Spatial wave field characteristics

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Summary:

- **Strong wave field variability present in open ocean, coastal ocean and partially ice covered ocean**
- **can be addressed with different methods**
- **need to address definition of dominant wave**

Funded by

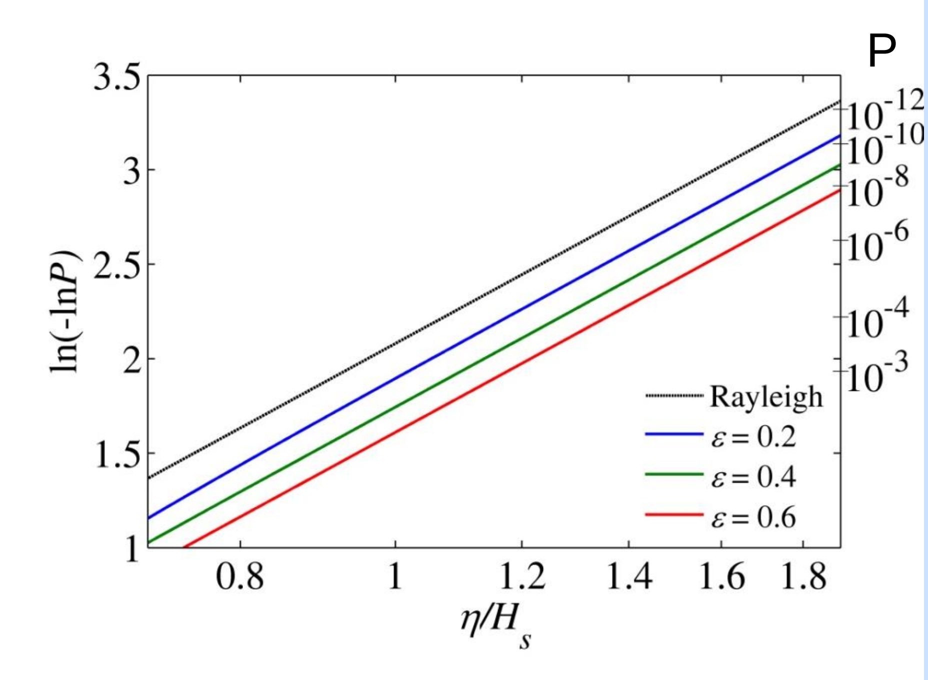
(Original) motivation:
Non-stationarity of wave field affects rogue wave statistics

Assume wave height time series with significant wave height H_s but 2 stationary halves:

$$H_1^2 = H_s^2(1+\varepsilon)$$
$$H_2^2 = H_s^2(1-\varepsilon)$$

(H_s is always calculated from entire record length)

$$P\left(\frac{\eta}{H_s} > z\right) = \frac{1}{2}\left[exp\left(\frac{-8z^2}{1+\varepsilon}\right) + exp\left(\frac{-8z^2}{1-\varepsilon}\right)\right]$$

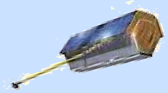


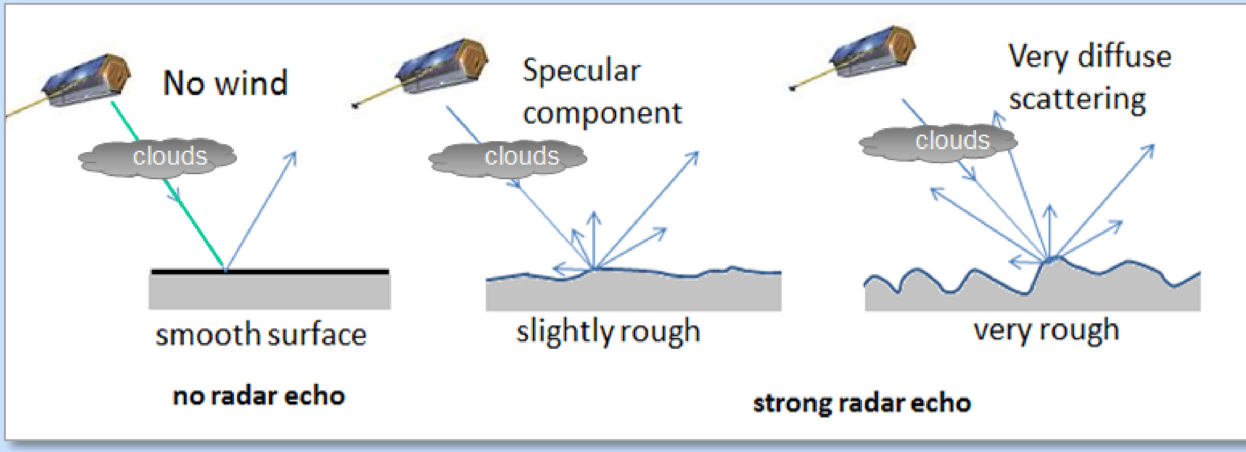
Rogue wave occurrence in a non-stationary record of two equal length parts (coloured lines) is much higher than if the record were treated as 2 stationary parts (black).

From Gemmrich & Garrett, NHESS 2011

What about spatial inhomogeneity of wave field?

Methods (remote sensing): TerraSAR-X (DLR)

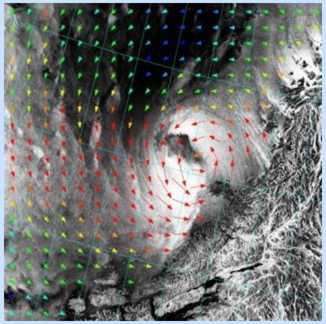




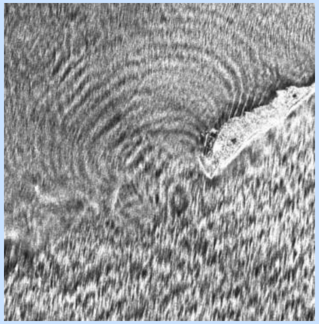
- **Sunlight independent (active sensor)**
- **Signal penetrates the clouds**
- **1.25m resolution**
- **Swath width: 30 km**

Empirical algorithms for retrieval of
- significant wave height
- wind speed

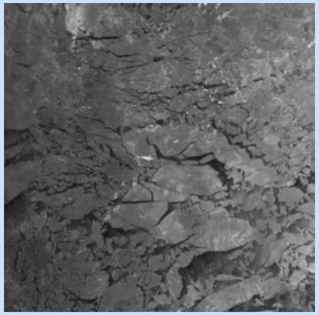
(M. Bruck 2015; A. Pleskachevsky 2015)



Wind

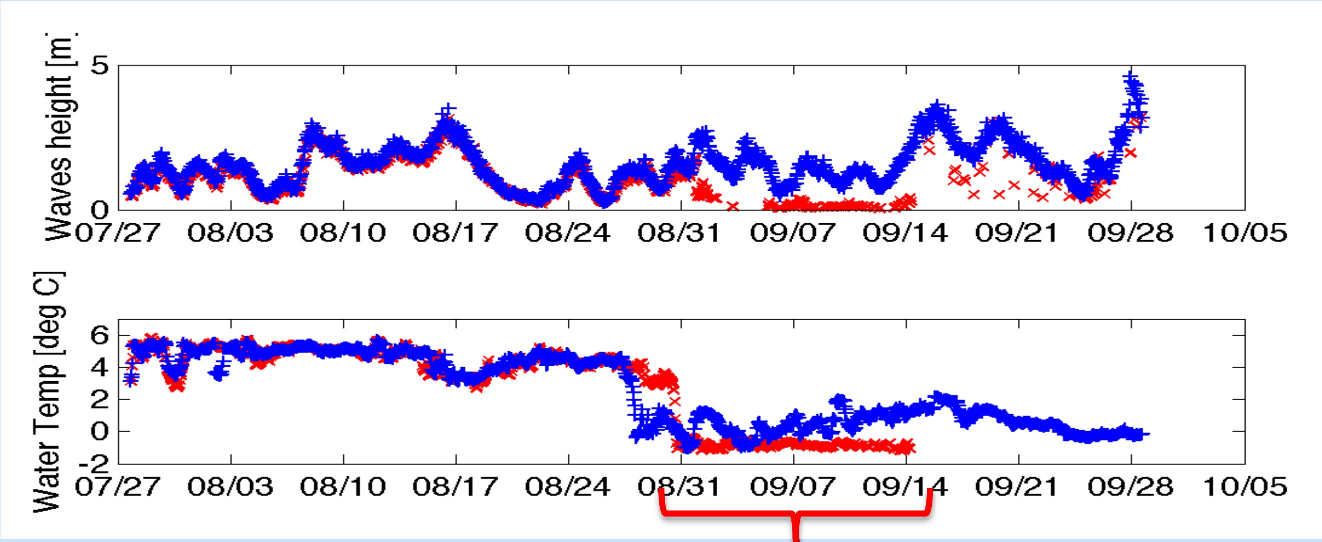


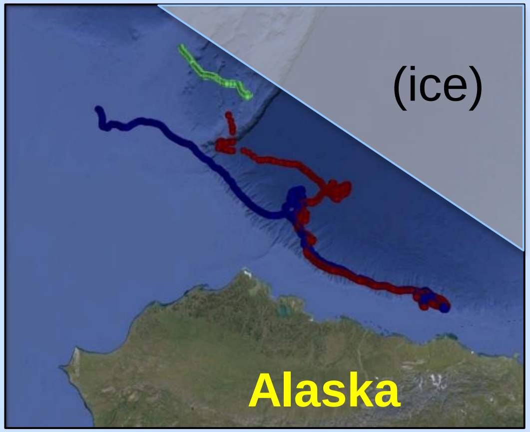
Sea State



Ice and Icebergs

Methods (in-situ): SWIFT , waveglider (APL)





Methods (model): WAVEWATCH-III® model (NRL)

$$\frac{\partial N}{\partial t} + \nabla \cdot \vec{c} N = \frac{S}{\sigma}$$

$$S = S_{in} + S_{ds} + S_{nl4}$$

N = spectral density of wave action
c = propagation speed
k = wave number
σ = relative radial wave frequency
Θ = wave direction

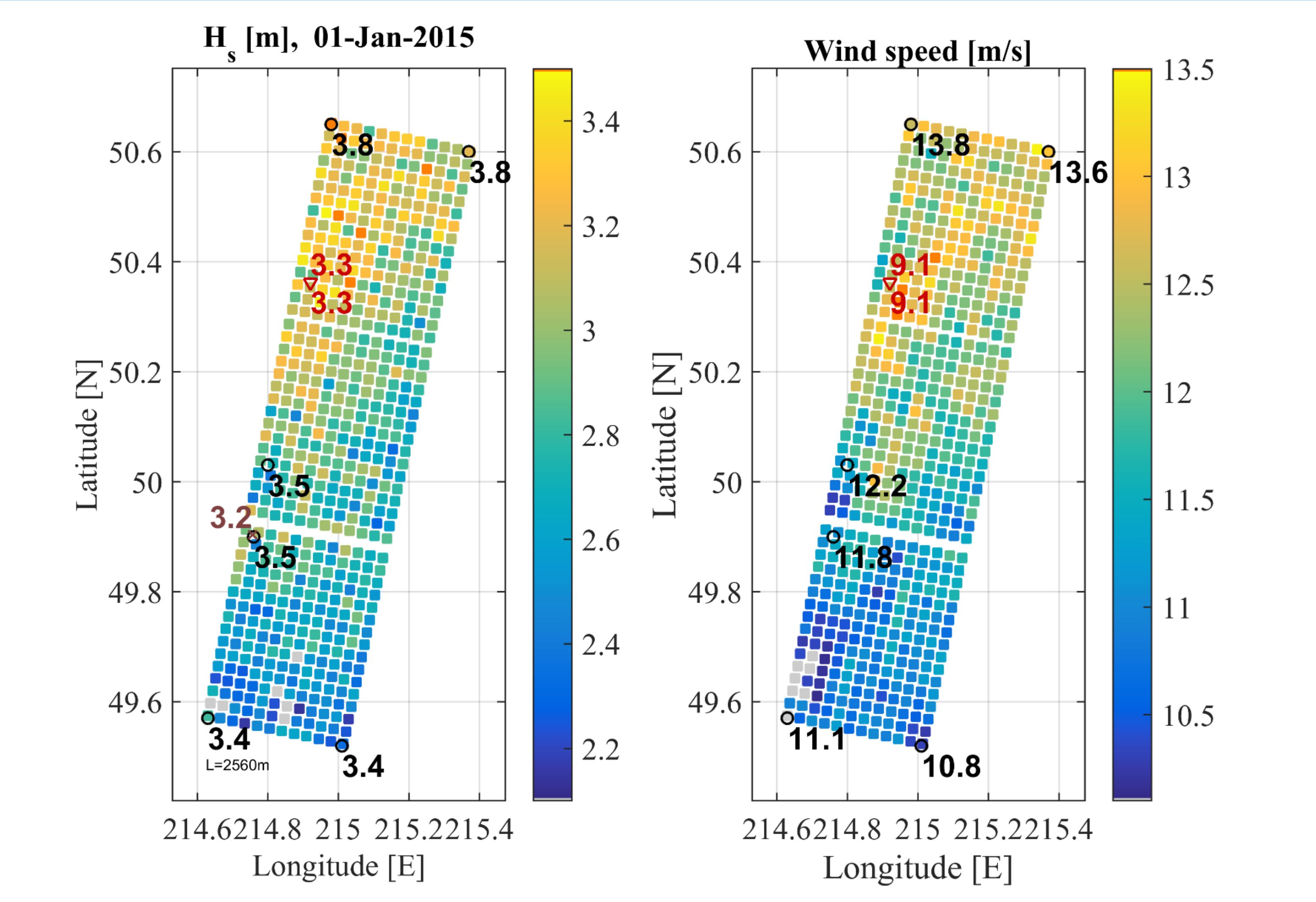
$$S_{ds} = S_{br} + S_{bot} + \underbrace{S_{ice}}_{\text{new}}$$

