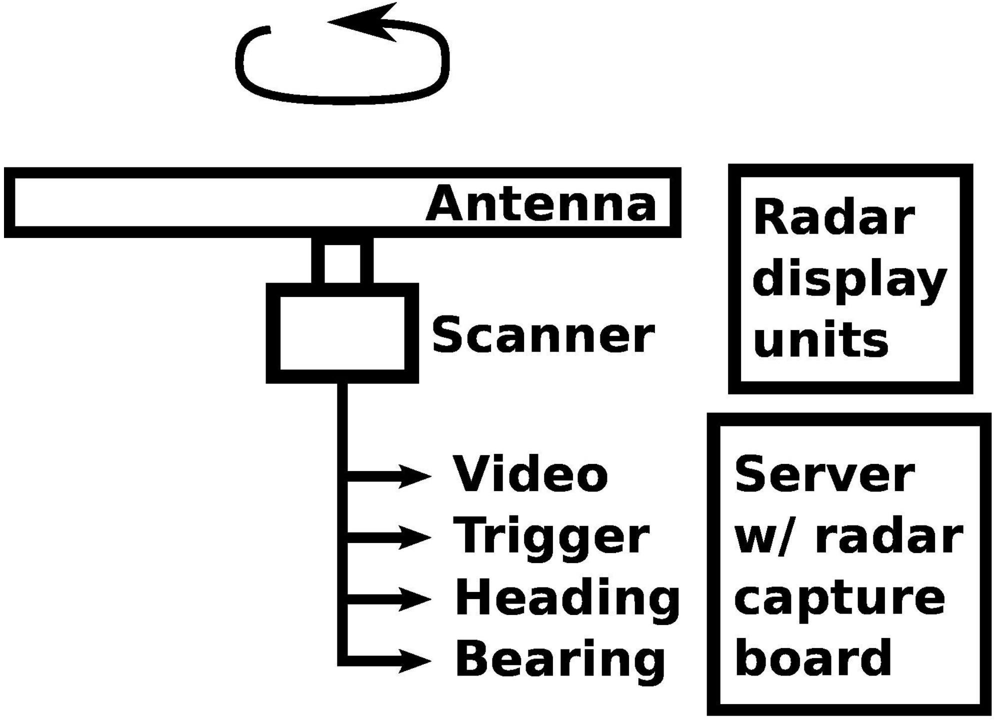
Routine near-surface current and shallow-water bathymetry mapping capabilities for research vessels with science marine X-band radars

Björn Lund, Neil J. Williams, and Hans C. Graber

University of Miami

Science Marine X-band Radar Basics

Sources: gemrad.com, sperrymarine.com



Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

OceanWaves

SeaDarQ NORTEK

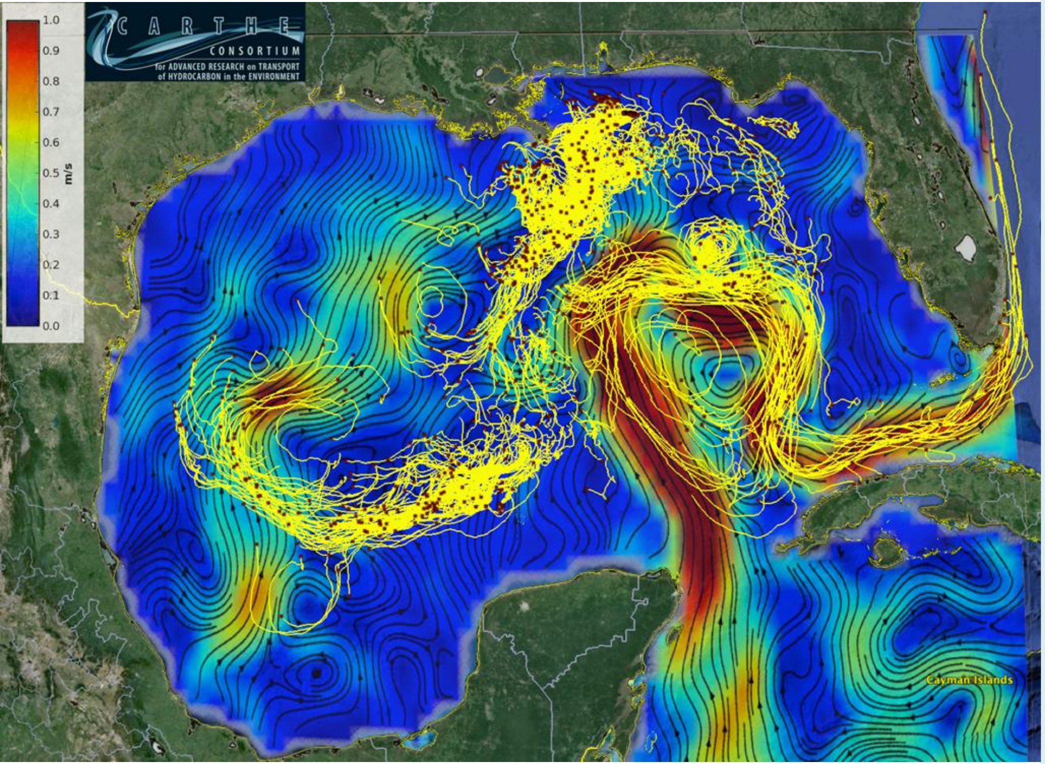

R/V Sikuliaq
SIKULIAQ

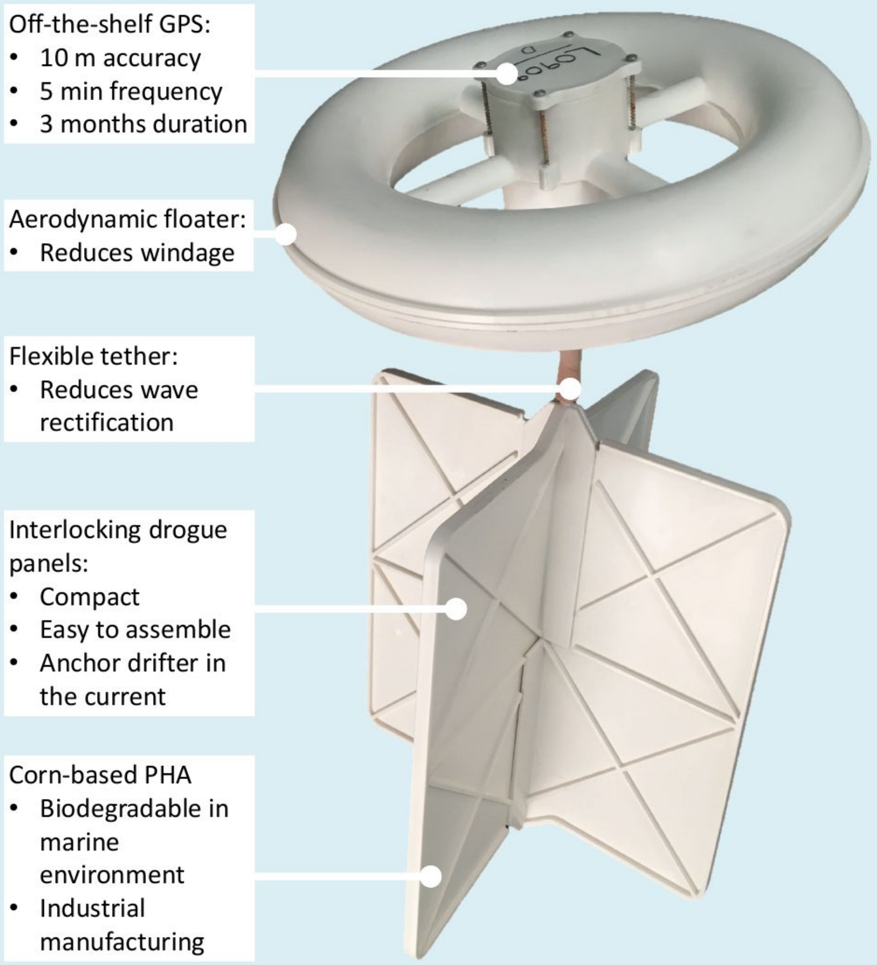

R/V Roger Revelle


R/V Neil Armstrong


R/V Oceanus

LASER Experiment





Novelli et al. (2017)

LASER drifter
U.S. Provisional Patent No. 62/369,593

Sources: carthe.org/blog, greenwaveinstruments.com

Science Marine X-band Radar Specs

- 9.4 GHz (X-band)
- 2.3 m HH polarized antenna
- 12.5 m antenna height
- 2 s antenna period
- 2 kHz pulse frequency
- 10.5 m range resolution
- Coherent on receive
- Developed at HZG

Marine Radar "Calibration"

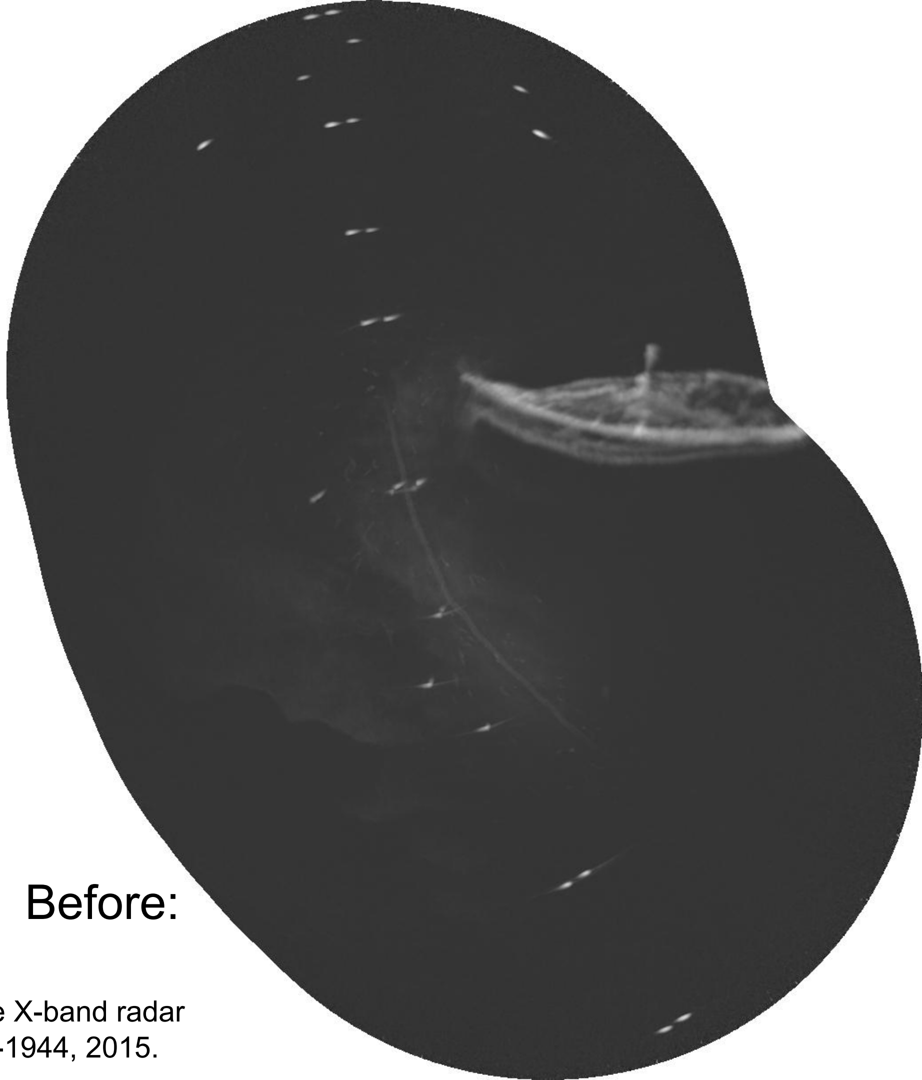
Maximize contrast of land targets by iteratively correcting:

- Azimuthal misalignment (−2.92°)
- Range offset (−15 m)
- Temporal offset (0 s)

Following McCann & Bell, 2018.

Slight heading offsets lead to significant errors in current estimates' across-track component (Lund et al., 2015).

Before:



B. Lund, H. C. Graber, K. Hessner, and N. J. Williams. On shipboard marine X-band radar near-surface current "calibration". J. Atmos. Oceanic Technol., 32(10):1928-1944, 2015.

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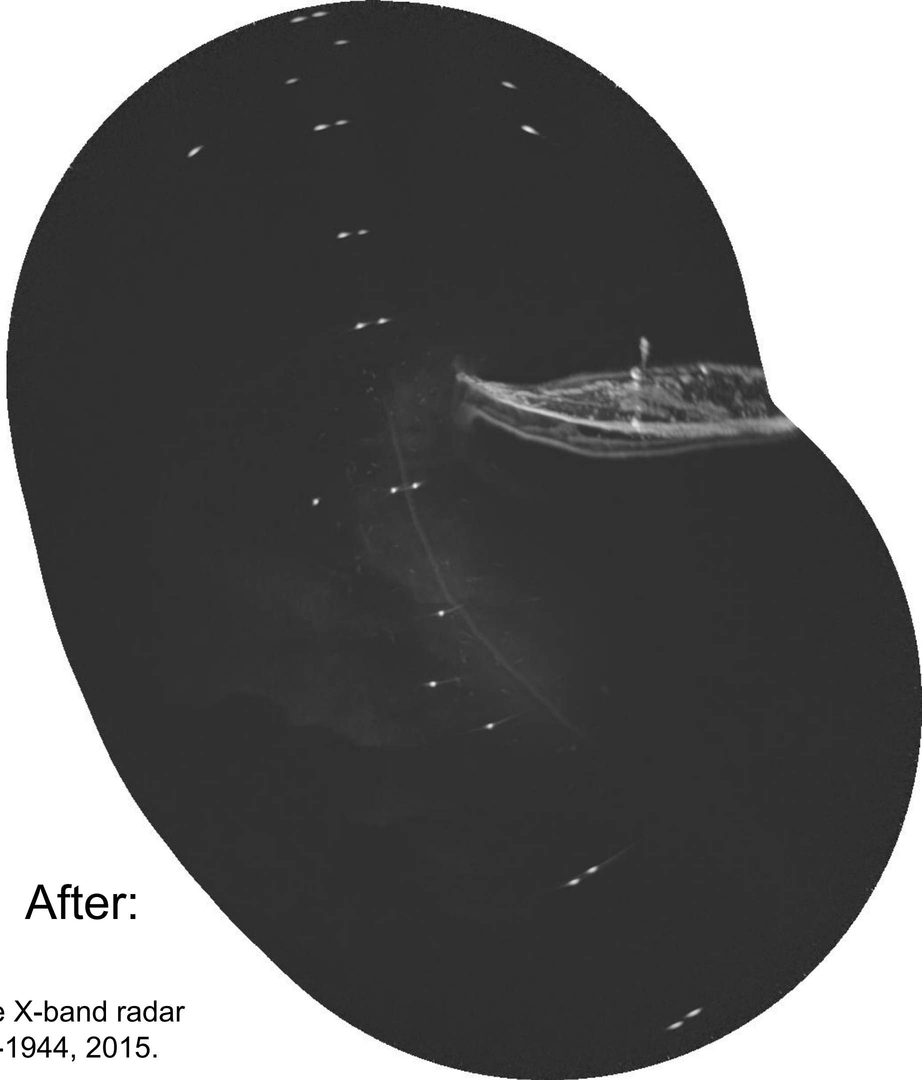
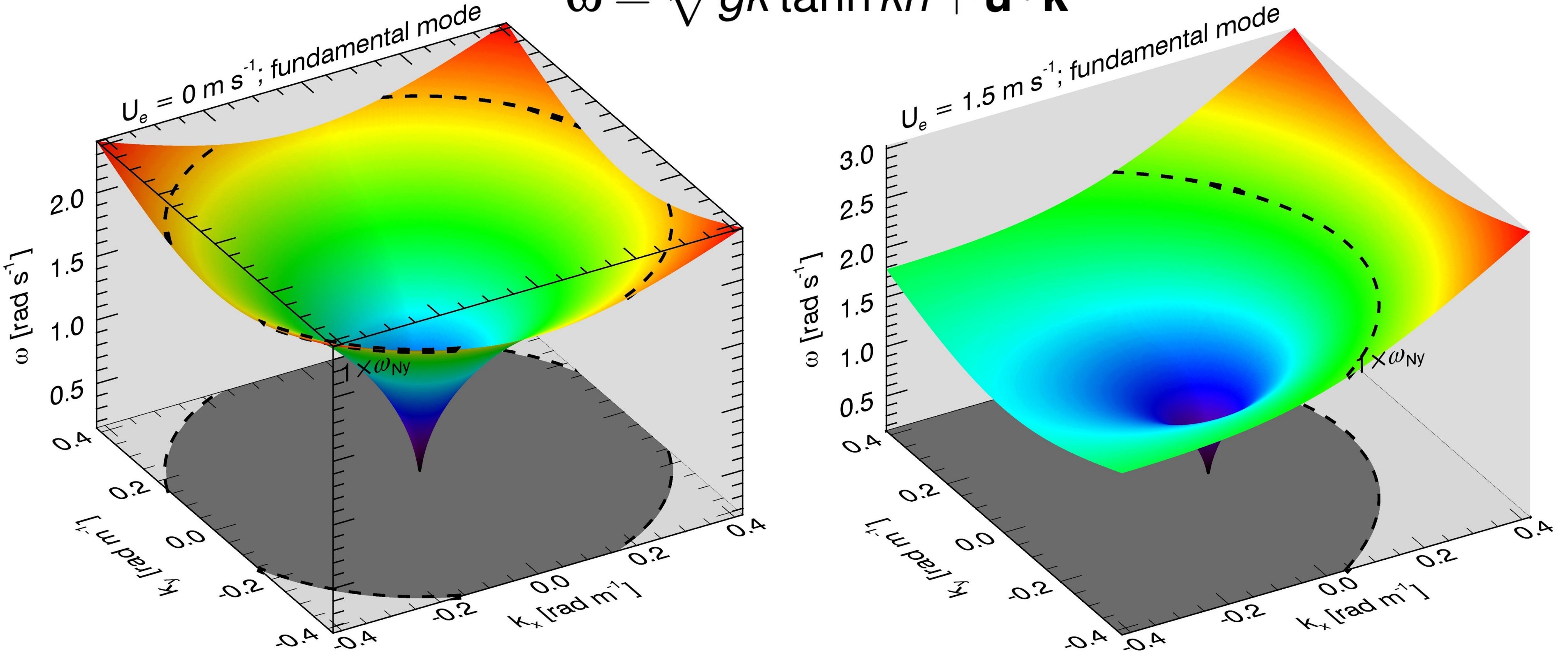
After:



