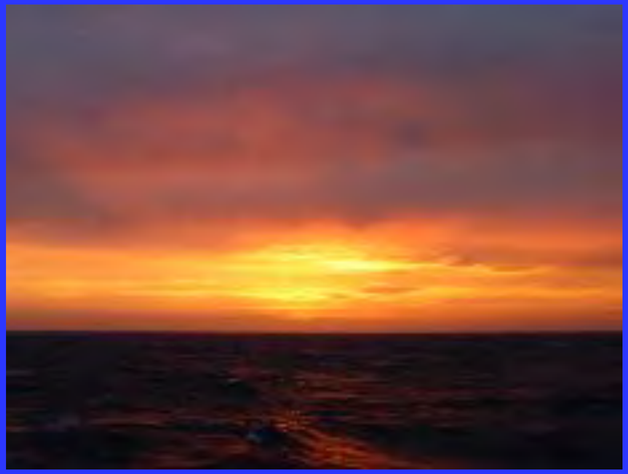
TTIDE: The Tasman Tidal Dissipation Experiment

CLIVAR PSMI Webinar February 14 2017

Mixing
The *Deep* Sea



Field phase: January-March 2015

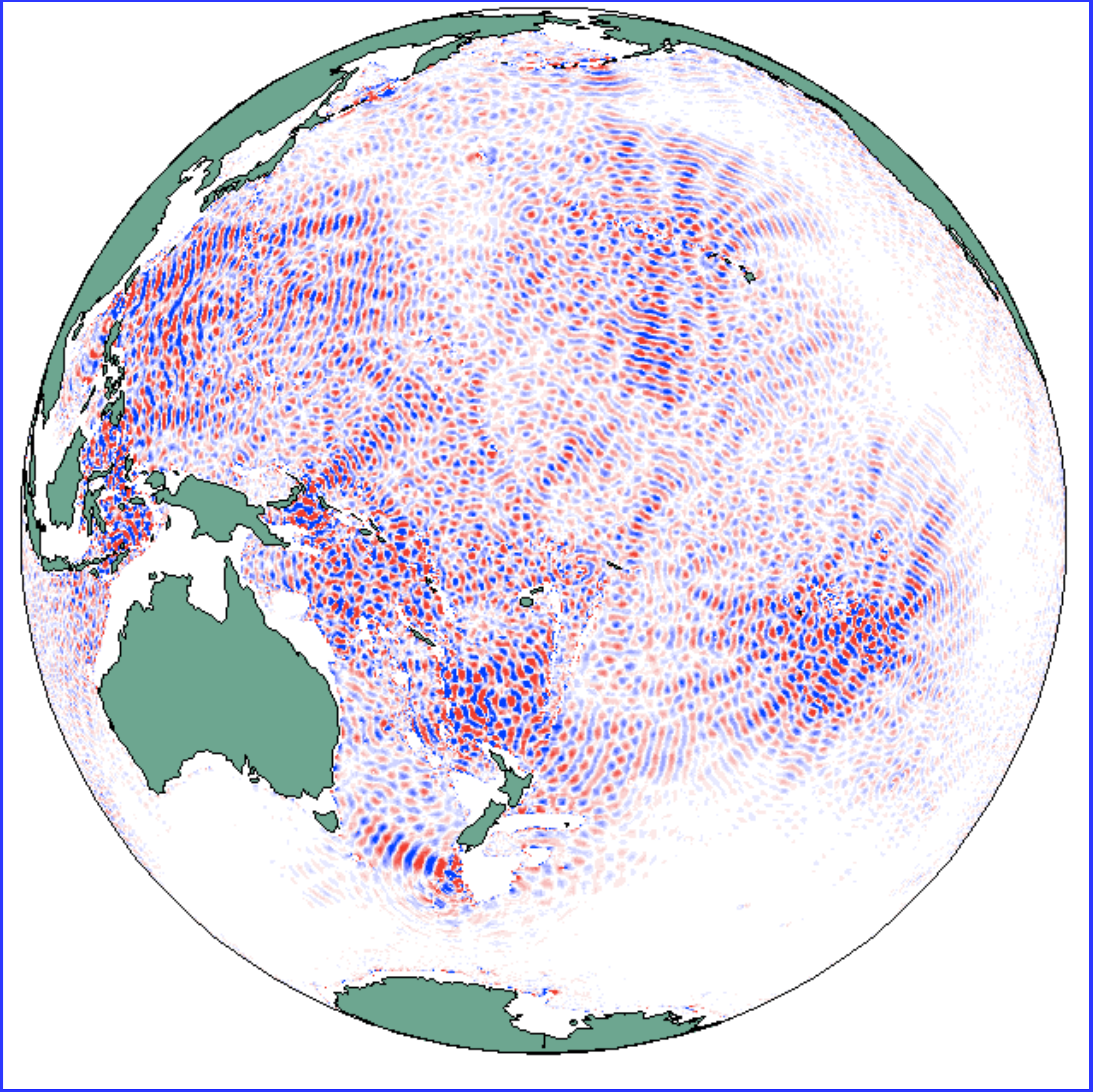
Issue for today:

Climate modelers need realistic parameterizations for diffusivities of scalars & momentum. Any parameterization must be relevant at climatological scales and be able to respond to changing climatological conditions.

The physical phenomena involved in establishing these diffusivities in the deep sea are only now being identified. Achieving a global parameterization from a very limited series of local process experiments is the present challenge.

Roughly 1-2 TW is required to maintain a diffusivity consistent with the overturning circulation of the present ocean. Is this energy provided as the end result of a cascade through processes included in a climate model or through a separate (semi-) parallel cascade?

Pacific
Semi Diurnal
Baroclinic
Tidal Beams

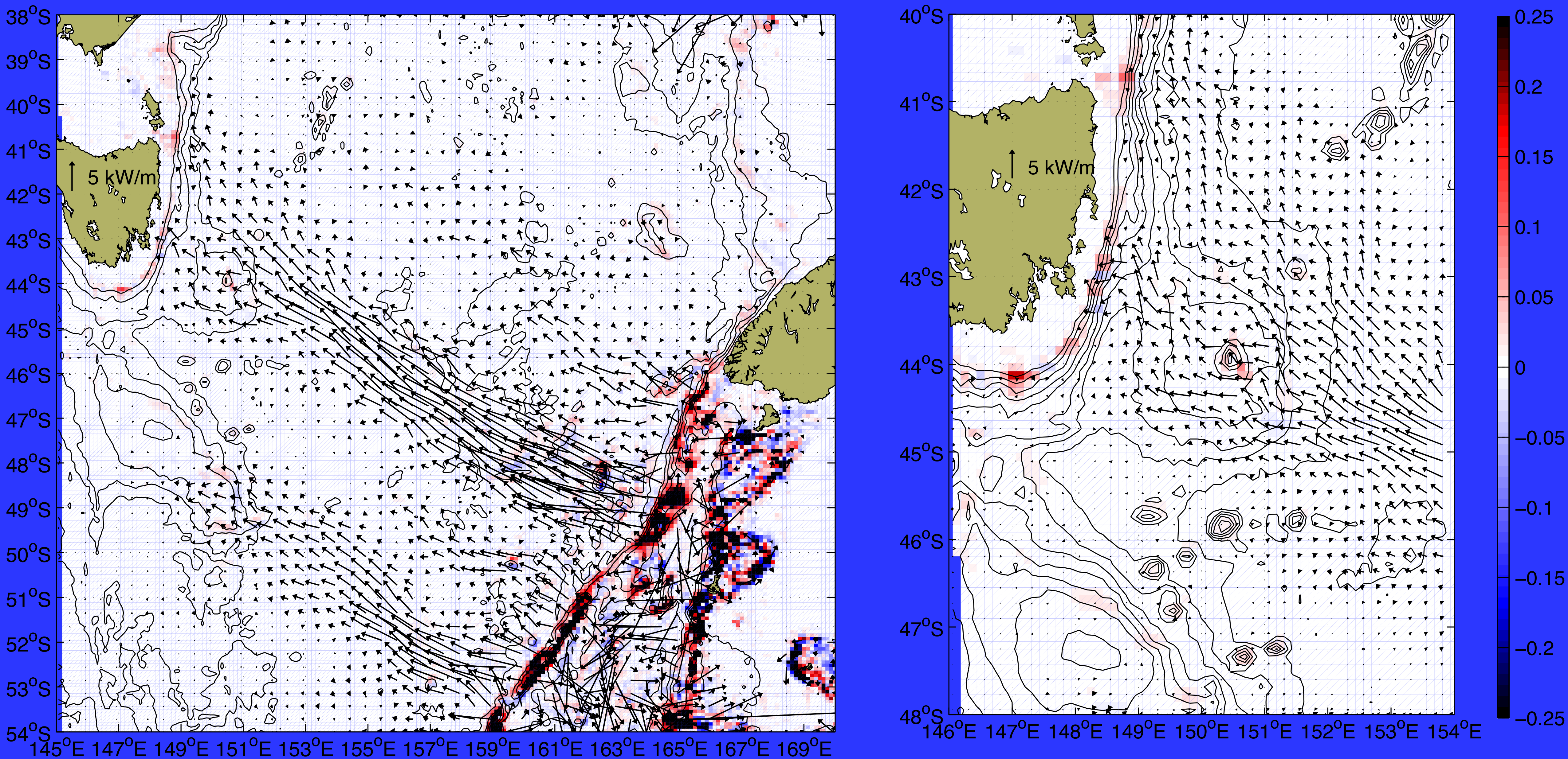


H. Simmons

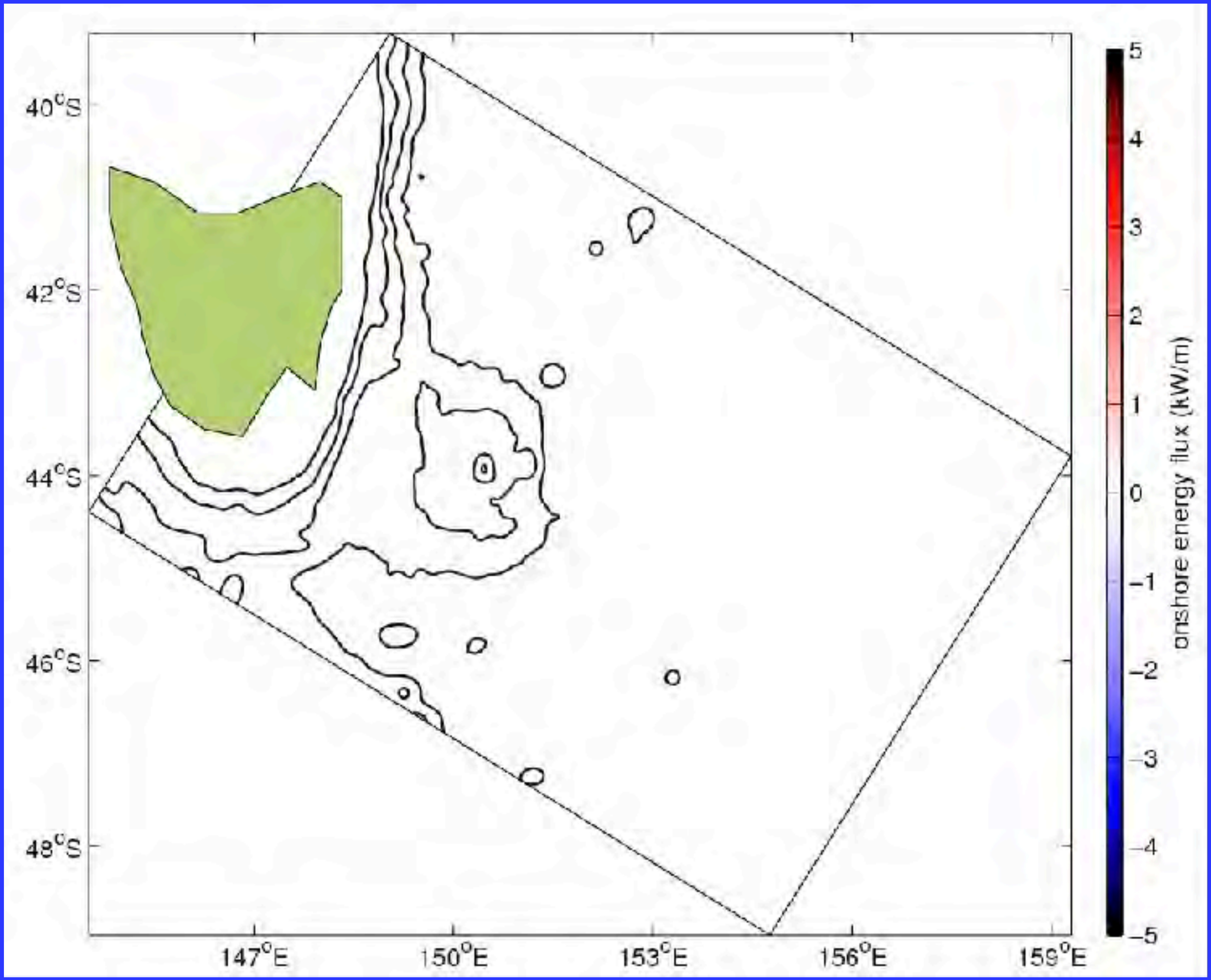
Preliminary TTide Simulations

Harper Simmons & Dmitry Braznikov (UAF), Sam Kelly (U Minn Duluth)

GOLD global model

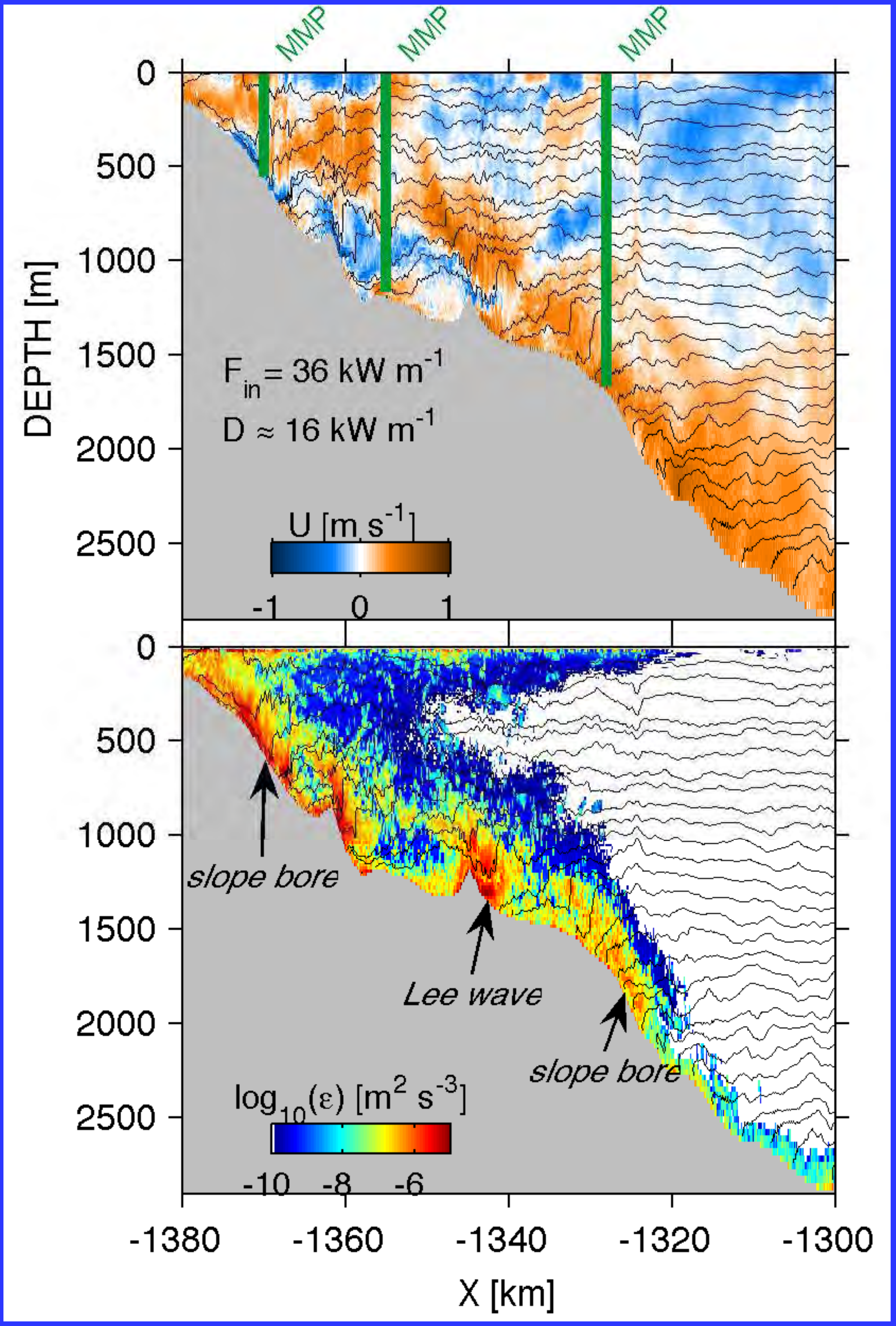


Simulation



Harper Simmons

Anticipated Shoaling and Mixing on the Deep Slope

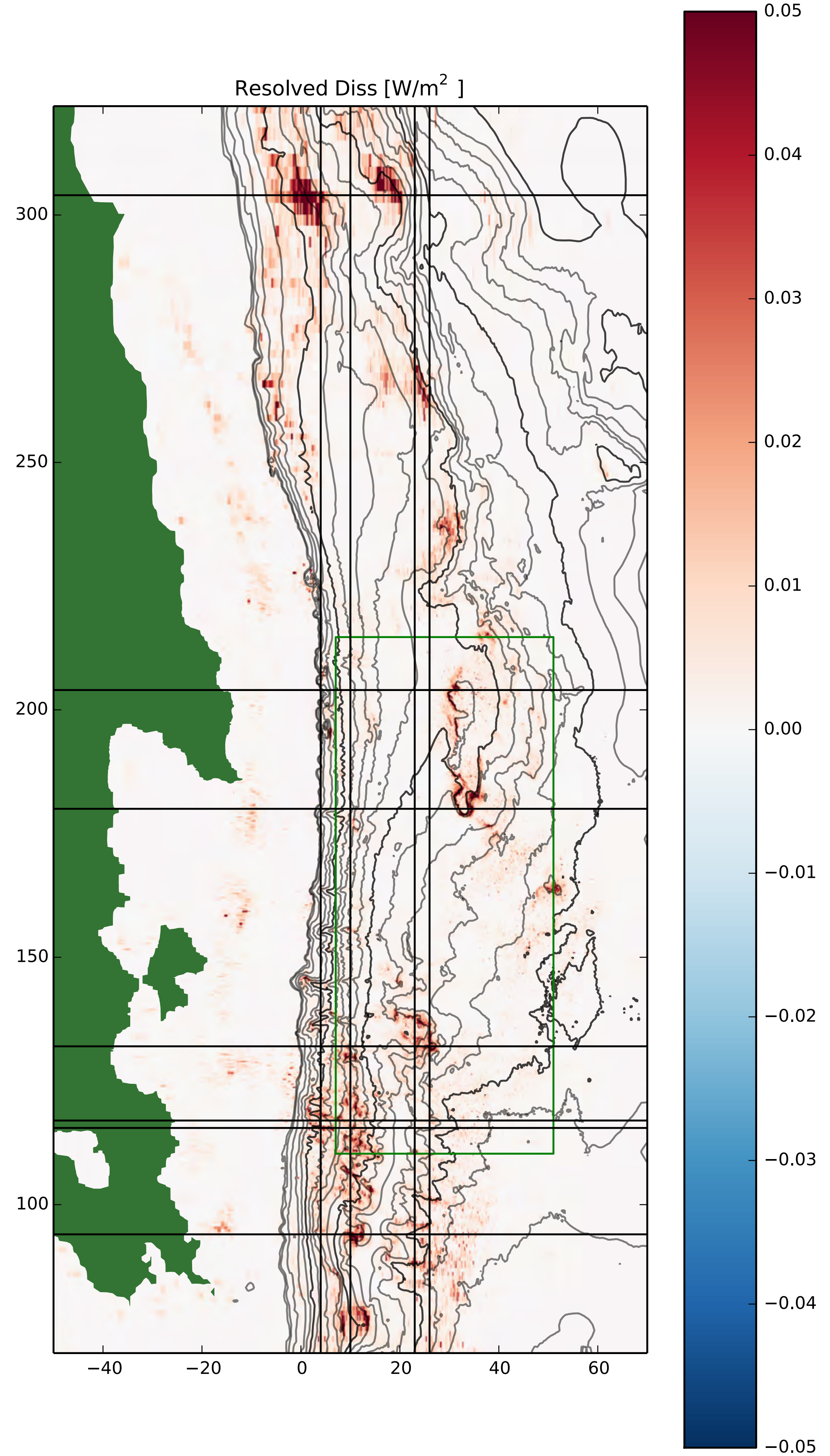


J. Klymak
MIT GCM

Anticipated Shoaling and Mixing on the Slope

J. Klymak

MIT GCM



TTIDE Experiment Format

2013-2015

Satellite Observations

- Zhao & Alford
  - Altimetry

Numerical Studies

- Klymak
  - MIT GCM
  - Idealized & Realistic
- Simmons & Braznikov
  - GOLD & ROMS
  - Global to Regional

Glider Surveys

- Johnston- Rudnick
  - Tidal Focus
- Robertson, Rainville
  - Mesoscale Focus

Experiment Format:
TTIDE: R.V. Revelle

January-March 2015

LegI: Alford, MacKinnon, Nash, et. al.

a) McLane, T-chain moorings, ADCPs

b) L-ADCP, microstructure surveys

Leg II: Pinkel, Lucas, Jones, et. al.

Fast-CTD surveys

Leg III: Alford, Nash, et.al.

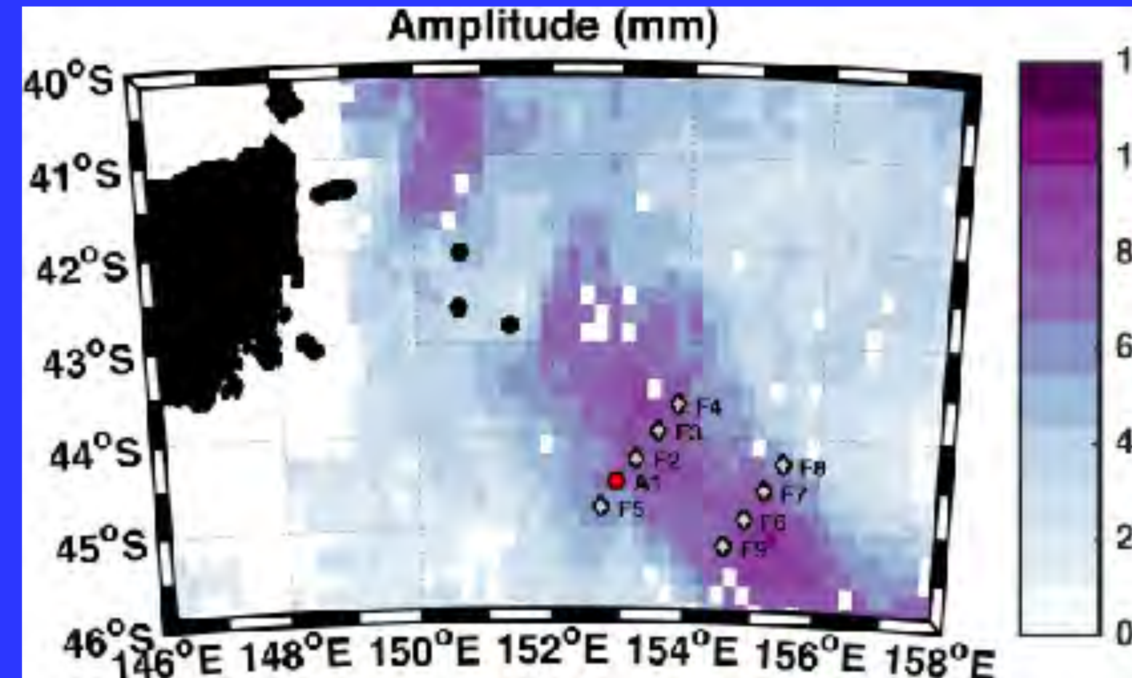
a) L-ADCP, microstructure surveys

b)Mooring recovery

TBEAM: R.V. Falkor

Waterhouse, Kelly, et. al.