- polar stereographic grid, **~16 km resolution**
- **ice source function** S_{ice} by NRL (Rogers & Zieger, 2014)
- thin ice: Visco-elastic model (Wang & Shen, JGR, 2010)
- thick ice: "turbulence under ice" dissipation (Ardhuin, pers. com.)
- **ice concentration** and thickness: Navy implementation of CICE
- **winds**: operational analyses (NAVGEM)

Results:

2 case studies in open ocean (North Pacific, Station P)
1 case study in coastal ocean (Hecate Strait, BC coast)
2 case studies in partially ice covered ocean (Beaufort Sea)

Open ocean (1): remote sensing H_s and wind speed

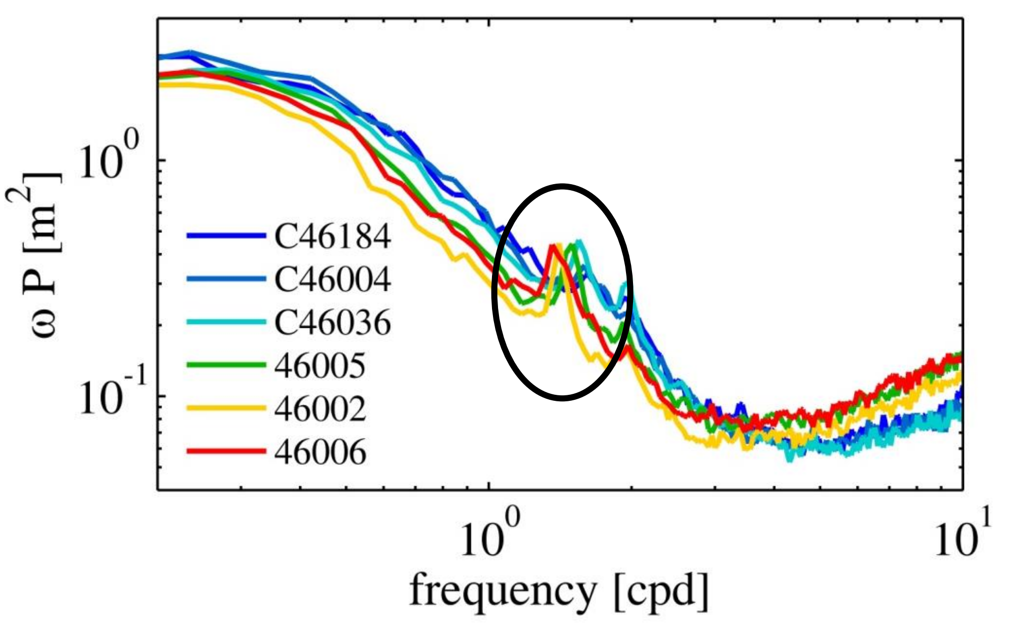


black: WW3 model results/input
red: SWIFT measurement
magenta: wave buoy measurement

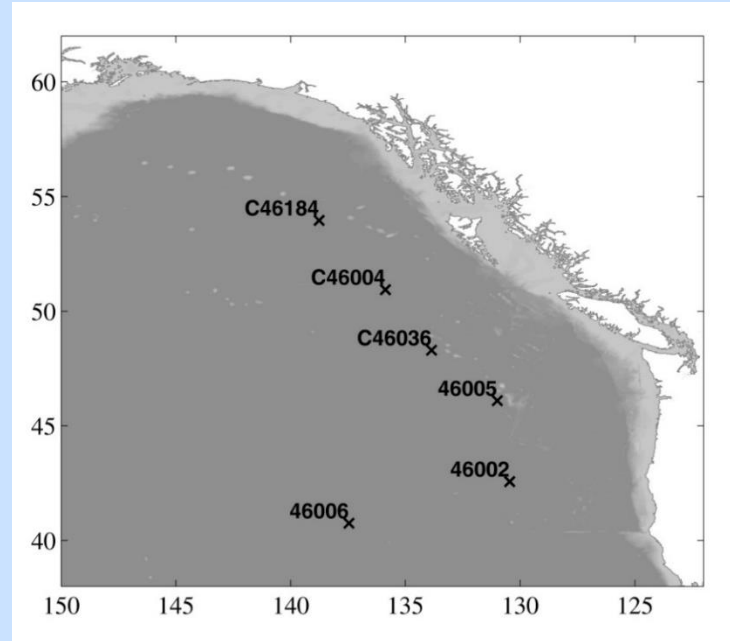
WW3: ΔH_s = 0.4 m, Δu = 3m/s
TSX: ΔH_s = 1.0 m, Δu = 3m/s

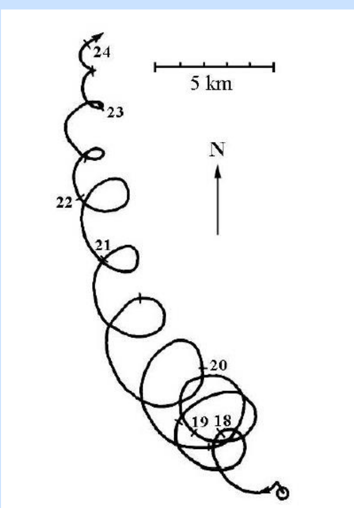
Waves interacting with wind-induced inertial currents

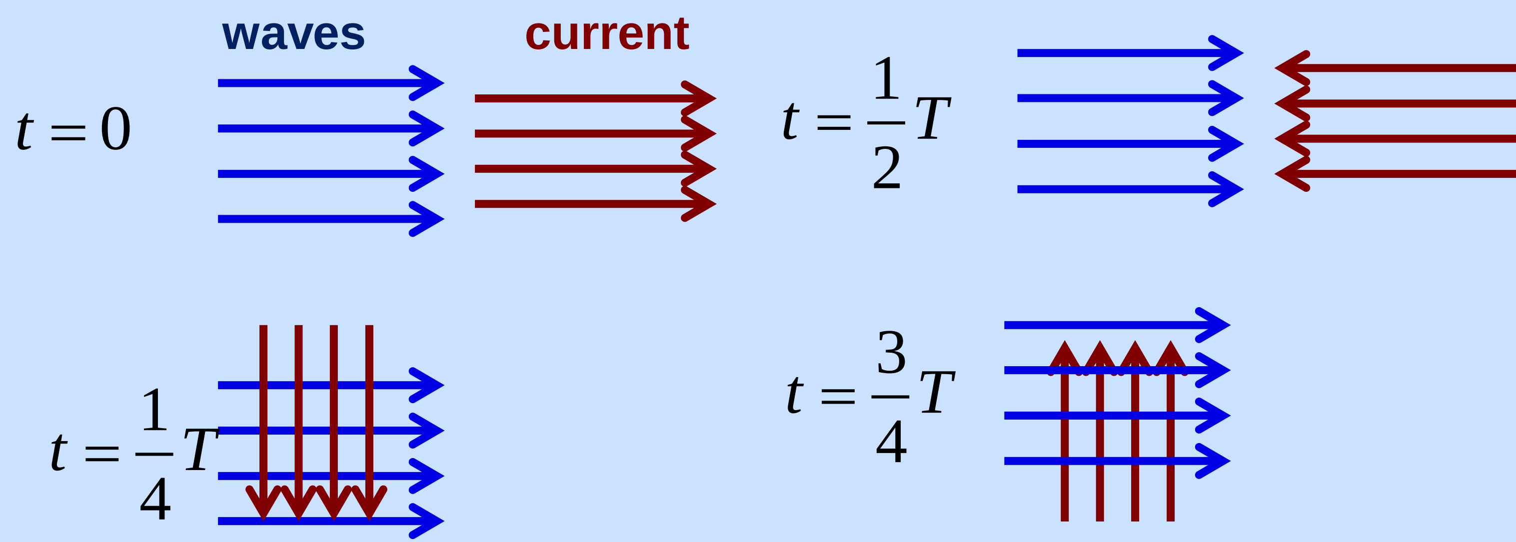
Significant wave heights, offshore NE Pacific



