Coastal Altimetry: Challenges and Status

Ted Strub (Oregon State University, US)
Numerous Other Colleagues

- Introduction to the Challenges
    - ***Challenge Type 1 – Mechanics of Alongtrack SSH Retrieval***
    - ***Challenge Type 2 – Resolving Small Spatial and Temporal Scales***
- Approaches and Progress
- Updated State of the Art: Wednesday – Paolo Cipollini

- Hobart OSTST: March, 2007
  - ***Presentations/discussions highlighted efforts by many individuals and larger initiatives in developing coastal altimetry methods.***
  - ***Identified the need for coordination – suggested a workshop***

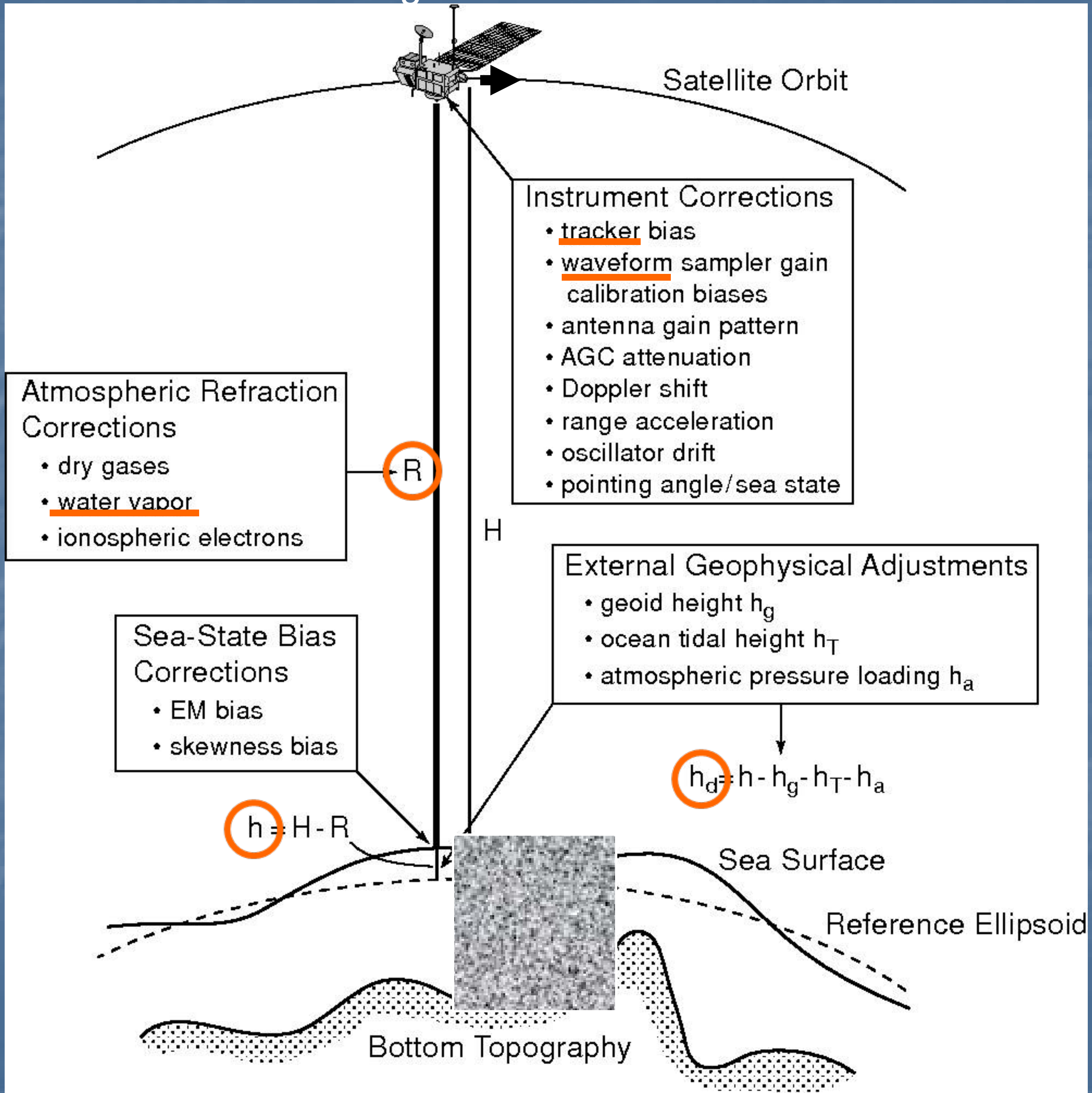
- 1st Coastal ALT Workshop (CAW-I): Feb, 2008.
  - ***Identified an active community working on similar problems.***
  - ***Established a baseline error budget for coastal regions***
  - ***Began collaborations and planned future work***
  - ***PISTACH (CNES) and COASTALT (ESA) initiatives begin***

- CAW-II – Nov, 2008
  - ***Reported on Progress***
  - ***PISTACH, COASTALT mid-term; Initial data sets***
  - ***OSTST – Beginning of new efforts including data services***

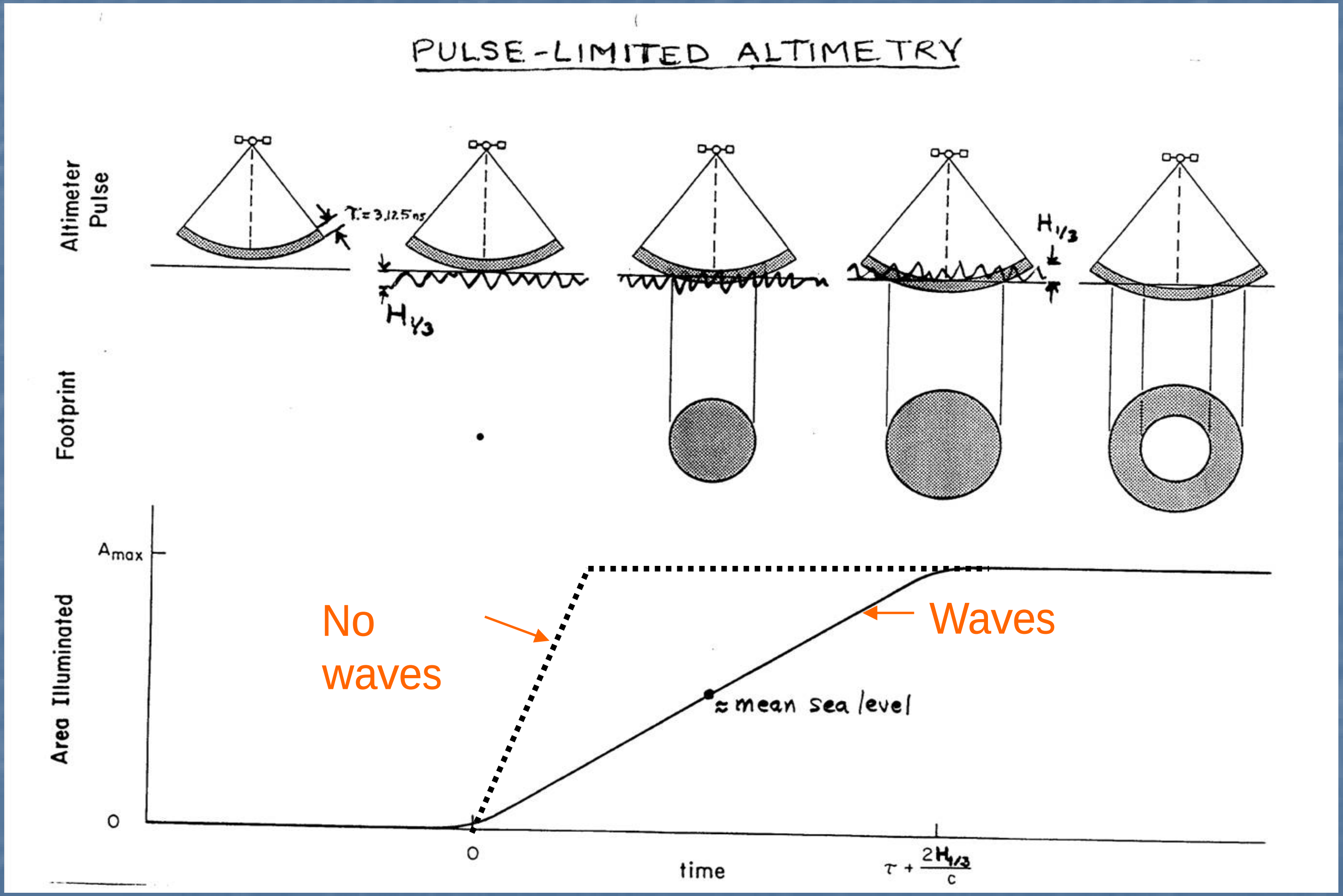
- CAW-III: Sept, 2009 (tentative)
  - ***PISTACH, COASTALT final reports and next steps. OSTST progress, others ...***

Challenge Type I – Along-track SSH Data Retrieval

What happens to the altimeter signal when there is land within 0-50 km of nadir?

