Wide Swath Simultaneous Measurements of Winds and Ocean Surface Currents

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Thanks!

- The JPL DFS/ERM team for design of the DFS/ERM scatterometer

- Bertrand Chapron (IFREMER) and Frabrice Collard (CLS) for discussions of surface current measurements from SAR Doppler

Motivation

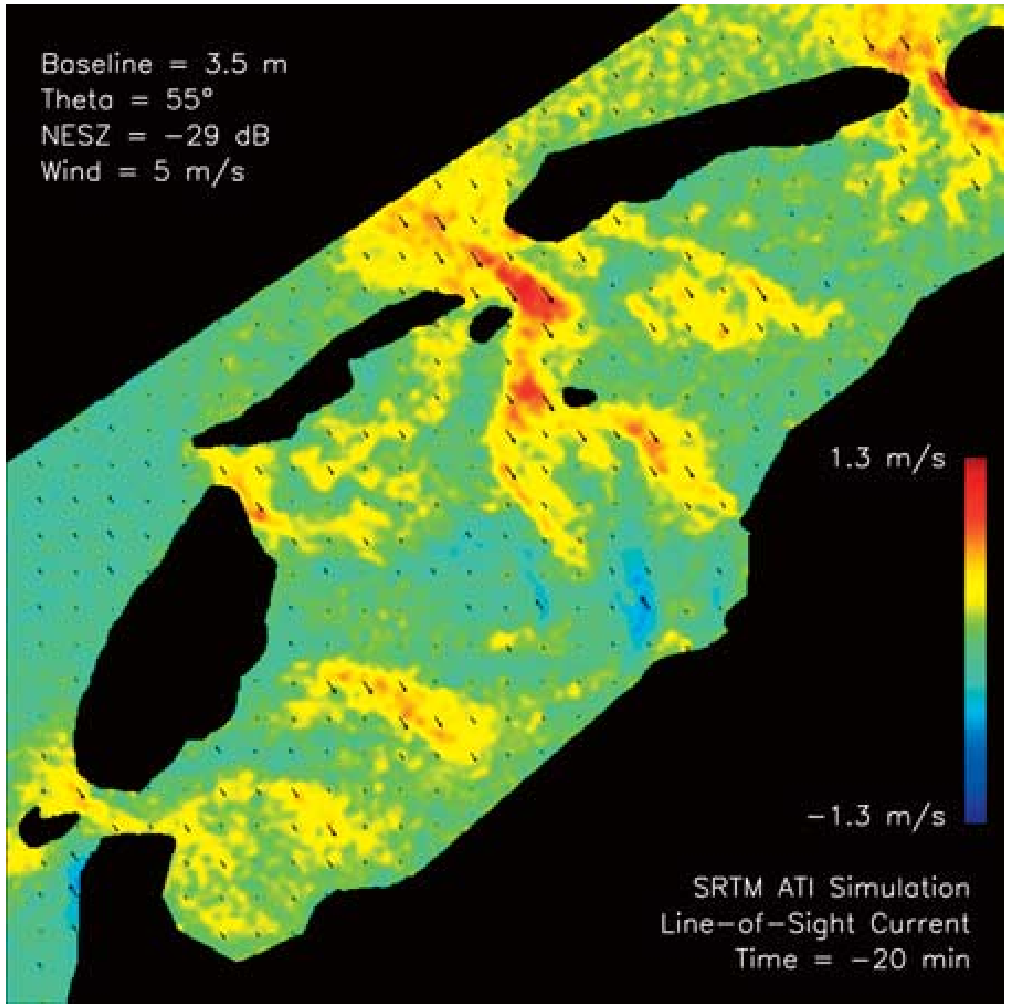
- Ocean surface currents are one of the key variables in ocean circulation:
  - heat transport and surfaces fluxes
  - impact ocean productivity and marine biological communities
  - social impacts: disaster management, shipping
- There is an intrinsic two-way coupling between ocean currents and surface winds
  - Surface currents modulate wind stress through kinematic effects and SST wind modulations
  - Variations in surface winds can have a significant impact on vertical circulation and the mixed layer
- There are currently no planned global direct measurements of surface currents
  - SWOT and altimeters measure geostrophic components (optimal interpolation required for nadir altimeters)
  - Ekman component indirectly inferred from scatterometer winds (OSCAR, CTOH)
- ***Is there a cost efficient way to measure global surface winds and currents simultaneously?***

Ground Rules

- No new mission called for: propose a low cost enhancement to current state of the art scatterometers
  - Use the Ku-band portion of the DFS scatterometer candidate for GCOM-W2
- Demonstration to show feasibility and a long-term upgrade path
- Measurement goals (same order of magnitude as OSCAR, TCOH)
  - Spatial resolution: 25 km
  - Measurements collected simultaneously with the wind (about 2x per day)
  - Final data product averaged over 10 days
  - Wind component error O(10 cm/s) or better

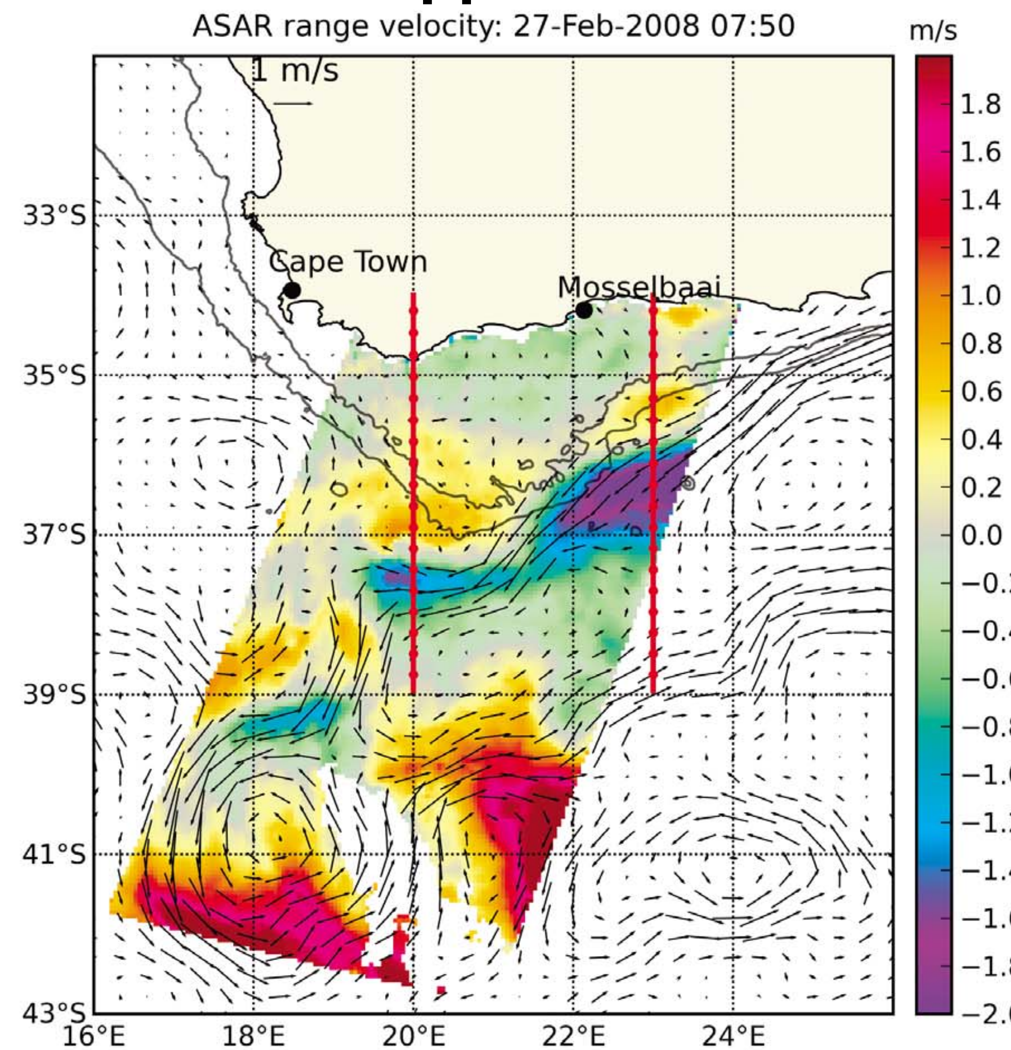
Limitations of Measurements to Date

Along-track Interferometry



R. Romeiser, H. Breit, M. Eineder, H. Runge, P. Flament, K. De Jong, and J. Vogelzang, "Current measurements by sar along-track interferometry from a space shuttle," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 43, no. 10, pp. 2315–2324, 2005.