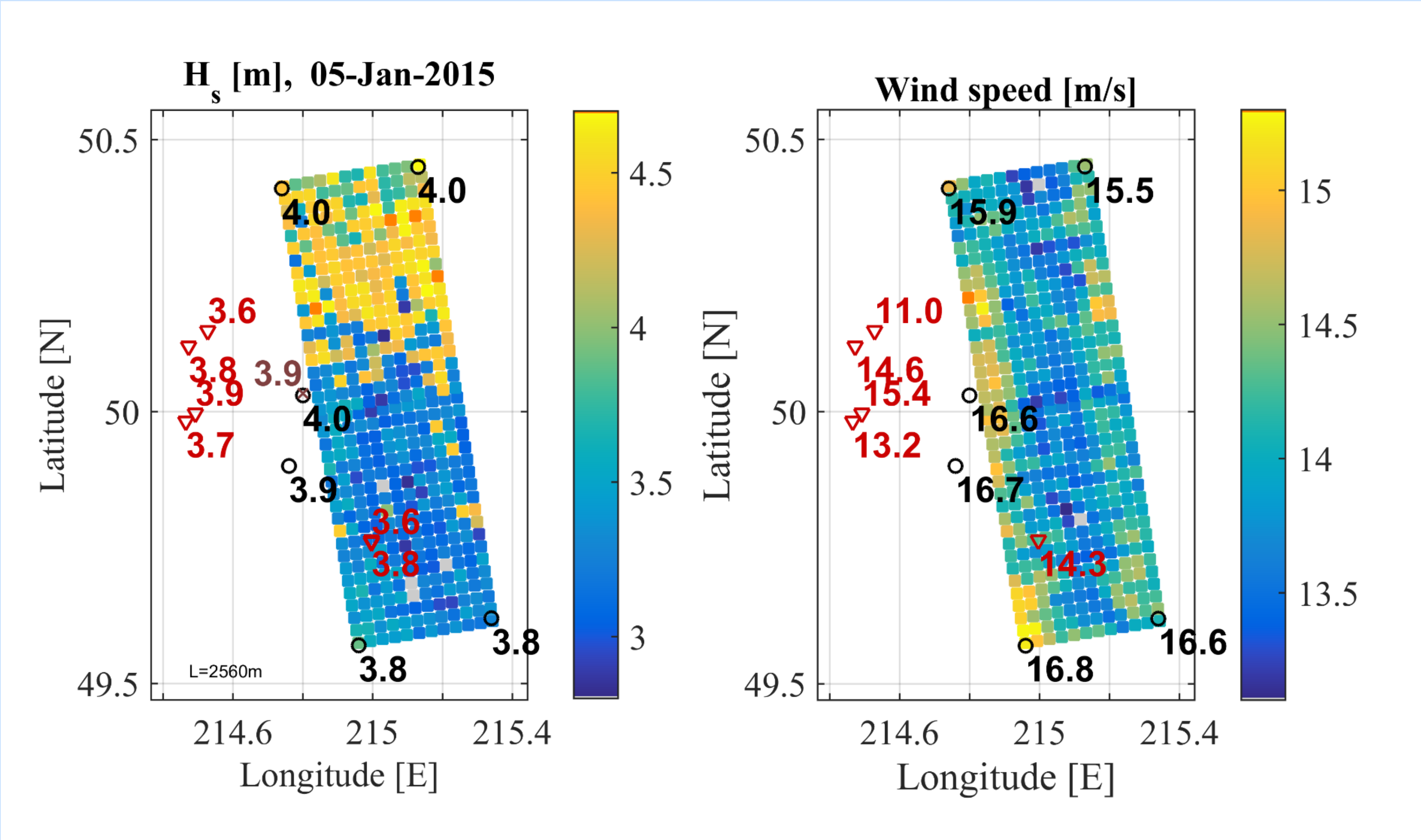
See Gemmrich & Garrett, JPO 2012







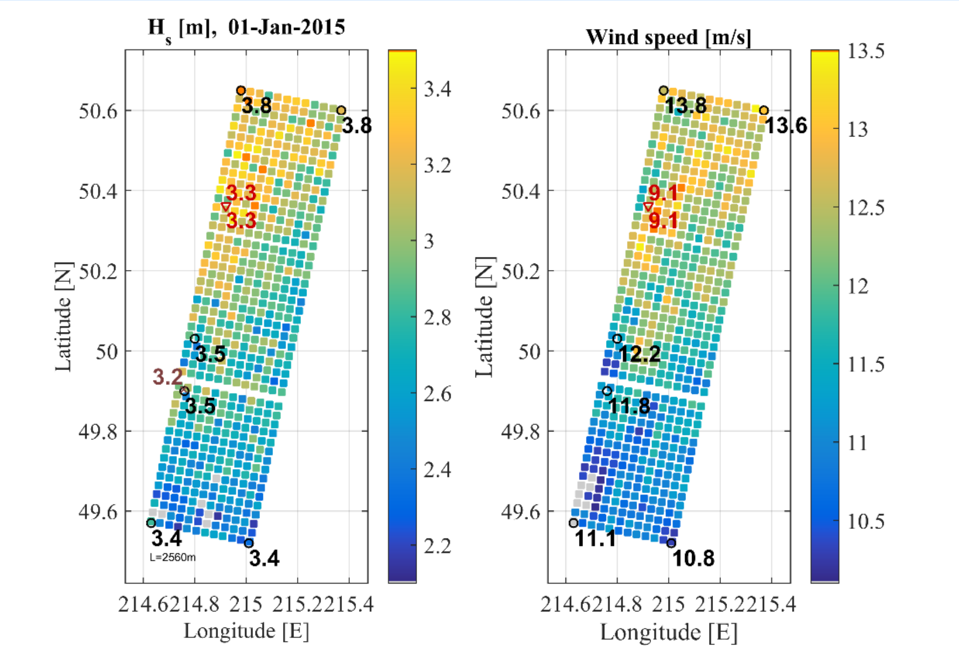
Open ocean (2): remote sensing H_s and wind speed



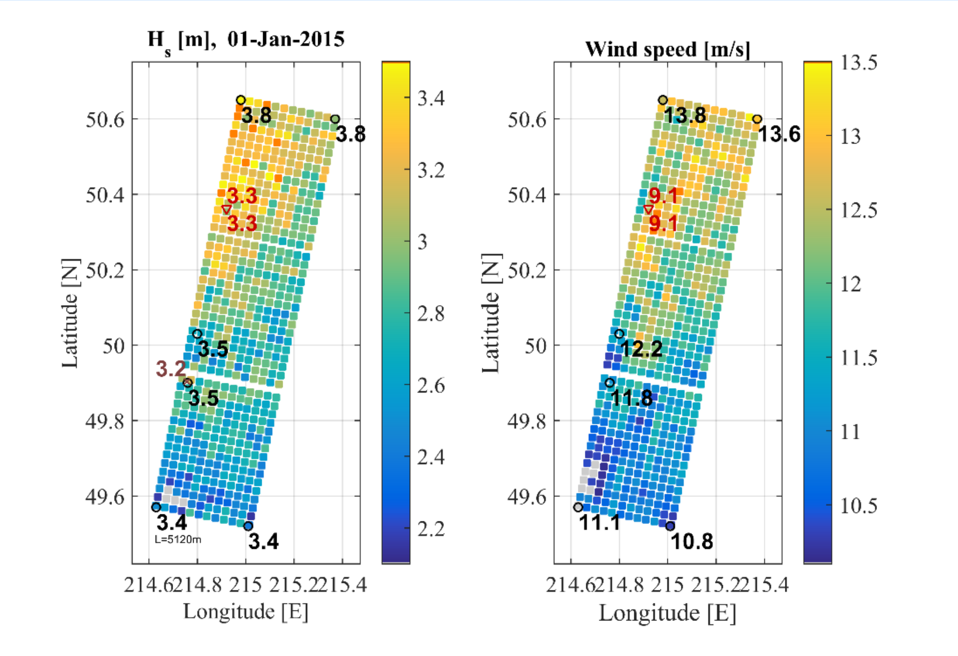
black: WW3 model results/input
red: SWIFT measurement
magenta: wave buoy measurement

WW3: ΔH_s = 0.2 m
TSX: ΔH_s = 1.0 m

Record size, open ocean (1). (Spatial → temporal record length)

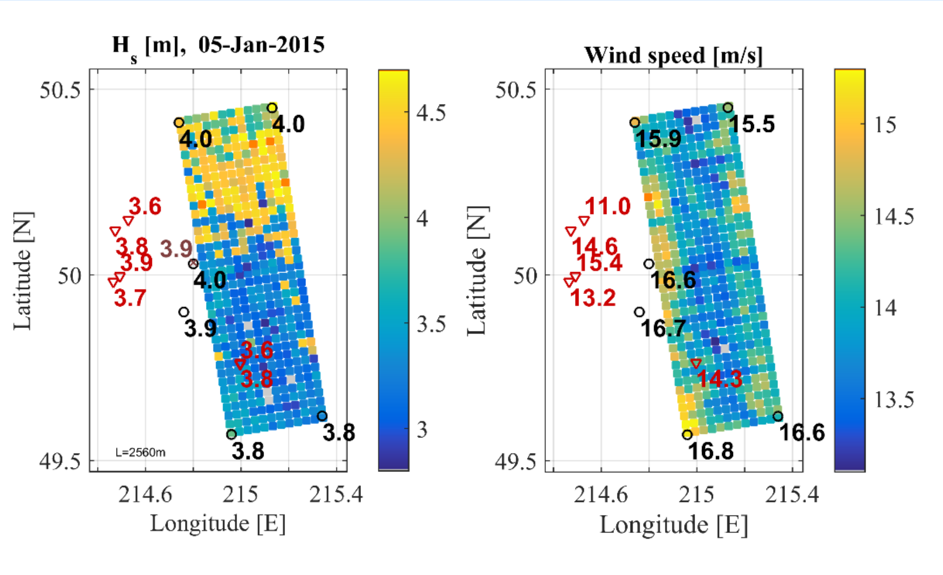


Wave/wind parameters based on
2560m x 2560m area
≈ 28 wave lengths
→ equivalent to 45 min record

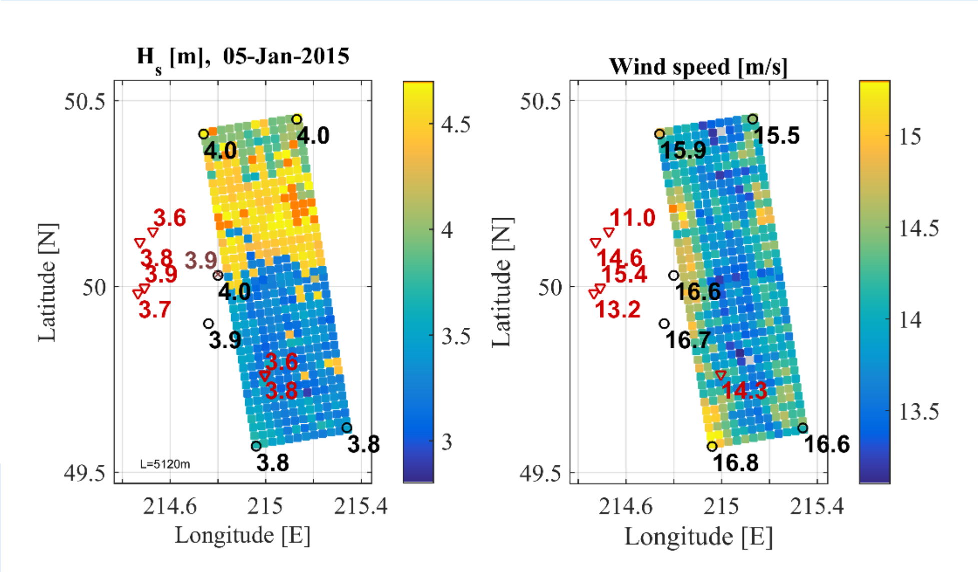


Wave/wind parameters based on
5120m x 5120m area
≈ 56 wave lengths
→ equivalent to 3 h record

Record size, open ocean (2). (Spatial → temporal record length)



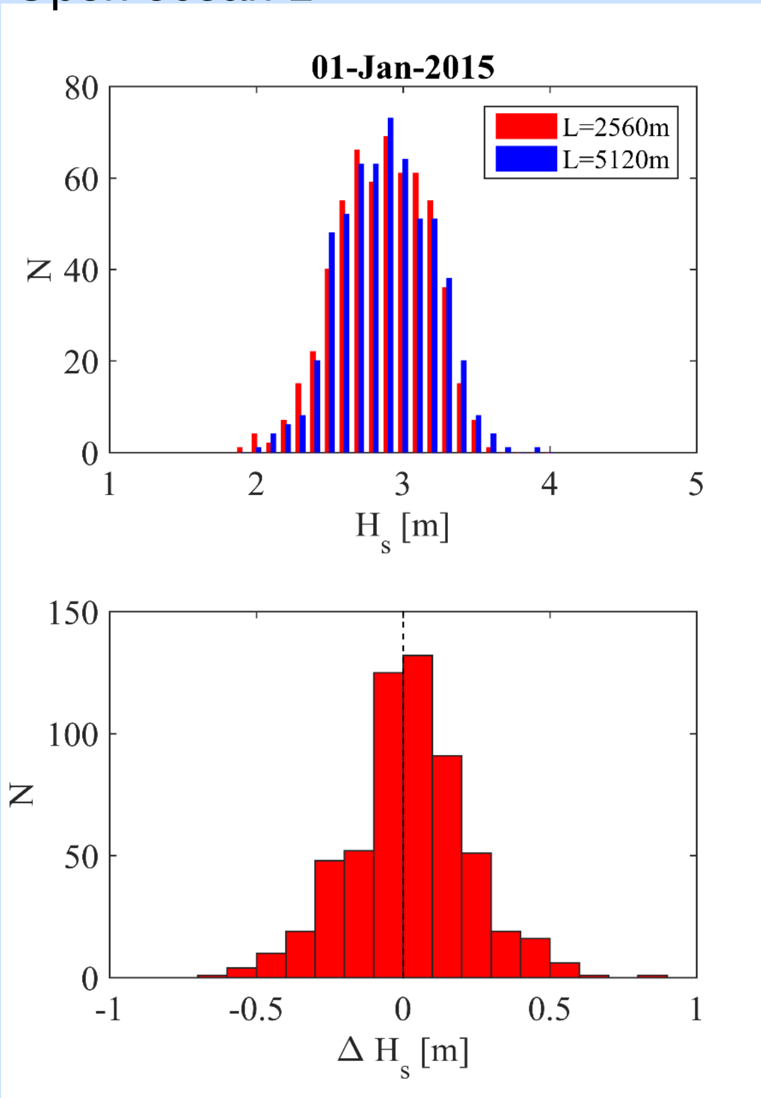
Wave/wind parameters based on
2560m x 2560m area
≈ 13 wave lengths
→ equivalent to 15 min record



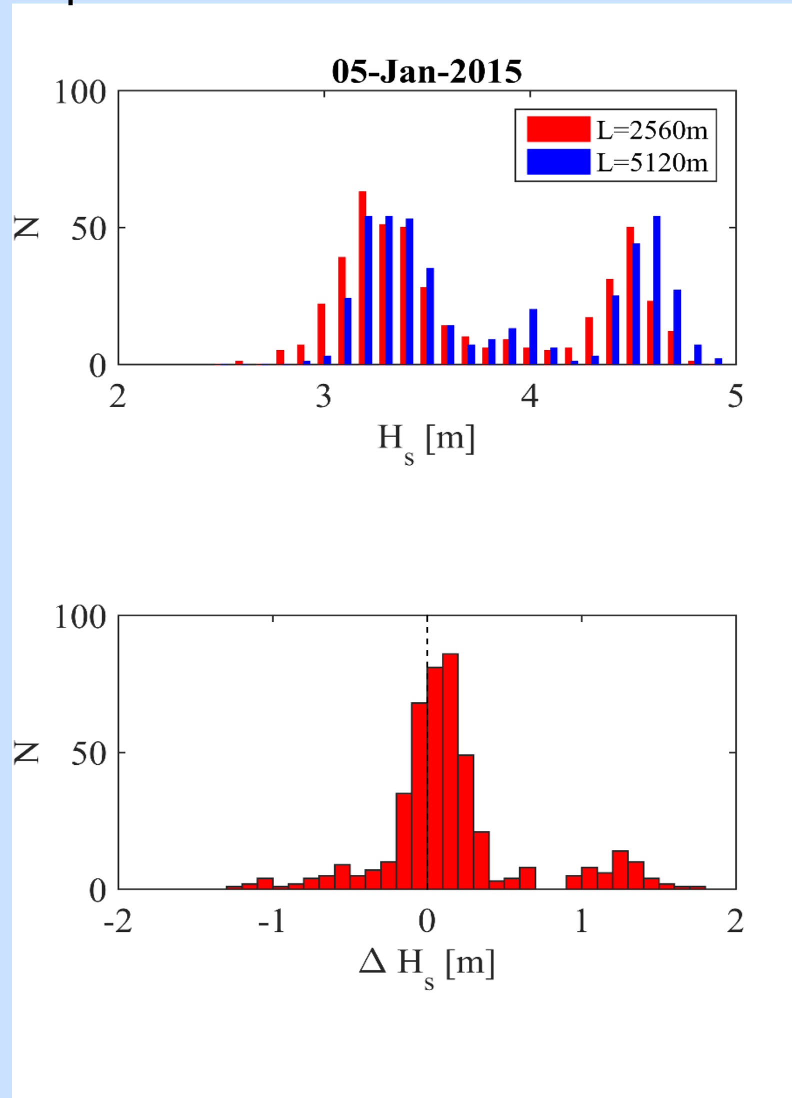
Wave/wind parameters based on
5120m x 5120m area
≈ 26 wave length
→ equivalent to 1h record

