ON THE REMOVAL OF COHERENT AMBIGUITIES IN SAR INTERFEROGRAMS: A STUDY FOR HARMONY

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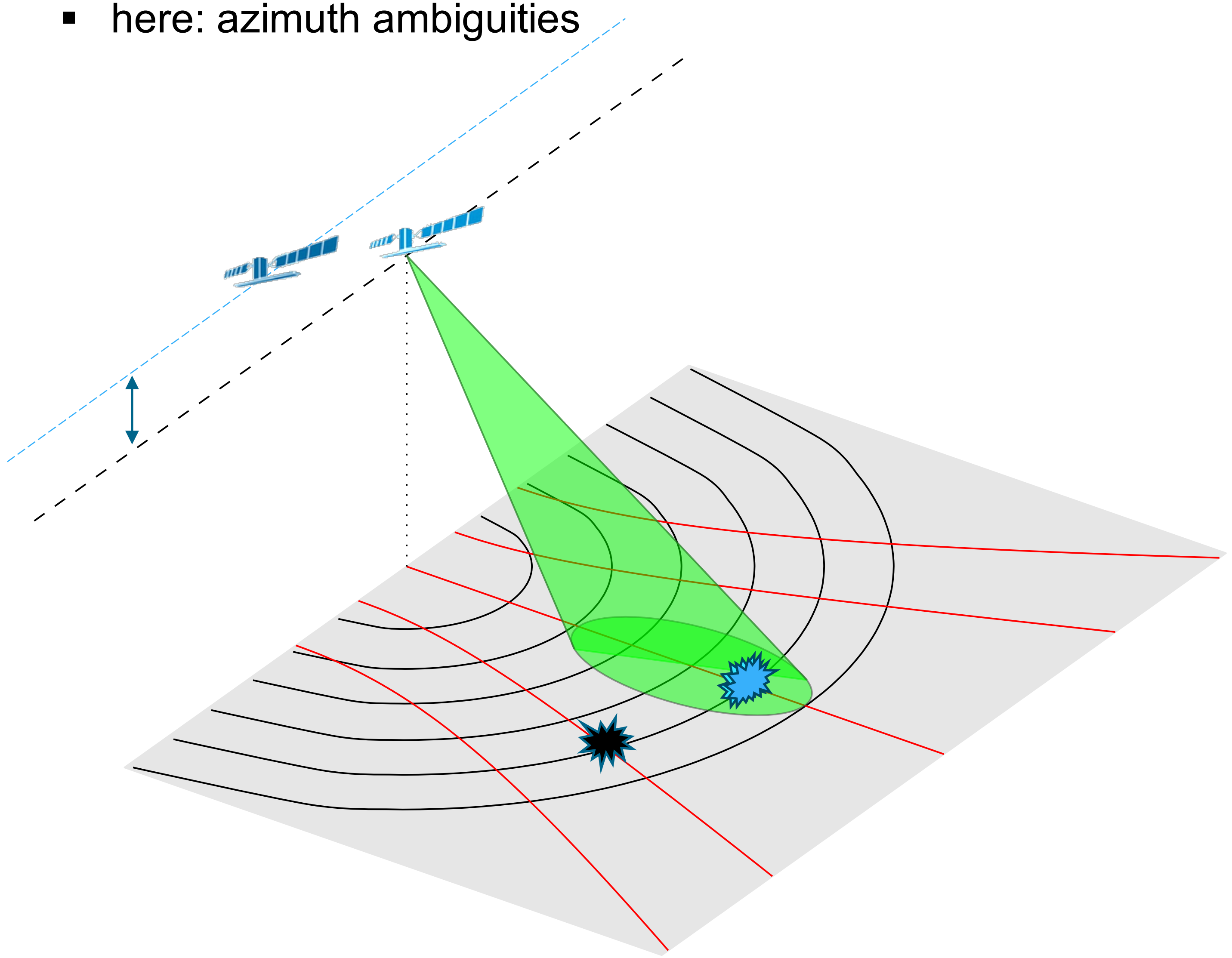
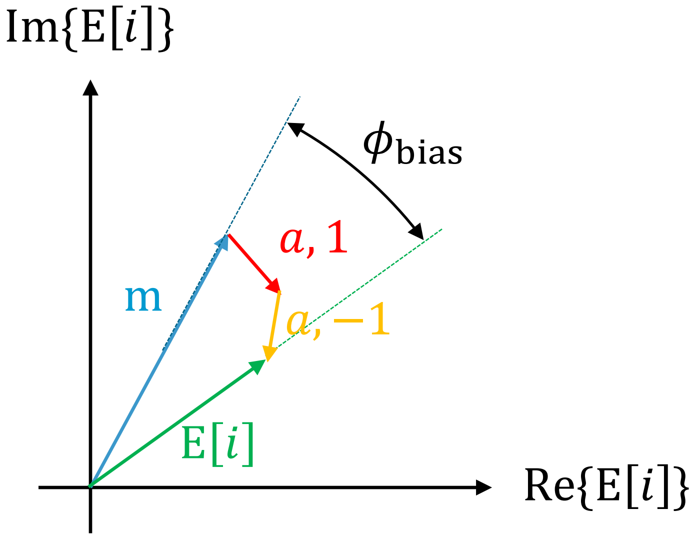
DLR

Interferometric Phase Errors by Coherent Ambiguities

- here: azimuth ambiguities

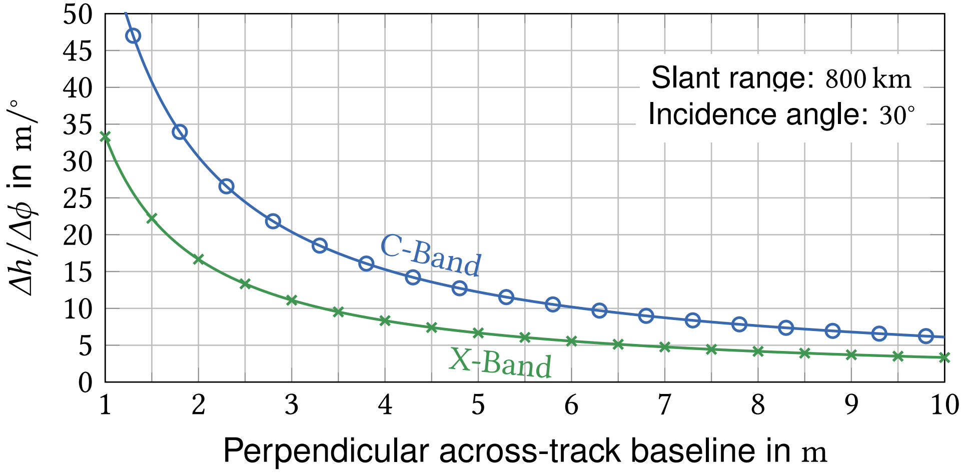




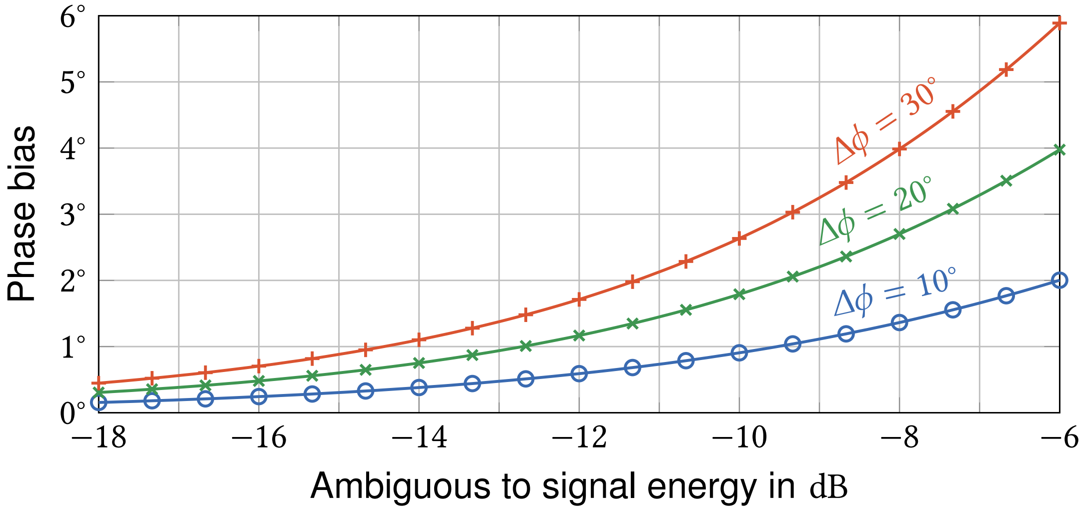
$$\mathrm{E}[i] = I_{\mathrm{m}} \mathrm{e}^{\mathrm{j}\phi_{\mathrm{m}}} + I_{\mathrm{a},1} \mathrm{e}^{\mathrm{j}\phi_{\mathrm{a},1}} + I_{\mathrm{a},-1} \mathrm{e}^{\mathrm{j}\phi_{\mathrm{a},-1}} + \cdots$$

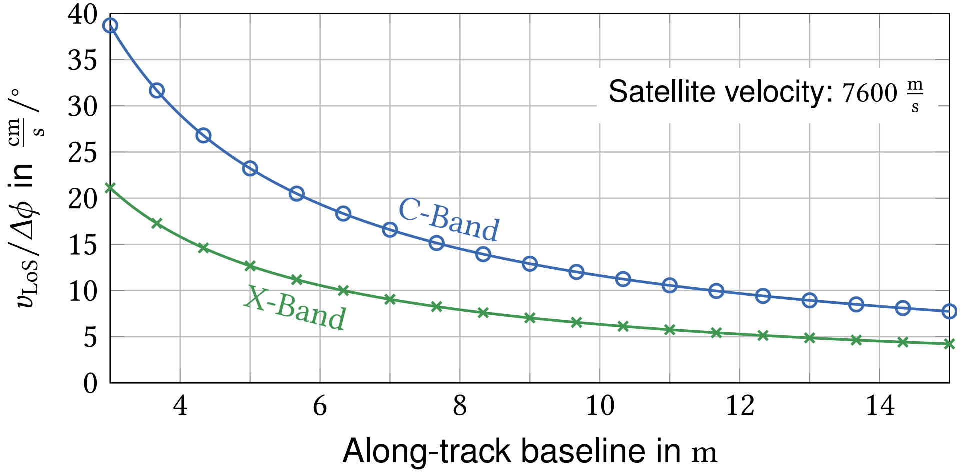
Interferometric Phase Errors by Coherent Ambiguities

