Deriving Wind Speed from Synthetic Aperture Radar Images

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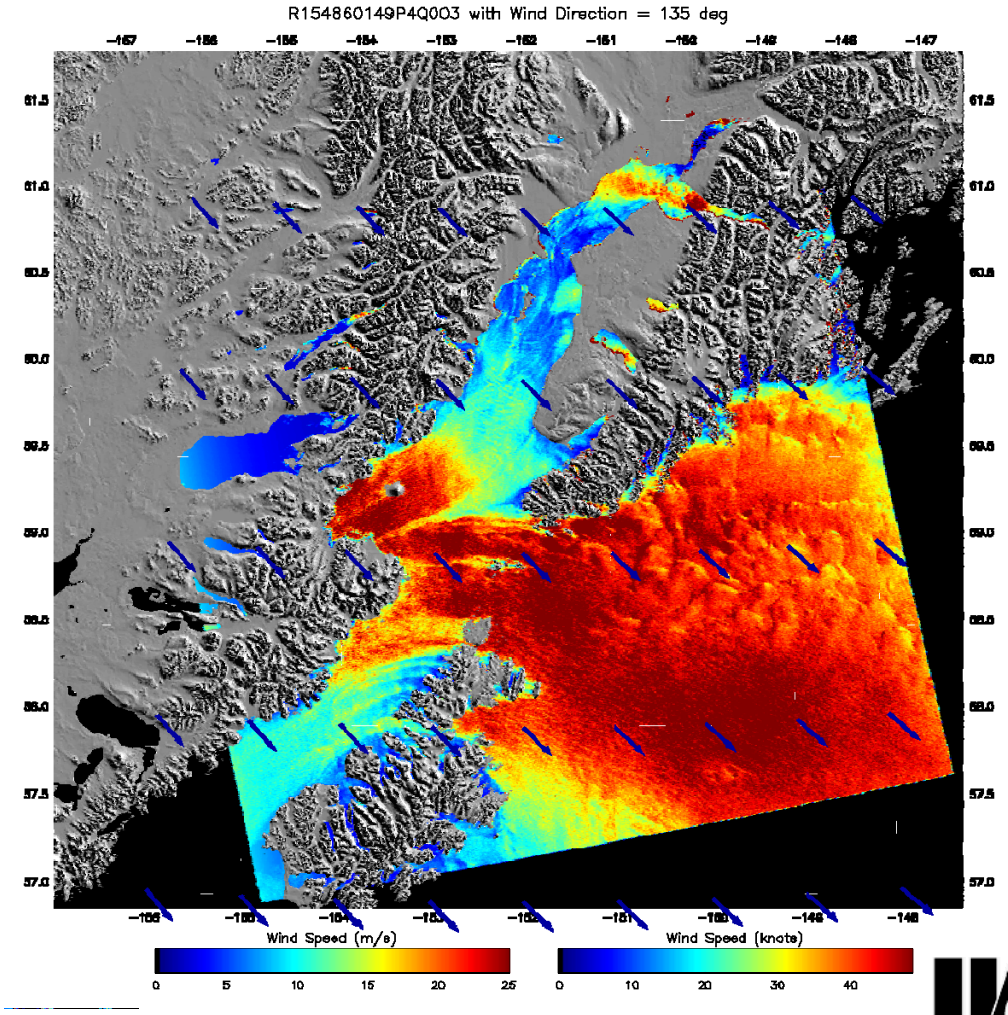
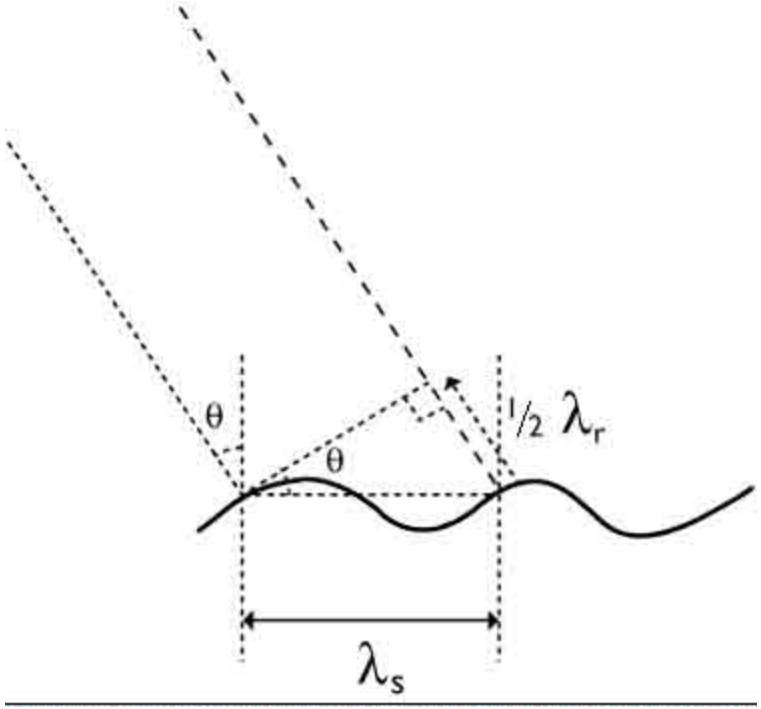
Outline

- Bragg scattering
- CMOD algorithms
- Scatterometers
- SAR data
- Applications
  - Hurricanes
  - Gap flow
  - Barrier jets
  - Vortex shedding
  - Internal waves
- Data quality issues



Bragg scattering

- Resonant phenomena when distance between flat surfaces in the direction of view is ½ the instrument wavelength.
- Assumed the dominant mechanism in radar backscatter over water.



http://earth.esa.int/applications/data_util/SARDOCS/spaceborne/Radar_Courses/Radar_Course_II/bragg_scattering.htm

CMOD algorithms

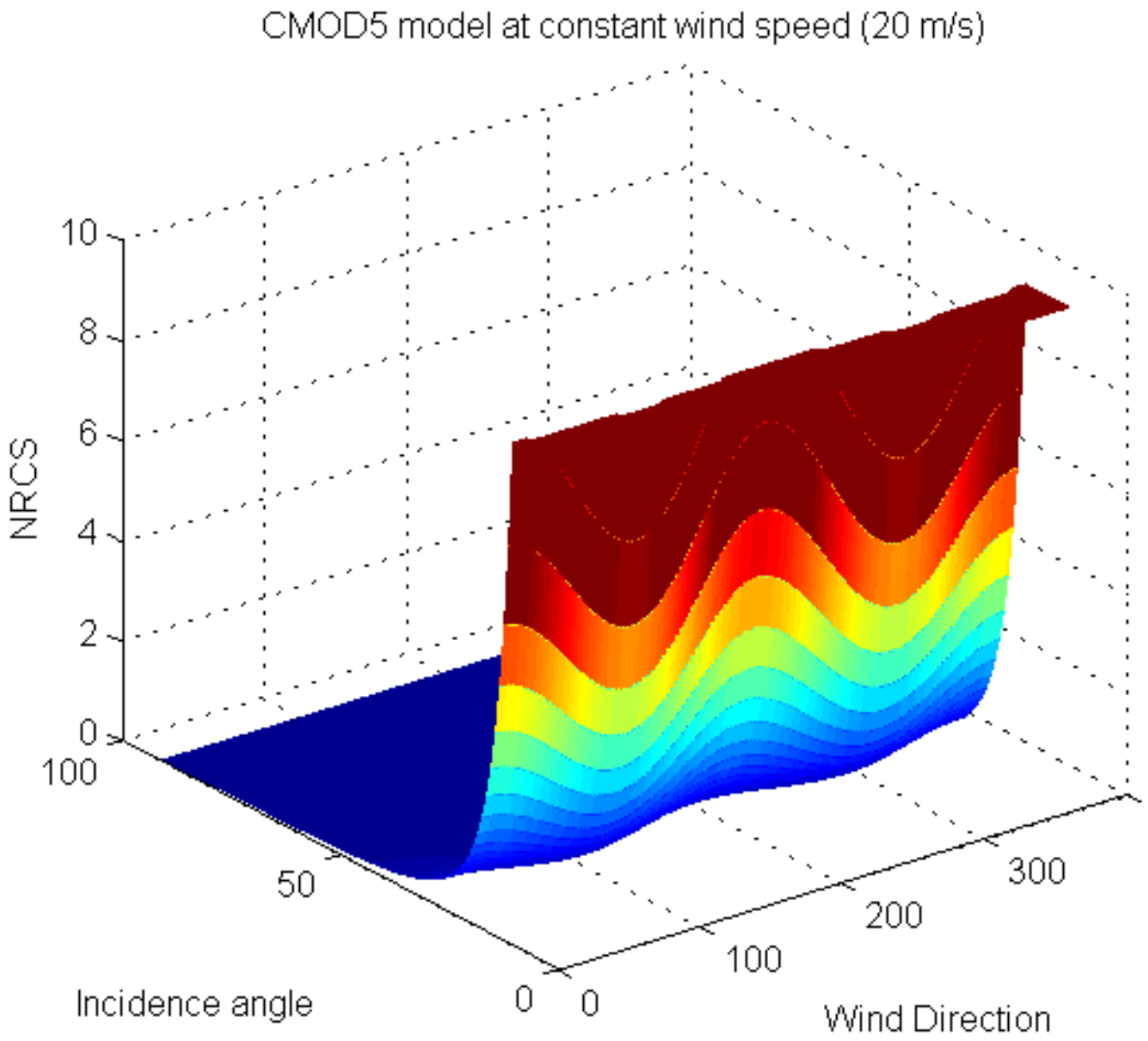
- All models Radar Cross Section as functions of at least these three:
  - Wind speed (v)
  - Wind direction with respect to sensor (φ)
  - Incidence angle (θ)
- Version # (CMOD1-5) refers to different ways of estimating B values
- CMOD5 uses 28 parameters nested in B values.
- Parameterized empirically

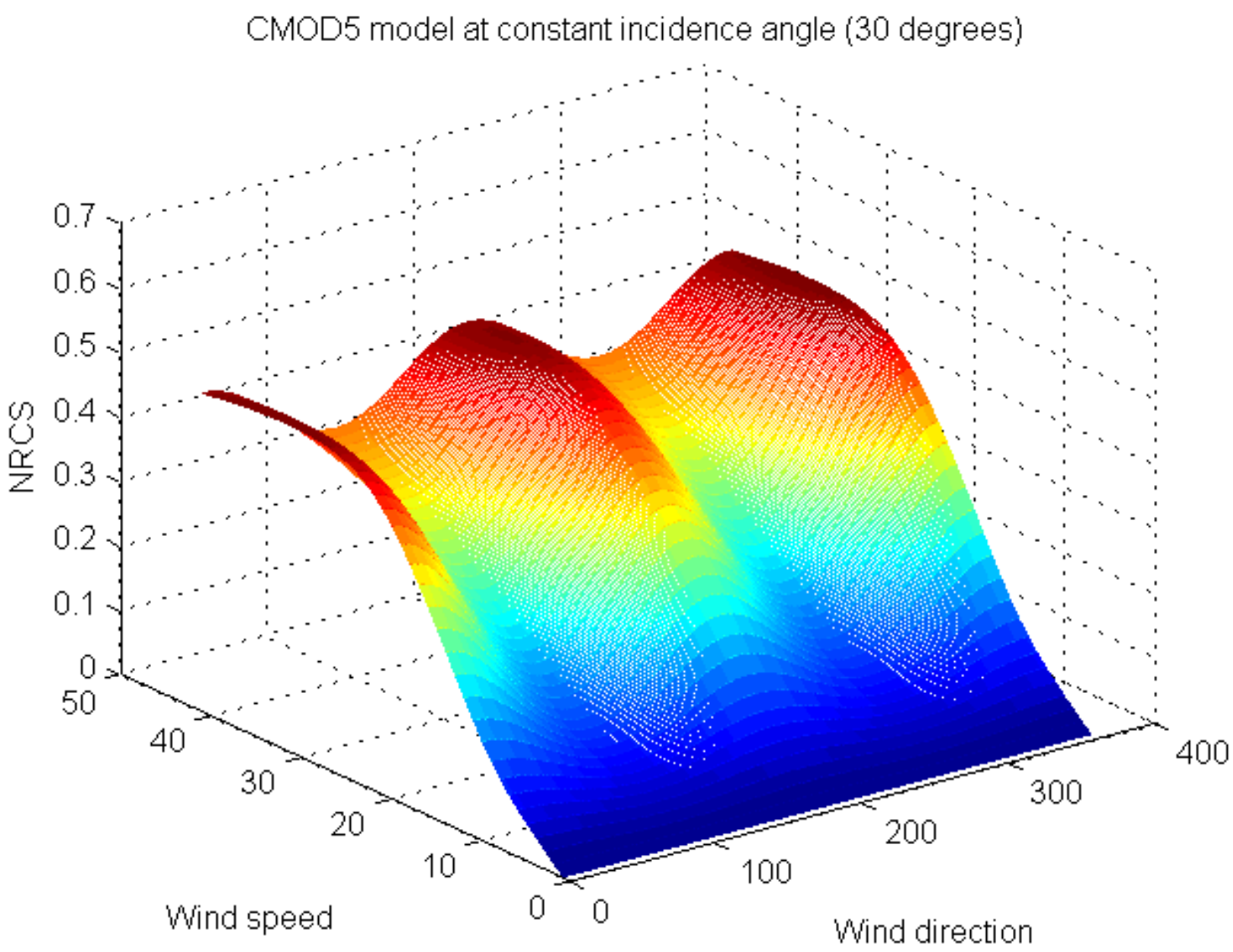
$$\sigma_0^{dB}(v,\phi,\theta) = B0(v,\theta)(1 + B1(v,\theta)\cos(\phi) + B2(v,\theta)\cos(2\phi))^{1.625}$$

Using CMOD

- Invert to yield wind speed by knowing
  - NRCS
  - direction
  - incidence angle
- Necessary to know these parameters (duh!)
  - Not actually easy to know all these well enough.

- For SAR
  - Conversion from VV to HH for RADARSAT-1
  - Band conversion necessary if different from C-band


CMOD5 model at constant wind speed (20 m/s)
NRCS
10
8
6
4
2
0
100
50
0
Incidence angle
0
100
200
300
Wind Direction


CMOD5 model at constant incidence angle (30 degrees)
NRCS
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
40
30
20
10
0
Wind speed
0
100
200
300
400
Wind direction

Scatterometers

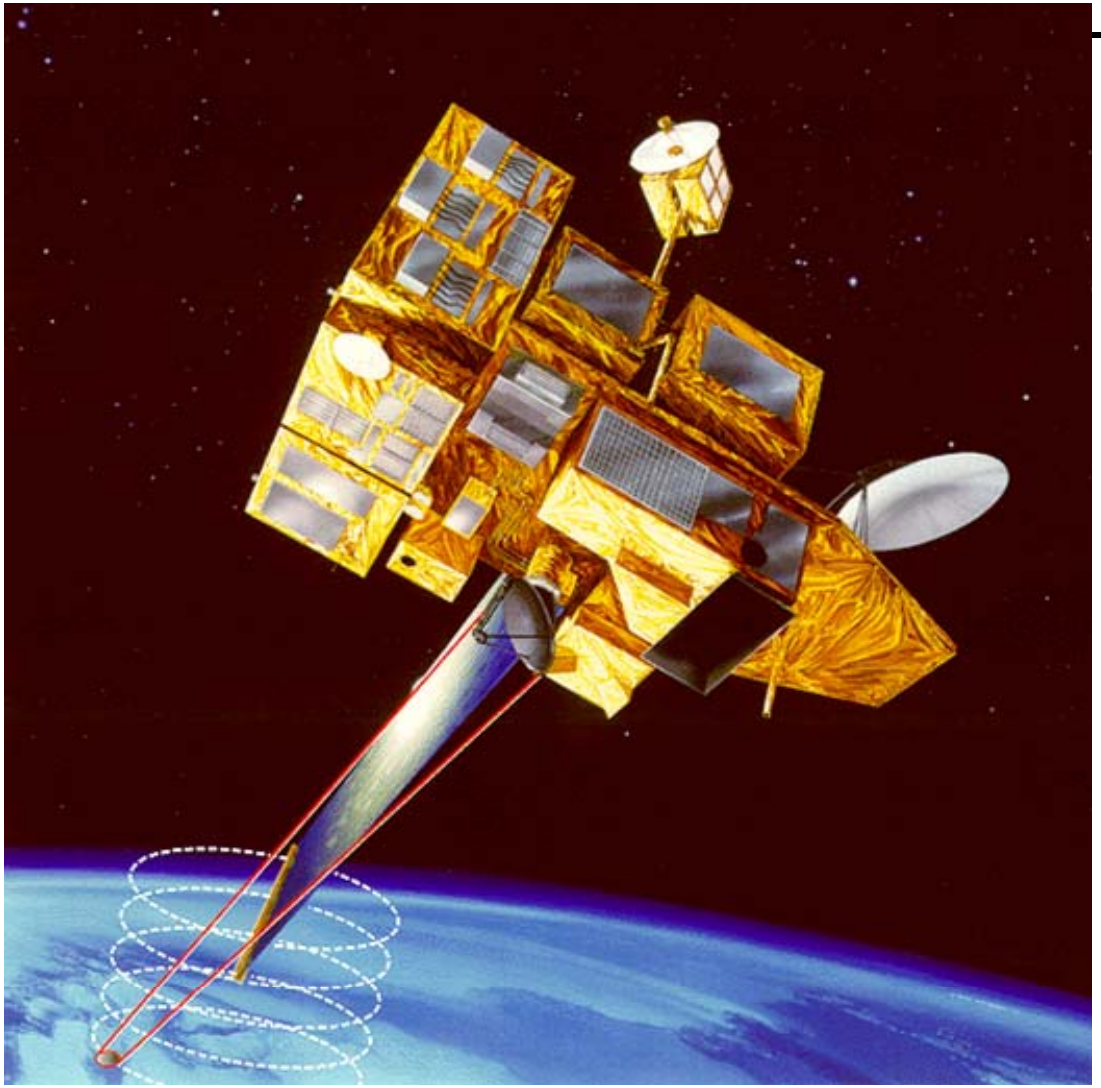


Image courtesy of MERS: http://www.mers.byu.edu/images/Seawinds/seawinds_hires.gif