Offshore mooring and L-ADCP surveys to quantify the incident flux offshore



TSHELF: R.V. Revelle

Jones, Lucas, Schlosser, et al.

On-shelf moorings to quantify upper-ocean consequences of deep ocean processes

TTIDE, TBEAM, TSHELF Geography

Northern Slope

Less incident energy but near-critical slope is efficient at dissipating it. Expect high-mode conversion, bottom bores,…

Southern Slope

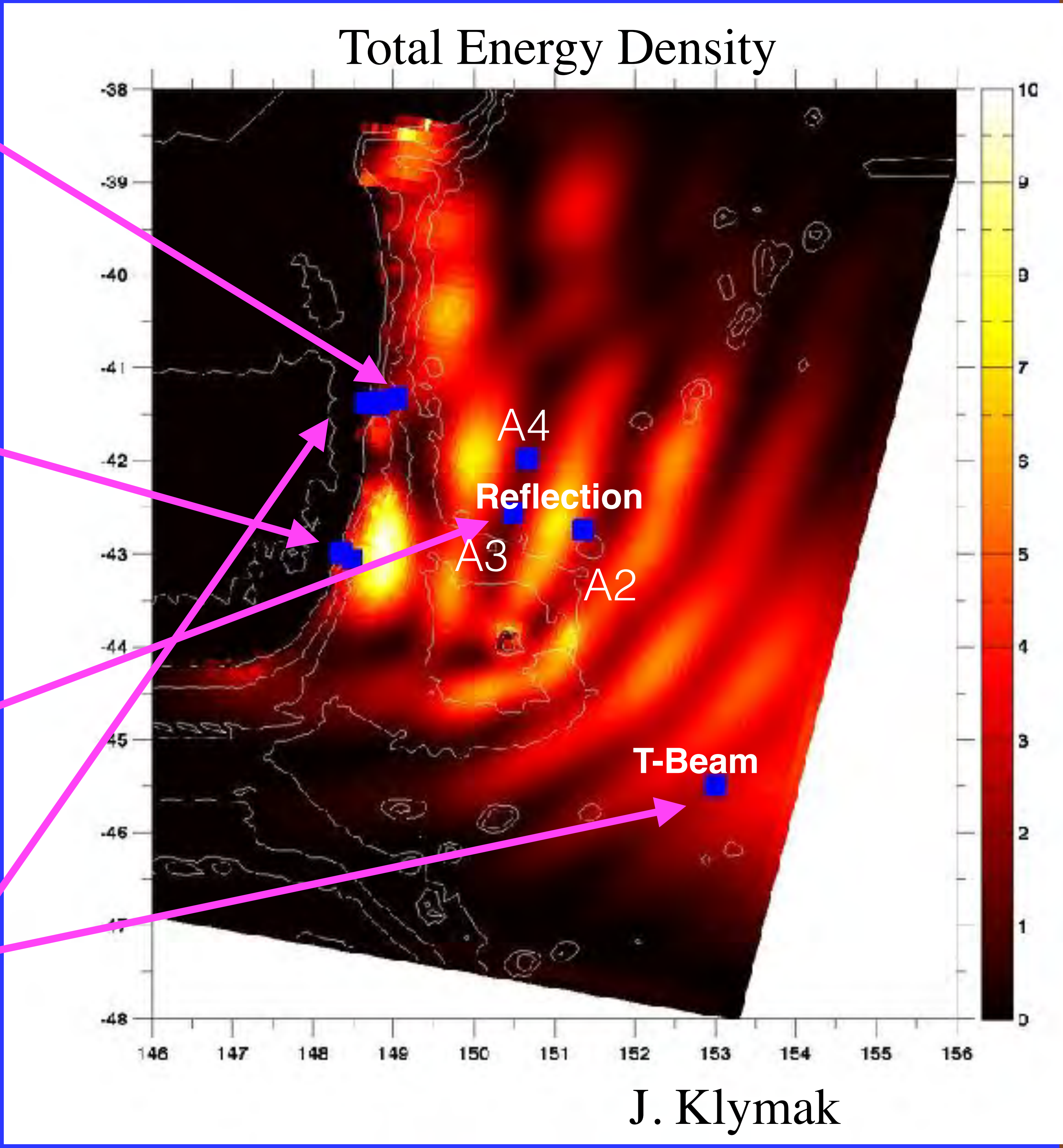
Center of the “main” incident beam. Very supercritical. Local dissipation physics includes along-shore corrugations, possibly down-going high-mode beam.

Reflection Antenna

Designed to do plane-wave fits to incident and reflected waves.

T-Beam

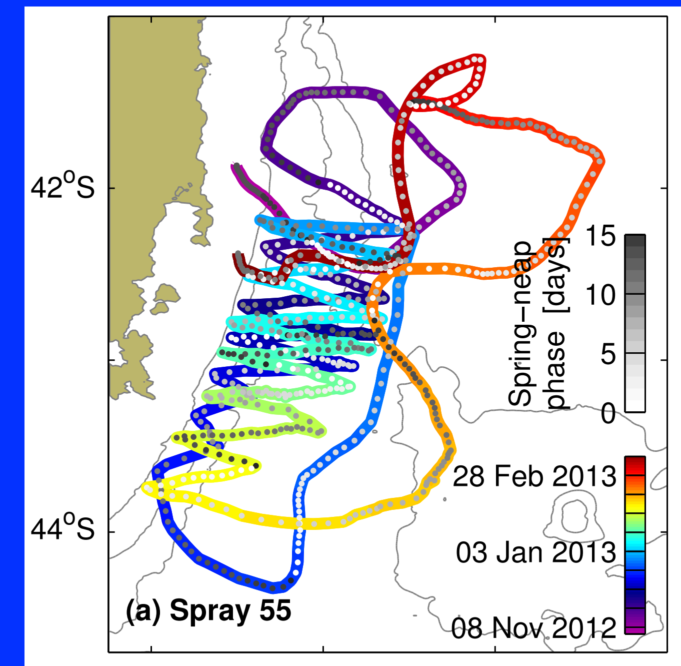
T-Shelf

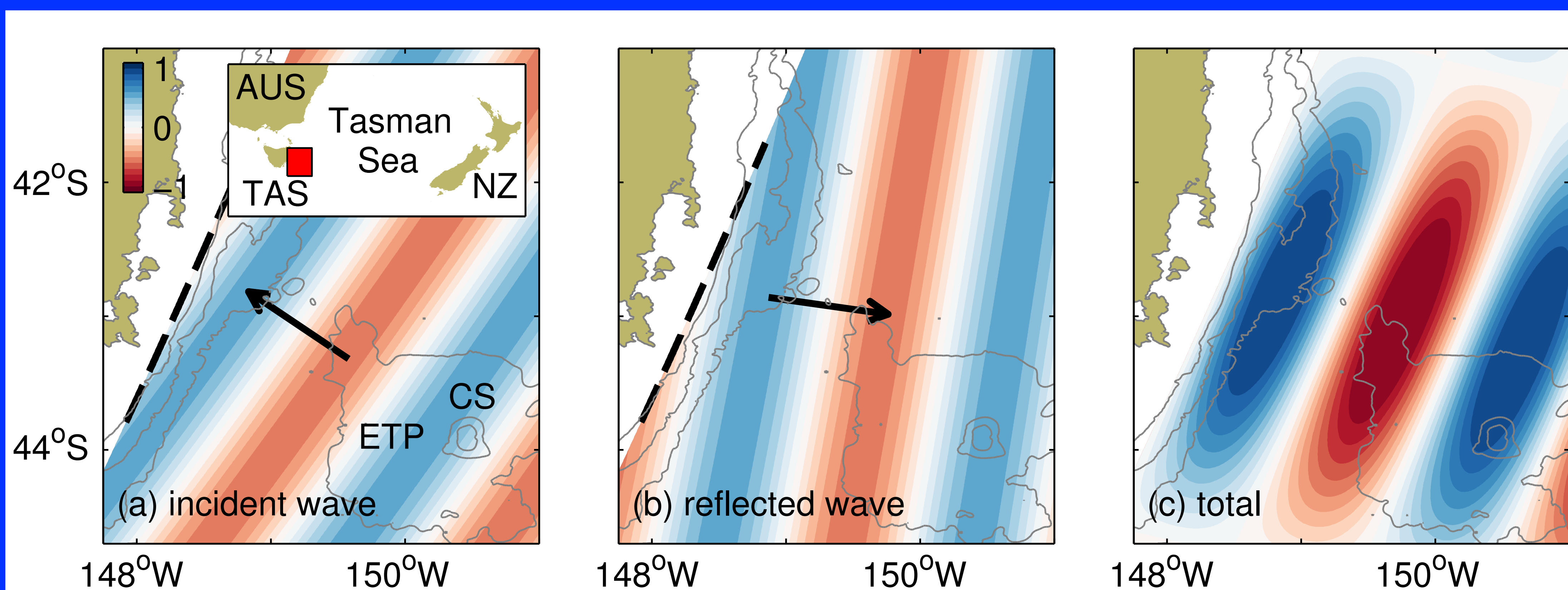


Glider Surveys

Shaun Johnston
Dan Rudnick

Luc Rainville
Robin Robertson





Northern Array

Southern Array

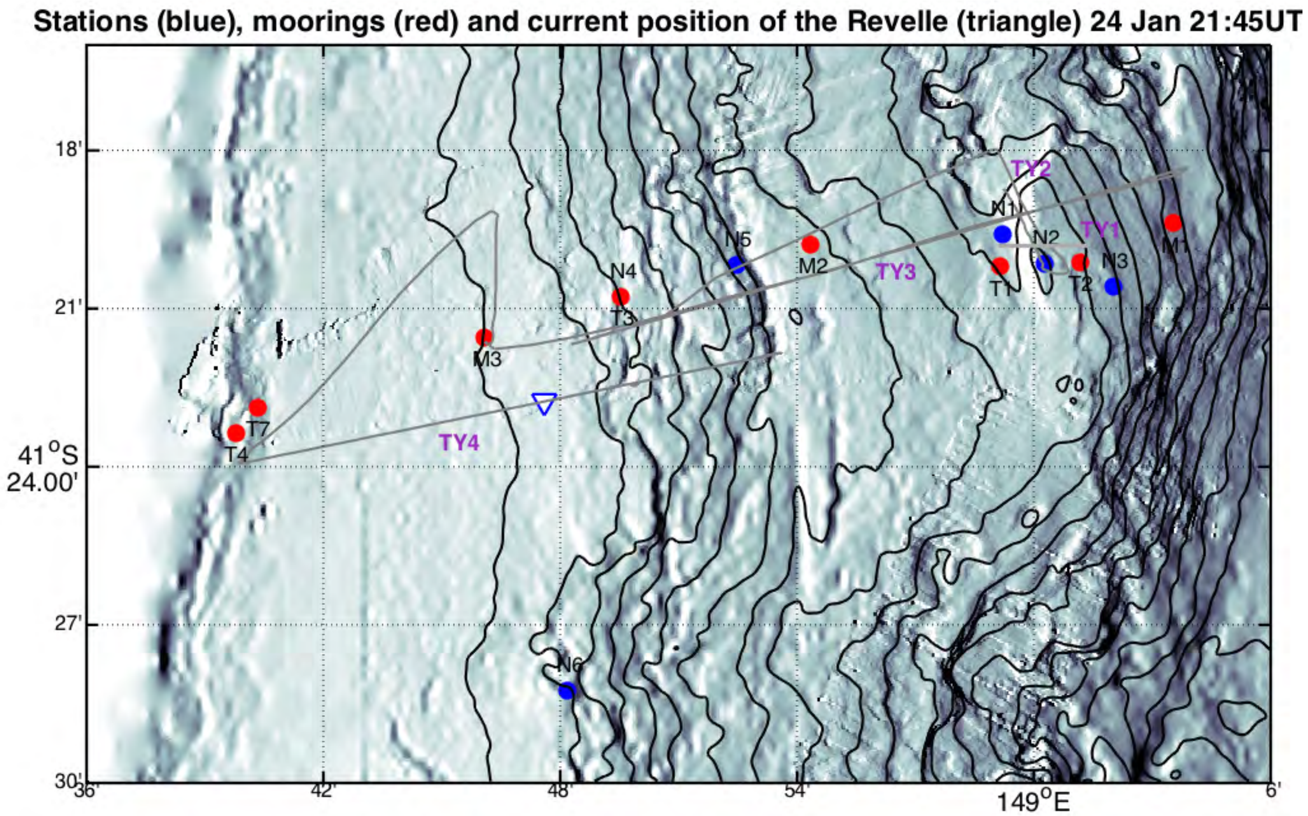
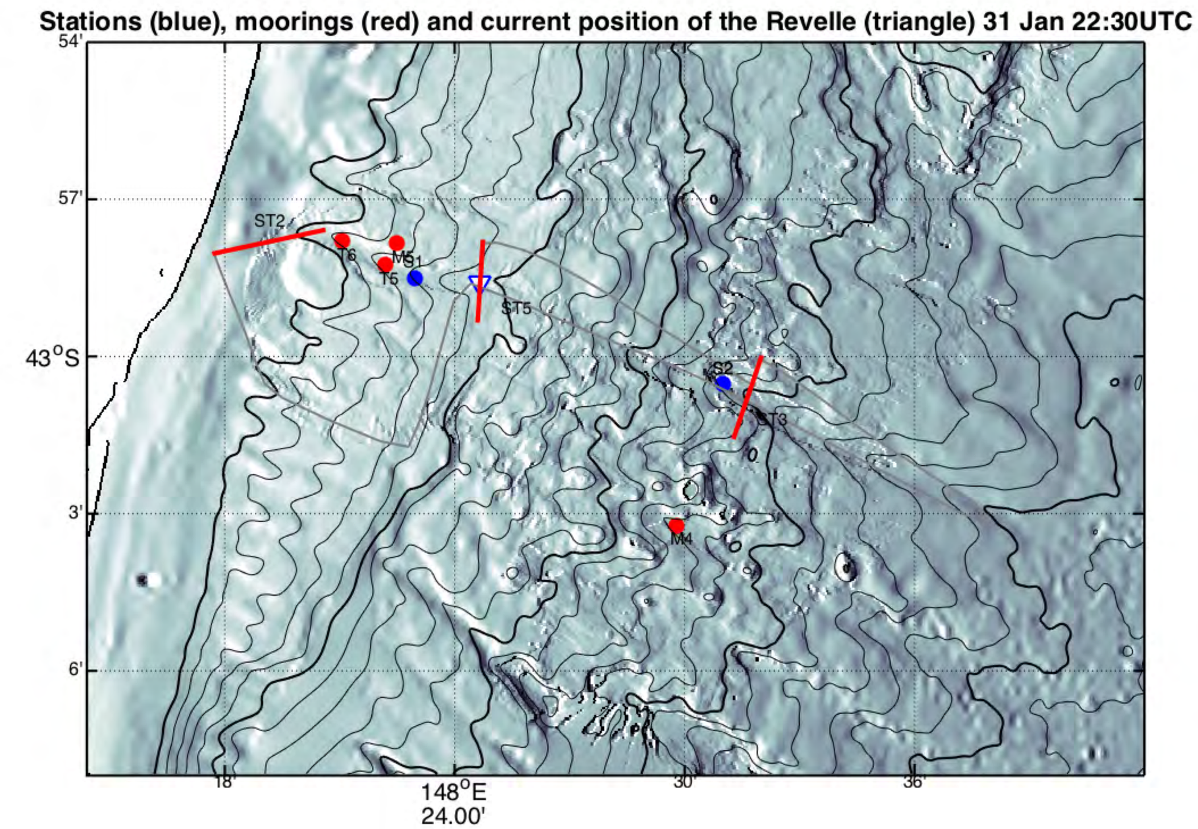


Figure 4: Overview map of the northern region. McLane "flux" moorings in red, T-chain mooring
blue, CTD time-series stations in green, to-yos in magenta, Falkor in orange.



map of the southern region. McLane "flux" moorings in
s stations in green, tow-yos in magenta, Falkor in orange.

Dissipative

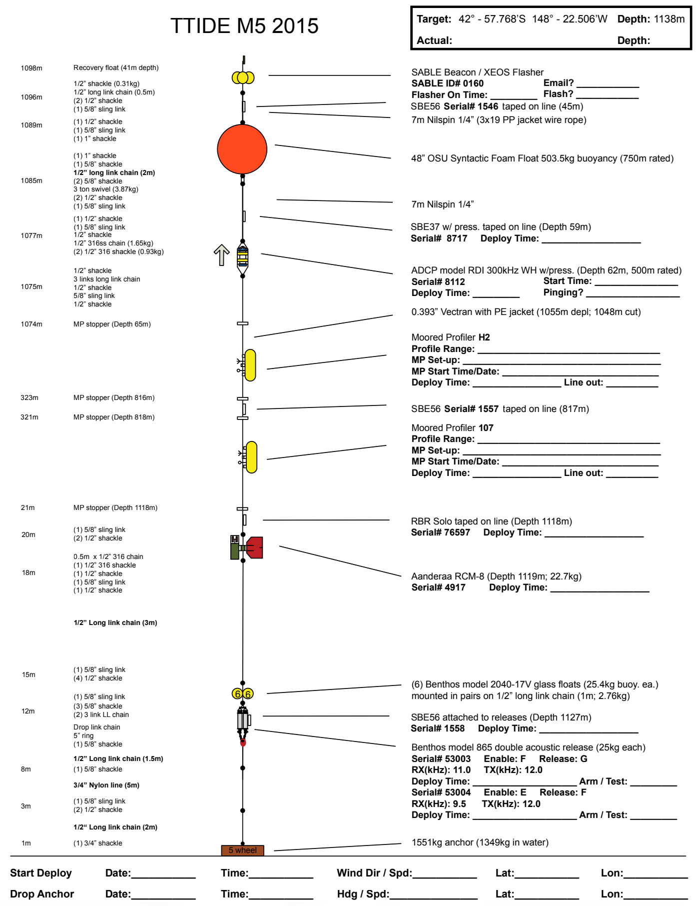
Reflective

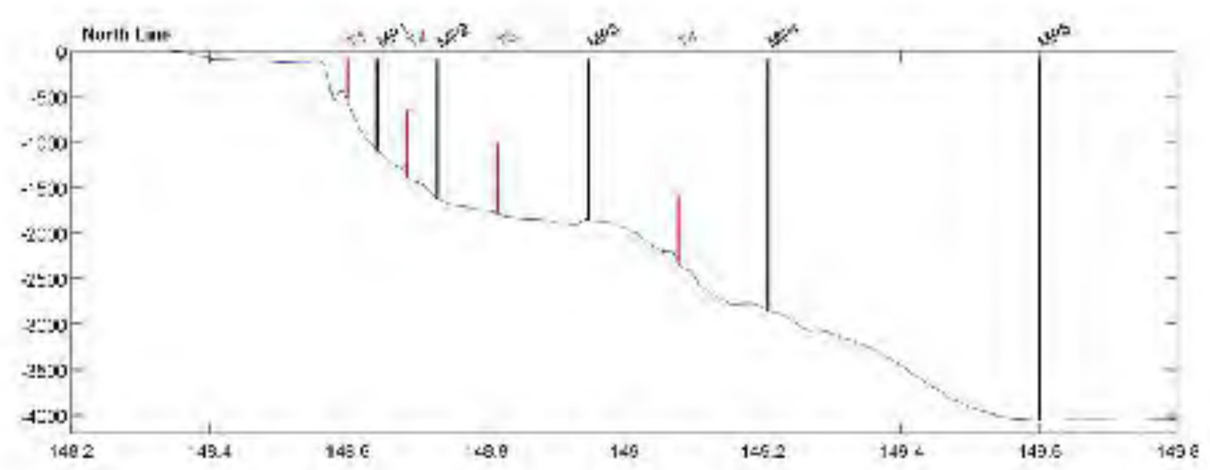
Figure 2: (left) Revelle's deck full of TTIDE mooring gear. (right) The TTIDE CTD with 150-KHz downlooker and Sea Batteries (orange).

