Ocean wave measurements by TerraSAR-X
Waves Travelling into Sea Ice
East Greenland Case

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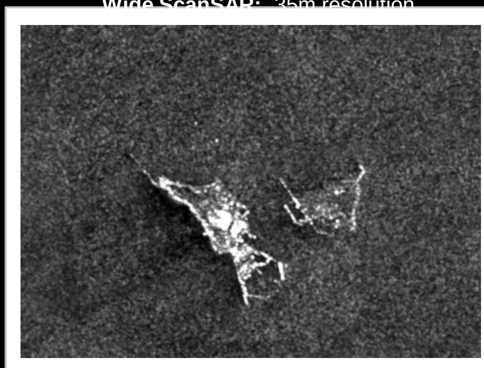
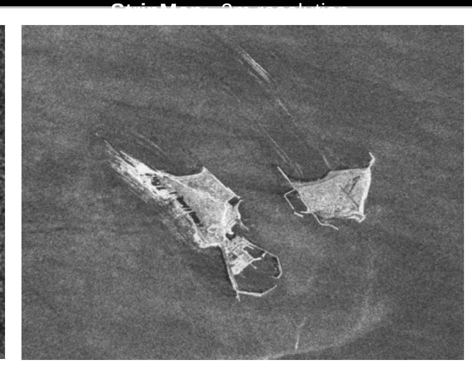
Satellites: X-band SAR (Synthetic Aperture Radar) TerraSAR-X and TanDEM-X

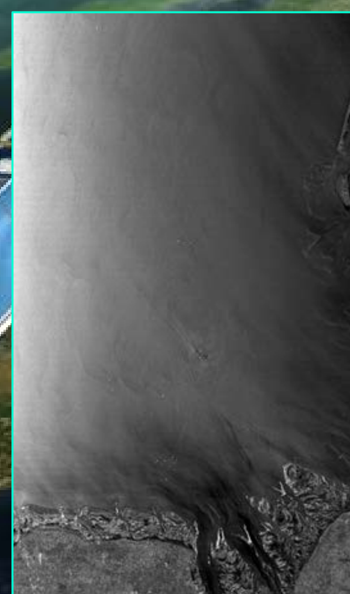




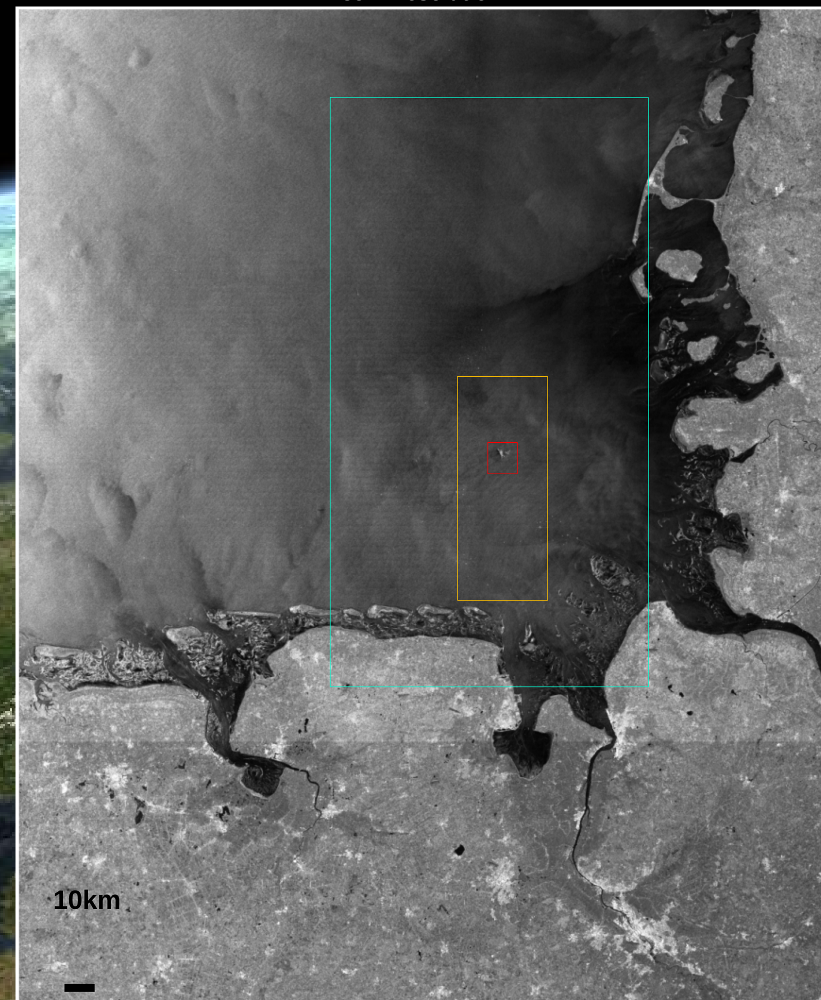
-Radar signal penetrates clouds
-No sun light is necessary

SpotLight 10km

Stripmap 30km



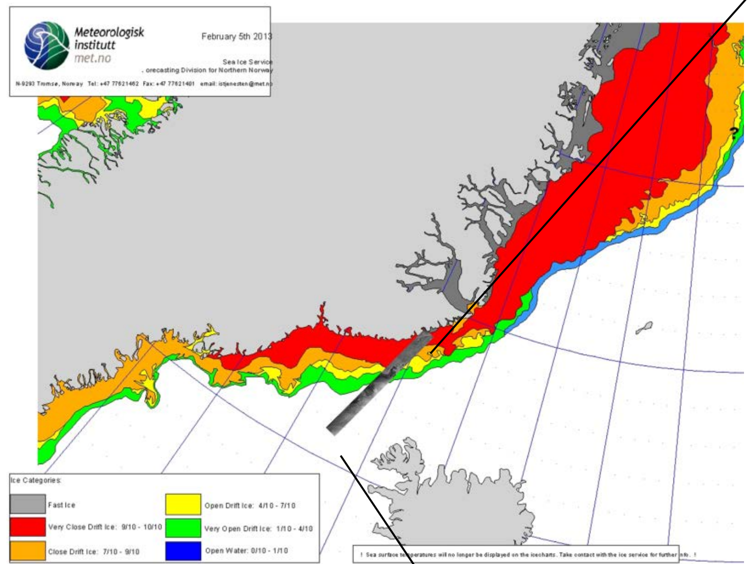
ScanSAR 100km



Wide ScanSAR 250km

DLR

Sea State and Eddies at the Sea Ice Boundary



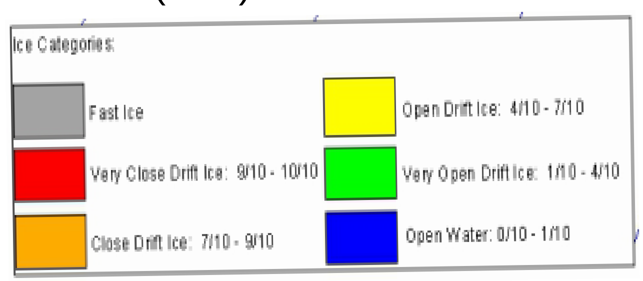
Sequence of TS-X images off the coast of Eastern Greenland, strip 300 km acquired on Feb.5th,2013, 8:40 UTC,

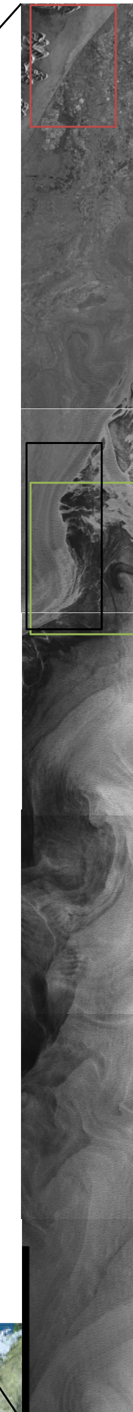
From top to bottom, typical signatures of

