The Near-Specular Altimeter Waveforms of Small Inland Water Bodies

R. Abileah[1], S. Vignudelli[2] , Andrea Scozzari[3]

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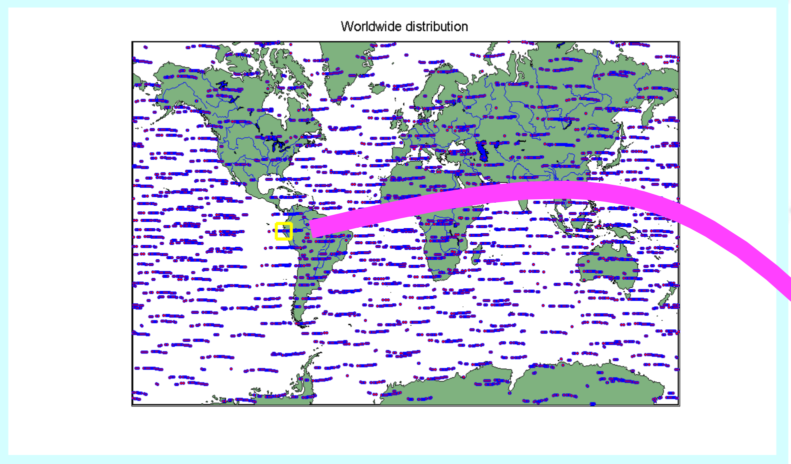
Outline

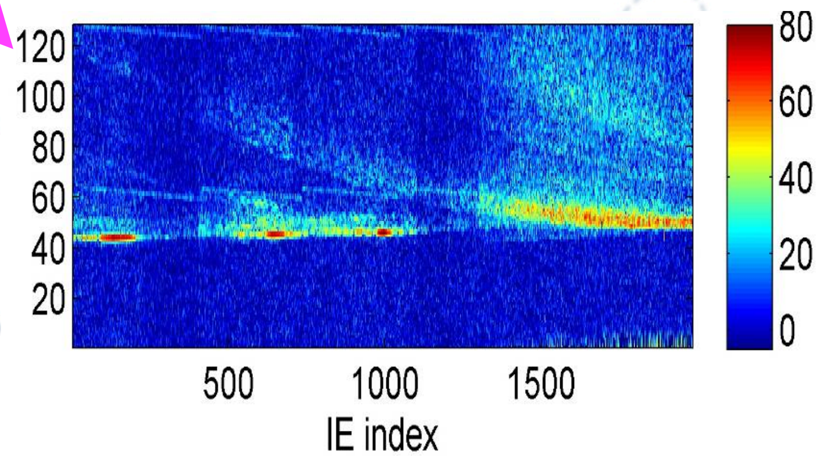
- Some inland waters look like single scatterers (specular)
- Five distinguishing characteristics of specular water targets
- *"Zero*-Doppler" processing and retracking
- Rethinking
  - PRF
  - Inland applications for radar altimeters

This investigation based entirely on ENVISAT Individual Echoes (IE)

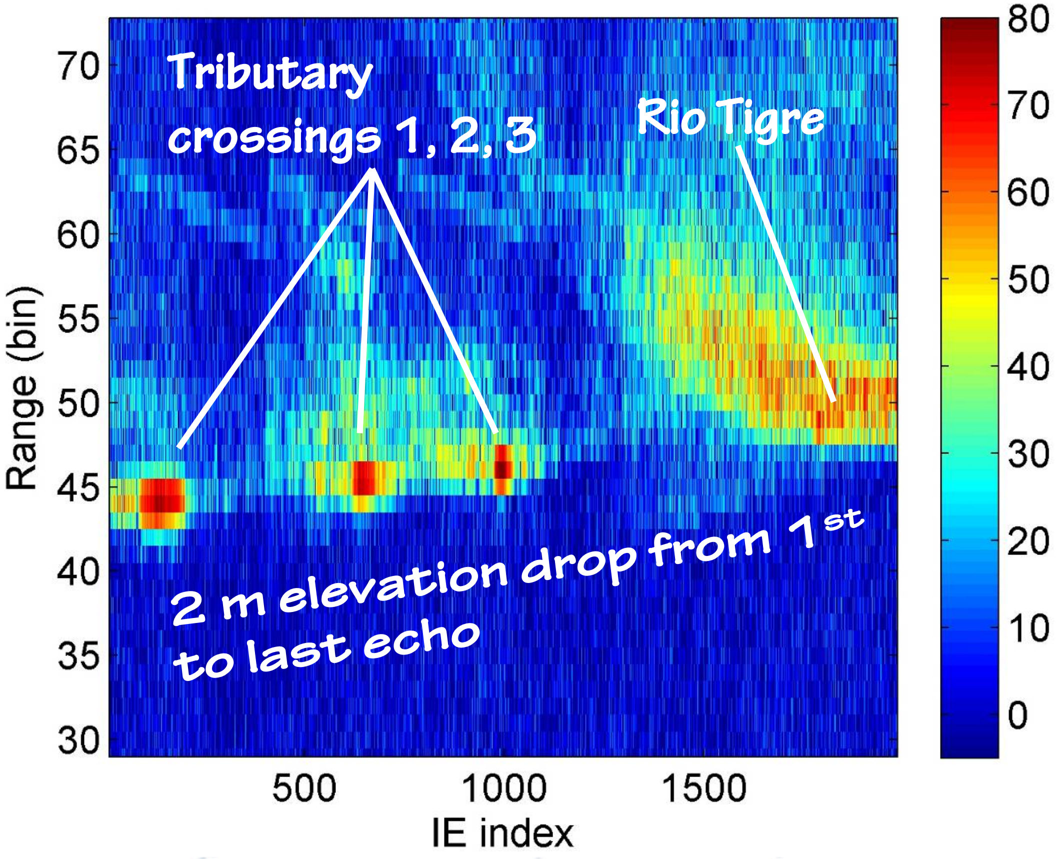


Worldwide distribution of 1-second IE records (Nov 2007)

