

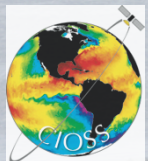


Using HF radar coastal currents to correct satellite altimetry

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University of Colorado at Boulder

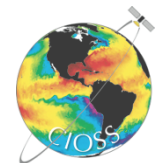
6th Coastal Altimetry Workshop, Sept 2012, Riva Del Garda, Italy



Outline

- Retrieval of CODAR SSH
- Comparison CODAR with Jason-2 altimeter SLA and with PISTACH retrackerers
- Cases that fit well/ cases that diverge
- Explore the reasons why as a function of sea state

Goal: to determine if we can use the CODAR SSH to improve the retracking methodology of the J2 waveforms in the coastal regions.

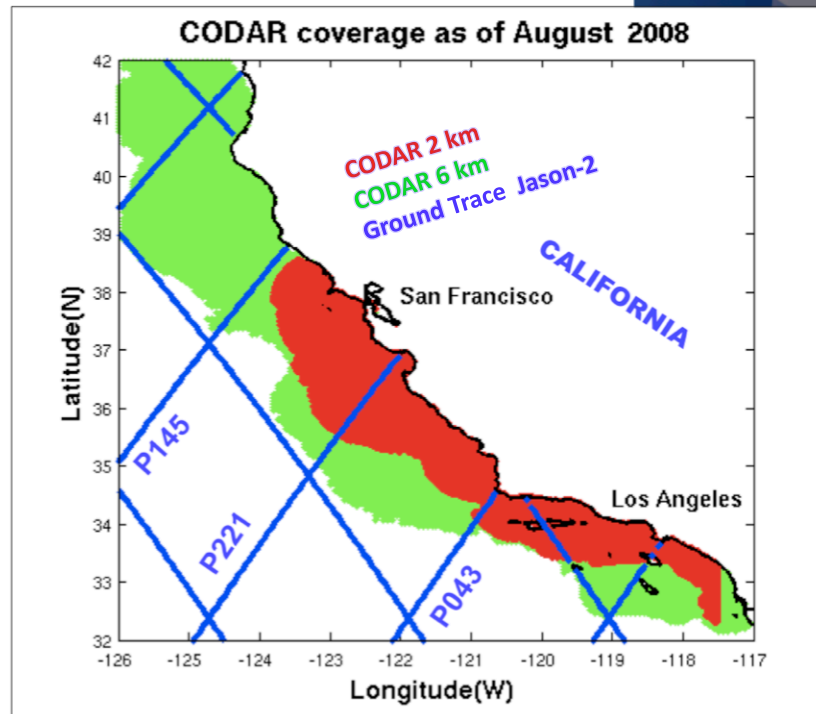
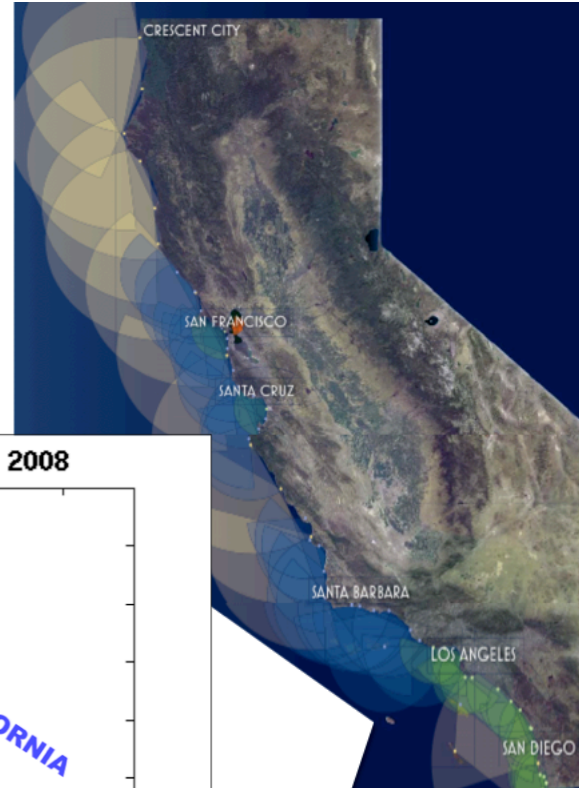


CALIFORNIAN DATA SET

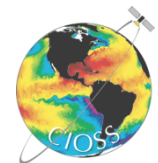


	Long range	Short range
Frequencies	4.66 MHz	13.54 MHz
Resolution	6 km	2 km
Up to	150 km	50 km offshore

At least 2 radar overlapping fields are needed to derive the currents

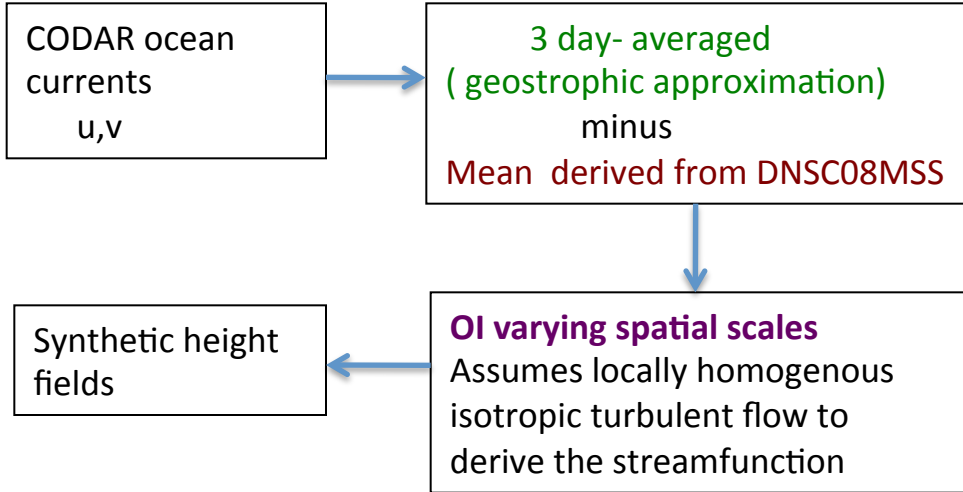
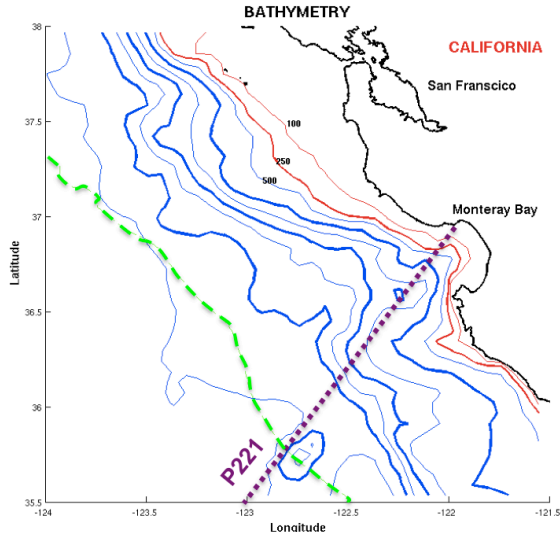


Using 2008 & 2009 hourly CODAR measured ocean surface currents on a resampled and post processed 6 km and 2 km grid.

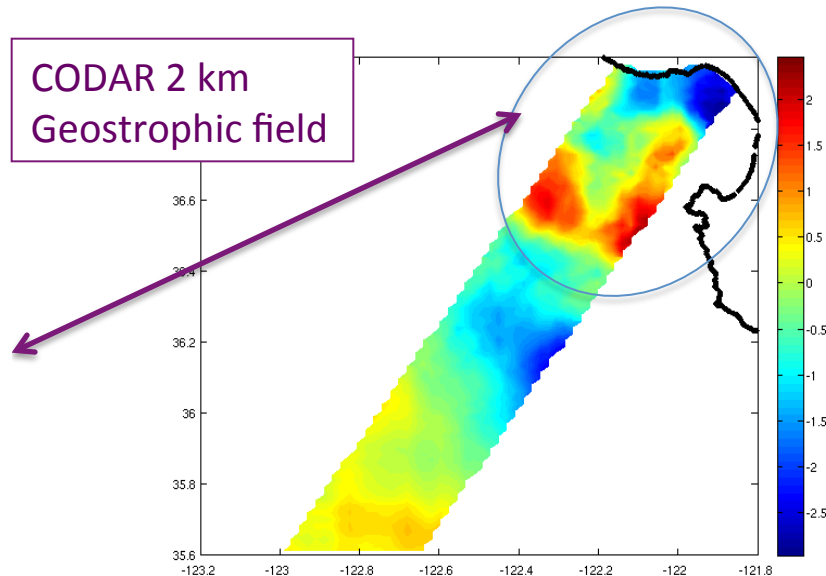
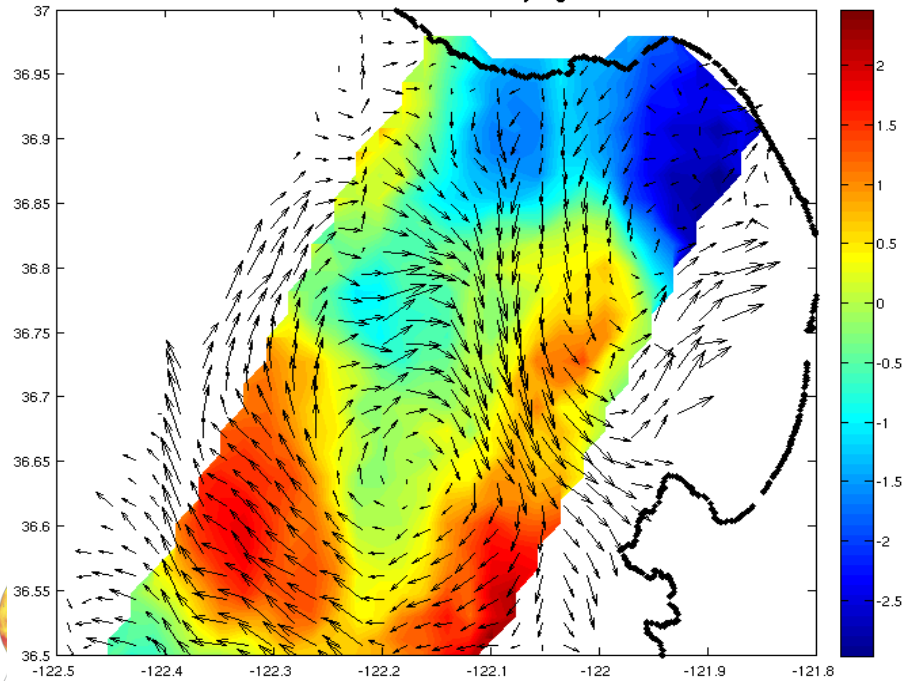


CODAR Geostrophic heights field

Region of P221 ; Monterey bay.