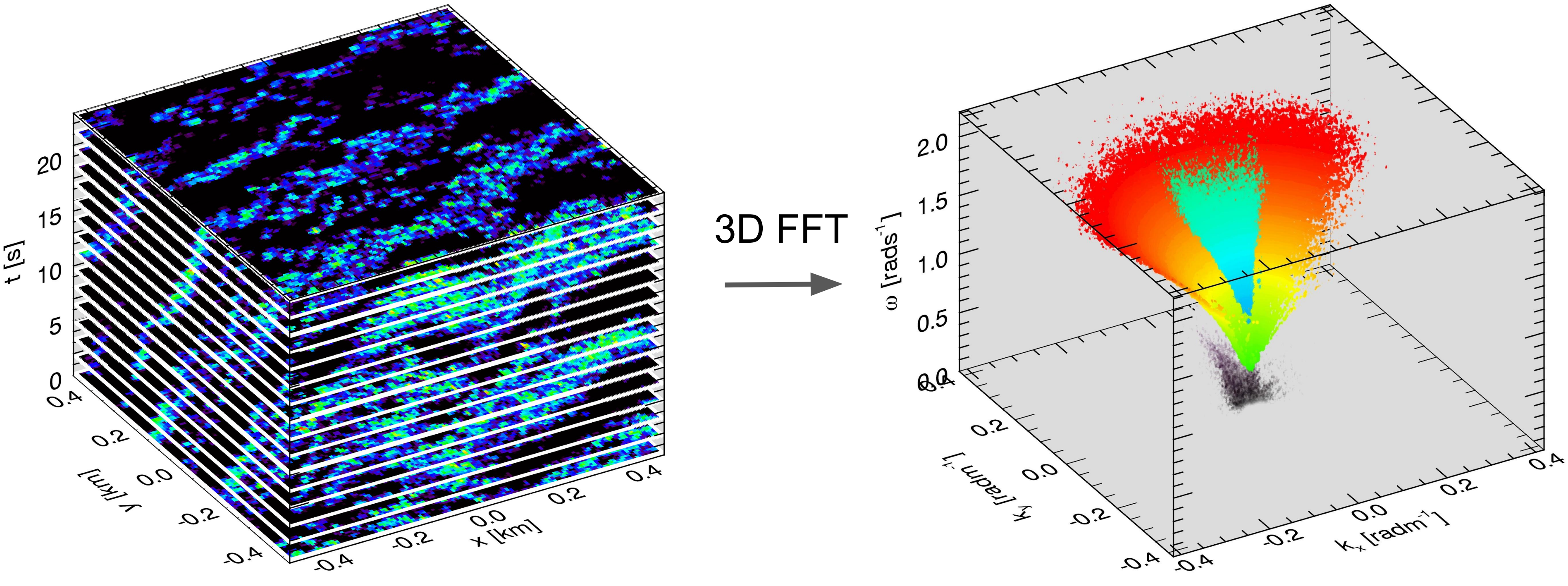
B. Lund, H. C. Graber, K. Hessner, and N. J. Williams. On shipboard marine X-band radar near-surface current “calibration”. J. Atmos. Oceanic Technol., 32(10):1928-1944, 2015.

Near-surface Current Retrieval Basics

$$\omega = \sqrt{gk \tanh kh} + \mathbf{u} \cdot \mathbf{k}$$



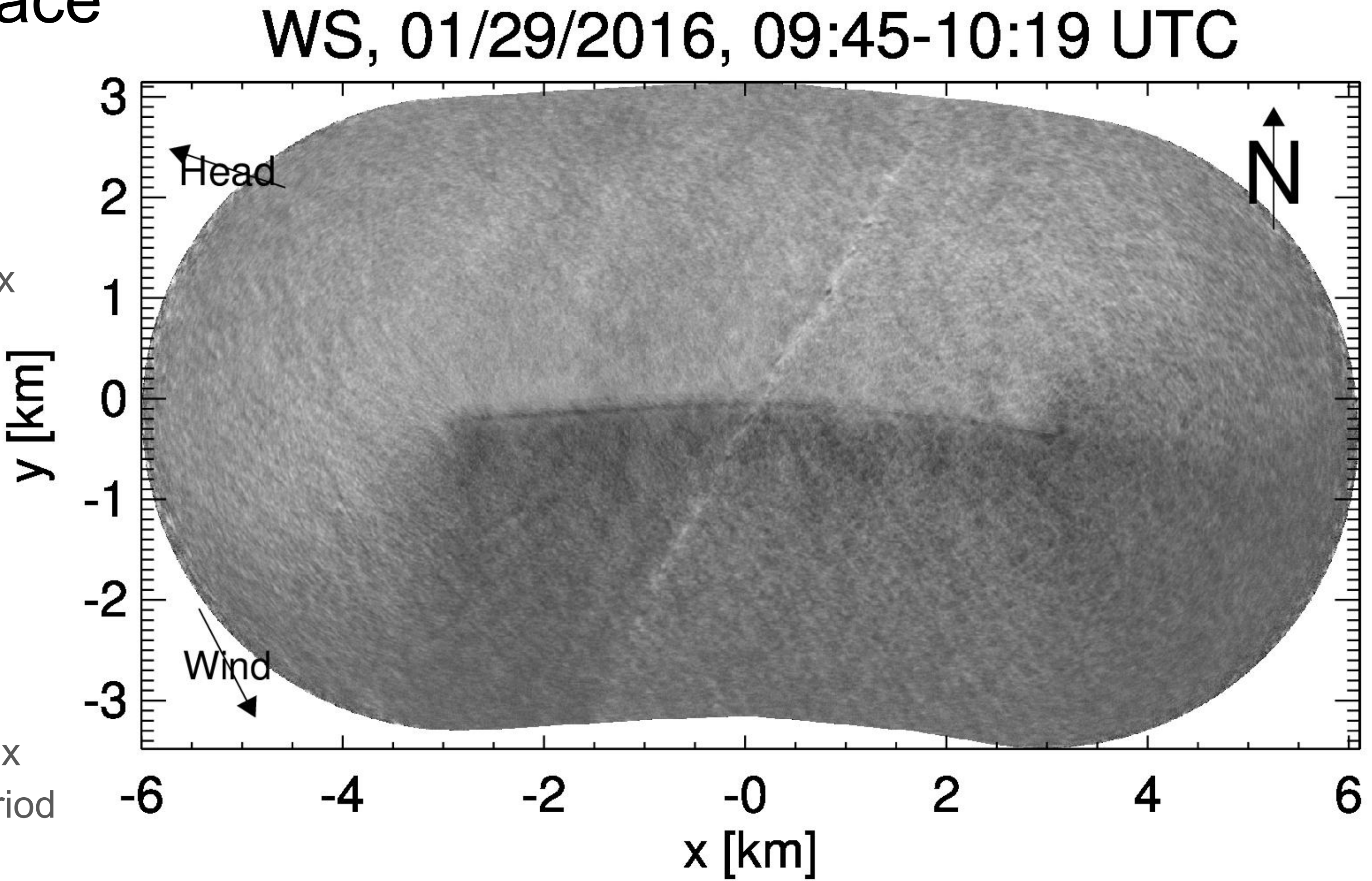
Near-surface Current Retrieval Basics



Young et al. (1985), Senet et al. (2001)

Near-surface Current Retrieval

- Analysis box radius of 476.25 m (~0.7 km^2)
- 40% max overlap between neighboring boxes
- ~30 min max analysis period



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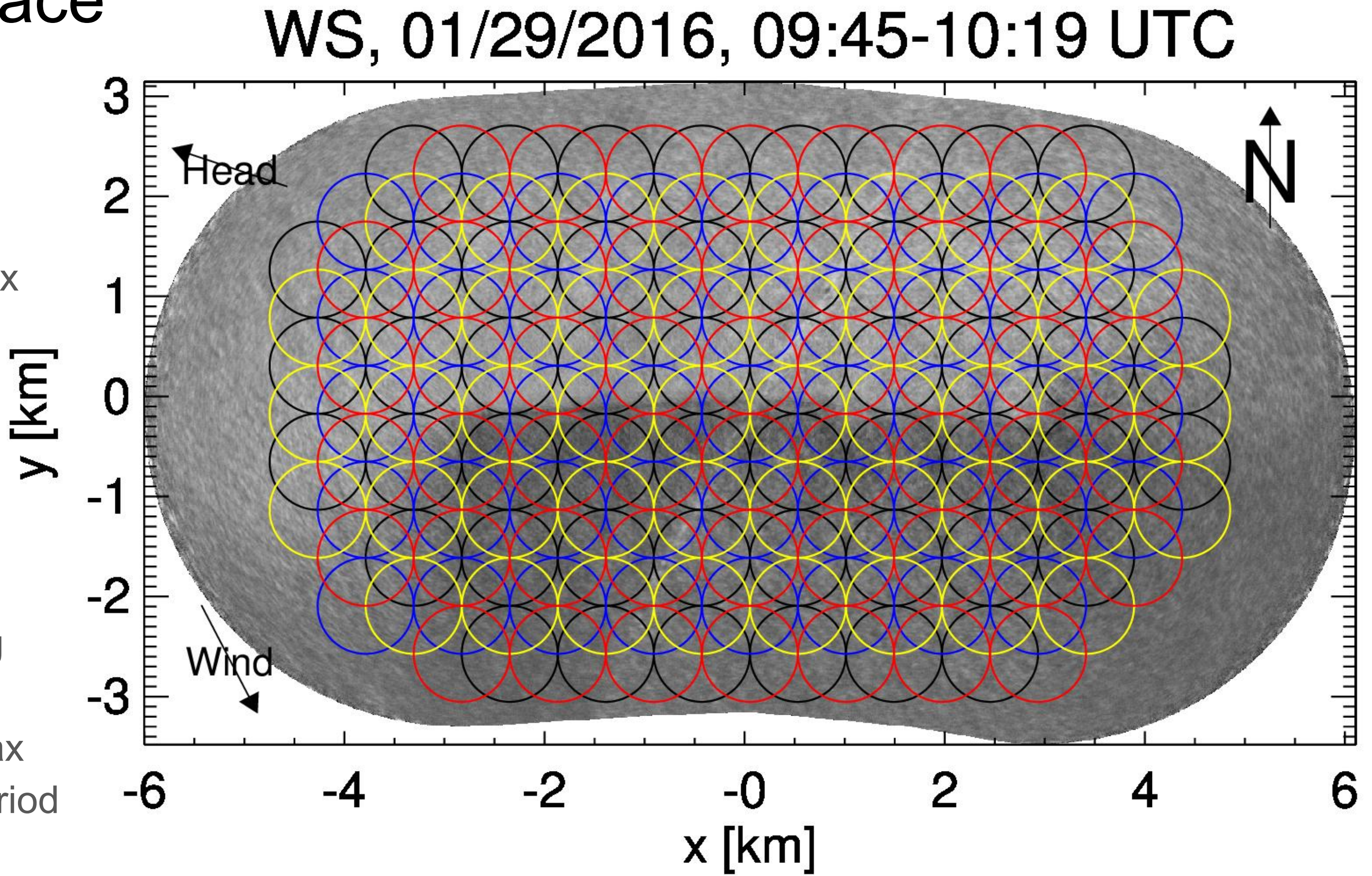
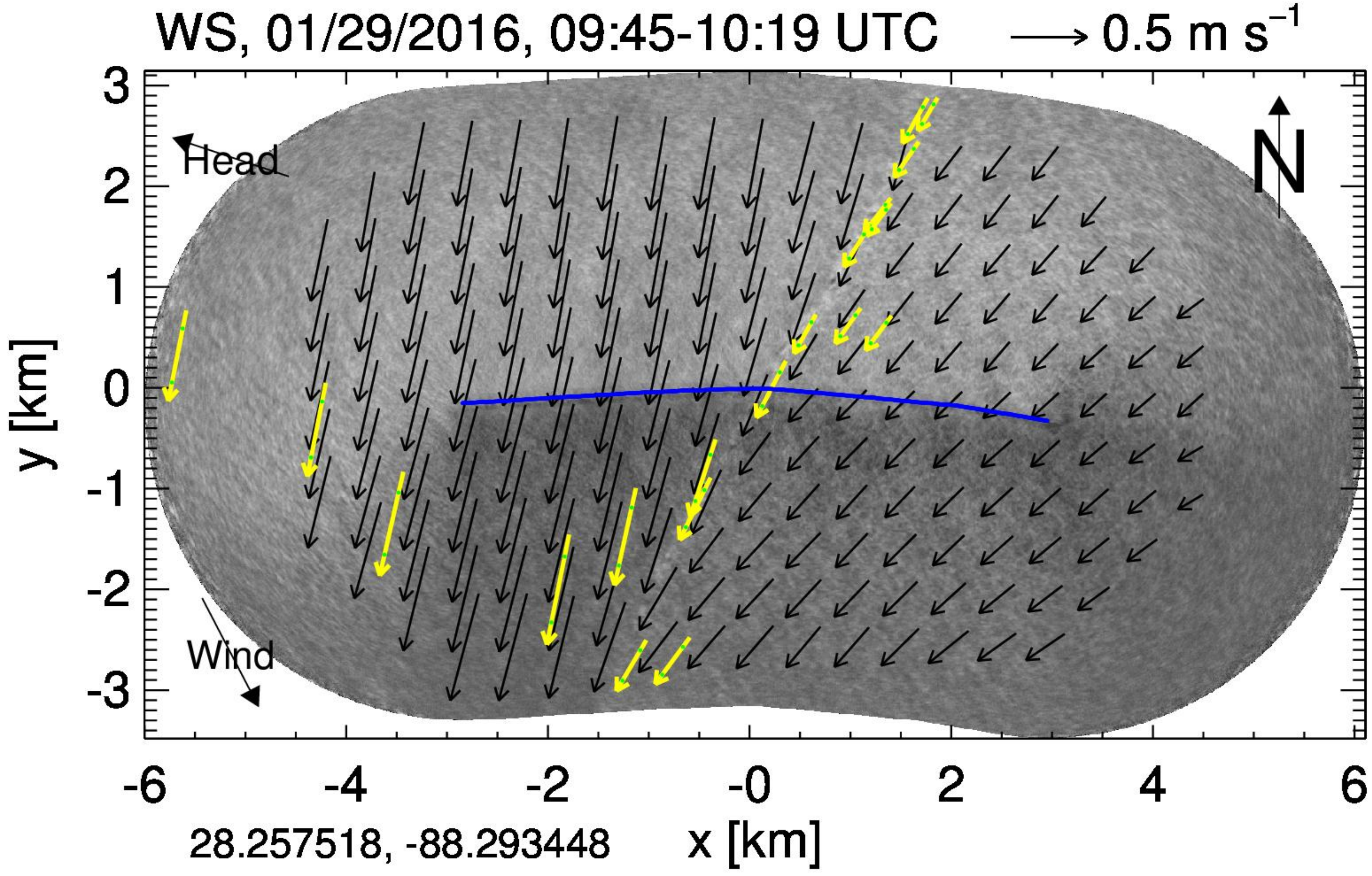




WS, 01/29/2016, 09:45-10:19 UTC
0.5 m s⁻¹
N
Head
Wind
3
2
1
0
-1
-2
-3
y [km]
-6
-4
-2
-0
2
4
6
x [km]
28.257518, -88.293448

Radar–Drifter Comparison

Analysis periods (with gaps):