1-second record vicinity of Rio Tigre, Peru; Amplitude in dB re noise

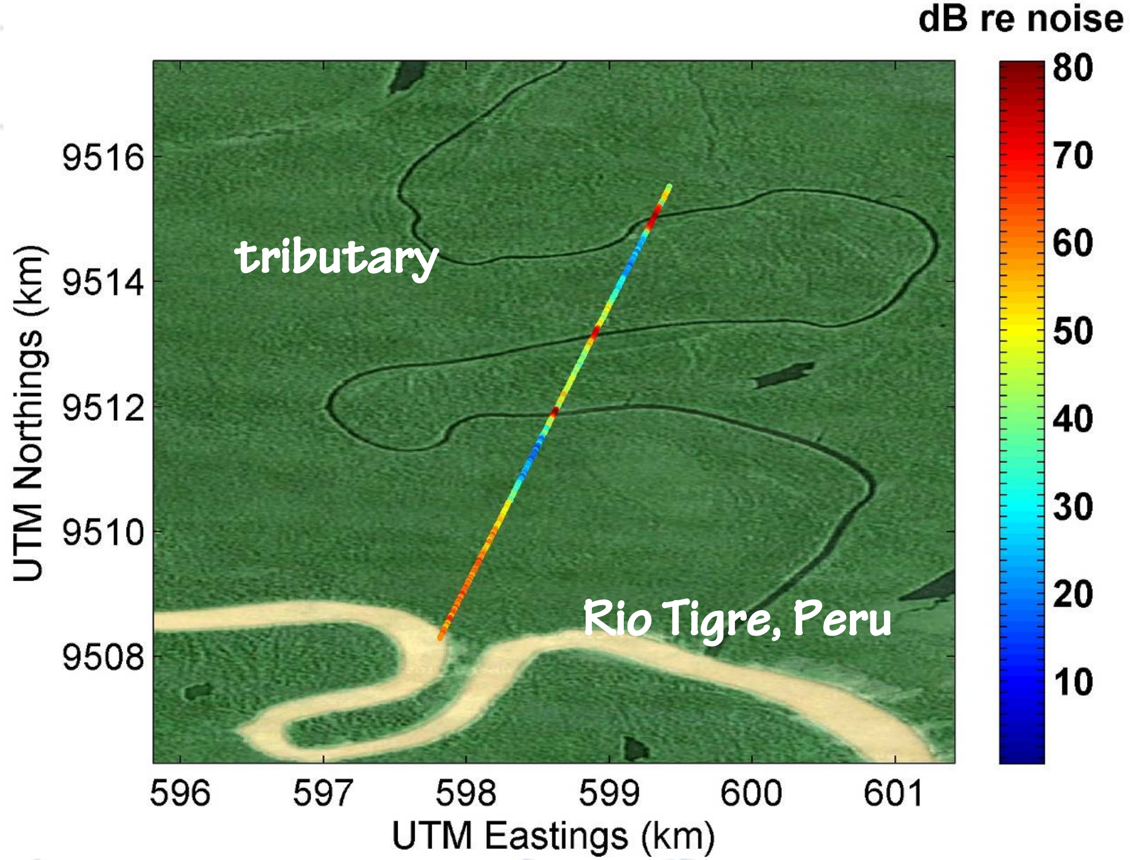


Radargram

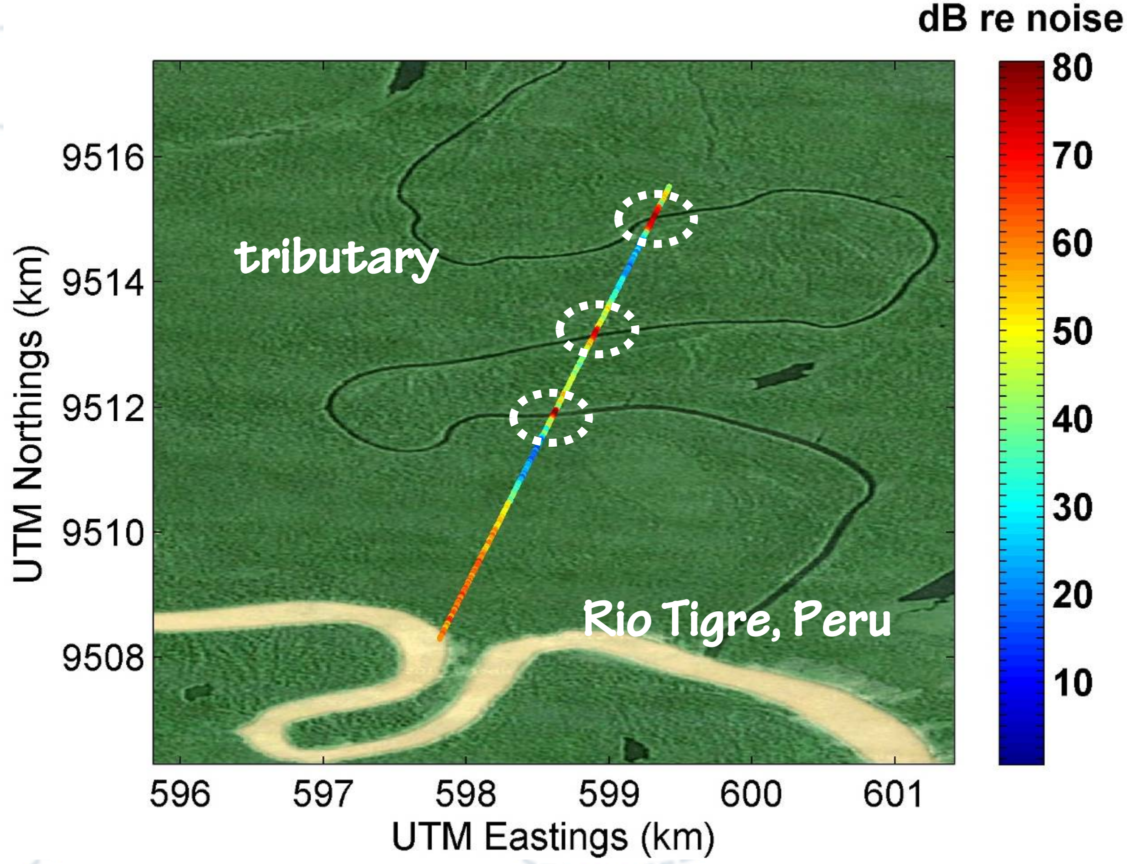

Tributary
crossings 1, 2, 3
Rio Tigre
2 m elevation drop from 1st
to last echo
Range (bin)
70
65
60
55
50
45
40
35
30
500
1000
1500
IE index
80
70
60
50
40
30
20
10
0