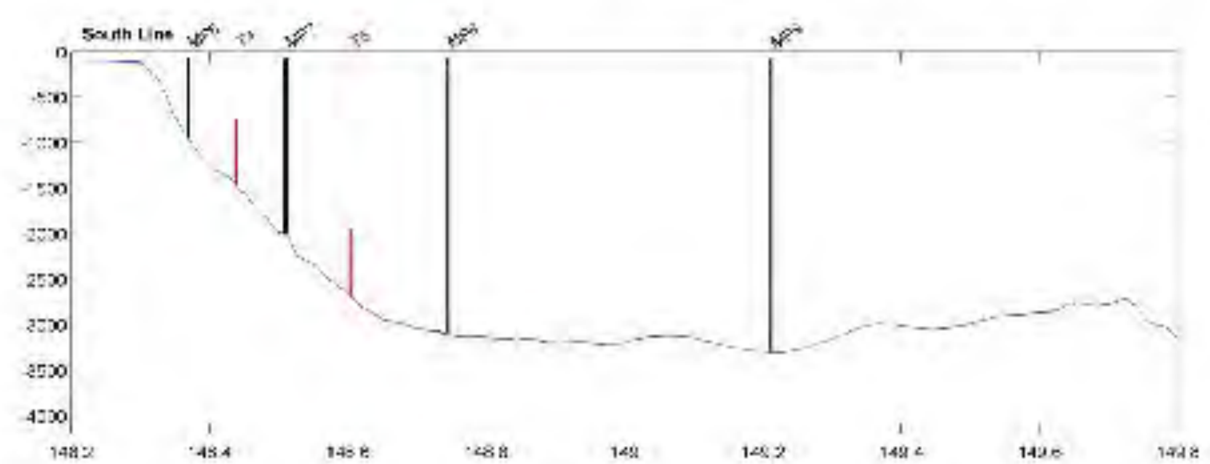
Leg I Moorings

3 A moorings
- 1 TBEAM mooring (an extra A mooring)
- 6 "long term" T moorings
- 8 "long term" M moorings
- 1 T and 1 M "short term" moorings (deployed and recovered within 2 weeks)

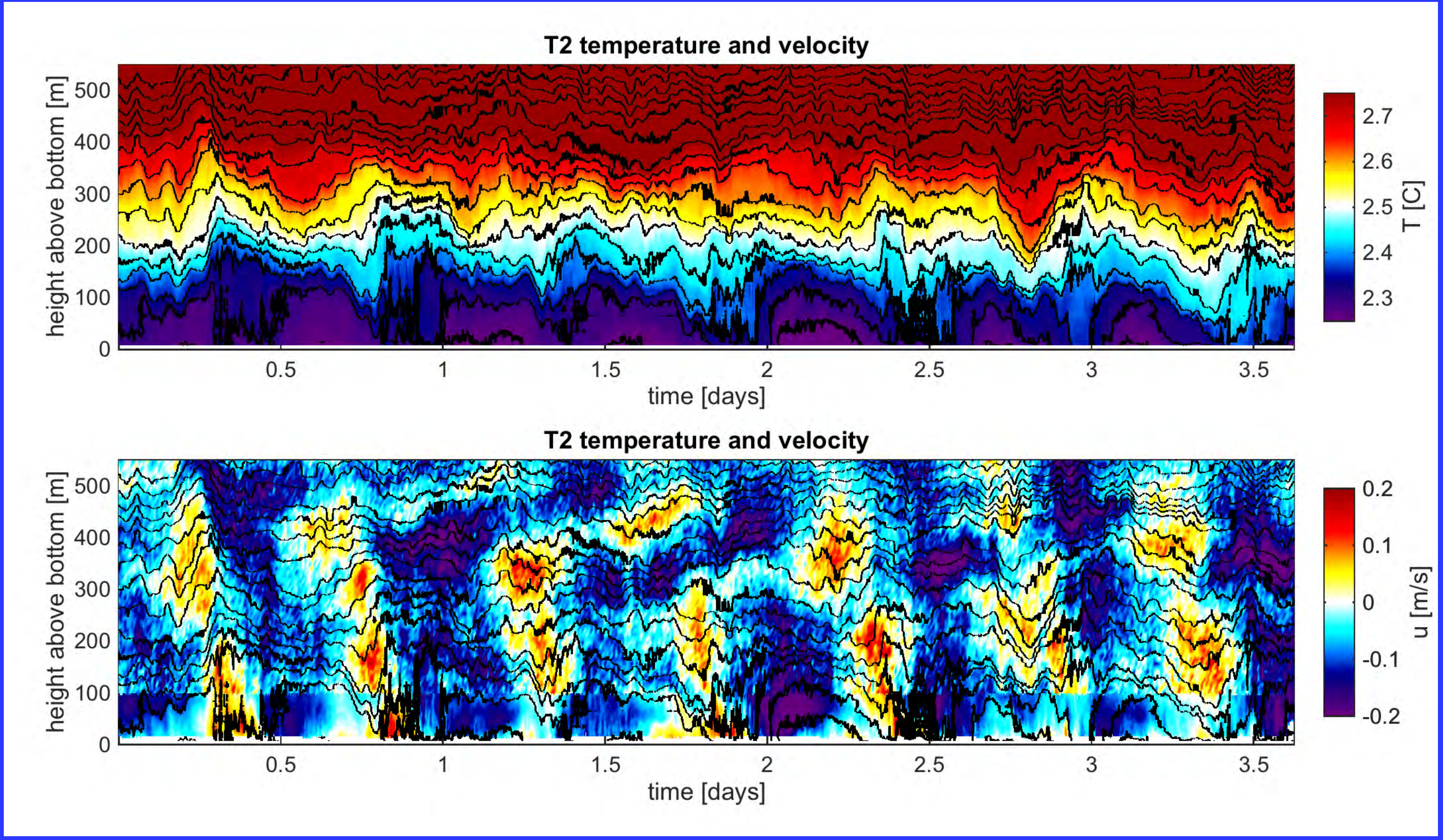
- 12 McLanes
- 23 ADCPs
- 15 Aanderaa current meters
- 210 Thermistors
- 10 CTDs
- 4 Chipods





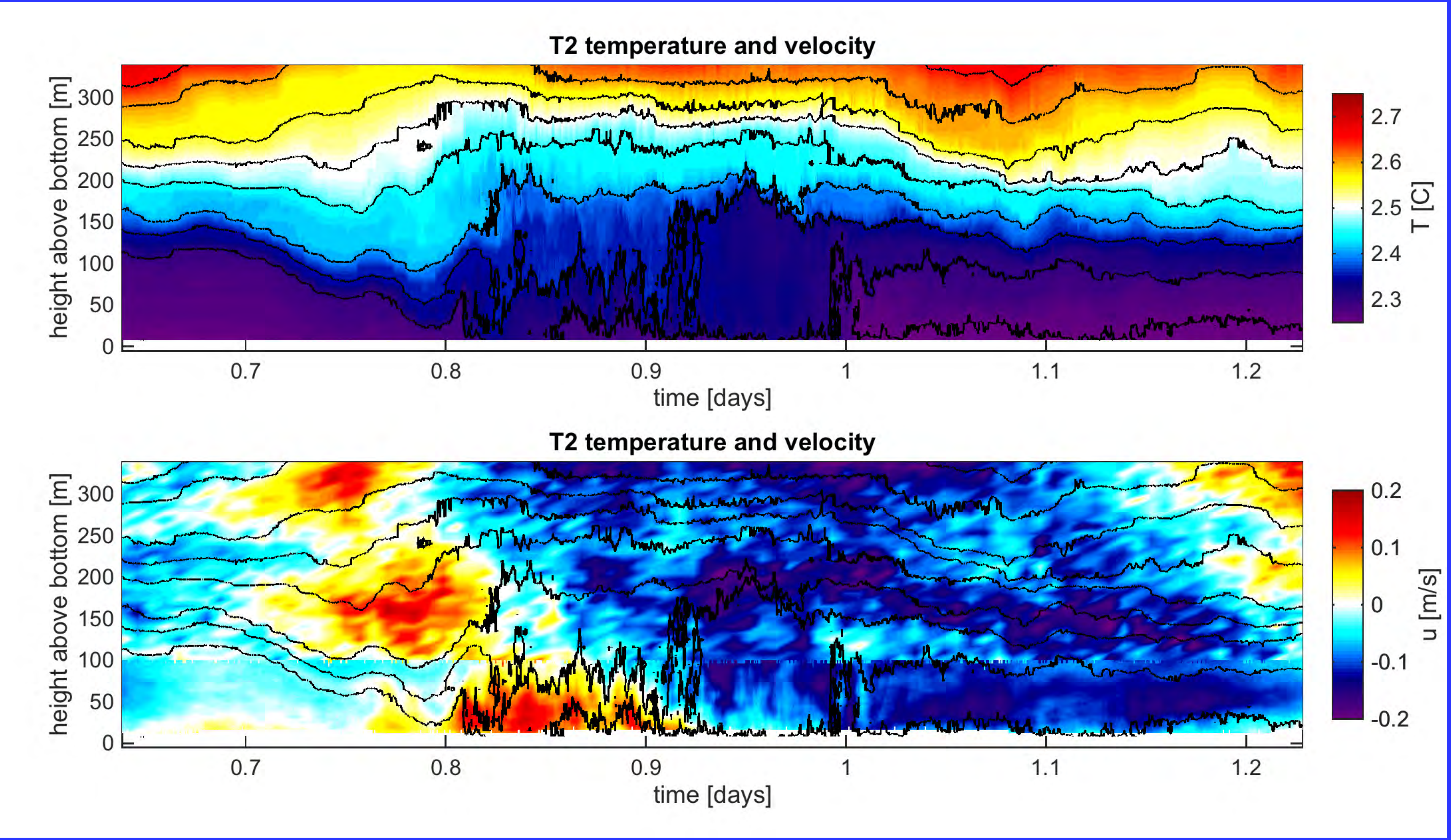


Temperature Chain: 3.5 day record



Nash

Temperature Chain: 0.5 day closeup



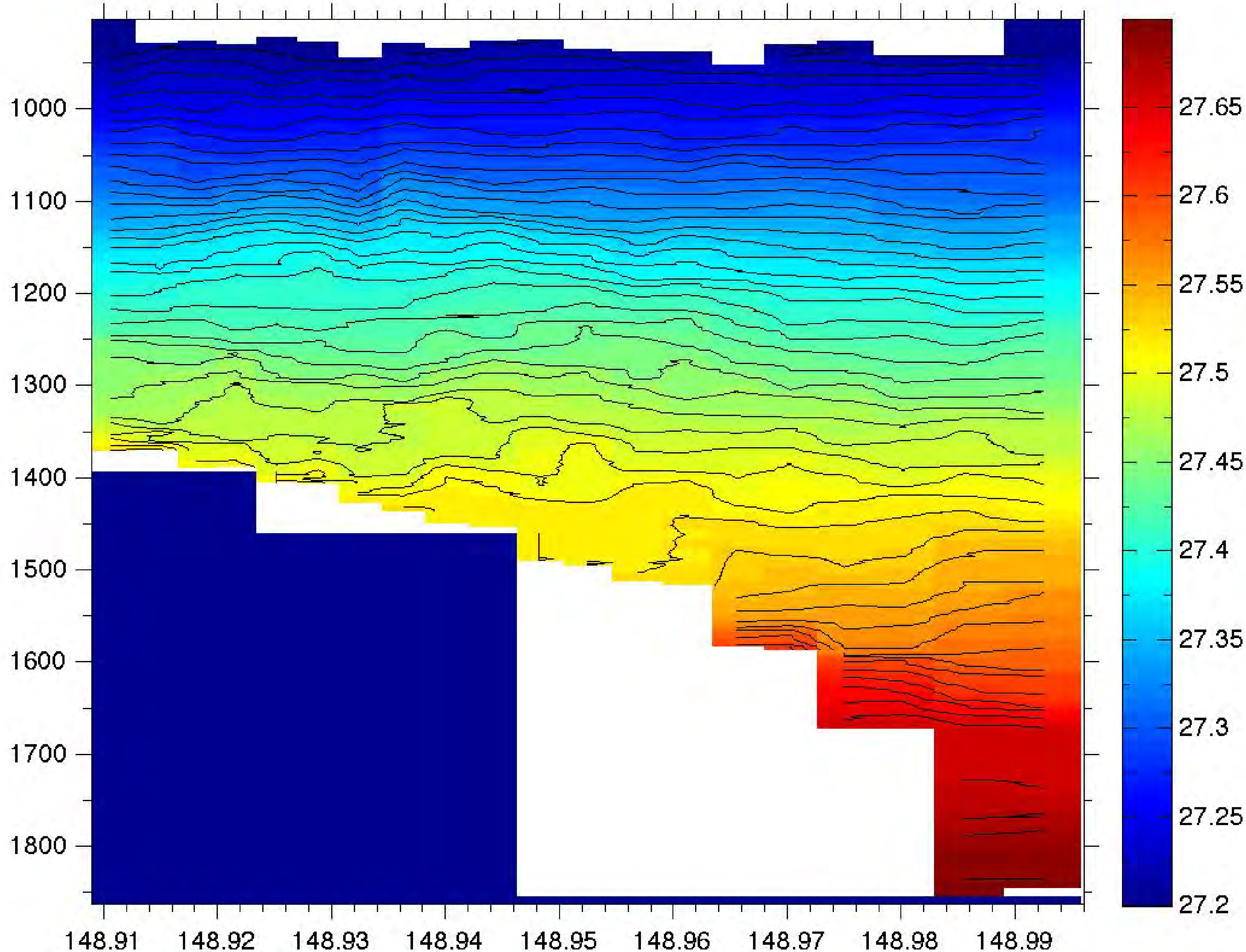
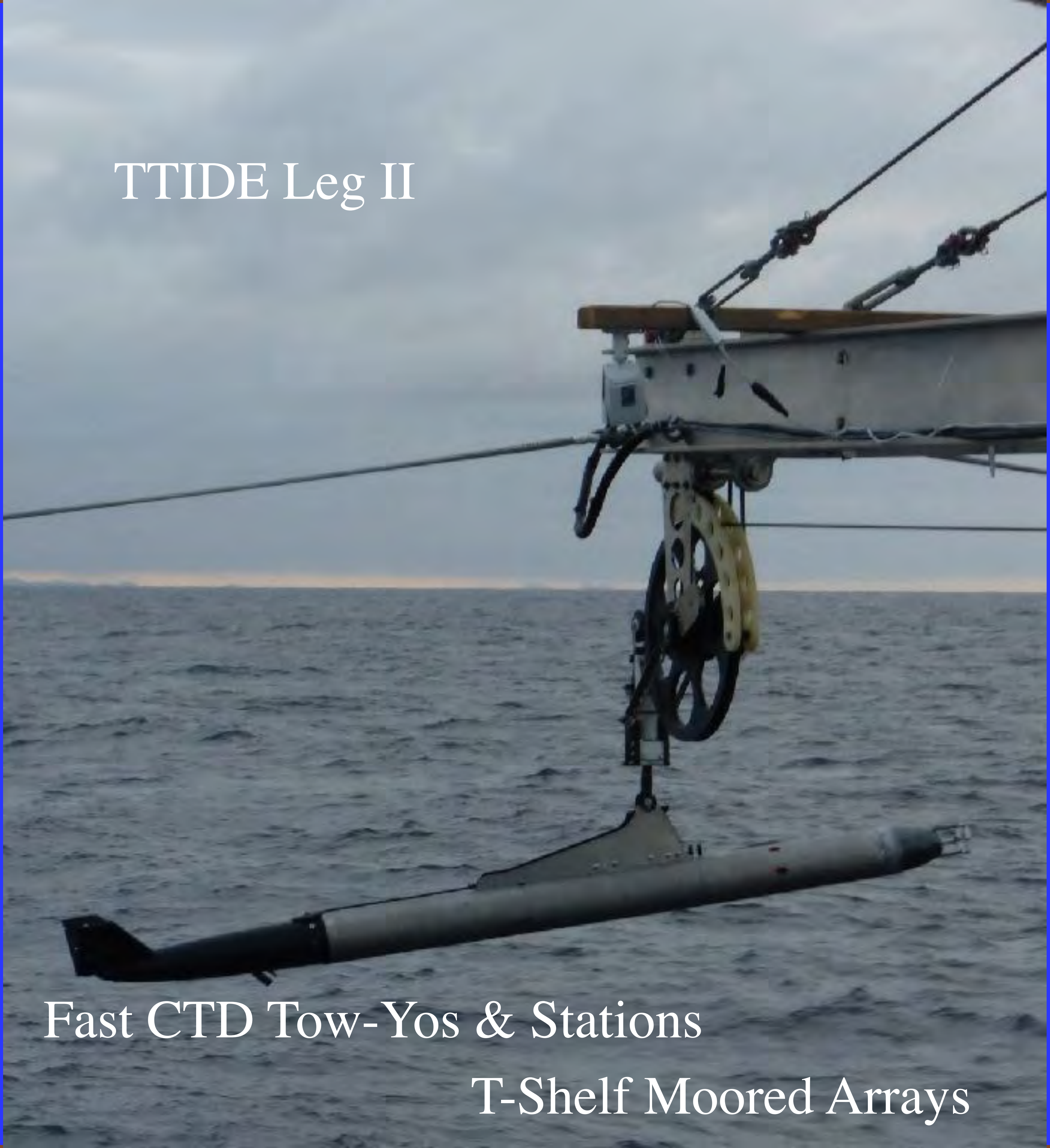
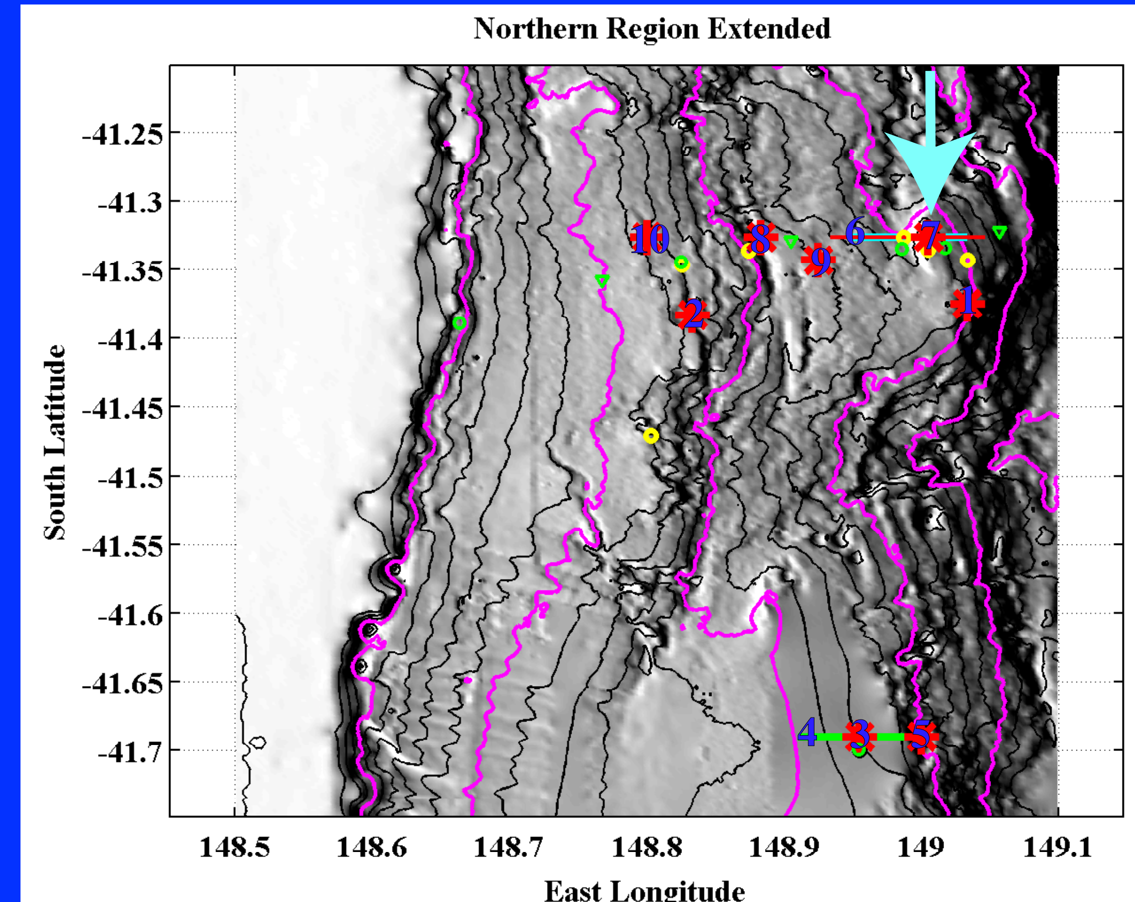


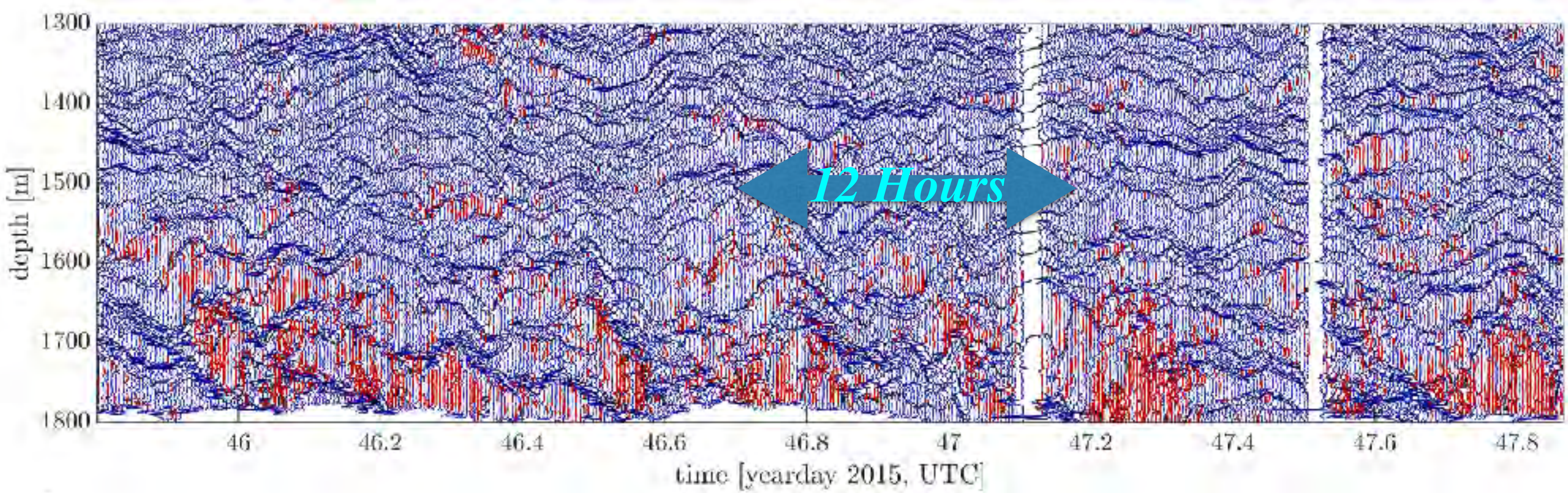
Figure 15: Tow-yo 6 on the critical part of the slope at the middle region.


