Coastal ocean circulation near Palmer Station Antarctica: Observations from a glider mounted ADCP

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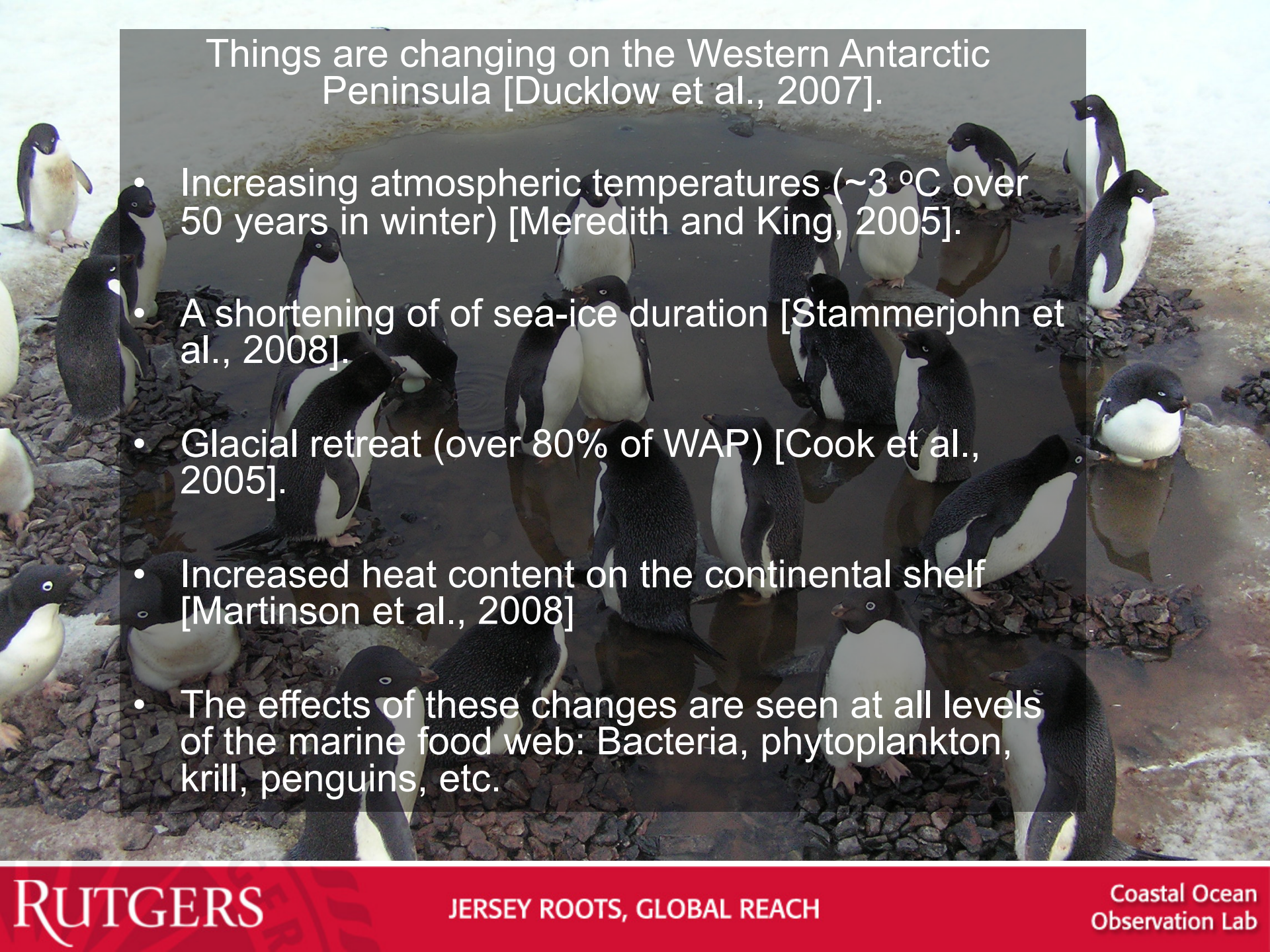
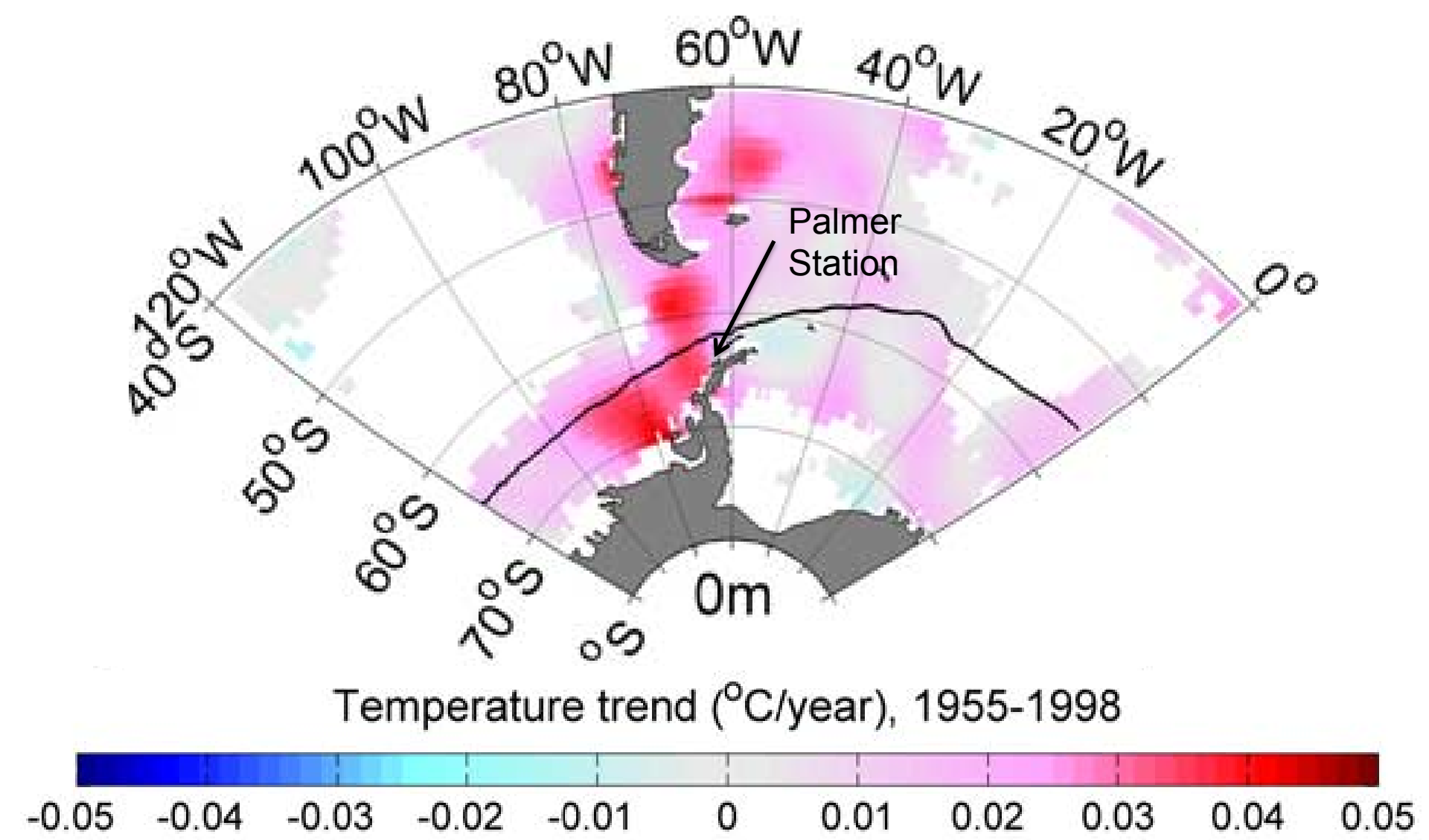
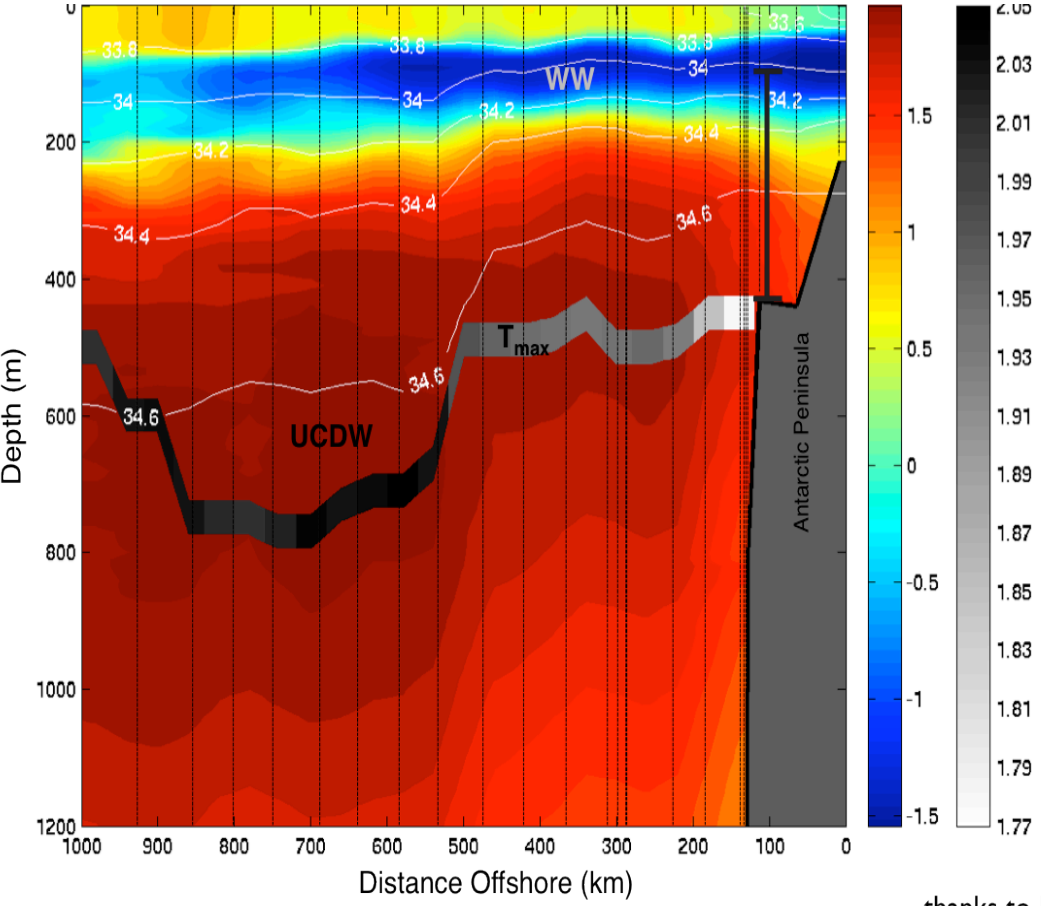


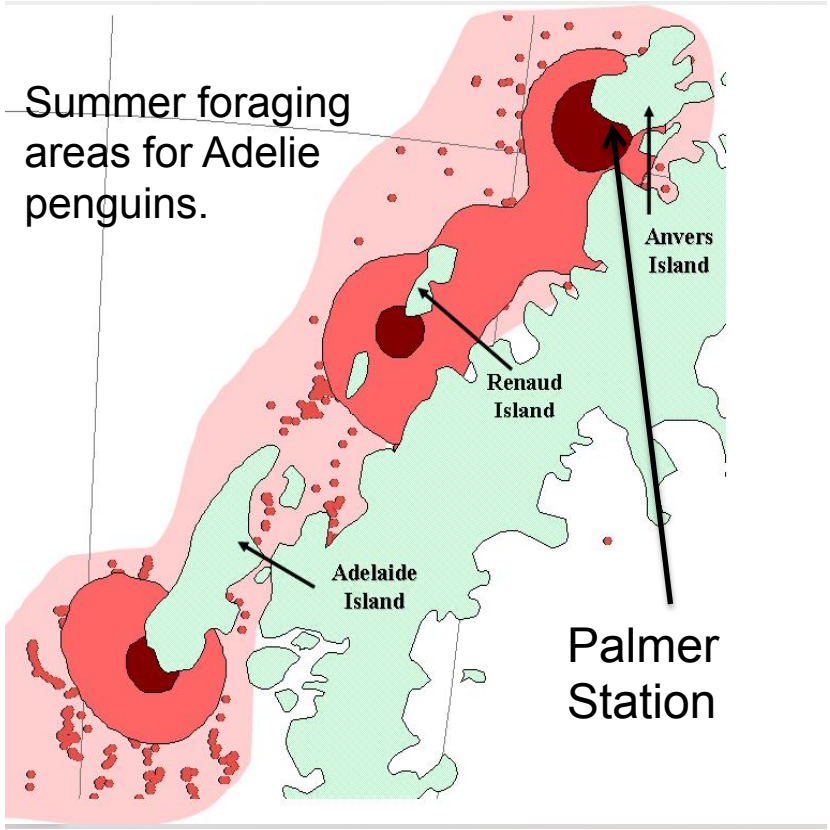
Things are changing on the Western Antarctic Peninsula [Ducklow et al., 2007].

- Increasing atmospheric temperatures (~3 ^{o}C over 50 years in winter) [Meredith and King, 2005].
- A shortening of of sea-ice duration [Stammerjohn et al., 2008].
- Glacial retreat (over 80% of WAP) [Cook et al., 2005].
- Increased heat content on the continental shelf [Martinson et al., 2008]
- The effects of these changes are seen at all levels of the marine food web: Bacteria, phytoplankton, krill, penguins, etc.



Meredith et al. (2005)



