Robust Automated Residual Motion Correction for Repeat Pass SAR

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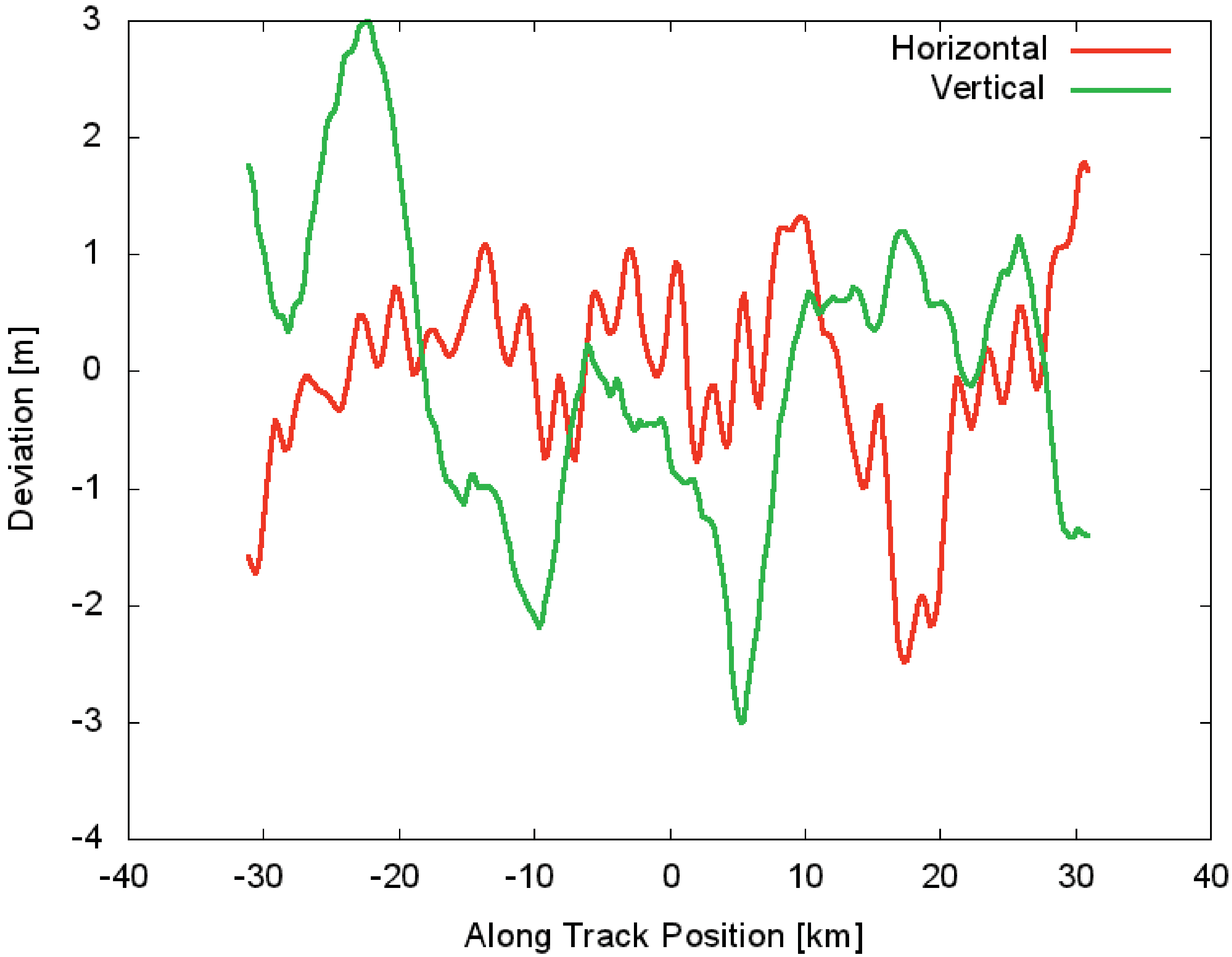
Outline

- Introduction to residual motion errors
- Mitigation strategy
- Measurement noise
- Improving robustness

