The Prospects for Future Satellite Mapping of Mesoscale and Submesoscale Vorticity

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Future Satellite Instruments for Observations of Mesoscale to Submesoscale Variability

1. Surface Water and Ocean Topography Mission

SWOT will observe SSH across a swath of width 120 km with a 20 km nadir gap, a footprint size of 1 km and a measurement error of 2.74 cm. The scheduled launch date is 2021.

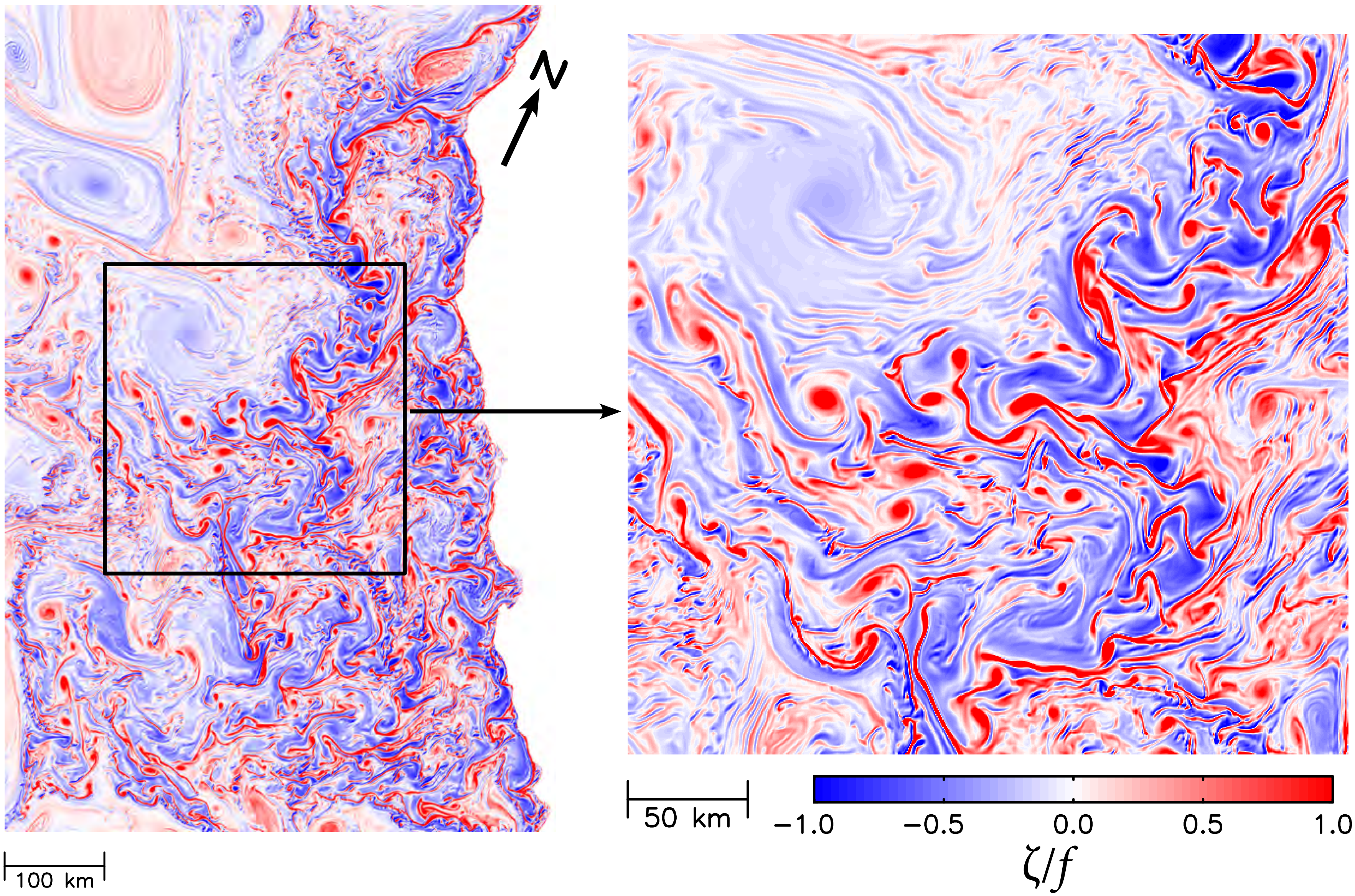
This requires <u>double</u> differentiation to get geostrophic vorticity ζ_g.

2. Winds and Currents Mission Concept

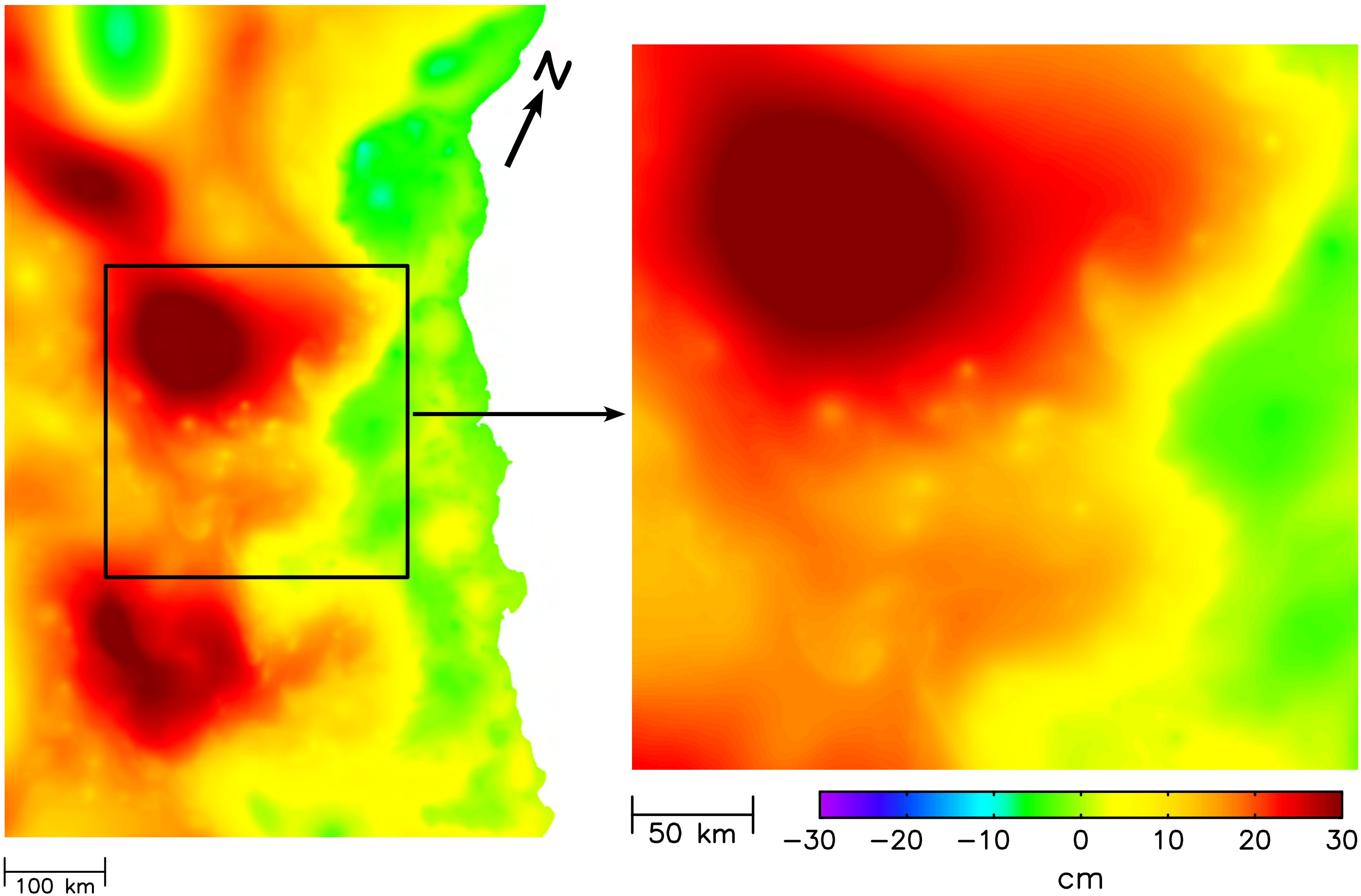
WaCM will observe surface winds and surface ocean velocity across a swath of width 1300 km with a 100 km nadir gap and a footprint size of 5 km. The baseline measurement errors are 0.5 m/s for surface currents. WaCM is under consideration for the <u>Decadal Survey for Earth Science from Space</u>. The earliest possible launch date is 2023.

This requires <u>single</u> differentiation to get vorticity ζ and is not subject to limitations of the geostrophic approximation.