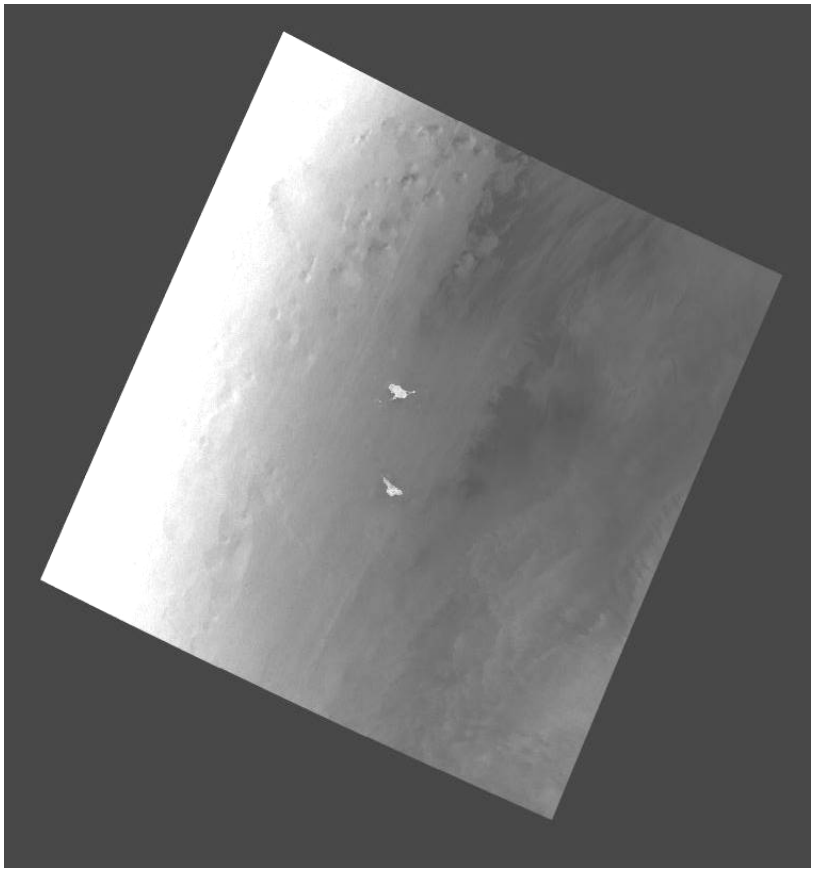
- Measure the surface cross section at a number of aspect angles and polarizations.
- Spatial resolutions of only 25–50 km
  - applicable more to the open ocean than to coastal areas.
- Complementary to SAR data.
- SeaWinds (on QuikSCAT)
  - uses a rotating dish antenna with two spot beams
  - sweep in a circular pattern.
  - Radiates in a continuous, 1,800-kilometer-wide band
  - ~ 400,000 measurements, 90% of Earth's surface in one day.
  - Link:

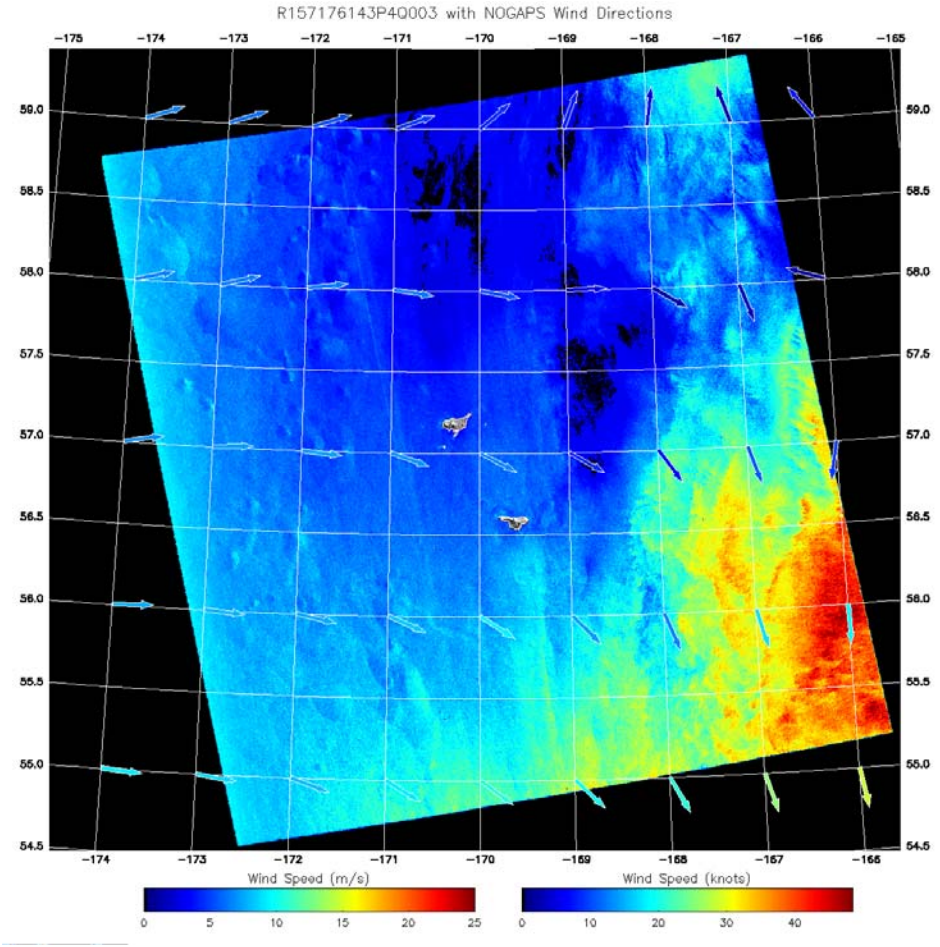
SAR data

- Resolution 10-100m (native)
- Smaller incidence angle range
- Single azimuth angle
- Radar cross section must be calibrated

- Need wind direction as input
  - Linear features in SAR image (wind rows)
    - Usually successful, but not always
  - From modeling
    - NOGAPS (1º X 1º grid)
    - Uses Scatterometer data in model!
    - Low resolution
    - Time / space mismatch
  - Some other / blended methods

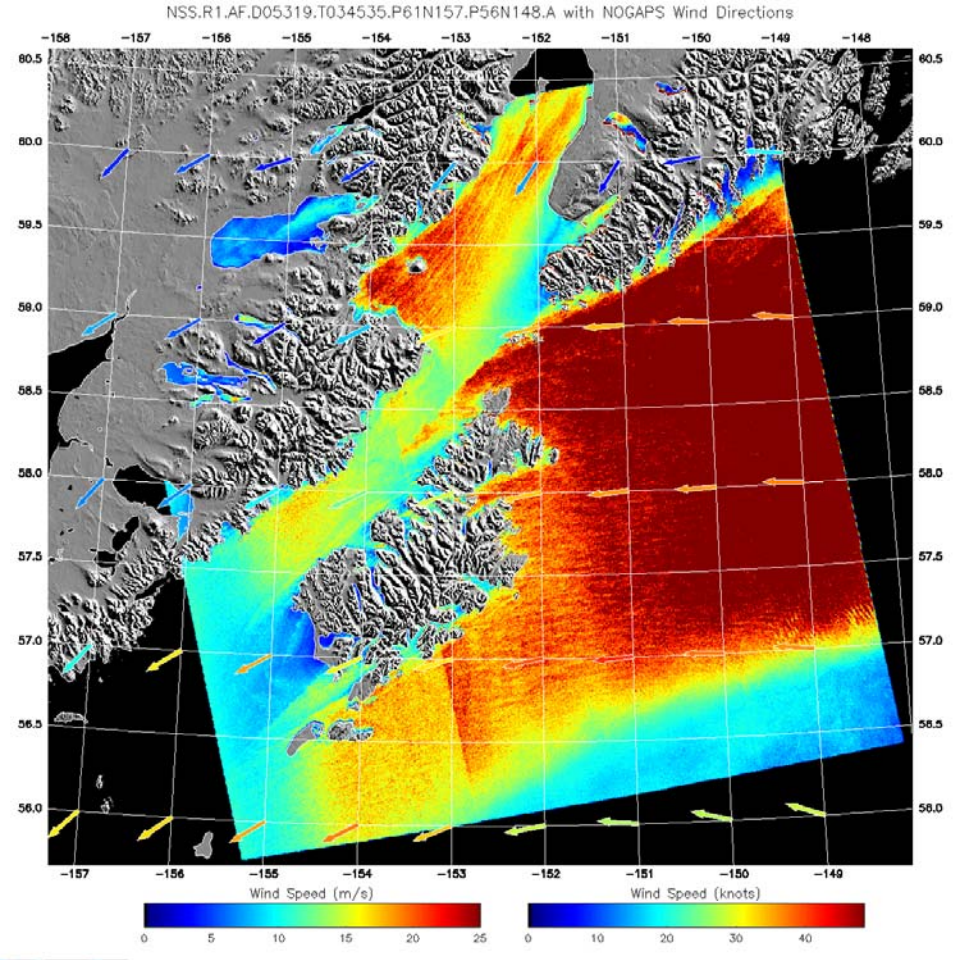
SAR → wind speed



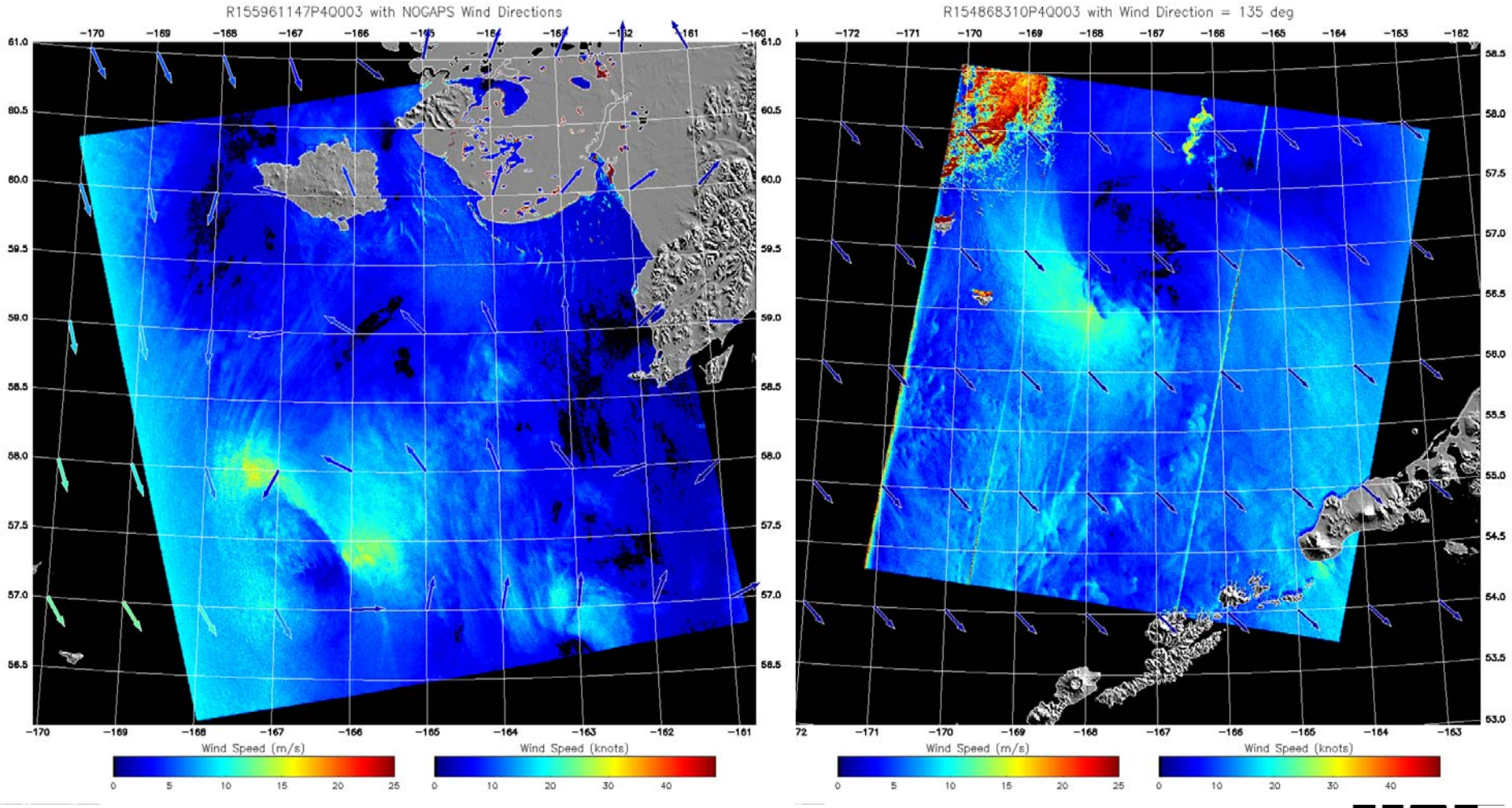


Applications

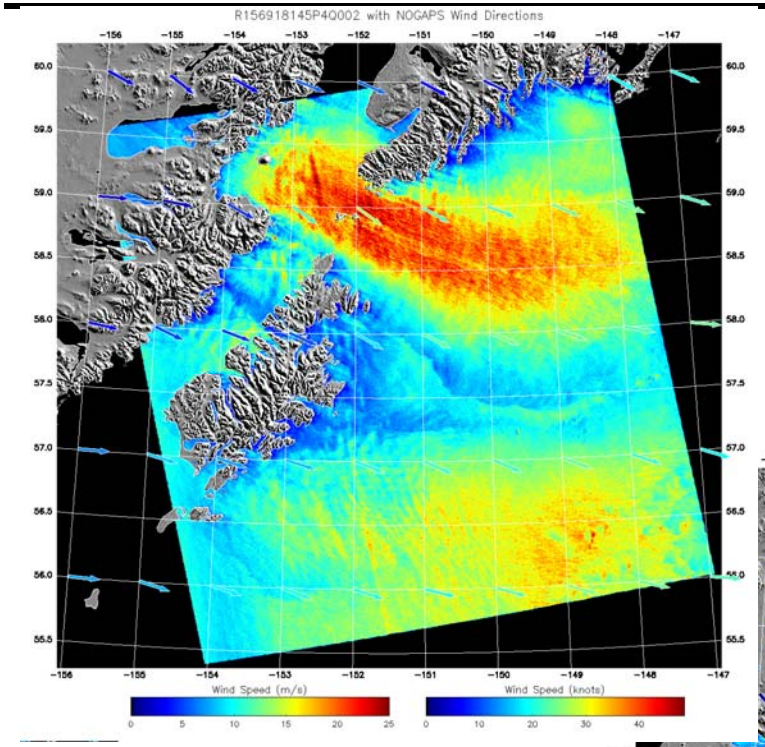
- Where greater precision is needed
- Along coastlines
- Rapidly changing wind speed or direction
- To observe structure of phenomena