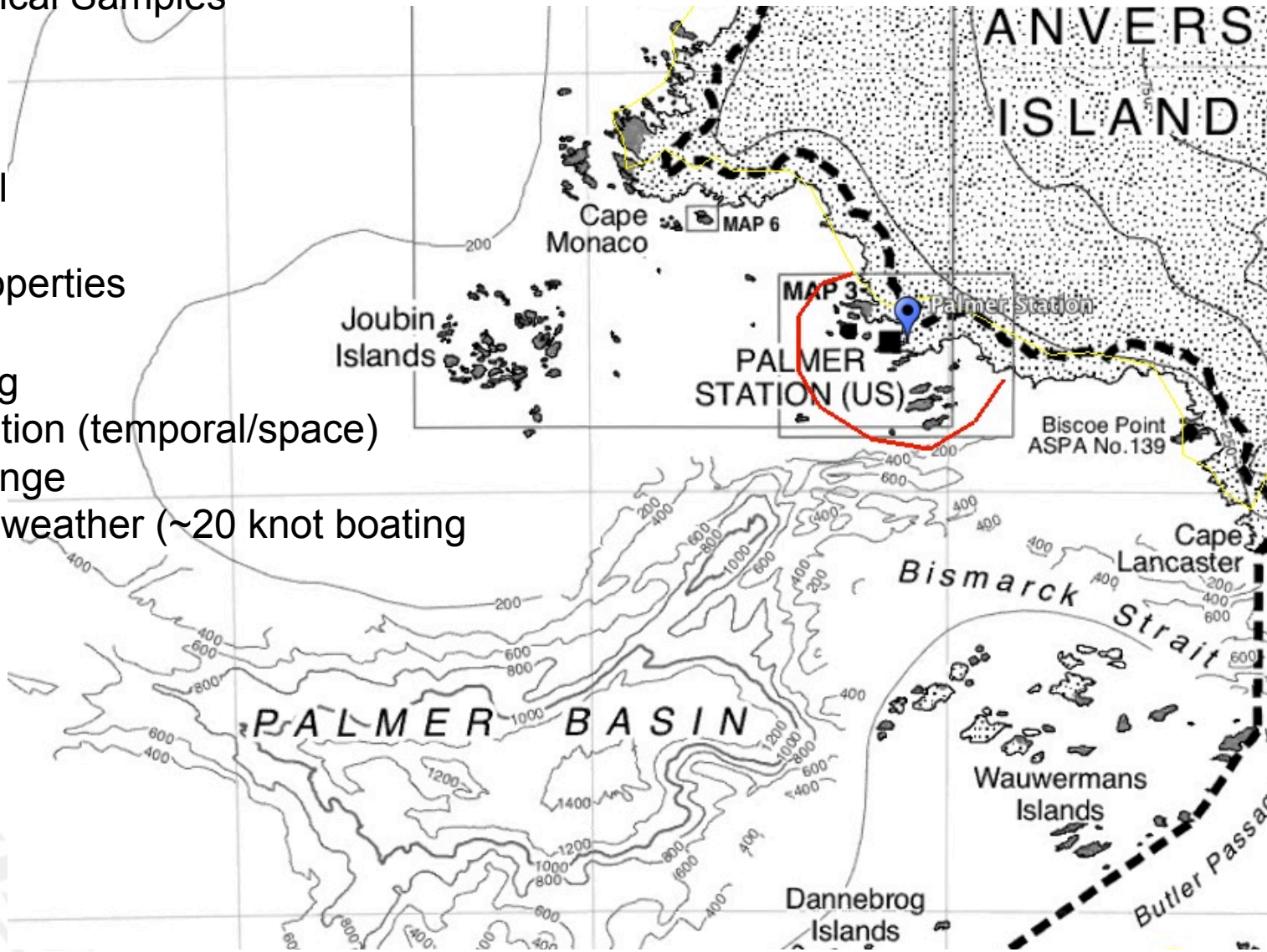


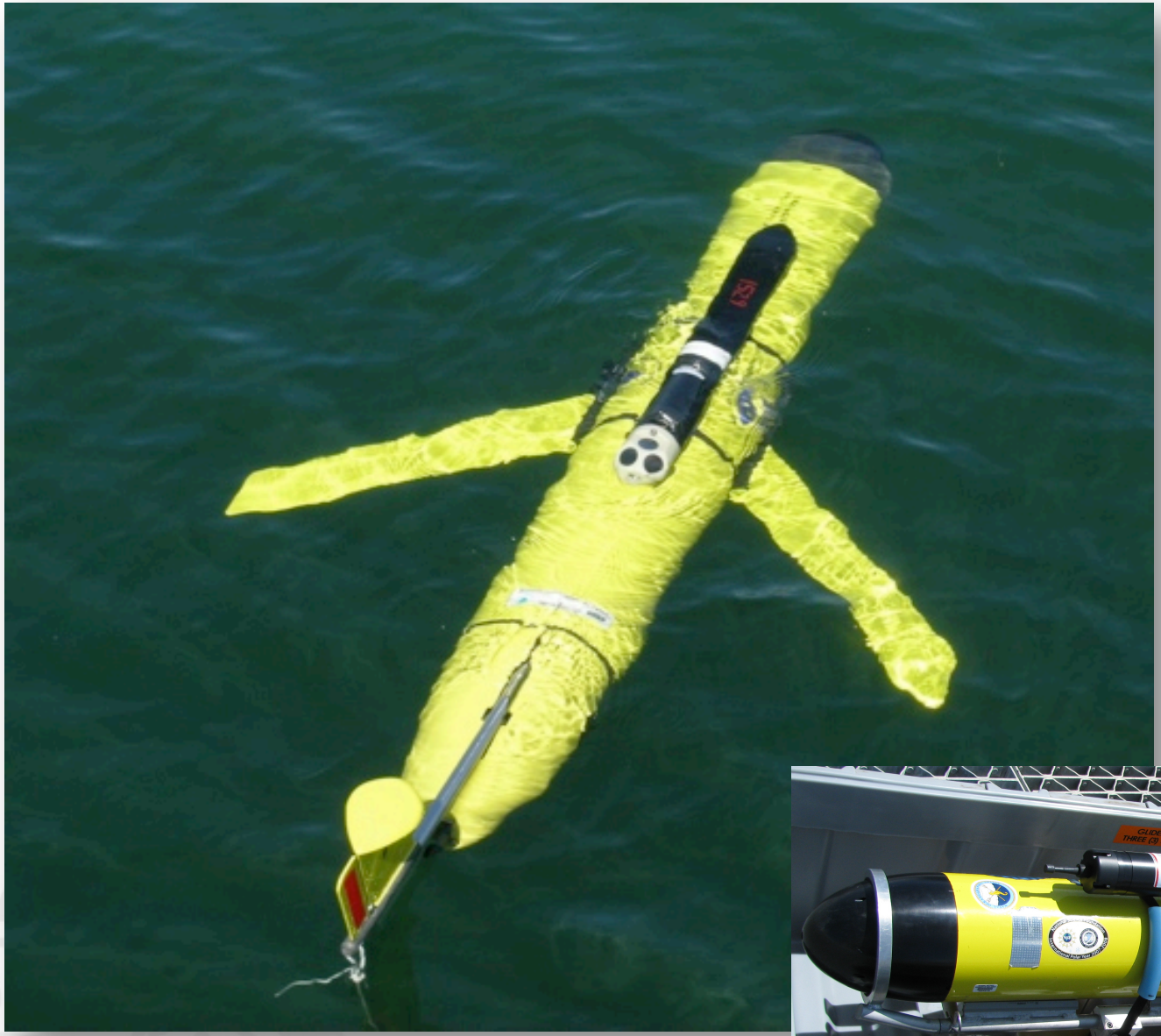
thanks to Doug Martinson

Modeling and observational studies have shown Upper Circumpolar Deep Water (UCDW) penetrating onto the continental shelf, particularly through submarine troughs and canyons, such as those found at Palmer Station, a Penguin foraging hotspot [Martinson et al., 2008, Dinniman et al., 2011].

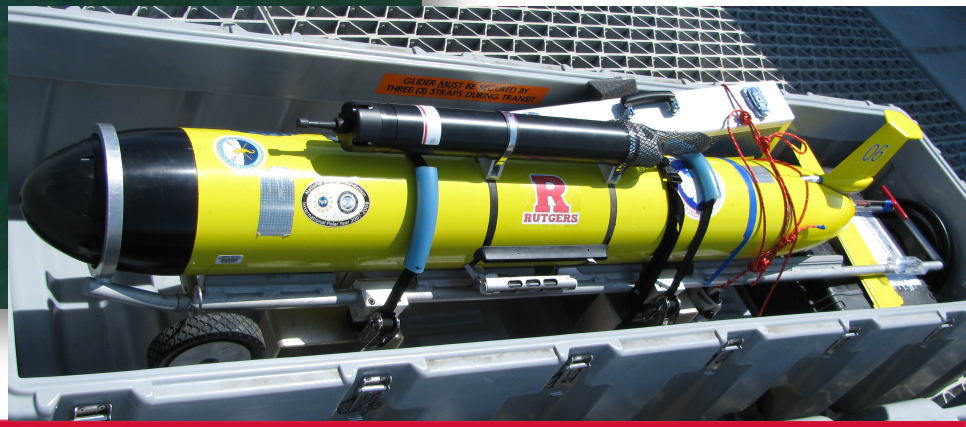
Palmer LTER

- Over 20 years of sampling
- Biological/Physical Samples
  - Temp
  - Salinity
  - Depth
  - Chlorophyll
  - Nutrients
  - Optical Properties
  - Etc.
- Zodiac sampling
  - Low resolution (temporal/space)
  - Limited Range
  - Limited by weather (~20 knot boating limit)






1
3
2


GLIDER MUST BE SECURED BY
THREE (3) STRAPS DURING TRANSIT.
R
RUTGERS

Objectives

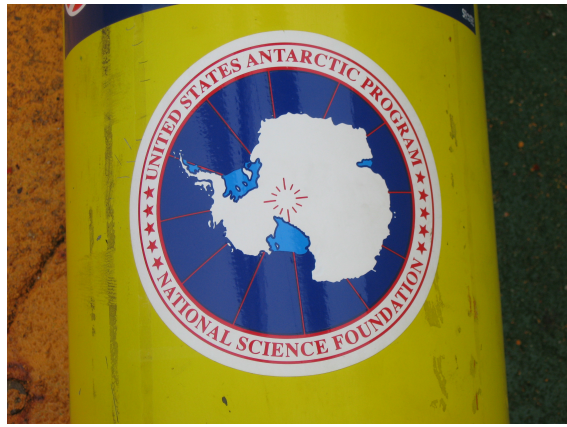
1) Identify the local physical forcing over the Palmer Deep.
    - Tidal and wind forcing.

2) Demonstrate the viability of gliders to act as virtual moorings in extreme environments.

3) Translate glider mounted Acoustic Doppler Current Profiler (ADCP) data to realistic currents.

Buoyancy pump in → the glider pulls in 0.5 L of water

When surfacing to connect glider inflates air bladder



Glider begins to dive downward

Push pump out→ glider inflects and begins to climb to the surface

Nortek Aquadopp Profiler:

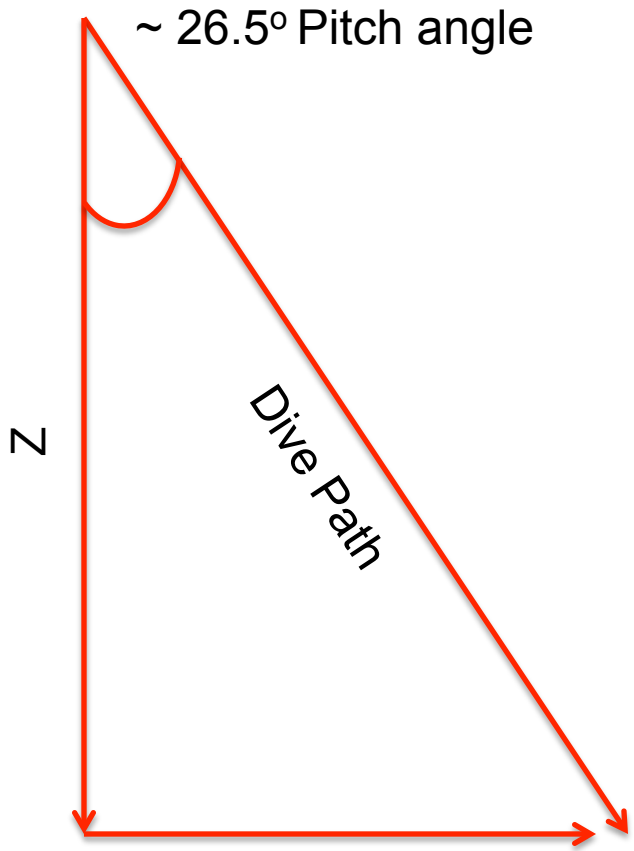
1 MHz Custom glider head – Upward looking
- Instrument pitch reads 0 at glider pitch of 26.5^{o}

10 Meter profile length
- 1 meter bins
- 0.4 meter blanking distance
- 1 profile per second – Average of 6 pings

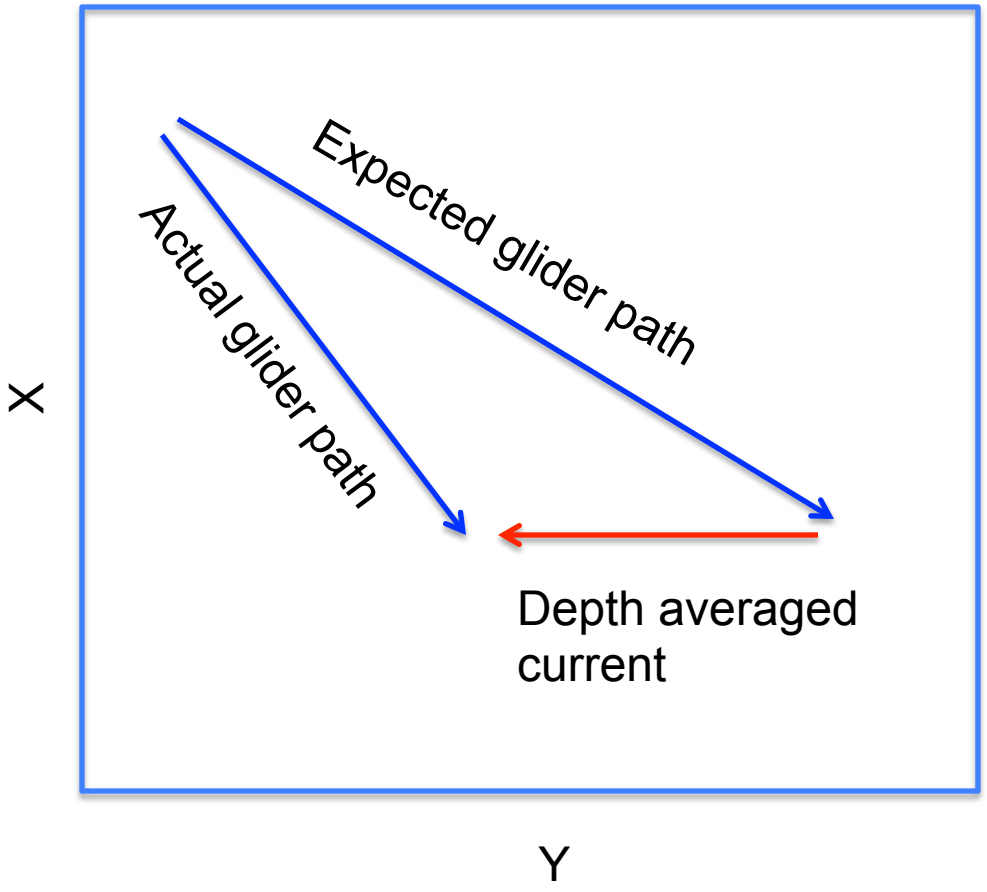
3 beams – collected in Beam coordinates and transformed to ENU during post-processing

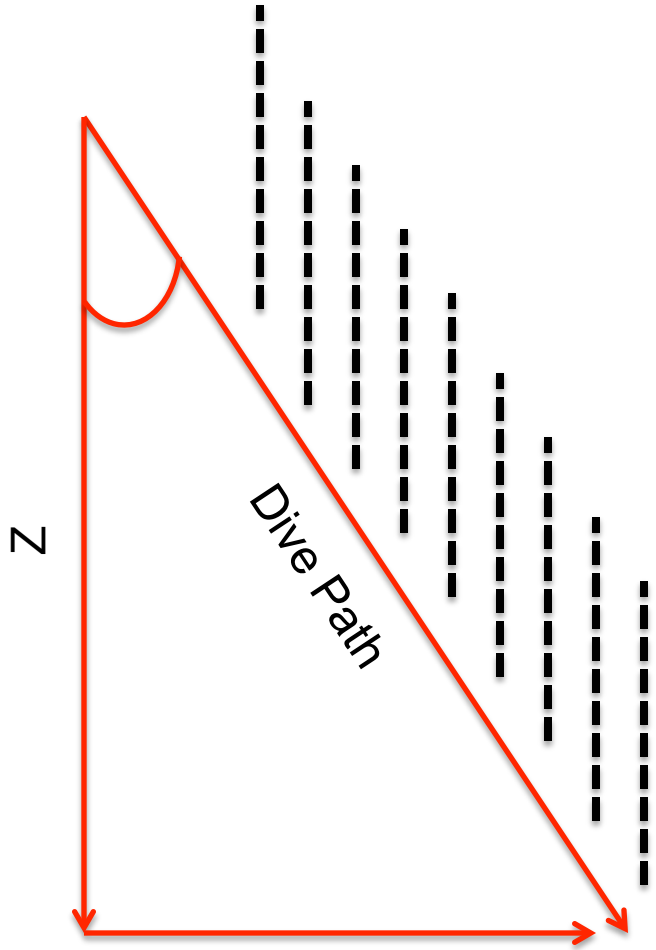
Also measures temperature, pressure, tilt and heading and is internally logging and powered (~30 day deployment).

Traditional Depth Averaged Currents

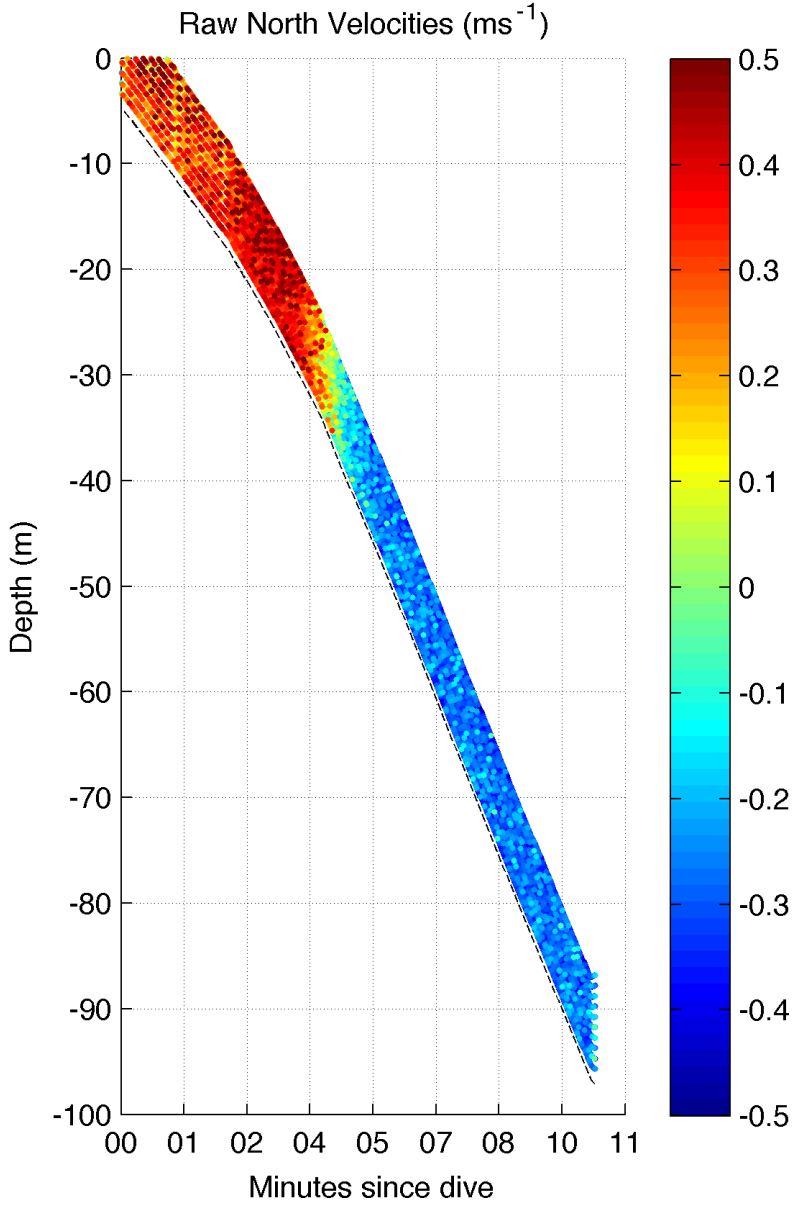


Calculated Glider Horizontal Velocity





Estimated Glider Horizontal Velocity



Shear Least Squares Method

Unknowns

$$(u,v)_r = (u,v)_w - (u,v)_g,$$

Water Velocity Relative to Glider

Ocean Velocity at Measurement cell

Glider velocity at same time as ocean velocity

Assume that $(u,v)_w$ is constant over time between glider surfacing (~ 1 hour to resolve tides in this case).