- Phase biases relevant systematic errors, e.g.
  - XTI X-Band 3 m baseline
  - ATI C-Band 10 m baseline

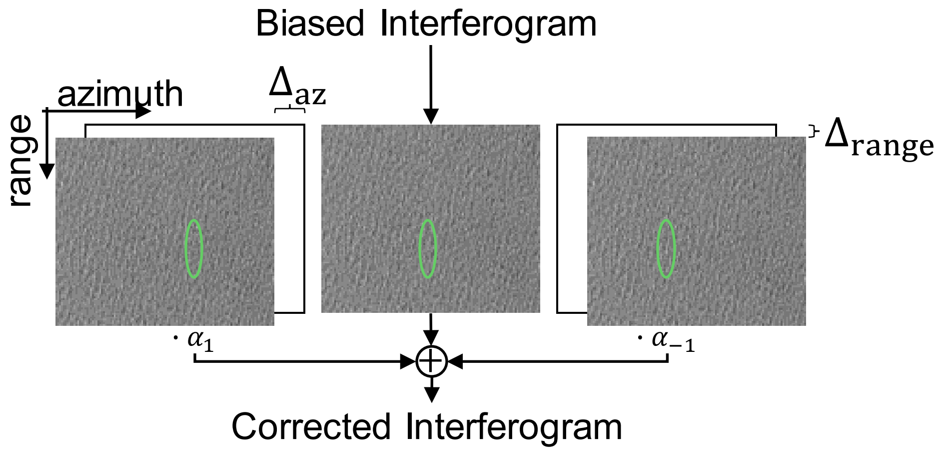


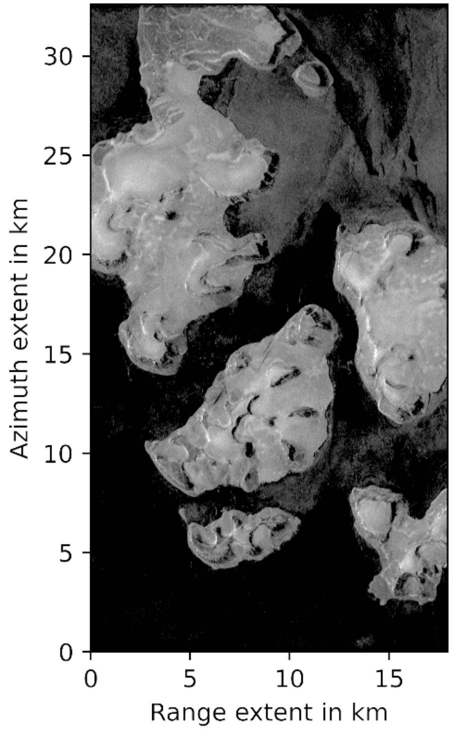
- Coherence loss [Villano and Krieger, IEEE GRSL 2012]