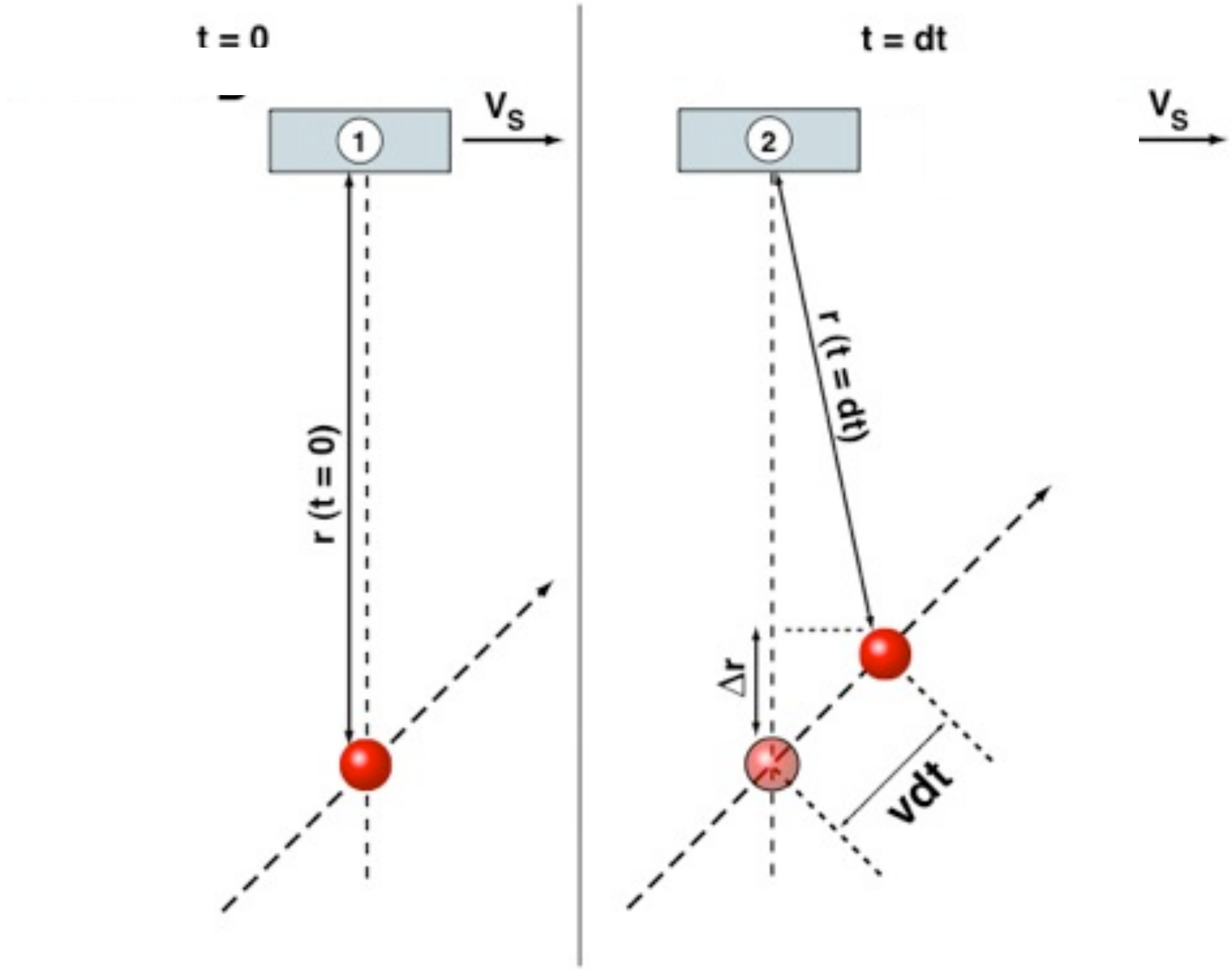
SAR Doppler Centroid

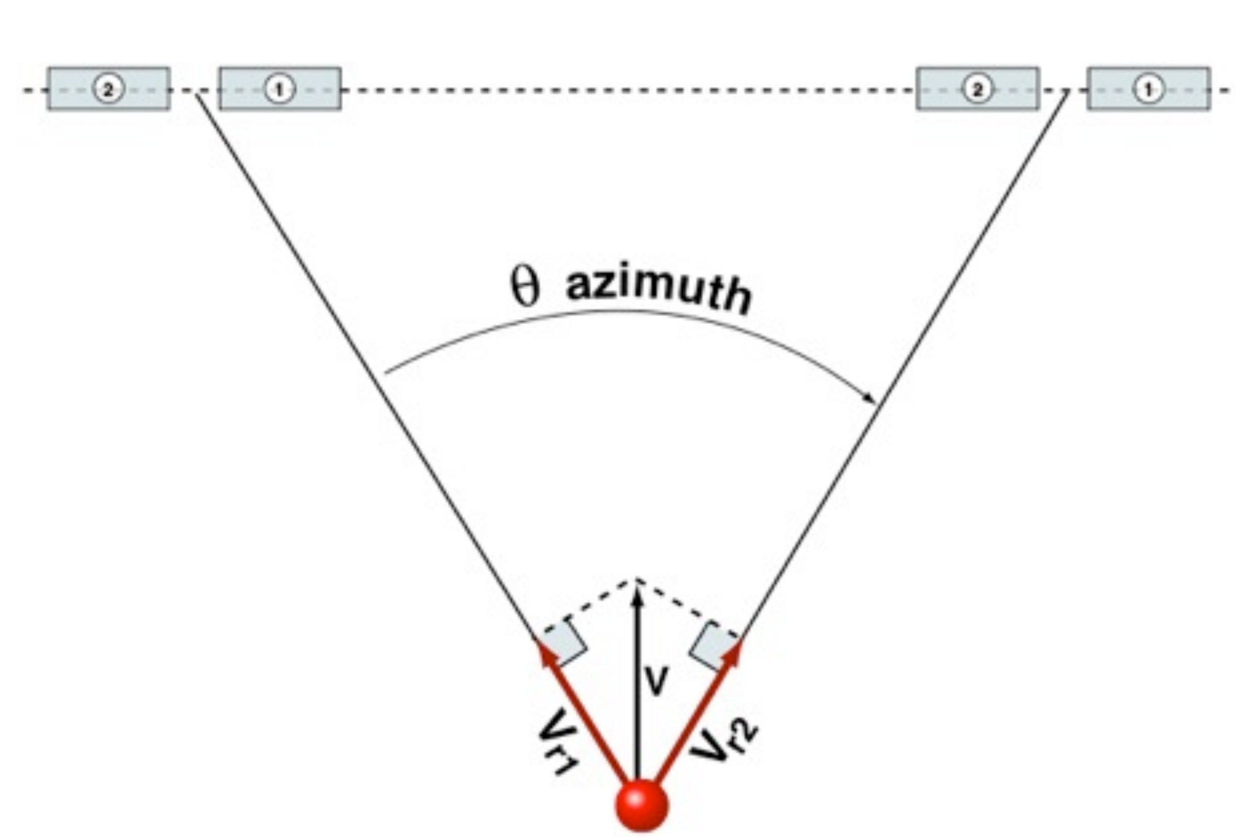


M. Rouault, A. Mouche, F. Collard, J. Johannessen, and B. Chapron, "Mapping the agulhas current from space: An assessment of asar surface current velocities," *Journal of Geophysical Research (Oceans)*, vol. 115, no. C14, p. 10026, 2010.

