Remote Sensing at the Cooperative Institute for Oceanographic Satellite Studies: CIOSS Research – On the Edge(s)

Ted Strub and Countless Others

On the Edge(s)

- Of knowledge
- At the air-sea vertical boundary
- Along the horizontal coastal land-sea boundary
- At the high end of spectral and spatial (and species) resolution

- Modeling as a necessary complement to ocean remote sensing, extending fields in the vertical (subsurface ocean and into the atmosphere), into dynamics, and into the future (prediction)

- Outreach – extending knowledge to the next generation (the edge of the workforce), the present workforce (the edge of dissemination) and in workshops that bring different groups together with common interests (organizational edges)

Ocean Color – “Risk Reduction”

COAST and Risk Reduction Activities

- The Coastal Ocean Applications and Science Team (COAST) was created in August 2004 to support NOAA to develop coastal ocean applications for HES-CW:
  - Mark Abbott, is the COAST team leader,
  - COAST activities are managed through CIOSS, Ted Strub, Director
  - Curtiss Davis, Senior Research Professor at COAS, is the Executive Director of COAST.
- Initial activity to evaluate HES-CW requirements and suggest improvements
- Paul Menzel Presented GOES-R Risk Reduction Program at the first COAST meeting in September 2004 and invited COAST to participate.
  - Curt Davis and Mark Abbott presented proposed activities in Feb. 2005.
  - Proposal Submitted to NOAA Sept 6, 2005.
  - Proposal Funded July 21, 2006.

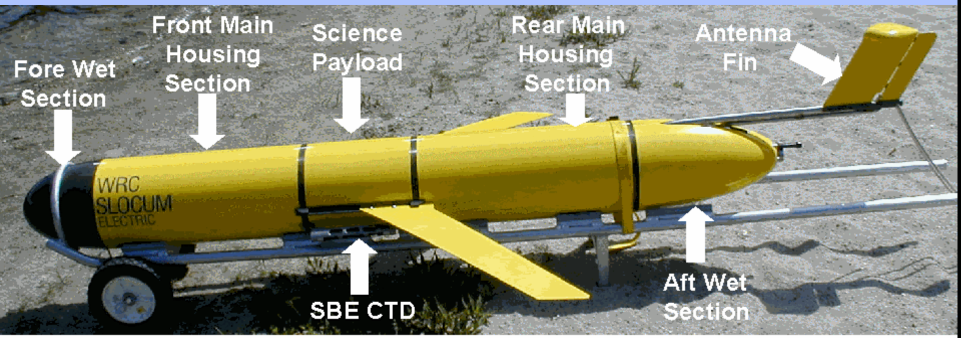
Proposed Experiments to Collect Simulated HES-CW data

- There are no existing data sets that include all the key attributes of HES-CW data:
  - Spectral coverage (.4 – 1.0 μm)
  - High signal-to-noise ratio (>300:1 prefer 900:1, for ocean radiances)
  - High spatial resolution (<150 m, bin to 300 m)
  - Hourly or better revisit
- Propose field experiments in FY2006-2008 to develop the required data sets for HES-CW algorithm and model development.
- Airborne system:
  - Hyperspectral imager that can be binned to the HES-CW bands
  - Flown at high altitude for 20 km x 20 km scenes every 30 min
  - Endurance to collect repeat flight lines every half hour for up to 6 hours
  - Spectroscopy Aerial Mapping System with On-Board Navigation (SAMSON) Hyperspectral Imager (Florida Environmental Research Inst.)
- Proposed three experimental sites:
  - 2006 Monterey Bay (September 3-16, 2006, coastal upwelling, HABs)
  - 2007 New York/Mid Atlantic Bight (August, river input, urban aerosols)
  - 2008 Mississippi River Plume (Sediment input, CDOM, HABs)

Hyperspectral Image data collected with SAMSON

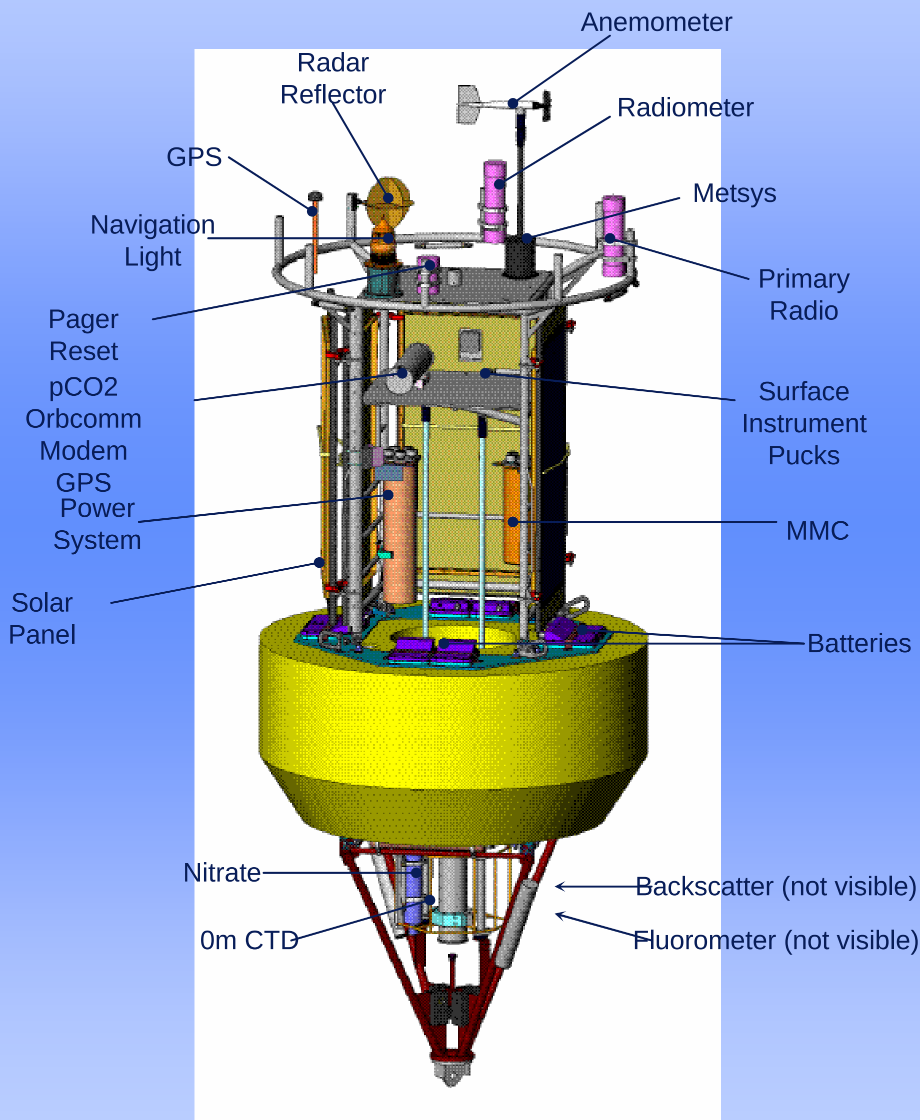
- The Florida Environmental Research Institute (FERI) Spectroscopic Aerial Mapper with On-board Navigation (SAMSON).
- SAMSON collects 256 channels in the VNIR (3.5 nm resolution over 380 to 970 nm range) at 75 frames per second, with a SNR, stability, dynamic range, and calibration sufficient for coastal ocean spectroscopy.
- Data sampled at 5 m GSD and binned to 100, 300, 375 and 500 m to evaluate need for higher GSD.
  - Binned data will have SNR in excess of 1000:1

Rutgers Slocum electric WEST COAST GLIDER 2006



Science Payloads

Two Ships and long-term mooring available for Experiment

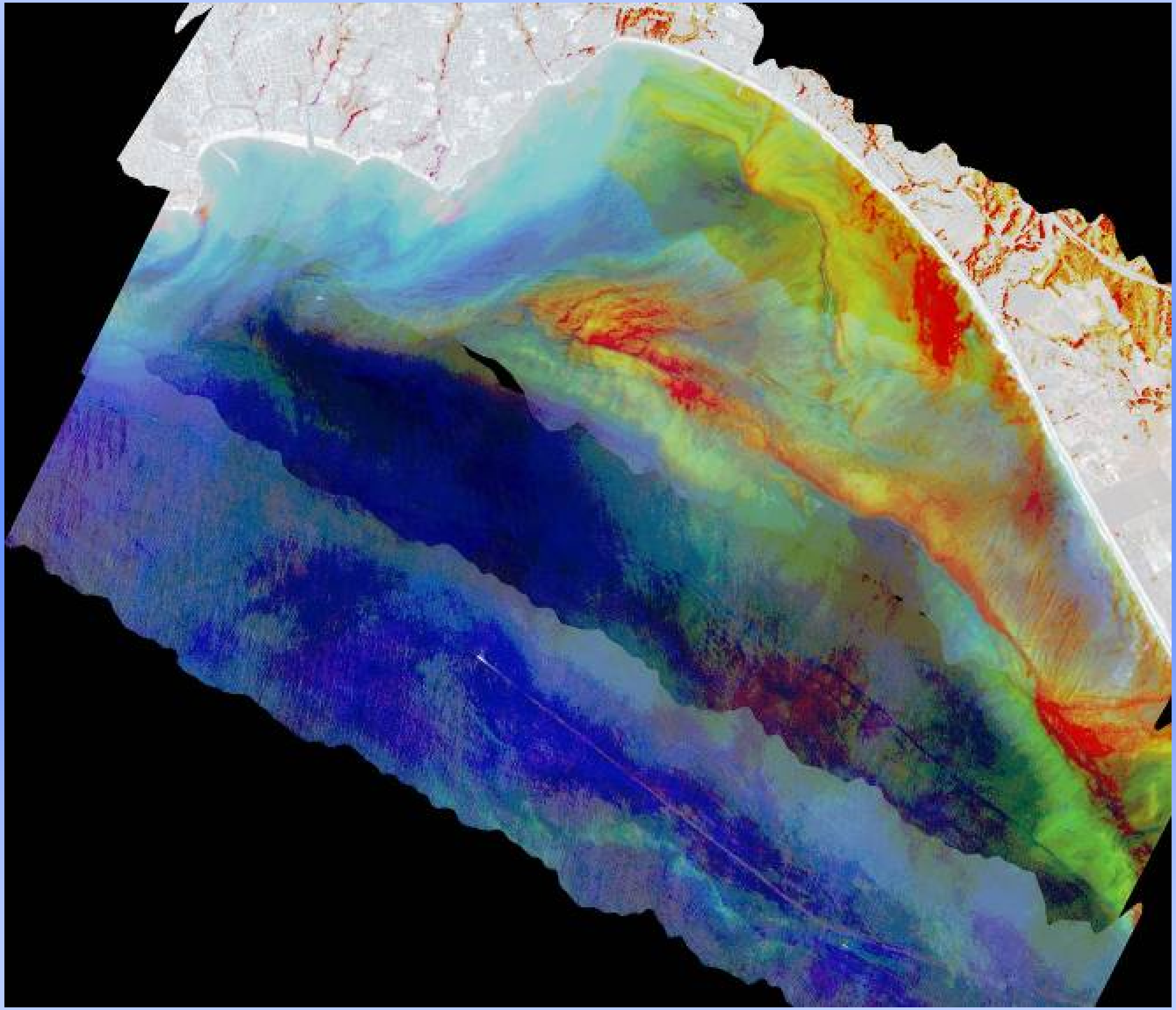


M0 Mooring

R/V Shana Rae

R/V John H. Martin

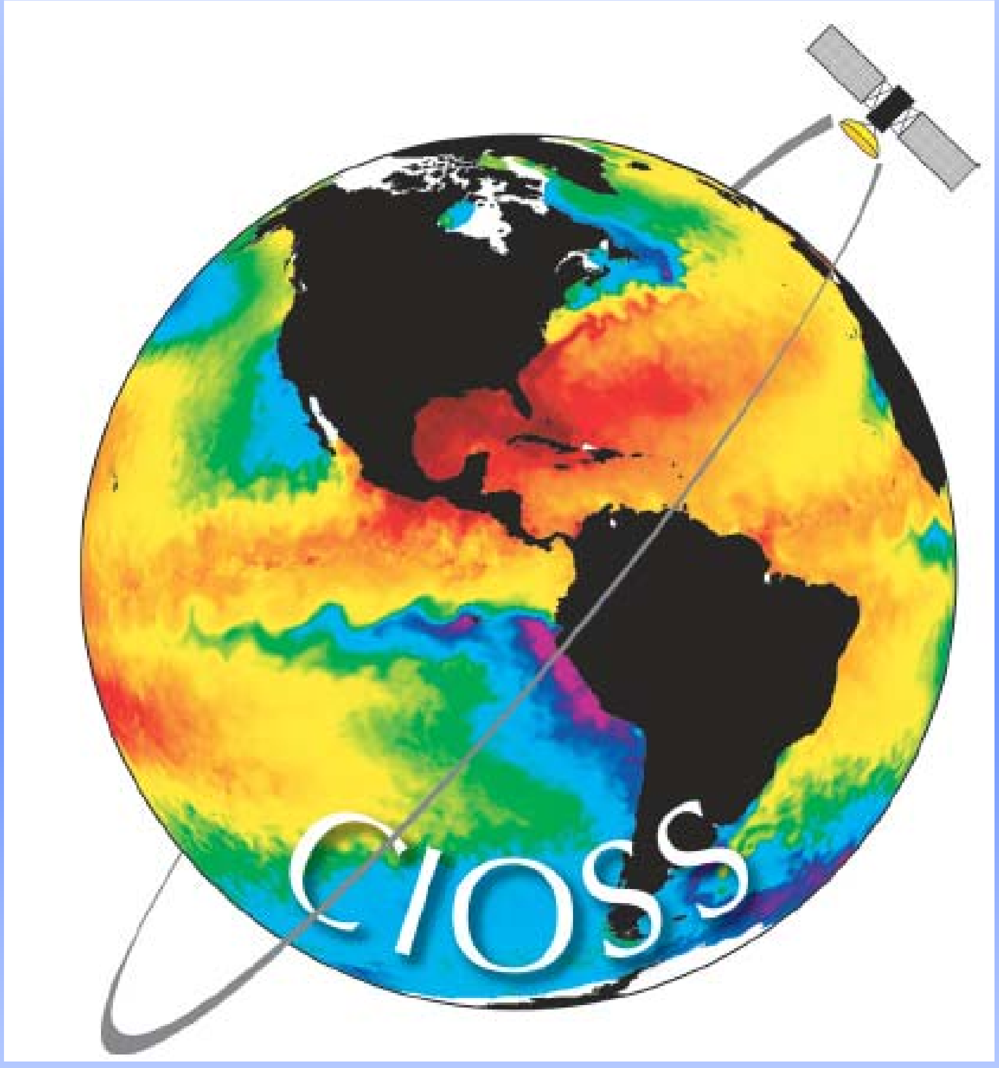
September 12, 2006
Grid 03: 10:07 - 10:32



Primary species *Akashiwo sanguinea*

FERI SAMSON data

Air-Sea Interaction



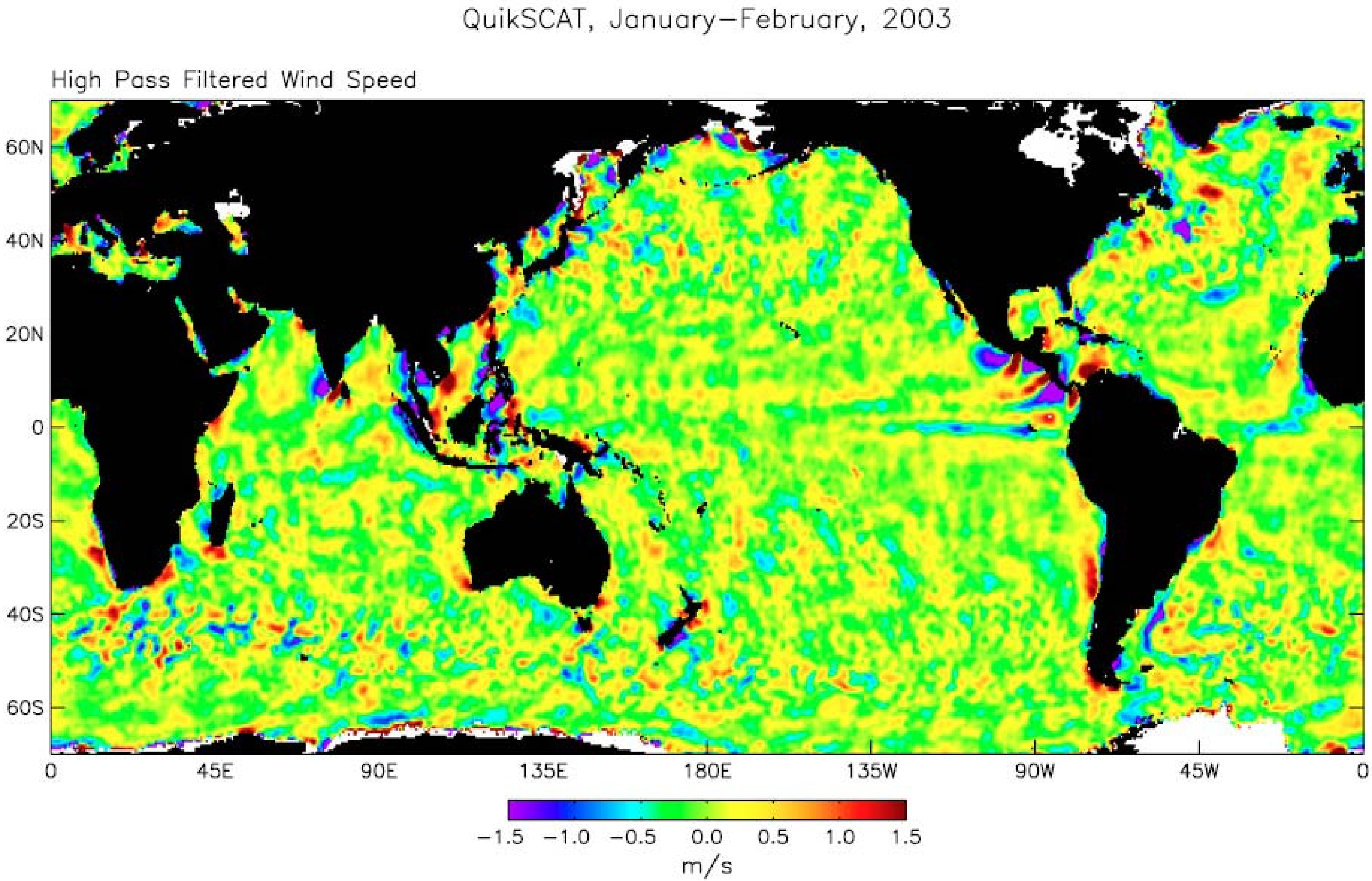
Progress in Air-Sea Interaction Research

OSU Participants: Dudley Chelton, Roger Samelson, Eric Maloney (PIs)
Qingtao Song (post-doc)
Michael Schlax (Research Assistant)
Craig Risien, Larry O'Neill (grad students)
Jennifer Rolling (REU student)

Overview:

- *Development of QuikSCAT-based wind climatologies (COGOW & QuikCOW).*
- *Mentoring of summer REU student (Jenny Rolling).*
- *Participation in establishment of requirements for future satellite missions for measurements of ocean vector winds (Miami workshops and NRC workshop).*
- *SST influence on surface winds:*
  - *observational studies from QuikSCAT and AMSR*
  - *modeling studies from the WRF, COAMPS and ECMWF models*
- *SST influence on tropospheric winds above the marine boundary layer.*
- *Efforts to improve the ECMWF global forecast model.*
- *Coupled modeling to investigate feedback effects of SST-induced perturbations of the wind stress field on the ocean.*

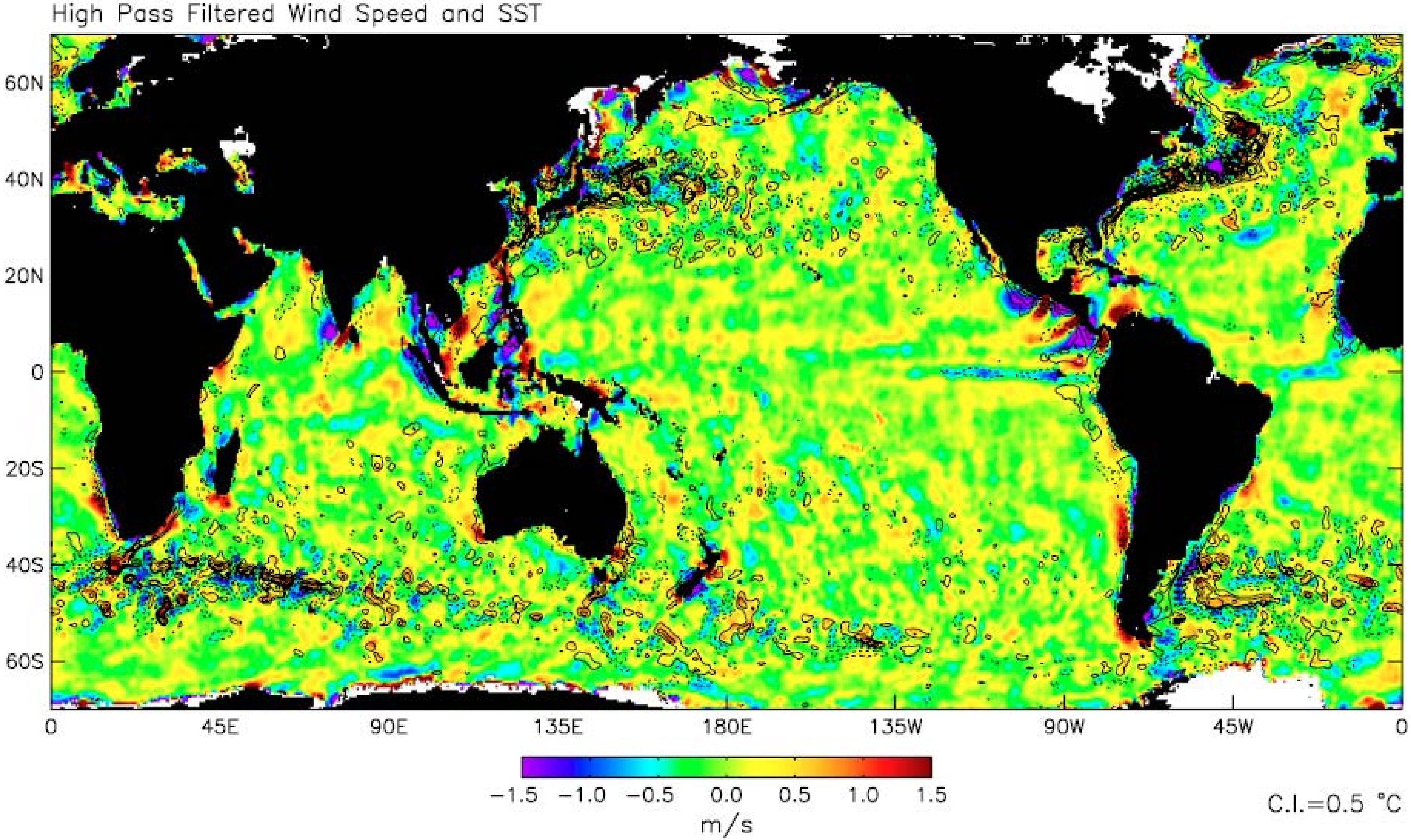
2-Month Average Wind Speed
(spatially high-pass filtered)