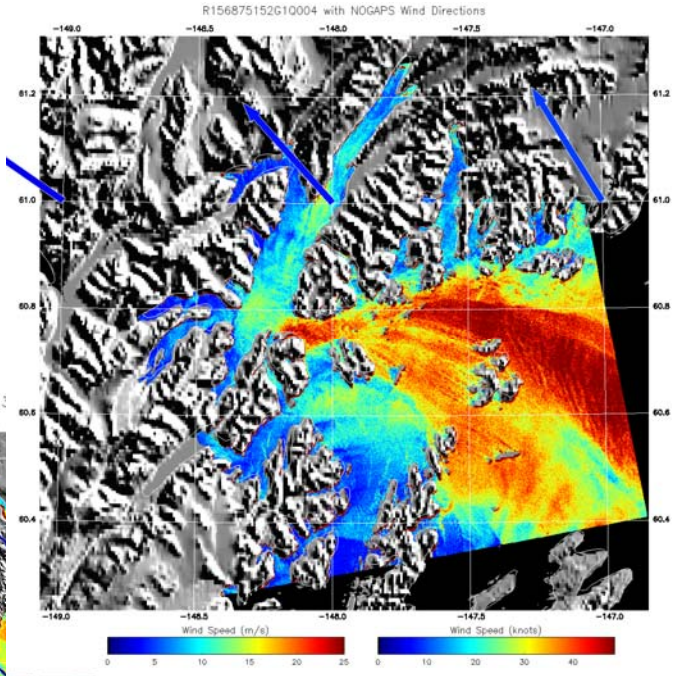


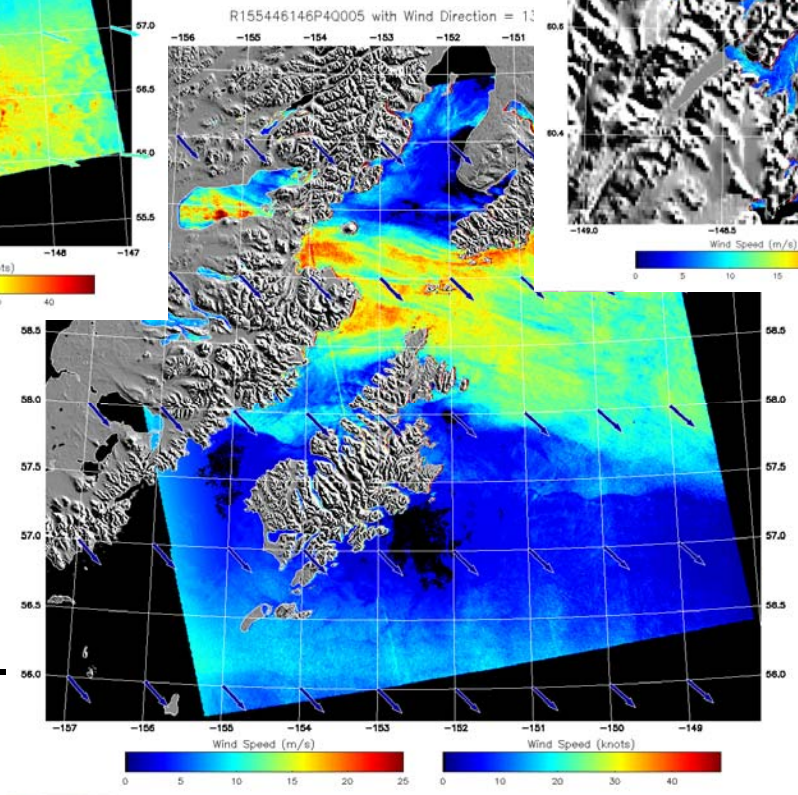
Hurricanes, polar lows



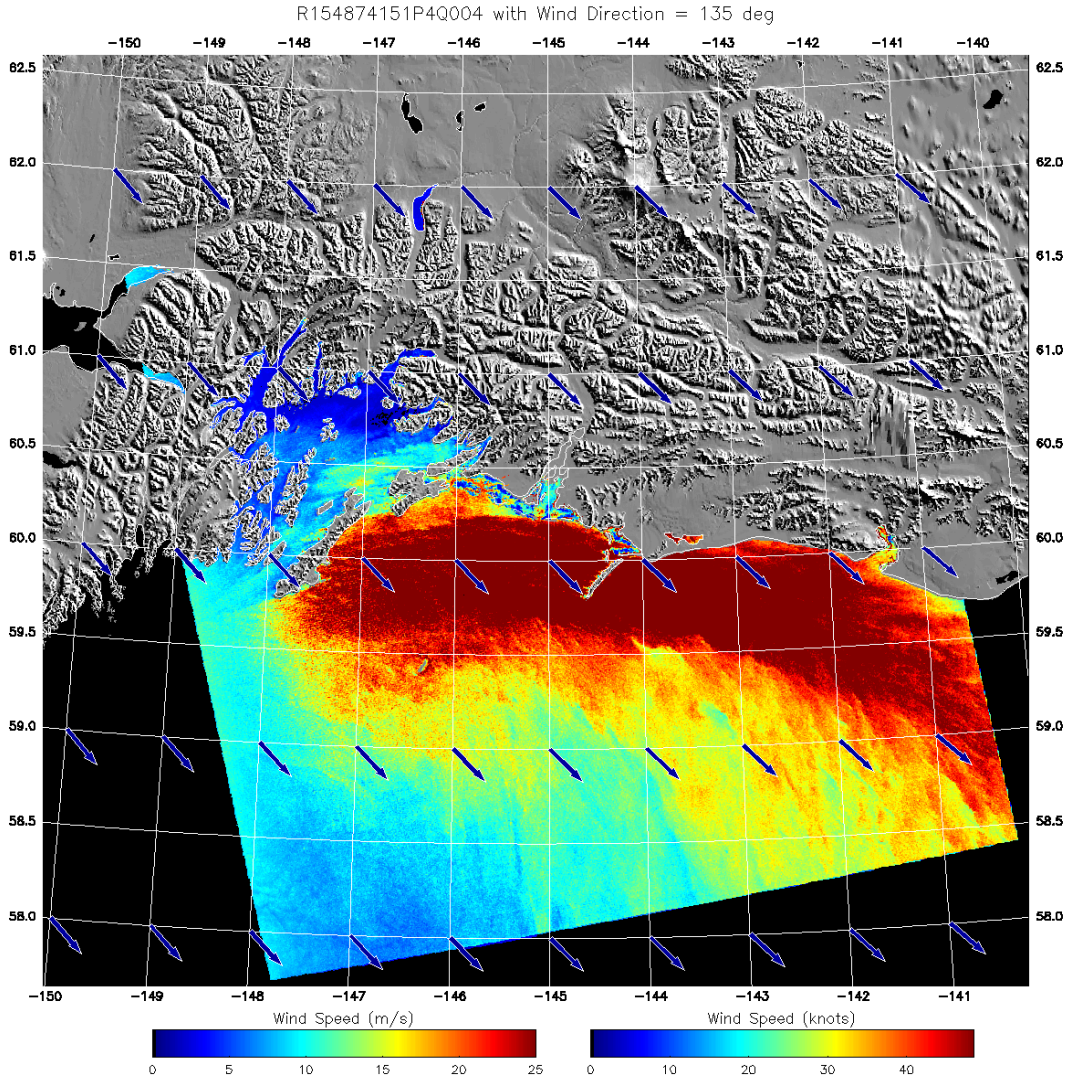
Gap flow


R156918145P4Q002 with NOGAPS Wind Directions
Wind Speed (m/s)
Wind Speed (knots)

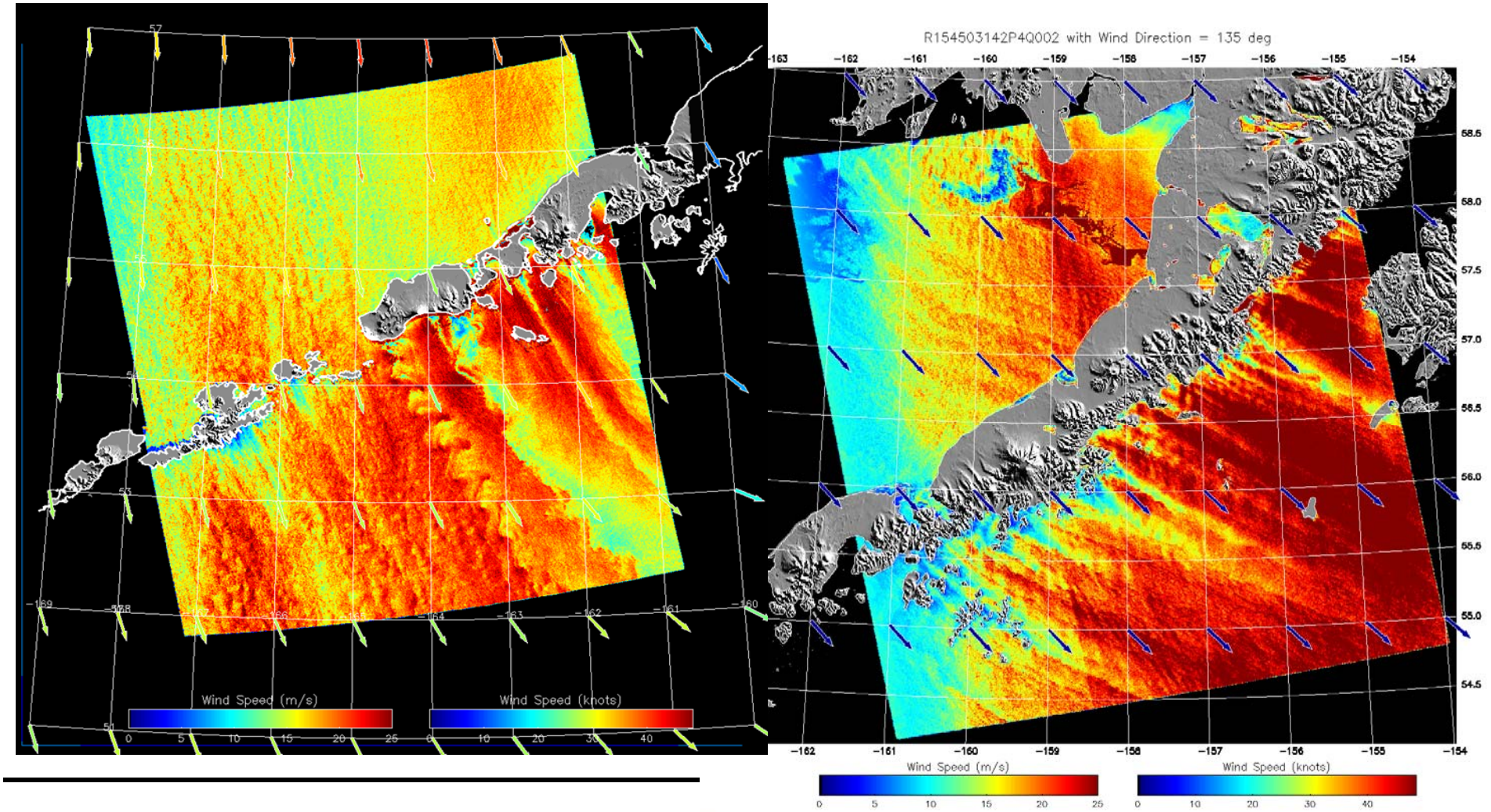

R156875152G1Q004 with NOGAPS Wind Directions
Wind Speed (m/s)
Wind Speed (knots)


R155446146P4Q005 with Wind Direction = 1
Wind Speed (m/s)
Wind Speed (knots)