TTIDE Leg II
Fast CTD Tow-Yos & Stations
T-Shelf Moored Arrays

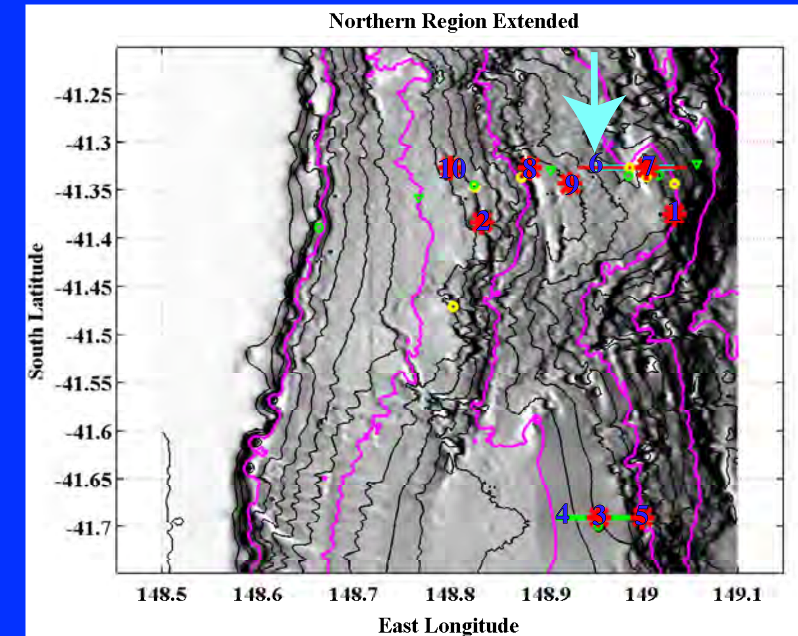
Site 7

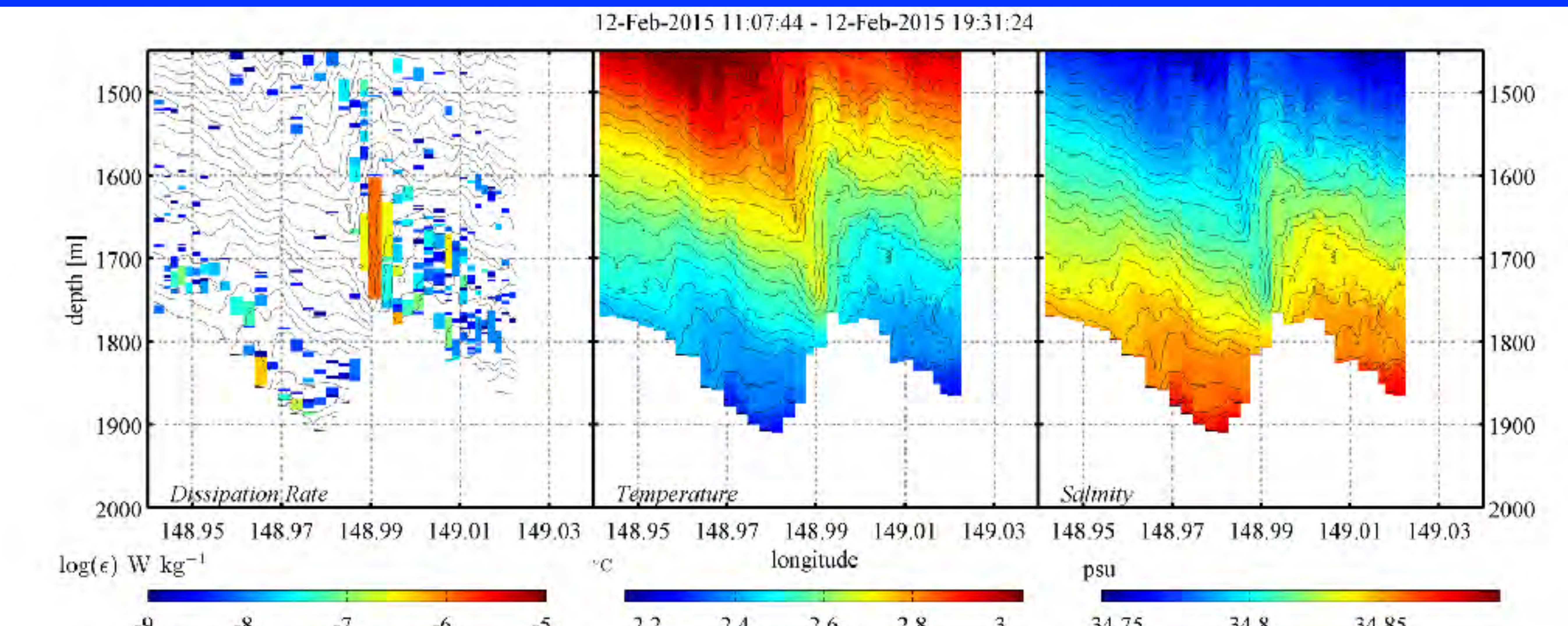
On Top of Klymak Rise

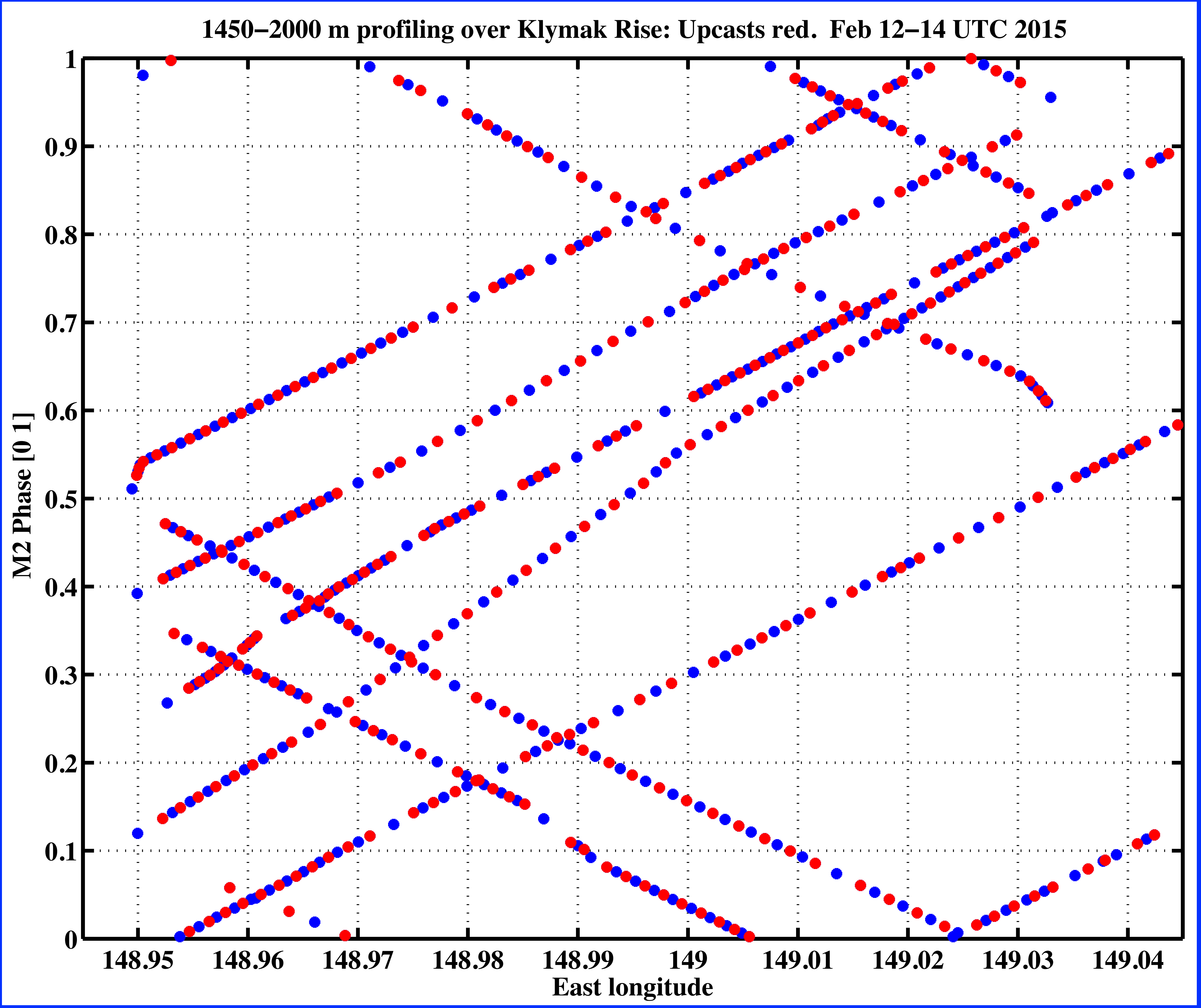




Site 6 (transect) crossing 2



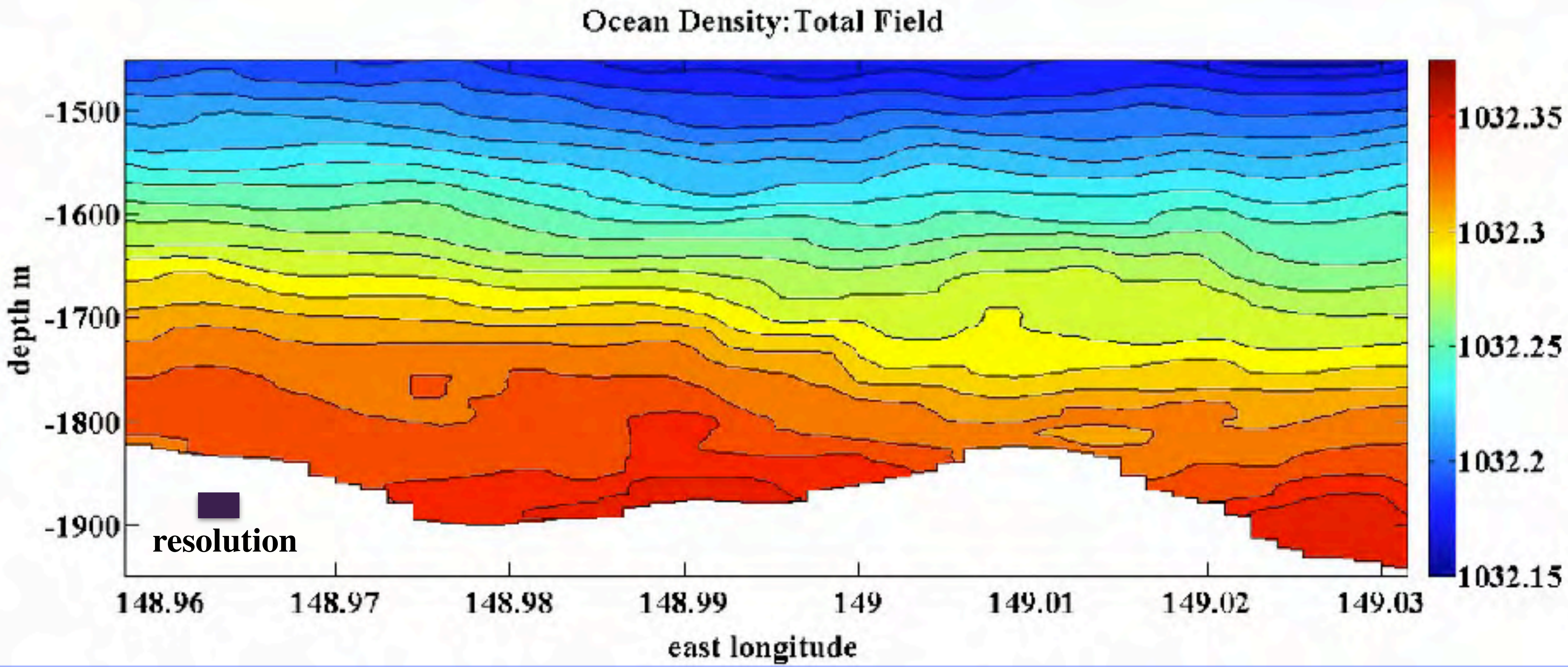




1450−2000 m profiling over Klymak Rise: Upcasts red. Feb 12−14 UTC 2015
M2 Phase [0 1]
East longitude
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
148.95
148.96
148.97
148.98
148.99
149
149.01
149.02
149.03
149.04

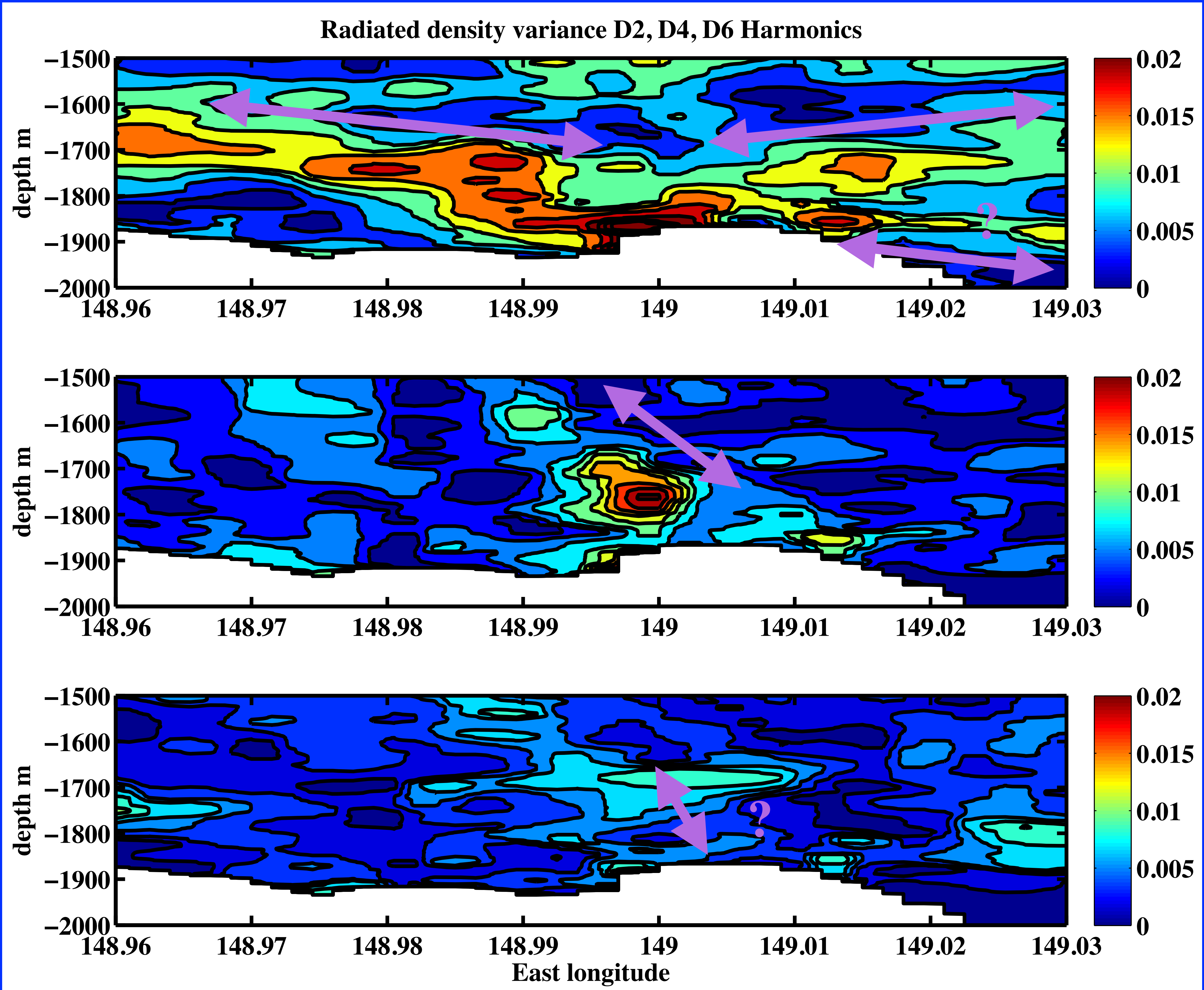
Caution: Not a numerical simulation

Fast CTD Repeated -Track Run over Klymak Rise



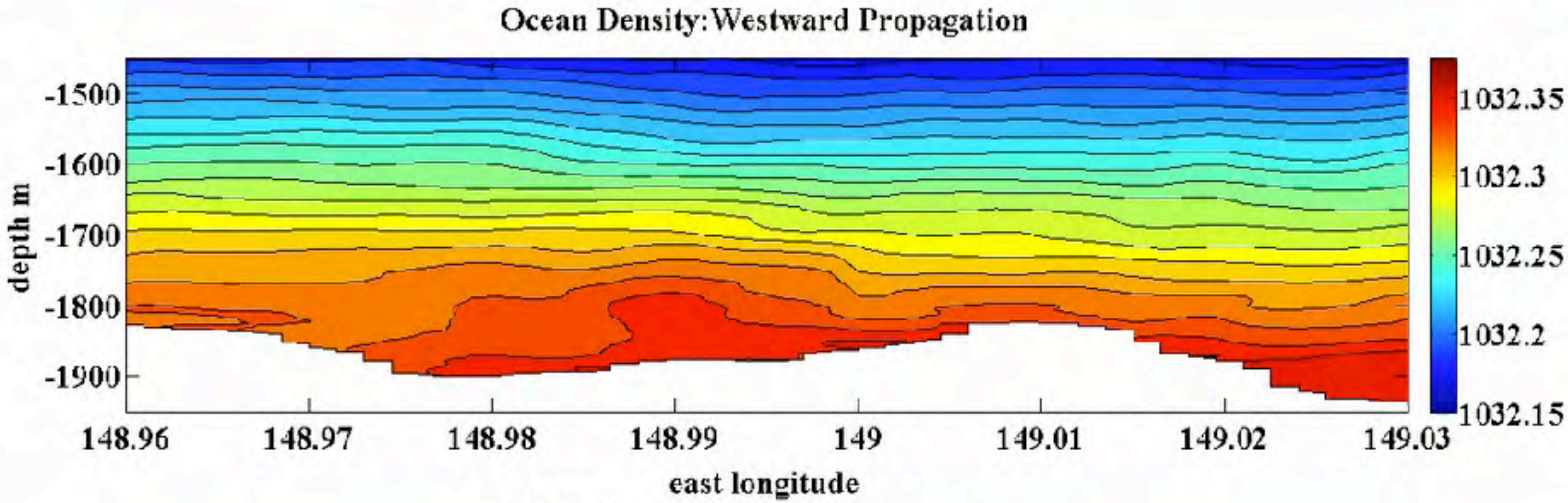
~ 8 km

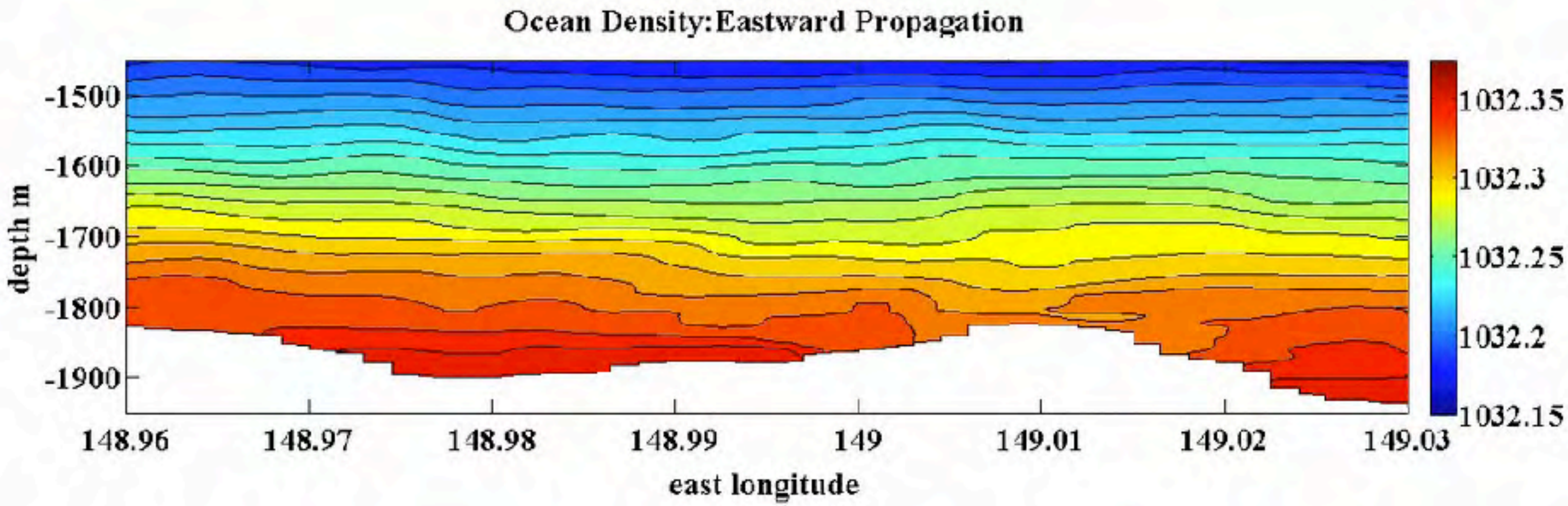
Data interpolated to 54 stations in longitude,
Fit to D_2 , D_4 , D_6 frequencies

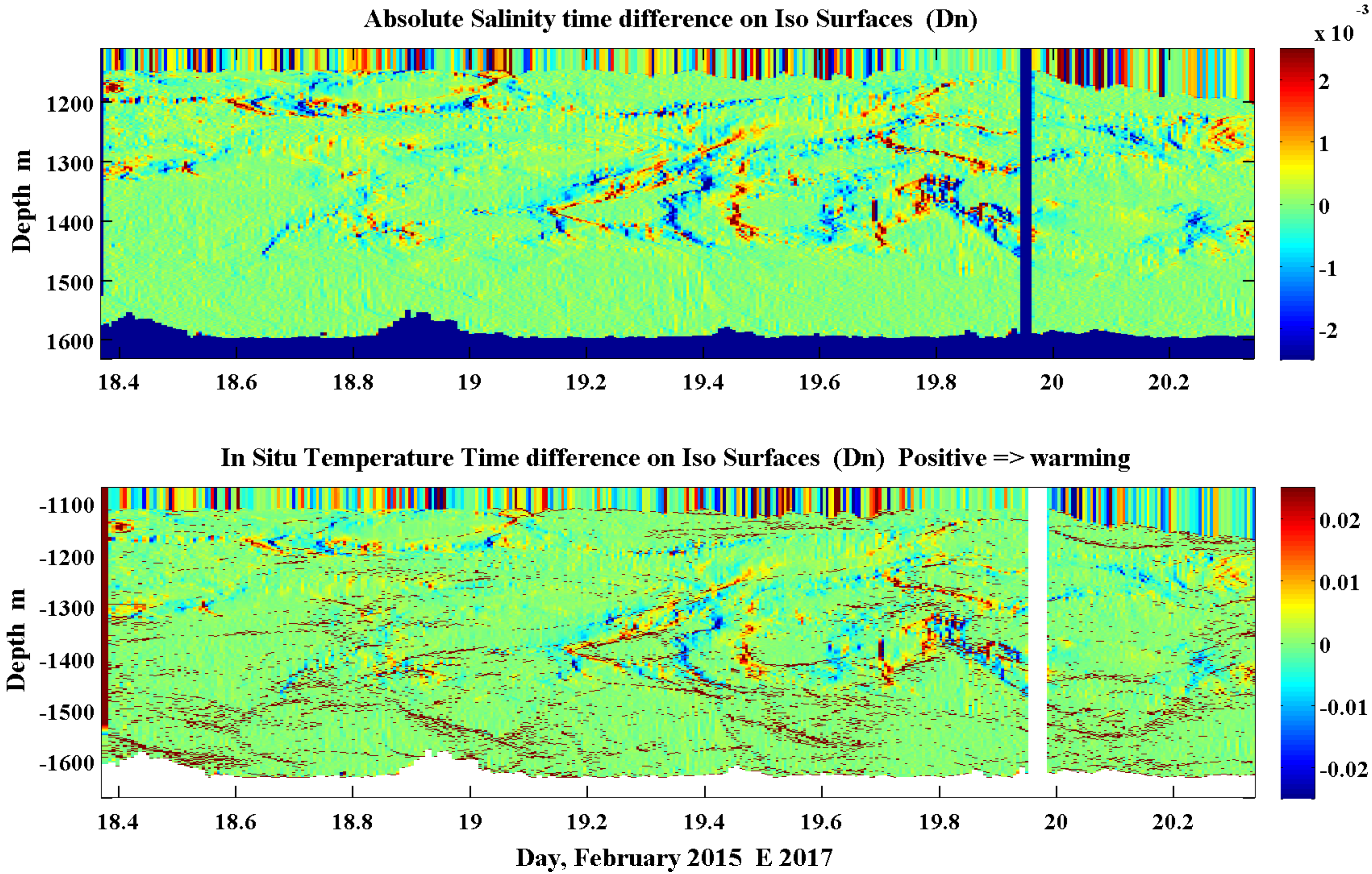


Radiated density variance D2, D4, D6 Harmonics
depth m
−1500
−1600
−1700
−1800
−1900
−2000
148.96
148.97
148.98
148.99
149
149.01
149.02
149.03
0.02
0.015
0.01
0.005
0
?
East longitude

Caution: Based on only five cycles of the D_2 Tide






Absolute Salinity time difference on Iso Surfaces (Dn)
x 10^-3
Depth m
1200
1300
1400
1500
1600
18.4
18.6
18.8
19
19.2
19.4
19.6
19.8
20
20.2
2
1
0
-1
-2
In Situ Temperature Time difference on Iso Surfaces (Dn) Positive => warming
-1100
-1200
-1300
-1400
-1500
-1600
0.02
0.01
0
-0.01
-0.02
Day, February 2015 E 2017

TTIDE Summary

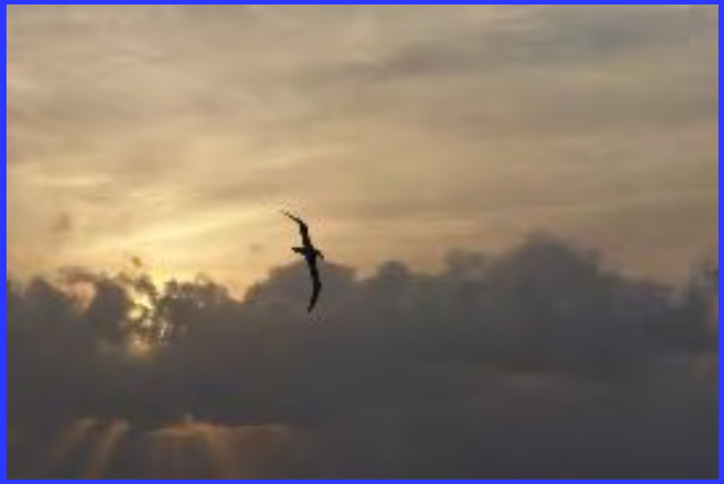
A ~0.5-1.5 GW M_2 tidal beam is propagating from the Macquarie Ridge northwestward across the Tasman Sea.

The beam appears robust relative to lateral refraction by the energetic mesoscale

A large fraction (60-90%) of the incident flux is reflected from the Tasman Slope, particularly in the south.