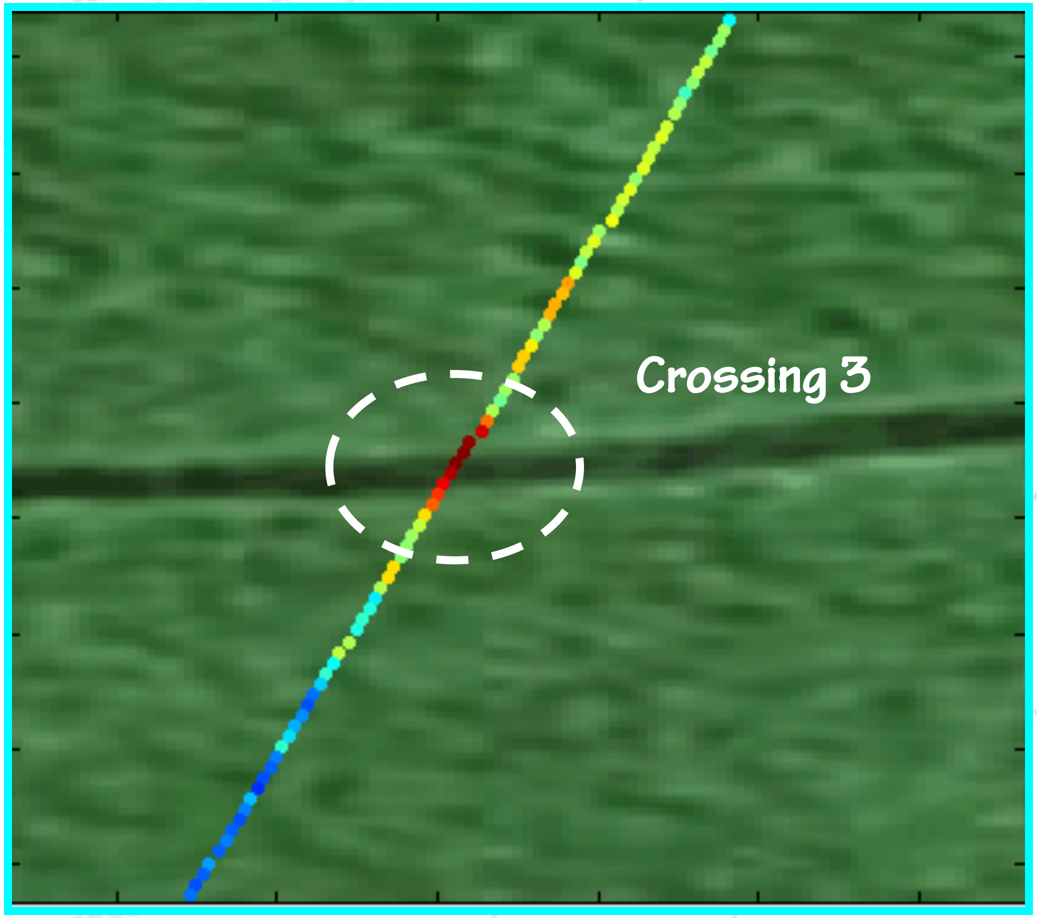
Peak power

superimposed on LANDSAT image



Peak power
superimposed on LANDSAT image




Crossing 3

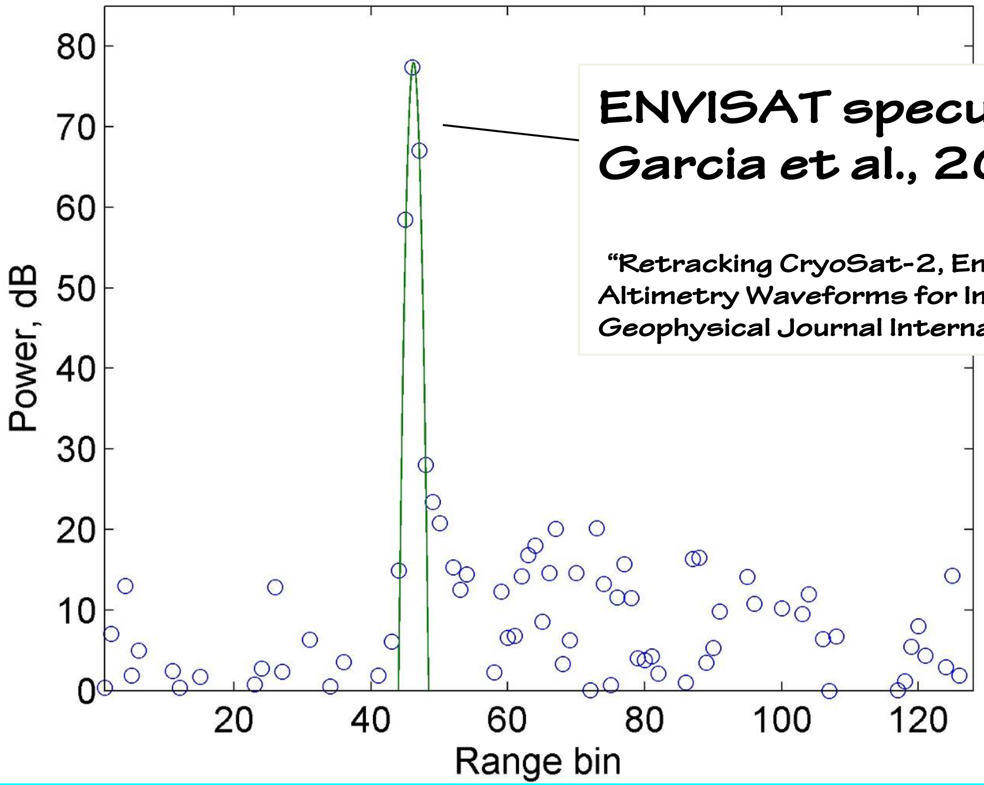
Five ways to characterize specular echoes

- Power
- Range waveform
- Along-track lobing
- Coherence
- Doppler

Following slides illustrate these characteristics with crossing No. 3

(P_0, r_0)

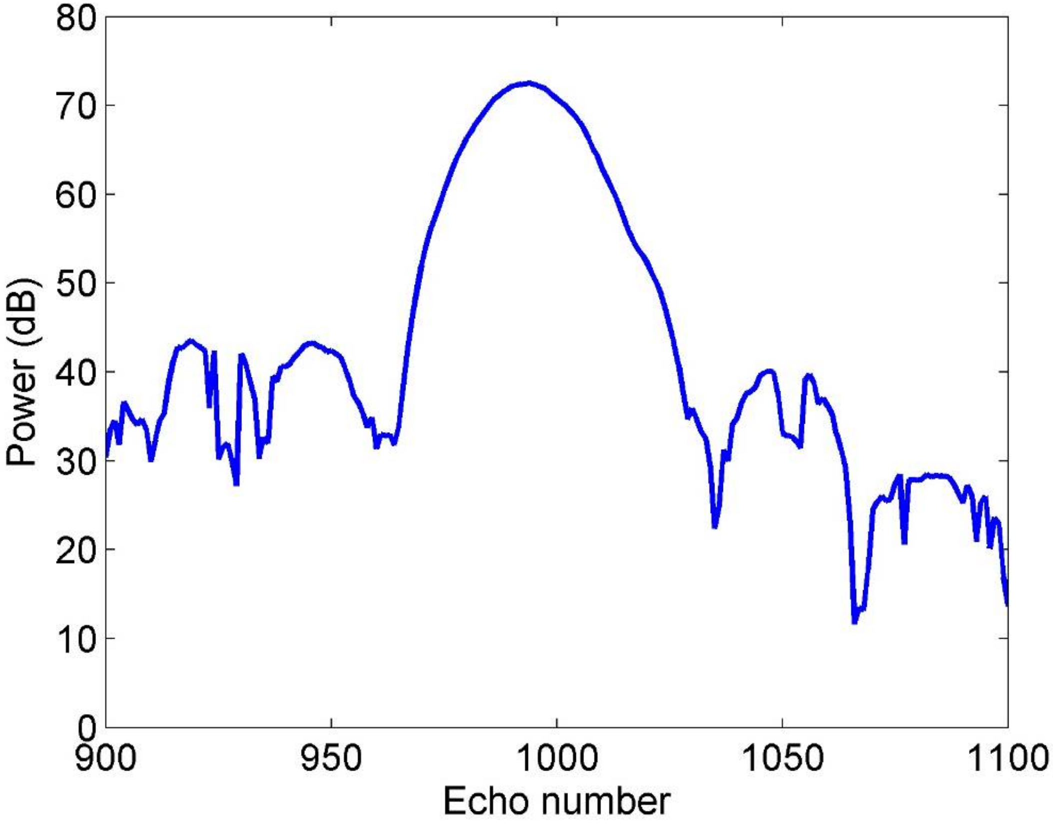
Range waveform



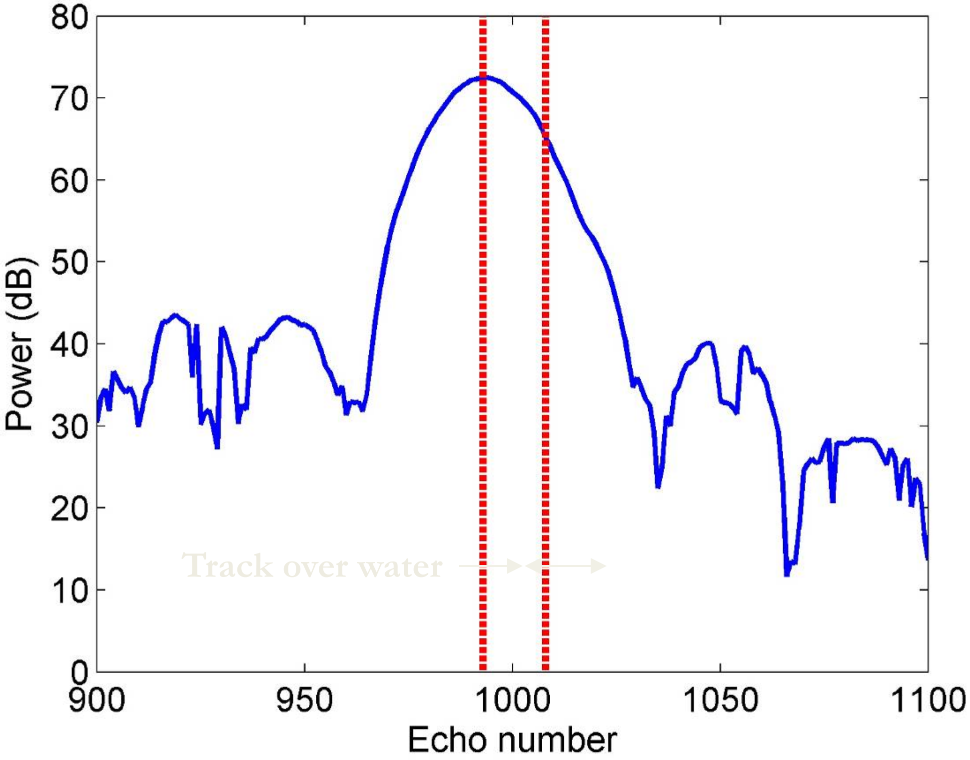
ENVISAT specular waveform, from Garcia et al., 2014, Eq. 2

"Retracking CryoSat-2, Envisat, and Jason-1 Radar Altimetry Waveforms for Improved Gravity Field Recovery", *Geophysical Journal International*