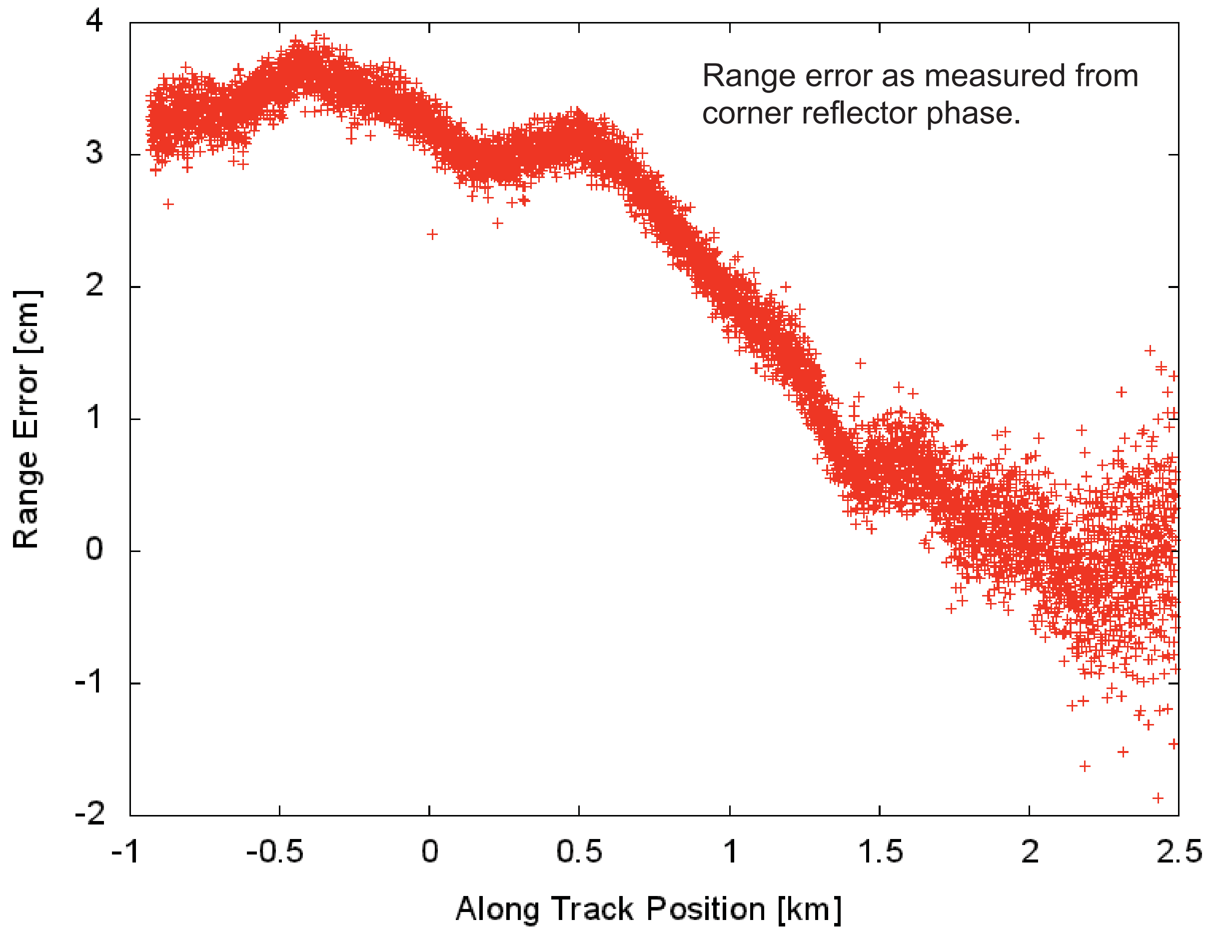
Residual Motion Errors

- Airborne SAR trajectories deviate significantly from desired flight path.
  - Requires topography- and aperture-dependent motion compensation.