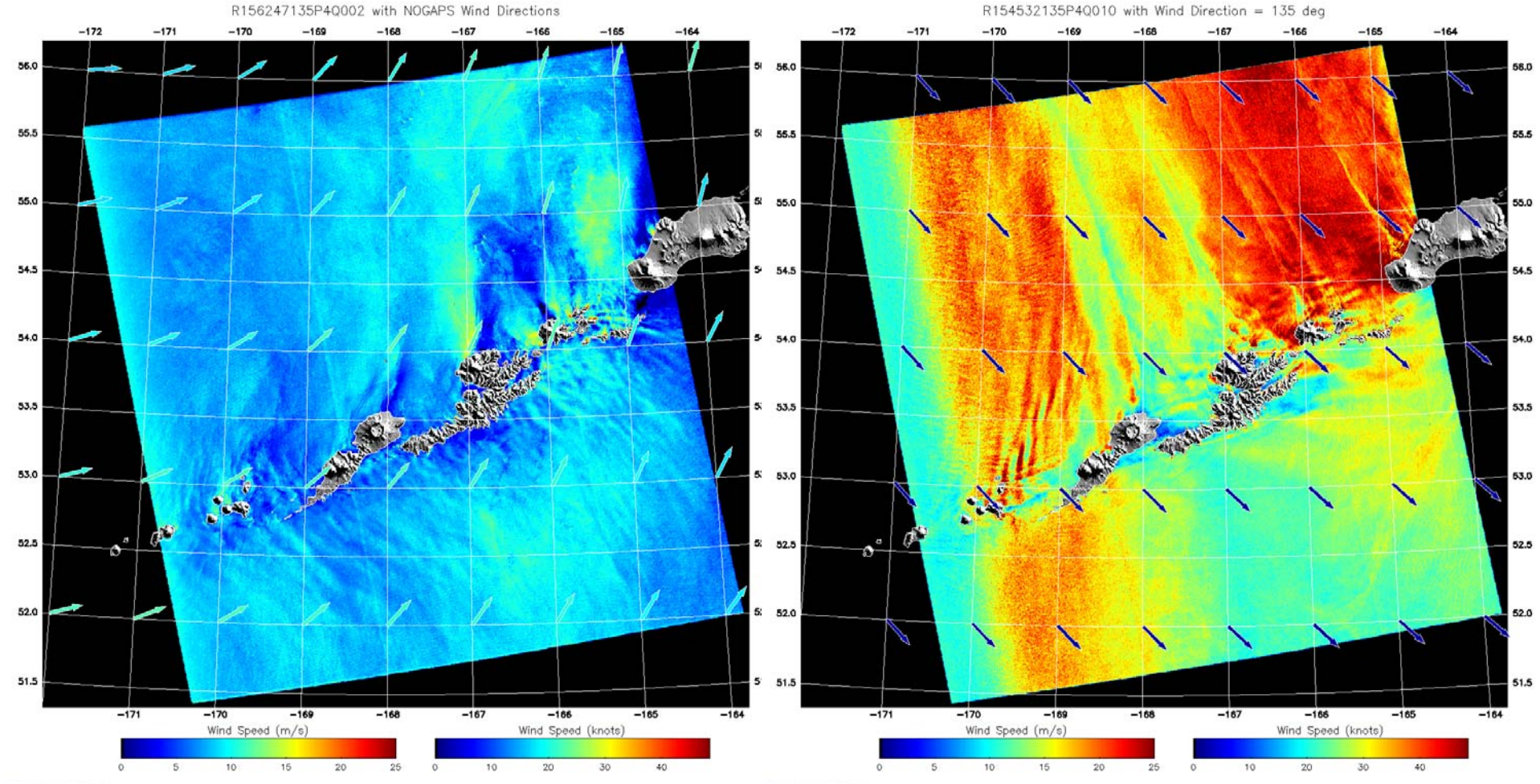
Barrier jets



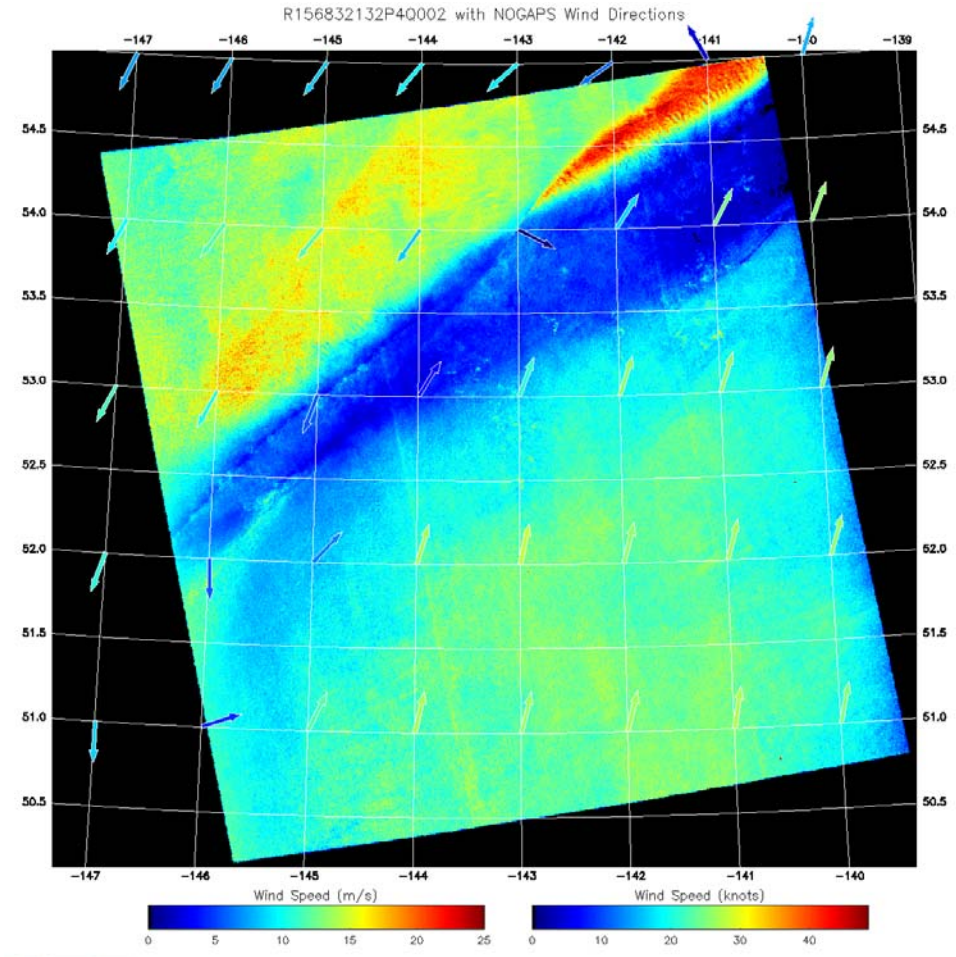
Vortex shedding

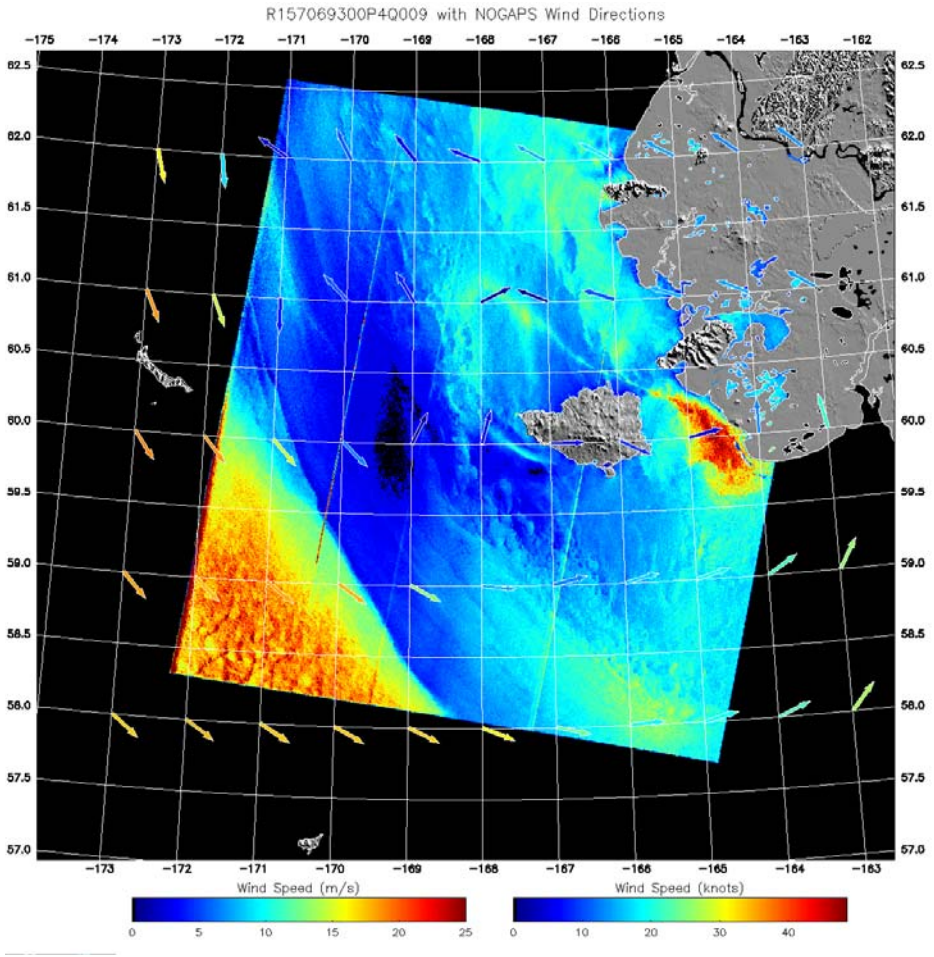


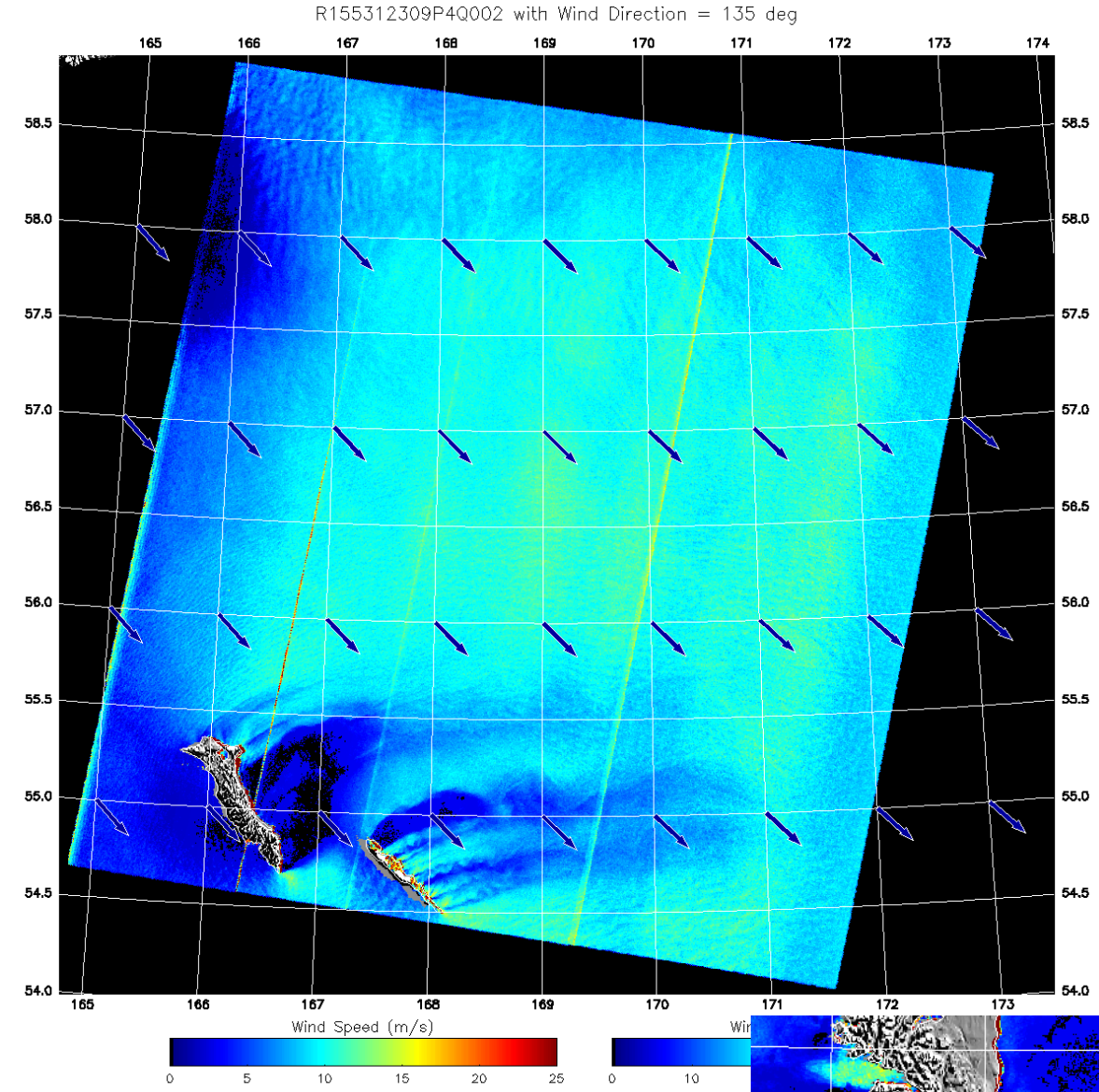
Internal waves



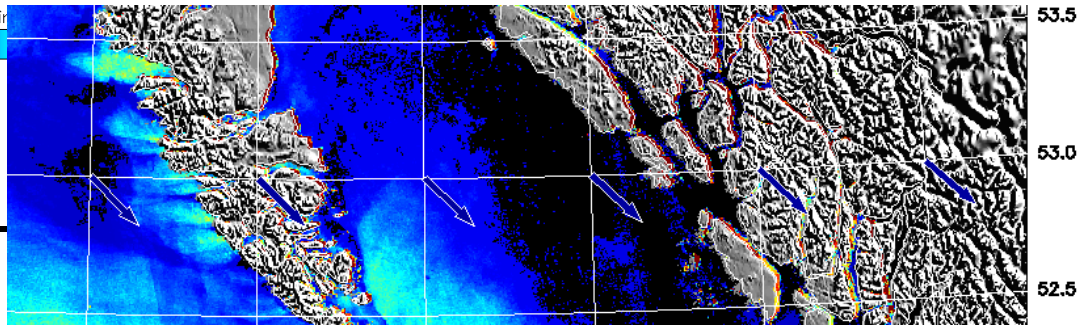
Storm fronts



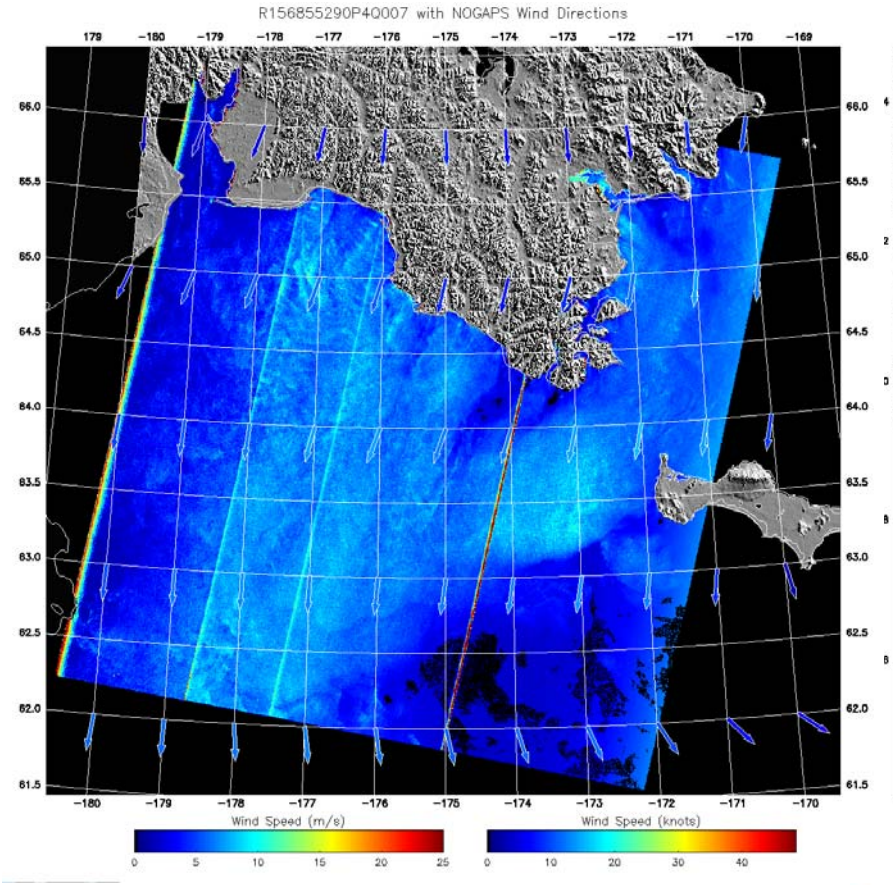




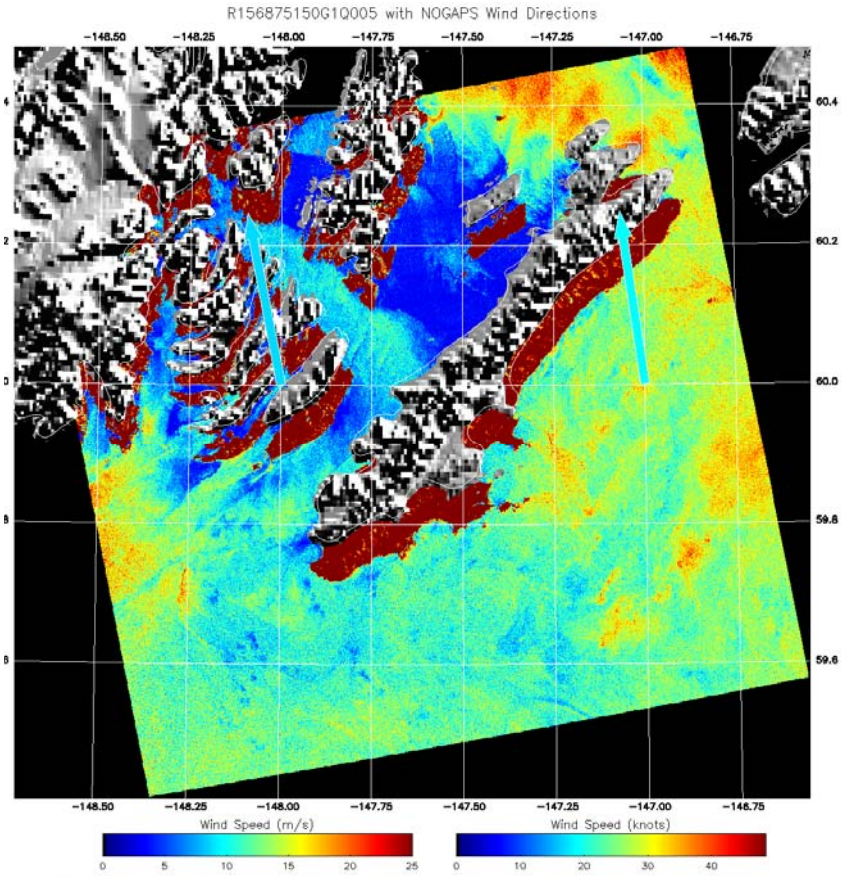
Lee shadowing



Data quality issues

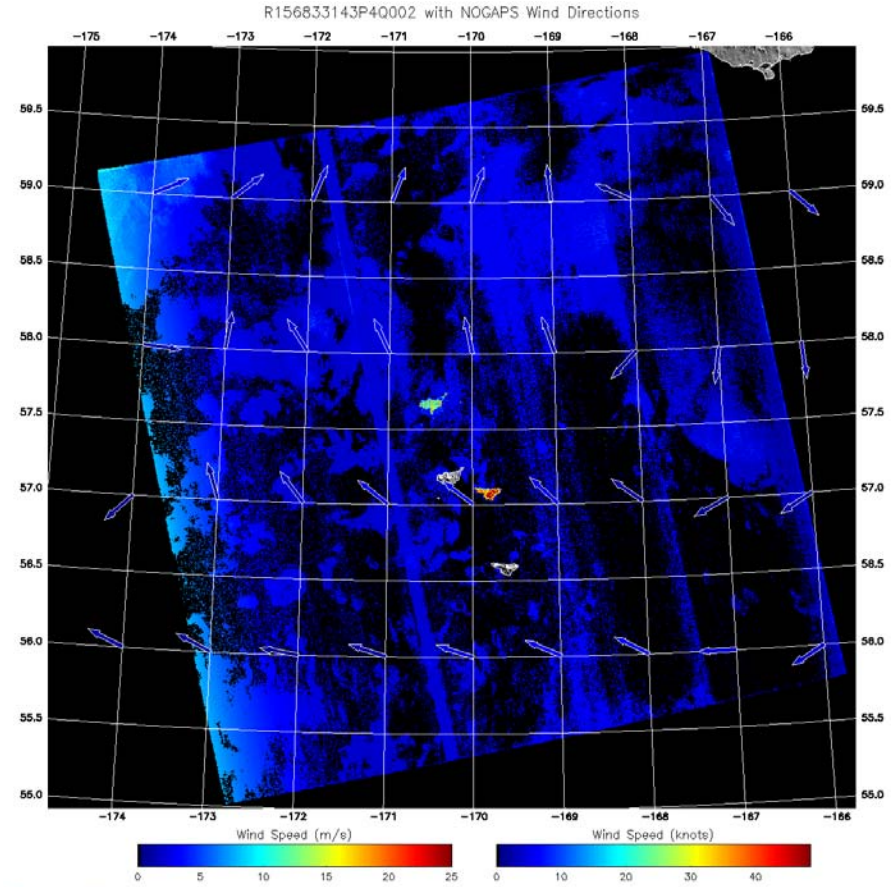


Beam seams

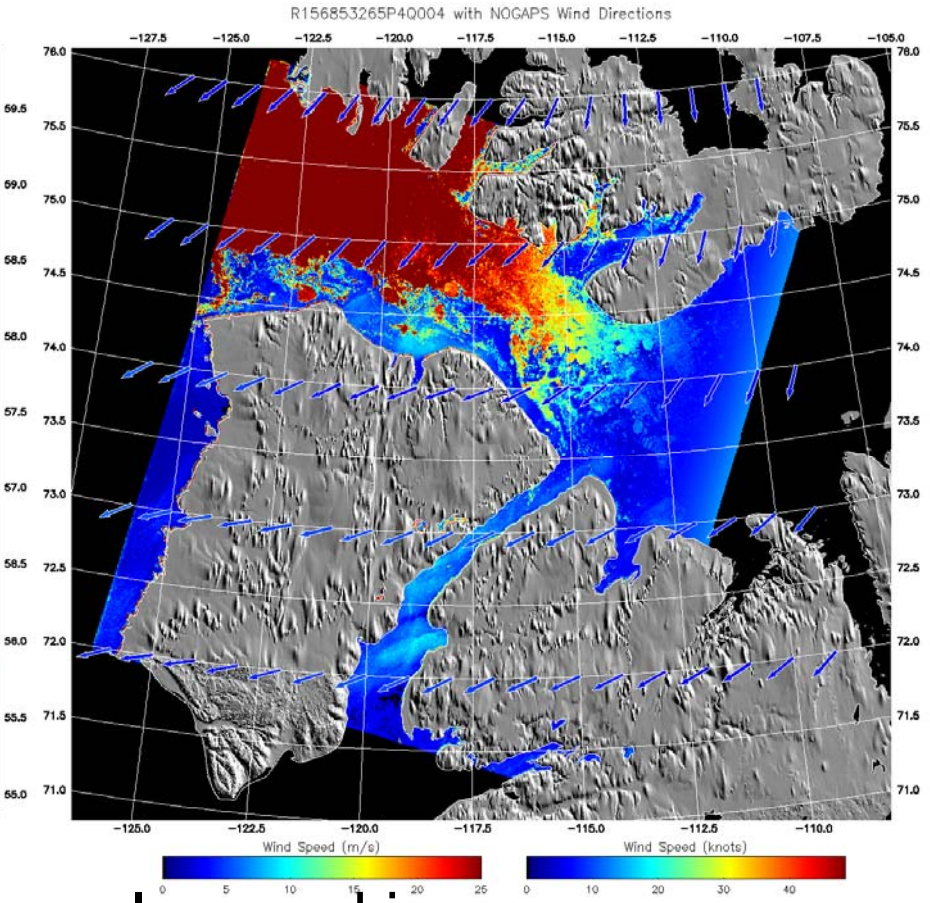


PRF Ambiguity

Data quality issues