- The line of sight component of the surface current has been measured from space using ATI and SAR Doppler centroids
- These techniques are very expensive, measure only one component, have a very limited swath, and it is very expensive to collect global data (high data rate and power).
- To get from Dopplers to surface velocity (Chapron et al., 2005) it is necessary (and sufficient) to have coincident winds. The accuracy is limited when model winds are used.

Measurement Concept





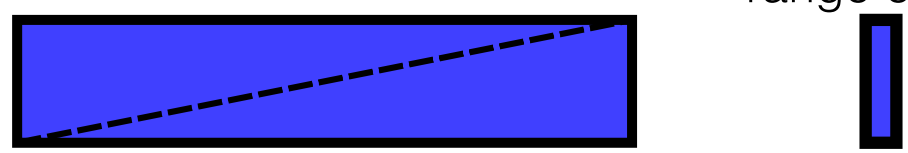
Pulse-pair Phase Difference: $\Delta\Phi = 2k\Delta r$

Radial velocity component: $v_r = \Delta r/dt = \Delta\Phi/(2kdt)$

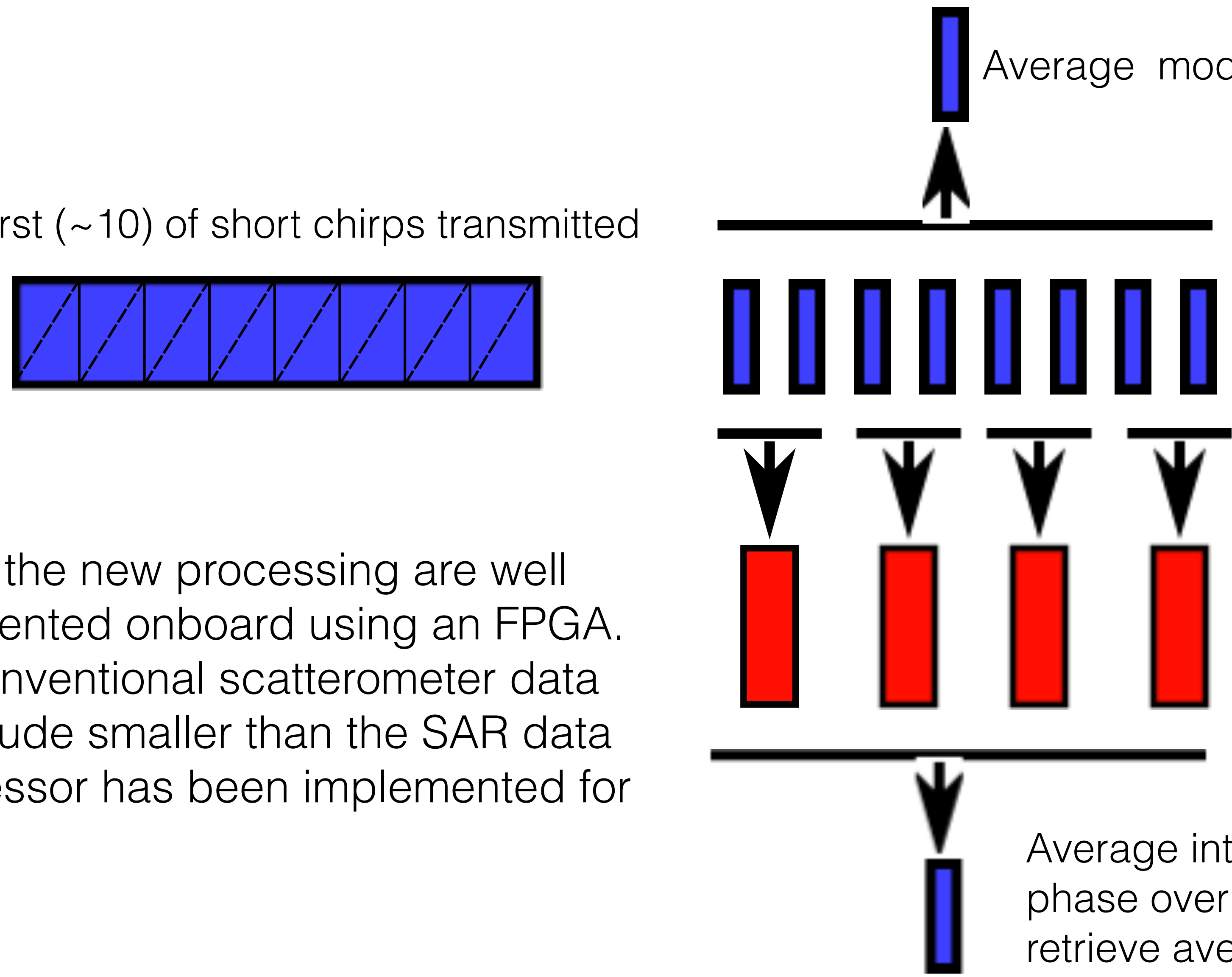
Vector currents are estimated by combining multiple (2-4) radial velocity measurements

- Conventional scatterometers transmit a long (1.5 msec) pulse
- Transmit instead N (~10) closely spaced shorter duration pulses with the same bandwidth (spatial resolution) and estimate Doppler by comparing return pulse phase differences.

Conventional Scatterometer



Doppler Scatterometer



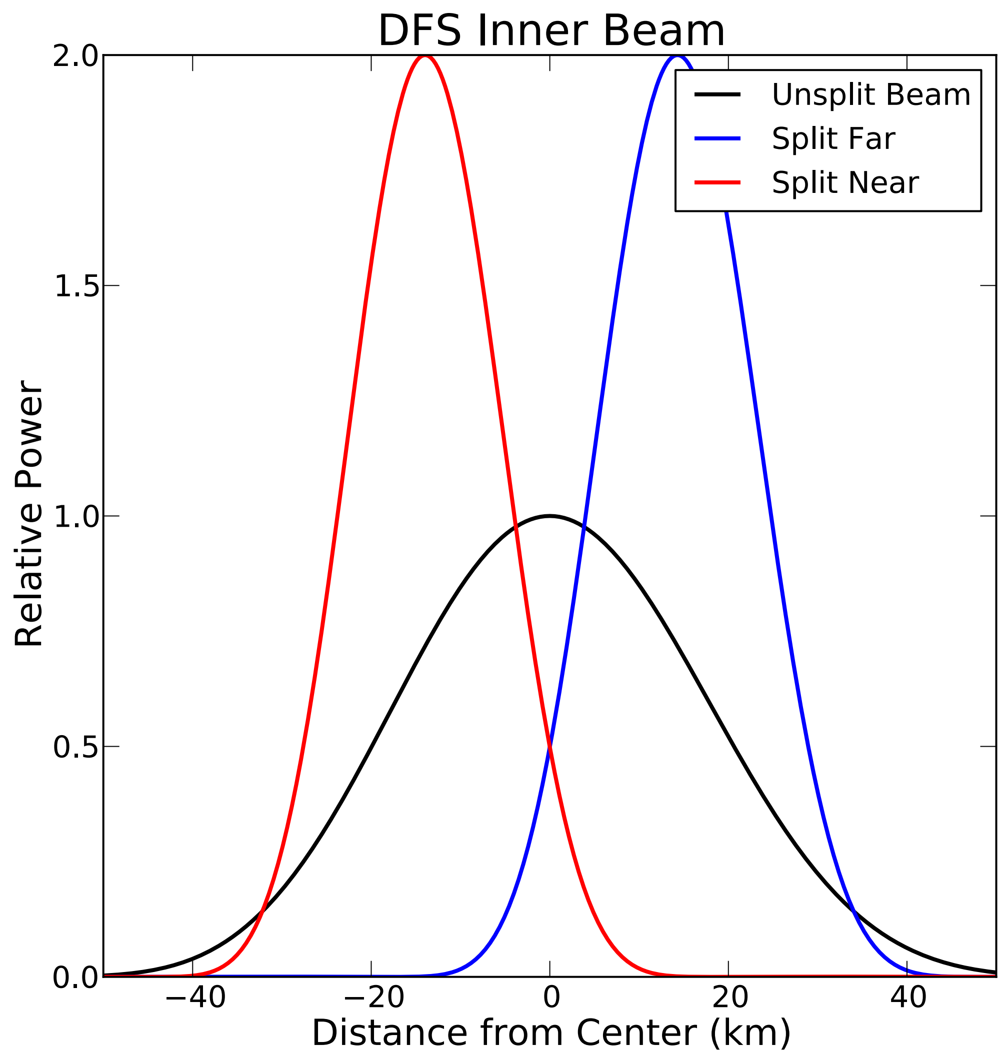
The added processing steps in the new processing are well understood and can be implemented onboard using an FPGA. The final data rate is ~2x the conventional scatterometer data rate and many orders of magnitude smaller than the SAR data rate. A more complicated processor has been implemented for SWOT.