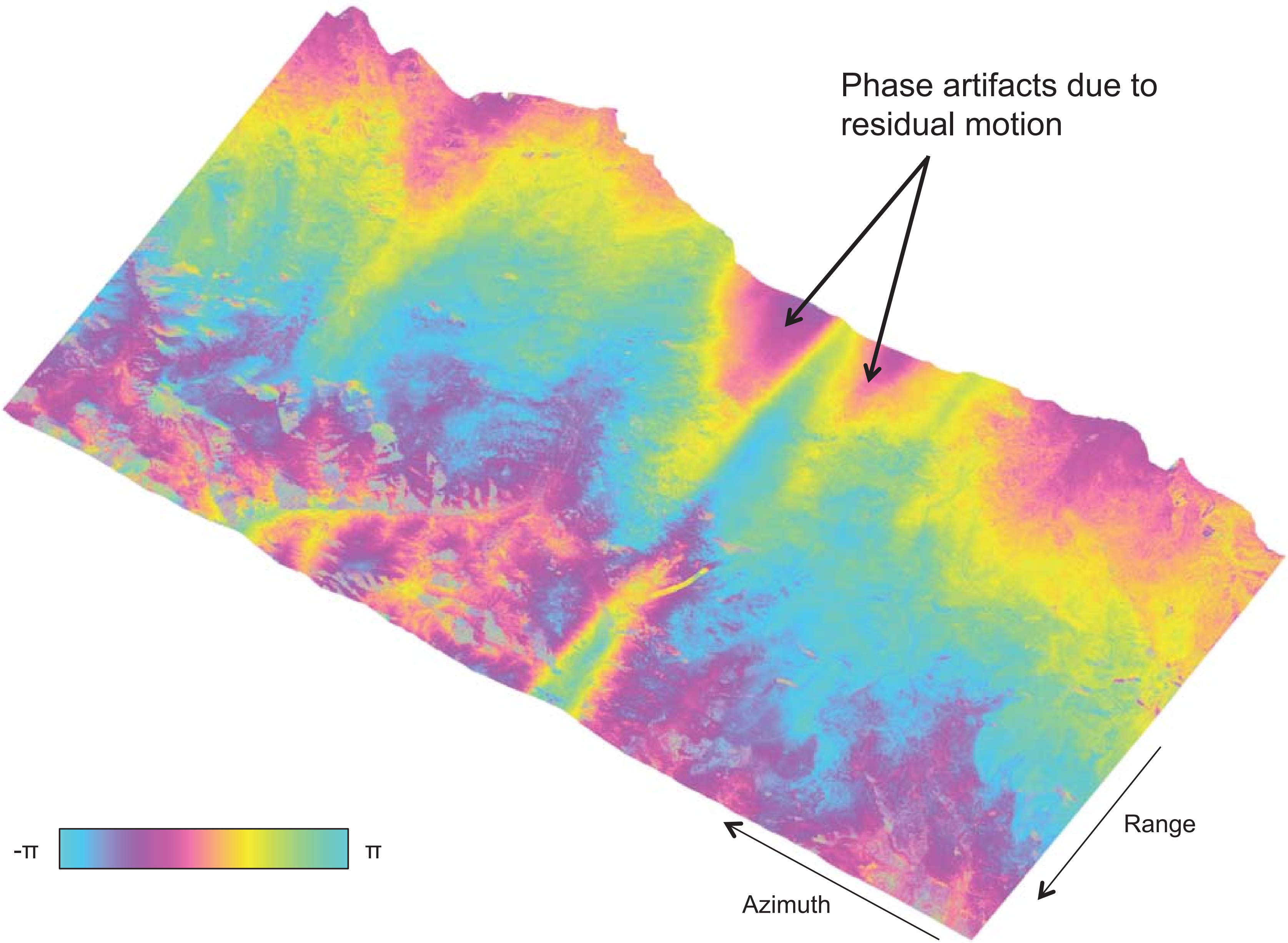
Residual Motion Errors

- Even with perfect motion compensation algorithms, limits of motion measurement accuracy present enormous challenges for exploitation of SAR phase
  - Post-processed GPS/INU position accuracy on the order of 5 cm
  - L-Band SAR wavelength of about 25 cm



Note: Corner position also subject to measurement error.

Residual Motion Errors



Residual Motion Correction

- Need a way to estimate motion errors from the data itself!
- Consider a simplified model
  - Linear motion
  - Linear motion error

