Describing the wind field in a Norwegian fjord using synchronized Doppler LIDARs

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Ferry free E39 in West/Norway

- 8 fjords to cross
- Fjord widths 2-7.5 km
- Fjord depths 300-1300 m
- High and variable climate loads
- What are the appropriate design loads?

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Extensive observational campaign

- A 50 – 100 m high met mast at ends of each crossing.
- Min. 4 years of 10 Hz obs. of 3D wind at 3-4 elevations in masts.
- Additional masts to investigate horizontal coherence
- Wave and current buoys
- **Two pairs of synchronized LIDARs**

Observational data in the open domain. Corroborated by up to 10 years of meso-scale (500 m X 500 m) and CFD simulations (~100 m X ~100 m).

Lidar campaign in Halsafjorden: Sept. ’17 – June’18

Eastern side: Åkvika

Minni
WC400s-6
IP: 192.168.30.35

Klara Ku
Camera

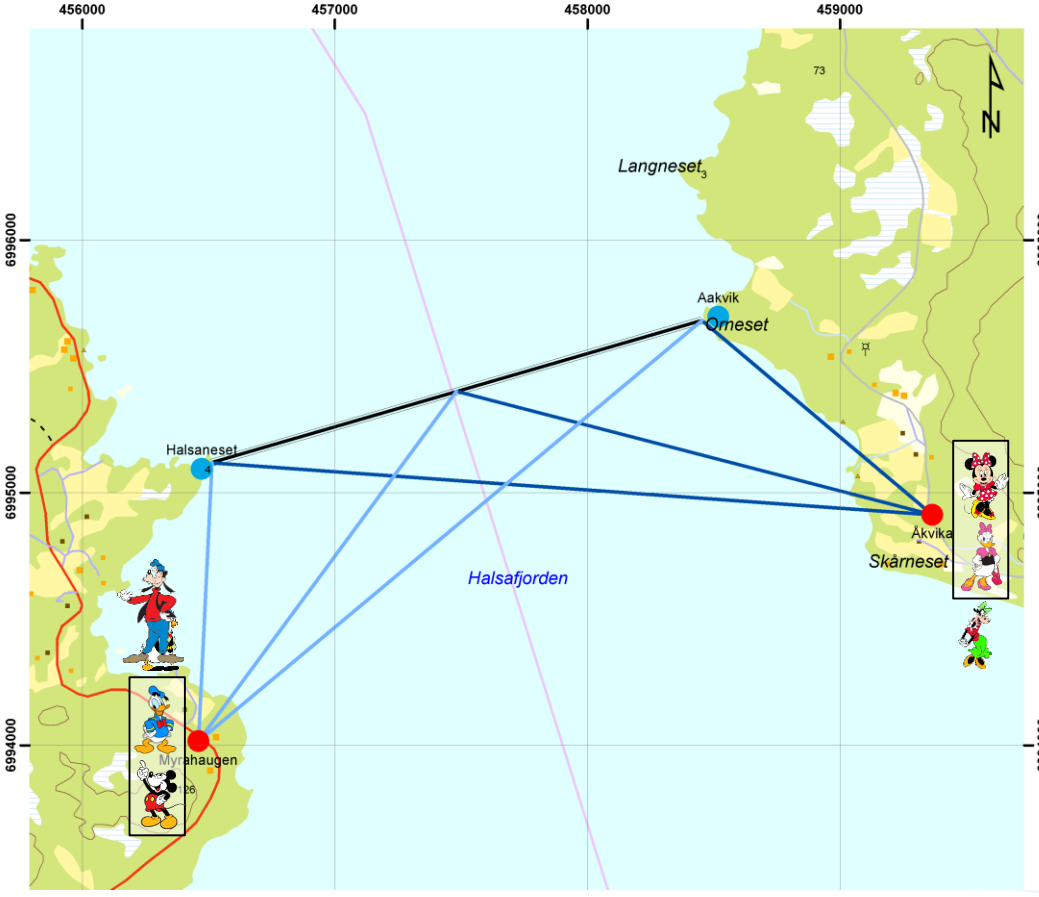
Dolly
WC400s-12
IP: 192.168.30.36

Western side: Myrahaugen

Mikke
WC400s-10
IP: 192.168.30.38

Langbein
Camera

Donald
WC400s-13
IP: 192.168.30.37



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Lidar campaign in Halsafjorden: Sept. ’17 – June’18