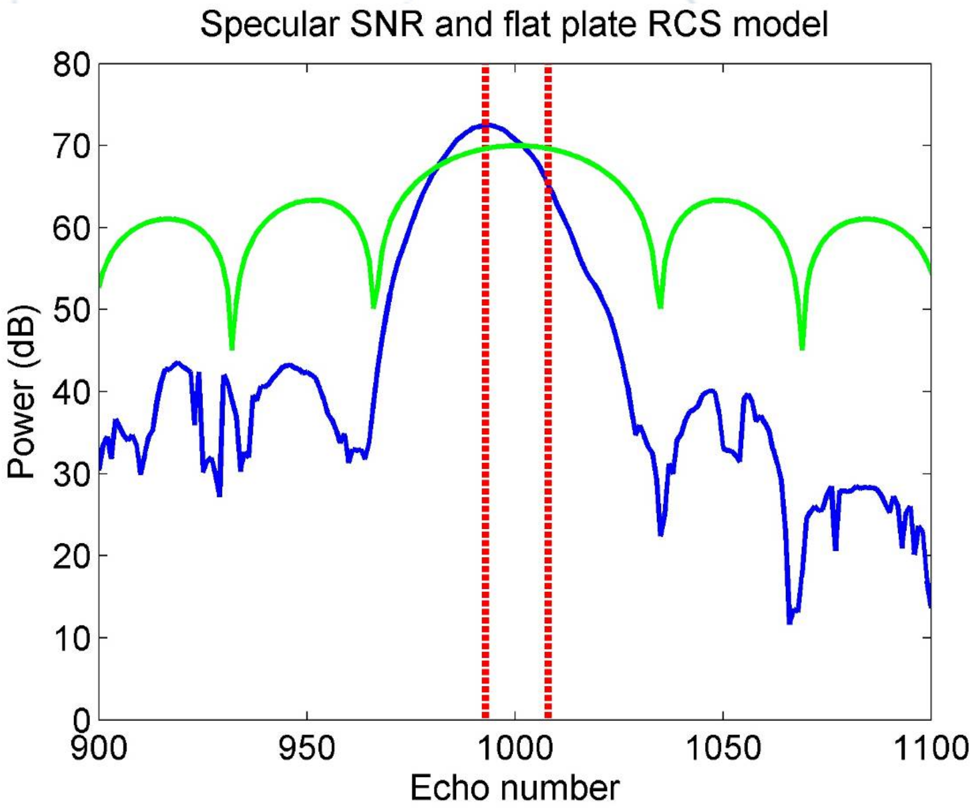
Along-track lobing



Along-track lobing

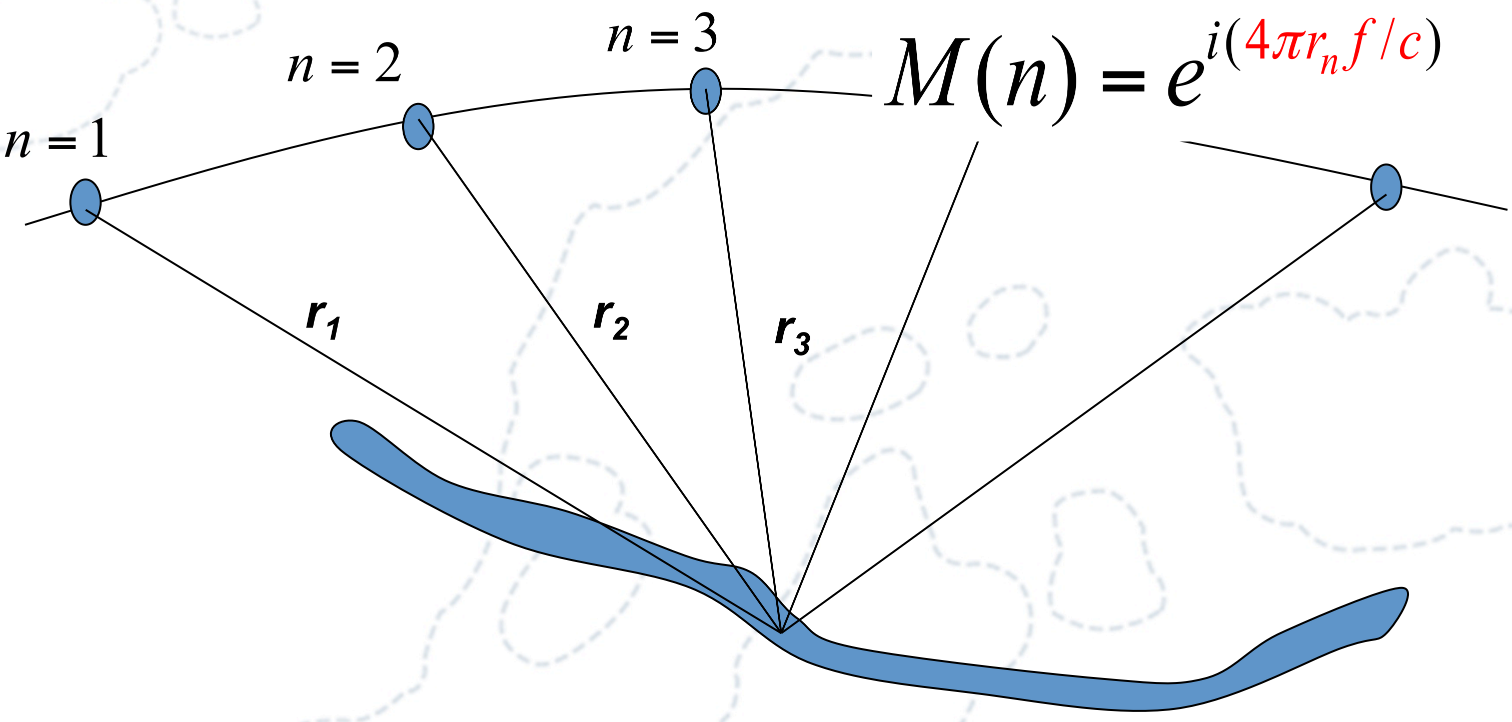


Along-track lobing

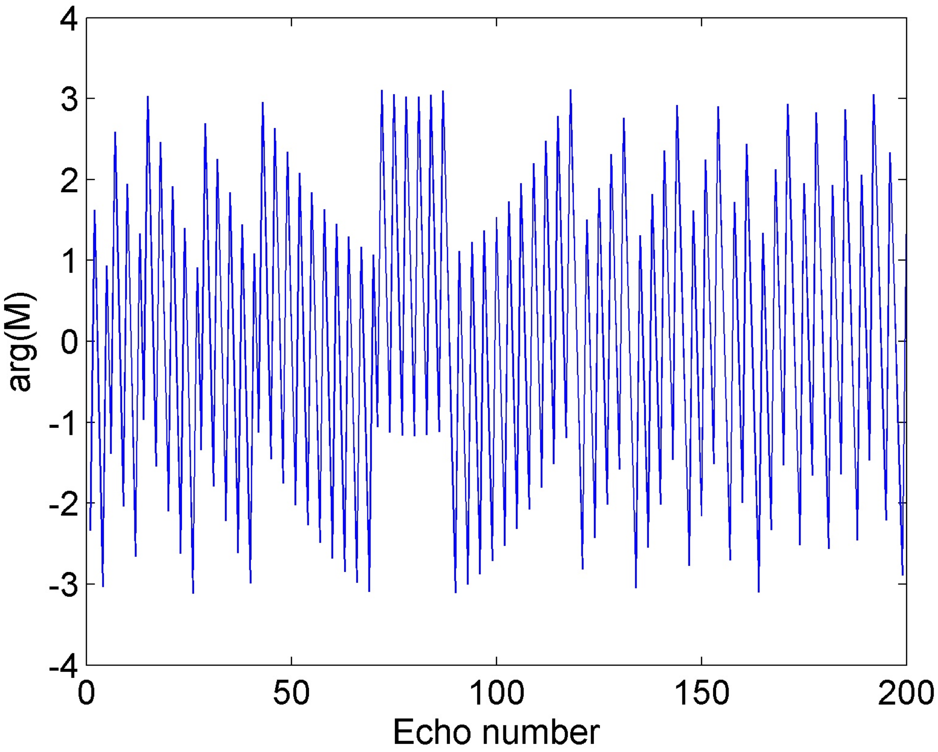


Model for complex specular echoes

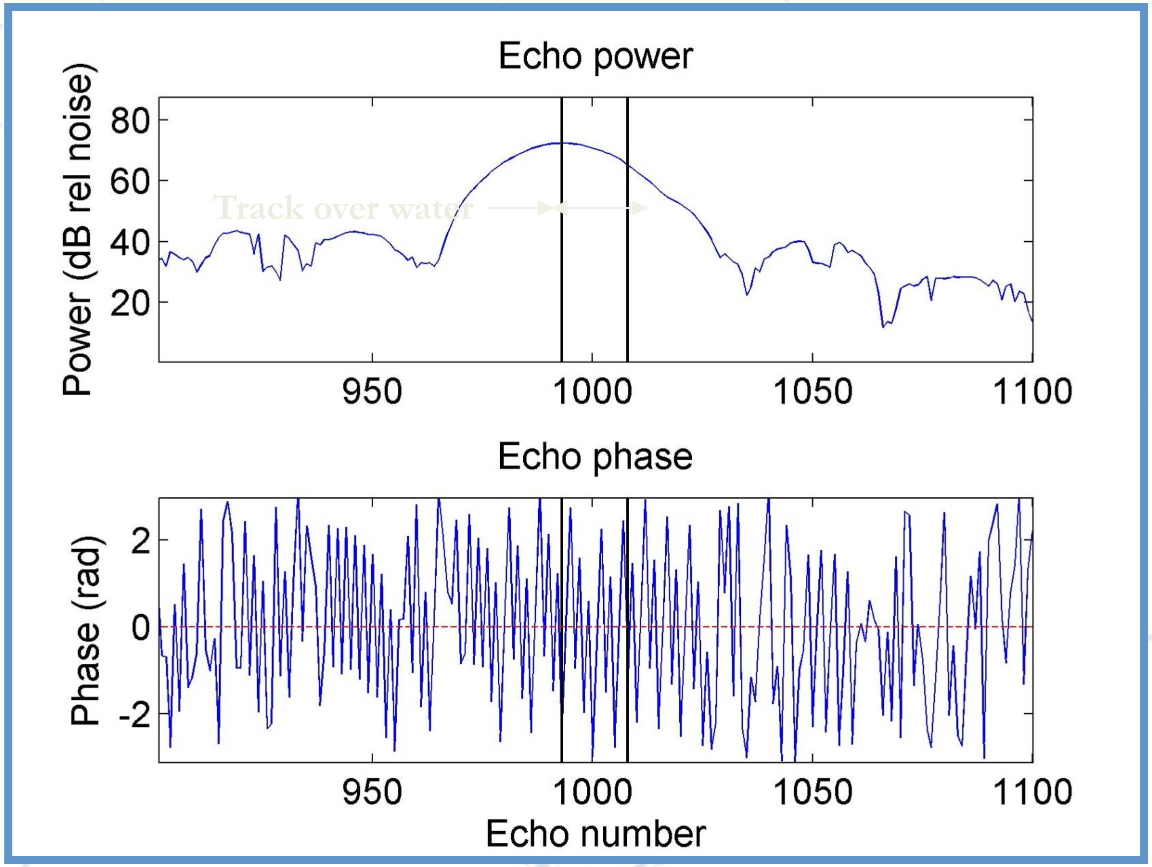
$$M(n) = e^{i(4\pi r_n f/c)}$$



Model echo phase (example)



Coherence (1/3)



Coherence (2/3)

