Synthetic-Aperture Radar Images of California Coastal Waters under Upwelling Conditions

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Committee:
Pierre Flament, chairman
Mark Merrifield
Eric Firing

Outline

I Introduction to the Experiment

II AVHRR Views of the California Current

III ERS-1 SAR Views of the California Current

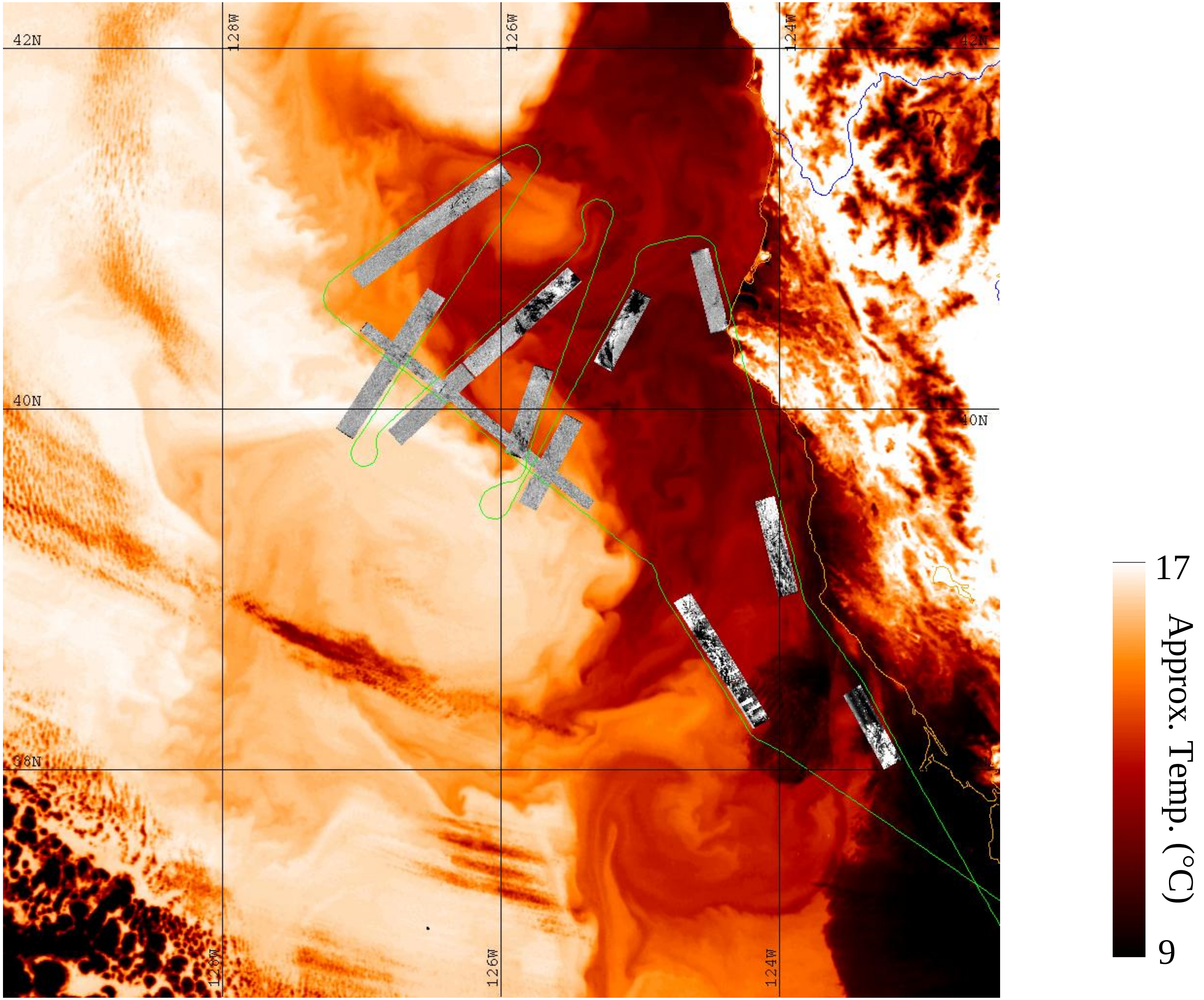
IV Principles of SAR Imaging and an Estimate of Small Wave Coherence from AIRSAR C-band

V AIRSAR Views of the California Current

VI Comparison of Model Results to SAR Images of a Jet

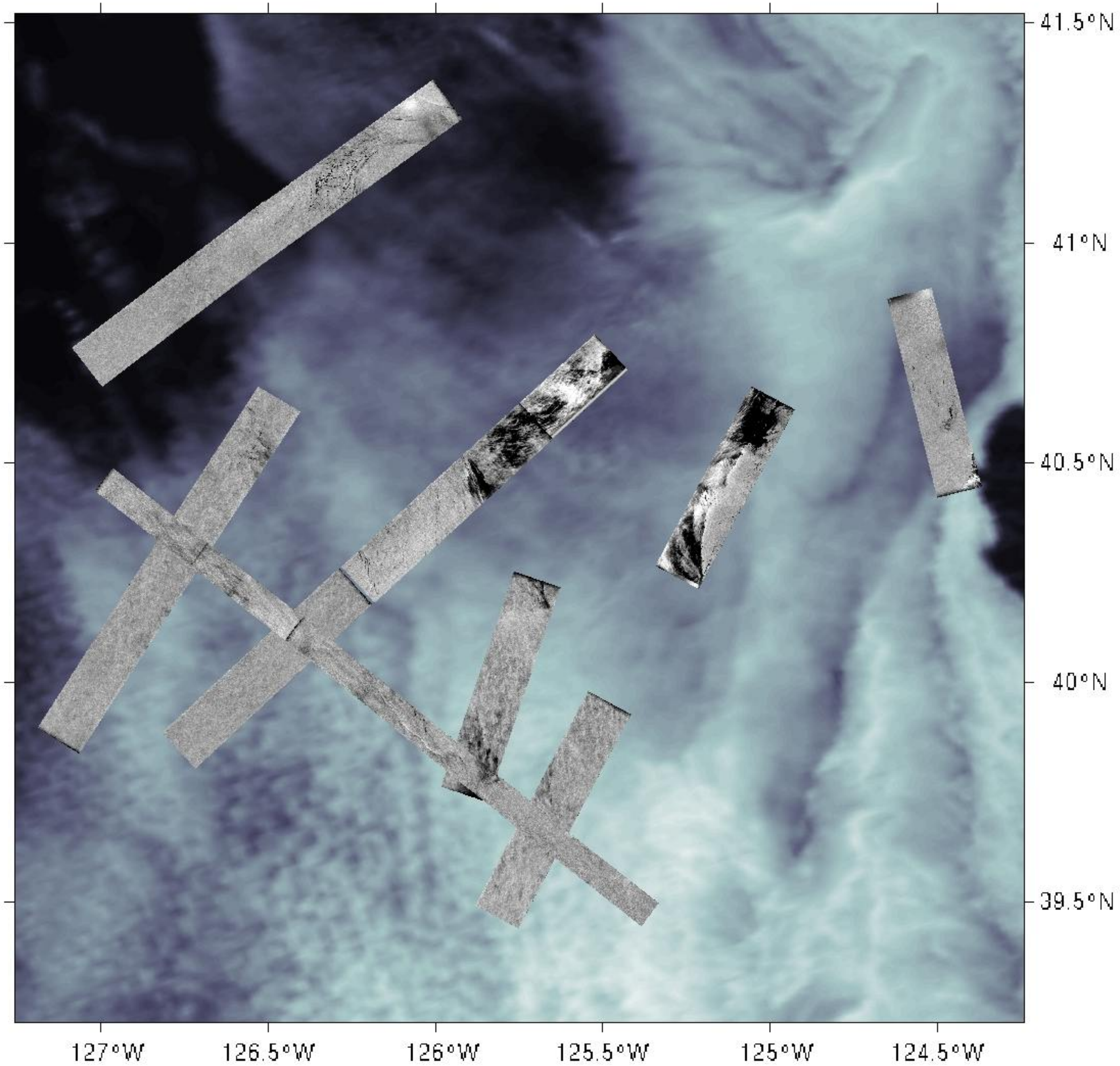
VII Conclusions

AVHRR ch_4 09/07/89 03:22 / SAR 09/08/89 16:47-19:08

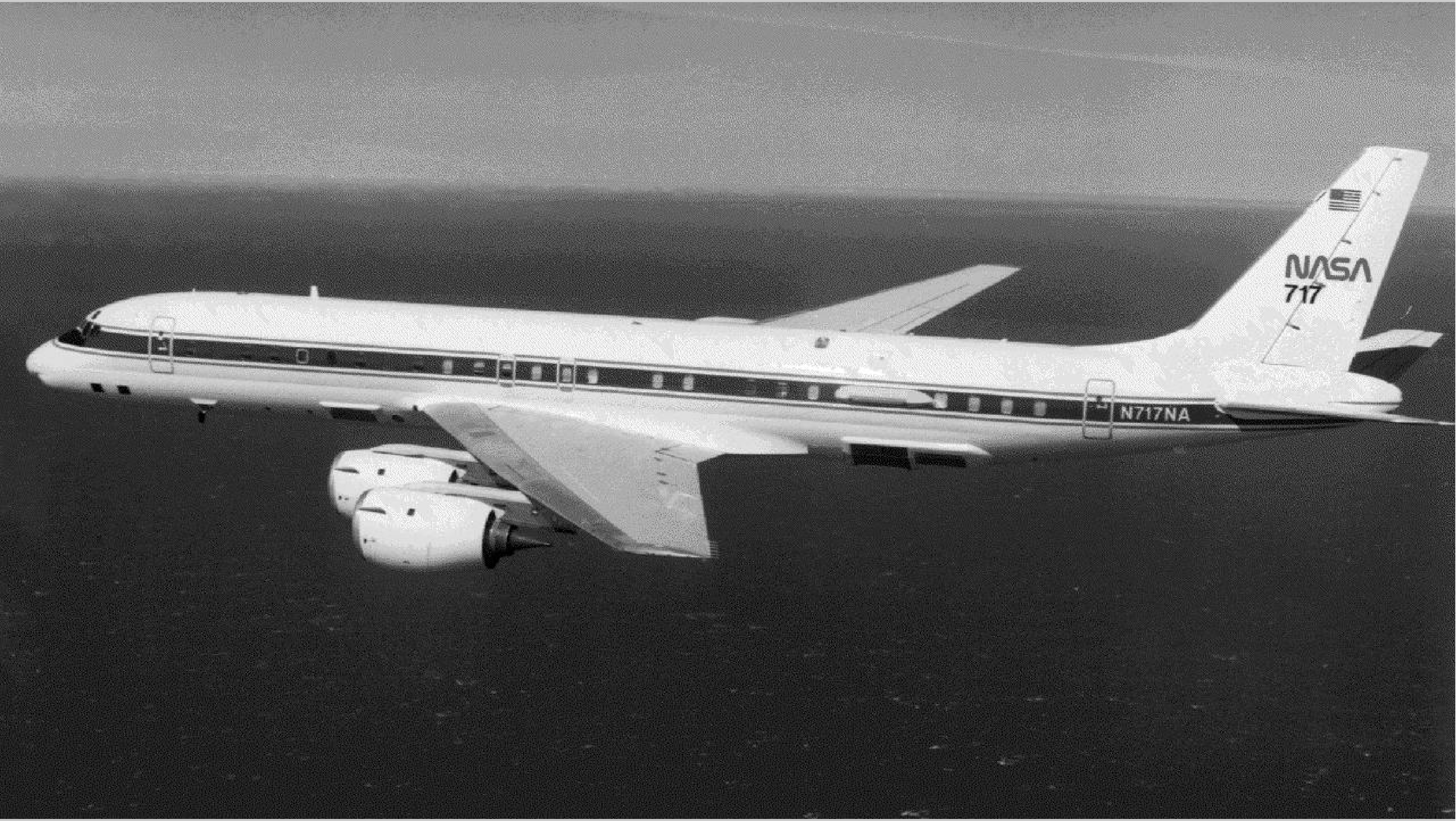


ch_4:
10.3-11.5 µm
thermal IR

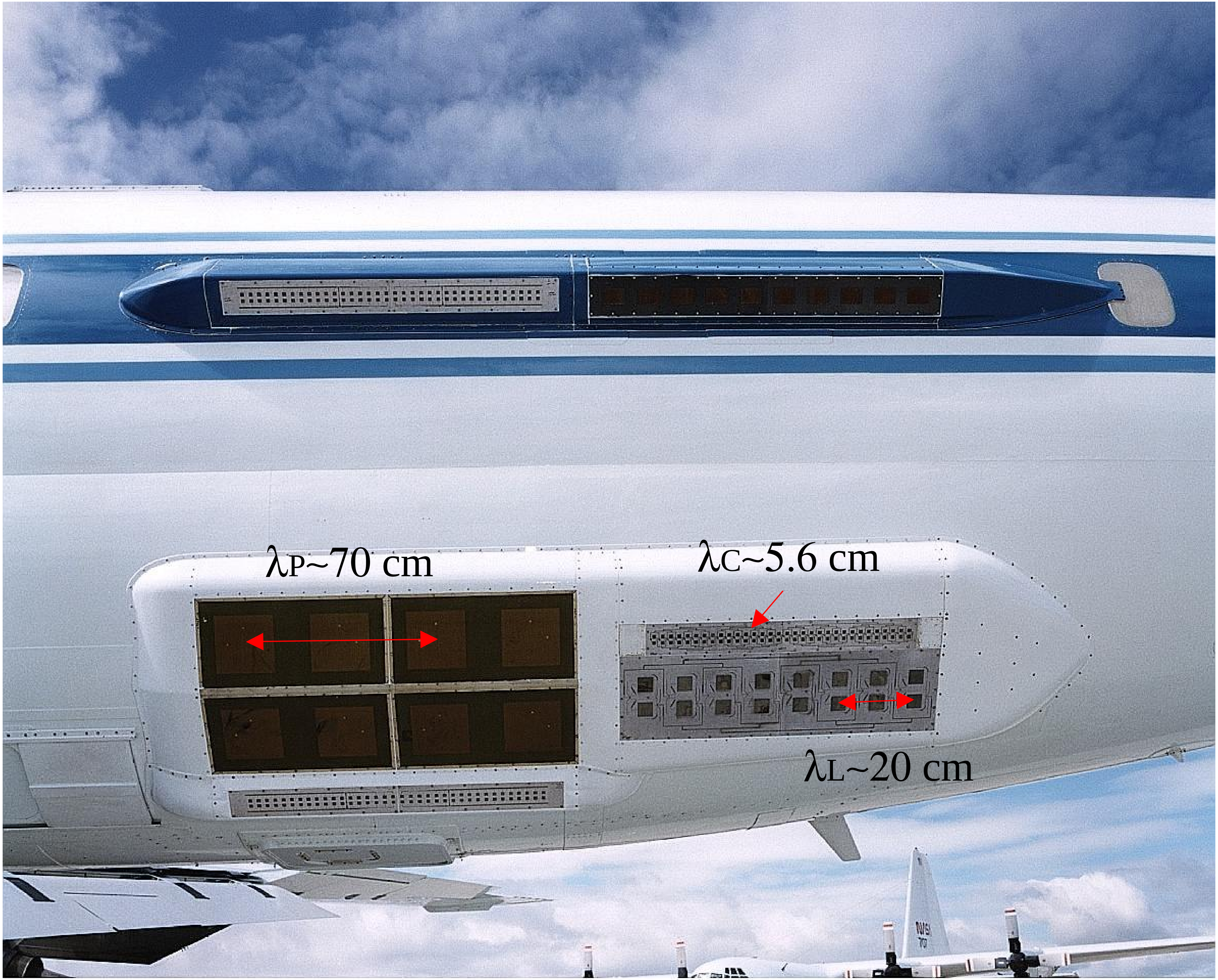
09/08/89 21:07 AVHRR ch_1 (Optical) / SAR L-band



NASA AIRSAR DC-8

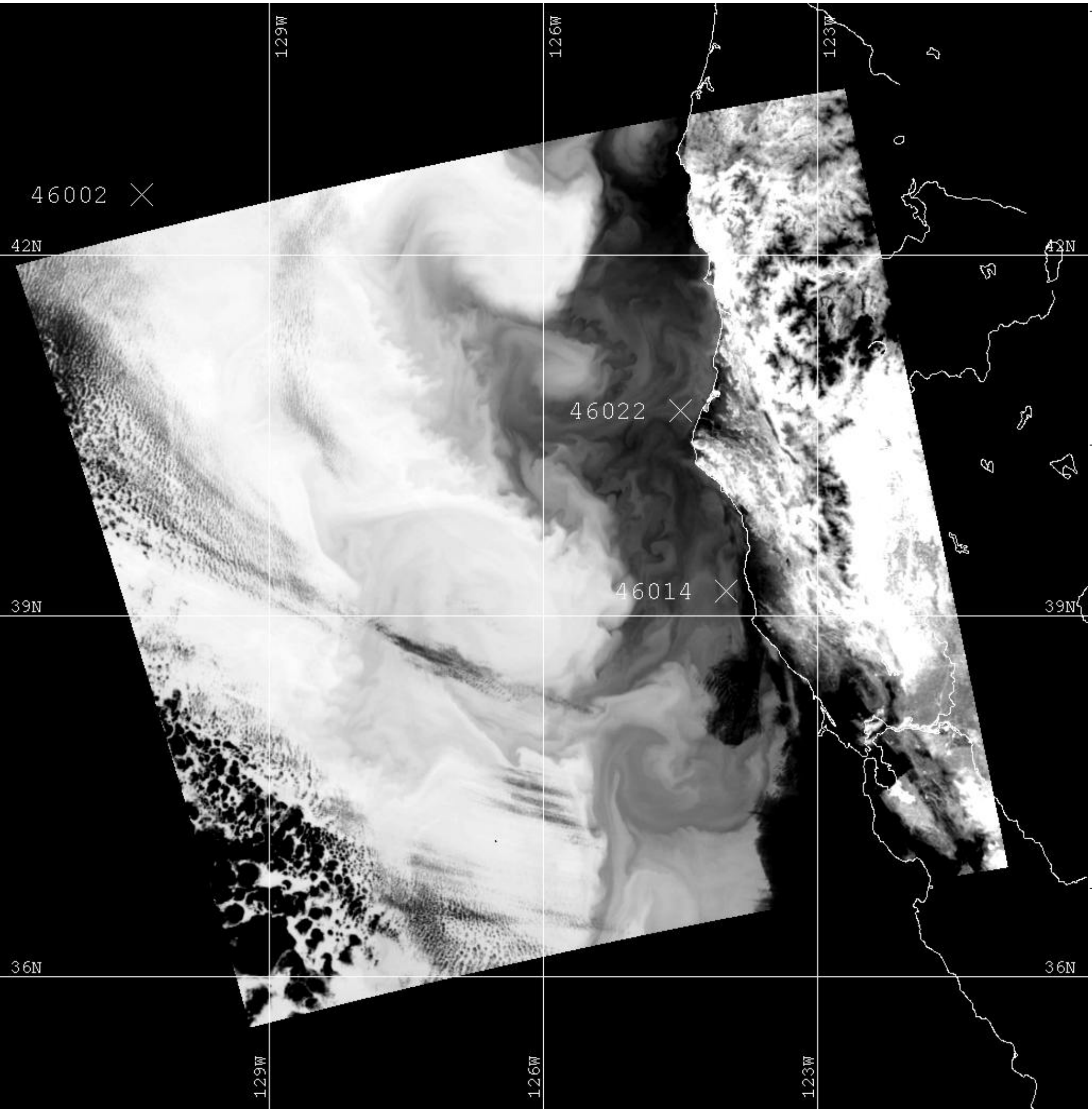


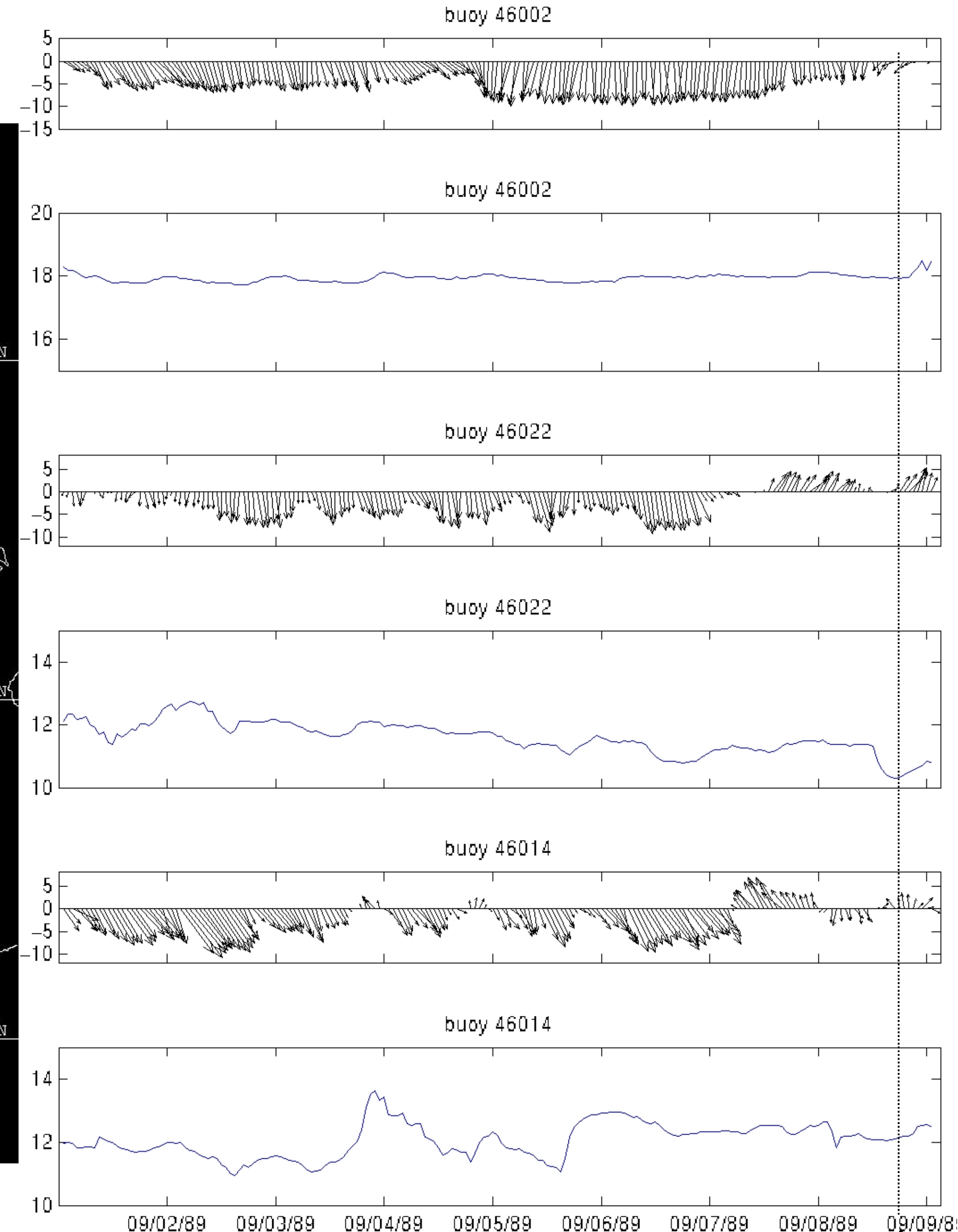
Ceiling~10000 meters Speed~220 meters/second



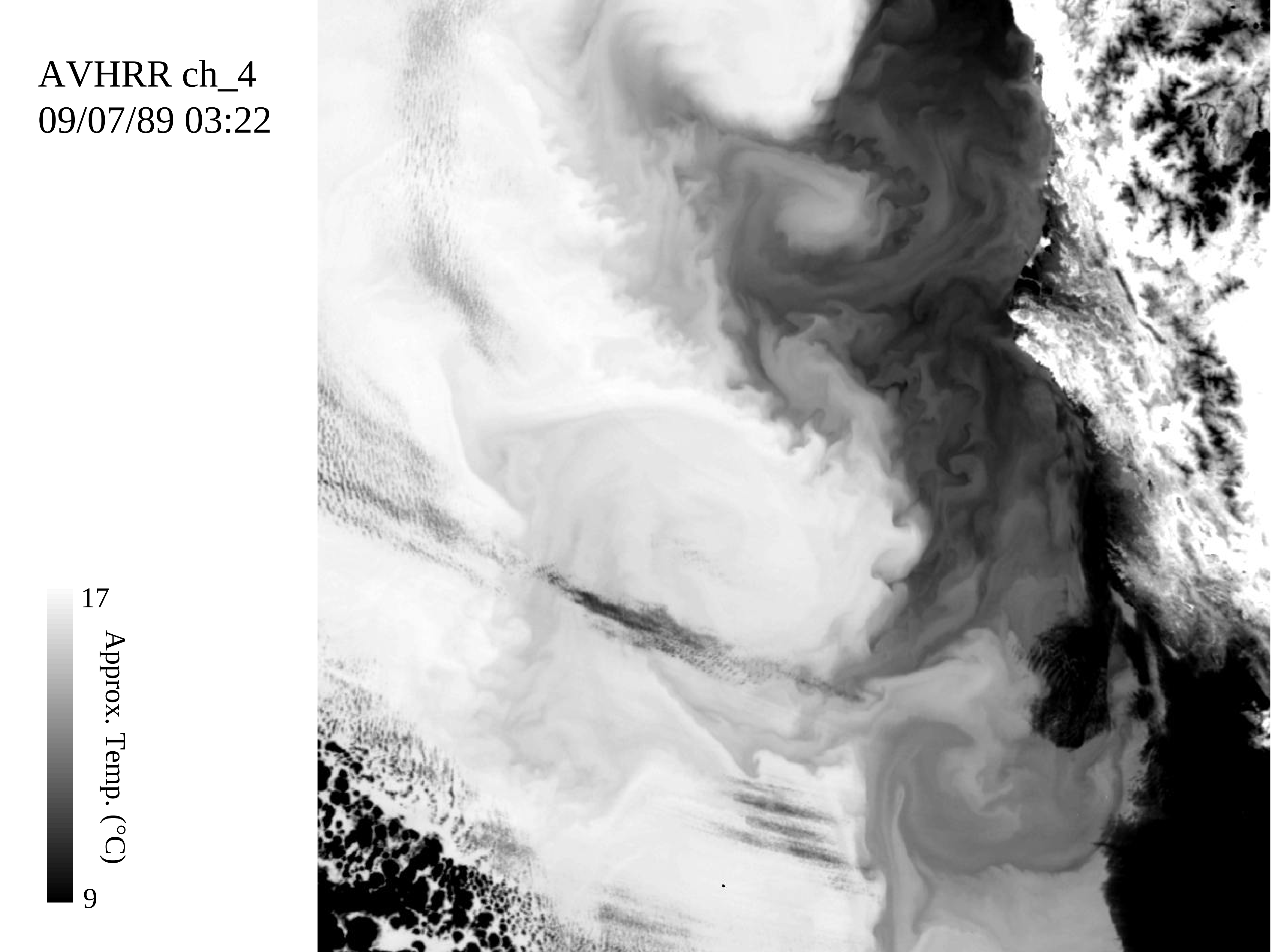
Dryden Flight Research Center EC98-44485-1 Photographed 26MAR1998
Airborne Synthetic Aperture Radar (AIRSAR) on left rear fuselage of DC-8 (NASA/Wood)