Vorticity from a Model of the CCS with 0.5 km Grid, Smoothed to 1 km Resolution of SWOT



Sea Surface Height from a Model of the CCS with 0.5 km Grid, Smoothed to 1 km Resolution of SWOT



SWOT and WaCM Error Standard Deviations

	SWOT with 1 km footprint	SWOT with 5 km footprint	WaCM with 5 km footprint
SSH	2.74 cm	0.56 cm	--
u,v	2.17 m/s	0.29 m/s	0.35 m/s
speed	3.07 m/s	0.41 m/s	0.50 m/s
ζ/f	39.1	4.1	2.9

SWOT and WaCM data clearly must be smoothed to reduce these large errors!!!

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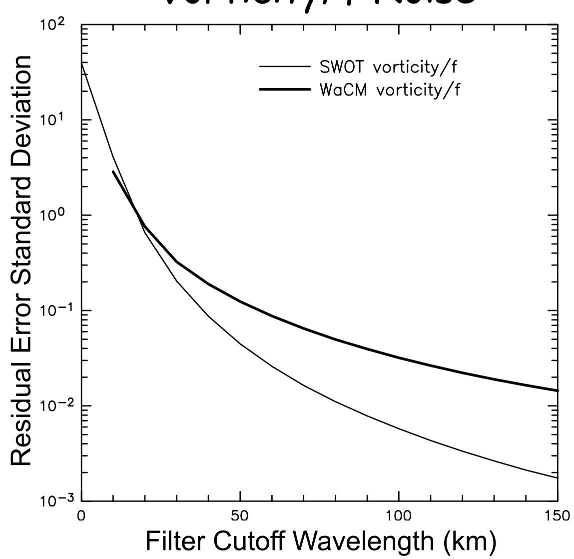
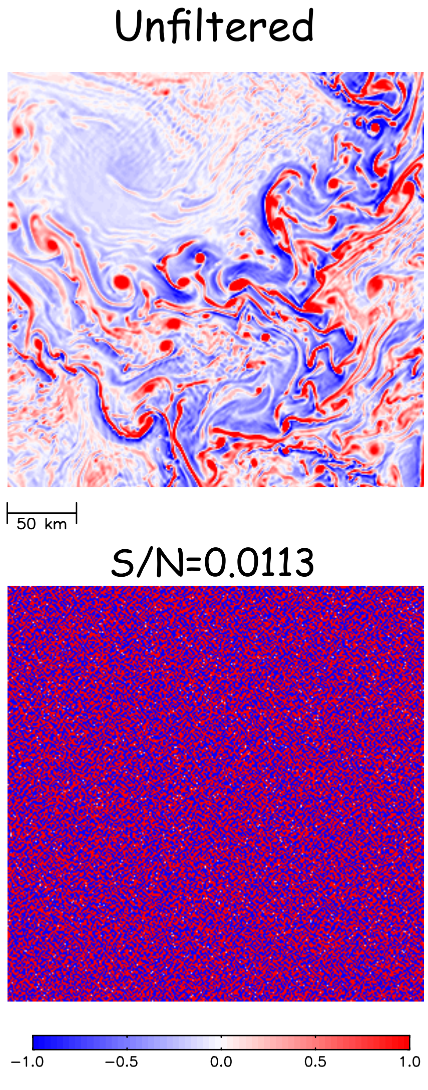
Vorticity/f Noise



The faster reduction of errors for SWOT is because of the very different spectral characteristics of its velocity errors from the response function for centered difference estimates of the derivatives.

Spatially Smoothed SWOT Snapshots of Vorticity/f
Error-Free and with 2.74 cm Uncorrelated Noise



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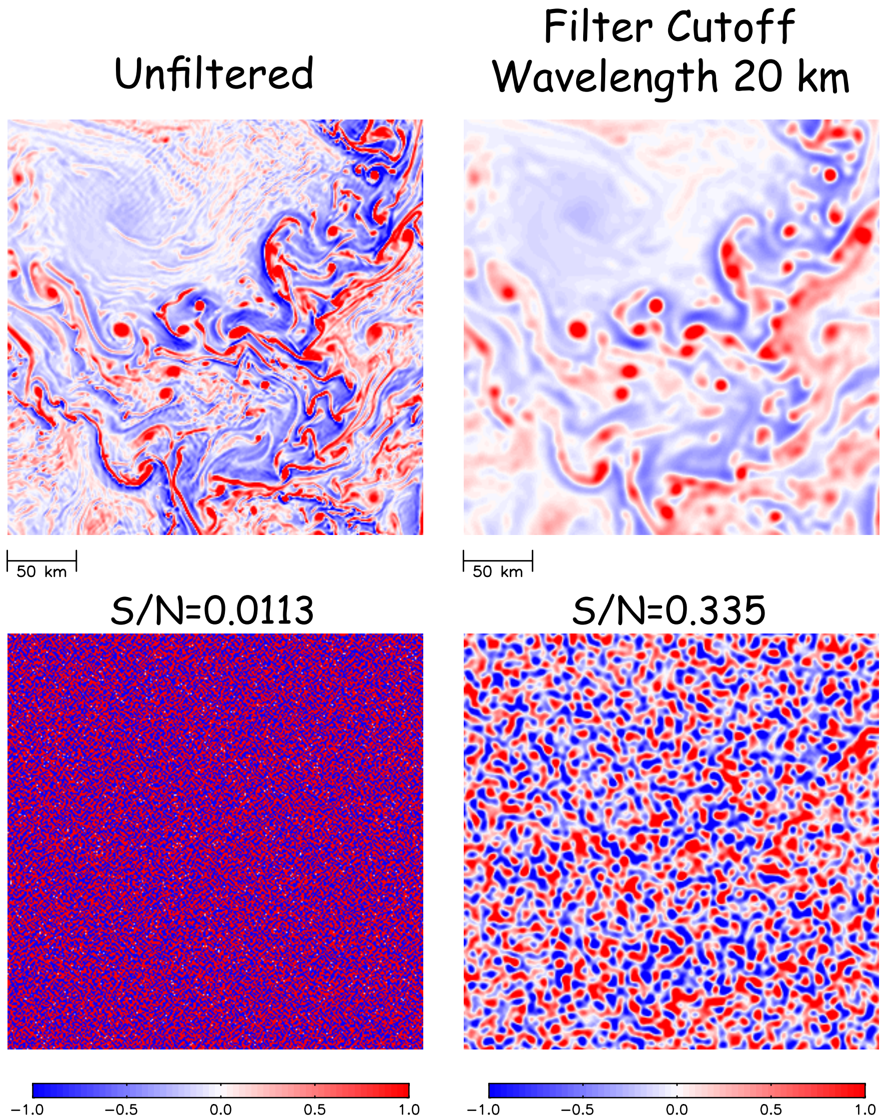

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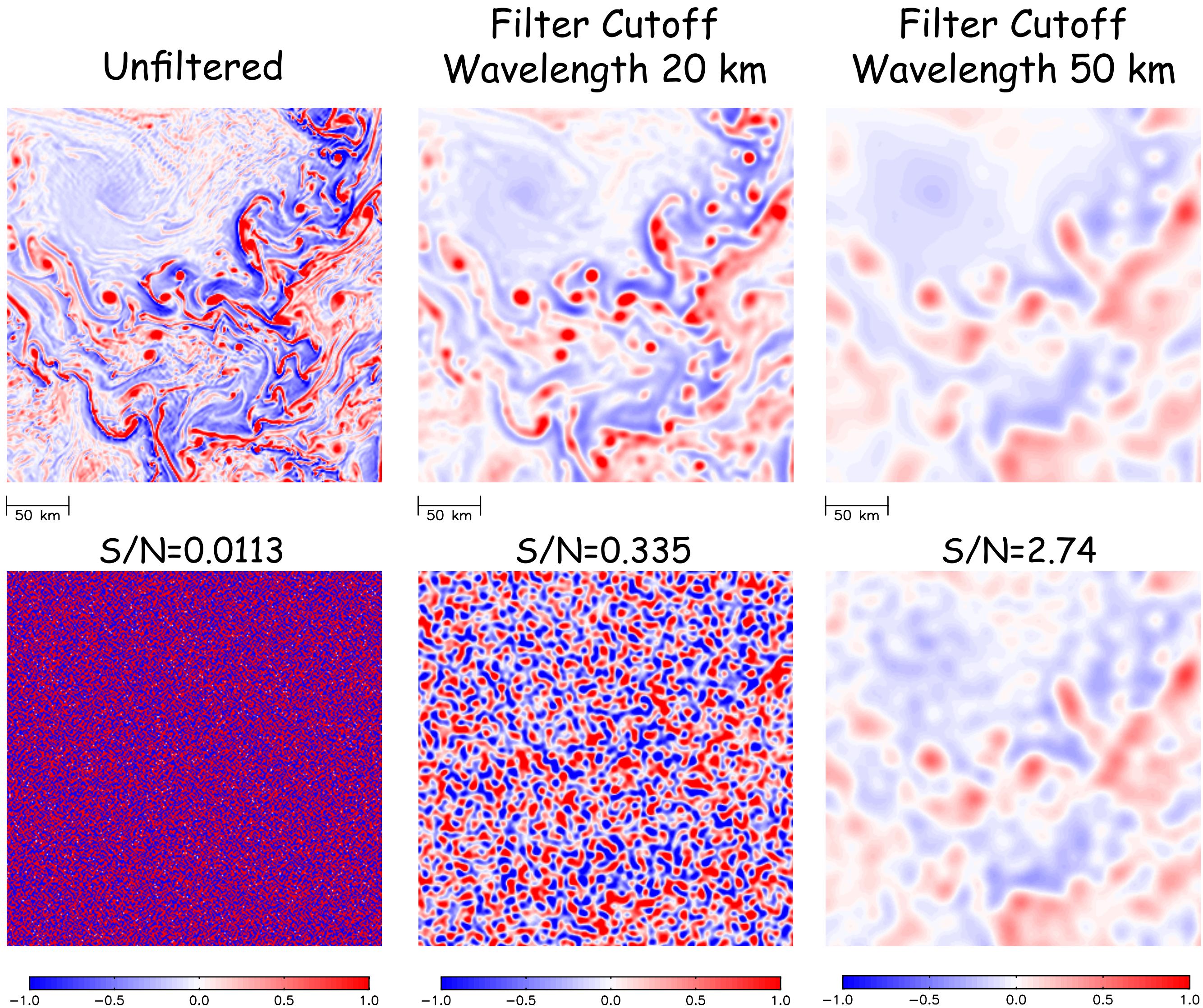

