Multi-Channel SAR Research at the US Naval Research Laboratory

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U.S. NAVAL RESEARCH LABORATORY

Summary:

- Developed a multi-channel SAR (MSAR) designed to explore applications that exploit detailed measurements of scene motion
- Successfully demonstrated the system through correction of distorted maritime SAR signatures

Outline:

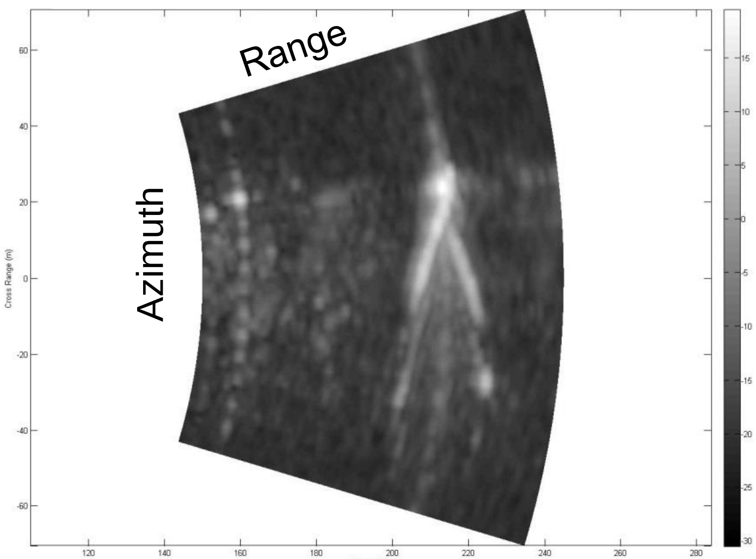
- Brief review of the effects of scene motion on SAR imagery
- Description of Velocity SAR (VSAR) processing for distortion correction
- Description of NRL MSAR system
- Summary of representative results from 2014 and 2015 deployments
- Discussion of channel balancing in the presence of multipath

Effects of Scene/Target Motion on SAR Signatures

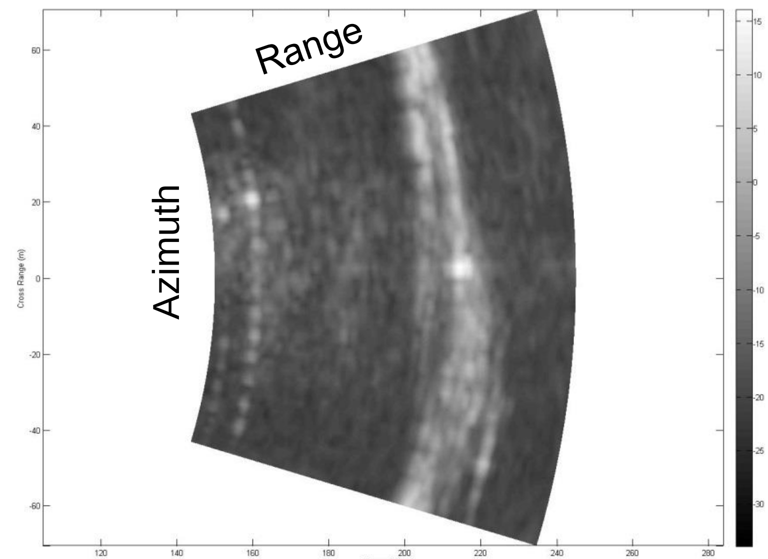
- Platform motion is essential to SAR, *but scene motion causes distortion*
  - Radial motion: azimuthal offsets, a.k.a. "train off the track" distortion, $\frac{R}{V_p} v_{Dop}$
  - Radial acceleration and azimuthal motion: azimuth defocusing
- Issue is significant for marine applications, since complex motion is pervasive
  - Signatures not only displaced, but smeared as well
- Multi-channel SAR solution: *measure* scene motion spectrum, then correct for it

NRL program objective: Demonstrate with an actual airborne MSAR

Real Aperture Radar Image



SAR Image (emulated)



NRL FOPAIR Imagery, Small boat on the Chesapeake Bay

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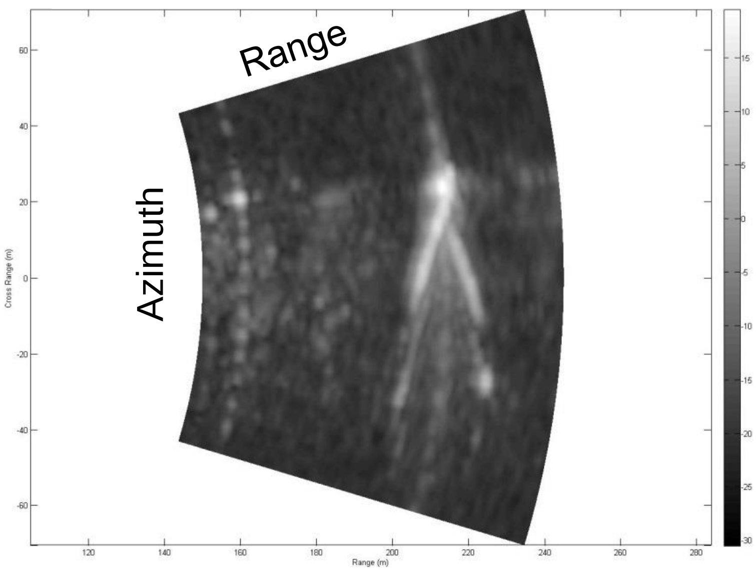
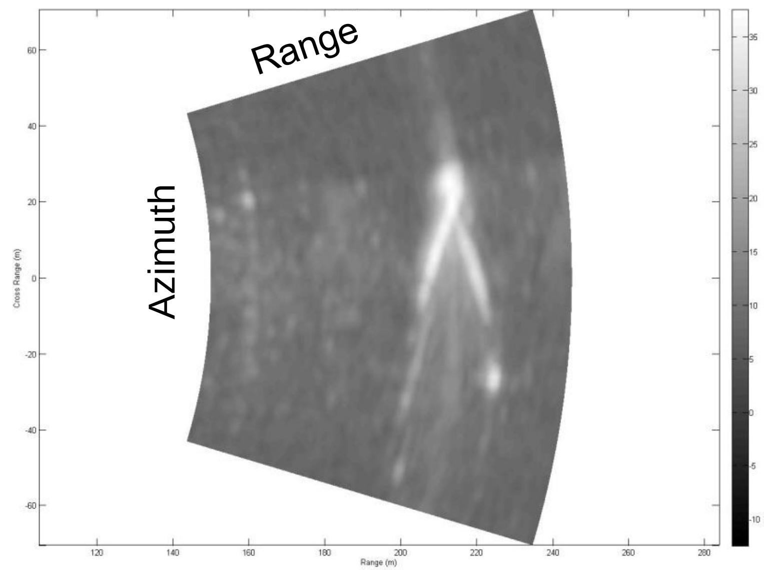
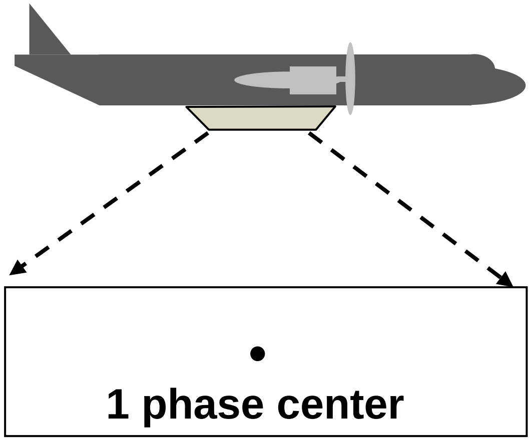


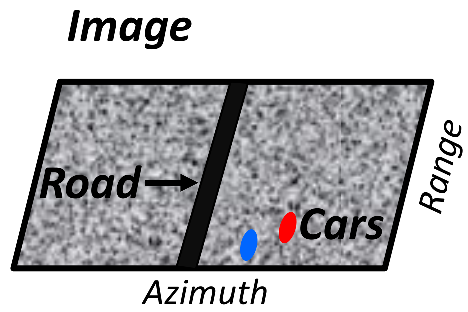
Corrected VSAR Image (emulated)