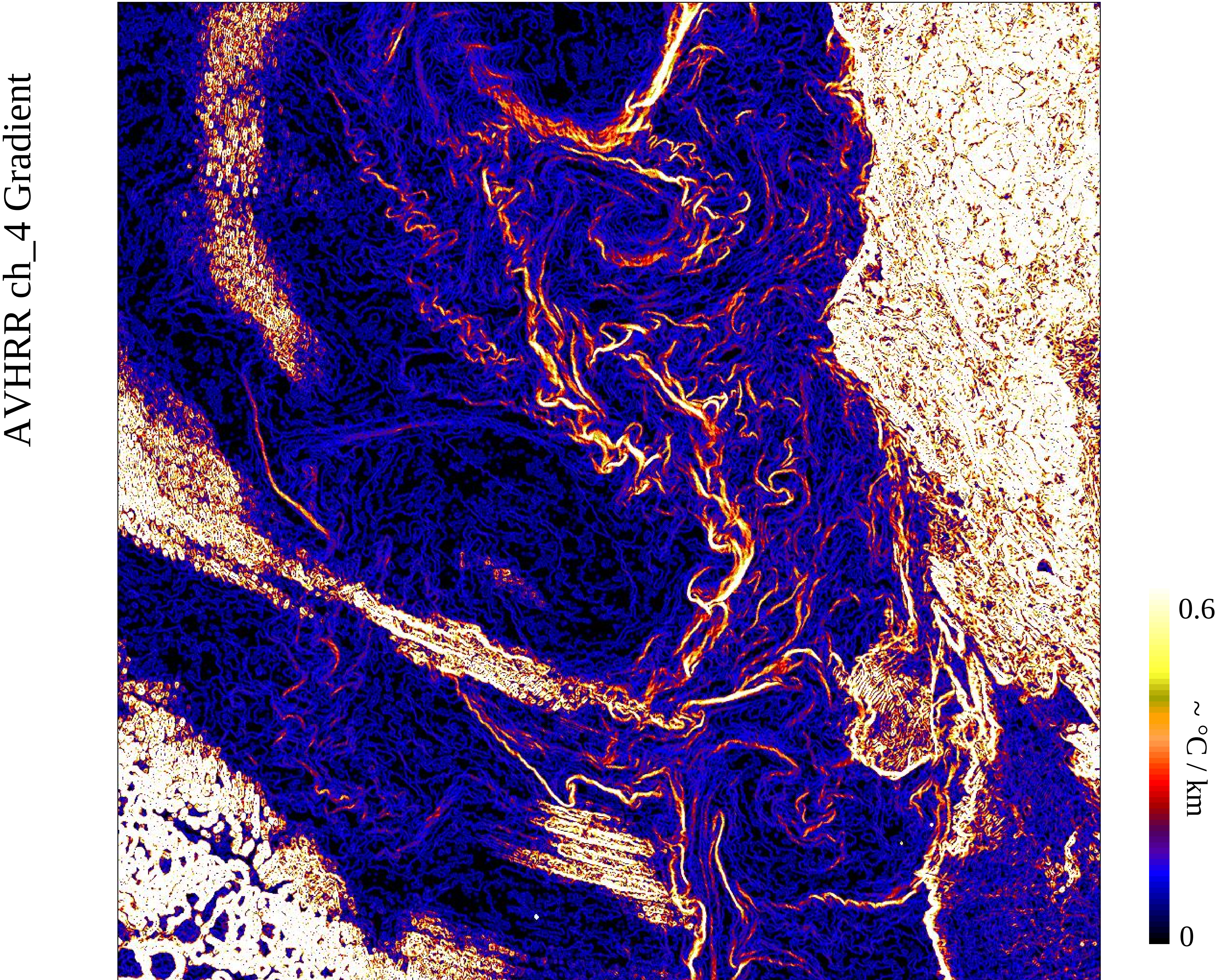
Wind and SST from NOAA Buoys



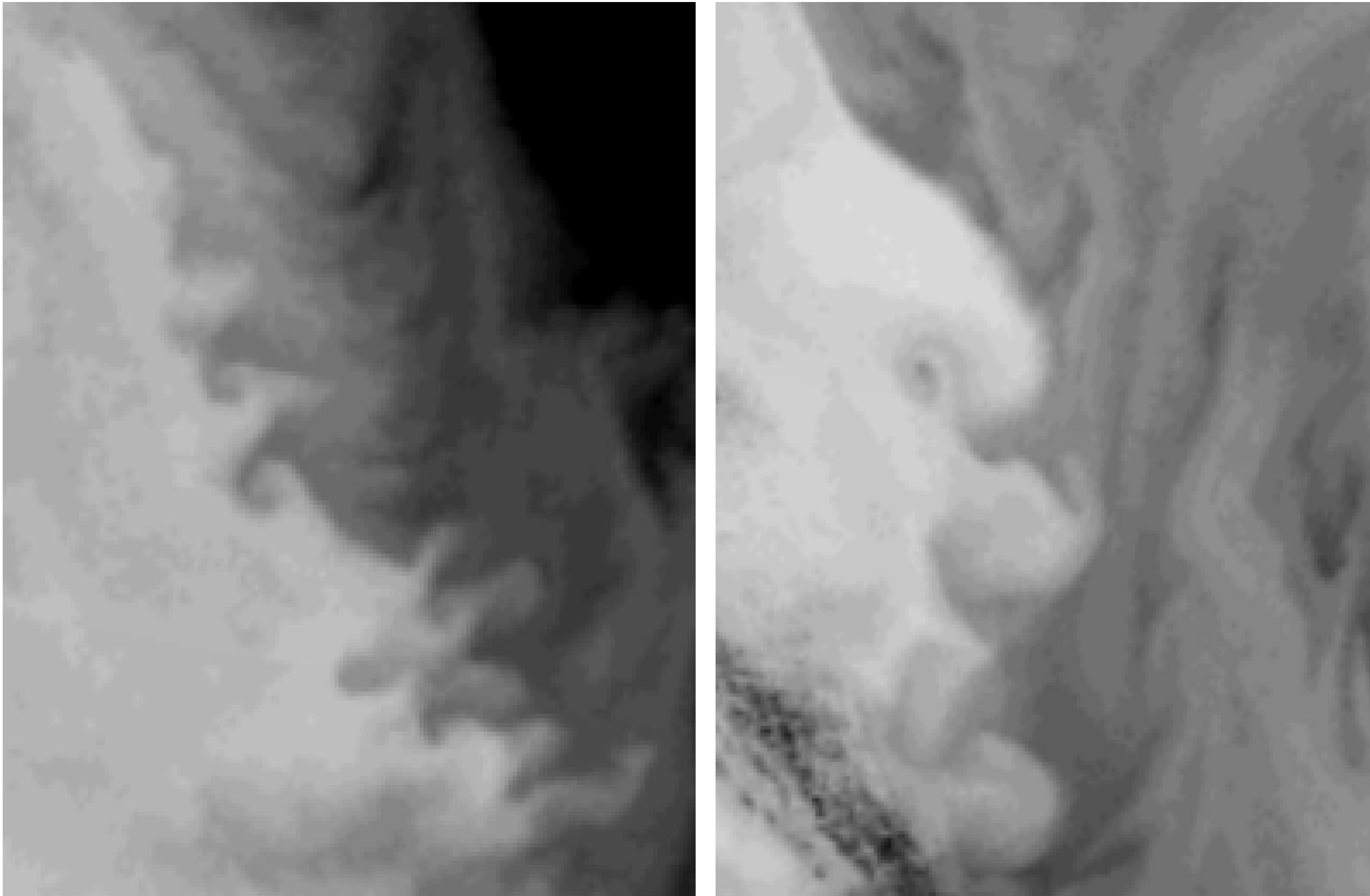


Time of AIRSAR Flight

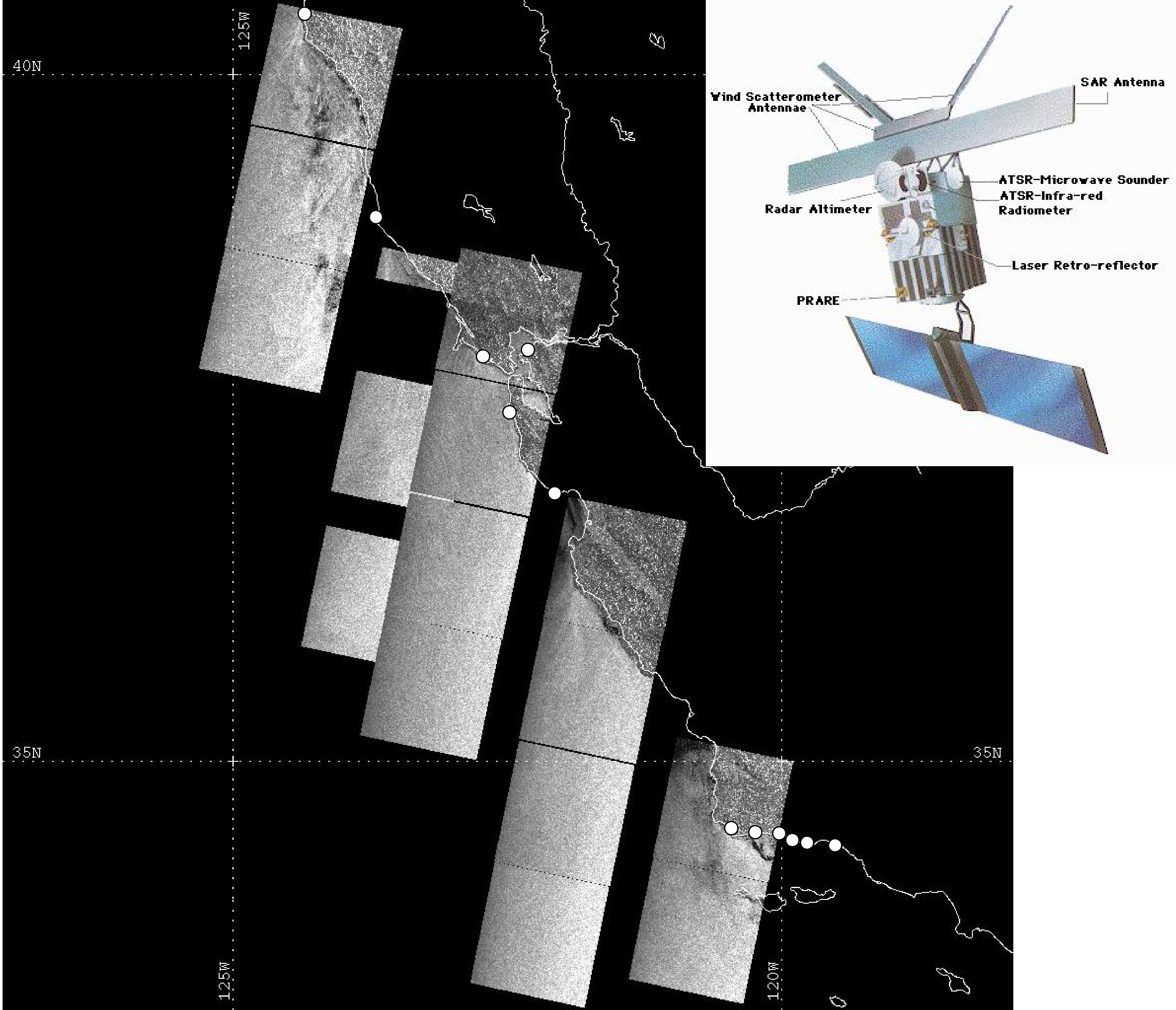

AVHRR ch_4
09/07/89 03:22
17
Approx. Temp. (°C)
9

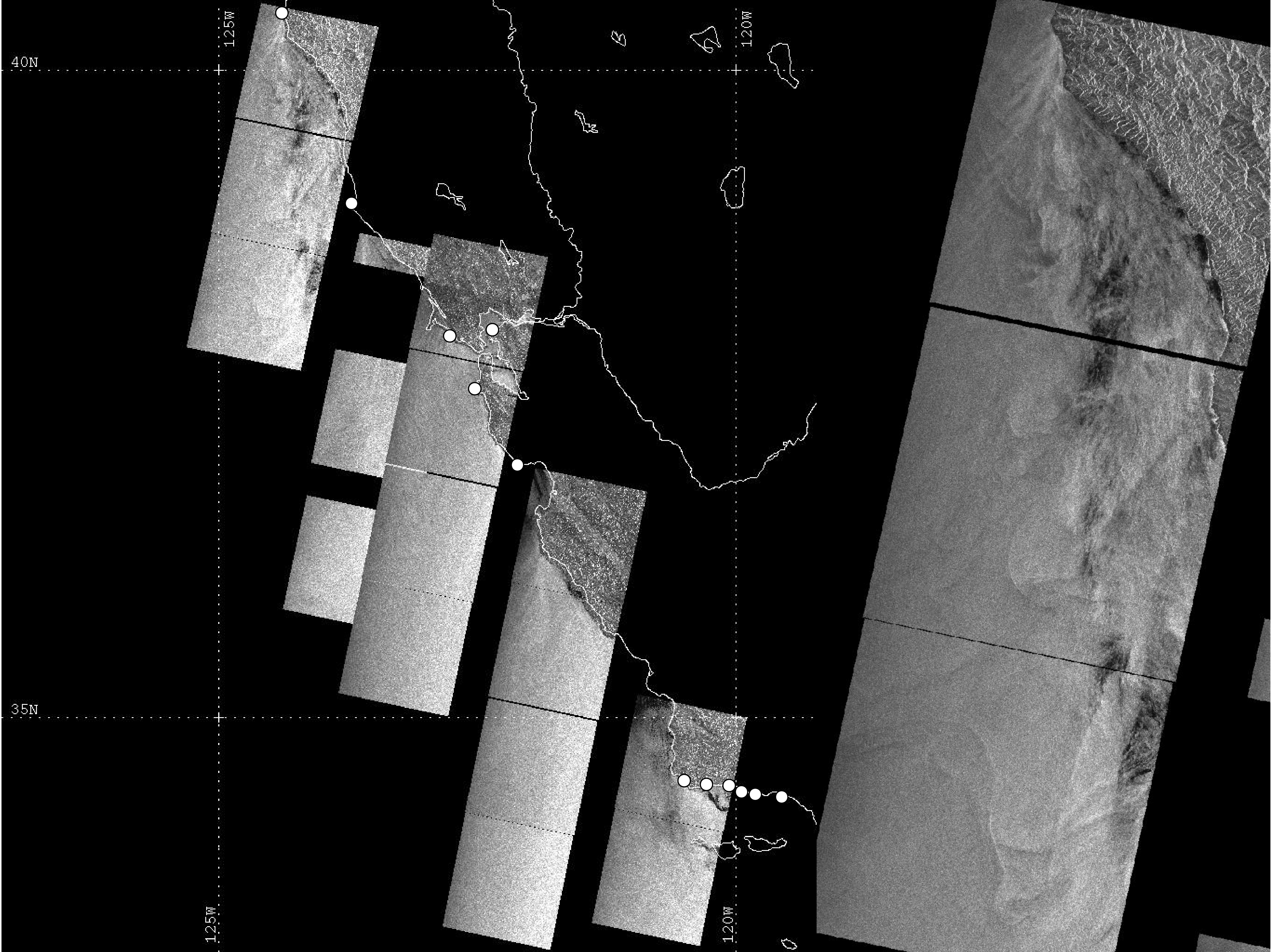

AVHRR ch_4 Gradient
0.6
~°C / km
0

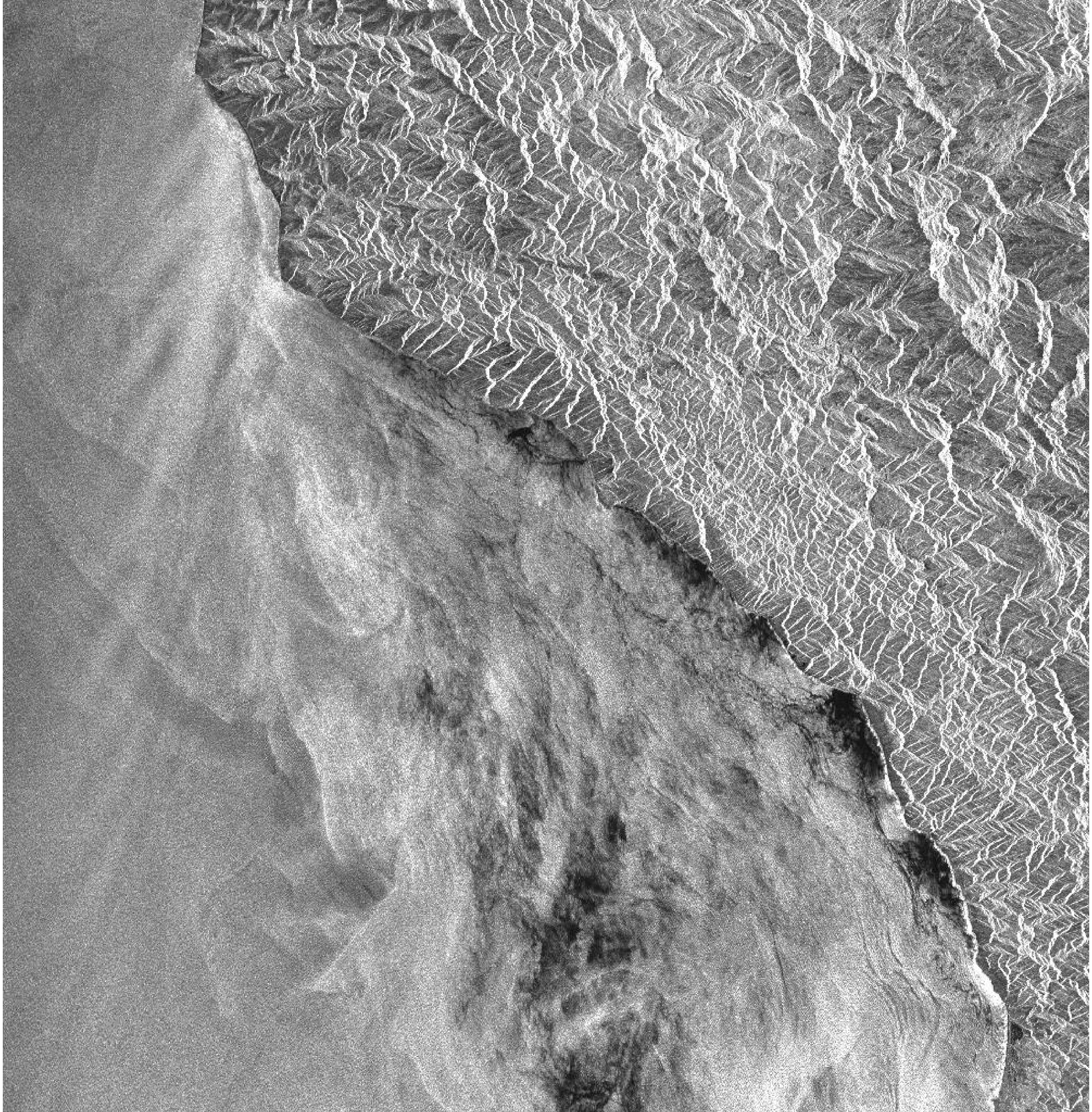
Unstable Shear Flow --> Vortex Generation