Record size

Open ocean 1



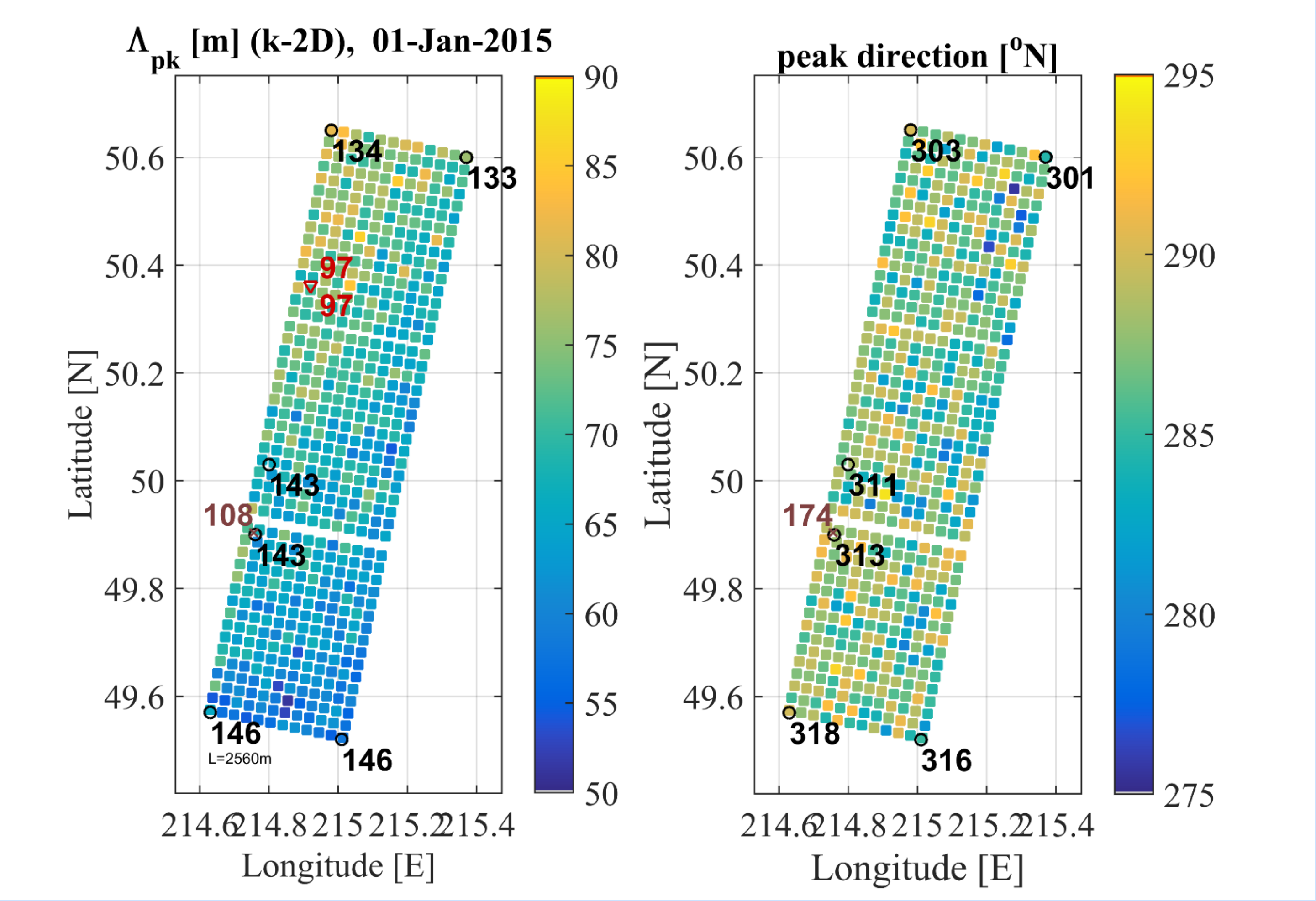
Open ocean 2



56 – 28 wave lengths record size: Little effect

26 – 13 wave lengths record size: Larger area → greater H_s

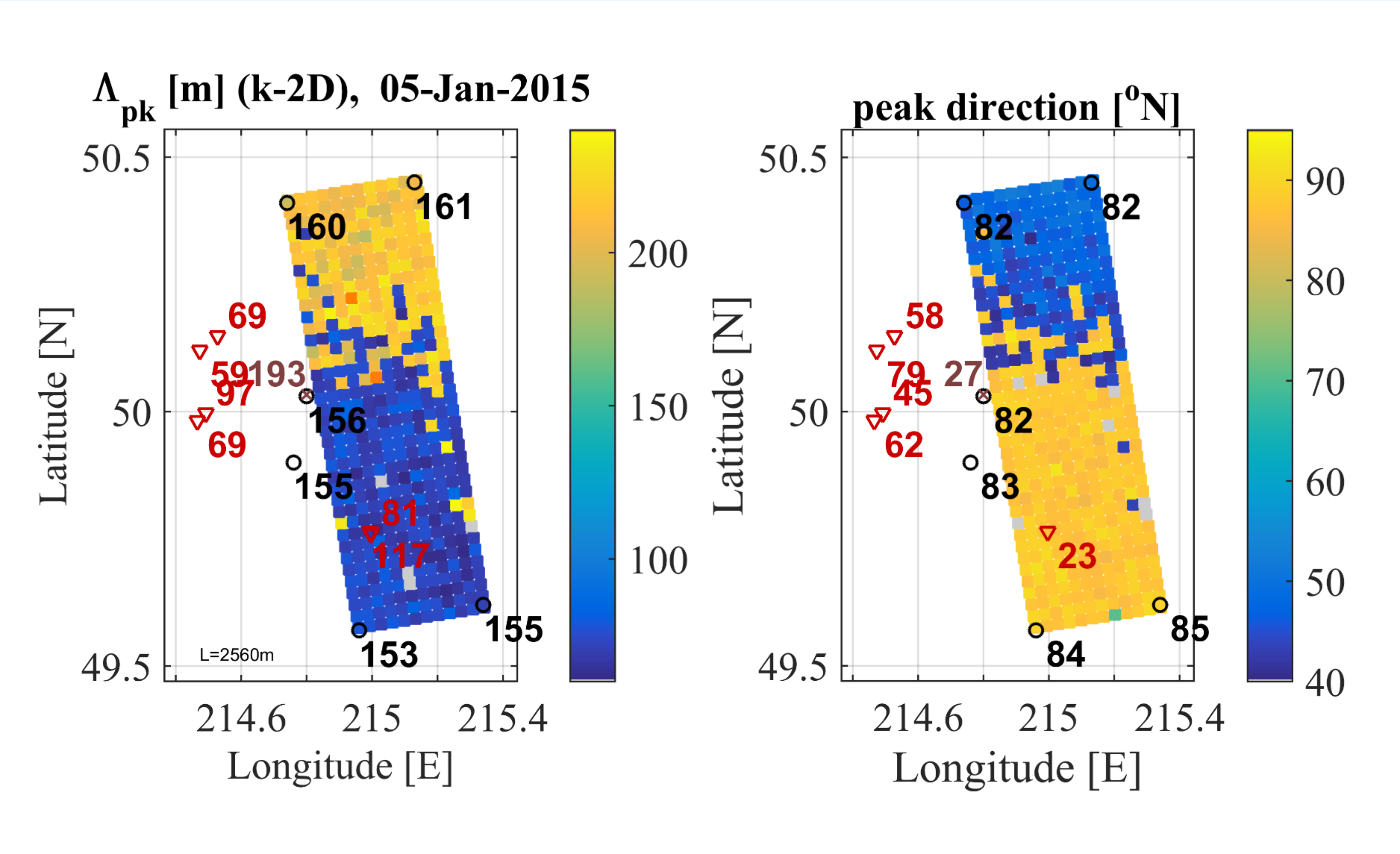
Open ocean (1): dominant wave length, and direction



WW3:	$\lambda \approx$140 m
TSX:	$\lambda \approx$ 70 m
Datawell:	$\lambda \approx$110 m
SWIFT:	$\lambda \approx$100 m

black: WW3 model results/input
red: SWIFT measurement
magenta: wave buoy measurement

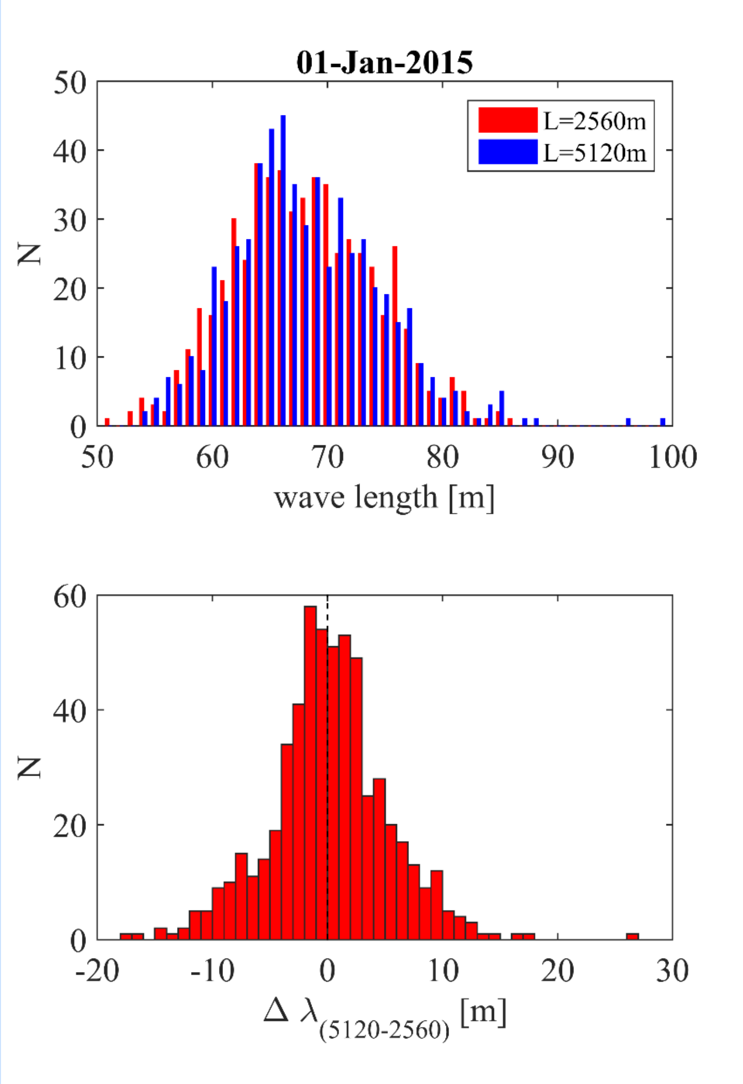
Open ocean (2): dominant wave length, and direction