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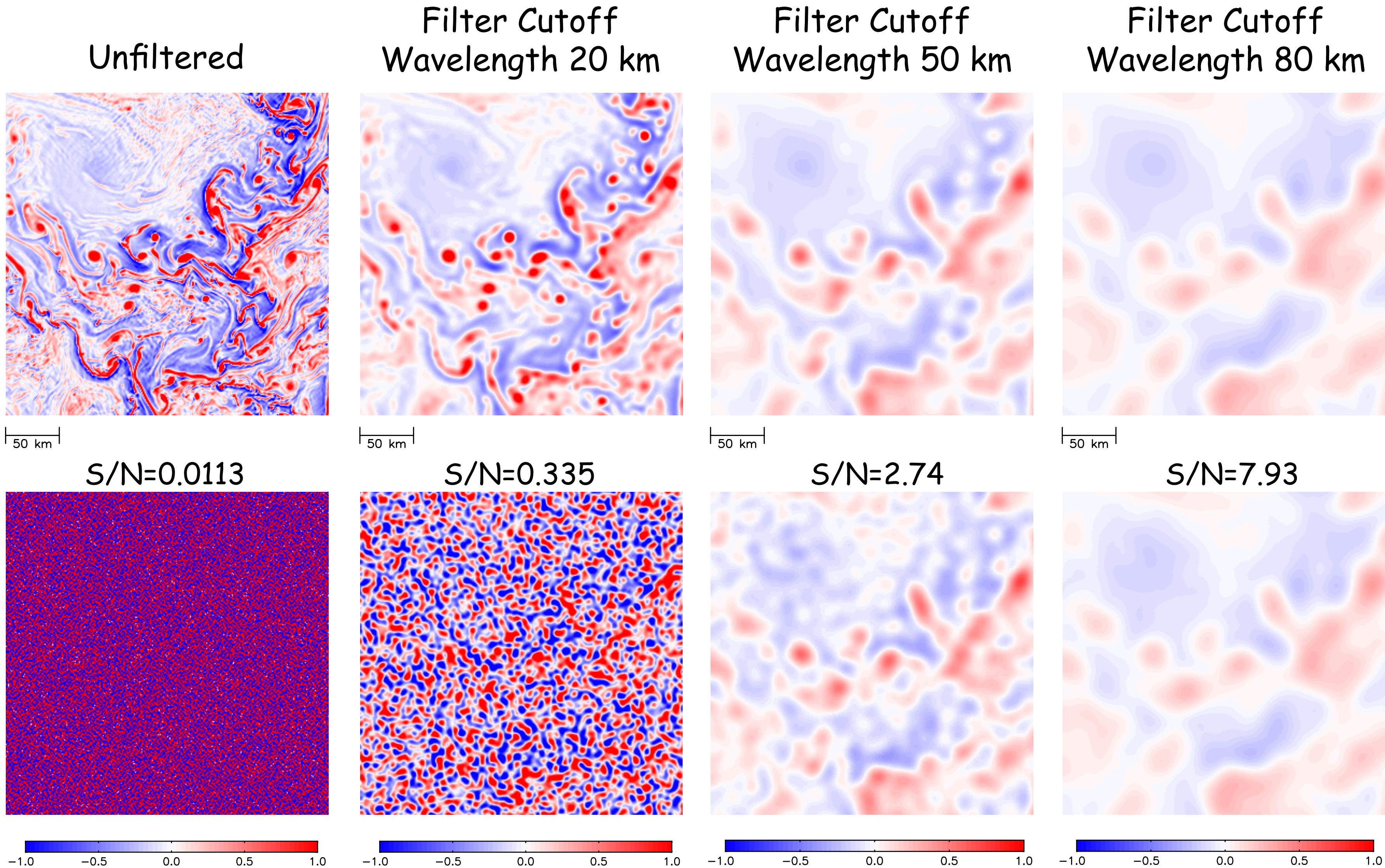
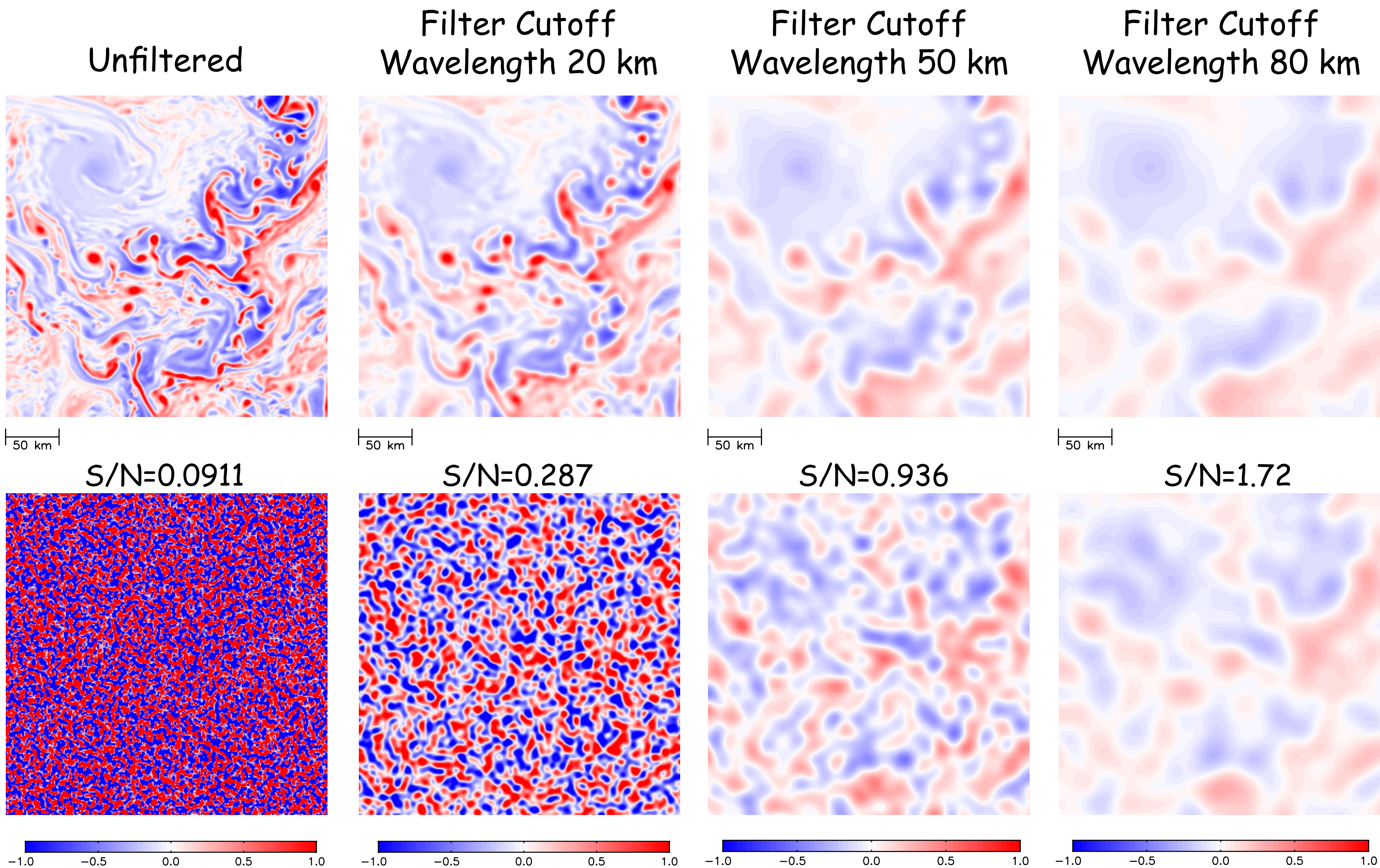
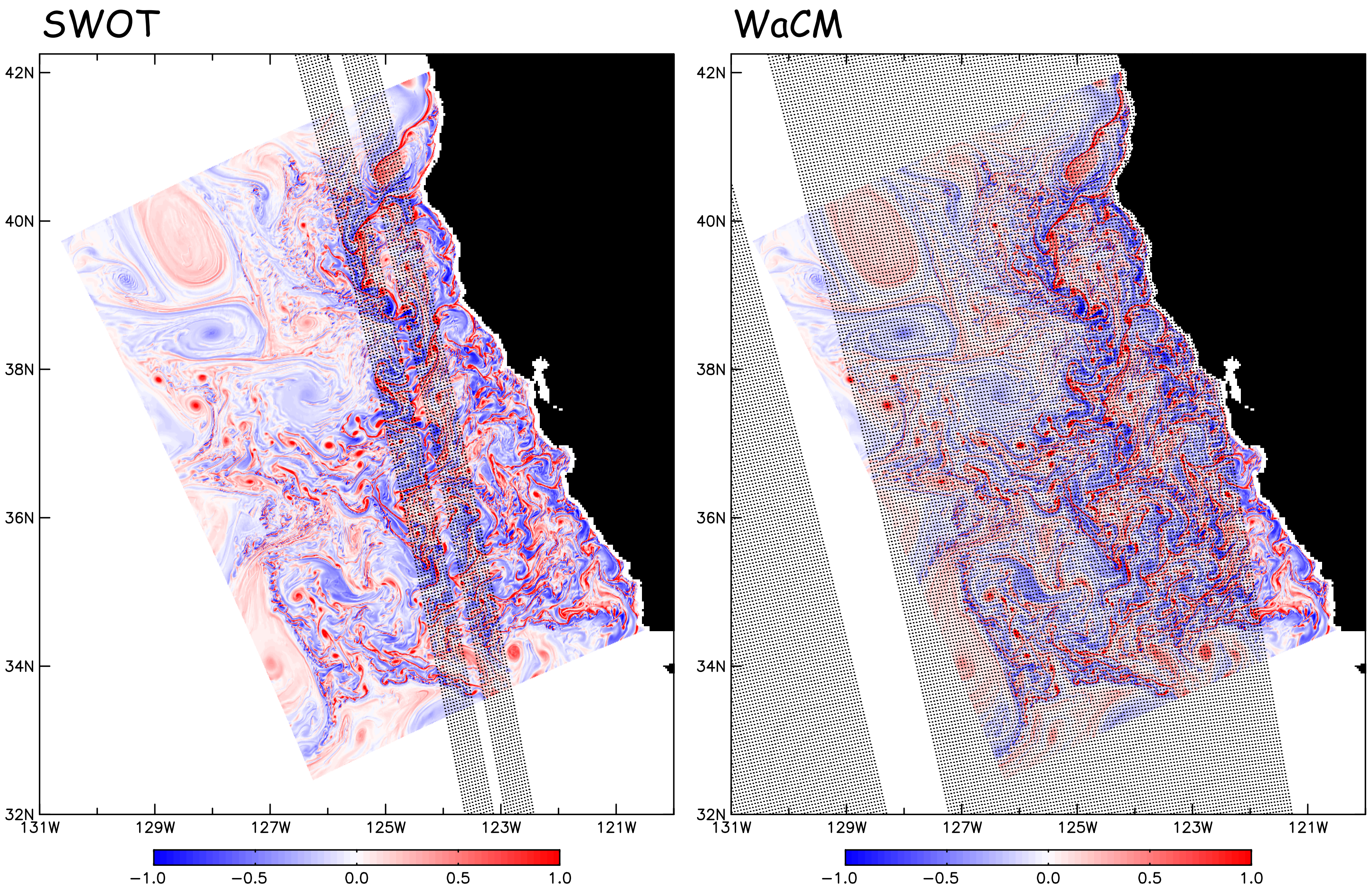