1-lag auto-coherence

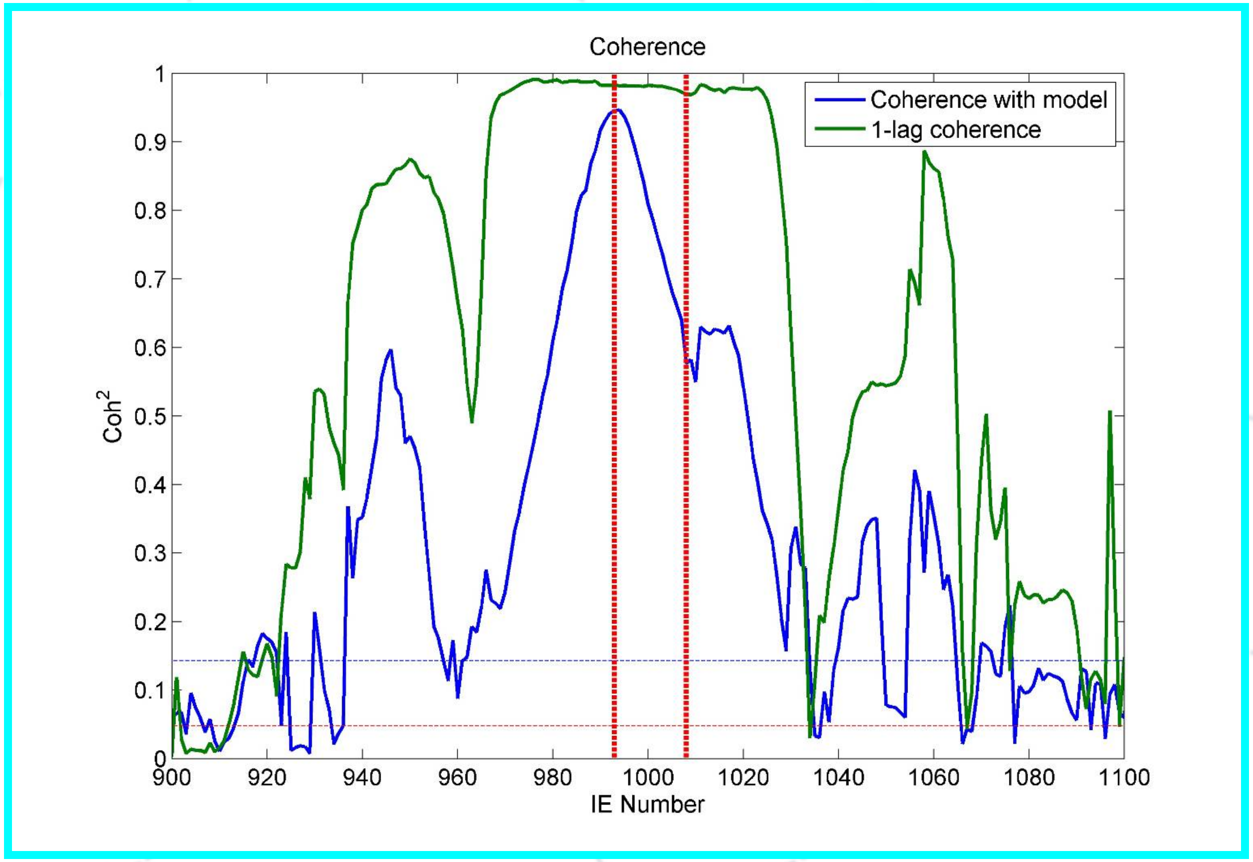
$$|\gamma|^2 = \frac{\left|\sum_n C(n)C^*(n+1)\right|^2}{\sum_n |C(n)|^2 \sum_n |C(n+1)|^2}$$

Coherence with respect to model M

$$|\gamma|^2 = \frac{\left|\sum_n C(n)M^*(n)\right|^2}{N\sum_n |C(n)|^2}$$

Coherence (3/3)

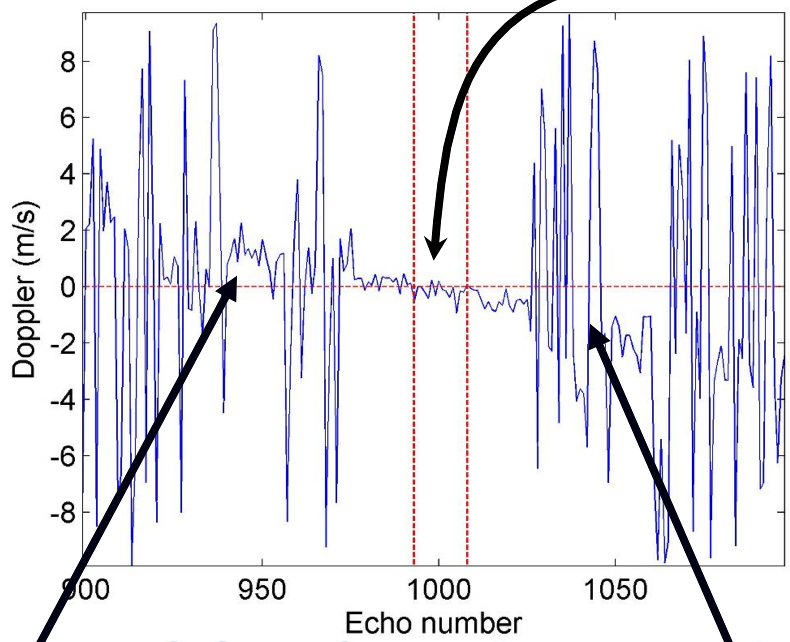
(In a moving 21-echo window)