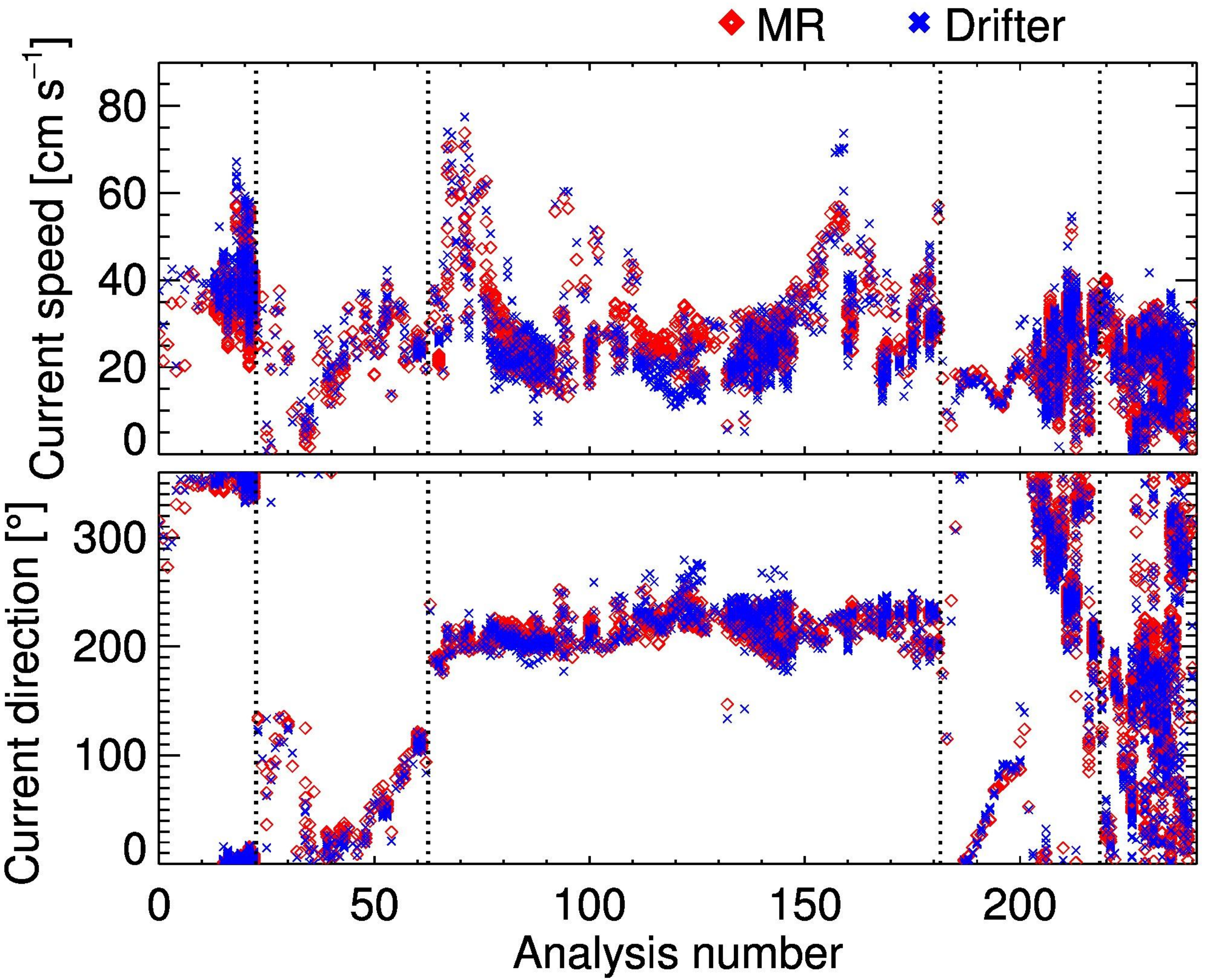
(1) 01/20, 16:00 UTC-
01/21, 19:00 UTC

(2) 01/25, 17:00 UTC-
01/26, 22:00 UTC

(3) 01/28, 17:00 UTC-
02/01, 13:00 UTC

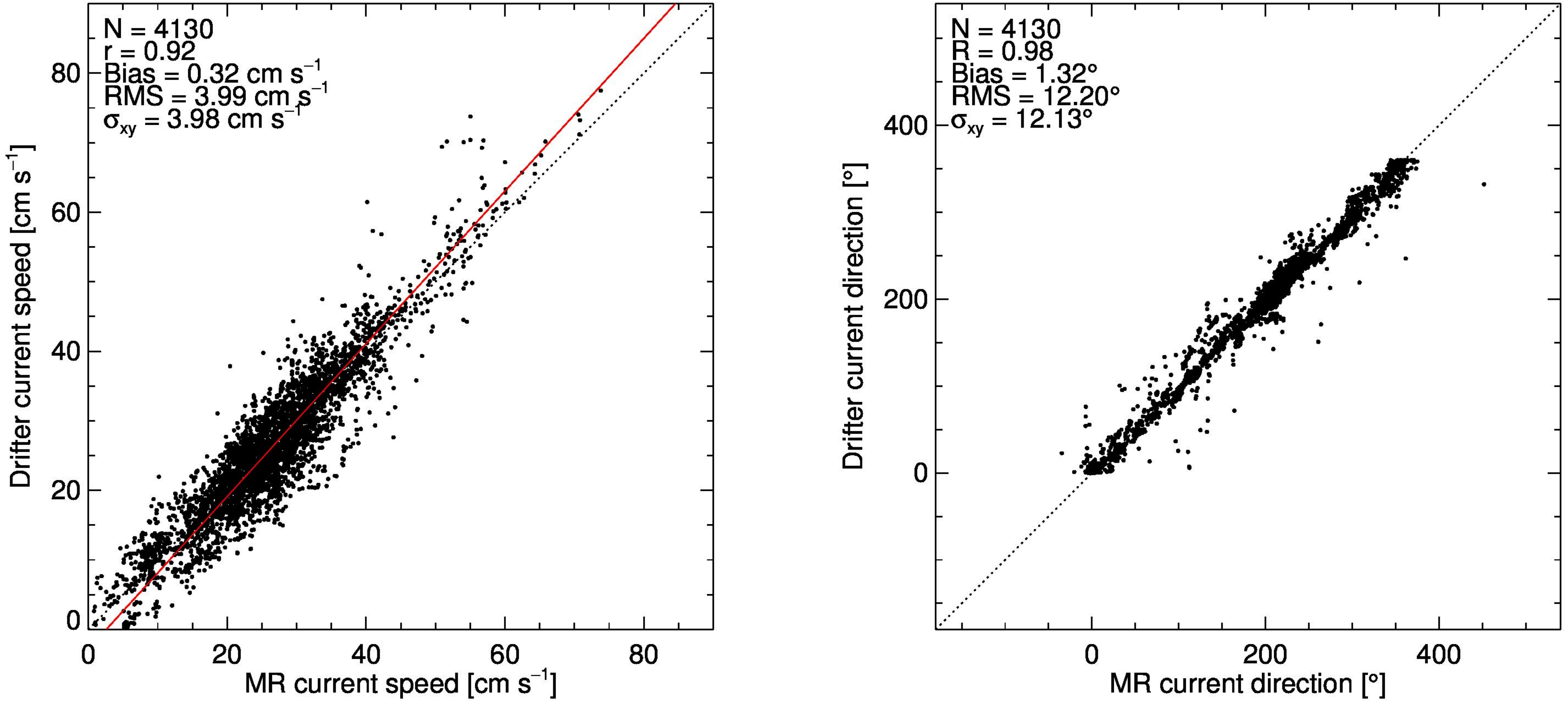
(4) 02/06, 06:00 UTC-
02/07, 21:00 UTC

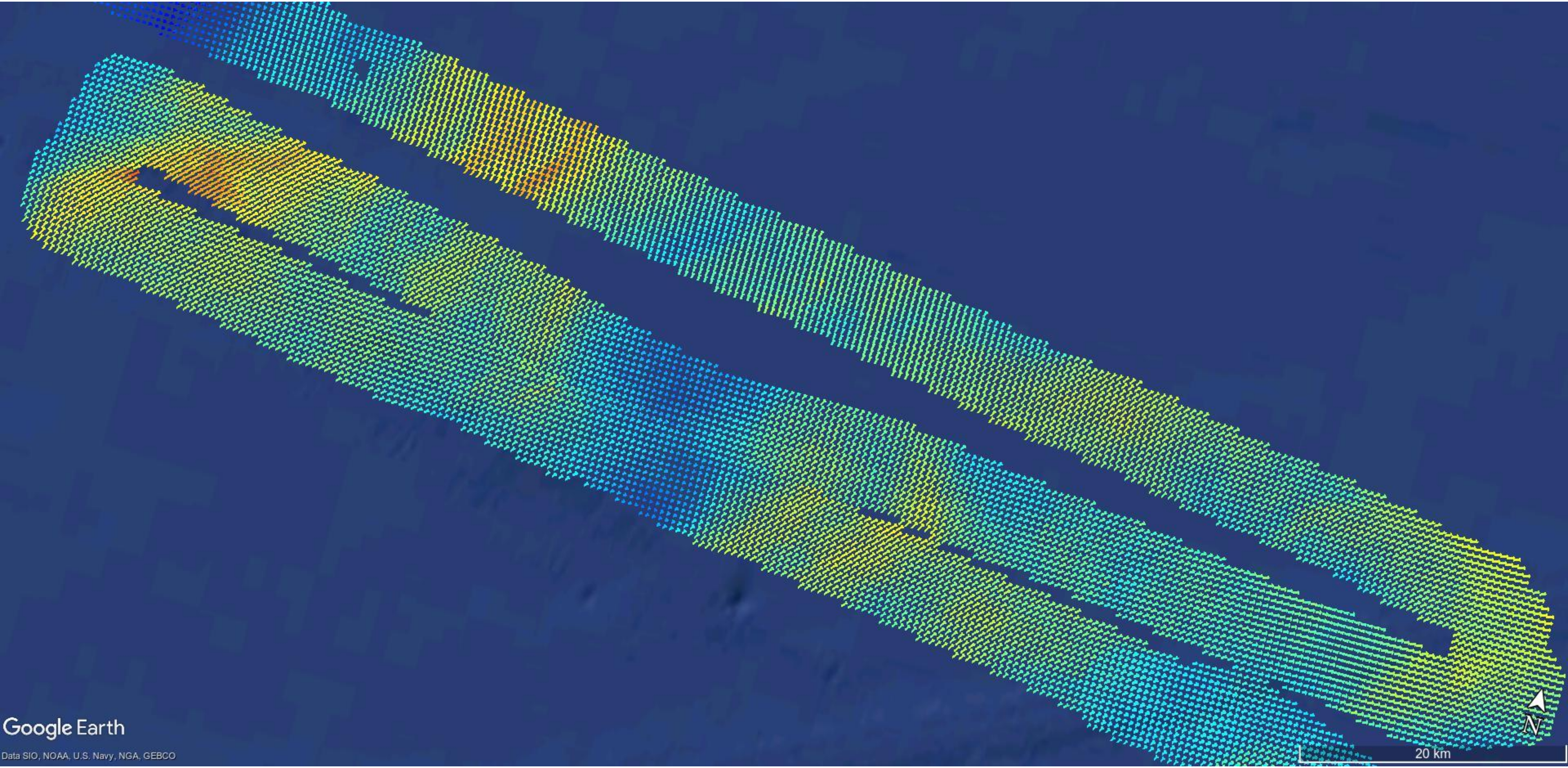
(5) 02/10, 22:00 UTC-
02/12, 19:00 UTC

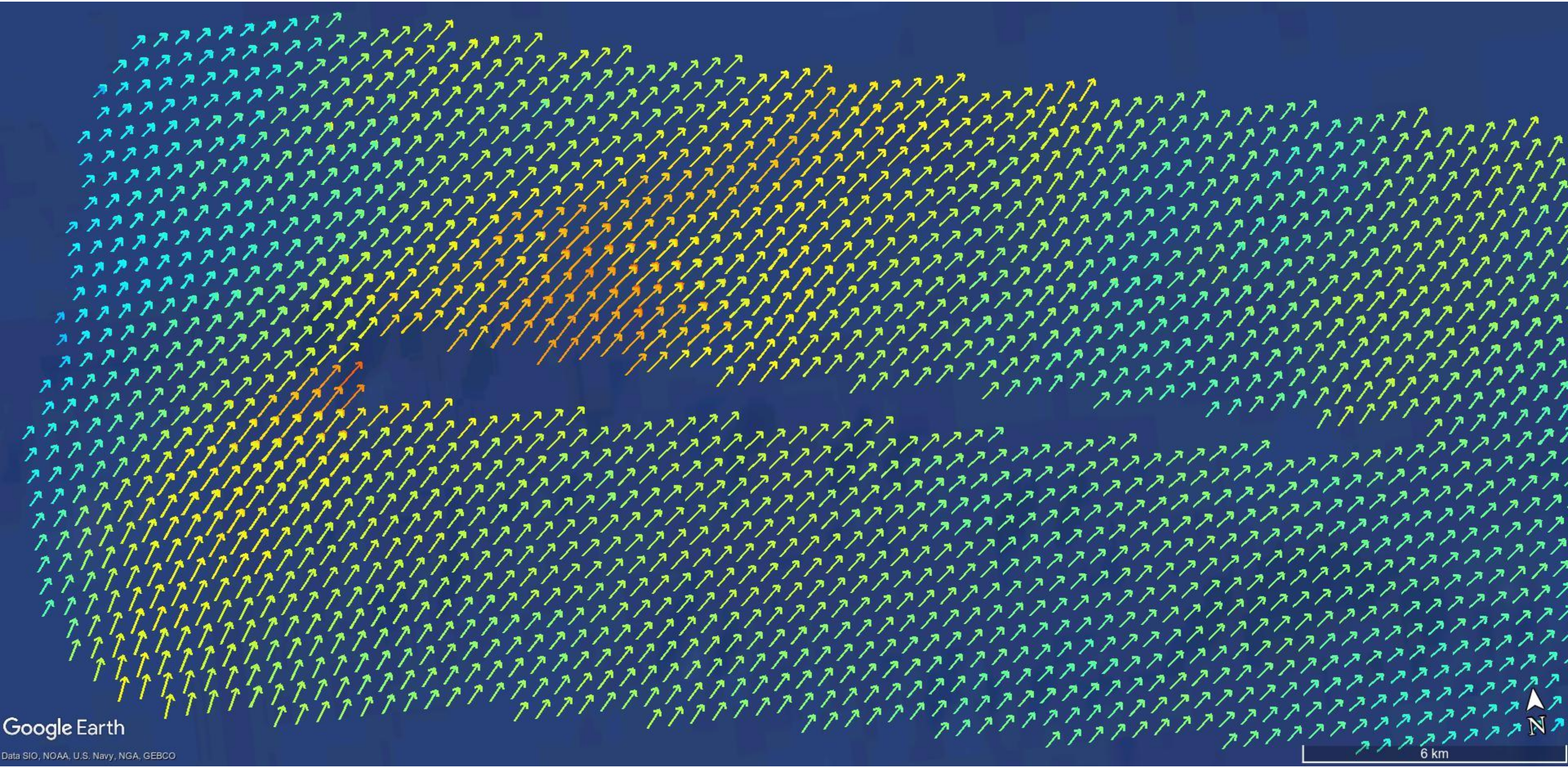


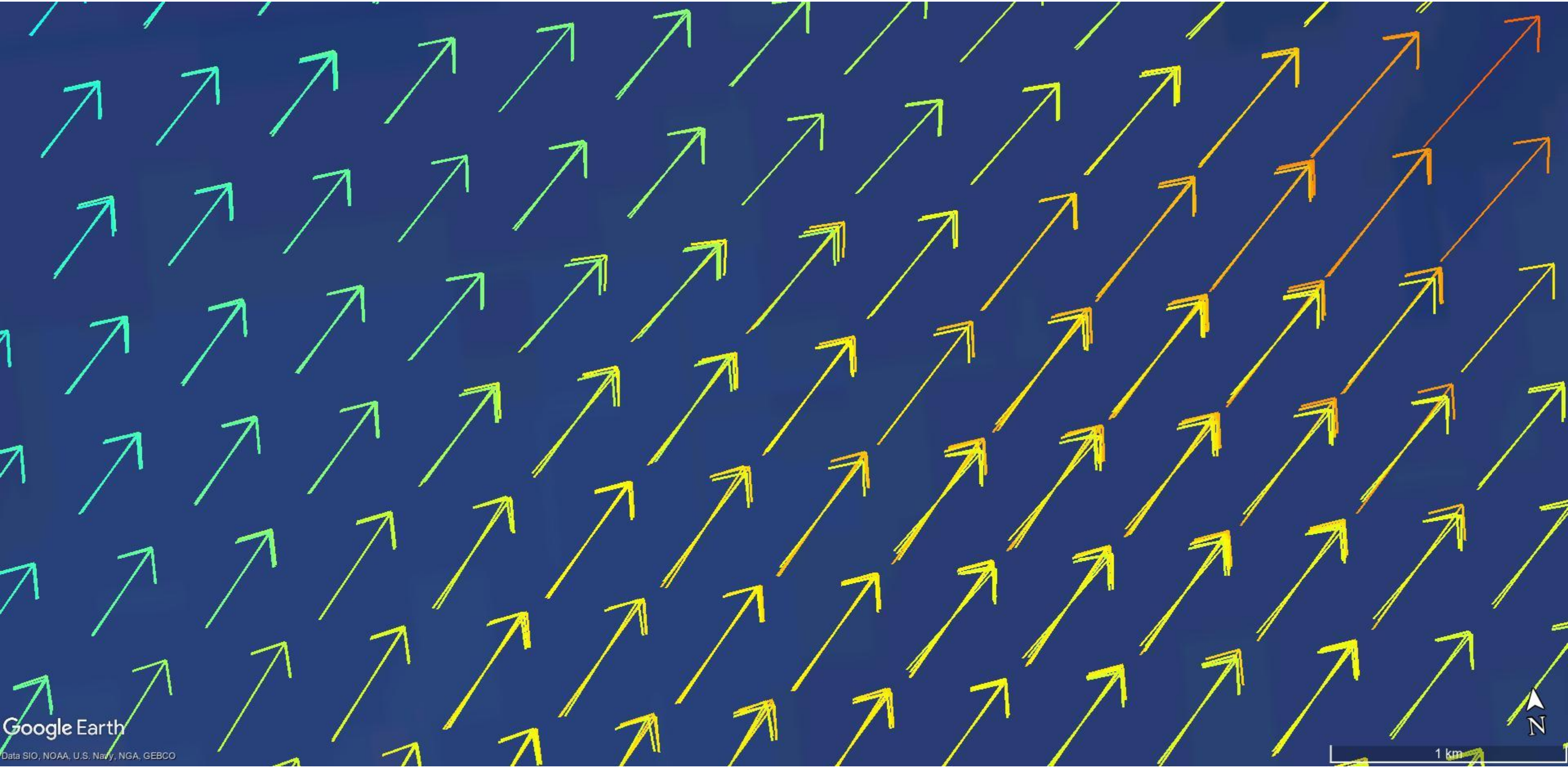
Radar–Drifter Comparison

B. Lund, B. K. Haus, J. Horstmann, H. C. Graber, R. Carrasco, N. J. M. Laxague, G. Novelli, C. M. Guigand, and T. M. Özgökmen. Near-surface current mapping by shipboard marine X-band radar: A validation. J. Atmos. Oceanic Technol., 2018.