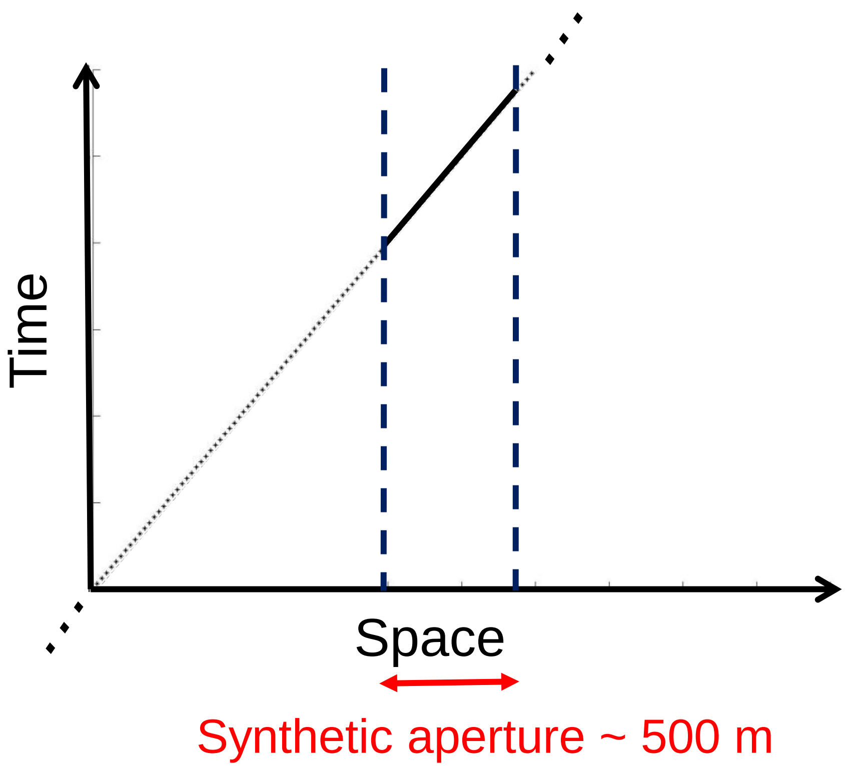


NRL FOPAIR Imagery, Small boat on the Chesapeake Bay

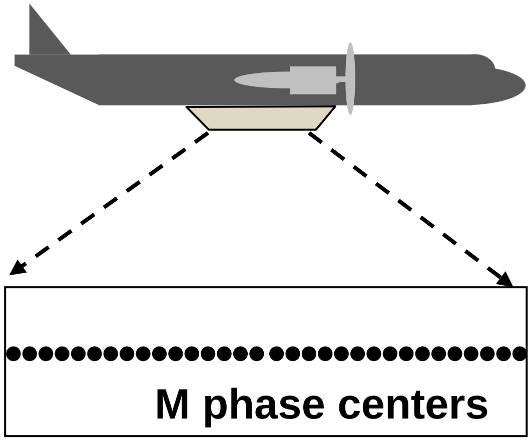
Formation of a Standard SAR Image

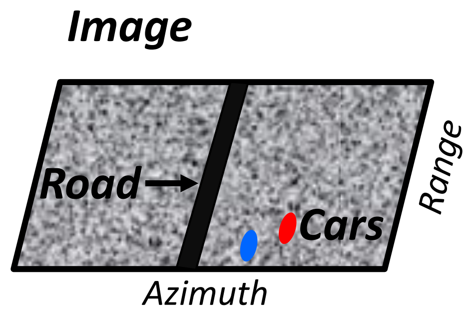


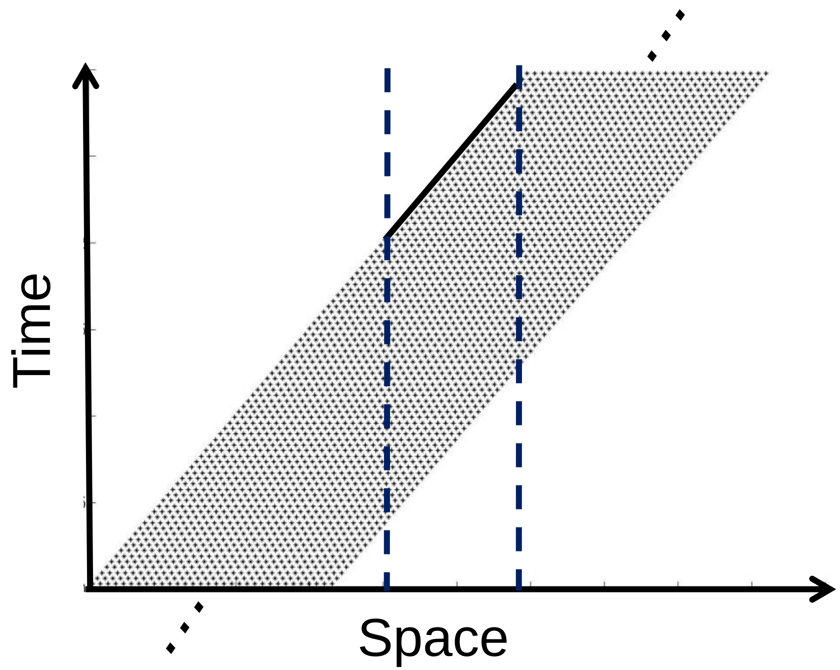




Formation of an MSAR Image Stack







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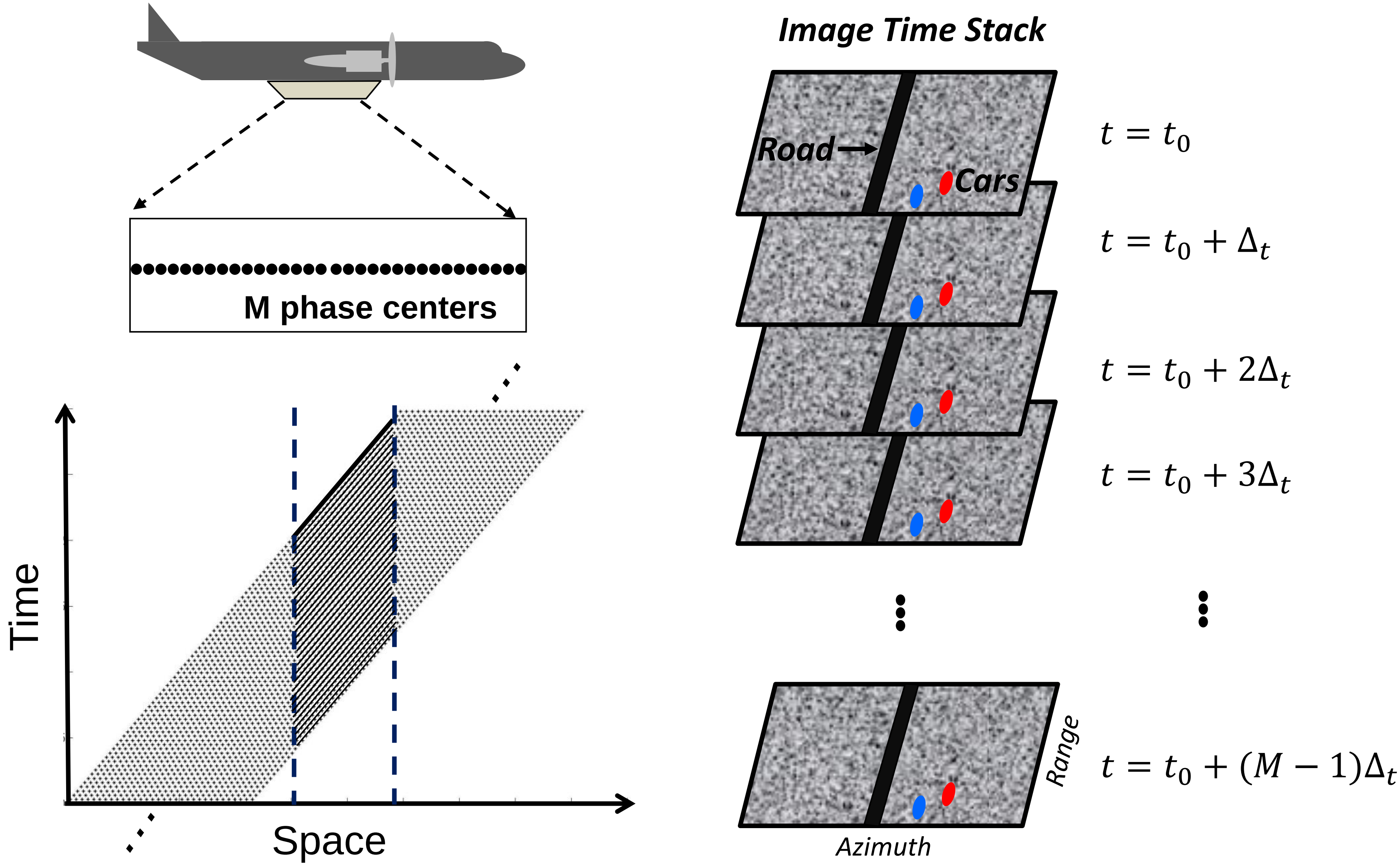
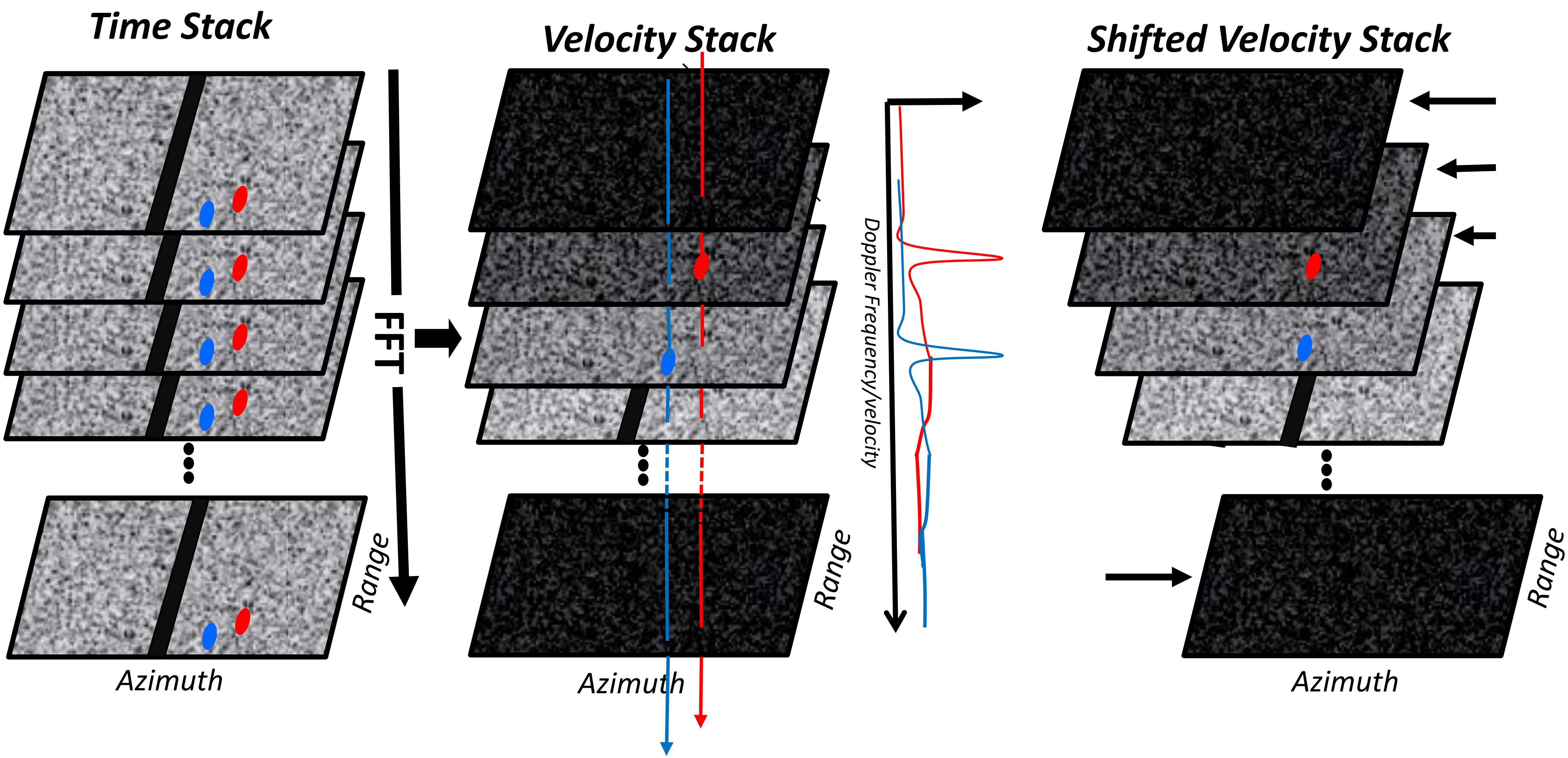