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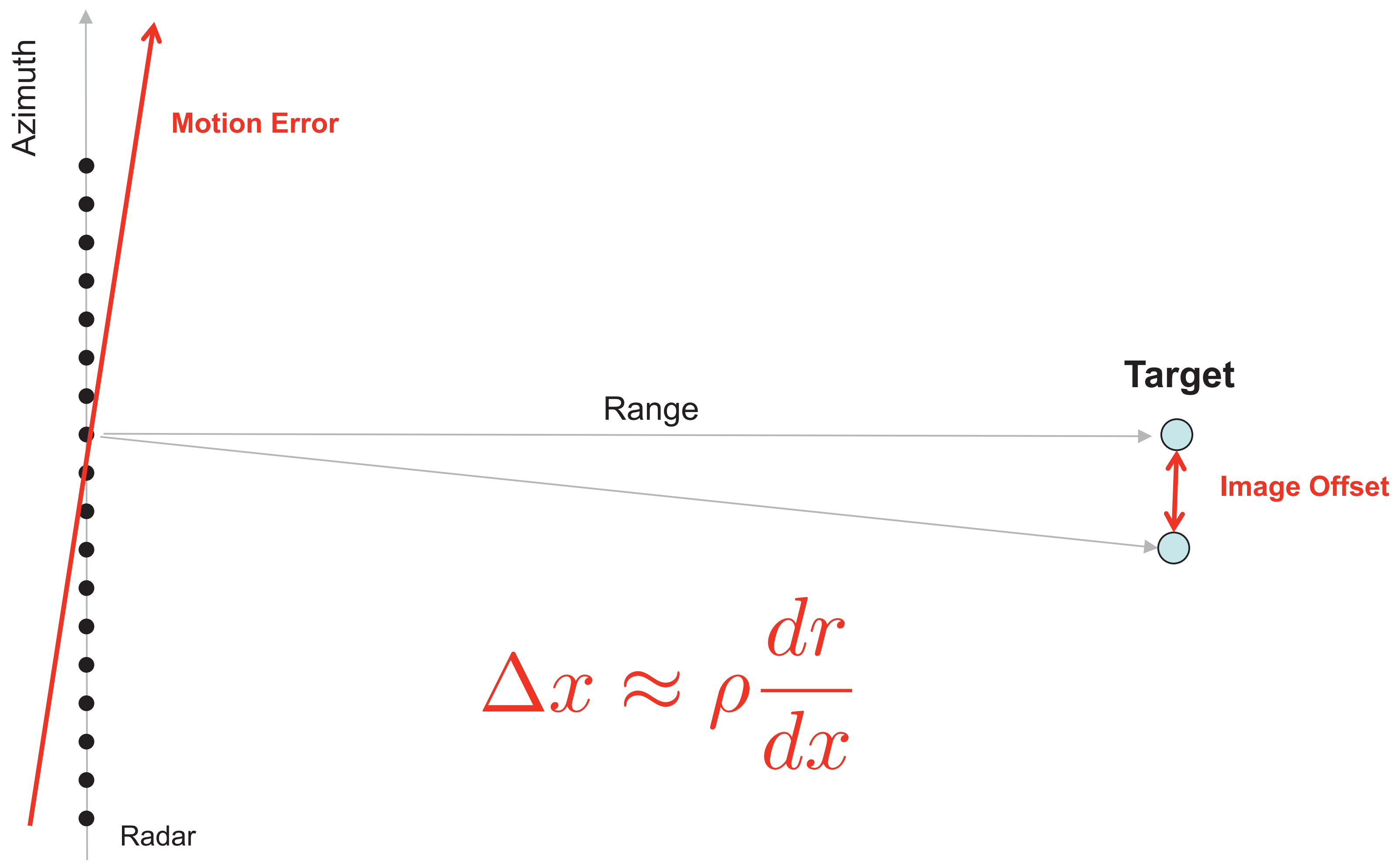


$$\Delta x \approx \rho \frac{dr}{dx}$$

Residual Motion Correction

- Linear part of position error shifts the SAR impulse response
  - Scaled by range, so small slopes (e.g., 1 cm per km) mean big offsets

- More complicated model used for UAVSAR
  - Range variation of squint and look angles
  - Electronically steered antenna

$$\Delta s = \left[\frac{\sin\alpha \langle \vec{b}, \hat{\ell} \rangle - \langle \vec{b}, M\hat{n} \rangle + \rho \hat{\ell}_c \frac{\partial b_c}{\partial s} + \rho \hat{\ell}_h \frac{\partial b_h}{\partial s}}{\langle \hat{v}, \hat{n} \rangle - \sin\alpha \langle \hat{v}, \hat{\ell} \rangle} \right] \langle \hat{v}, \hat{s} \rangle$$