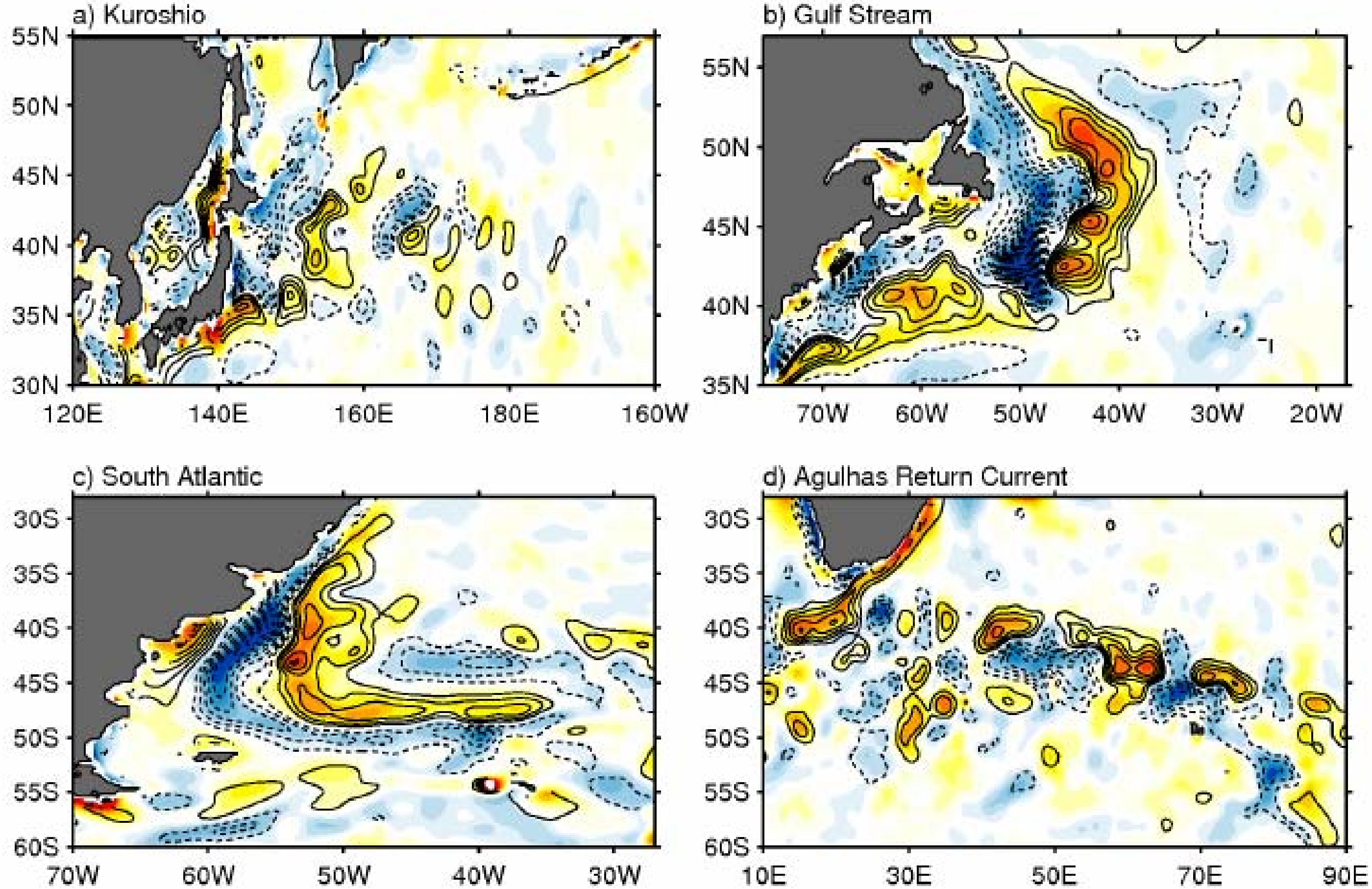
2-Month Average Wind Speed with SST Contours

(spatially high-pass filtered)

QuikSCAT, January–February, 2003



Spatially High-Pass Filtered QuikSCAT Wind Speed and AMSR-E SST Maps



1-yr averaged for 2003

Difference between warm and cool SSTs ~2-3 m/s

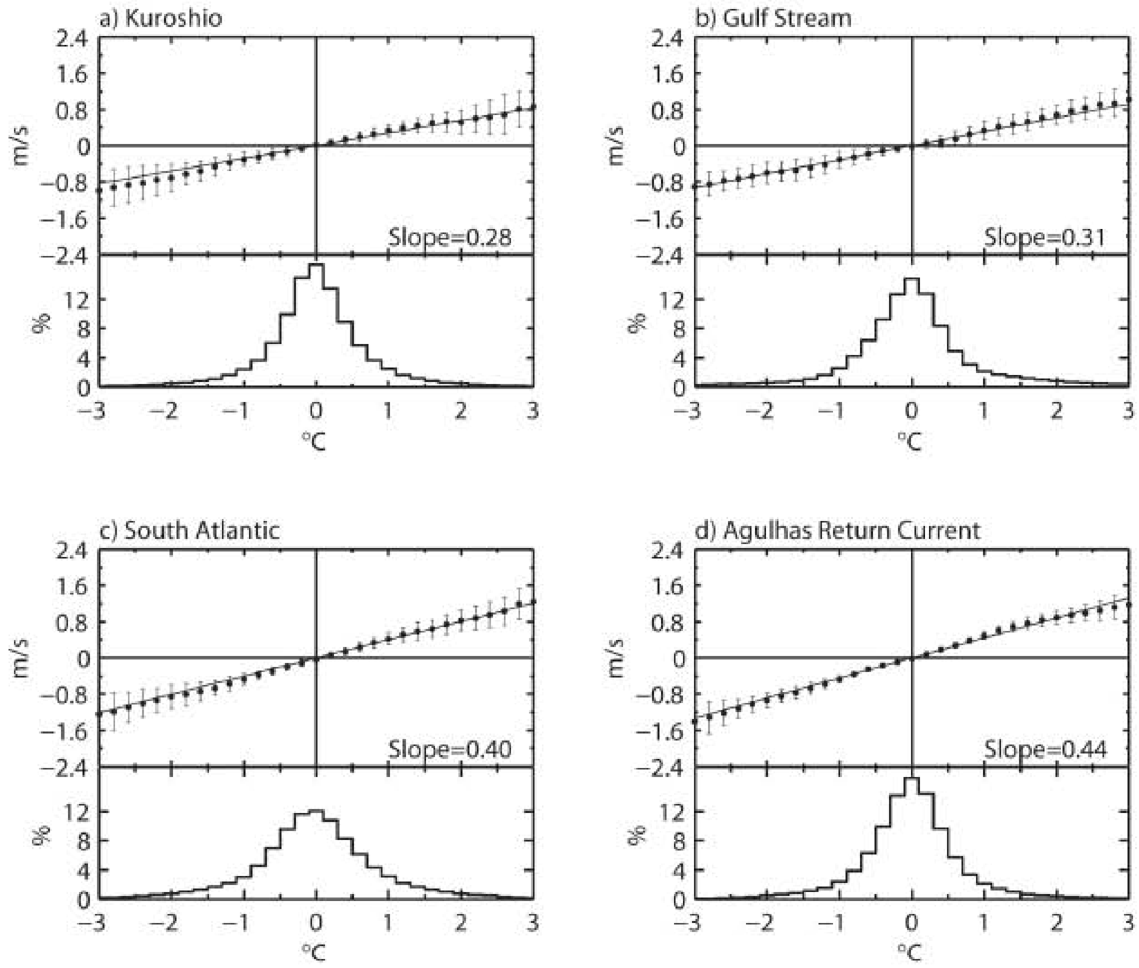
Solid contours = warm SST perturbations

Dashed contours = cool SST perturbations

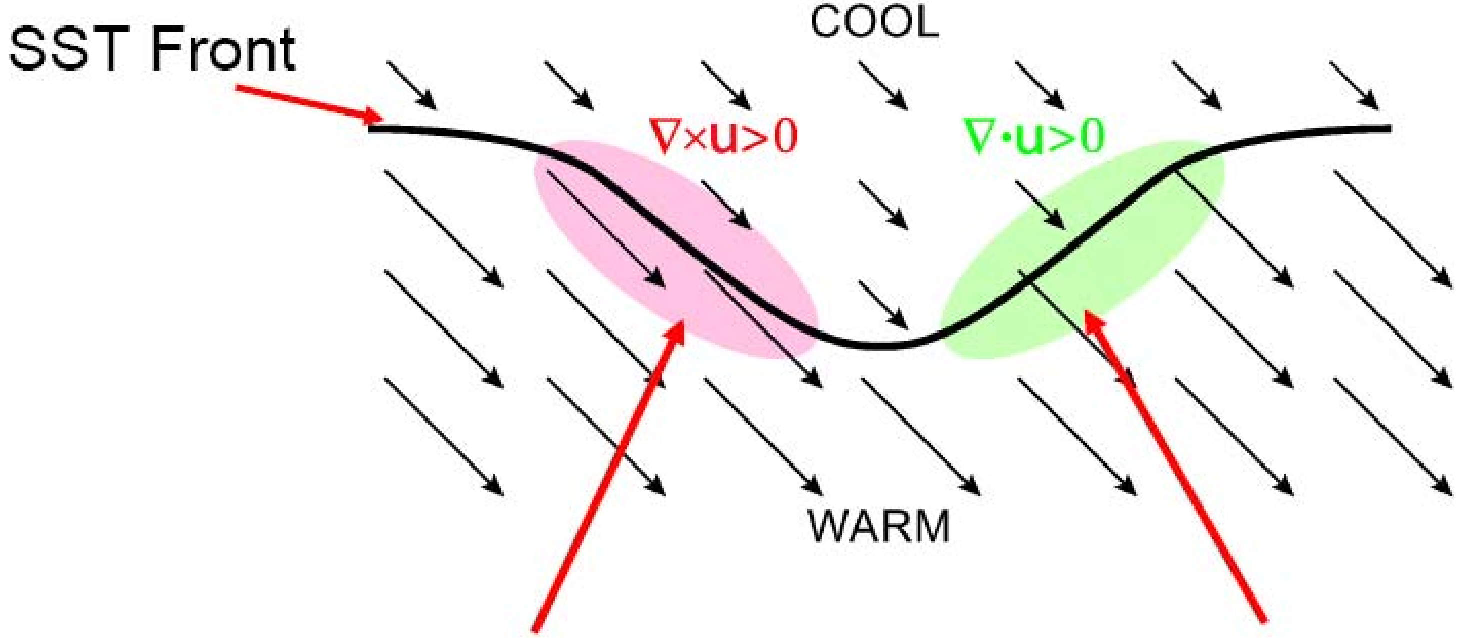
SST Influence on Wind Speed

Winds are locally stronger over warm water and weaker over cold water.

Coupling Between Wind Speed and SST



Formation of Vorticity and Divergence Perturbations Near SST Fronts



Vorticity associated with crosswind SST gradient as winds blow along SST isotherms

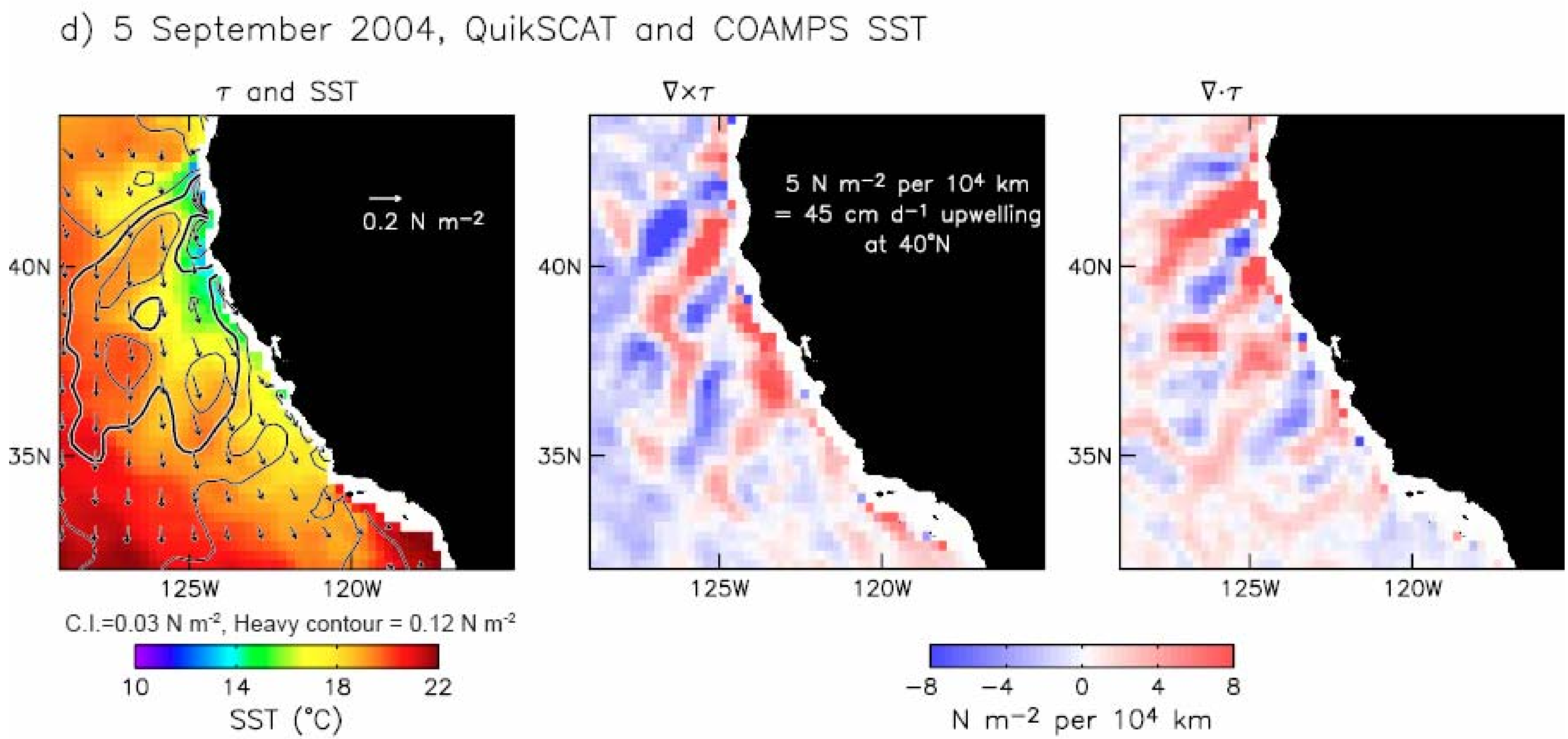
Divergence associated with downwind SST gradient as winds blow across SST isotherms

Question

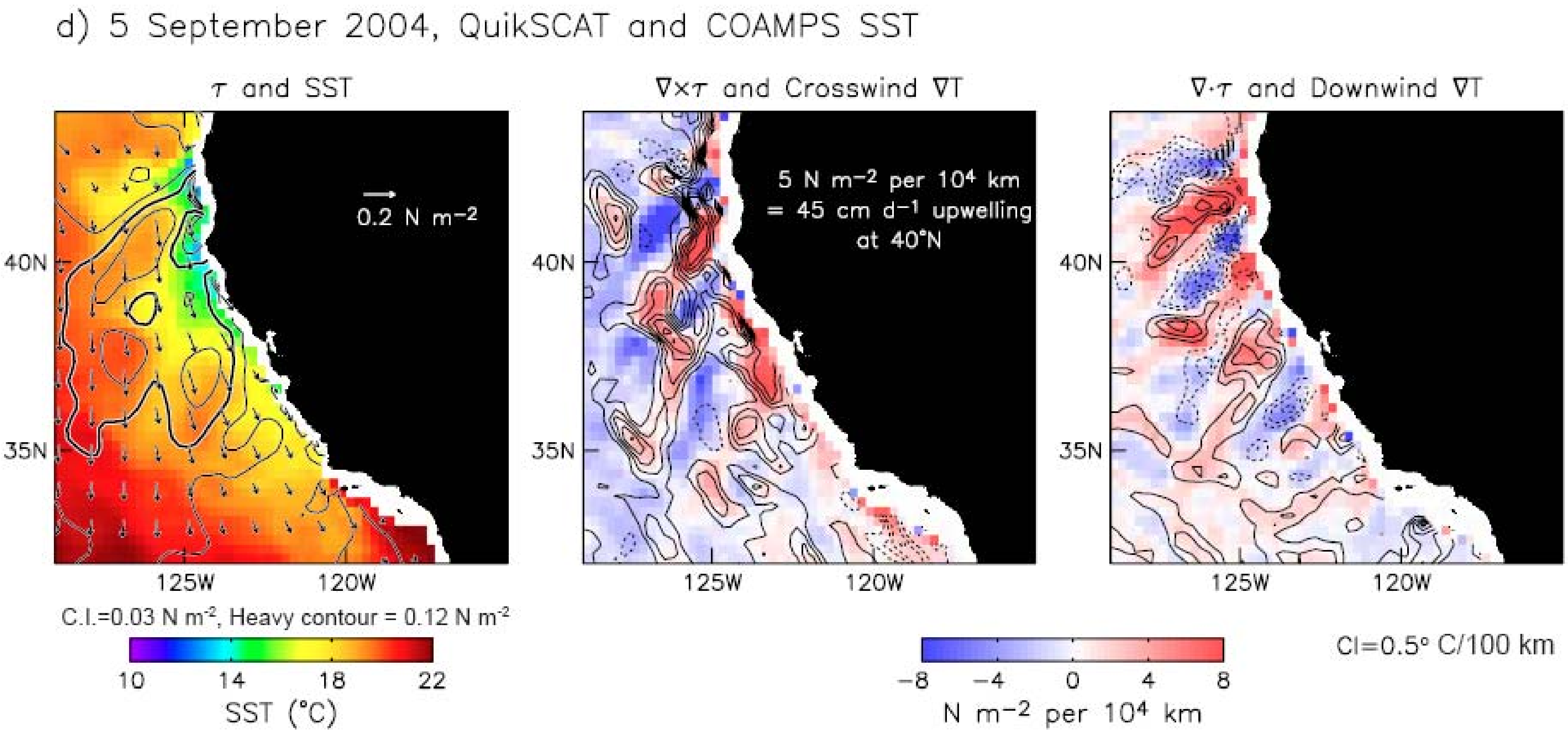
On how small a scale does the SST influence surface winds?

Pretty small, e.g., the California Current System....

QuikSCAT 29-Day Average Centered on 5 September 2004

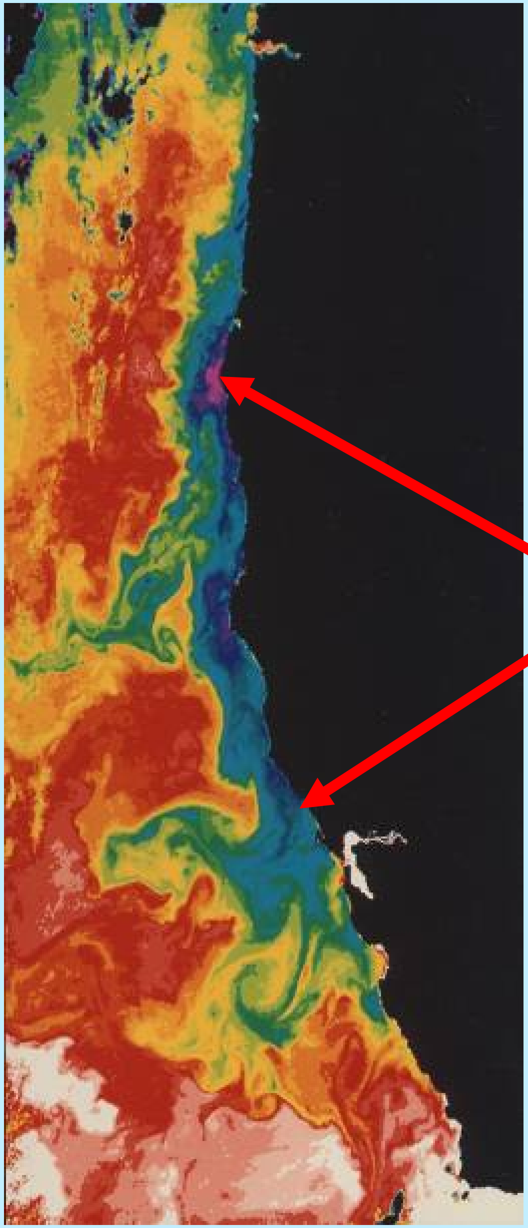


QuikSCAT 29-Day Average Centered on 5 September 2004



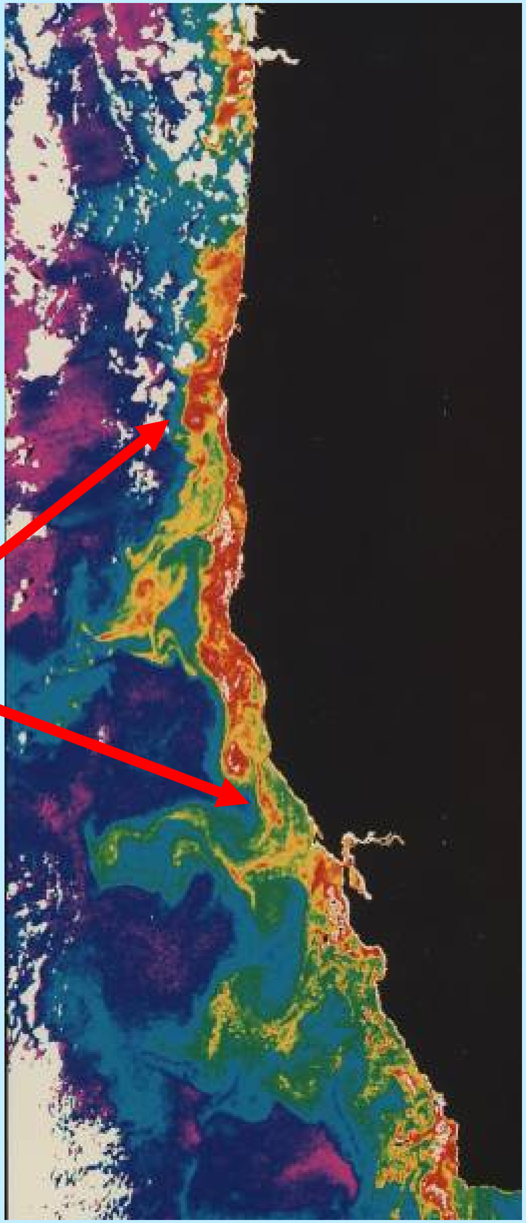
QuikSCAT resolution ~25 km (30-km gap near land)