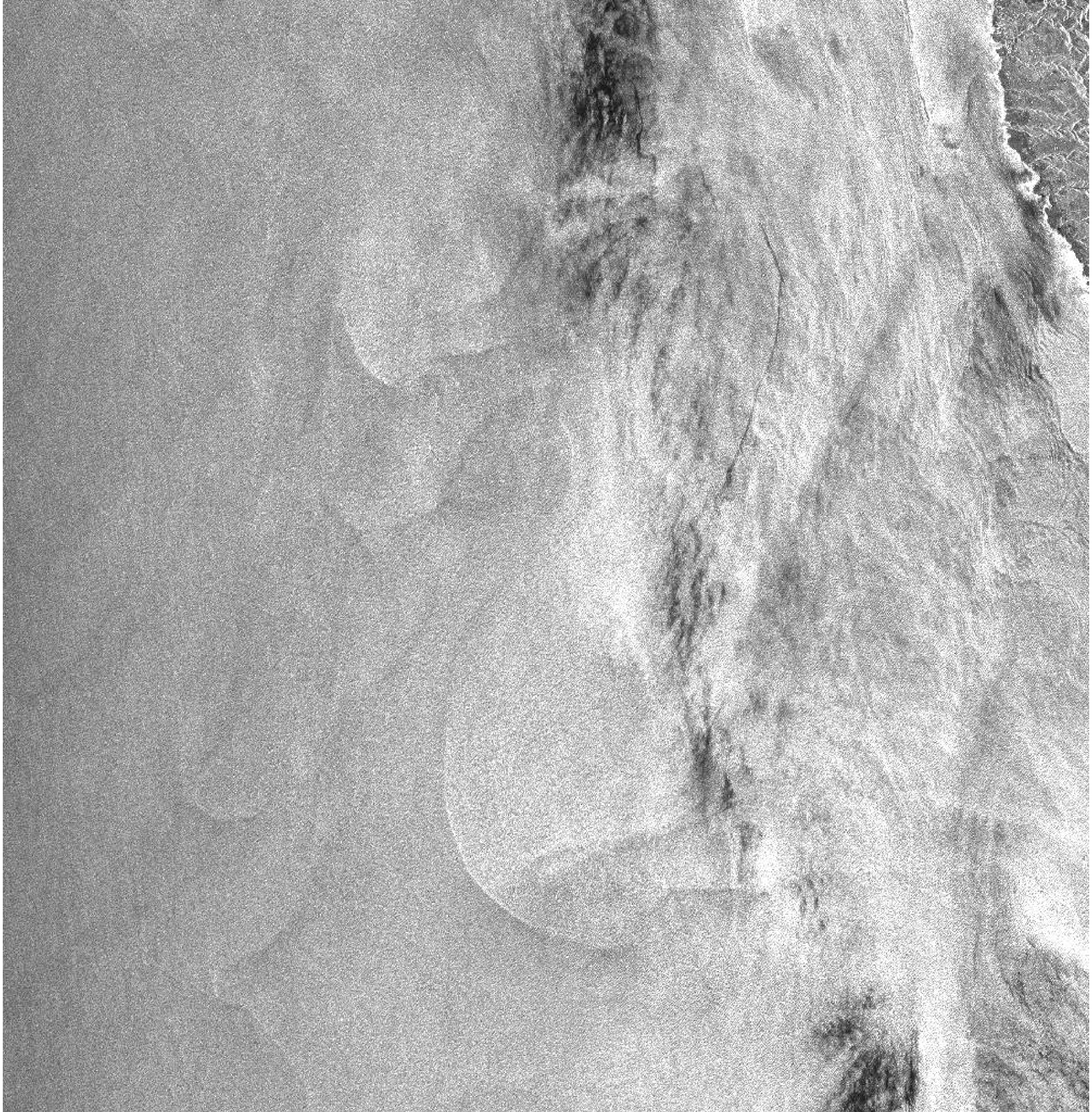


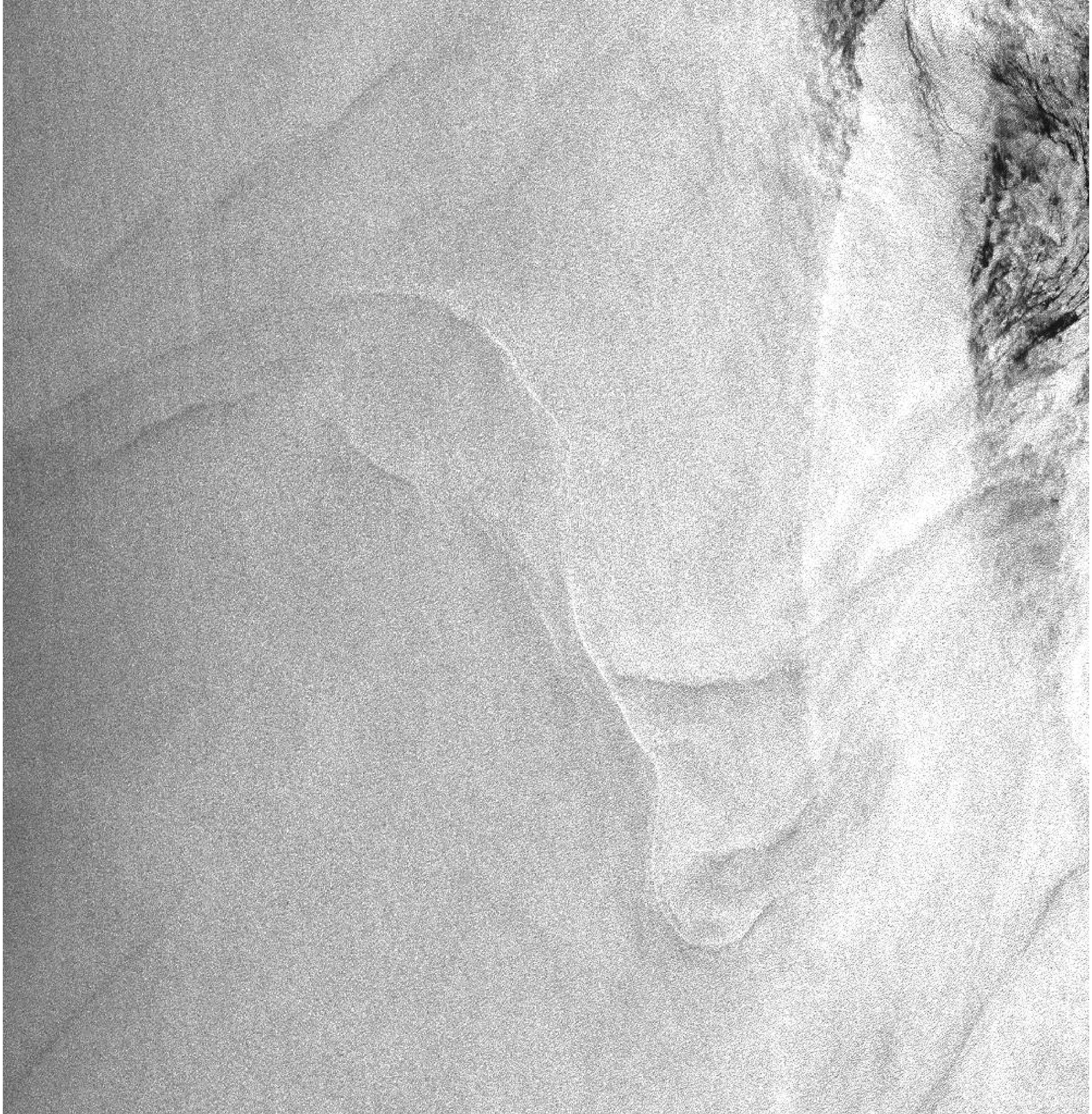
ERS-1 SAR Jul/Aug 1993

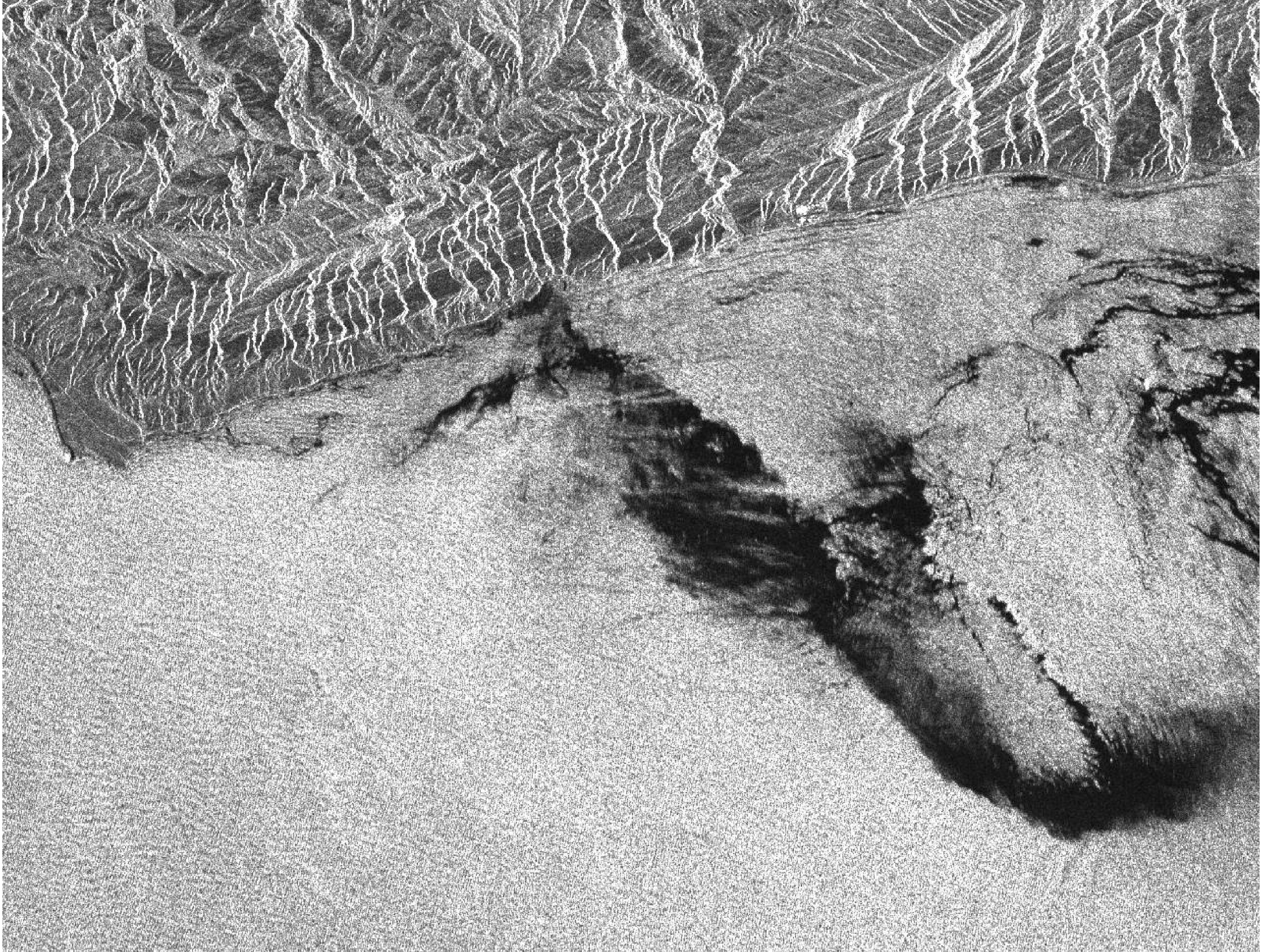



125W
120W
40N
35N
125W
120W

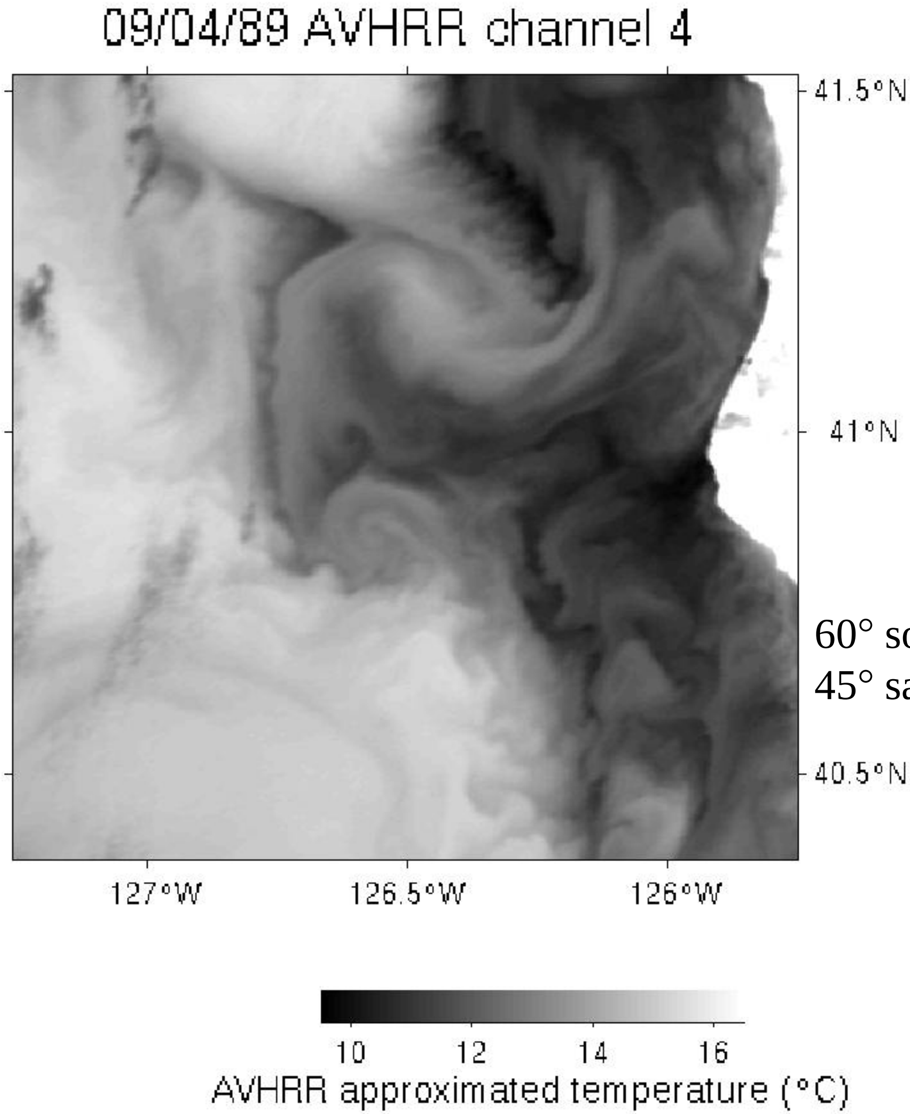




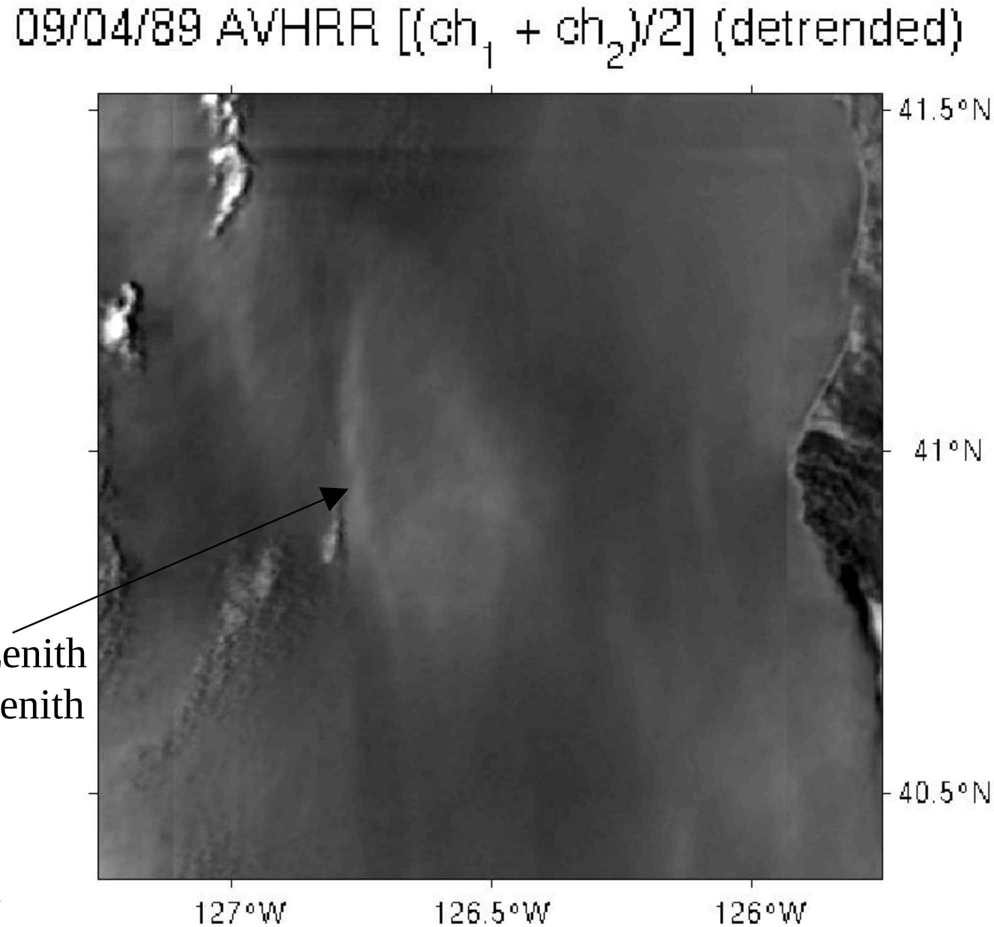




09/04/89 Optical Signal



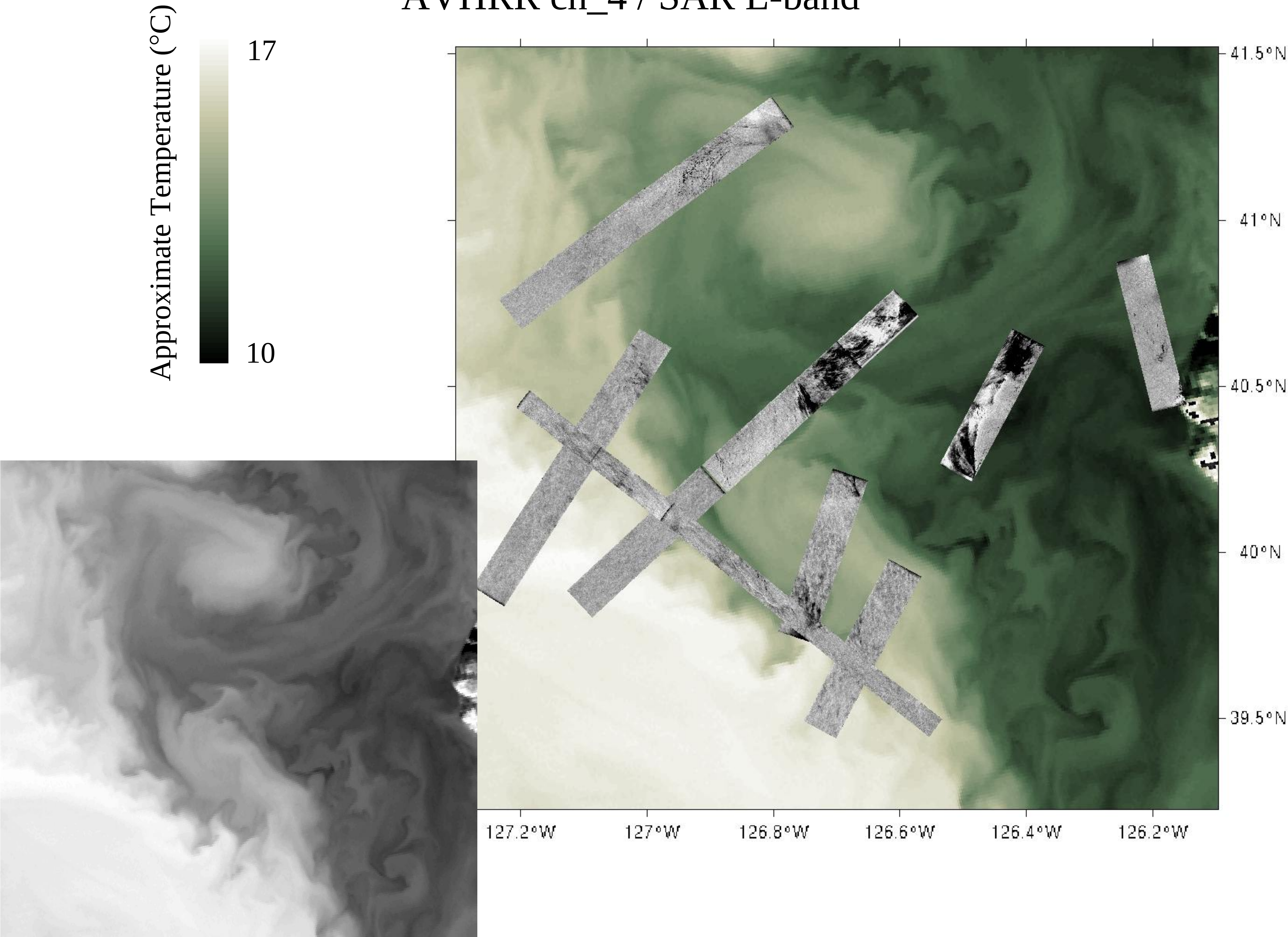
60° sol_zenith
45° sat_zenith

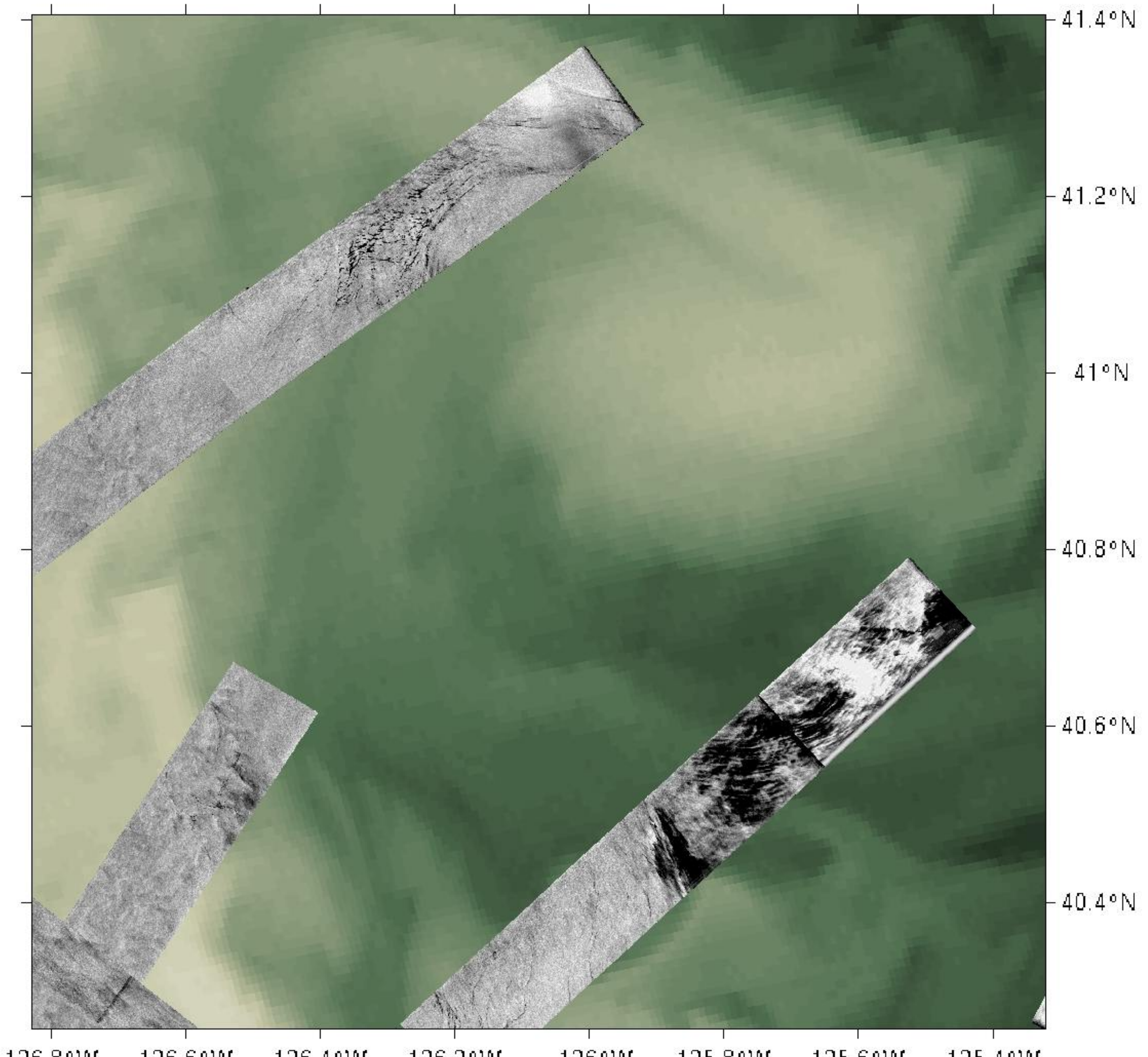


Increase in surface slope spectrum at 6°
(or marine stratus forming above fronts)

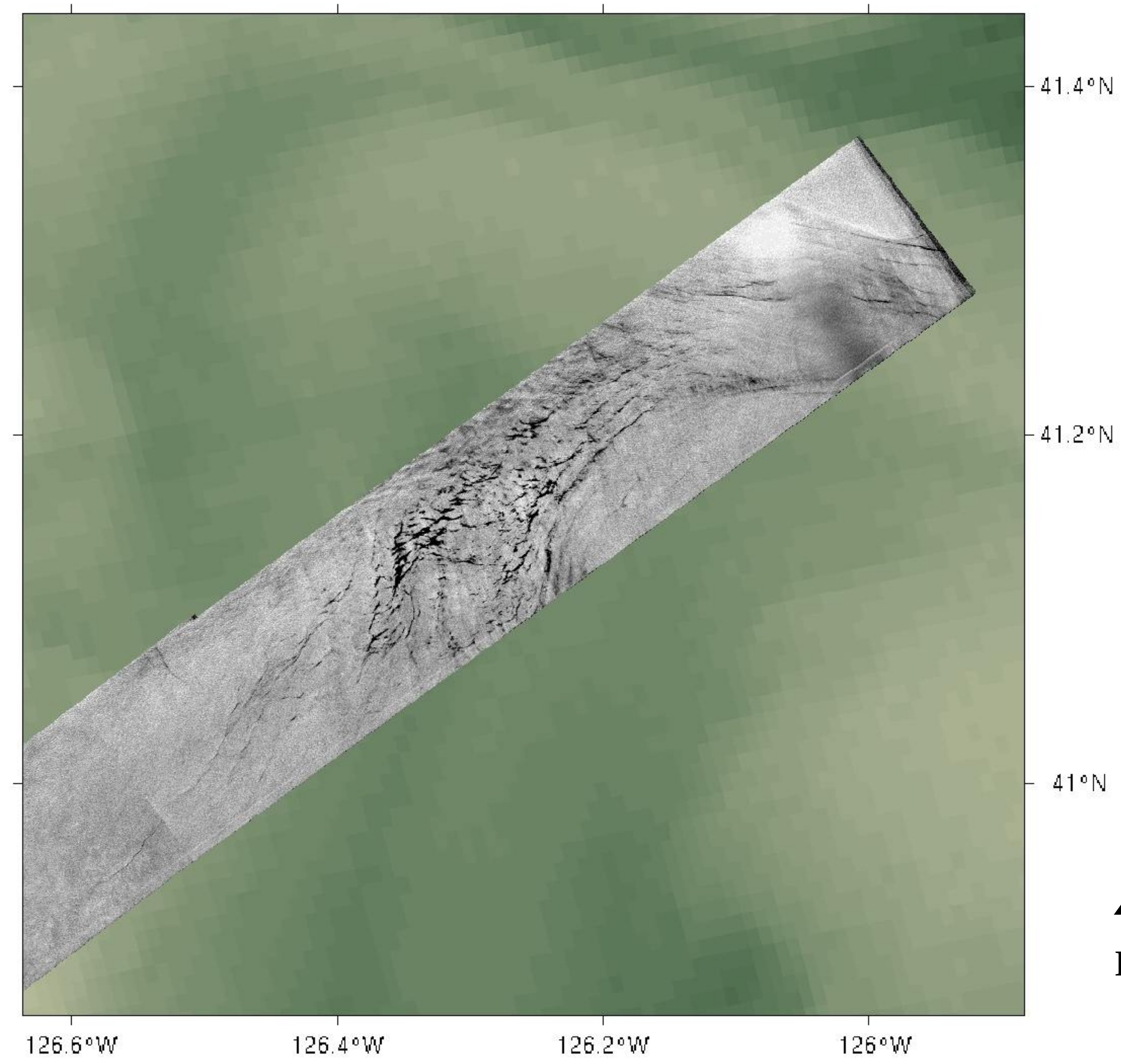
ch_1:	ch_2:
0.55-0.68 µm	0.72-1.10 µm
yellow-red	red-near IR

AVHRR ch_4 / SAR L-band



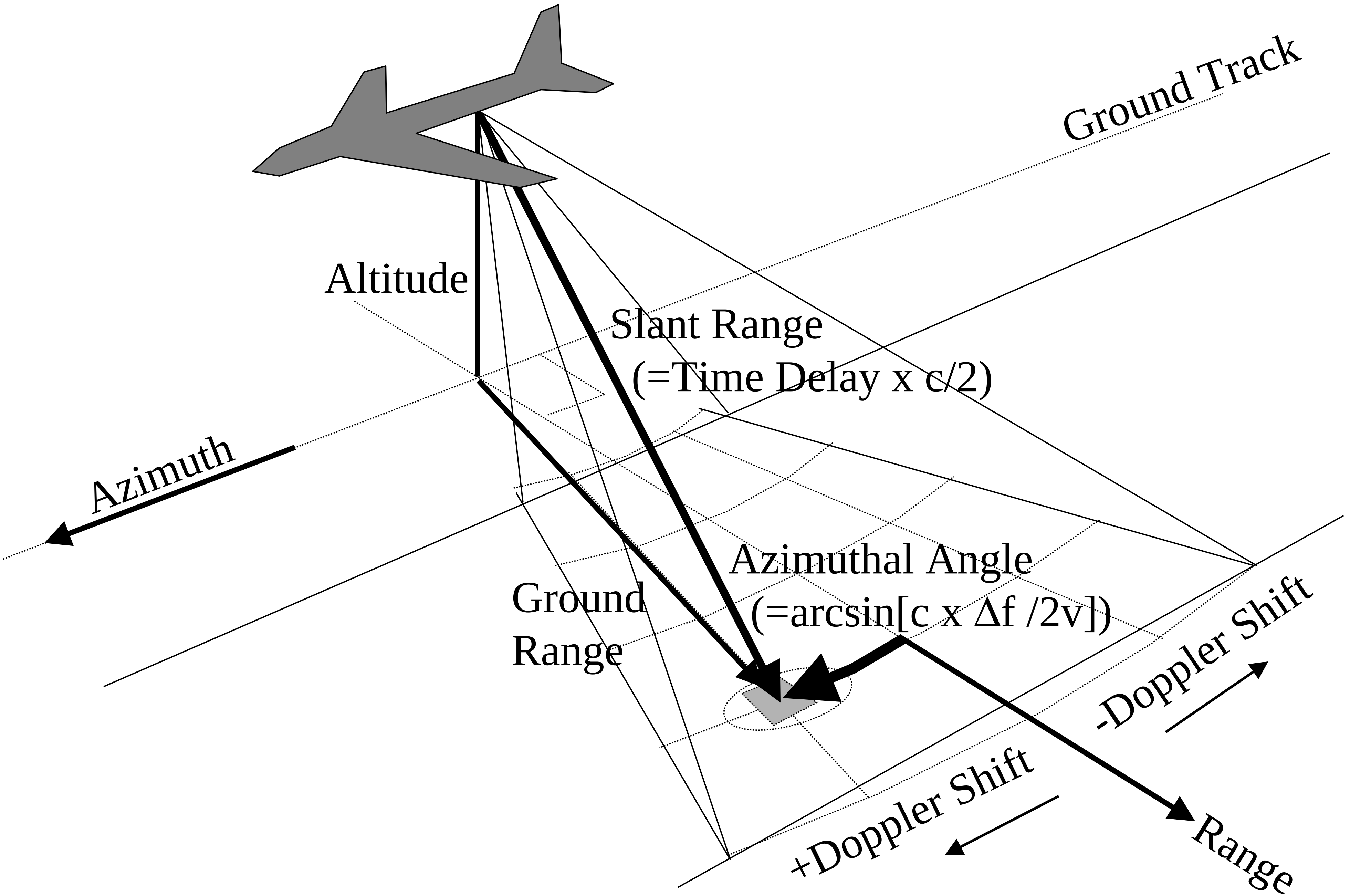


41.4°N
41.2°N
41°N
40.8°N
40.6°N
40.4°N
126.8°W
126.6°W
126.4°W
126.2°W
126°W
125.8°W
125.6°W
125.4°W

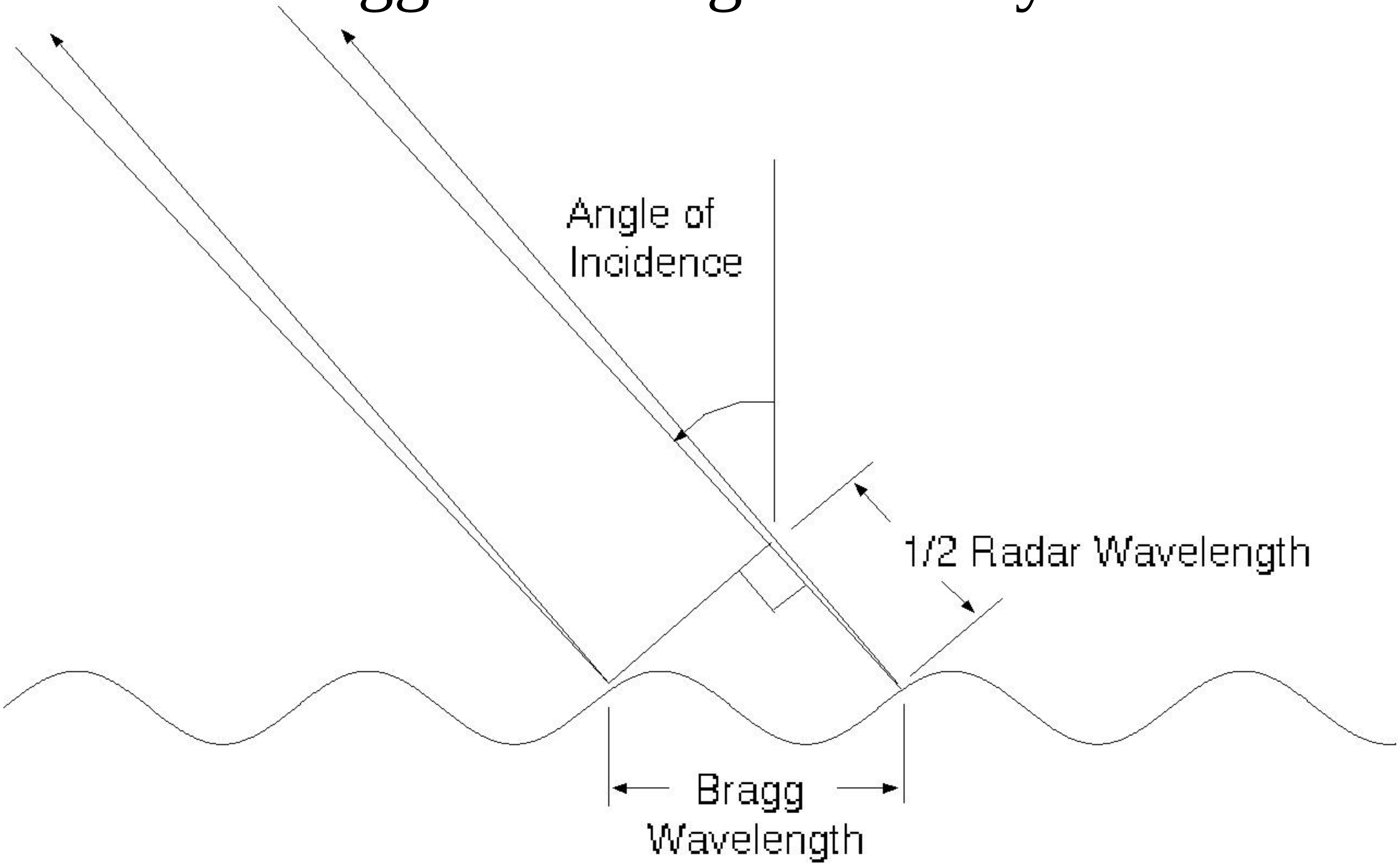


λ~1 km

SAR IMAGING GEOMETRY



Bragg Scattering Geometry



$$\lambda_{Bragg} = \lambda_{radar}/2\sin\theta$$

AIRSAR Bragg Wavelengths

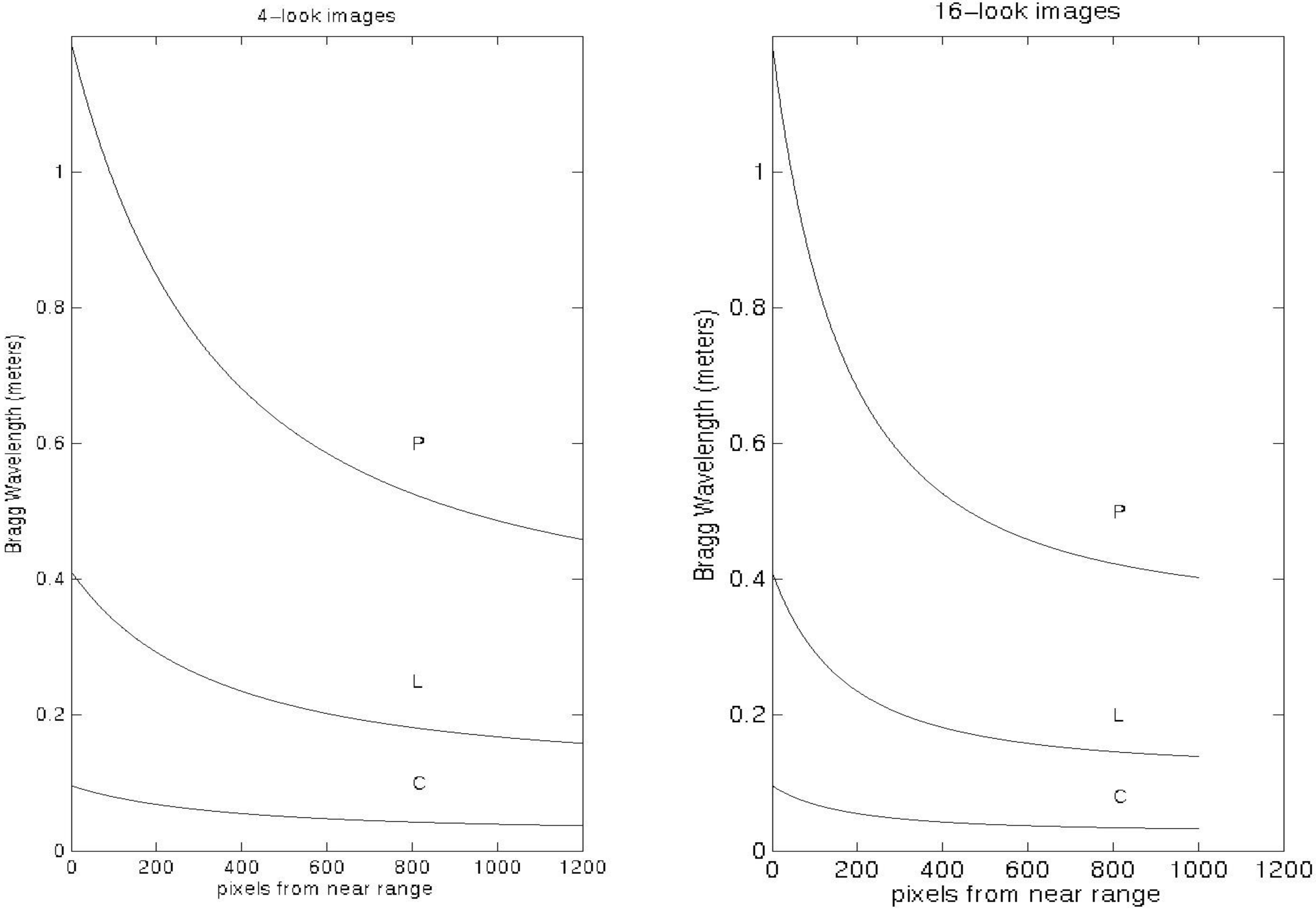
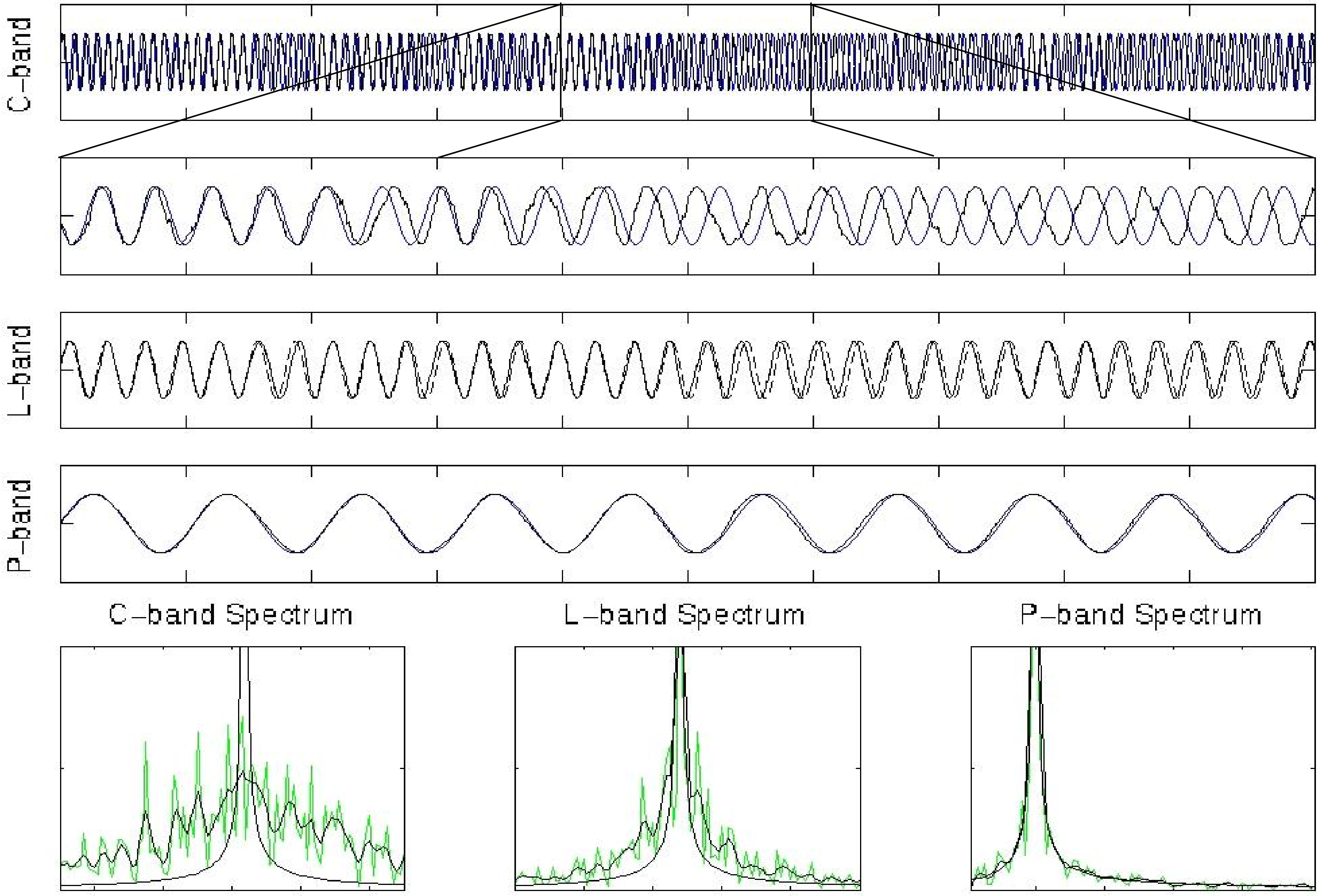
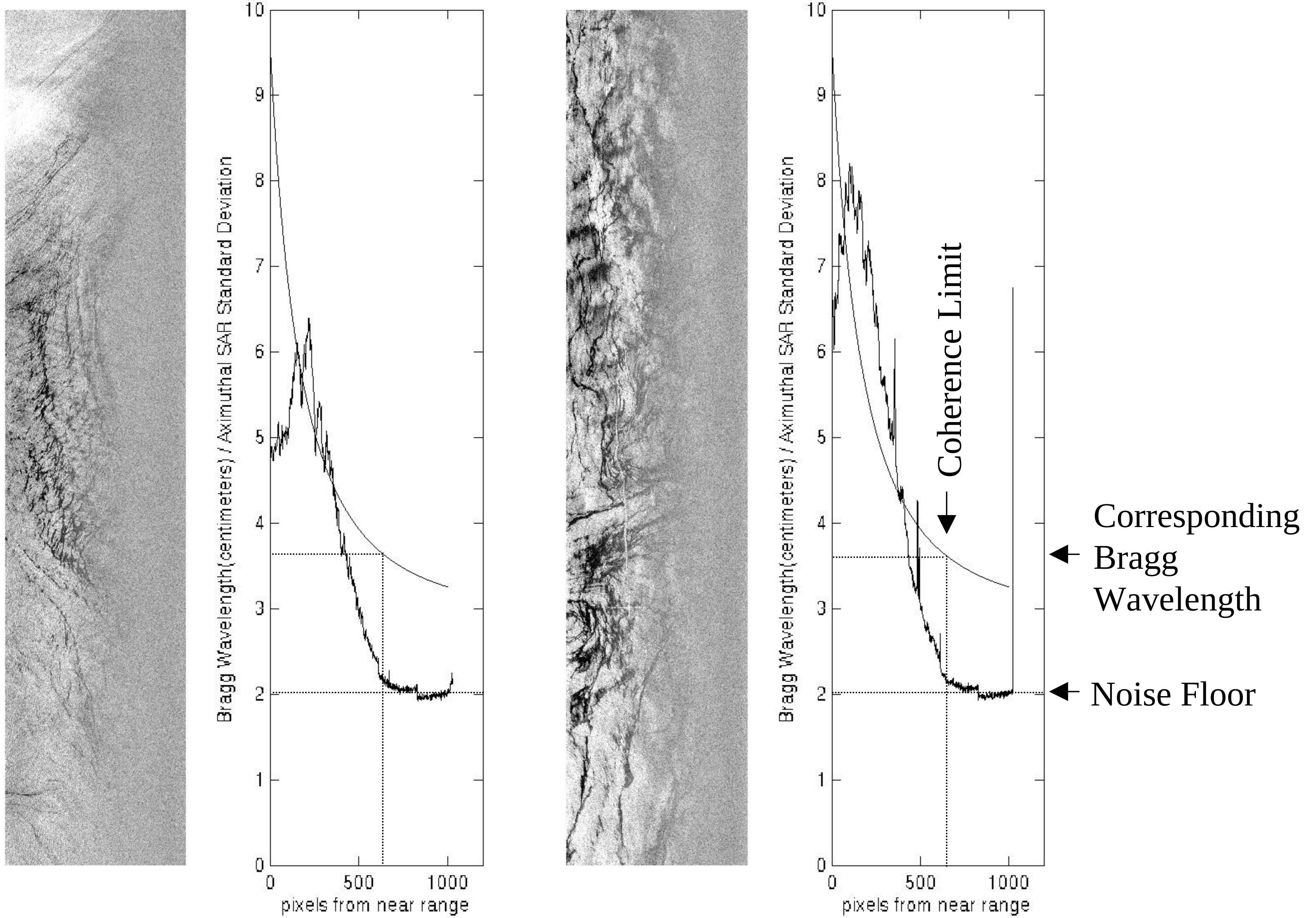