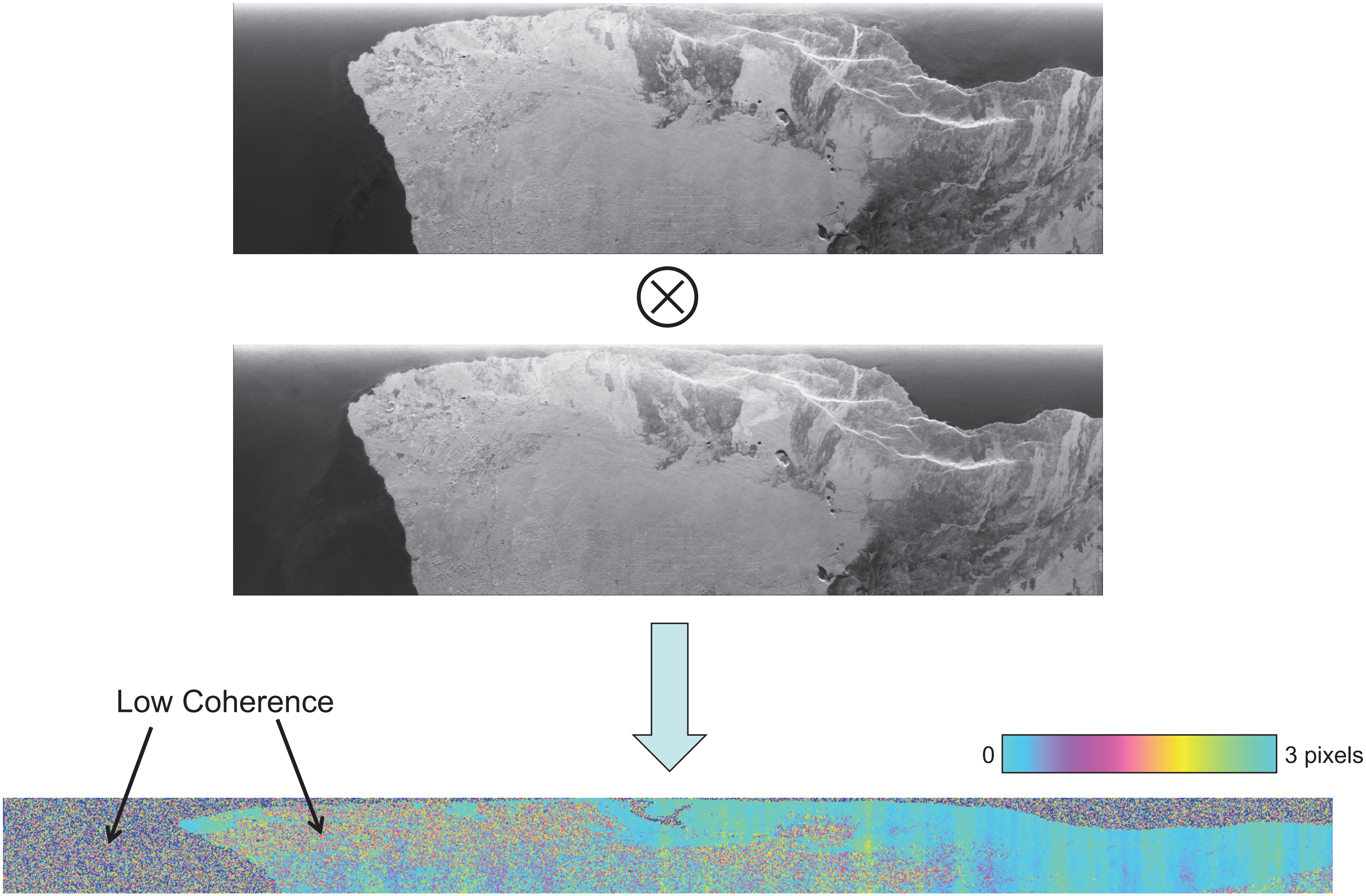
- Flavor is the same: slope of residual motion shifts the targets
- **Strategy: Measure shifts and invert the model**

Hensley *et al*, “Residual Motion Estimation for UAVSAR,” 2009 IEEE Radar Conference

Image Offsets

- Method requires measurement of geometric shifts.
- Obtain the measurement by incoherent cross-correlation of the images comprising the InSAR pair
  - Relative offset, so can only solve for relative motion
- Quality of motion estimates and InSAR products very sensitive to offset measurements
- Quality of offset measurement highly variable!
  - Cross-correlation accuracy naturally depends strongly on image coherence.
- **Need a way mitigate impact of bad offset measurements**