-ice floes and solid ice,

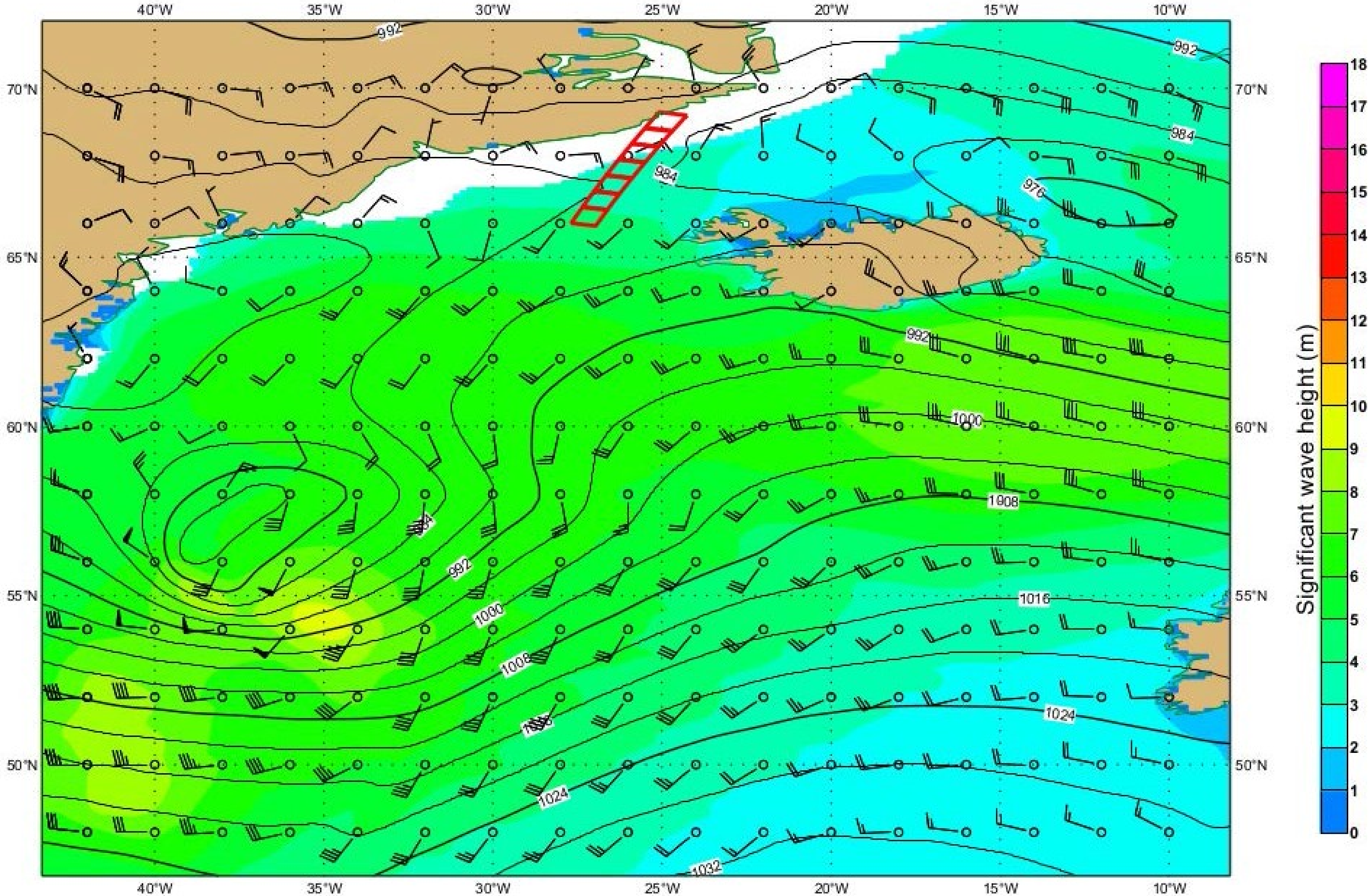
-pancake ice,

-frazil ice (dark)