- Shear is independent of glider motion.
  - Calculate dU/dz and integrate over 1 meter bins. (baroclinic)
  - Constrain with the hourly depth averaged velocity. (barotropic)

Visbeck et al. (2002) and Todd et al. (2011)

$$\mathbf{Gm} \cong \mathbf{d}$$

Raw velocities from ADCP

$$\mathbf{d} = \begin{bmatrix} u_{1,2} & u_{1,3} & u_{1,4} & u_{1,5} & u_{2,2} & \cdots & u_{2,5} & \cdots & u_{N,5} \end{bmatrix}^{\mathrm{T}}$$

Glider and ocean velocities

$$\mathbf{m} = \begin{bmatrix} u_{g,1} & \cdots & u_{g,N} & u_{w,2} & \cdots & u_{w,N+4} \end{bmatrix}^{\mathrm{T}}$$

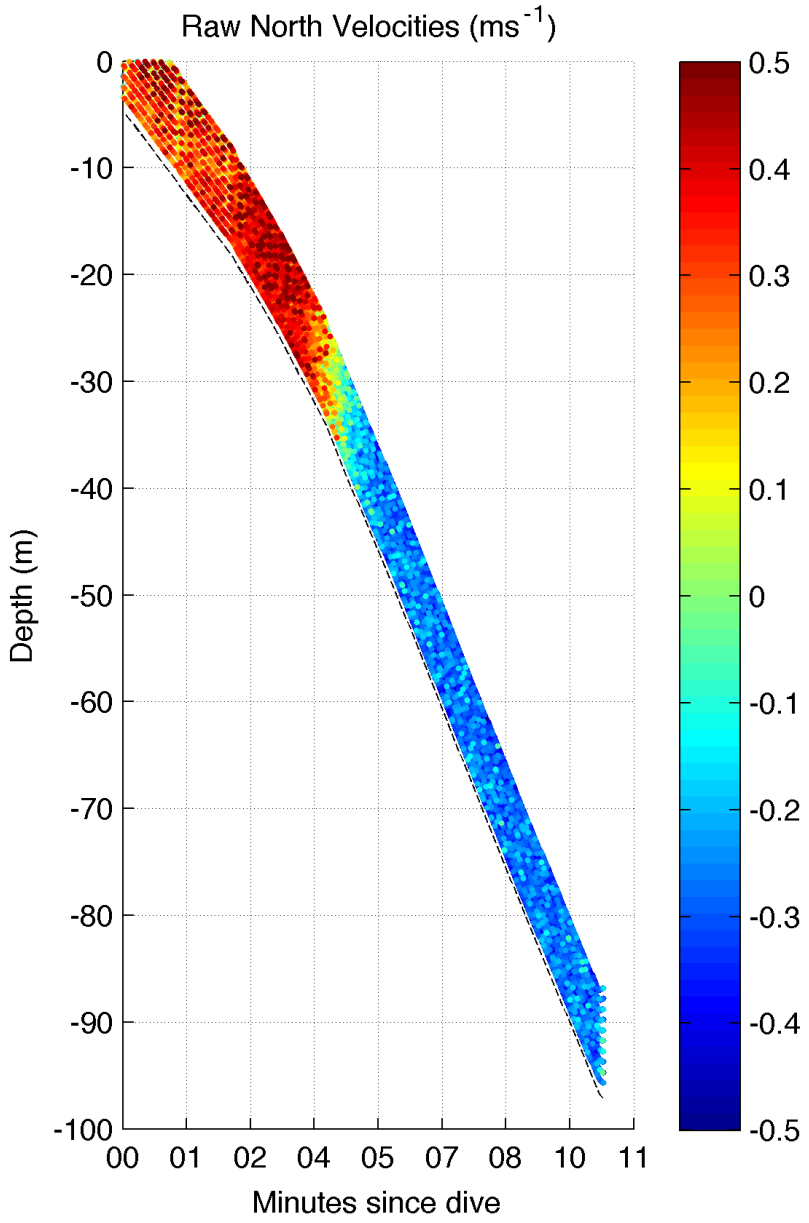
G matrix of coefficients:

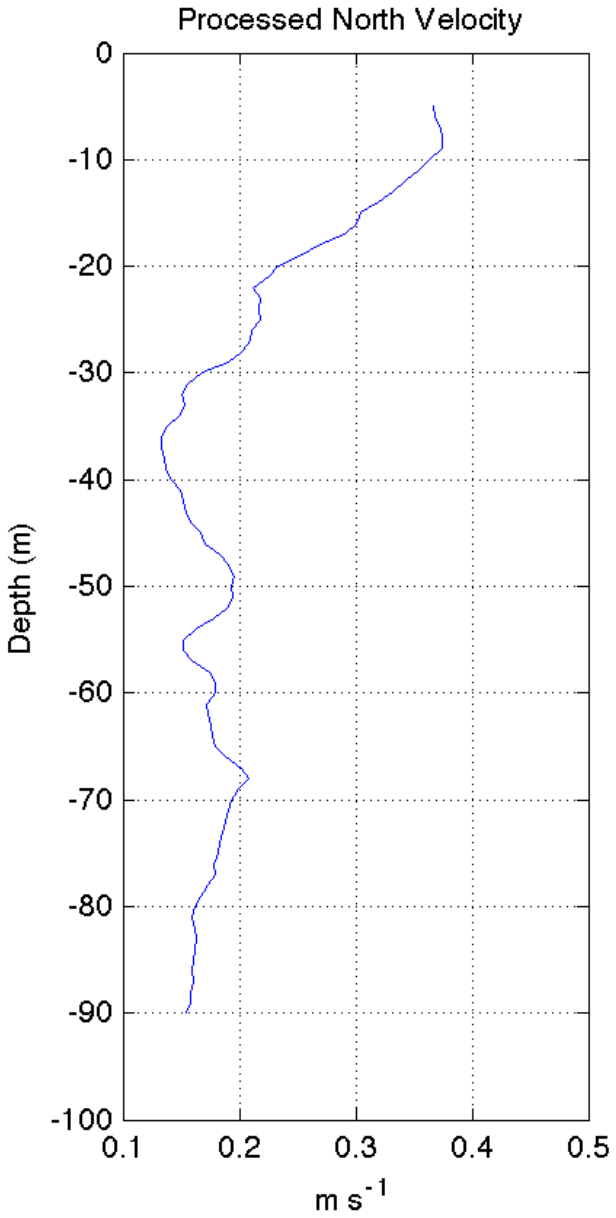
$$\mathbf{G} = \left[\begin{array}{ccccc|ccccccc} -1 & 0 & 0 & \cdots & 0 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 \\ -1 & 0 & 0 & \cdots & 0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 \\ -1 & 0 & 0 & \cdots & 0 & 0 & 0 & 1 & 0 & 0 & \cdots & 0 \\ -1 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 & 1 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 & 0 & 0 & 1 & 0 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 & 0 & 0 & 0 & 1 & 0 & \cdots & 0 \\ 0 & -1 & 0 & \cdots & 0 & 0 & 0 & 0 & 0 & 1 & \cdots & 0 \\ 0 & 0 & -1 & \cdots & 0 & 0 & 0 & 1 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & -1 & 0 & 0 & 0 & 0 & 0 & \cdots & 1 \end{array}\right]$$

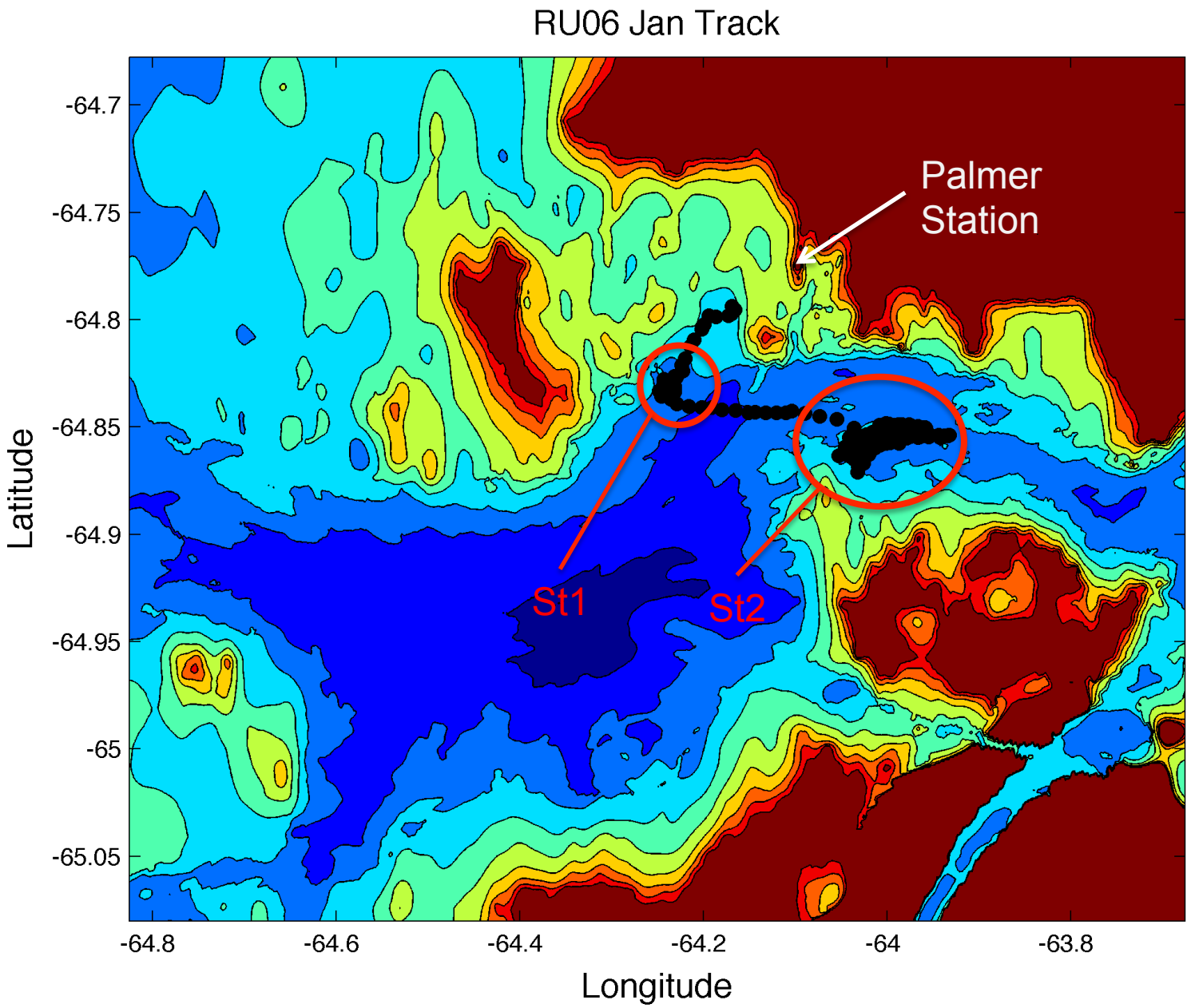
Solution by Least Squares:

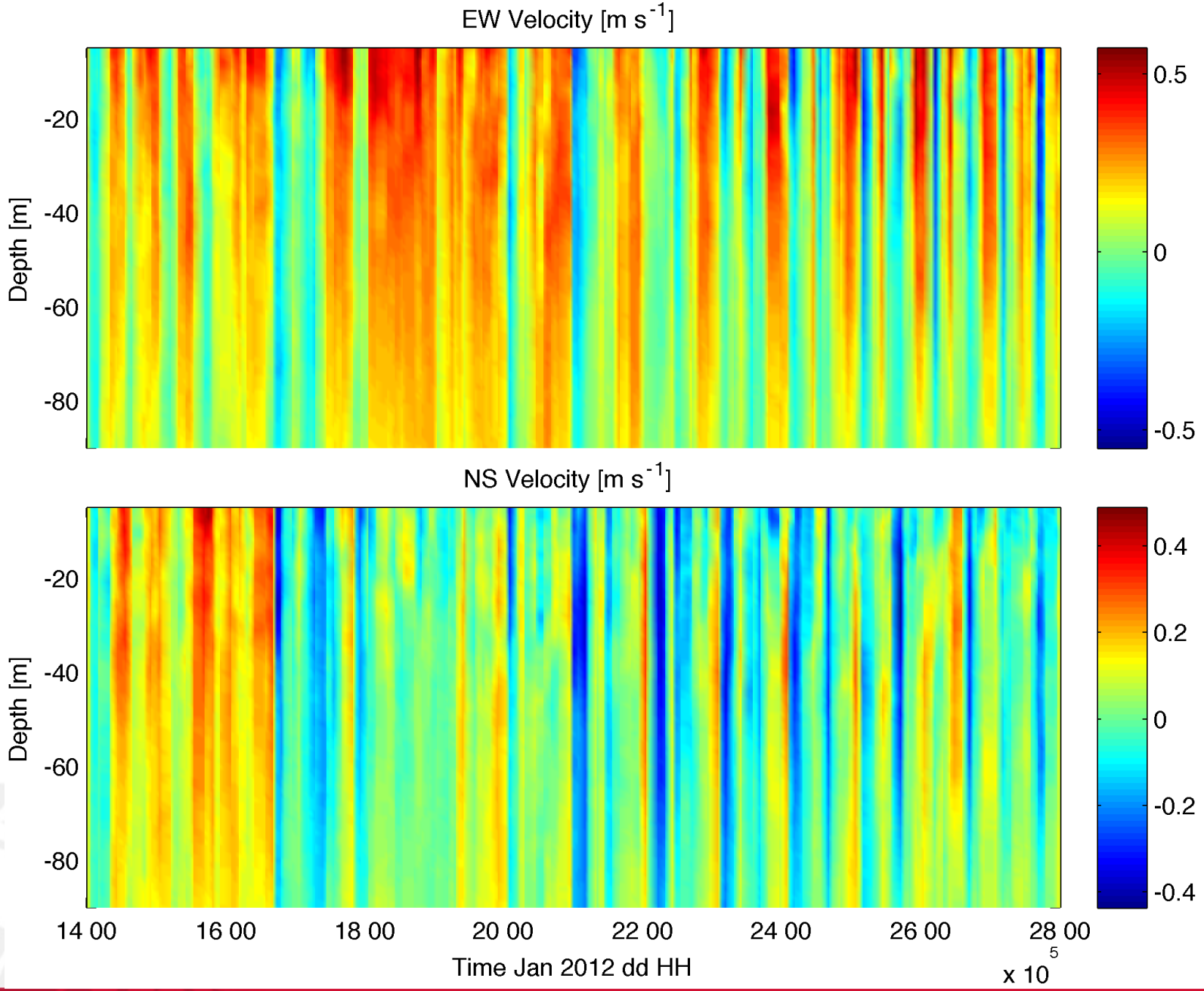
$$\mathbf{m} = \left(\mathbf{G}^{\mathrm{T}}\mathbf{G}\right)^{-1}\mathbf{G}^{\mathrm{T}}\mathbf{d}.$$

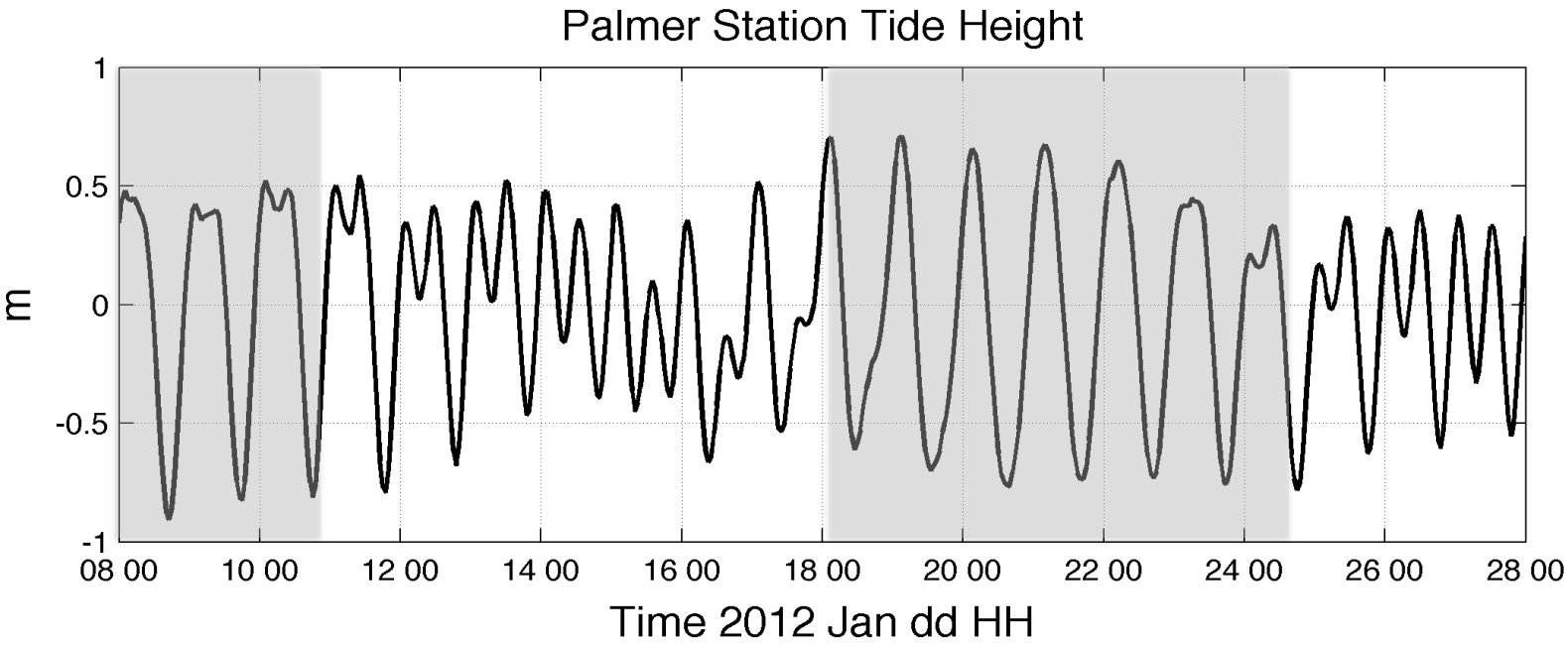
Visbeck et al., (2002) and Todd et al., (2011)


Raw North Velocities (ms-1)
Depth (m)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
00
01
02
04
05
07
08
10
11
Minutes since dive
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5


Processed North Velocity
Depth (m)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0.1
0.2
0.3
0.4
0.5
m s-1


RU06 Jan Track
Palmer Station
St1
St2
Latitude
-64.7
-64.75
-64.8
-64.85
-64.9
-64.95
-65
-65.05
Longitude
-64.8
-64.6
-64.4
-64.2
-64
-63.8


EW Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.5
0
-0.5
NS Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.4
0.2
0
-0.2
-0.4
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5