- Images look the same: motion information is in the ***phase*** of the complex pixels

Velocity SAR (VSAR*) Processing

- Doppler processing converts the image *time-stack* into a *velocity stack*
- Shifting each velocity image by $\frac{R}{V_p} v_{Dop}$ corrects azimuthal misplacement

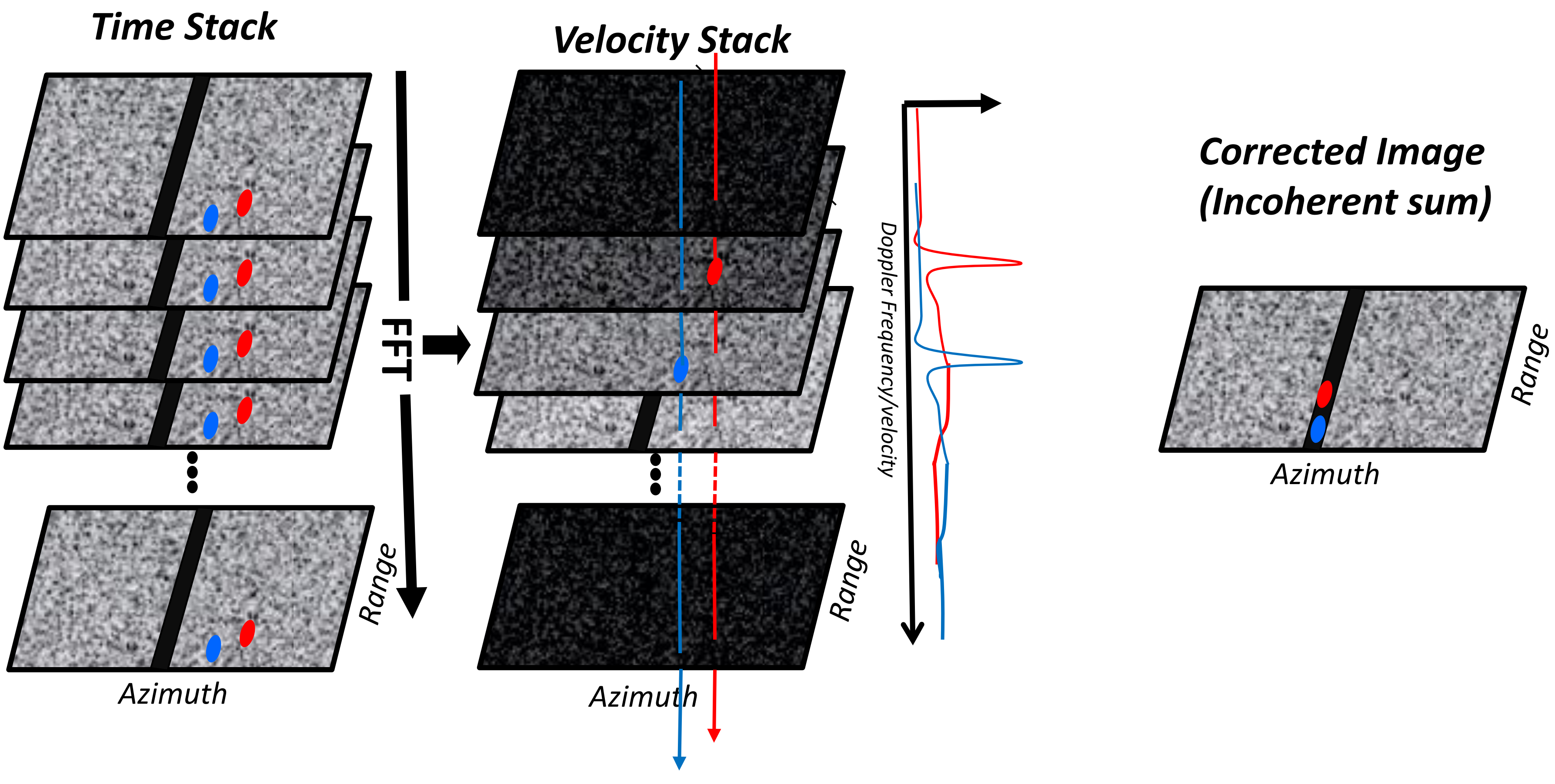


***Friedlander and Porat, IEEE TAES, Vol. 34, No. 3 JULY 1998**

Friedlander and Porat , IEE Proc.-Radar, Sonar Navig., Vol. 144, **No. 4, August 1997*

Velocity SAR (VSAR) Processing

- An incoherent sum down the corrected velocity stack forms a single corrected image
- Effective for complicated maritime signatures, not just point targets
- Only corrects distortion induced by radial motion, but this dominates marine imagery