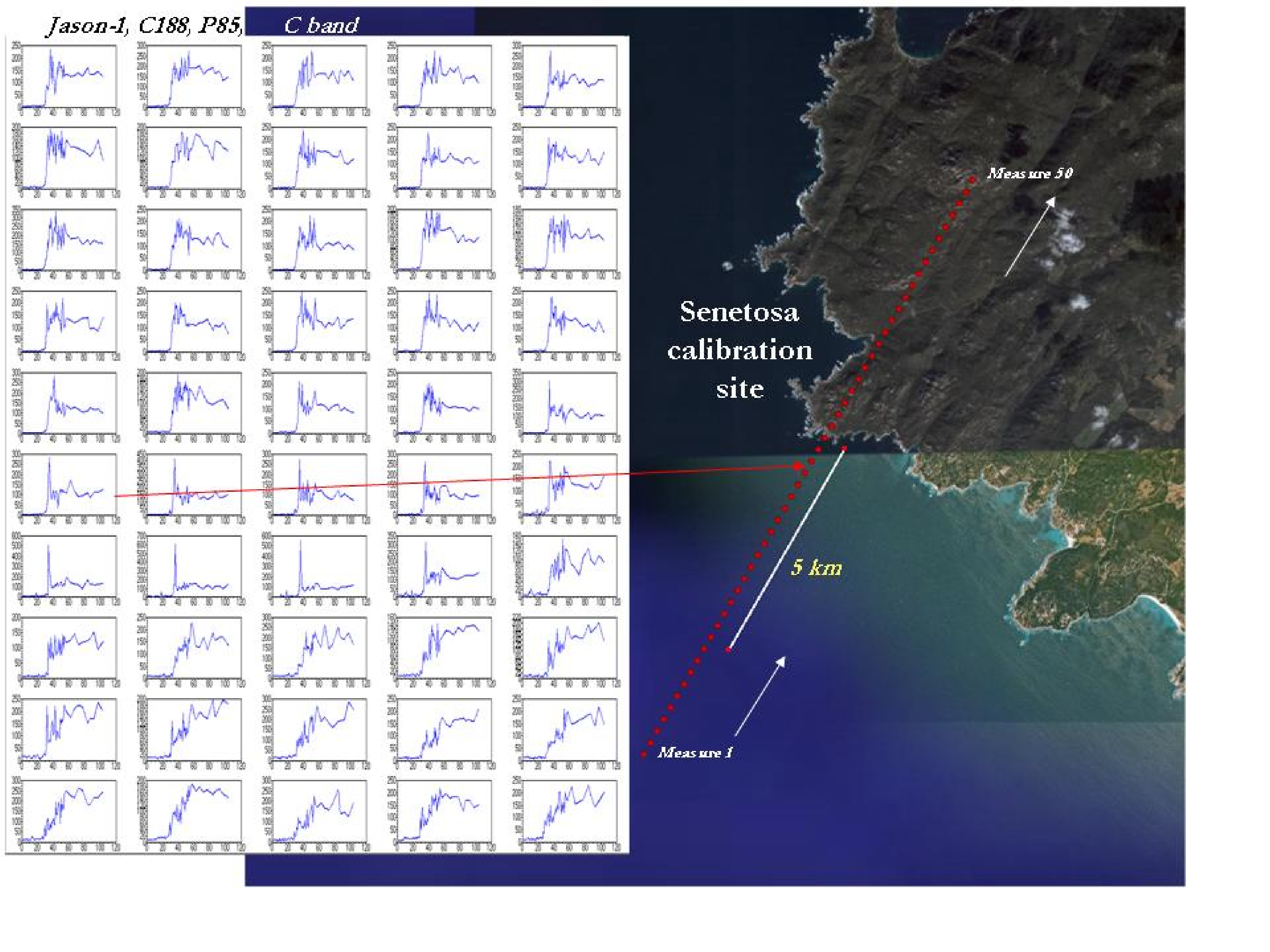


TRACKING: How do we determine the timing of the returned signal? The reflecting area grows as a circle, then as an annulus with a constant area. The reflected power of the radar signal does the same. The mean or median power rise defines the time of the returned signal. The slope gives the SWH.



If the annulus hits land, the area over land reflects less signal, so the power goes down in the tail of the returned signal.

Real 20 Hz waveforms, as the altimeter approaches land. The constant power "plateau" decreases, producing a leading edge that reduces to a spike.

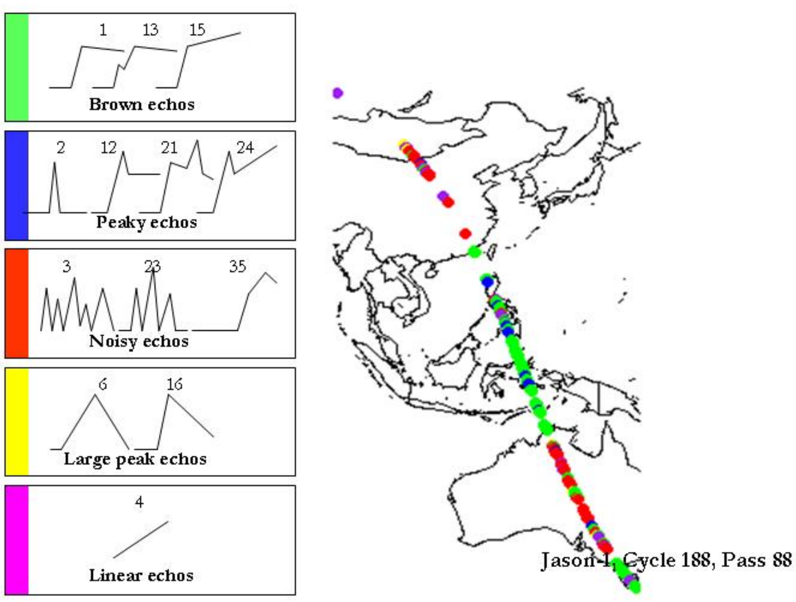


“Adaptive Trackers” have many possible “models” of the returned waveform shape, decide which model is represented by a given returning signal, then fit that model to determine the timing of the returned signal.

This may cause jumps in the estimated SSH, if the tracker switches between models rapidly. ***Also, some models give no estimate of SWH or SSB.***

Jason-2 (June, 2008) has several experimental tracking modes, also using a digital elevation map to adjust the receiving window. The goal is to retrieve signals from coastal regions and terrestrial lakes and large rivers.

Adaptive retrackers



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

** REMEMBER:

90% of returns over the ocean are like the traditional “Brown” model for points farther than **10 km** from land. Retracking can improve results even closer.

Wet Troposphere "Path Delay" (PD)

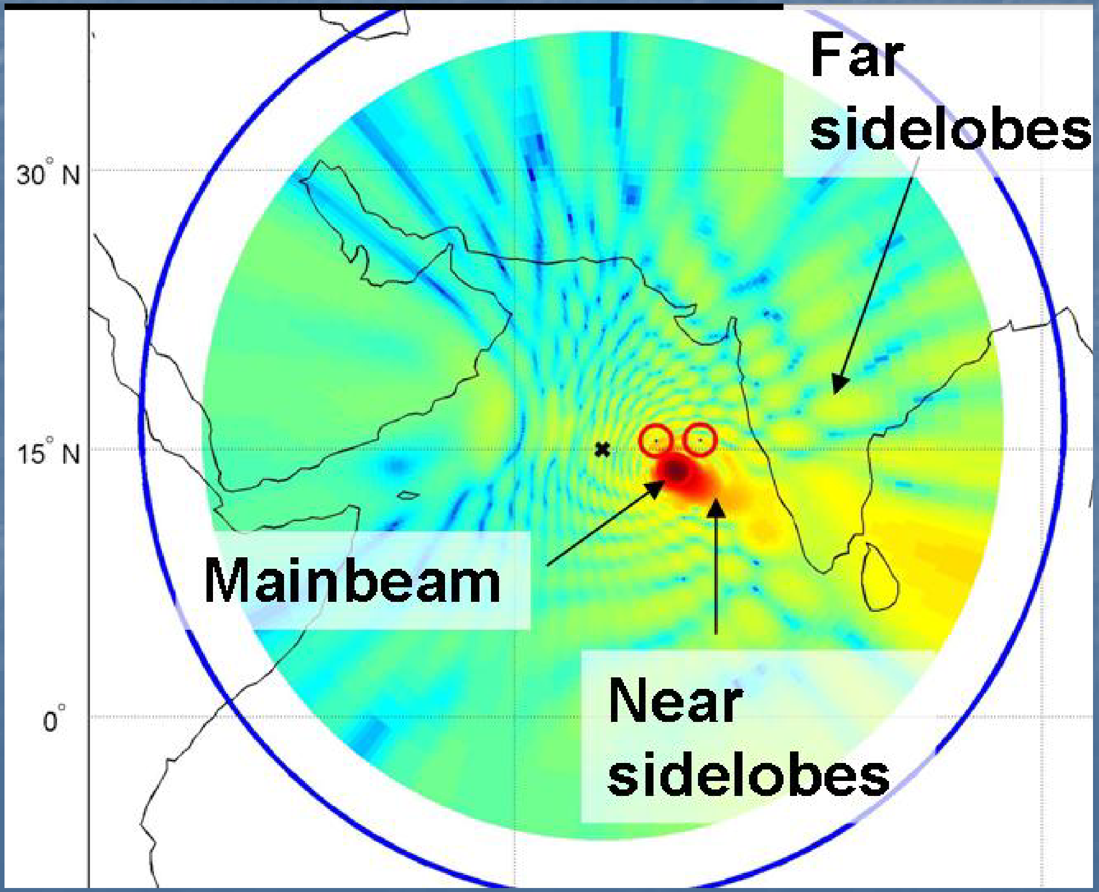
The radar signal changes speed, depending on the material that it passes through (the speed of light is only constant in a vacuum). "Dry gasses" are well mixed in the atmosphere, with little spatial variability. Water vapor is highly variable. We estimate the "total integrated water vapor" in the column of atmosphere between the satellite and the ocean using a multi-channel passive microwave radiometer on board the altimeter's satellite.

The radiances received at the sensor are converted to TB, "brightness temperature." Land has nearly twice the emissivity of water, so appears brighter. So when land is within the "footprint" (approximately 50-100 km in radius), it contaminates the calculation of the wet tropo PD.