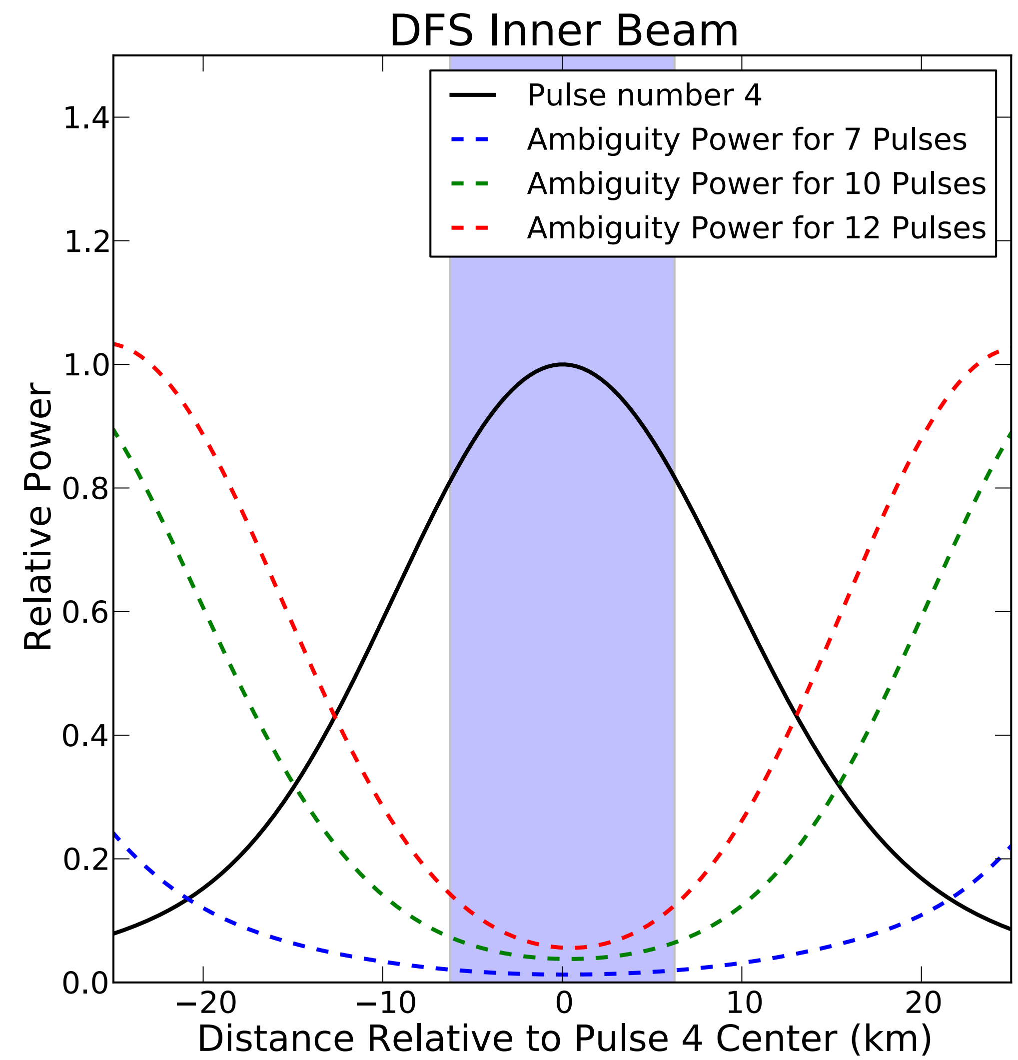
- Range ambiguities: can two pulses from different places arrive at the same time?

- Doppler bandwidth: is the phase coming from pulse to pulse correlated?

- When you chop the transmit pulse into smaller pulses, you lose SNR but gain looks: what will be the effect on retrieved winds?

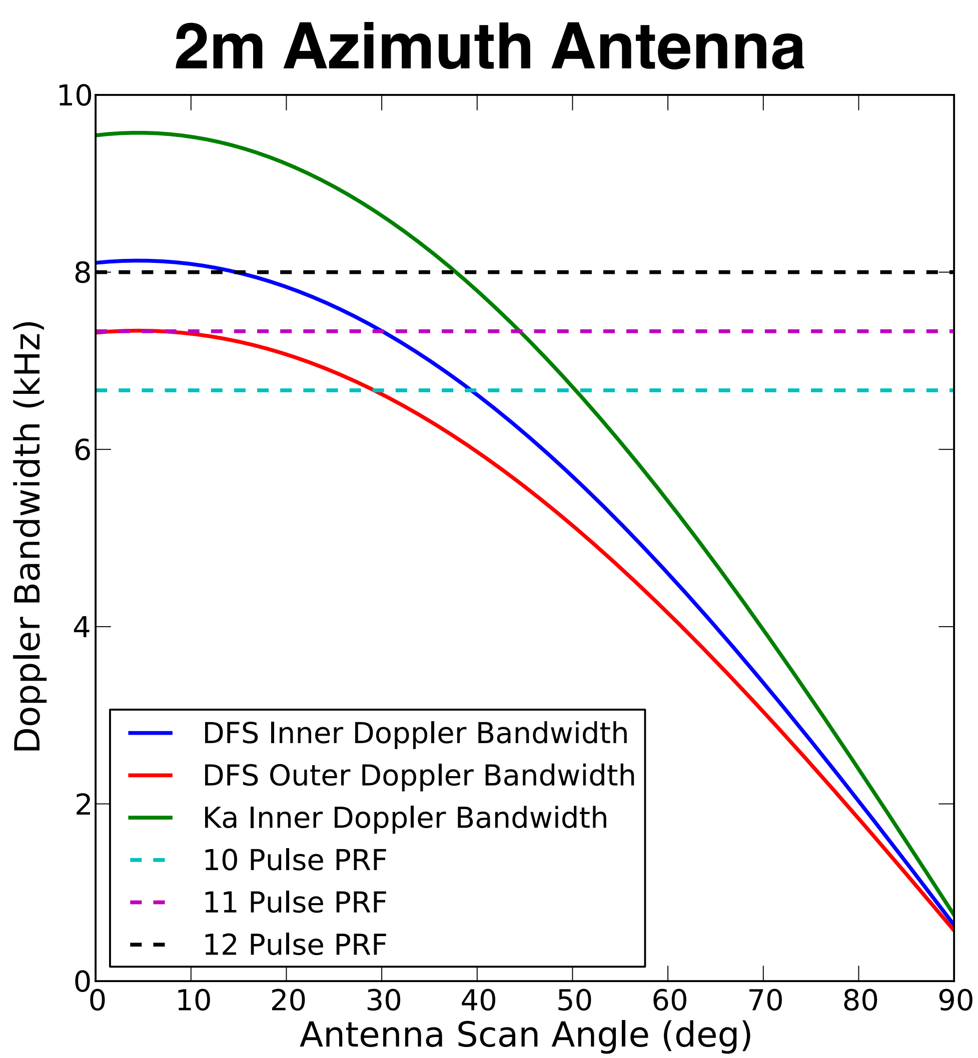
Splitting the Beam to Reduce Range Ambiguities