*Friedlander and Porat, IEEE TAES, Vol. 34, **No**. 3 JULY 1998*

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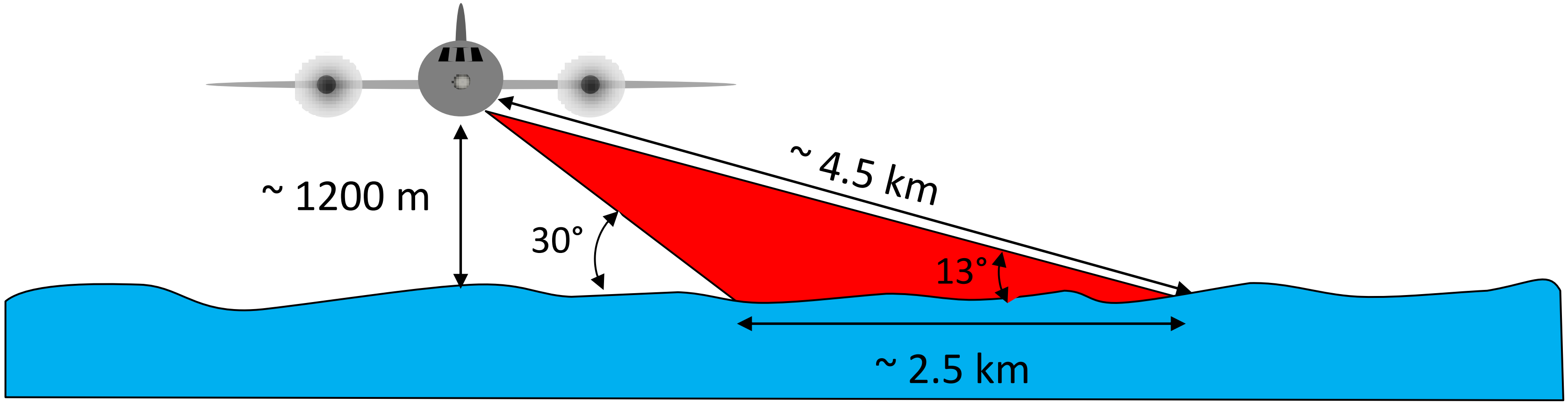
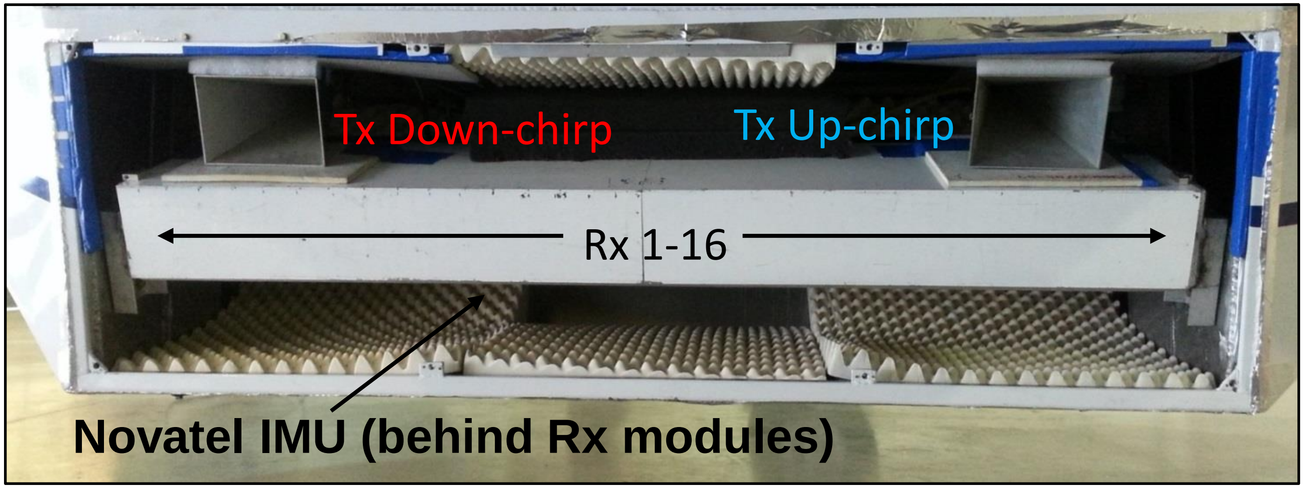
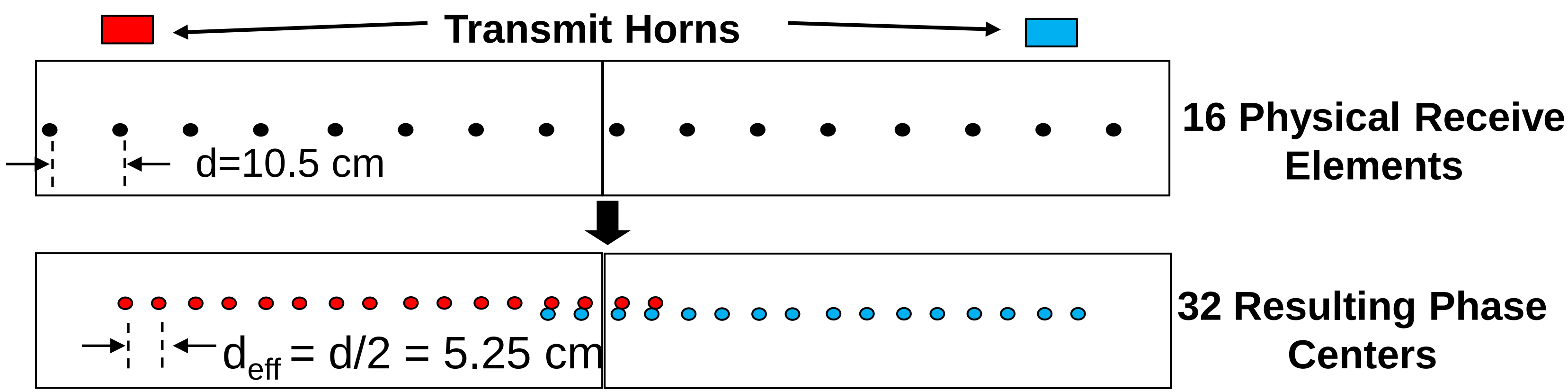
NRL MSAR Basic Specifications

- X-band (9.875 GHz CF)
- Bandwidth: 220 MHz
- Waveform: LFM, both up and down chirps
- Peak and average power: 1.4 kW, 210 W
- **Phase centers: 32 along-track**
- Polarization: VV
- Platform: Saab 340
- **IMU: Novatel**
- **Data recorder: NRL custom-built, 4-channel, 800 MB/s sustained**



32 Phase Center Array





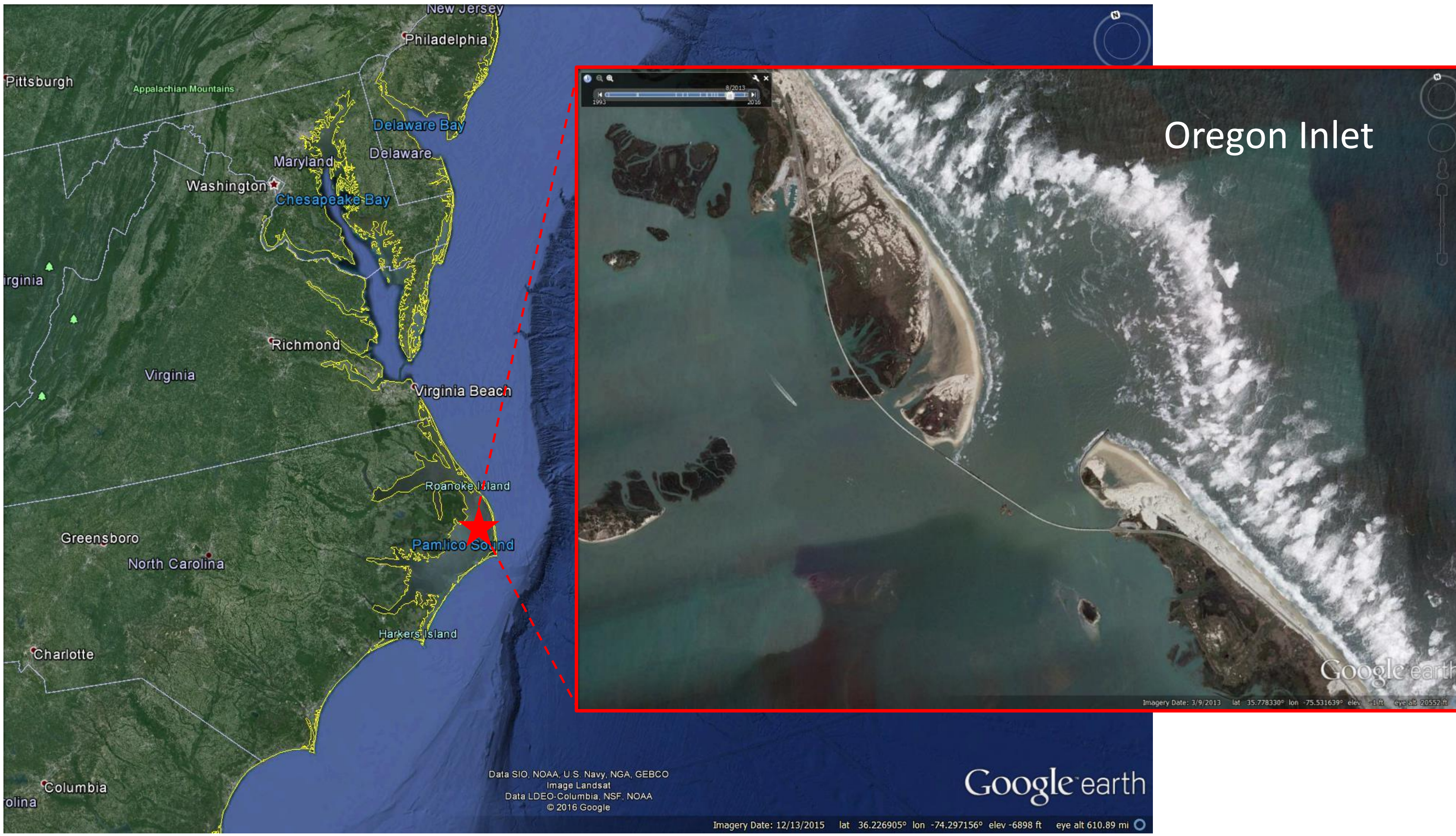
- Minimum and maximum unambiguous velocities, assuming VSAR-type processing:

At V_p=70 m/s (Saab 340) $$v_{\min} = \frac{V_p \lambda}{2 d_{eff} M} \cong 0.7\ m/s \qquad v_{\max} = \frac{V_p \lambda}{4 d_{eff}} \cong 10\ m/s$$