Doppler velocity

(Doppler after VertVel adjustment)

Doppler = 0 when river is at nadir (assuming spherical Earth)



Approaching Doppler

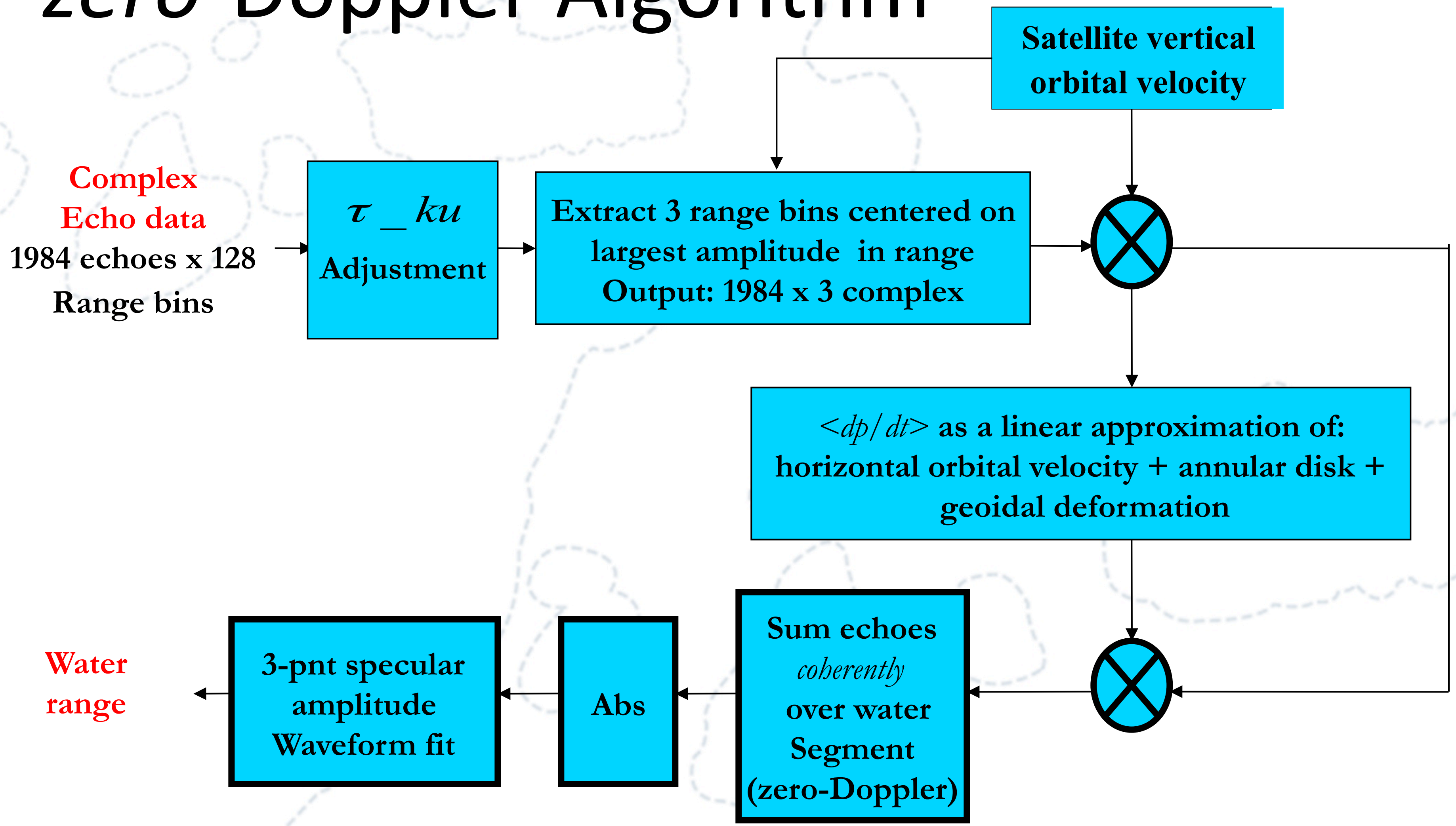
Receding Doppler

Summary

- Five characteristics of specular echoes were shown
  - Power ~70-80 dB re noise
  - Waveform agrees with Garcia et al., 2014
  - Along track lobing partially explained with rectangular plate RCS model
  - Coherence ~1
  - Doppler = 0 when water is at nadir

Next: Combine the above into a retracking algorithm

zero-Doppler Algorithm



Doppler Processing -Retracking

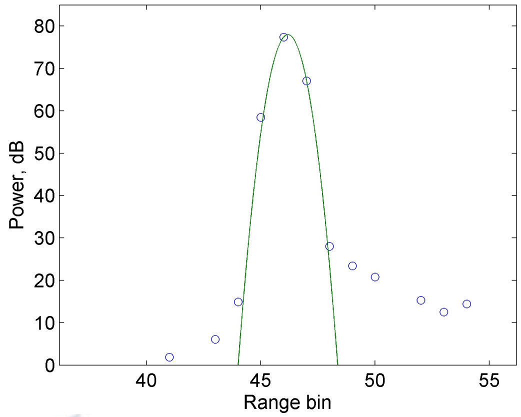
Coherent summing of N echoes

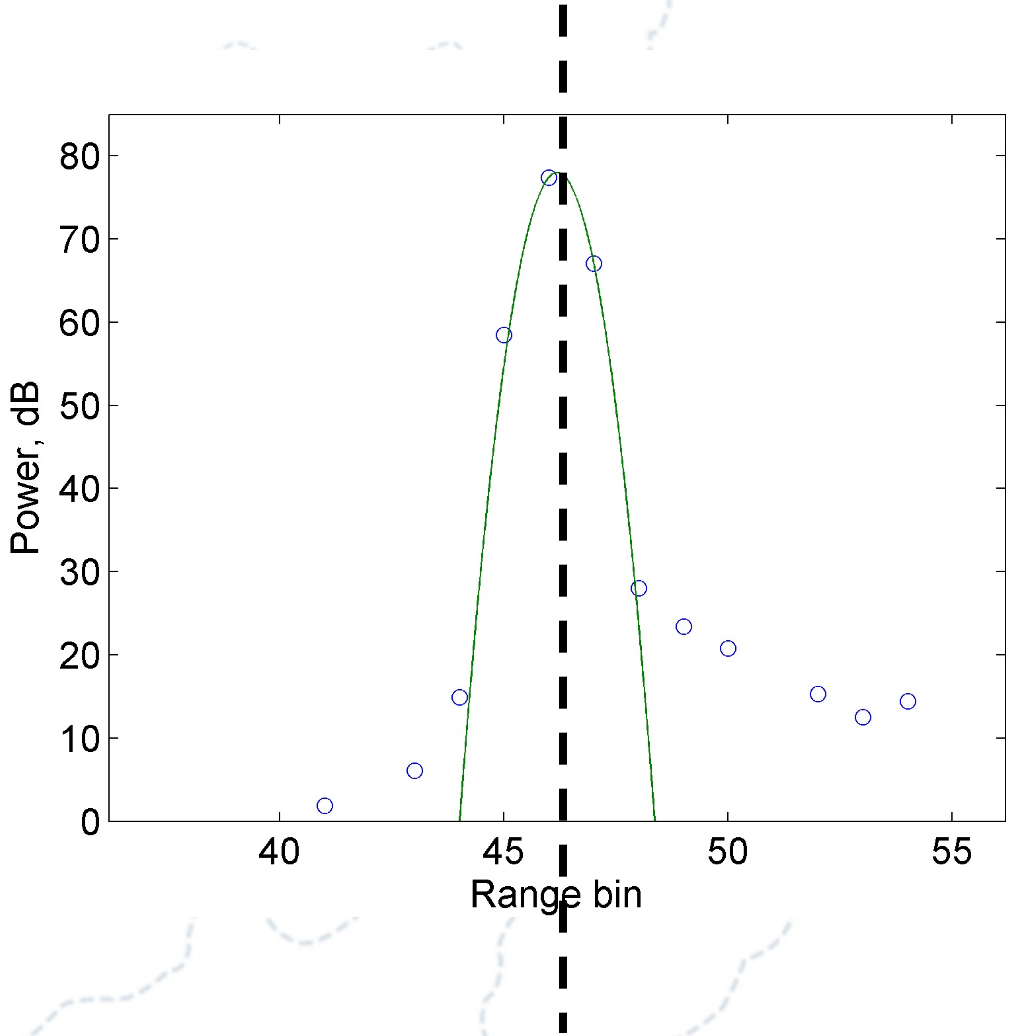
$$P_{n,r} = \left| \sum_{n'} C(n-n',r) M^{*}(n') \right|^2$$