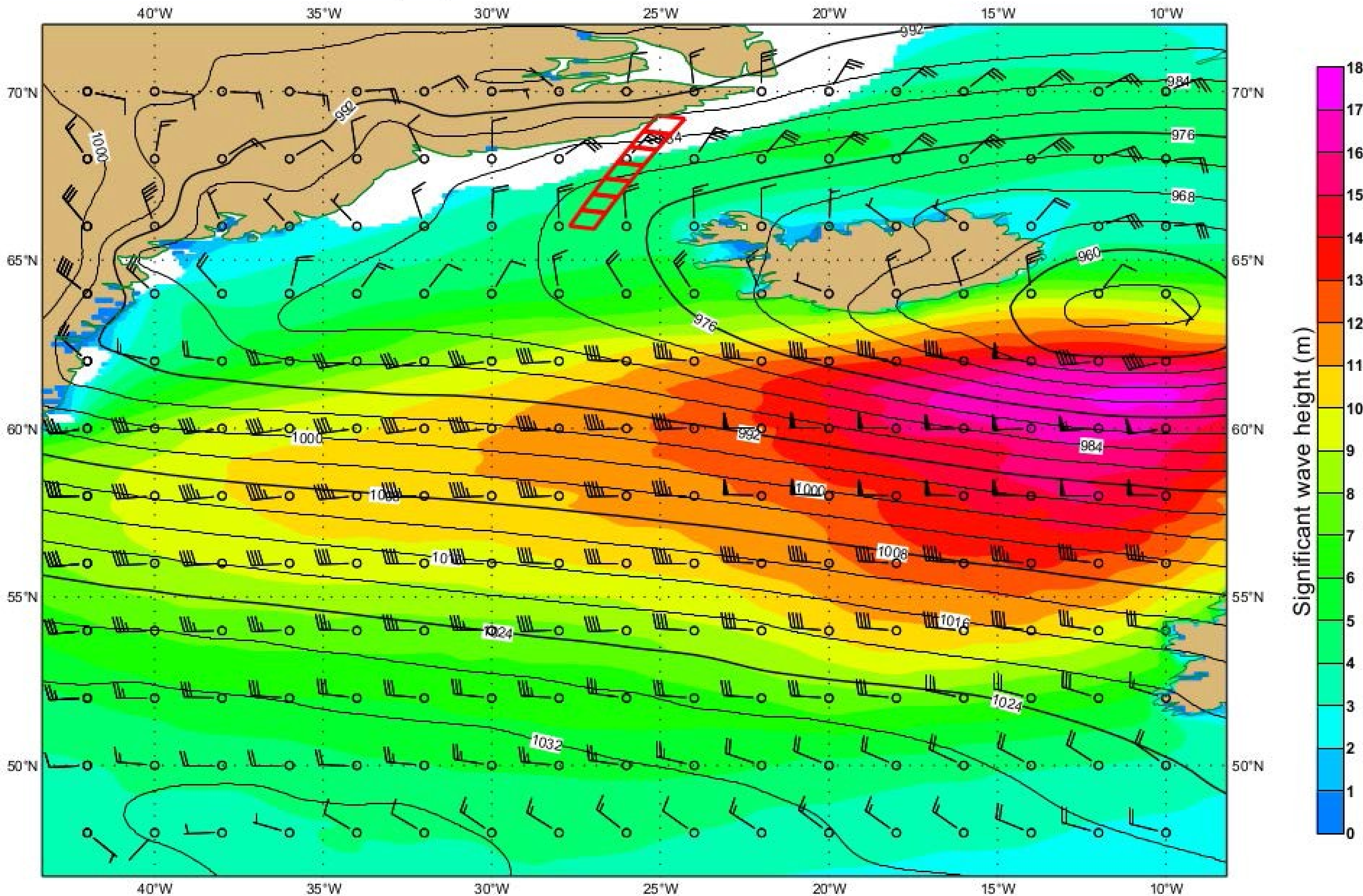


Synoptic situation on 2013-02-03 6UTC



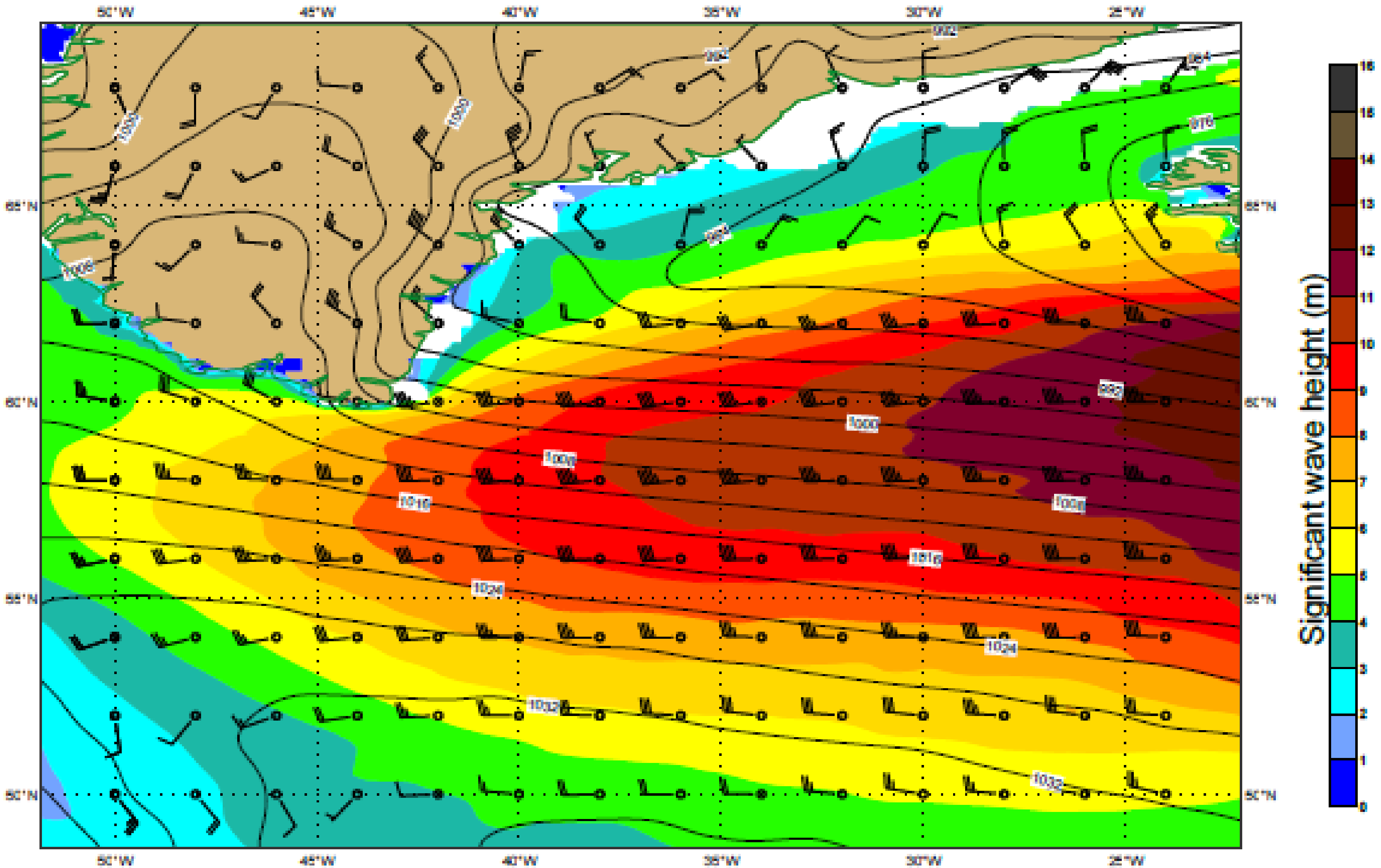
DLR

Synoptic situation on 2013-02-04 6UTC



DLR

Monday 04 February 2013 06 UTC ecmf t+0 VT:Monday 04 February 2013 06 UTC surface Mean sea level pressure
Monday 04 February 2013 06 UTC ecmf t+0 VT:Monday 04 February 2013 06 UTC surface 10 metre U wind component/10 metre V wind component
ecmf Analysis VT: Monday 04 February 2013 06 UTC meanSea Significant height of combined wind waves and swell



Monday 04 February 2013 18 UTC ecmf t+0 VT:Monday 04 February 2013 18 UTC surface Mean sea level pressure
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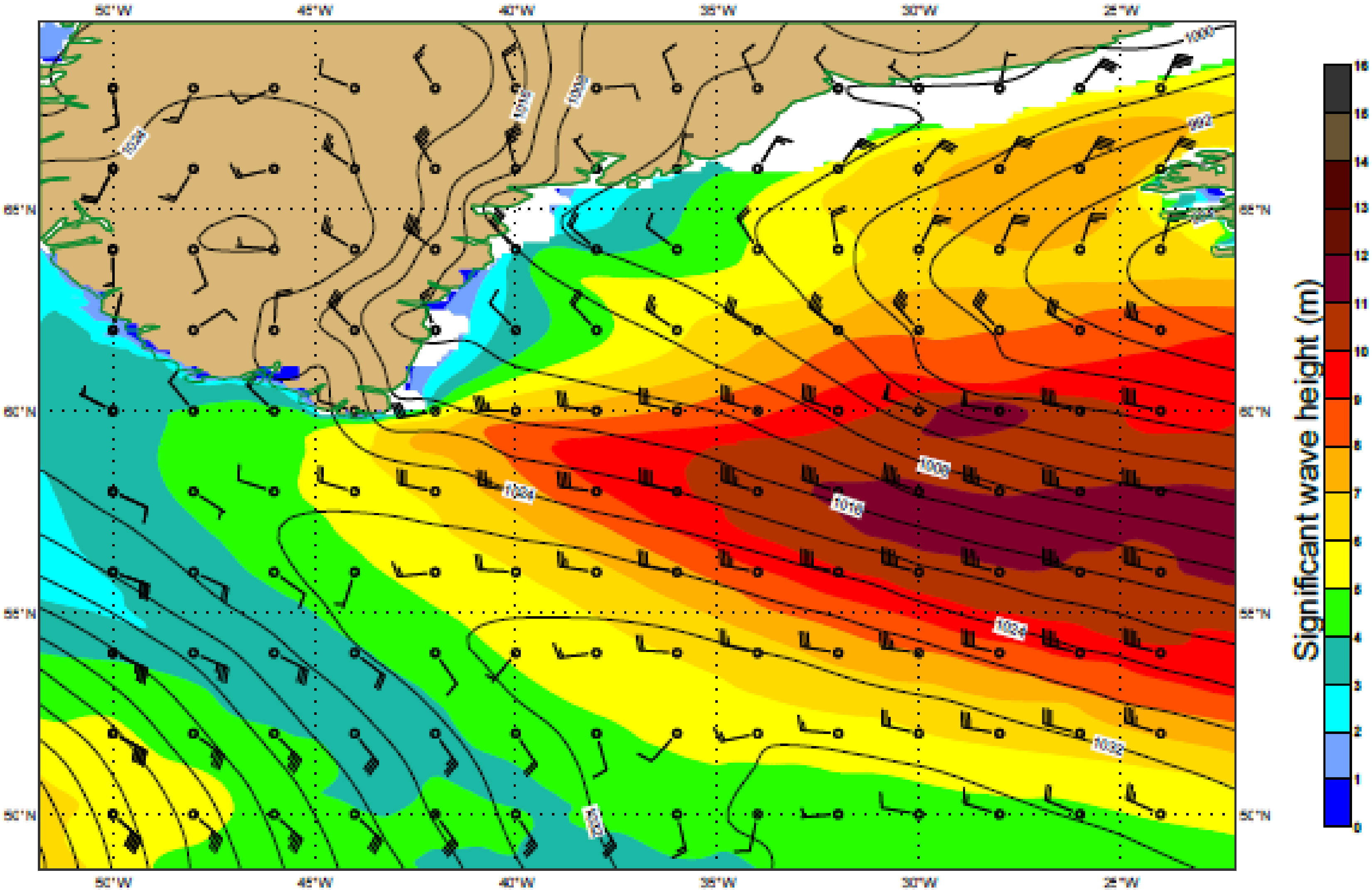
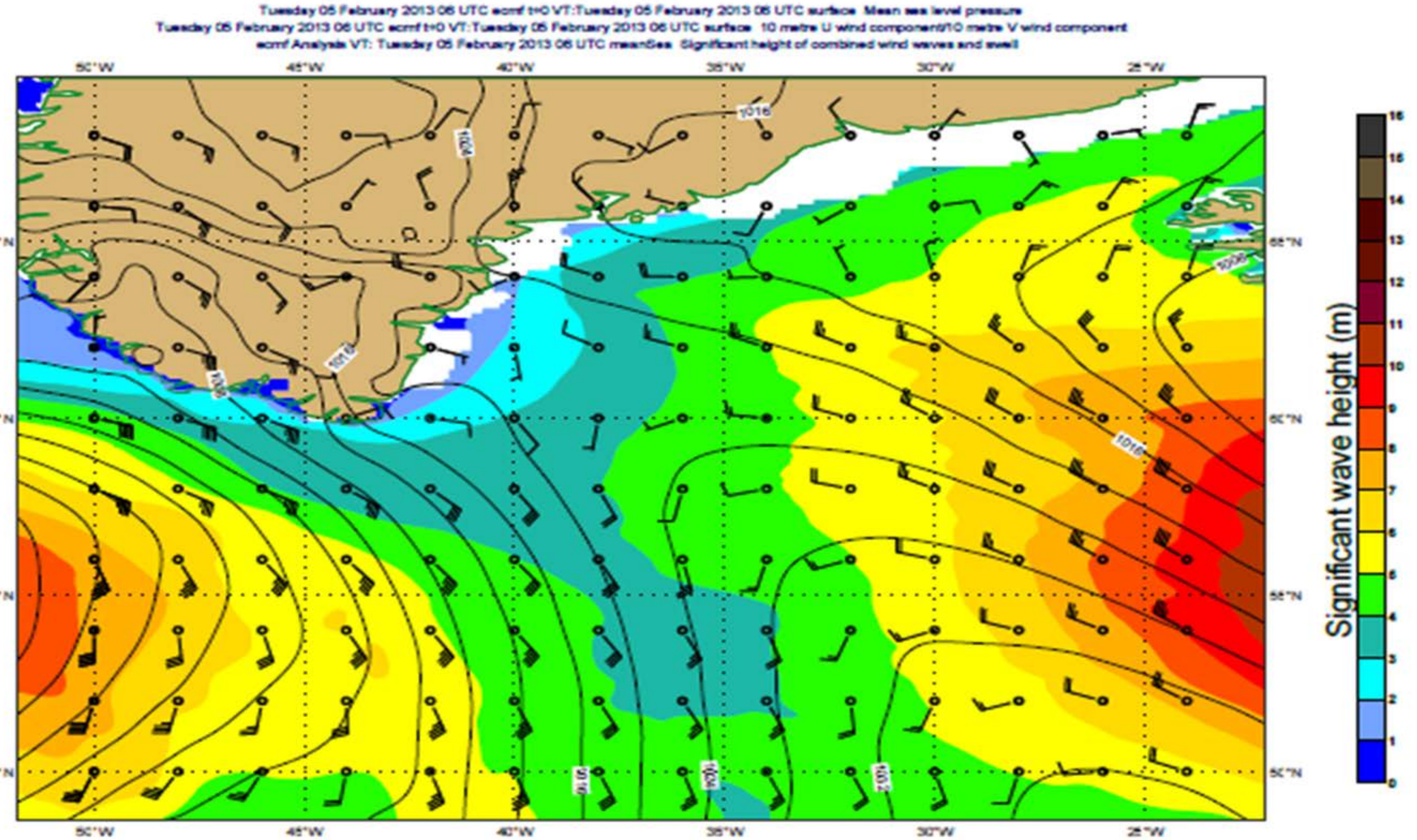
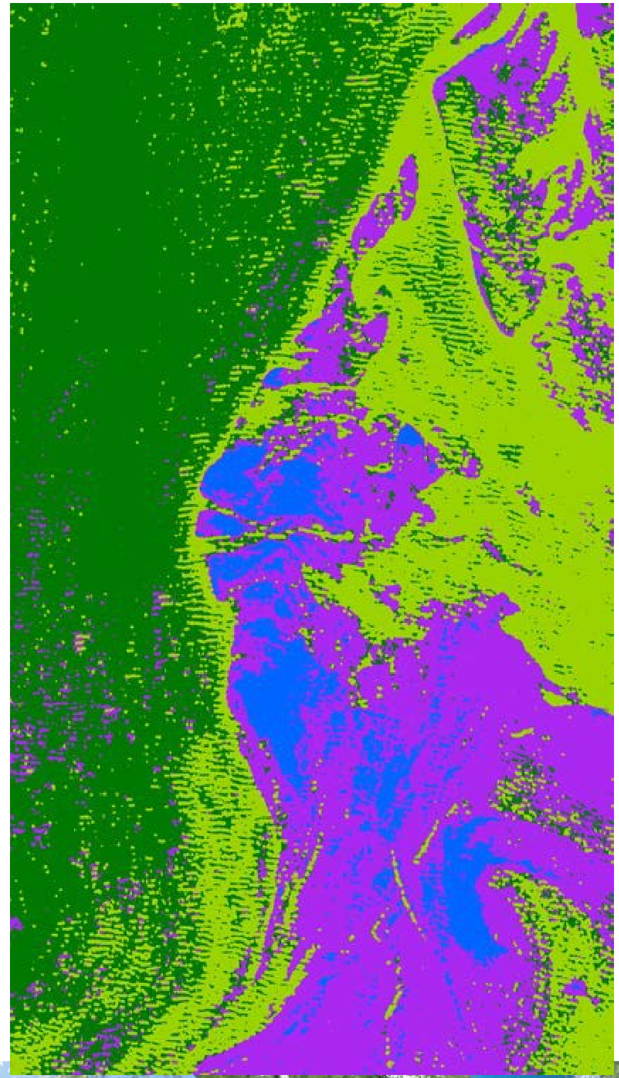