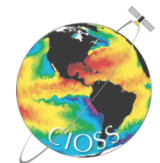
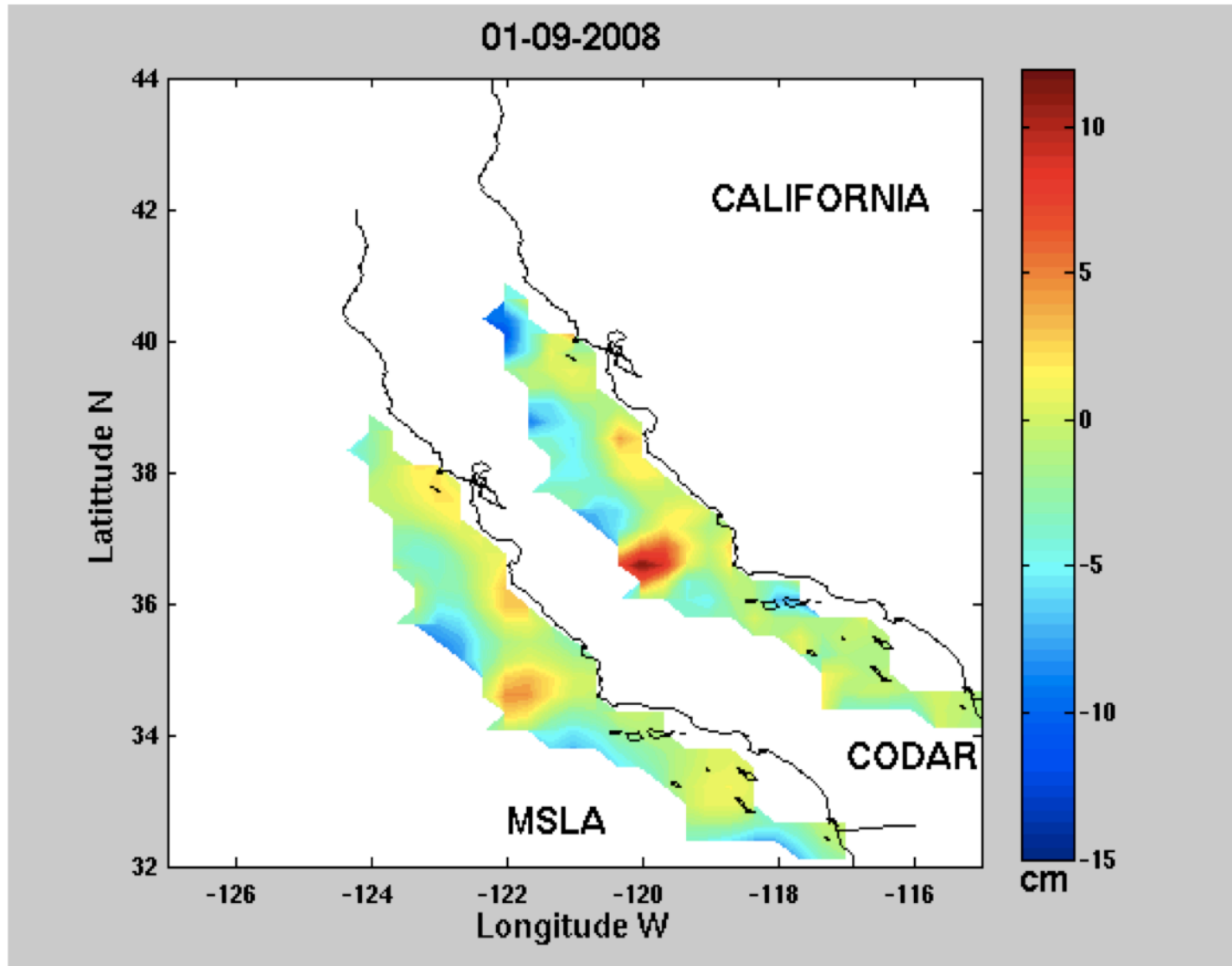
Cod2k 090608-090908 Varying Cov



CODAR & weekly Merged MSLA

Aviso product:
Weekly merged
MSLA on a $1/3^\circ \times 1/3^\circ$ grid, for
2008

CODAR SSH
computed
directly on the
MSLA grid.



Codar and J2 SLA for 2009



JASON-2 Corrected SSH

In particular

- Composite Wet tropospheric correction from Pistach L2
- GIM (Global Ionospheric Map) ionospheric corr
- SSB included (may not be reliable over continental shelf)

3 retrackings from Pistach L2 product

- **MLE4** : standard open ocean retracking in GDR product
 - **Red3** : MLE3
 - **Ice3** : 30 % threshold
- } Done on a smaller window selected around the leading edge

No standard editing related to range, because examining the improvement of the retracked SSH is one objective

Low pass filtering

1-Hz

20-Hz

25 km
50 km

7 km
21 km

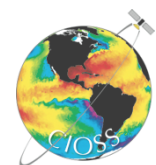
Mean of time series removed

CODAR SSH

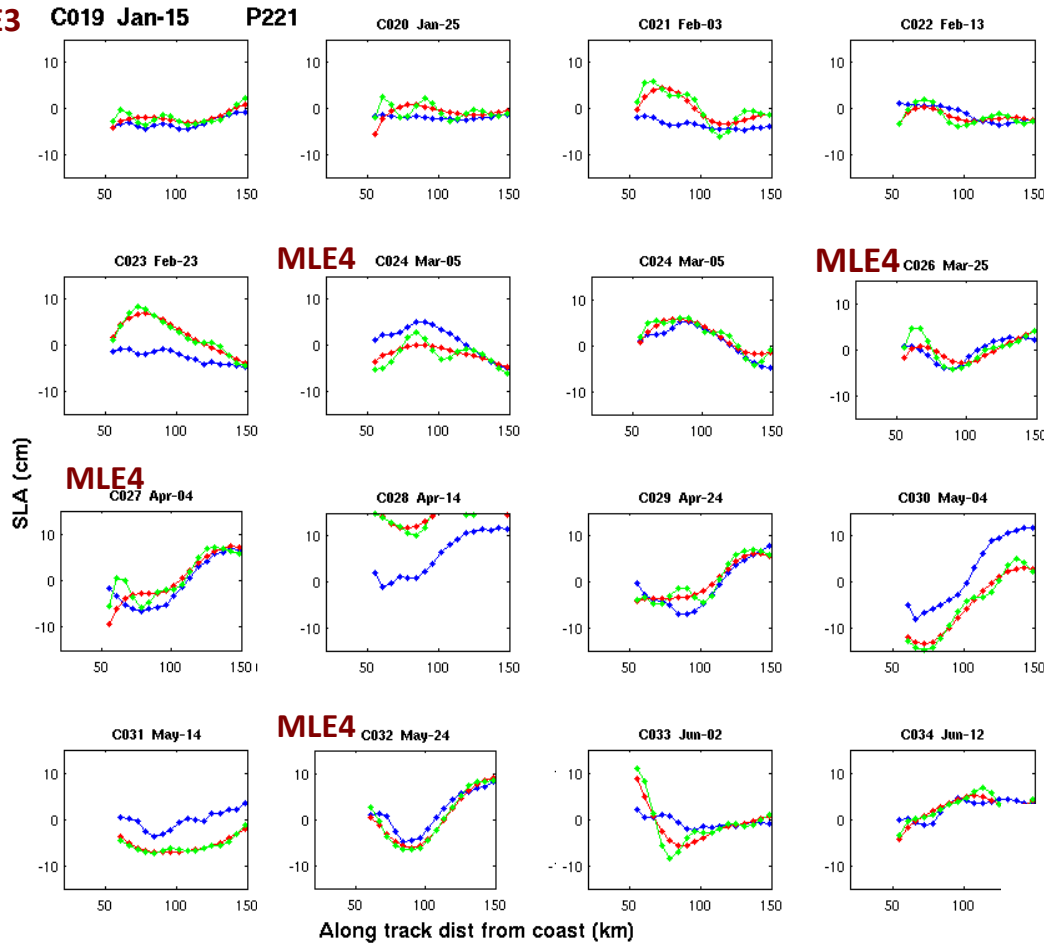
Interpolated at the J2 Pass

Mean of time series removed

Comparison SLA



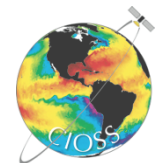
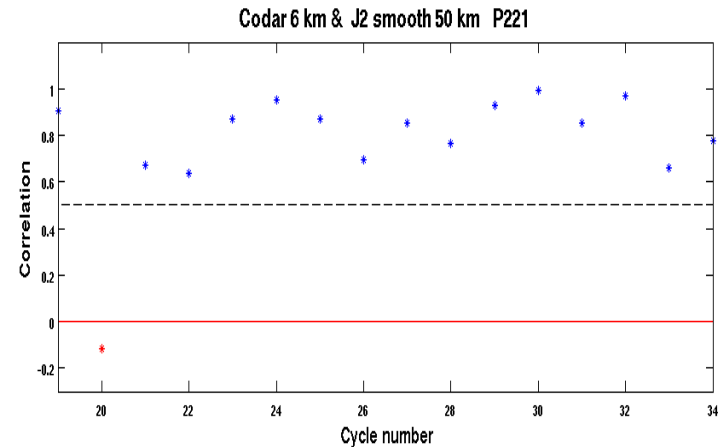
1-Hz J2 retracker & 6-km-CODAR for P221



Here we only keep the best visually retracker fit either Ice3 or MLE4, for the first 16 cycles of 2009