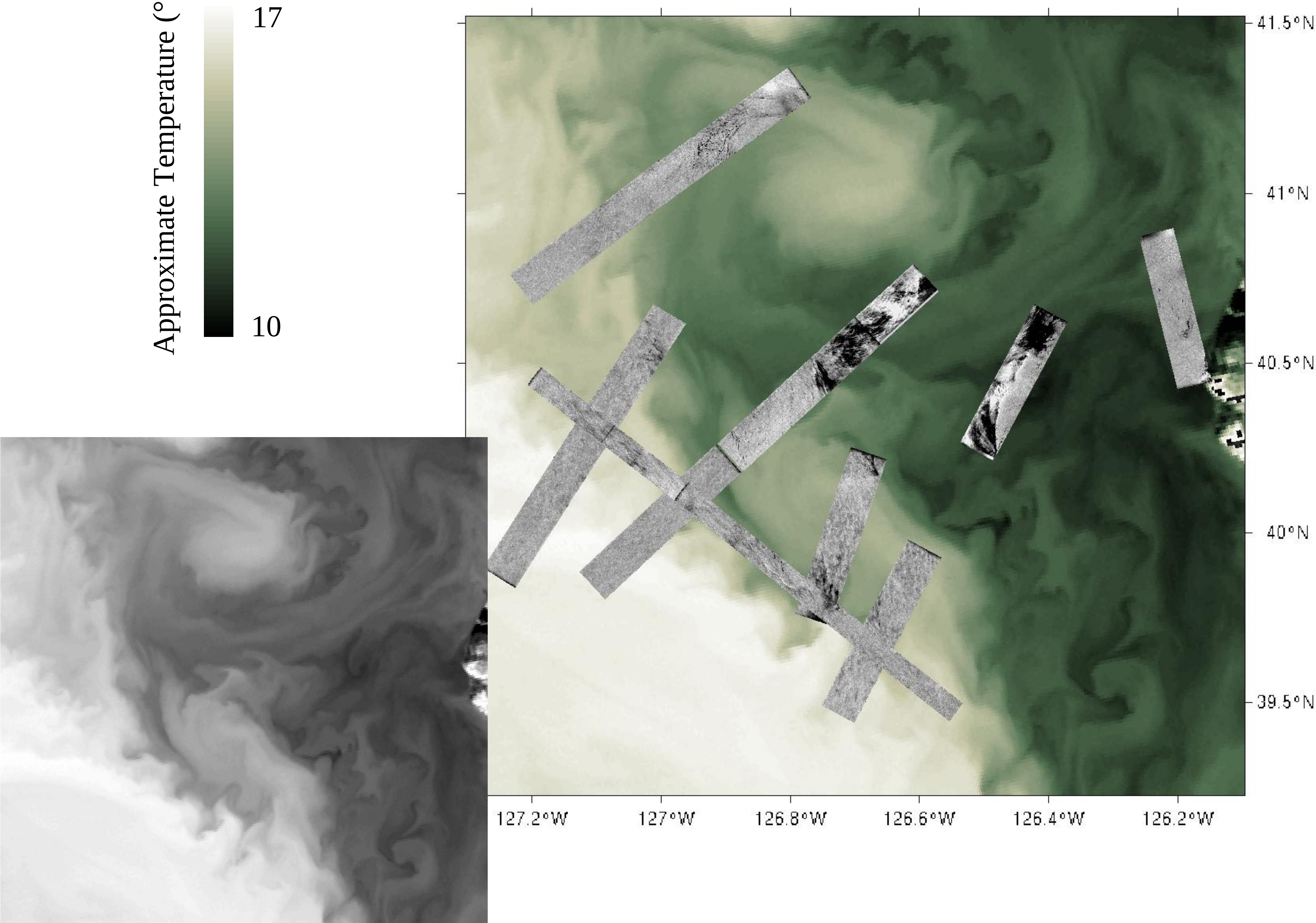
Illustration of the Effect of a Random Perturbation on Phase Coherence



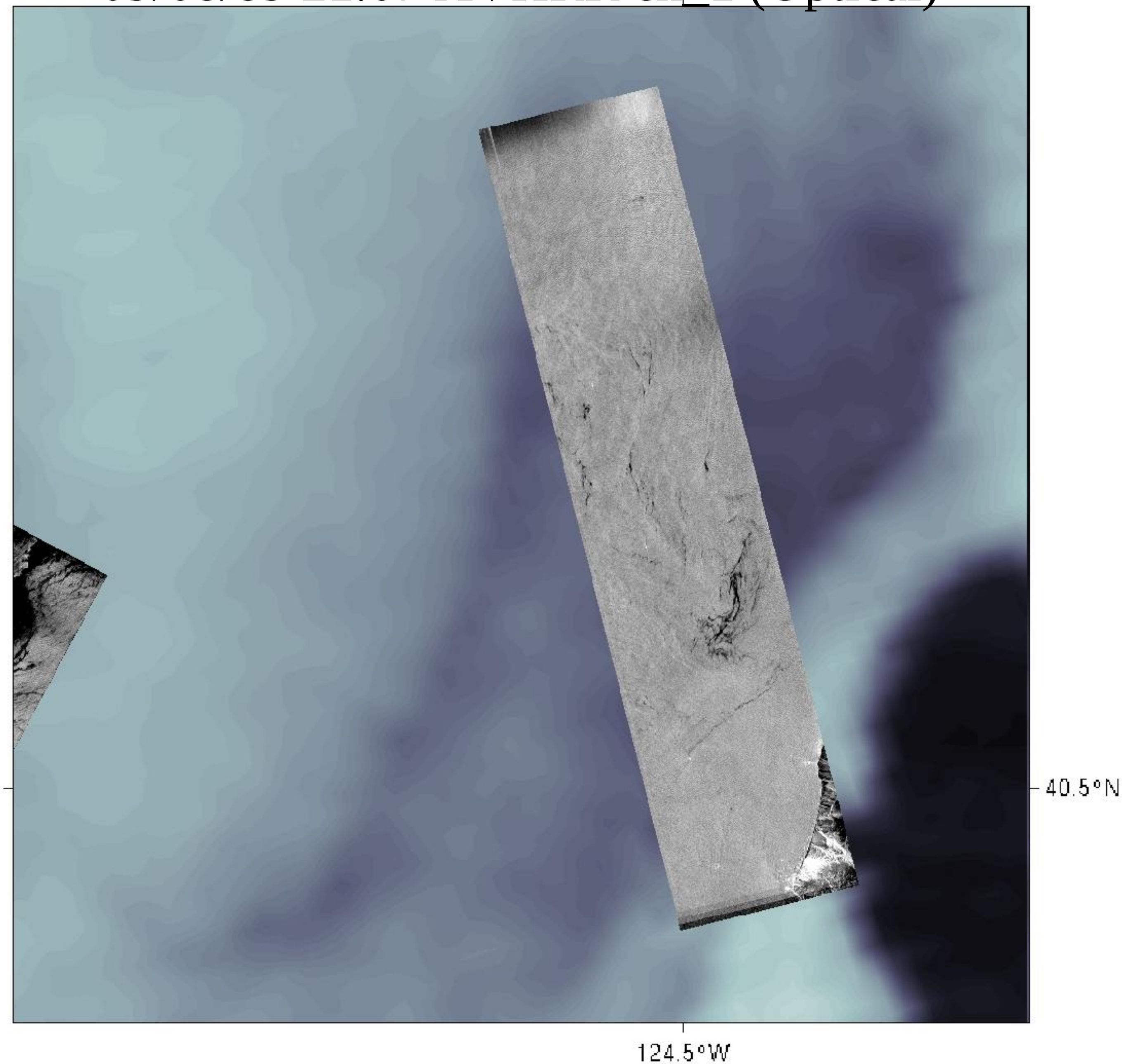
AIRSAR C-band Bragg Wave Incoherence at Shallow Incidence Angles



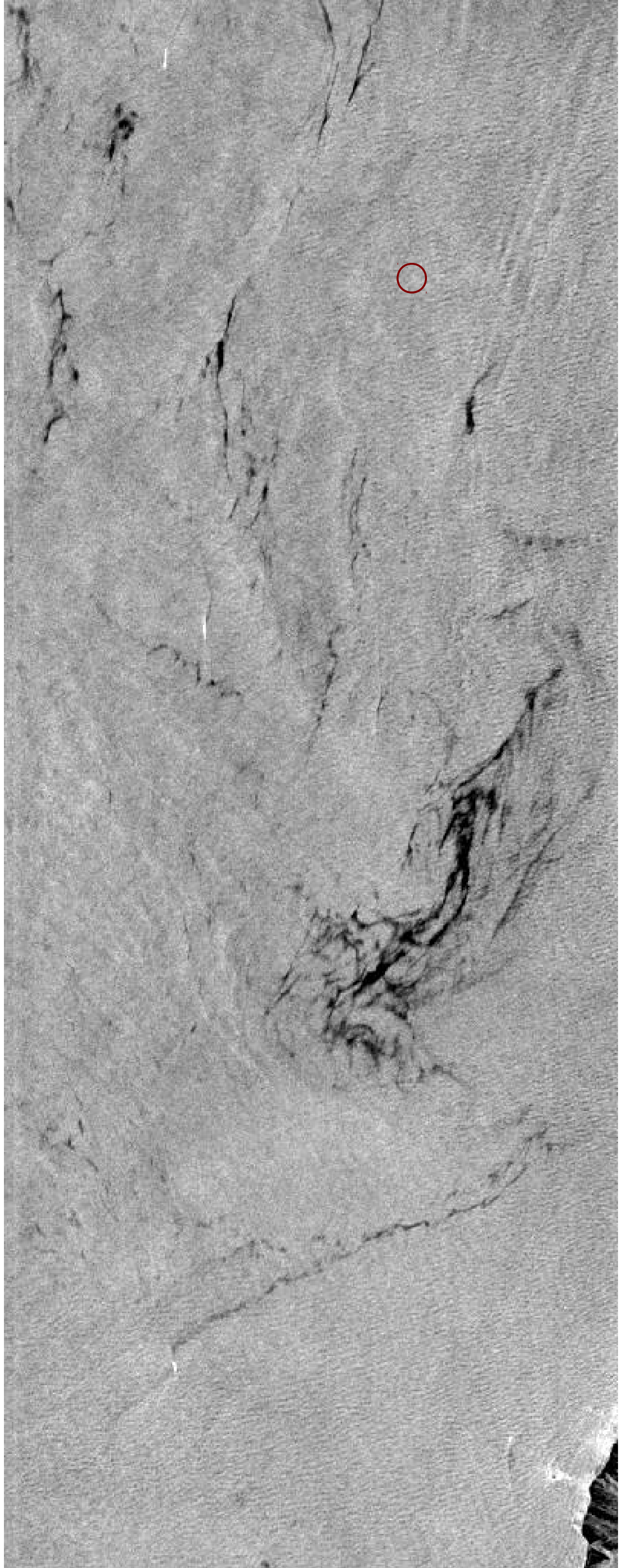
AVHRR ch_4 / SAR L-band



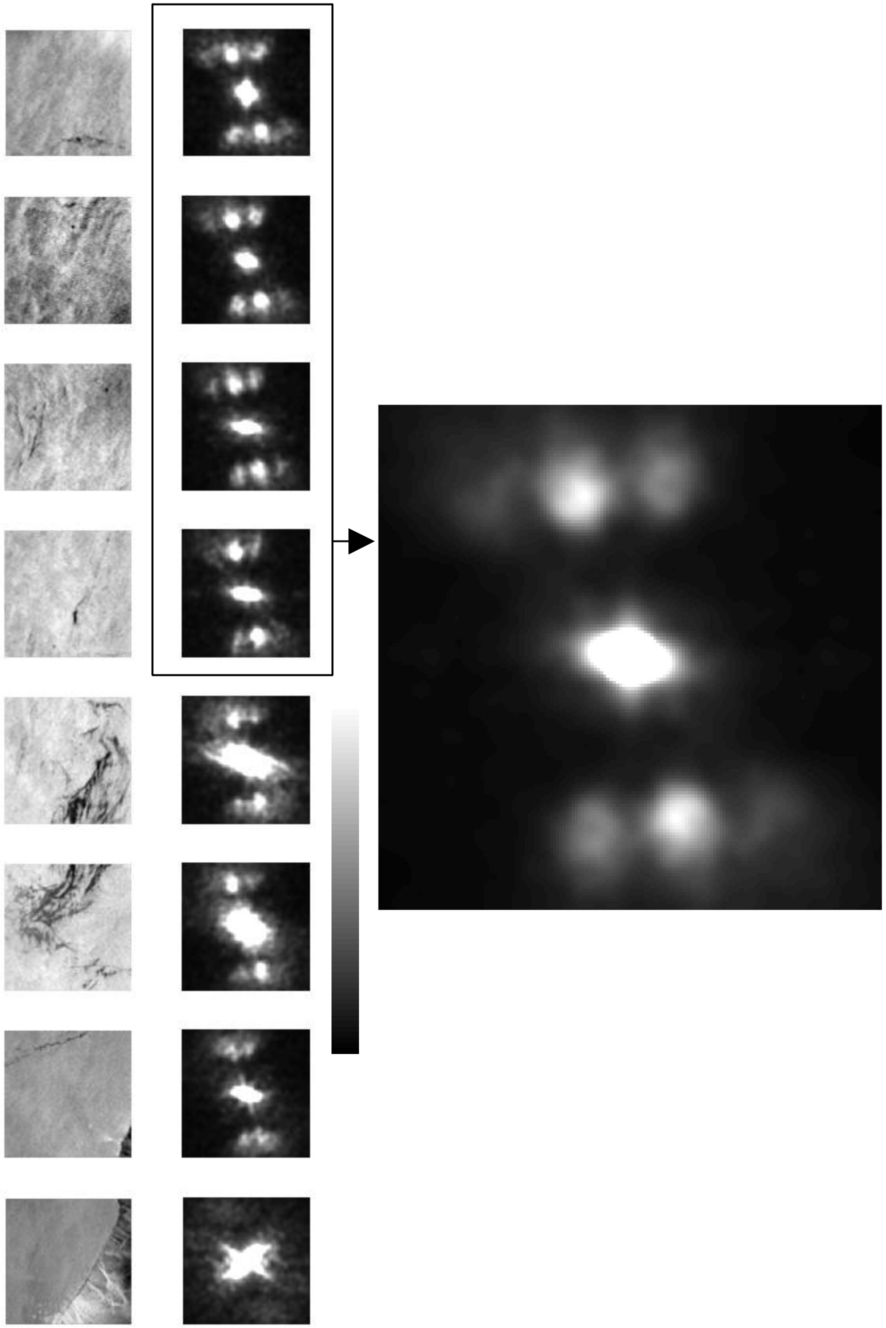
09/08/89 21:07 AVHRR ch_1 (Optical)