- Cycle through all 32 combinations of Tx and Rx antennas in 320 microsec (8 pulses)

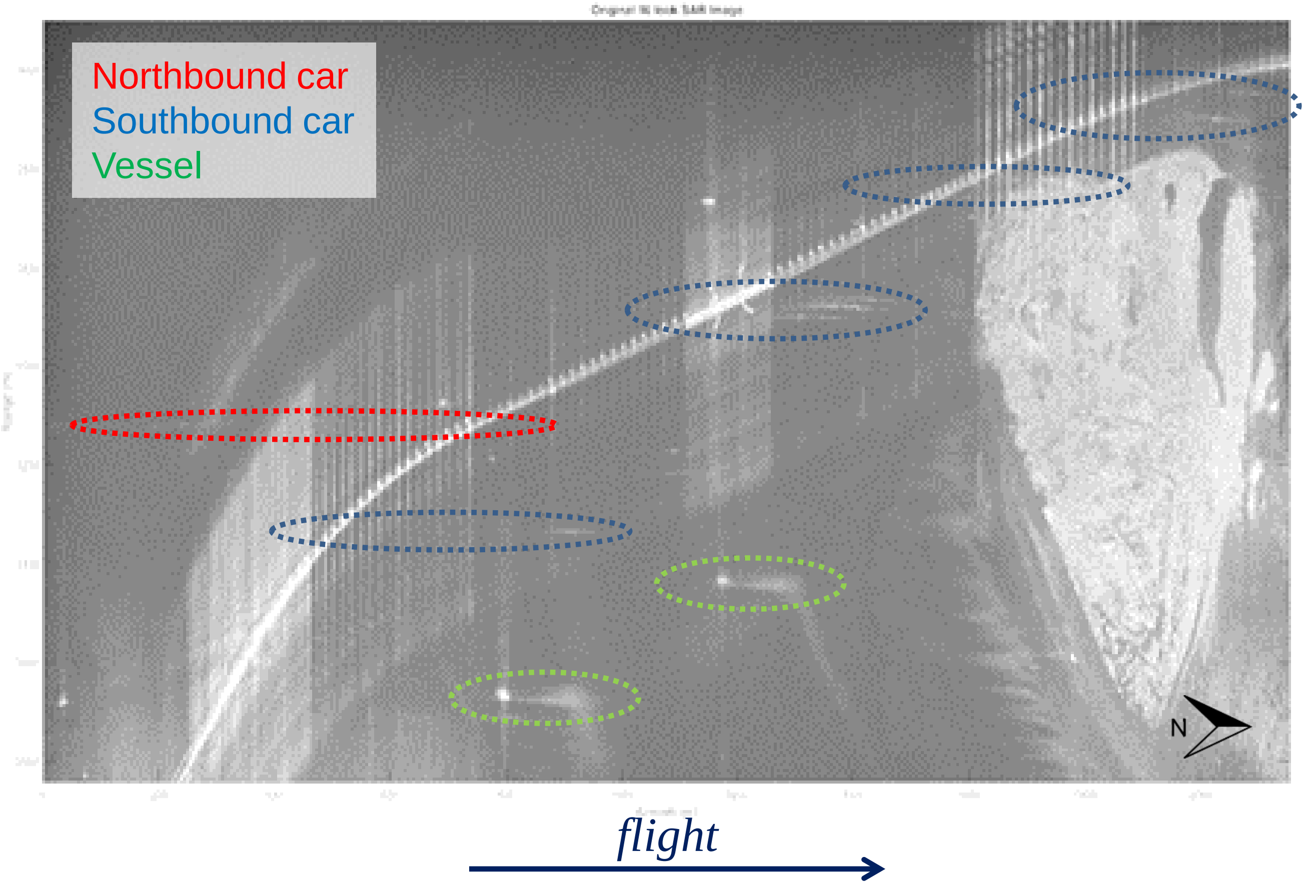
October-November 2015 Deployment

- Data collected in along the Outer Banks of North Carolina, USA
- Many moving targets of opportunity: cars, waves, and boats



VSAR Analysis: Correction of Hard Target Displacements

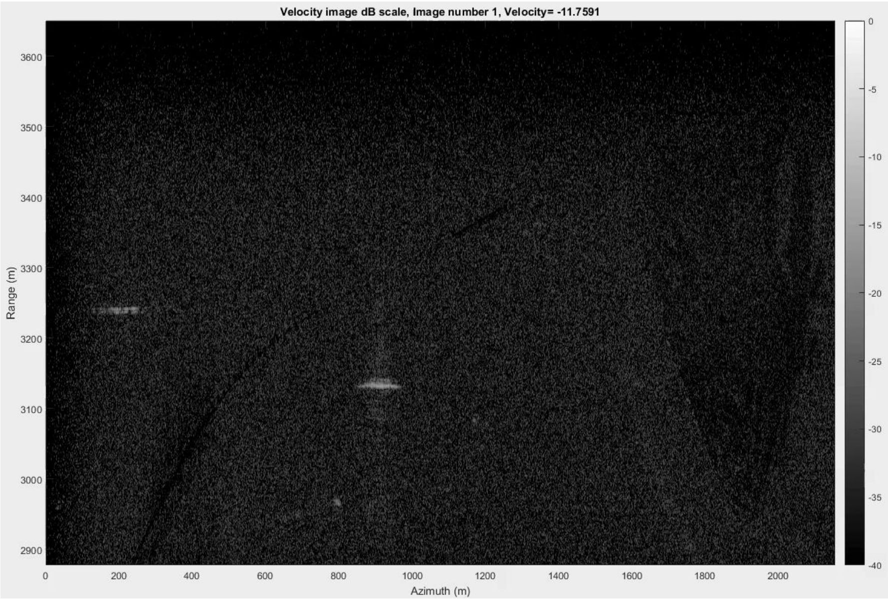
Animation: click to start



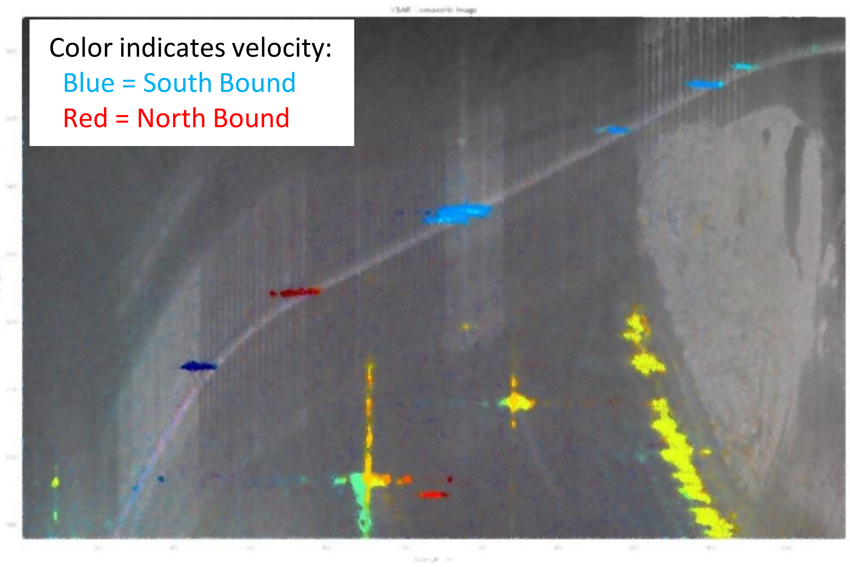
- VSAR places cars back on the bridge and boats back on their signatures
- Range streaks caused by bright bridge and high sidelobes (since remedied!)
- Cars signatures much more visible in velocity stack (next slide)