2x{Codar}
SSH filt 25 km
SSH filt 50 km

The averaged correlation is now 0.82 instead of 0.7

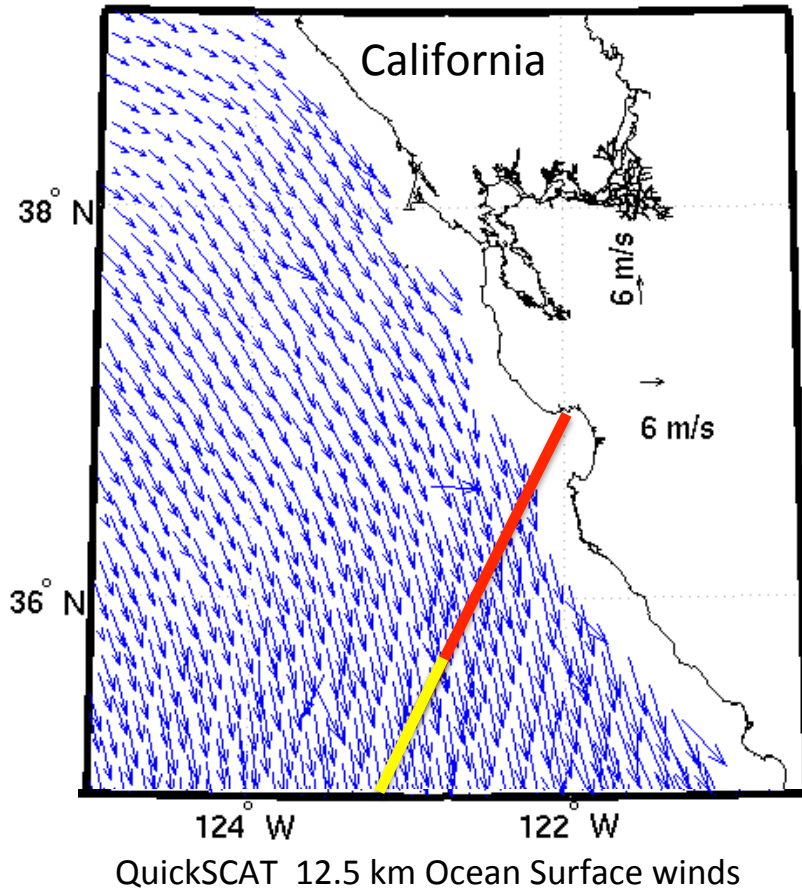


J2 20-Hz Case1: Medium Winds & Good fit

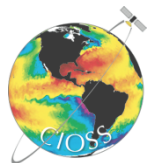
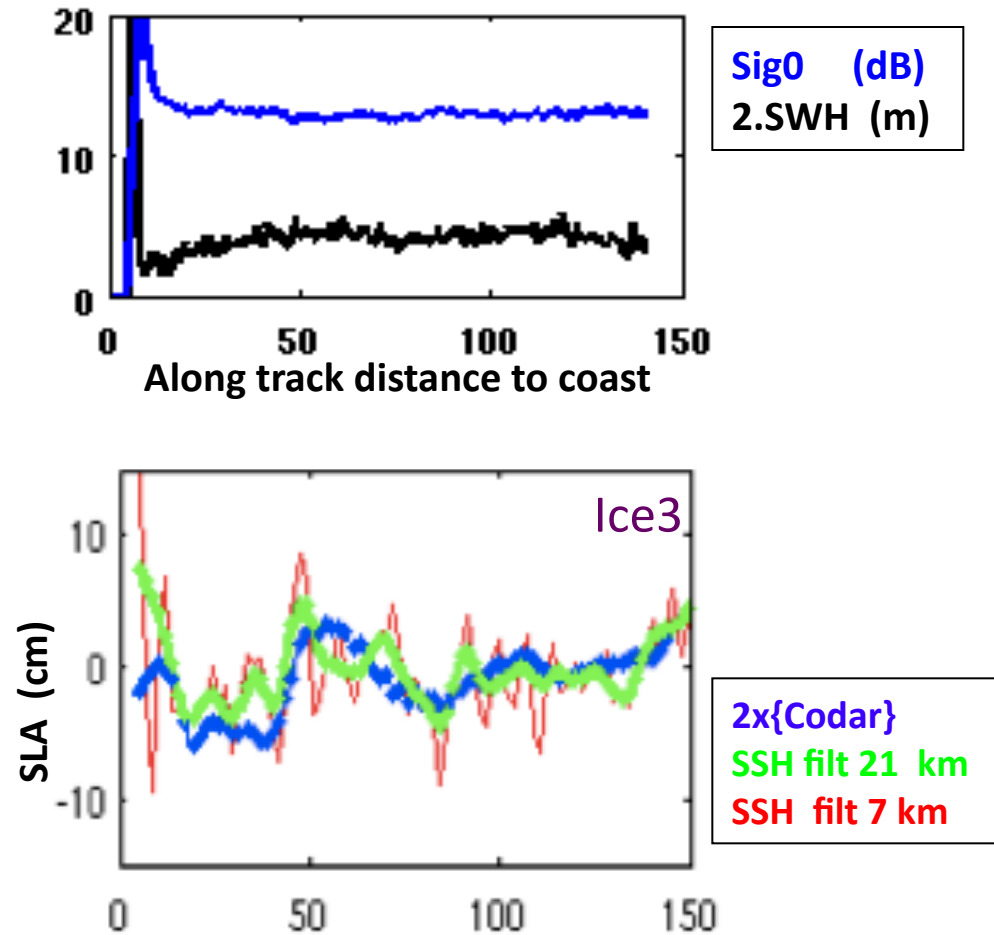


P221

May 14 at 2:00 Strong winds



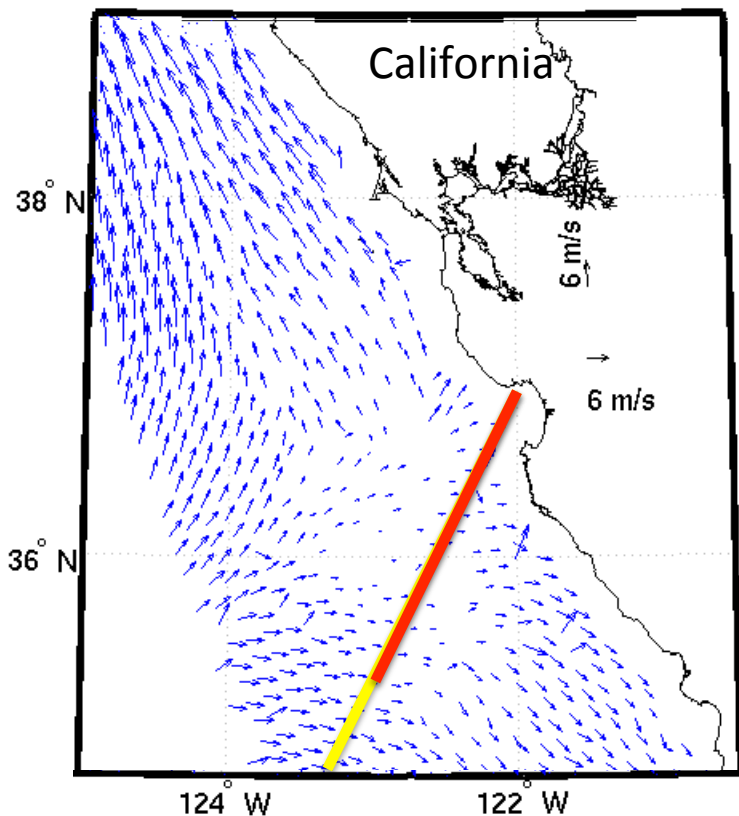
J2, C031 May 14 at 2:00 UTC



J2 20-Hz Case2 : Low Winds & Sig0 Blooming



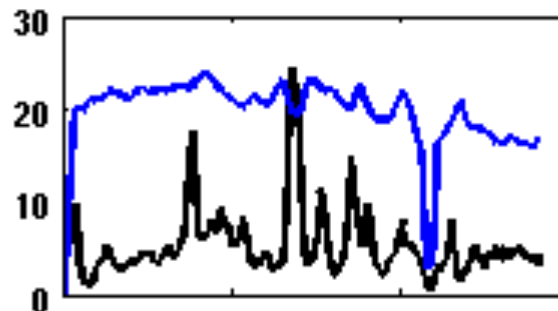
May 04 at 13::00 UTC: Low Winds



QuickSCAT 12.5 km Ocean Surface winds

P221

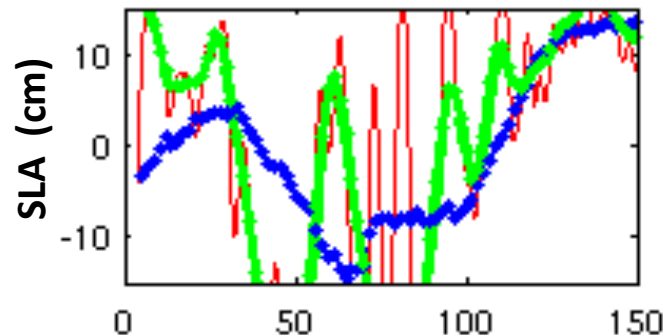
J2, C030 May 04



At 5:00 UTC

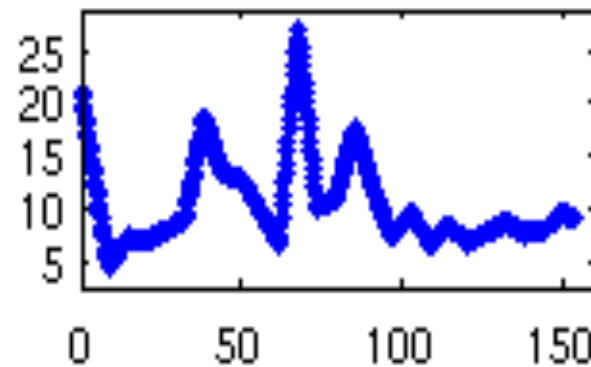
Sig0 (dB)
2.SWH (m)

C030 May-04



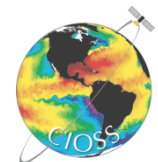
Ice3
Not Corrected
for SSB

2x{Codar}
SSH filt 21 km
SSH filt 7 km



SSB (cm)
Not valid for
Non Brownian
WF

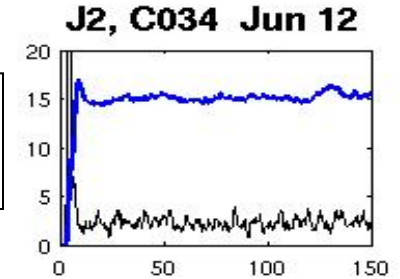
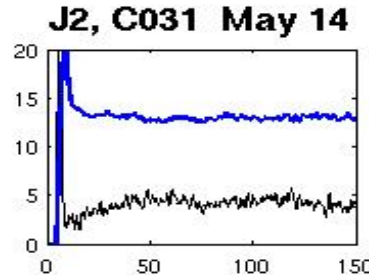
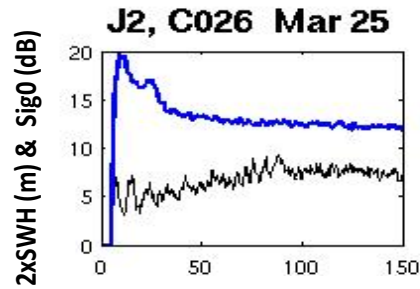
Along track distance to coast



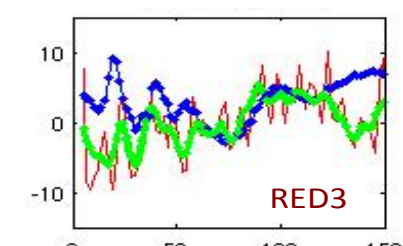
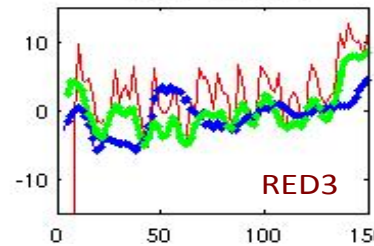
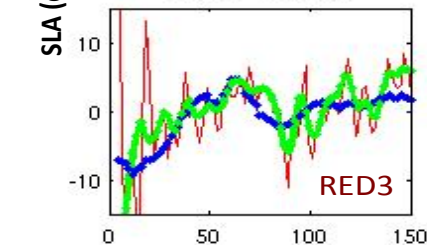
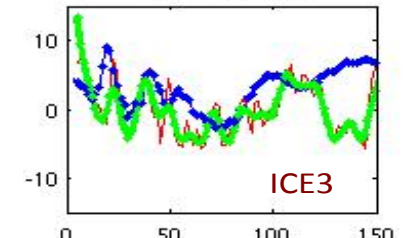
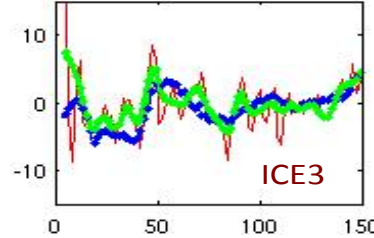
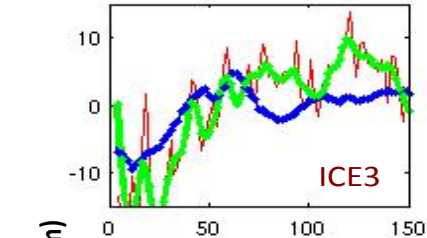
Behavior of Ice3 and Red3 range related to the sea state



Jason-2 Pass 221



2x{Codar}
SSH filt 21 km
SSH filt 7 km



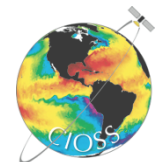
Along track distance to coast

After the close to shore blooming event (< 30 km), Red3 performs better, though it seems noisy.