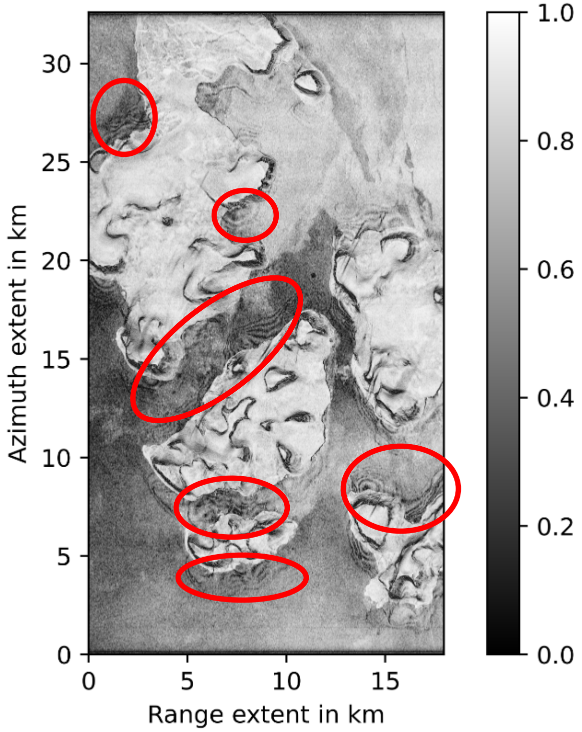


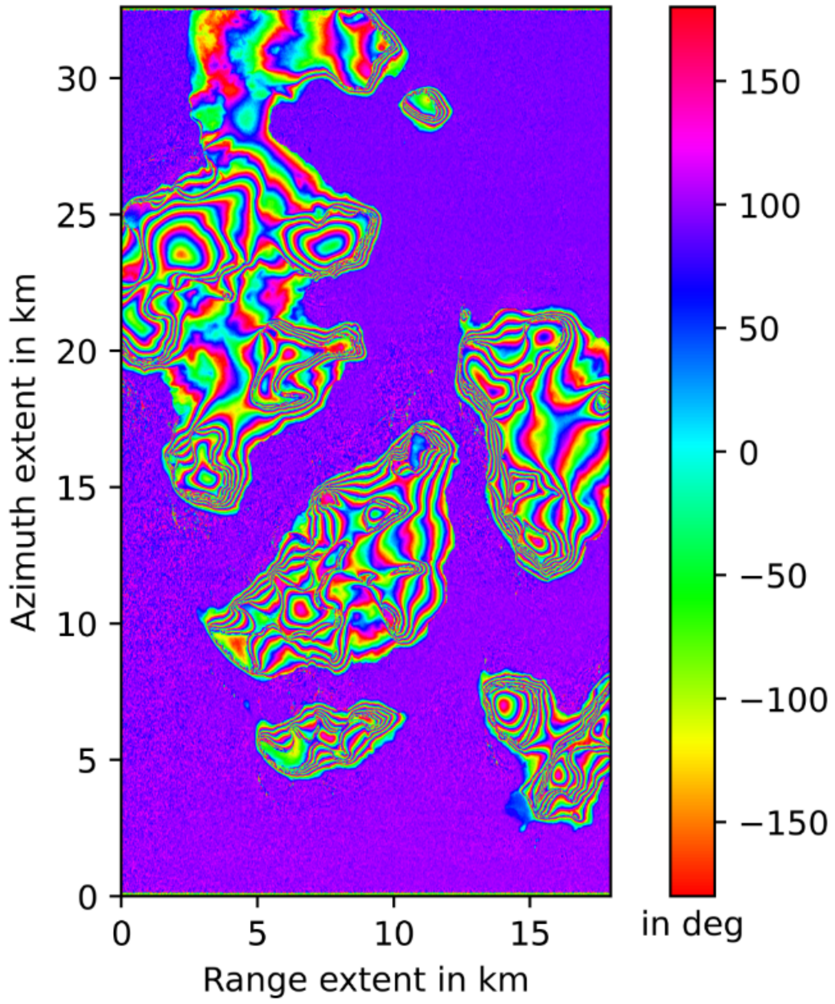


Removal Using Shifted Interferograms







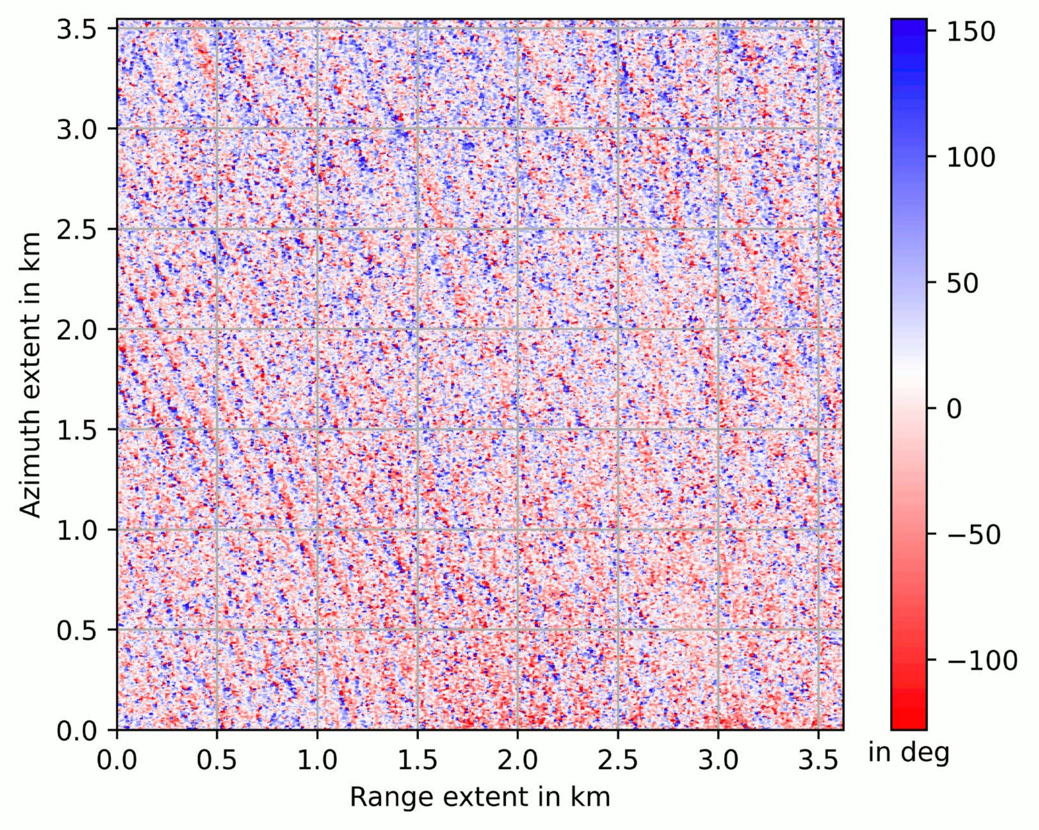


Interferogram with artificial ambiguities

Interferogram after removal of ambiguities

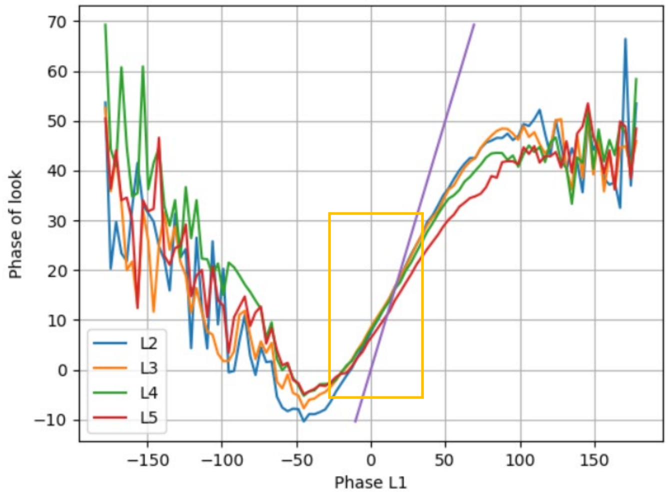
Short-Time Behavior of InSAR Measurements of Oceans

- Sub-looks of sliding spotlight data

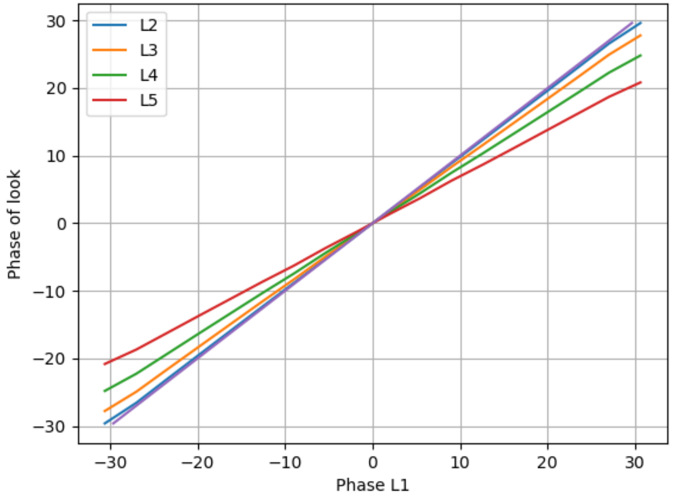


$$h_{\mathrm{amb}} = 36.5\ \mathrm{m}$$
$$B_{\mathrm{ATI}} = 83.2\ \mathrm{m}$$

- TanDEM-X spotlight data

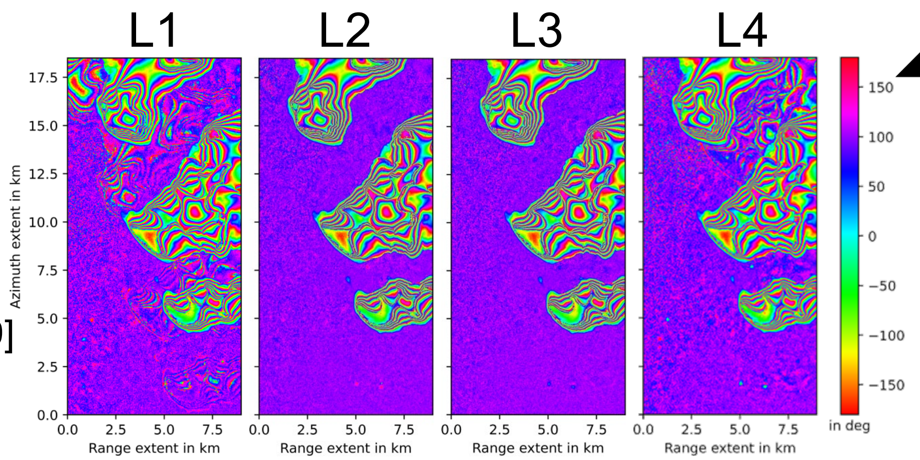


- Modeled monochromatic wave

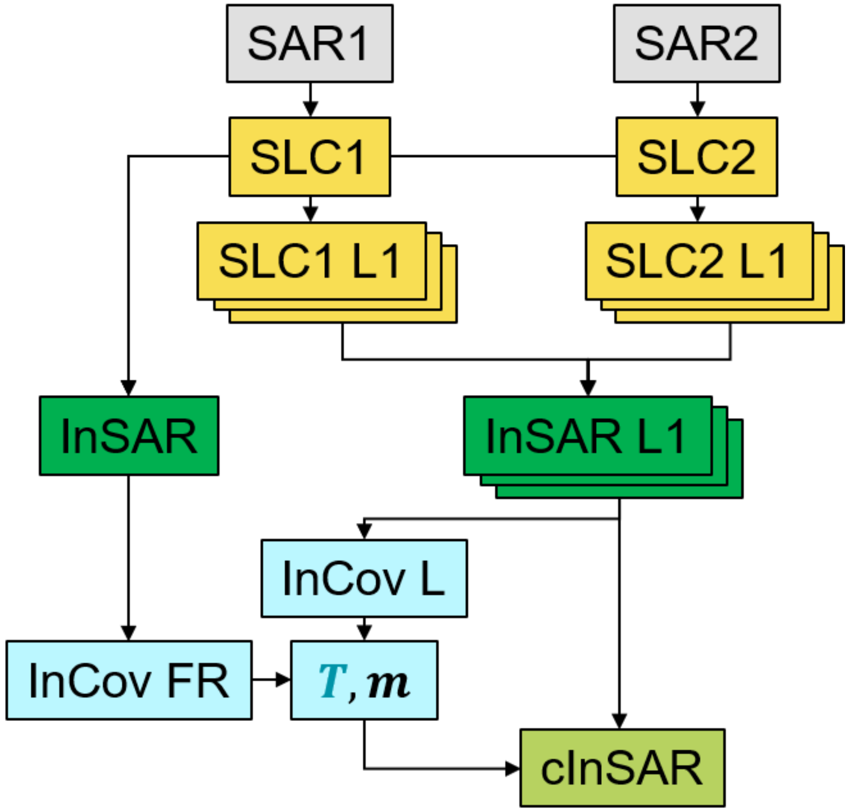


Algorithms

- Infinite Impulse Response Equalizer
  - Advanced "shift technique" [López-Dekker et al., IGARSS 2019]
  - Stable signatures beyond synthetic aperture time



- Ambiguity Diversity
  - $\hat{\boldsymbol{s}}_{\mathrm{AD}} = \boldsymbol{T}^{\mathrm{H}}\boldsymbol{i} + \boldsymbol{m}$
    - $\boldsymbol{T}^{\mathrm{H}} = \mathrm{Cov}[\boldsymbol{s},\boldsymbol{s}]\boldsymbol{A}^{\mathrm{H}}\,\mathrm{Cov}[\boldsymbol{i},\boldsymbol{i}]^{-1}$
    - $\boldsymbol{m} = (\boldsymbol{I} - \boldsymbol{T}^{\mathrm{H}}\boldsymbol{A})\mathrm{E}[\boldsymbol{s}]$
  - Strictly model based
    - $\mathrm{Cov}[\boldsymbol{i},\boldsymbol{i}] = f(\boldsymbol{A}, \mathrm{NESN}, \beta, \ldots)$
    - $\mathrm{Cov}[\boldsymbol{s},\boldsymbol{s}] = f(\sigma^0, \mathrm{U}_{10}, S_{\mathrm{ATI}}, \ldots)$
  - Semi-adaptive
    - $\mathrm{Cov}[\boldsymbol{i},\boldsymbol{i}] \approx \hat{C}_{\boldsymbol{ii}} = \frac{1}{N}\sum_N \boldsymbol{i}\,\boldsymbol{i}^{\mathrm{H}}$, $\mathrm{Cov}[\boldsymbol{s},\boldsymbol{s}] \approx \hat{C}_{\boldsymbol{ss}}$
    - $\boldsymbol{A}$ is modelled