Phase despin according to model M

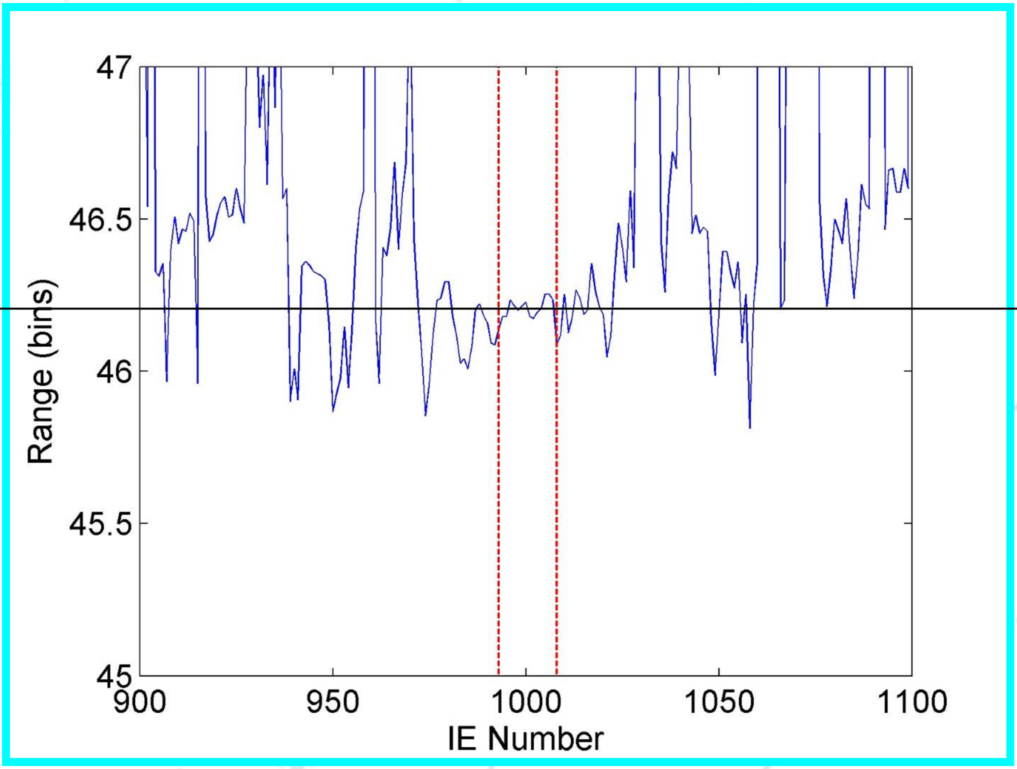
Cost function (L^2 metric) minimization

$$\min \sum_{r'} \left| P(n,r') - P_n \exp^{-(\tau(r'-r_n))^2/2\sigma_p^2} \right|^2$$

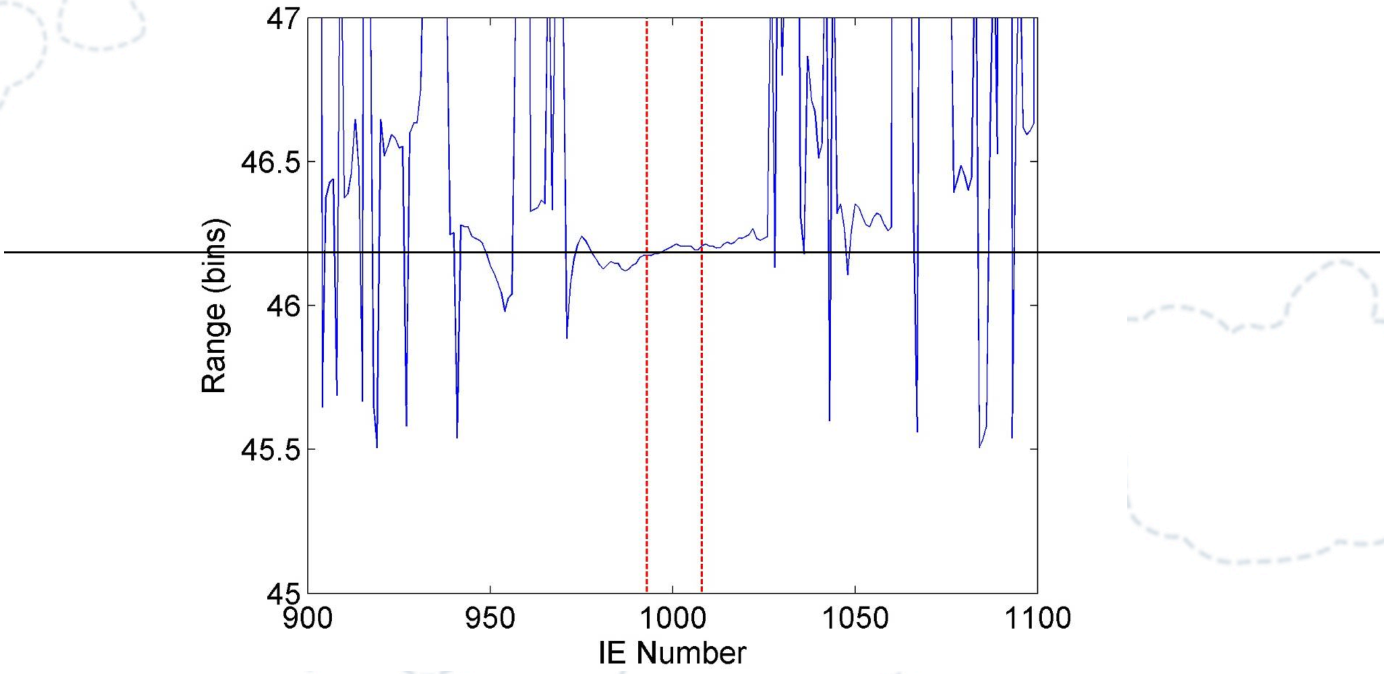



Power, dB
0
10
20
30
40
50
60
70
80
40
45
50
55
Range bin

Range without coherent averaging



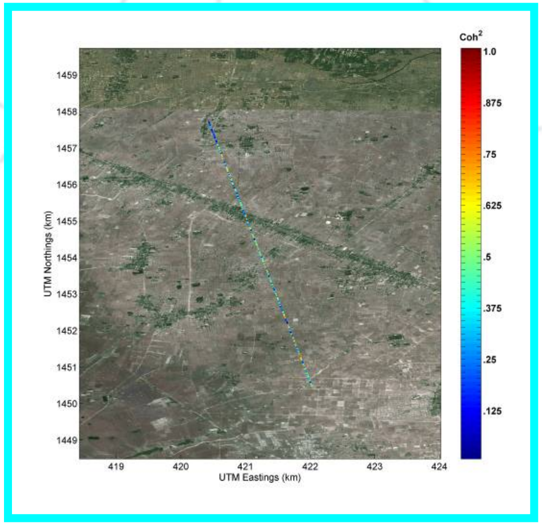
Range with coherent summing on a moving 11 echo window