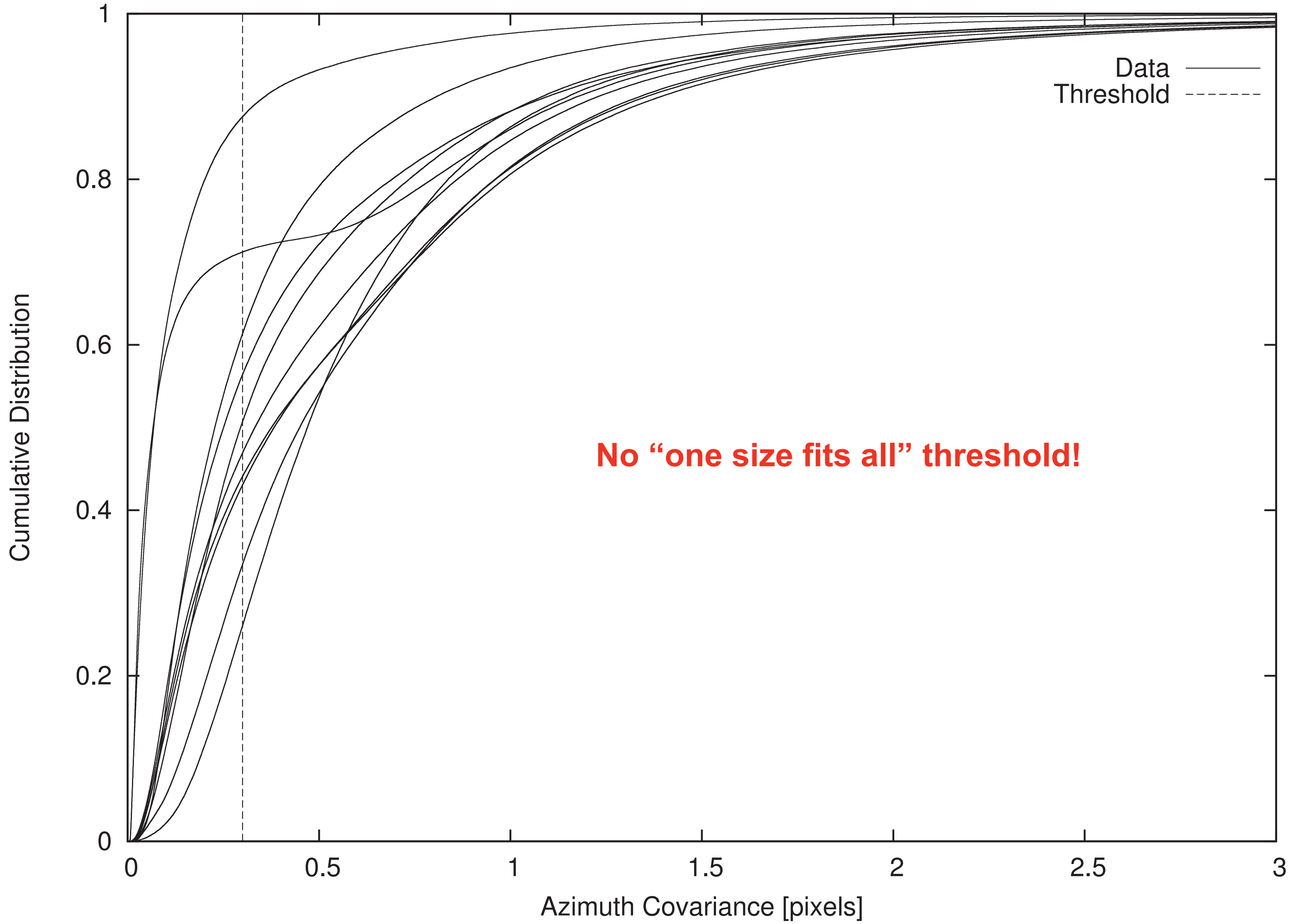
Image Offsets



Improving Robustness

- Simplest mitigation strategy is to mask data based on coherence threshold
  - Alternatively use estimated offset variance, closely related to coherence.
- Choice of threshold extremely important to residual motion estimation
  - Too low could pass too much noise
  - Too high could pass too little signal
- Challenging in a high-throughput environment
  - Limited *a priori* knowledge of scene statistics
  - Frequently requires hand-tuning for best results

Improving Robustness



Improving Robustness

- Should try to exploit the available data to infer an appropriate threshold.
- Heavy tails of offset distributions suggest a statistical approach
- Try a two-component ("good" and "bad") mixed-normal model of the cumulative distribution function