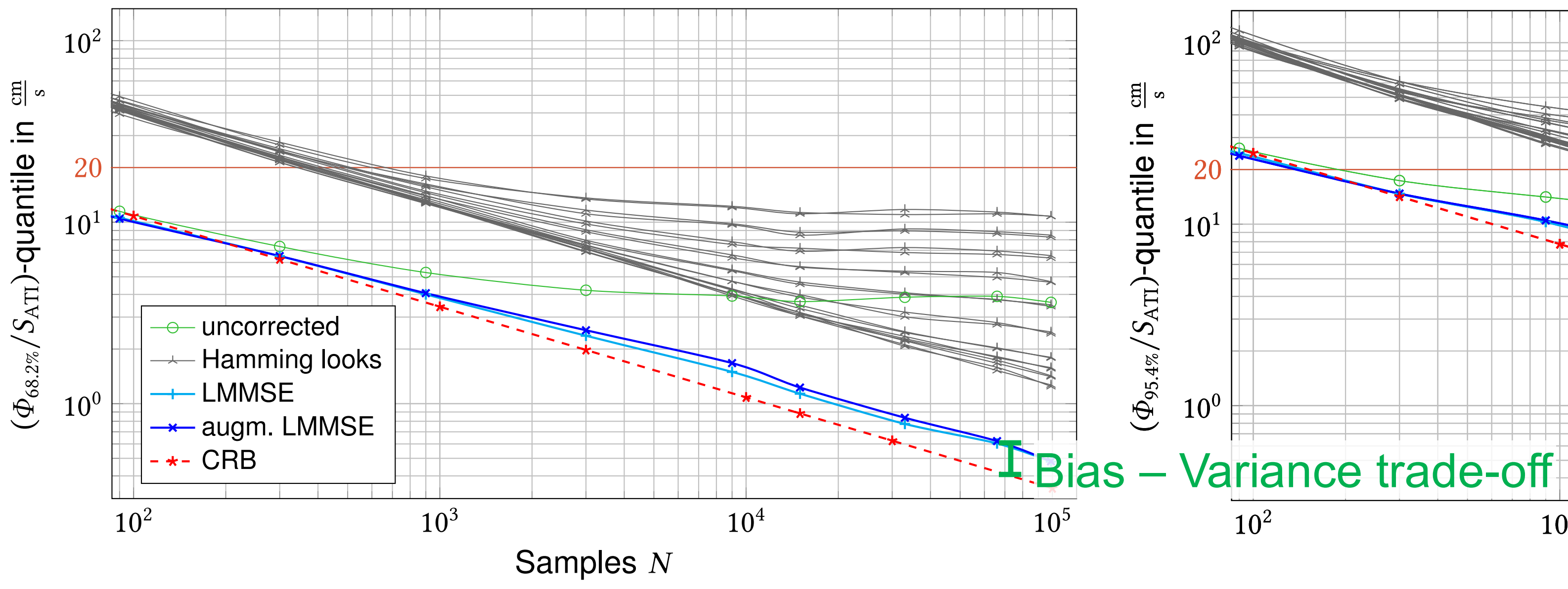


Monte-Carlo Performance Evaluations

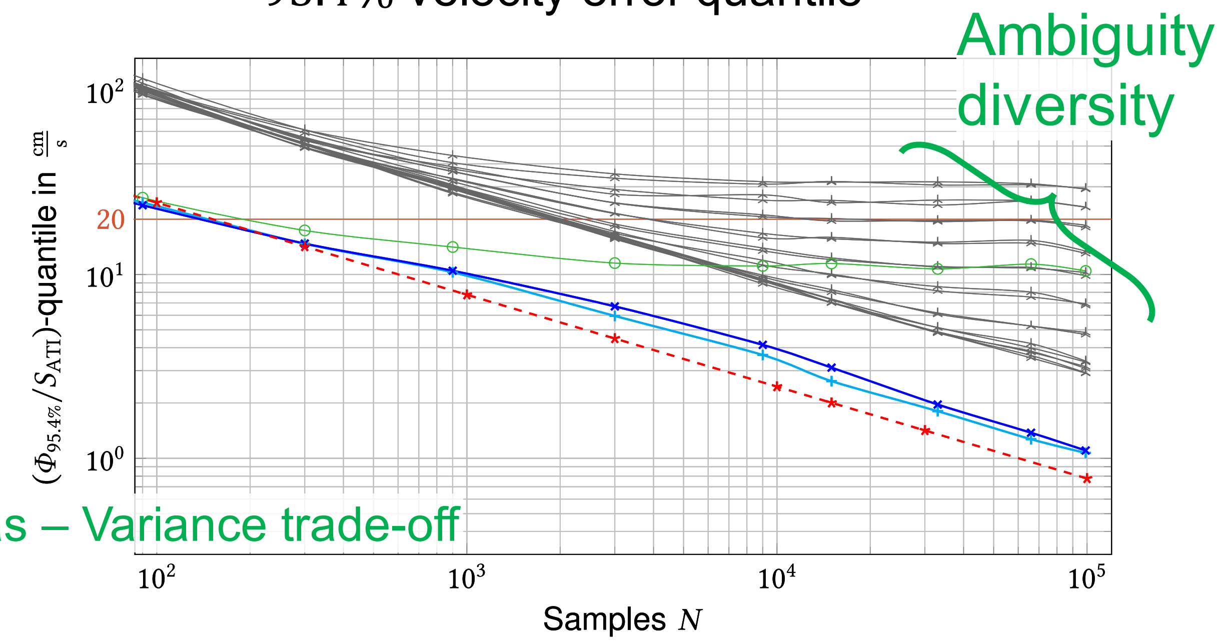
- Homogeneous simulated oceanic scene for Harmony's stereo (ATI) phase

- Sea state 6, $U_{10} = 15.23\,\frac{\mathrm{m}}{\mathrm{s}}$
- $\mathrm{E}\left[\sigma_i^0\right] = -5.9\ \mathrm{dB}$
- NESN $-20\ \mathrm{dB}$

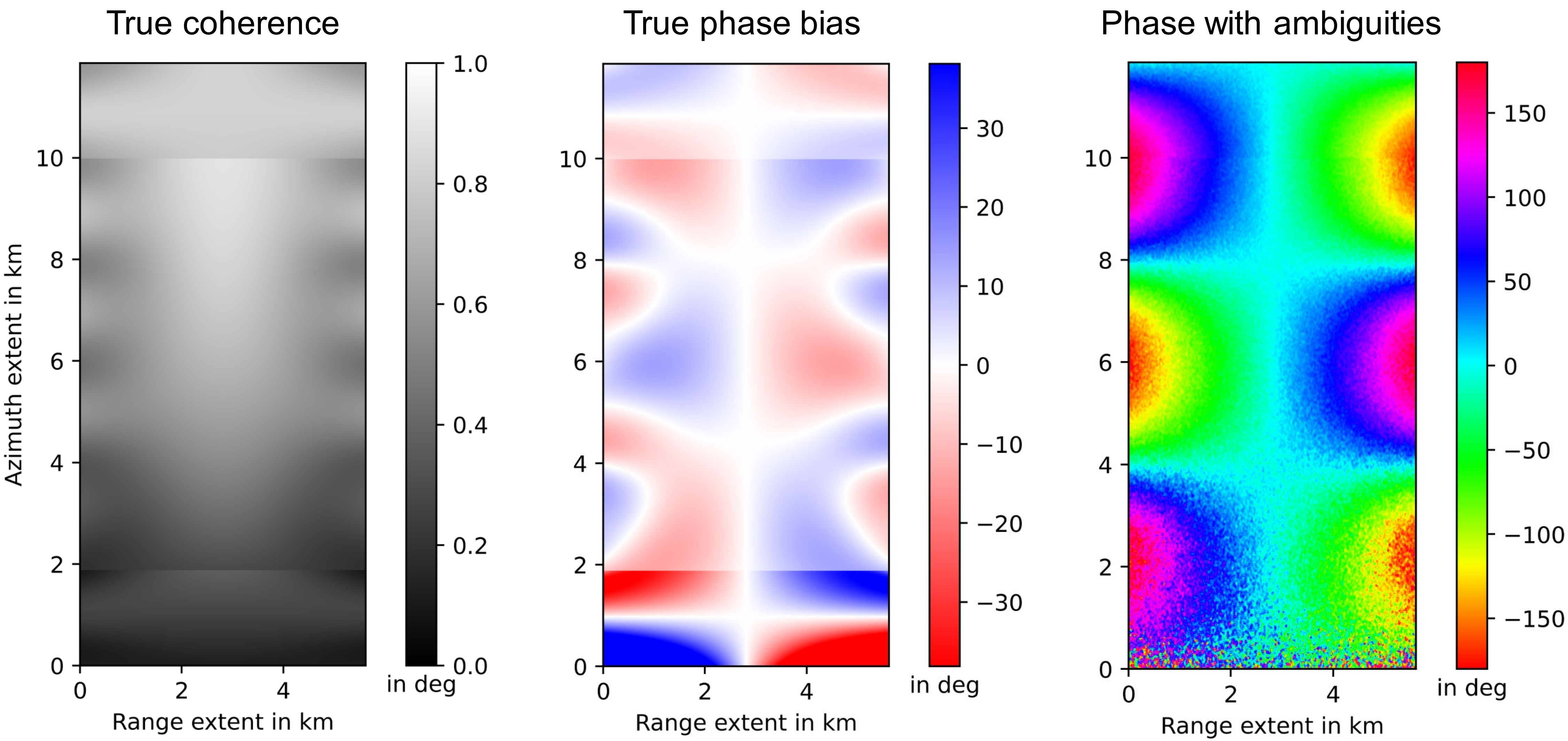
68.2% velocity error quantile



95.4% velocity error quantile



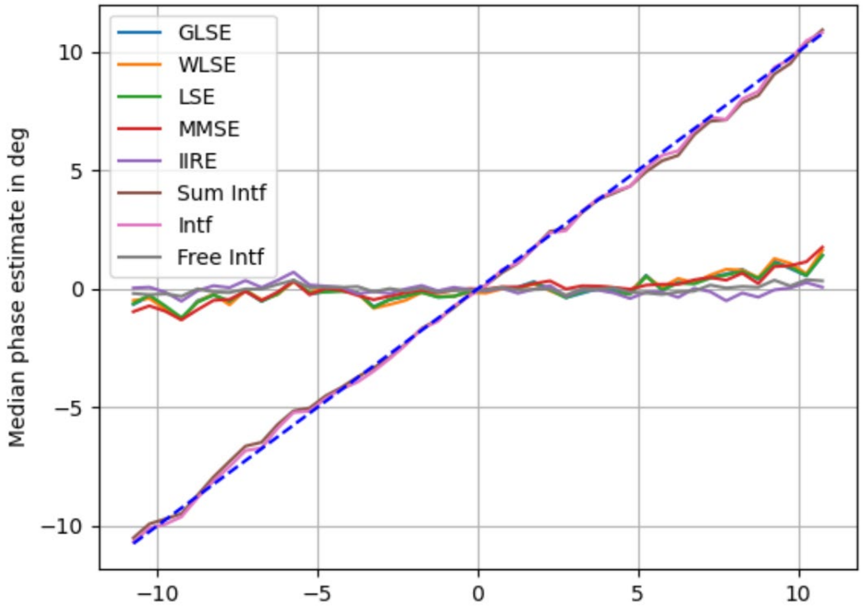
Performance Evaluation – Synthetic Gaussian Scene



$$\mathrm{AASR} = -5.96\ \mathrm{dB},\ \ \alpha_{\mathrm{left}} = -8.98\ \mathrm{dB},\ \ \alpha_{\mathrm{right}} = -8.98\ \mathrm{dB}$$