DLR

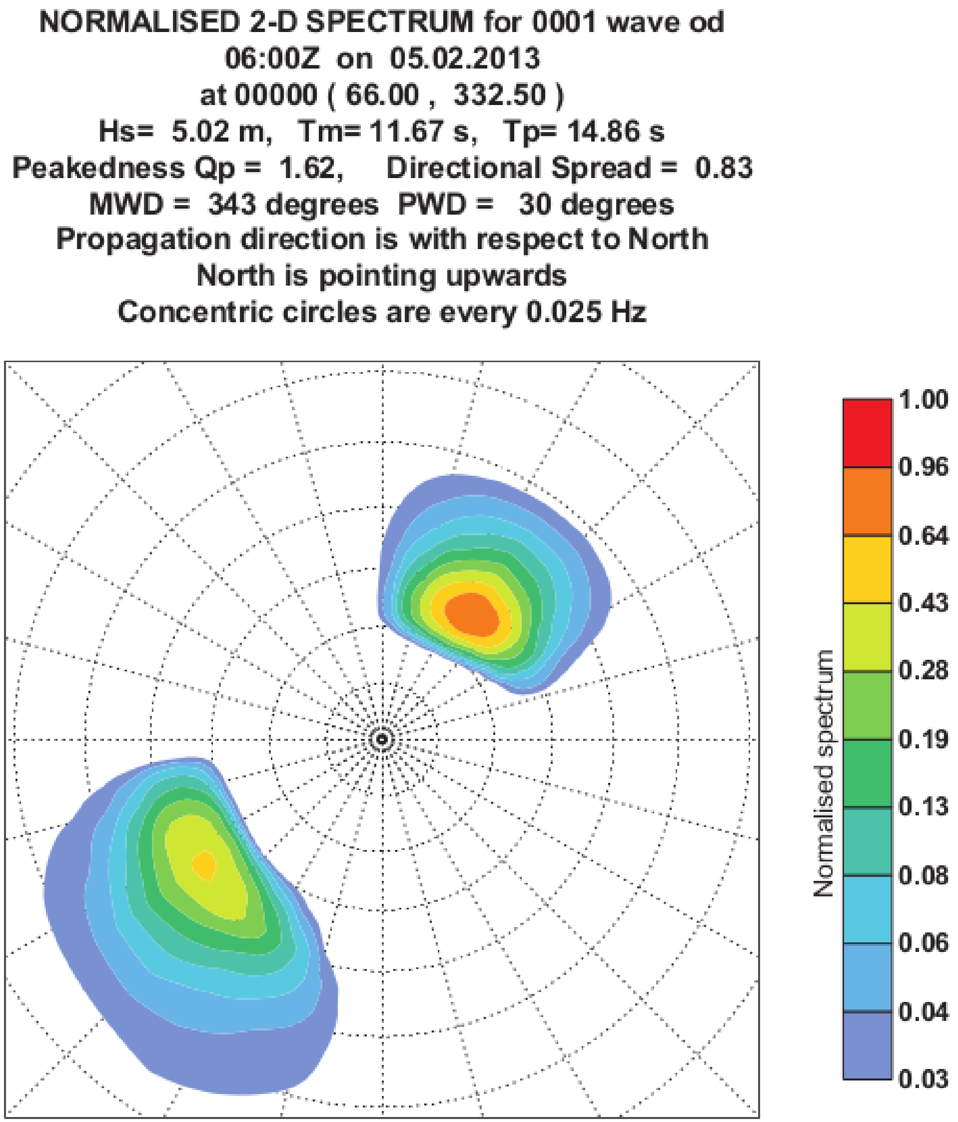


Tuesday 05 February 2013 06 UTC ecmf t+0 VT:Tuesday 05 February 2013 06 UTC surface Mean sea level pressure
Tuesday 05 February 2013 06 UTC ecmf t+0 VT:Tuesday 05 February 2013 06 UTC surface 10 metre U wind component/10 metre V wind component
ecmf Analysis VT: Tuesday 05 February 2013 06 UTC meanSea Significant height of combined wind waves and swell
50°W
45°W
40°W
35°W
30°W
25°W
65°N
60°N
55°N
50°N
Significant wave height (m)

Left: Stripmap image which is part of the TS-X scene shown .
Right: Classification of ice types for the image shown on the left. Blue is open water/nilas, magenta is young ice, bright green is thin first year ice, and dark green is thick first year ice.