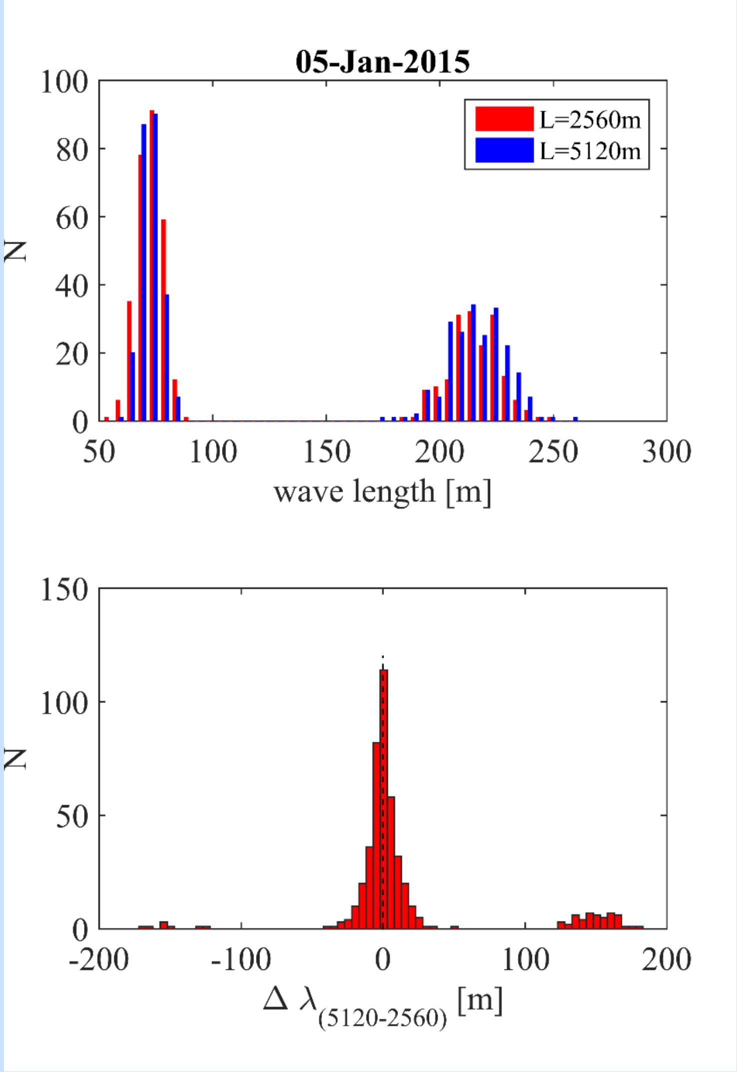


black: WW3 model results/input
red: SWIFT measurement
magenta: wave buoy measurement

WW3: $\lambda \approx 160$ m
TSX: $\lambda \approx 90 \rightarrow 220$ m
Datawell: $\lambda \approx 190$ m
SWIFT: $\lambda \approx 70$ m

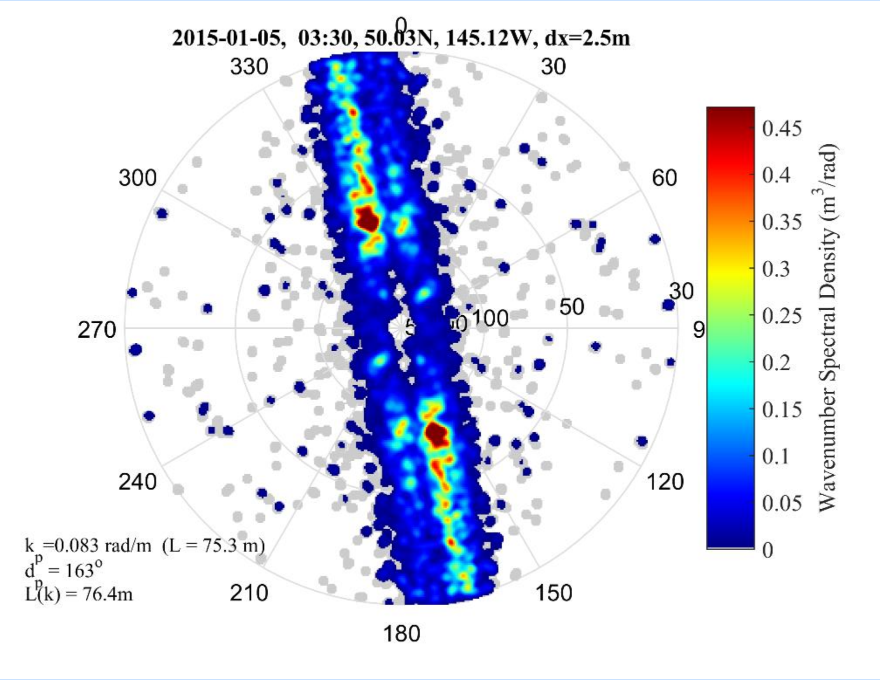
Open ocean: dominant wave length, and direction – record size

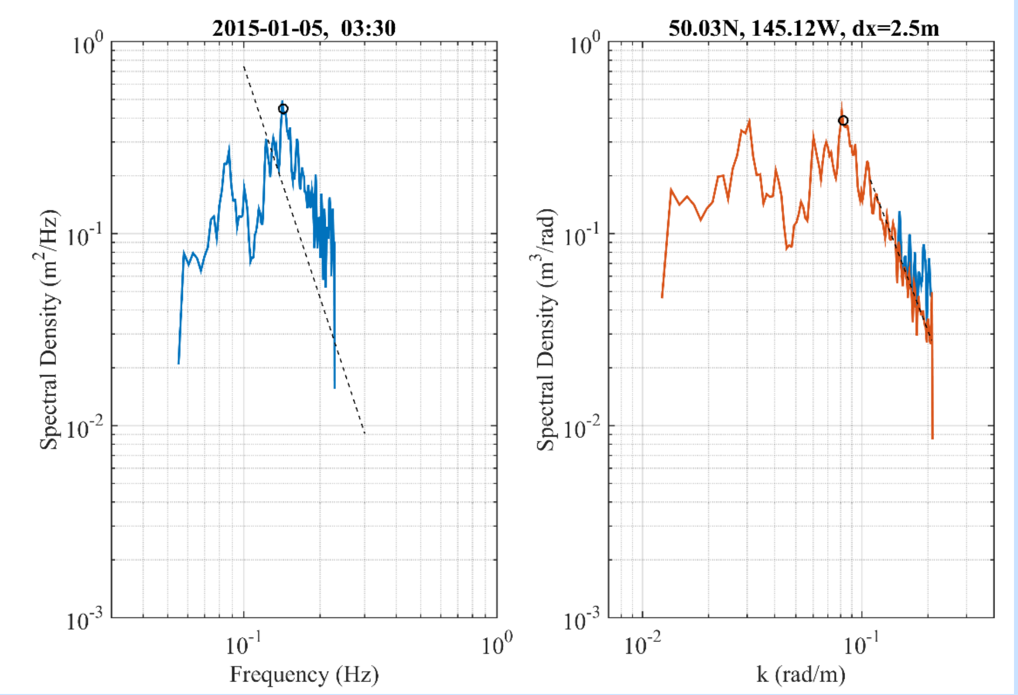




Little effect of record size on wave length retrieval

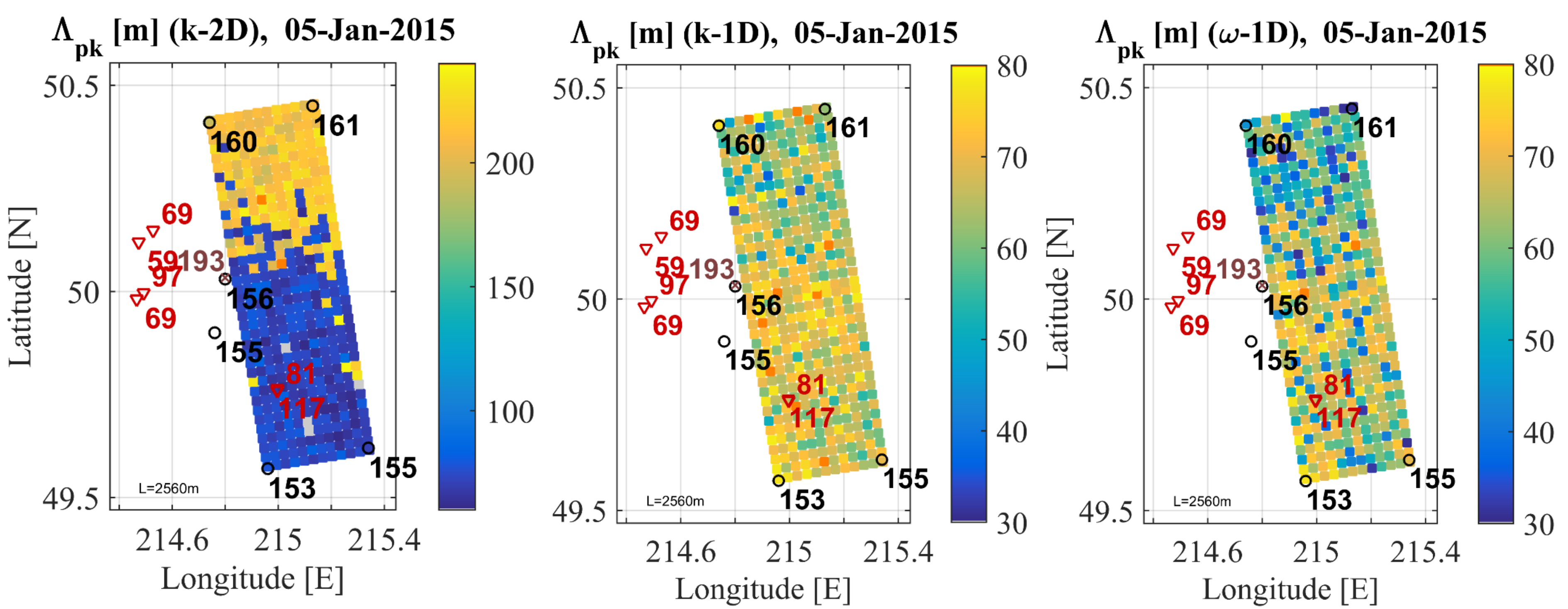
What is the dominant wave length ?





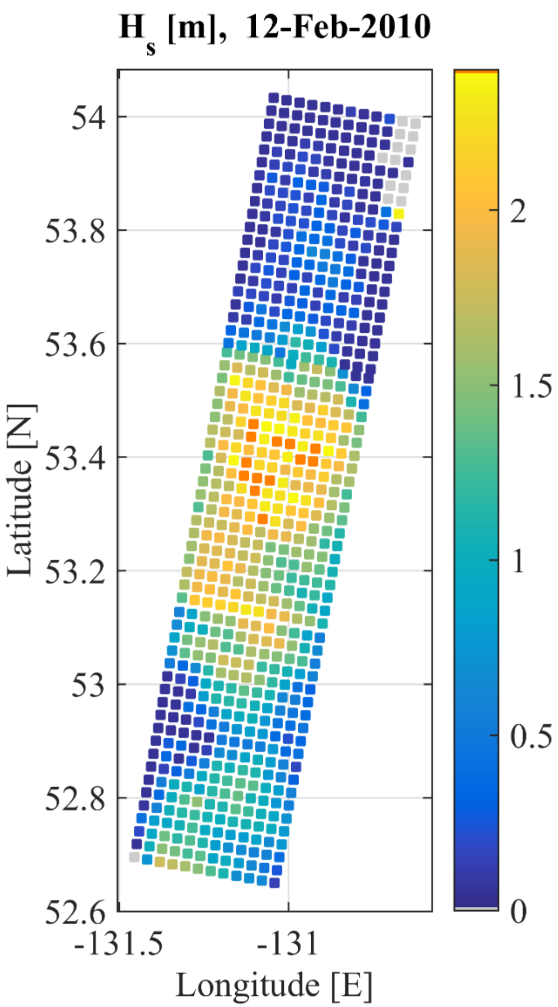
2-D k-spectrum, 1-D ω-spectrum, 1-D k-spectrum

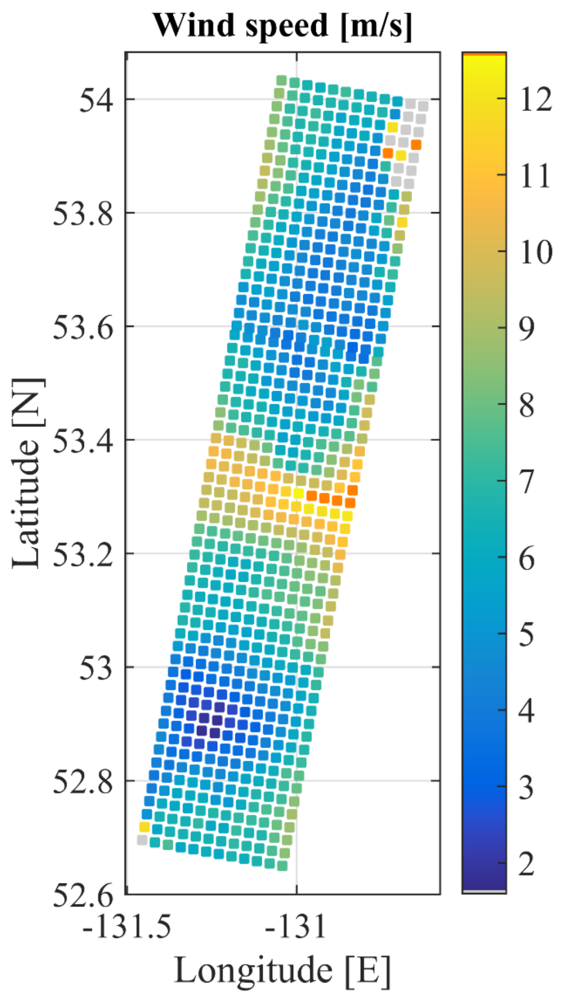
What is the dominant wave length ?