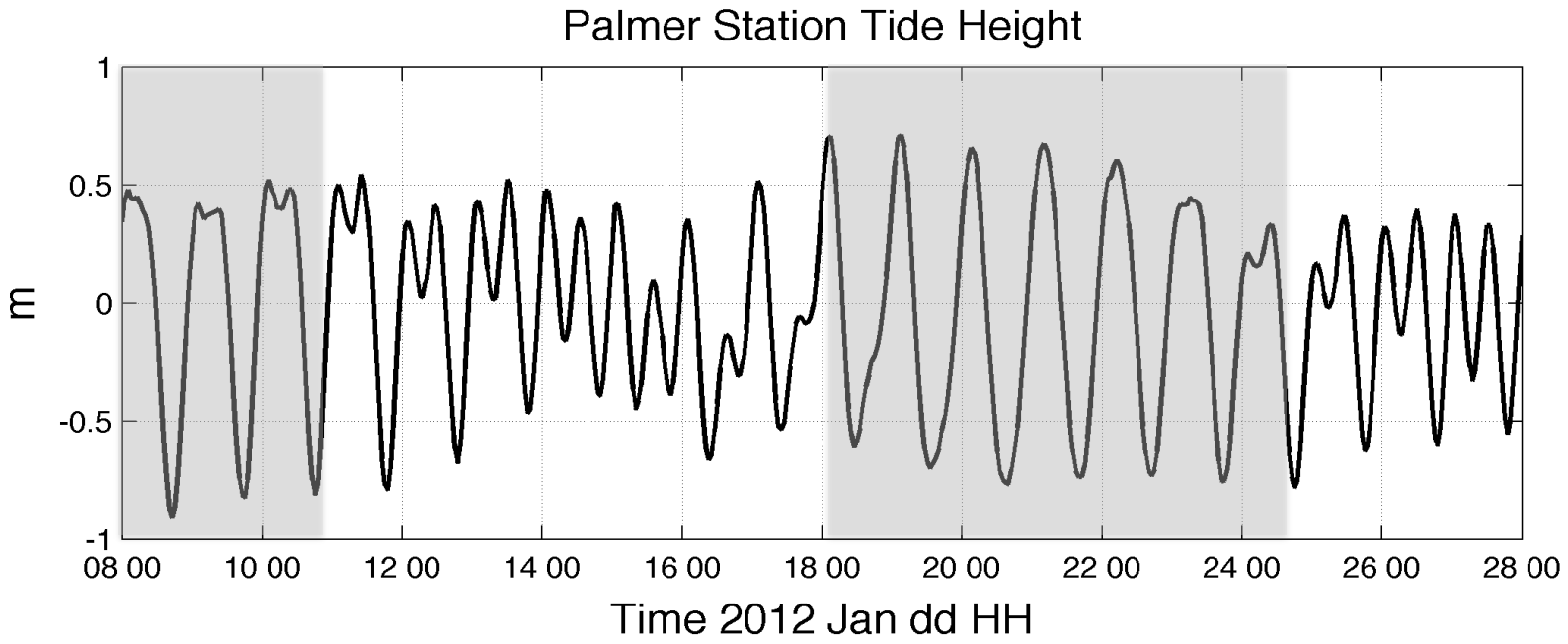
Mixed phase tide –

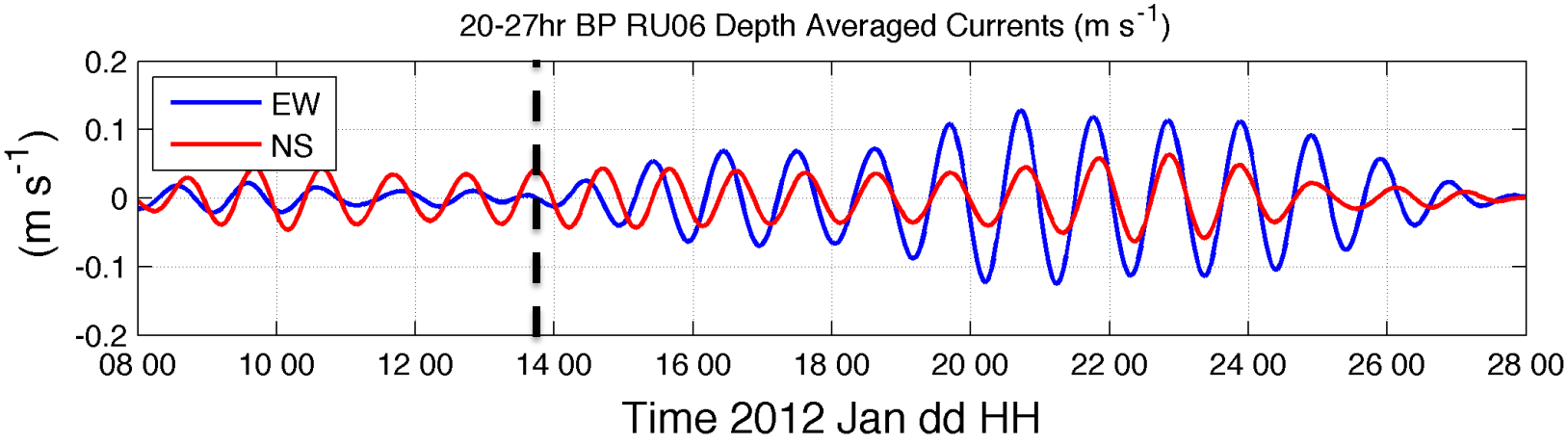
Diurnal – K1 and O1 ~ 23 - 25 hrs

* Amplitudes of ~1.2 meters

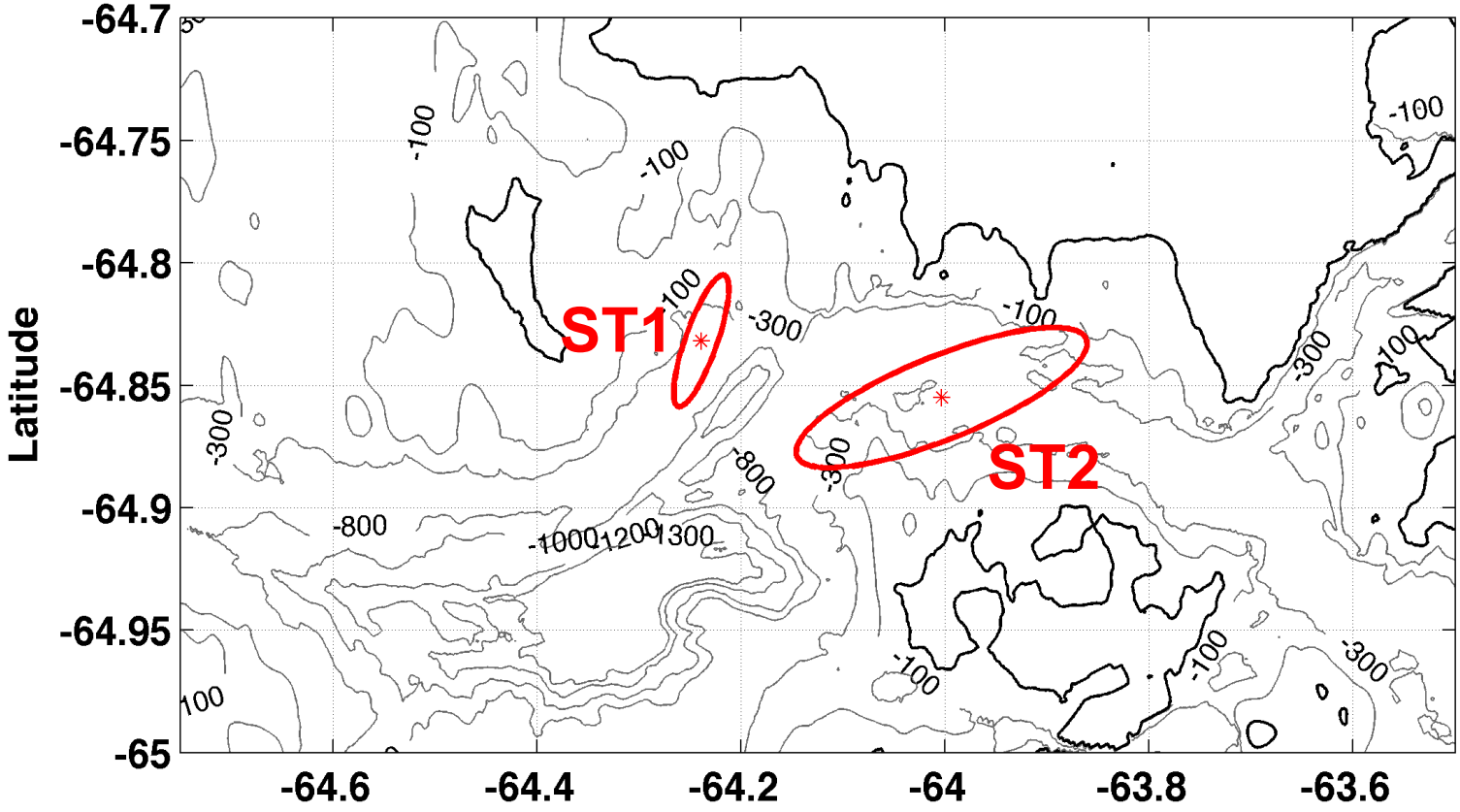
Semi-diurnal – M2 and S2 ~ 12 hrs

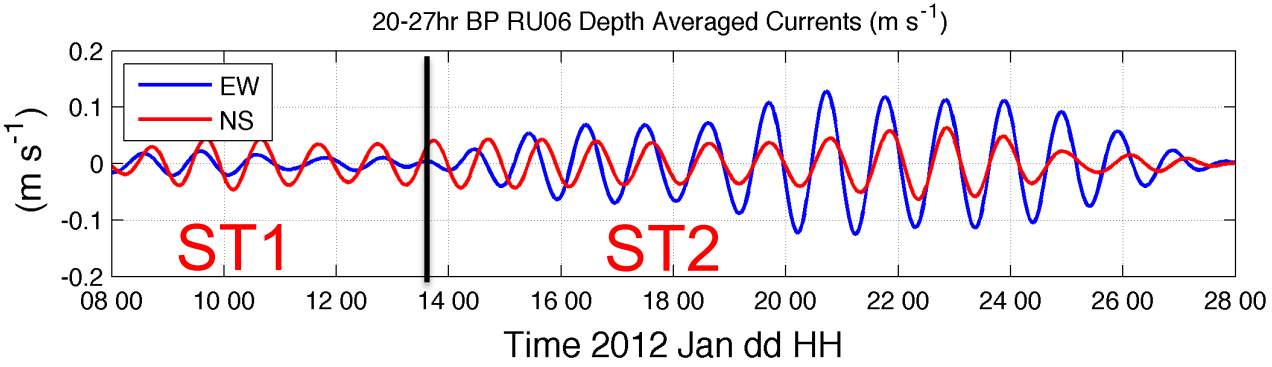
- Amplitudes of ~0.8 meters
- Inertial period ~ 13.25 hr

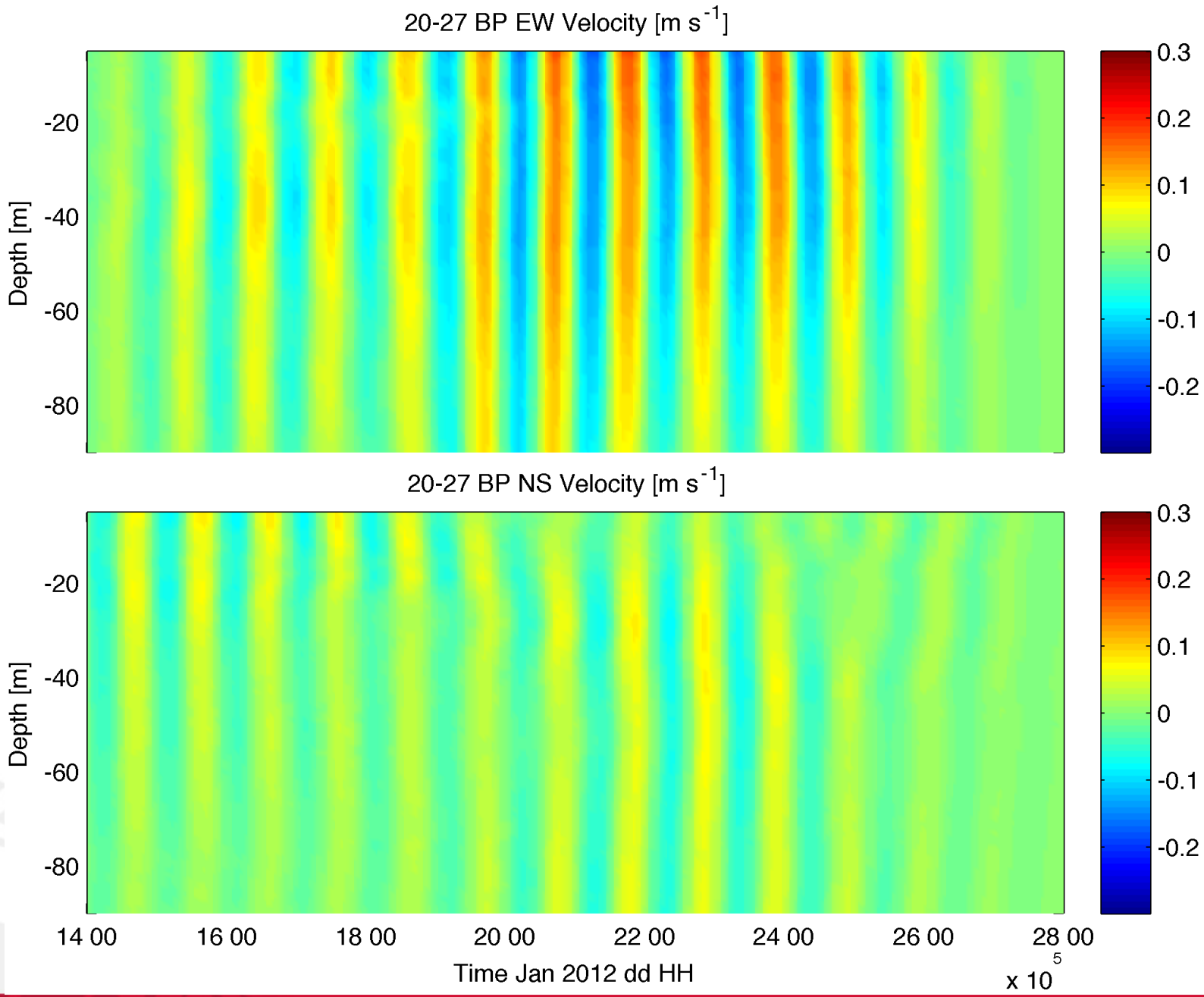

Palmer Station Tide Height
m
1
0.5
0
-0.5
-1
08 00
10 00
12 00
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH

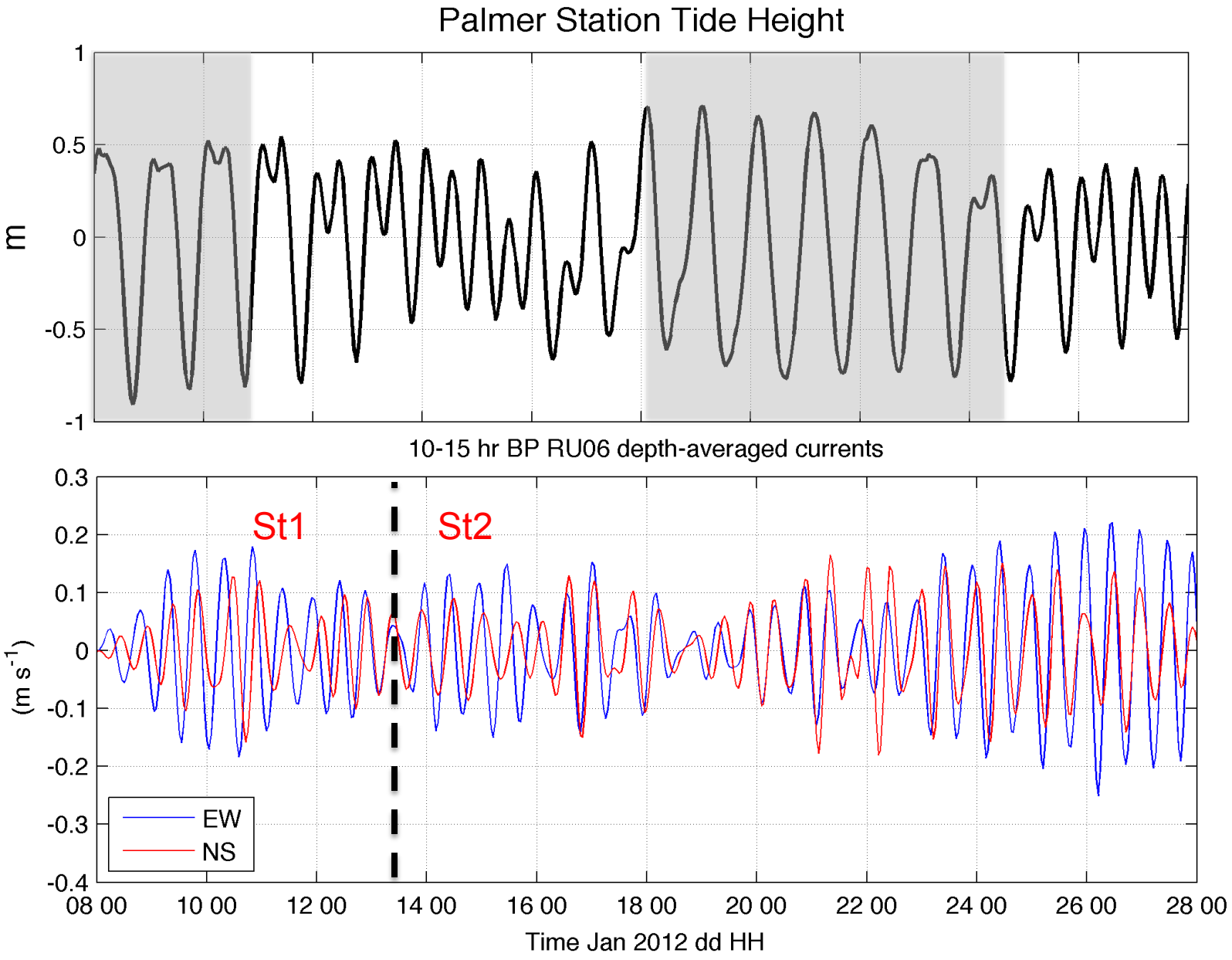

20-27hr BP RU06 Depth Averaged Currents (m s-1)
EW
NS
(m s-1)
0.2
0.1
0
-0.1
-0.2
08 00
10 00
12 00
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH