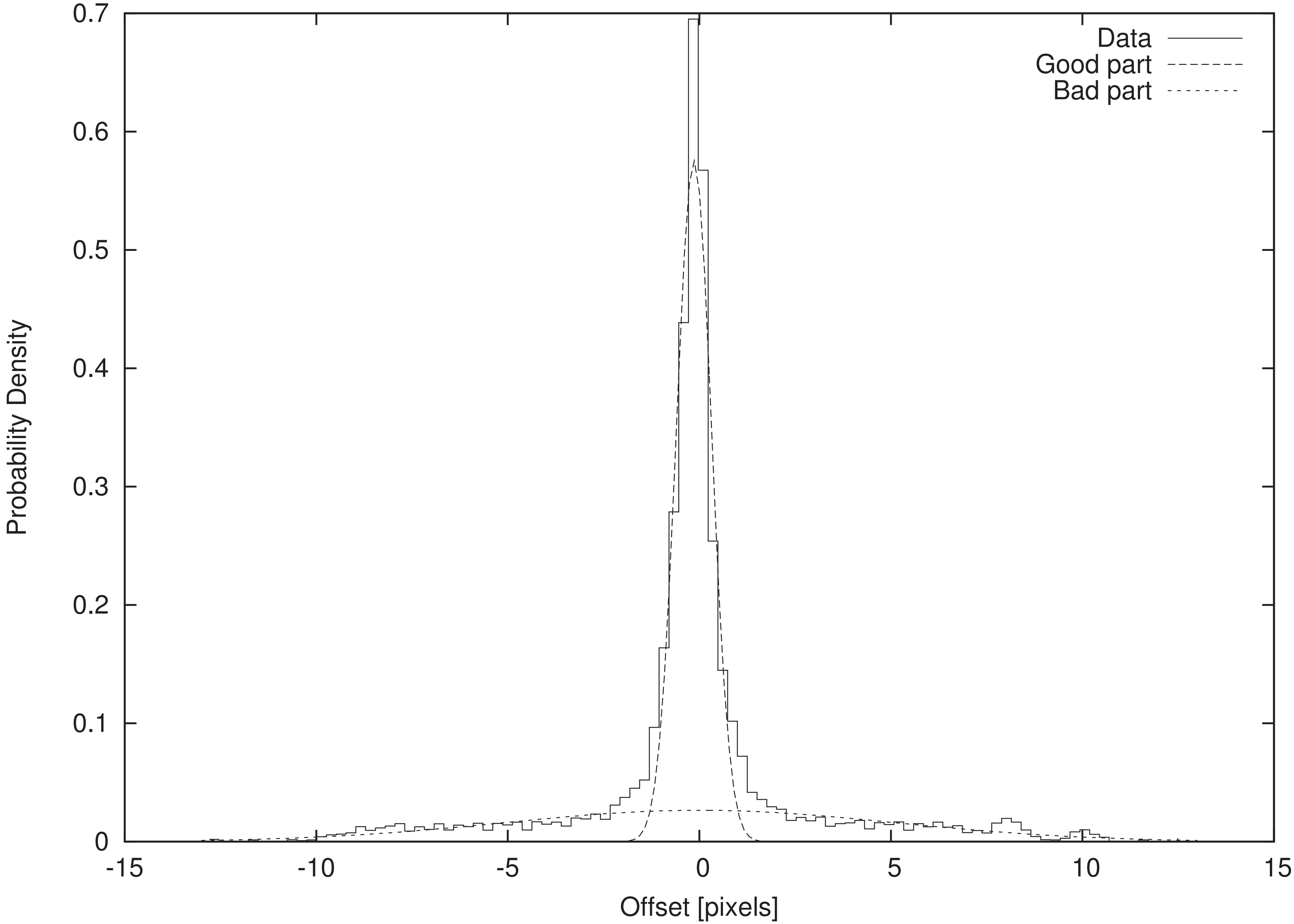
$$y(x) = (1 - \beta)\, \phi(x, \mu_g, \sigma_g) + \beta\, \phi(x, \mu_b, \sigma_b)$$

$$\phi(x, \mu, \sigma) = \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{x - \mu}{\sigma\sqrt{2}}\right)\right]$$

x is the offset
y is the offset CDF, estimated by sorting the data
β is the fraction of "bad" data
μ is the mean
σ is the standard deviation

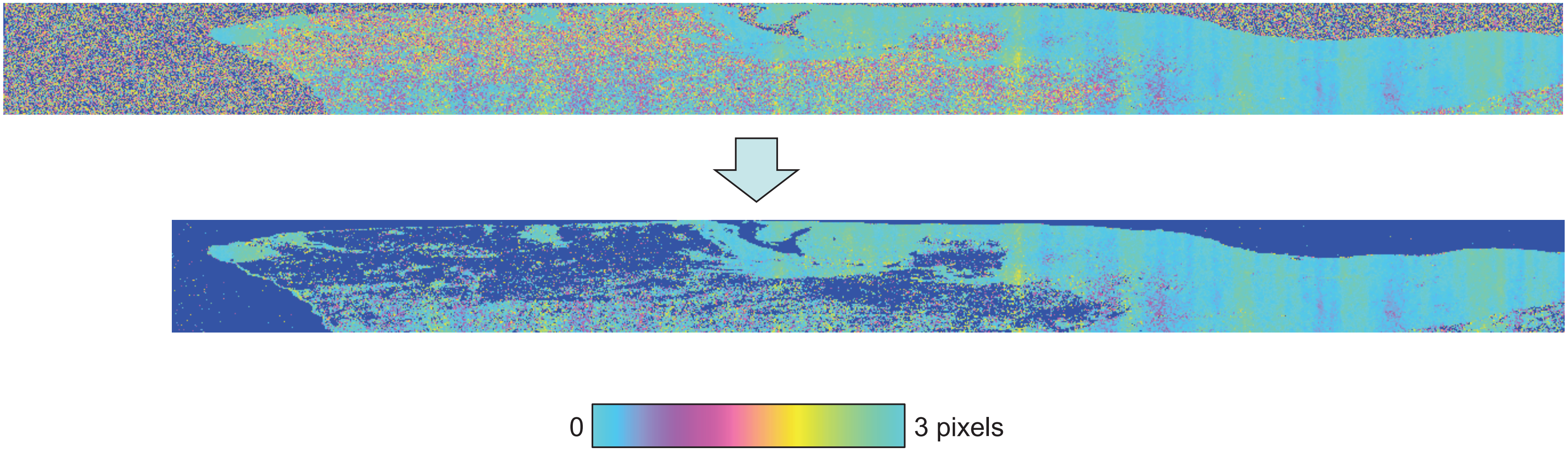
- Use the estimate of the amount of the "bad" component to pick the threshold