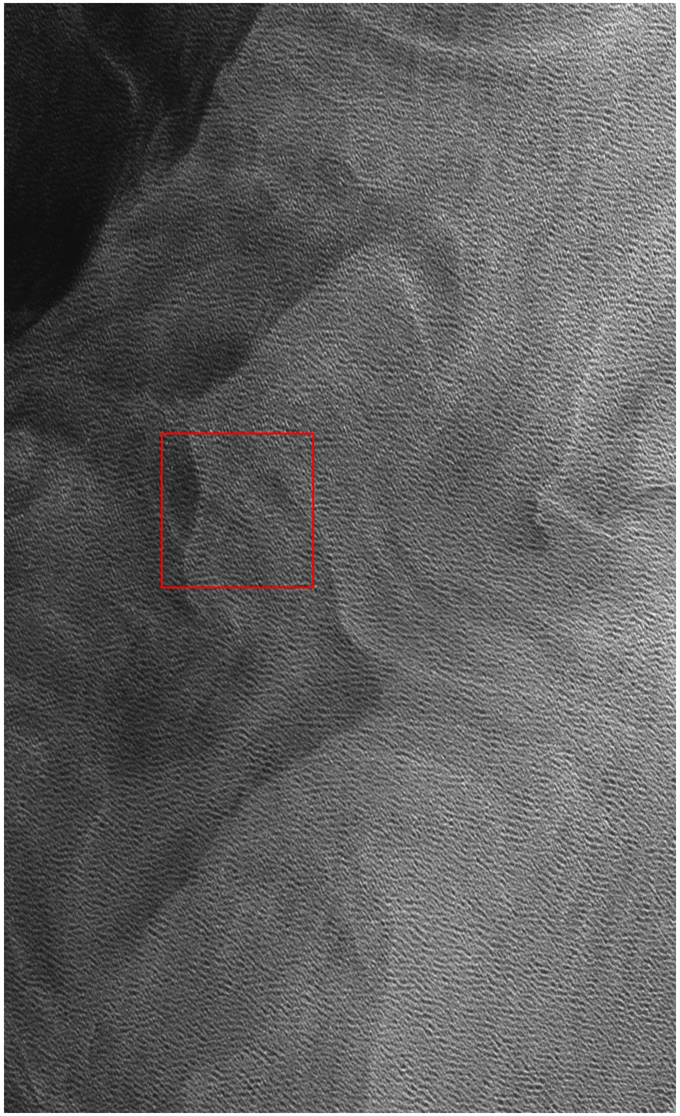


Wave Model Spectrum ECMWF

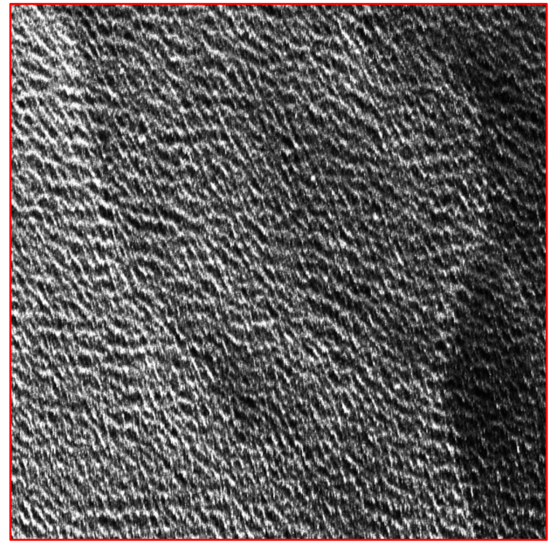


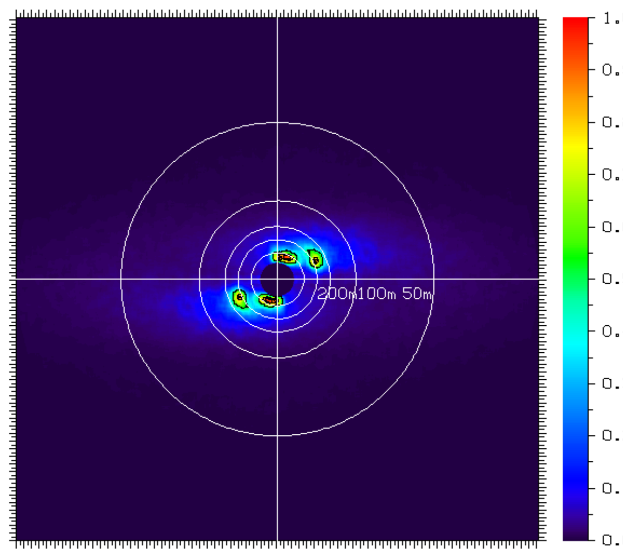
wave spectra from ECMWF
long and short/young swell consistent with TS-X shown

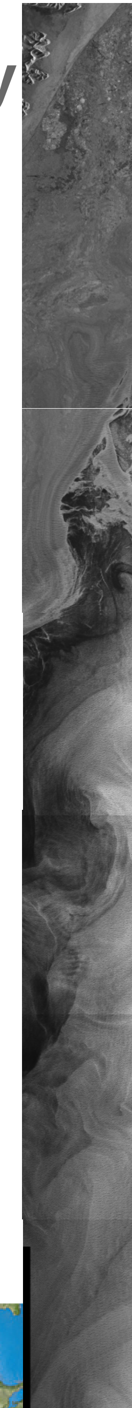
2D Spectra from TS-X at the Sea Ice Boundary