Coastal Scatterometry



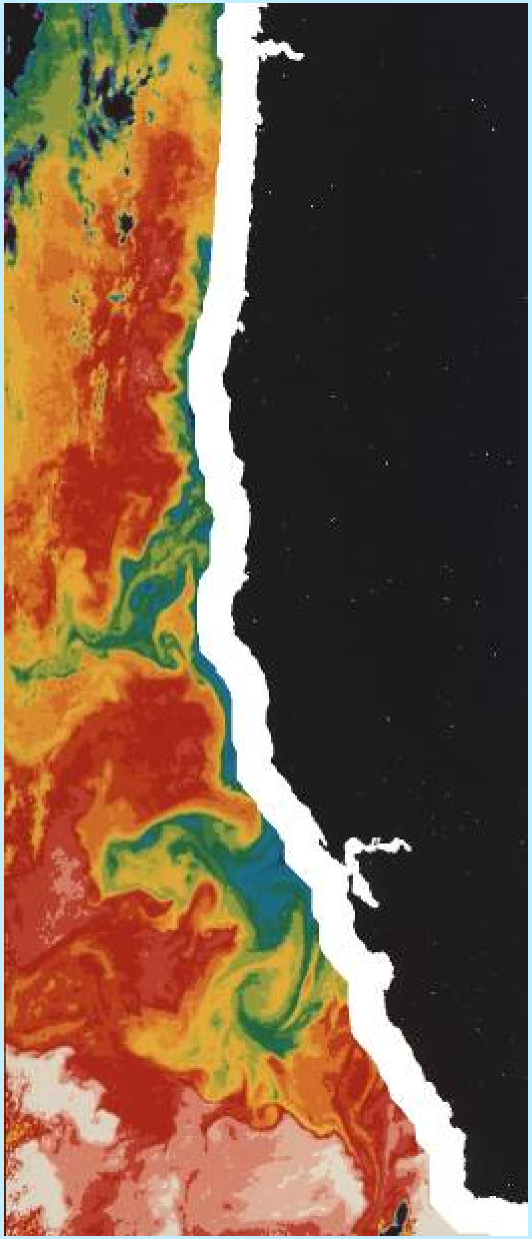
Summer CZCS Image of
US West Coast

Equatorward winds cause coastal upwelling
-- Low SST near coast
-- High productivity
-- Complex air-sea interaction



Temperature

Pigment

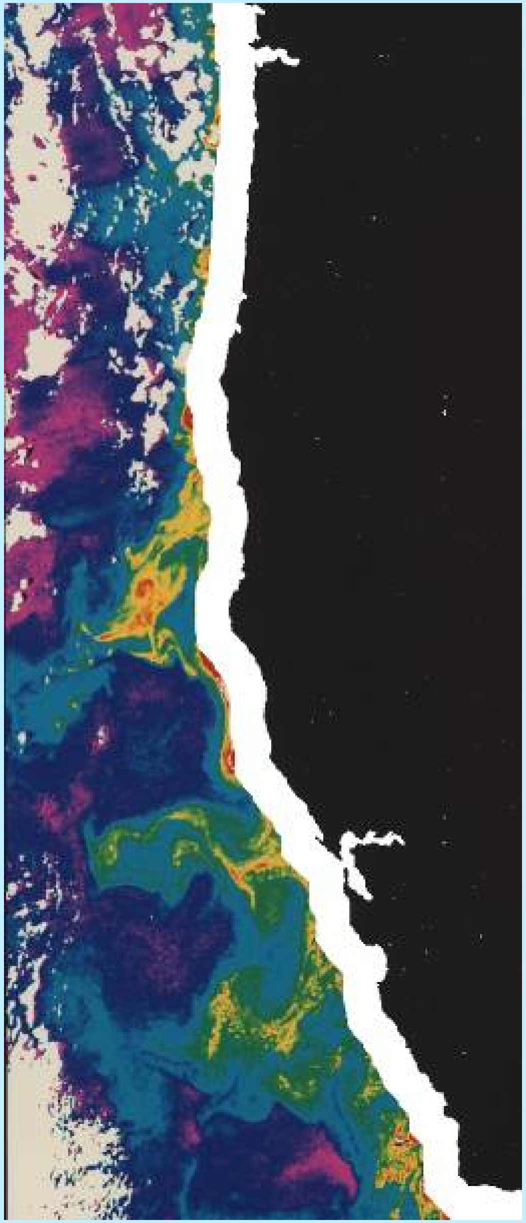


Temperature

Effect of 30 km scatterometer land mask

NO accurate wind data over the critical upwelling region

High resolution winds will allow study of air-sea interaction in coastal upwelling areas



Pigment

Statistical Land Mask Determination

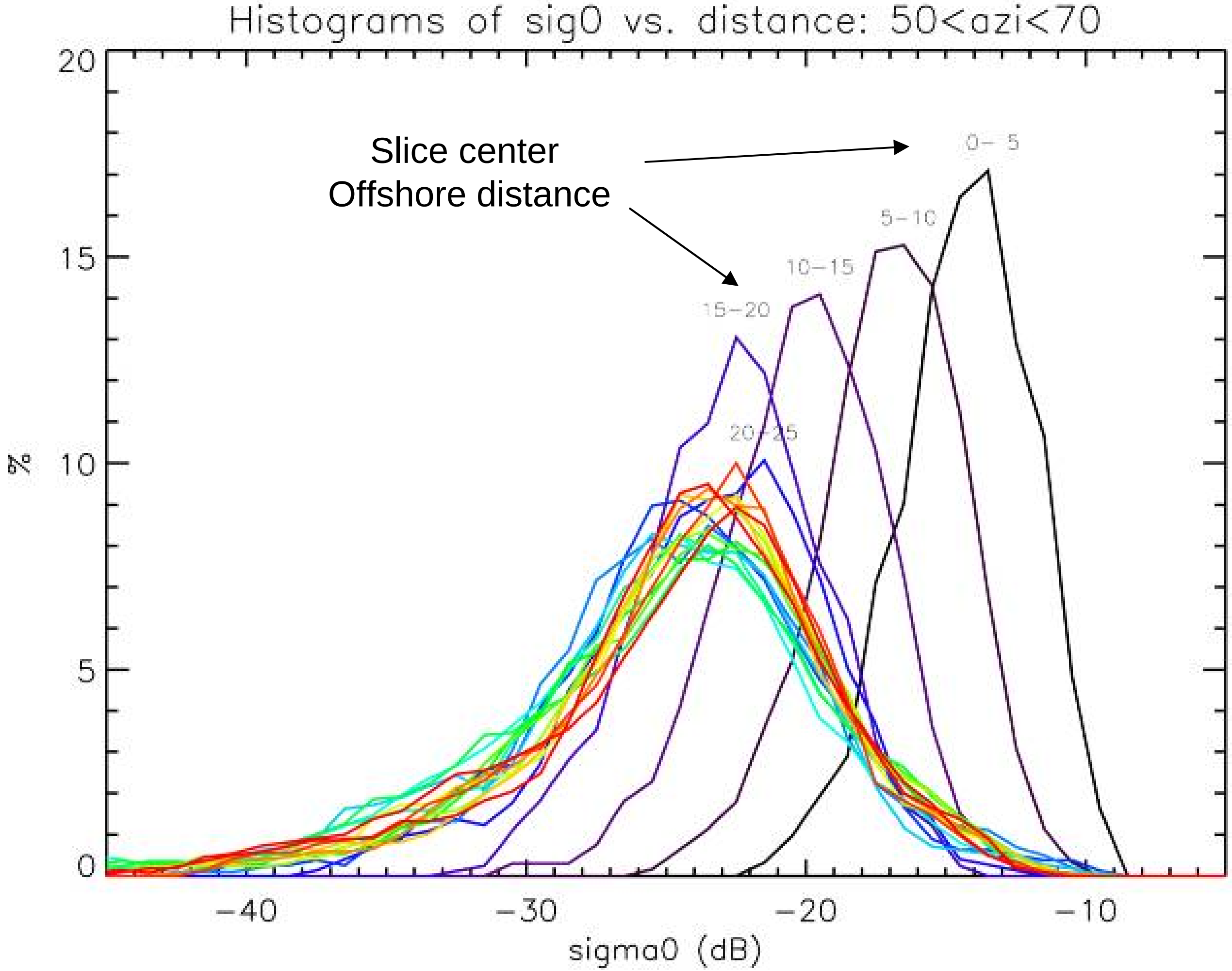
- Basic assumptions:
  - Accurate wind scatterometer wind retrieval requires that temporal changes in scatterometer backscatter (σ_o) measurements result from changes in winds – and thus changes in wind-generated ocean roughness
  - Land-contaminated σ_o (at fixed viewing geometry) will vary much less than wind-induced ocean σ_o variability (even in the presence of atmospheric effects, and seasonal vegetation and snow/soil moisture variability)

- Approach:
  - 6-year QuikSCAT mission provides many σ_o measurements at each geographical location and from the same viewing geometry
    - Each coastal geographical location has been imaged many times each from several different viewing geometries (azimuth angle relative to North); effect of land will vary with viewing geometry
  - Calculate sample σ_o distributions along coastal offshore-directed transects for fixed viewing geometry; σ_o distributions should not vary with distance from coast when sufficiently offshore
  - Calculate effective land mask for ***each*** geographical location, ***each*** beam (v-pol or h-pol), and ***each*** scatterometer viewing geometry (azimuth); this requires the long QuikSCAT data set for statistical stability/sampling

Example Preliminary Calculation

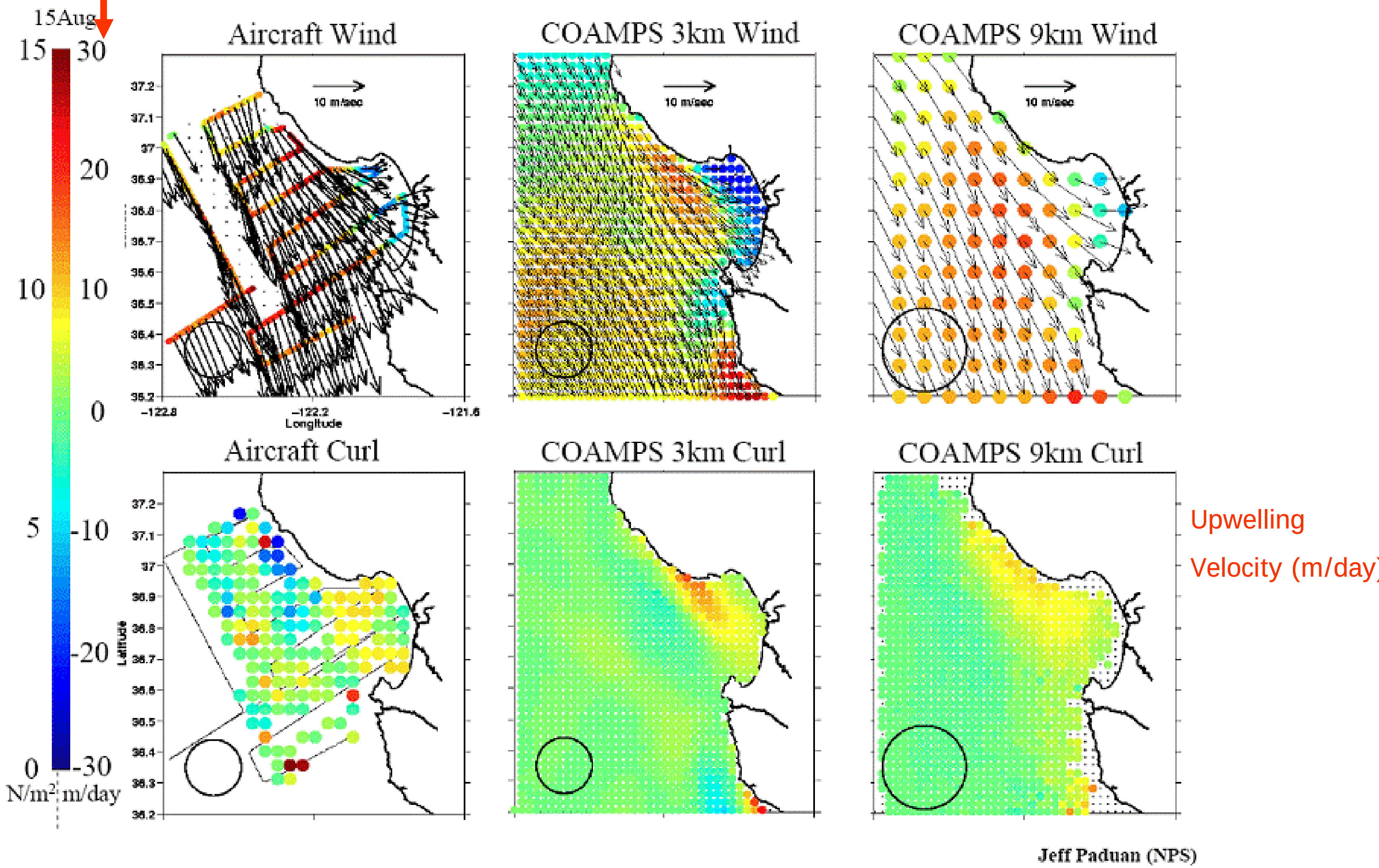
- 37 weeks of QuikSCAT data
- All slices (~3 x 25 km resolution); 50-70^o azimuth
- Transect off US West Coast, 50^o N

- 20 km landmask may be possible at this location and viewing geometry



Images courtesy of Tracy Haack

AOSN Aircraft Observations, August 2003



Strub

Coastal Modeling

Pilot real-time Oregon coastal ocean forecast model:

Daily updates of 3-day forecasts (since June 2005)

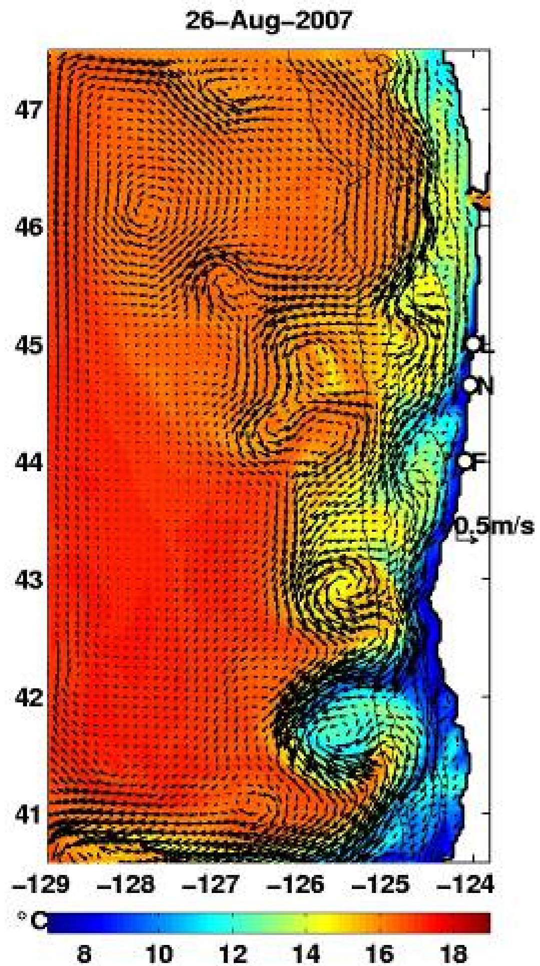
ROMS

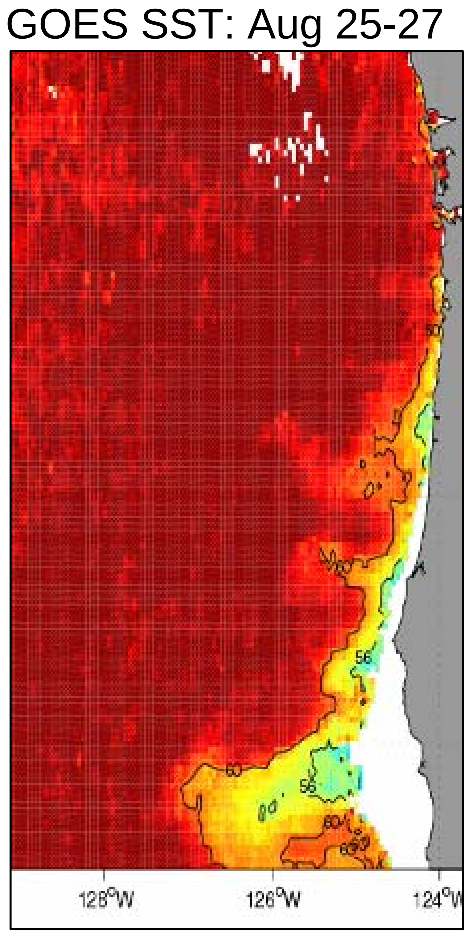
dx = 3 km, 30 s-layers

w/ turbulence parameterized (Mellor & Yamada 1982)

Atmospheric forcing: NOAA NAM (ETA) forecasts

Boundary conditions: monthly climatology from 9-km NCOM-CCS (2000-2004) (Kindle et al.)





http://www-hce.coas.oregonstate.edu/~orcoss/SSCforecast.html

www.orcoos.org

Model-data verifications:

Using:

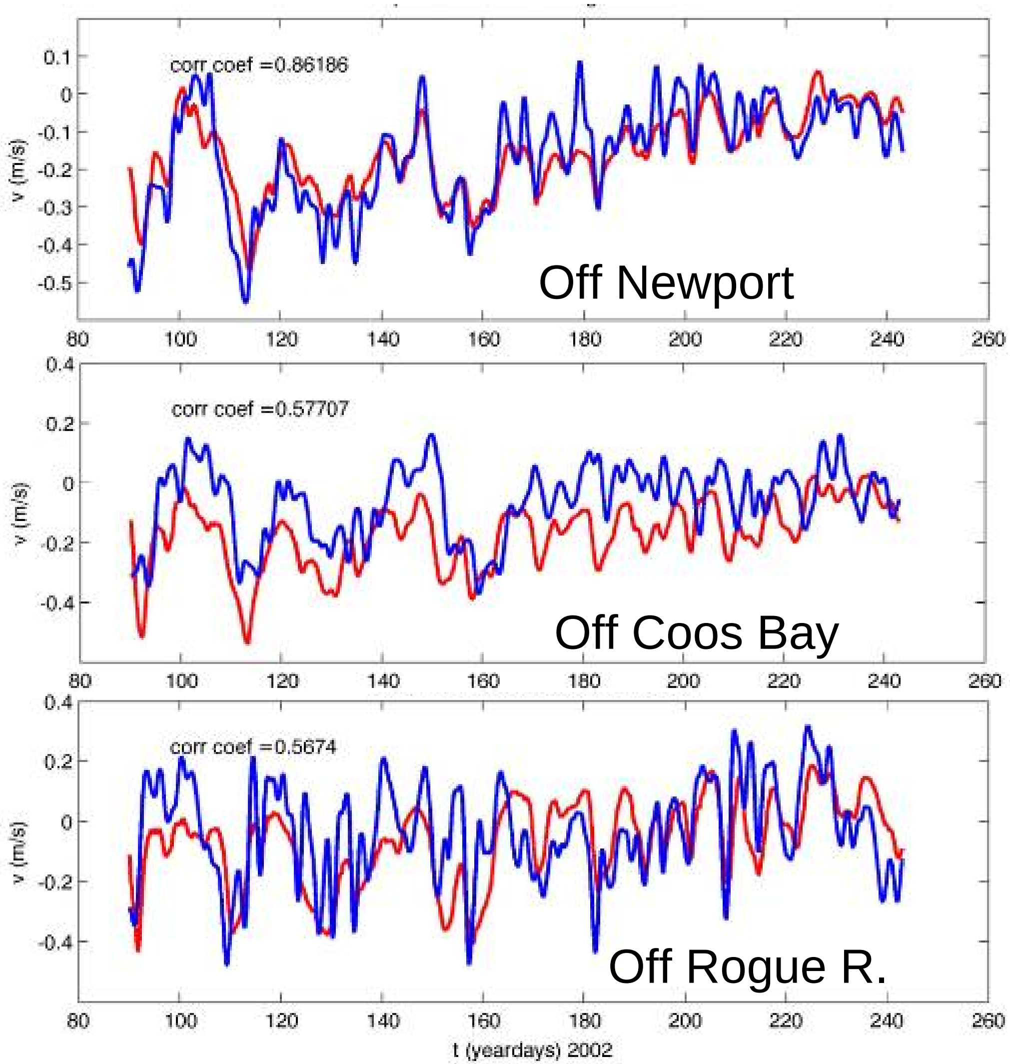
- near-real time data (SSH altimetry, HF radar, GOES SST)

- archived data in hindcast studies (COAST'01, GLOBEC'02)

Shown: alongshore depth-ave currents at mid-shelf mooring locations:

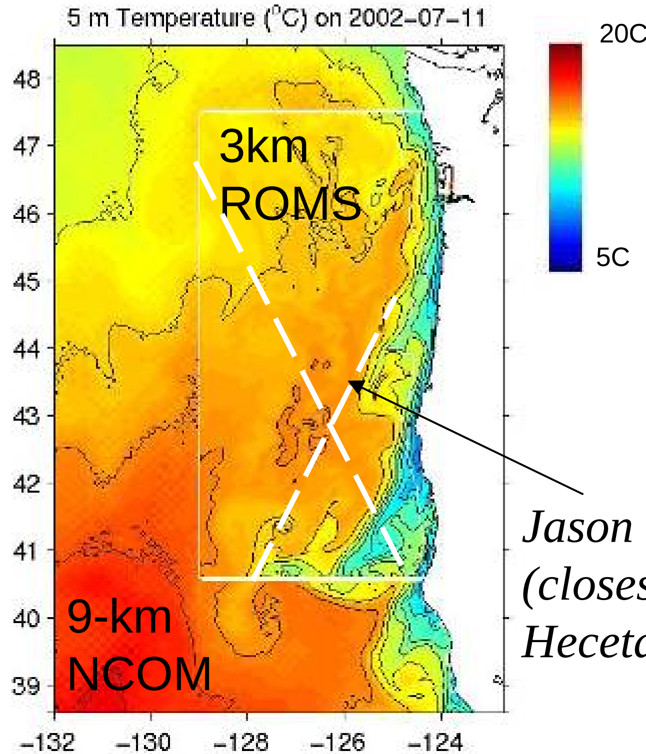
model (Koch, Erofeeva, Choi)

obs (Kosro, Hickey, Ramp)



Upgrading the model to a limited-area version with nesting into NCOM-CCS allowed to improve prediction of coastal currents

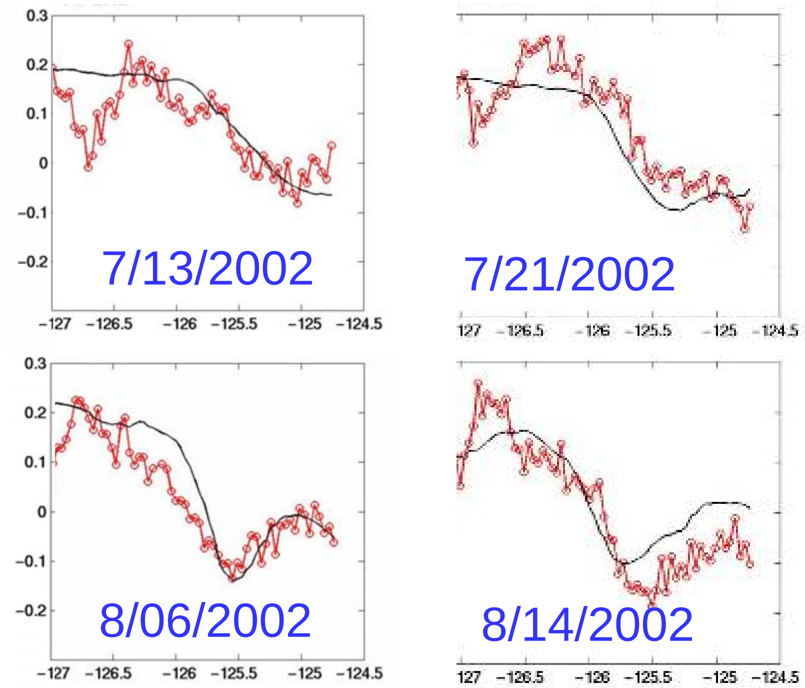
SSH: Comparisons with alongtrack satellite altimetry



Jason Track (closest to Heceta B.)