High SWH

No blooming events Ice 3 performs well and better. Sig0 stays below 15 dB SWH < 2.5 m

Ice3 behaves well closer than 50 km, then Red3 until a little blooming event around 140 km Sig0 is about 15 dB SWH < 1.5 m



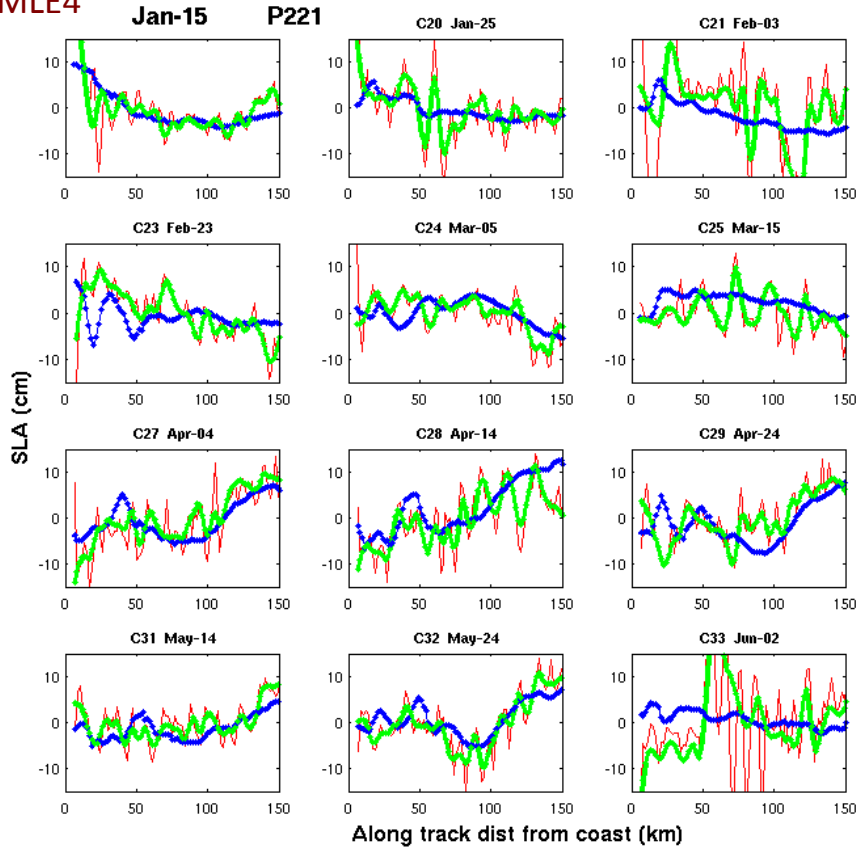
Editing Spurious 20-Hz data



Removing Blooming events ($\text{sig0} > 16$ dB) and $\text{SHW} > 5$ m for **20 Hz MLE4** data then using same filtering process as before

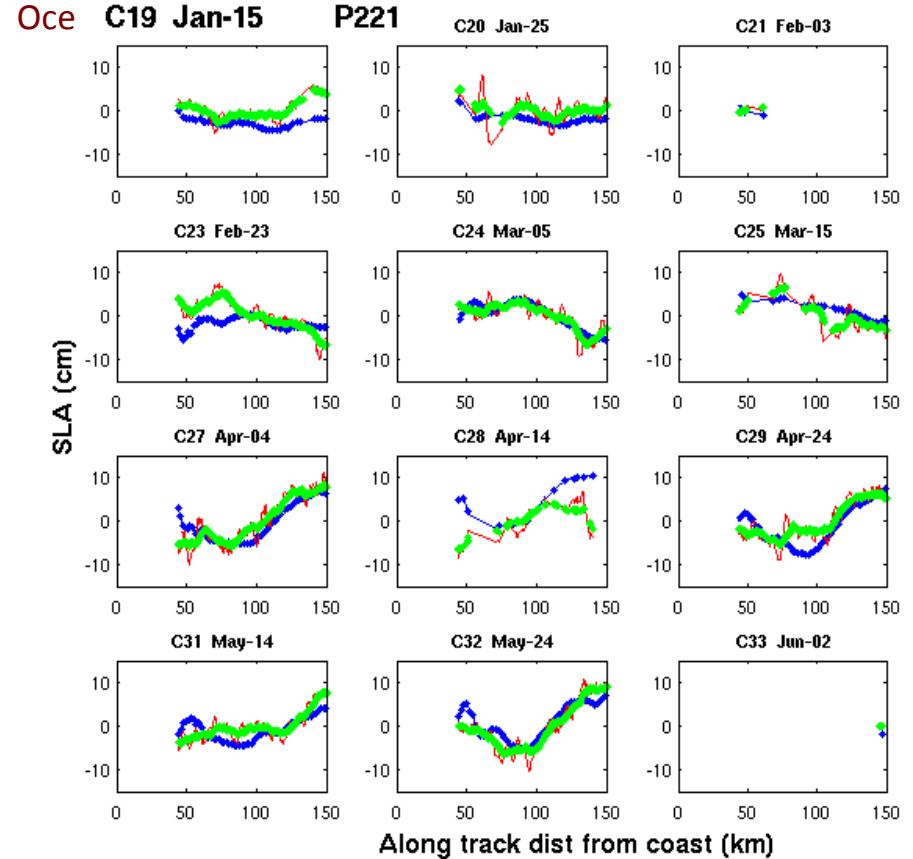
Before

MLE4



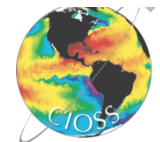
After

Oce



2x{Codar}
SSH filt 21 km
SSH filt 7 km

Cleaner relationship between CODAR and J2 SLA derived from MLE4
Will enable to assess the quality of the match.