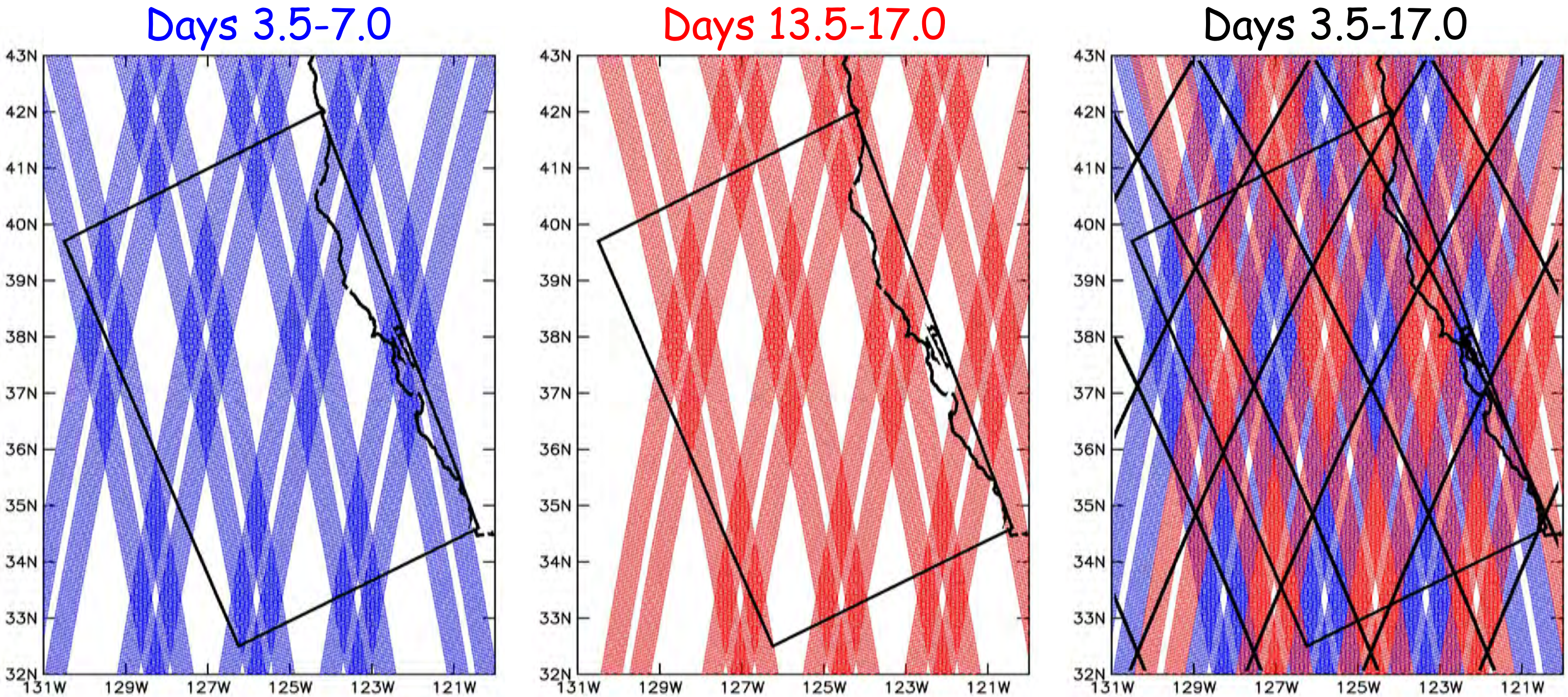
Spatially Smoothed WaCM Snapshots of Vorticity/f
Error-Free and with 0.5 m/s Uncorrelated Noise