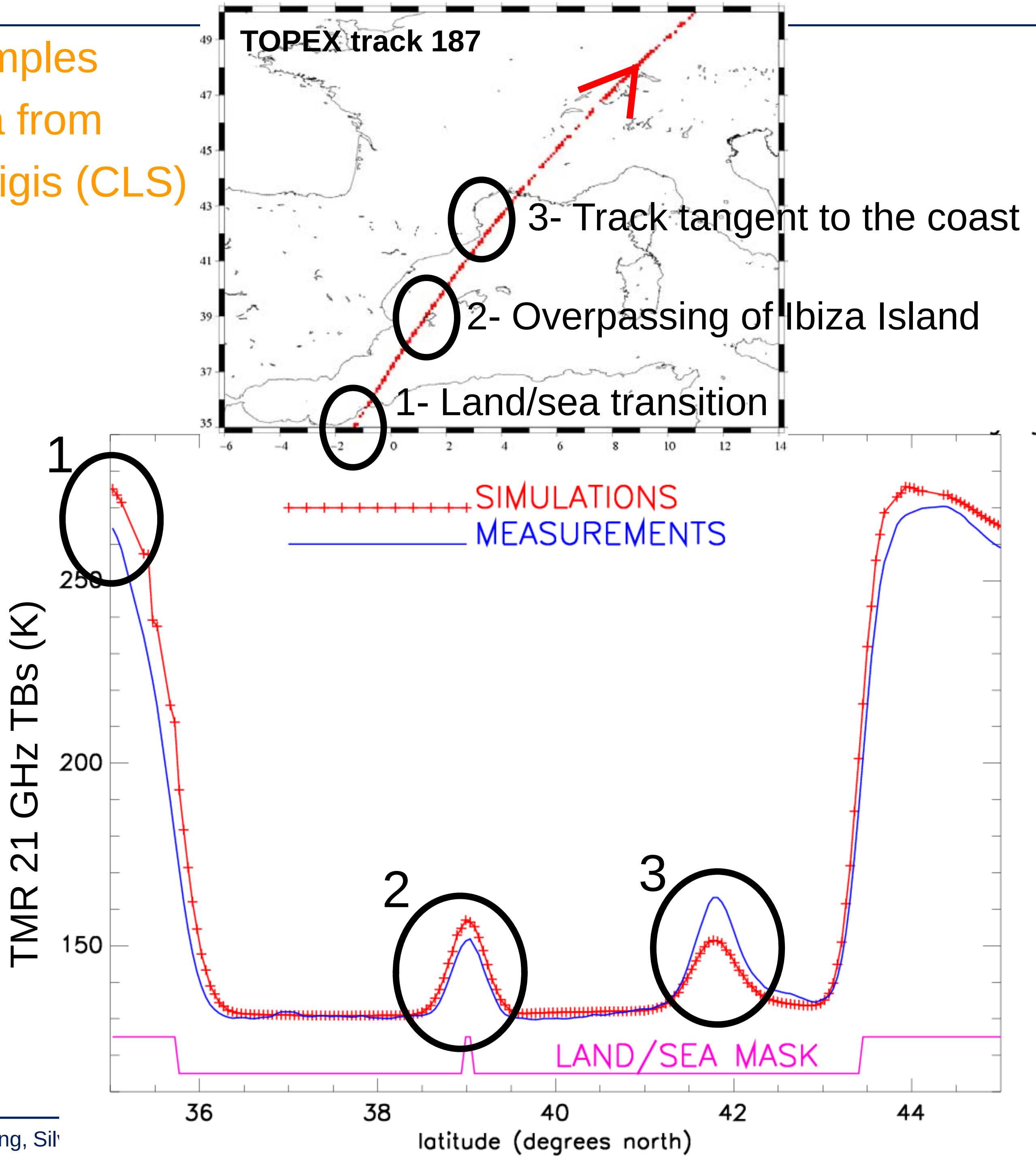
One approach is the estimate the proportion of the footprint over land and subtract the land's signal. But the footprint is not really an oval (next figure).

Wet Troposphere “Path Delay” (PD)

The footprint is not really an oval, but a more complex mainbeam and sidelobes making up an antenna pattern. Present radiometer retrievals account for the sidelobes but not the part of the “mainbeam” over land. Attempts are being made to account for the land proportion in the signal.



Some examples of real data from Estelle Obligis (CLS)

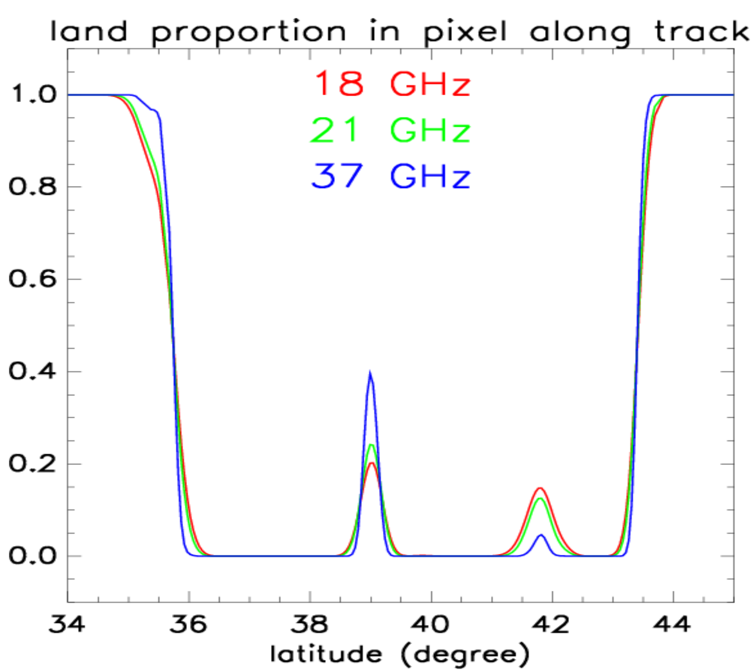


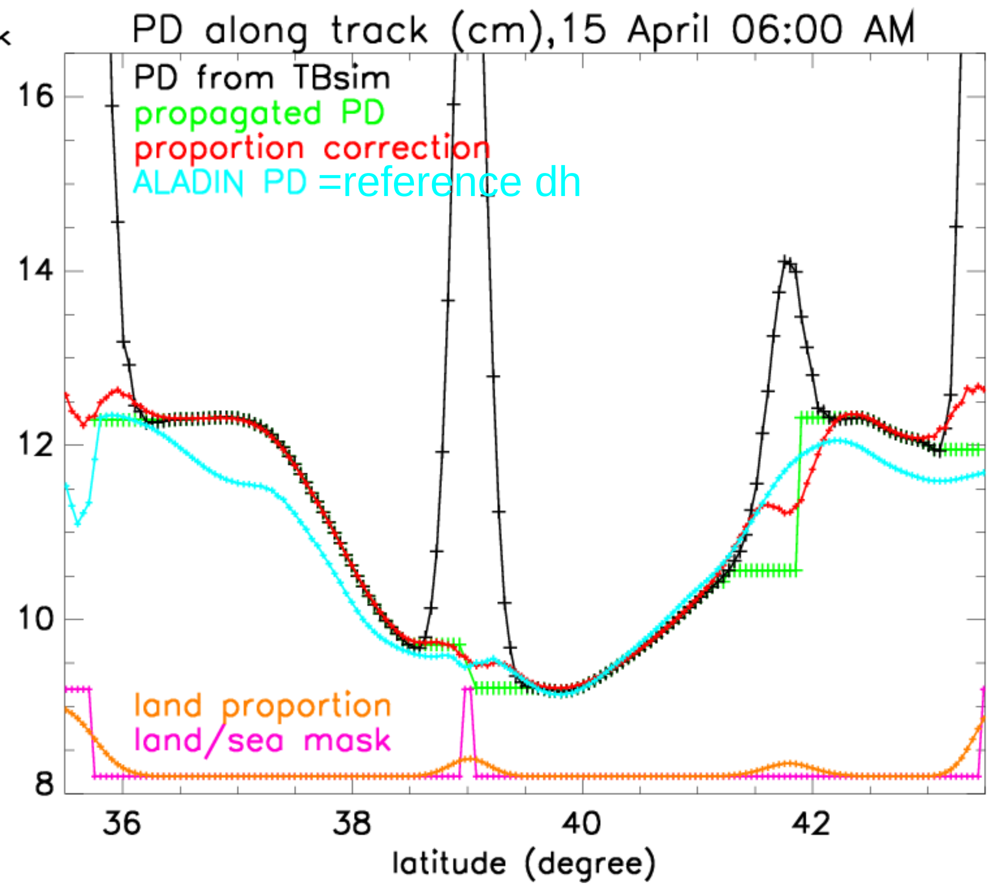
How should these data be processed ?

First method : Using the proportion of land in the footprint

corr (*p* , *f*) = [TBland(*f*) – TBsea (*f*)] × ***p*** (*f*)

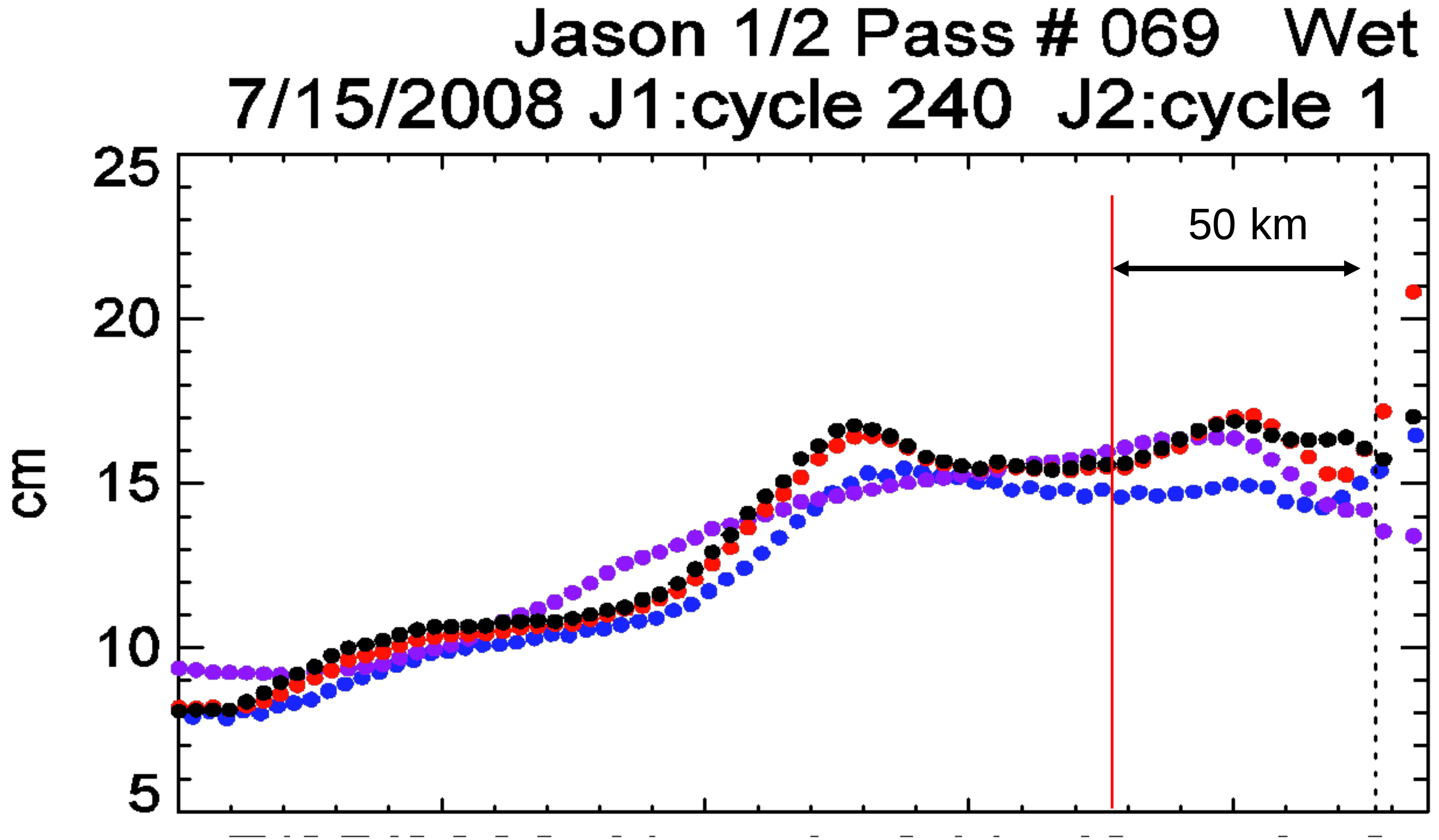
p : *Gaussian smoothing of a land/sea 0.01° mask*