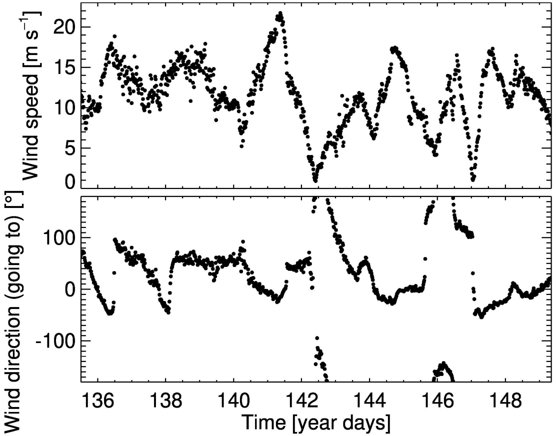


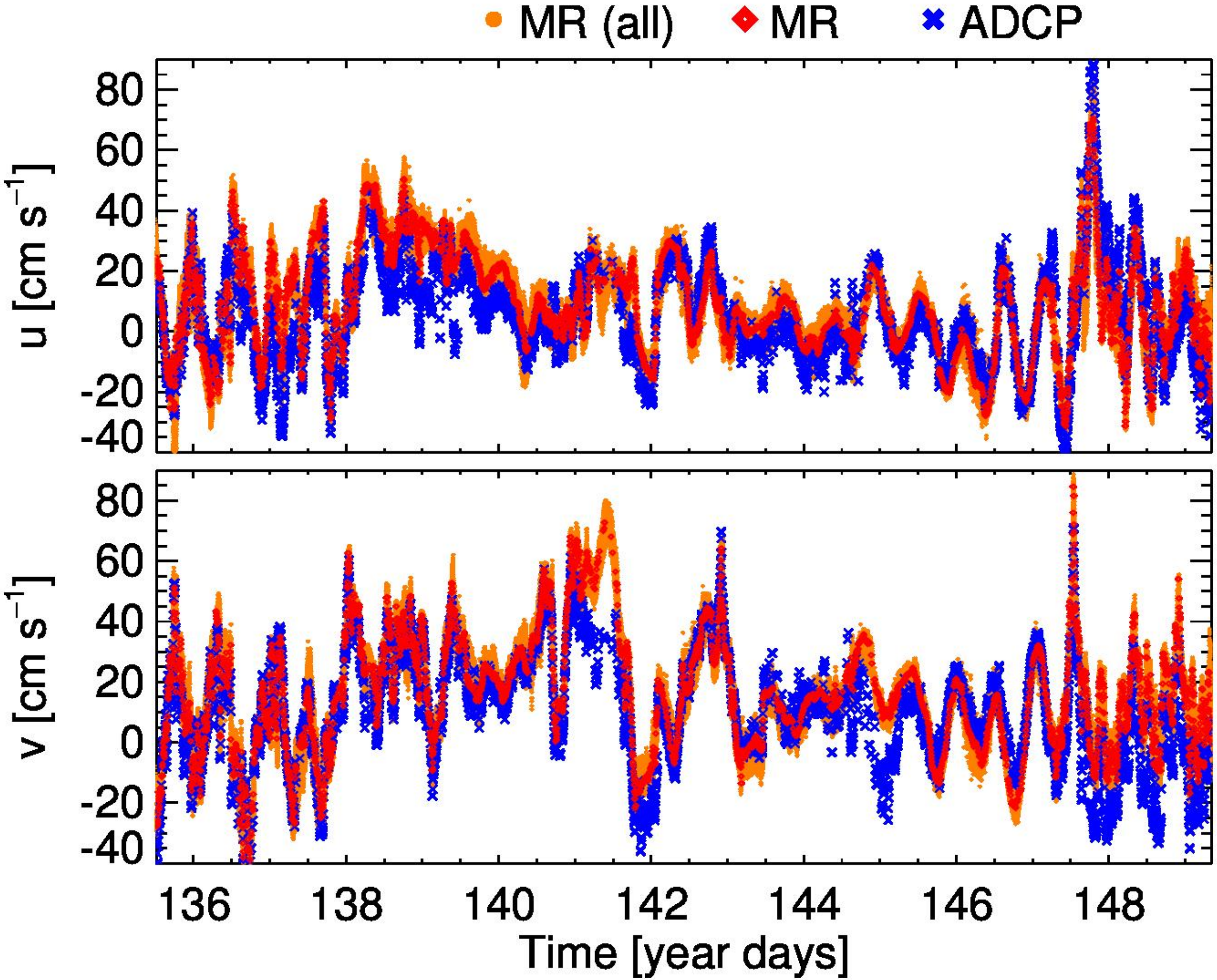

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
20 km
N


Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
6 km
N

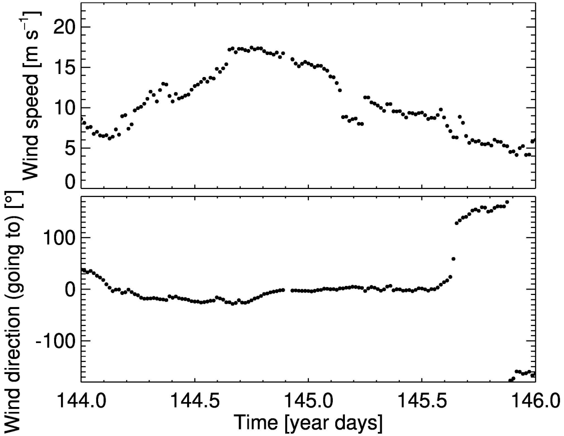

Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
1 km
N

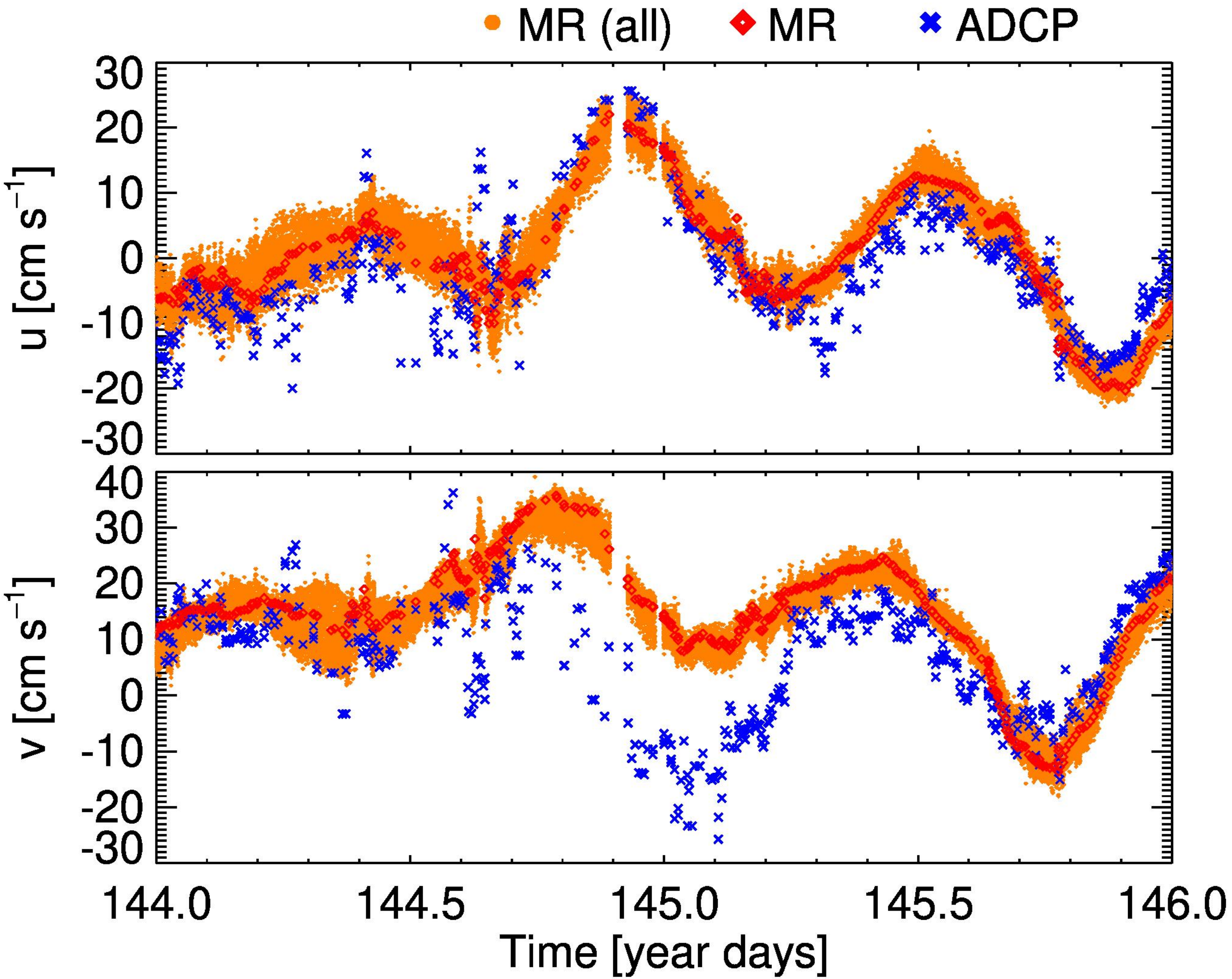
Radar-ADCP Comparison



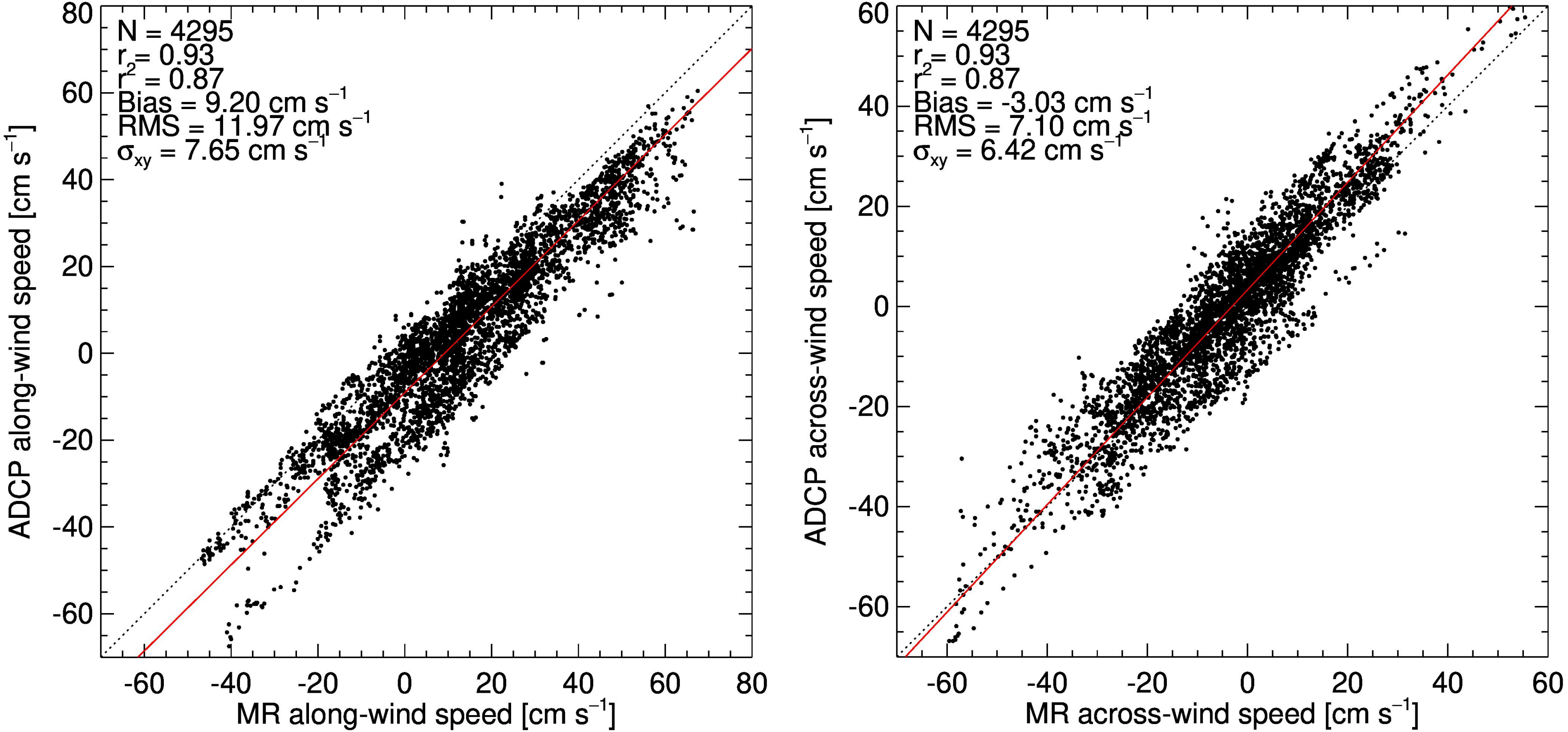


Radar-ADCP Comparison





Radar-ADCP Comparison



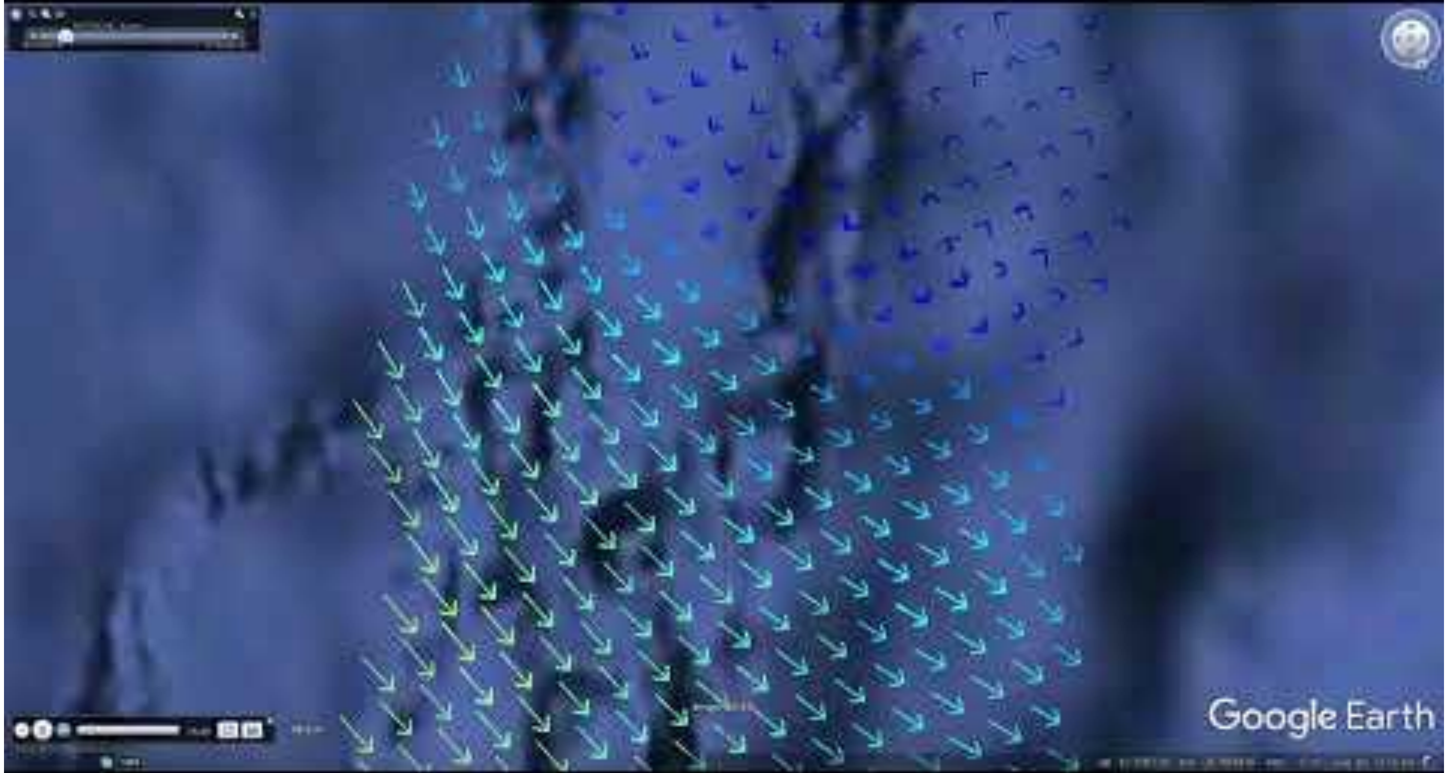
Shipboard Science Marine X-band Radar

Challenges

- Proprietary radar raw data formats
- High radar raw data volumes of 0.5-2 TB/day
- High accuracy auxiliary heading and position measurements required
- Radar data must be calibrated for heading offsets
- Complexity and computational cost of scientific radar analysis
- Display, quality control, access, and interpretation of results
- Raw data archiving and sharing