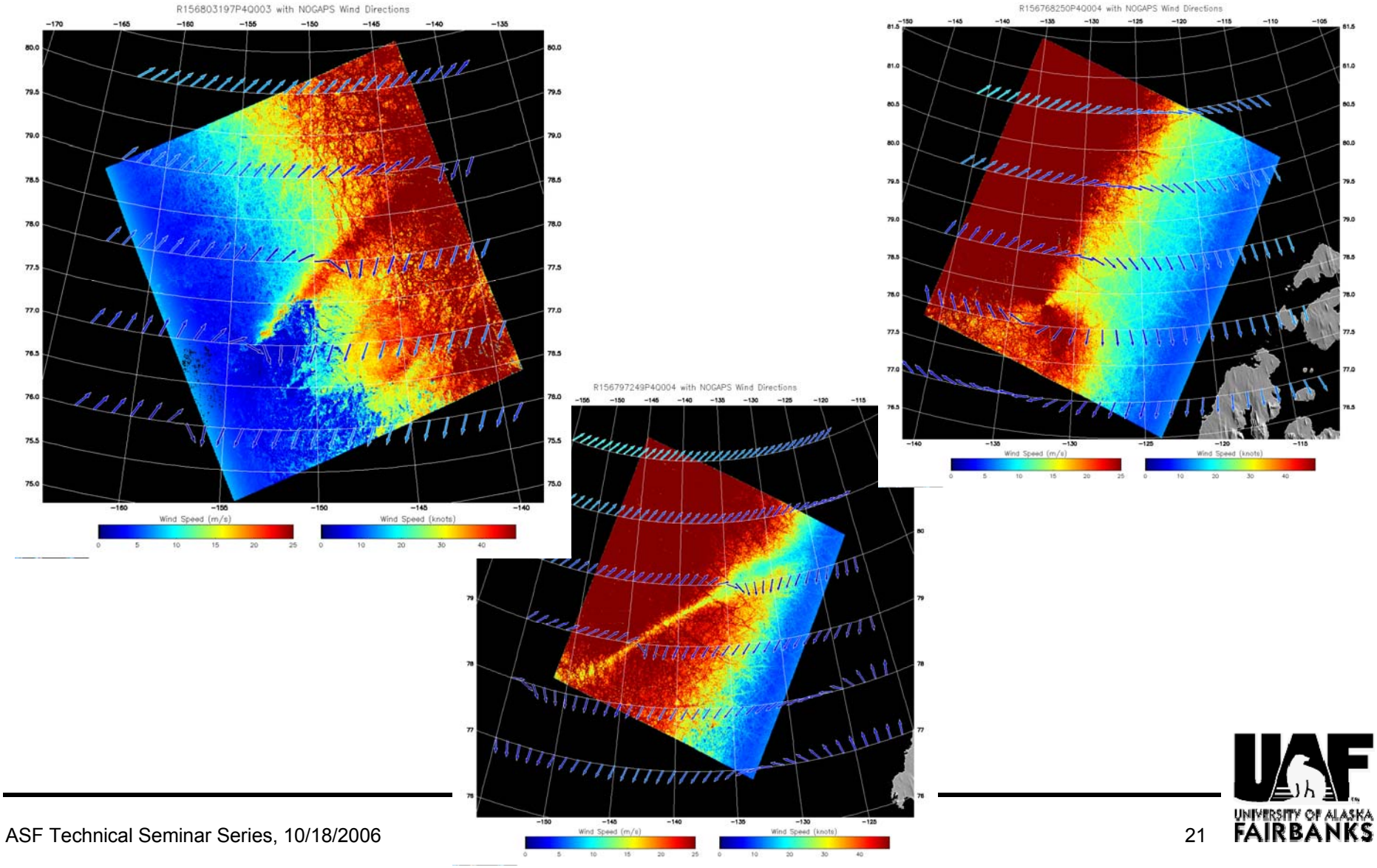


Noise floor

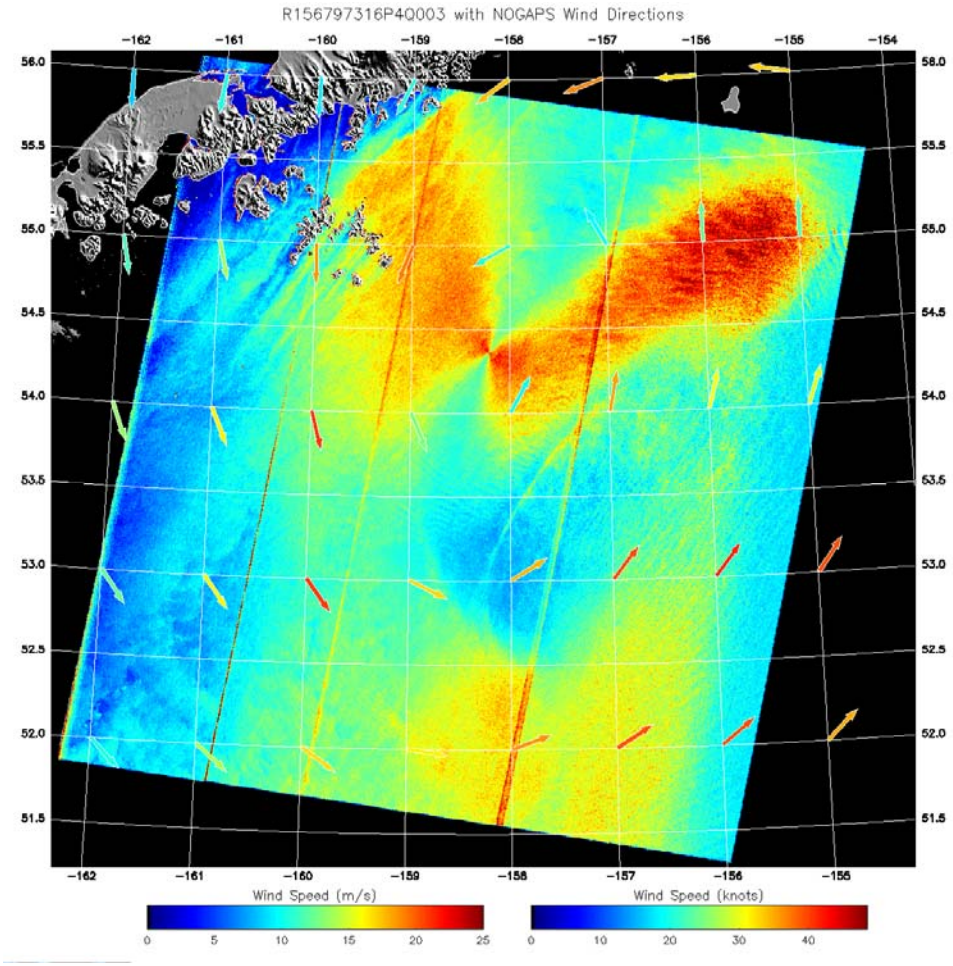


Ice masking

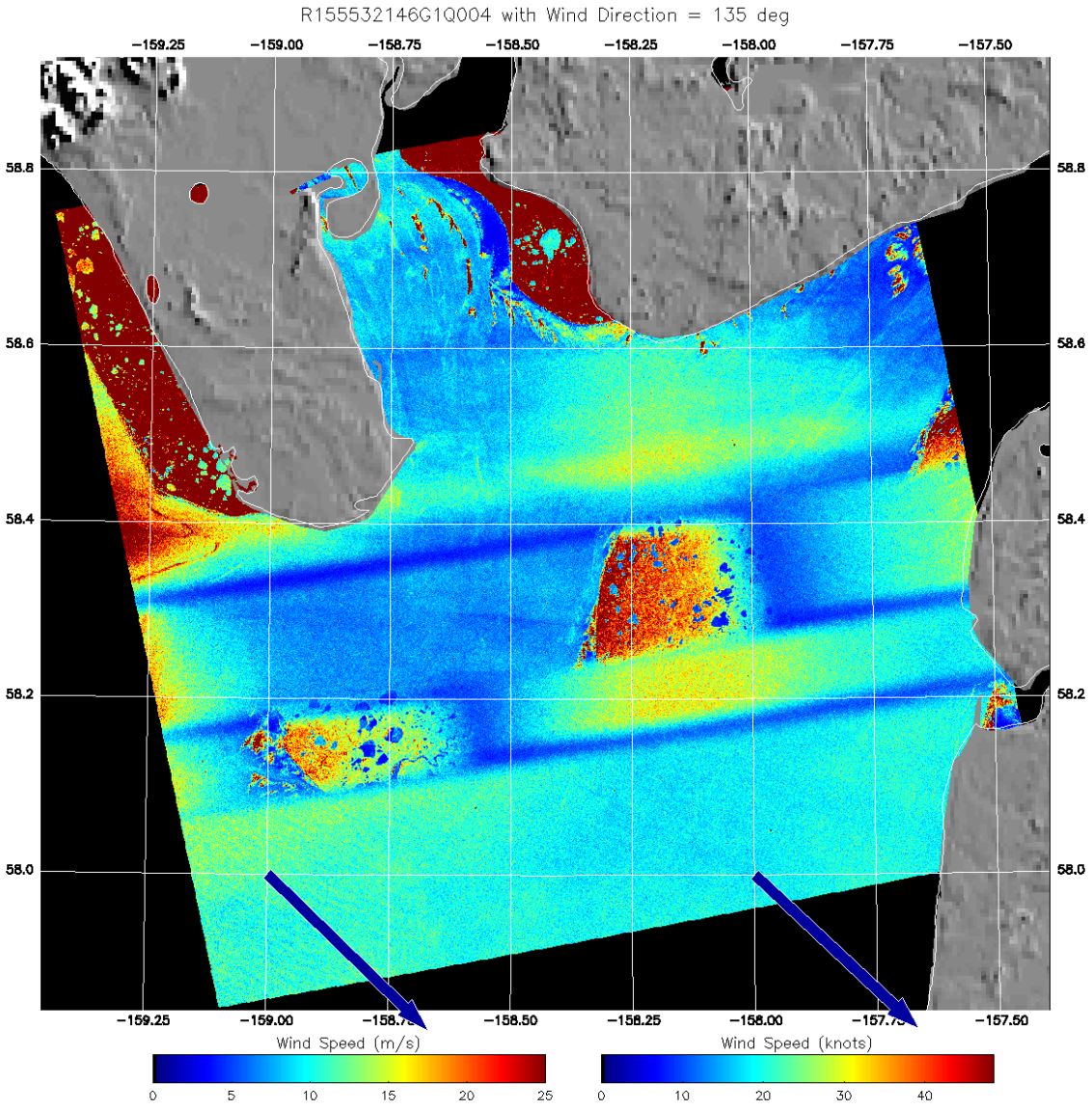
DQ Issues: Wind direction estimates



DQ: model mismatch

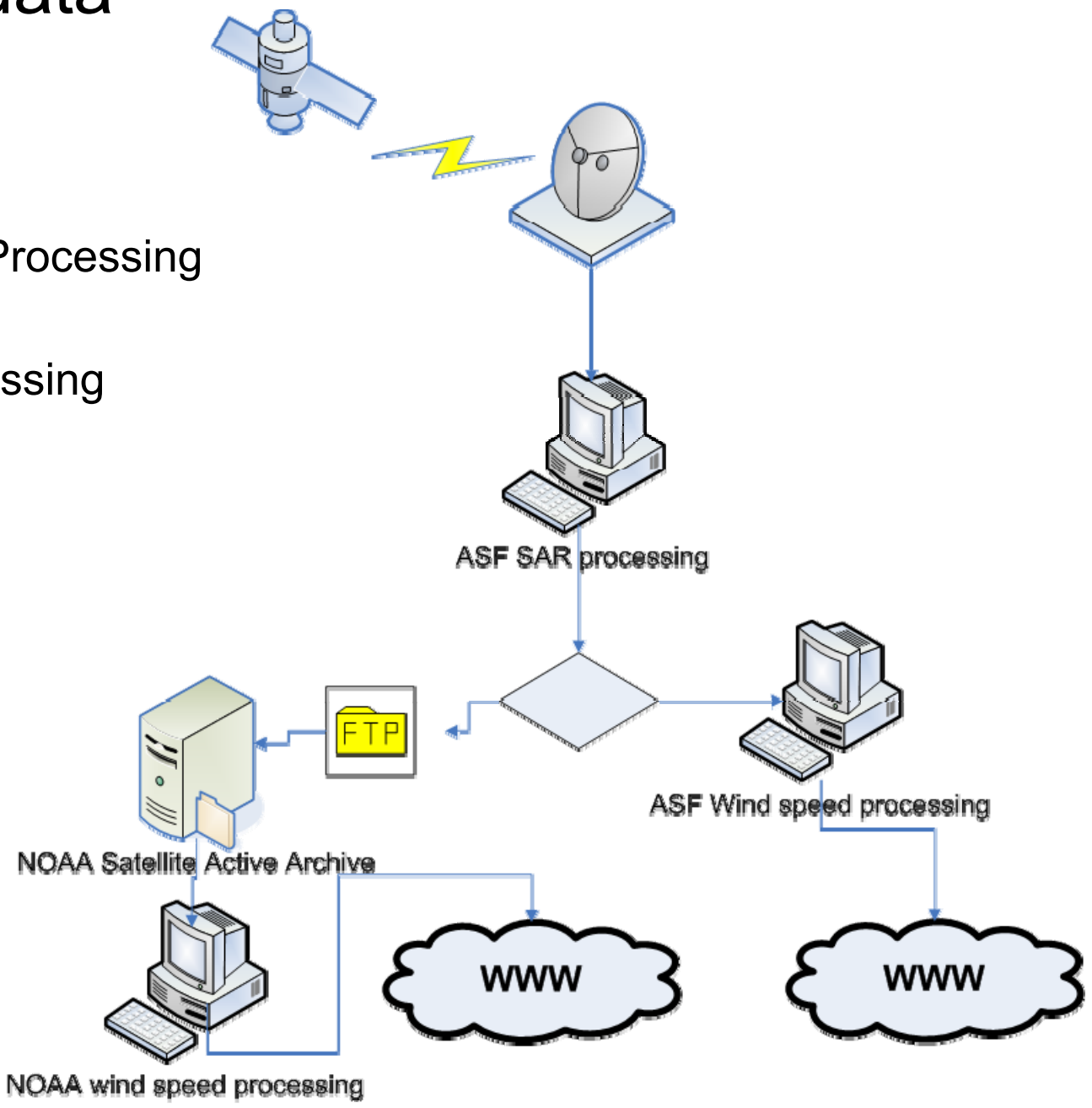


DQ: SAR processing errors



Wind speed data flow

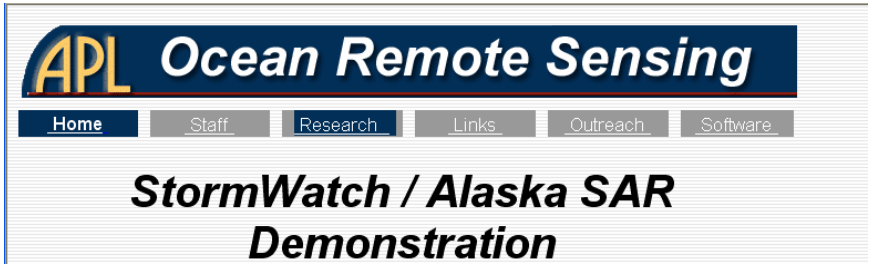
- Latencies
  - Downlink & SAR Processing
    - <2 hours
  - Wind speed processing
    - <15 minutes
  - ftp to lower 48
    - 15-30 minutes
  - Waiting latencies
    - ~ 1 hour