Eastern side: Åkvika

Minni
WC400s-
IP: 19[illegible].30.35

Klara Ku
Camera

Polly
WC400s-12
IP: 192.168.30.36

LIDARs

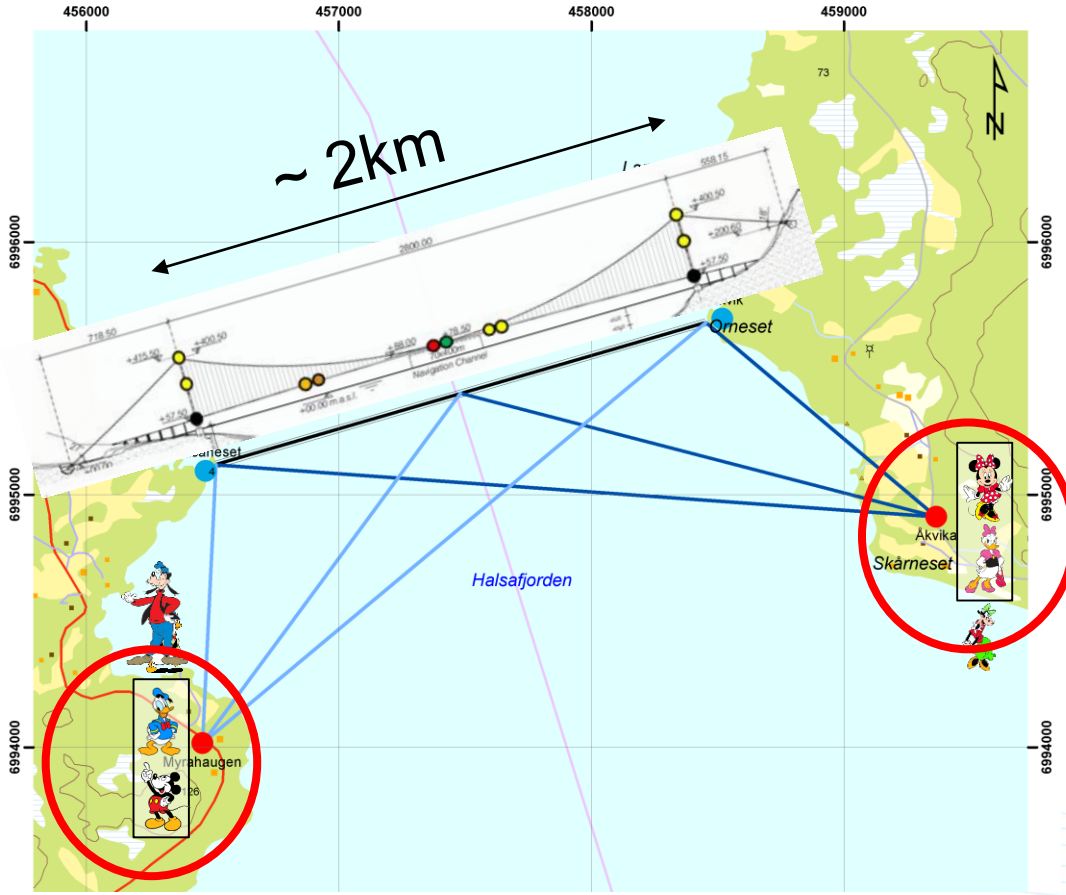