The coherent mix of incident, reflected, and locally generated tides produces a complicated internal standing wave pattern in the western Tasman Sea.

Issues:



Mid-water vs sea-floor mixing rates

Up-slope bores vs forward-reflected waves

Forward and back-scattering to higher modes

Local generation vs distant source influence

Diurnal energy & trapped shelf modes

Standing wave patterns due to high M_2 reflectivity

~10 km-scale features matter *a lot* for organizing the mixing.
The *micro*-bathymetry of the deep ocean is important.

Thanks to all TTIDE volunteers and our Tasmanian hosts!!

practical considerations (real)

TTIDE INITIALLY PLANNED AND PROPOSED IN *2008-9*
HEIGHT OF ECONOMIC “DOWNTURN”

PROGRAM ACCEPTED IN 2011-12
PERIOD OF MAX FINANCIAL IMPACT TO NSF

BAREBONES PROGRAM FUNDED

MODELING AND GLIDER RECON INDICATES COMPLEXITY OF SITE

PILOT CRUISE CANCELLED ON ECONOMIC GROUNDS

MAIN FIELD PROGRAM DELAYED 1 YEAR BY SHIP AVAILABILITY
(TRANSITING THE REVELLE FROM ASIA TO THE SOUTHERN OCEAN IS VERY EXPENSIVE)

NSF TTIDE FUNDS ARE COMMITTED & DISBURSED TO VARIOUS PLAYERS, BUT LANGUISH FOR 12 MONTHS, MID-PROGRAM

BURN RATE OF RESEARCH-TEAM SALARIES DIALED BACK BUT NOT ZEROED

TTIDE TURNS TO SCHMIDT OCEAN INSTITUTE FOR FALKOR SUPPORT FOR TBEAM
NSF FUNDS WATERHOUSE & KELLY TO EXECUTE TBEAM

JANUARY MARCH 2015 FIELD PROGRAM
ENABLED BY A MASSIVE INJECTION OF SEAGOING VOLUNTEERS, FROM AUSTRALIAN UNDERGRADS TO THE CURRENT HEAD OF CLIVAR.
FIELD TEAMS DEPLOY / RECOVER MASSIVE MOORING ARRAY WITH NEAR FLAWLESS EXECUTION

RELIABILITY OF MCLANE PROFILERS IN SOUTHERN OCEAN TROUBLING,
LADCP PROFILING VERY DIFFICULT IN ROARING FORTIES

INSTRUMENTS ARE “BACK IN THE LAB” WITHIN 3 MONTHS OF FORMAL PROGRAM END

TTIDE CONTINUES, INFORMALLY

DATA ANALYSIS MEETING IN SD JANUARY 2017

practical considerations
(surreal)

BLOG WARS

TBEAM

https://schmidtocean.org/cruise/tracking-the-tasman-seas-hidden-tide/

TTIDE

https://scripps.ucsd.edu/projects/ttide/

https://scripps.ucsd.edu/projects/ttide/category/video/

TTIDE EOS REVIEW
What Flows Beneath
vol 97 #1 Jan 2016

EOS : On the Cover
Melting glacier water meanders to the ocean, where it *plummets* toward the seafloor. Internal ocean waves mix warm surface water with cold deep water, maintaining the oceans in a steady state.

"force" "thrust" "drive" "probe" or *forget it!*

High-latitude climate forcing and tidal mixing by the 18.6-year lunar nodal cycle and low-frequency recruitment trends in Pacific halibut (*Hippoglossus stenolepis*)

Kenneth S. Parker, Thomas C. Royer, and Richard B. Deriso

Parker, K.S., T.C. Royer, and R.B. Deriso. 1995. High-latitude climate forcing and tidal mixing by the 18.6-yr lunar nodal cycle and low-frequency recruitment trends in Pacific halibut (*Hippoglossus stenolepis*). p. 447–459. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Abstract: Upper layer ocean temperatures in the northern North Pacific Ocean have increased by more than 2°C in the decade starting with 1972, and have declined since 1986. Proxy time series indicate this to be part of a low-frequency fluctuation in synchrony with atmospheric behavior. The 18.6-yr lunar synodic declination cycle is suggested as the cause for this variability through the systematic tidal modulation of the mean ocean circulation. Enhanced or declining production trends over a nearly 60-yr recruitment abundance record for Pacific halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska have been found to correspond directly with this lunar nodal tide climate forcing. The number of age-8 recruits to a carefully controlled commercial fishery for the period 1927–83 displays a sinusoidal cycle with an 18.7-yr period clearly identified by spectral analysis. Sixty percent of the variance in the recruitment series is accounted for by the lunar nodal cycle. Furthermore, most of the recently observed ocean and air temperature increases in the North Pacific are associated with this decadal-frequency tidal forcing, rather than with global warming. Nutrient enhancement and productivity dynamics related to systematic long-period oscillations in the tidally-modulated mixing patterns and horizontal advection processes are discussed as induced mechanisms for possible causal relationships.

Geophysical Research Letters
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Oceans

Possible explanation linking 18.6-year period nodal tidal cycle with bi-decadal variations of ocean and climate in the North Pacific

Ichiro Yasuda, Satoshi Osafune, Hiroaki Tatebe

First published: 22 April 2006 Full publication history
DOI: 10.1029/2005GL025237 View/save citation
Cited by: 34 articles

View issue TOC
Volume 33, Issue 8
April 2006

Abstract

[1] Bi-decadal climate variation is dominant over the North Pacific on inter-decadal timescale; however the mechanism has not been fully understood. We here find that the bi-decadal variations in the North Pacific climate and intermediate waters possibly relate to the 18.6-year period modulation of diurnal tide. In the period of strong diurnal tide, tide induced diapycnal mixing makes surface salinity and density higher and the upper layer shallower along the Kuril Islands and the east coast of Japan. Simple model results suggest that the coastal depth adjustment by baroclinic Kelvin waves enhances the thermohaline circulation, the upper-layer poleward western boundary current and associated heat transport by about 0.05PW. This could also explain the warmer SST in the Kuroshio Oyashio Extension regions, where positive feedback with Aleutian Low might amplify the bidecadal variations. The 18.6-year tidal cycle hence could play a role as a basic forcing for the bi-decadal ocean and climate variations.

On the Late Pleistocene ocean geochemistry and circulation

Robin S. Keir

First published: August 1988 Full publication history
DOI: 10.1029/PA003i004p00413 View/save citation
Cited by: 111 articles

View issue TOC
Volume 3, Issue 4
August 1988
Pages 413–445

Abstract

A box model of the atmosphere and ocean was developed to investigate how geochemical distributions extant during the late Pleistocene may have come about. The model simulates the regional distribution of calcium carbonate dissolution as well as the chemical oceanography and atmospheric CO_2, $\delta^{13}C$ and radiocarbon. If the downward biological flux of particulate carbon increases by a factor of 2 to 3 in the Antarctic and if this increase is combined with a relative increase of the Atlantic sector Antarctic Bottom Water (AABW) versus North Atlantic Deep Water (NADW) source ratio from 1:3 to about 2:1, then the model predicts several changes that seem to be recorded in the sedimentary record, as follows: (1) A global redistribution of nutrients and ^{13}C from the intermediate to deep water takes place with the Atlantic intermediate water phosphate decreasing 0.6 μmole kg^{-1} and the $\delta^{13}C$ increasing 0.3 to 0.5‰. (2) The dissolved oxygen level of the deep sea is reduced from an average of about 180 to 70 μmole kg^{-1}, but the intermediate water oxygen declines only a small amount. (3) The decrease in intermediate water nutrient concentration results in lower average organic carbon and calcium carbonate production in the warm surface ocean. (4) The atmospheric CO_2 decreases by 90 to 110 ppm. (5) Initially, a global increase in calcium carbonate dissolution occurs which is followed by a relaxation toward better preservation than exists for the present ocean. In the model in this paper the reduction of NADW by itself does not produce these effects. Rather, the nutrient decrease that does occur is found mostly in North Pacific intermediate water, and the model atmospheric CO_2 decrease is only 10 to 30 ppm. It is observed that 92% of the atmospheric CO_2 change takes place according to a 280-year time constant in the model. This corresponds to the response time of the upper ocean and atmosphere to a change in the stationary state atmospheric PCO_2. Thus, according to this model the time lag between the nutrient-based cause and the atmospheric CO_2 response is not expected to be particularly large.

Decadal Climate Variability: Is There a Tidal Connection?

RICHARD D. RAY

NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 14 June 2006, in final form 8 November 2006)

ABSTRACT

A possible connection between oceanic tides and climate variability arises from modulations in tidally induced vertical mixing. The idea is reexamined here with emphasis on near-decadal time scales. Occasional extreme tides caused by unusually favorable alignments of the moon and sun are unlikely to influence decadal climate, since these tides are of short duration and, in fact, are barely larger than the typical spring tide near lunar perigee. The argument by Keeling and Whorf in favor of extreme tides is further handicapped by an insufficiently precise catalog of extreme tides. A more plausible connection between tides and near-decadal climate is through "harmonic beating" of nearby tidal spectral lines. The 18.6-yr modulation of diurnal tides is the most likely to be detectable. Possible evidence for this is reviewed. Some of the most promising candidates rely on temperature data in the vicinity of the North Pacific Ocean where diurnal tides are large, but definitive detection is hindered by the shortness of the time series. Paleoclimate temperature data deduced from tree rings are suggestive, but one of the best examples shows a phase reversal, which is evidence against a tidal connection.

TTIDE Summary

During January / March 2015, arrays of McLane profilers, ADCPs, and thermistor chains were deployed.

1) Southern Line :more reflective

2) Northern Line: more dissipative

3) Offshore Triangle: the "Reflection Array"

4) Offshore T-BEAM Incoming Flux mooring

5) On-shelf T-SHELF array

LADCP and Fast-CTD profiling from the R.V. Revelle.

LADCP survey of the incident beam from the RV Falkor

BLOG

https://scripps.ucsd.edu/projects/ttide/

https://scripps.ucsd.edu/projects/ttide/category/video/

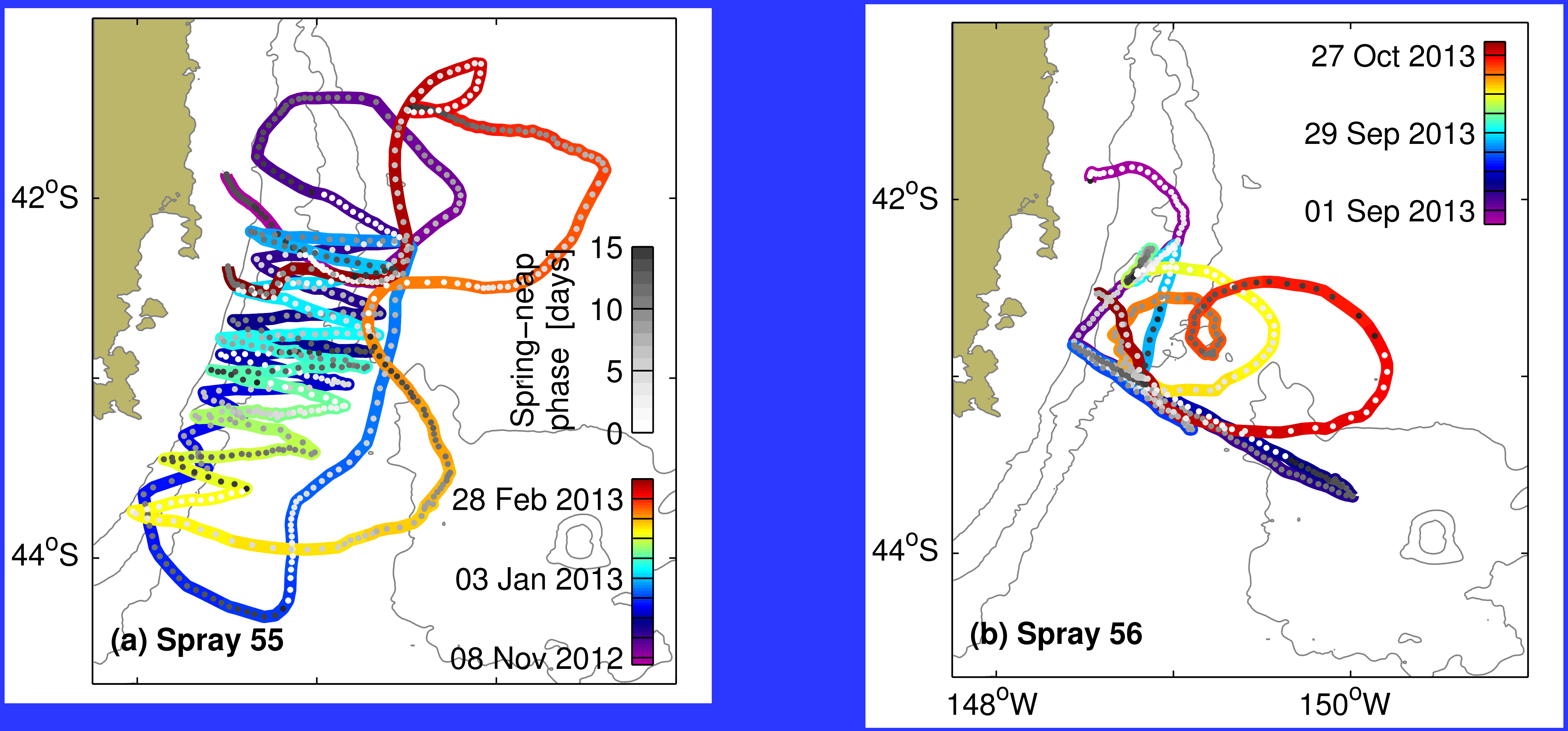


FIG. 2. Glider tracks for (a) *Spray* 55 and (b) *Spray* 56 are shown with color indicating time. Increasingly dark dots along the track denote increasing spring-neap phase, which is expressed in terms of days. In both cases, a wide range of phases is seen in the areas with greatest sampling. In Figure 2b, *Spray* 56 profiles for 2 weeks over the slope near 42.4°S (green to yellow colors).

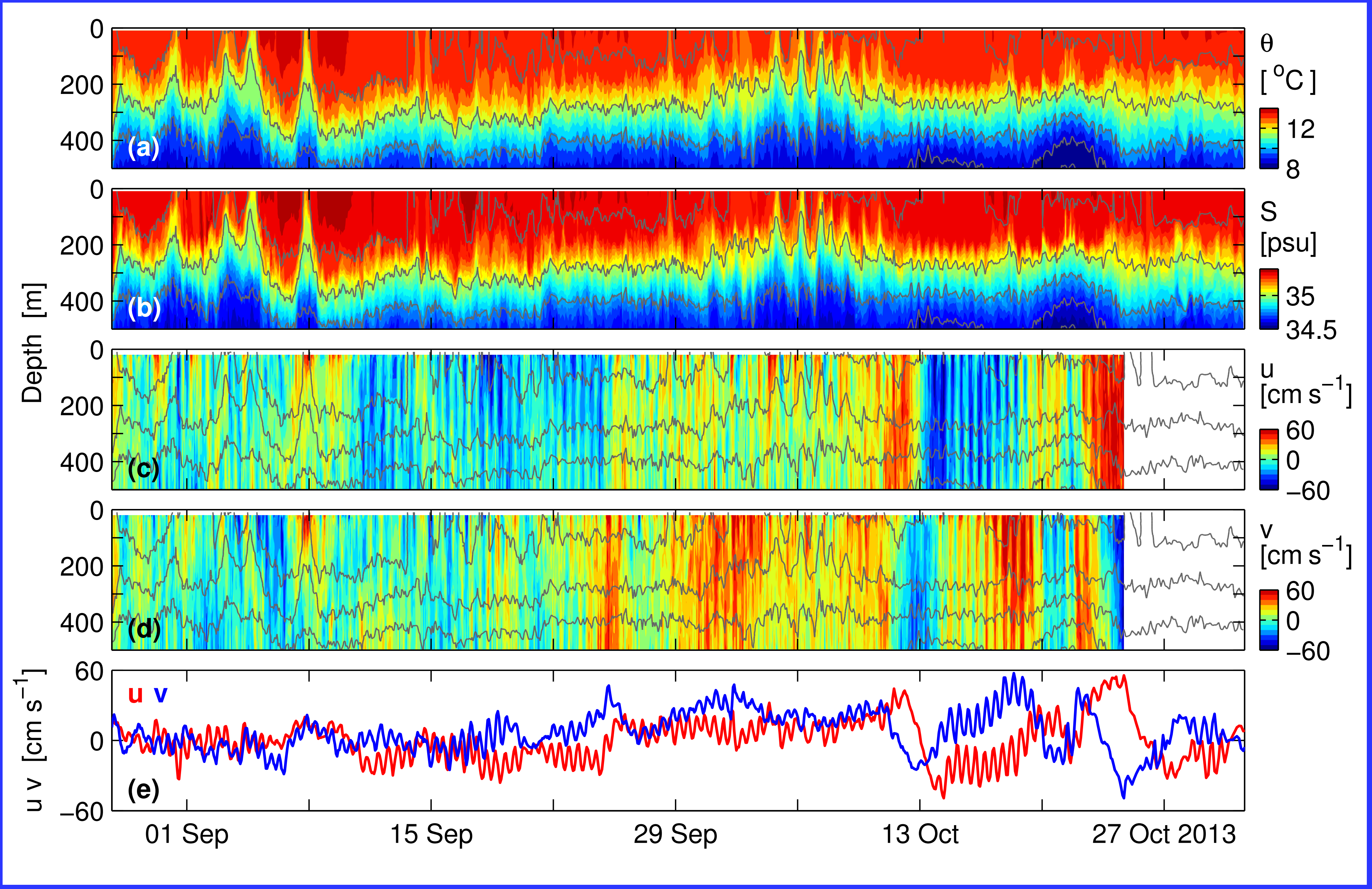


FIG. 3. Data from *Spray* 56 are shown with visible D_1 and D_2 oscillations and longer duration mesoscale variations in depth-varying (a) θ, (b) S, (c) u, and (d) v and also in (e) depth-mean u and v. σ_θ is contoured at 0.1 kg m^{-3} intervals (gray lines). A weakly-stratified surface layer extends to 200–300 m (Figures 3a–b).

Standing internal tides in the Tasman Sea observed by gliders

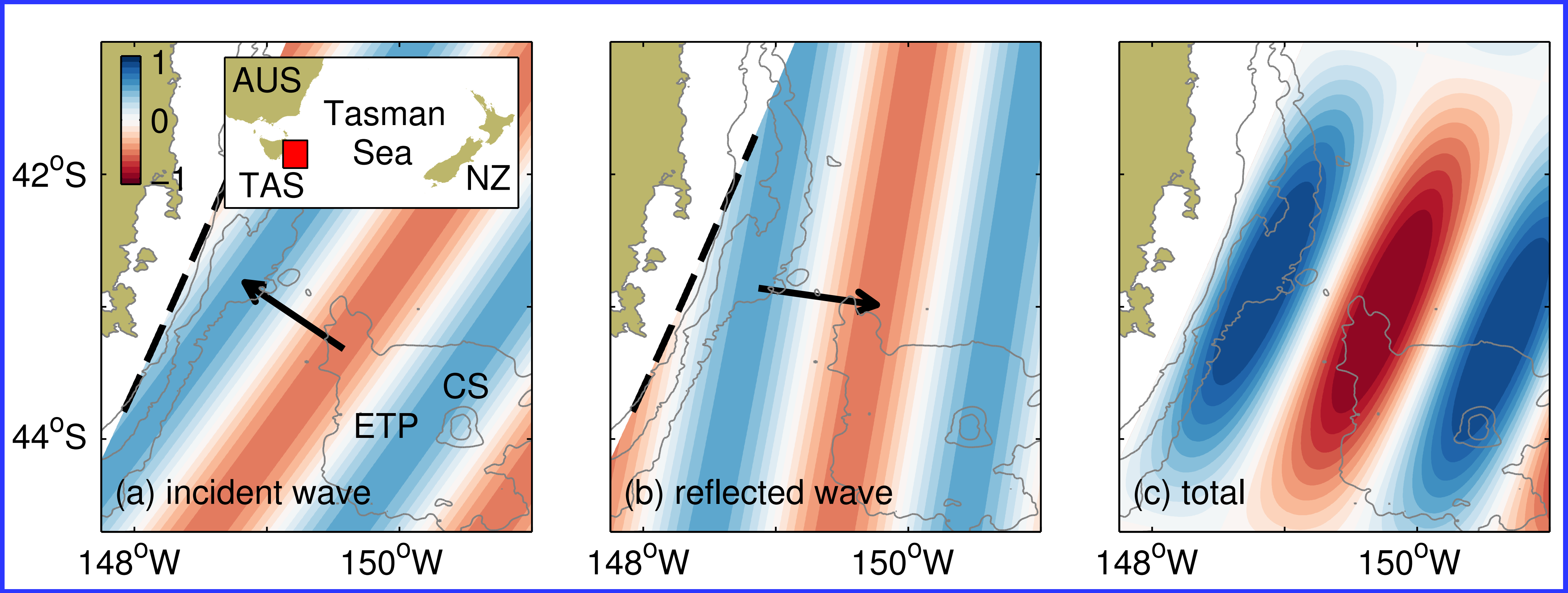
T. M. SHAUN JOHNSTON* AND DANIEL L. RUDNICK

Scripps Institution of Oceanography,
University of California, San Diego,
La Jolla, California

SAMUEL M. KELLY

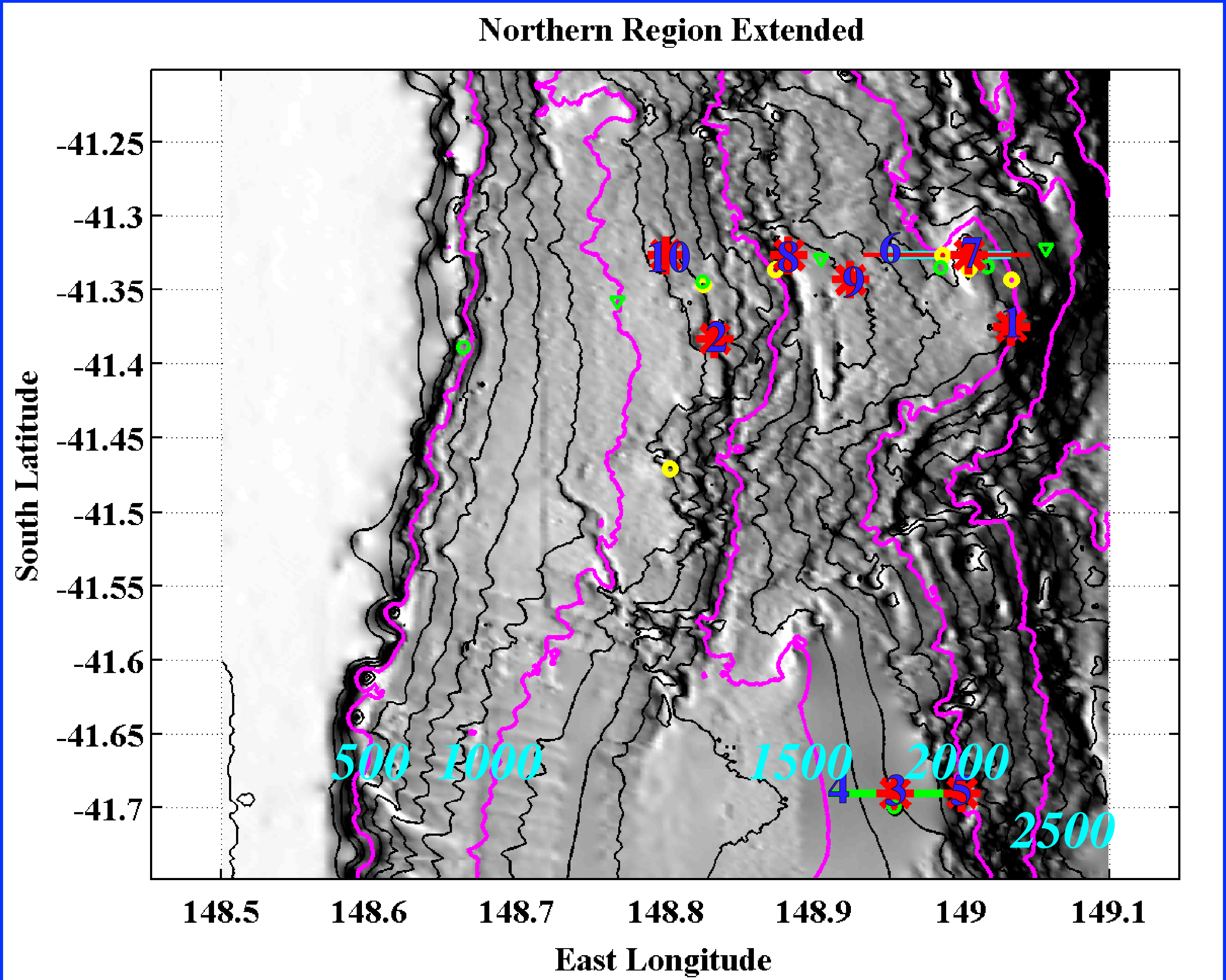
Large Lakes Observatory and Department of Physics,
University of Minnesota,
Duluth, Minnesota

FIG. 1. To illustrate the geometry of the internal tides (a) incident upon and (b) reflected from a coastal wall (dashed line), the instantaneous cross-slope velocity component of an idealized mode-1 Poincaré wave with a constant 150-km wavelength is shown superimposed on a map of Tasmania. The incident and reflected wave direction are shown (black arrows). The wall (dashed line along a bearing of 18°) is aligned with the steepest section of the slope. The incident and reflected waves combine to produce a standing wave in (c). The inset in Figure 1a shows the area under consideration (red box) in subsequent figures with AUS, TAS, and NZ denoting Australia, Tasmania, and New Zealand. Topography is contoured at 1000-m intervals. The East Tasman Plateau (ETP) is the broad rise offshore, which includes a steep pinnacle, the Cascade Seamount (CS).