Data archives

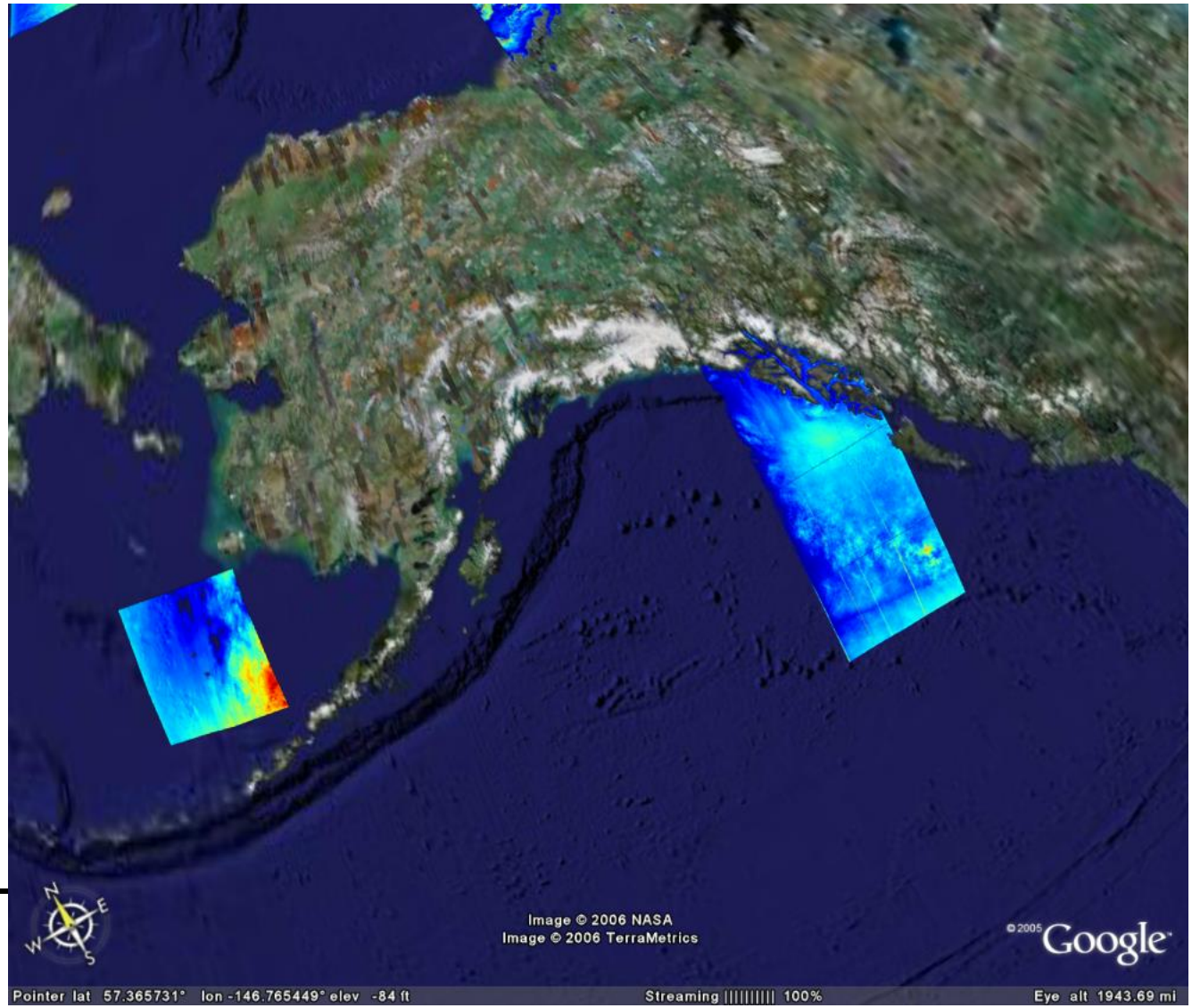
- Near-real time at ASF (wind.asf.alaska.edu)
  - Since Fall 2005

- Main archive at JHU-APL (http://fermi.jhuapl.edu/sar/stormwatch/index.html)
  - Since December 1997

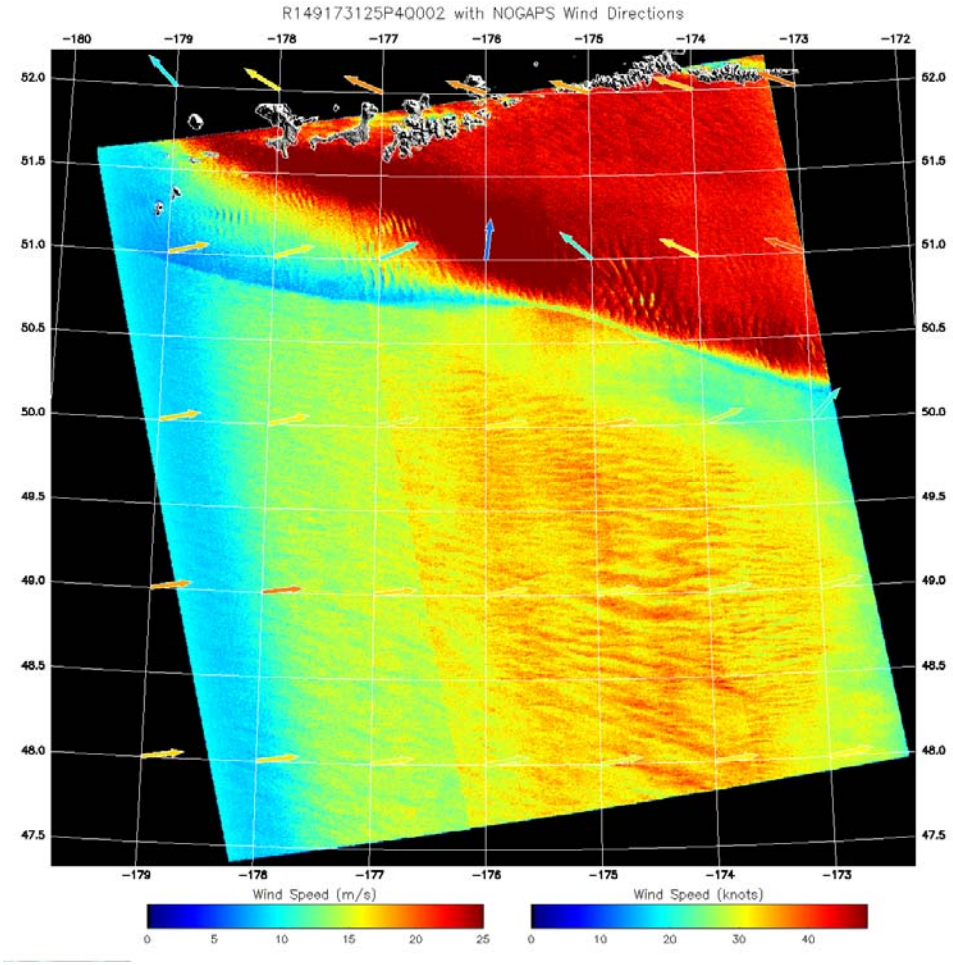


Up and coming

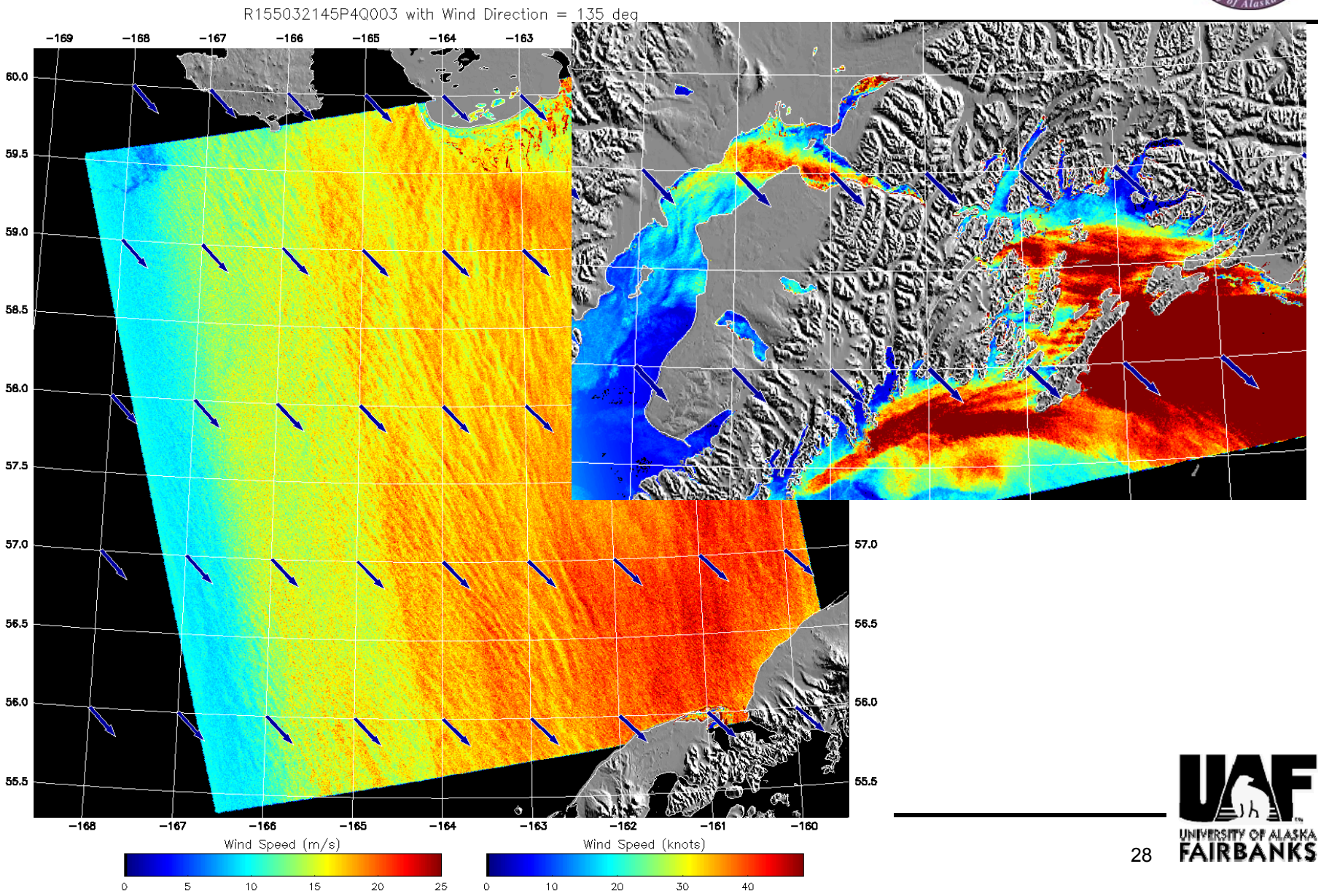
- Google Earth!
- Ice overlays.
- L-band modifications to CMOD algorithm