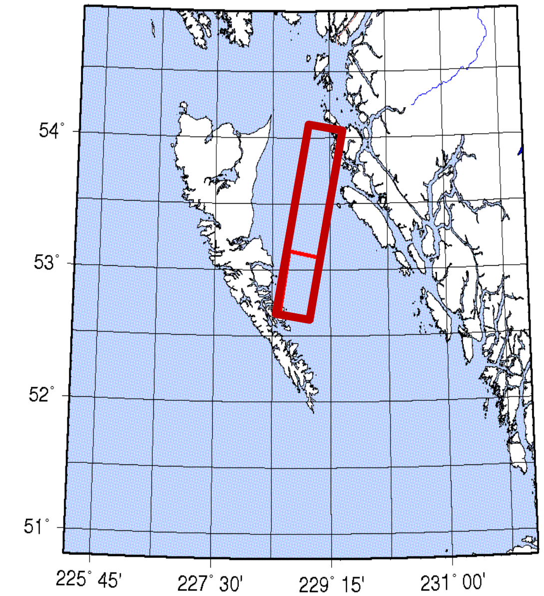


2-D k-spectrum resolves old and new wave filed
1-D k-spectrum: only new wave field
1-D ω-spectrum: only new wave field, smaller values

Coastal ocean: remote sensing H_s and wind speed

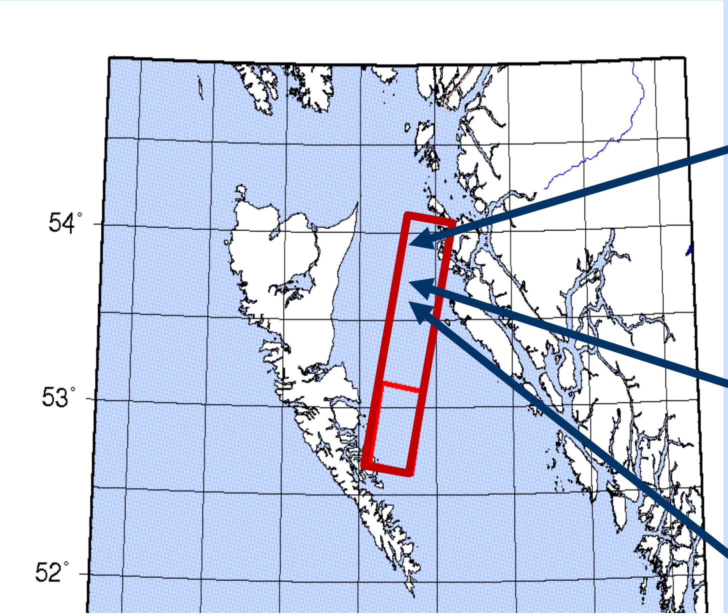


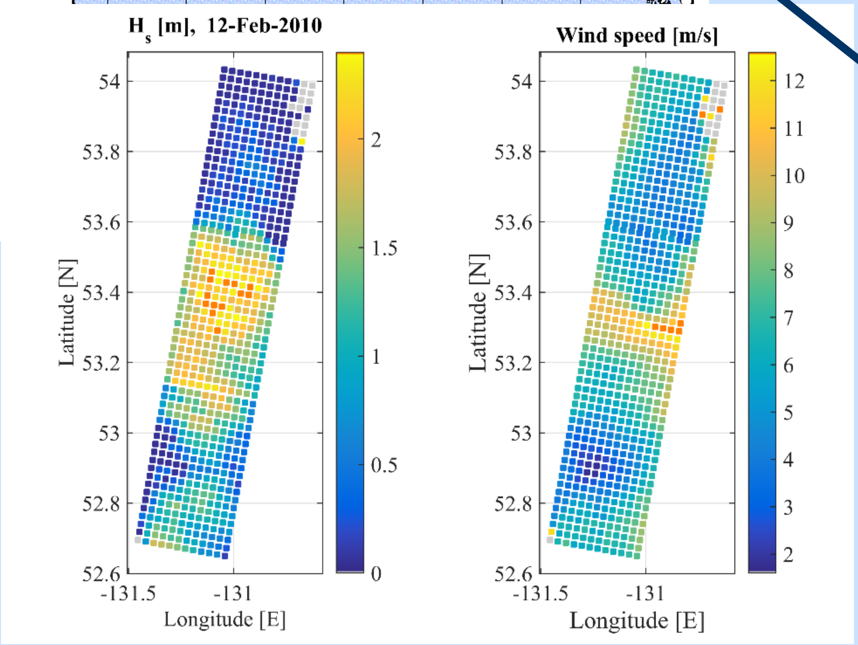


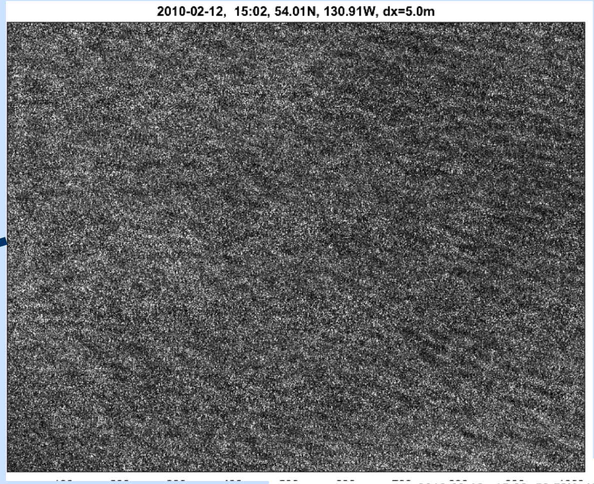


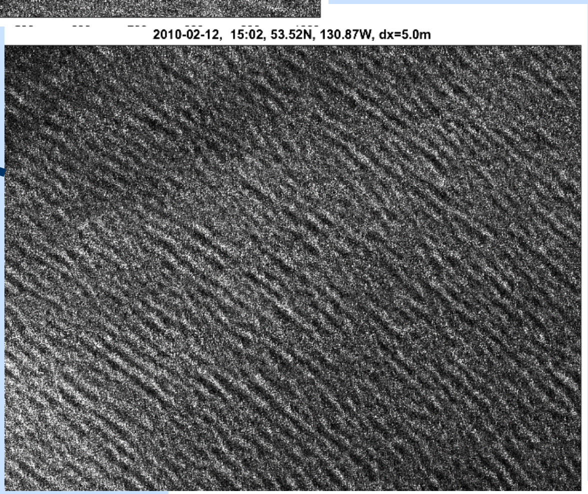