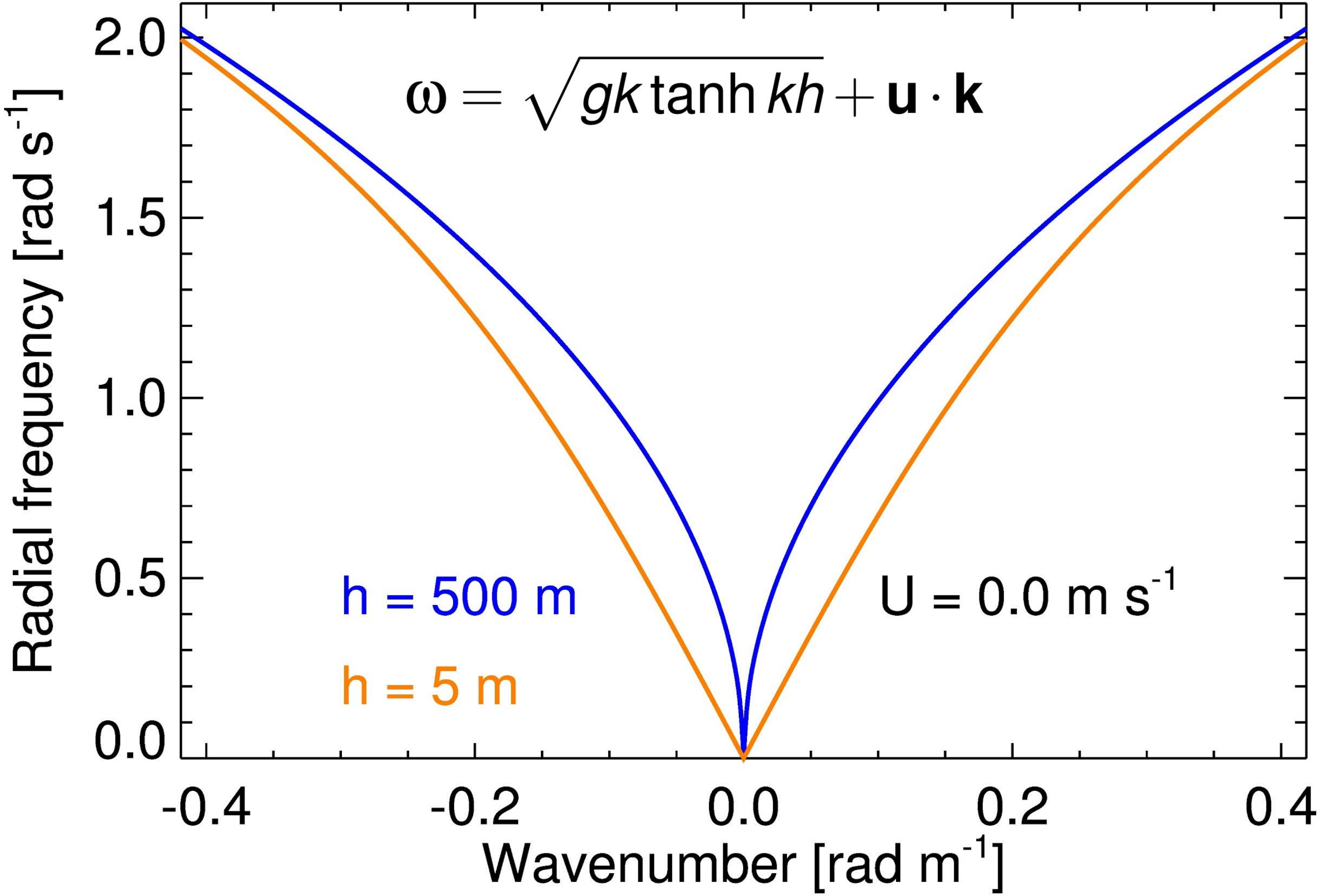
Benefits

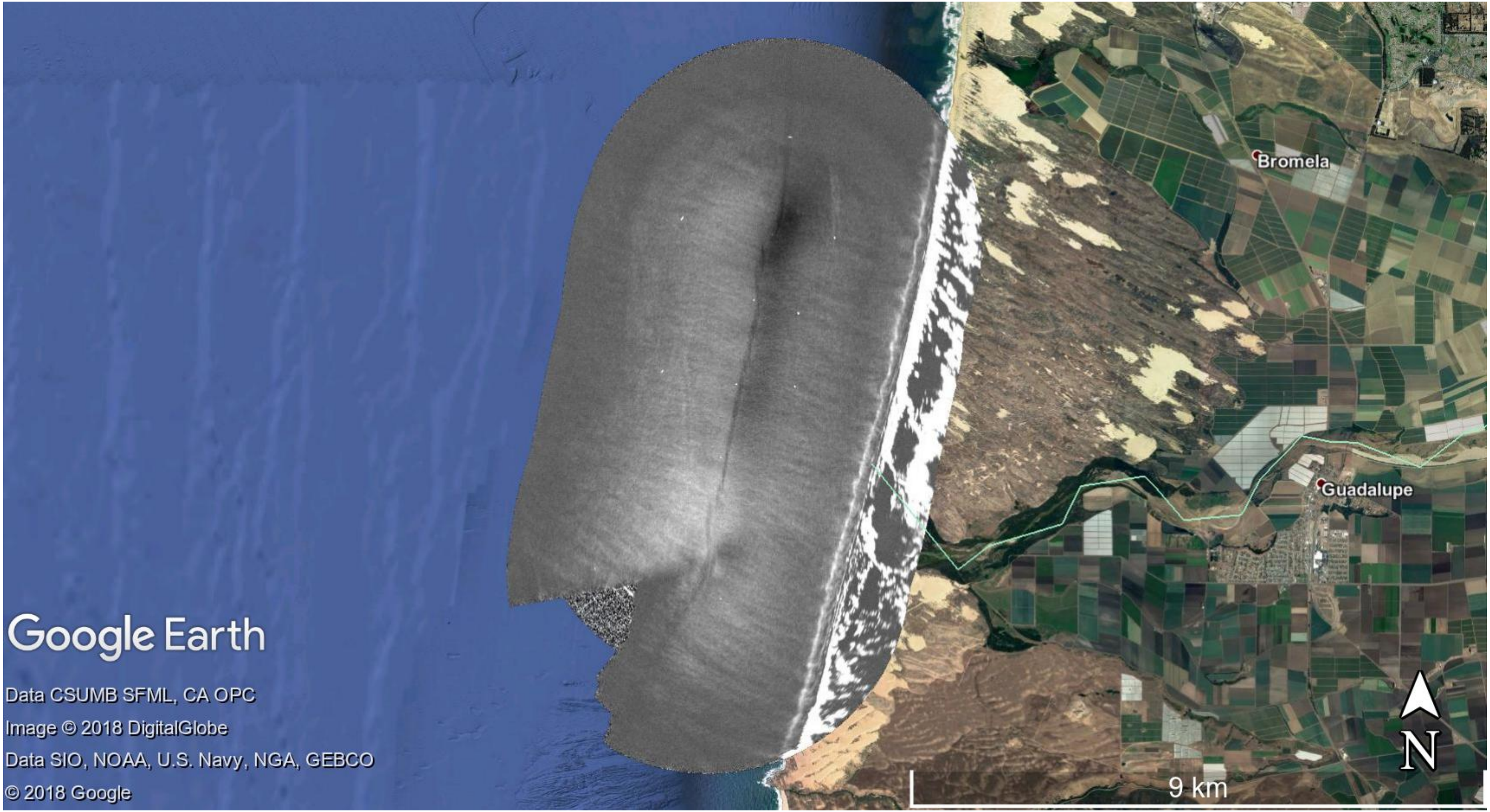
- Science products: Sea surface roughness images, surface wave spectra, sea ice drift maps, near-surface current maps, shallow-water bathymetry, …
- Improved ship and science operations
- Complement shipboard ADCPs by focusing on upper ocean and providing spatial perspective
- Near-surface current maps provide unique opportunity to study submesoscale upper ocean dynamics and air–sea interaction

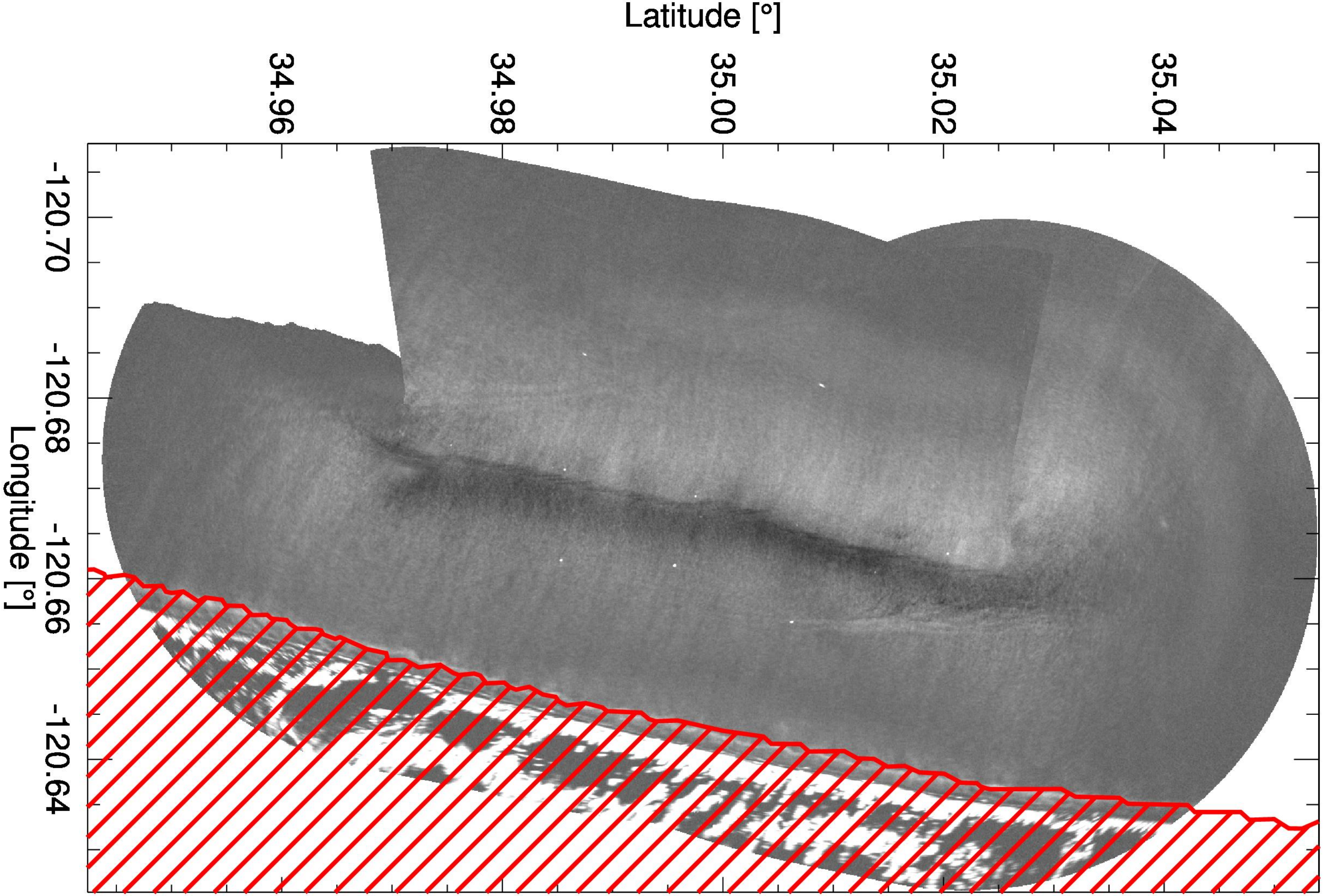

Google Earth

MR Depth Retrieval Basics

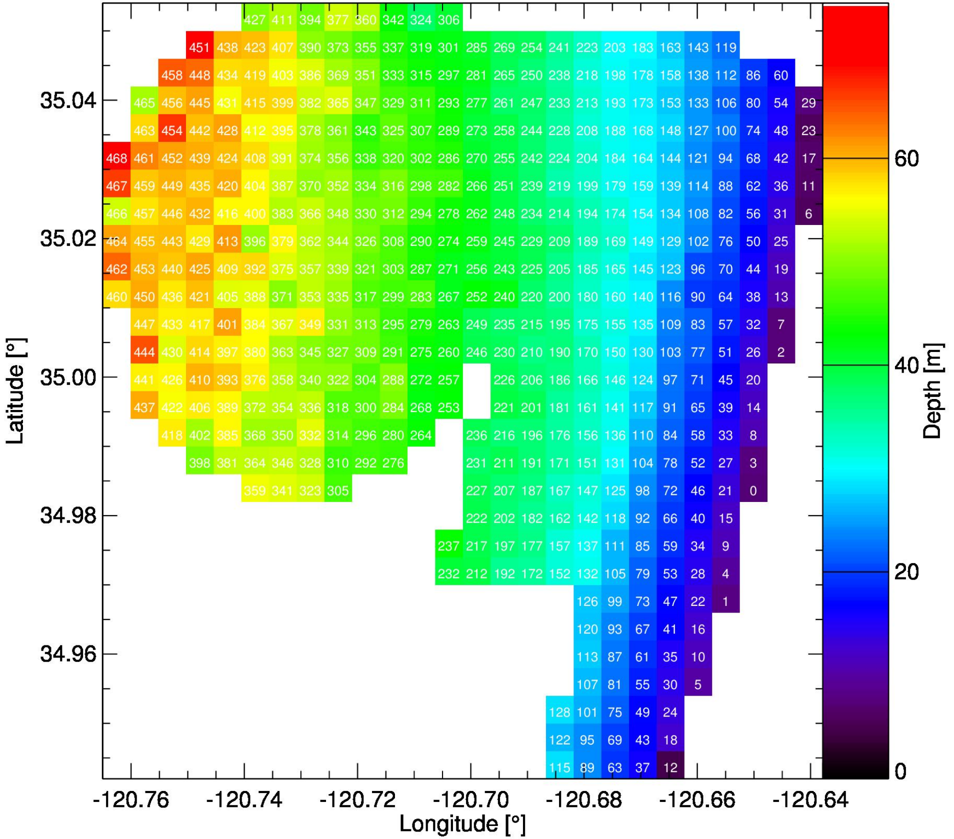
Linear dispersion relationship:



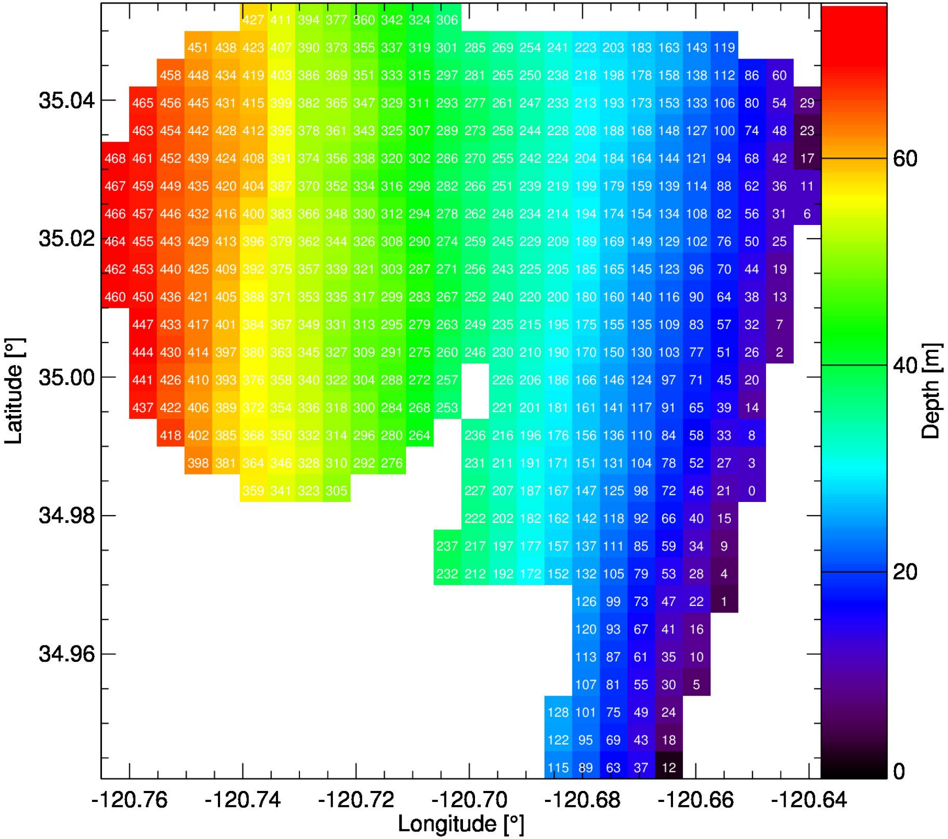

Bromela
Guadalupe
Google Earth
Data CSUMB SFML, CA OPC
Image © 2018 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2018 Google
9 km
N