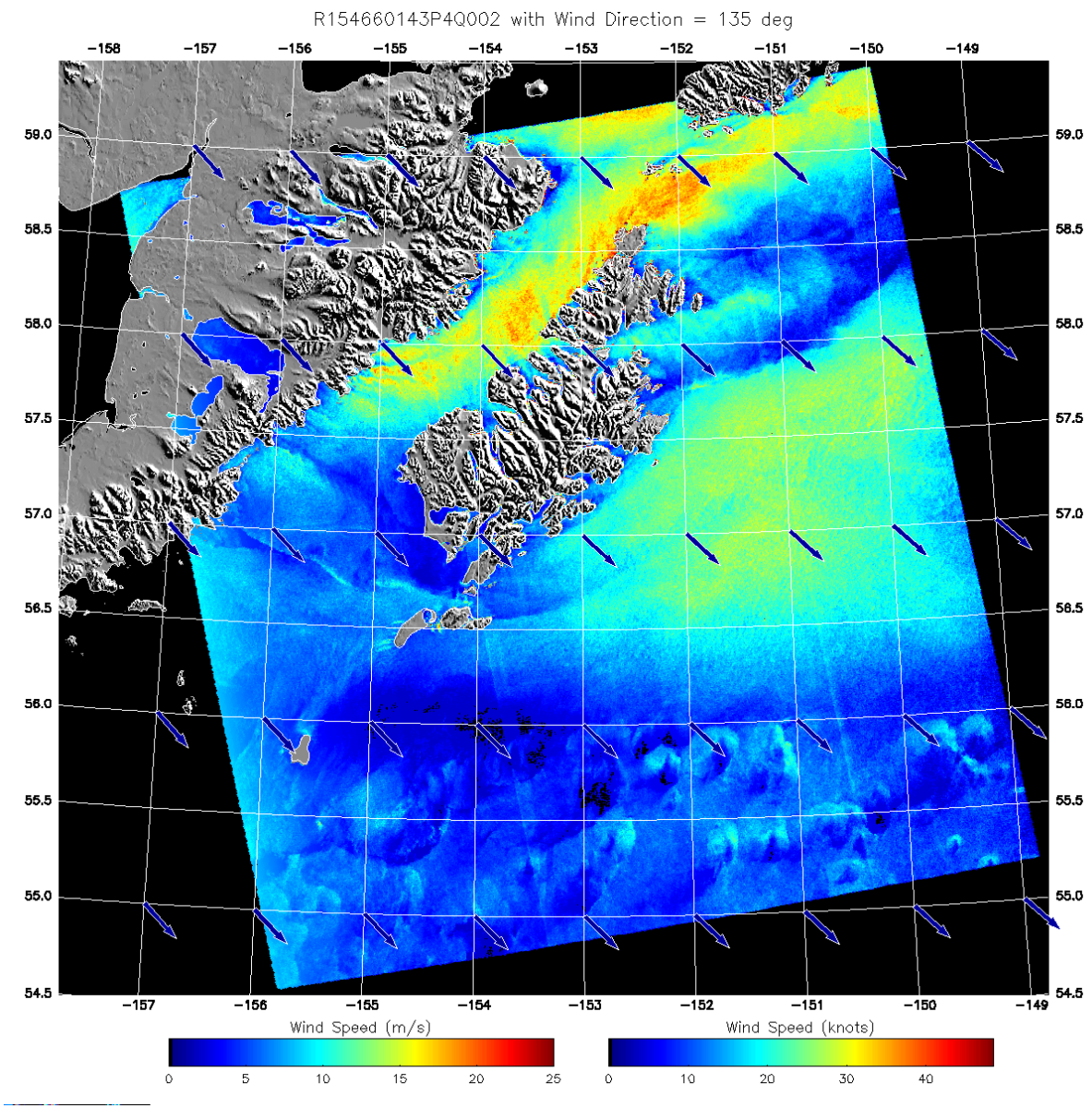


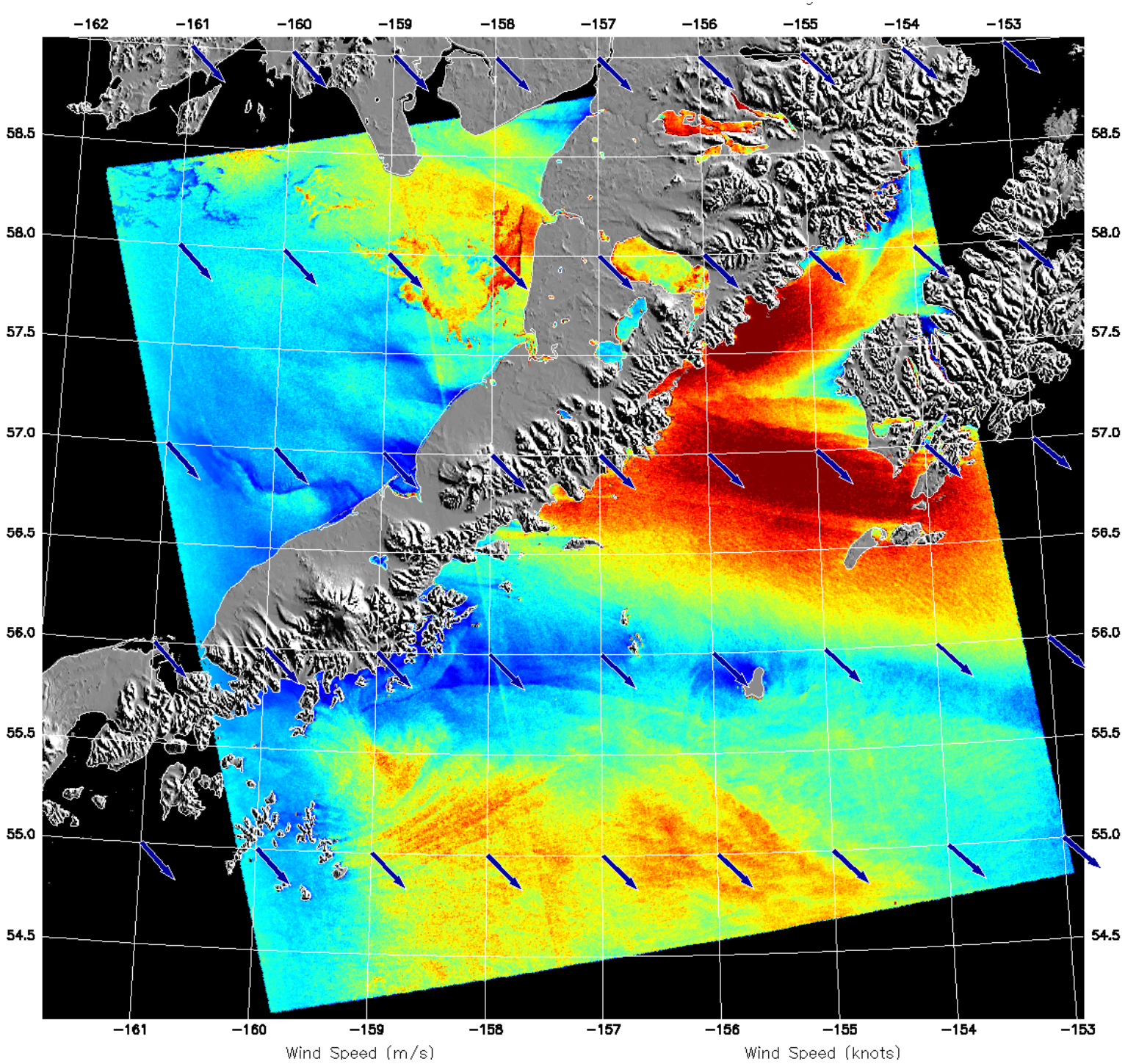
The END!

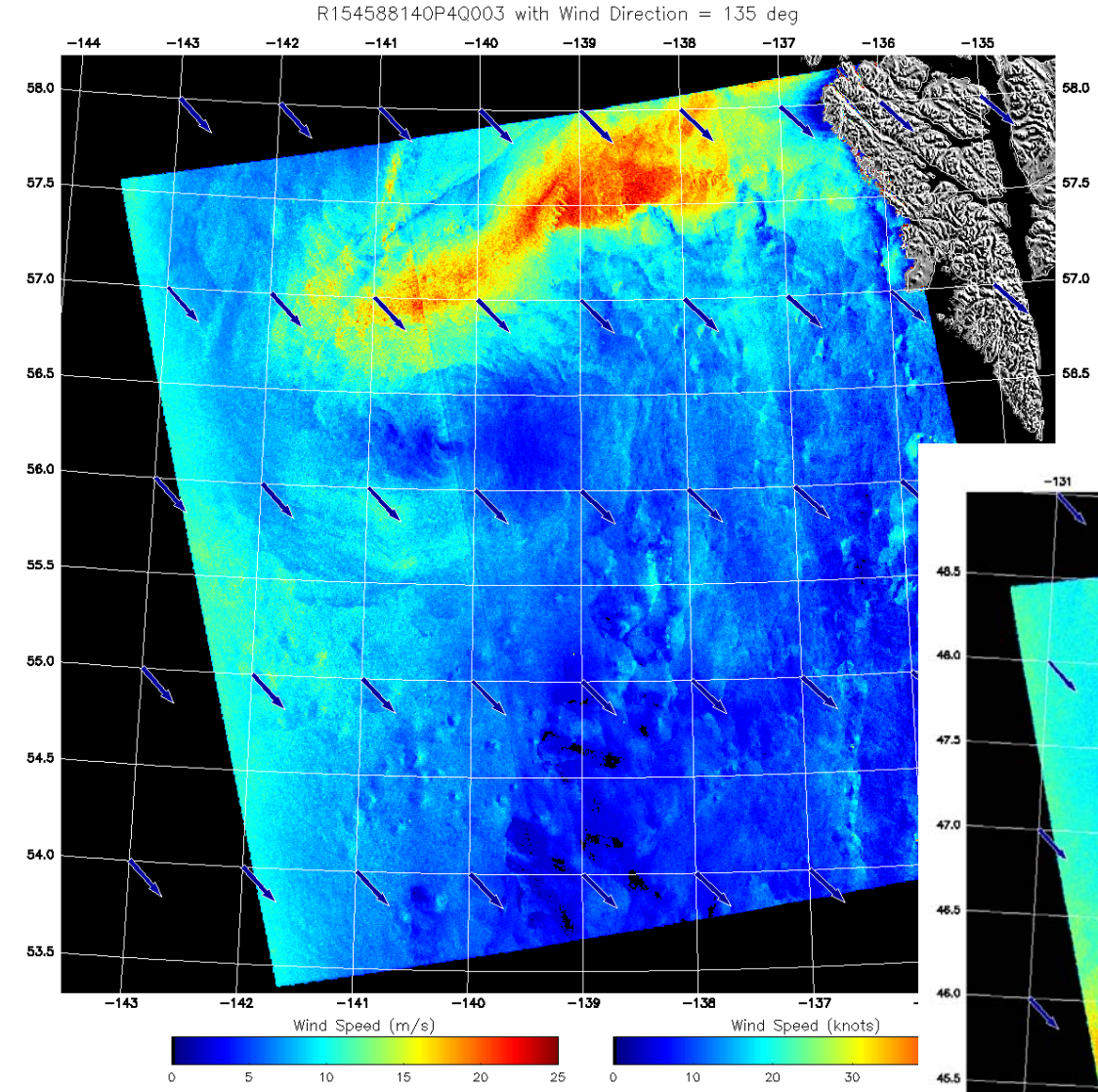

R149173125P4Q002 with NOGAPS Wind Directions
-180
-179
-178
-177
-176
-175
-174
-173
-172
52.0
51.5
51.0
50.5
50.0
49.5
49.0
48.5
48.0
47.5
Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
0
10
20
30
40

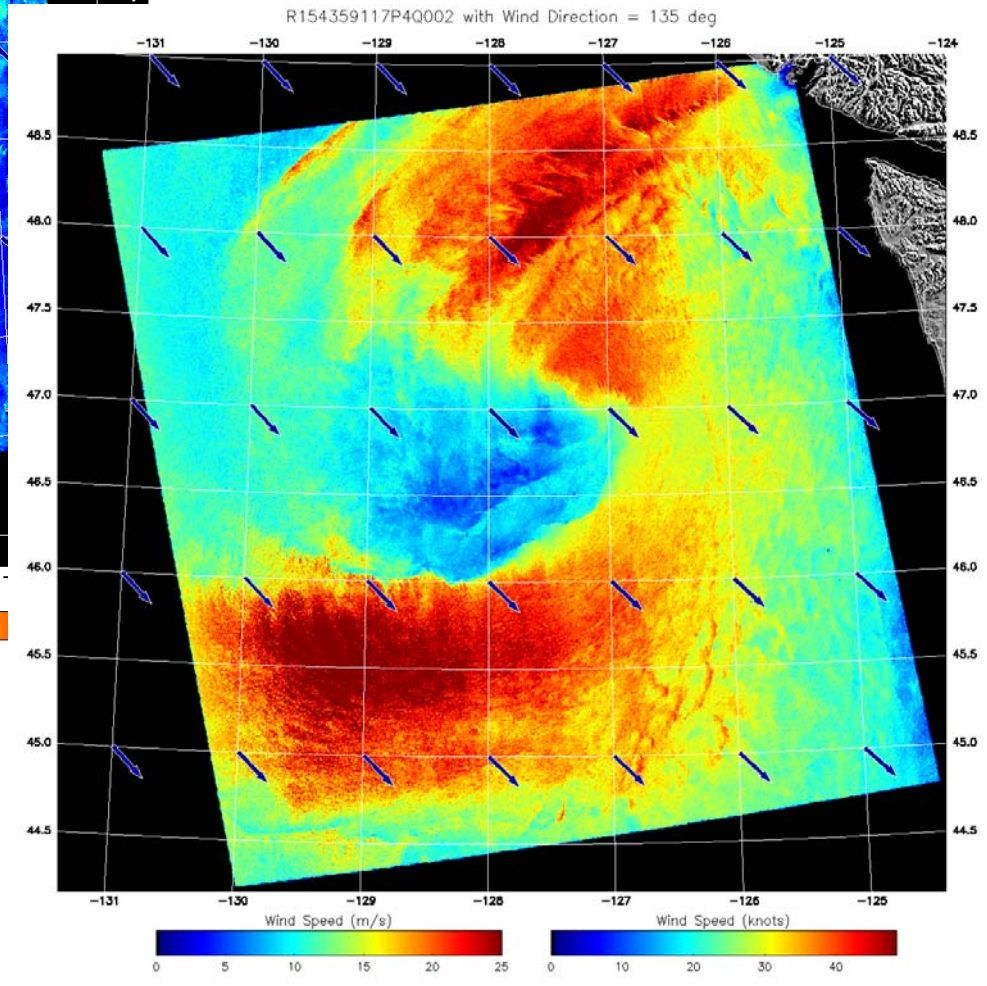
What is it?

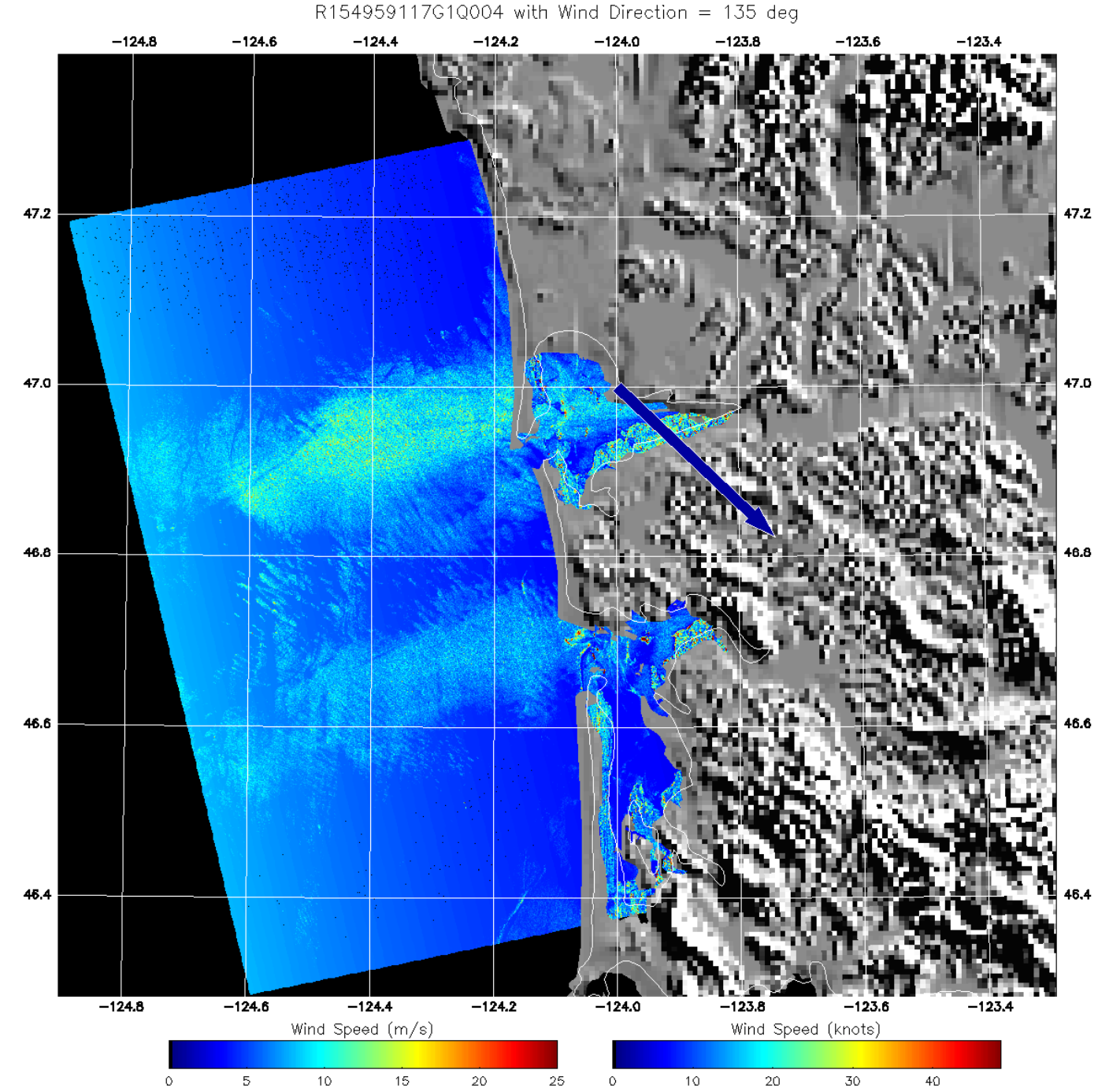

R155032145P4Q003 with Wind Direction = 135 deg
−169 −168 −167 −166 −165 −164 −163
60.0 59.5 59.0 58.5 58.0 57.5 57.0 56.5 56.0 55.5
−168 −167 −166 −165 −164 −163 −162 −161 −160
Wind Speed (m/s)
0 5 10 15 20 25
Wind Speed (knots)
0 10 20 30 40

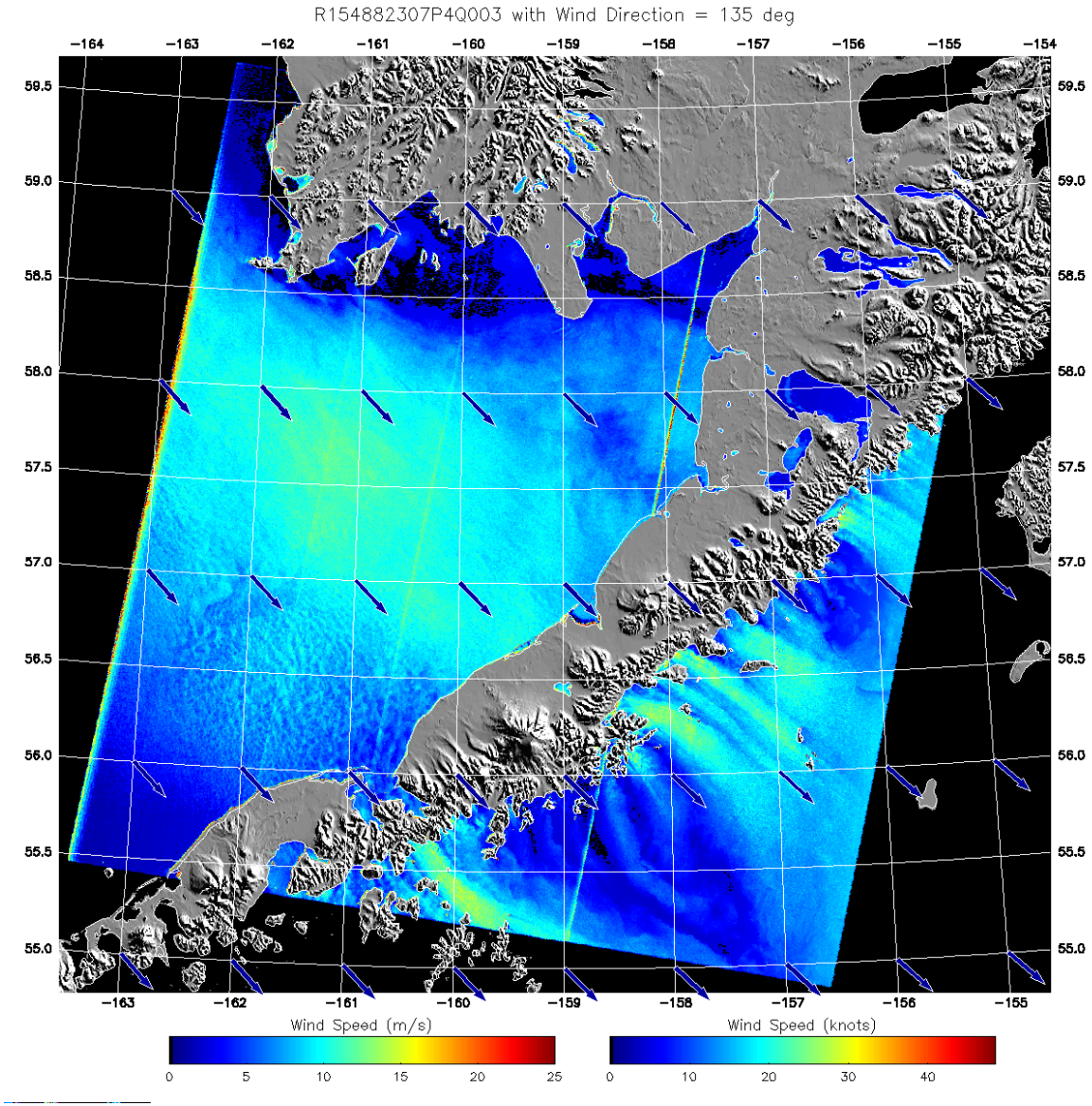

R154660143P4Q002 with Wind Direction = 135 deg
−158
−157
−156
−155
−154
−153
−152
−151
−150
−149
59.0
58.5
58.0
57.5
57.0
56.5
56.0
55.5
55.0
54.5
Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
0
10
20
30
40