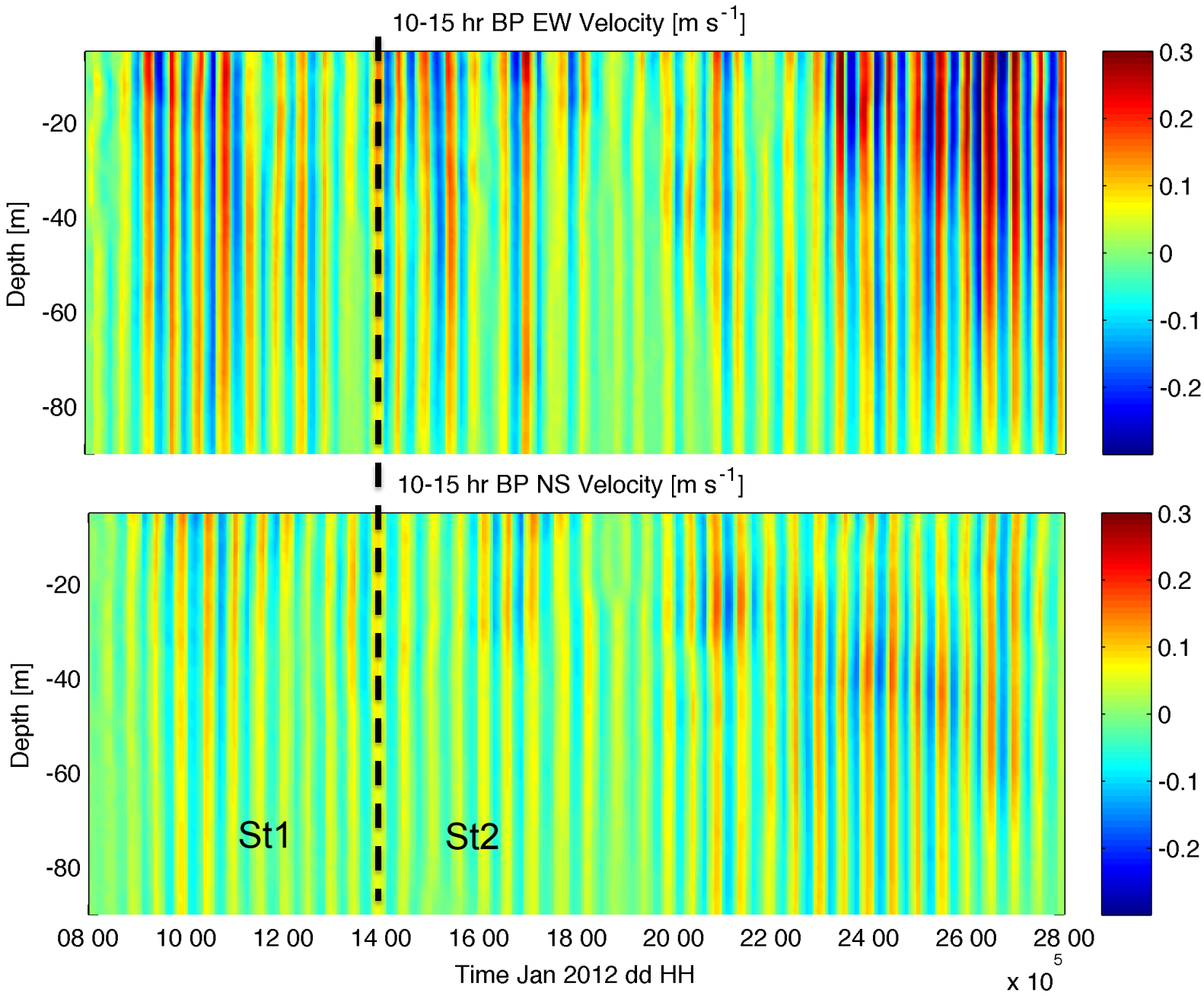
RU06 Diurnal Tidal Ellipses

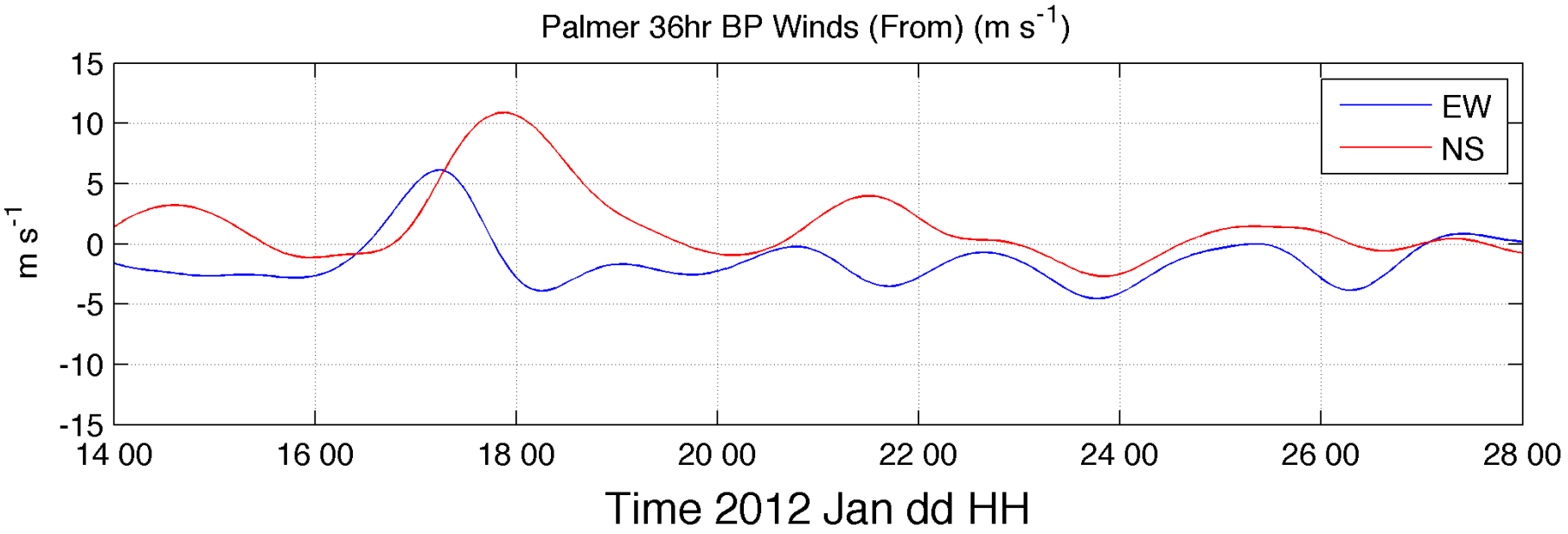


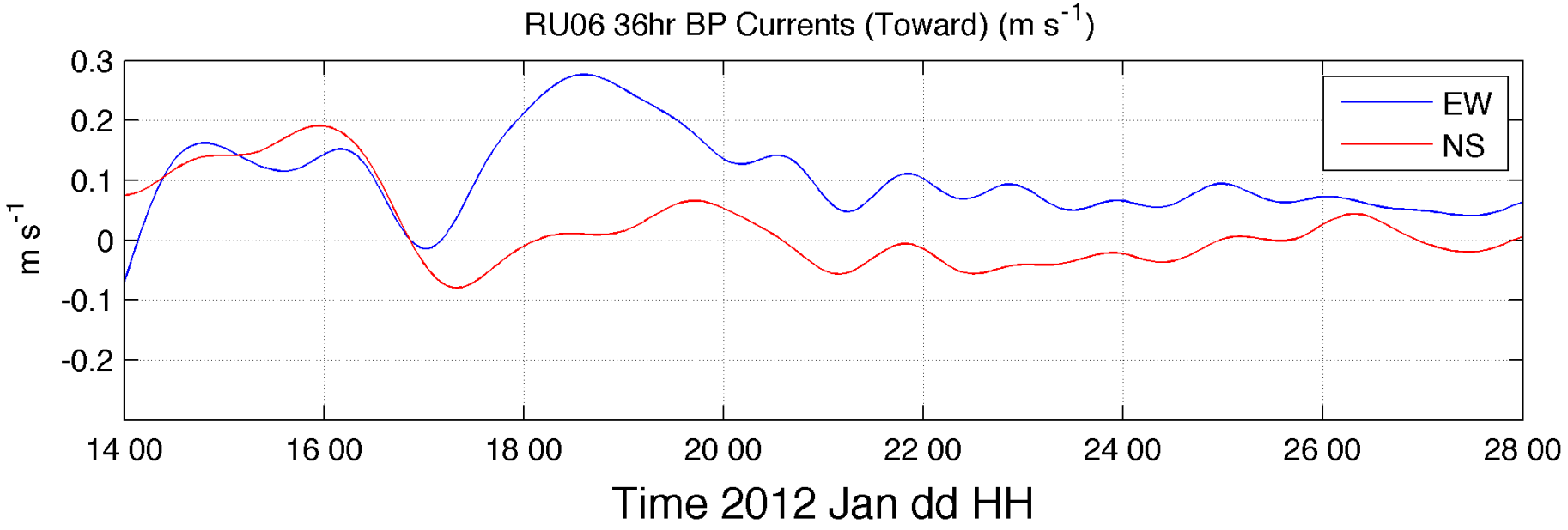


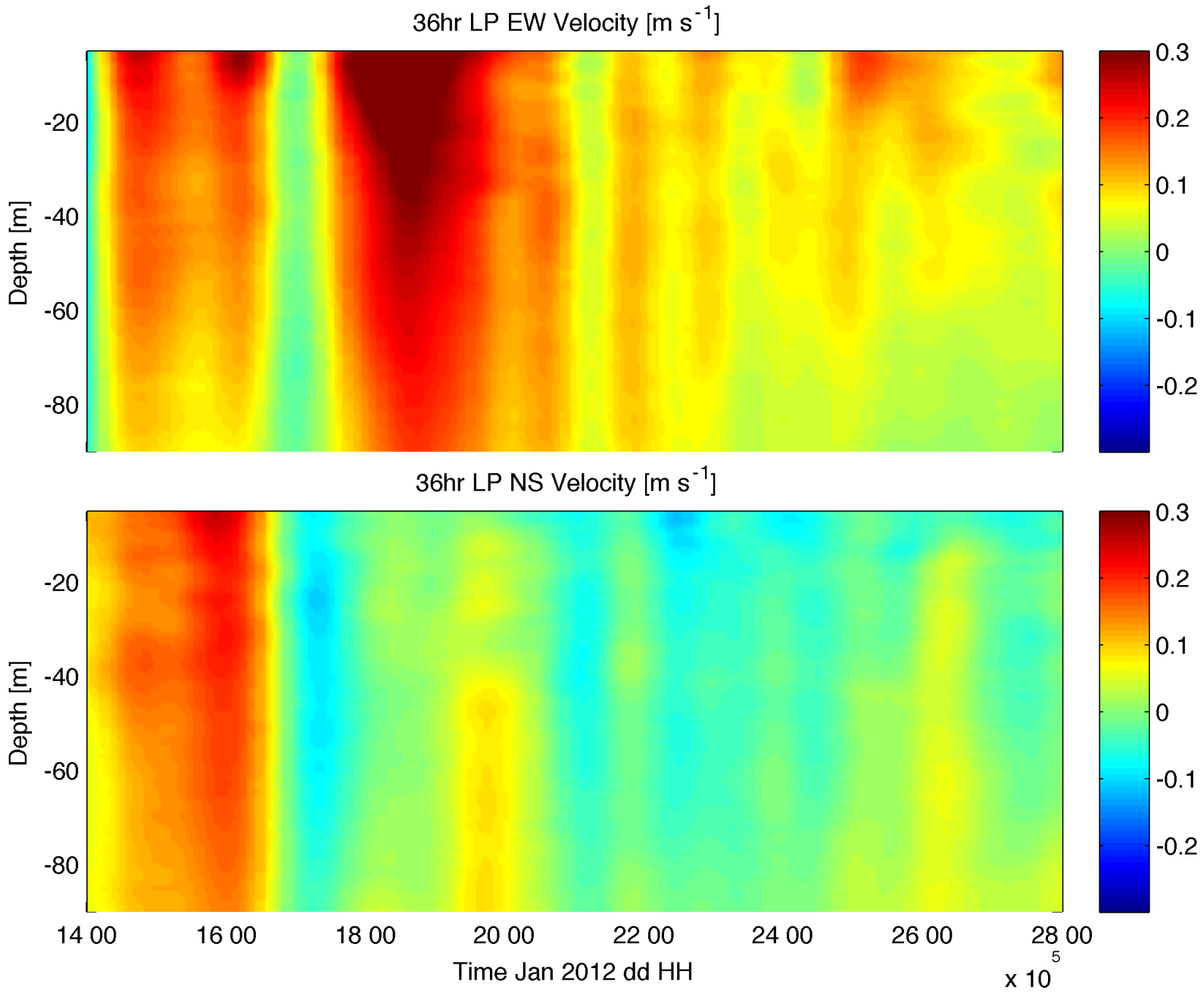

20-27 BP EW Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
20-27 BP NS Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5


Palmer Station Tide Height
m
1
0.5
0
-0.5
-1
10-15 hr BP RU06 depth-averaged currents
St1
St2
(m s-1)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
EW
NS
08 00
10 00
12 00
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH


10-15 hr BP EW Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
10-15 hr BP NS Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
St1
St2
0.3
0.2
0.1
0
-0.1
-0.2
08 00
10 00
12 00
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5


Palmer 36hr BP Winds (From) (m s-1)
15
10
5
0
-5
-10
-15
m s-1
EW
NS
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH


RU06 36hr BP Currents (Toward) (m s-1)
0.3
0.2
0.1
0
-0.1
-0.2
m s-1
EW
NS
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH


36hr LP EW Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
36hr LP NS Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5

Summary

1) Demonstrated the utility of deploying glider-mounted ADCPs to explore difficult to sample environments.

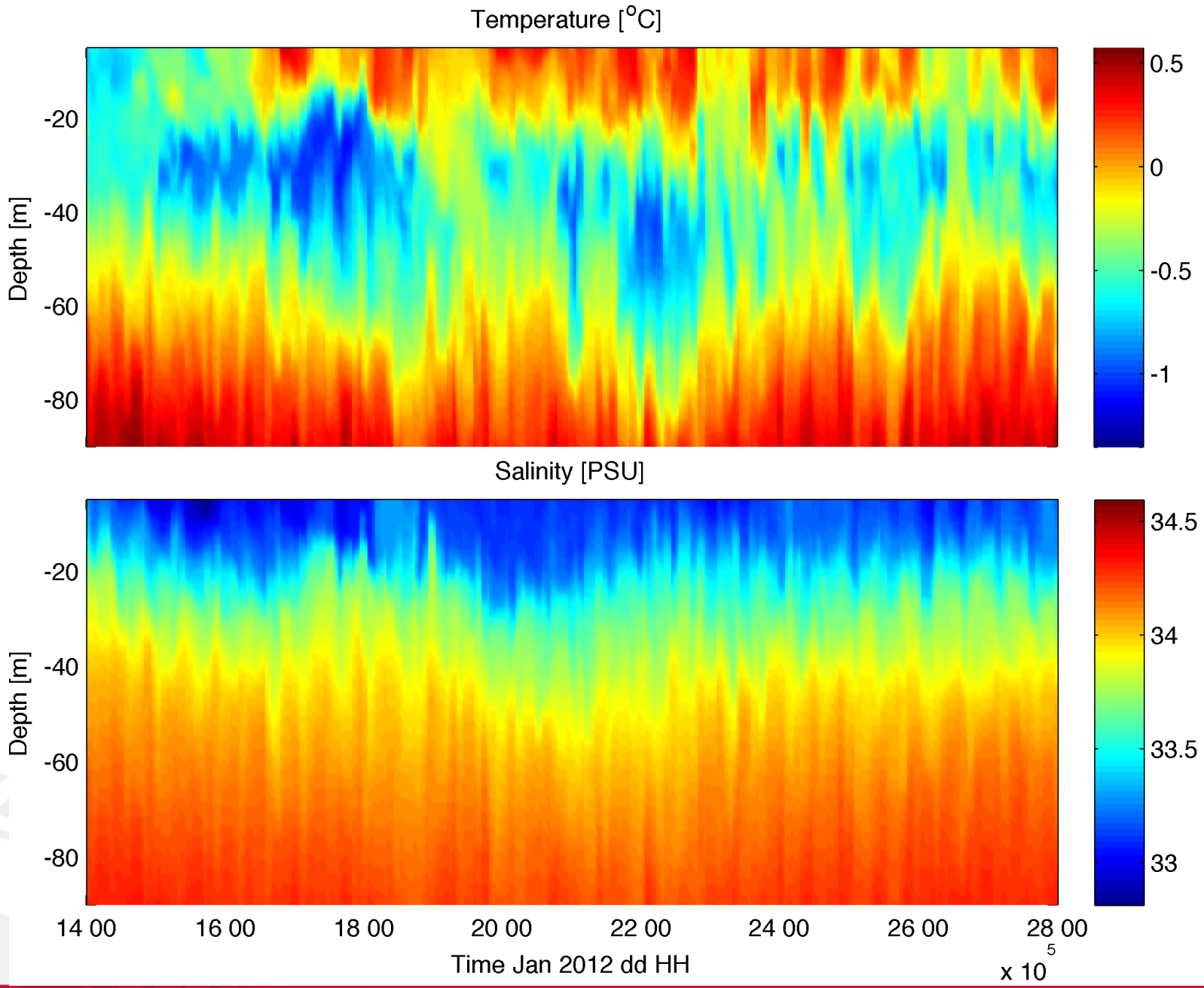
2) Collected ADCP data and resolved tidal, inertial and storm currents from a ‘virtually moored’ glider

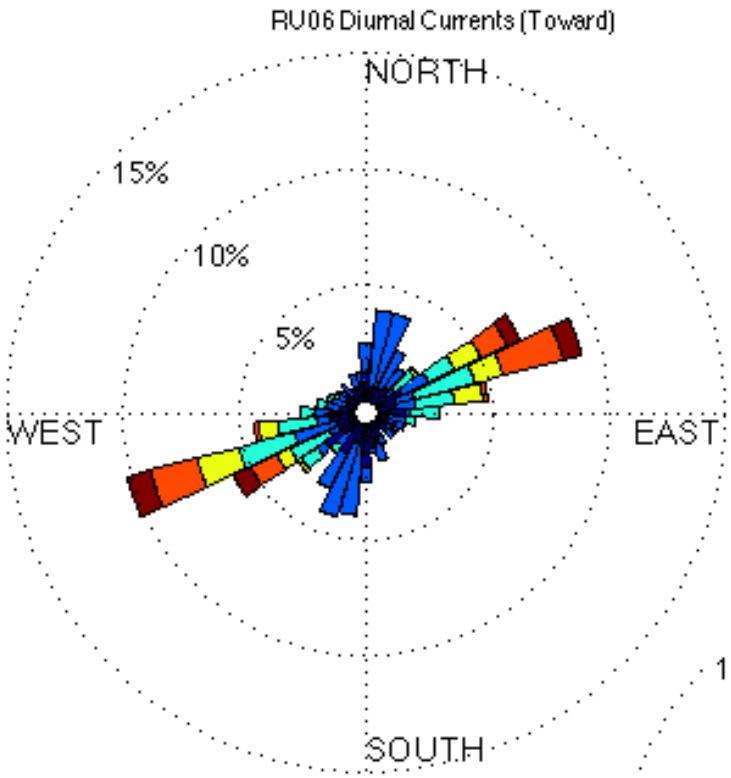
3) The upper 100 meters of the water-column near the mouth of the Bismark Strait is dominated by diurnal and inertial signals.
    1) Diurnal currents range from -0.2 to 0.2 m/s
    2) Inertial/semi-diurnal currents range -0.3 to 0.3 m/s
    3) Wind driven currents are nearly 0.3 m/s and penetrate below our working depth.