SWOT versus WaCM Measurement Swaths



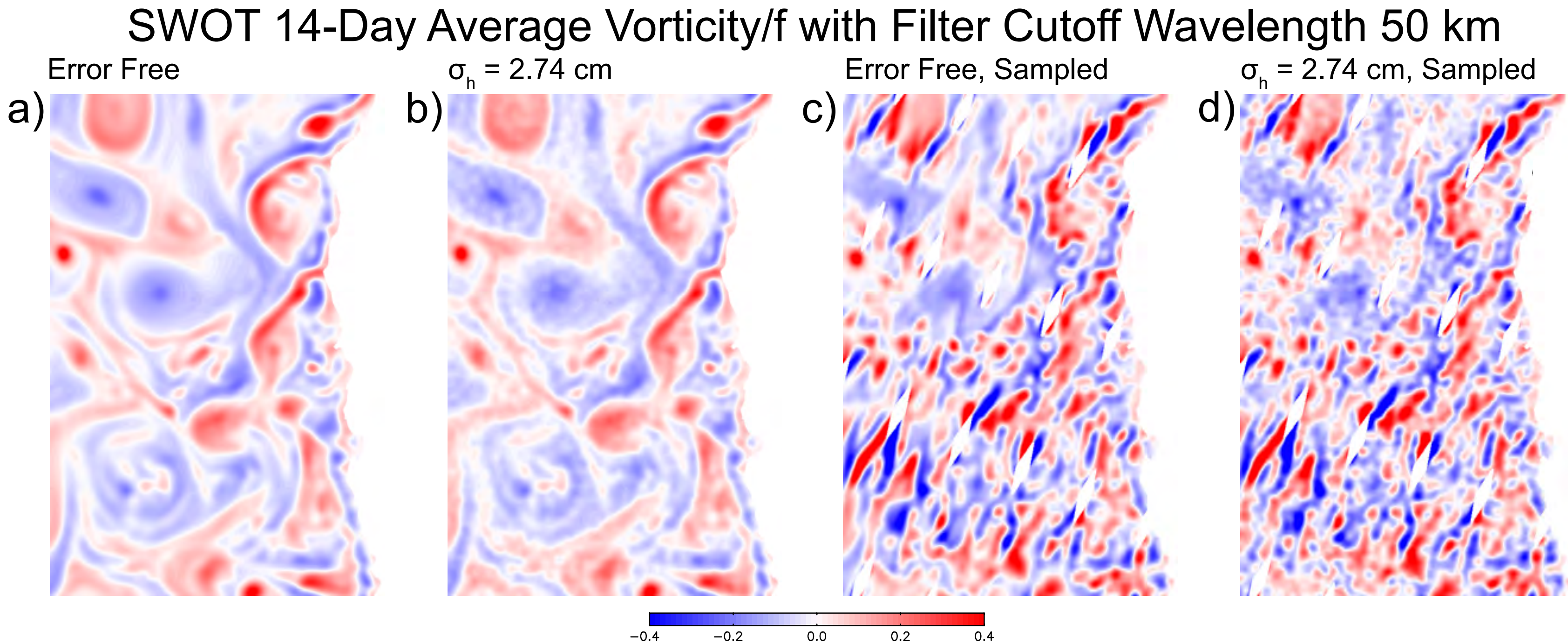
SWOT 4-Day and 14-Day Subcycles in the CCS Region during Each 21-Day Exact Repeat Period



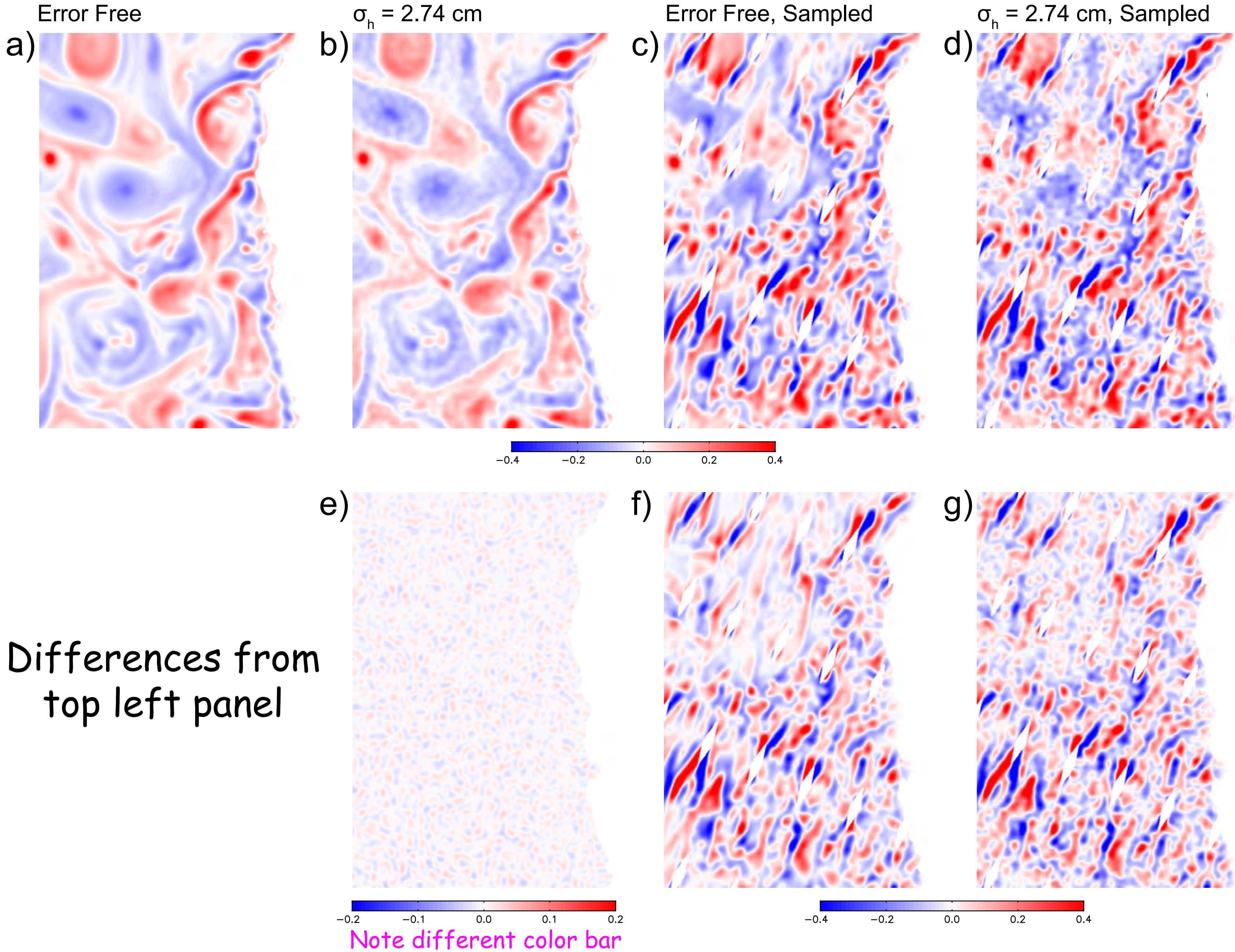
Black lines are TOPEX and Jason-1 & 2 ground tracks

The SWOT sampling pattern over the CCS consists of:

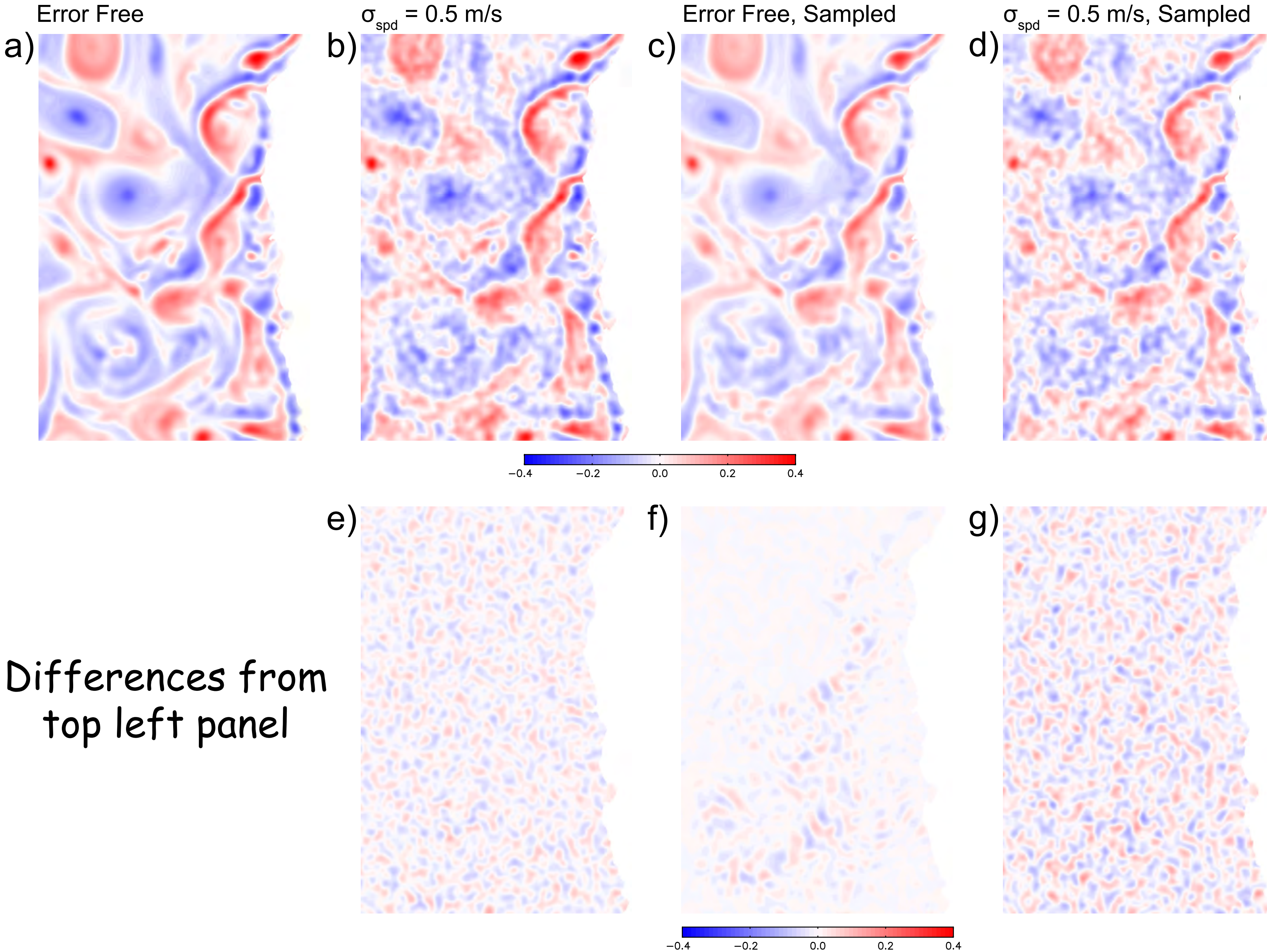
1. A coarse set of intersecting swaths over a 4-day period.
2. A 6.5-day gap with no coverage.
3. Another coarse set of intersecting swaths over a 4-day period that is offset longitudinally from the first 4-day subcycle.
4. Another 6.5-day gap with no coverage.