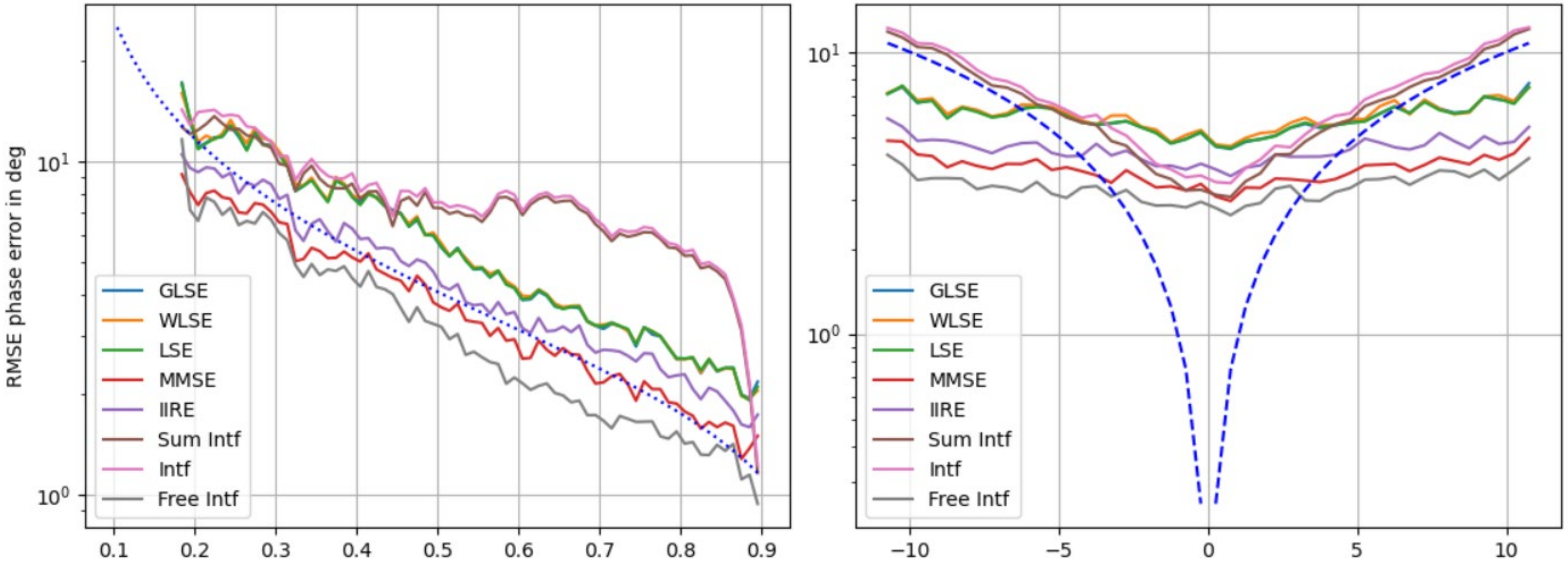
Performance Evaluation – Synthetic Scene (II)

Median phase error



True phase bias in deg

RMSE phase error

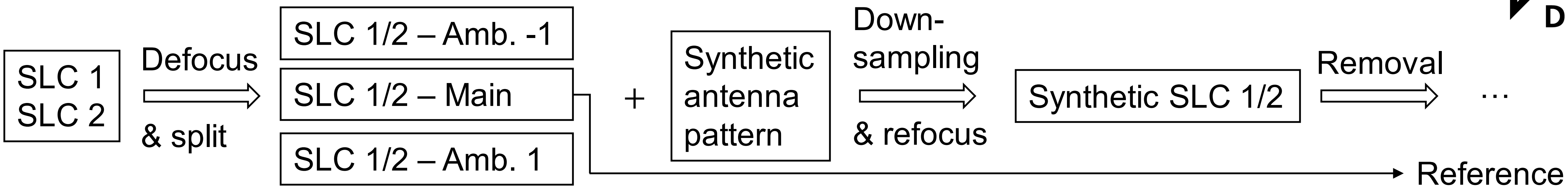


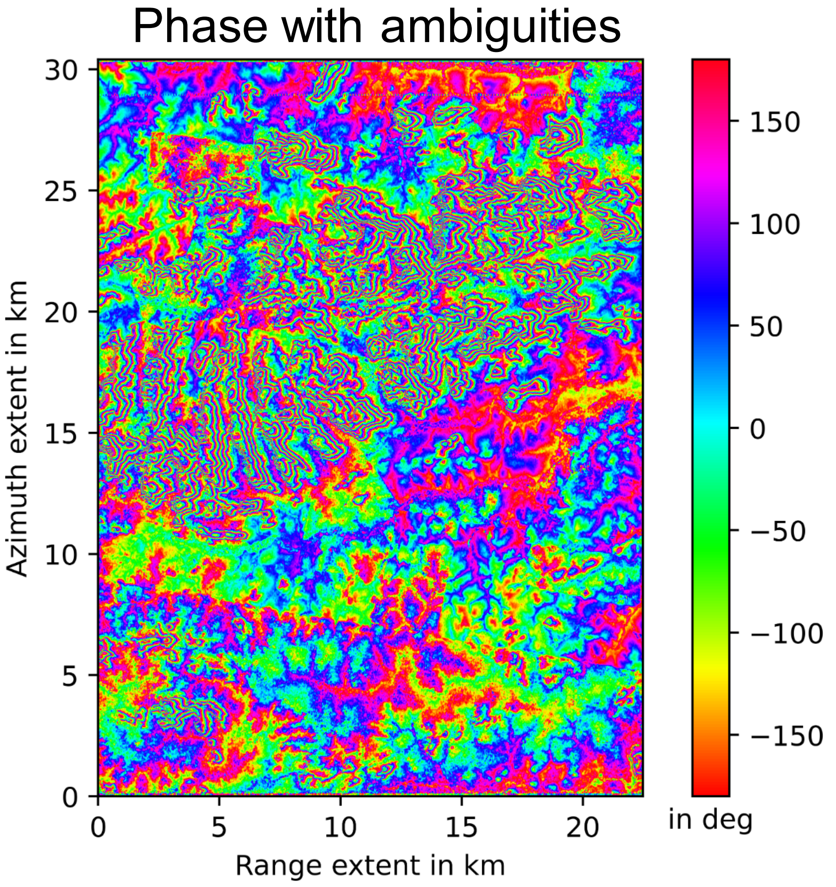
Coherence

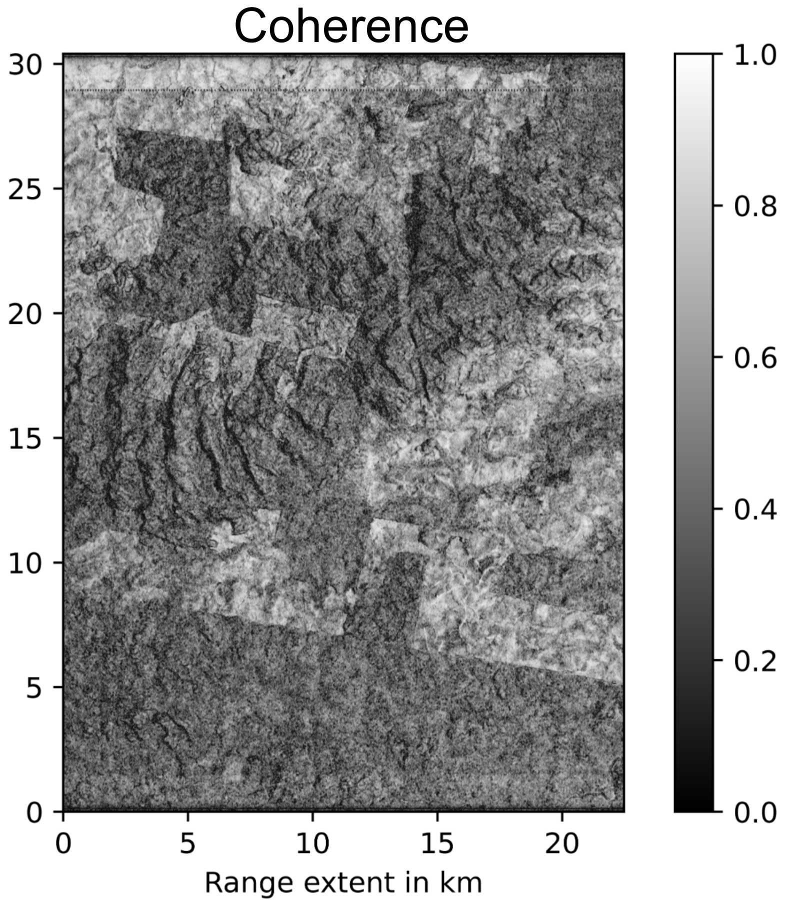
True phase bias in deg

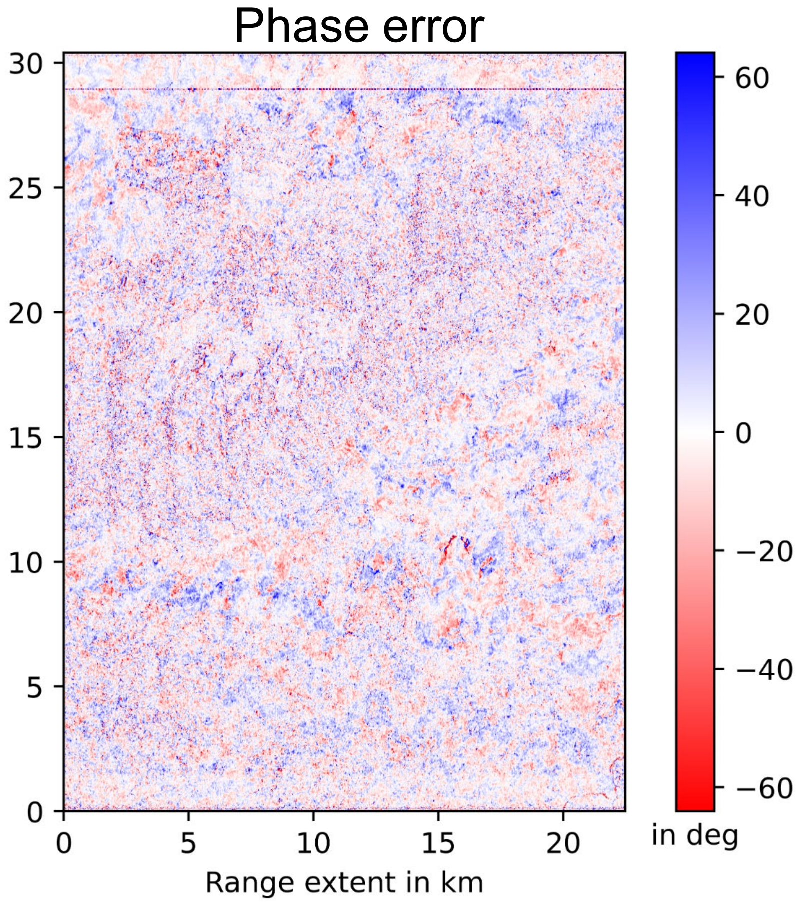
- Removal of phase bias
- at cost of increased phase noise