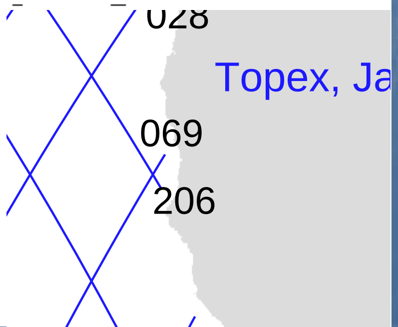




- Propagation method: introduces huge gaps
- Proportion method: gives the best results

S. Brown: New Wet PD (black) vs J2 (red) vs J1 (blue) vs ECMWF model (purple). Track 069

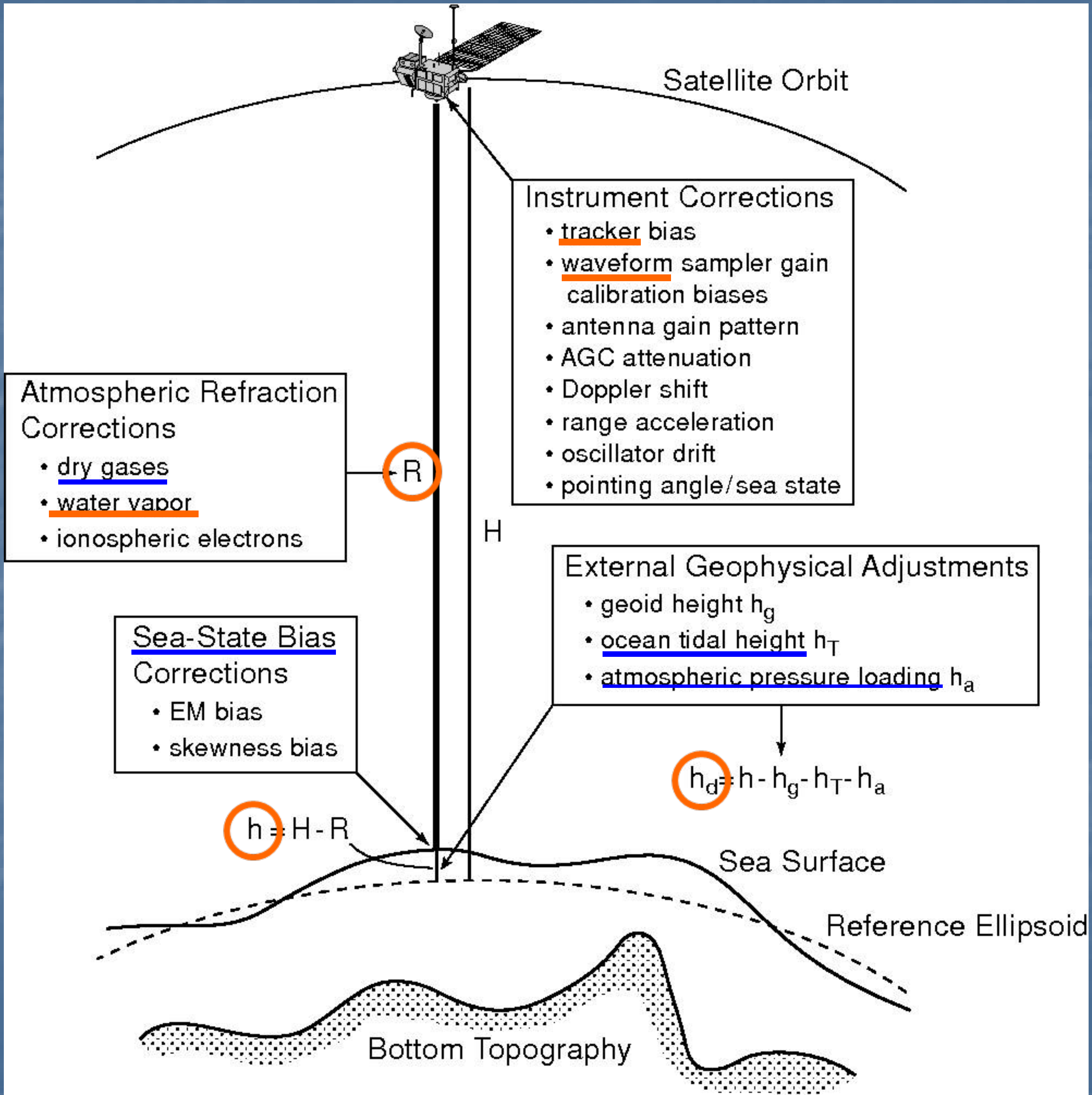




Summary – Shannon Brown Improved AMR Algorithm

- Simple near-land PD algorithm developed and applied to OSTM-AMR data
  - Easy implementation – uses existing AMR algorithm and no ancillary data required
- Simulations and comparisons with ECMWF demonstrate new PD retrieval in coastal region significantly improved over IGDR PD
  - → New algorithm error less than 1.5 cm in coastal region globally
- Detailed validation and algorithm improvement on-going
- Plan to make near-land PD product available soon (likely on GDR)
- Next steps are to apply algorithm to JMR and TMR data

Components of the Altimeter SSH Signal: Other "corrections" also change in the coastal ocean?

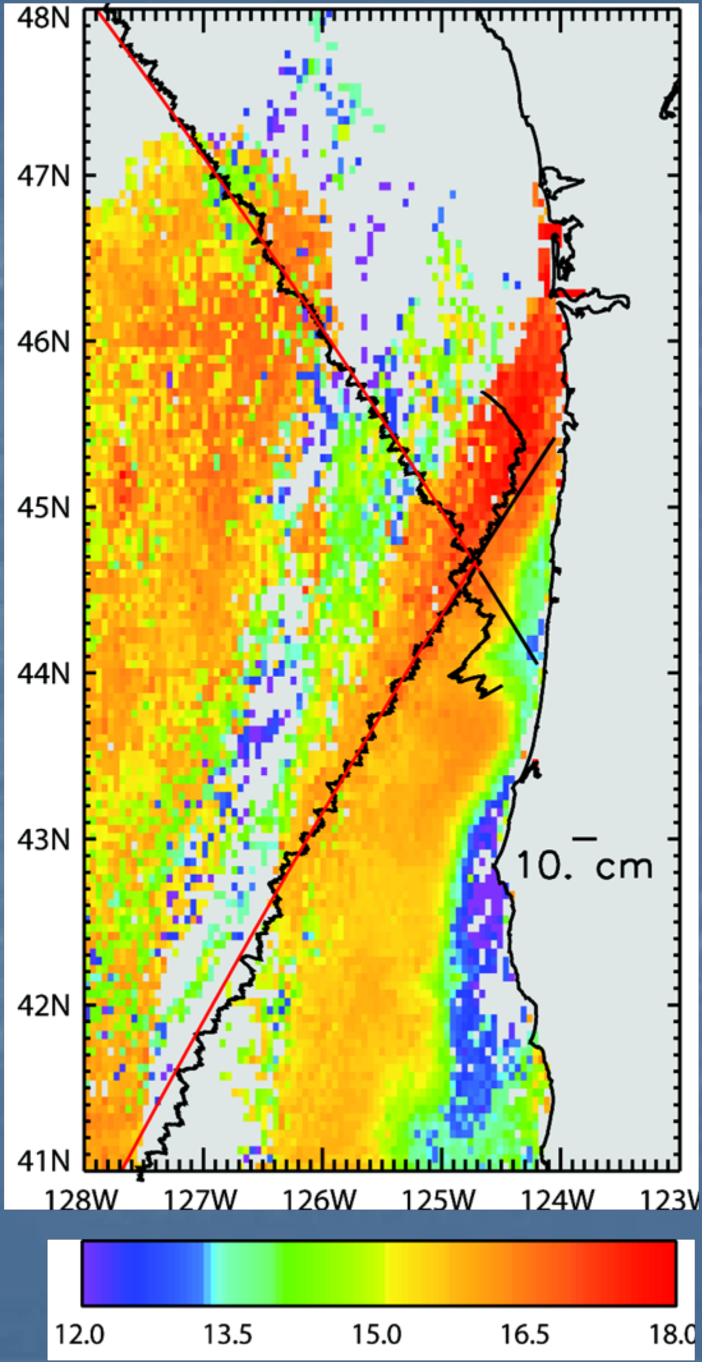


Challenge Type I, Present Status: Good progress is being made in retrieving alongtrack SSH near land. Rather than flagging data for multiple reasons in the 30-50 km next to land, we may be able to retrieve the alongtrack data to within ~0-5 km of land.