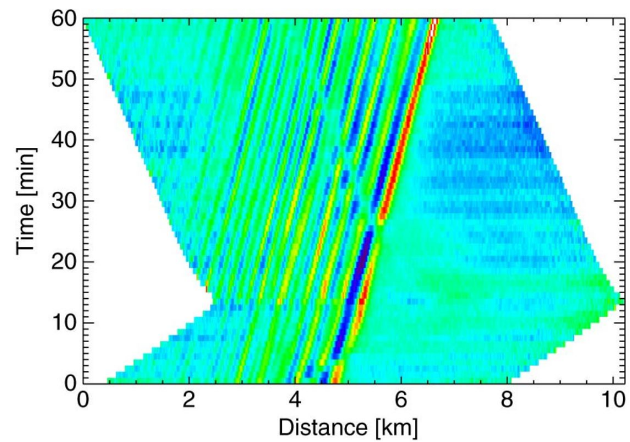

Latitude [°]
34.96
34.98
35.00
35.02
35.04
Longitude [°]
-120.70
-120.68
-120.66
-120.64

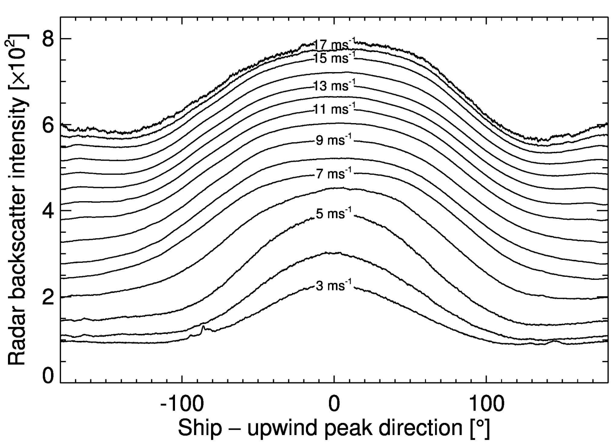
MR-derived bathymetry:

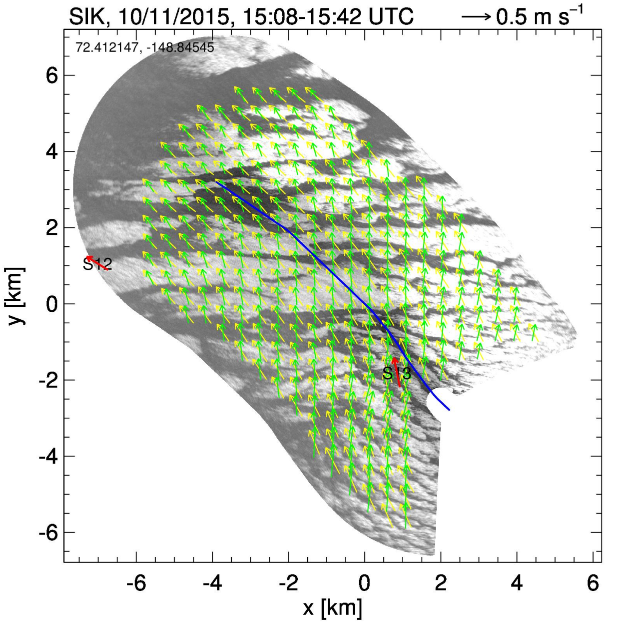


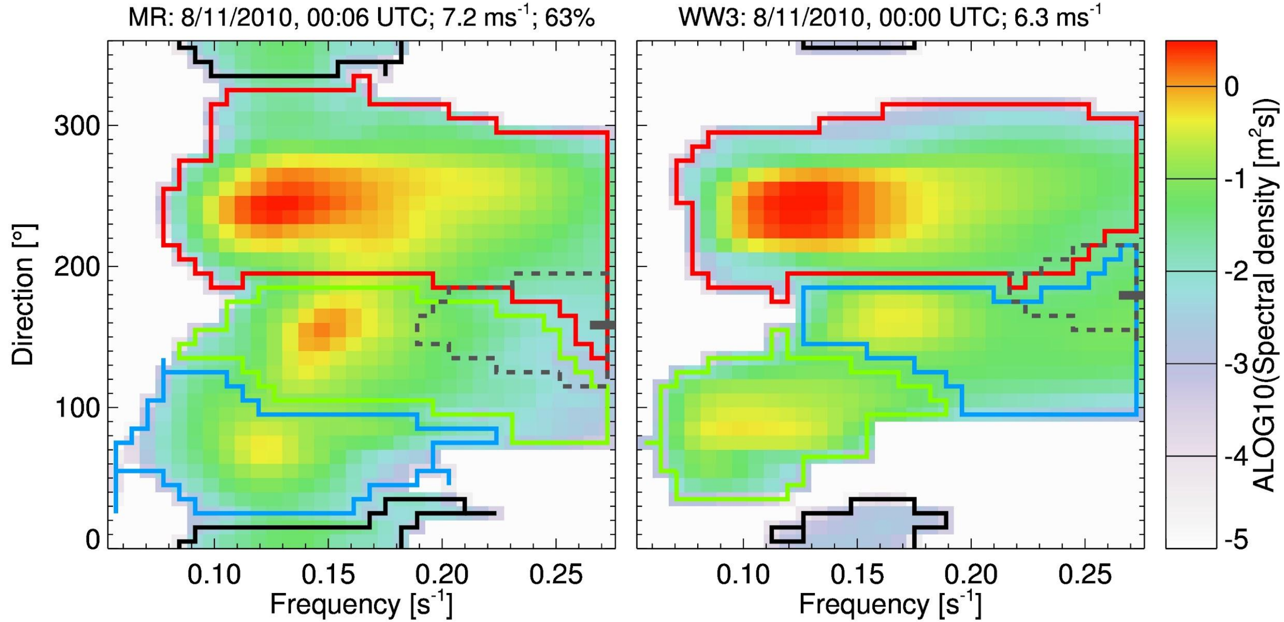
GEBCO bathymetry:

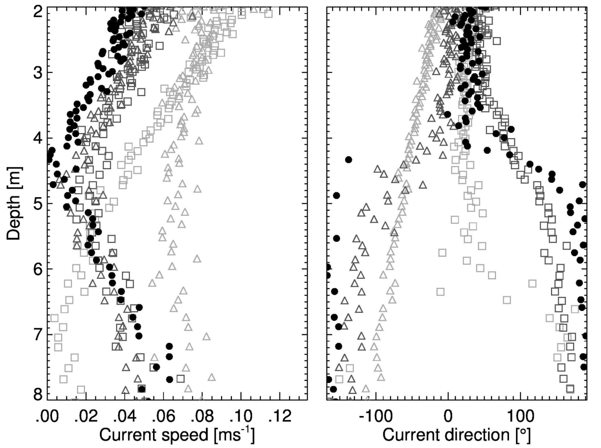



Time [min]
Distance [km]


Radar backscatter intensity [×10²]
Ship – upwind peak direction [°]
17 ms⁻¹
15 ms⁻¹
13 ms⁻¹
11 ms⁻¹
9 ms⁻¹
7 ms⁻¹
5 ms⁻¹
3 ms⁻¹


SIK, 10/11/2015, 15:08-15:42 UTC
→ 0.5 m s⁻¹
72.412147, -148.84545
S12
S13
y [km]
x [km]

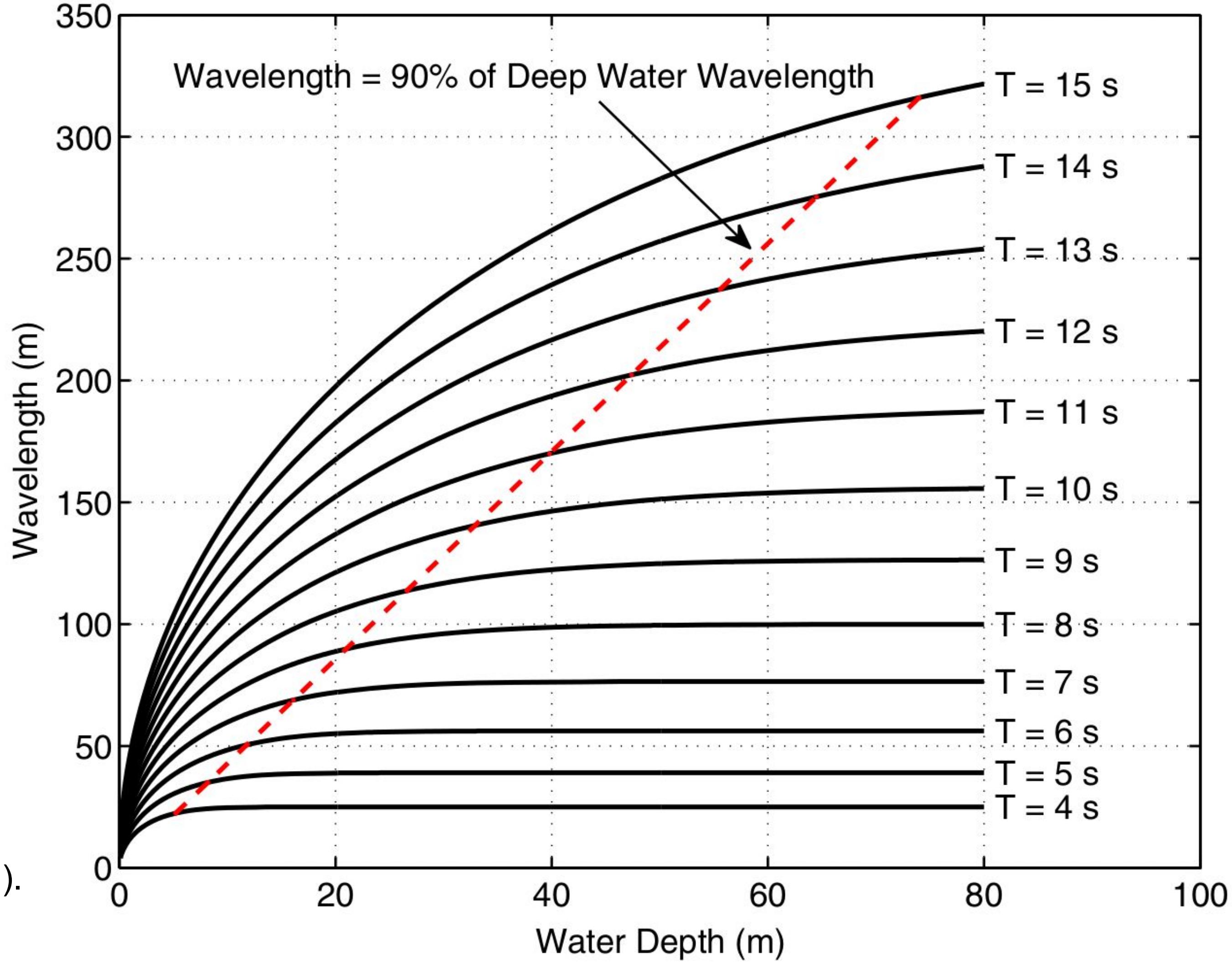

MR: 8/11/2010, 00:06 UTC; 7.2 ms⁻¹; 63%
WW3: 8/11/2010, 00:00 UTC; 6.3 ms⁻¹
Direction [°]
Frequency [s⁻¹]
Frequency [s⁻¹]
ALOG10(Spectral density [m²s])


Depth [m]
Current speed [ms⁻¹]
Current direction [°]

Backup

MR Depth Retrieval Basics

MR sensitivity to bathymetric changes increases with wavelength on which estimate is based.



Source: Bell and Osler (2011).

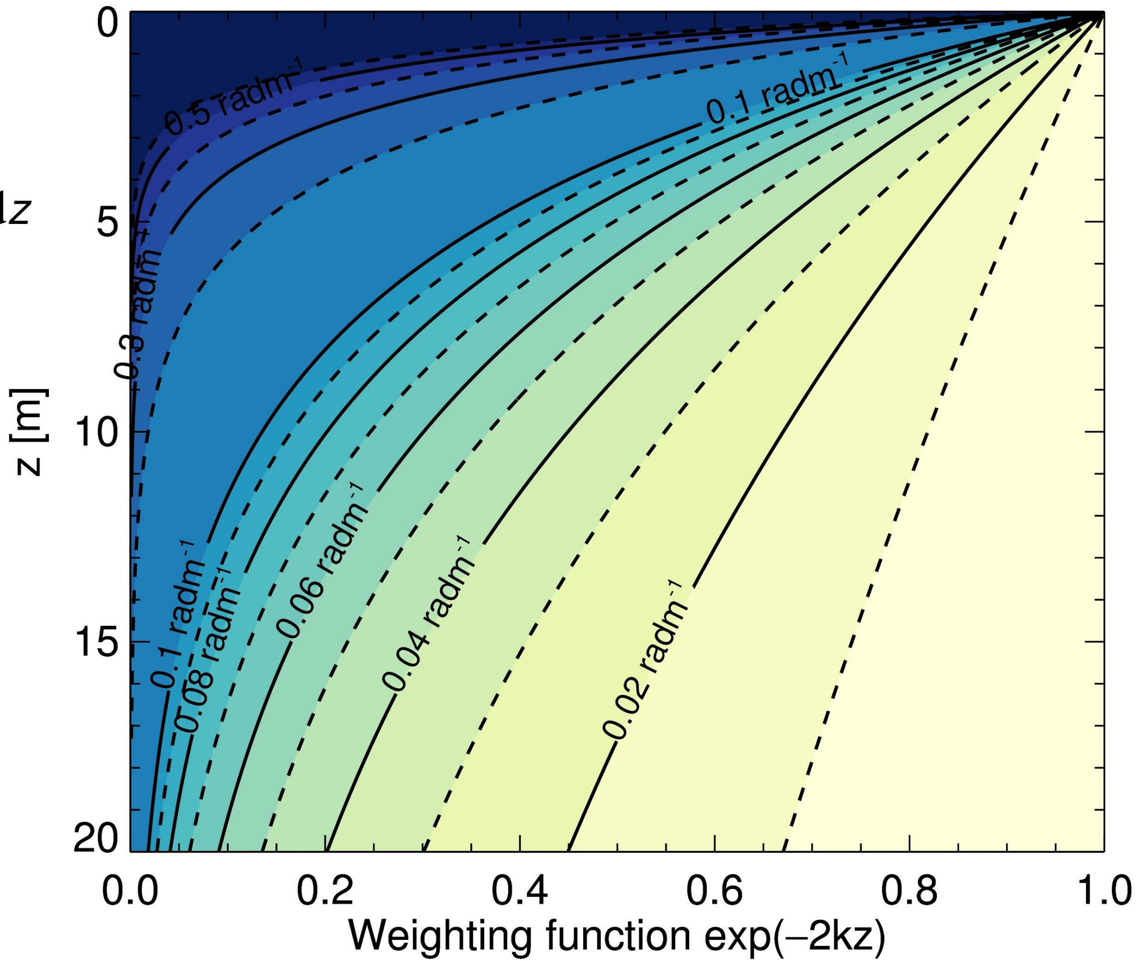
Effective depth

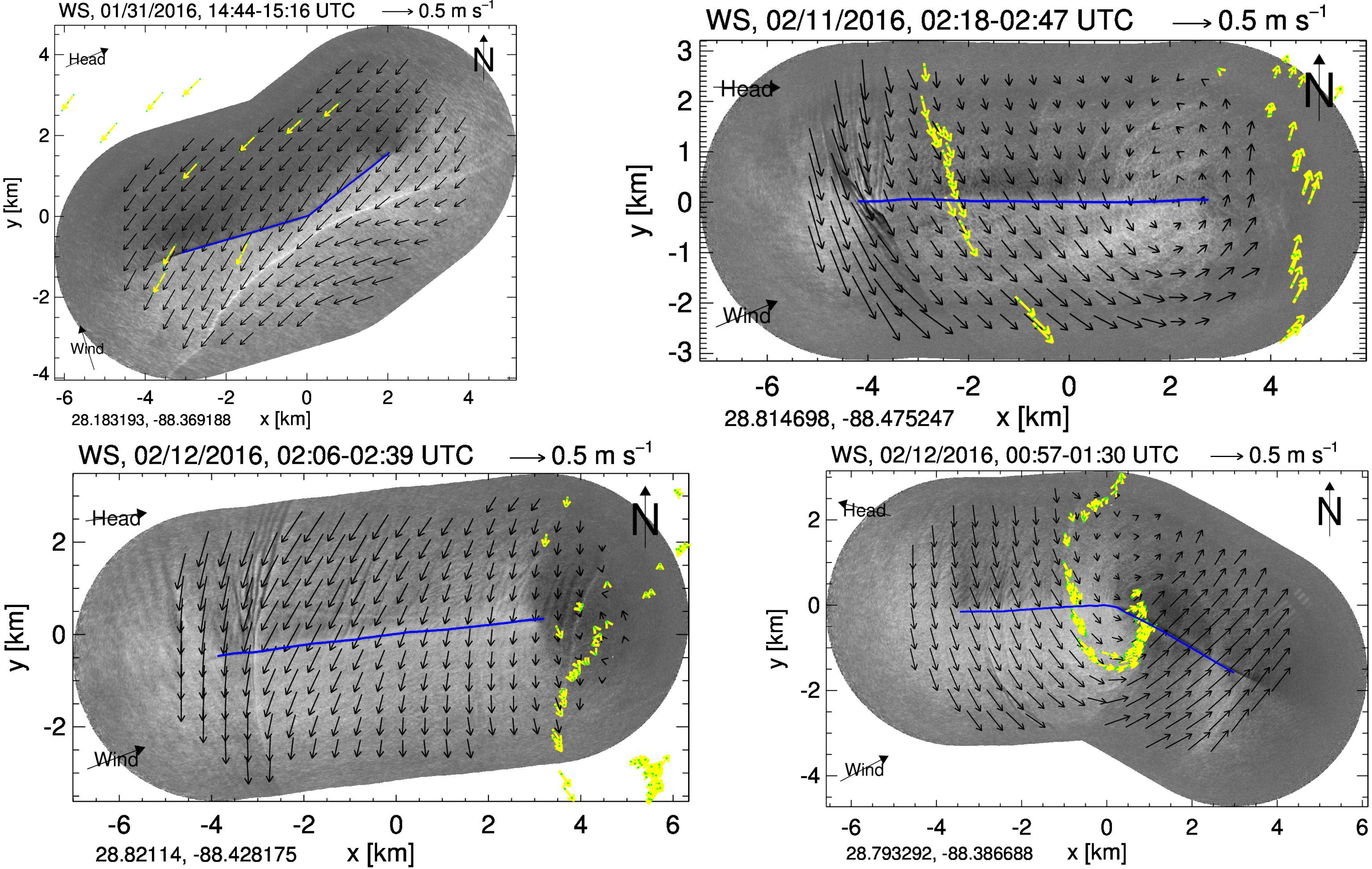
$$\mathbf{U}_E(k_D) = 2k_D \int_0^h \mathbf{U}(z)\exp(-2k_D z)\mathrm{d}z$$

$\mathbf{U}_E$ represents a weighted-mean of the upper ocean currents (Stewart & Joy 1974).