Validation on Land – Synthetic Ambiguities





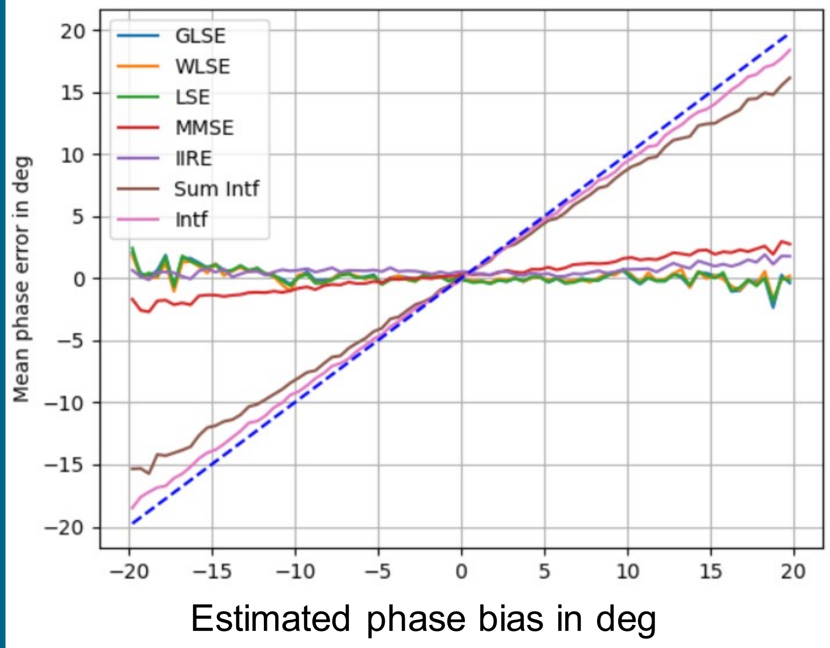




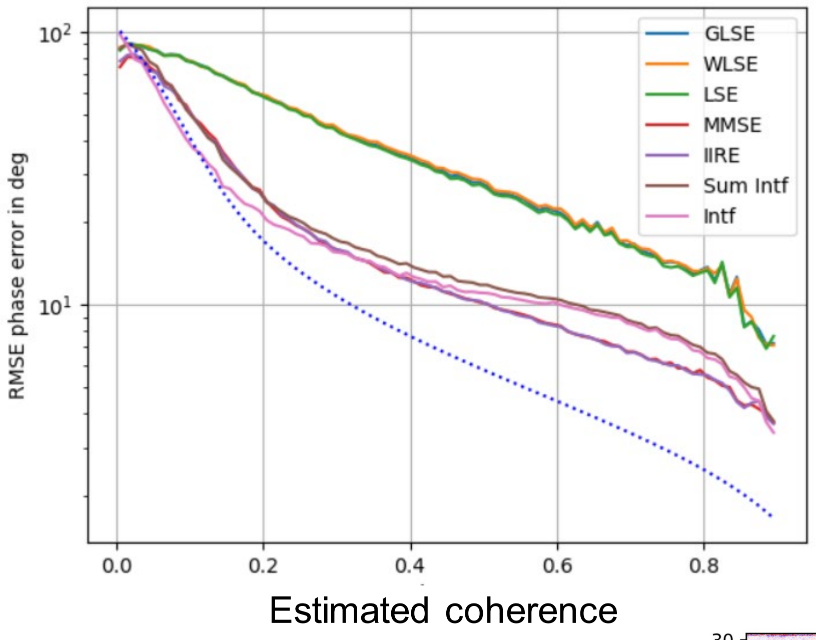
$$\mathrm{AASR} = -5.62\ \mathrm{dB},\ \ \alpha_{\mathrm{left}} = -8.63\ \mathrm{dB},\ \ \alpha_{\mathrm{right}} = -8.63\ \mathrm{dB}$$

Validation on Land – Synthetic Ambiguities (II)

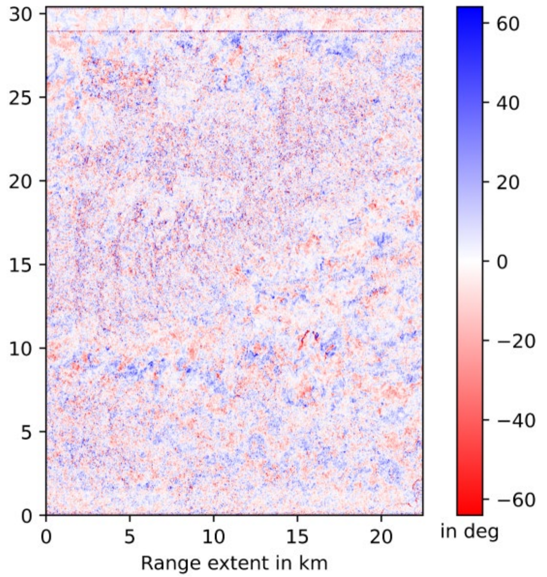
Median phase error



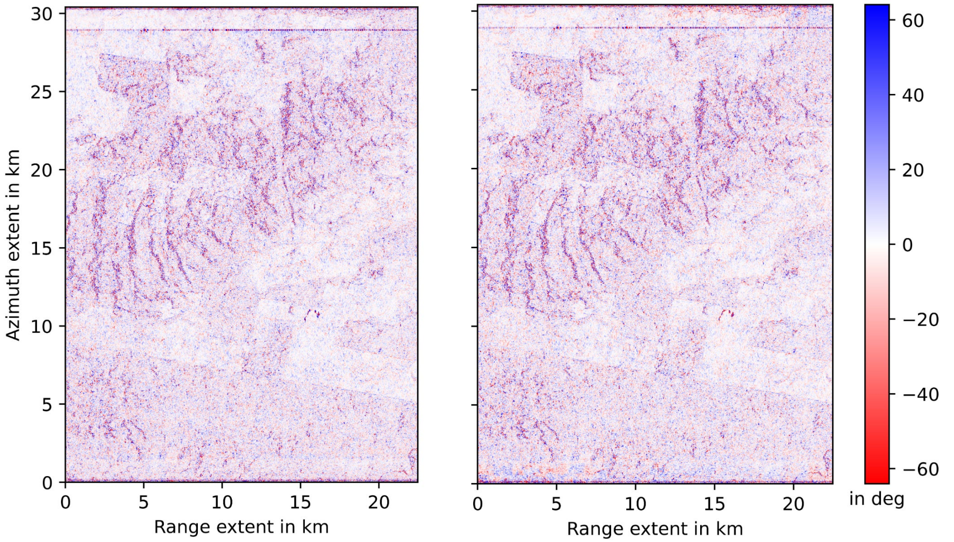
RMSE phase error



Phase error



IIRE MMSE

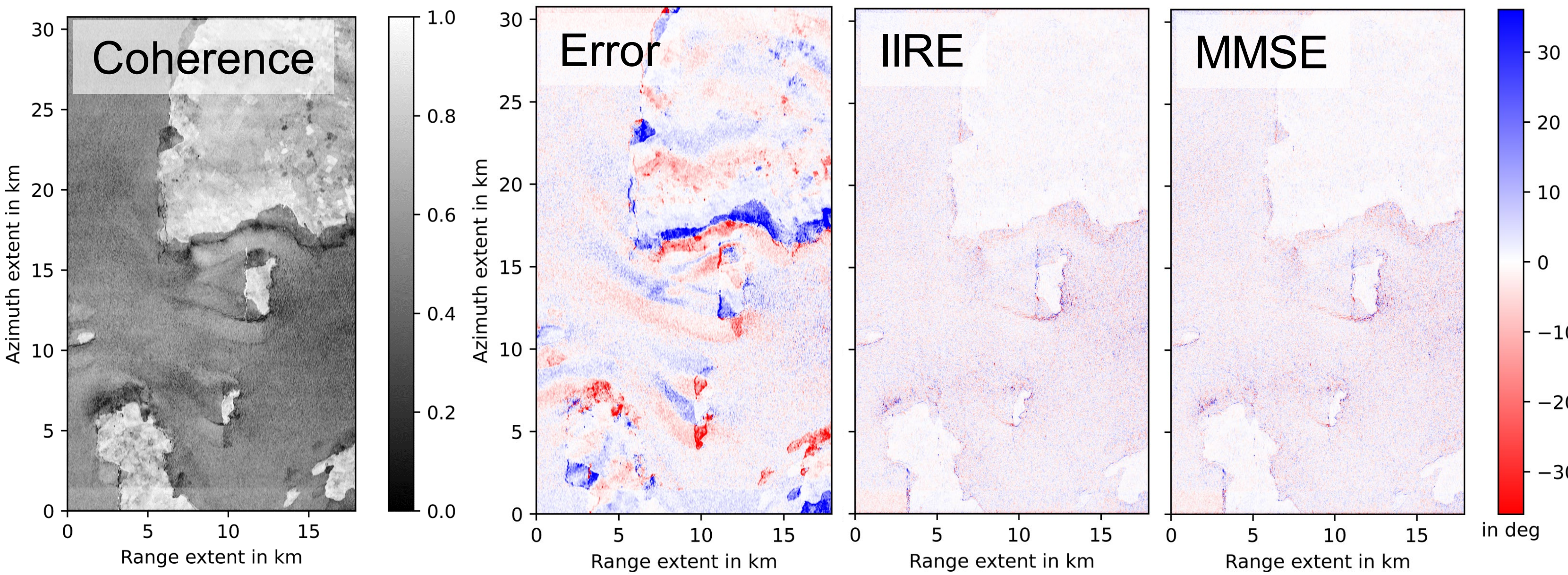


- Bias dominant in high coherence regions
- Phase noise of reference contributes in low coherence regions