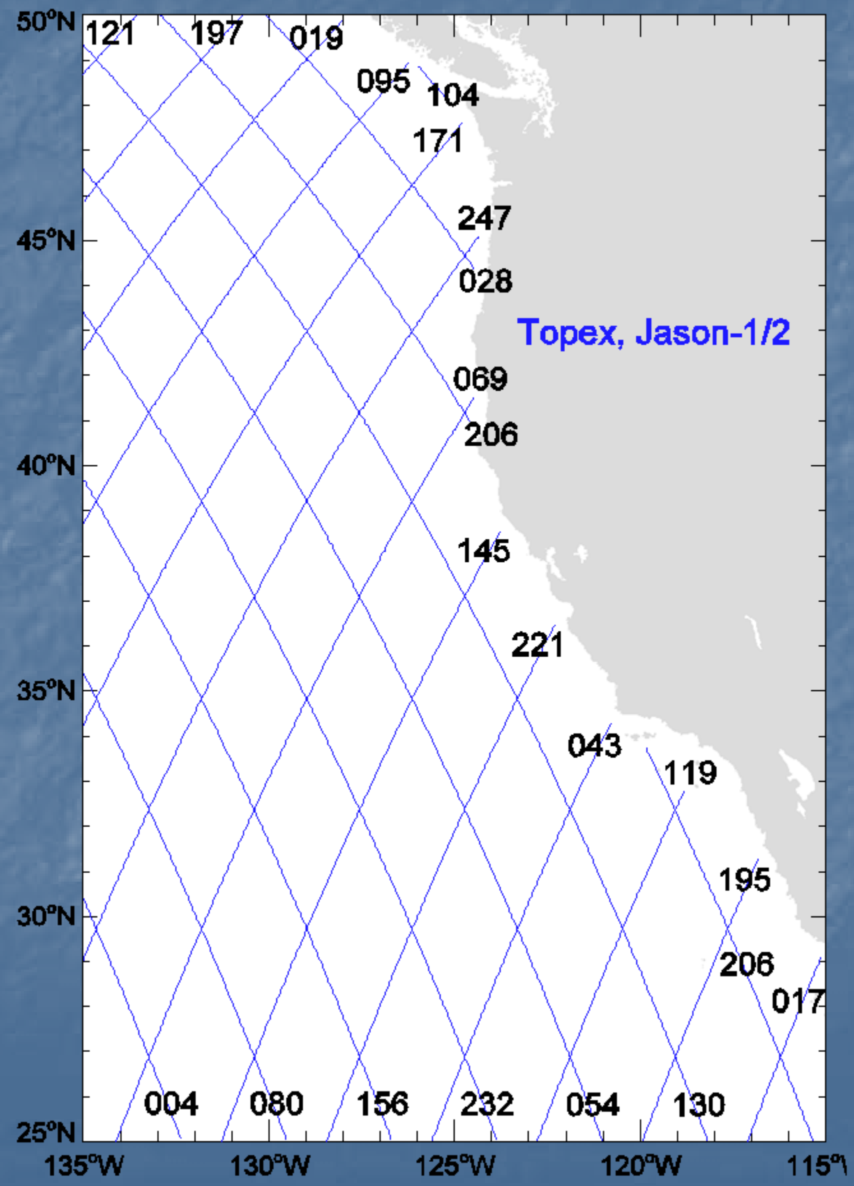
Challenge Type II: What do we do with it? How do we resolve the short time and space scales in the coastal ocean?

- ***Fly constellations of nadir or swath altimeters.***
- **** Combine altimeter data with other types of data: Tide gauges, Coastal Radars, Gliders, Moorings, Satellite SST and Color, …***
- **** Assimilate these data into coastal ocean circulation models.***

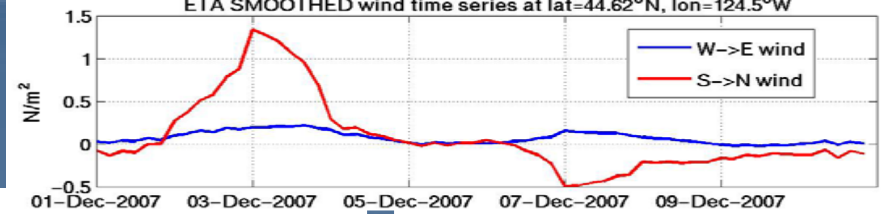
After we retrieve alongtrack SSH within 50 km of the coast, what can we do with it?

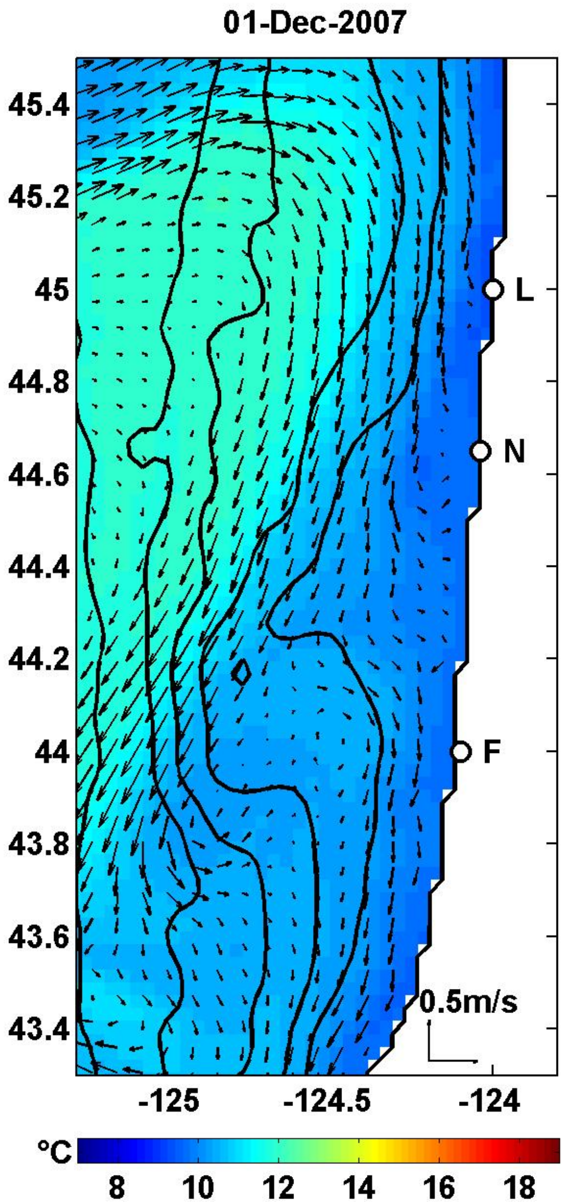


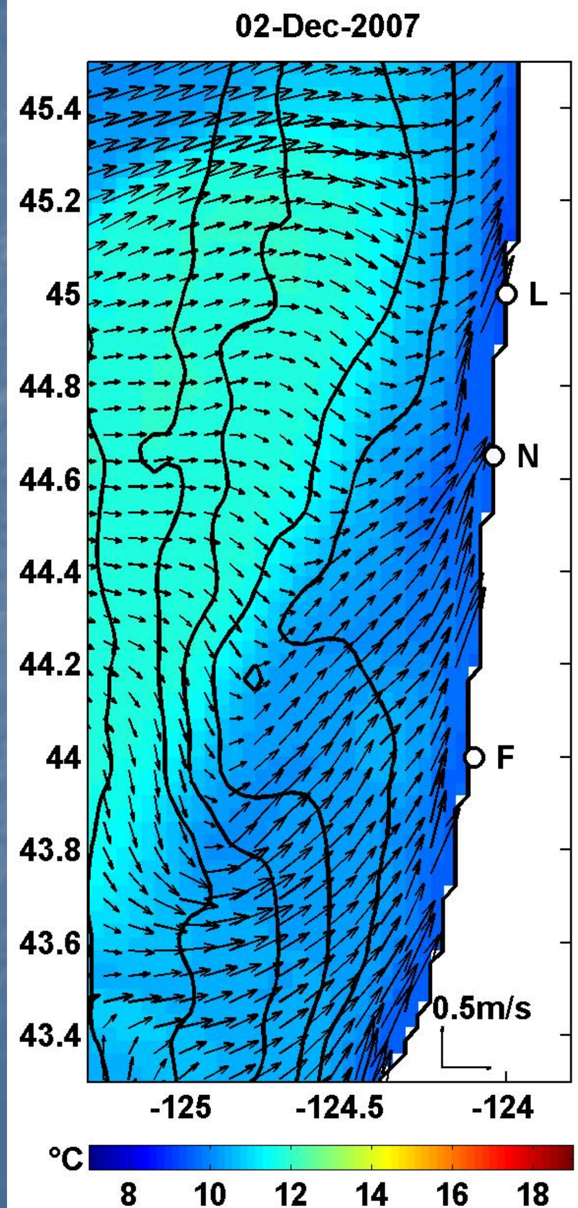
Tracks, separated by ~250-300 km, every 10 days, contain a great amount of information. But what scales do they miss? Synoptic and 2-D mesoscale.

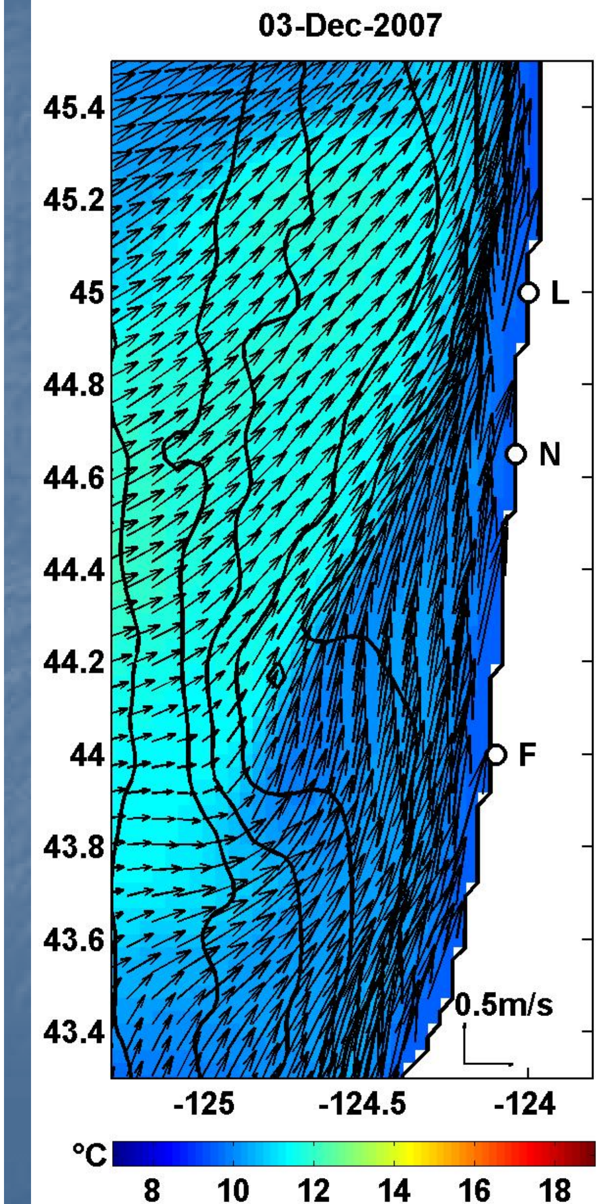


How fast does the ocean spin up in response to strong winds? 2 days.