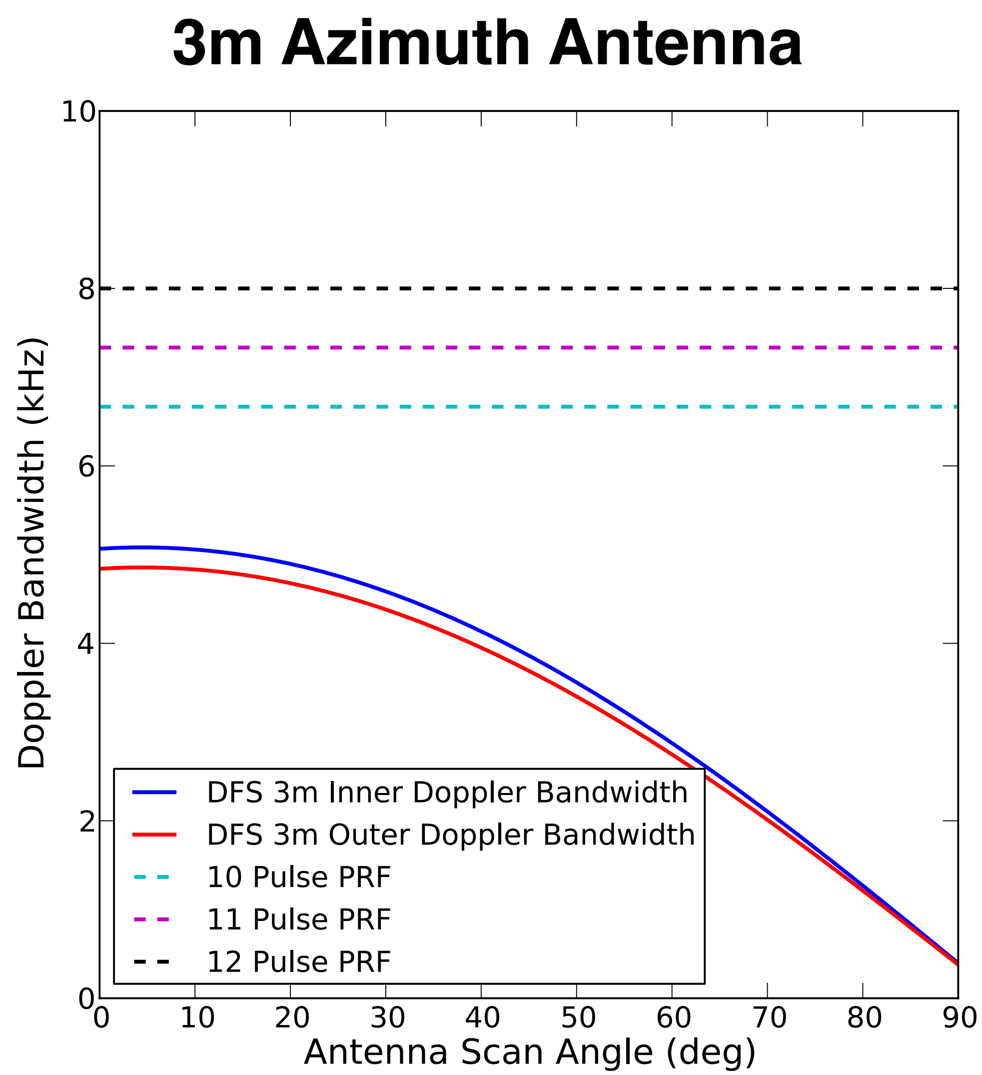




- The DFS footprint is too large to accommodate the high PRF needed to sample the Doppler appropriately
- Solution: increase the antenna height from ~1m to about ~2m (equal to azimuth width) to narrow the beamwidth by 2 and use contiguous H and V feeds to cover the same footprint. (This applies to both beams.)
- Restrict the processed area to that area with low enough range ambiguities.