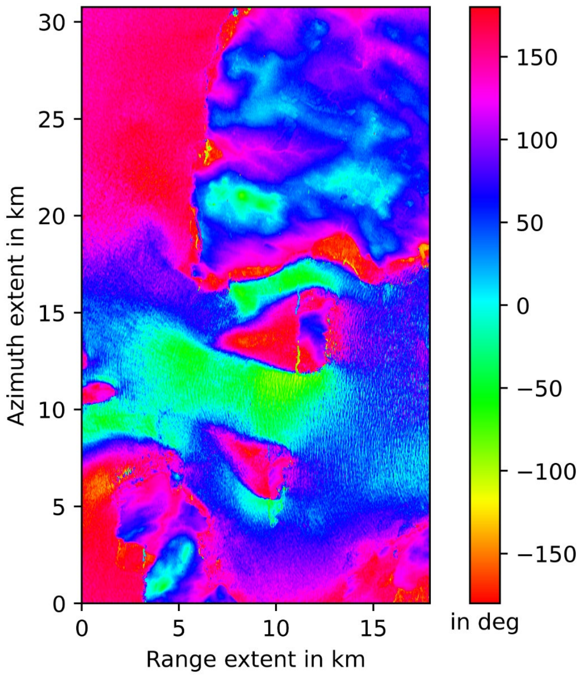
- Trade-off for MMSE technique
- Algorithm require tuning

Validation on Sea – Synthetic Ambiguities

$$\mathrm{AASR} = -9.34\ \mathrm{dB}$$
$$\alpha_{\mathrm{left}} = -12.35\ \mathrm{dB}$$
$$\alpha_{\mathrm{right}} = -12.35\ \mathrm{dB}$$

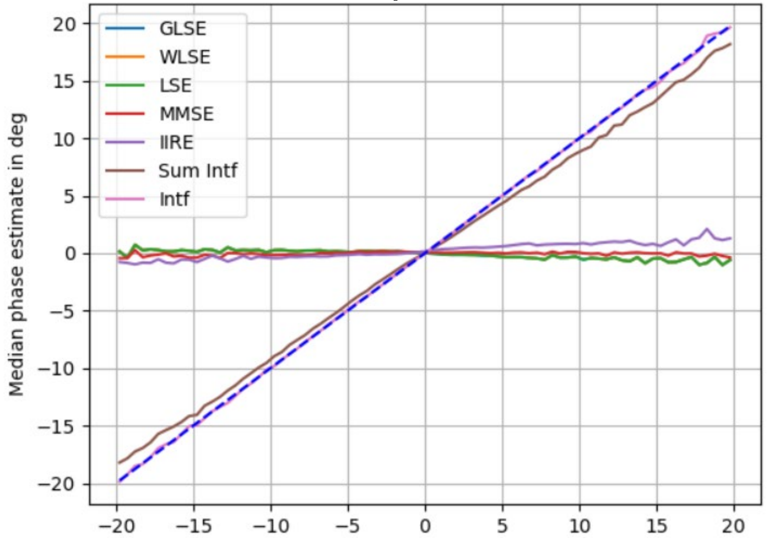


XTI and ATI phase



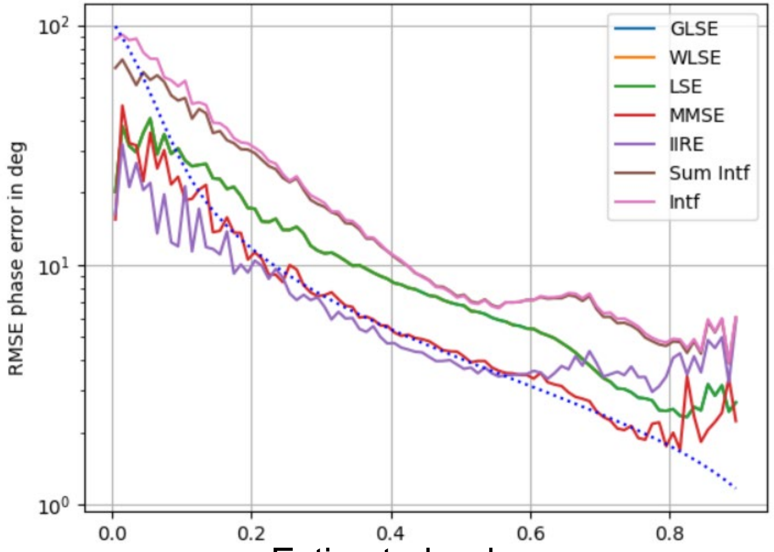
$$h_{\mathrm{amb}} = 203.2\ \mathrm{m}$$
$$B_{\mathrm{ATI}} = 40.3\ \mathrm{m}$$

Median phase error



Estimated phase bias in deg

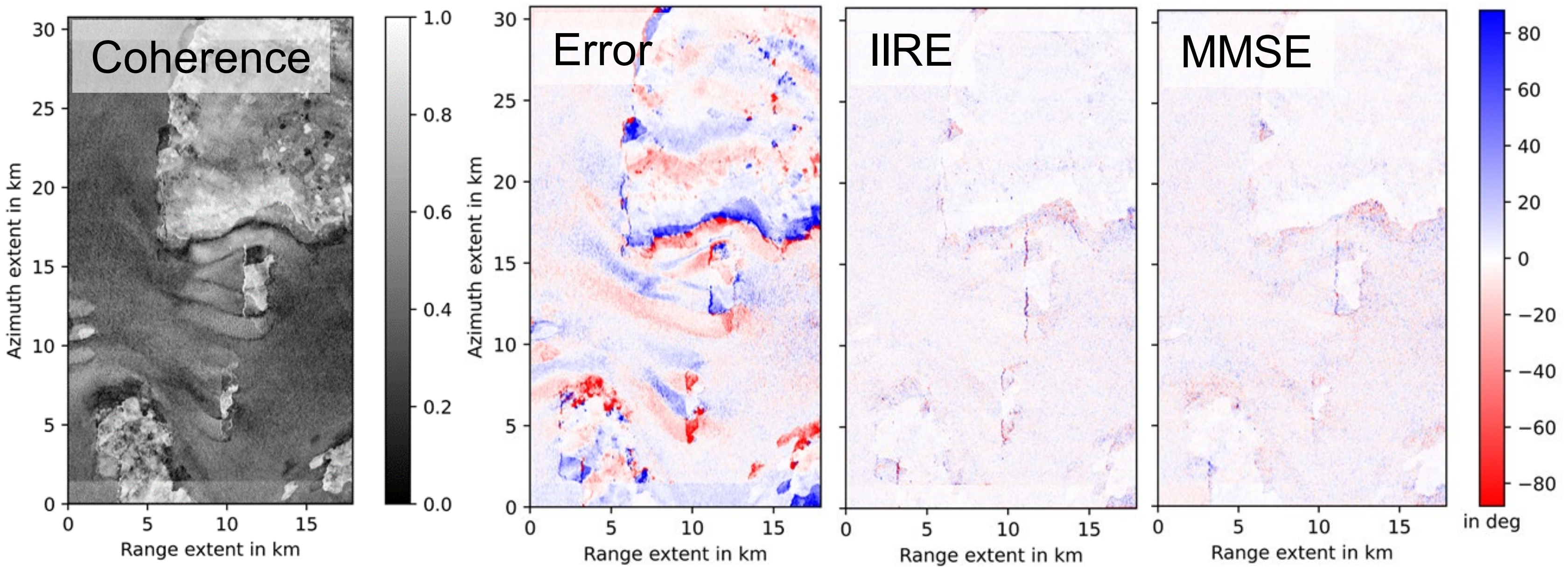
RMSE phase error



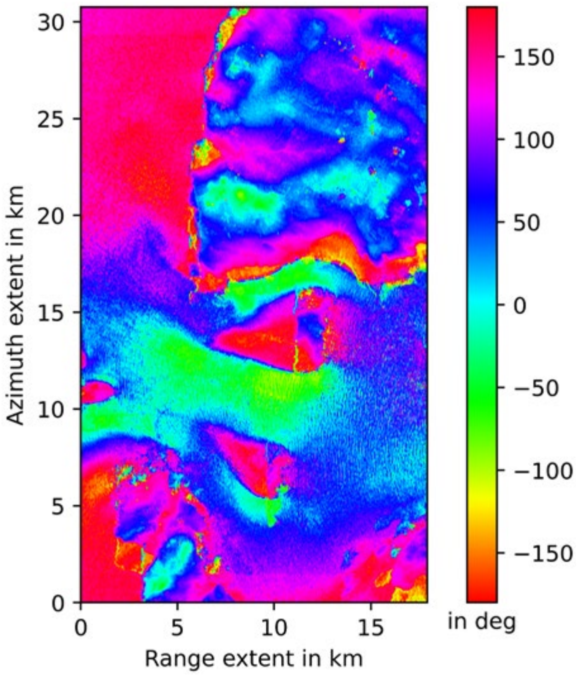
Estimated coherence

Validation on Sea – Synthetic Ambiguities (II)

$$\mathrm{AASR} = -4.89\ \mathrm{dB}$$
$$\alpha_{\mathrm{left}} = -7.90\ \mathrm{dB}$$
$$\alpha_{\mathrm{right}} = -7.90\ \mathrm{dB}$$