SWOT 14-Day Average Vorticity/f with Filter Cutoff Wavelength 50 km
Error Free
σh = 2.74 cm
Error Free, Sampled
σh = 2.74 cm, Sampled
a)
b)
c)
d)
−0.4
−0.2
0.0
0.2
0.4

SWOT 14-Day Average Vorticity/f with Filter Cutoff Wavelength 50 km



WaCM 14-Day Average Vorticity/f with Filter Cutoff Wavelength 50 km



Procedure for Defining Resolution Capability

1. Time-averaged maps of geostrophic velocity and vorticity were constructed 3 different ways from twice-daily snapshots of model output:

   "noise only" = Signal plus measurement noise over the full CCS model domain

   "sampling errors only" = Error-free signal sampled only within the swaths

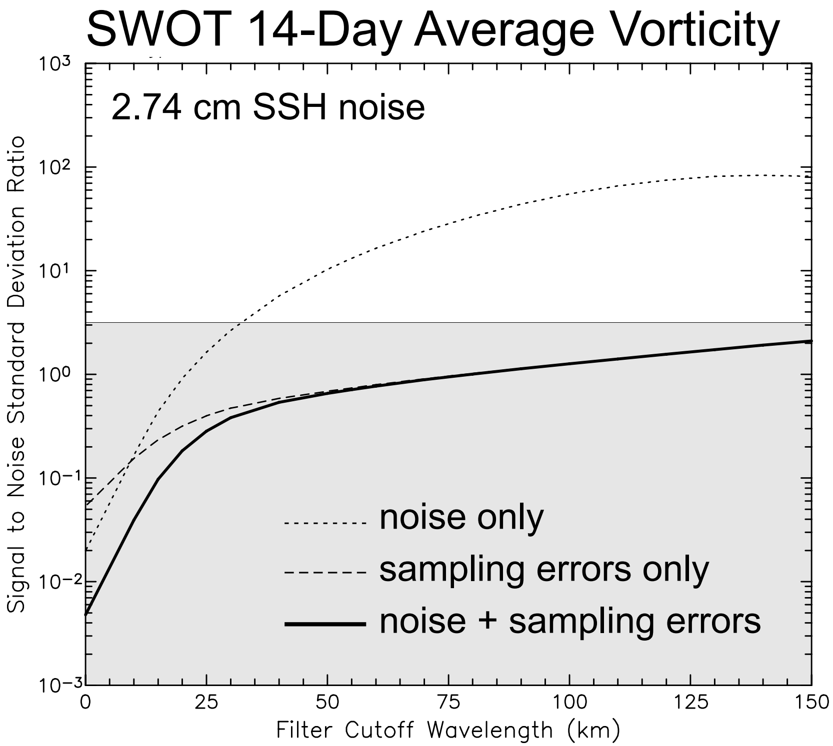
   "noise + sampling errors" = Signal plus measurement noise sampled only within the swaths

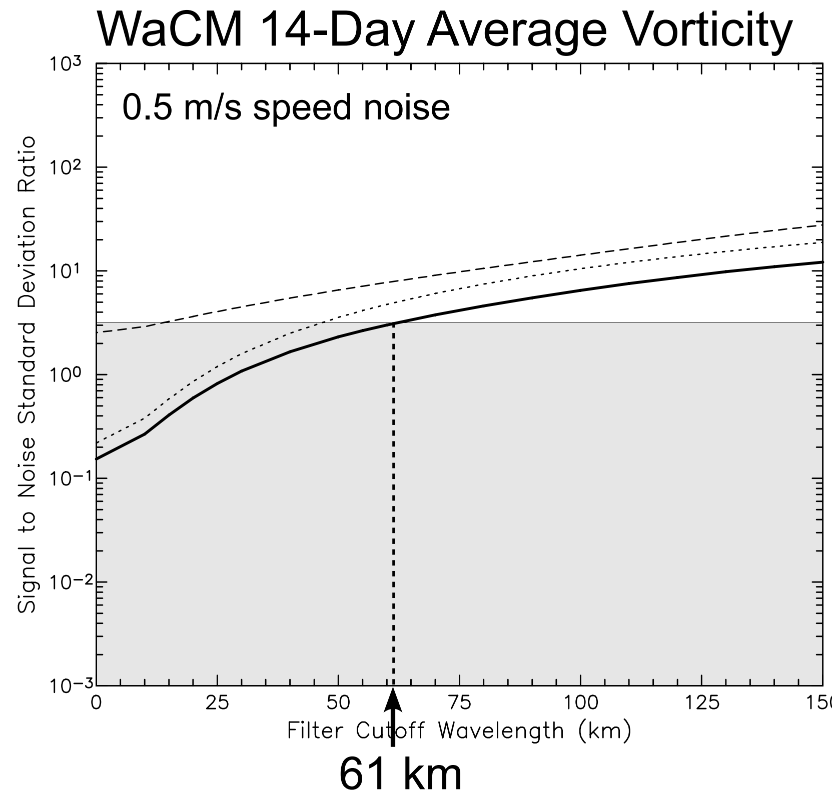
2. Each time-averaged field was smoothed spatially to reduce the effects of measurement and sampling errors.

3. The errors of each set of 3 fields were computed by subtracting the error-free true space-time averages.

4. The resolution capability was defined to be the filter cutoff wavelength at which the Signal-to-Error variance ratio is >10.

   - This corresponds to a standard deviation ratio of 3.16



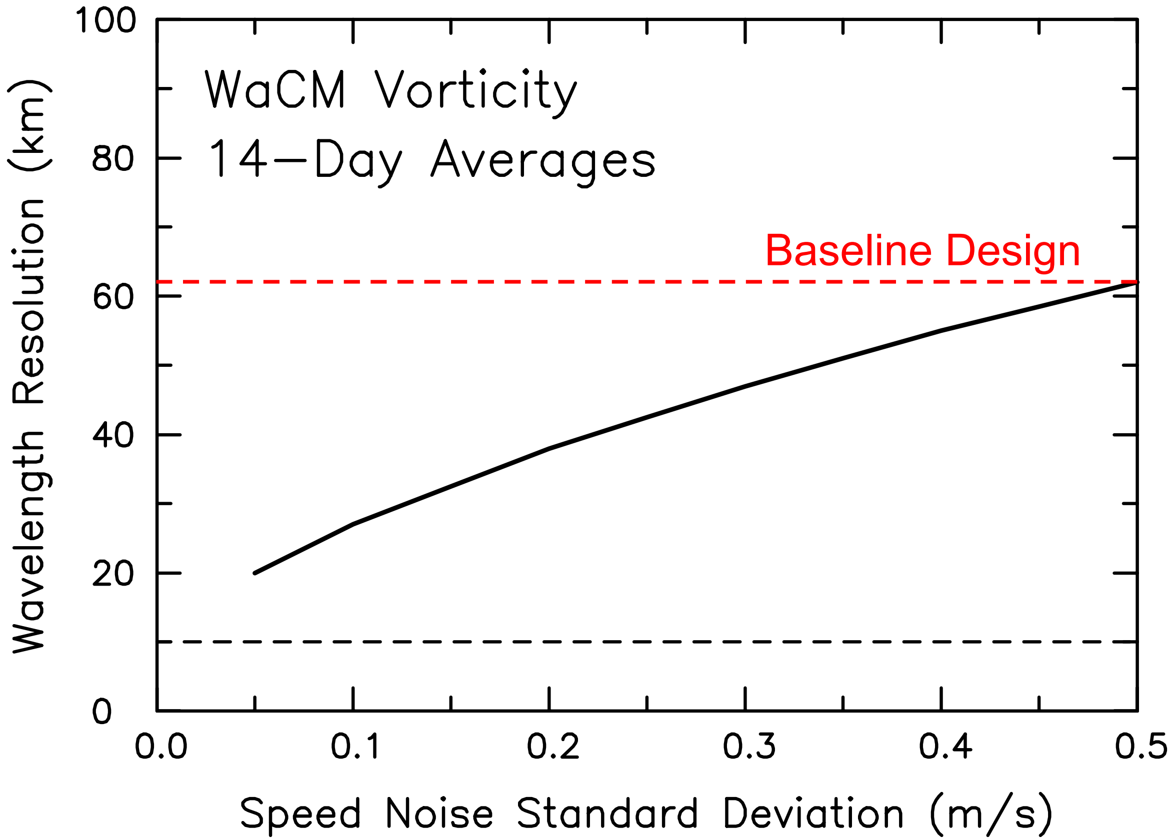


Note that a wavelength resolution of ~60 km corresponds to a feature radius scale of ~15 km.