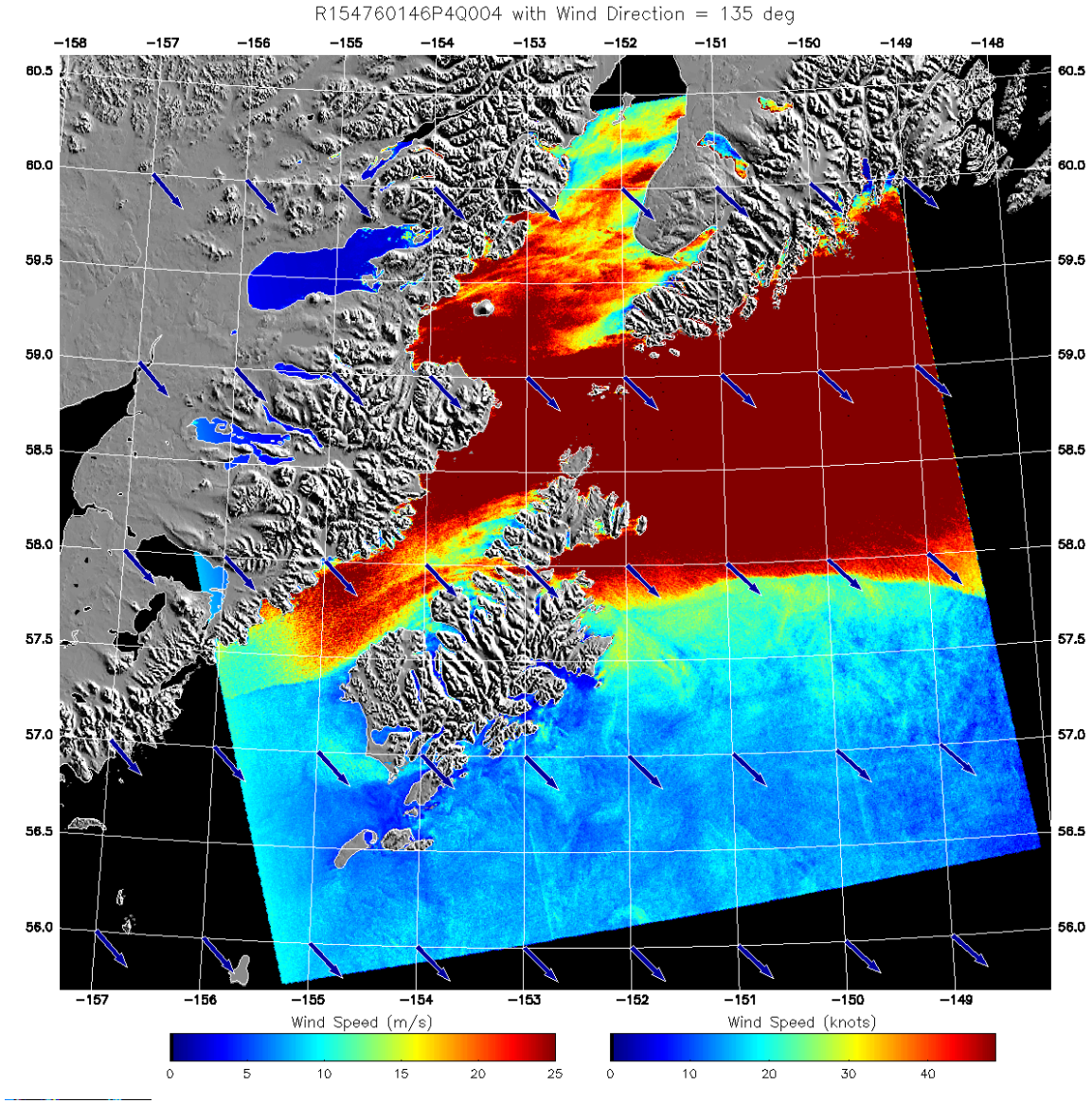

−162
−161
−160
−159
−158
−157
−156
−155
−154
−153
58.5
58.0
57.5
57.0
56.5
56.0
55.5
55.0
54.5
Wind Speed (m/s)
Wind Speed (knots)

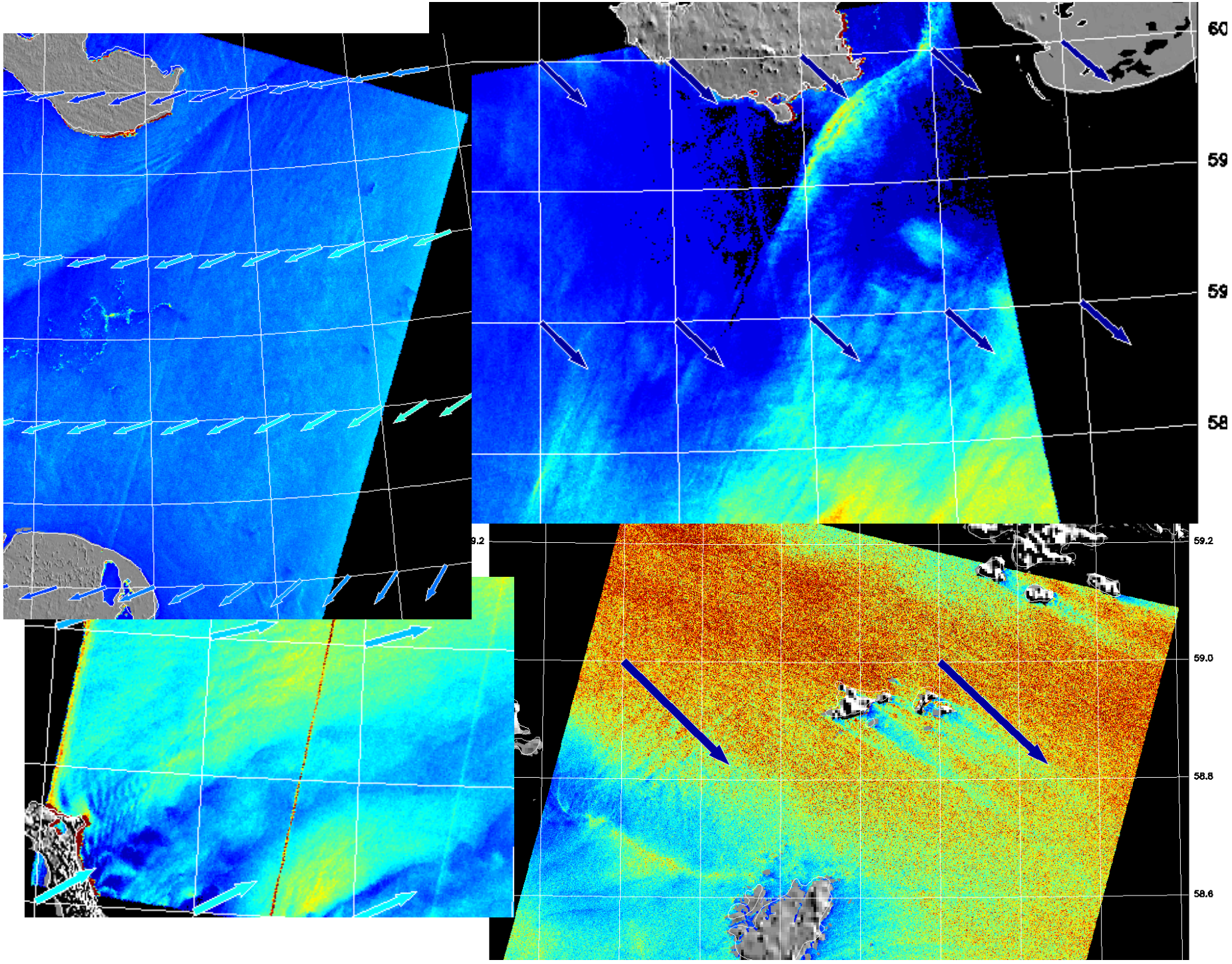

R154588140P4Q003 with Wind Direction = 135 deg
−144 −143 −142 −141 −140 −139 −138 −137 −136 −135
58.0 57.5 57.0 56.5 56.0 55.5 55.0 54.5 54.0 53.5
−143 −142 −141 −140 −139 −138 −137
Wind Speed (m/s)
0 5 10 15 20 25
Wind Speed (knots)
0 10 20 30

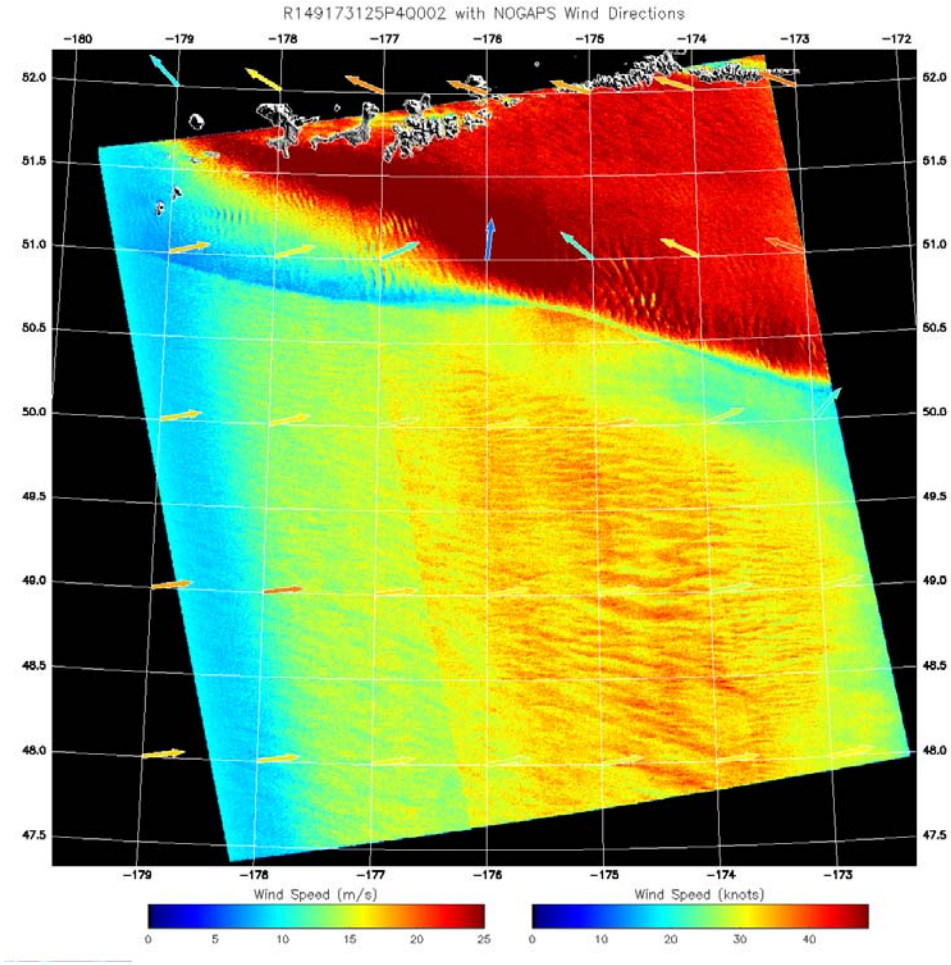

R154359117P4Q002 with Wind Direction = 135 deg
−131 −130 −129 −128 −127 −126 −125 −124
48.5 48.0 47.5 47.0 46.5 46.0 45.5 45.0 44.5
−131 −130 −129 −128 −127 −126 −125
Wind Speed (m/s)
0 5 10 15 20 25
Wind Speed (knots)
0 10 20 30 40

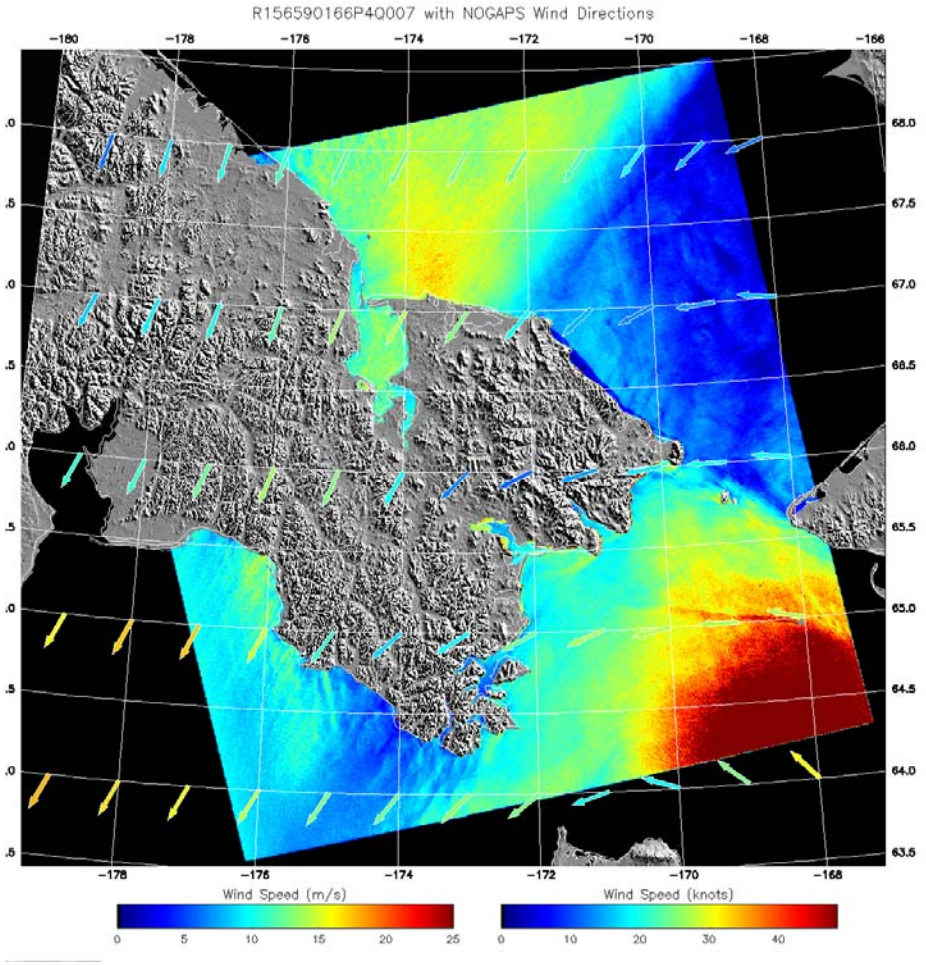

R154959117G1Q004 with Wind Direction = 135 deg
−124.8
−124.6
−124.4
−124.2
−124.0
−123.8
−123.6
−123.4
47.2
47.0
46.8
46.6
46.4
Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
0
10
20
30
40


R154882307P4Q003 with Wind Direction = 135 deg
−164
−163
−162
−161
−160
−159
−158
−157
−156
−155
−154
59.5
59.0
58.5
58.0
57.5
57.0
56.5
56.0
55.5
55.0
Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
0
10
20
30
40


R154760146P4Q004 with Wind Direction = 135 deg
−158
−157
−156
−155
−154
−153
−152
−151
−150
−149
−148
60.5
60.0
59.5
59.0
58.5
58.0
57.5
57.0
56.5
56.0
Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
0
10
20
30
40


60
59
59
58
59.2
59.0
58.8
58.6


R149173125P4Q002 with NOGAPS Wind Directions
Wind Speed (m/s)
0 5 10 15 20 25
Wind Speed (knots)
0 10 20 30 40


R156590166P4Q007 with NOGAPS Wind Directions
Wind Speed (m/s)
0 5 10 15 20 25
Wind Speed (knots)
0 10 20 30 40