Model-data comparisons

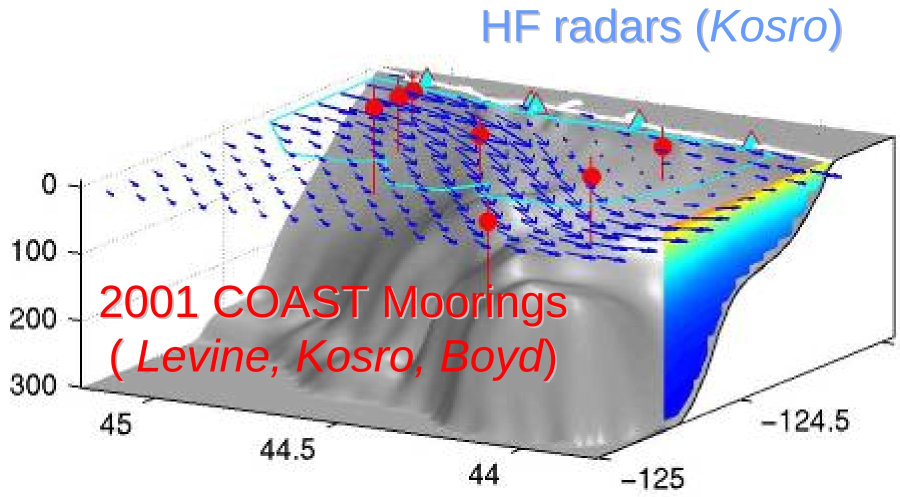
SSH along satellite tracks (ROMS – black, Jason – red):



Lower SSH associated w/ current separation near Heceta Bank (as well as Cape Blanco) is predicted by the model

Approach to Data Assimilation (DA)

Previous DA experience w/ nonlinear coastal model: simplified sequential OI



POM+Mooring obs. (Kurapov et al. JGR 2005a, 2005b, JPO 2005)

- *Distant effect of velocity DA*

- *Effect of velocity DA on other oceanic fields (incl. near-coast SSH, T, S, turbulence)*

- *Analysis of variability in the bottom BL dynamics*

Sections at 46N, upwelling event in June (167-169, 2001):

w/out CR | w/ CR

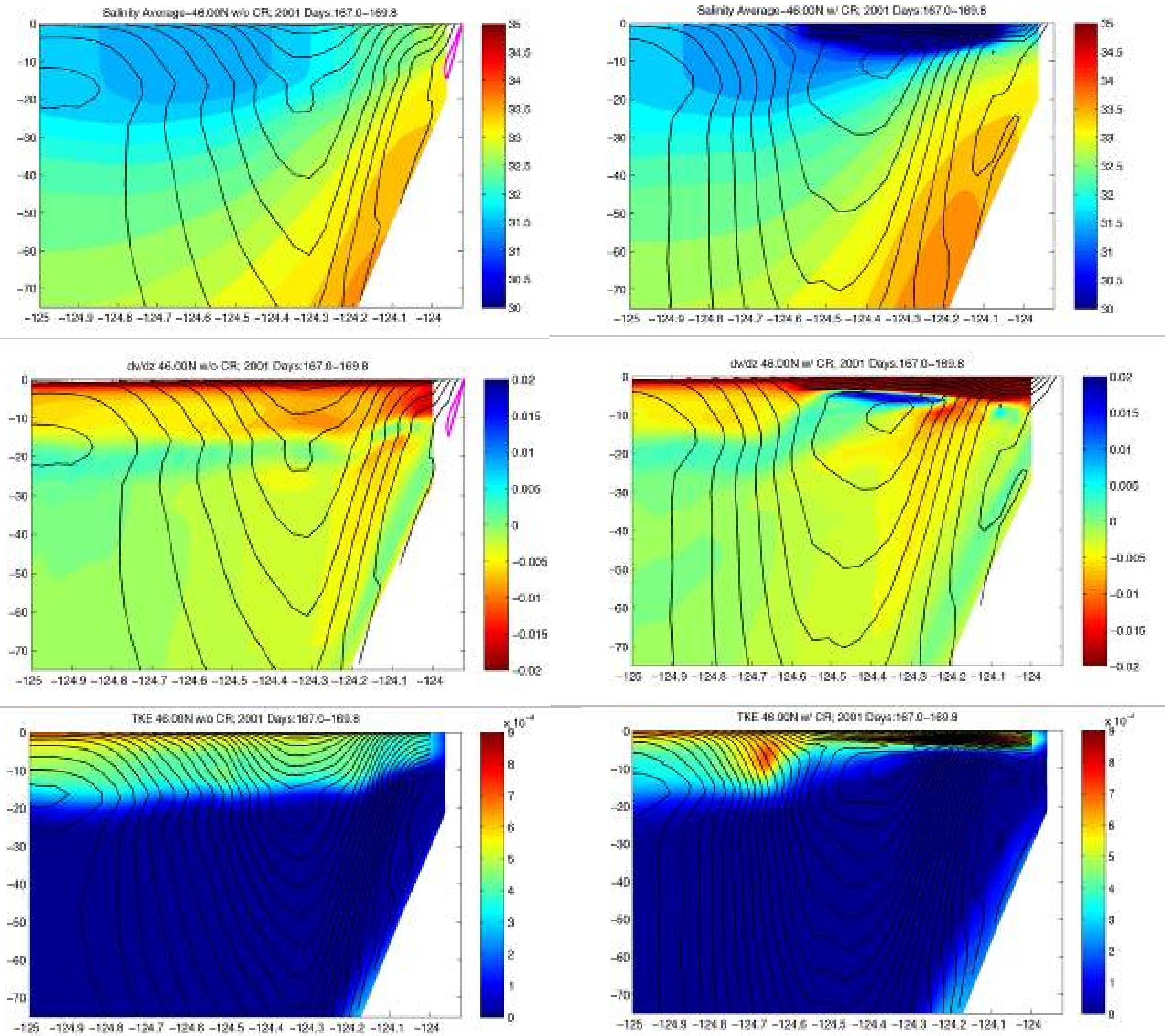
alongshore velocity (lines, each 5 cm/s)

Salinity (color)

d v / d z

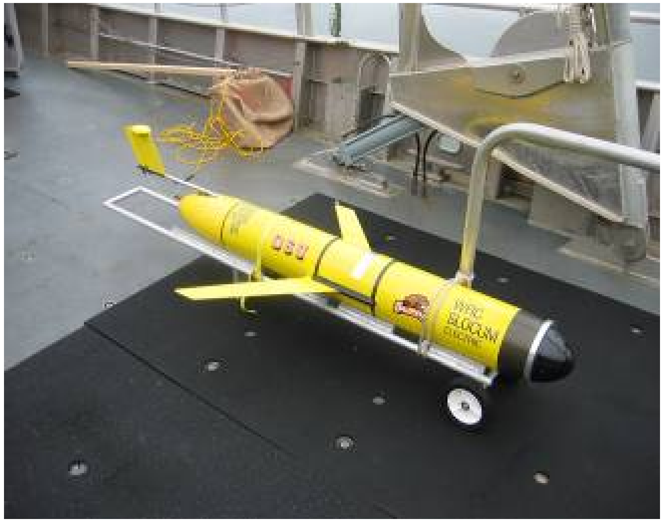
Turbulent KE (here, v lines each 2 cm/s)

The river plume changes the depth of the surf. BL



Vancouver Isl.
Seattle
RSN4
WA
Columbia R.
Portland
OR
RSN1
500m
80m
NEWPORT
150m
25m
OSU
Corvallis
Central Oregon Line
Mooring
Node

Gliders: Buoyancy propelled AUVs

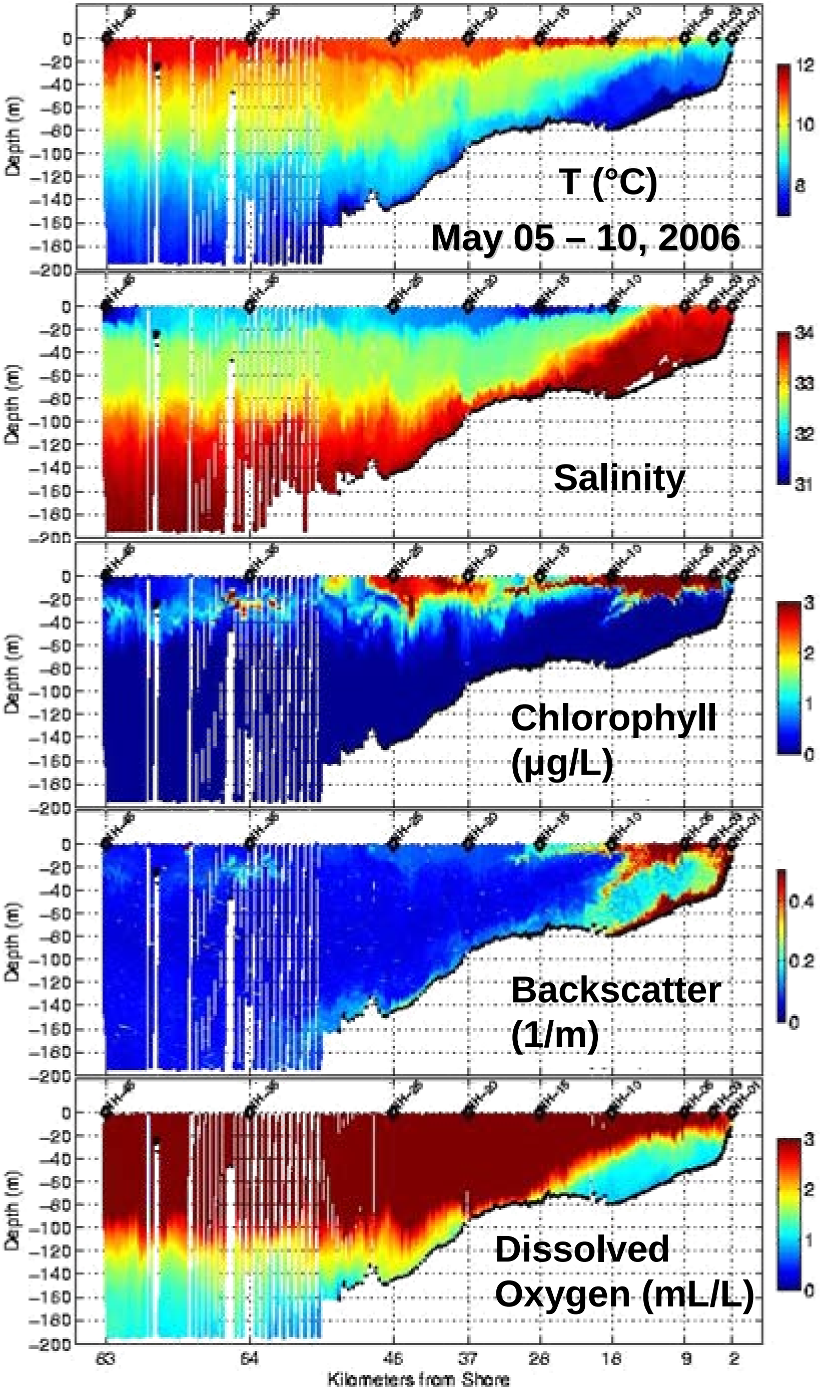


Coastal Glider

- 30-40 cm/s fwd speed
- 21-28 day endurance
- 200 m max depth
- CTD, chl, backscatter, CDOM, DO, currents
- GPS
- Iridium and radio communications
- 1.5 m long, 52 kg
- Active rudder – highly maneuverable
- $100K + $20/day

Deep Glider

- 15 cm/s fwd speed
- 6 month endurance
- 1000 m max depth
- CTD, chl, backscatter, CDOM, DO, currents
- GPS
- Iridium communications
- 1.8 m long, 52 kg
- Less maneuverable
- $130K + ?/day



Glider Sections

2-5 days per section (90 km)

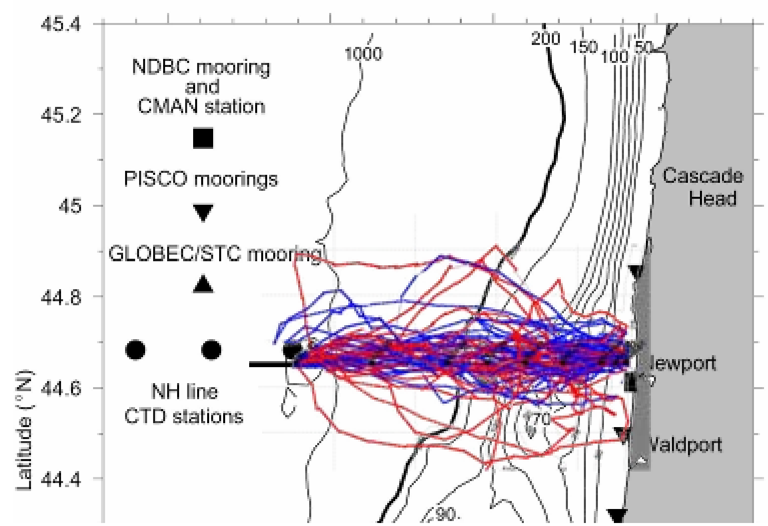
100 – 500 m along track resolution

0 to ~3 mab (200 m max)

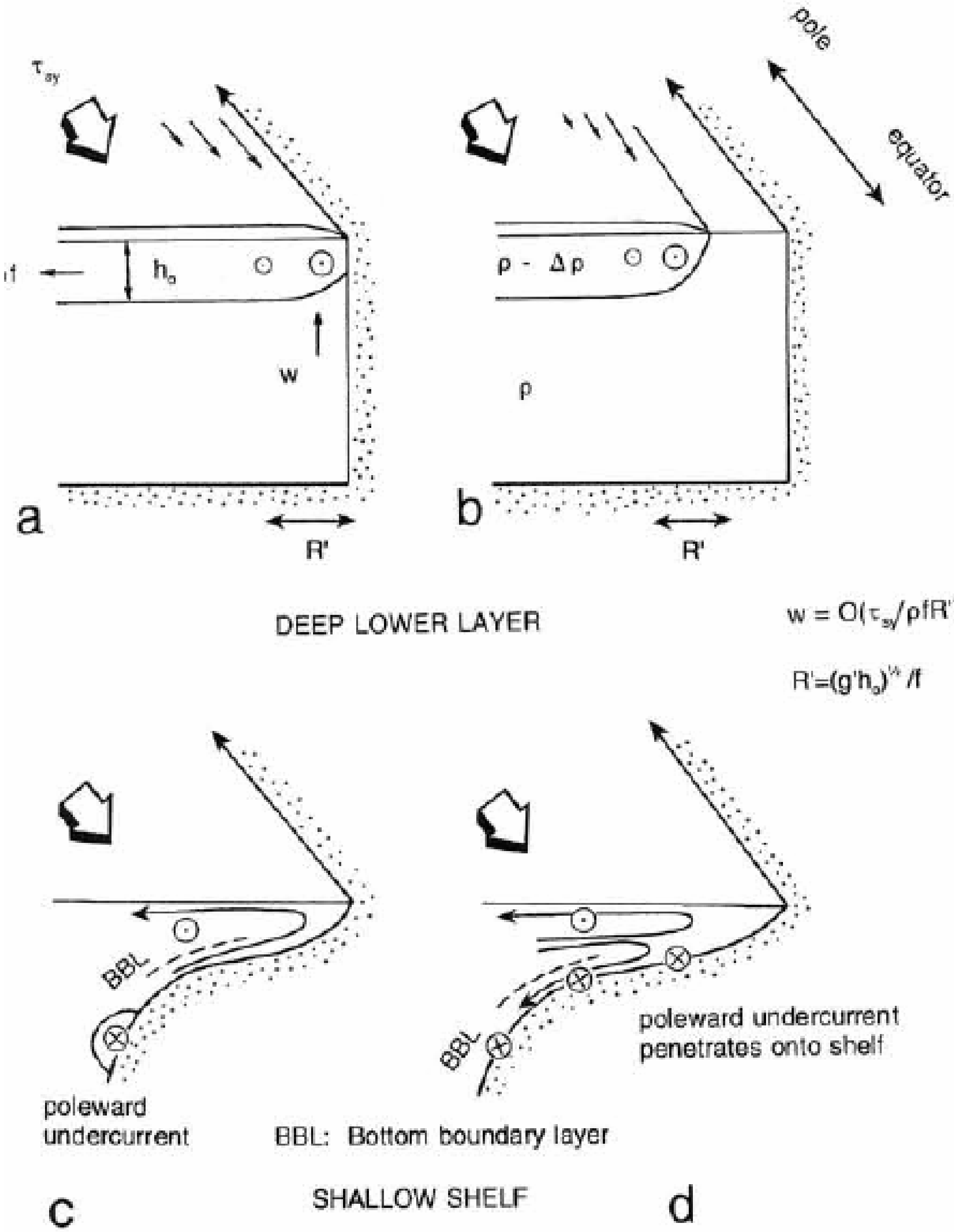
Surface every 6 hrs to get GPS fix, download data and receive new instructions (via Iridium)

21 day endurance

Also measures CDOM fluorescence and average currents



Coastal Altimetry – The Challenge



τ_sy
pole
equator
h_o
w
ρ - Δρ
ρ
a
b
R'
R'
DEEP LOWER LAYER
w = O(τ_sy/ρfR')
R'=(g'h_o)^½/f
BBL
BBL
poleward undercurrent
poleward undercurrent penetrates onto shelf
BBL: Bottom boundary layer
c
SHALLOW SHELF
d

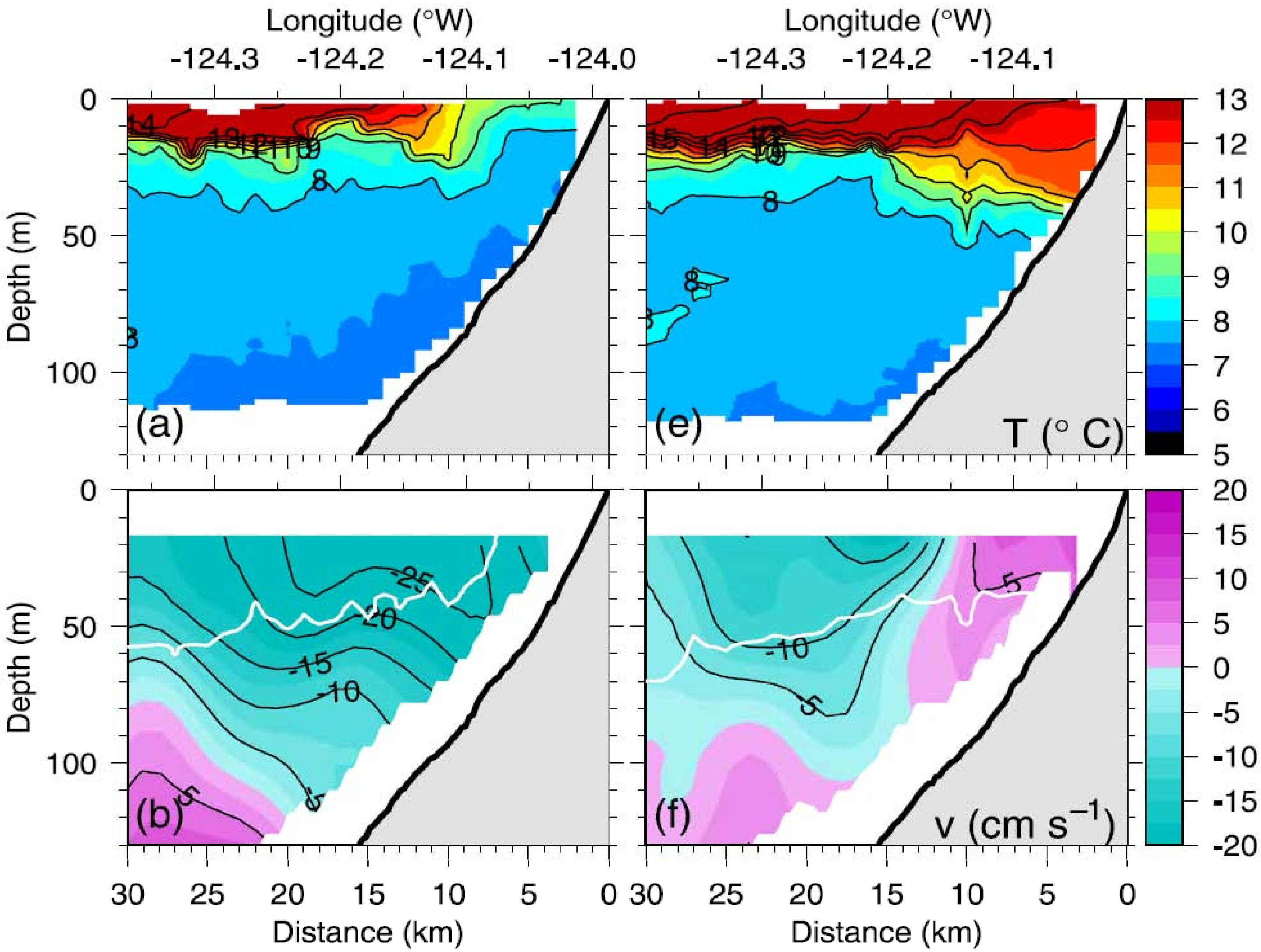


Figure 9. Vertical sections of properties measured near 45°N during (a–d) upwelling (45.11°N, 2256 UTC on 9 August 2001) and (e–h) downwelling (45.02°N, 2158 UTC on 25 August 2001) wind forcing. The 26.0 kg m^{-3} isopycnal is shown in white on plots of north-south velocity, chlorophyll, and buoyancy

J. Barth

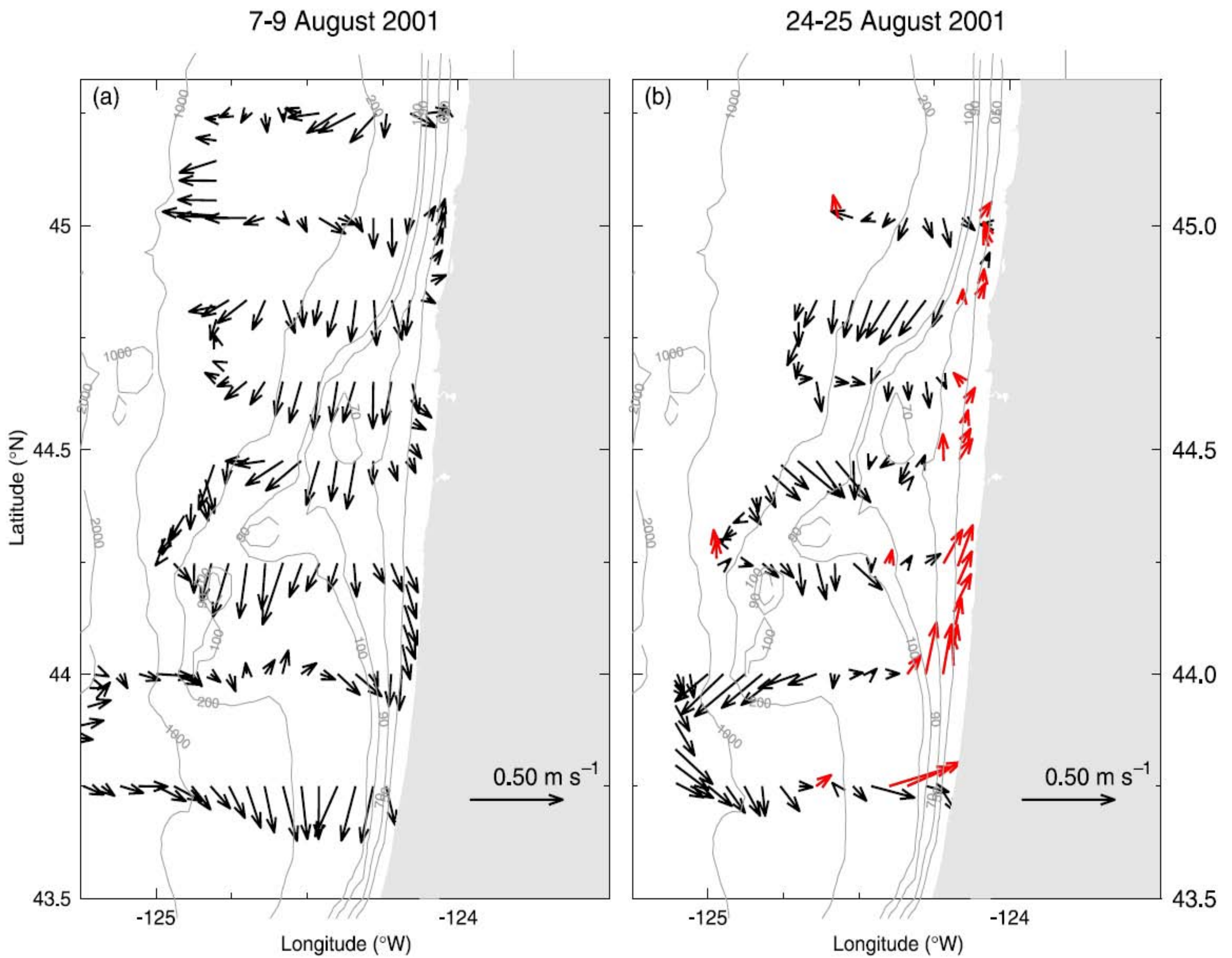


Figure 11. Velocity vectors at 25 m during (a) upwelling-favorable (7–9 August 2001) and (b) downwelling-favorable (24–25 August 2001) wind forcing. During downwelling, velocities with a northward component greater than or equal to 0.05 m s^{-1} have been colored red.