The resolution of SWOT estimates of geostrophic velocity is limited by sampling errors rather than measurement errors.

In contrast, the resolution of WaCM estimates of velocity is limited primarily by measurement errors rather than sampling errors.

Dependence of Wavelength Resolution Capability on WaCM Measurement Noise for Estimates of 14-Day Averaged Vorticity



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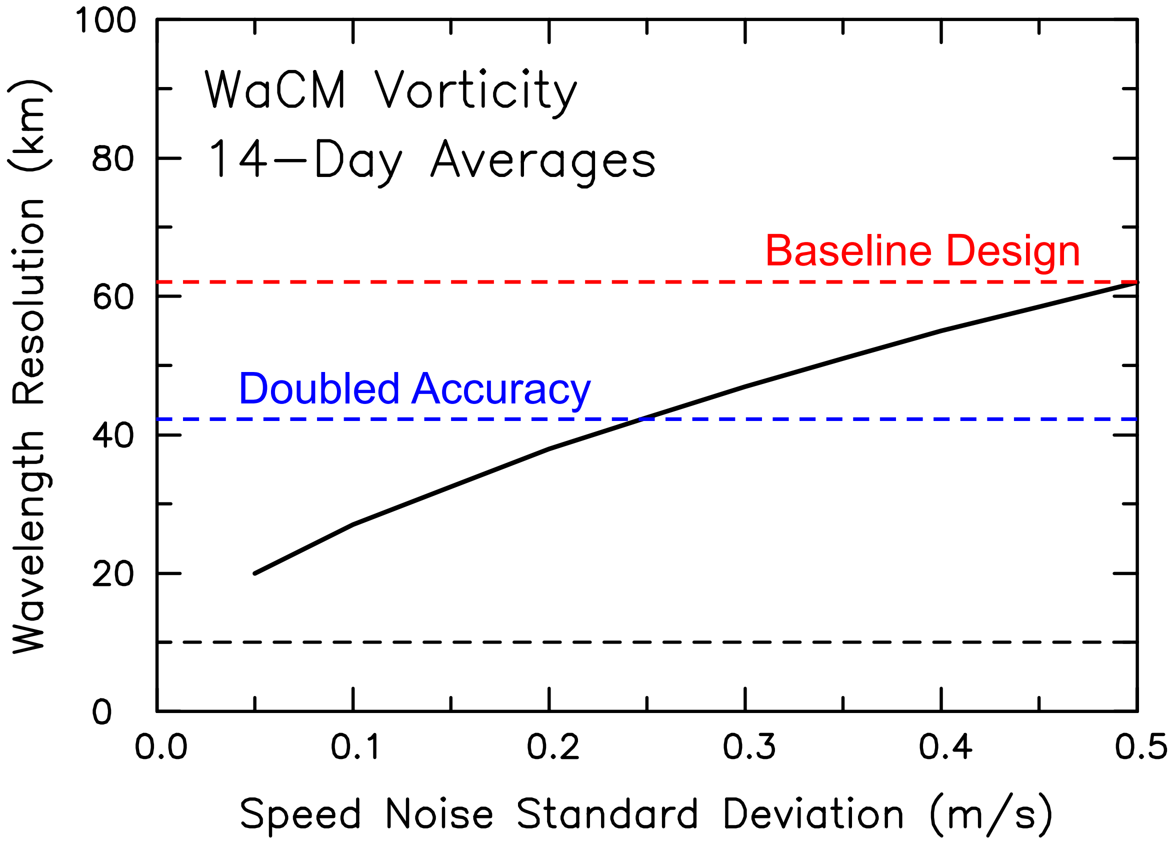
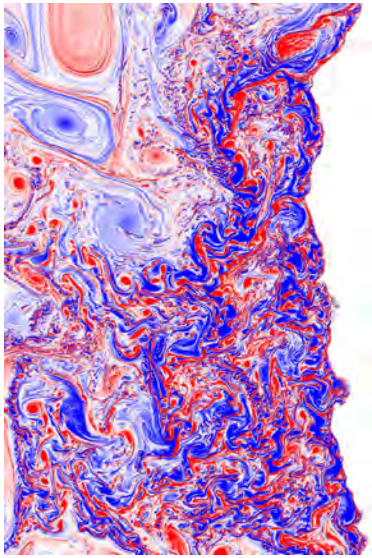
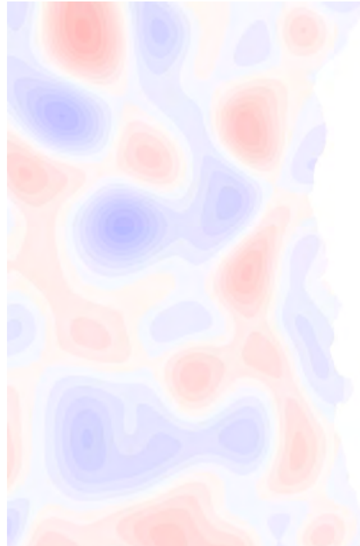


Vorticity/f with Various Space-Time Smoothing

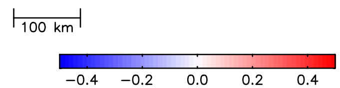
Goal
Snapshot, No Smoothing



Present Capability
30-day Average, 200 km Smoothing

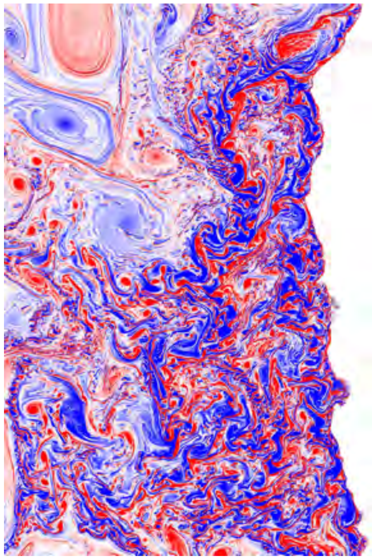


Present Resolution Capability:
30-day average, 200 km smoothing

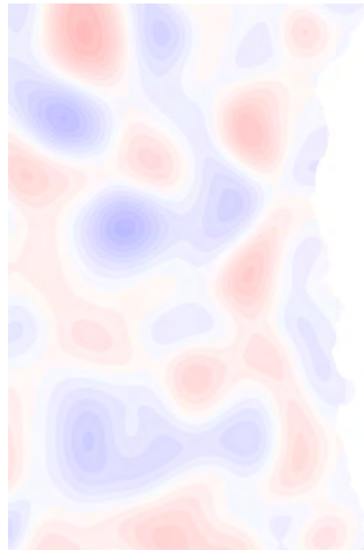


Vorticity/f with Various Space-Time Smoothing

Goal
Snapshot, No Smoothing

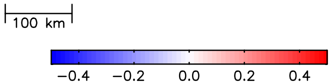


Present Capability
30-day Average, 200 km Smoothing

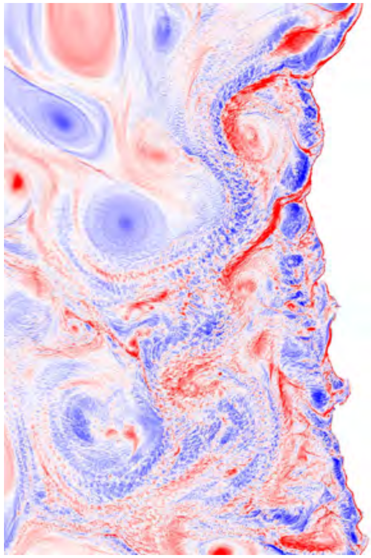


Present Resolution Capability:
30-day average, 200 km smoothing

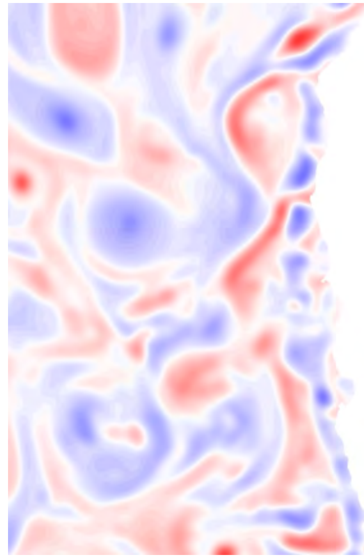
Resolution Capability with 0.5 m/s Errors:
14-day average, 60 km smoothing