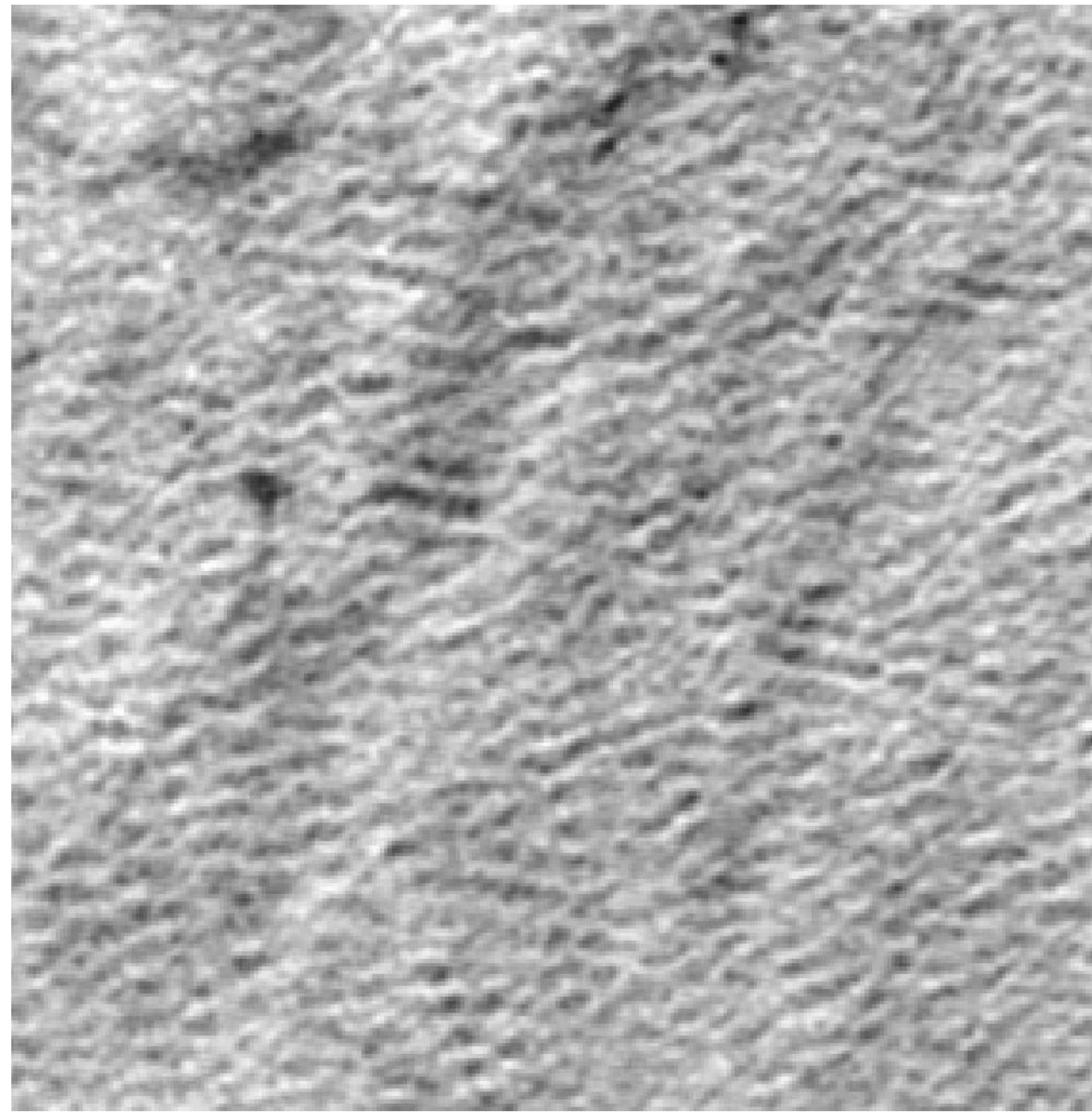


λ~250 m



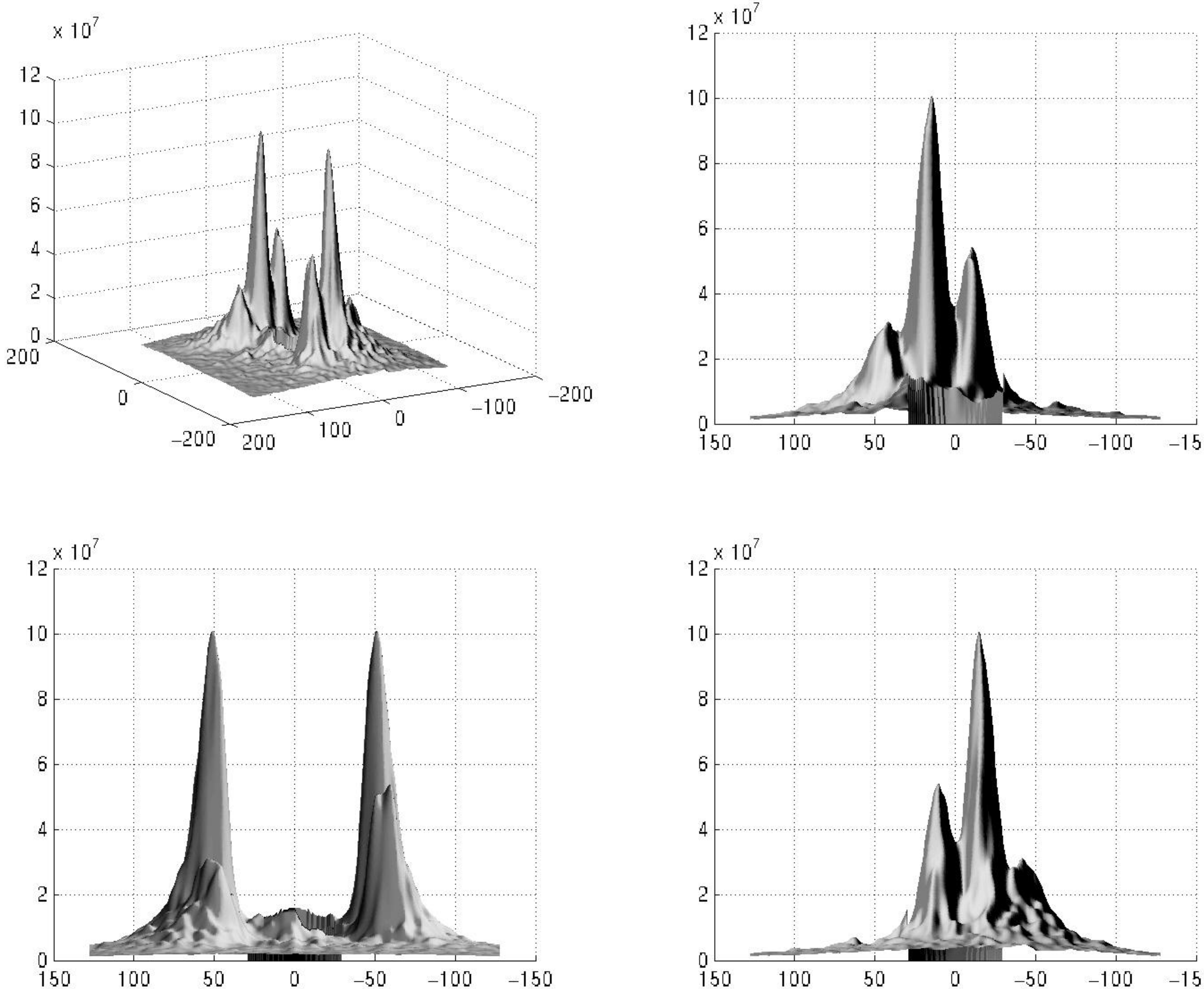
SAR Derived Swell Spectra

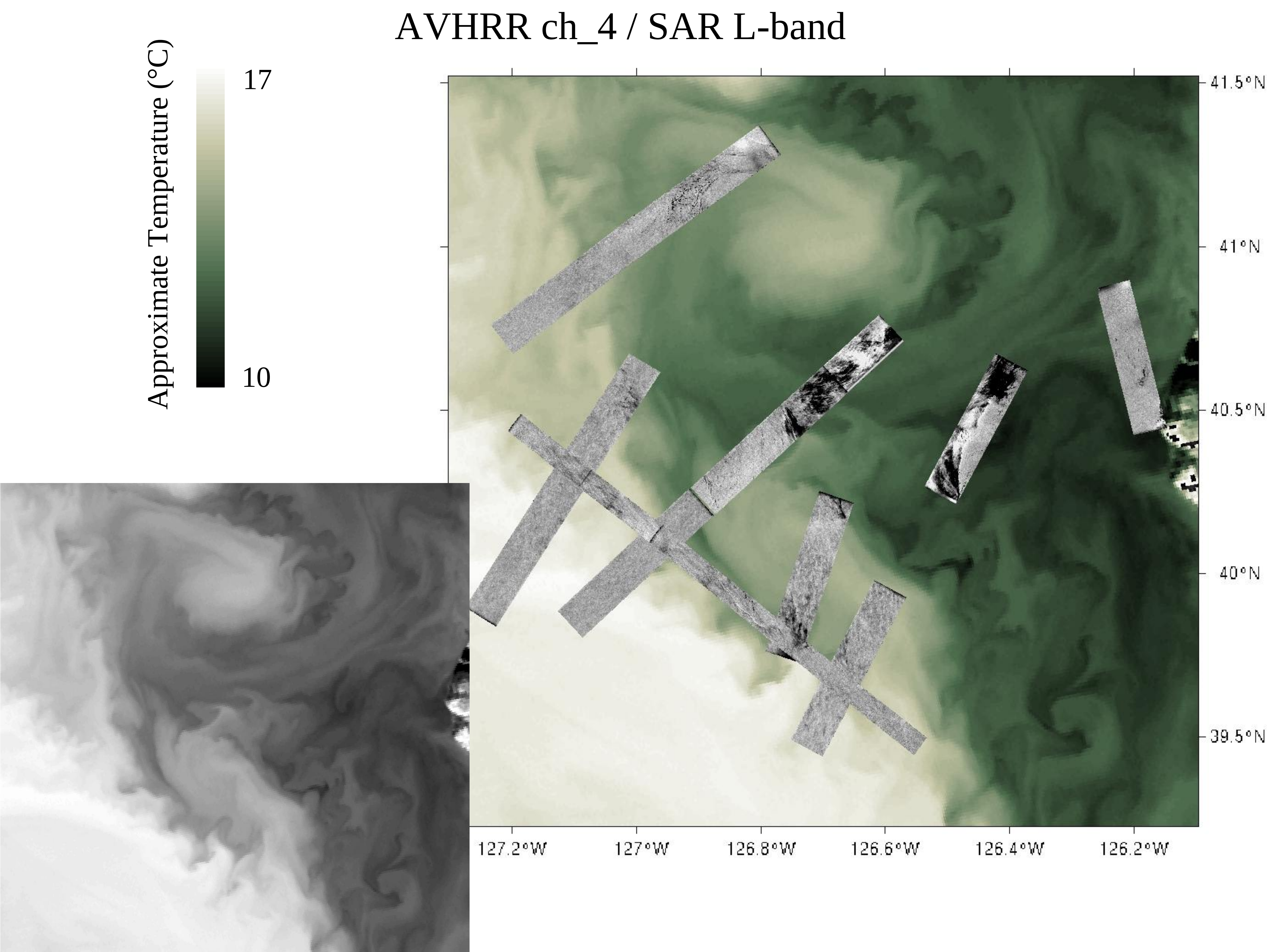




λ~120
m

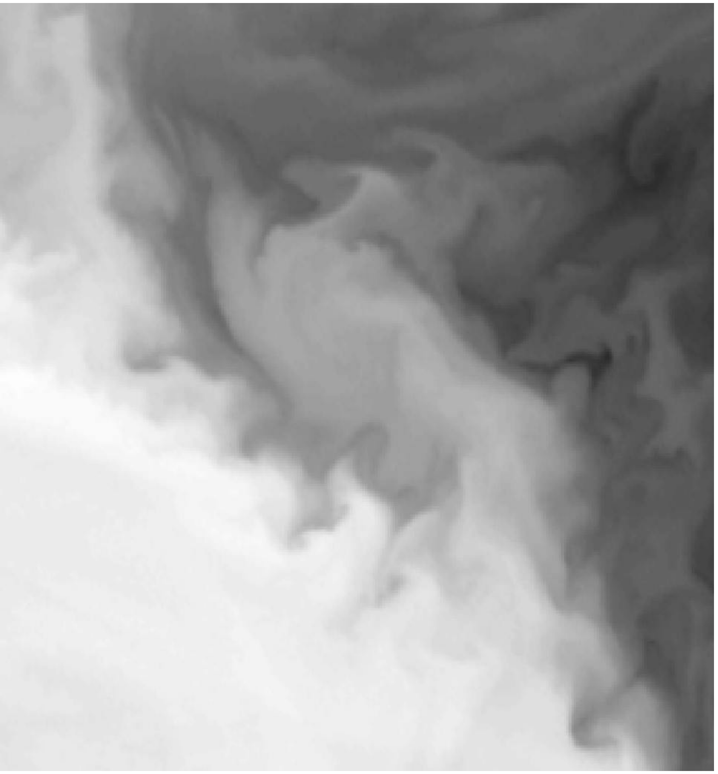
SAR Derived Swell Spectra

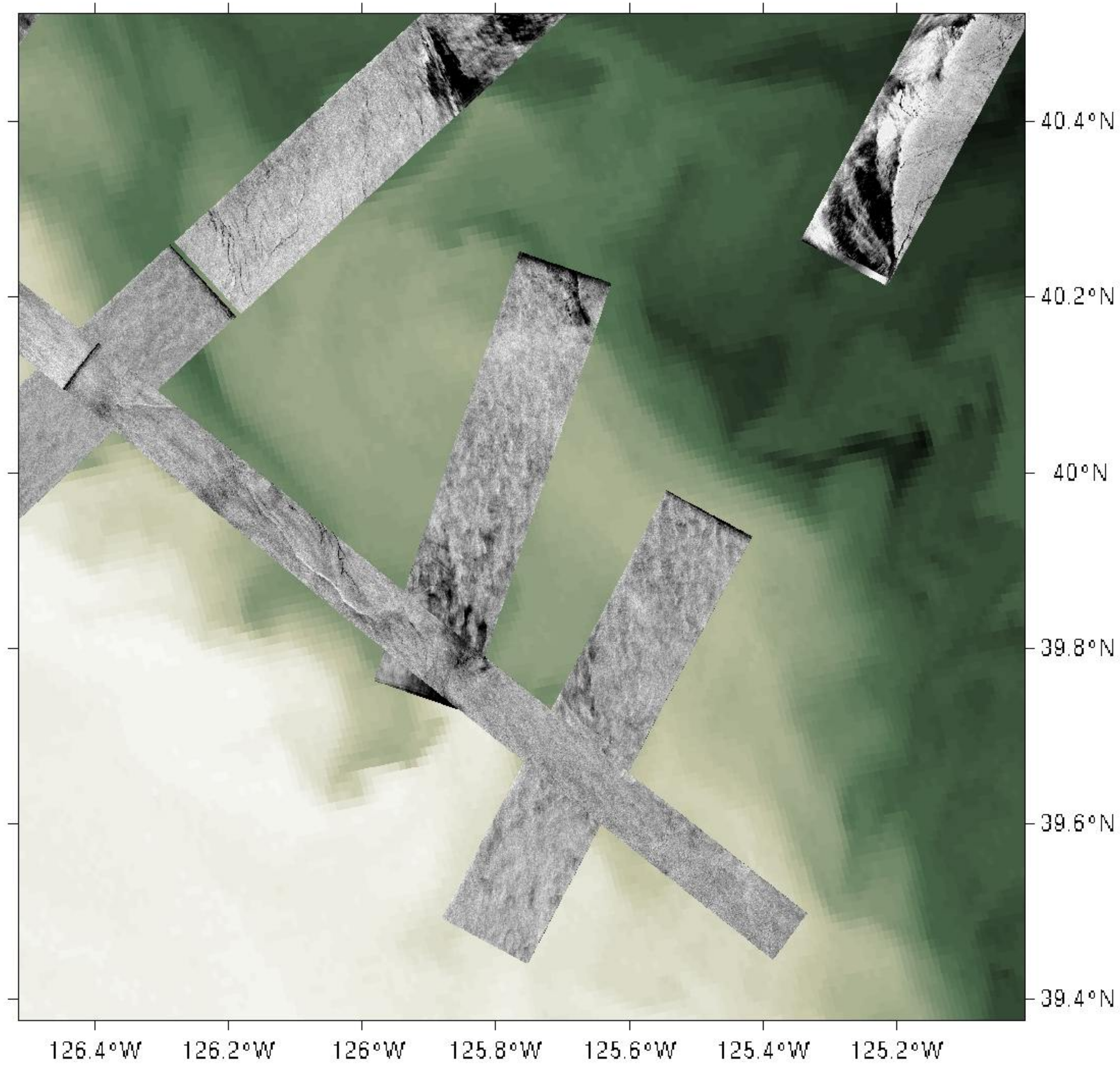


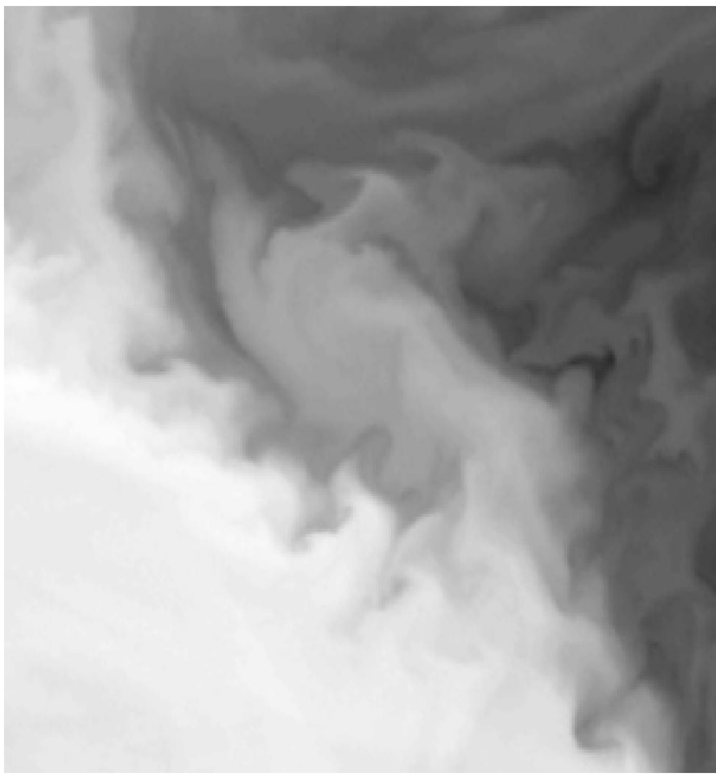


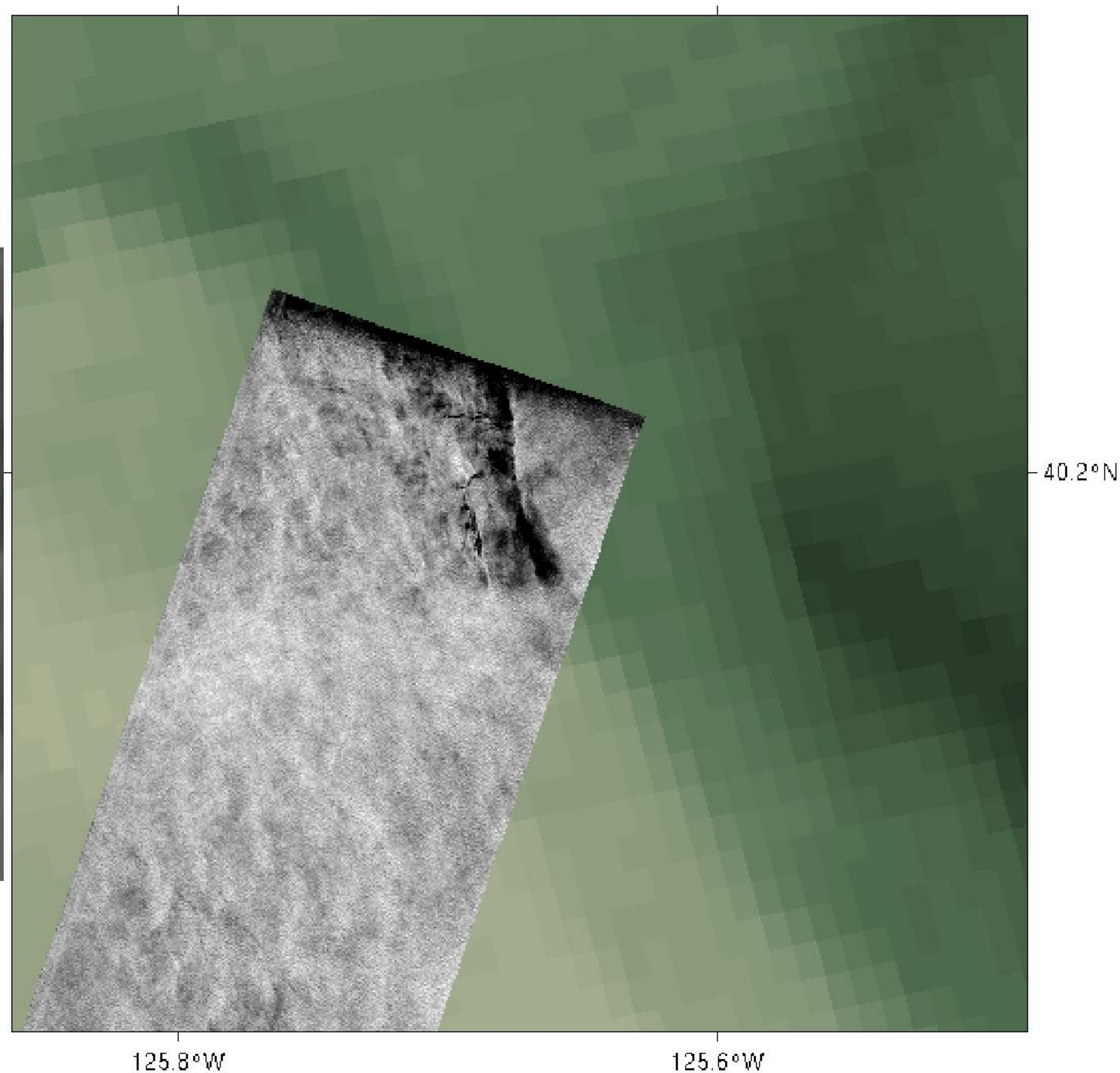
AVHRR ch_4 / SAR L-band
Approximate Temperature (°C)
17
10
41.5°N
41°N
40.5°N
40°N
39.5°N
127.2°W
127°W
126.8°W
126.6°W
126.4°W
126.2°W

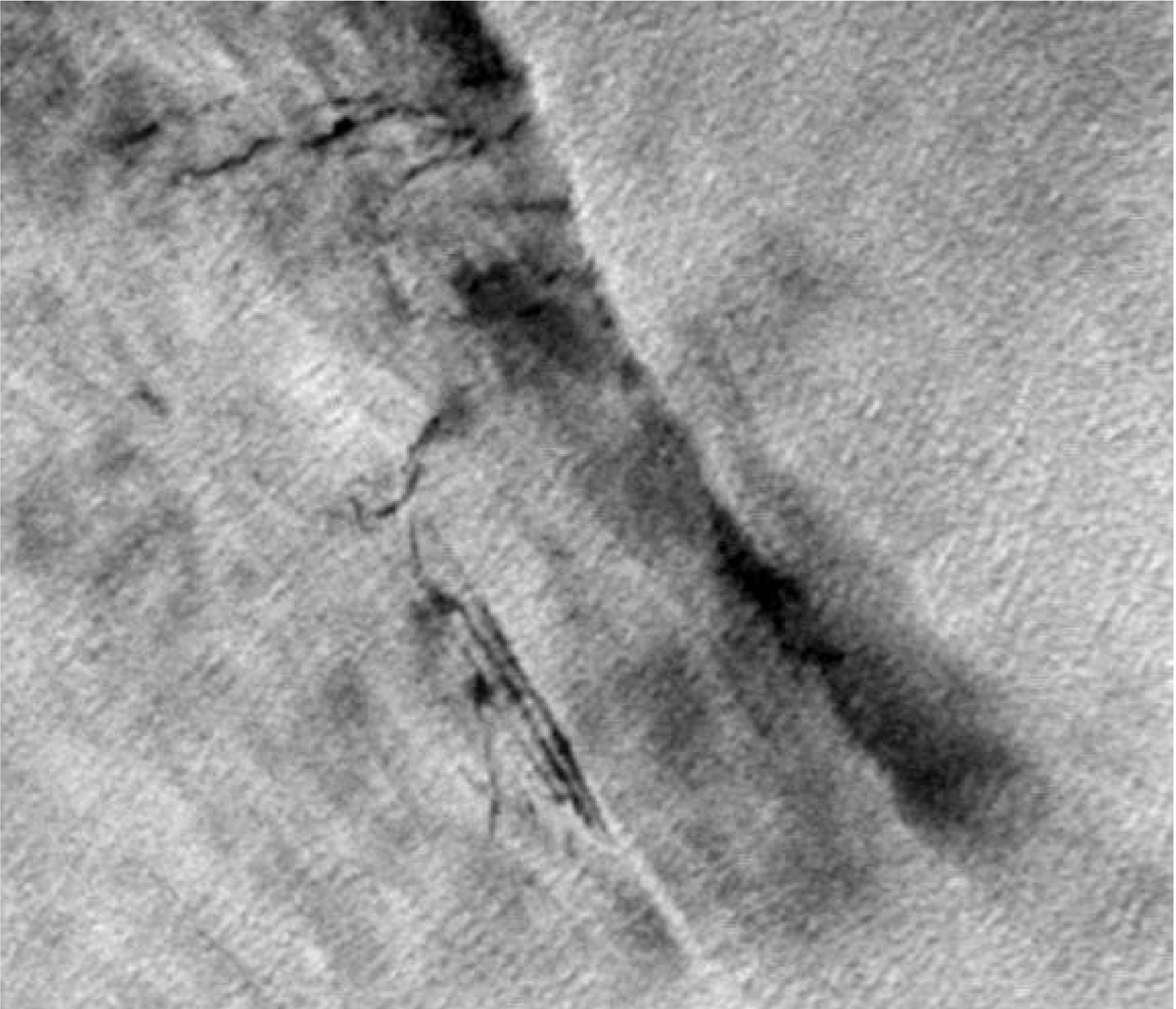
Cyclone



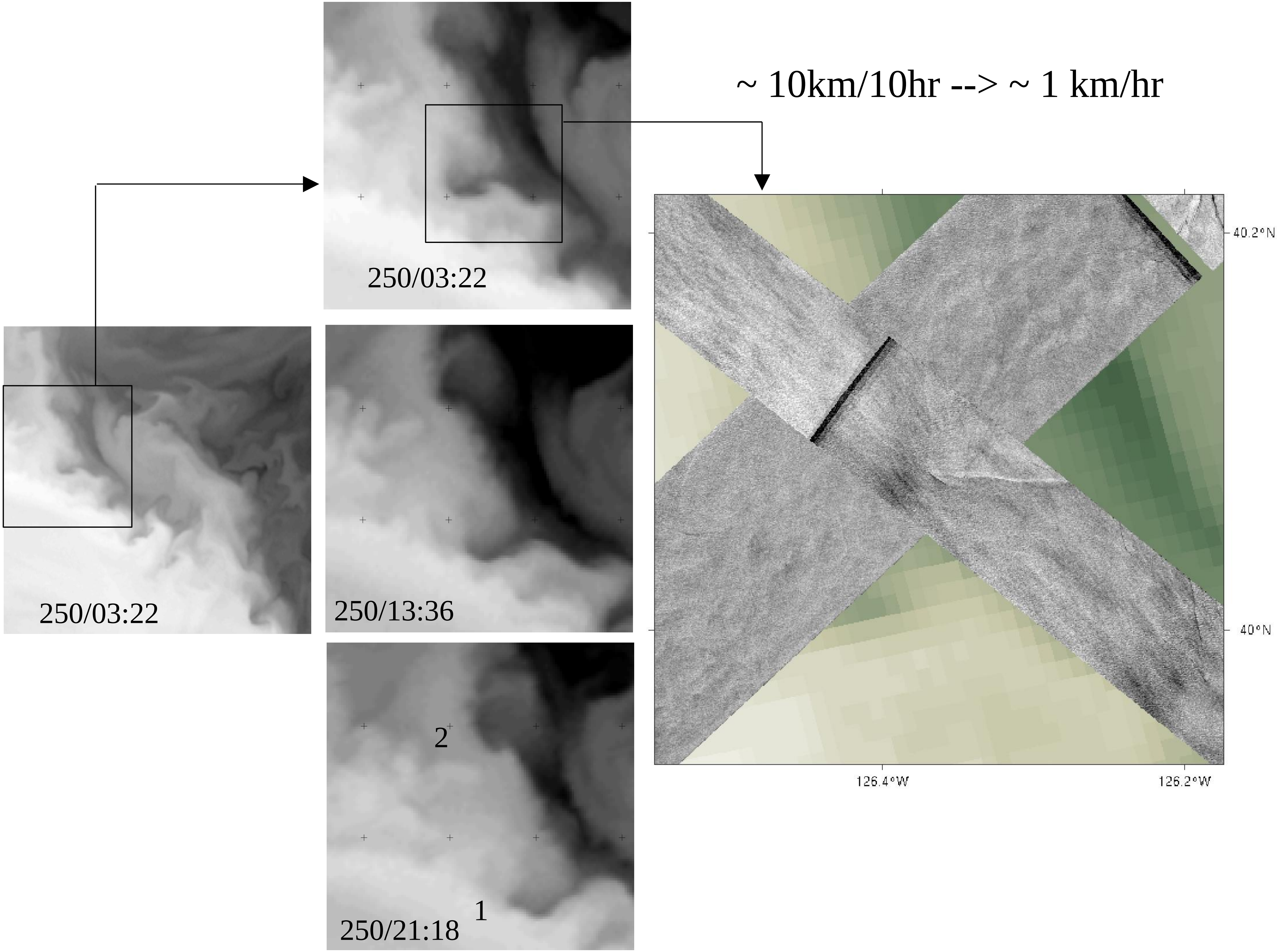

40.4°N
40.2°N
40°N
39.8°N
39.6°N
39.4°N
126.4°W
126.2°W
126°W
125.8°W
125.6°W
125.4°W
125.2°W

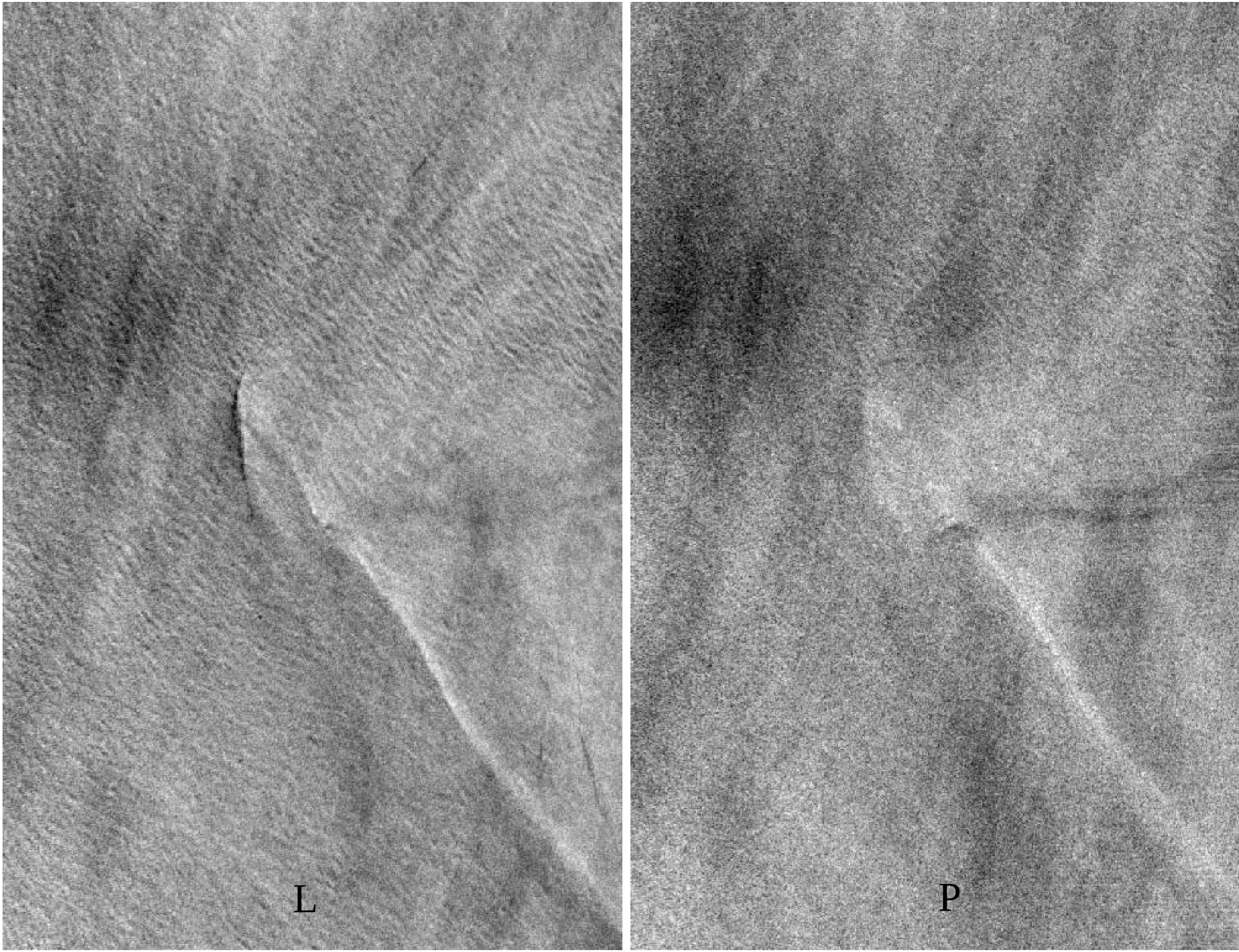



40.2°N
125.8°W
125.6°W

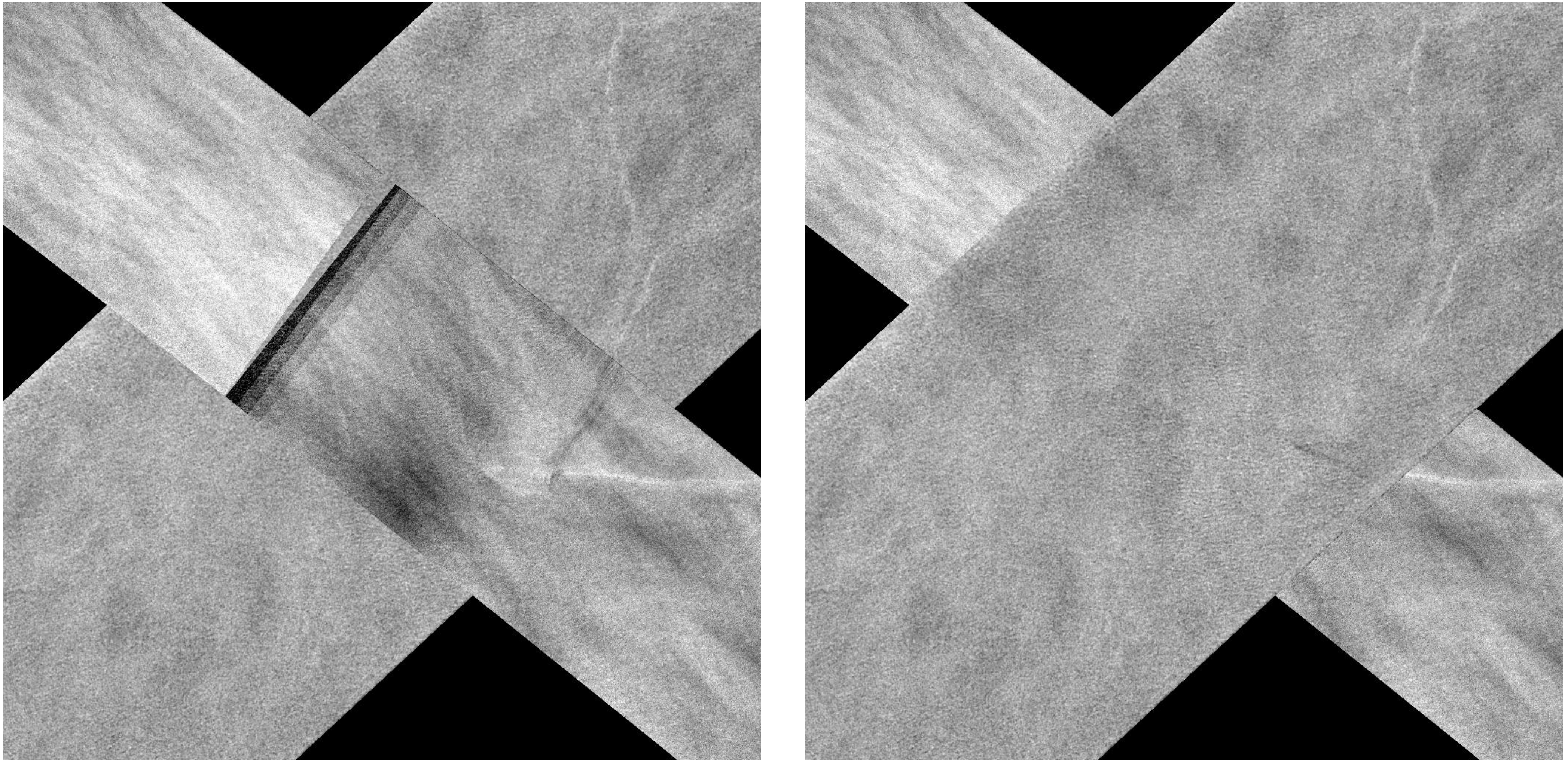


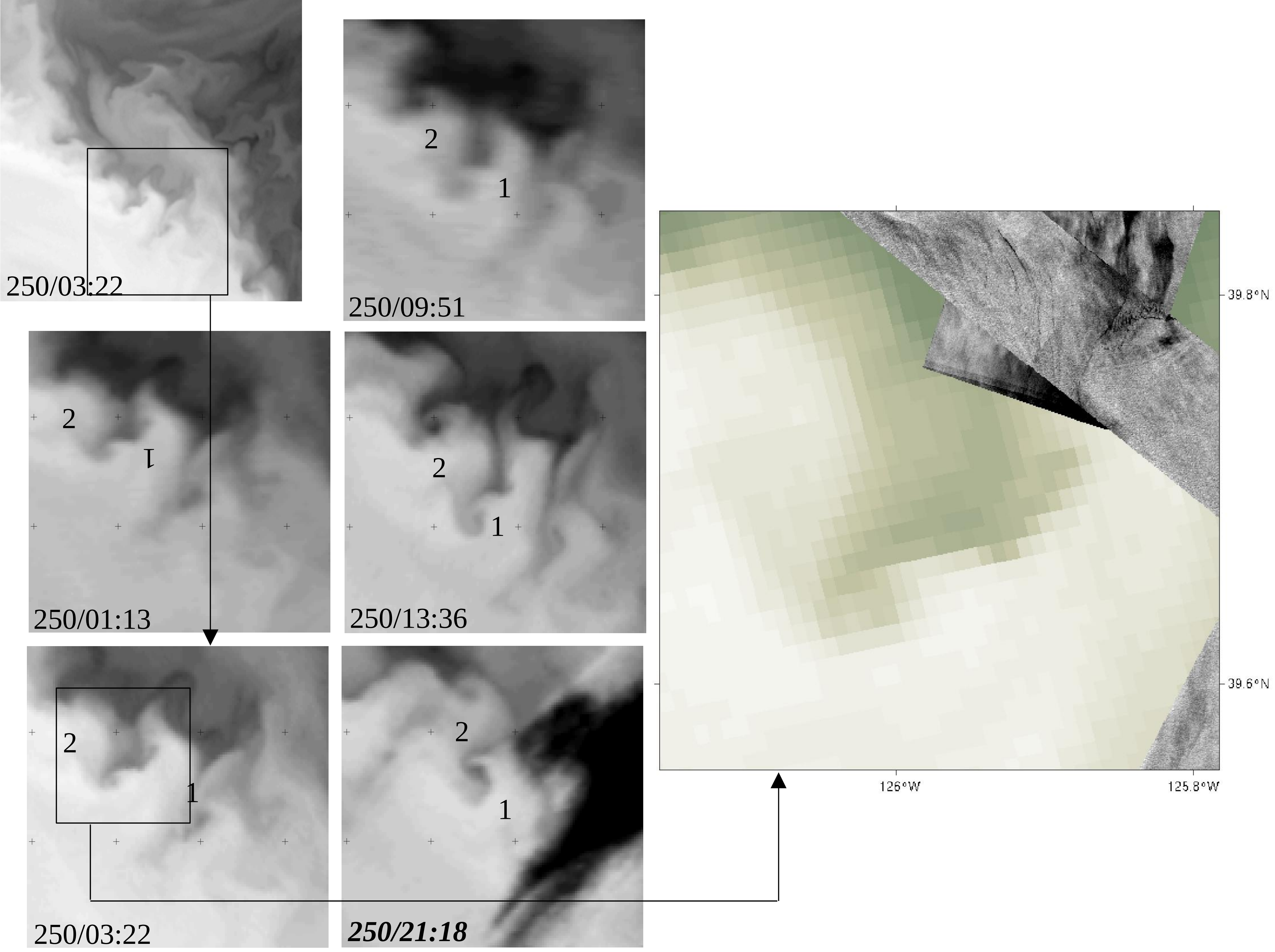
λ~120 m

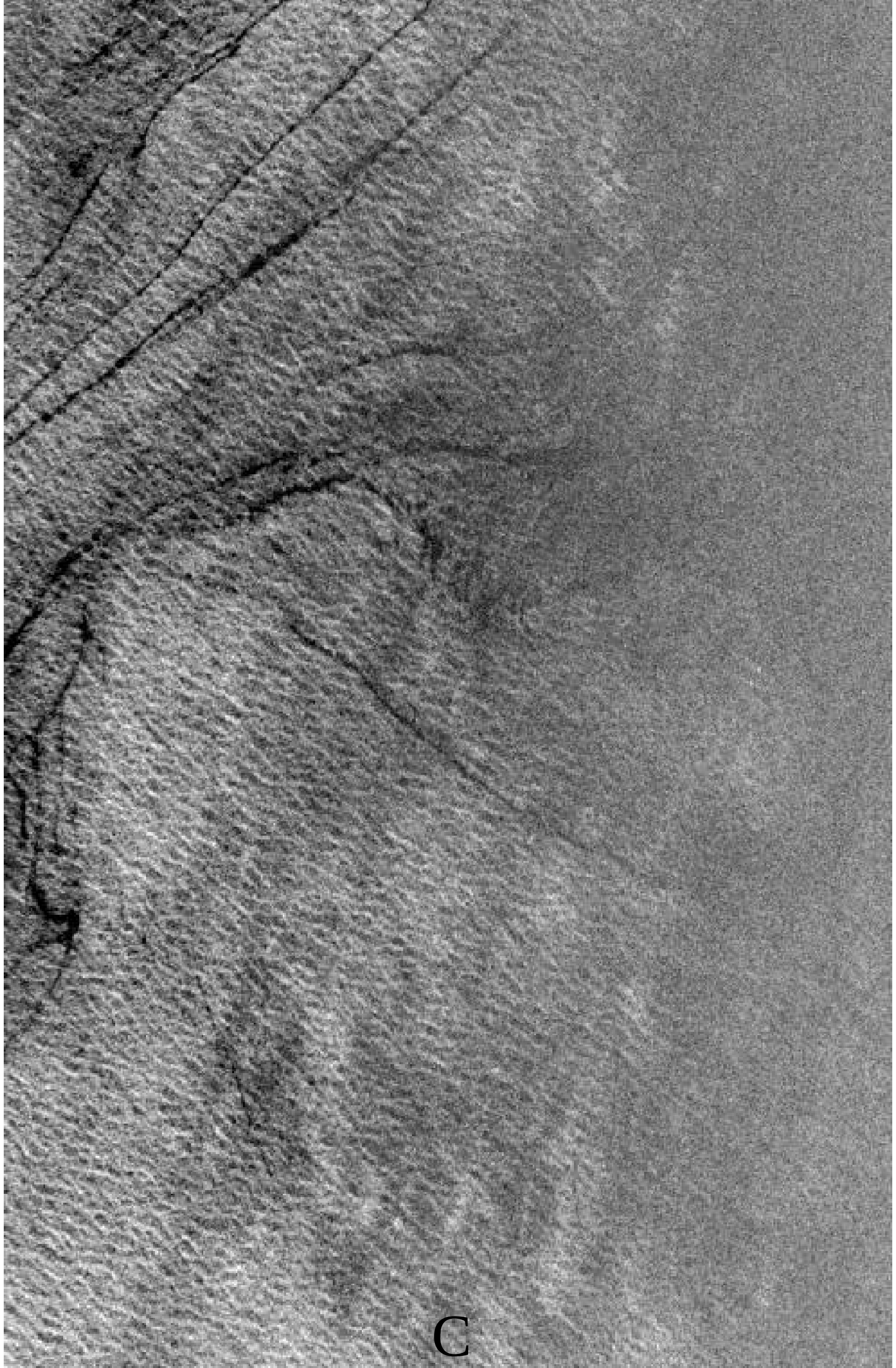

~ 10km/10hr --> ~ 1 km/hr
250/03:22
250/03:22
250/13:36
2
1
250/21:18
40.2°N
40°N
126.4°W
126.2°W