VSAR Analysis: Correction of Hard Target Displacements

VSAR Velocity Stack Animation



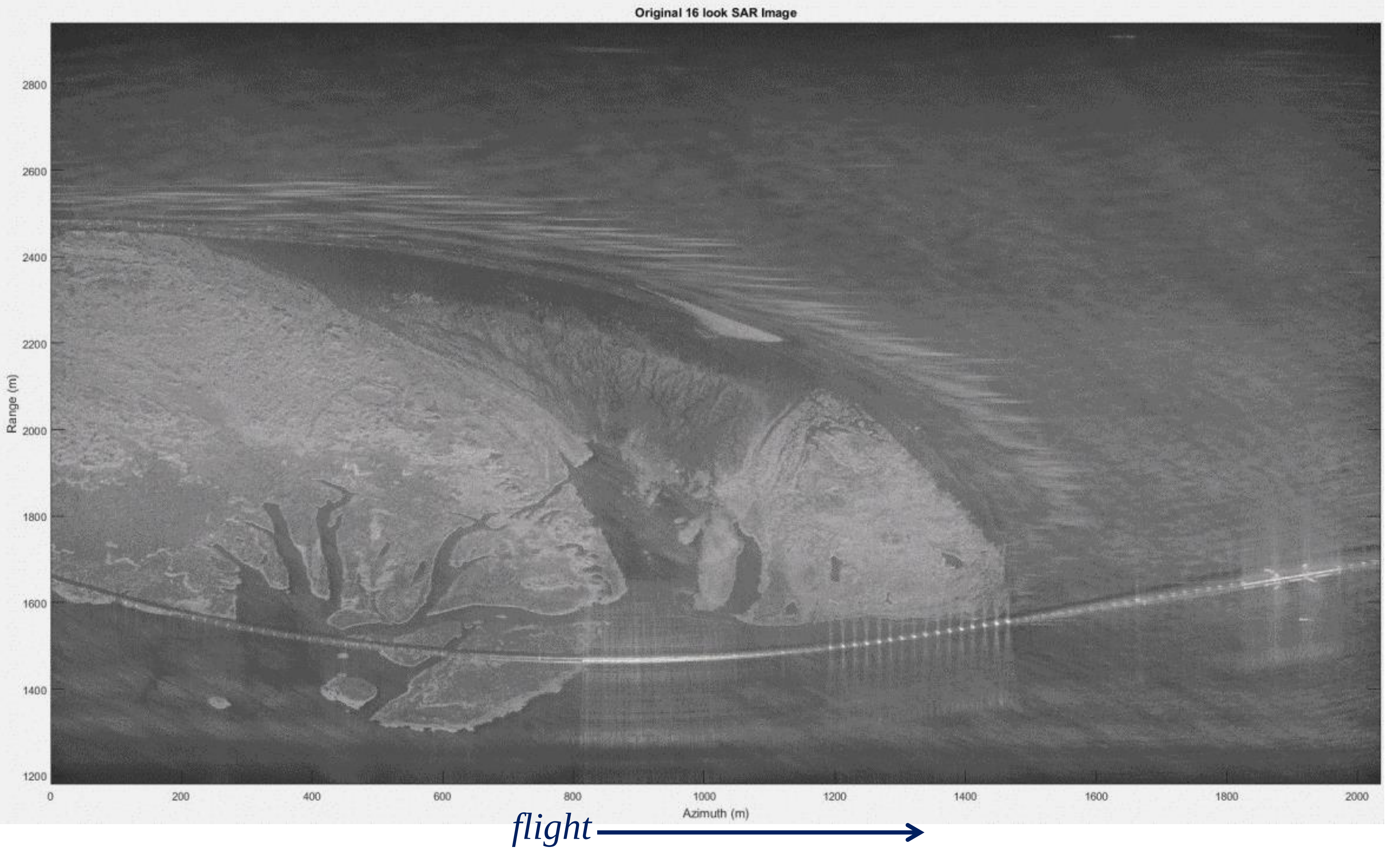
VSAR Composite Image



flight

- Vehicle signatures much more visible, due to Doppler filtering inherent in VSAR
- Vehicle speeds projected onto bridge within reasonable range of posted speed limit

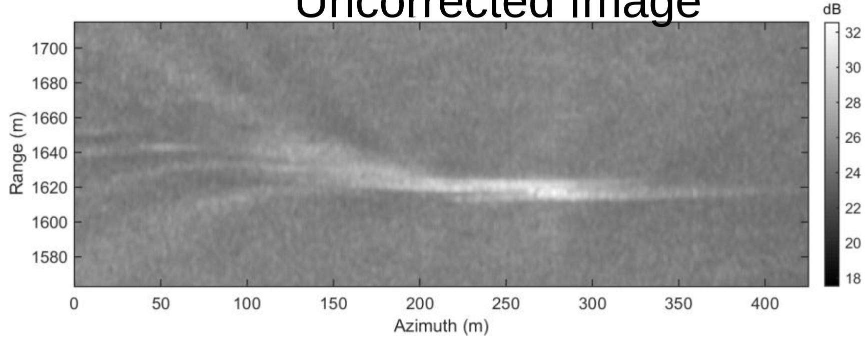
VSAR Analysis: Correction of Shoaling Wave Signature



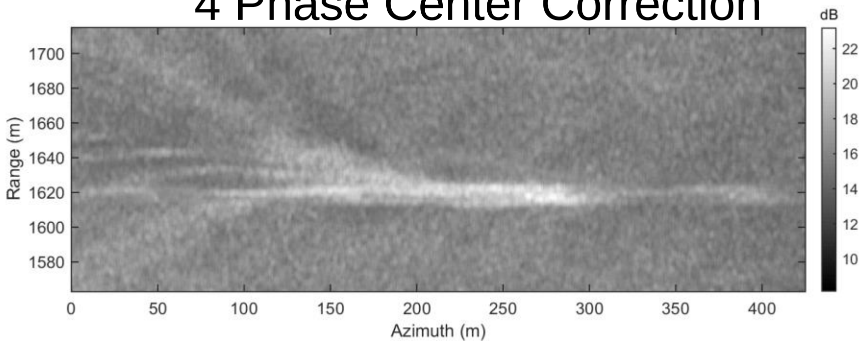
- VSAR also handles signatures characterized by a *range* of velocities
- Shoaling wave signatures are spread in azimuth due to wide velocity range
- Width of corrected signature is more representative of true breaker extent

VSAR Analysis: Correction of Vessel Signature

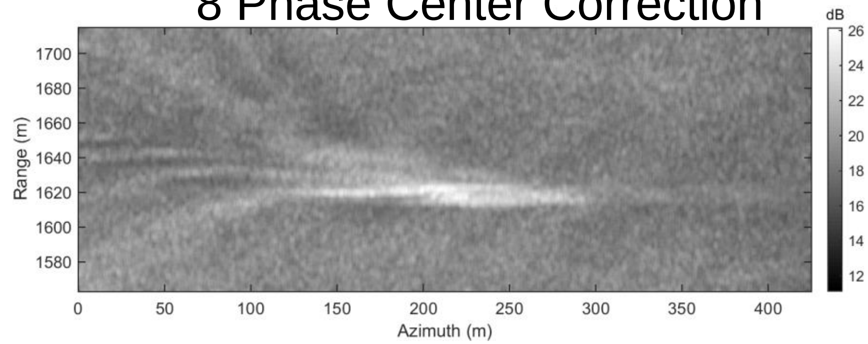
Uncorrected Image



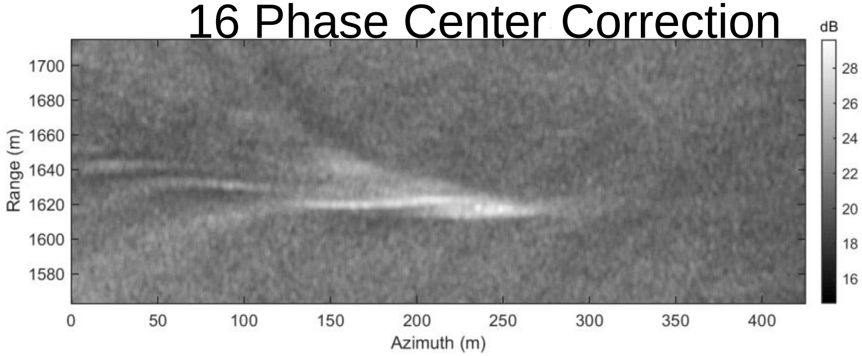
4 Phase Center Correction



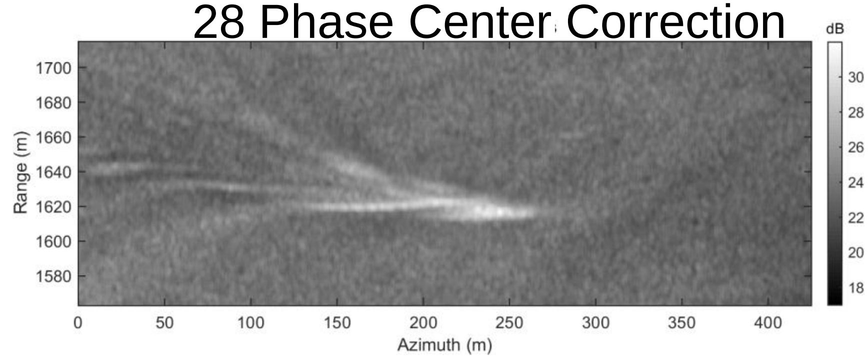
8 Phase Center Correction



16 Phase Center Correction



28 Phase Center Correction



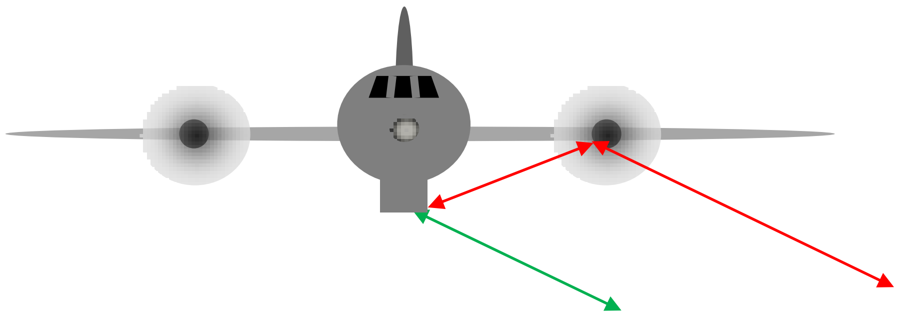
- Longer VSAR arrays produce finer velocity resolution and thus better fidelity

Channel Balancing

- Channel balancing is essential for effective VSAR: magnitude and phase variations from image to image *due to the system* must be removed.