14-day Average, No Smoothing

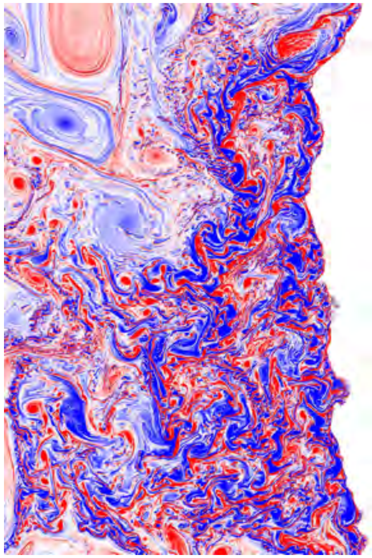


14-day Average, 60 km Smoothing

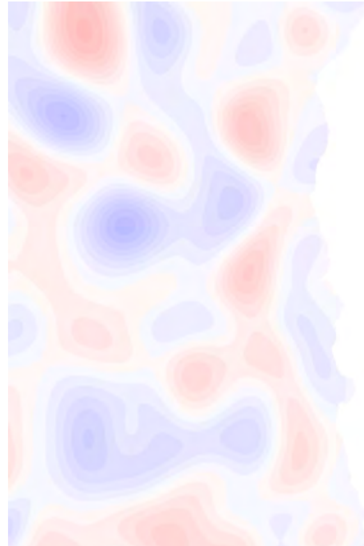


Vorticity/f with Various Space-Time Smoothing

Goal
Snapshot, No Smoothing



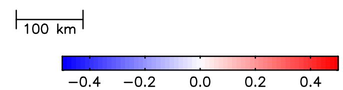
Present Capability
30-day Average, 200 km Smoothing



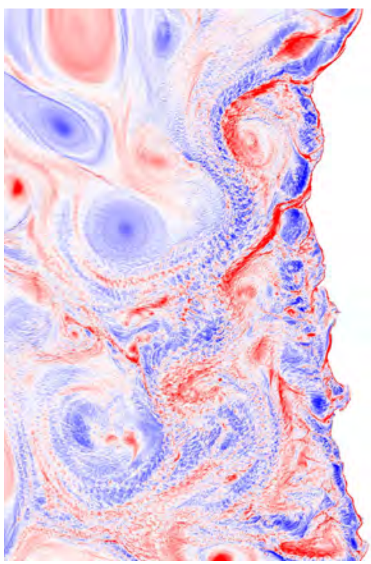
Present Resolution Capability:
30-day average, 200 km smoothing

Resolution Capability with 0.5 m/s Errors:
14-day average, 60 km smoothing

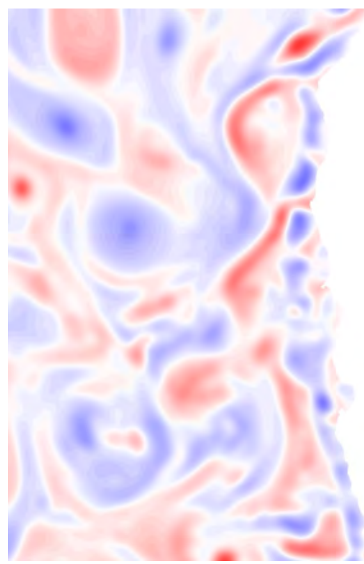
Resolution Capability with 0.15 m/s Errors:
14-day average, 40 km smoothing



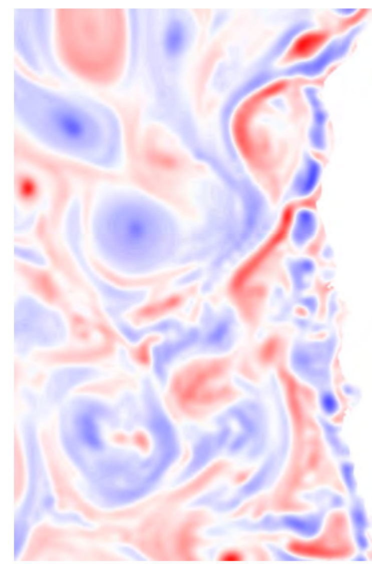
14-day Average, No Smoothing



14-day Average, 60 km Smoothing

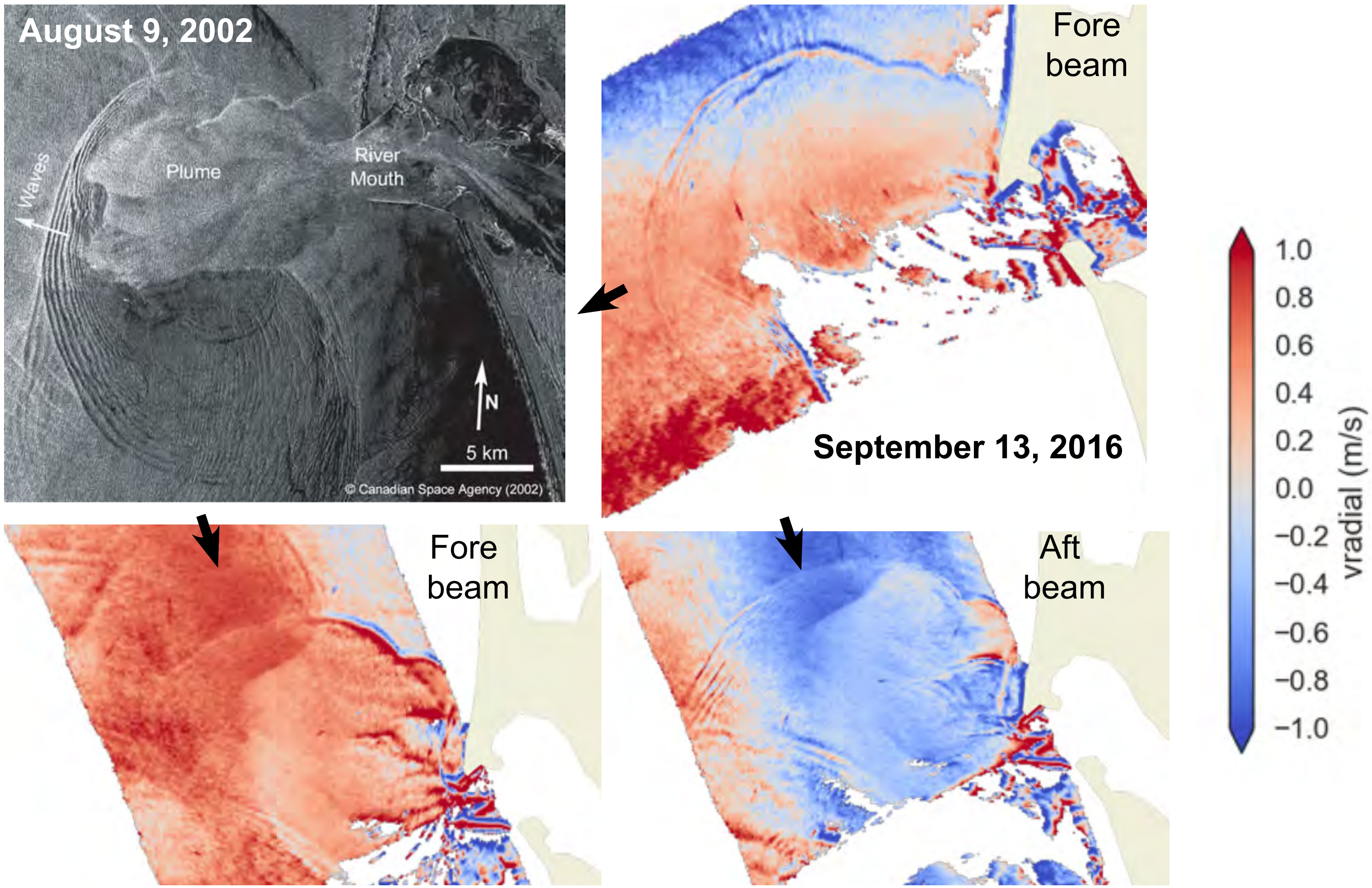


14-day Average, 40 km Smoothing



Columbia River Tidal Plume Front: August 2002 SAR Image and September 2016 DopplerScatt Observations of Radial Velocity

Courtesy of Ernesto Rodriguez, JPL



White areas within the measurement swaths are regions of low signal, likely attributable to suppression of Bragg scattering waves by biological surfactants in areas of low wind speeds.

Conclusions

- The effects of measurement and sampling errors are very different for WaCM and SWOT:

  Whereas SWOT is most limited by sampling errors because of its very narrow swath and the rapid evolution of submesoscale variability, WaCM is limited primarily by measurement errors.

- With a noise of 0.5 m/s in surface current measurements, WaCM would provide maps of surface current velocity and relative vorticity with a resolution of ~60 km in 14-day averages.

  This is significantly higher resolution than will be achieved from SWOT.

  This would also significantly improve the resolution capability of about 200 km and 30-day averages from presently available satellite data.

- Engineering improvements to reduce the baseline measurement noise below 0.5 m/s could push the resolution capability down into the submesoscale regime of wavelengths shorter than 50 km.

  Help will be needed from modelers to justify the added cost!

The Uniqueness of the WaCM Doppler Scatterometer Mission

Whereas conventional scatterometry measures the wind forcing and altimetry measures the ocean response, Doppler scatterometry measures <u>both</u> the wind forcing and the ocean response from a single instrument.

Furthermore, WaCM measurements of surface velocity are not limited by the geostrophic approximation.