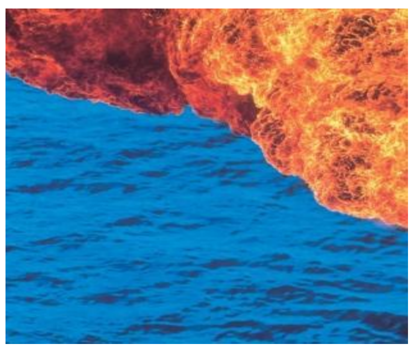
1. Established that Indonesian Straits are important source regions of internal waves affecting Australia's North West Shelf

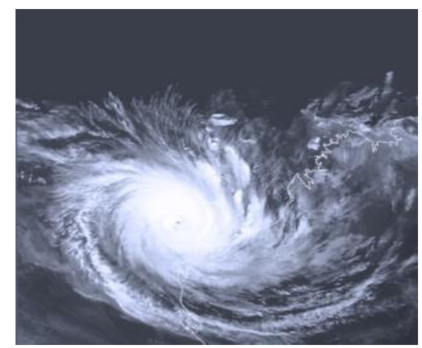
2. ISWs are highly sensitive to stratification. Stratification is very difficult to model (without drift)

3. Solitons lose lateral coherence as they propagate inshore

4. MITgcm requires further enhancement before it can reliably hindcast Internal Solitary Waves

Thank you





For further information:
stevejbuchan@hotmail.com
kenji.shimizu.rc@gmail.com