Improving Robustness



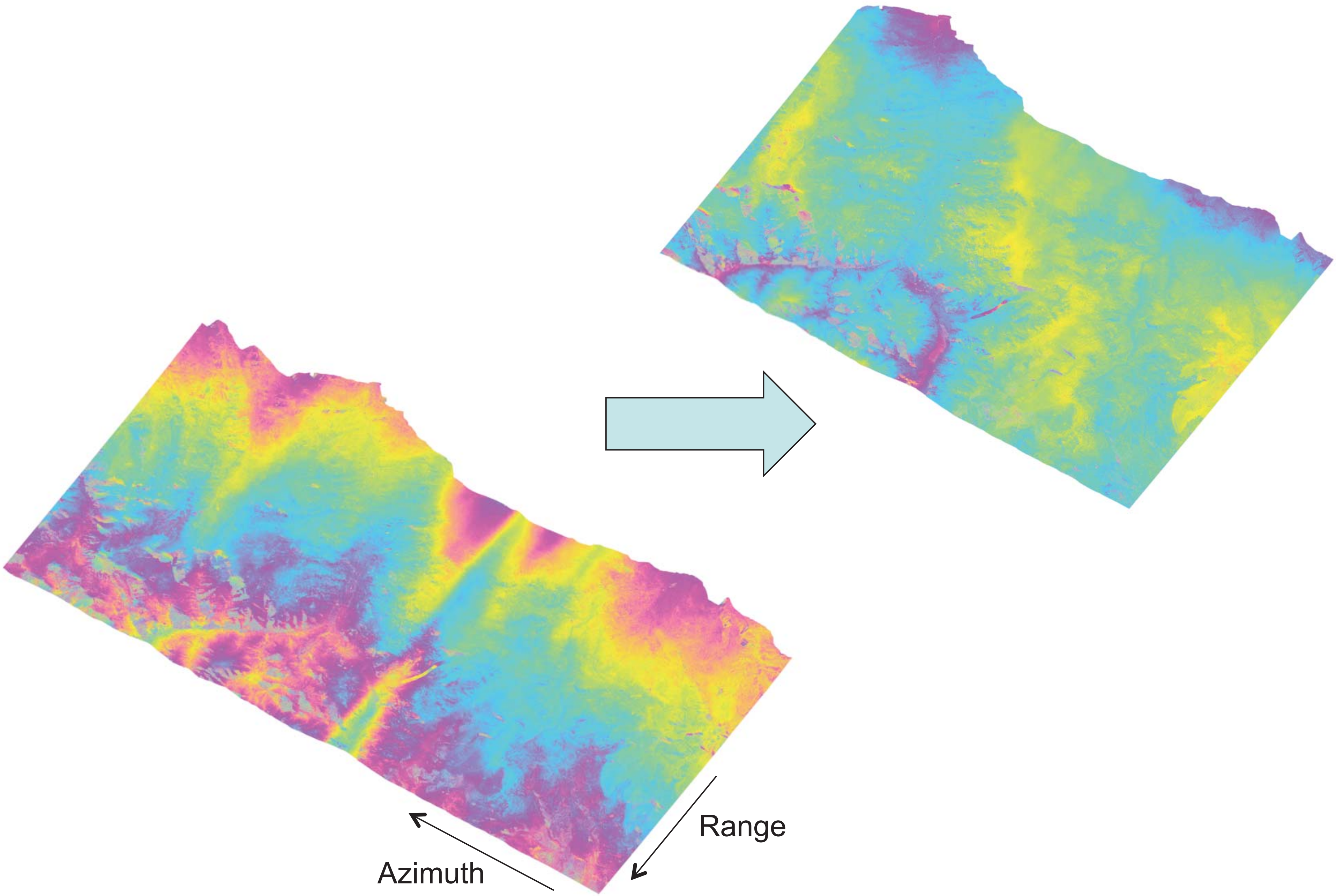
Improving Robustness

- Resulting thresholds prove satisfactory for a wide variety of scene types
- Eliminates need for time-consuming hand tuning of thresholds



Dark blue denotes culled data

Residual Motion Correction



Closing

- Questions / comments?