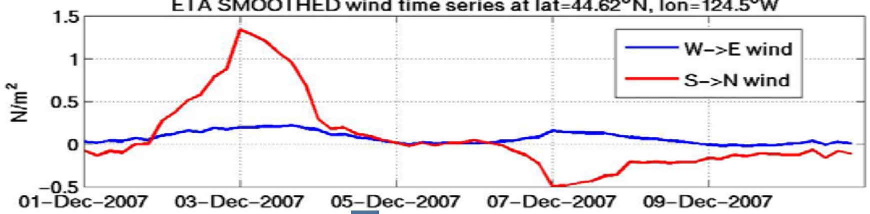


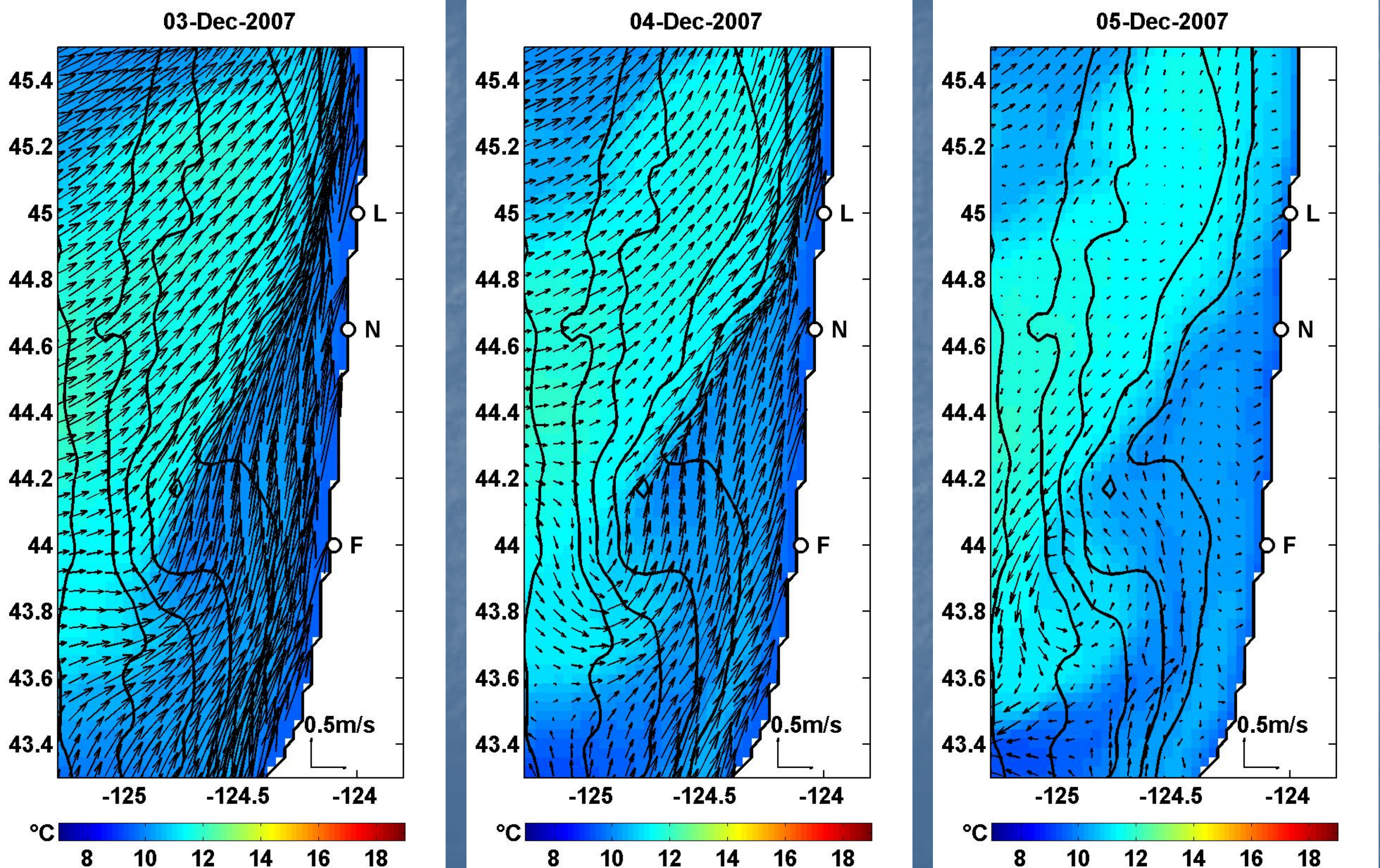




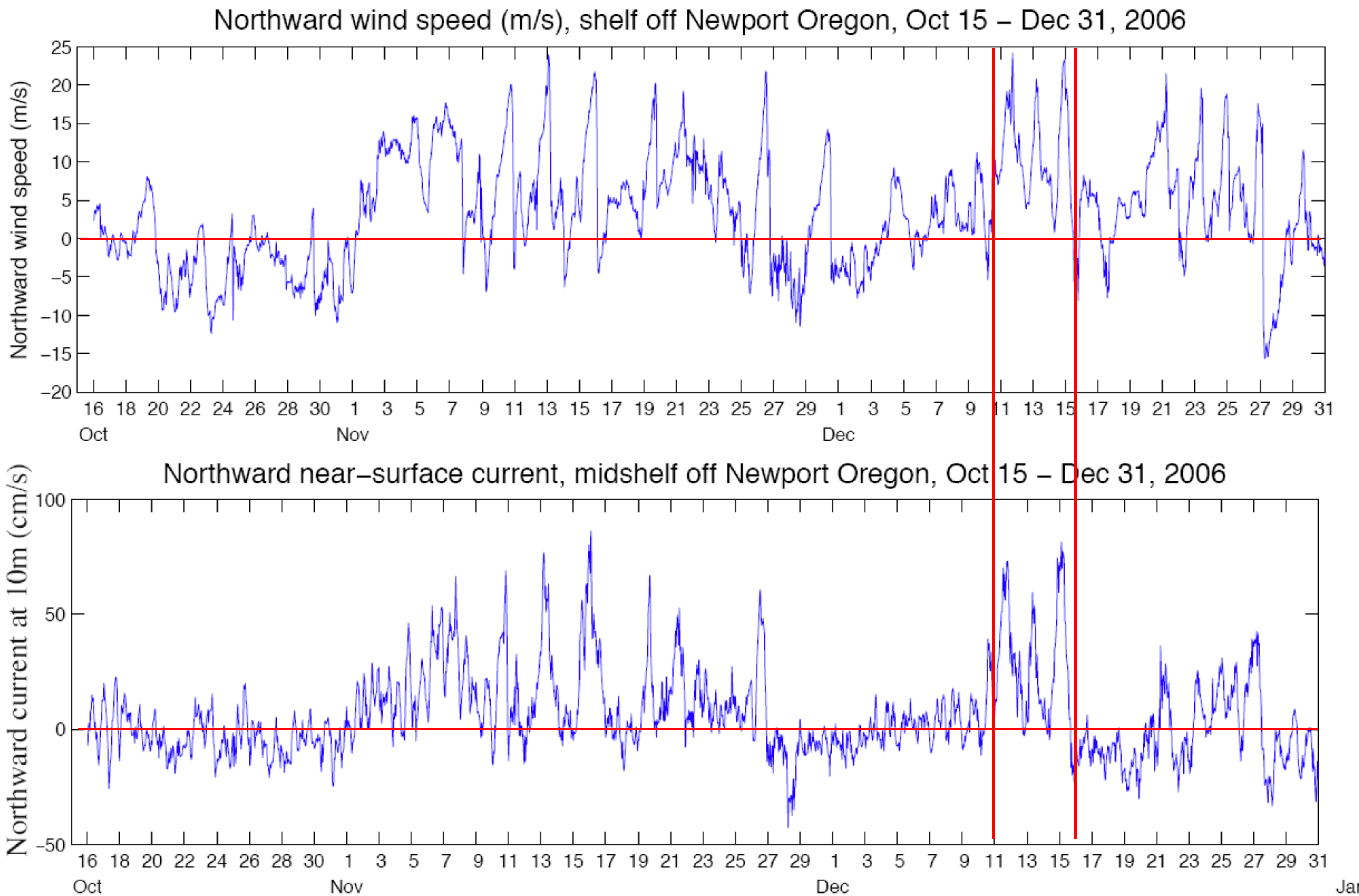
How fast does the ocean spin down when winds relax? 2 days.

Note spatial scales of 20-100 km.





The coastal ocean responds to winds on scales of 1-2 days. Winds (top); N-S Currents (bottom)



Northward wind (upper panel) and near-surface current (lower panel) on the shelf off Newport, Oregon, during Oct-Dec 2006. Winds were measured at NOAA buoy NDBC 46050, 20nm west of Newport. Currents were measured 10m below the surface in 81m water depth, 10nm west of Newport, at the GLOBEC long-term buoy NH10, and processed into hourly averages (Kosro).