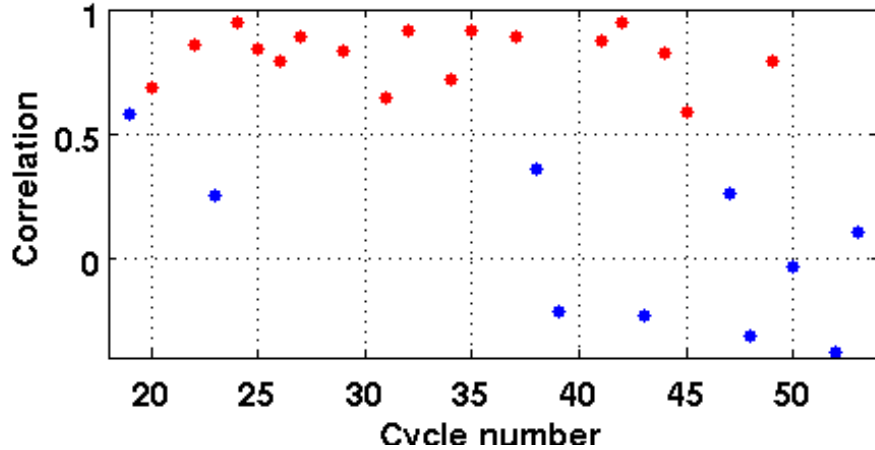


Editing Spurious 20-Hz data P221

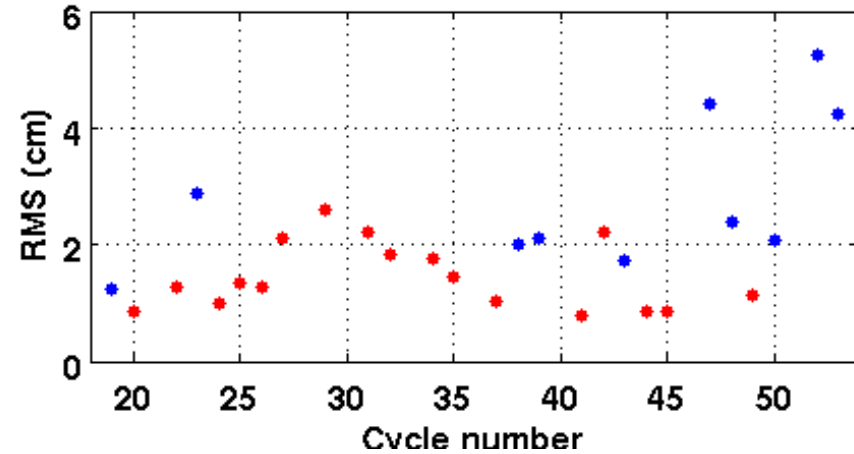


Statistics for J2 P221 in 2009

Correlation Edited J2 & Codar P221



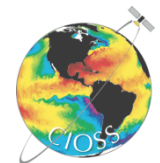
RMS Edited J2 & Codar P221



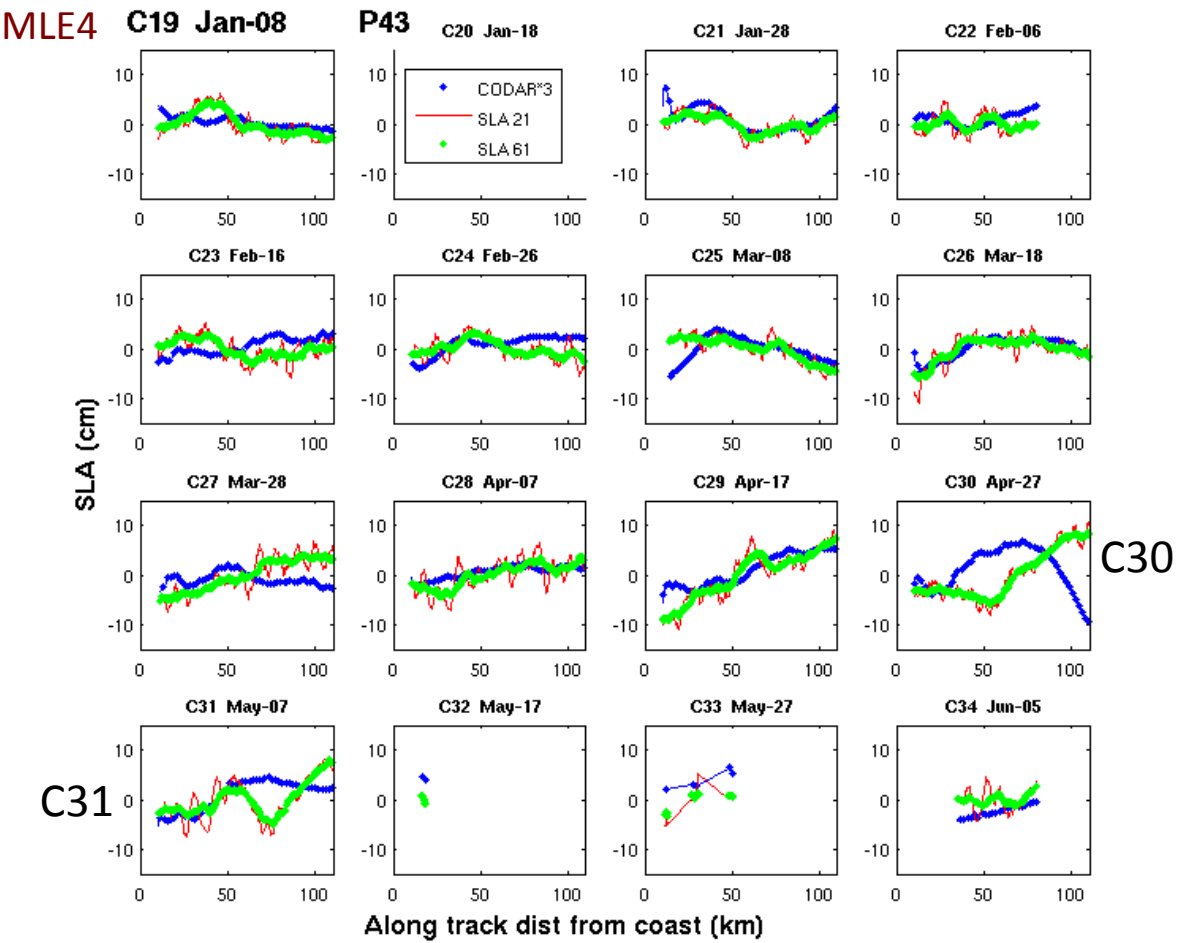
For 18 good cycles:

Mean Correlation 0.83

Mean RMS 1.4 cm



Editing Spurious 20-Hz data P43

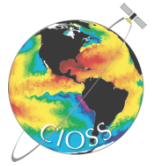


Good similarities.
Correlation not as good as for P221, one reason being that the SLA variations are smaller.

For 15 good cycles in 2009
Mean Correlation 0.75
Mean RMS 1.88 cm

We still need to explain the discrepancies in some cases:
C30 & C31

The match level depends on SNR:
- on the amplitude variations of the SLA
- on the noise level of the altimetry data, which depends on the sea state.



Cases of very good matches for P221, P43 & P145

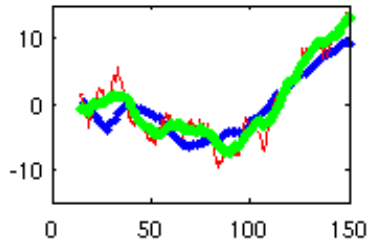


Cannot be the result of coincidence only

P145

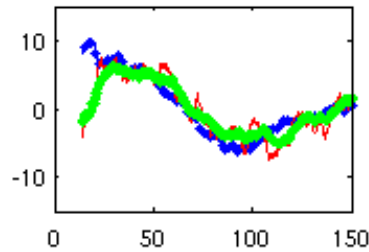
$\rho=0.95$

C31 May-11



$\rho=0.92$

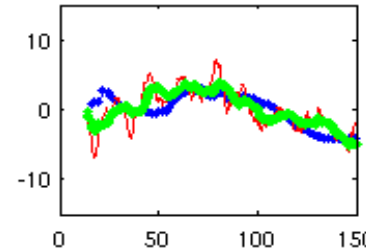
C49 Nov-05



145

$\rho=0.78$

C52 Dec-05

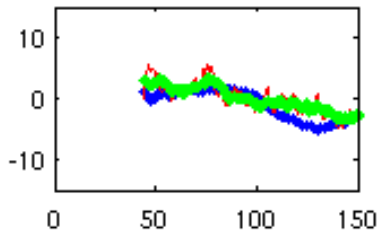


2x{Codar}
SSH filt 21 km
SSH filt 7 km

P221

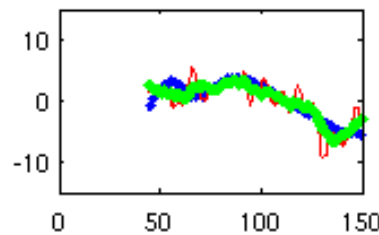
$\rho=0.85$

C22 Feb-13



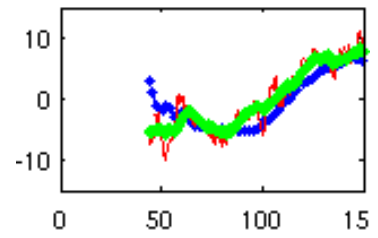
$\rho=0.94$

C24 Mar-05



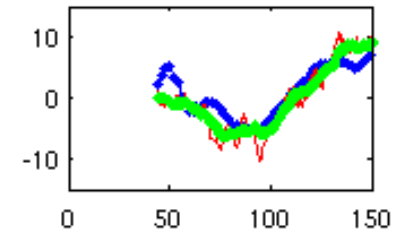
$\rho=0.89$

C27 Apr-04



$\rho=0.91$

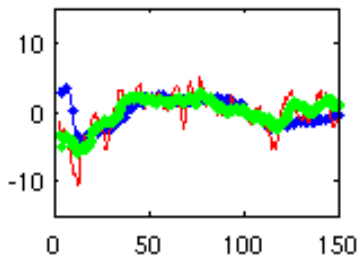
C32 May-24



P43

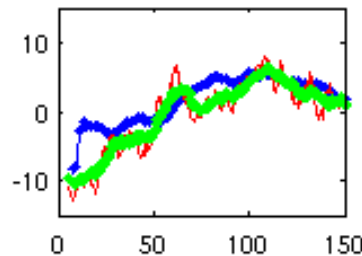
$\rho=0.79$

C26 Mar-18



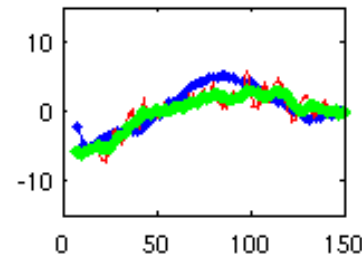
$\rho=0.84$

C29 Apr-17



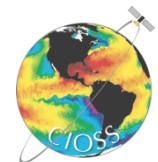
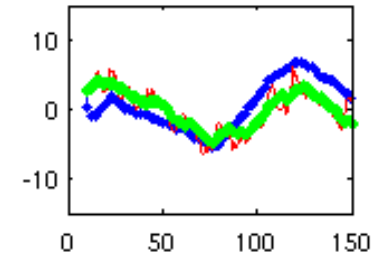
$\rho=0.86$

C37 Jul-05



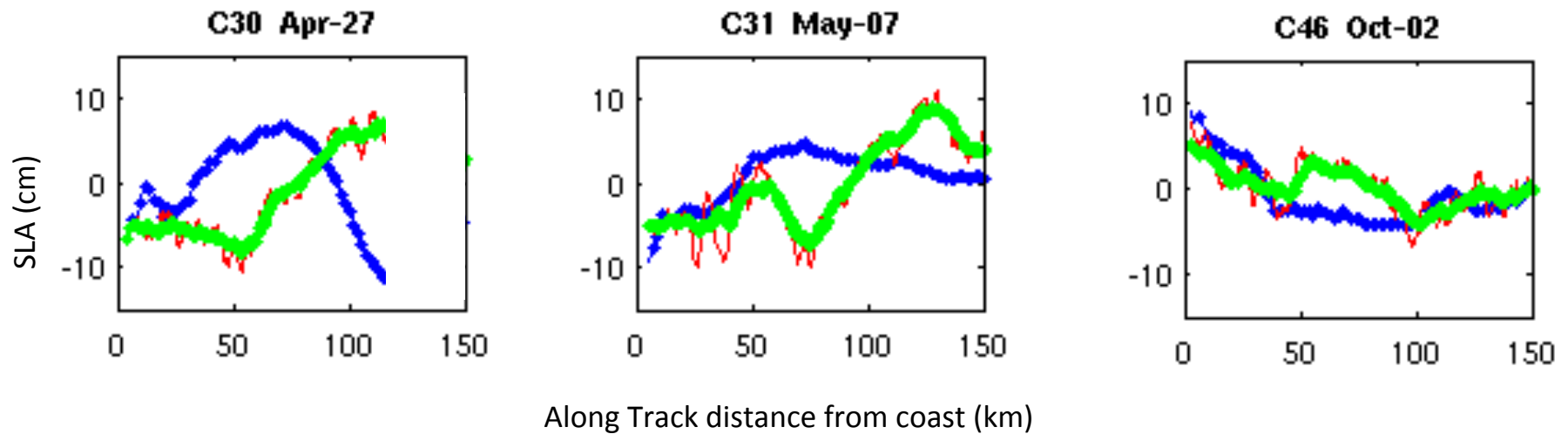
$\rho=0.71$

C43 Sep-03



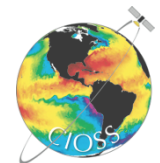
Some diverging cases

Here are some examples from J2 P43



What are the reasons?