Subscene 30km x 50km

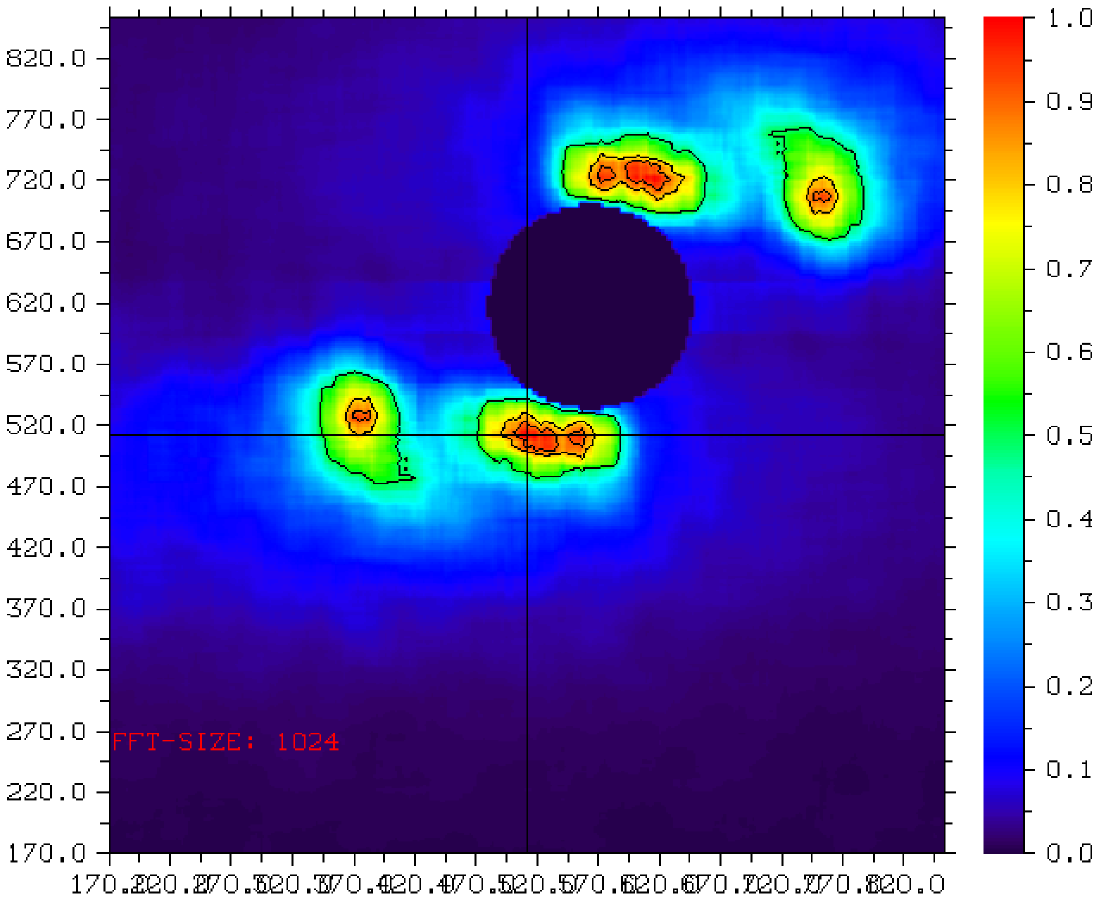






DLR

Maxima of TS-X Spectrum

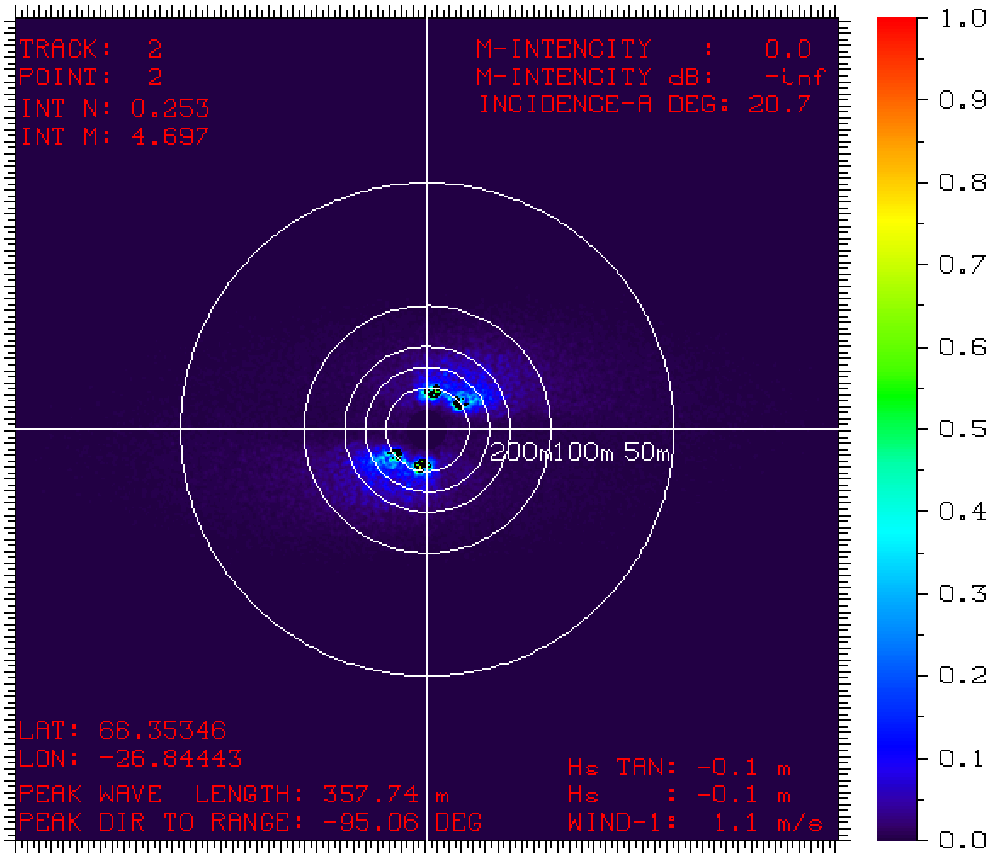


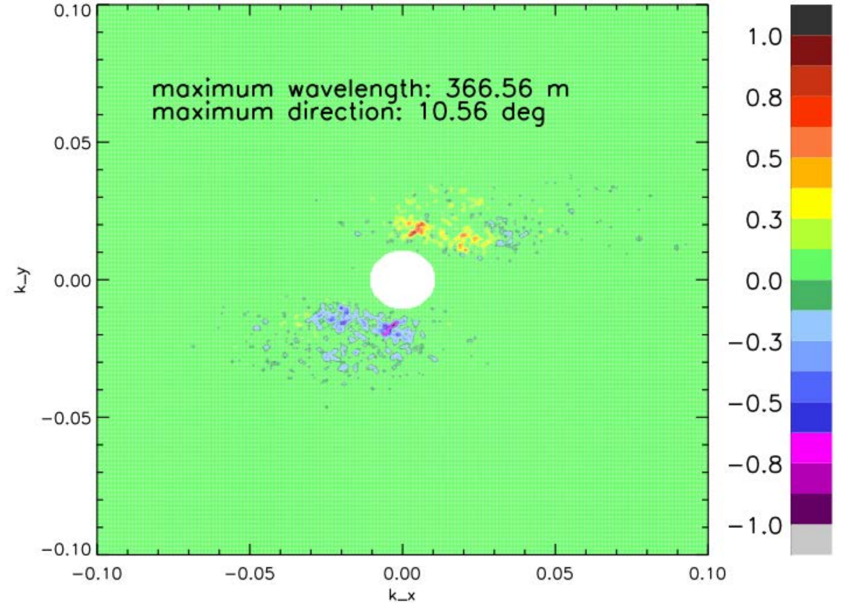
Fourier power spectrum showing 2 maxima:

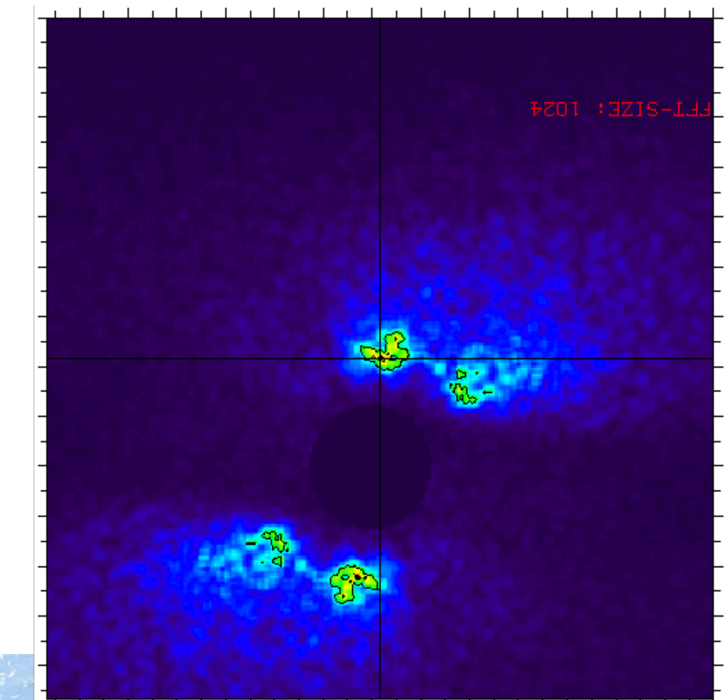
swell waves of more than 300 m length travelling close to azimuth direction,

shorter waves of ca. 180 m length travelling more in range direction

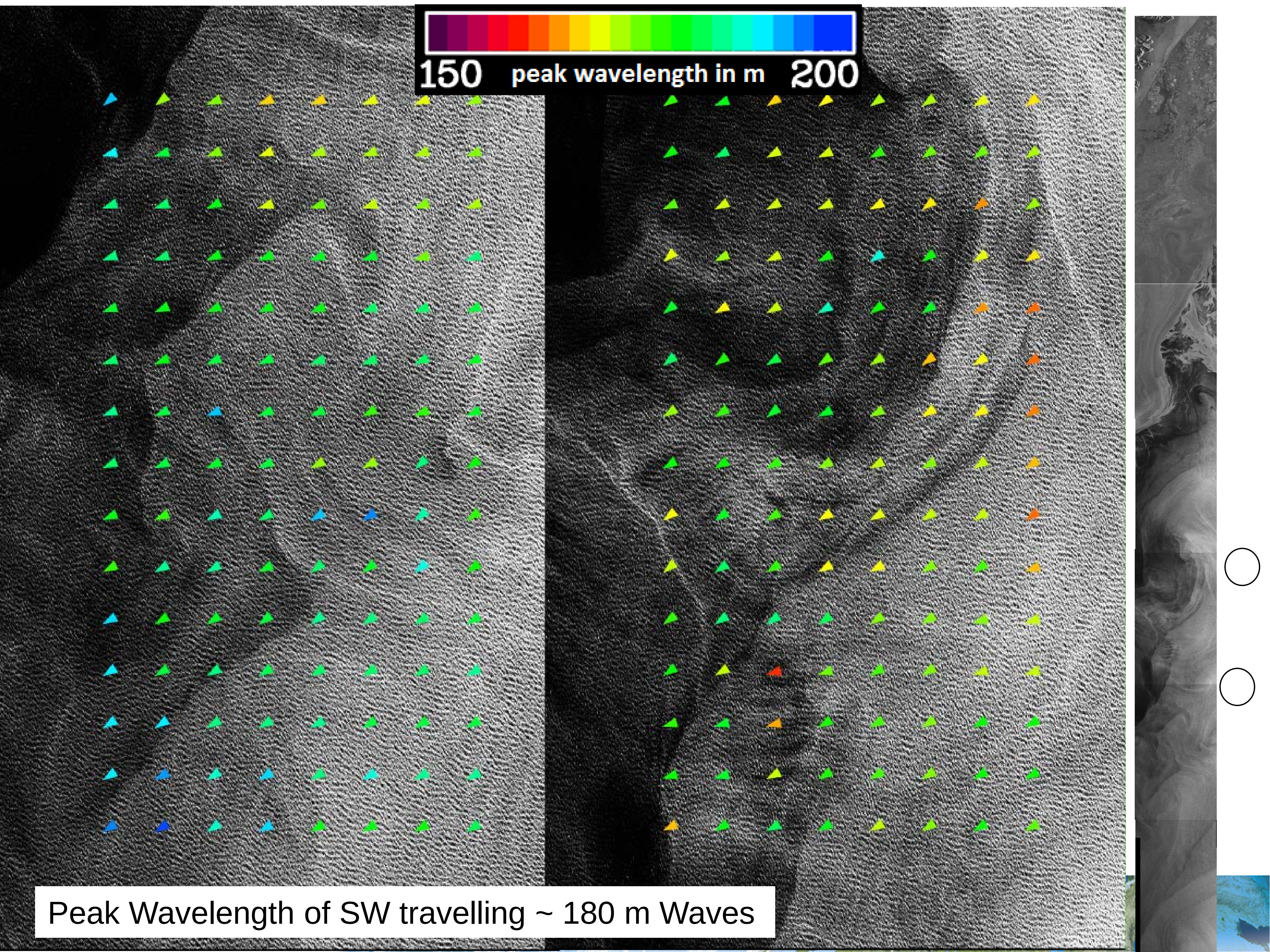
TS-X Cross Spectrum
Swell Peak of > 300 m waves







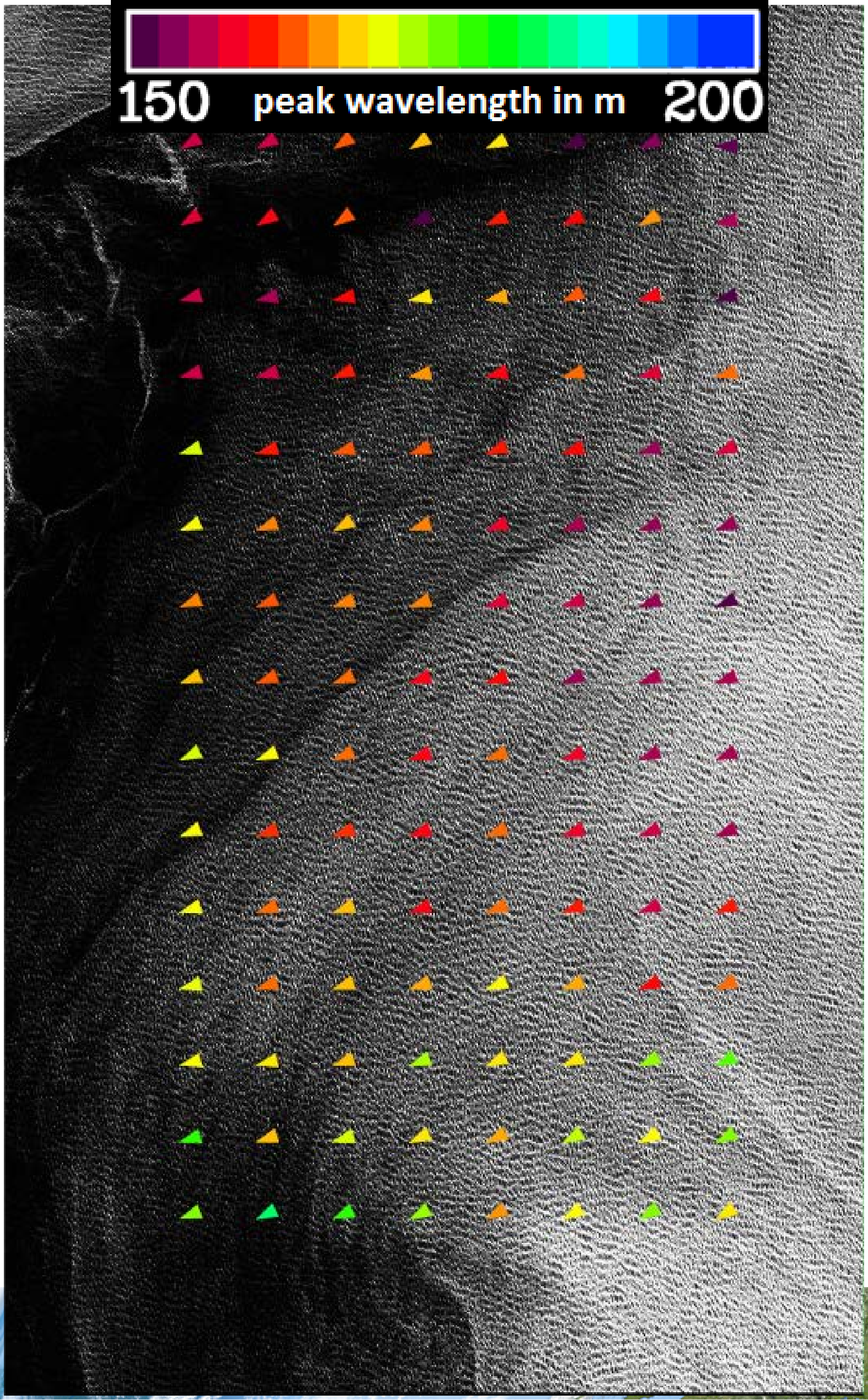
peak wavelength of 358 m and 367 m, travelling to NE