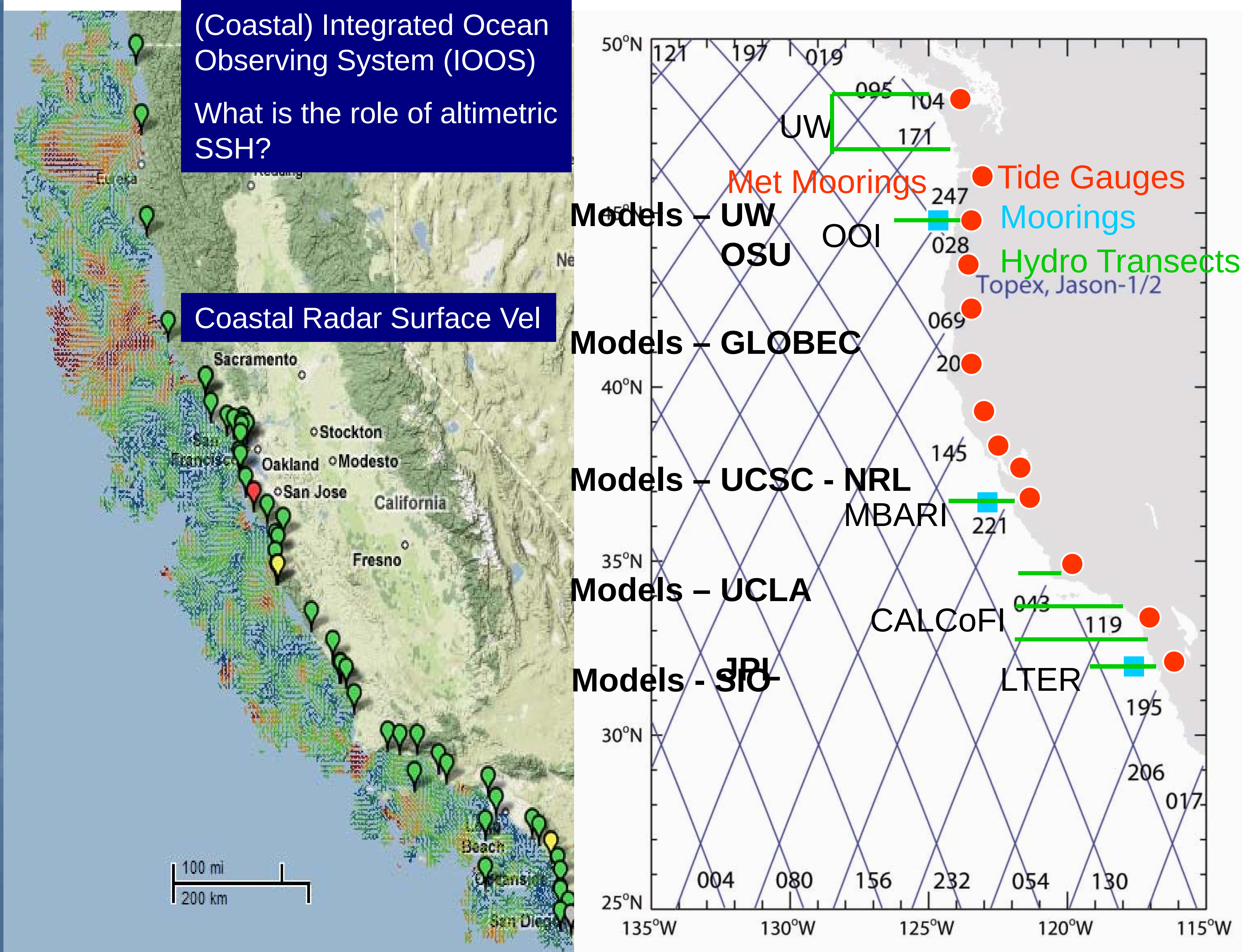
Single nadir or SWOT altimeters cannot resolve the short time and space scales in the coastal ocean. Only a constellation of SWOT altimeters could do this.

So…, what are the synergies between the altimeter observations within 50 km of land and other components of a coastal observing and modeling system?

Gliders? Moorings? Radars? Drifters? Other satellites (SST, CHL, Wind)?

Coastal ocean models? Atmospheric models?

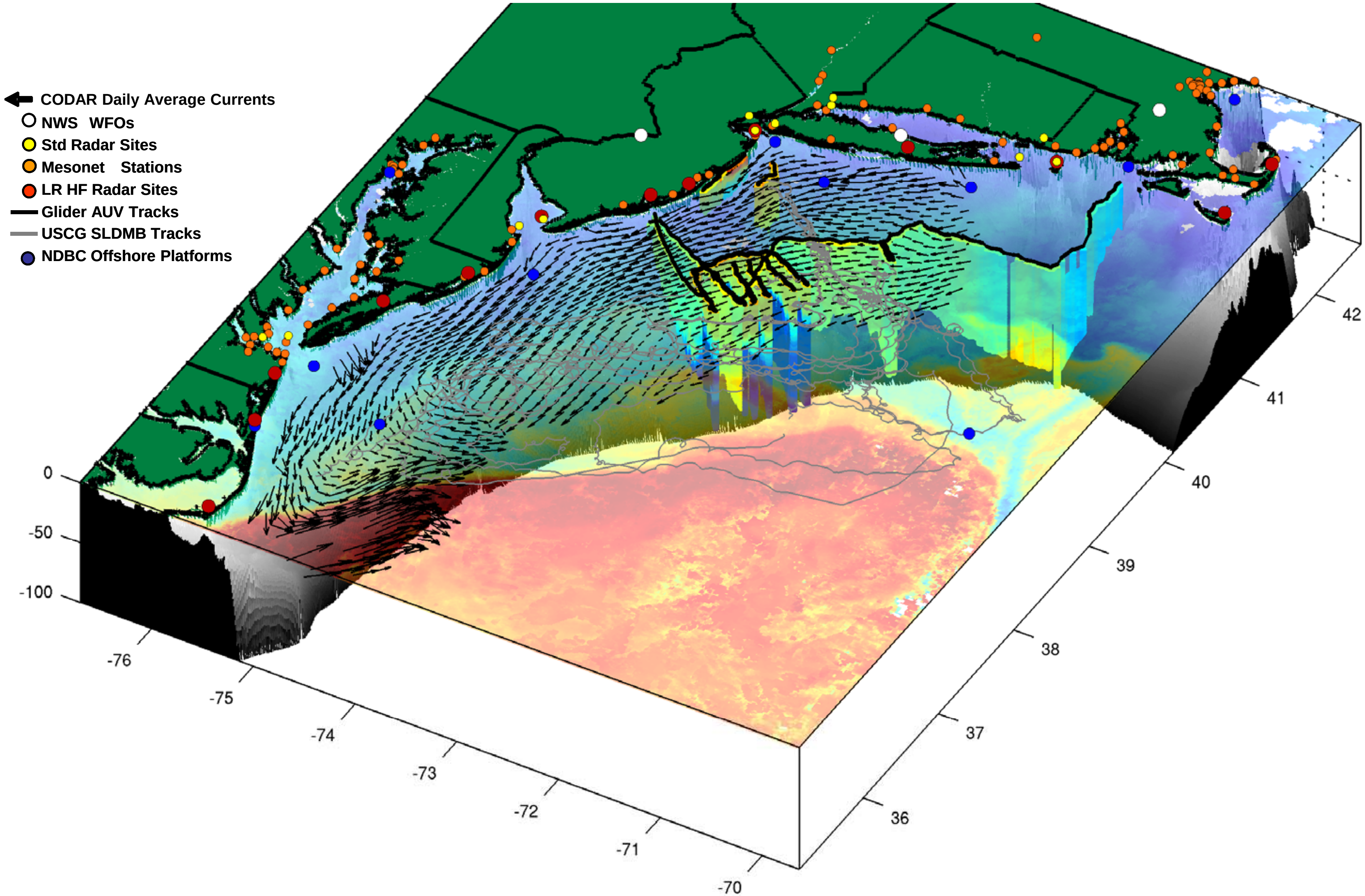
ALT + TG + Radar + Gliders + Models? + SST + Oc Color


(Coastal) Integrated Ocean Observing System (IOOS)
What is the role of altimetric SSH?
Coastal Radar Surface Vel
Eureka
Sacramento
Stockton
San Francisco
Oakland
Modesto
San Jose
California
Fresno
100 mi
200 km
50°N
45°N
40°N
35°N
30°N
25°N
135°W
130°W
125°W
120°W
115°W
121
197
019
095
104
171
247
028
069
20
145
221
043
119
195
206
017
004
080
156
232
054
130
UW
Met Moorings
Tide Gauges
Moorings
Hydro Transects
Topex, Jason-1/2
Models – UW
OSU
OOI
Models – GLOBEC
Models – UCSC - NRL
MBARI
Models – UCLA
CALCoFI
JPL
Models - SIO
LTER

Coastal Ocean Observing Systems

MARCOOS, GoMOOS, NERACOOS

for analysis, independent validation, and assimilation



Coastal Ocean Observing Systems

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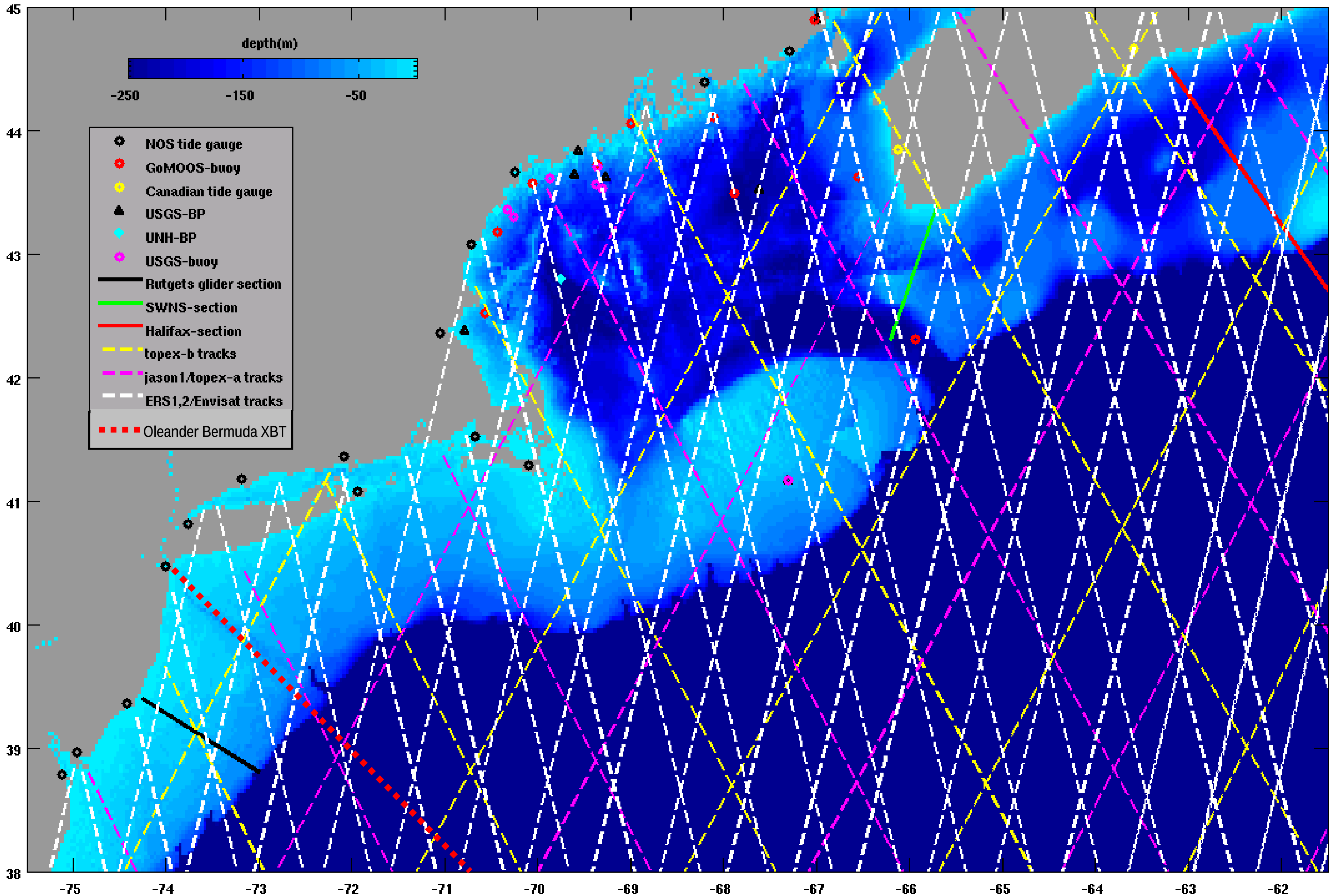