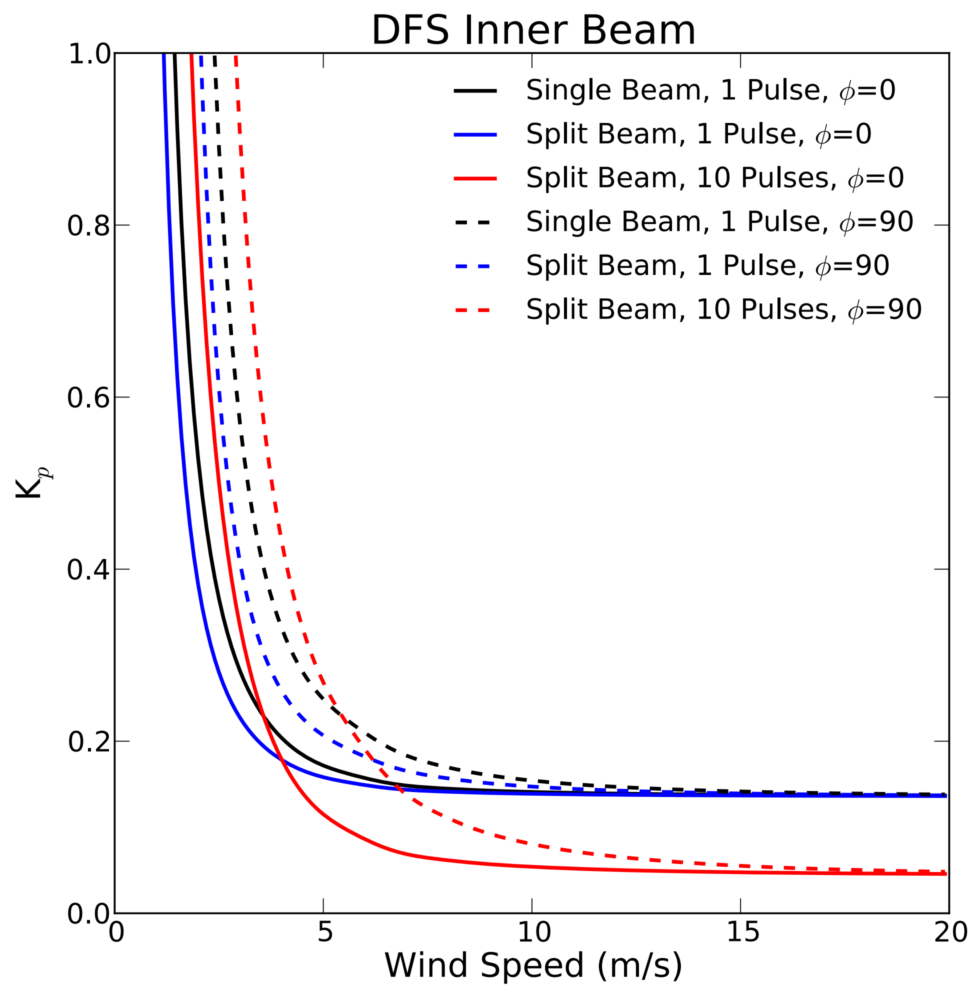
Doppler Bandwidth vs Scan Angle

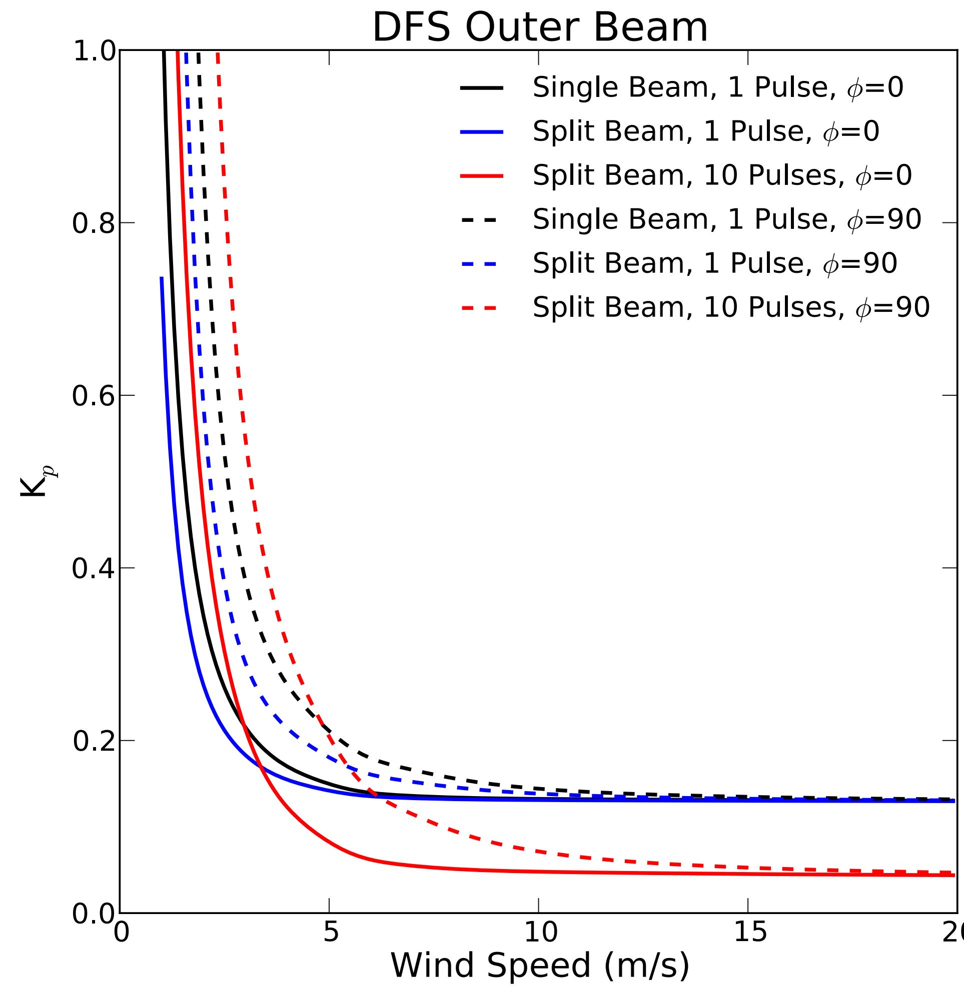




- The ocean Doppler has a finite bandwidth due (mostly) to the spread in angles in the azimuth direction. The PRF must be high enough to sample this bandwidth appropriately.
- The Doppler bandwidth decreases with scan angle, so by restricting the swath one can sample the signal adequately, even for an antenna that is “too small”.
- Restricting to angles above 30 degrees leads to reducing the swath by less than 20%.

Effect of SNR/Looks Trade for Scatterometry



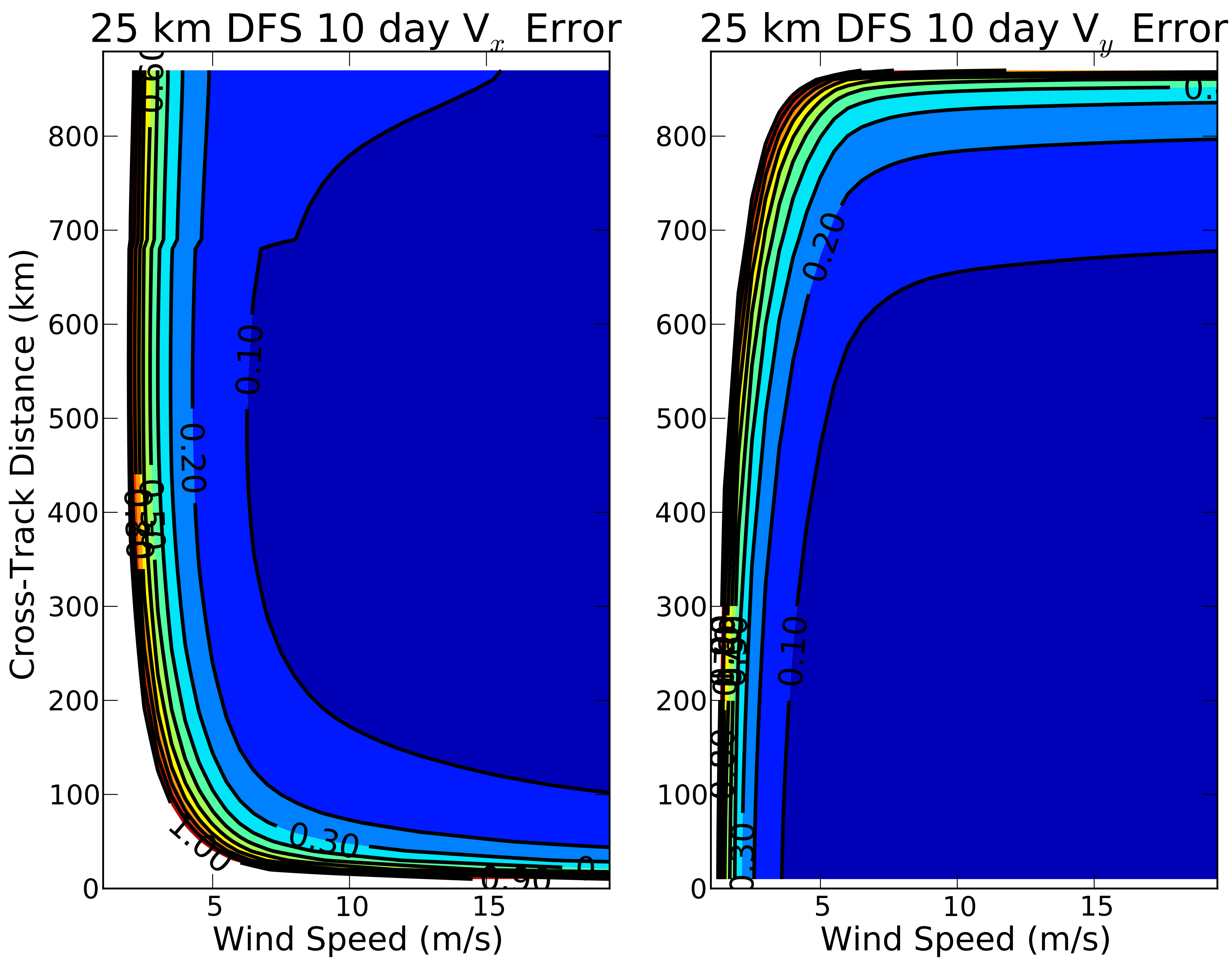


Wind retrieval performance is determined by

$$K_p = \frac{< \sigma_0^2 >^{1/2}}{< \sigma_0 >} = \frac{1}{\sqrt{N}} \sqrt{1 + \frac{2}{SNR} + \frac{1}{SNR^2}}$$

This optimized when N is equal to the SNR when only one pulse is used. For wind speeds above ~5 m/s, the performance actually improves when many smaller pulses are used.