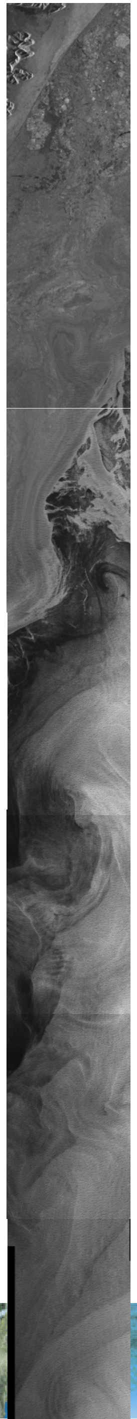


Peak Wavelength of SW travelling ~ 180 m Waves

swell waves of
150 to 200 m length
travelling in South-western direction,

Again velocity dispersion is observed





Wave Dispersion

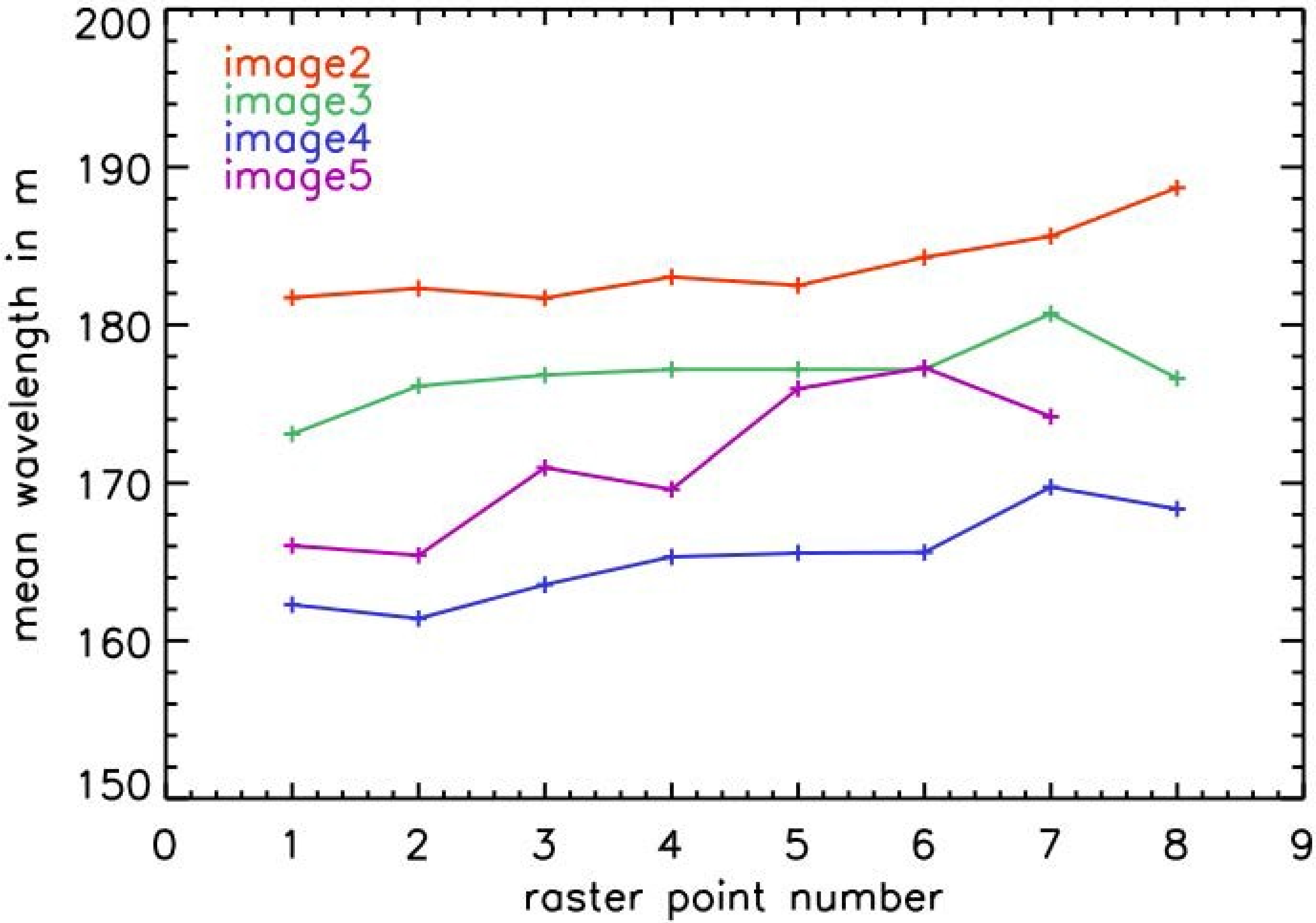


Illustration of the data on the peak wavelength obtained from the images 2 to 5.

Velocity Dispersion of Swell at a fixed time (contrary to a fixed place)

For storm distance D to the location of measurement there is the relation
For wave length L, group velocity v and travel time τ we have the relation:

$$D(L, \tau) = v(L)\,\tau = 0.5\,\mathrm{sqrt}(1.56 * L)\,\tau = 0.63\,\mathrm{sqrt}(L)\,\tau \qquad (1)$$

For wave length L and fixed τ, the distance D changes

$$dD/dL = 0.32\,\tau / \mathrm{sqrt}(L). \qquad (2)$$

For the considered case in open water we measure typical values dD/dL~ 1000. That gives the travel distance from (2) for L=400 m:
$\tau = 3.12\ {*}\mathrm{sqrt}(L)\,(dL/dx)^{-1} \sim 3.12 * \mathrm{sqrt}(400) * 1000 = 62\,400$ s.

The distance D from the storm center is D =1600 km
For the short peak L = 200m a similar calculation gives D = 372 km.

In Snodgrass et all : „Swell across the Pacific", a similar relation was derived to explain the shift of peak frequency for anchored wave sensors (at a fixed place).

DLR

Wave Length change due to ice sheet Thickness (after Wadhams and Squire)

In a continuos sheet of sea ice floating in infinite deep water the dispersion relation

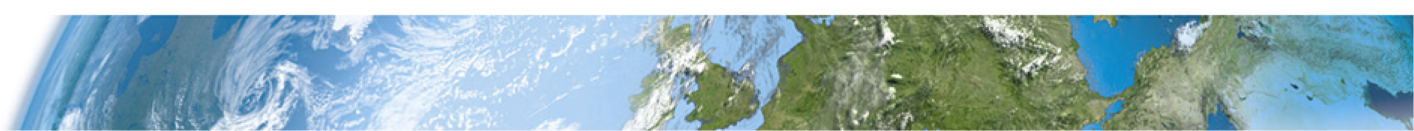
$$L\kappa^5 + (\rho g - \rho' h\omega^2)\kappa - \rho\omega^2 = 0,$$