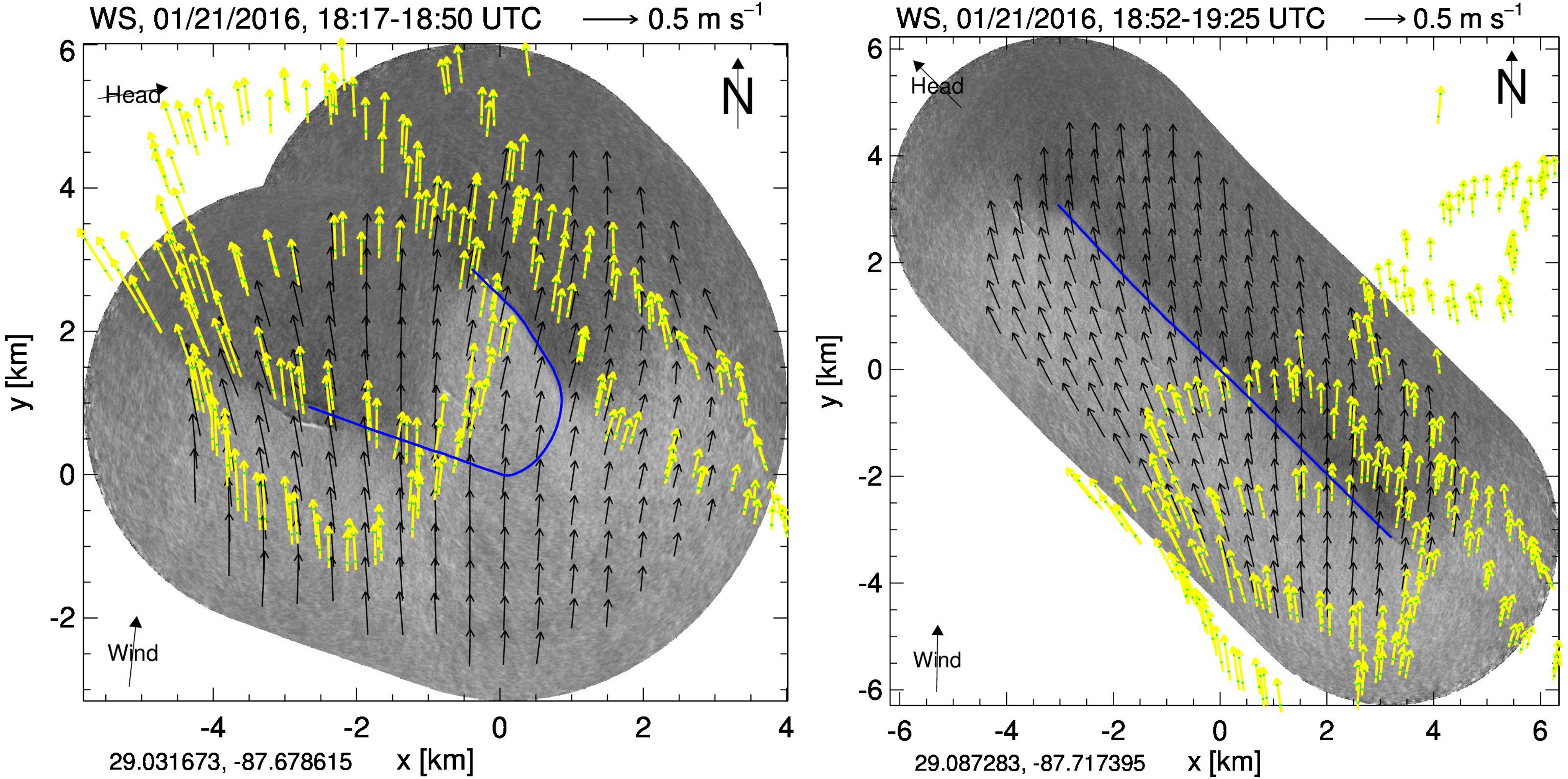
Linear current profile: Effective depth is 7.8 % of ocean wave length.

Logarithmic profile: 4.4 %.





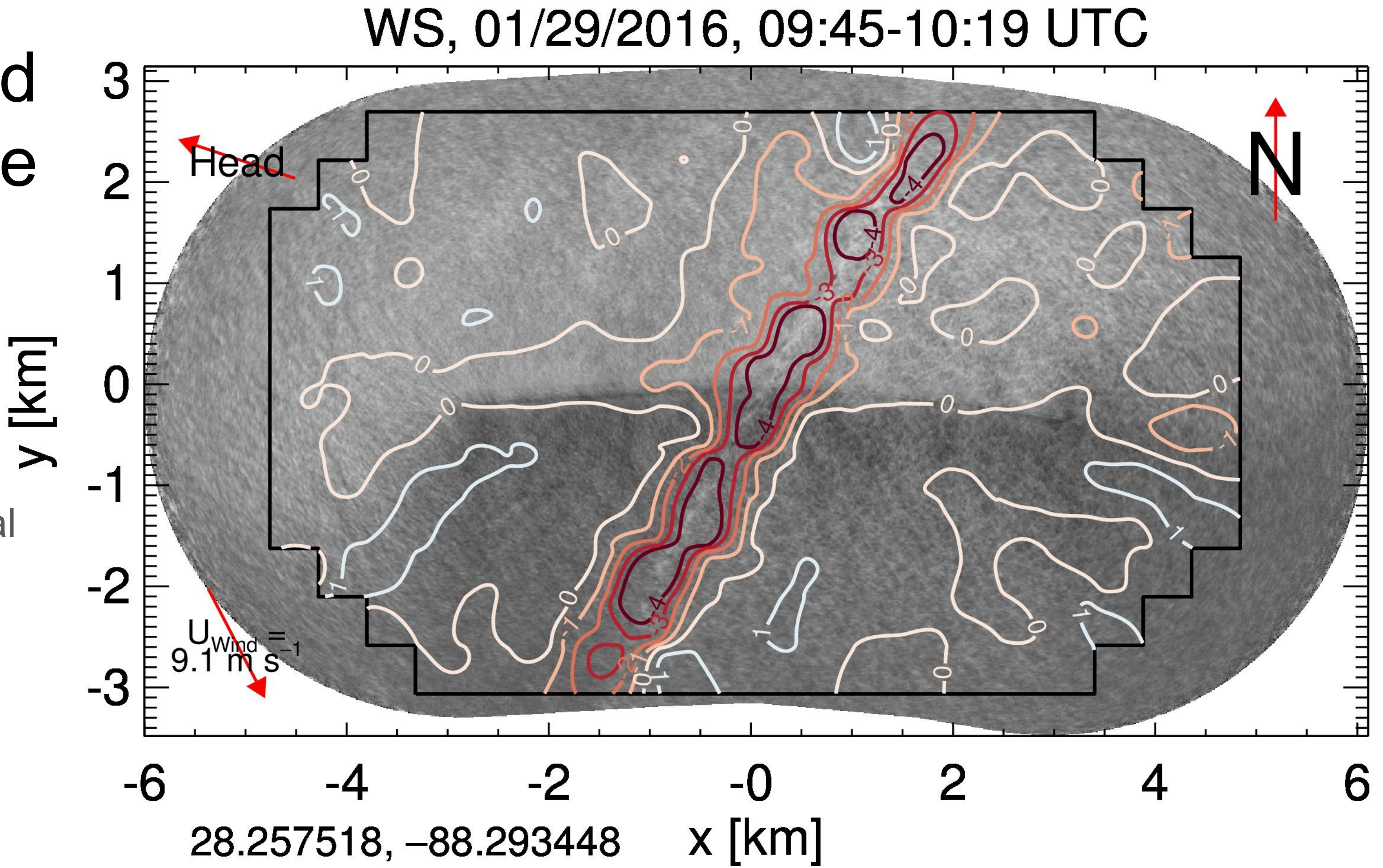
WS, 01/31/2016, 14:44-15:16 UTC
0.5 m s^{-1}
Head
Wind
N
y [km]
x [km]
28.183193, -88.369188
WS, 02/11/2016, 02:18-02:47 UTC
0.5 m s^{-1}
Head
Wind
N
y [km]
x [km]
28.814698, -88.475247
WS, 02/12/2016, 02:06-02:39 UTC
0.5 m s^{-1}
Head
Wind
N
y [km]
x [km]
28.82114, -88.428175
WS, 02/12/2016, 00:57-01:30 UTC
0.5 m s^{-1}
Head
Wind
N
y [km]
x [km]
28.793292, -88.386688



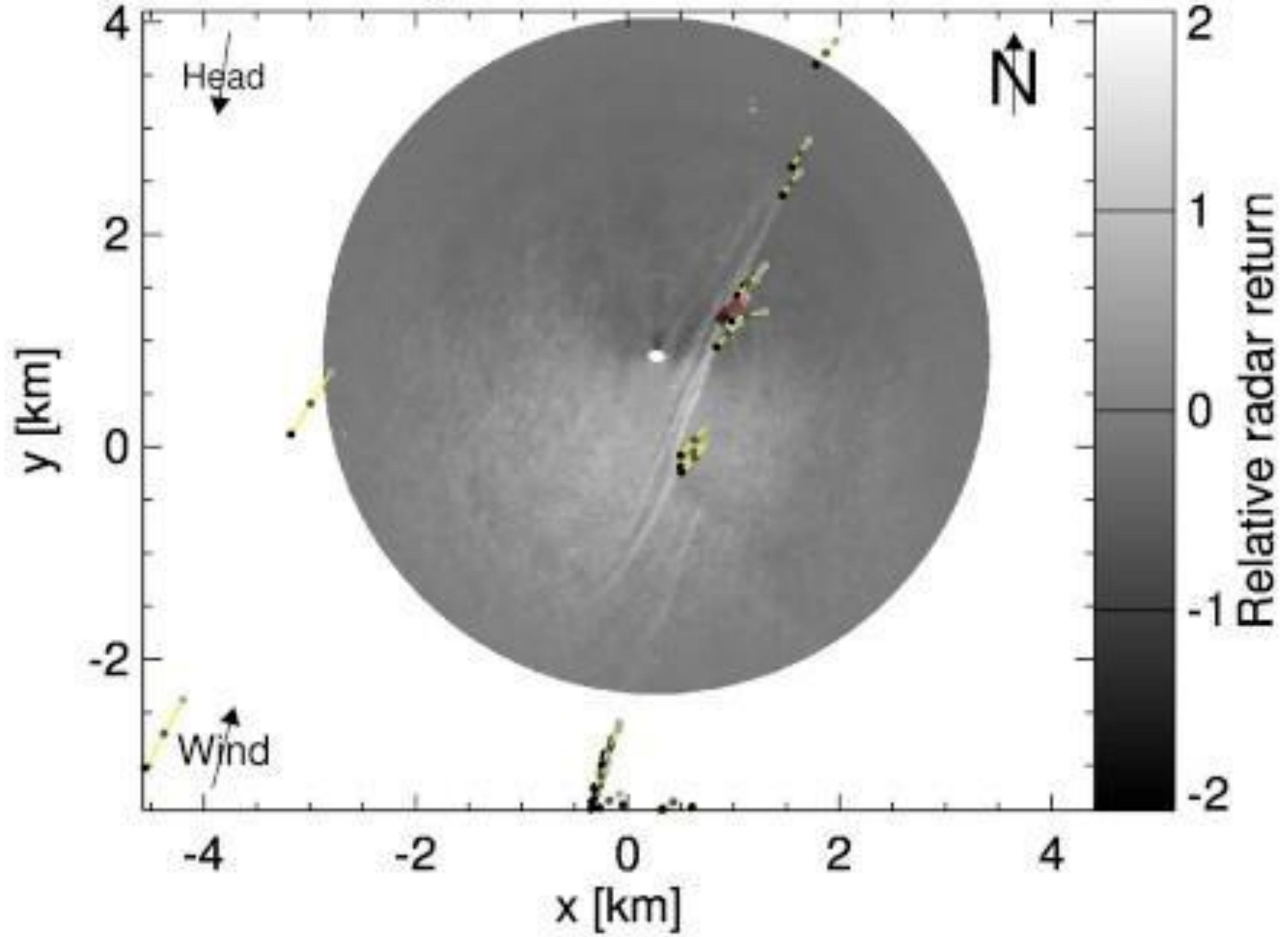
WS, 01/21/2016, 18:17-18:50 UTC
0.5 m s^{-1}
Head
N
Wind
y [km]
x [km]
29.031673, -87.678615
WS, 01/21/2016, 18:52-19:25 UTC
0.5 m s^{-1}
Head
N
Wind
y [km]
x [km]
29.087283, -87.717395

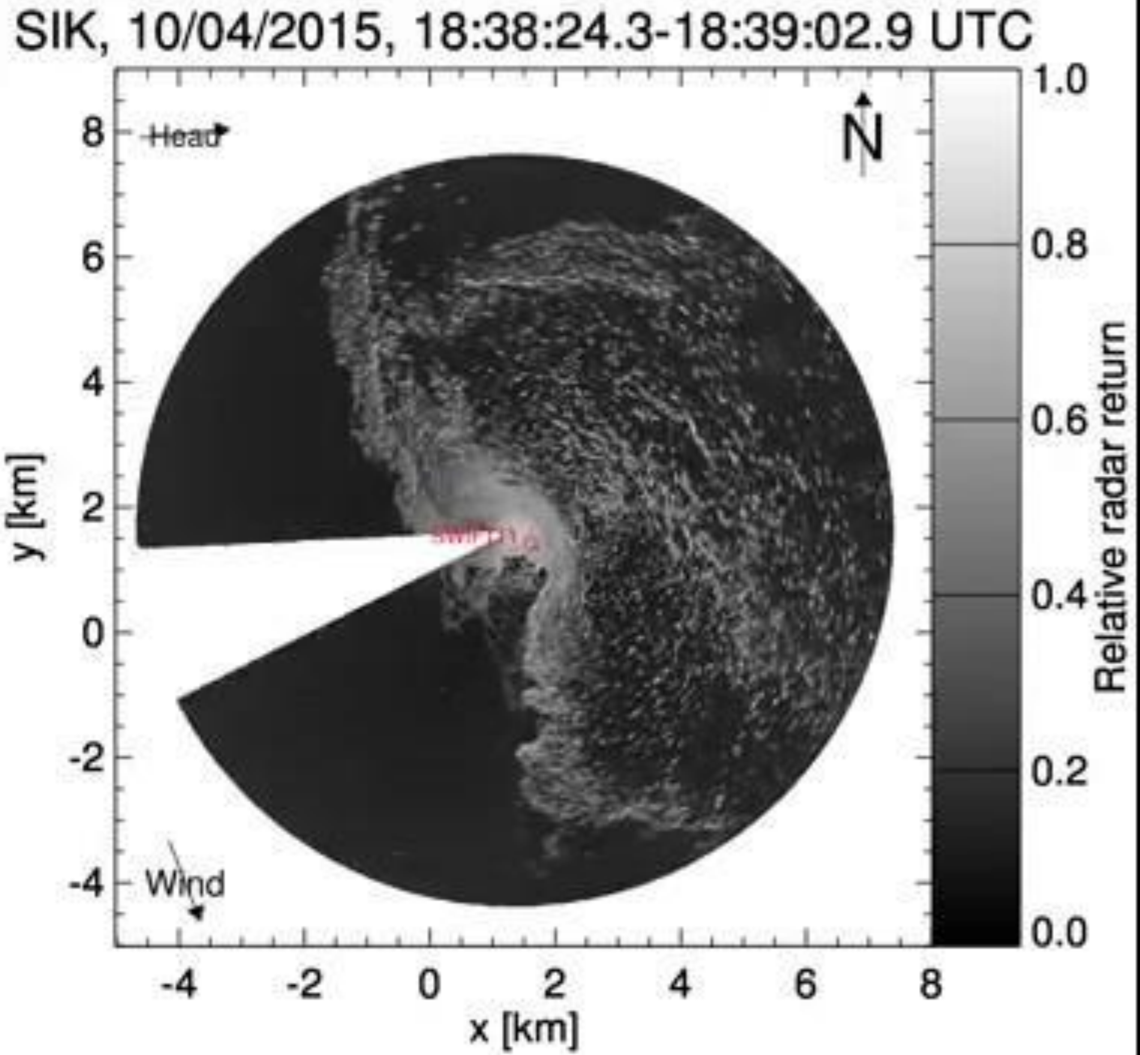
Normalized Divergence

- Convergent flow where back-scatter intensity peaks (frontal feature)
- Red: down-welling
- Blue: up-welling