J. Barth

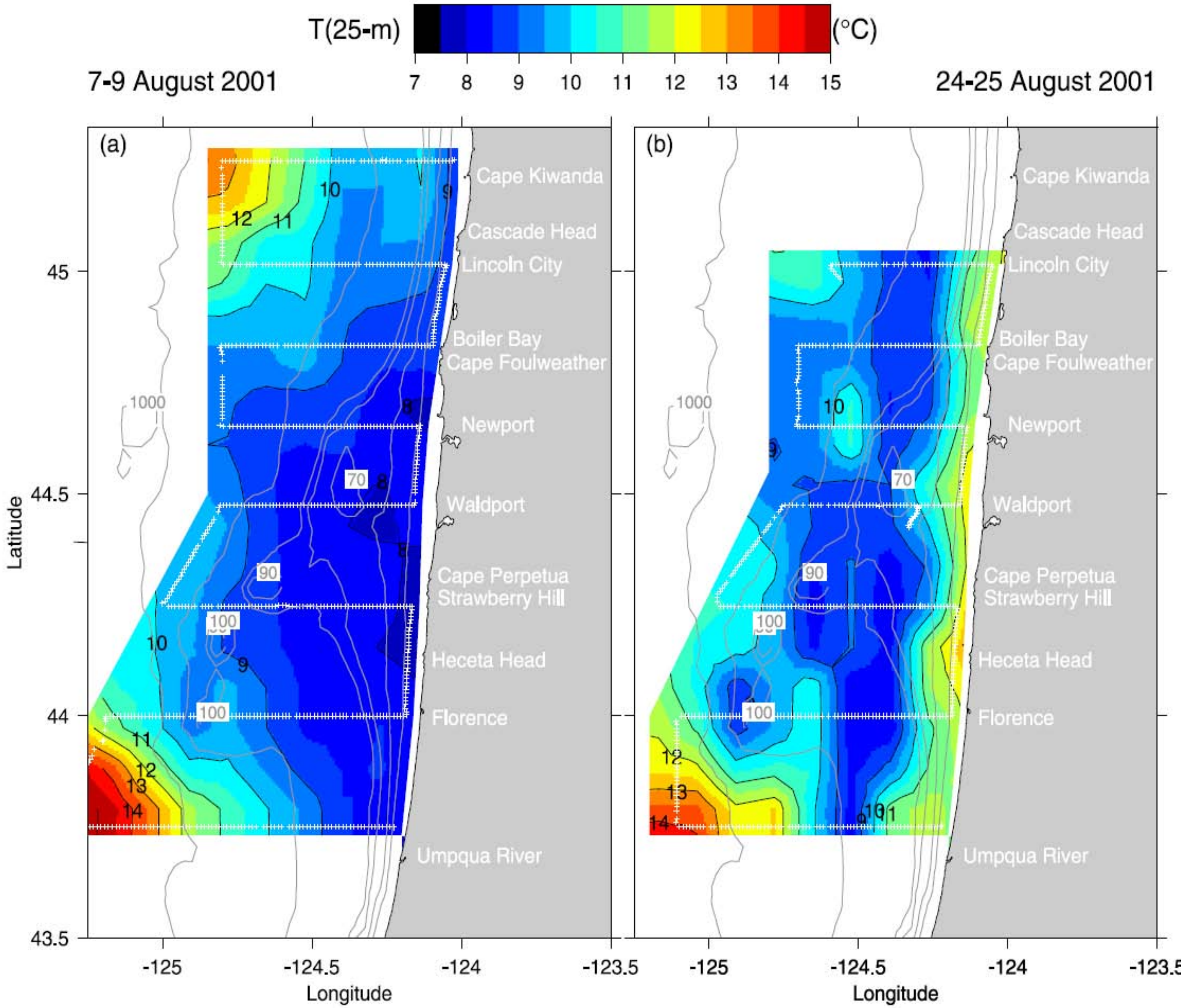


Figure 10. Maps of 25 m temperature (°C) during (a) upwelling-favorable (7–9 August 2001) and (b) downwelling-favorable (24–25 August 2001) wind forcing.

J. Barth

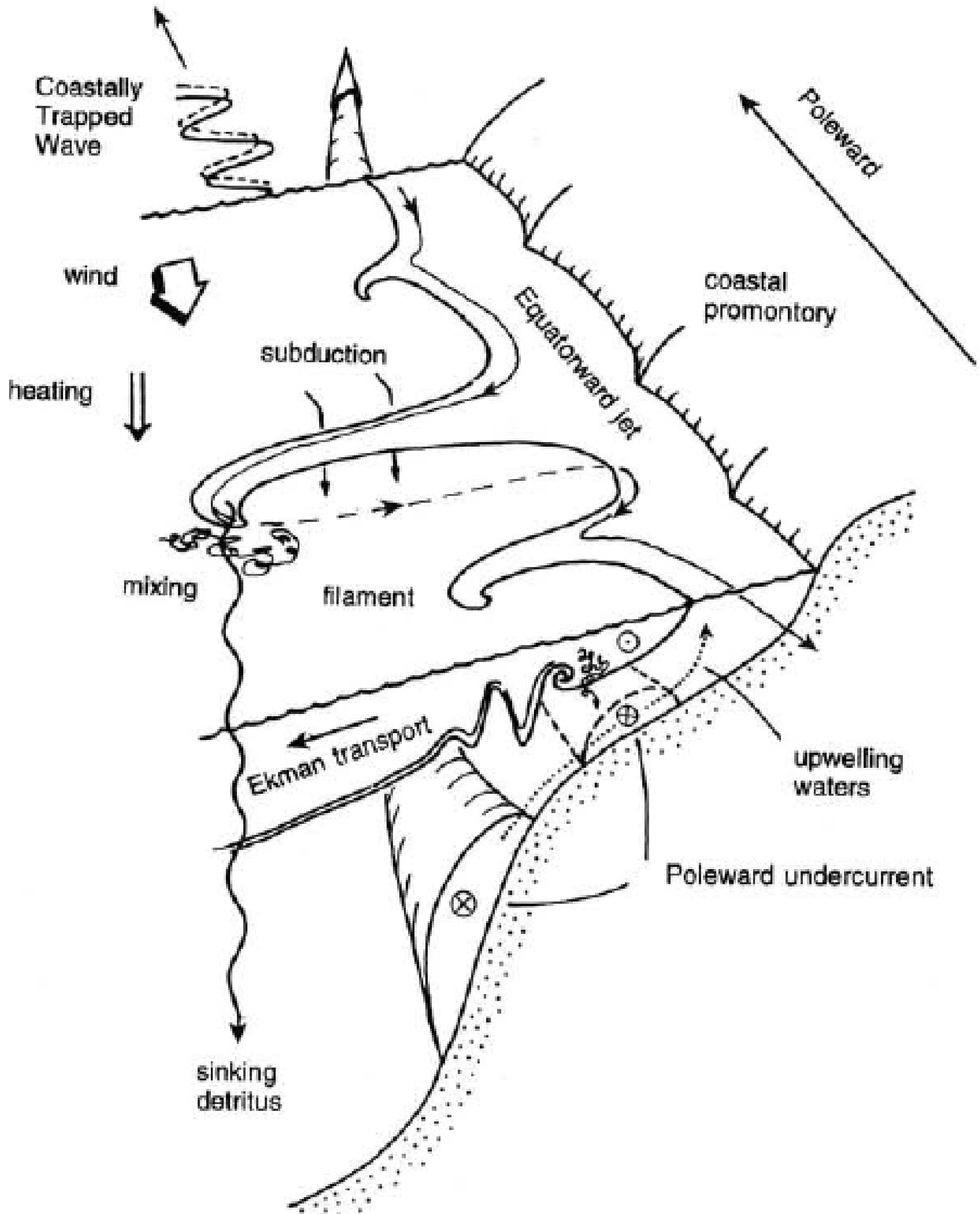
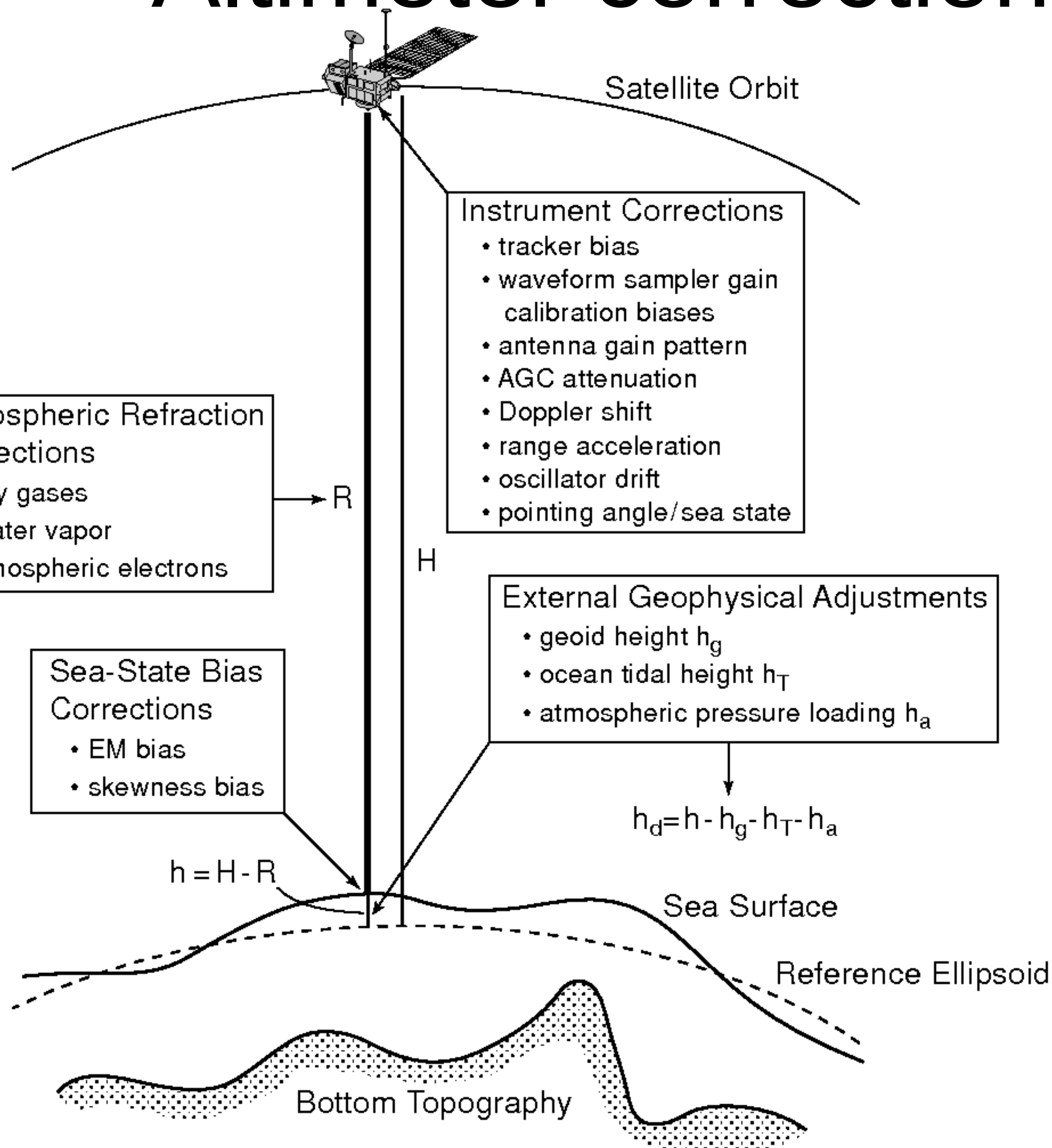


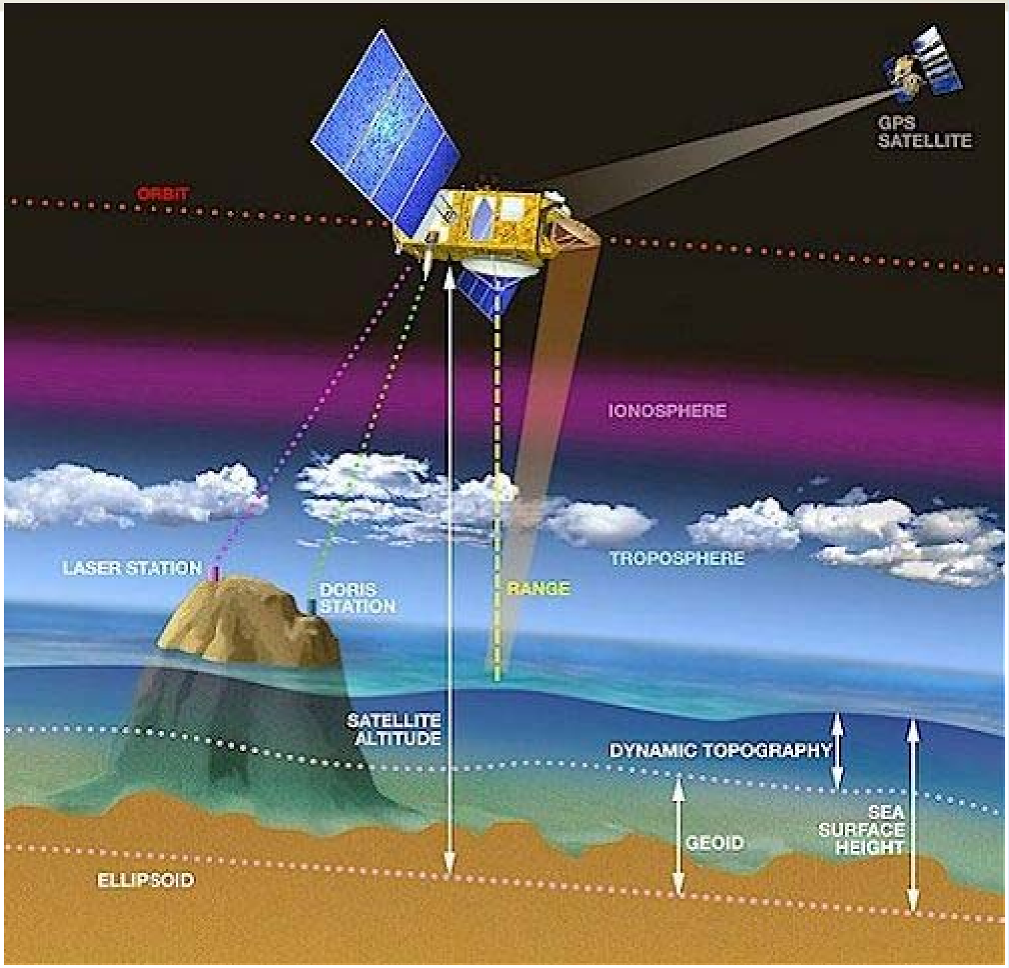
Fig. 2.4. Schematic of an upwelling system.

Coastal Altimetry – Tracking and Wet Troposphere

Altimeter corrections



The Playing Field



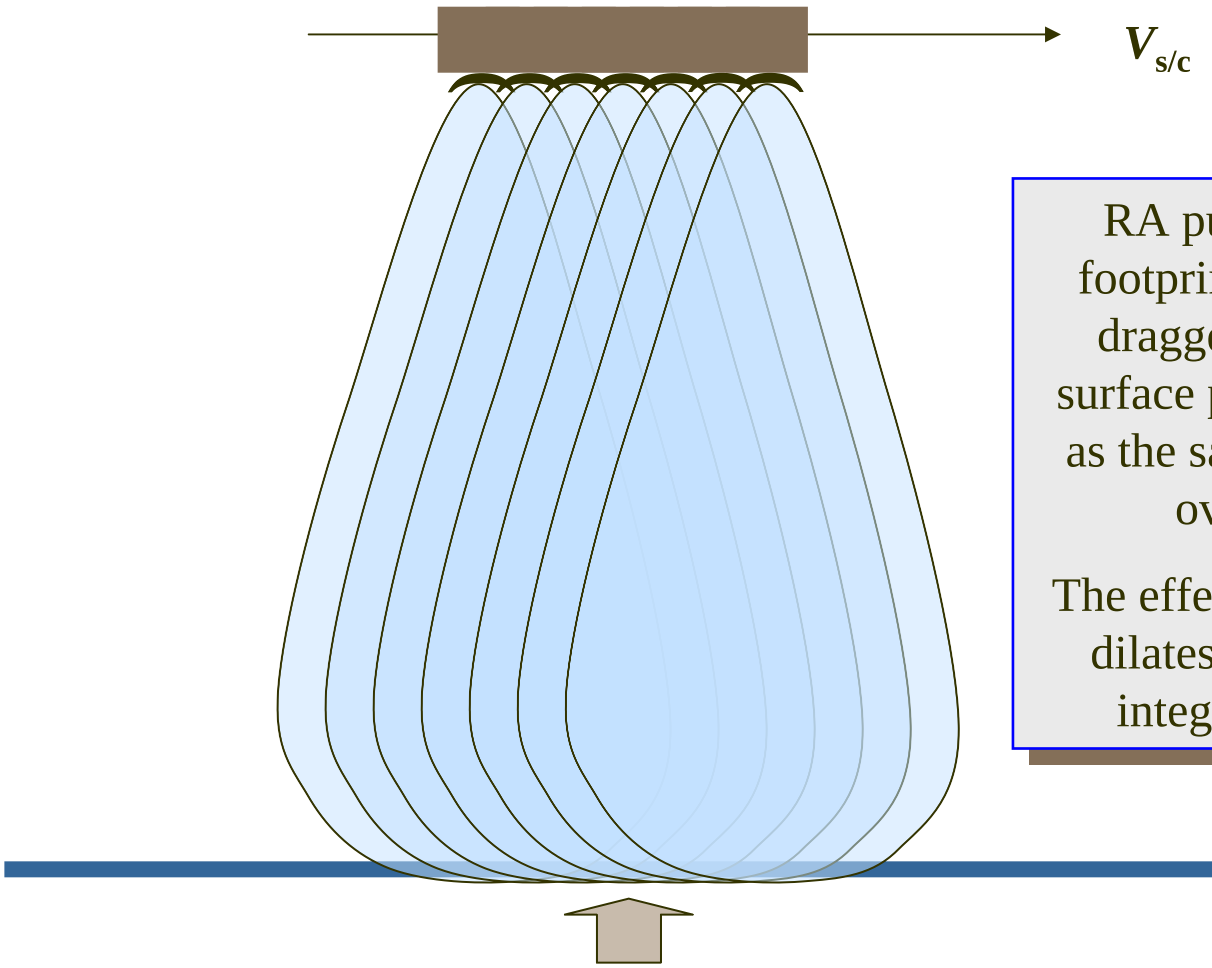
(Acknowledgement CNES/D. Ducros)

Pertinent parameters:

- SSH, SWH, WS, other*
- Averaging*
- *Antenna pattern (full)*
- *Pulse-limited footprint*
- *Radiometer pattern(s)*
- *Propagation delays*
- *Waveform integrity*
- *etc*