2x{Codar} (blue)
 SSH filt 21 km (green)
 SSH filt 7 km (red)



Waveform model

WF shape over the ocean (mean returned backscattered power)

WF(t) = Impulse response from smooth Sphere

*

Radar point target response

*

Joint probability density function of the surface slope and elevation

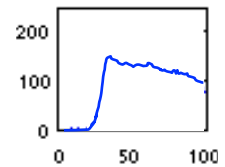


Classical Brown model :

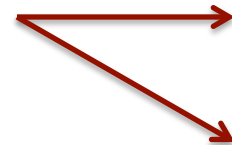
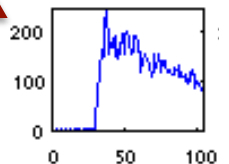
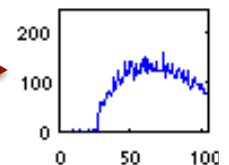
assumes a Gaussian shape of PDF

assumes homogeneity of the surface backscatter over the footprint

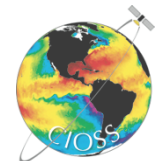
Not true for blooming events (low winds, surface slicks)



17.55 km



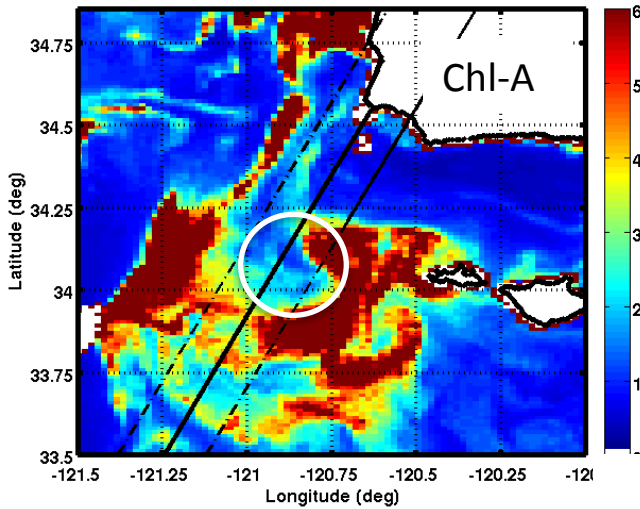
Interested in finding small non homogeneities in the footprint



Case 1: J2 C46 P43 C046 Oct 2, 2009 at 22:00

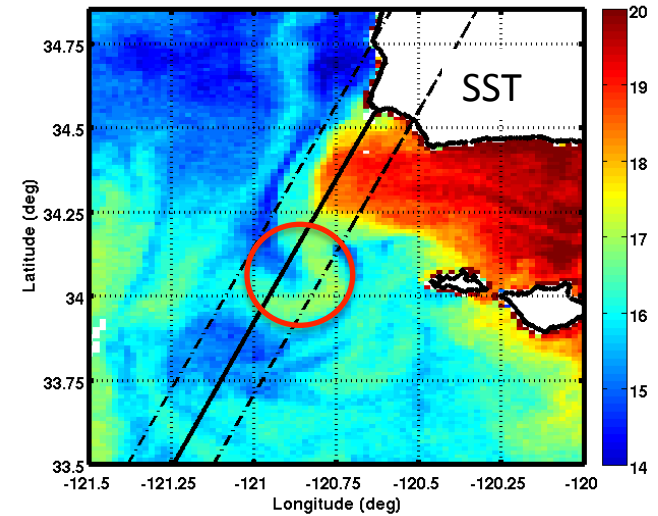


Modis Aqua Chloro-A 02-Oct-2009 21:05

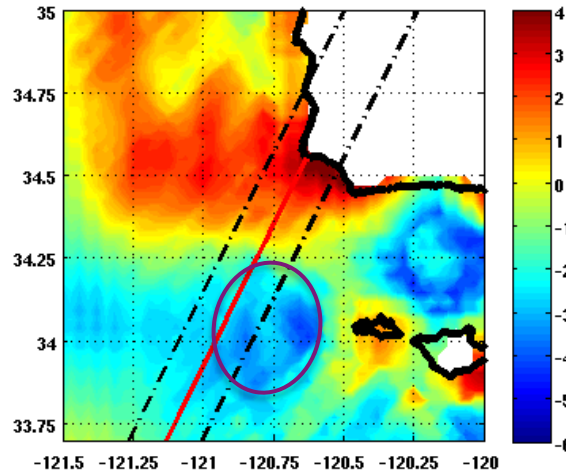


Modis and J2:
30 mn apart

Modis Aqua SST 02-Oct-2009 21:05

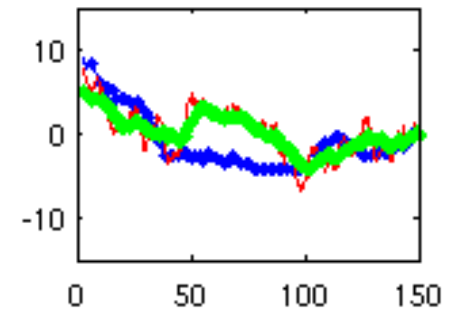


3-day CODAR SSH

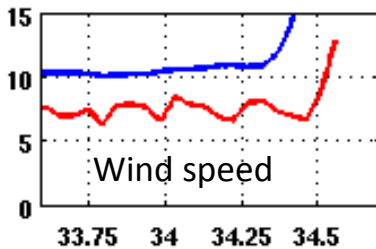


Winds are about 7-8 m/s
P43 passes on Eddy
about 20 km in
diameter?

C46 Oct-02



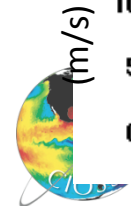
C046 Oct-02



Cyclonic eddy
no agreement with
altimetry

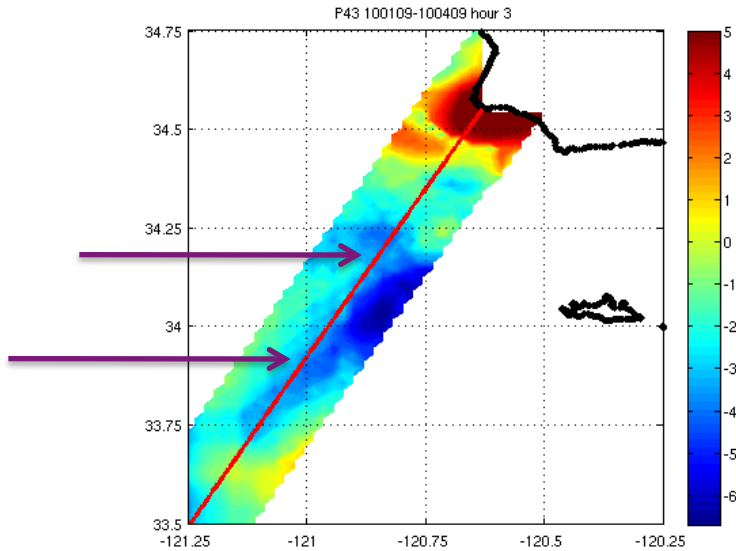
33.75	34	34.25	34.5	(Lat)

100	65	35	7	(km)

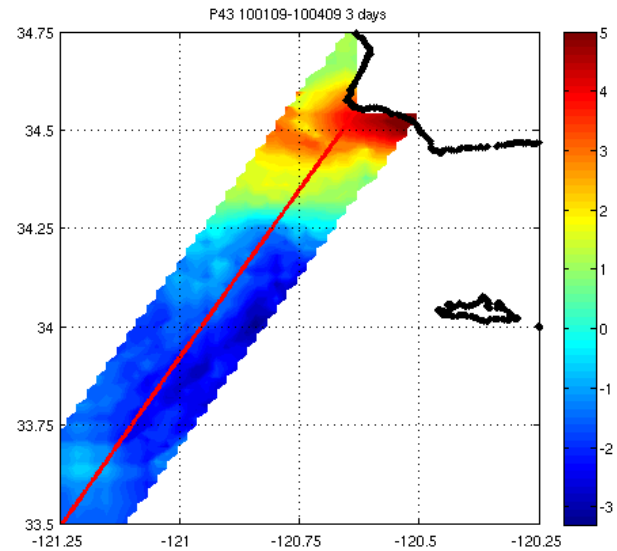


Closer inspection P43 C046 Oct 2, 2009

Codar 2 km 3 hour-average



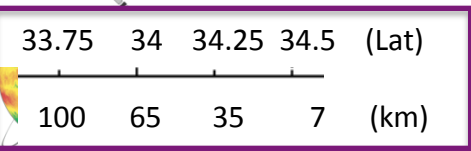
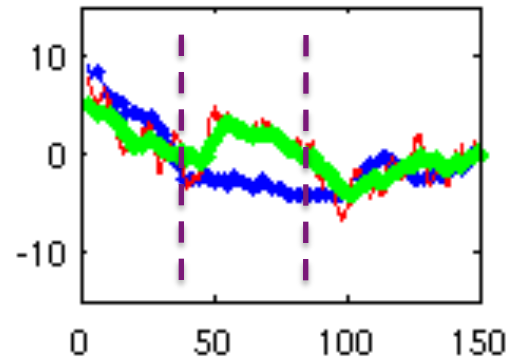
Codal 2 km 3 day-average



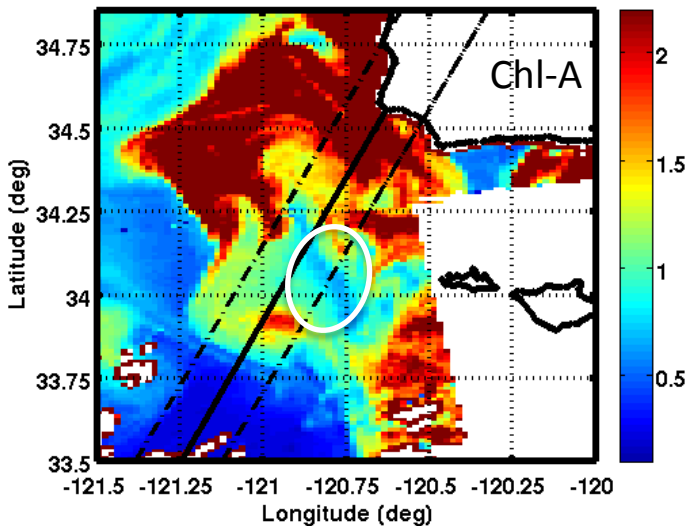
We depict an $\frac{1}{2}$ eddy in footprint that could be seen by central part of altimeter footprint from at least 33.9 till 34.2 (i.e. \sim 40 – 80 km)

Same field but smudged

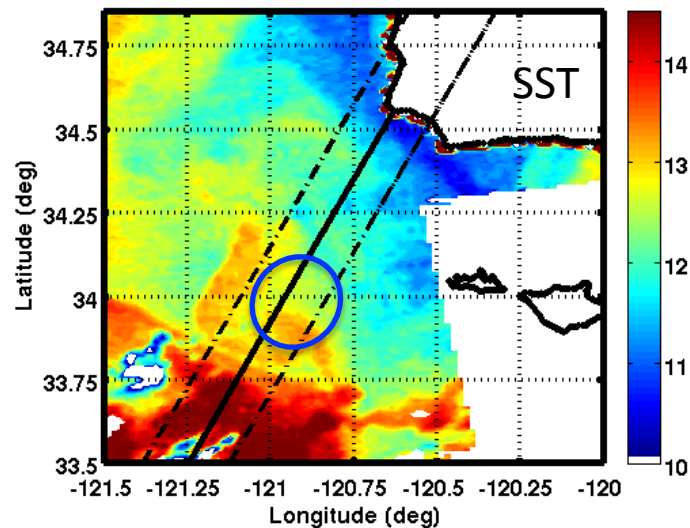
C46 Oct-02



Modis Aqua Chloro 07-May-2009 21:35

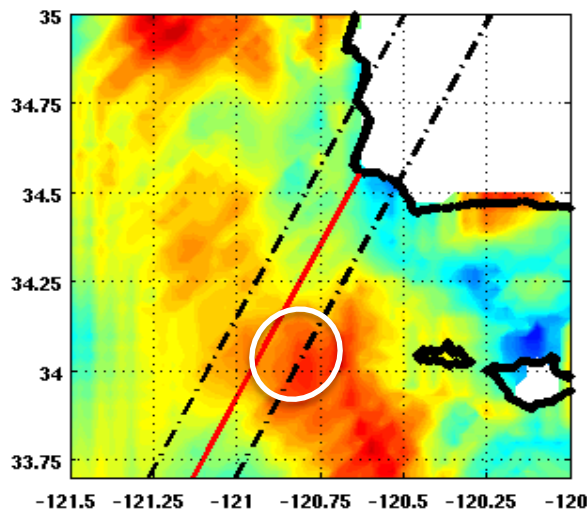


Modis Aqua SST 07-May-2009 21:35



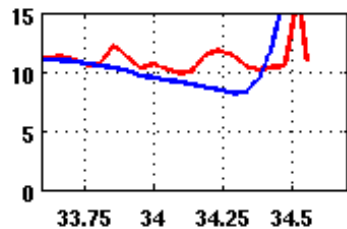
Modis & J2:
17 H apart

3-day CODAR SSH

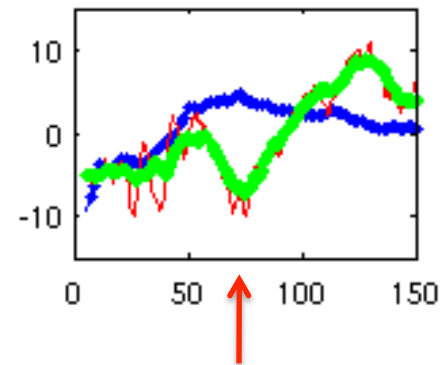


Winds are ~ 10-12 m/s
P43 passes on Eddy
about 20 km in
diameter.