ΔH_s = 1.5 m along 20km

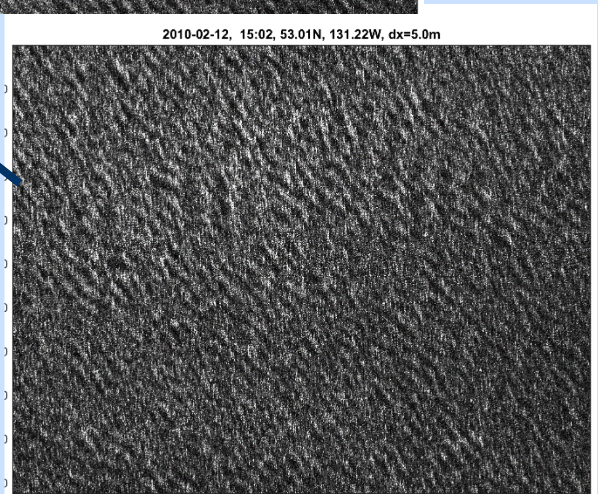
H_s variability



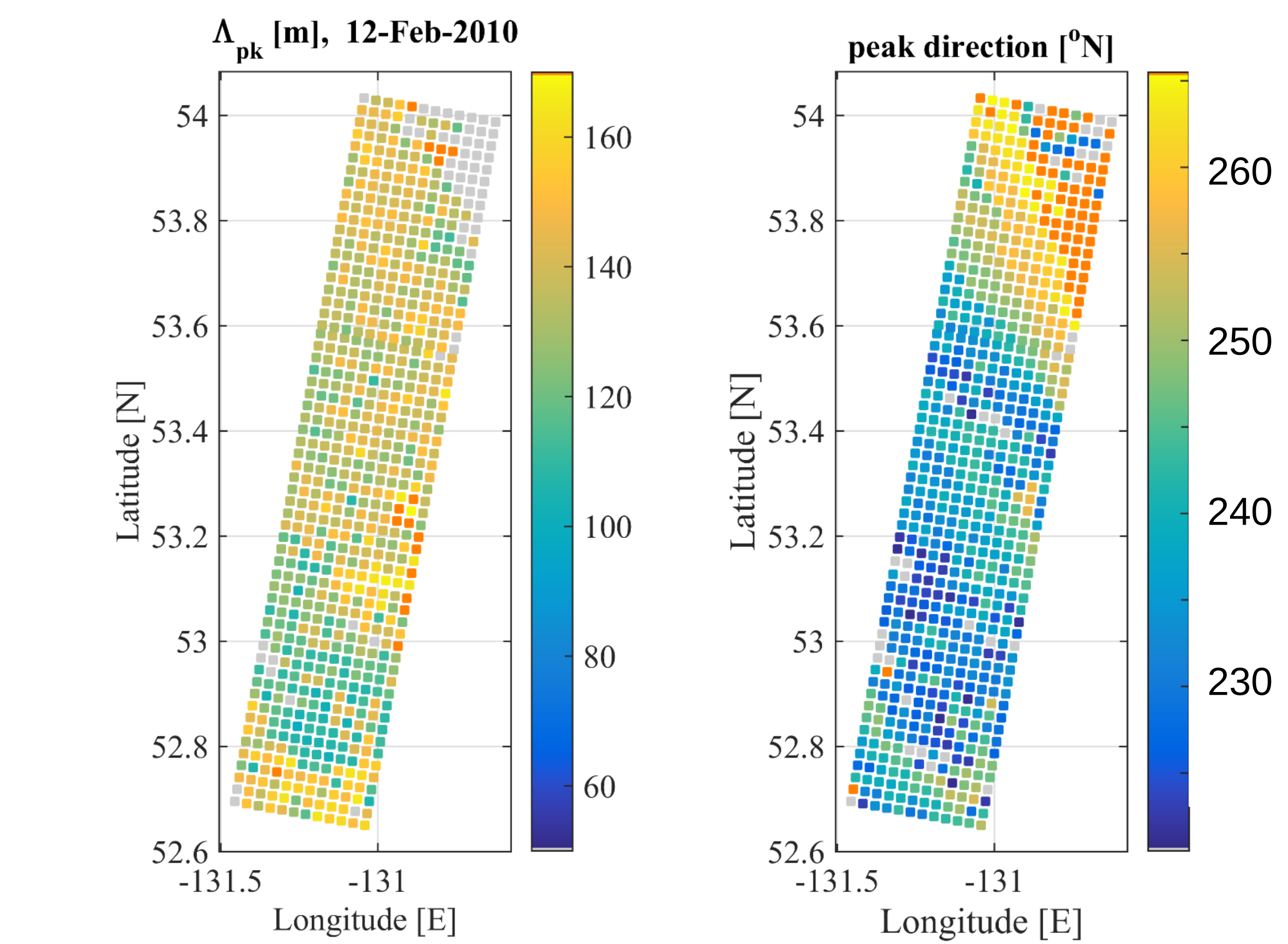


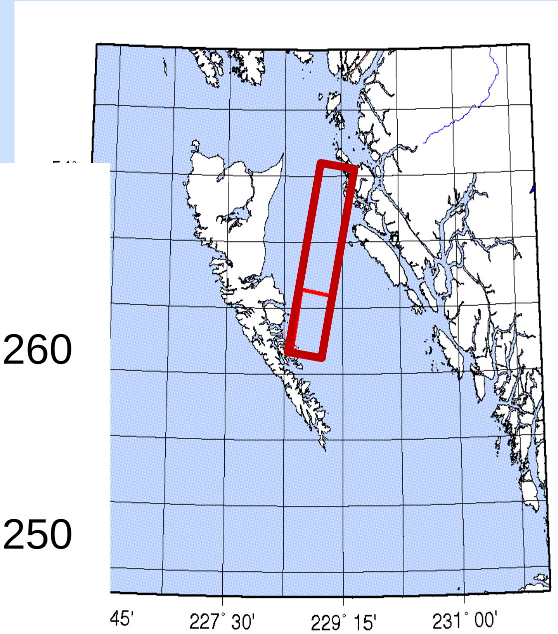




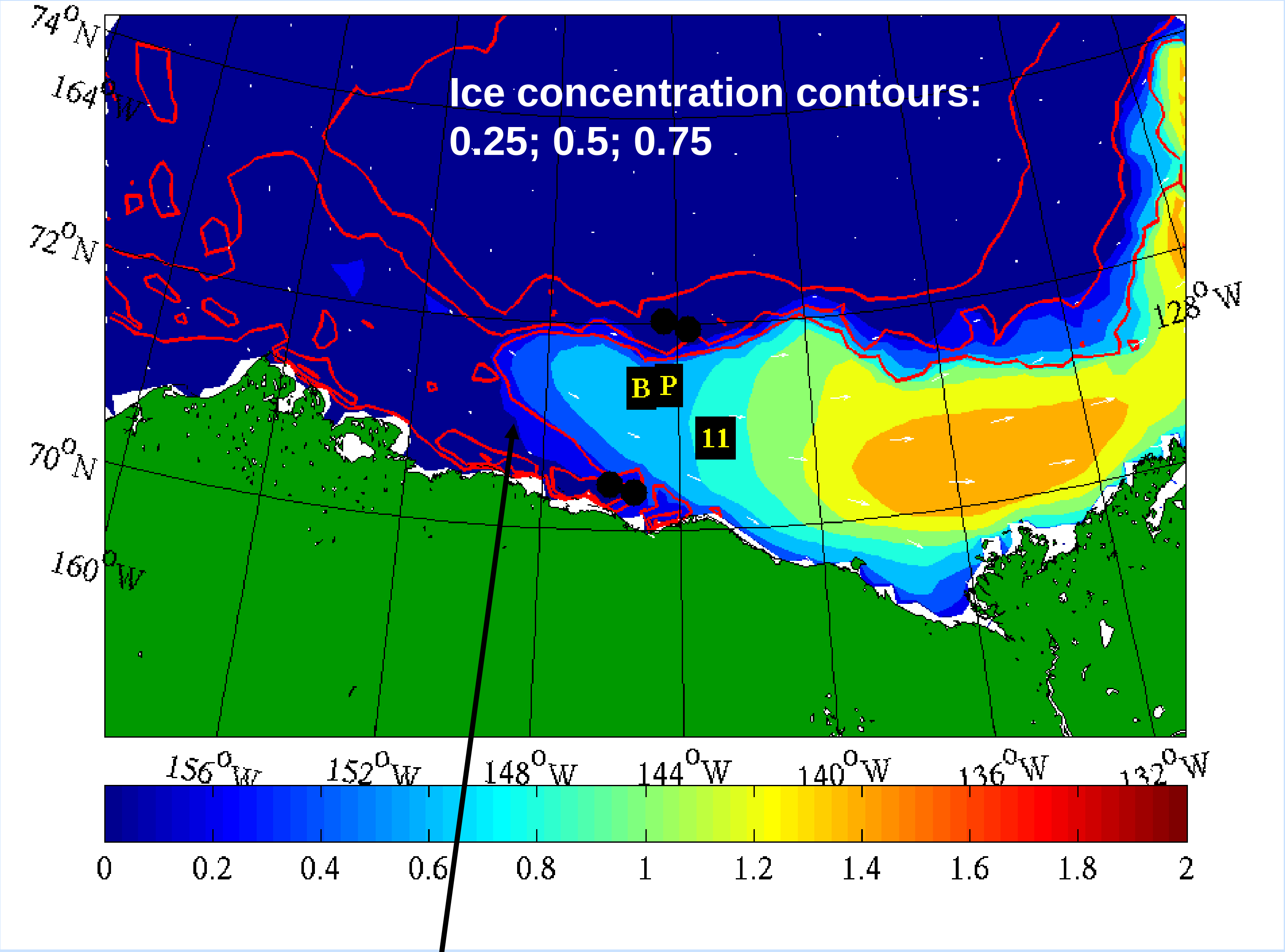


Coastal ocean: dominant wave length and direction



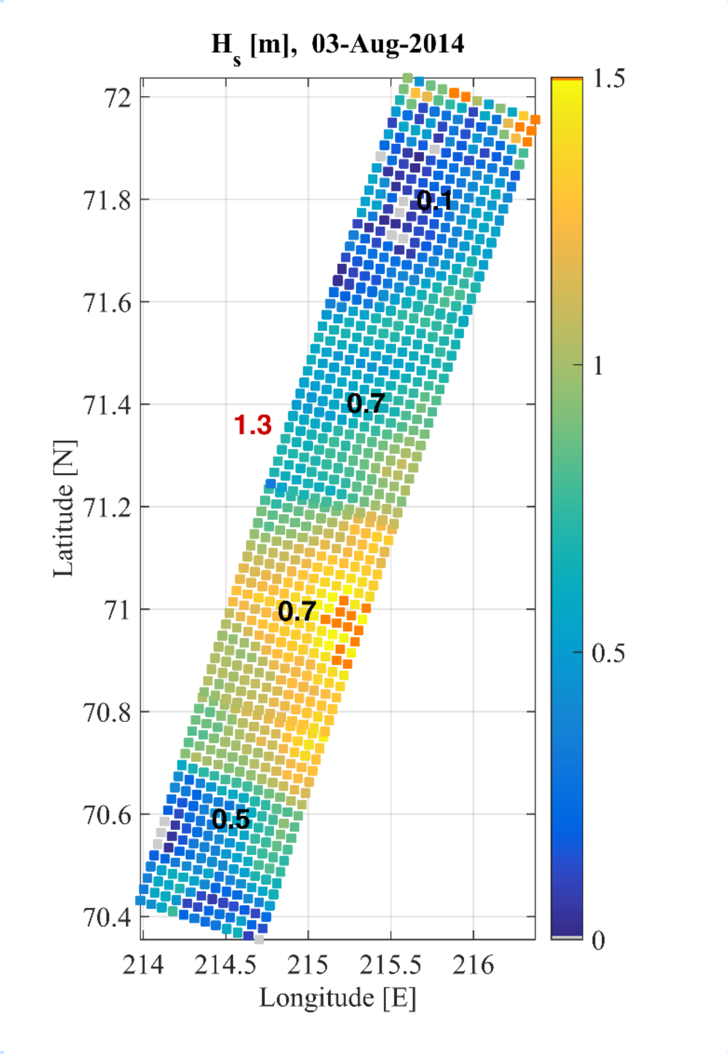


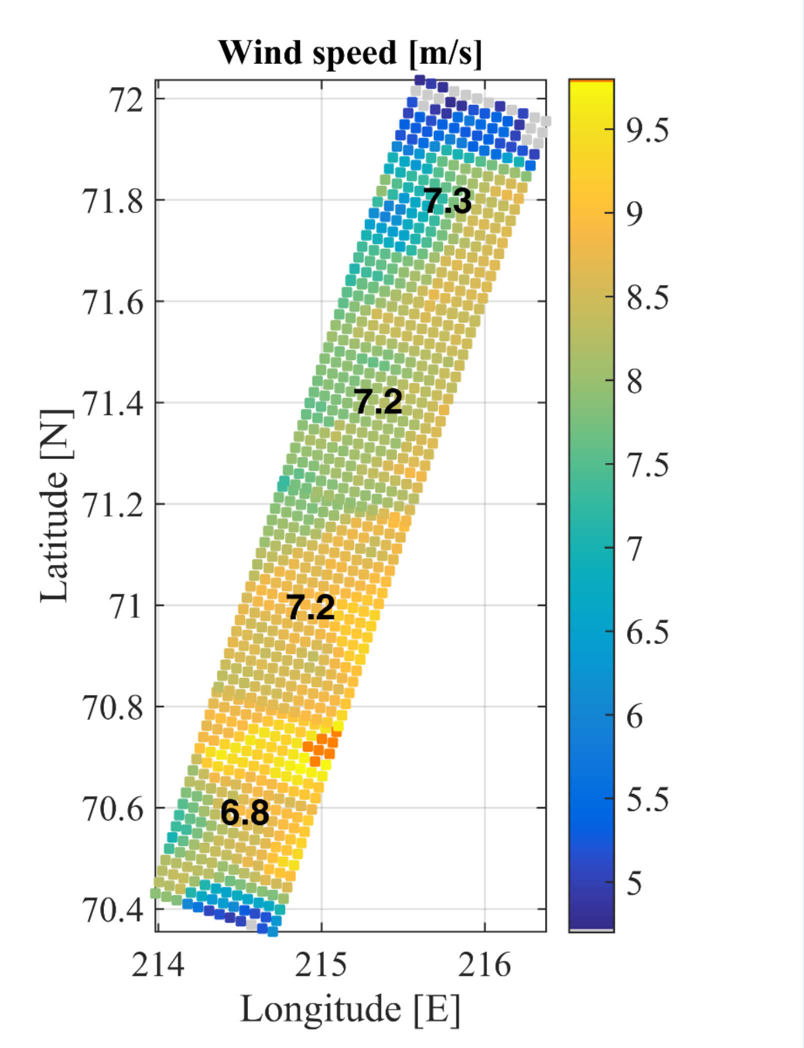
Beaufort Sea, partially ice covered (Aug 3): Model H_s