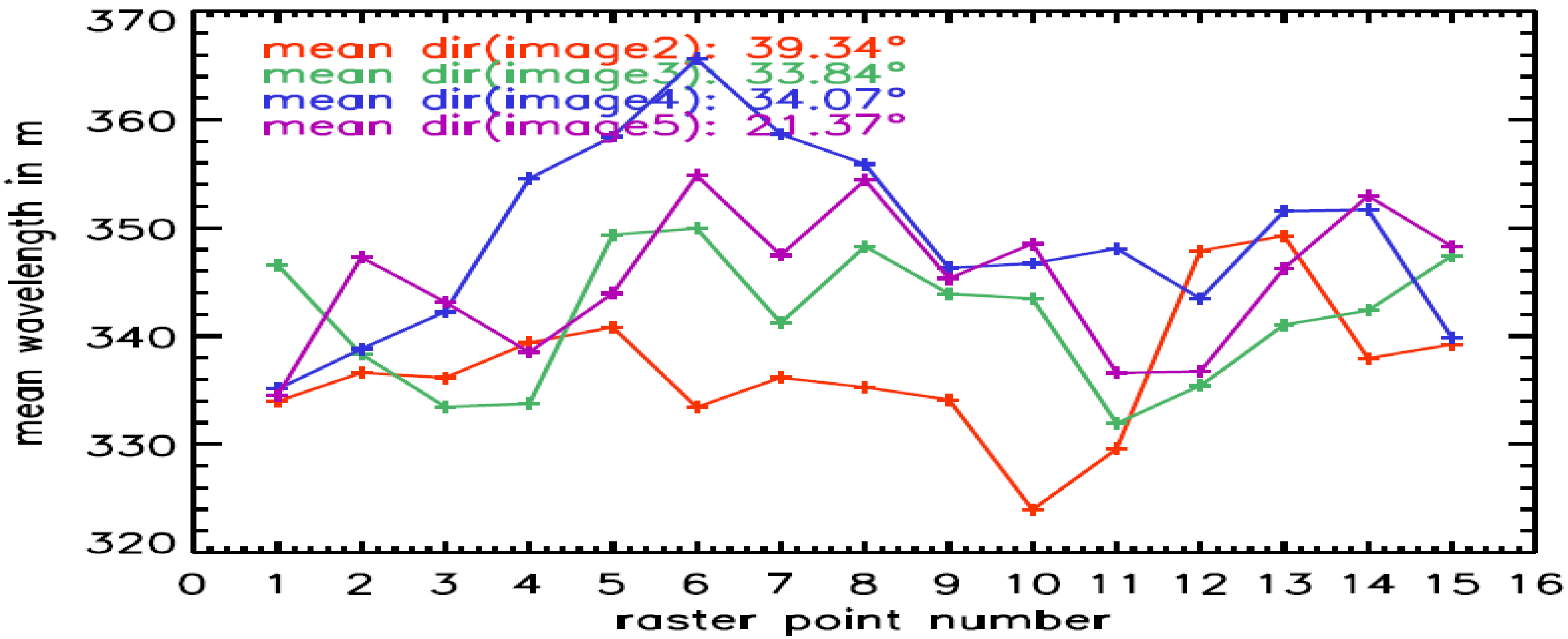
is recommended by Squire et al (1995).
h is the thickness of the ice sheet. Wadhams massload approximation is

$$(g/\omega^2 - \lambda/(2\pi)) = h\rho'/\rho$$

For constant ω the differences in h for two locations are proportional to differences in λ :

$$(\lambda_0 - \lambda)(\rho'/\rho)/(2\pi) = dh = h - h_0$$




mean dir(image2): 39.34°
mean dir(image3): 33.84°
mean dir(image4): 34.07°
mean dir(image5): 21.37°
mean wavelength in m
raster point number

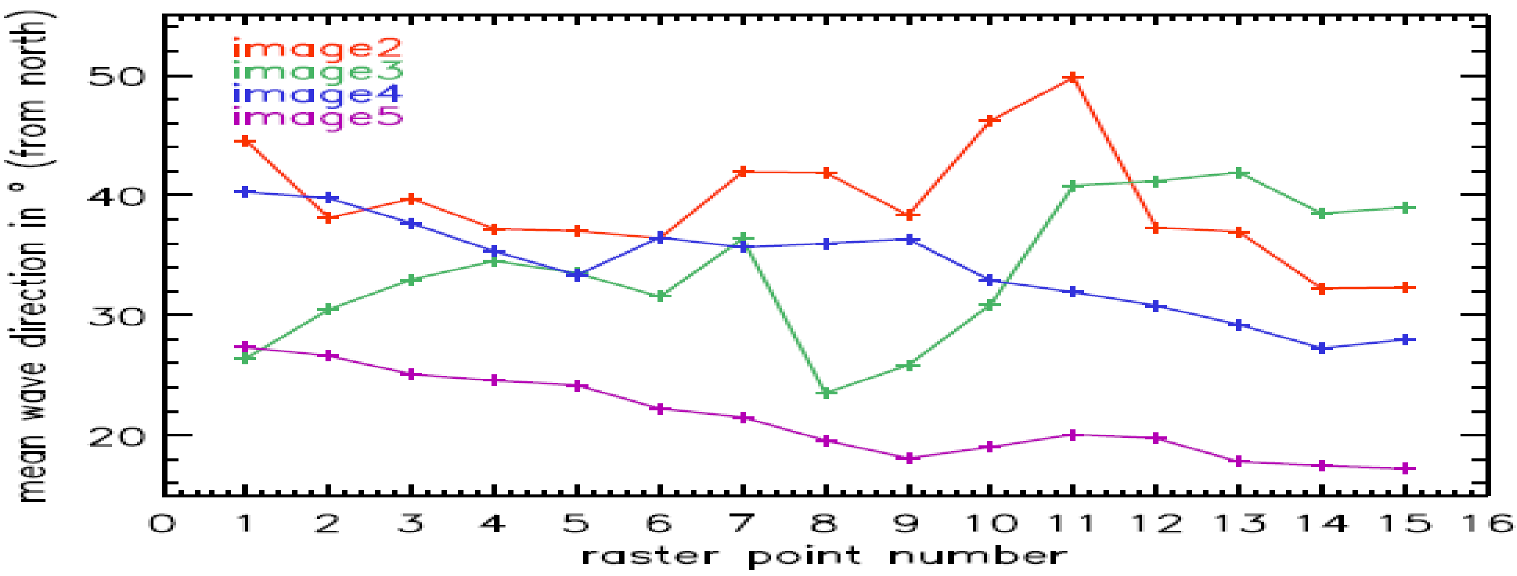
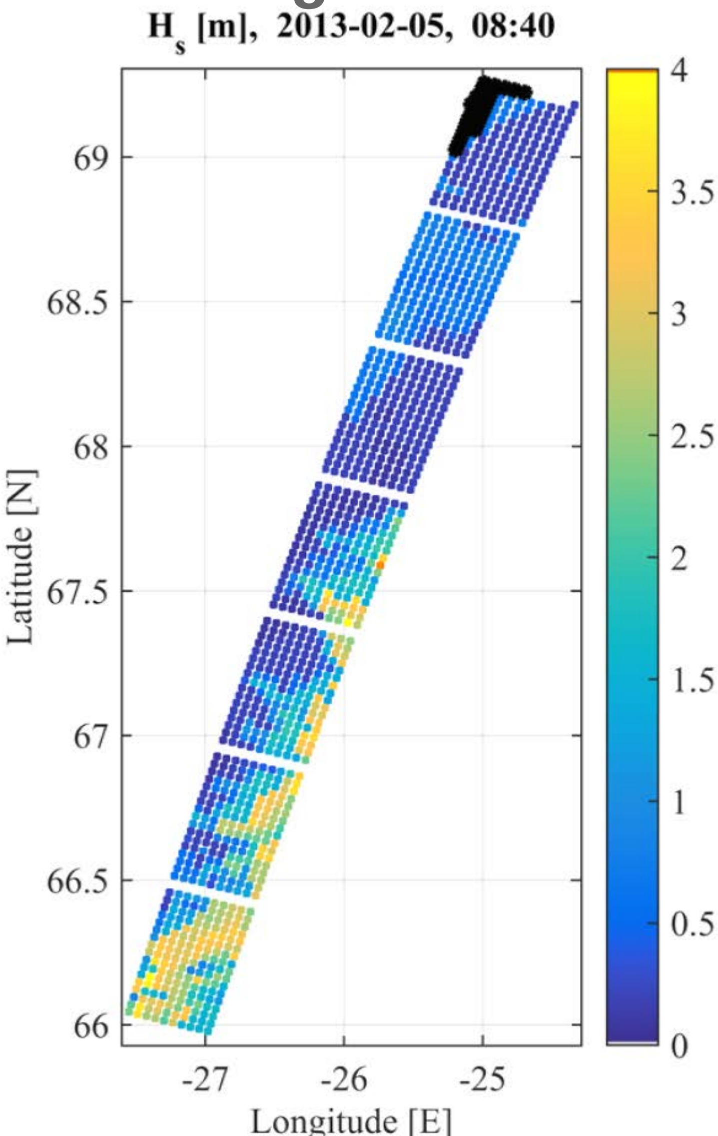


image2
image3
image4
image5
mean wave direction in ° (from north)
raster point number

Significant Wave Height at the Sea Ice Boundary



Swh starts from 3-4 m in the South in free open ocean

Decreases below 1m in the ice

Largest gradient of swh on the left

Dark appearance of grease ice on SAR image on the right are clearly related to Hs

XWAVE_Coast_1.9

Summary and Conclusions

-Spatial Ocean Wave Measurements over 300 km x 30 km between Greenland and Iceland in February 2013

-Measurements of 2D Spectra, Peak Wavelength and Direction, Significant Wave Height

- Comparison to ECMWF Wave Model

-Velocity Dispersion observable – leads to estimation of storm distance and ice thickness

-2 Peaks observed, with wave length 380m and 180m
-Measurement of behaviour in sea ice