C031 May-07

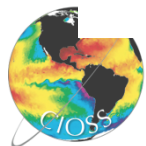


C31 May-07



75 km ~ lat 33.9°

Anticyclonic eddy
no agreement with
altimetry



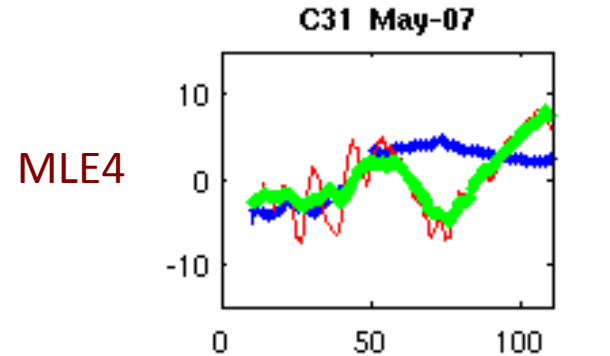
Case 2: P43 C031 May 7, 2009 (cont..)

PISTACH retrackers

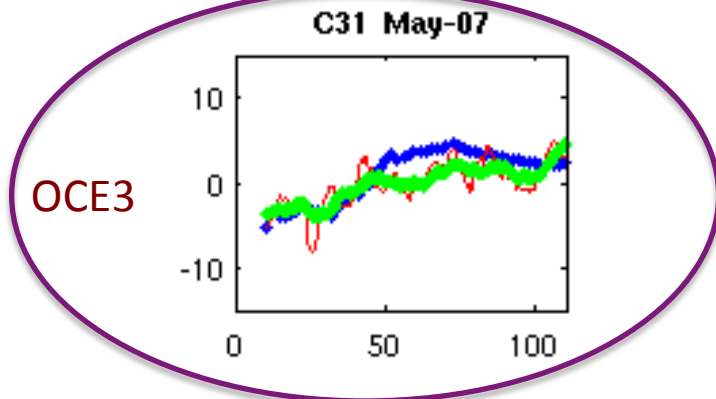
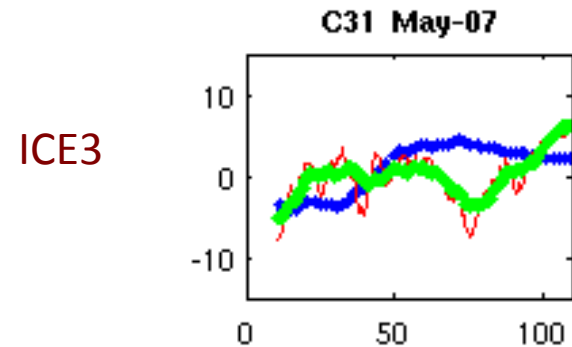
- MLE4
- Oce3: MLE3
on filtered waveforms

Next ones performed over a small window around the leading edge

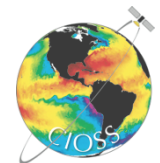
- Red3: MLE3
- Ice3: 30 % threshold,



RED3 Very similar to MLE4



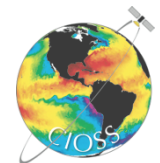
OCE3 fits well
which is unusual



Case 3: P43 C031 May 7 , 2009 (cont..)



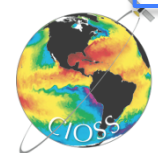
- The fact that OCE3 fits well, tends to prove that the mismatch is with the altimeter data. The ocean structure is not quite homogeneous and the waveforms differ slightly from the classical Brown model. Not enough so no flags are on.
- RED3 is similar to MLE4, so the problem is not in the tail end of the waveform.
- In this case OCE3 reduces the noise in the WF in an efficient way.



Conclusion



- We have shown that there is a good relationship between JASON & CODAR SSH, further than 20 km off the coast.
- By editing the J2 data of blooming events and high SWH, the relationship between CODAR and 20-hz altimetry has improved significantly.
- We looked at cases when the altimeter and Codar SLA diverge significantly.
- In these cases auxiliary information tend to be in favor of Codar.
- The WF may be corrupted by small scale ocean non-homogeneities, due to the presence of relatively small strong eddies in the coastal and continental shelf regions.
- Codar could help find some insights into the nature of the problem and clues on how to retrack these contaminated WF.
- Codar seems promising as a tool to evaluate the several retracking techniques.



FUTURE WORK

- To better understand the behavior and limitations of CODAR as a tool to infer SSH and correct for altimetry
- To improve error reduction in retracking using the Codar SSH as a reference, in the presence of blooming events, weaker inhomogenous ocean sea state and coastal WF deformations.



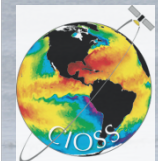
Questions?

Thank you

We would like to acknowledge CIOSS
and NOAA for their generous support

Carolyn Roesler, William J. Emery and Waqas Qazi

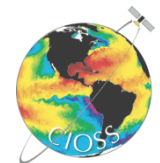
CCAR
Aerospace Eng. Sci. Dept.
University of Colorado at Boulder



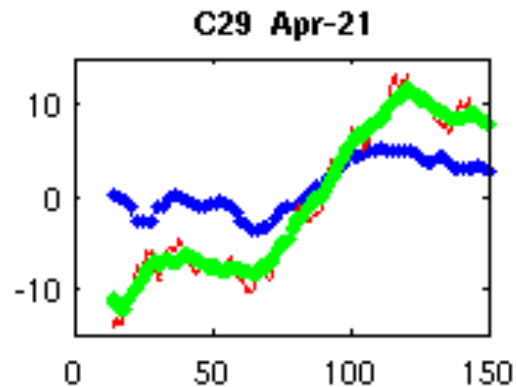
	Correlation		RMS	
	Mean	Std	Mean	Std
Large variations Noise 7 cm	0.85	0.1	1.36 cm	0.23 cm
Large variations Noise 4 cm	0.94	0.05	0.8 cm	0.13 cm
Small variations Noise 7 cm	0.62	0.2	1.3 cm	0.23 cm
Small variations Noise 4 cm	0.81	0.12	0.78 cm	0.13 cm

The match level depends on SNR:

- on the amplitude variations of the SLA
- on the noise level of the altimetry data, which depends on the sea state.

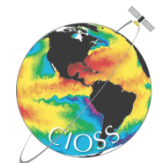


This study shows that the correlation depends not only on the level of the true signal, but also the level of the added noise. A correlation around 0.75-0.85 would in general be a good fit, with a mean RMS being around 1-1.3 cm.



This example from P145 C29 gives a high correlation. But it would have a poor RMS, due to a mismatch in the amplification factor of CODAR SSH.

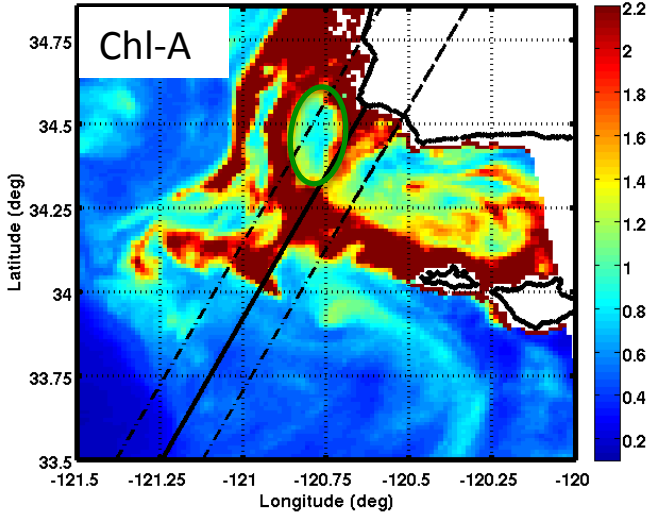
We still need to understand the physical reasons behind the CODAR amplification factor to improve its quality and better match the altimetry SSH.