Fetch limitation

Partially ice covered:
remote sensing H_s and wind speed

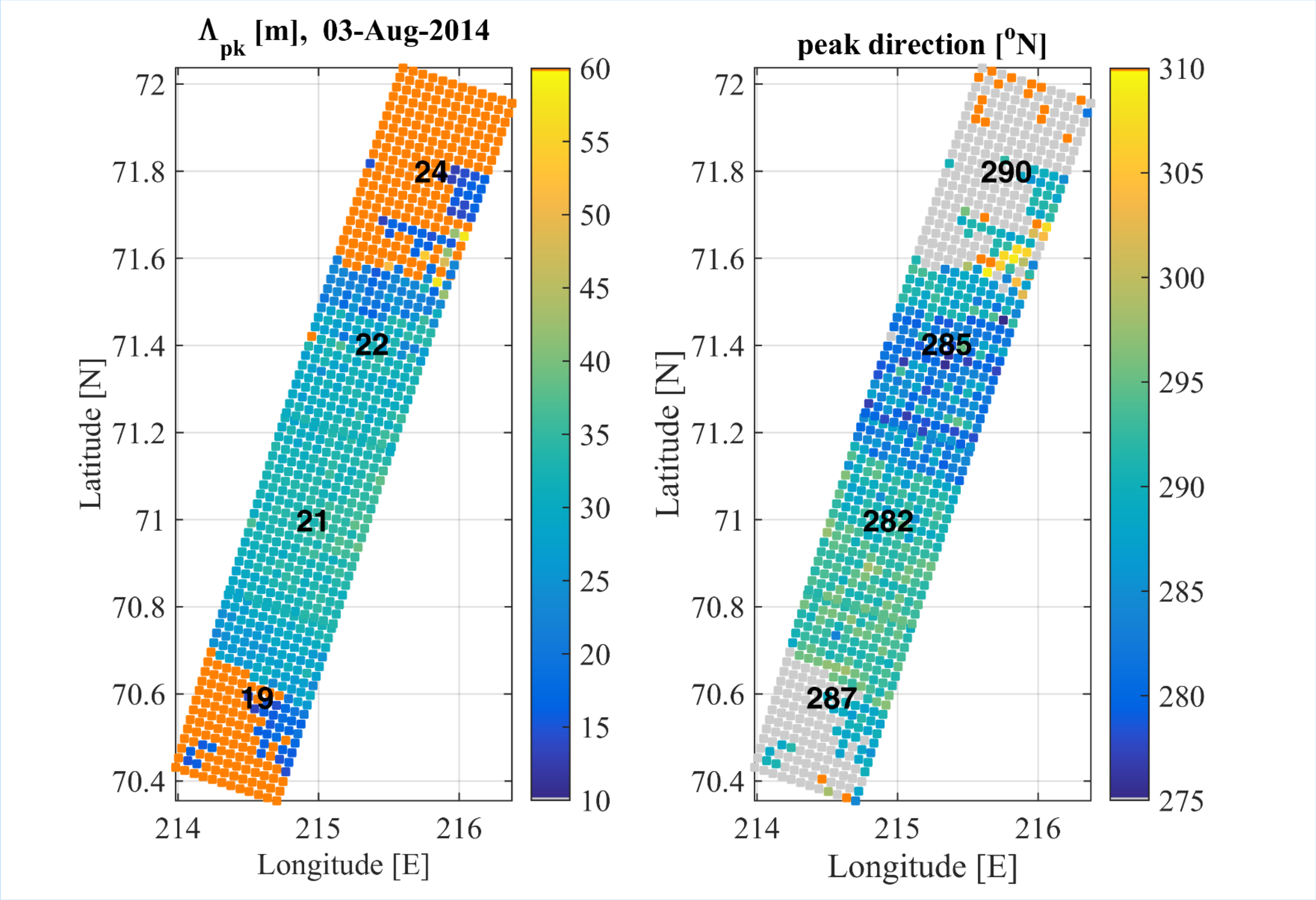




black: WW3 model results/input
red: SWIFT

WW3: low wind speed → lower Hs

Partially ice covered: remote sensing dominant wave length and wave direction

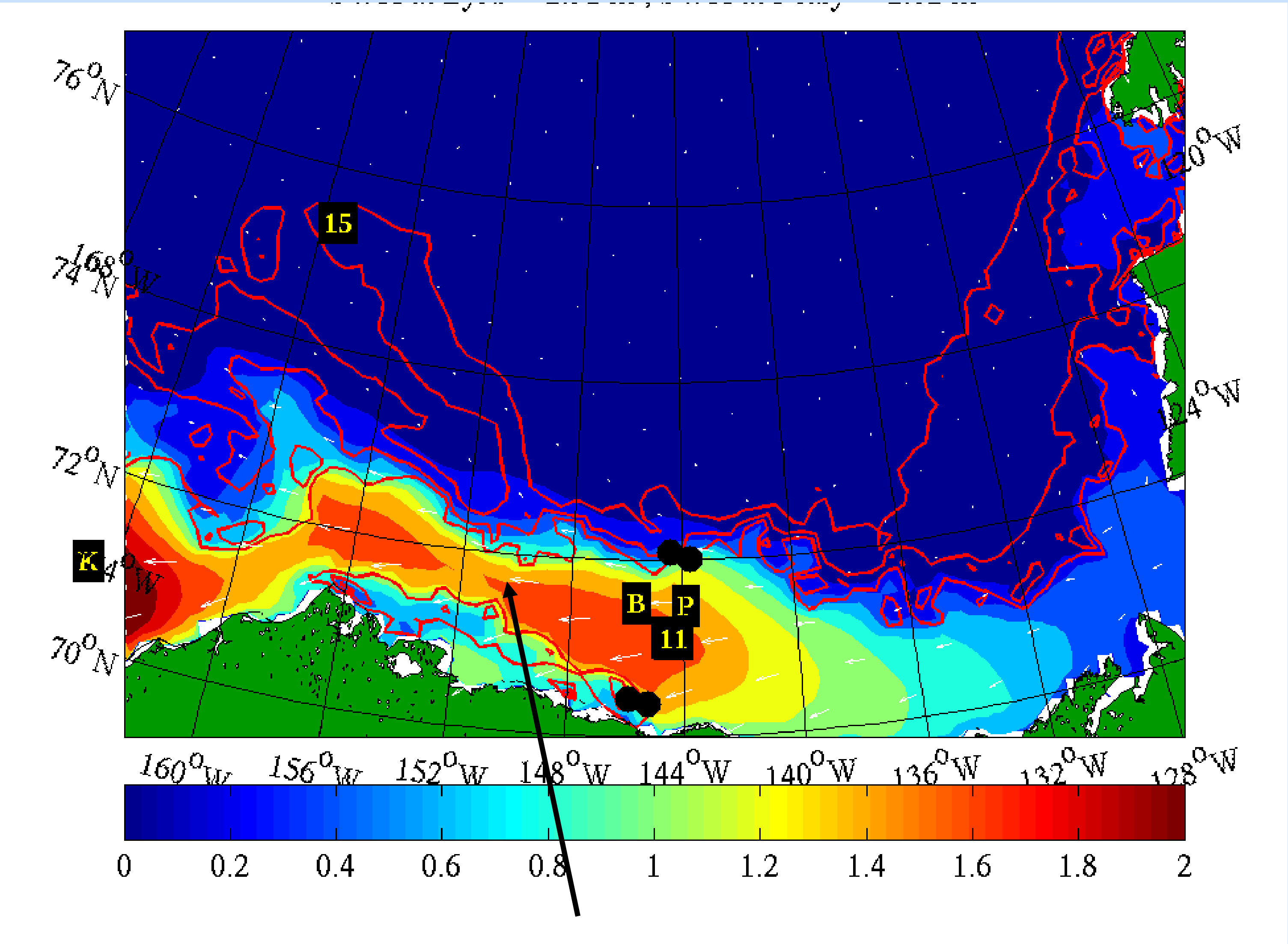


Numbers: WW3 model results

WW3: too short waves
SAR: dropouts in partial ice coverage

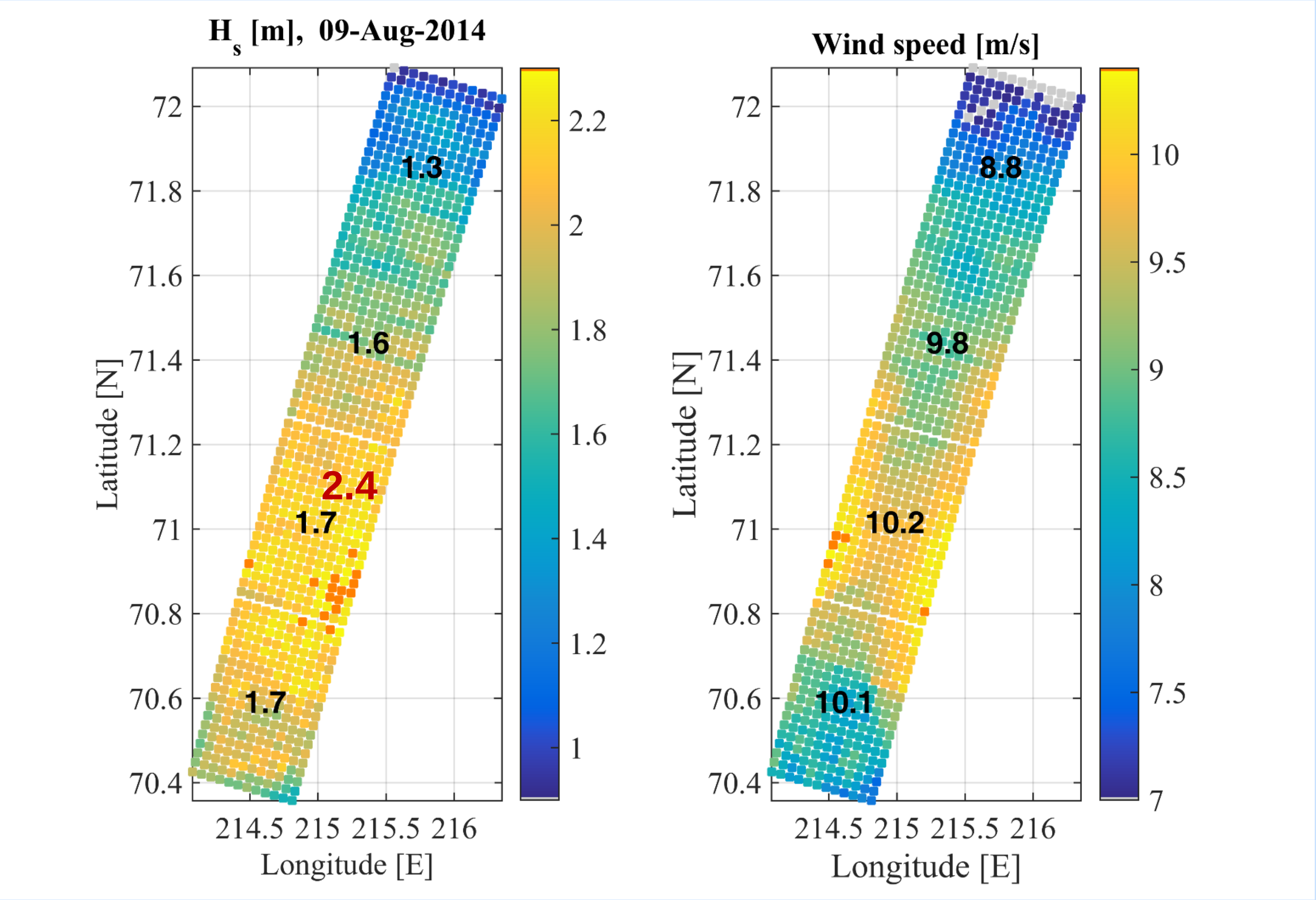
Beaufort Sea, partially ice covered

Decay phase of a ‘substantial event’ (Aug 9)



Potentially long fetch

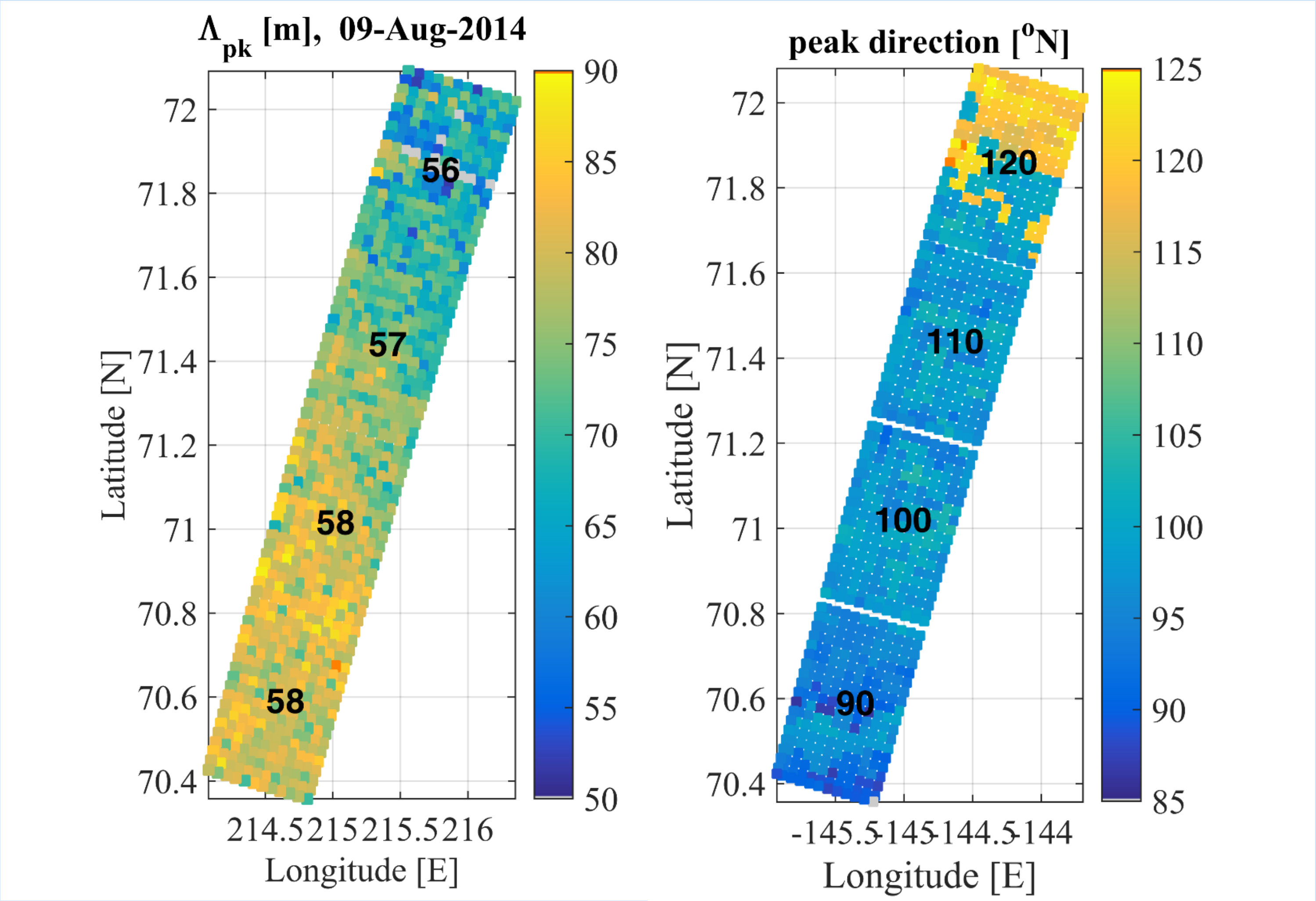
Beaufort Sea, decaying wave event: H_s and wind speed



black: WWW3 model results/input
red: SWIFT measurement

ΔH_s: 1m over 50 km
WW3 –SAR: capturing spatial variability
model: max H_s too low

Beaufort Sea, decaying event: remote sensing dominant wave length and wave direction



Numbers: WW3 model results

$\Delta\lambda$: almost double over 50km
WW3: too short waves, no spatial variability
direction correct, incl. variability

Summary

- Strong Hs gradients observed in open ocean,
  e.g. 2.2m – 3.5m in 40 km
- Not captured in WW3
- Need to understand the source of gradients (currents?)

- Strong Hs gradients observed in coastal ocean,
  e.g. 0.8m - 2.2m in 30 km

- very dynamic wave climate in late summer in the Beaufort Sea
- high spatial variability

- Need for definition of dominant wave in spatial measurement (peak of 2D-k, 1D-k, 1D-ω)

- Space-borne SAR best tool to study spatial wave field characteristics