Challenge I: Retrieve alongtrack SSH data within 50 km of the land. The problem is tractable and progress is being made.

Challenge II: Resolution of Coastal Ocean Dynamics on Short Time and Space Scales: <u>Altimeters can't do it alone. They are one (important) component of more complete coastal ocean observing/modeling systems.</u> The good news is that coastal regions are where other types of data can be relatively easily collected.

The proper design of these systems, i.e., the right mix of observing and modeling components, is still a topic of ongoing research.

Presentations and findings from the first Coastal Altimeter Workshop are available at:

http://cioss.coas.oregonstate.edu/CIOSS/altimeter_workshop.html

The recent EOS article (November 2008) and its Supplemental Material are there as well.

Source	Proximity, km	Horizontal scale, km	height error, cm	slope err, μrad
wet 0.5 deg, 6 hr model		100	2	0.2
wet ssmi	200			
wet wvr	> 50		< 1 cm	
wet wvr	20 - 50		< 3 cm	
tide model	locality-dependent	depth-dependent	12 cm	> 1
IB	l.-d. (shelf depth)	60 -120 km	1 - 5 cm	~0.5 ?
SSB, precision	20 km	(from SWH estimate)	2 cm	
SSB, accuracy	l.-d.	long	3 cm bias	

CAW-I Findings, tracking

We expect “standard” (Brown model) retracking to be adequate seaward of 20 km from the coast.

90% of waveforms are Brown-like seaward of 10 km from the coast.

Constrained retracking can reduce noise.

Adaptive (non-Brown model) retracking can recover data closer to the coast, however, intercalibration of the track point and wind- and wave-dependent biases will need to be studied.

CAW-I Findings, wet troposphere, 1

Atmospheric “rivers”~200 km wide increase IWV near the coast.

0.5°, 6-hourly models lack structure with ± 2 cm Ku-delay and less than 100 km half-wavelength

High-resolution coastal models show model gradients of 5 to 6 cm of delay per 100 km.

WVR can be used > 50 km from coast; at closer distances, land emissivity causes several cm of error.

SSMI land contamination begins 200 km from the coast.

CAW-I Findings, wet troposphere, 2

Two parallel mitigation strategies are in development.

1, based on correction of brightness temperatures for fraction of land contamination

2, filling holes with model data, possibly adjusted for a bias or bias and slope.

Future missions may consider the use of higher-frequency channels.

CAW-I Findings, tides

Tides are strongly dependent on bathymetry.

Compound tides (e.g., M4) have significant amplitude in shallow water and may contribute 6.6 cm to the global RMS misfit of models to gauges.

RMS errors in models are around 2.4 cm in deep water and ~12 cm in shallow water, but this value is highly dependent on locality.

The wavelength of the tide error will depend on depth.

The best approach may be to merge local and global models, but this is resource and labor intensive.

CAW-I Findings, IB

The ocean's response to pressure forcing at shorter than 20 day periods is not as simple as an inverted barometer.

The MOG2D/DAC model shows a big (how big?) improvement over simple IB, especially at coastal and high-latitude areas.

(What length scale is the error that is improved?)

The S1/S2 atmospheric tides need further investigation.

Local models should be developed.

CAW-I Findings, Sea State Bias

SSB is EM, skewness and tracker-dependent.

To first order, SSB is 1 to 5 (typically 3) % of SWH.

Present models adjust SSB based on SWH and U10.

New, three-parameter models (SWH, U10, age) differ from two-parameter models by 2 cm in shallow water and at SWH < 1.5 m.

Local empirical coastal models differ from global-average models by $\pm$ 3 cm.

Wave-current interactions are not yet accounted for.

CAW-I Findings, SWH

Altimeter data are a very useful source of SWH profiles in the deep ocean.

Deep ocean SWH data are typically averaged for six seconds for comparability with large-scale wave models.

Correlation scales appear to fit the Monaldo model.

In coastal areas, SWH correlation scales can be as short as the wavelength.

Satellite orbit sampling issues show up as differences in apparent wave height climatologies.

CAW-I Findings, Programs

Currently, agencies treat coastal altimetry data acquisition as one of a group of secondary objectives, of lower priority than open oceans.

Coastal experts and coastal user needs should be more involved in pre-launch design and post-launch cal/val.

Source	Proximity, km	Horizontal scale, km	height error, cm	slope err, μrad
wet 0.5 deg, 6 hr model		100	2	0.2
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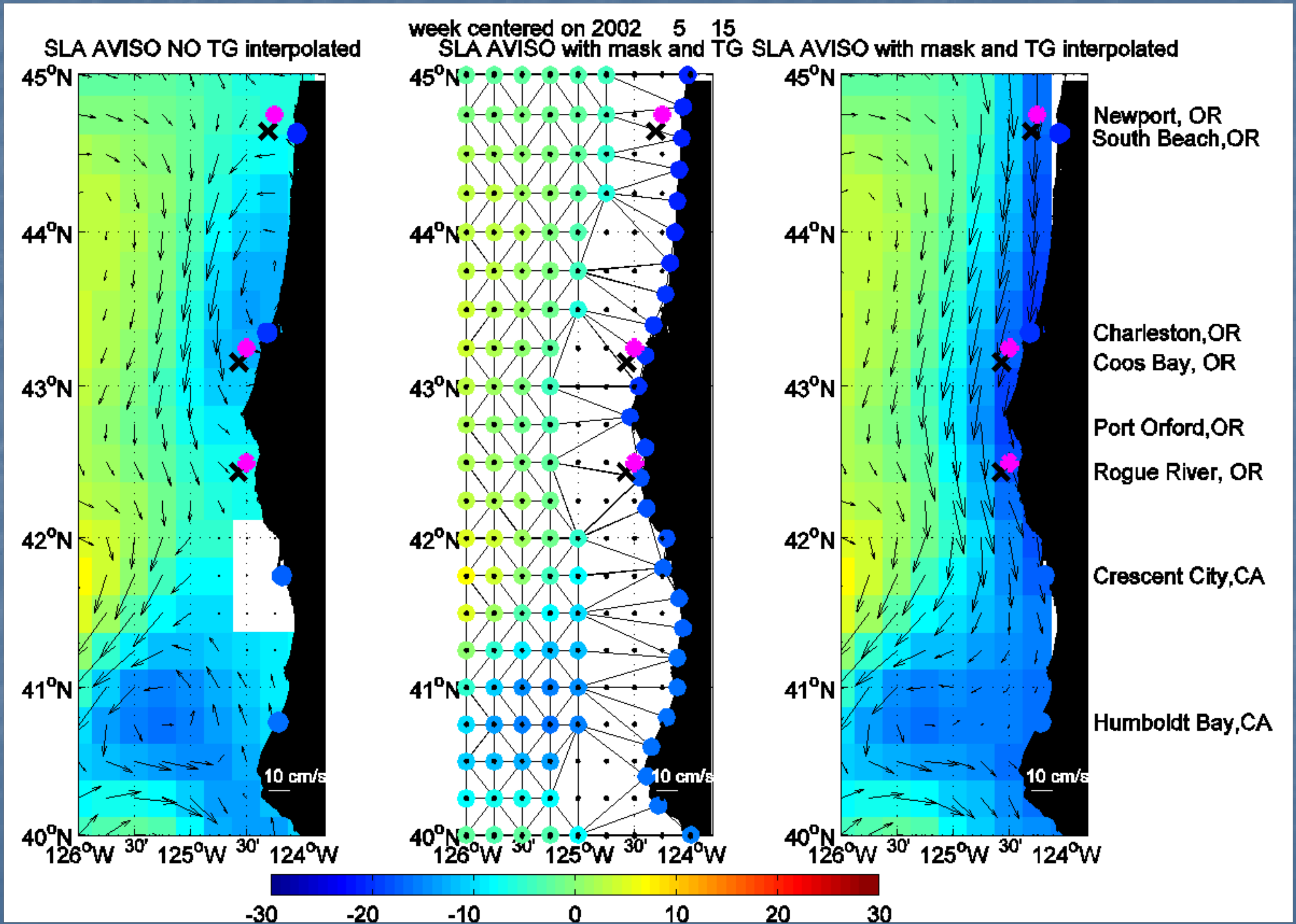
SSB, precision	20 km	(from SWH estimate)	2 cm	
SSB, accuracy	l.-d.	long	3 cm bias	

One approach – use the available gridded SSH fields; blank out the values within ~50 km of land; interpolate to tide gauges on land. This avoids the coastal ALT data.

** Can we actually recover the alongtrack data in this region? What can we do with it?



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Links

Vector-averaging techniques and HF Radar quality control have been applied to generate the real-time vectors.

This is a demonstration of the **NOAA HF Radar National Server and Architecture Project**. HF Radar is used to remotely measure ocean surface currents.

vectors | 25 hr avg 2008-10-30 13:00:00 UTC | time lapse | buoys/stations | sites | Data Age (in hours): 0-3 4-12 13+