* *Themes of this brief*

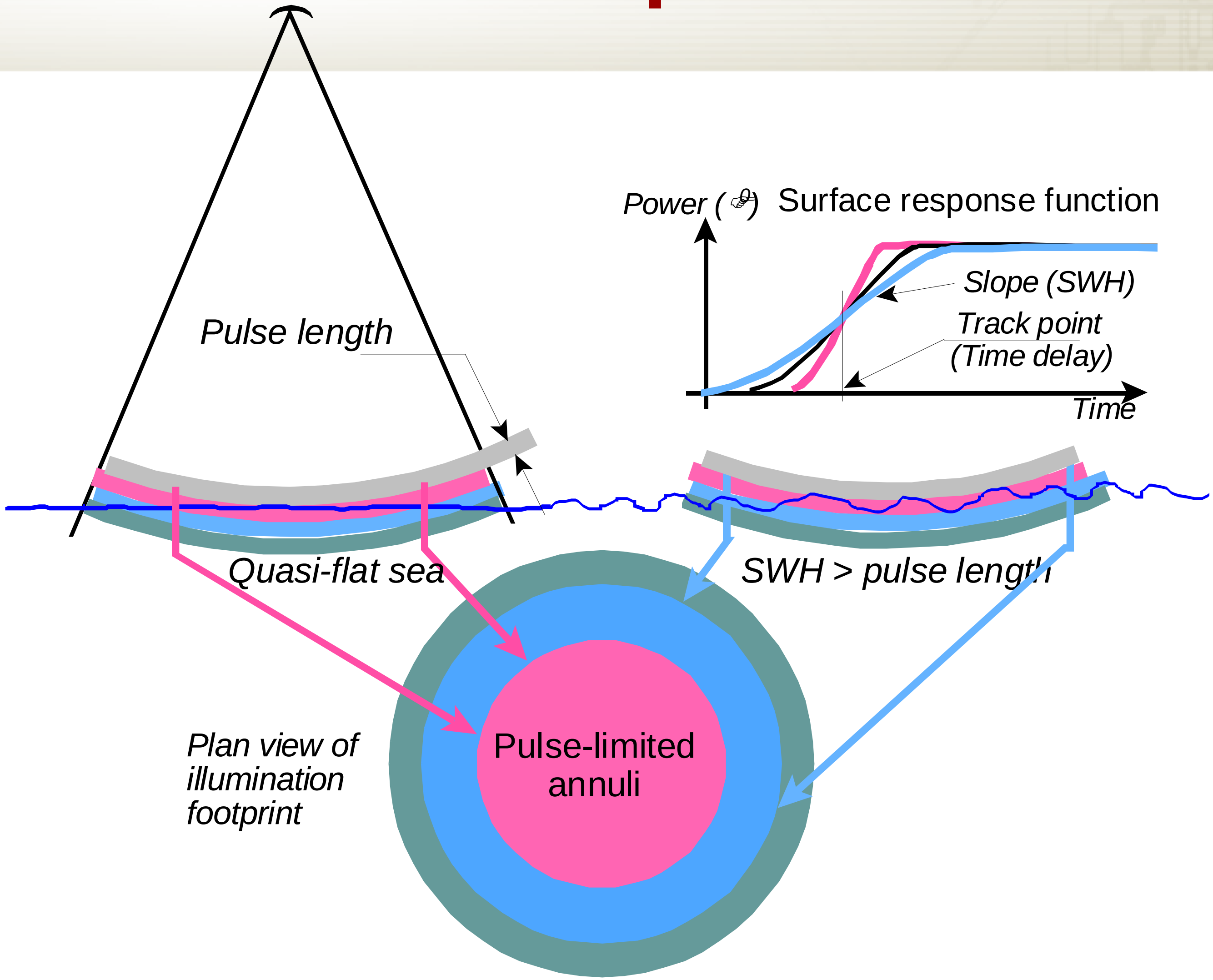
Conventional ALT footprint scan



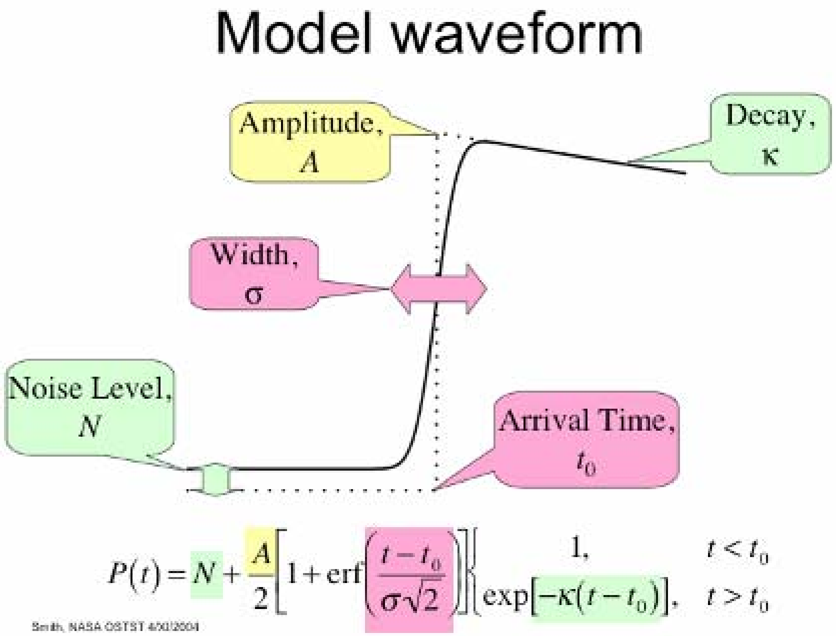
RA pulse-limited footprint in effect is dragged along the surface pulse by pulse as the satellite passes overhead.

The effective footprint dilates with longer integration time

Pulse-Limited Footprint ~ SWH



"Simple" (Brown model) retracking

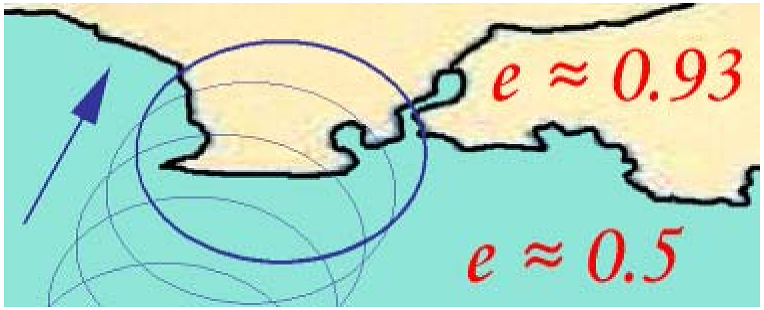


If the reflecting surface is homogeneous (open ocean, not coastal), the antenna is simple, and the antenna mispointing is small, then a 5 parameter ("Brown") model adequately fits the waveform.

Arrival time yields range. Rise width yields SWH. Amplitude and AGC yield σ_0. Plateau decay yields off-nadir pointing.

3) How are water vapor radiometers on board altimeters affected by land in the footprint ?

- The same way as the other radiometers (SSM/I, TMI, AMSU…)

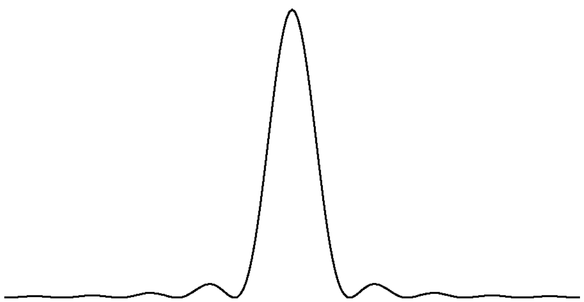


- Land emissivity nearly twice sea emissivity + **more variable in space and time**

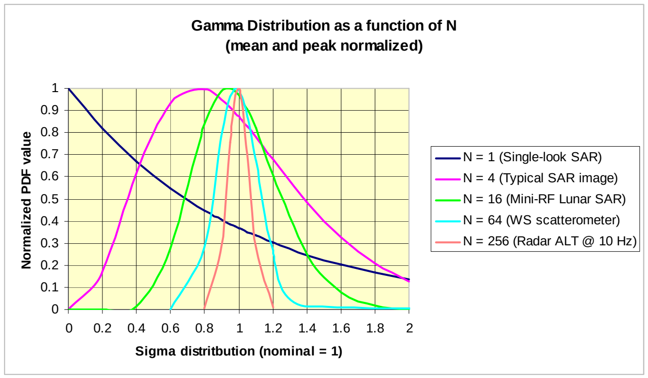
- For a surface temperature of 300K, a 10% land contamination will increase the TB of more than 10K !

- Classical algorithm developed assuming sea surface emissivity modelling are no more valid

Why on-board tracking? -1



Instrument bandwidth limits the precision in a single range measurement to about 50 cm.



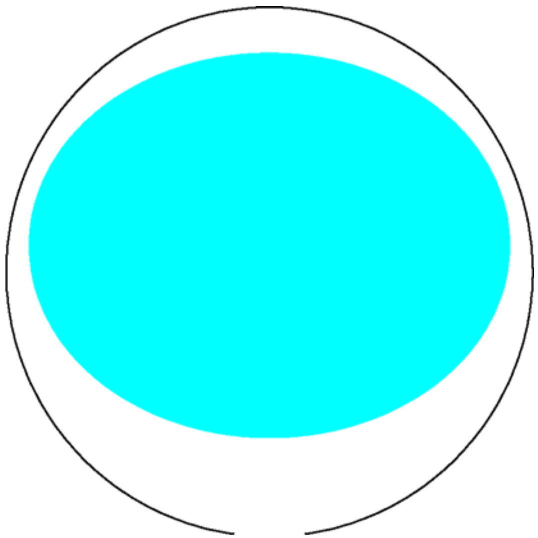
The single-measurement signal-to-noise ratio is 1:1.

Conventional altimeters use "incoherent averaging" to achieve better SNR and finer precision.

This requires two things:

1. Signal must remain aligned during averaging (the instrument must be "tracking" correctly).
2. Measurements must be uncorrelated; pulse repetition frequency limited to ~2.5 kHz or less. This is NOT true of an instrument using SAR processing, e.g. CryoSat-2, Sentinel-3, NEWEX, Water/HM.

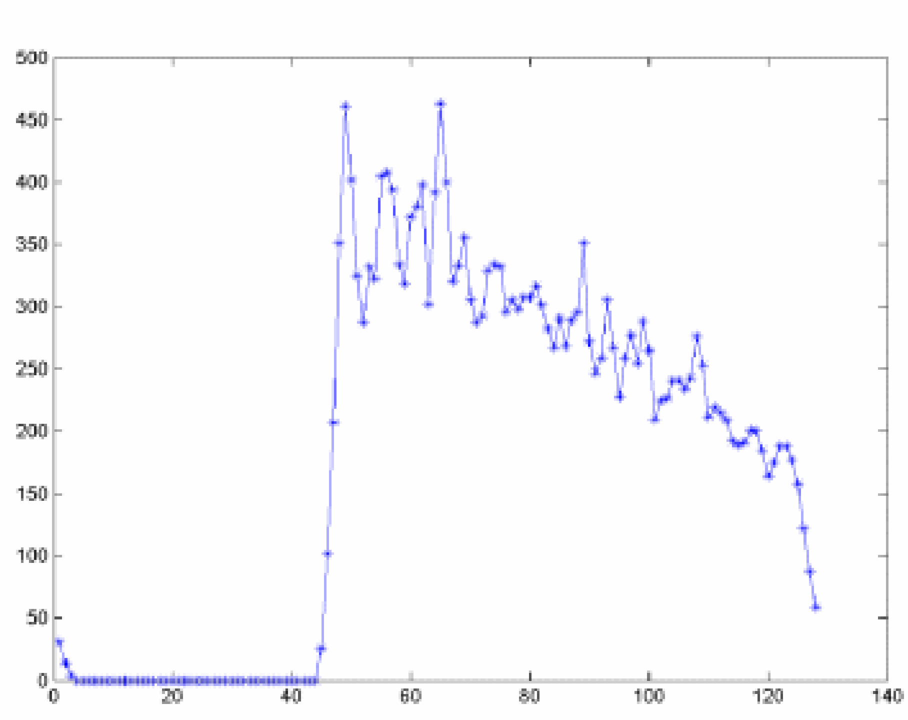
Why on-board tracking? -2



Both the orbit and the Earth are elliptical. This causes the range between instrument and target to move by ~25 m/s. An on-board "tracker" forecasts the expected range and range-rate to align successive pulses for averaging.

If the statistical properties of the reflecting surface (wave height, sigma-0) and range and range-rate have been smoothly varying for 2 to 3 seconds, then the forecast of the track point will be fairly accurate, and the received waveforms may be averaged properly. (Jason-2 may forecast via real-time orbit and elevation model look-up; instruments to date use the "tracker" to follow the past history of recently measured range values.)

The available waveform

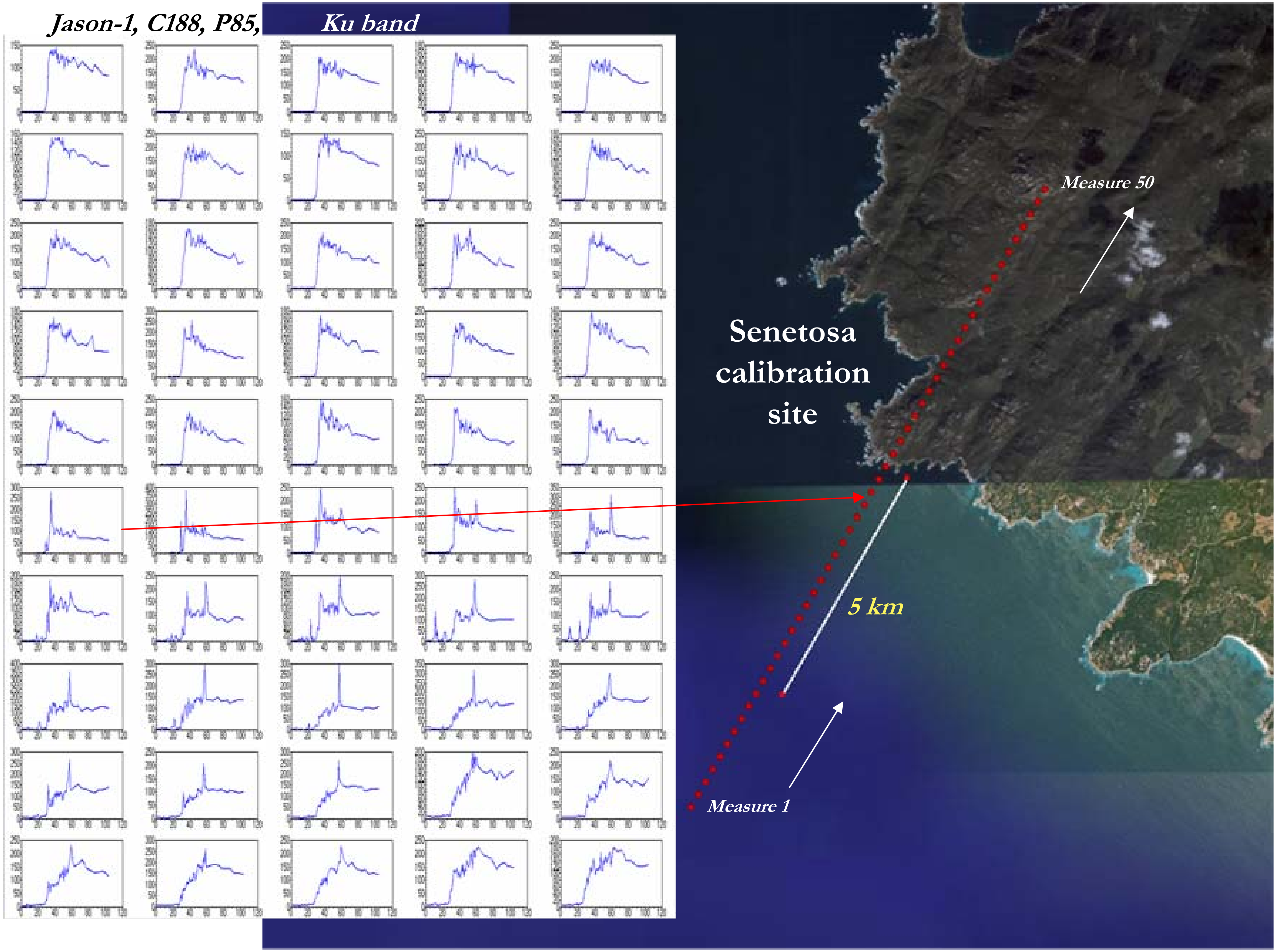


The on-board tracker's forecast of *r*, *dr*/*dt* are used to average pulses received over ~0.05 s.

The average waveform (shown here) is used on-board to update the tracker's forecast.

Usually only this average waveform, available at 20 Hz sampling rate, is available to us for further processing.

Noise is always proportional to power. The waveform has this simple shape only if the reflecting surface is statistically homogeneous (all ocean, not mixed w/land).



Jason-1, C188, P85, Ku band
Senetosa calibration site
Measure 50
5 km
Measure 1

Types of retrackers

"Simple" retrackers:

- Fit a Brown model to each waveform independently.
- Maximum likelihood weighting increases noise in SSH!
- (Is this the standard ocean data product?)

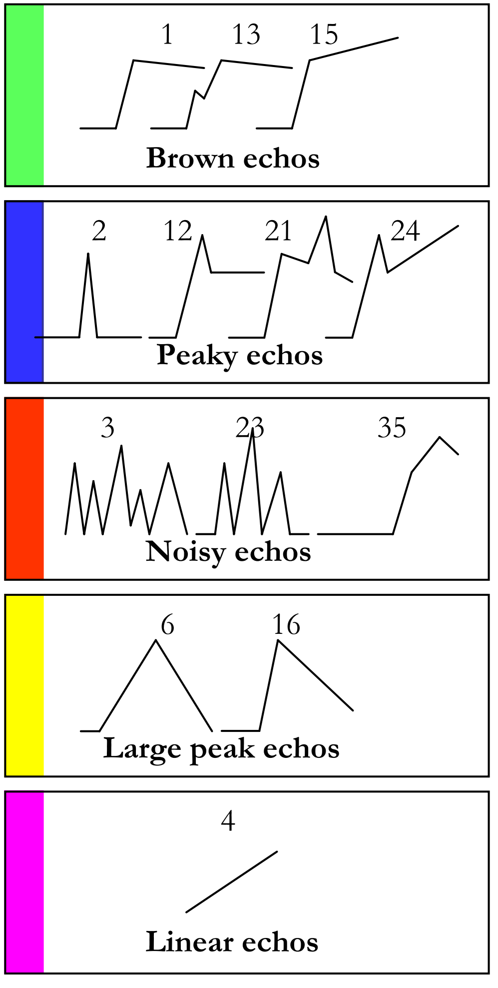
Constrained (smoothing) retrackers:

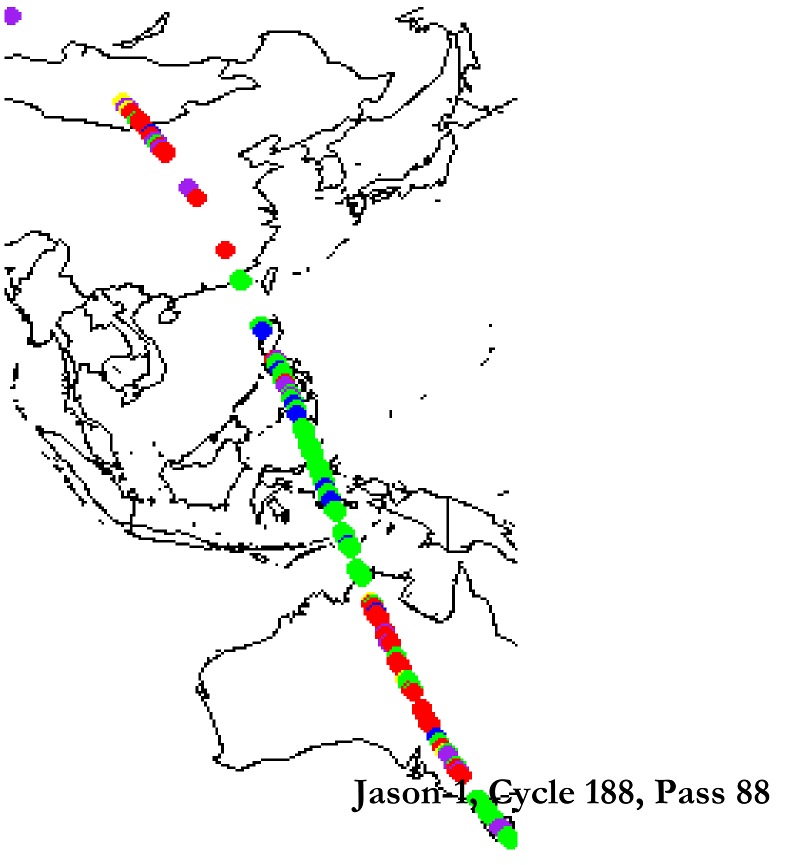
- "Simple" retracking with constraints added to reduce SSH noise.
- Reduce freedom in other parameters, introducing along-track correlation in other variables.

Adaptive retrackers:

- Fit different models to different waveforms.
- May recover data from heterogeneous surfaces (coast).
- Track point bias (height calibration) and SSB can change.

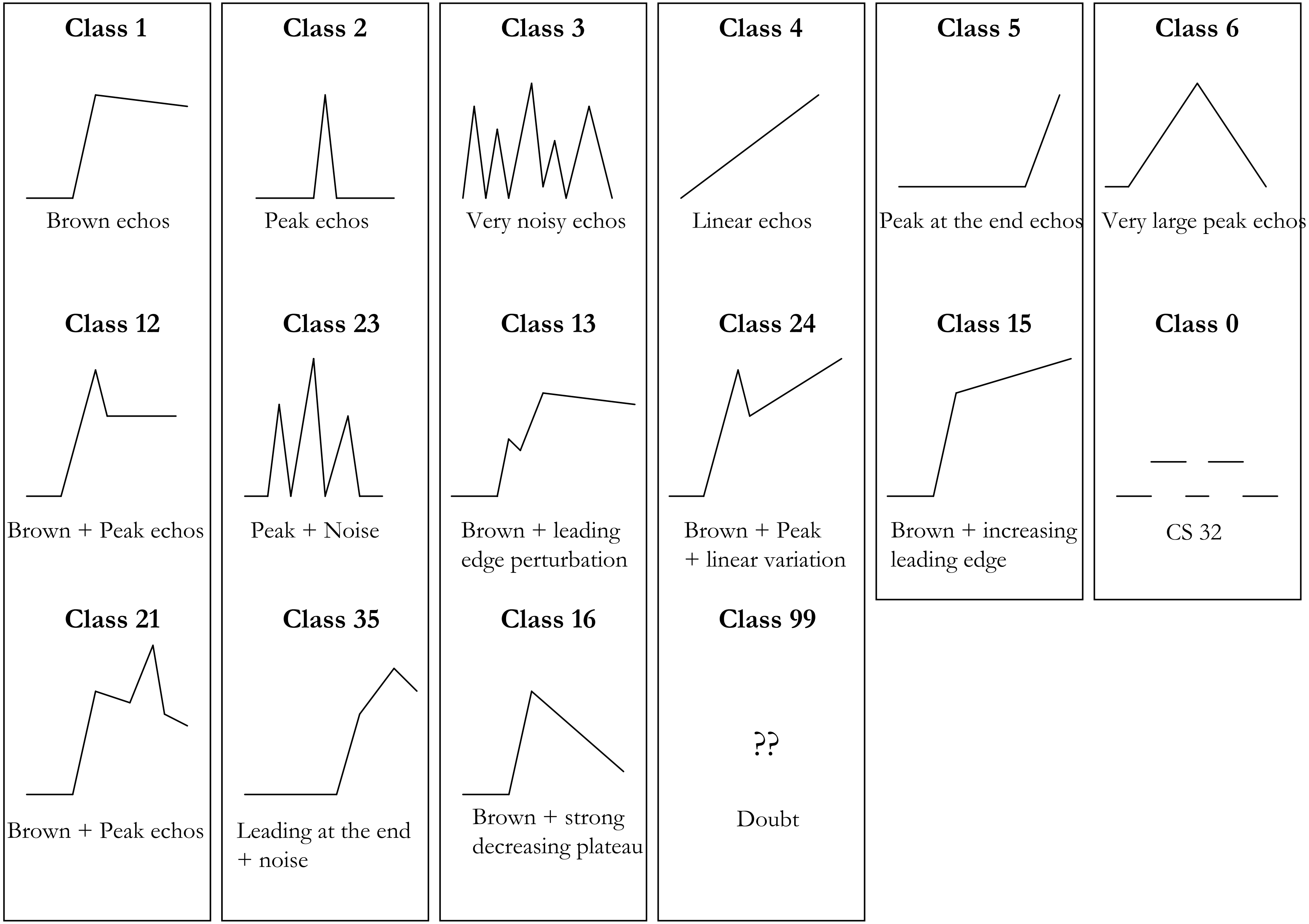
Adaptive retrackers





Attempt to model all waveform shapes, not only the Brown model shape expected of a homogeneous ocean surface.