- We use an adaptive method [*Gierull*, 2003]
  - Determines average range and az variation for each channel, then removes it
  - Assumes scene is dominated by stationary backscatter (Thanks to bridge and land in our Oregon Inlet imagery)

- In our NRL MSAR, system-induced imbalance is generated by aircraft multipath



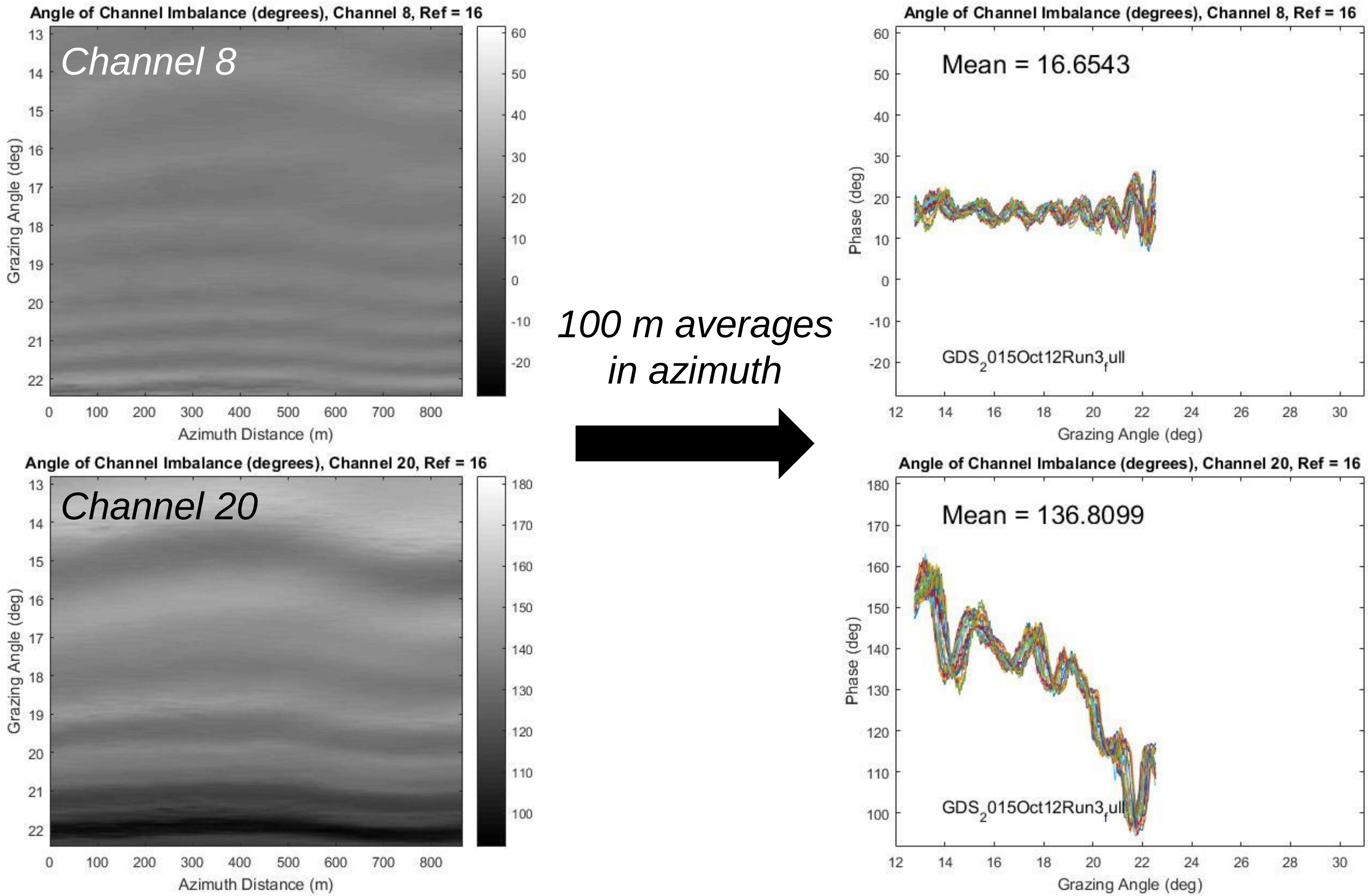
Undesired scattering path differs from phase center to phase center

Coherent addition of direct (intended) and multipath signals generates phase fringes, aka "phase screens"

- Issue: How to balance ocean-only scenes, dominated by motion?
  - Apply corrective phase screens derived from land imagery?
  - *Model* the phase screens, then use results to derive a correction?
  - Apply adaptive algorithm as-is and hope wave motion averages out?

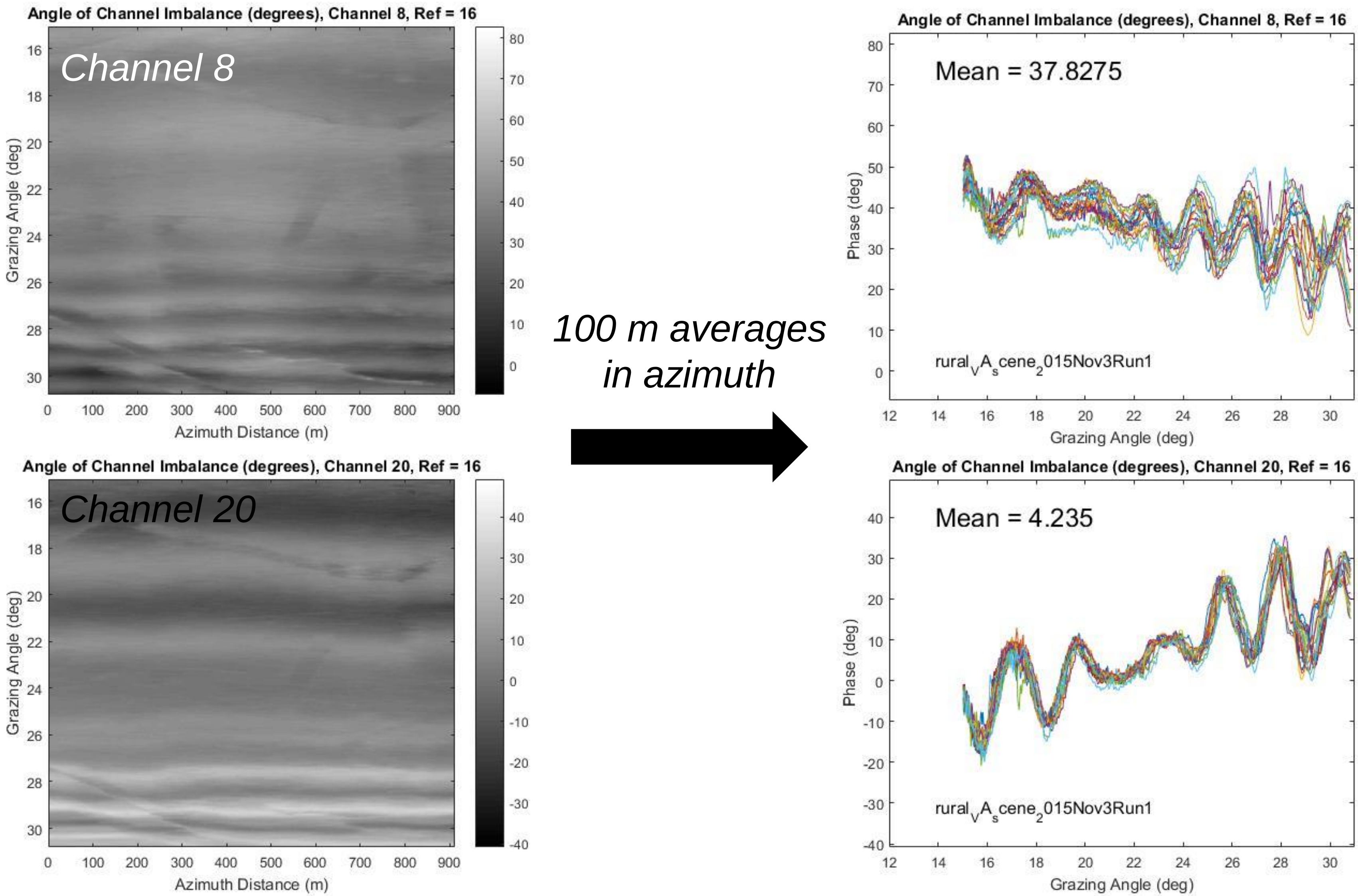
Example Phase Screens (2 of 32), Great Dismal Swamp

- Great Dismal Swamp is huge, flat, and uniformly forested: perfect test site
- Phase patterns differ from channel to channel, but vary with aircraft roll



Example Phase Screens (2 of 32), Flat Rural Scene

- Patterns unfortunately different from those measured over Great Dismal Swamp
- Difference due to change in aircraft pitch/yaw?