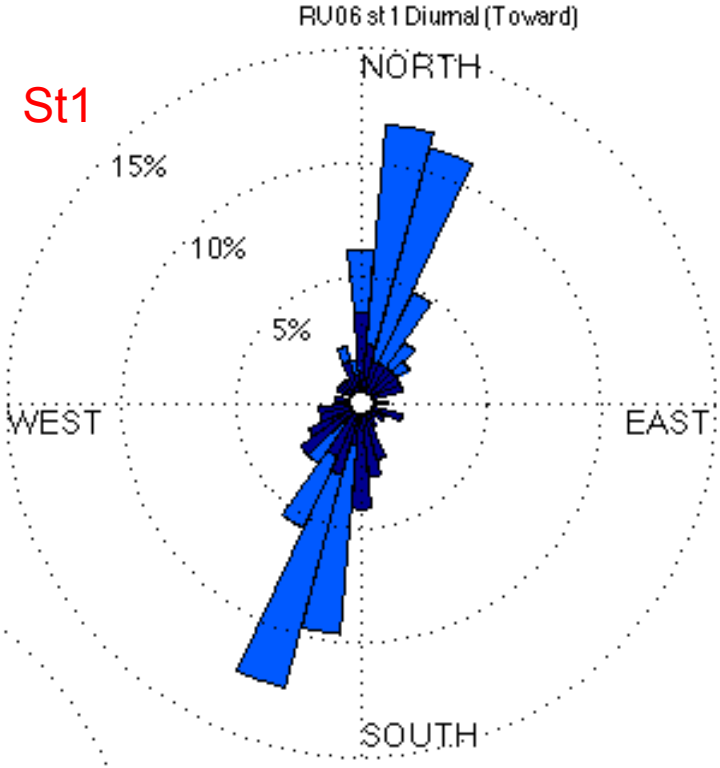
Thank you!

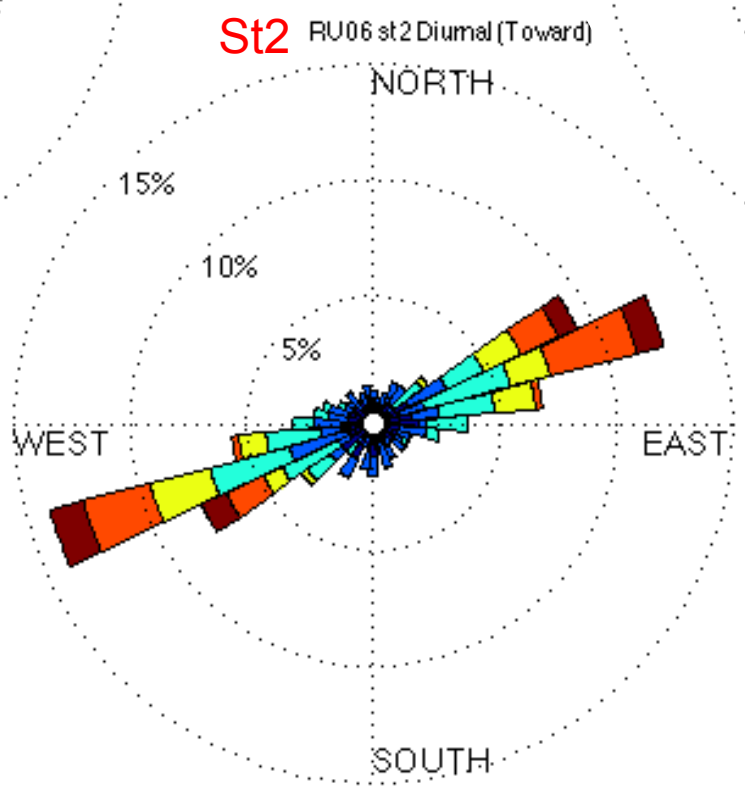
- Advisors
  - Scott Glenn
  - Oscar Schofield
- Committee members
  - Josh Kohut
  - Doug Martinson
  - Sharon Stammerjohn
- Coastal Ocean Observation Lab
- National Science Foundation
- Teledyne-Webb
- Nortek USA
- Ocean Observing Initiative (OOI)
- United States Antarctic Program

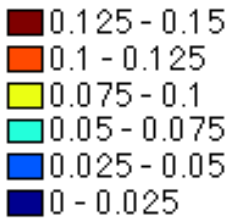
- Palmer Station
- Crew of the Laurence M. Gould
- This work was supported by a Nortek USA Student equipment grant / and a Teledyne Webb Glider graduate student fellowship.

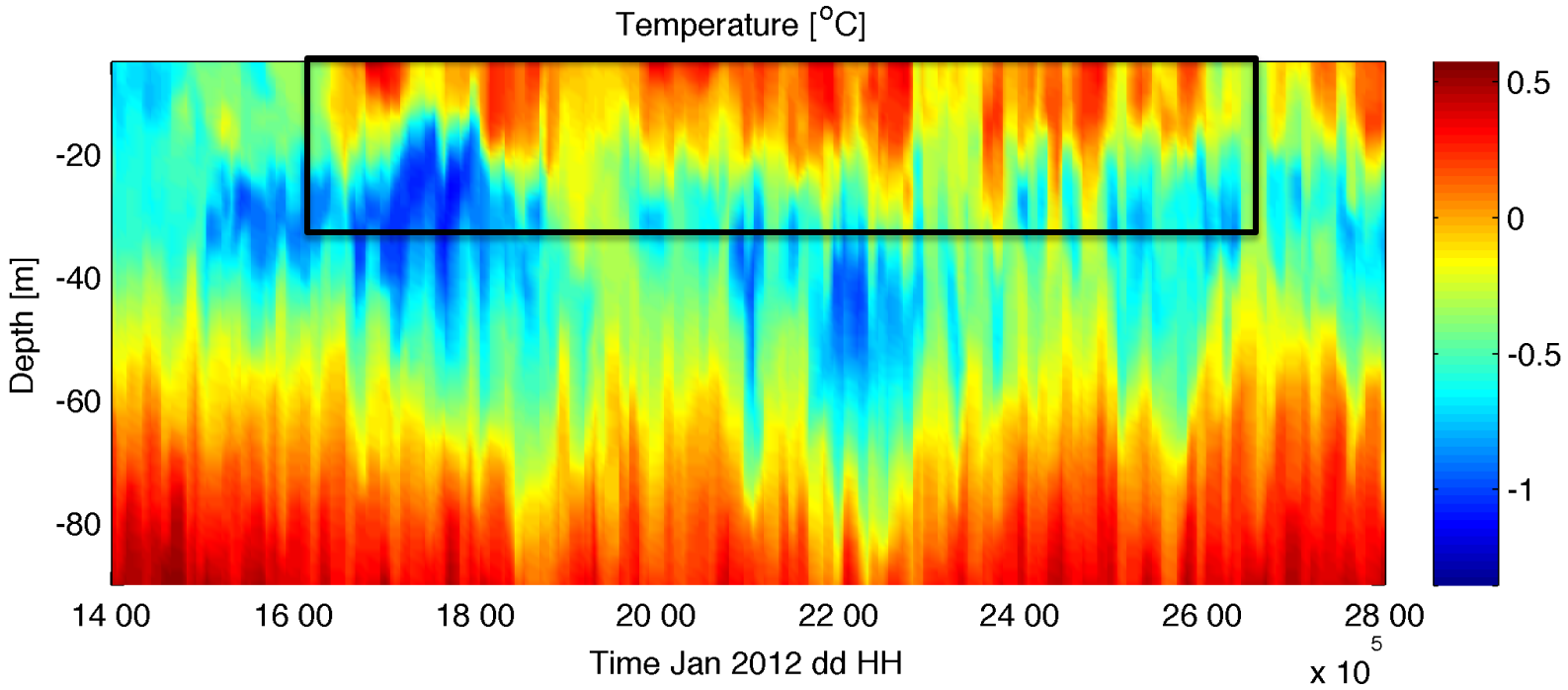

Temperature [°C]
Depth [m]
-20
-40
-60
-80
0.5
0
-0.5
-1
Salinity [PSU]
Depth [m]
-20
-40
-60
-80
34.5
34
33.5
33
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5


RU06 Diurnal Currents (Toward)
NORTH
15%
10%
5%
WEST
EAST
SOUTH

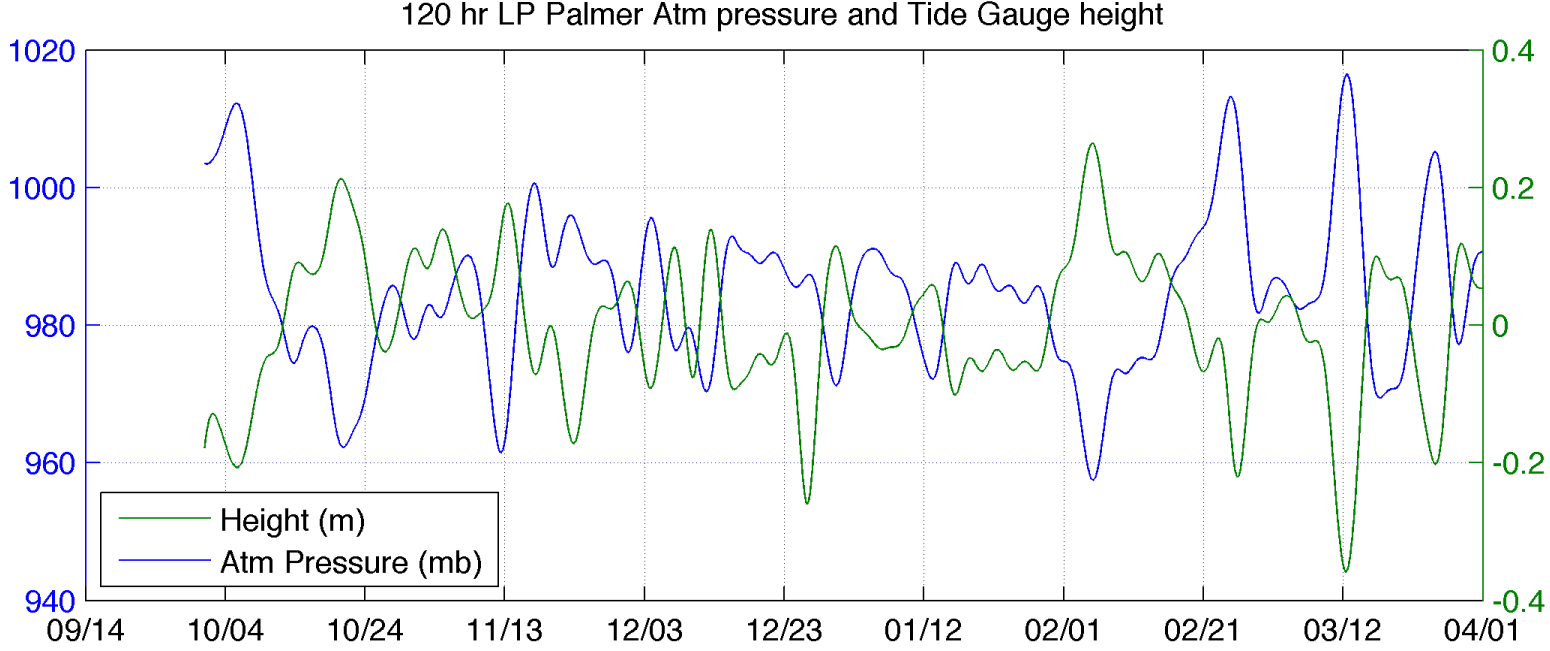

St1
RU06 st1 Diurnal (Toward)
NORTH
15%
10%
5%
WEST
EAST
SOUTH


St2
RU06 st2 Diurnal (Toward)
NORTH
15%
10%
5%
WEST
EAST
SOUTH

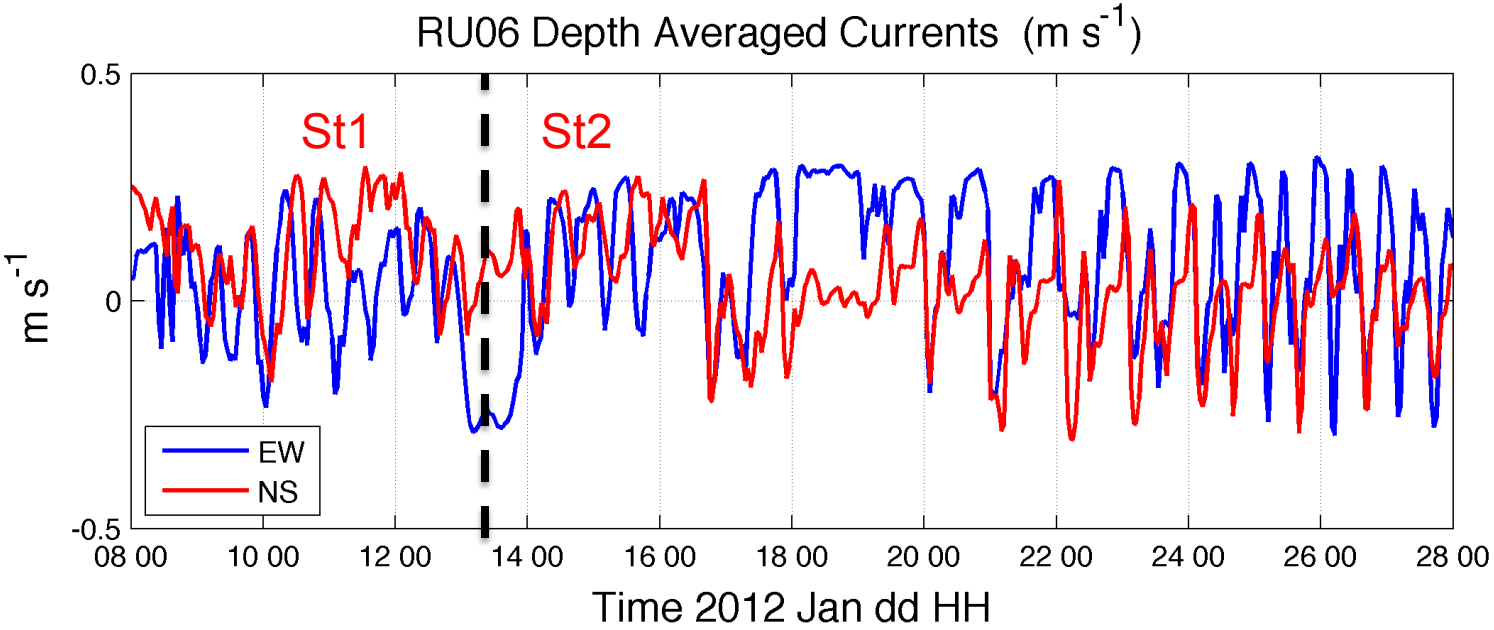

0.125 - 0.15
0.1 - 0.125
0.075 - 0.1
0.05 - 0.075
0.025 - 0.05
0 - 0.025

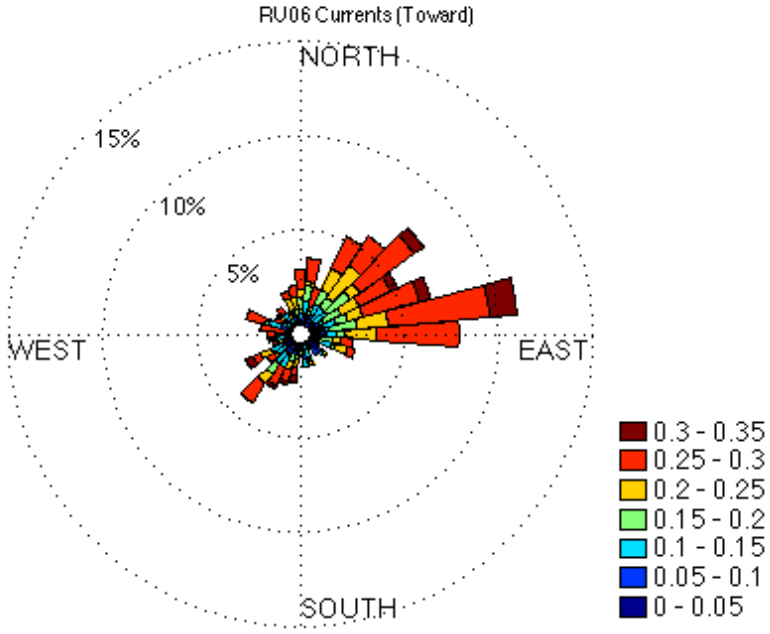


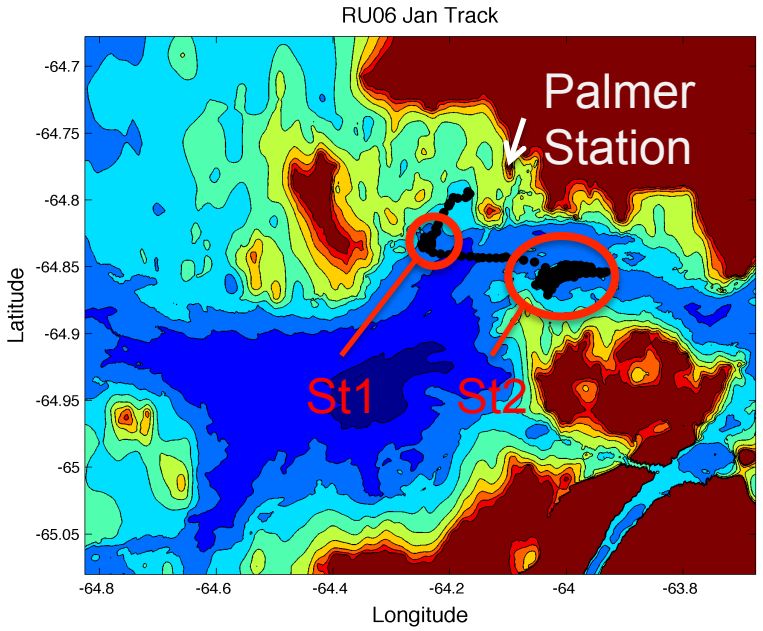
Warm surface water advected over the 'virtual mooring location' likely from the shallow near-shore area where it had been warmed due to solar insolation and freshened due to glacial melt and precipitation.