Waveforms classification



Coastal waveform conclusions

Land may alter the shape of ocean waveforms when the nadir point is within 20 km of the coast.

If the coastal land is not mountainous and σ_0 is low, the waveform distortion may be mild until quite close to the coast, and simple (Brown model) retracking may work*.

Adaptive retrackers can recover data under a variety of conditions on land and ice as well as ocean, and these can be used where the simple Brown model fails.

*For discussion: are other problems (wet delay, tides, ?) more serious than retracking under these conditions?

Conclusions, retracking - 1

The following applies to retracking everywhere, whether in the open ocean or the coastal zone:

1. Waveform noise introduces random errors in estimated parameters (range, SWH, σ_0, attitude).
2. These estimation errors are inevitably correlated (among one another, not necessarily along-track).
3. Noise in one parameter (e.g., range) may be reduced by restricting the degrees of freedom, at the expense of enforcing along-track smoothness in another parameter (e.g., SWH).

Along-track smoothness of parameters (other than attitude) is certainly wrong at the coast.

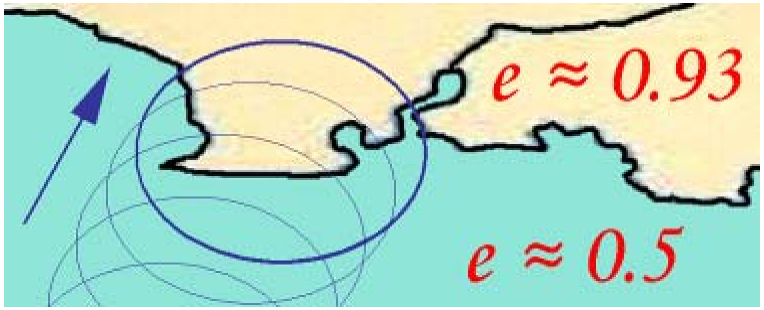
Conclusions, retracking - 2

Retrackers that adapt to changing waveform shapes may enhance data recovery close to the coast, ***however:***

1. Loss of information in the plateau region will degrade estimates of σ_0 and attitude, and is likely to change the bias in estimates of range and SWH.
2. As a consequence of 1, the SSH bias and the Sea State Bias may be unknown and may have jump discontinuities whenever the adaptive tracker branches to a new waveform shape or type.

3) How are water vapor radiometers on board altimeters affected by land in the footprint ?

- The same way as the other radiometers (SSM/I, TMI, AMSU…)



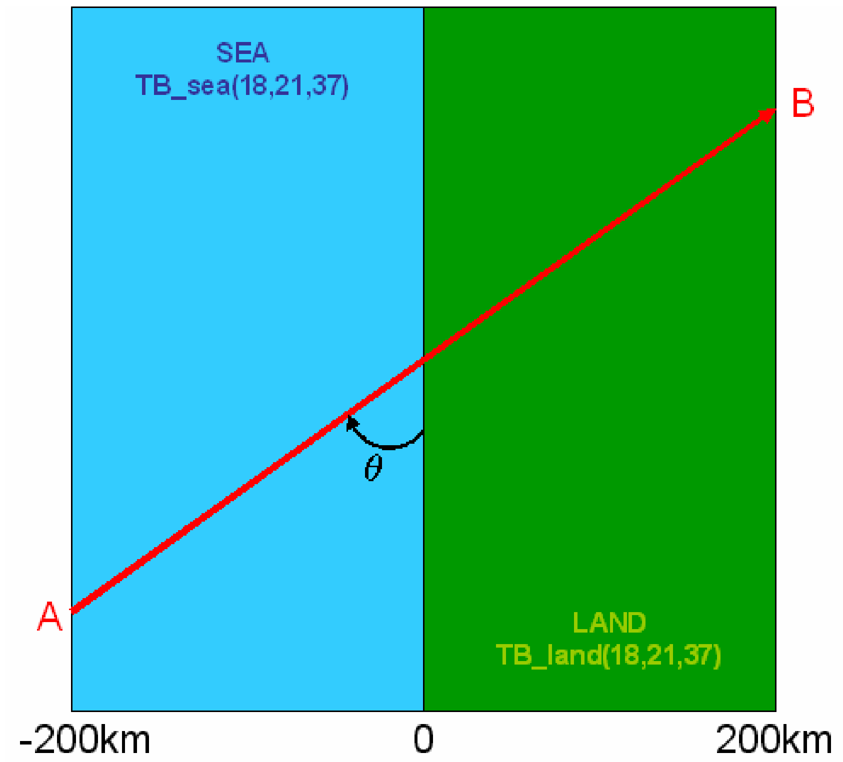
- Land emissivity nearly twice sea emissivity + **more variable in space and time**
- For a surface temperature of 300K, a 10% land contamination will increase the TB of more than 10K !
- Classical algorithm developed assuming sea surface emissivity modelling are no more valid

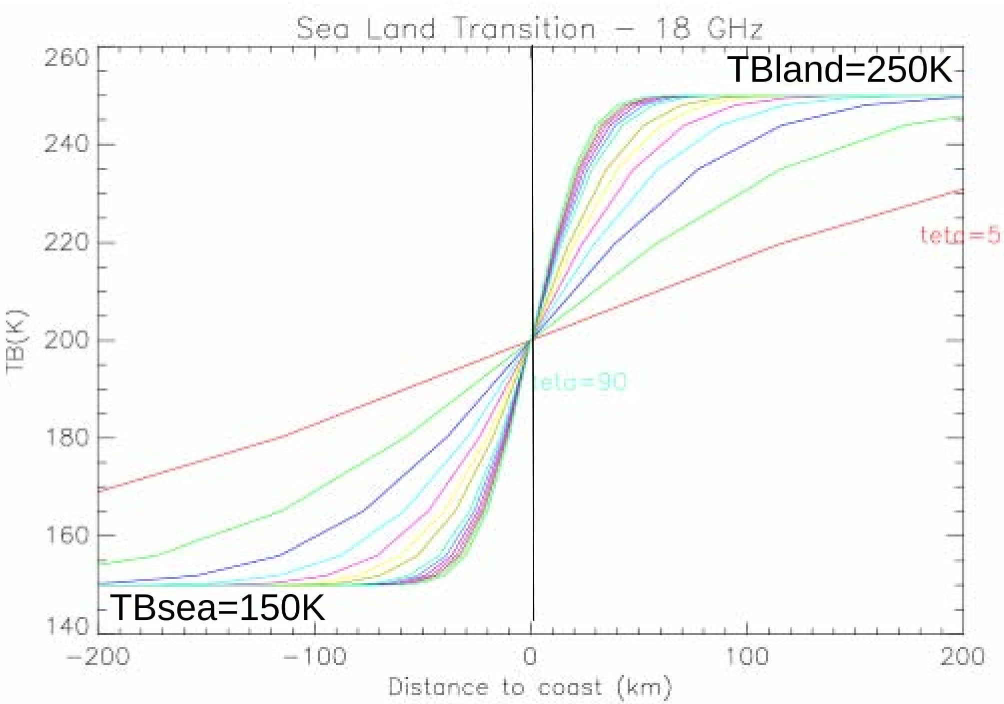
3) How are water vapor radiometers on board altimeters affected by land in the footprint ?

TB contamination by land depends on:

- radiometer antenna pattern (gaussian shape)
- land surface emissivity and temperature
- proportion of land in the footprint

Simulation on a simple case

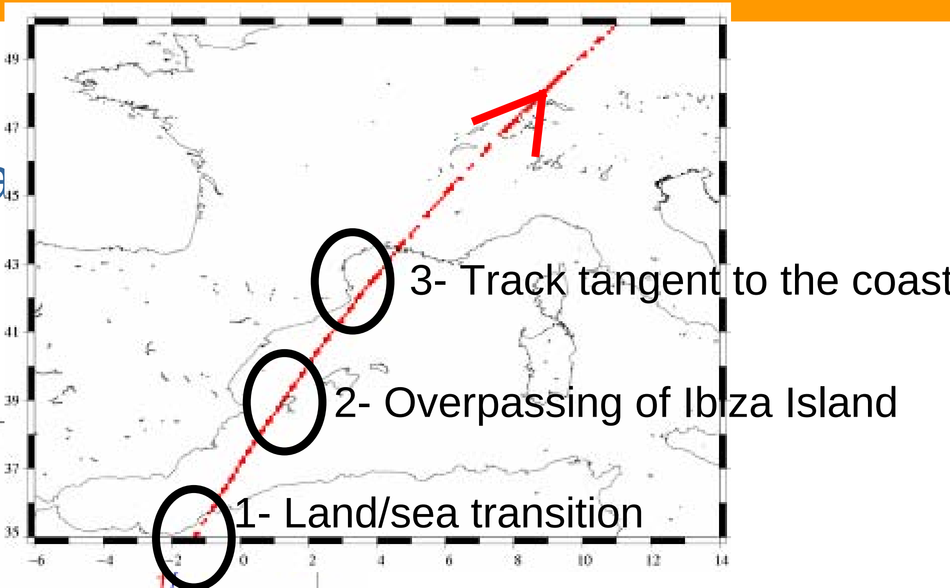


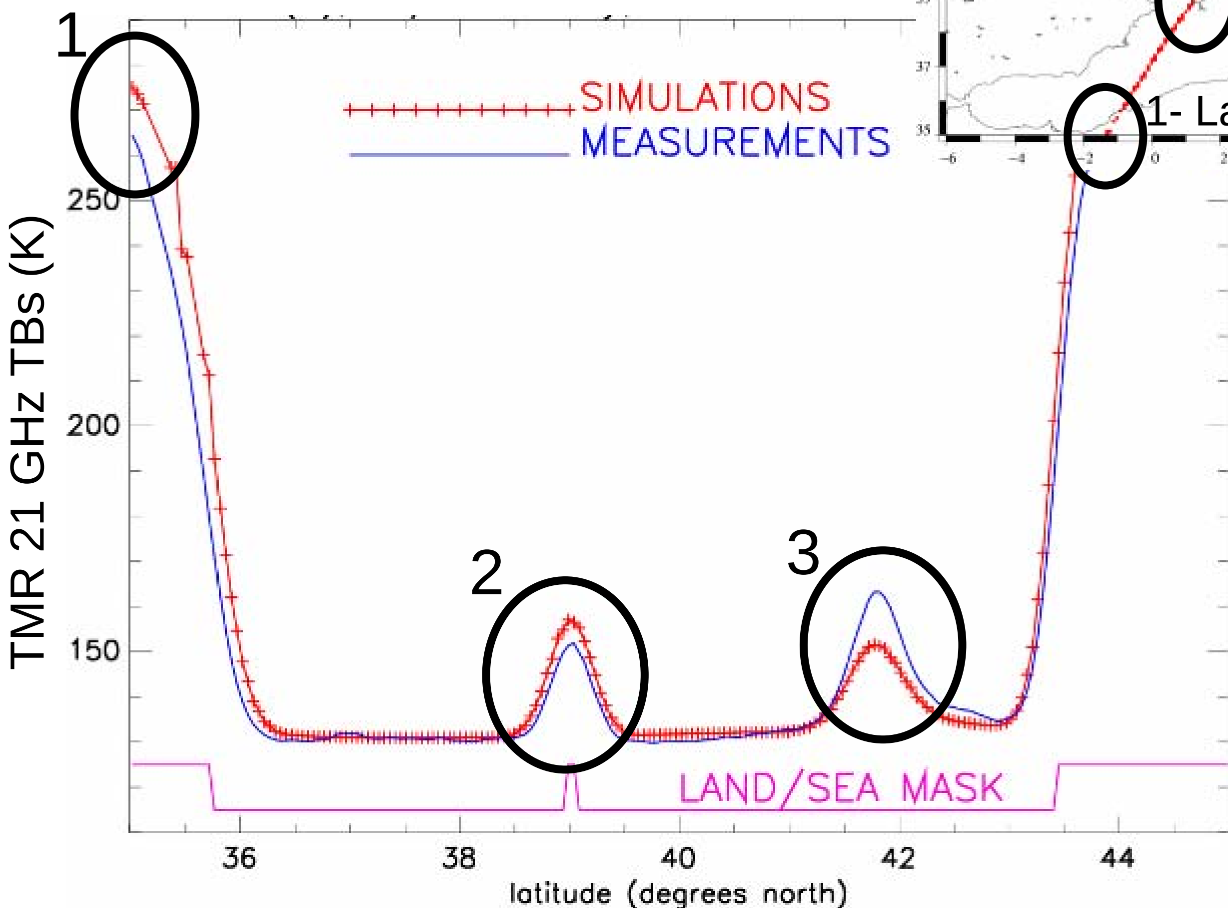


3) How are water vapor radiometers on board altimeters affected by land in the footprint ?

TB contamination

Some example of real data

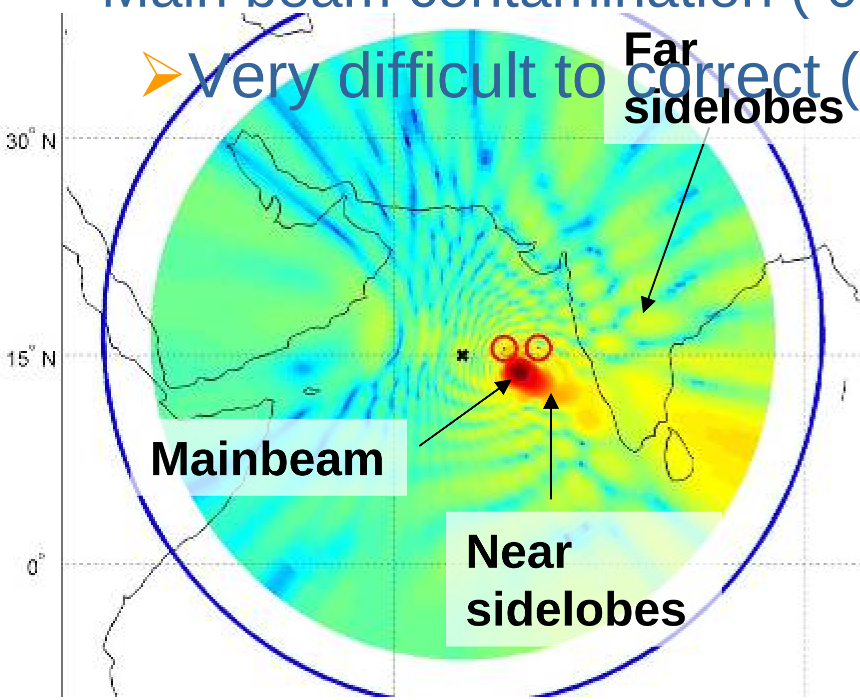


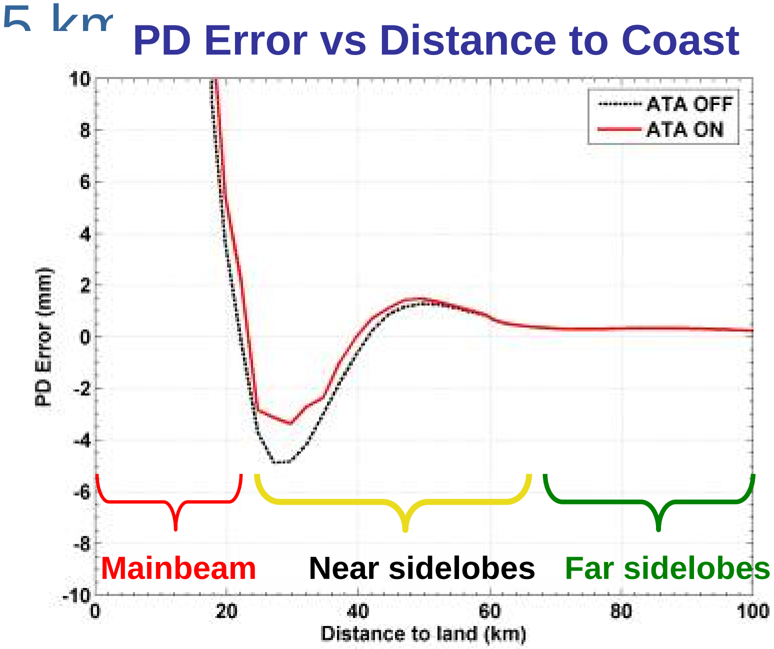


3) How are water vapor radiometers on board altimeters affected by land in the footprint ?

Land contamination can be divided into three categories

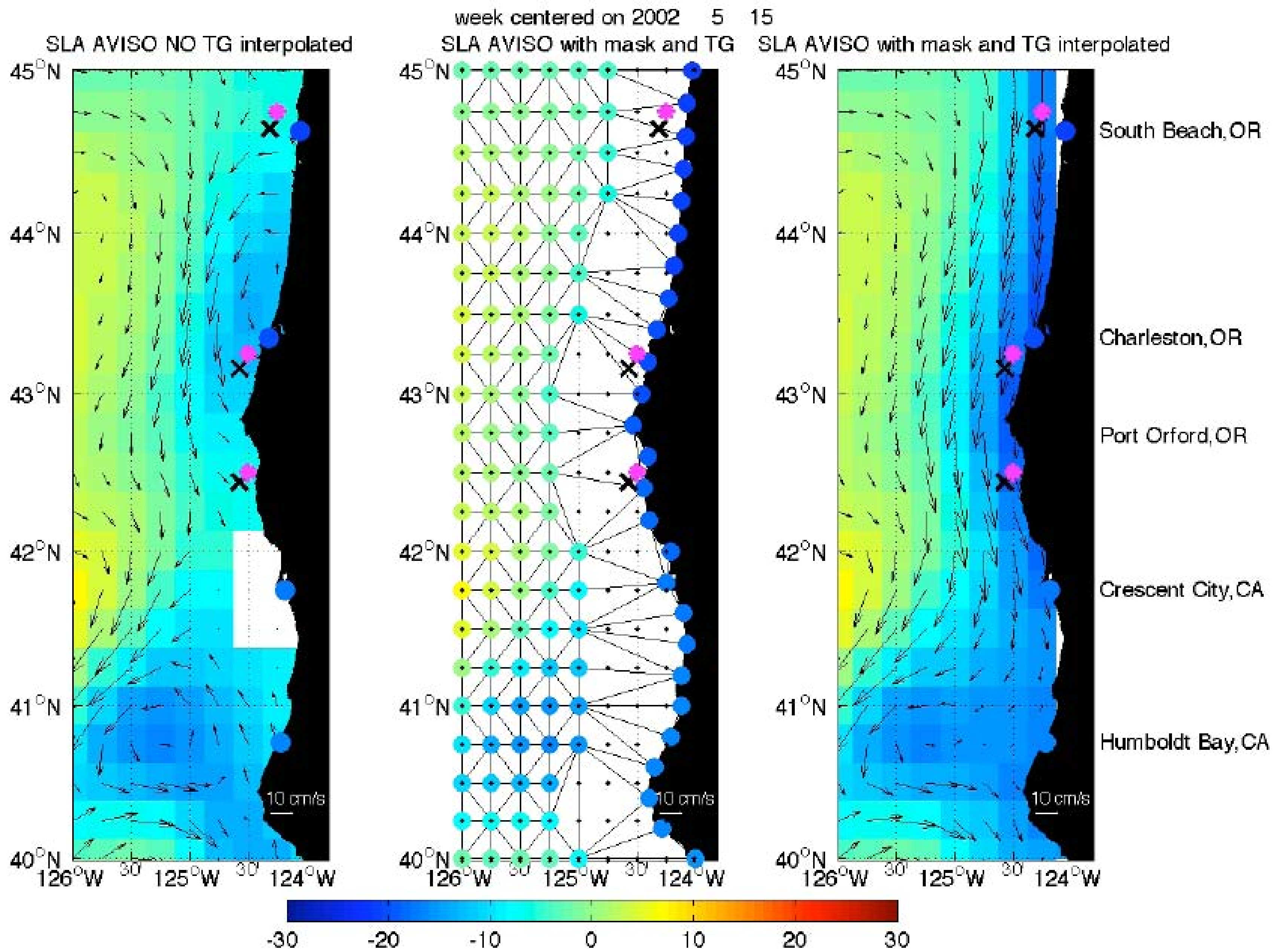
- Far sidelobe contamination (> 75 km from coast)
  - ➢Correctable to acceptable levels (~ 1mm)
- Near sidelobe contamination (25 – 75 km from coast)
  - ➢More difficult, but correction is possible (~2-4 mm)
- Main beam contamination (0 – 25 km
  - ➢Very difficult to correct (20-