L
P

SAR P-band Crossing

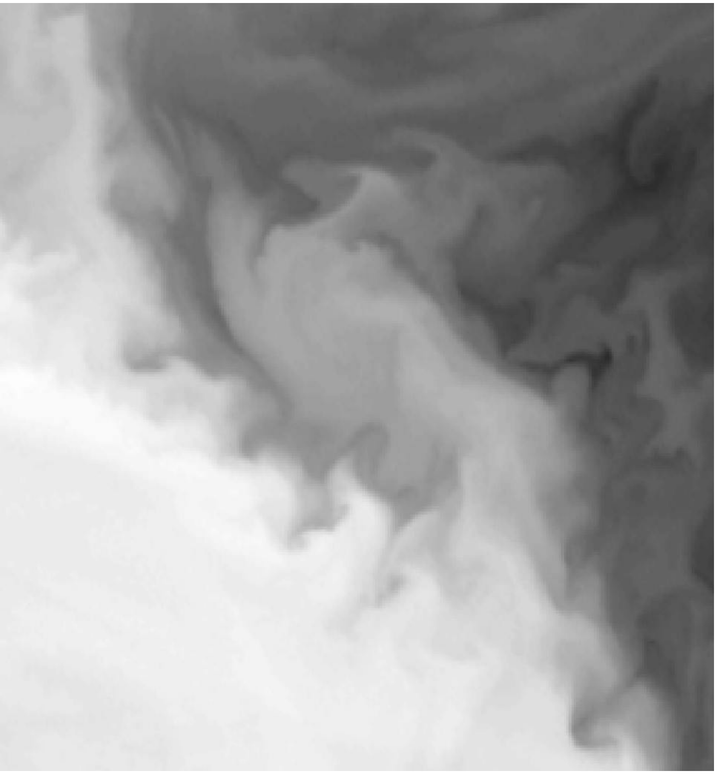


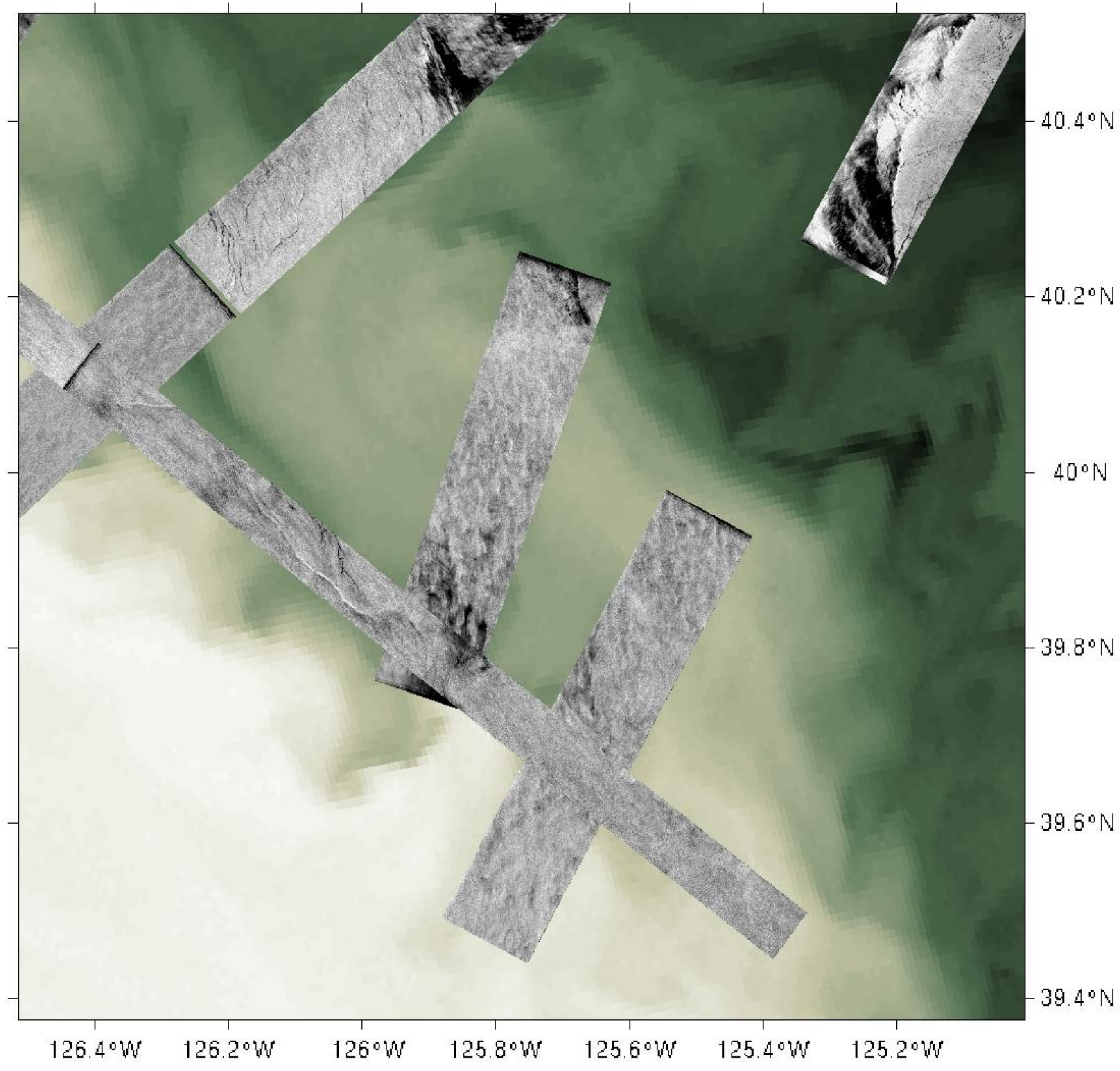

250/03:22
250/09:51
2
1
250/01:13
2
1
250/13:36
2
1
250/03:22
2
1
250/21:18
2
1
39.8°N
39.6°N
126°W
125.8°W



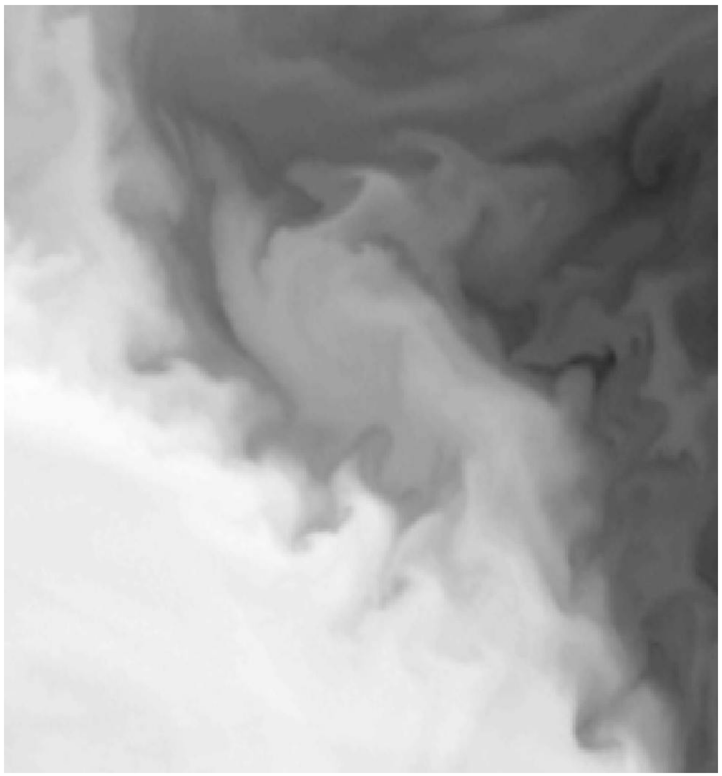
λ~220

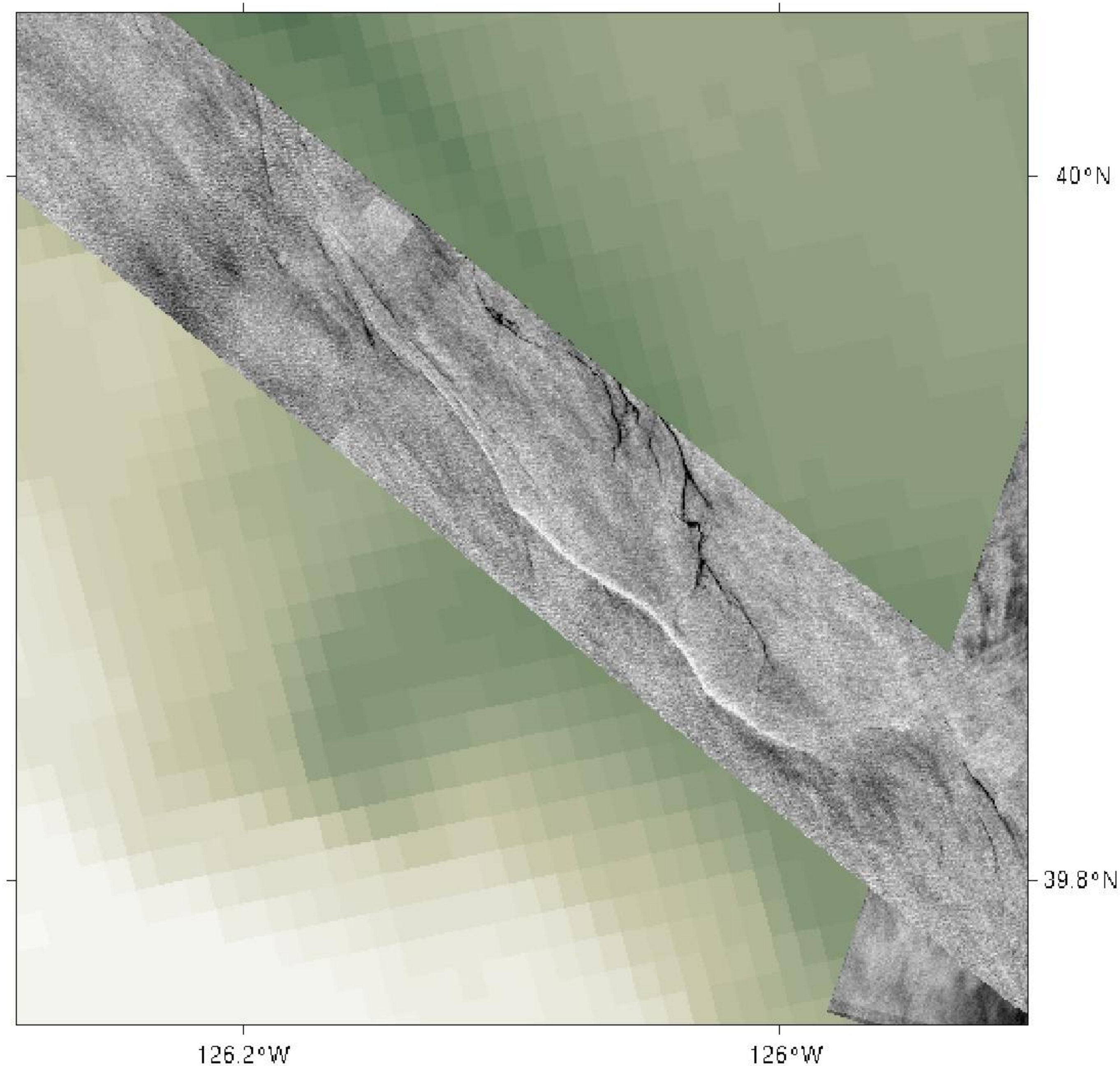
Cyclone





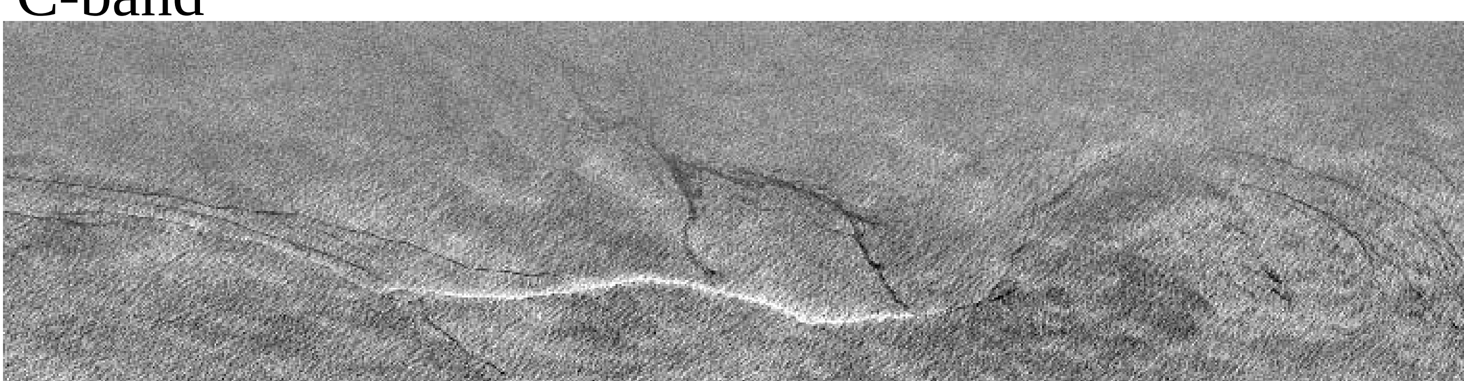
40.4°N
40.2°N
40°N
39.8°N
39.6°N
39.4°N
126.4°W
126.2°W
126°W
125.8°W
125.6°W
125.4°W
125.2°W