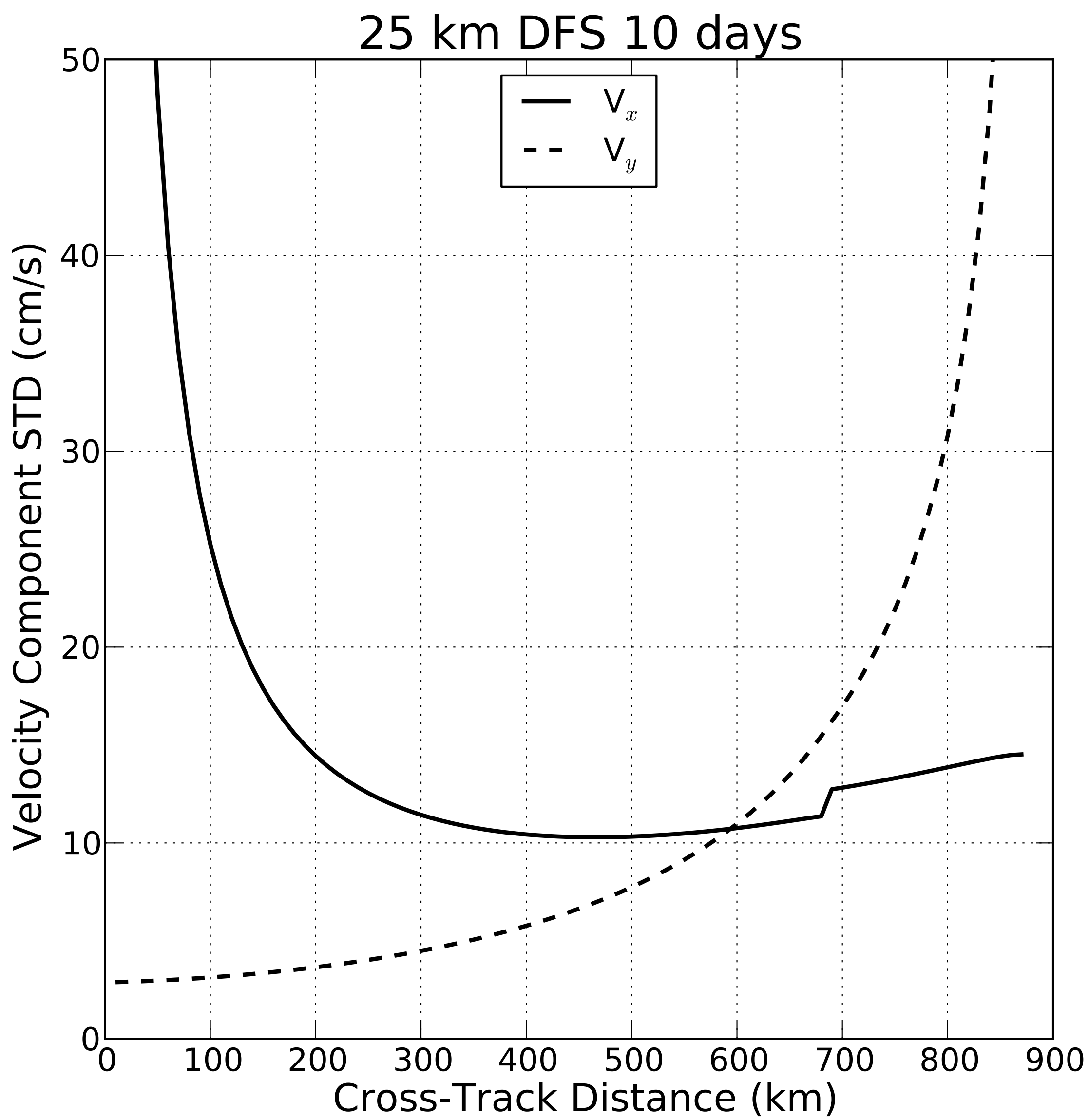
Velocity Component Errors



- Footprint size: ~12 km
- Averaging to 25 km done after surface current vector estimation.
- Vector current estimation assumes 4 (or 2 outer swath) azimuth looks. In practice, more are obtained with typical scatterometer coverage.
- Averaging to 10 day sampling done assuming typical global scatterometer revisit time to estimate the number of samples over the averaging time.

V_x is the across-track (~zonal) component.
V_y is the along-track (~meridional) component.