Western side: Myrahaugen

Mikke
WC400s-1[illegible]
IP: 192.16[illegible].30.38

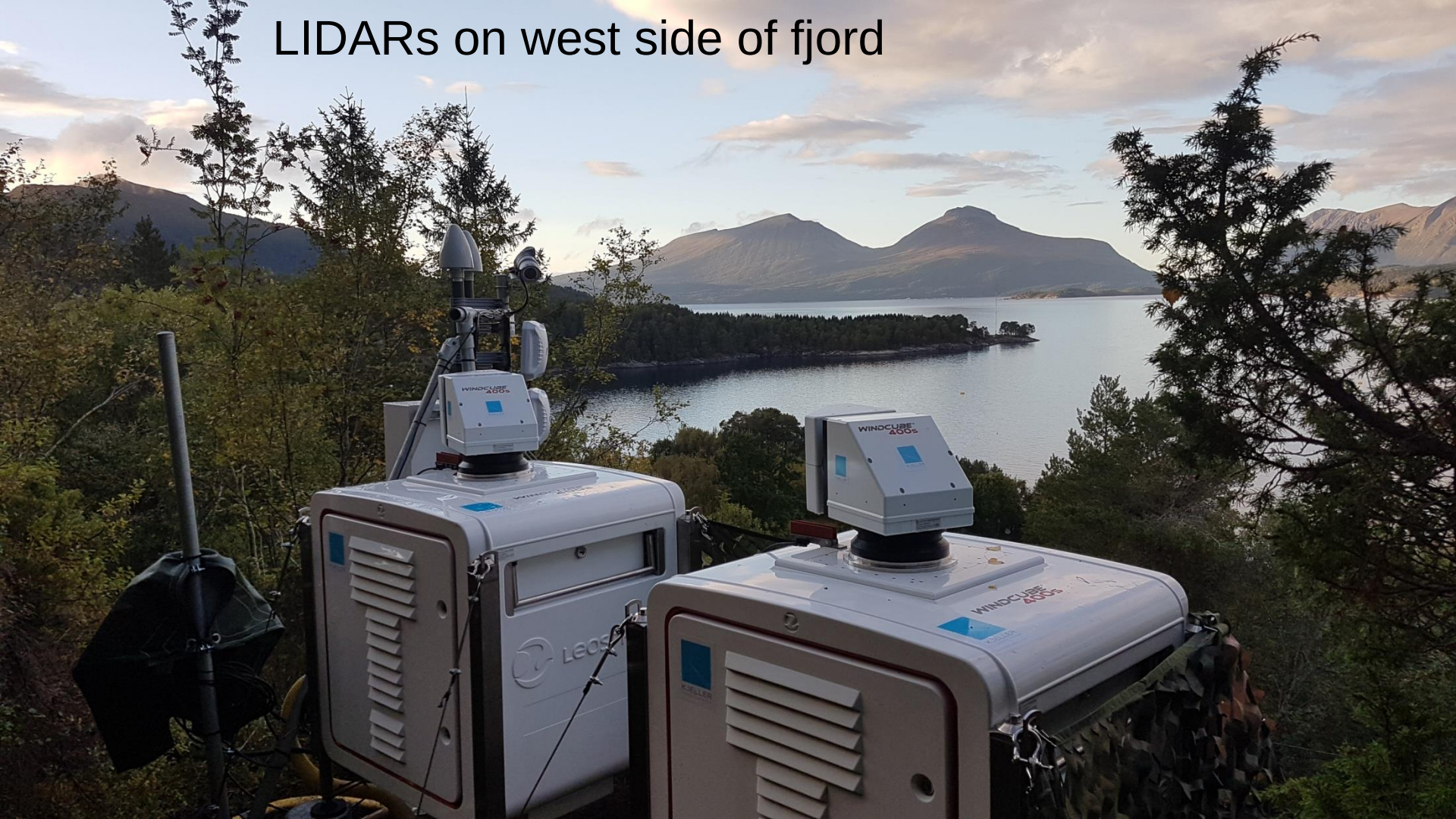
Langbein
Camera