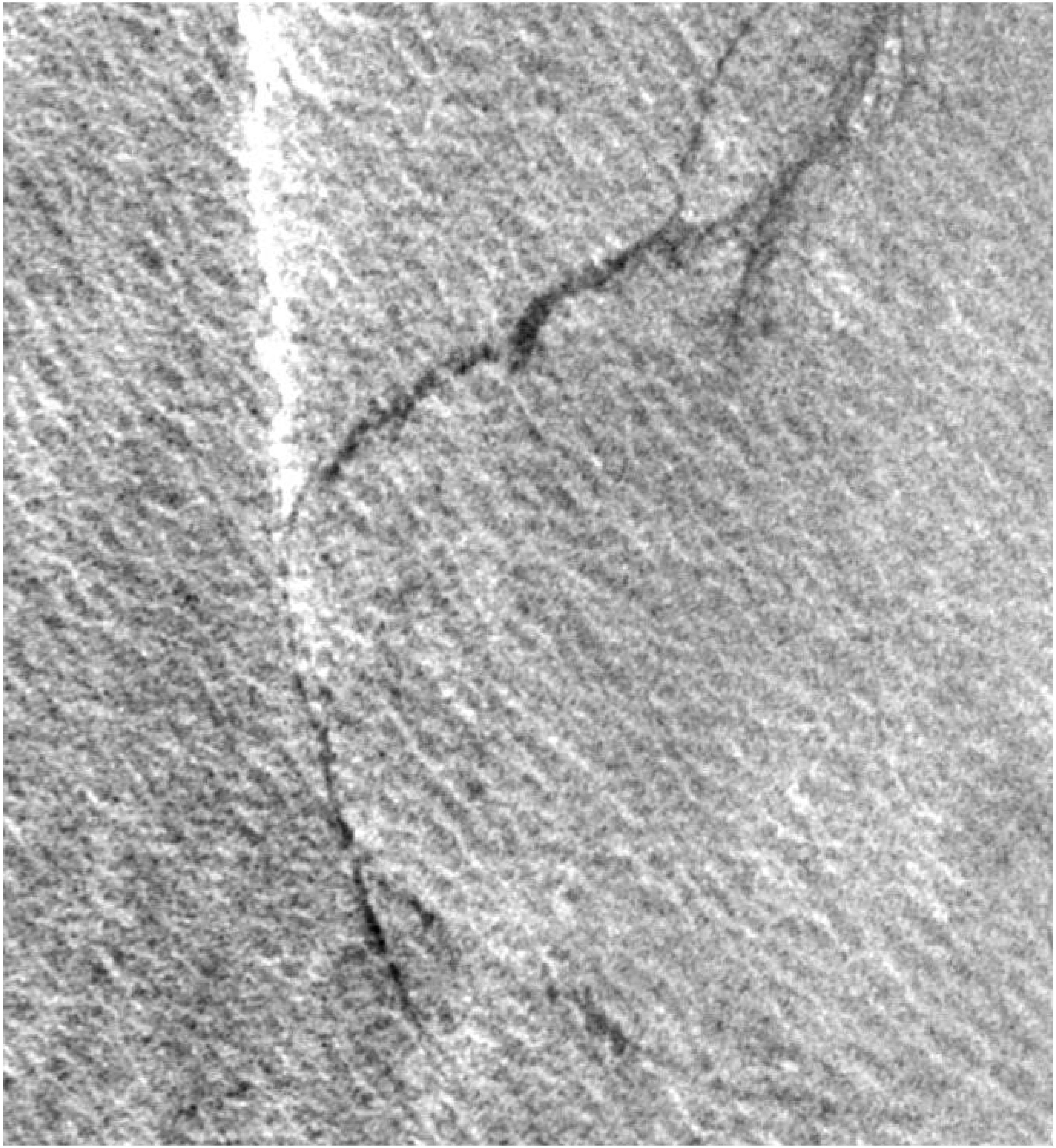


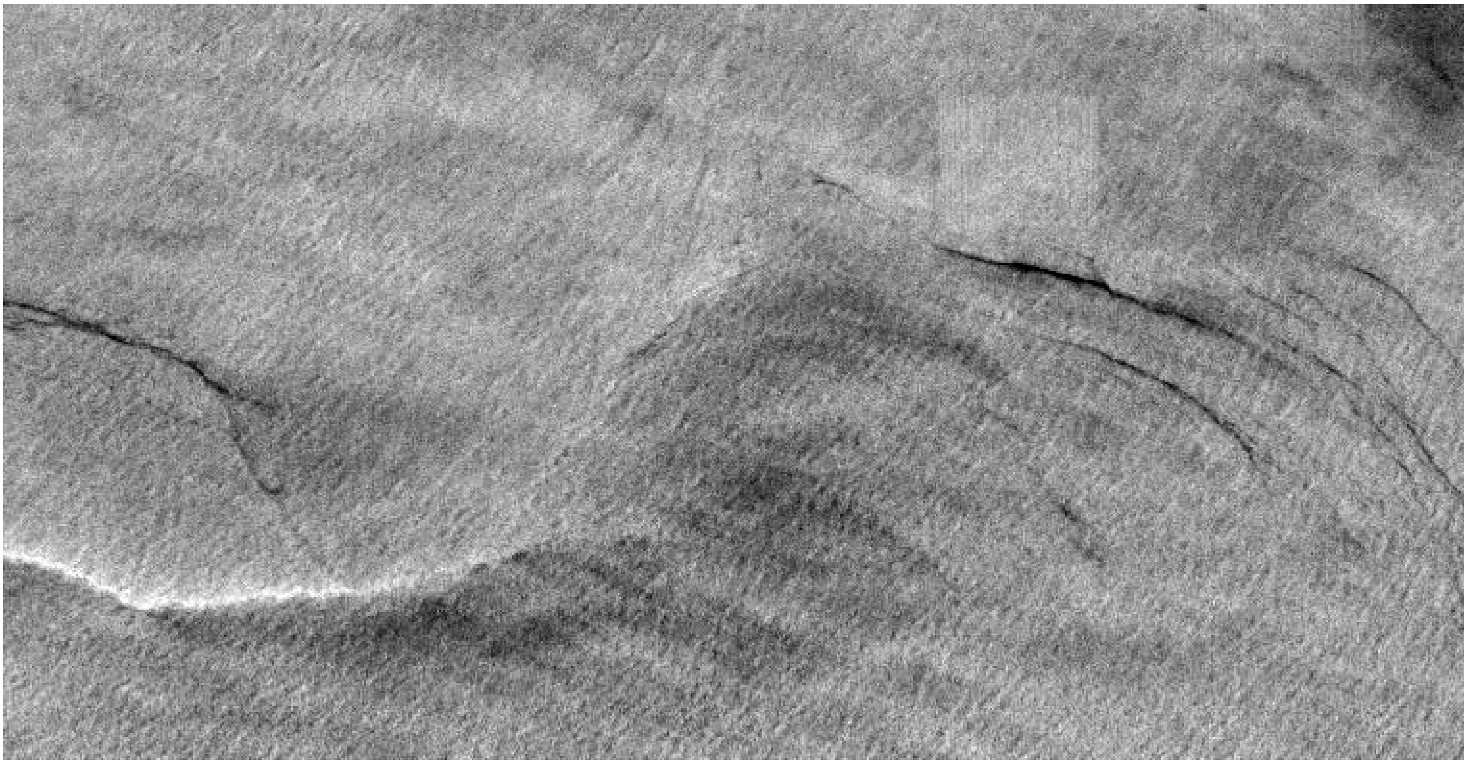


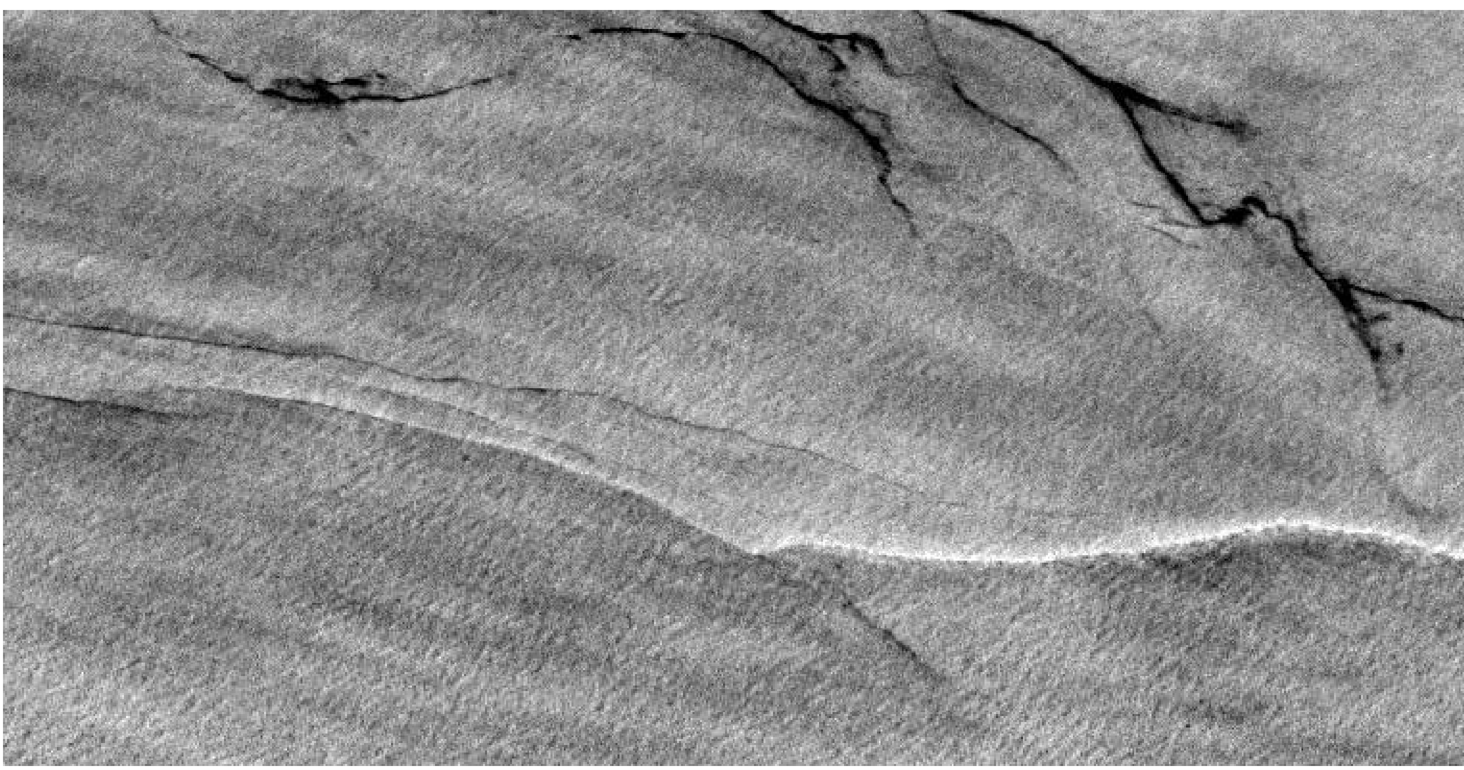
40°N
39.8°N
126.2°W
126°W

C-band

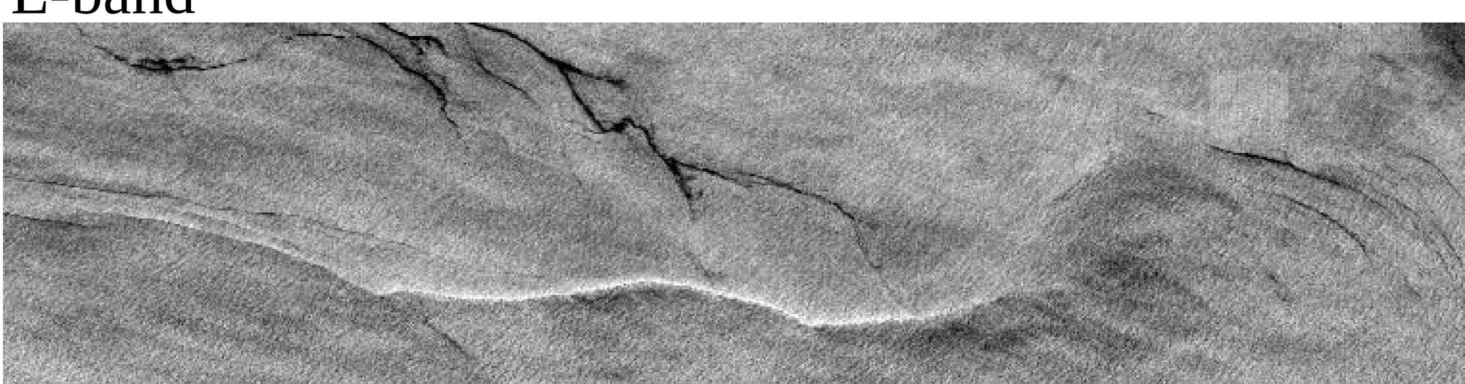




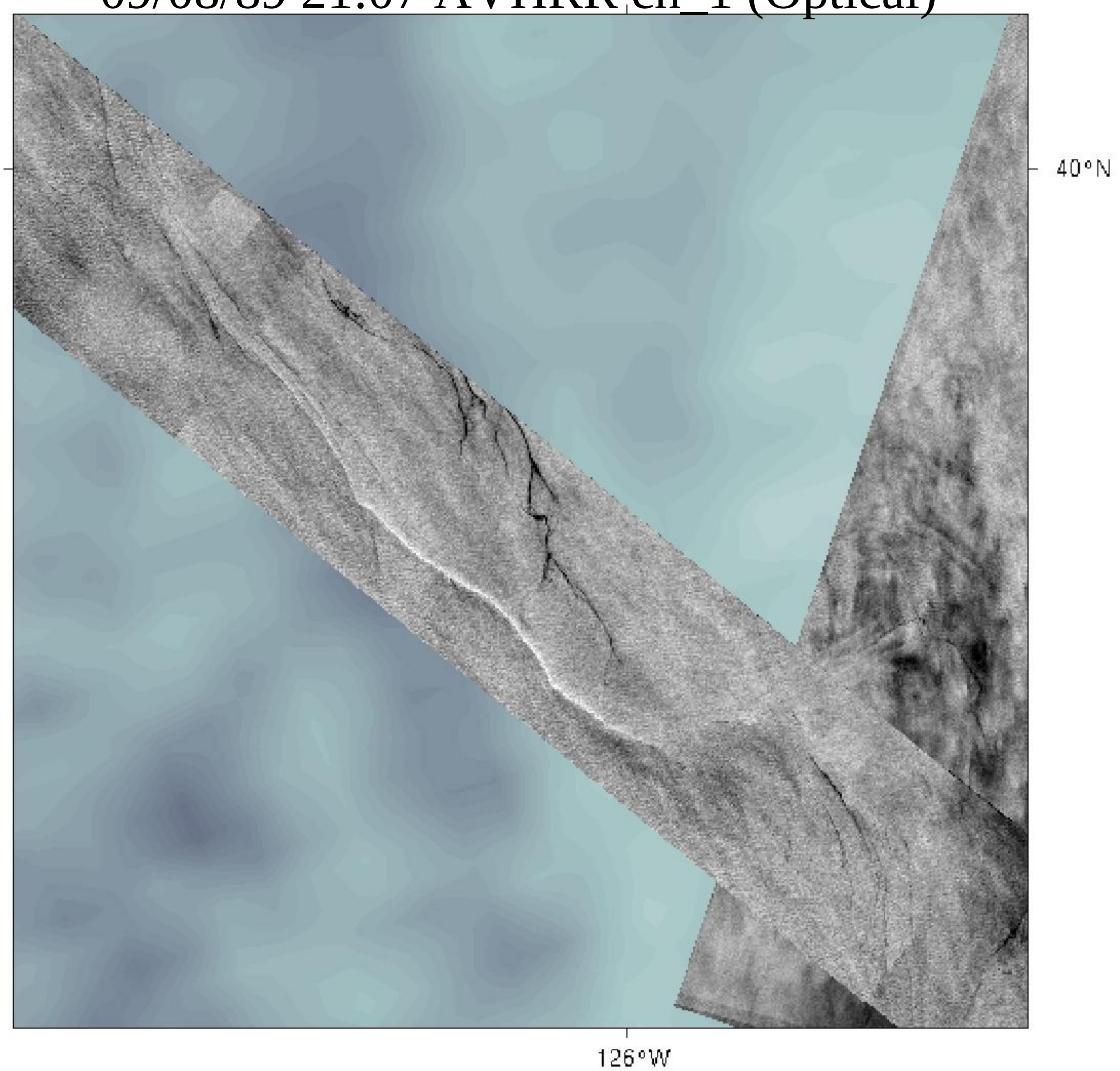


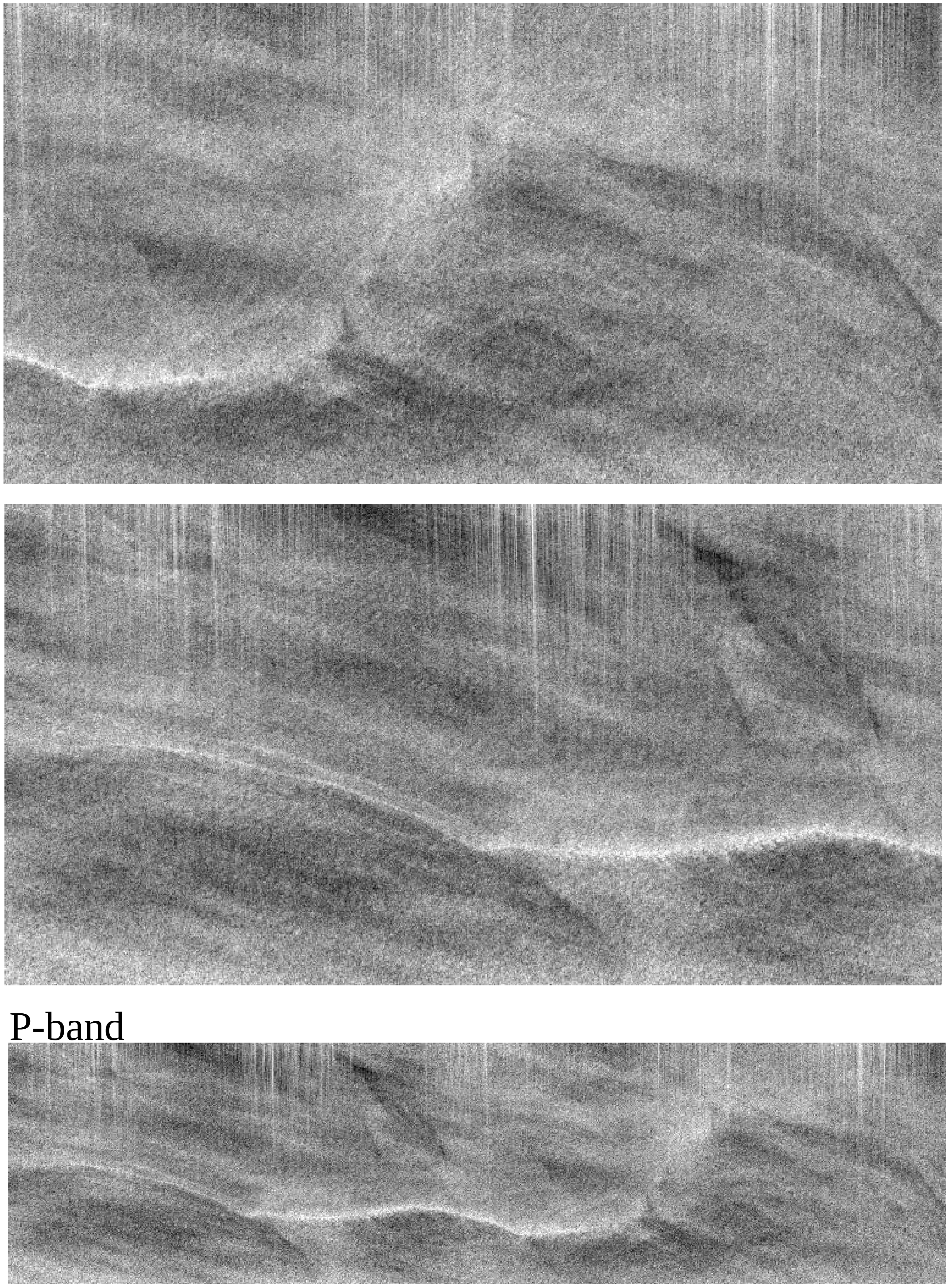


L-band

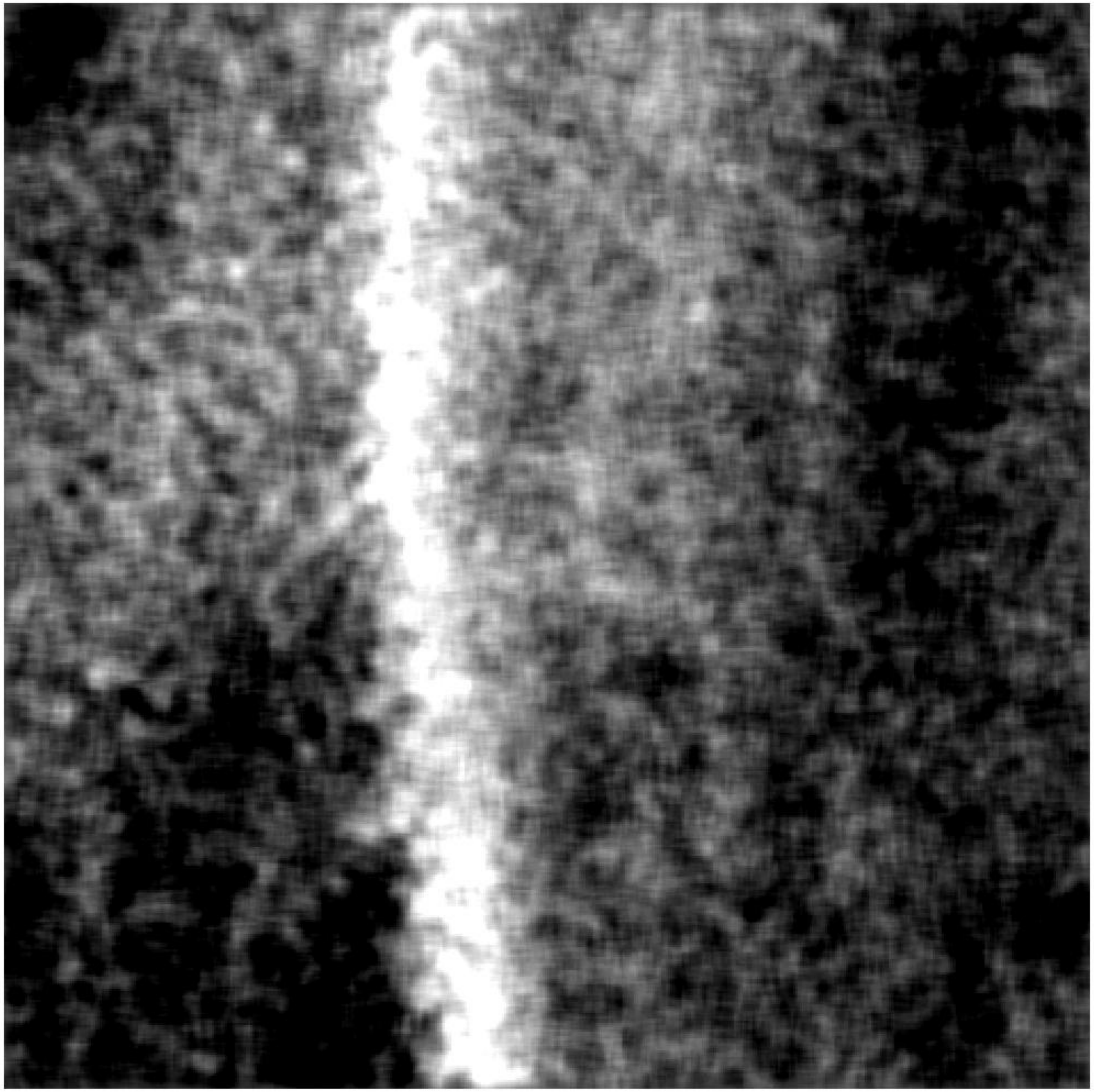


09/08/89 21:07 AVHRR ch_1 (Optical)



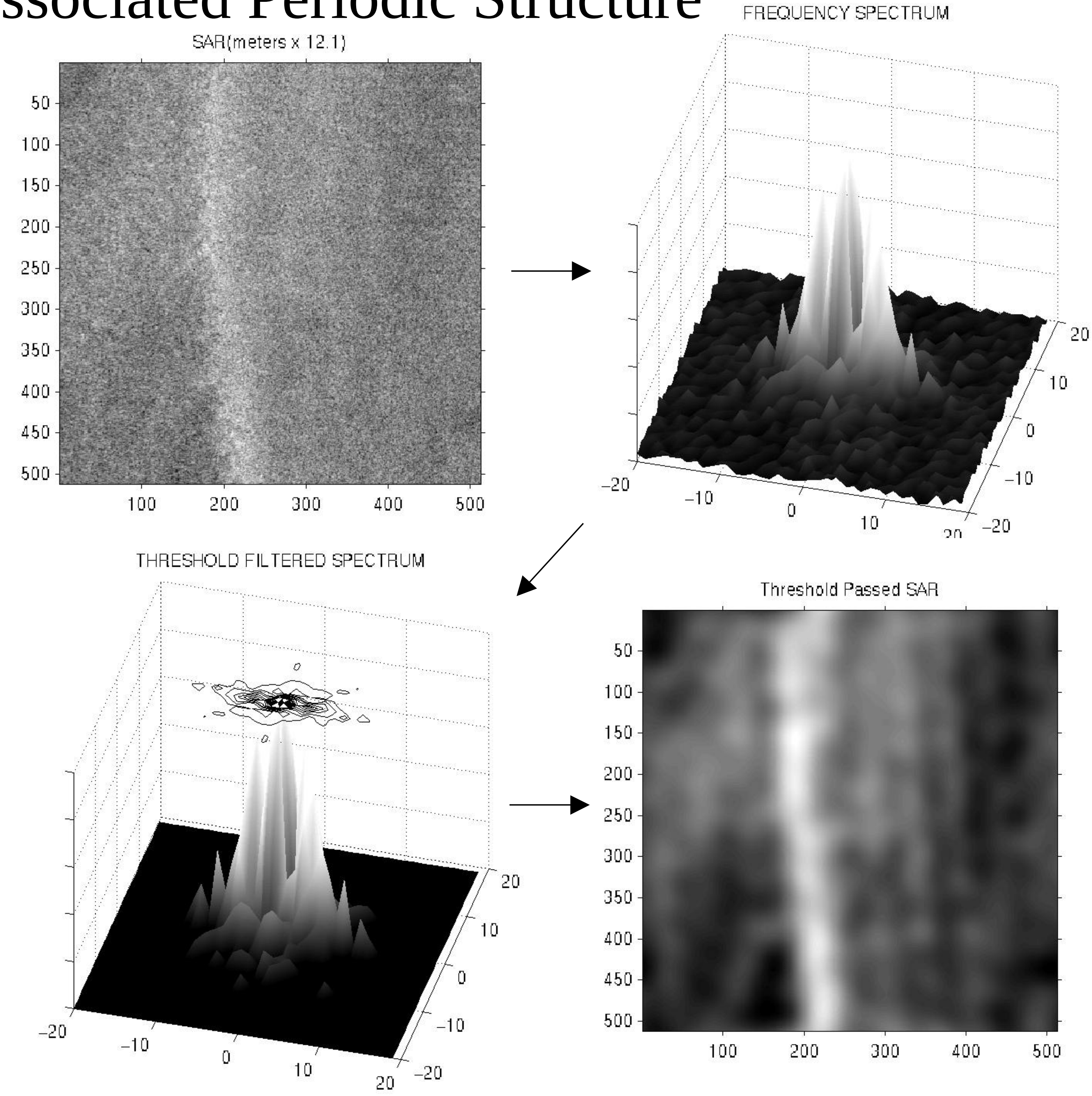

P-band

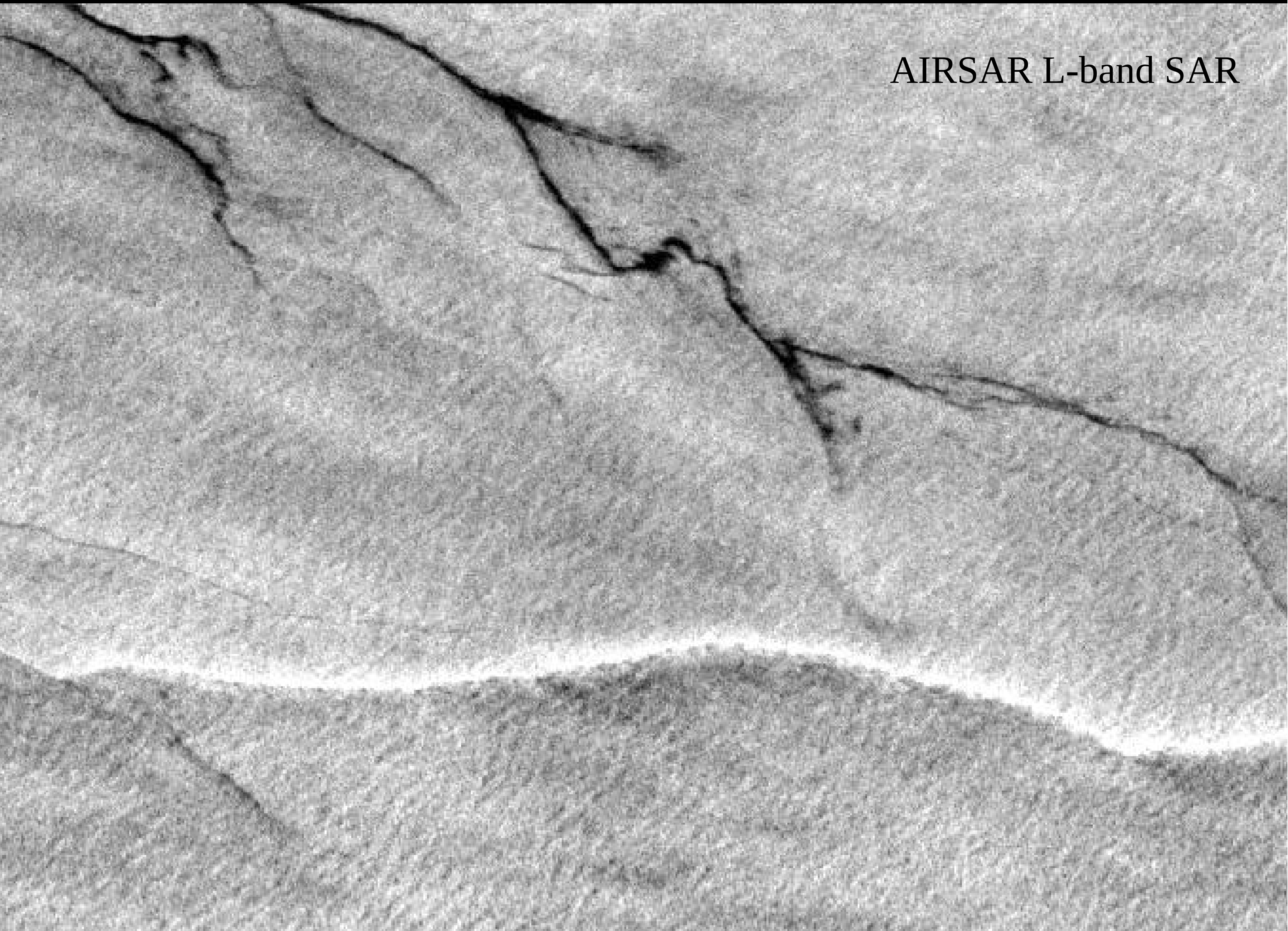
(9x9 Boxcar Mean)



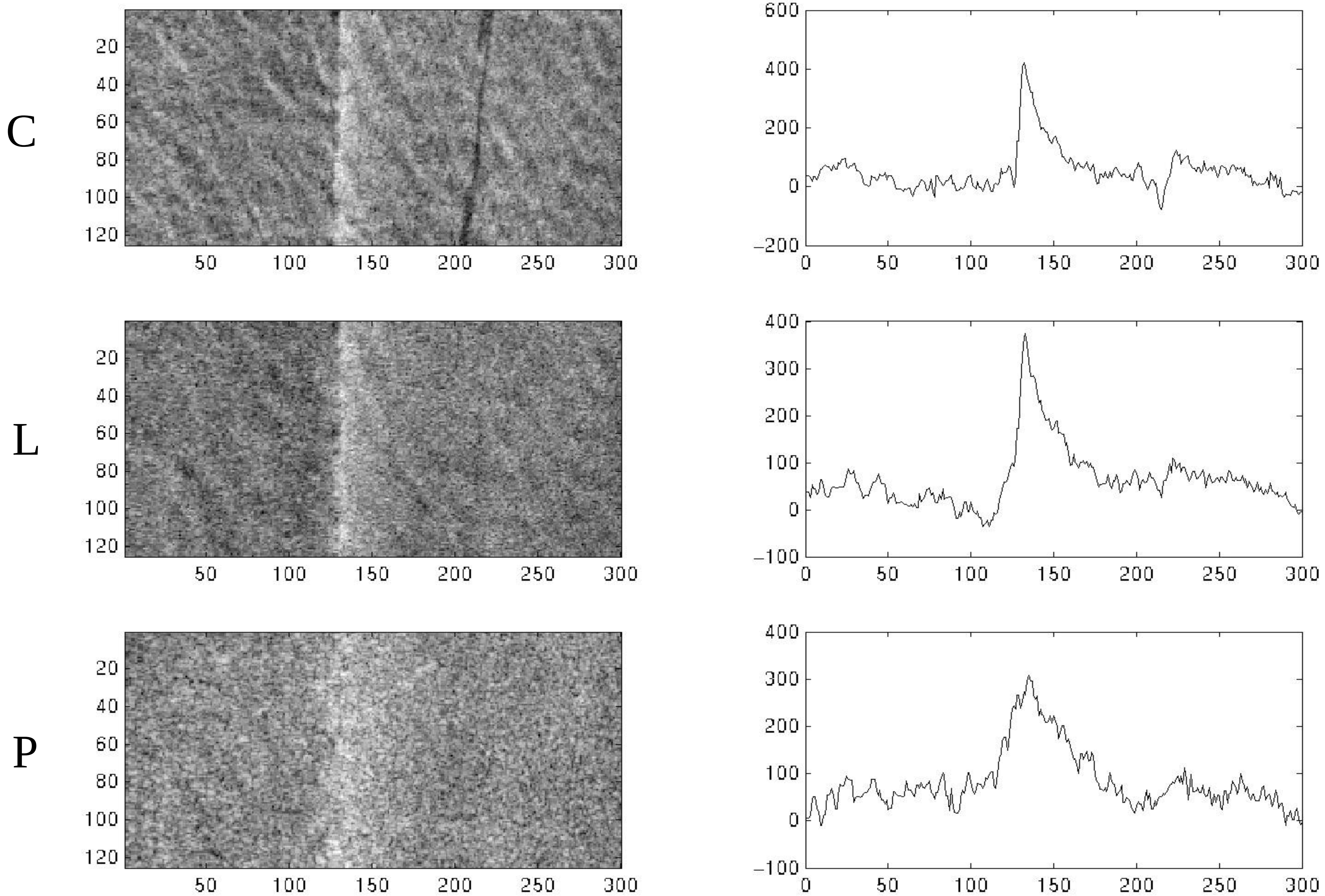
λ~300
m

Jet Associated Periodic Structure




AIRSAR L-band SAR

SAR Profile Across Azimuthal Front



Wave Modulation Theory of Longuet-Higgins and Stewart

The change in phase velocity, wave number, angle, and amplitude are given by:

$c/c_o = 1/[1-(v/c_o)\sin\theta_o]$

$k/k_o = [1-(v/c_o)\sin\theta_o]^2$

$\sin\theta = \sin\theta_o/[1-(v/c_o)\sin\theta_o]^2$

which hold for

$v/c_o \leq [1-(\sin\theta_o)^{1/2}]/\sin\theta_o$

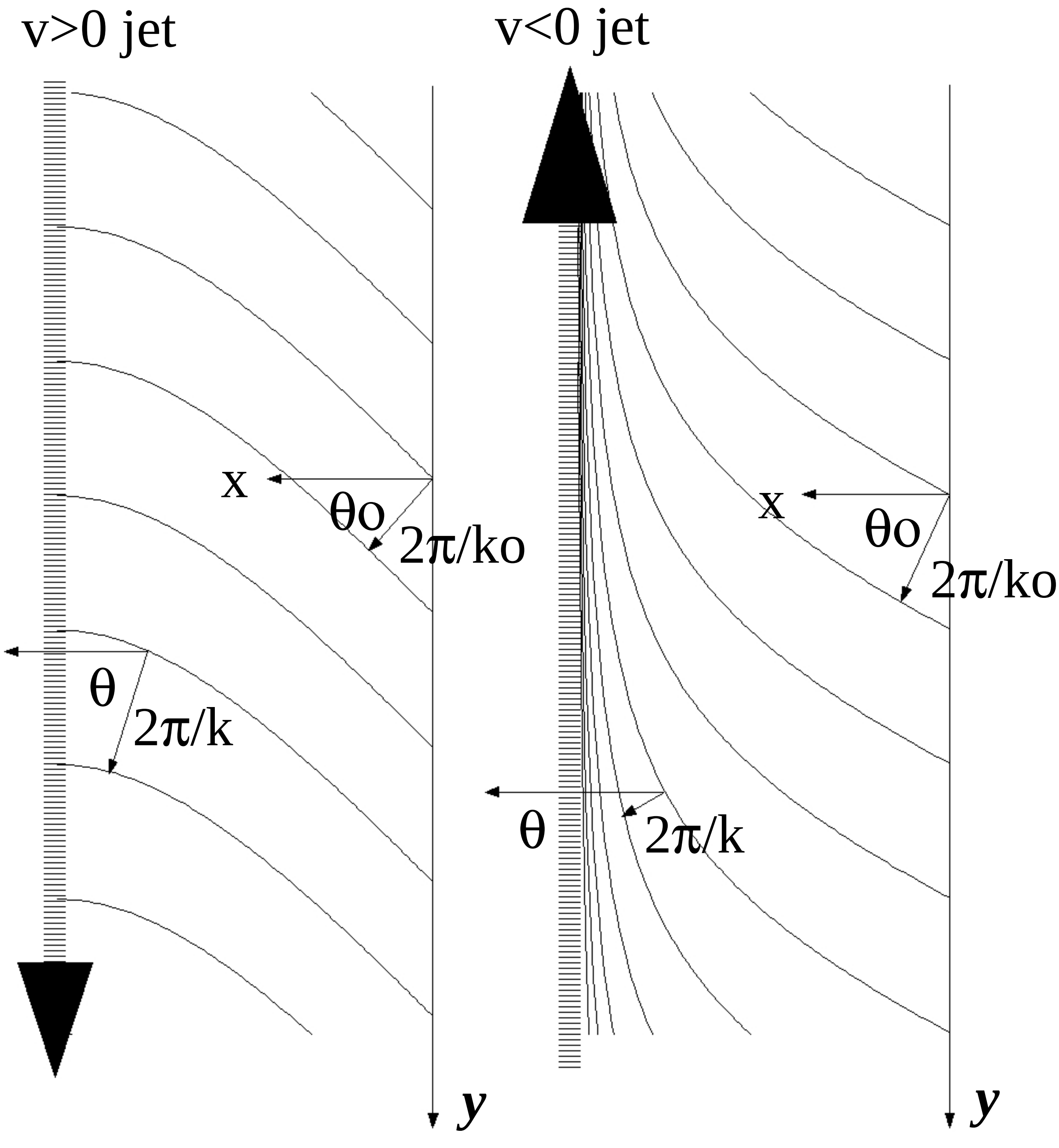
and

$a/a_o = (E/E_o)^{1/2} = (\sin 2\theta_o/\sin 2\theta)^{1/2}$

For

$v/c_o > [1-(\sin\theta_o)^{1/2}]/\sin\theta_o$

total reflection occurs

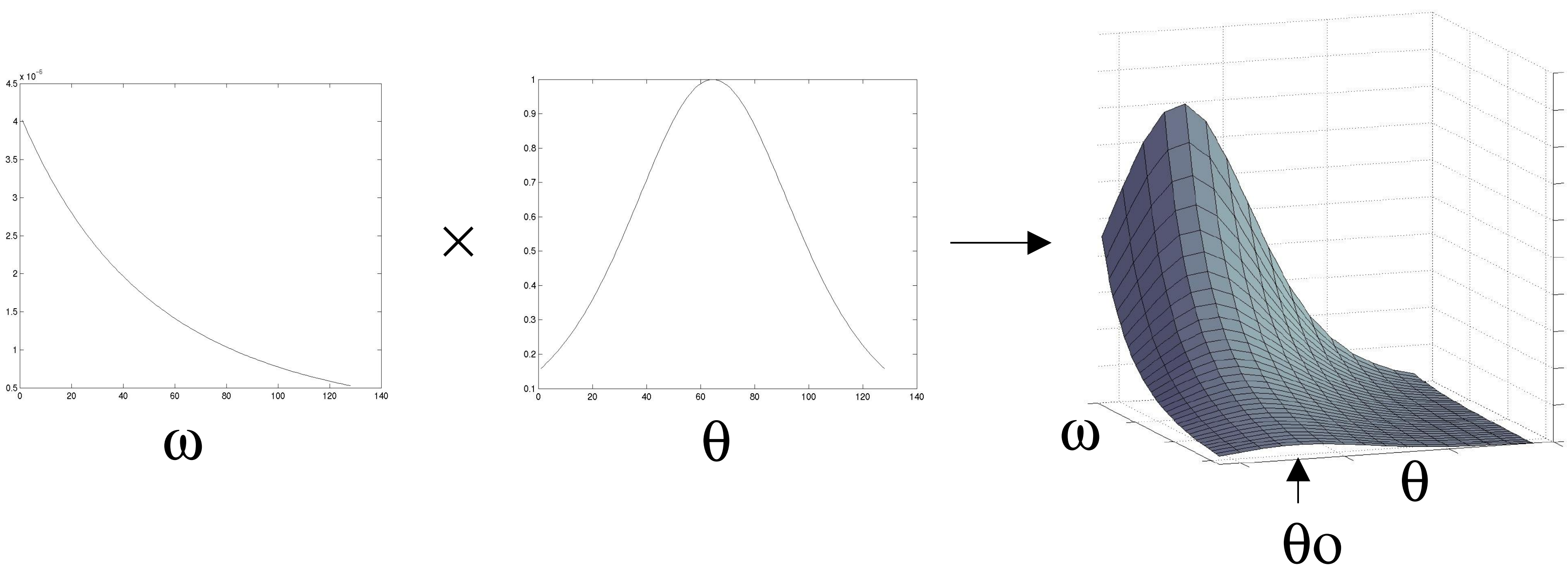


Wave Field Used in the Numerical Simulation

(Piersen-Moskowitz Spectrum) × (sech^2 angular distribution)

$$Fo \sim \omega^{-5} e^{-(5/4)(\omega/\omega_p)^{-4}} \times \mathrm{sech}^2(\theta - \theta o)$$

where $\omega_p = 0.13\pi g/u_{10} \sim 0.6$ hz



Model Assumptions:

Velocity bunching effects are negligible:

In this case this means net surface convergence across the front is small compared to semigeostrophic jet velocity.