XTI and ATI phase



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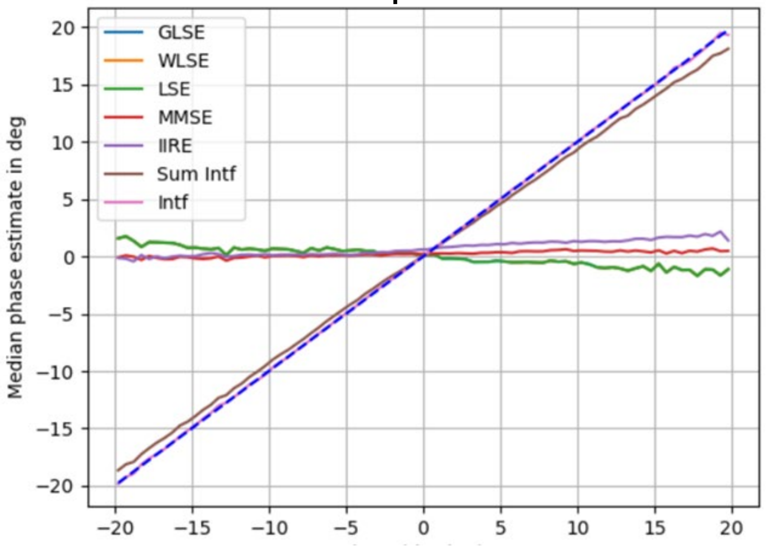
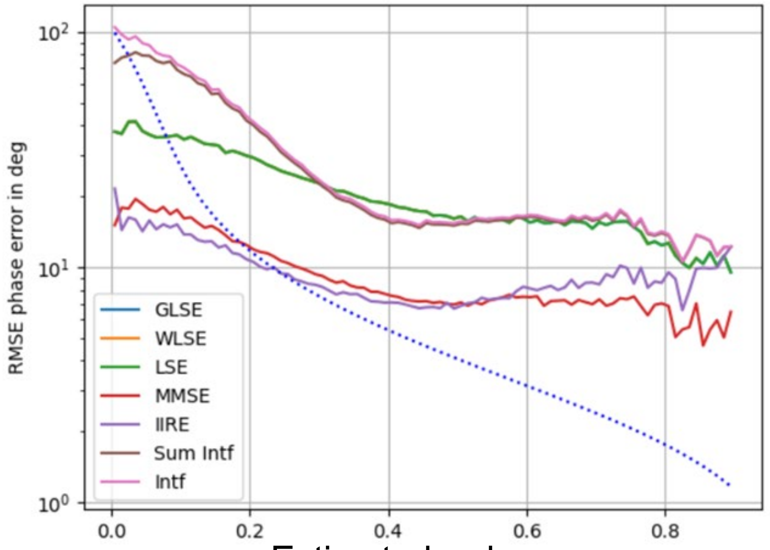
Median phase error



Estimated phase bias in deg

RMSE phase error



Estimated coherence

Validation on Sea – Ocean Raw Data Simulator

$U_{10} = 10\,\frac{\mathrm{m}}{\mathrm{s}}$

$\mathrm{TSC} = 1\,\frac{\mathrm{m}}{\mathrm{s}}$

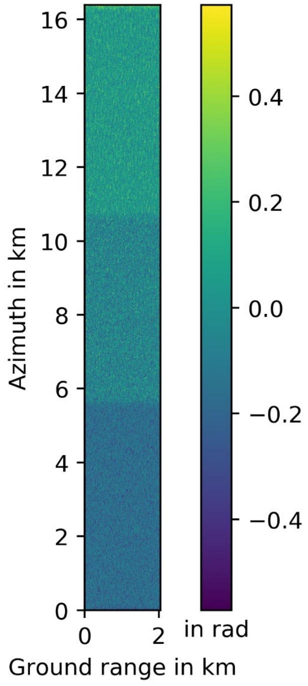
No noise, 4x4 Samples

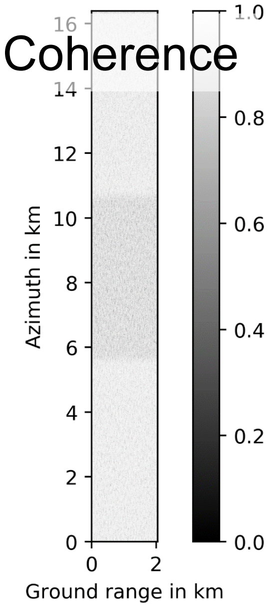
$\mathrm{AASR} = -4.15\ \mathrm{dB}$

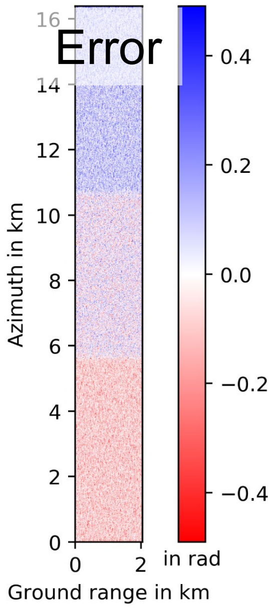
$\alpha_{\mathrm{left}} = -7.17\ \mathrm{dB}$

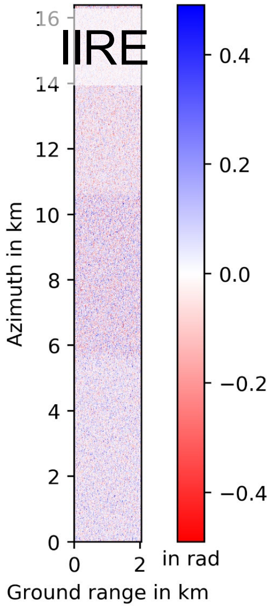
$\alpha_{\mathrm{right}} = -7.17\ \mathrm{dB}$

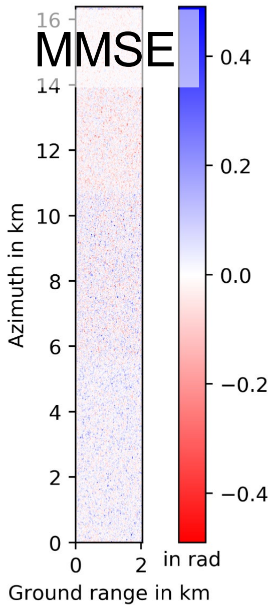
ATI phase



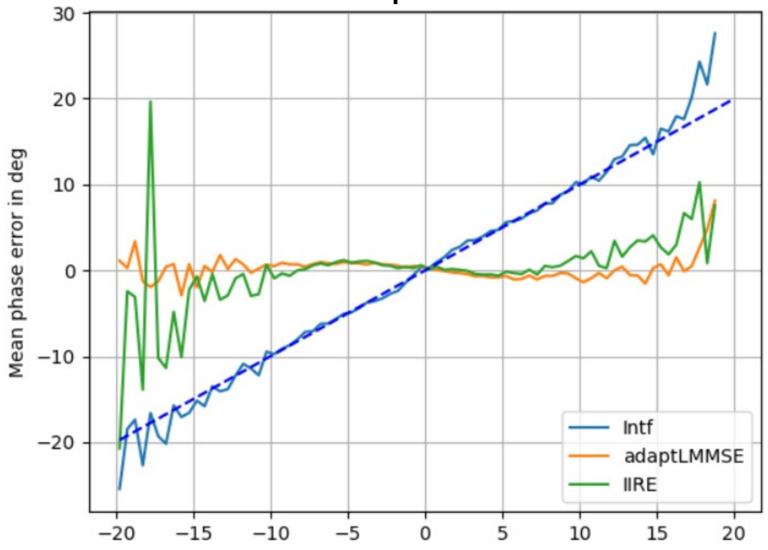






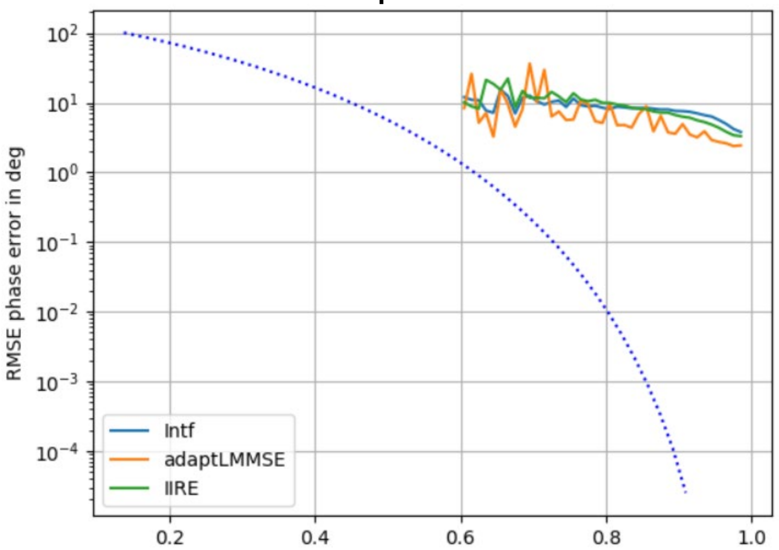


Median phase error



Estimated phase bias in deg

RMSE phase error



Estimated coherence

Conclusions

- Slowly spatially varying biases are well removed
  - Currents, smooth surfaces

- Evaluation sensitive to errors in reference data
  - Contributes with phase noise

- RMS error increases at medium to high coherences
  - Shows potential to improve

- Surface velocities show impact
  - How to cope with non-geometric geophysical (wave) Doppler?
  - Impact of waves and fine structures (within TSC product resolution)

Real data – Real Ambiguities … way forward