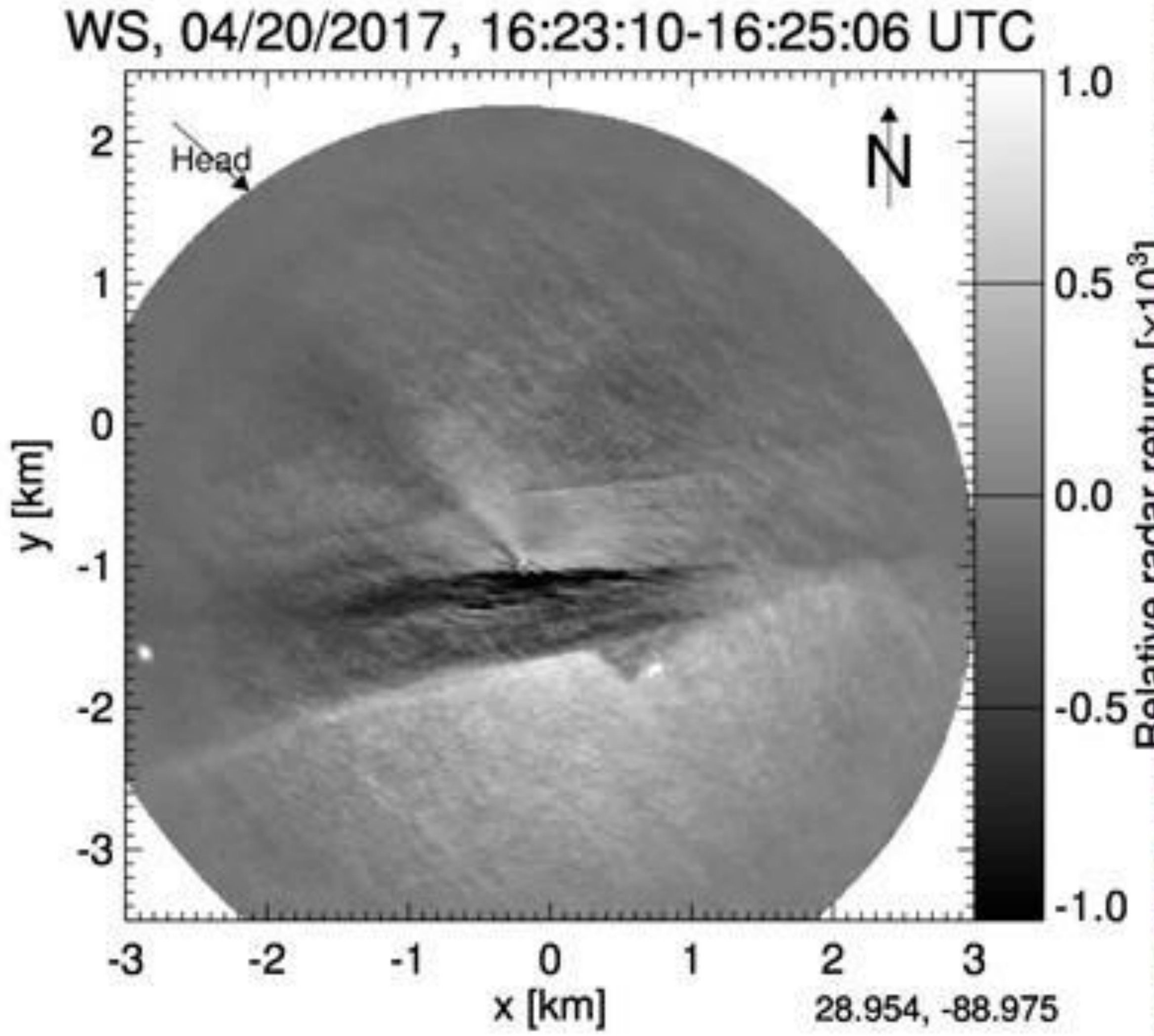


WS, 01/30/2016, 18:04:00.80-18:05:58.43 UTC

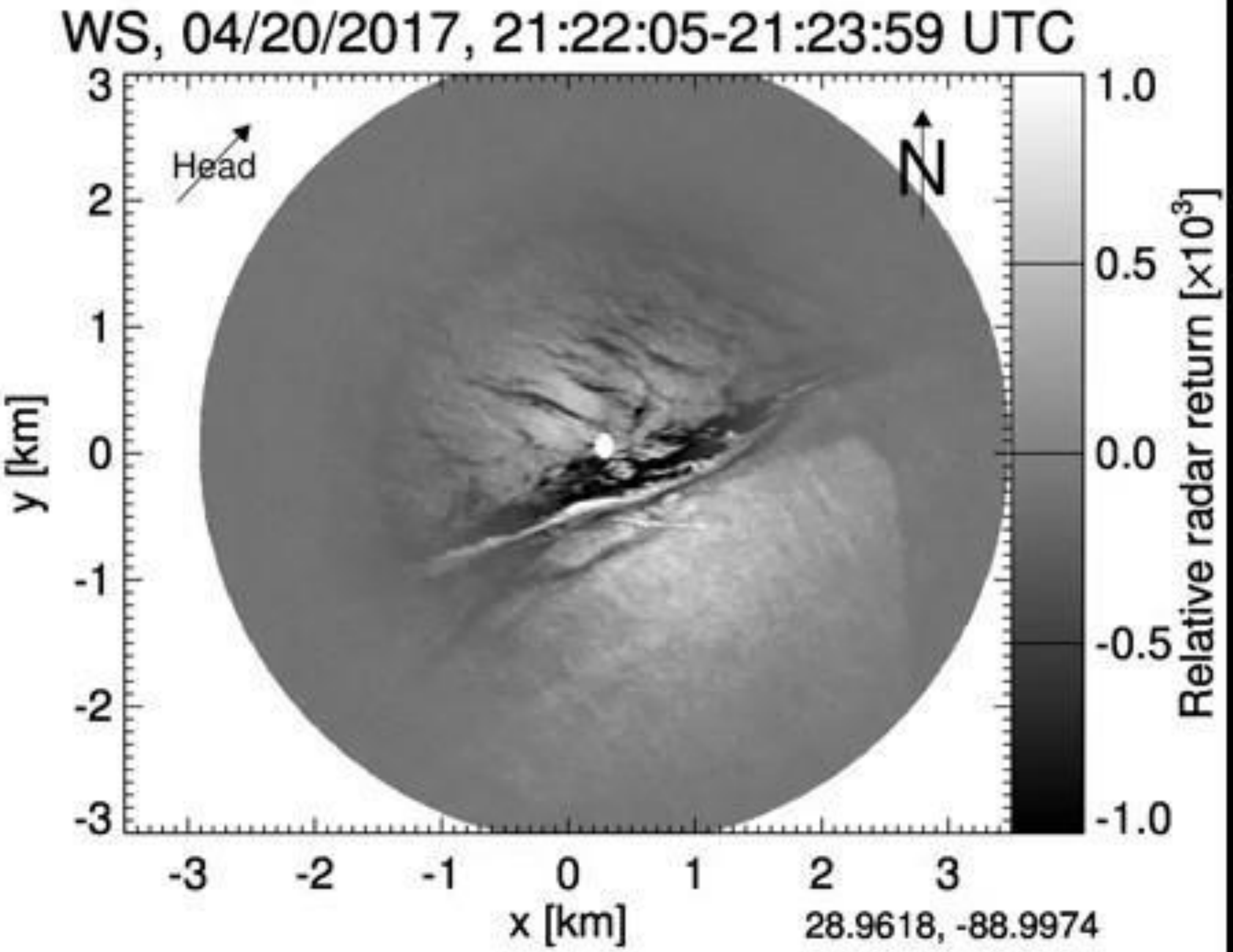




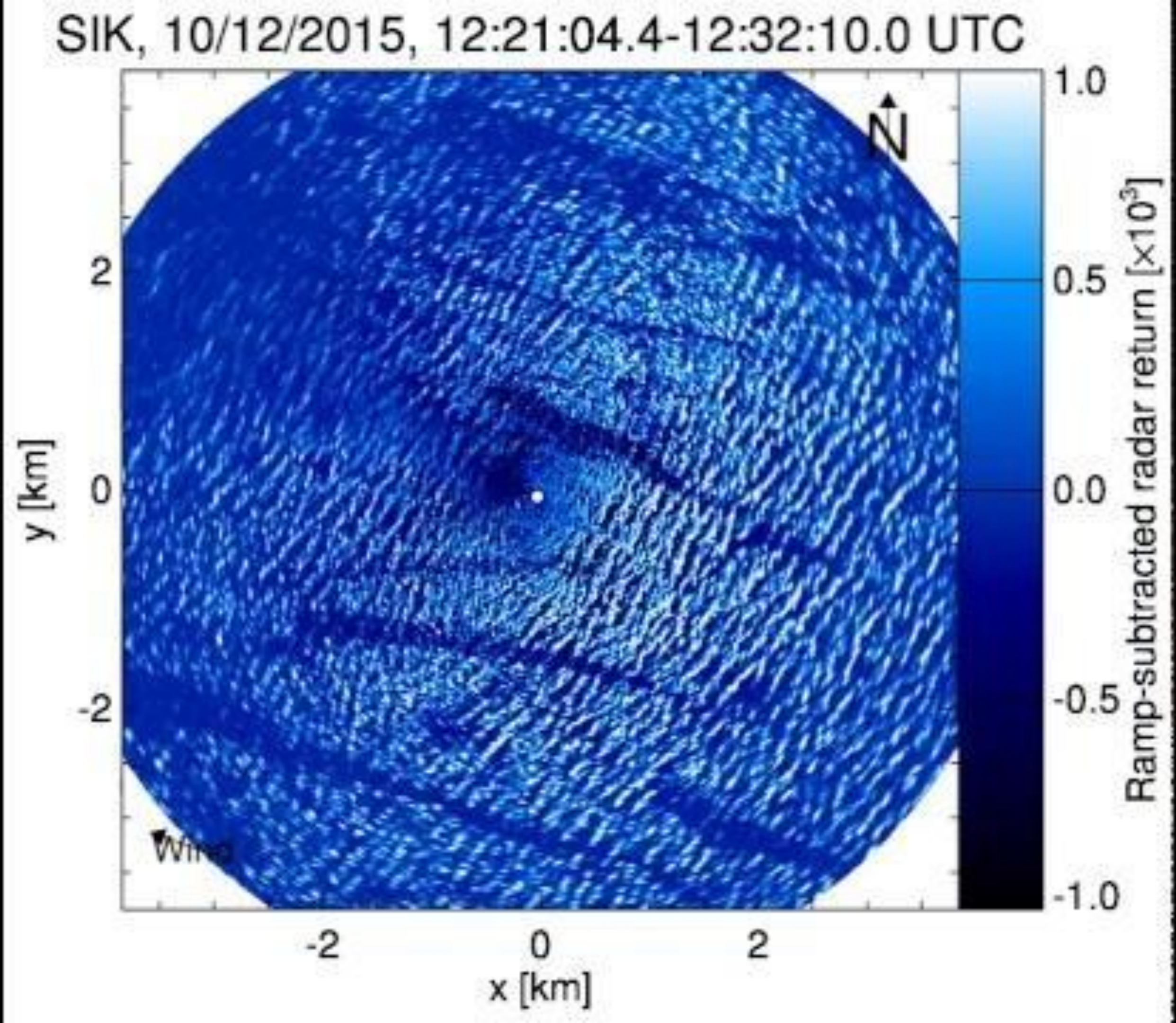
Thomson et al. (2018).



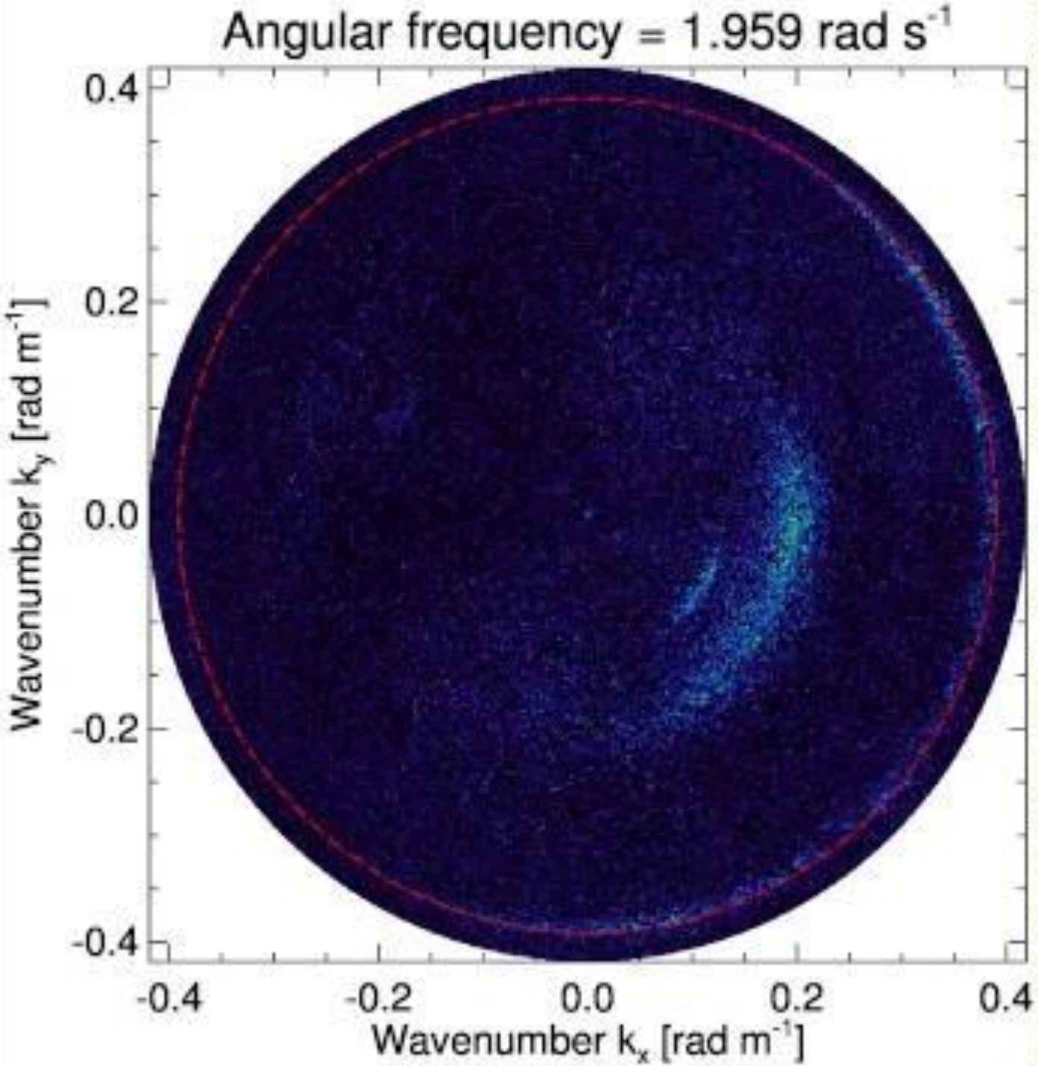
WS, 04/20/2017, 16:23:10-16:25:06 UTC
Head
N
y [km]
x [km]
Relative radar return [x10^3]
1.0
0.5
0.0
-0.5
-1.0
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
28.954, -88.975



Androulidakis et al. (2018)



SIK, 10/12/2015, 12:21:04.4-12:32:10.0 UTC
N
Wind
y [km]
2
0
-2
x [km]
-2
0
2
Ramp-subtracted radar return [×10³]
1.0
0.5
0.0
-0.5
-1.0


Angular frequency = 1.959 rad s-1
0.4
0.2
0.0
-0.2
-0.4
Wavenumber ky [rad m-1]
-0.4
-0.2
0.0
0.2
0.4
Wavenumber kx [rad m-1]