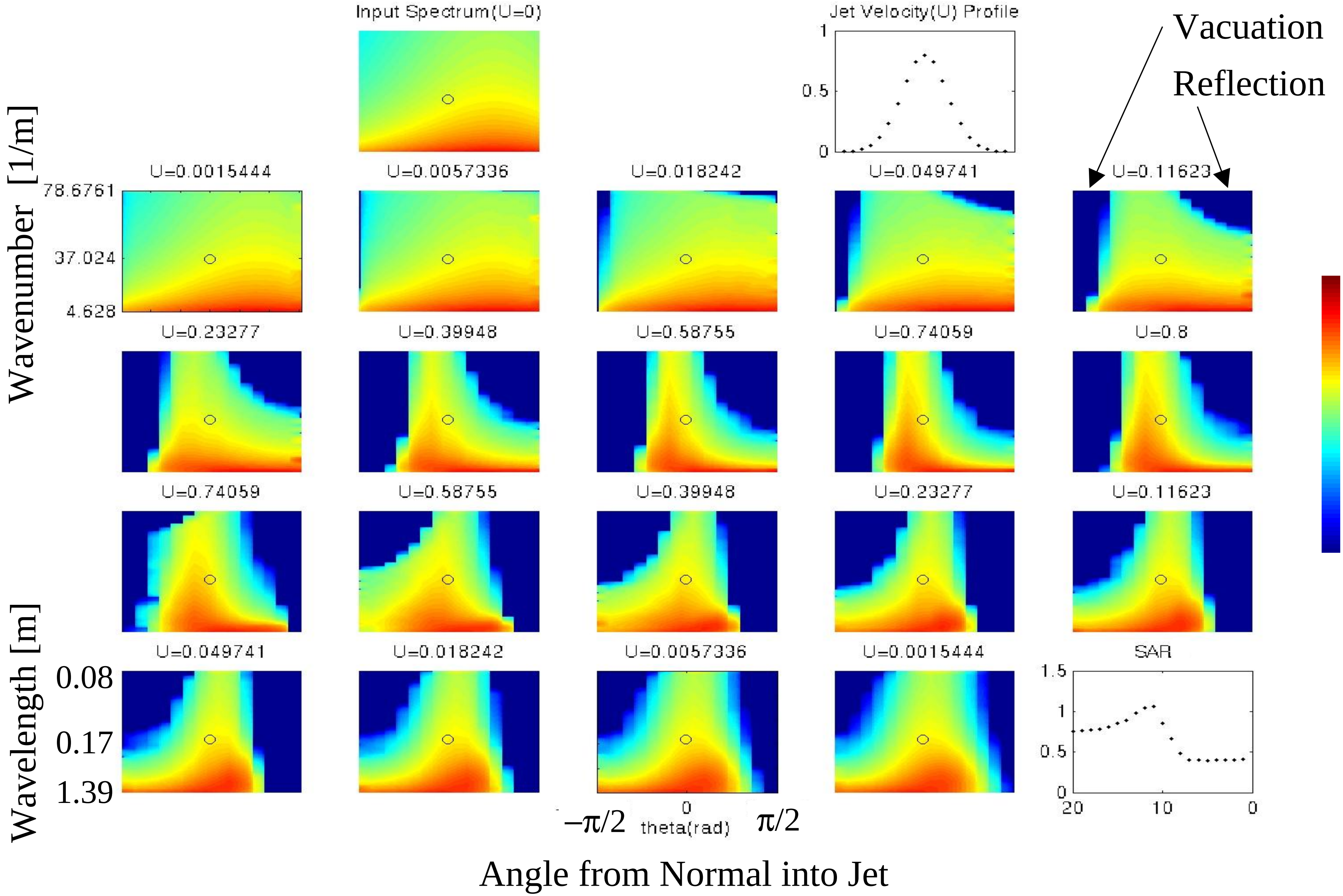
First order Bragg scattering is dominant:

Scattering from waves an integer multiple of the first order Bragg wavelengths contribute substantially less to the normalized radar cross section than scattering from the smallest Bragg wavelength.

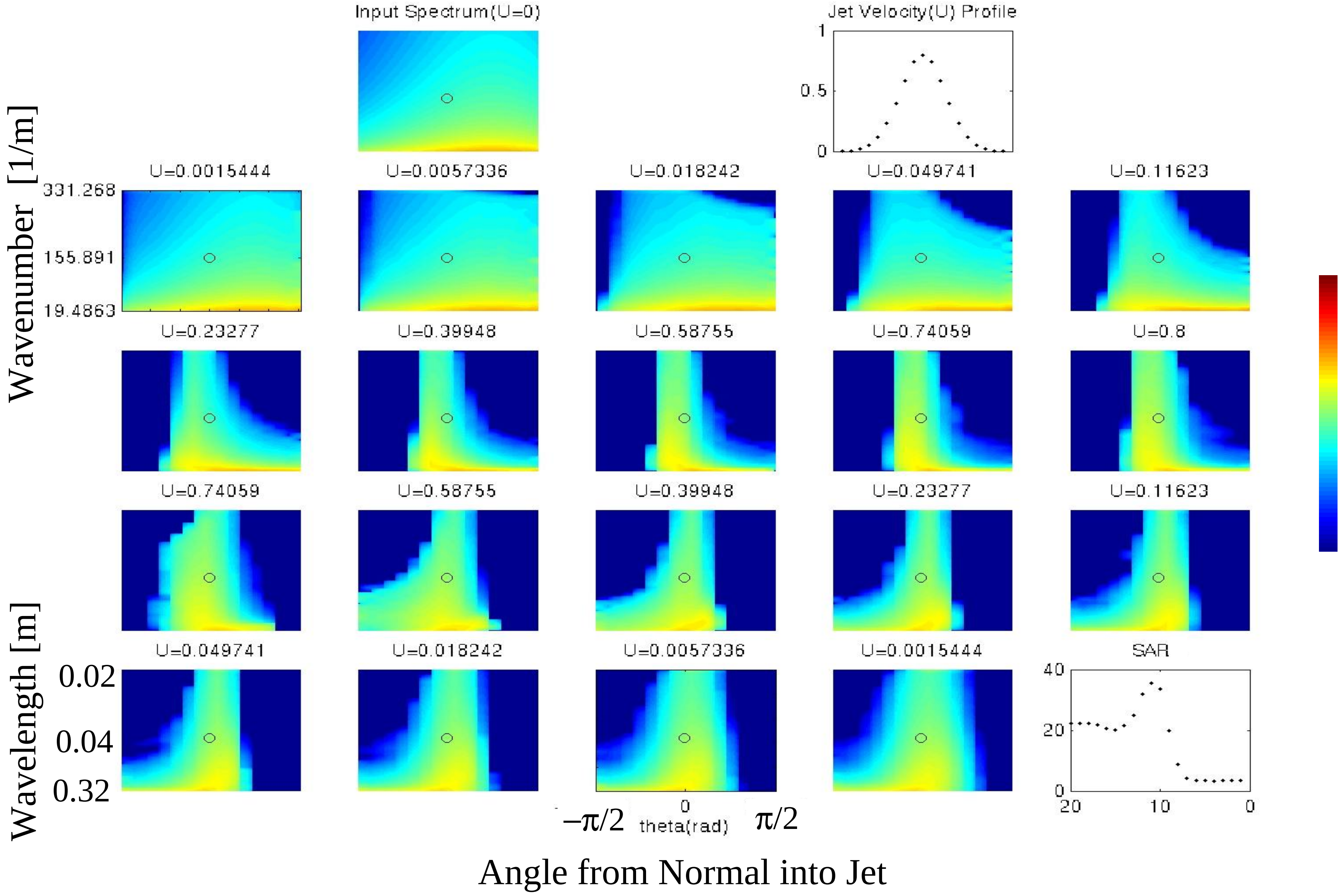
All reflection at critical shear is incoherent:

This implies a negligible first order Bragg return from reflected components of the wave field.

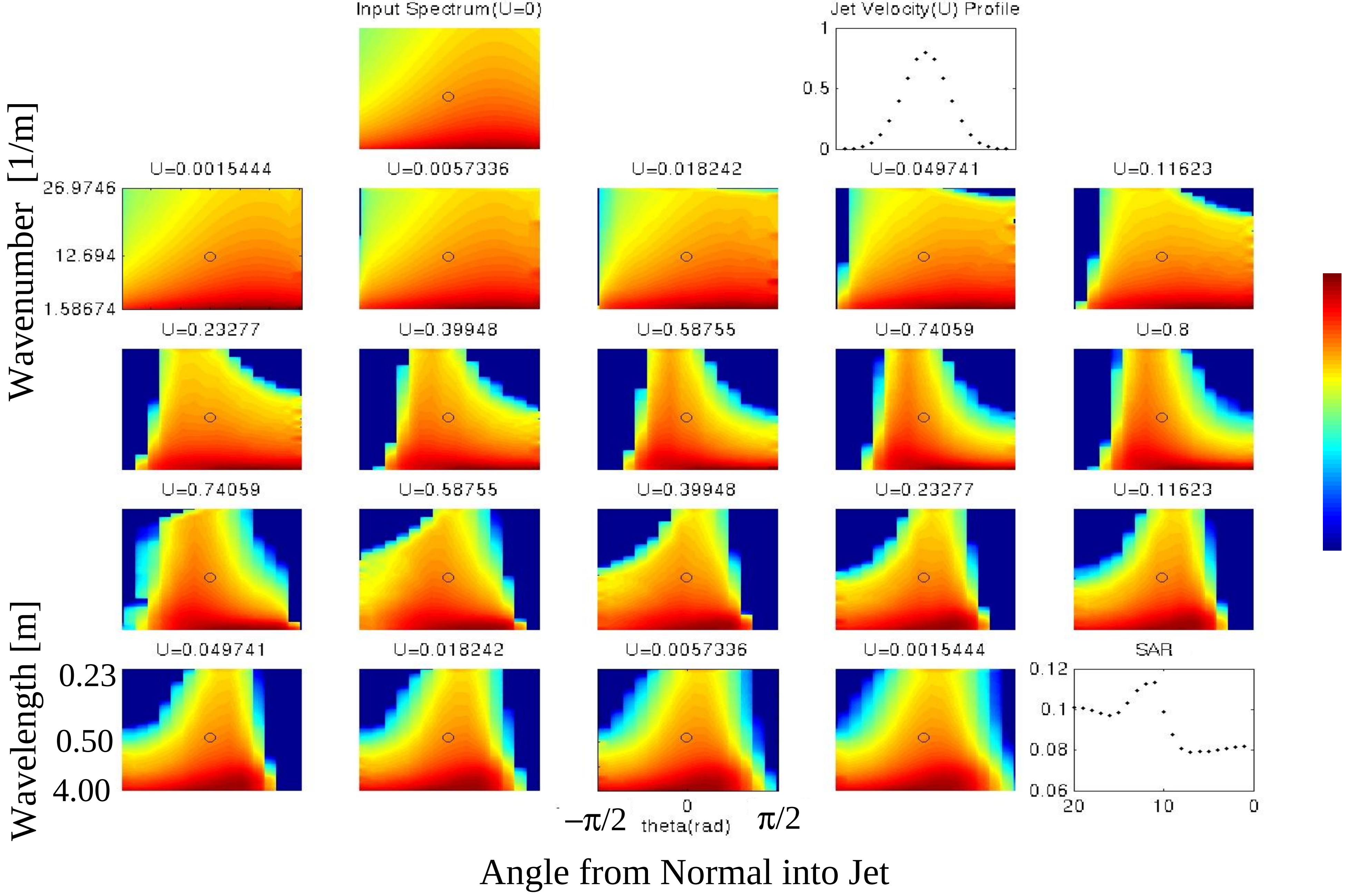
Model results for L-band AIRSAR Profile of Southeastward Azimuthal Gaussian Jet



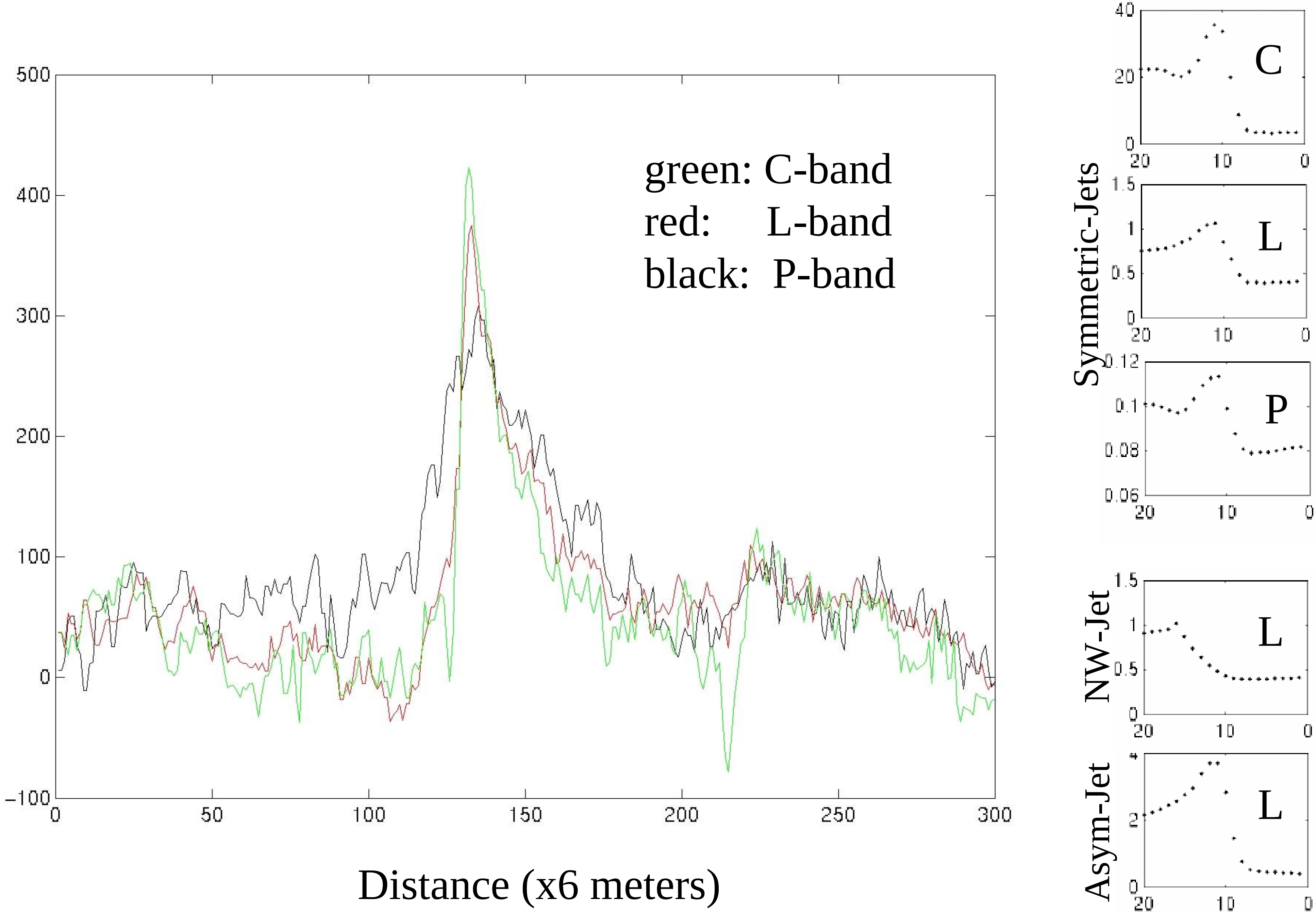
Model results for C-band AIRSAR Profile of Southeastward Azimuthal Gaussian Jet



Model results for P-band AIRSAR Profile of Southeastward Azimuthal Gaussian Jet



SAR Backscatter Profile Across Azimuthal Front



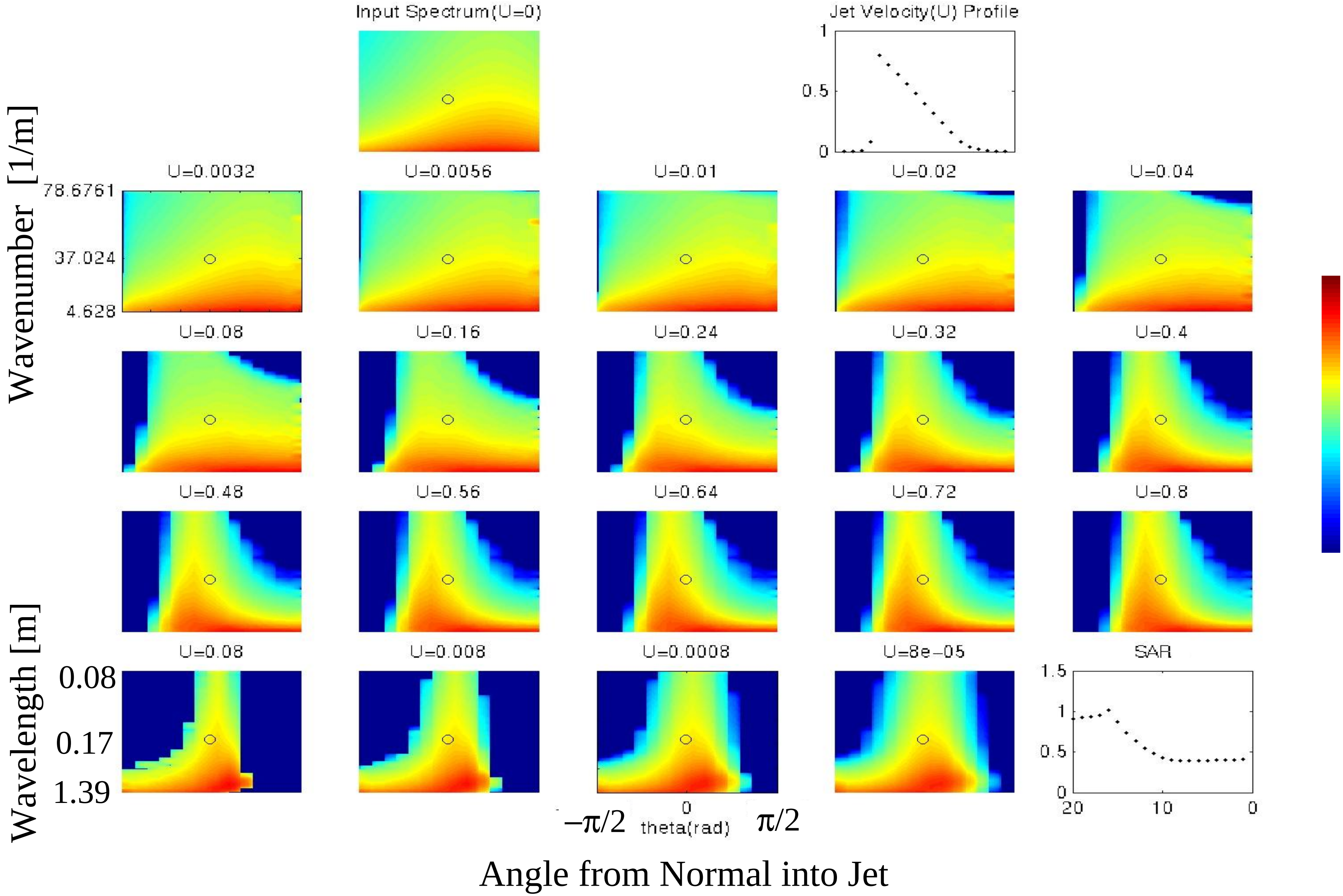
Conclusions

- Ocean wave coherence at the spatial scale of the AIRSAR C-band spatial resolution approaches zero just below 4 cm wavelength.

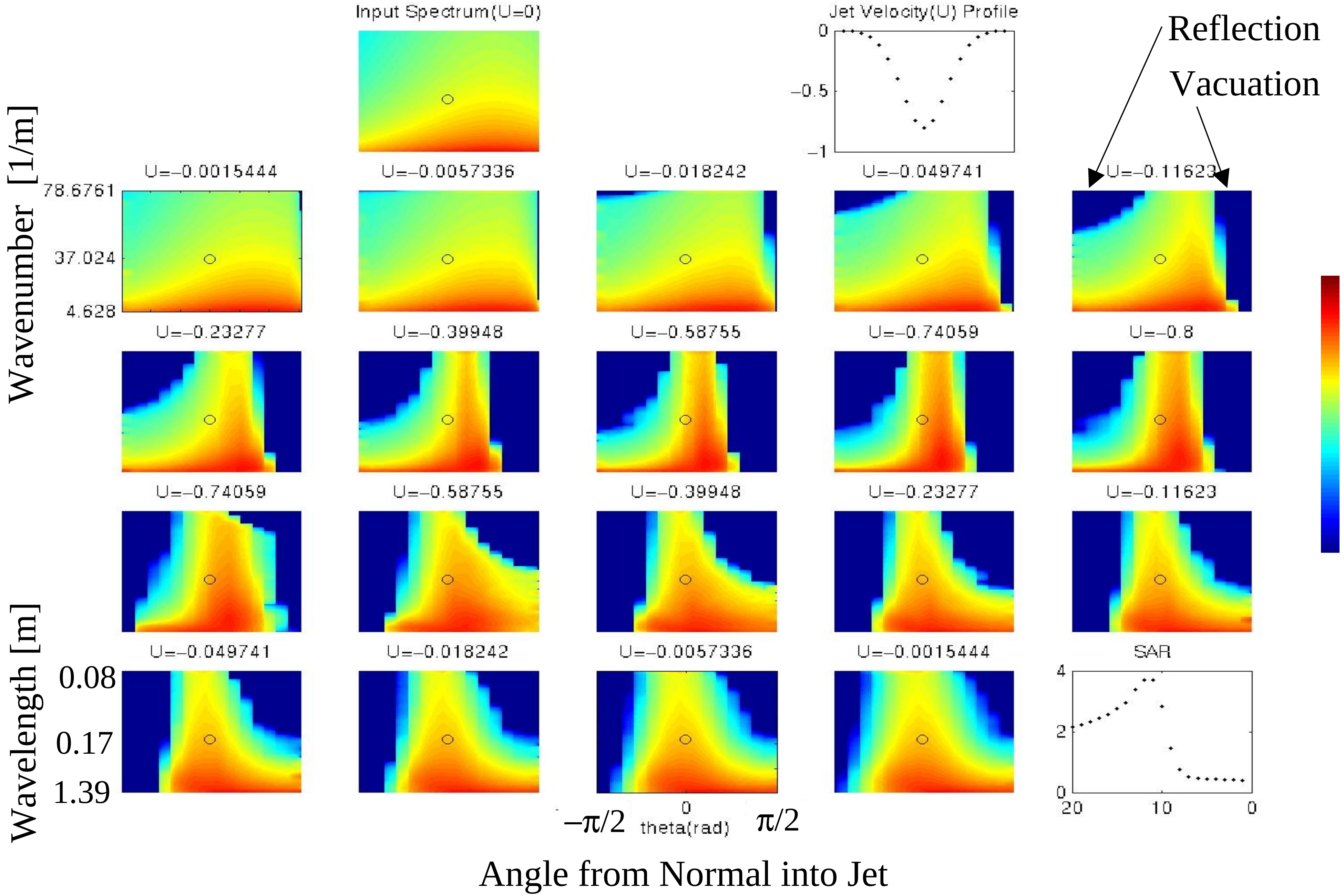
- SAR imaged internal waves in this stratified upwelling environment are strongly front associated.

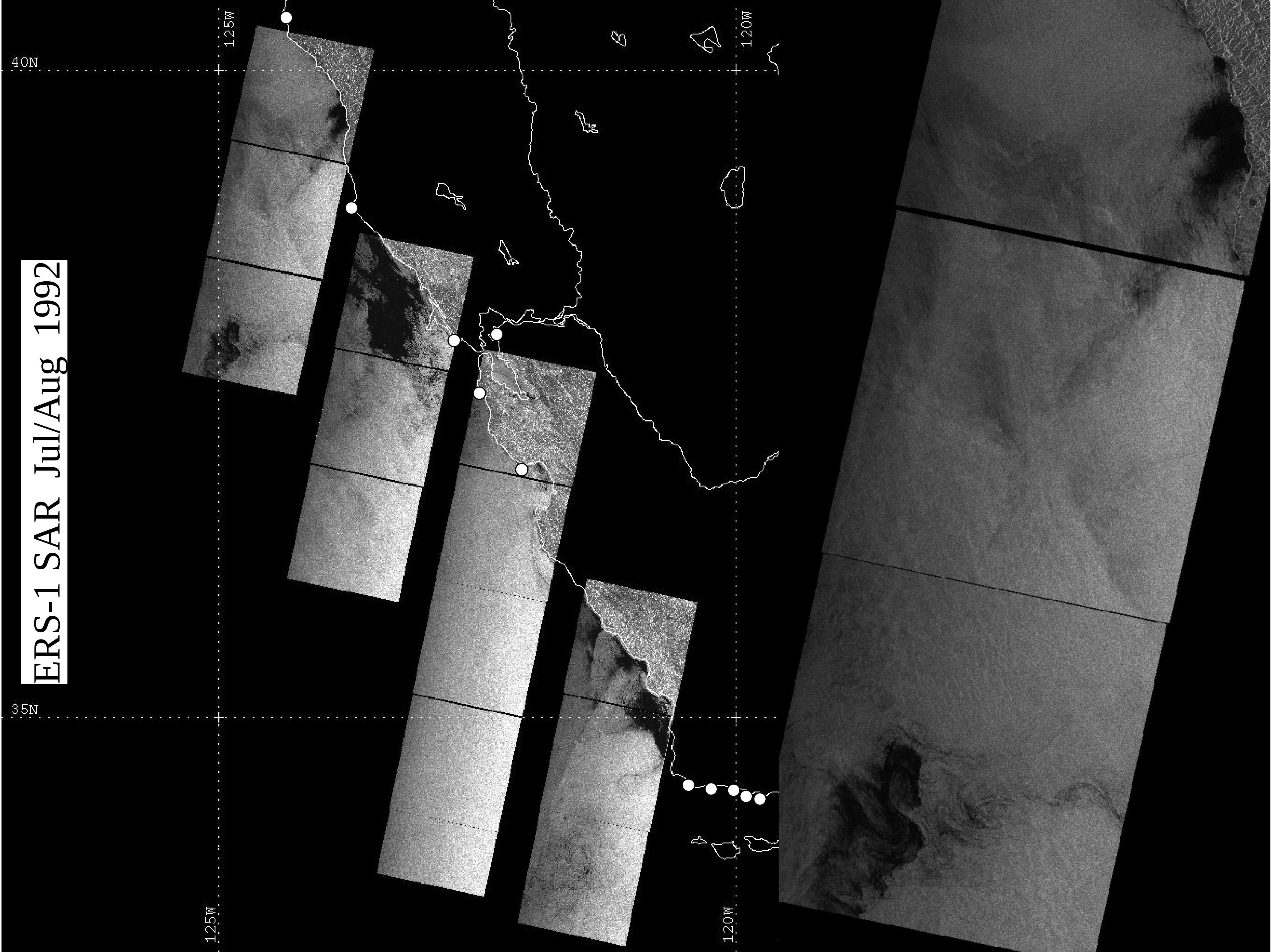
- Comparison of "simplest" model results with SAR data suggest wave breaking at a semi-geostrophic front for wavelengths of 7 cm and 25 cm, and no breaking, but rather turbulence induced damping (due to the breaking of smaller waves), for wavelengths of 77 cm.

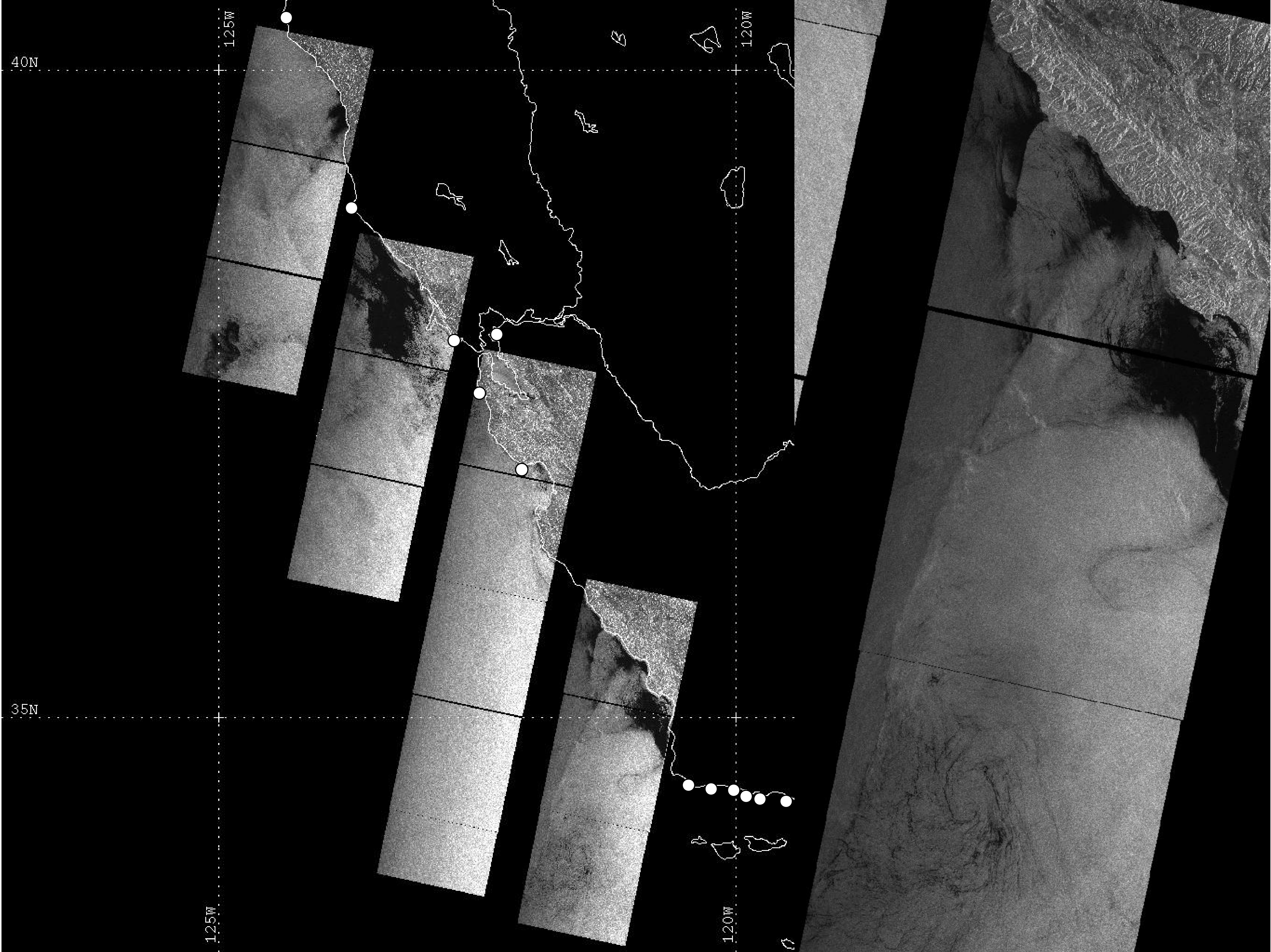
Model results for L-band AIRSAR Profile of Southeastward Azimuthal Asymmetric Jet



Model results for L-band AIRSAR Profile of Northwestward Azimuthal Gaussian Jet




ERS-1 SAR Jul/Aug 1992
40N
35N
125W
120W
125W
120W



125W
120W
40N
35N
125W
120W