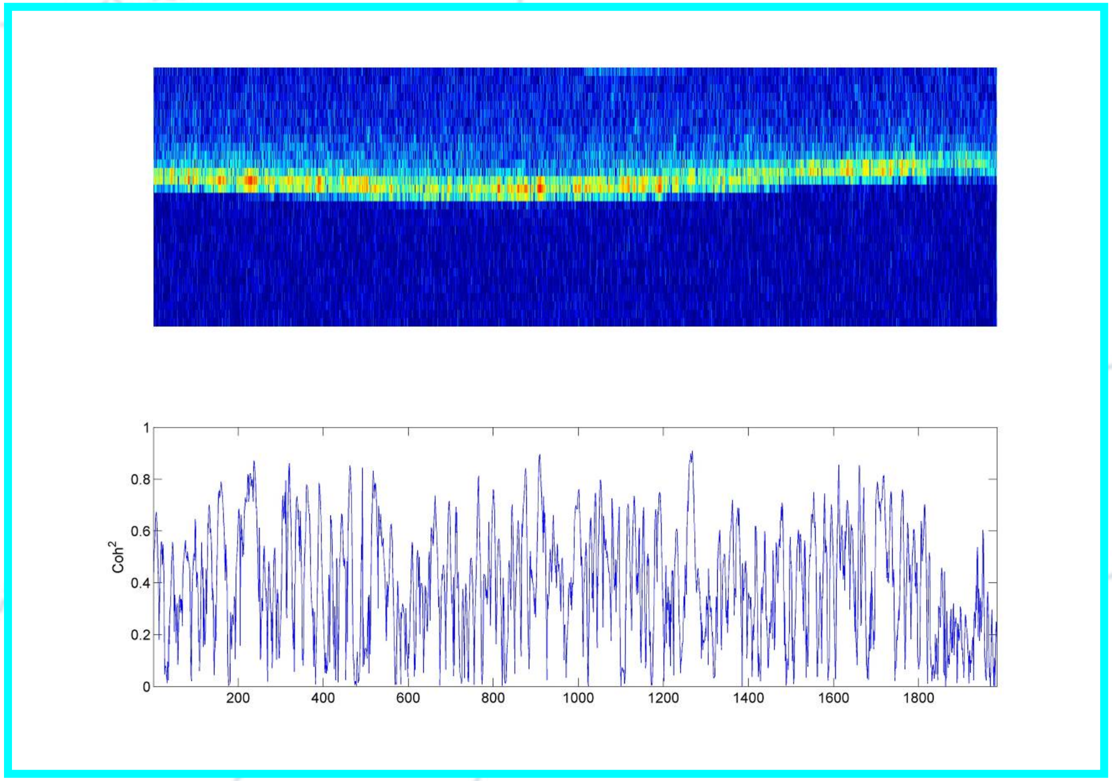
Floodplain and coastal

Tonle Sap Floodplain, Cambodia

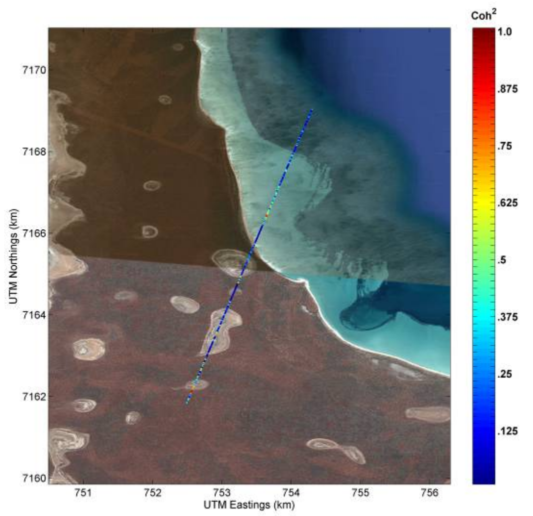
IE data, November 2, 2007
(Peak water level – J. Benveniste)

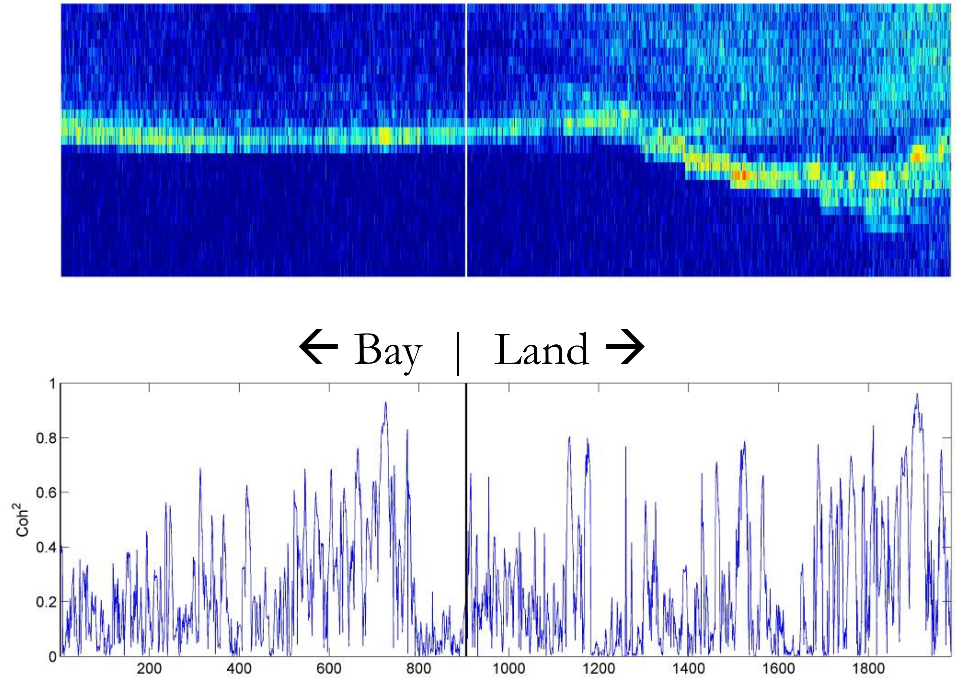


Track superimposed on DigitalGlobe, January 7,2012 image
(Dry season – month of lowest water level)



Francois Peron National Park Shark Bay AU





Conclusions

- Altimetry over specular surfaces is fundamentally different than conventional ocean altimetry
  - Walsh theorem does not apply
  - Low PRF sufficient (e.g., ENVISAT 2 KHz)
  - Full interleaving desired
  - No 'land interference'
  - *zero-Doppler* replaces *delayed-Doppler*
  - *SAR*vatore stacking with 0-Doppler is conceptually the same

Specular waveform most useful for rivers & floodplains

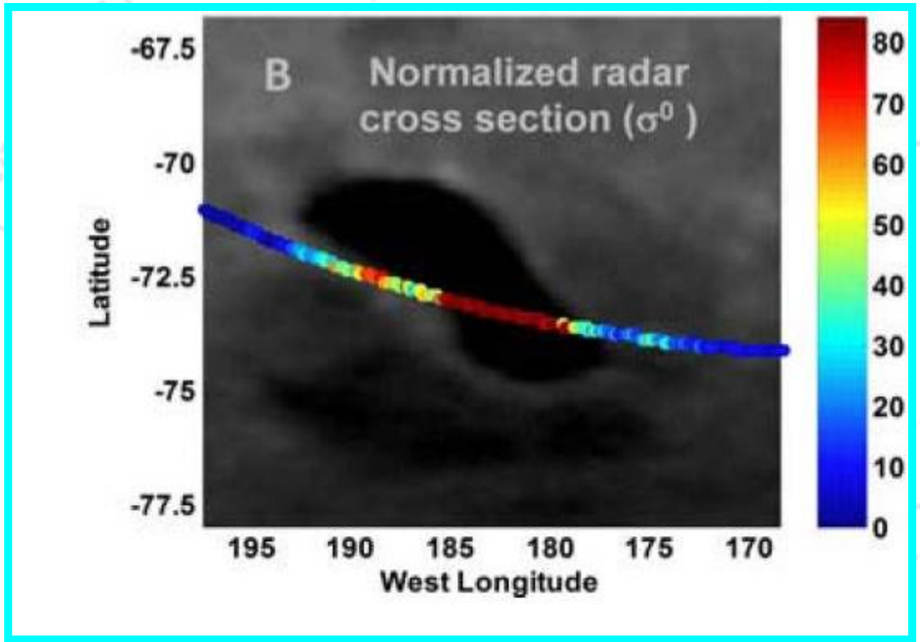
Further details presented in a companion poster

- Algorithm walkthrough with Rio Tigre
- Post Monsoon Granges River basin

Acknowledgments

- ESA provided IE data
- Walter Smith made valuable comments on early draft

Thank you



Specular backscatter from Titan's Ontario Lacus
Wye et al., GRL, 2009