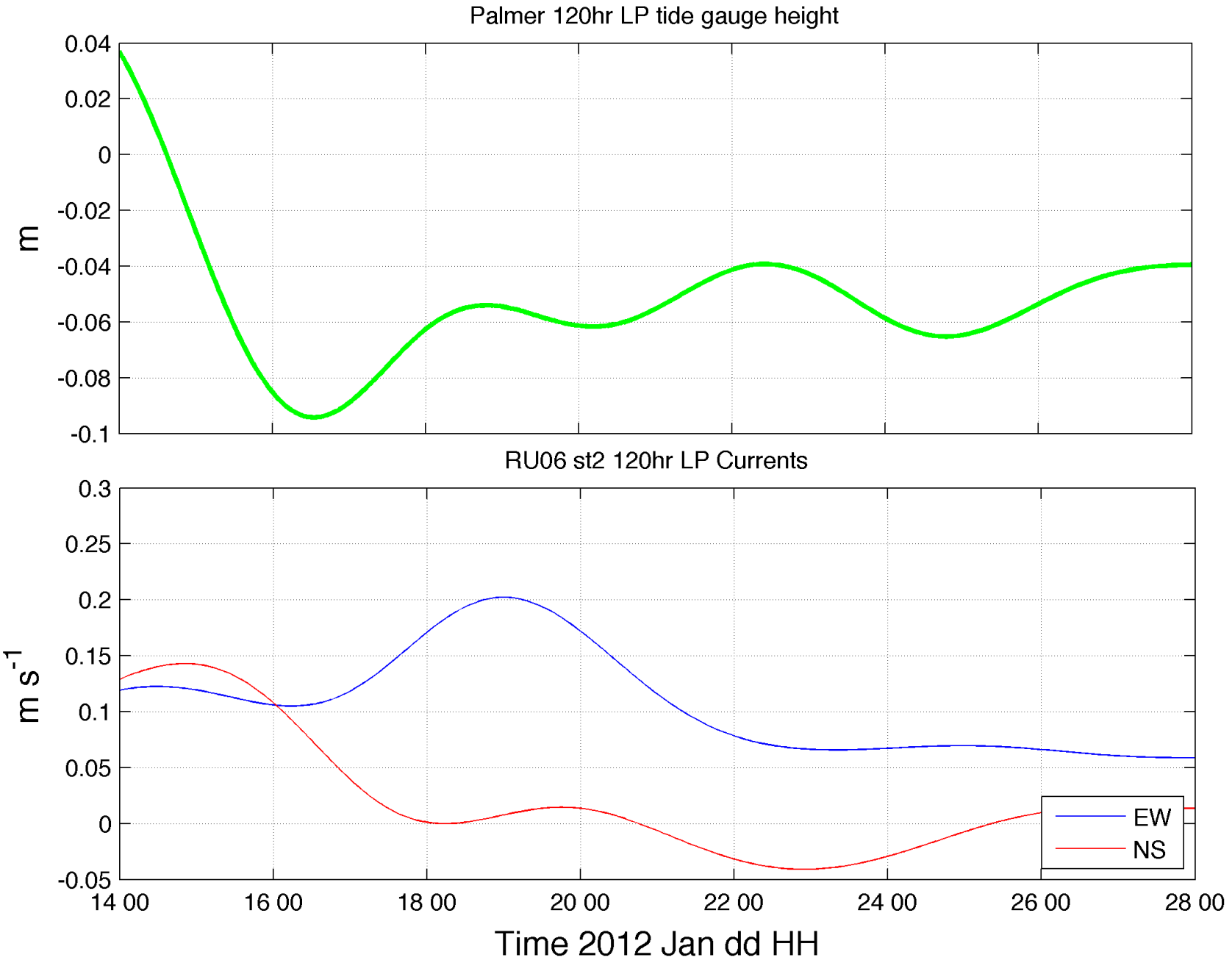


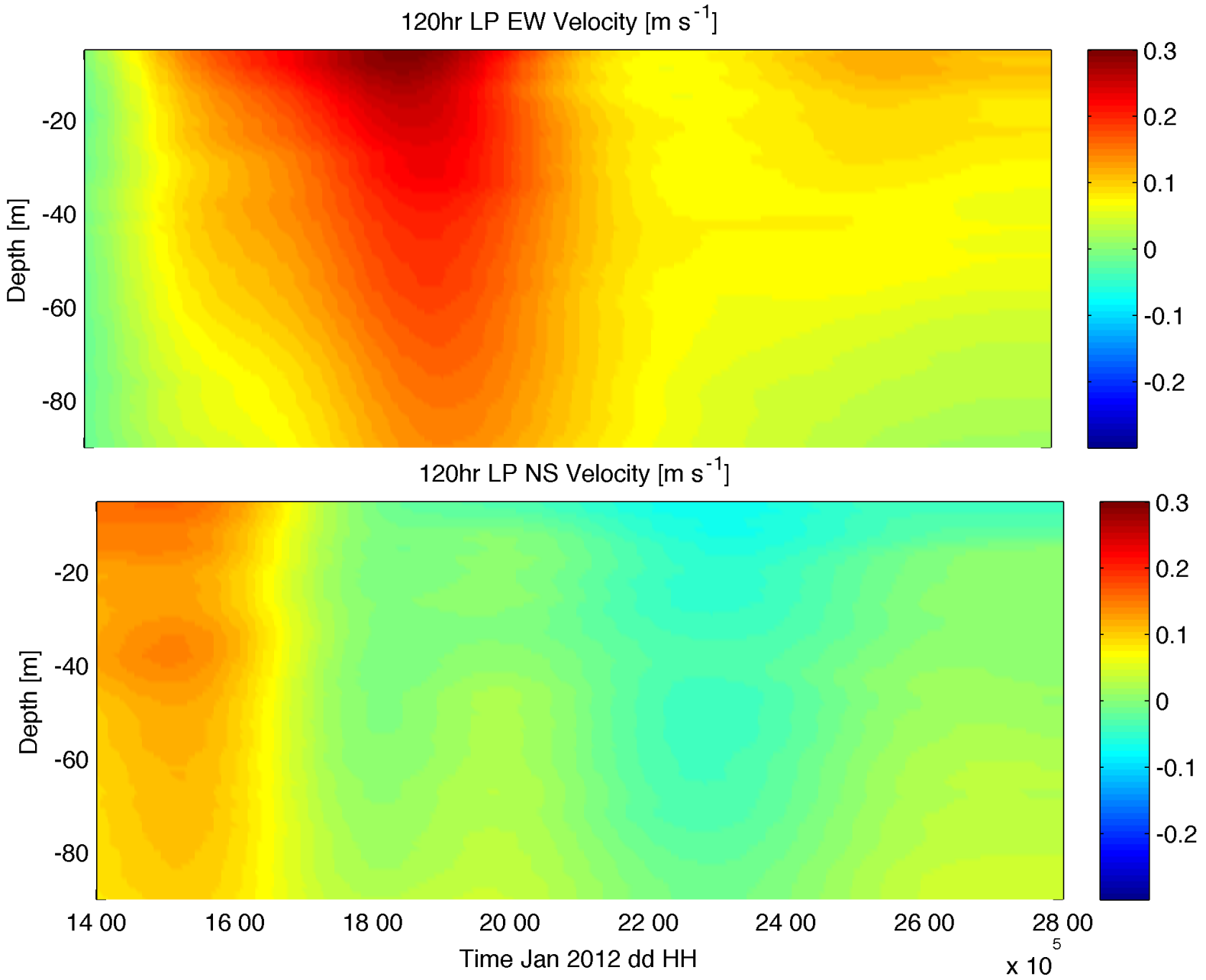
Out of phase relationship Cross-correlation of - 0.85 for October to April


RU06 Depth Averaged Currents (m s-1)
St1
St2
EW
NS
m s-1
0.5
0
-0.5
08 00
10 00
12 00
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH

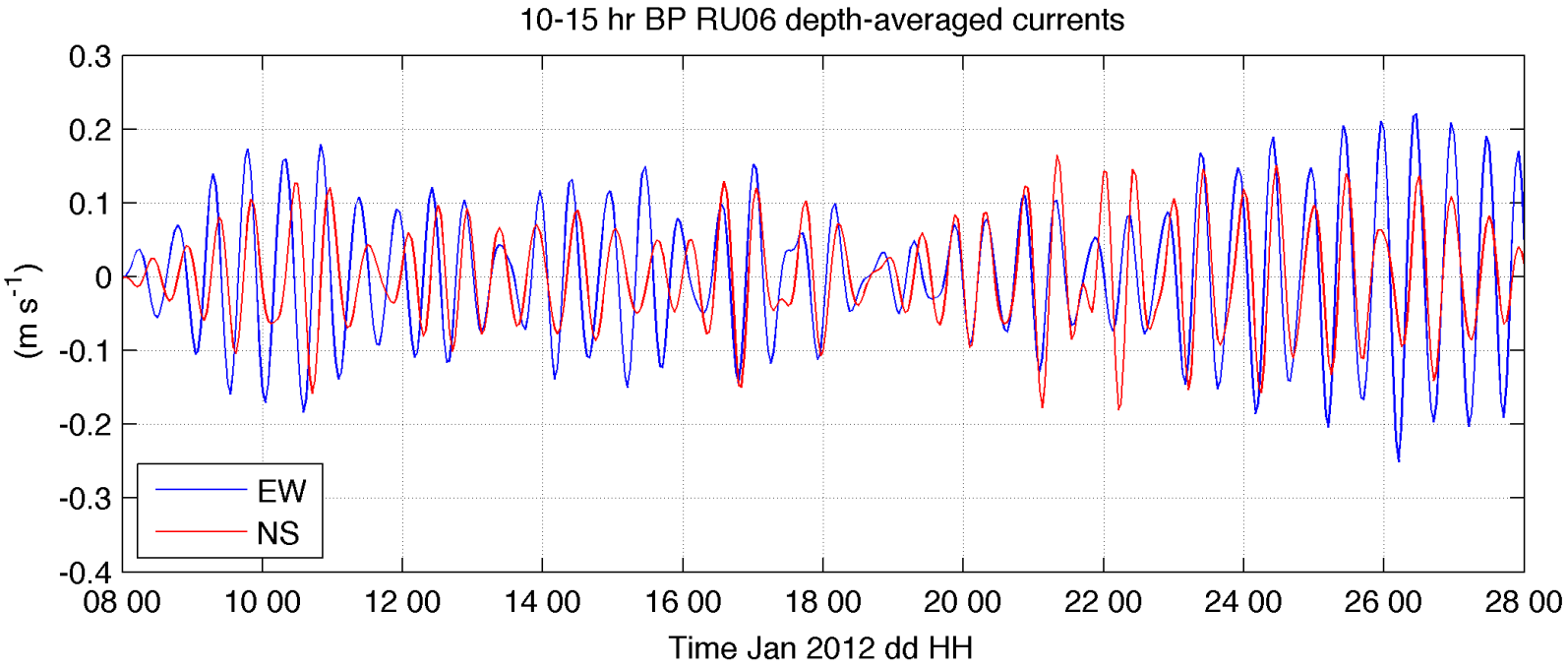

RU06 Currents (Toward)
NORTH
15%
10%
5%
WEST
EAST
SOUTH
0.3 - 0.35
0.25 - 0.3
0.2 - 0.25
0.15 - 0.2
0.1 - 0.15
0.05 - 0.1
0 - 0.05

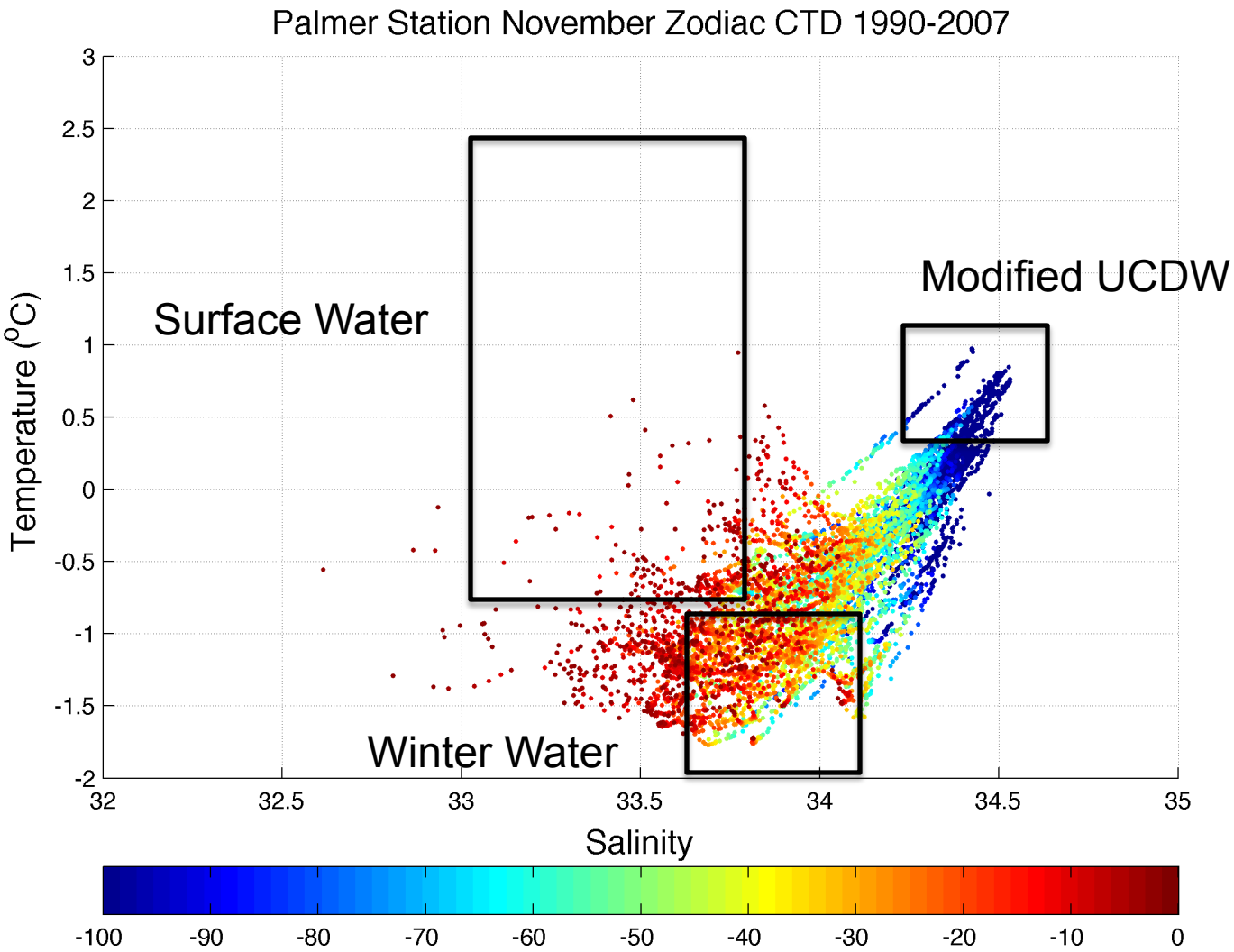

RU06 Jan Track
Palmer Station
St1
St2
Latitude
-64.7
-64.75
-64.8
-64.85
-64.9
-64.95
-65
-65.05
-64.8
-64.6
-64.4
-64.2
-64
-63.8
Longitude