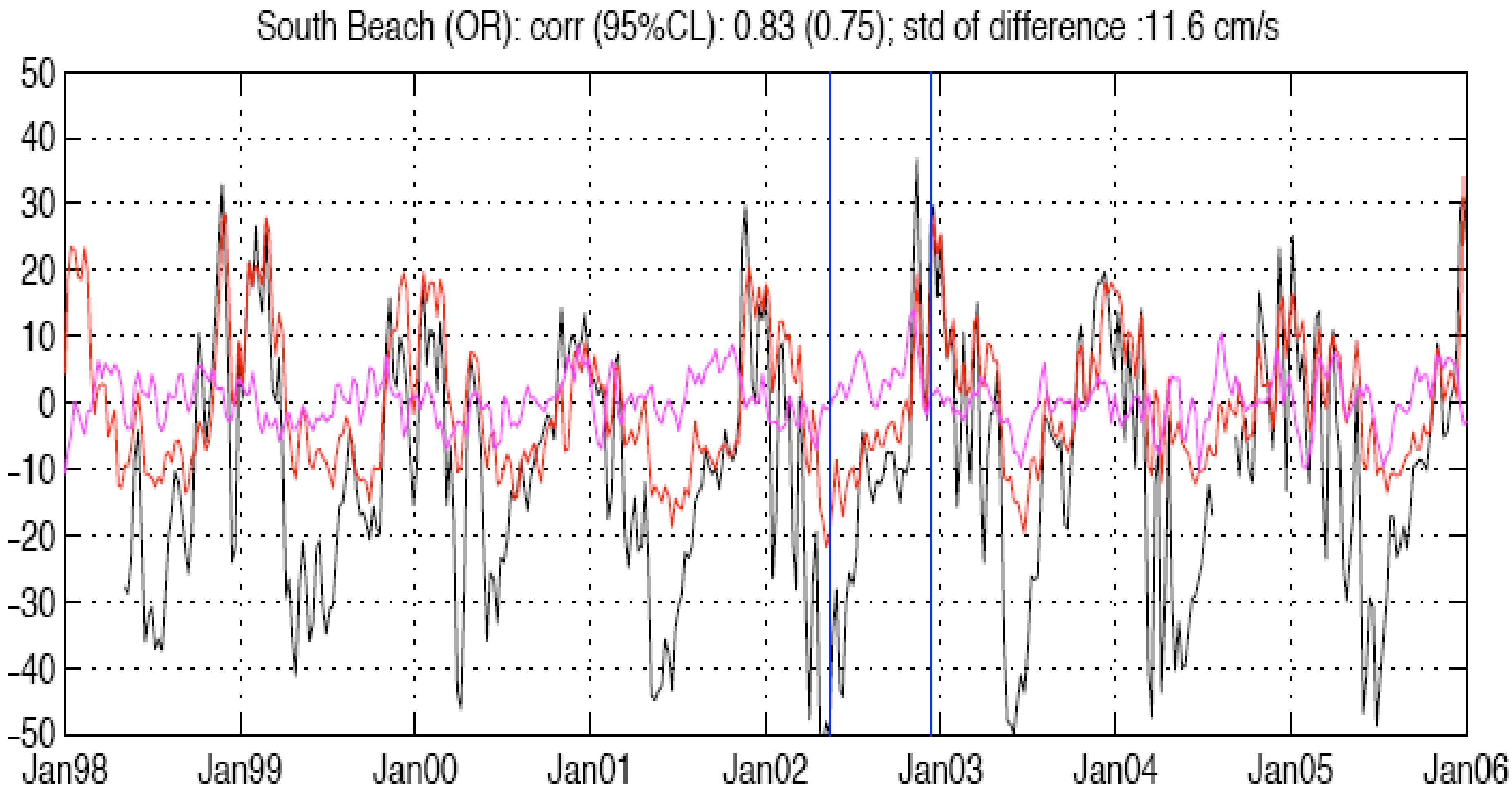


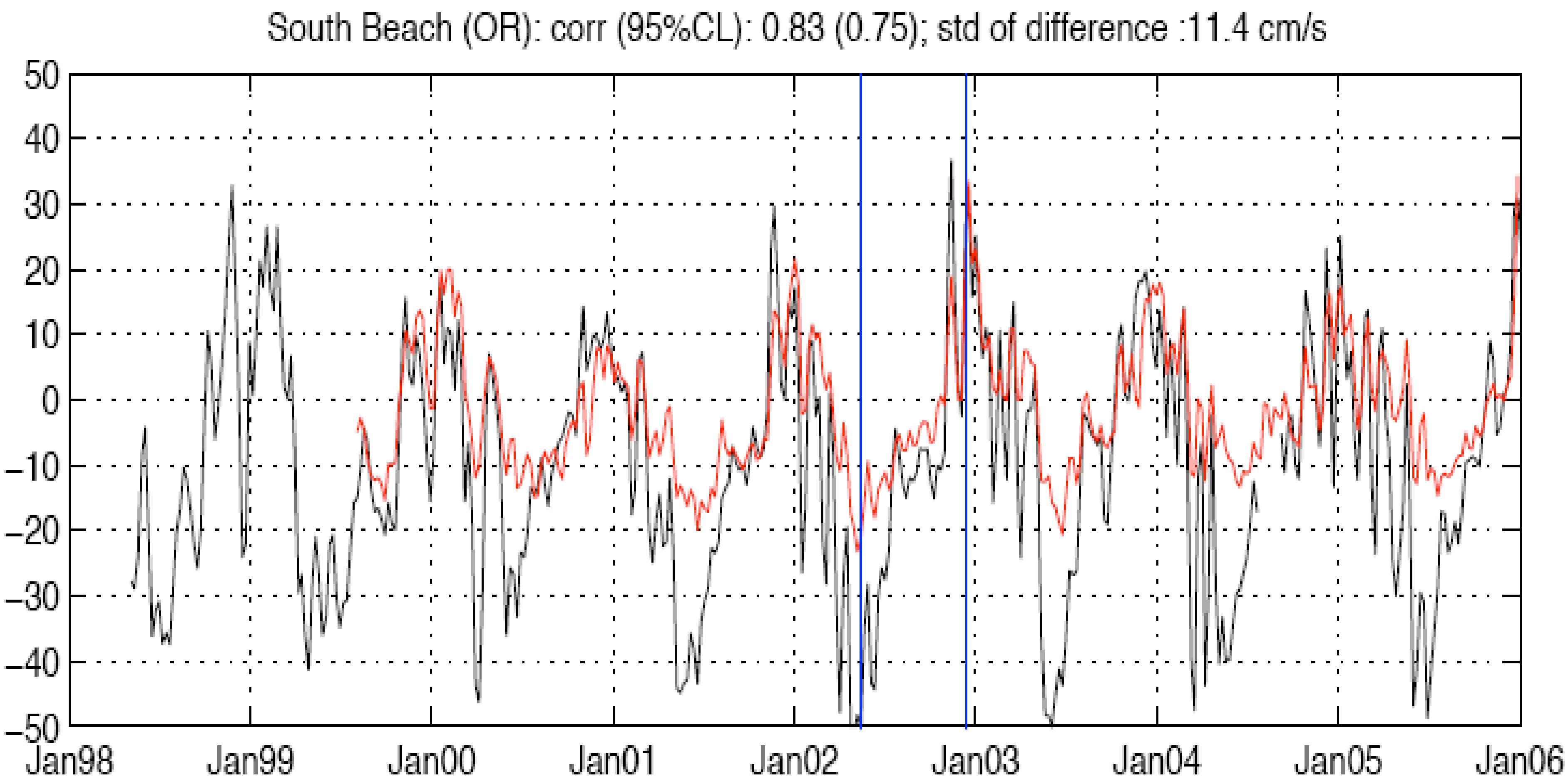


S. Brown

Coastal Altimetry – What Simple People Do


week centered on 2002 5 15
SLA AVISO NO TG interpolated
SLA AVISO with mask and TG
SLA AVISO with mask and TG interpolated
45°N
44°N
43°N
42°N
41°N
40°N
126°W
30'
125°W
30'
124°W
10 cm/s
South Beach,OR
Charleston,OR
Port Orford,OR
Crescent City,CA
Humboldt Bay,CA
-30
-20
-10
0
10
20
30

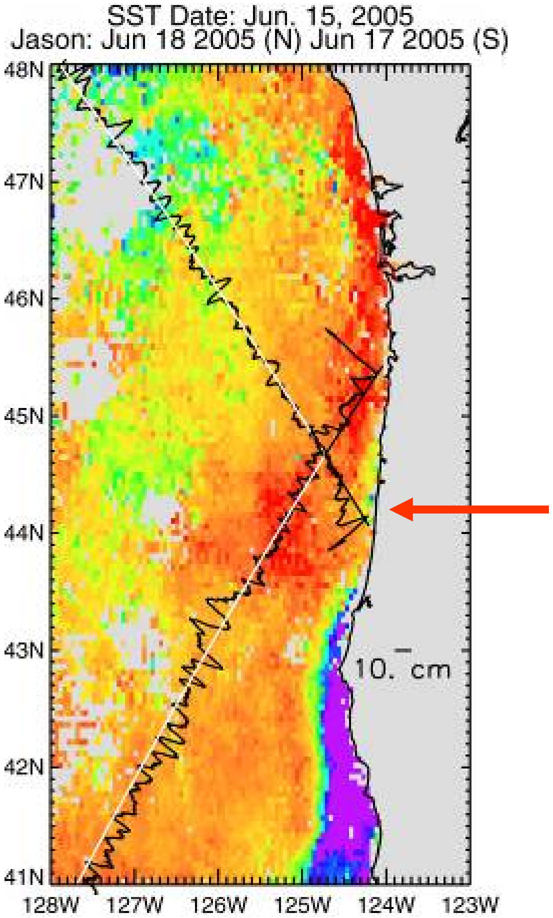

South Beach (OR): corr (95%CL): 0.83 (0.75); std of difference :11.6 cm/s
50
40
30
20
10
0
-10
-20
-30
-40
-50
Jan98
Jan99
Jan00
Jan01
Jan02
Jan03
Jan04
Jan05
Jan06


South Beach (OR): corr (95%CL): 0.83 (0.75); std of difference :11.4 cm/s
50
40
30
20
10
0
−10
−20
−30
−40
−50
Jan98
Jan99
Jan00
Jan01
Jan02
Jan03
Jan04
Jan05
Jan06

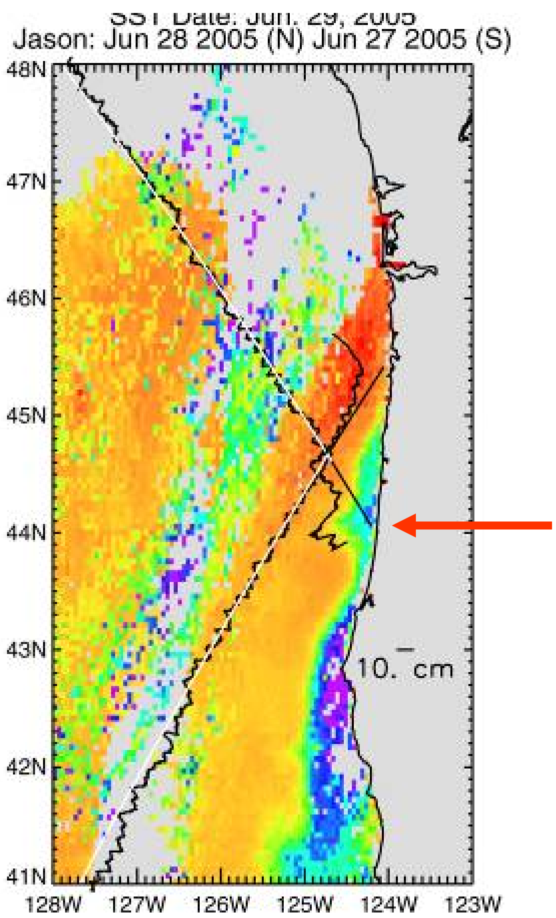
Extending the Altimeter Alongtrack SSH to the Coast

2005

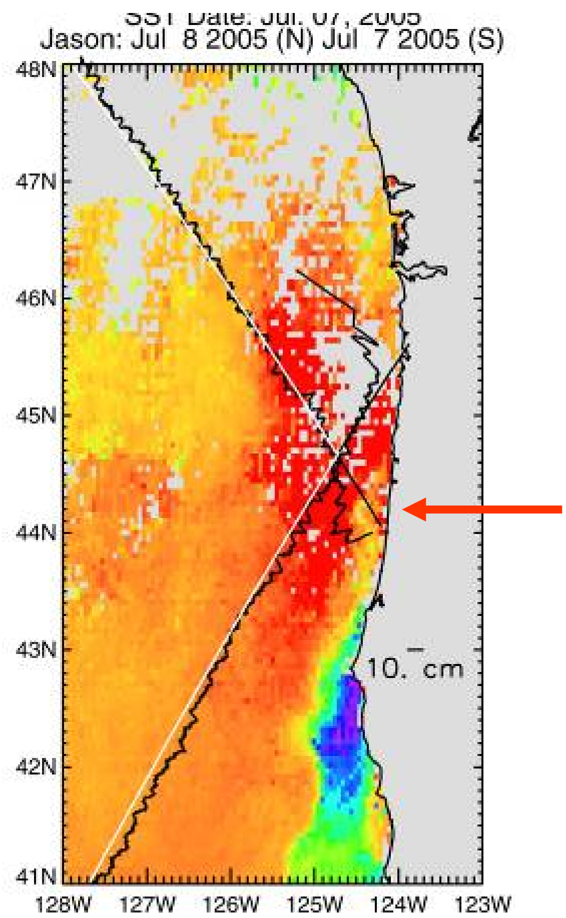
~ June 18



~ June 28



~ July 8



Signal of 20-30 cm when then altimeter crosses the upwelling jet and dense upwelled water. Within 20-50 km of the coast.

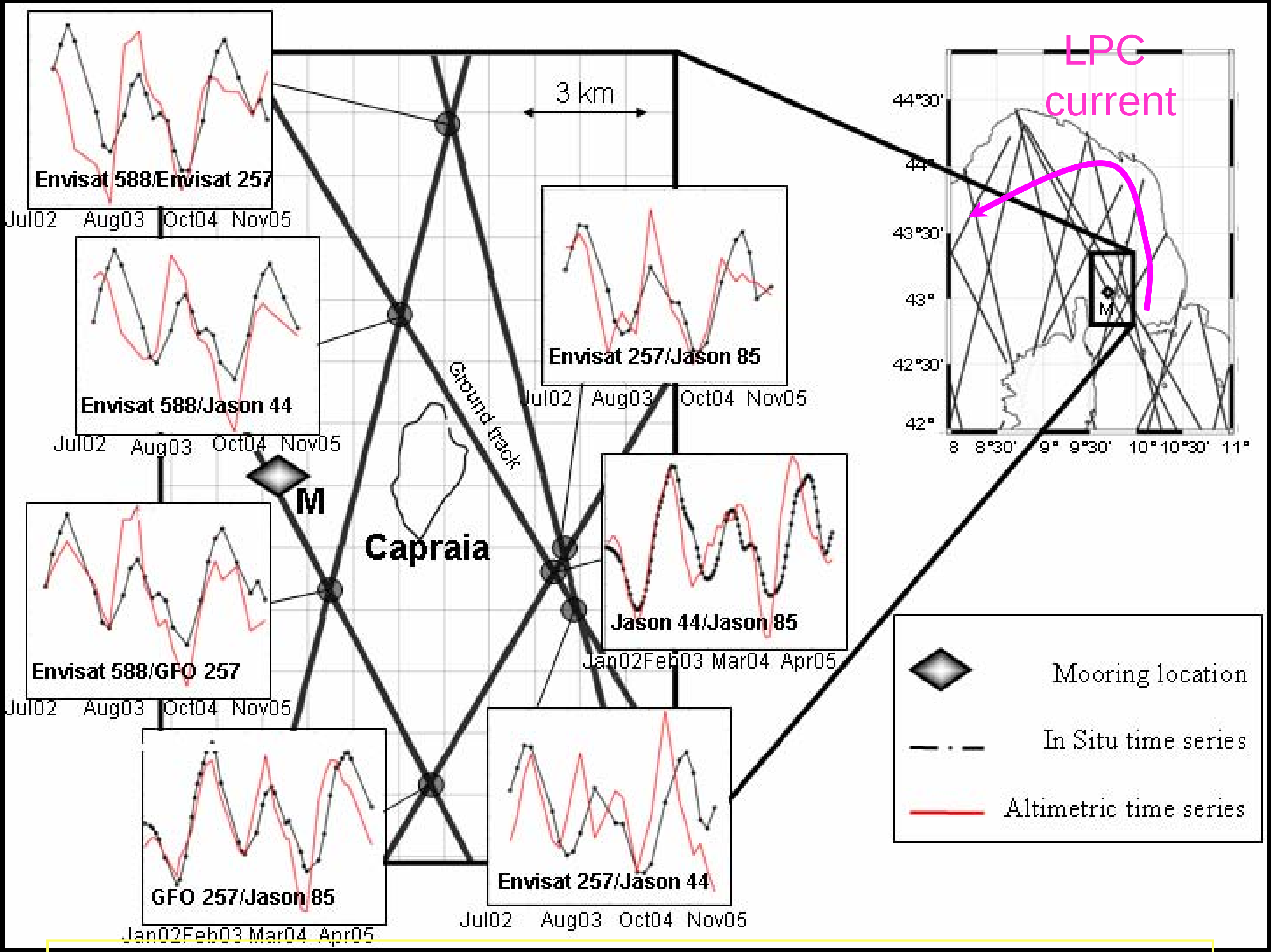
Coastal Altimetry –

Virtual Current Meters and Transects

LPC monitoring

Crossover method

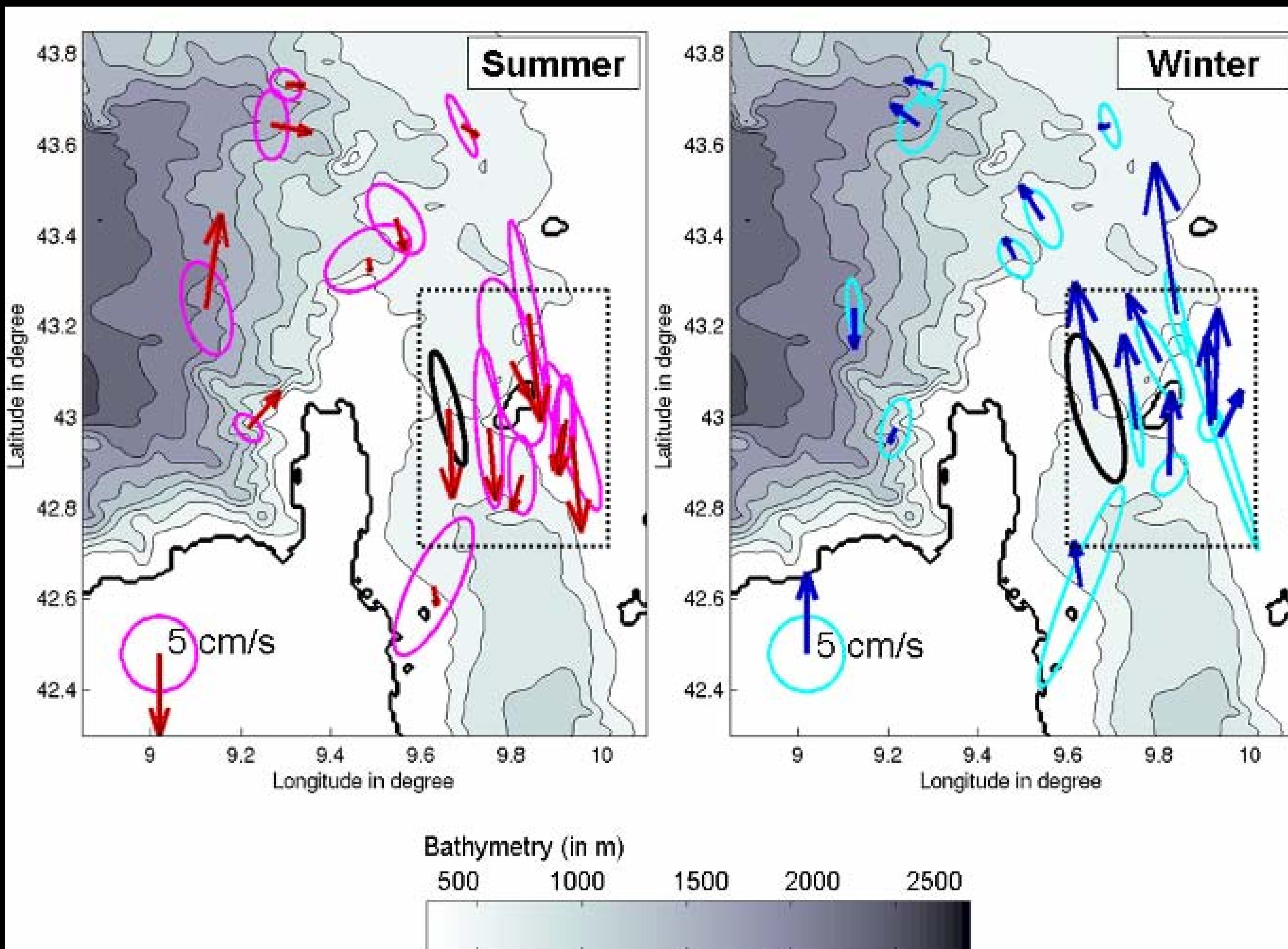
Meridional components of geostrophic velocity anomalies



Good agreement beteween altimetry and in-situ (r~07)

LPC monitoring

Crossover method



Method:

- Based on Morrow et al., (1994) and generalized at a multi-satellite configuration

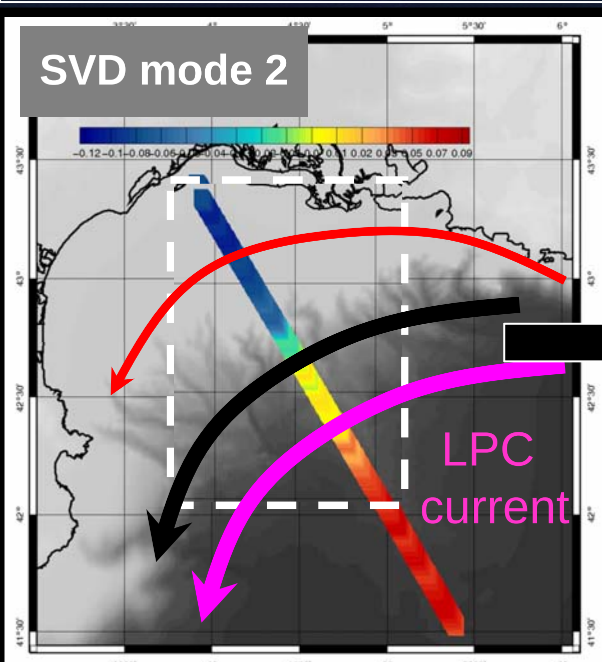
Results:

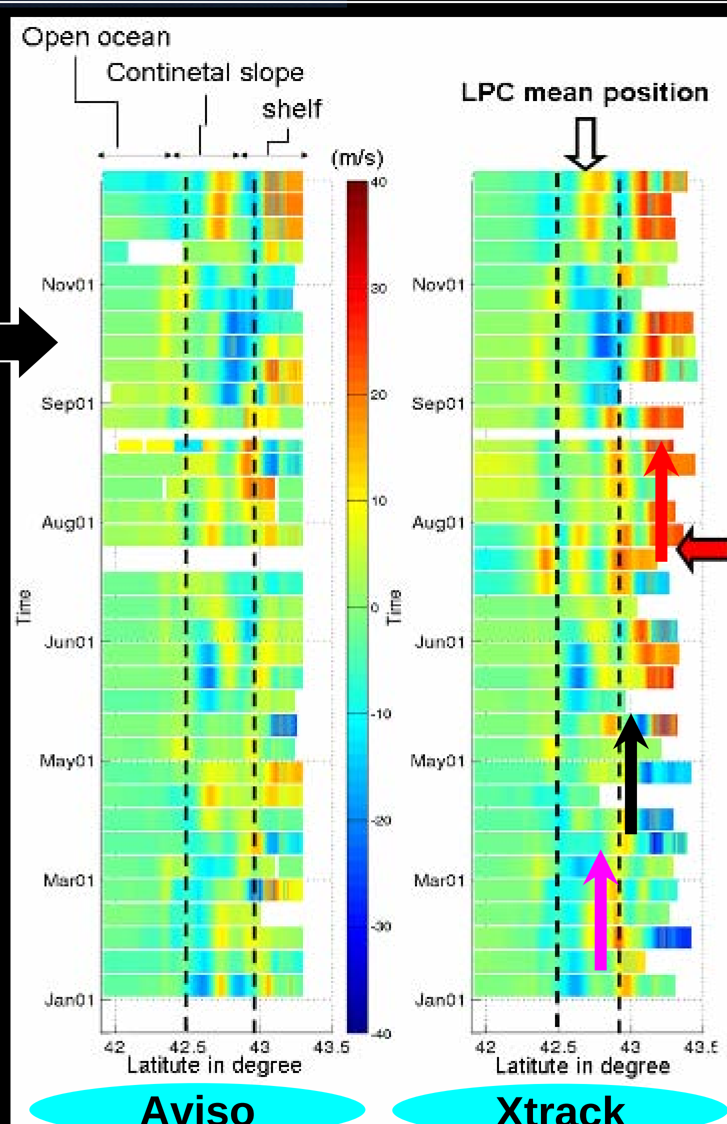
- Good coherency with the in-situ measurement (r>0.7)
- Allow to precisely monitor the ECC current in area where official product are badly adapted

Altimetry may be use to constraint the OGCM forcing

LPC monitoring

Seasonality, Shelf intrusion





LPC intrusion
See also André et al. (2005)

On the Edge(s)

- Of knowledge
- At the air-sea vertical boundary
- Along the horizontal coastal land-sea boundary
- At the high end of spectral and spatial (and species) resolution

- Modeling as a necessary complement to ocean remote sensing, extending fields in the vertical (subsurface ocean and into the atmosphere), into dynamics, and into the future (prediction)

- Outreach – extending knowledge to the next generation (the edge of the workforce), the present workforce (the edge of dissemination) and in workshops that bring different groups together with common interests (organizational edges)