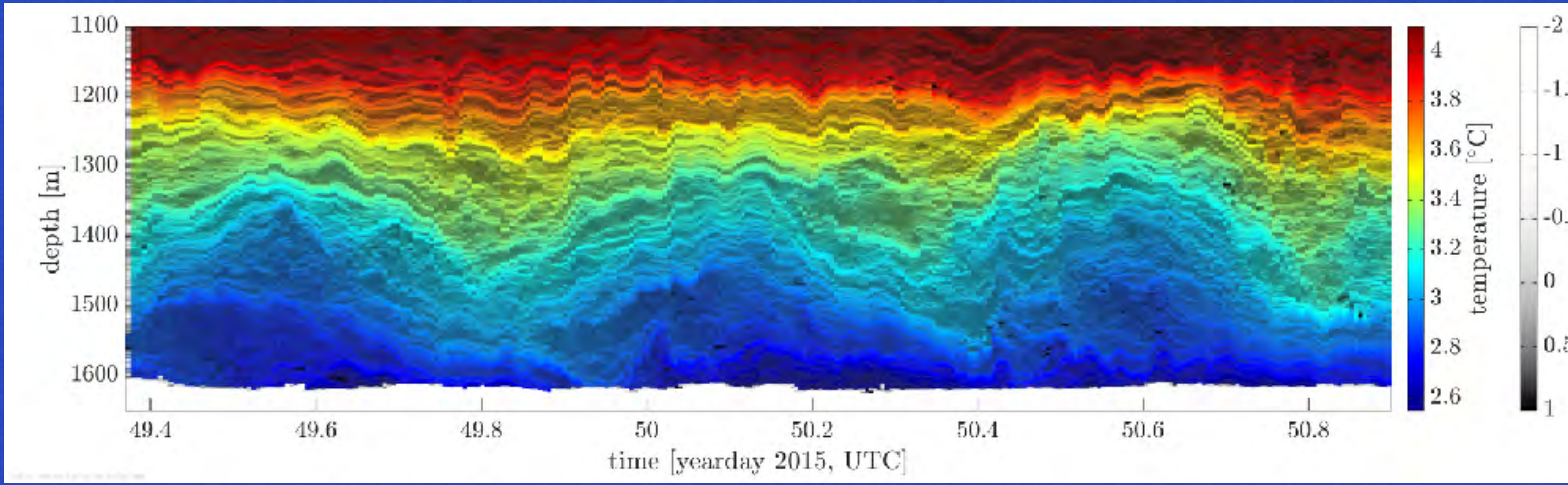


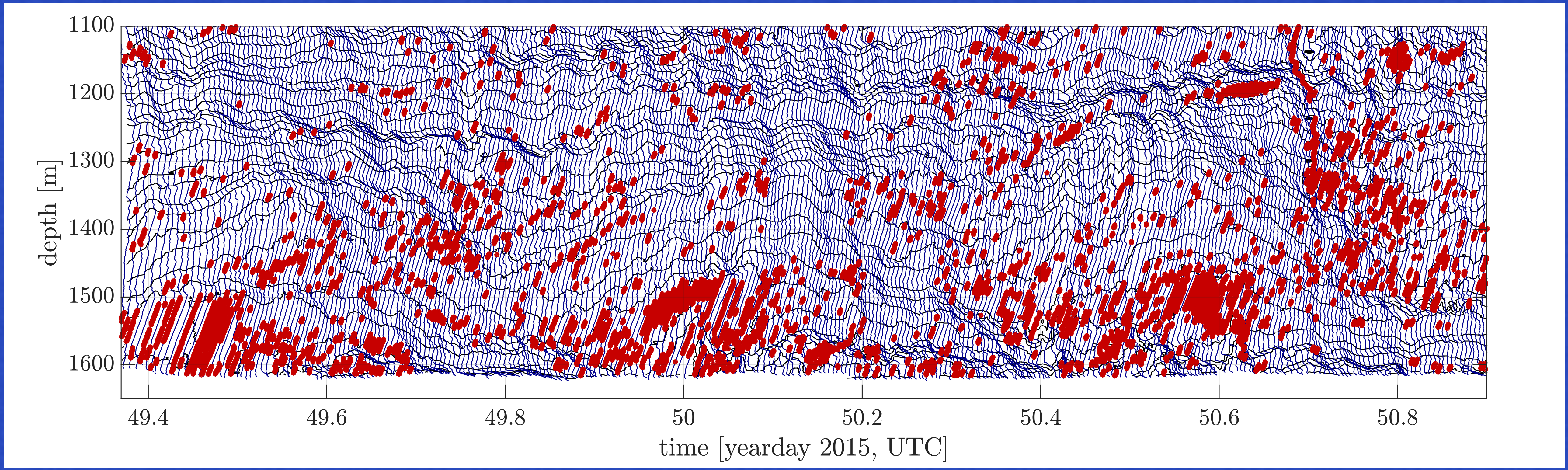



Leg II Site Summary



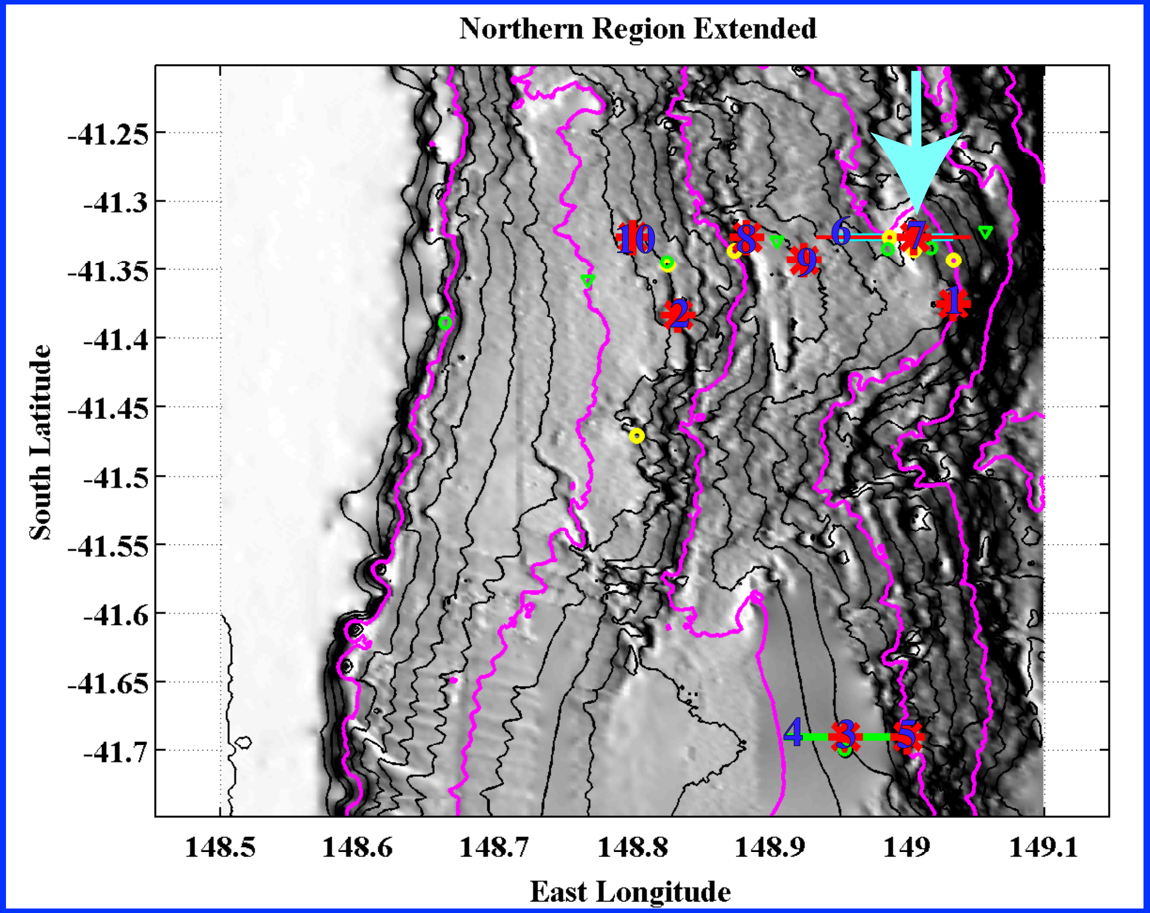
Shoaling tides at 1625 m depth on the Tasman Slope

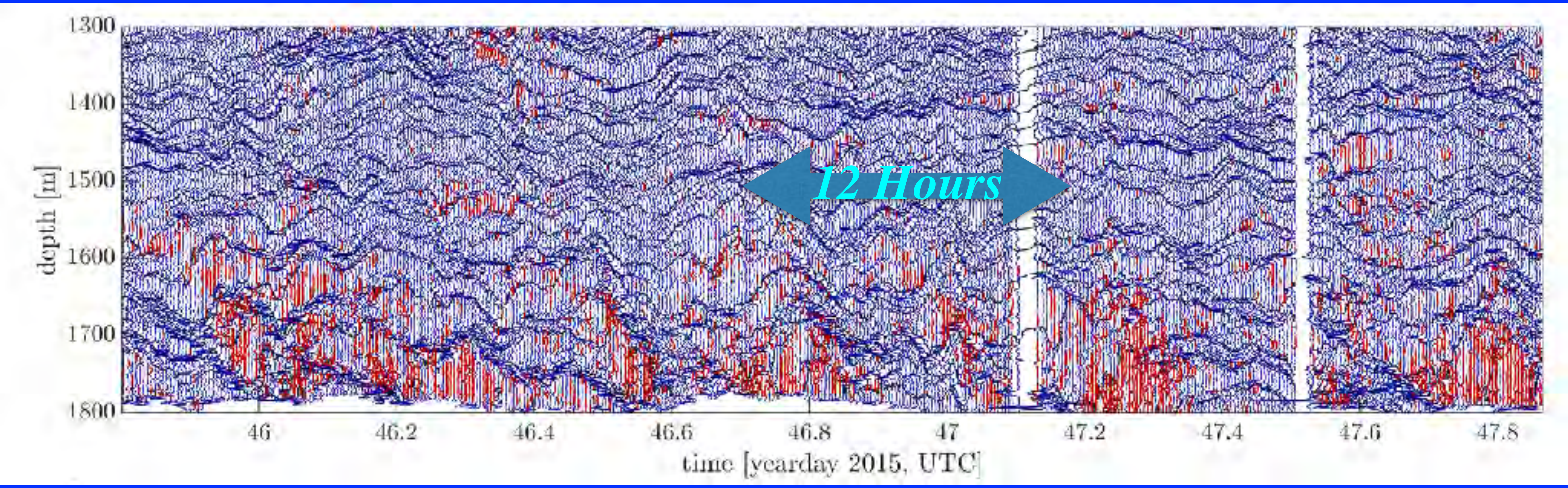




Site 7

On Top of Klymak Rise





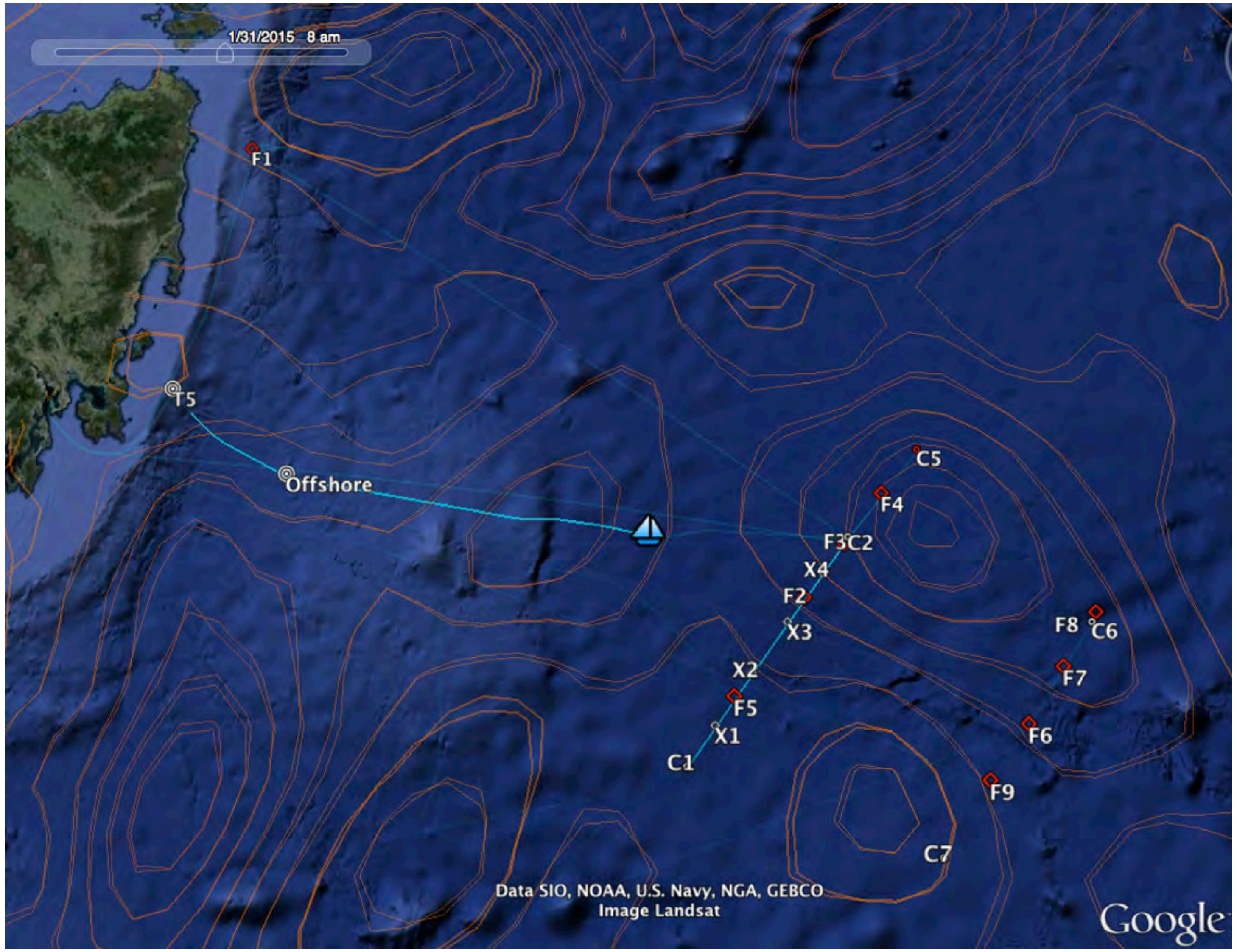
Preliminary results from T-Beam

R/V Falkor Cruise 17 Jan – 13 Feb

- LADCP-CTD stations: F1-F9
- Shipboard survey lines:
  C1-C2, C2-C4, T5-Offshore
- XBT stations: X1-X4

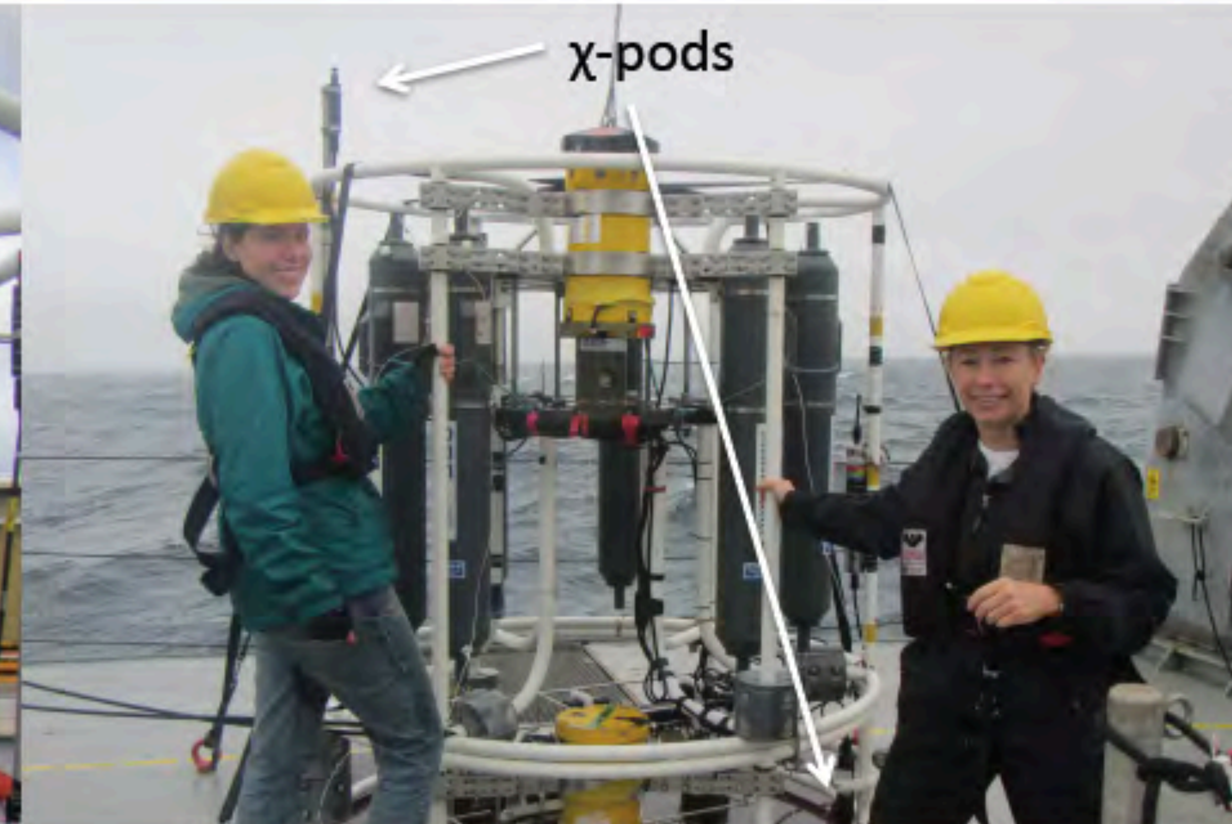
"Energy flux" transect lines:
C1-C5 and C6-C7.