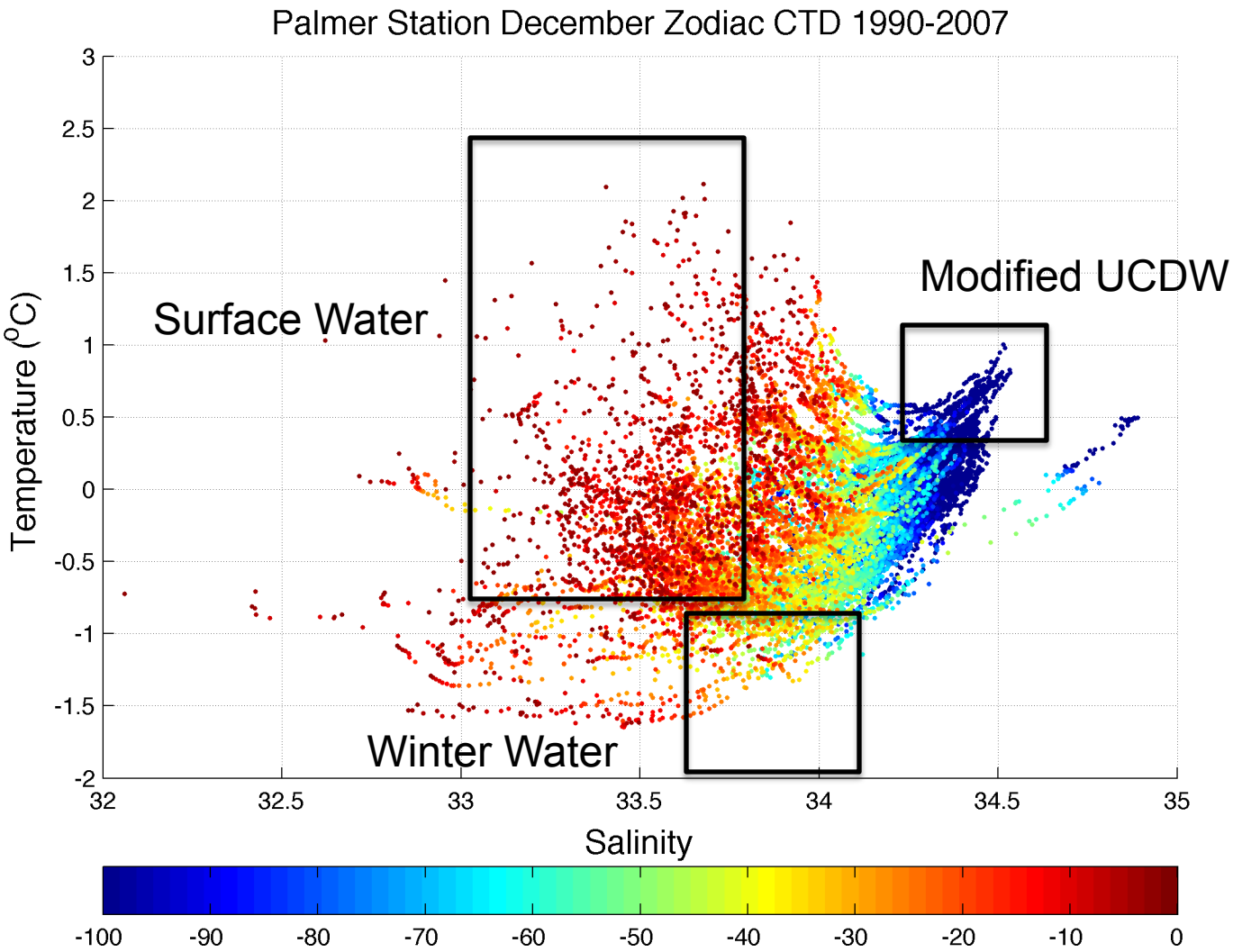

Palmer 120hr LP tide gauge height
m
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
RU06 st2 120hr LP Currents
m s-1
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
EW
NS
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time 2012 Jan dd HH

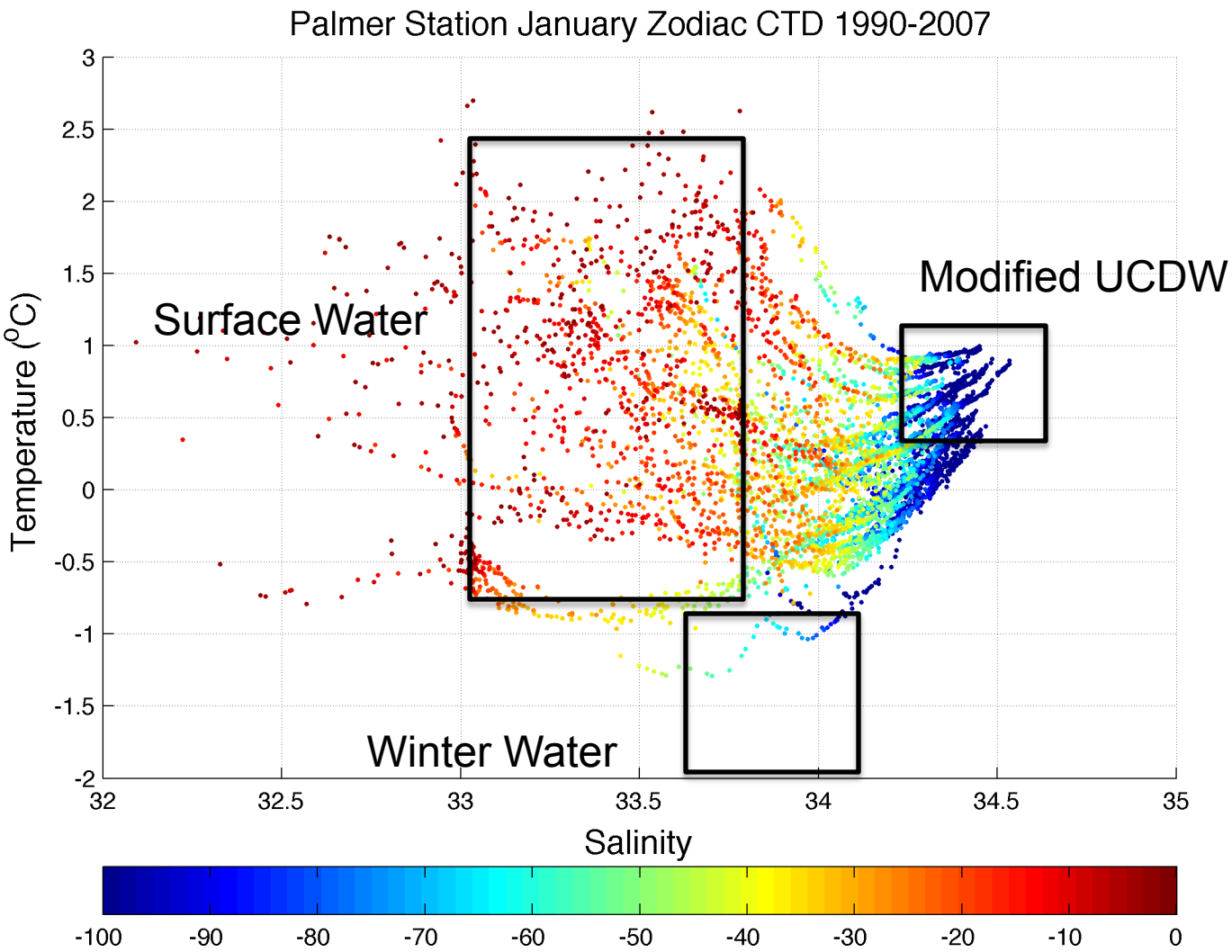

120hr LP EW Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
120hr LP NS Velocity [m s-1]
Depth [m]
-20
-40
-60
-80
0.3
0.2
0.1
0
-0.1
-0.2
14 00
16 00
18 00
20 00
22 00
24 00
26 00
28 00
Time Jan 2012 dd HH
x 10^5

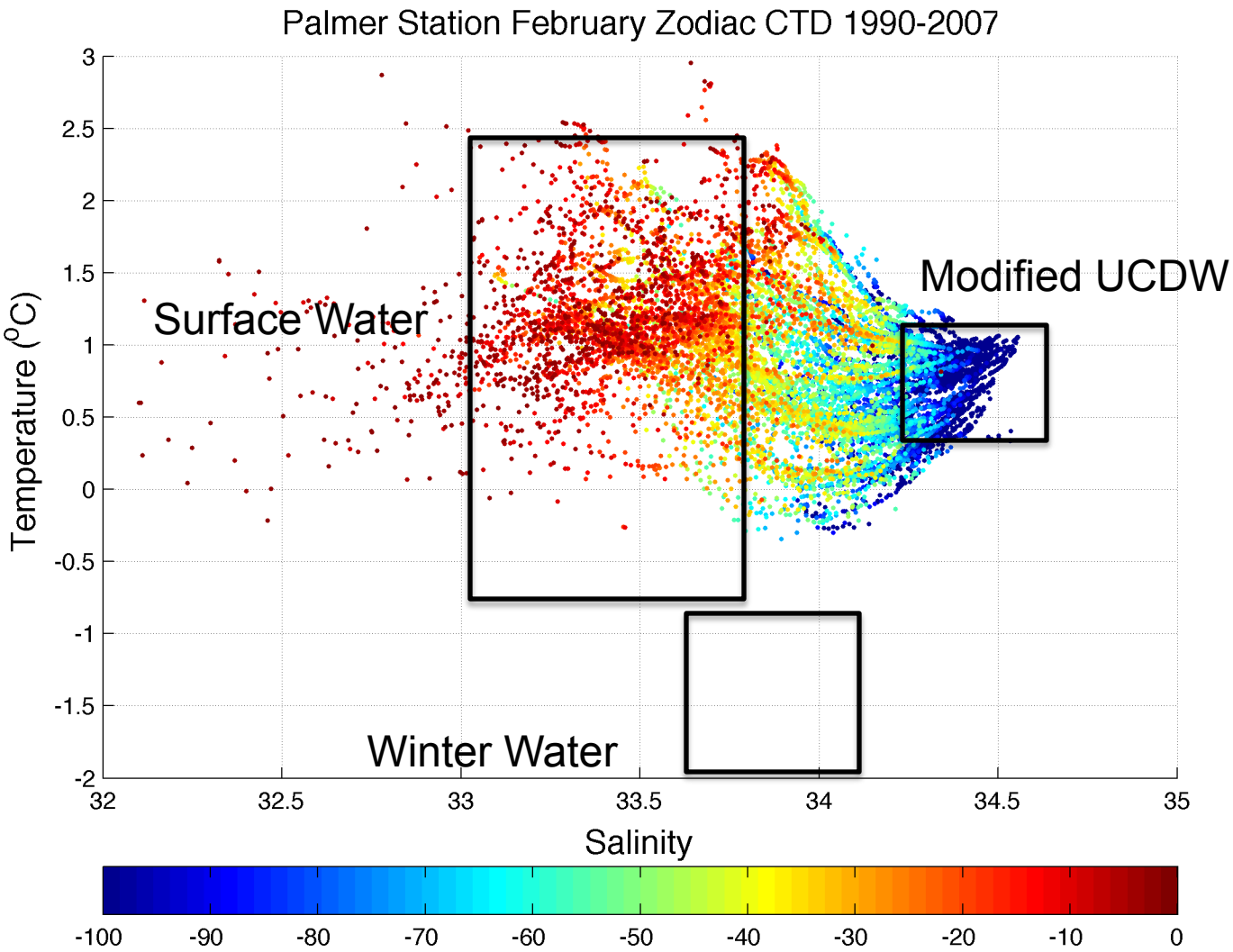
Results from a Barotropic tidal model in the region predict semi-diurnal tides are small and weak < 0.05 m s^{-1}.

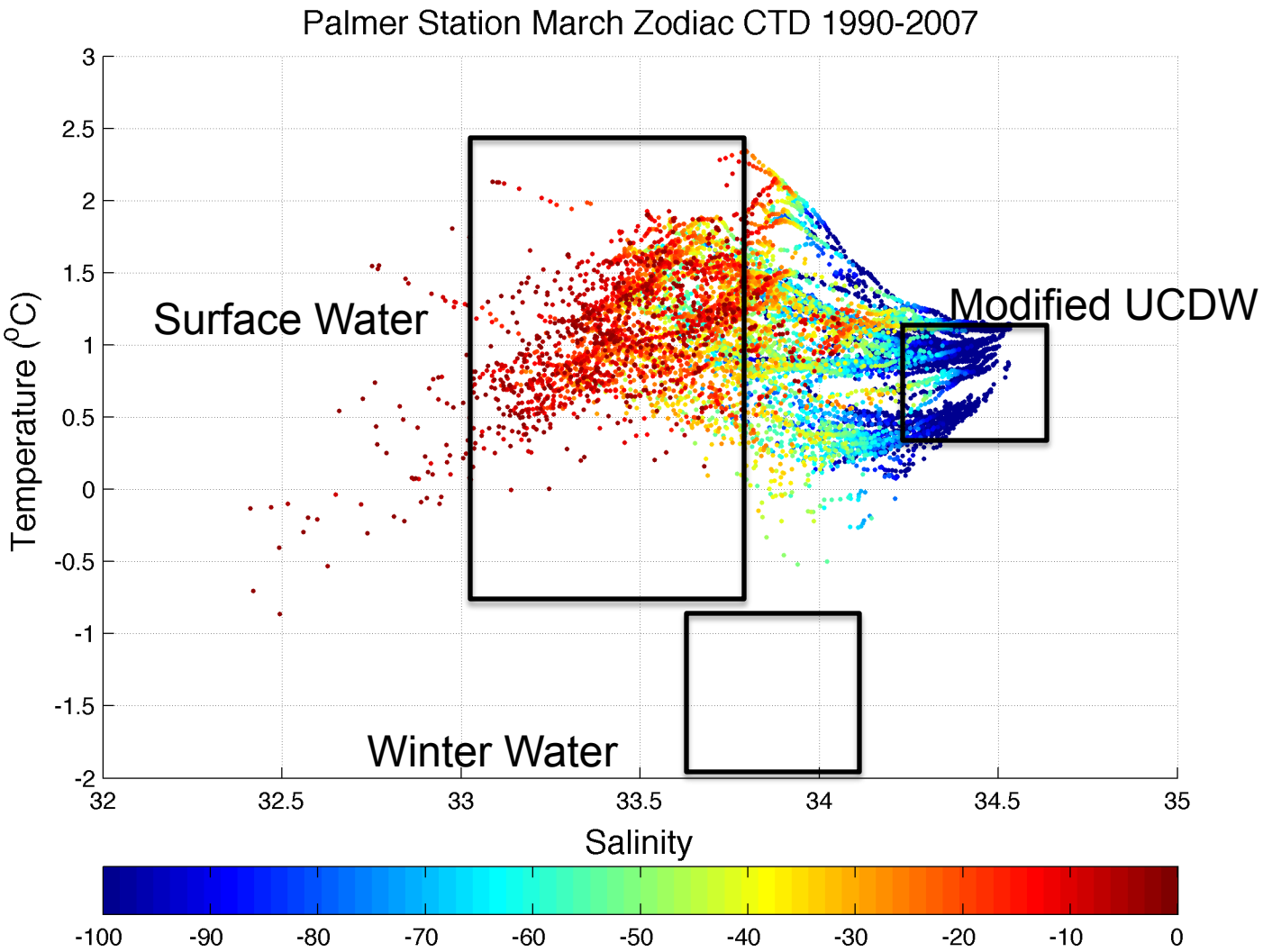


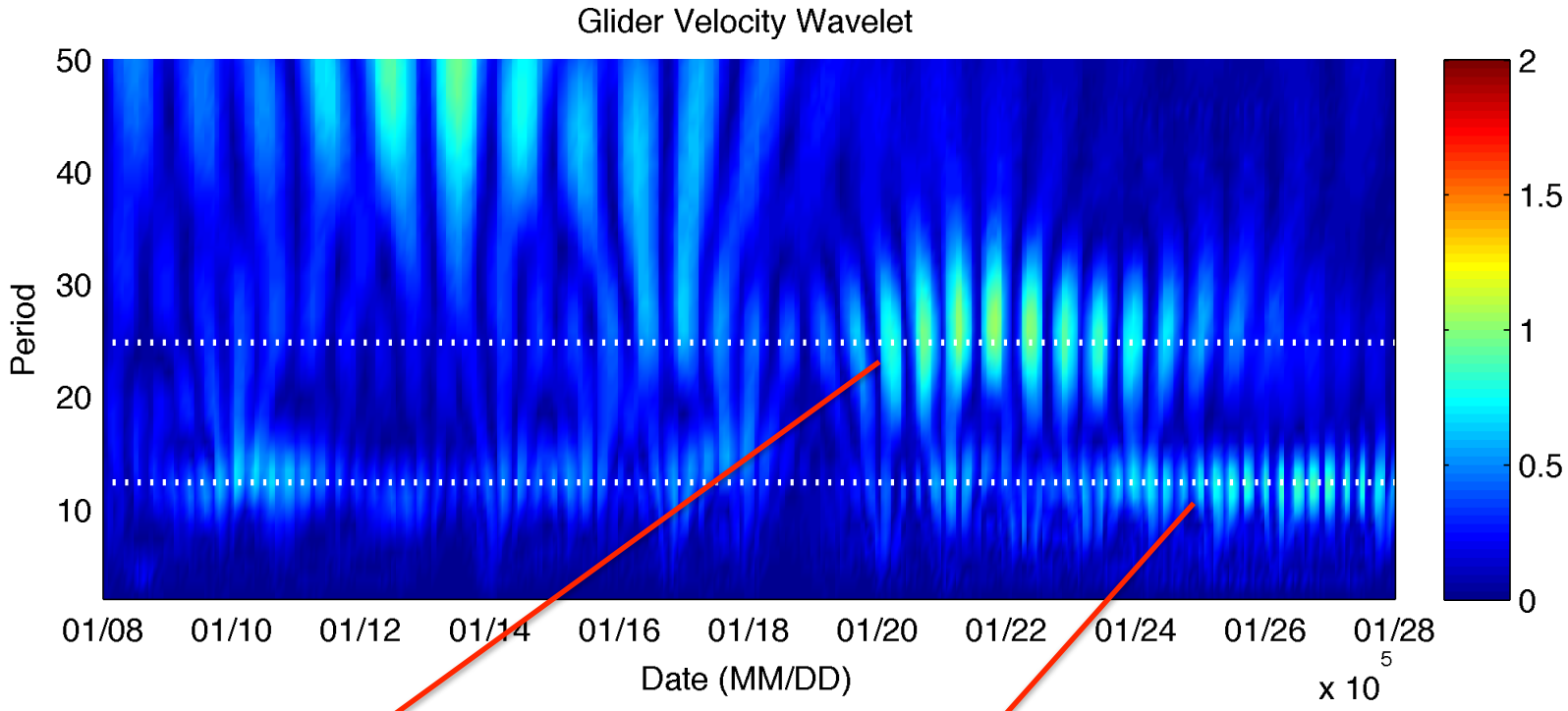

Palmer Station November Zodiac CTD 1990-2007
Surface Water
Modified UCDW
Winter Water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5
35
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0


Palmer Station December Zodiac CTD 1990-2007
Surface Water
Modified UCDW
Winter Water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5
35
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0


Palmer Station January Zodiac CTD 1990-2007
Surface Water
Modified UCDW
Winter Water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5
35
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0


Palmer Station February Zodiac CTD 1990-2007
Surface Water
Modified UCDW
Winter Water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5
35
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0


Palmer Station March Zodiac CTD 1990-2007
Surface Water
Modified UCDW
Winter Water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5
35
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0



Diurnal

semi-diurnal/Inertial