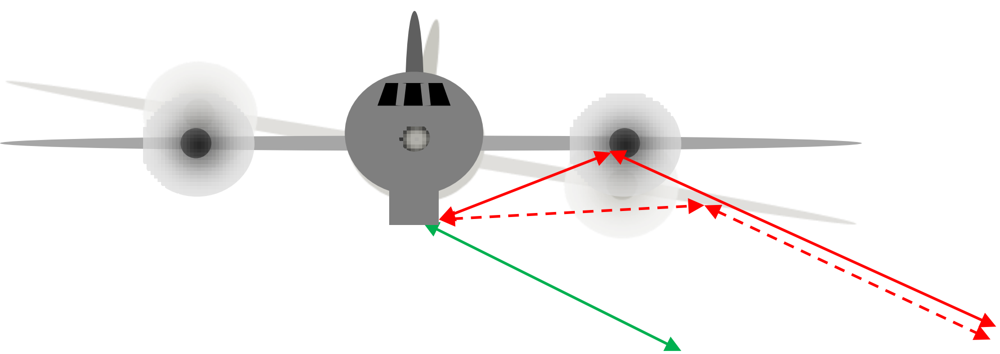


Multipath Modeling

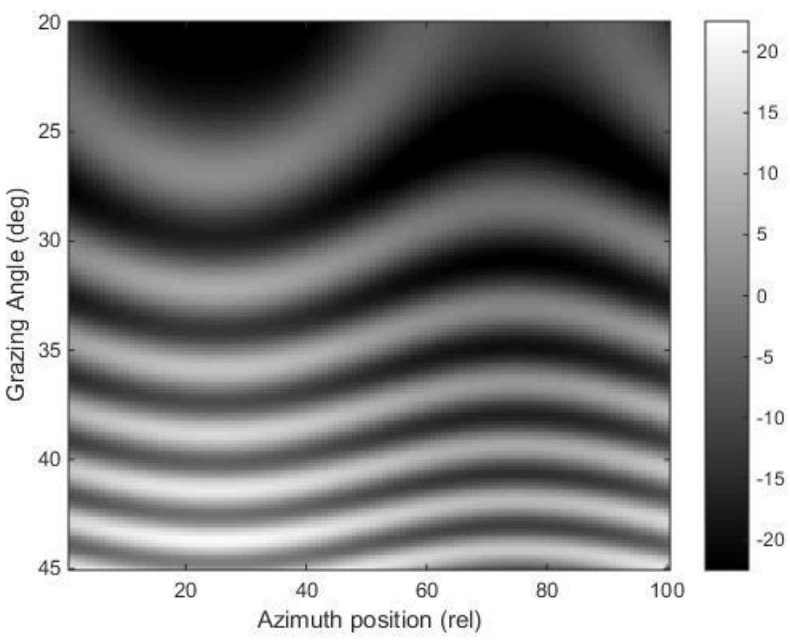
- Models involve initially unknown parameters for location (either of antenna or scattering point) and scattering strength

- Parameters estimated using measured phase patterns and measured aircraft attitude data

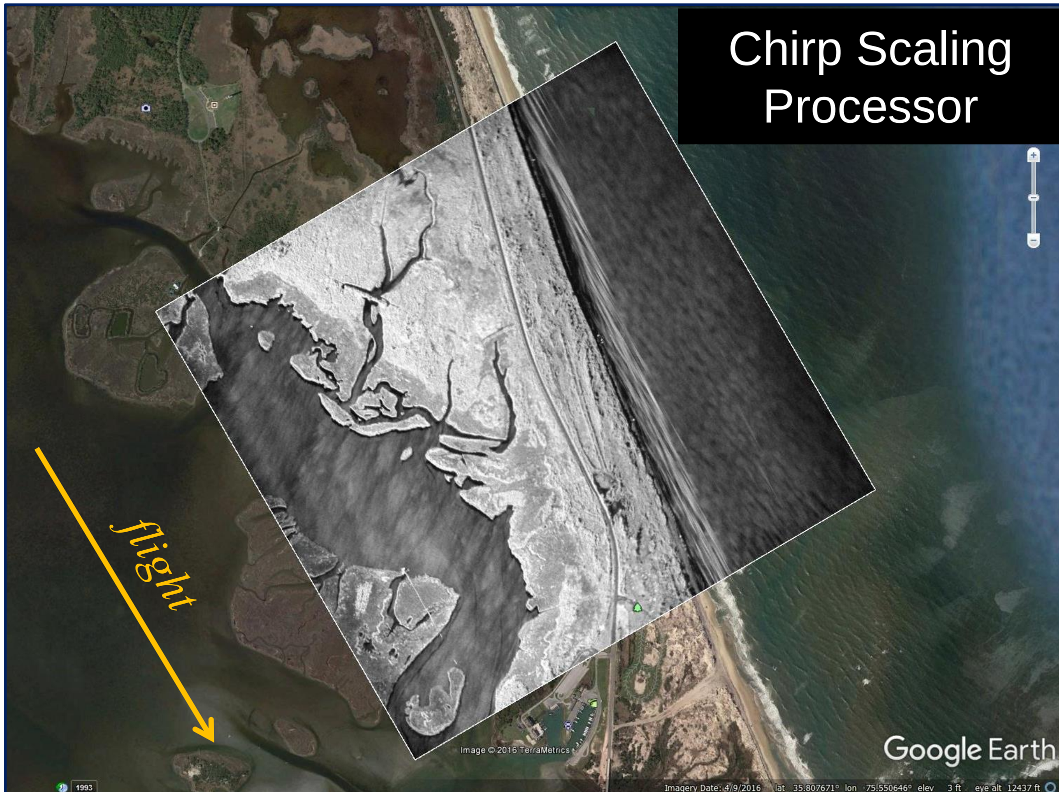
- Modeling effort will begin in earnest after this meeting
  - Intend to use model developed by *Pinheiro* et al (IGARSS 2009)
  - Assumes reflection occurs on wing: location parameter corresponds to antenna height uncertainty



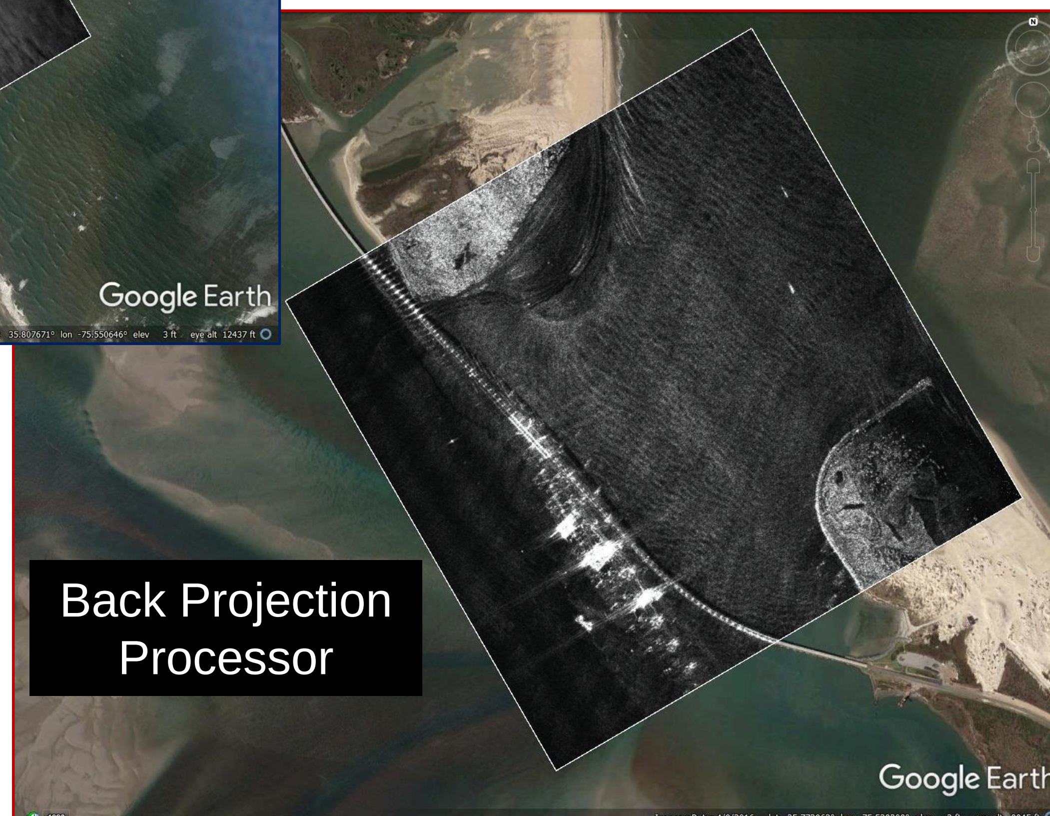
Modeled phase screen with aircraft roll



Example Imagery, October 2016



- Data collected October, 2016 over the NC Outer Banks



- Replaced original chirp-generation hardware with two-channel arbitrary waveform generator (Tektronix AWG70002A)
- Range sidelobes greatly reduced
- Dynamic range also improved through receive chain adjustment

Summary

- Developed a 32 phase-center SAR for detailed measurement of scene motion
- Demonstrated the system experimentally with data collected over the Mid-Atlantic coast of the USA
    - Measured vehicle velocities and corrected their signatures
    - Corrected more complicated signatures of shoaling wave and vessels
- Currently wrestling with the challenge of balancing the channels in the presence of strong aircraft multipath