Sea surface height from altimetry from 31 Jan 2015

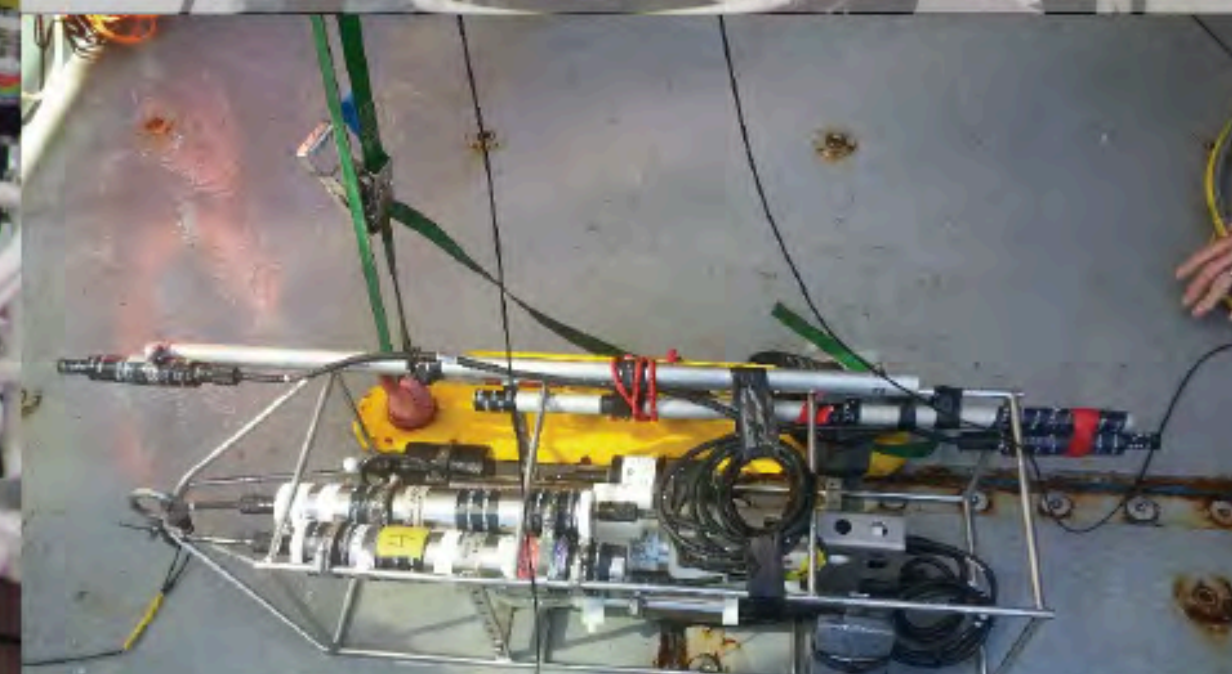


Waterhouse Kelly Rainville

a) Original CTD set up: CTD 911, 2 ADCPs, 2 sea batteries, 4 χ-pods, 8 bottles



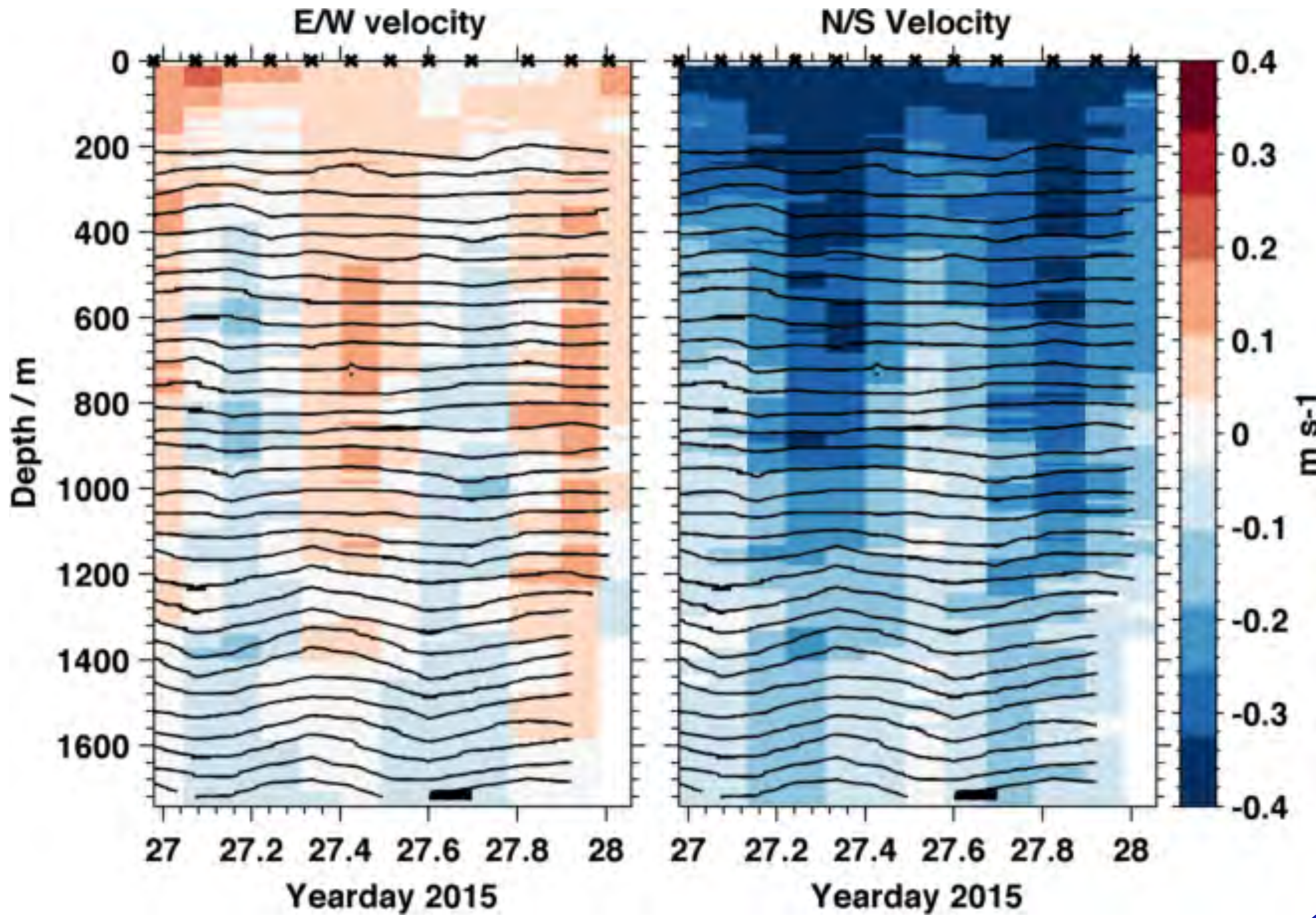
b) Modified CTD set up (no batteries)



c) Small CTD package: equipped with radiometer, fluorescence, backscatter and oxygen sensors, and two χ-pods

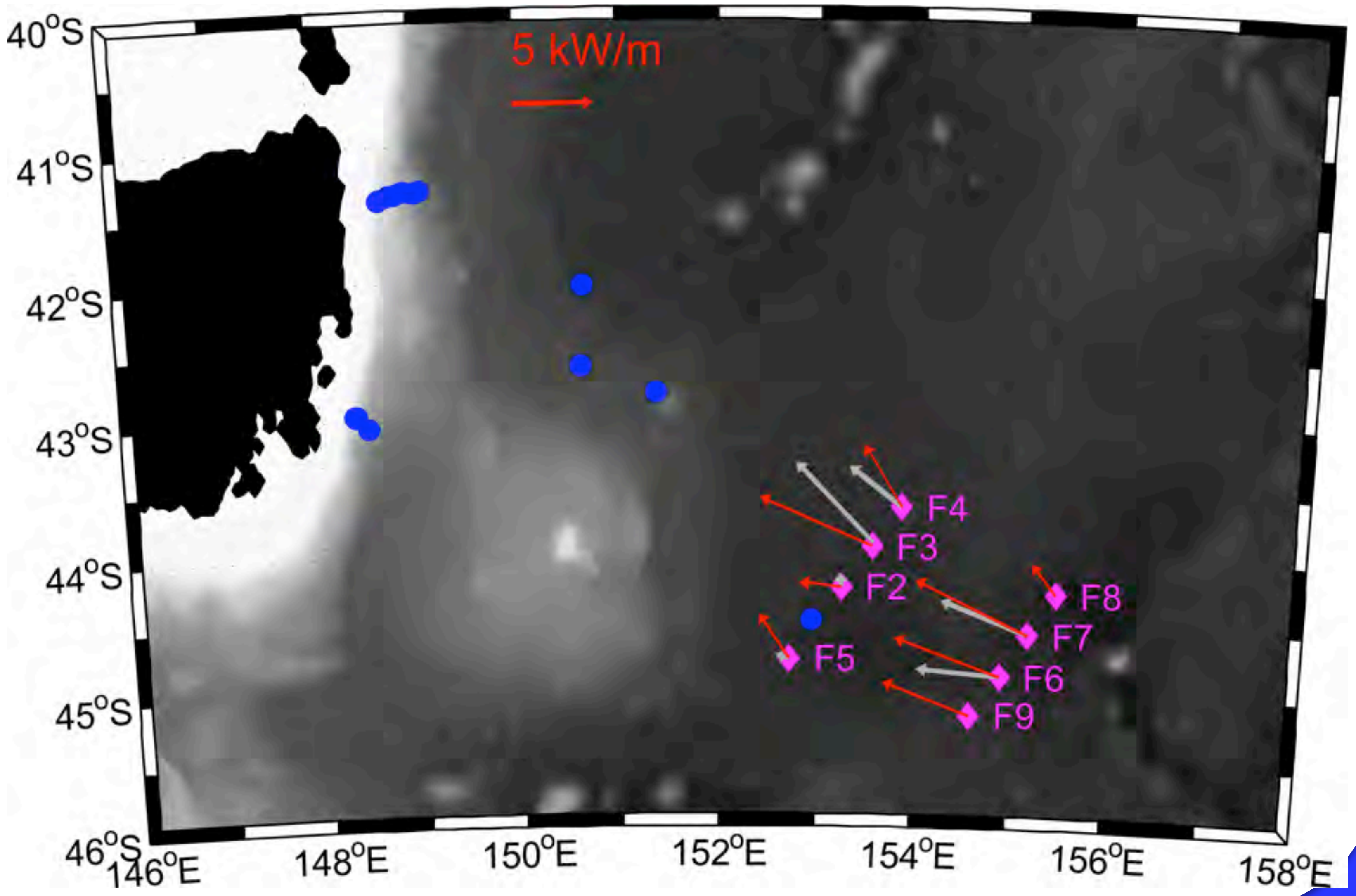
LADCP station F3

- Better temporal coverage
- Larger pressure perturbations
- Large energy flux



Semidiurnal mode-1 energy fluxes

- Fluxes are based on two fitting methods
- Fluxes at A1 will fill in the picture
- Still optimizing fits to minimize uncertainty



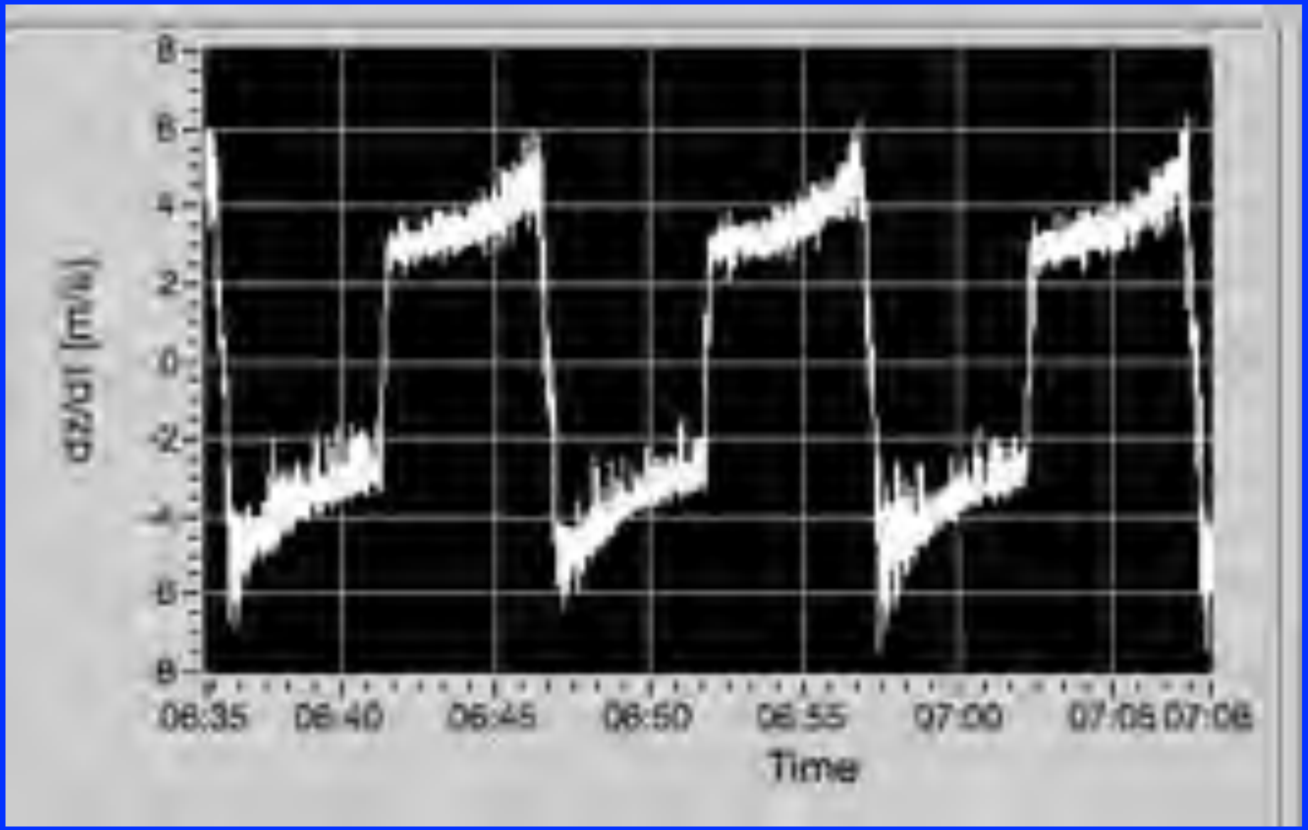
TTIDE Ship & Mooring Program

Legs I & III

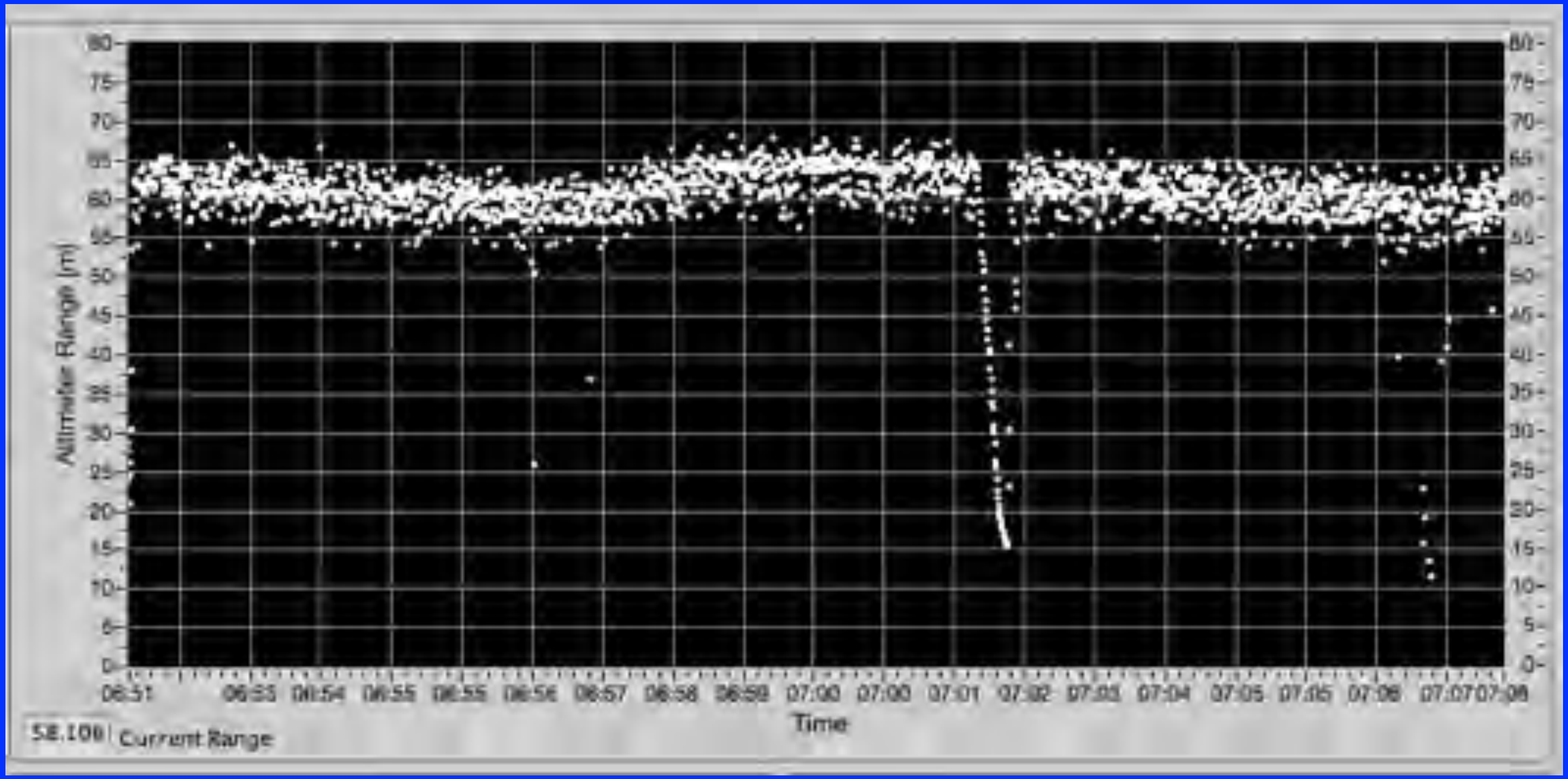
Matthew Alford
Jen Mackinnon
Jonathan Nash
Harper Simmons

Leg II

Rob Pinkel
Drew Lucas
Nicole Jones
Robin Robertson



FCTD Drop Rate



FCTD Sea-floor Detection

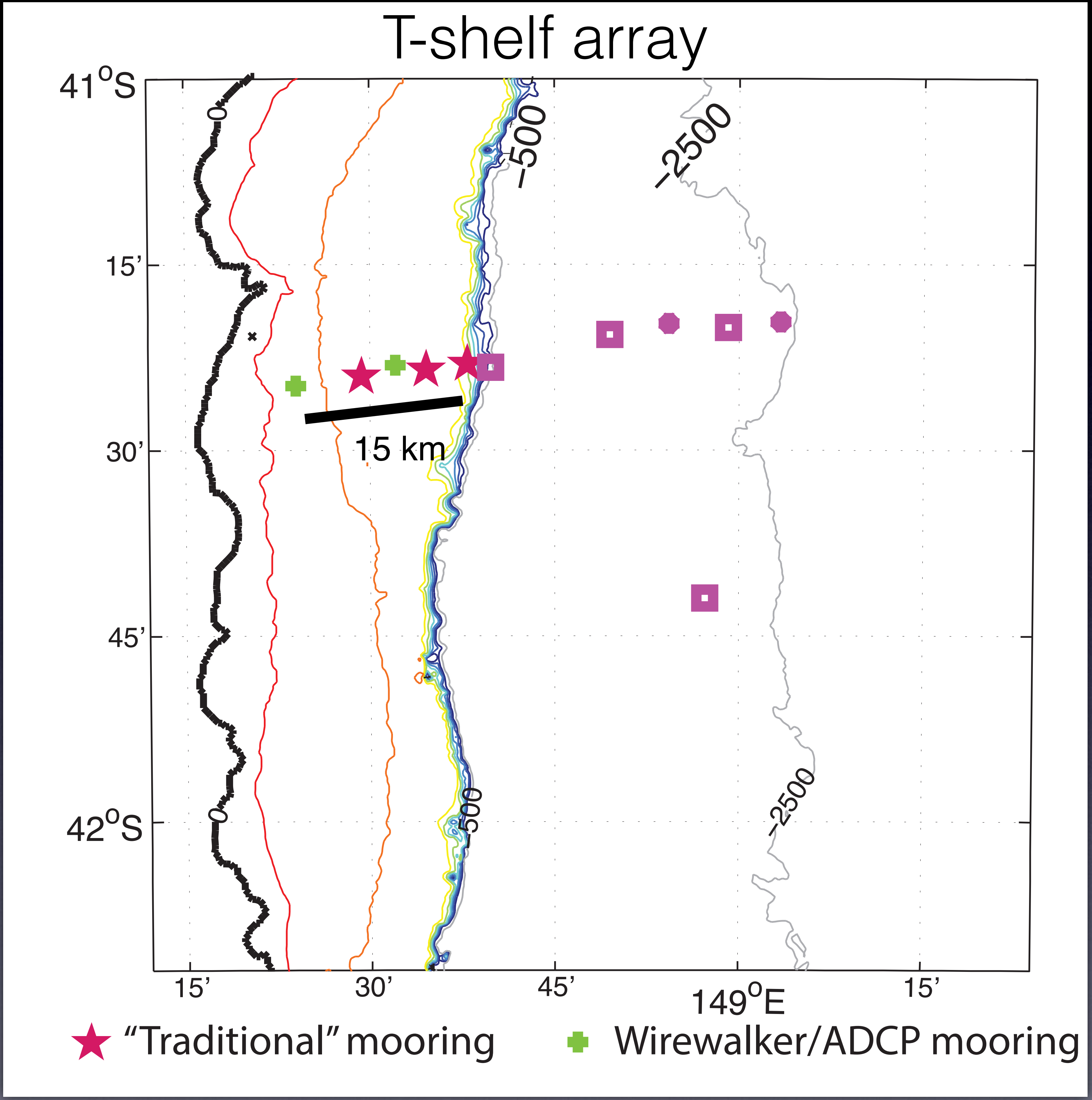
T-Shelf:

Funded by Australian Research Council and UWA to study *sediment resuspension processes associated with the internal wave field.*

Broader goal was to quantify energy/mass/momentum fluxes over the shelf, relate to various forcing.

Initial hypothesis was that the remotely incident internal tide would be a major player.

Approach: mooring array for leg-II, 24 hour shipboard CTD yo-yo

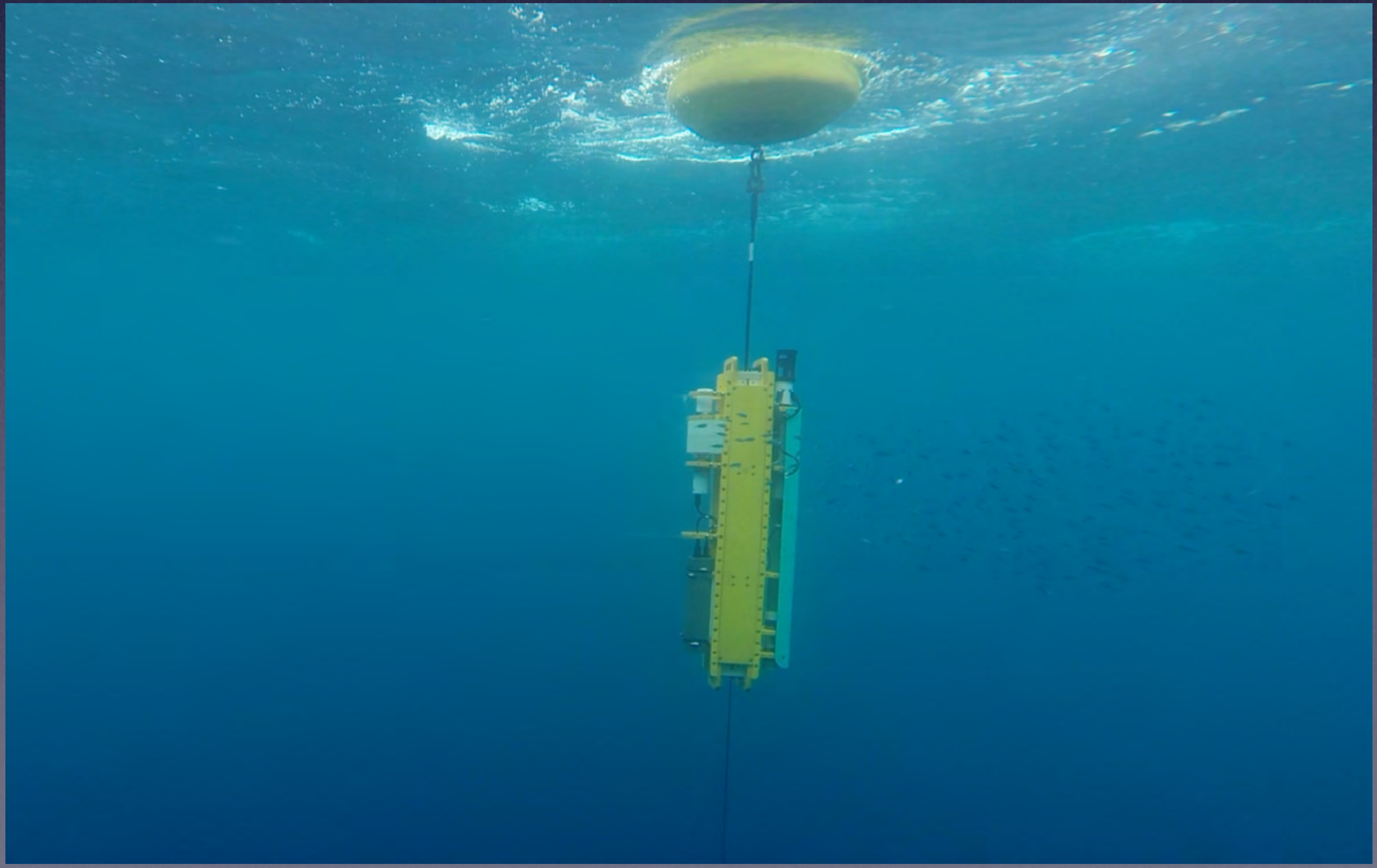


T-shelf moorings

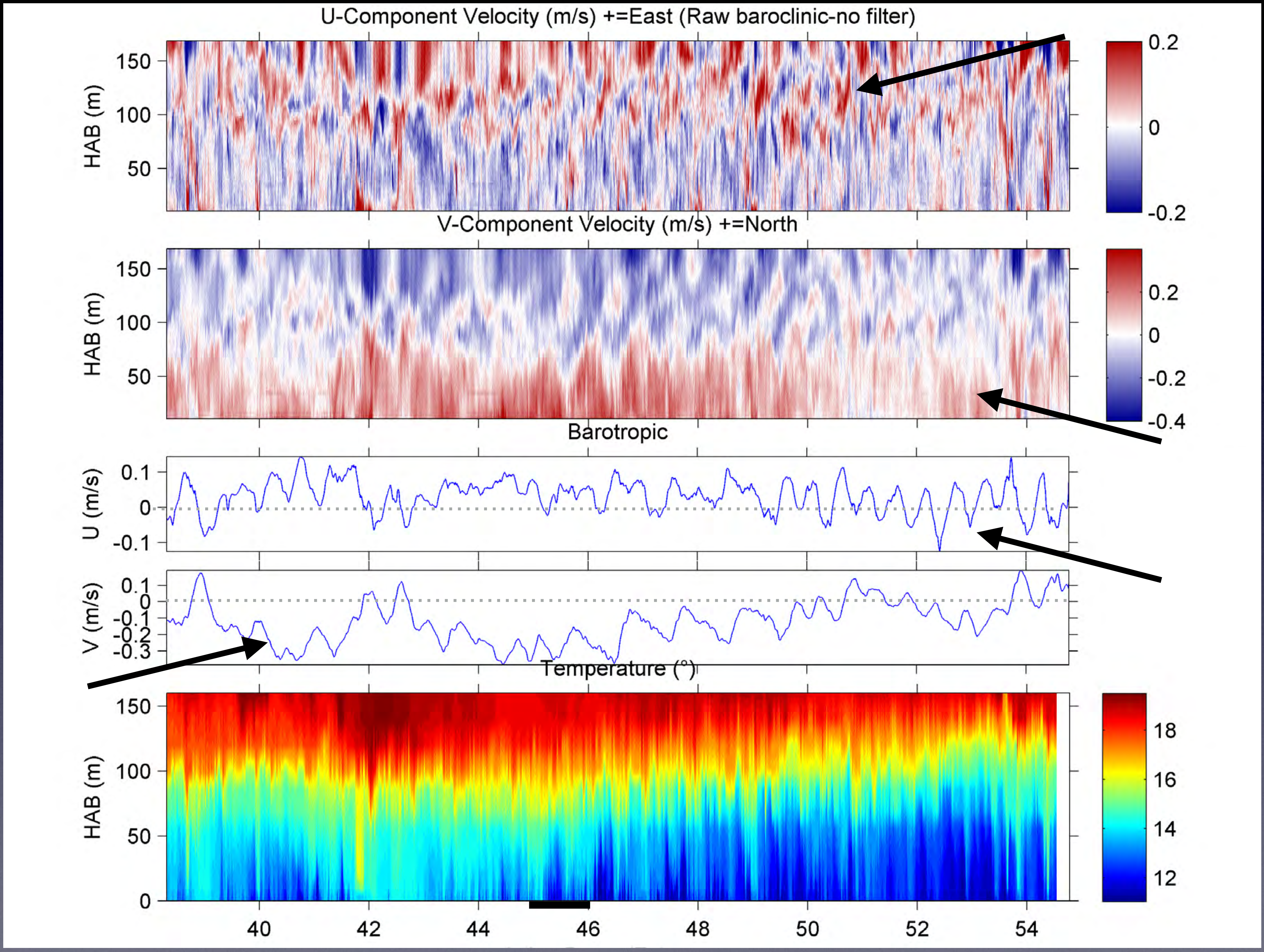
Shelf-break (175m depth):
Bottom frame with upward looking 300 and 1200 kHz ADCPs, ADV, optical backscatter. Adjacent mooring w/ upward looking 150 kHz ADCP, 5-20m separated T and C/T sensors, near bottom intensified sampling.