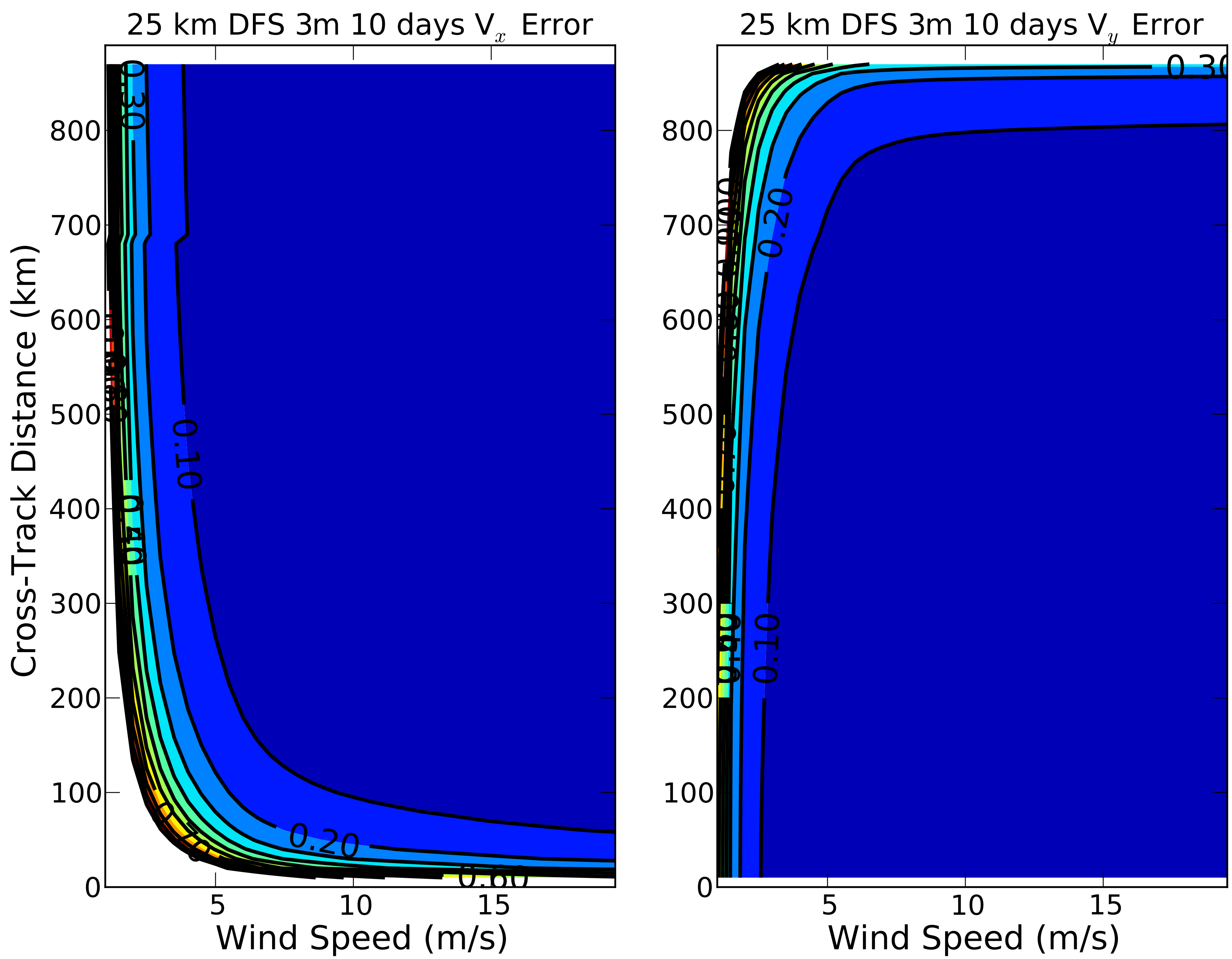
Wind Averaged Component Errors



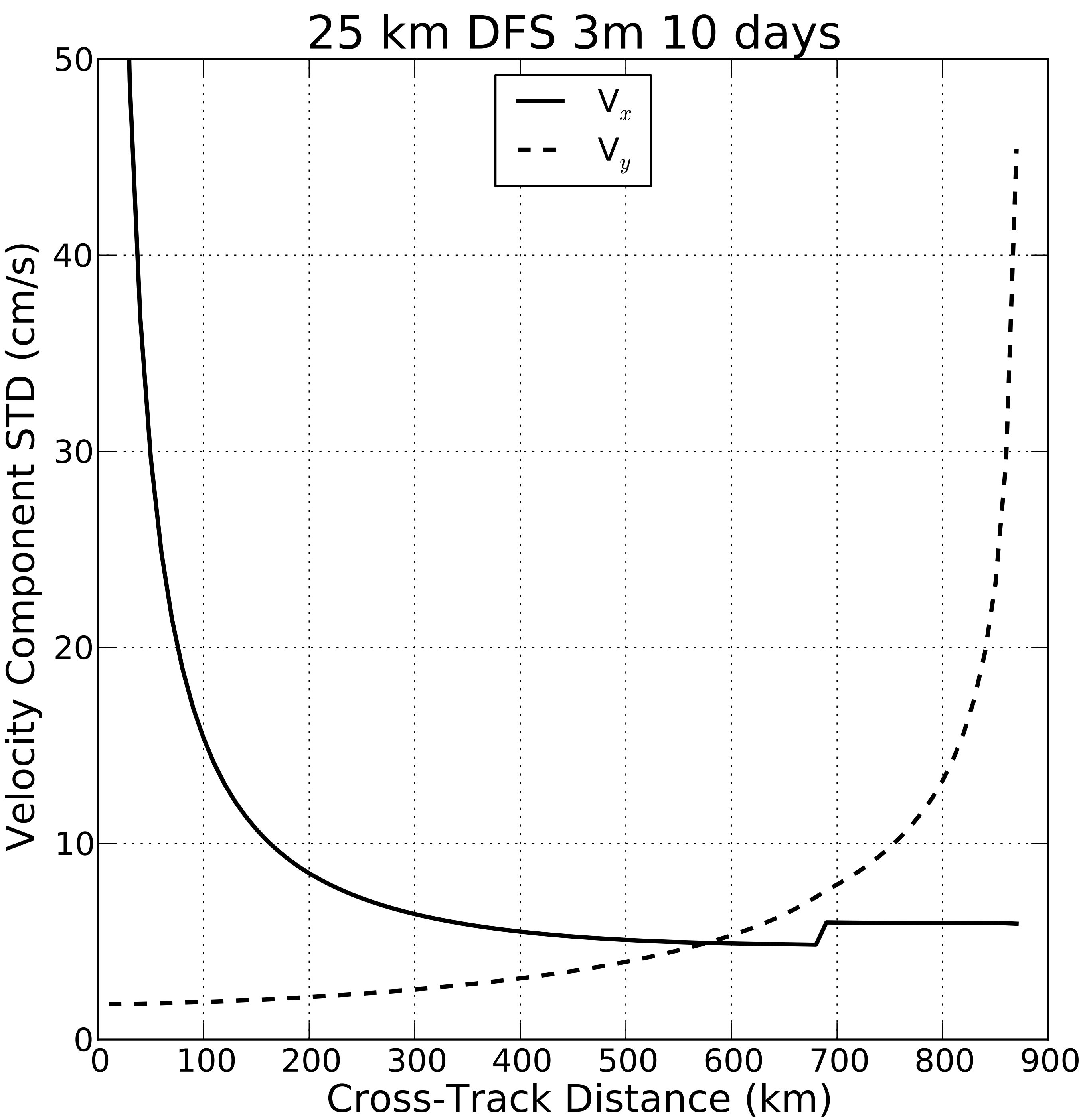
To avoid lack of sensitivity at low wind speeds, restrict surface current (but not wind) retrievals for winds above 5 m/s.

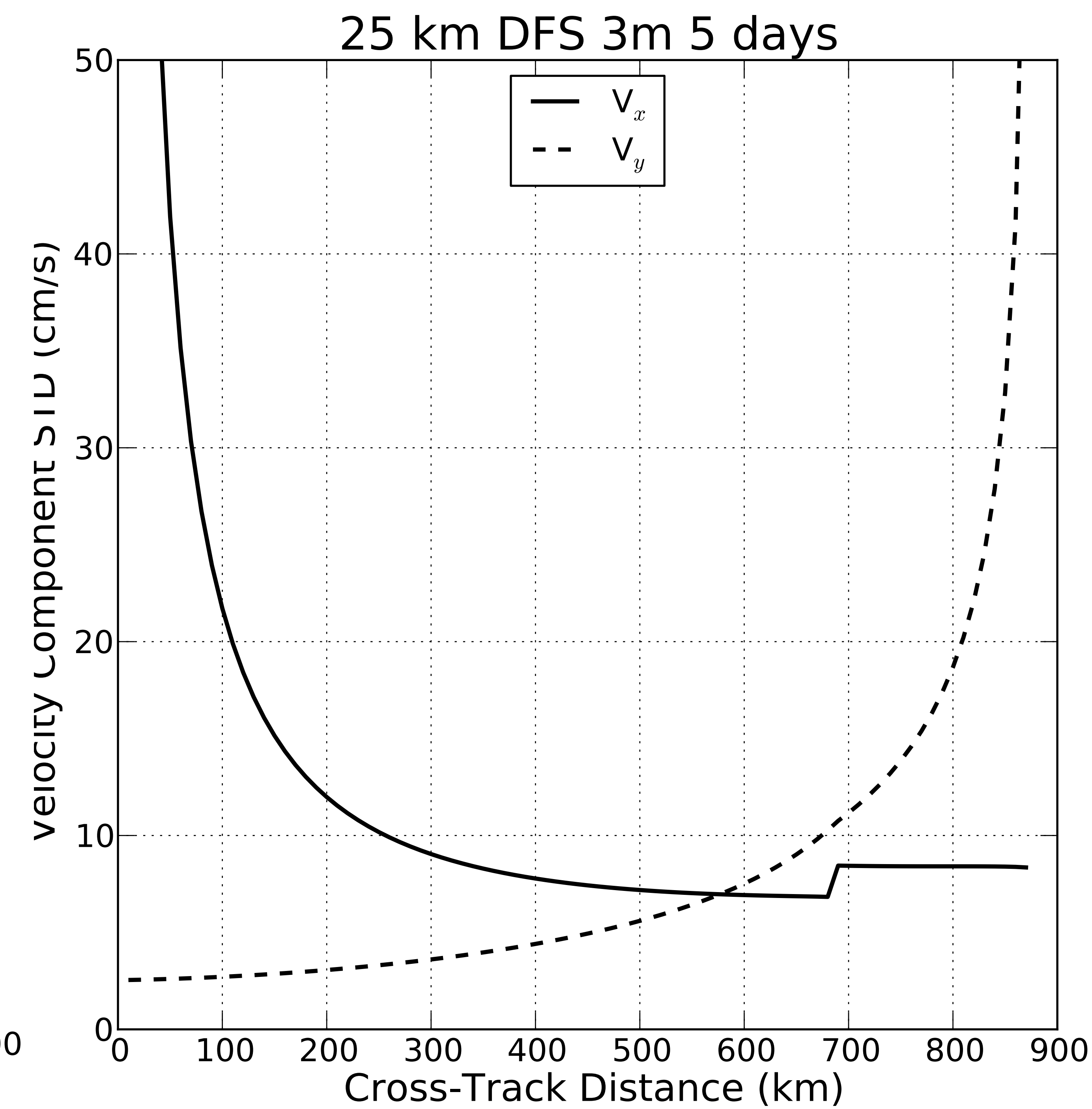
Account for this in the number of samples in 10 days by assuming a Rayleigh distribution for the winds.

Component Errors: 3 m Antenna



Wind Averaged Component Errors: 3m





Conclusions

- It is possible to incorporate a ocean surface current measurement together with a scatterometer measurement with relatively small changes to a pencil beam scatterometer design.
- The accuracies that can be achieved by modifying the existing DFS design are compatible with measuring many interesting ocean and coastal features.
- Further improvements could be achieved by going to a wider antenna or, potentially, going to a Ka-band design.
- Detailed designs for these higher capability features have not been performed yet. The DFS design has significant heritage and review, so the modifications proposed should be feasible.