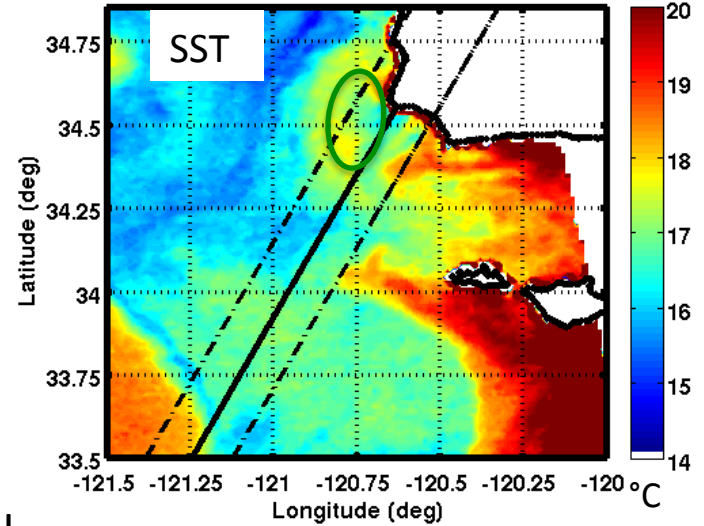
Case 1: J2 C43 P43 Sept 3, 2009 at 4:00



Modis Aqua Chloro-A 03-Sep-2009 21:35



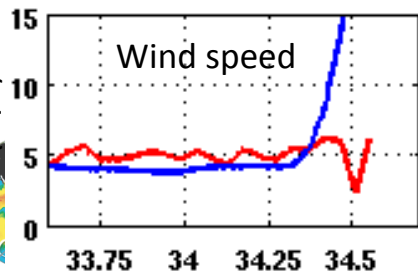
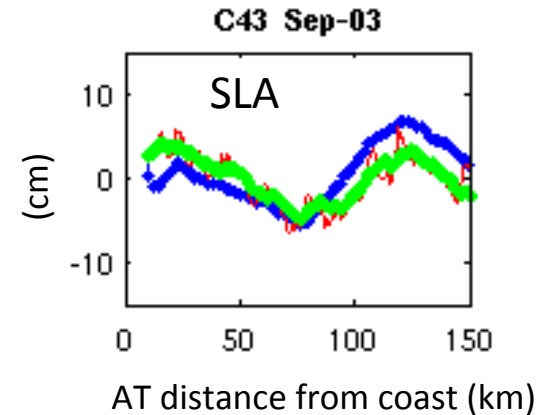
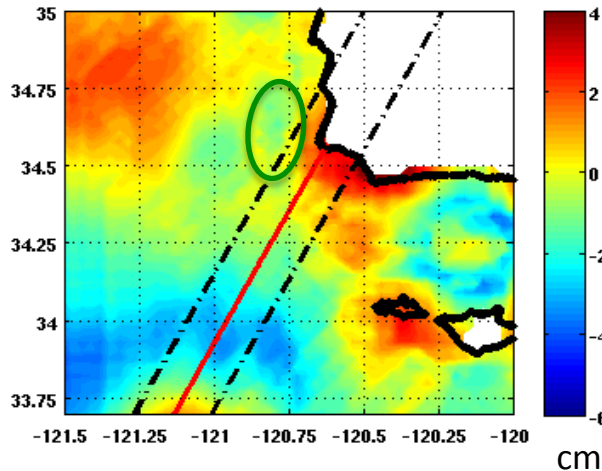
Modis Aqua SST 03-Sep-2009 21:35



Modis and J2:
17 H apart

Weak eddy
P43 is in the edge of the eddy
Winds are low ~ 5 m/s
No slick
Symmetrical features

3-day CODAR SSH

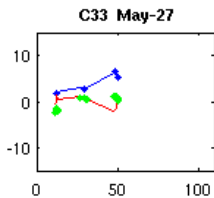
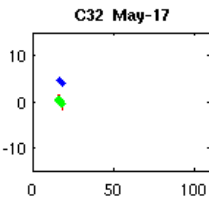
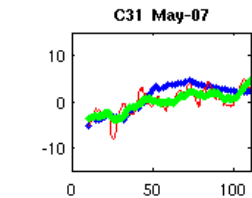
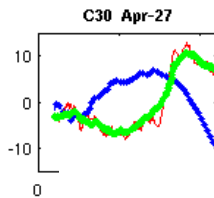
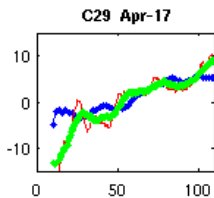
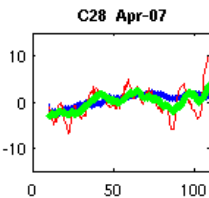
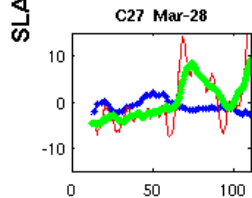
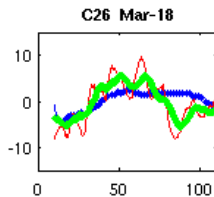
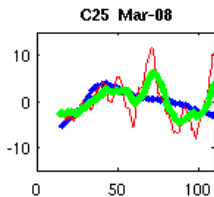
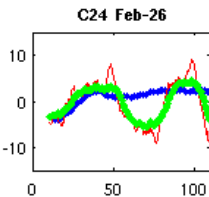
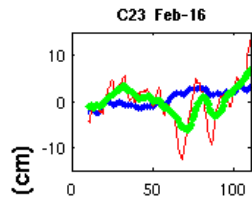
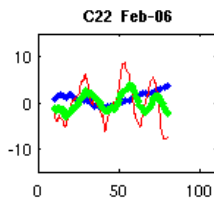
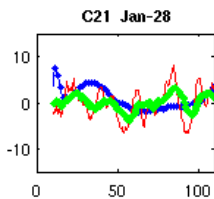
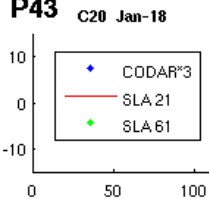
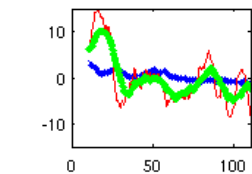


Good agreement

33.75	34	34.25	34.5	(Lat)
100	65	35	7	(km)

OCE3 C19 Jan-08

P43

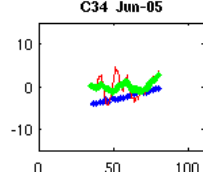
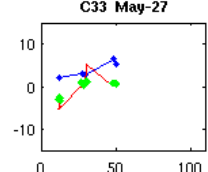
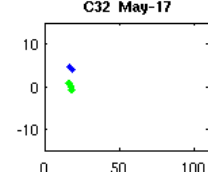
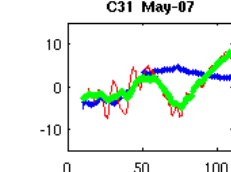
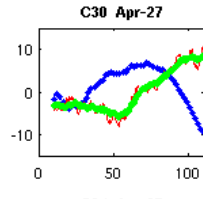
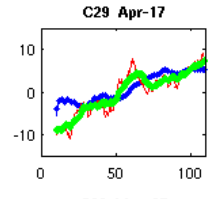
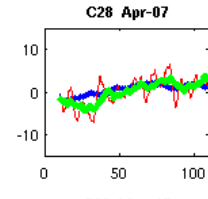
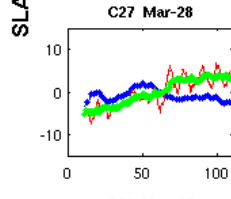
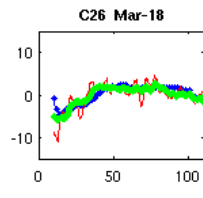
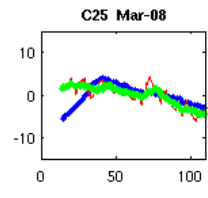
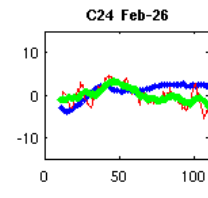
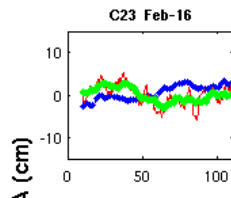
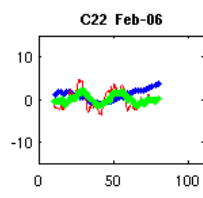
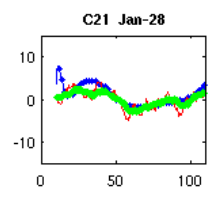
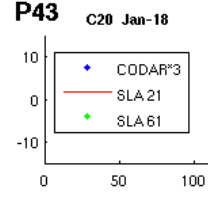
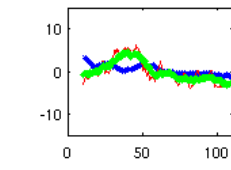


SLA (cm)

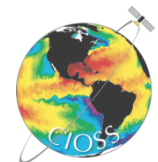
Along track dist from coast (km)

SLA C19 Jan-08

P43

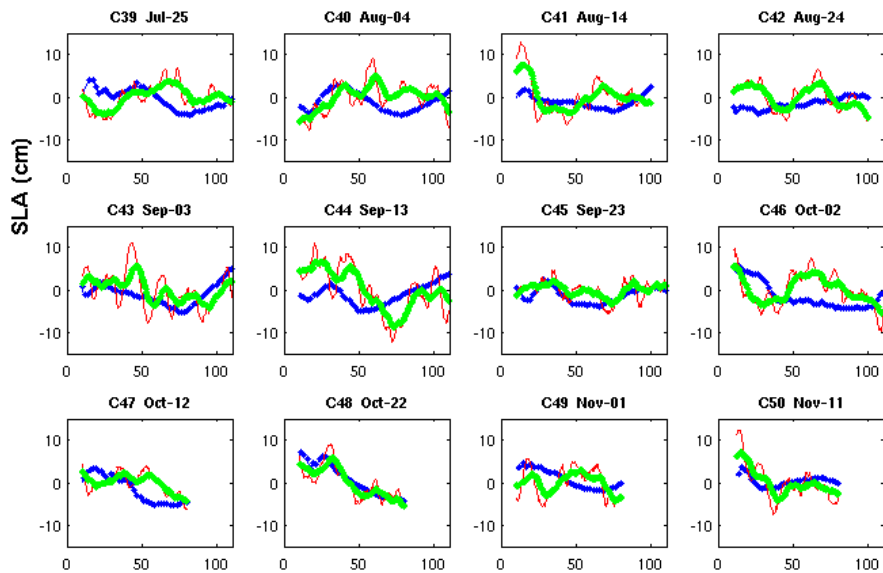
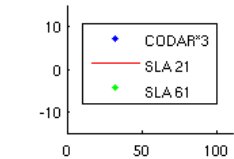


SLA (cm)



OCE3 C35 Jun-15

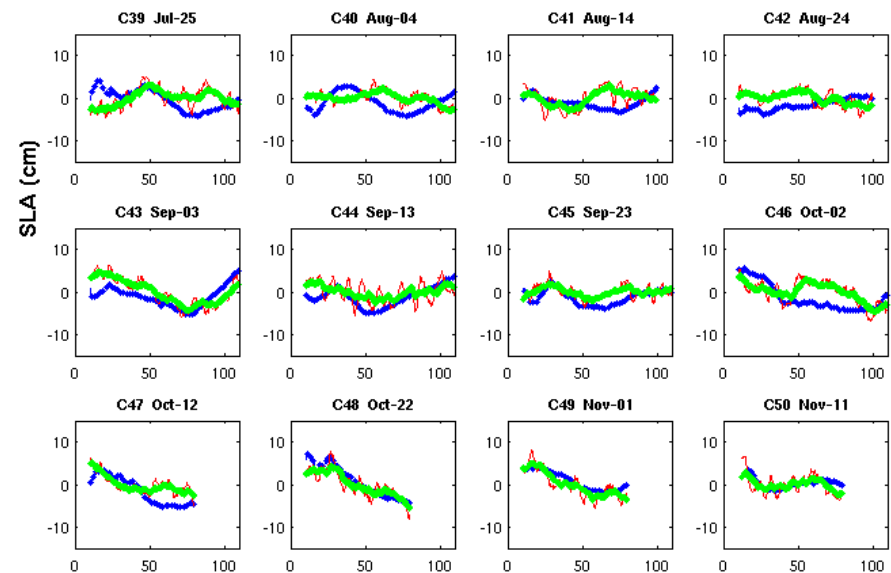
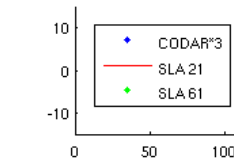
P43



Along track dist from coast (km)

SLA C35 Jun-15

P43



Along track dist from coast (km)