Outer-shelf (115m depth):
Upward looking 300 kHz ADCP, OBS, ADV plus motion package 10 MAB, T and C/T with 5 m separation until 45 MAB, 10 m sep. until 100m.

Mid-shelf (100m depth):
Upward looking 300 kHz ADCP, OBS, T and C/T with 2.5-5 m separation until 45 MAB, 10 m sep. until 100m.

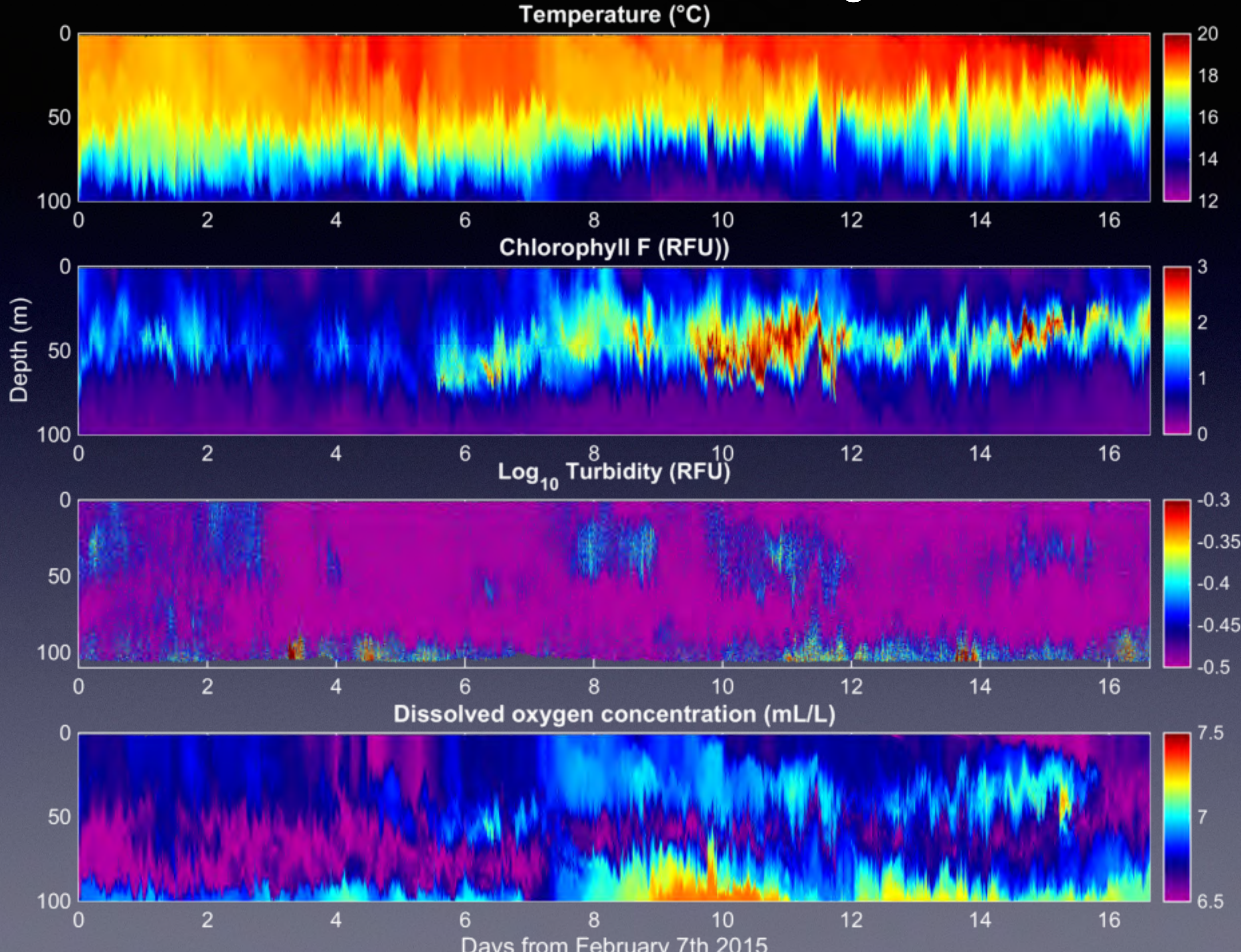


Shelf-break mooring (prelim analysis T. Schlosser)

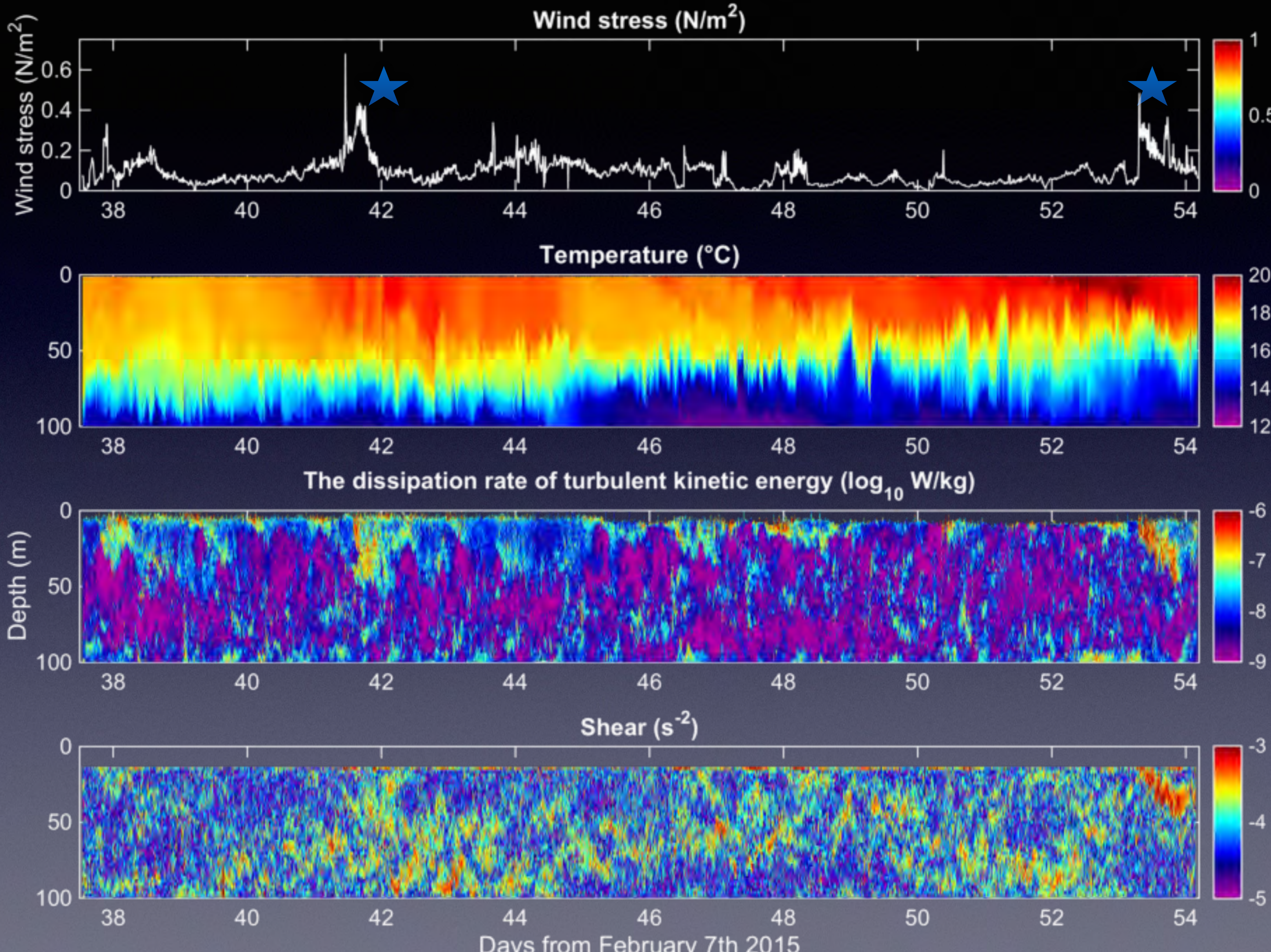


Julian Day

WW outer-shelf mooring



WW outer-shelf mooring (Thanks to Jonathan for χ processing)



T-shelf: Summary and next steps.

- Extensive 16d shelf record of physical and sediment dynamics.
- Excellent data recovery, including perhaps the longest continuous records of microstructure over the shelf.
- Subinertial flow dominated by poleward transport at and above the pycnocline.
- Important contribution of near-inertial, K1, and, less so, the M2 tide. Apparent in both barotropic and baroclinic currents.
- Very energetic and complicated internal wave field at frequencies higher than M2.

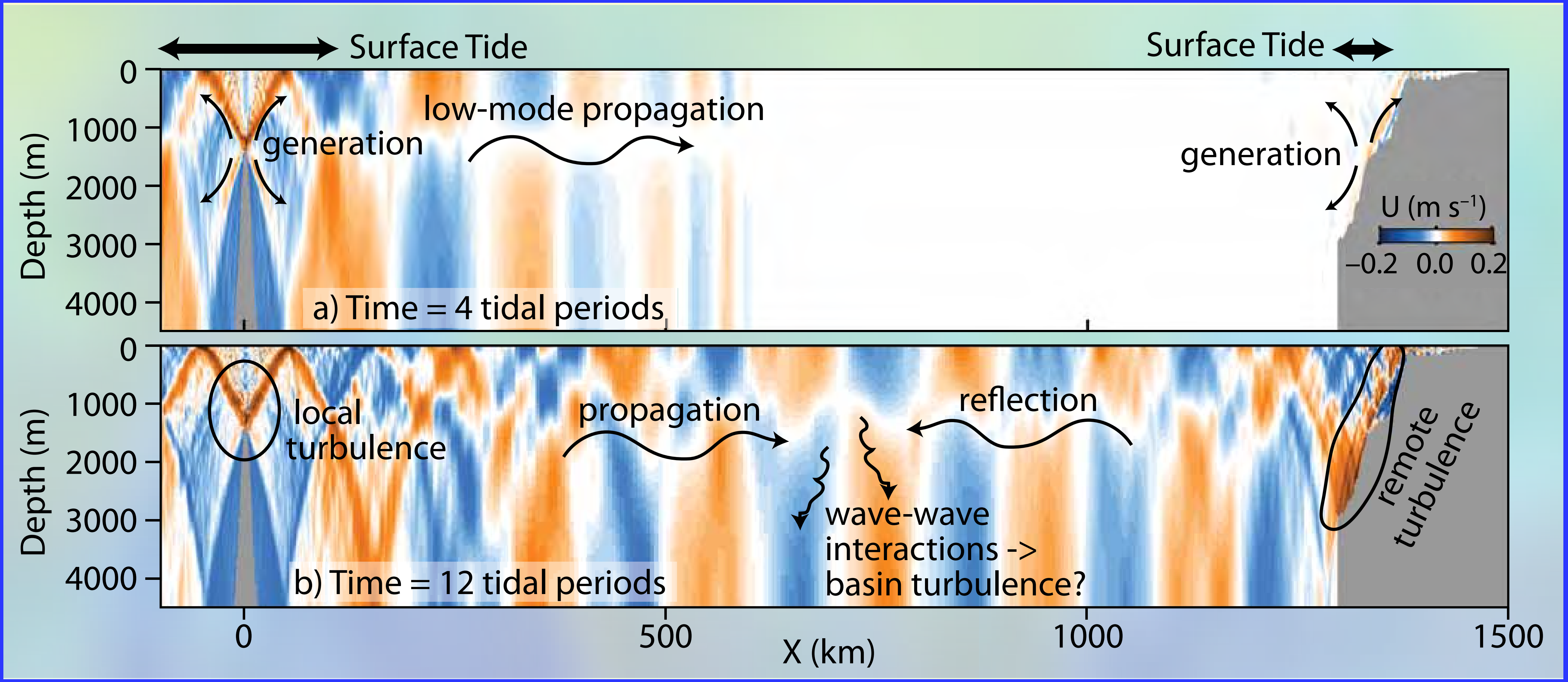
Next steps:

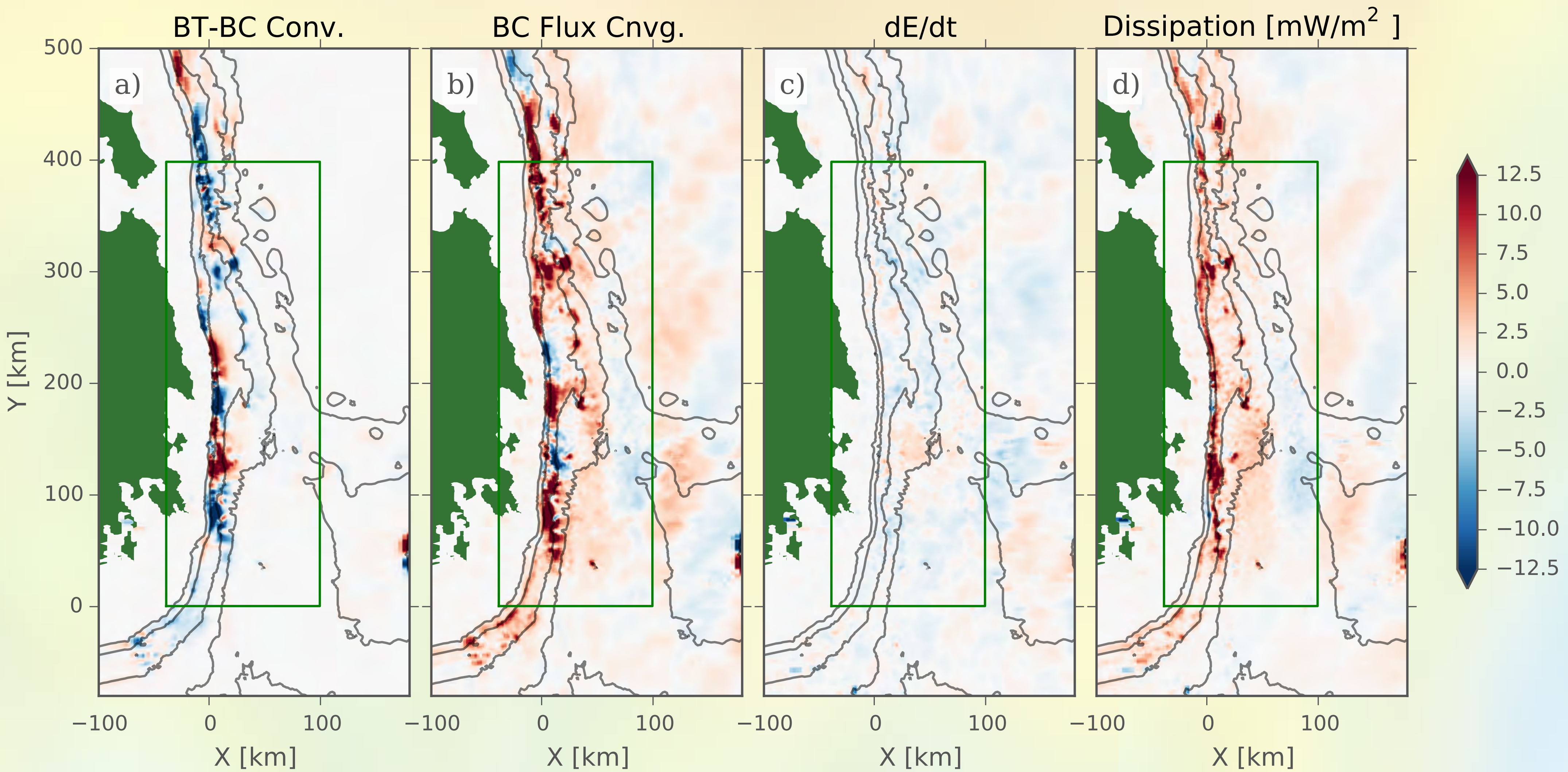
These data will form the basis of dissertation of Tamara Schlosser (UWA), co-advised by Jones and Lucas.

Analysis of mixing from χ, in particular building intuition into near-surface turbulent processes.

The sediment story… is there one?

TTIDE Modeling: Jody Klymak

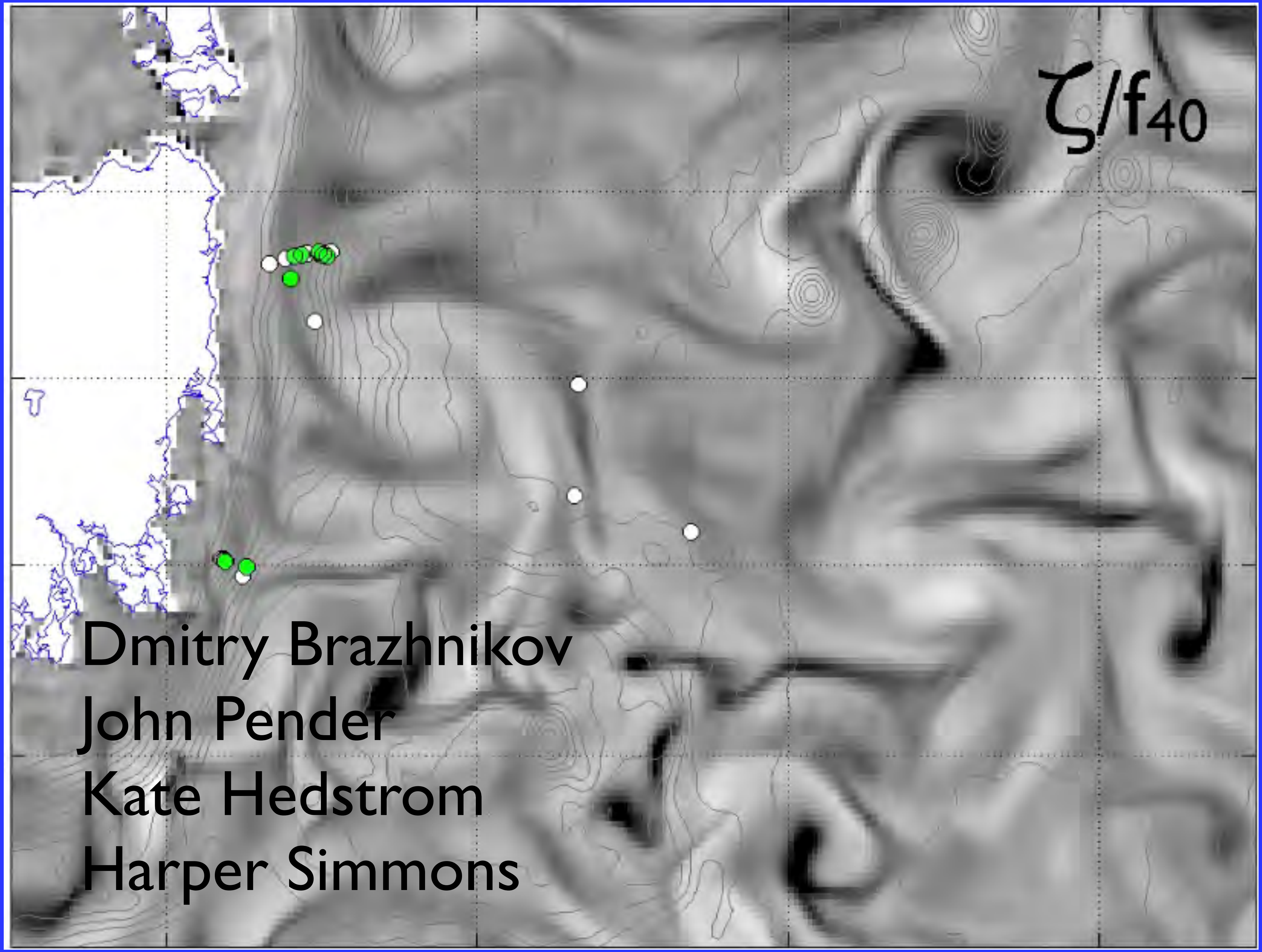



BT-BC Conv.
BC Flux Cnvg.
dE/dt
Dissipation [mW/m2]
a)
b)
c)
d)
Y [km]
X [km]
X [km]
X [km]
X [km]
500
400
300
200
100
0
−100
0
100
12.5
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−12.5

ROMS Simulations of the Tasman Sea

t0 = Jan 1 2015, dx = 0.03125° (~2.5km) , M2+S2+O1+K1

HYCOM initial condition and sponges, MERRA fluxes + tides



Sea surface relative vorticity (ζ/f_{40})