Donald
WC400s-13
IP: 192.168.30.37

LIDARs

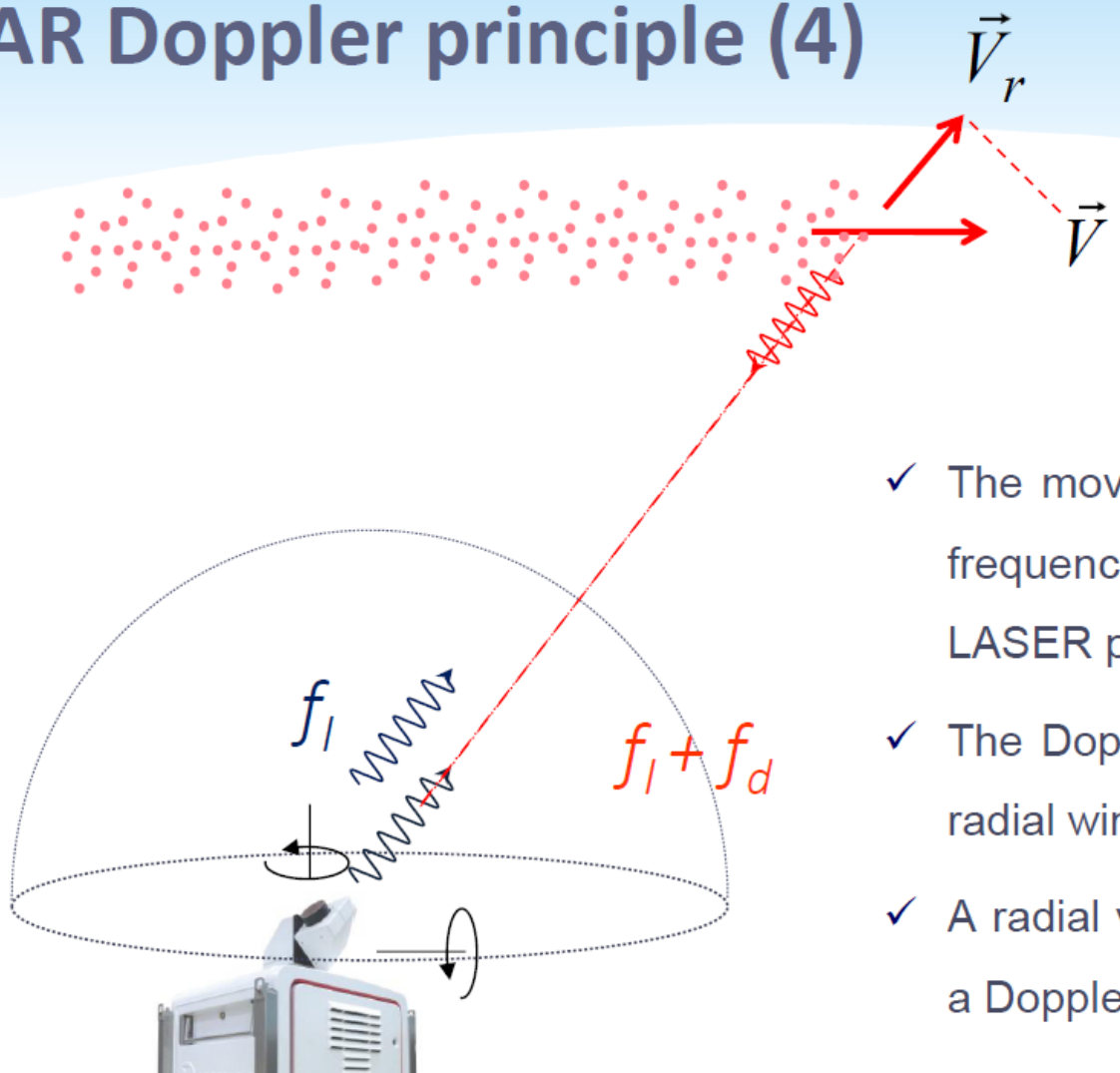


LIDARs on west side of fjord



LIDARs on east side of fjord

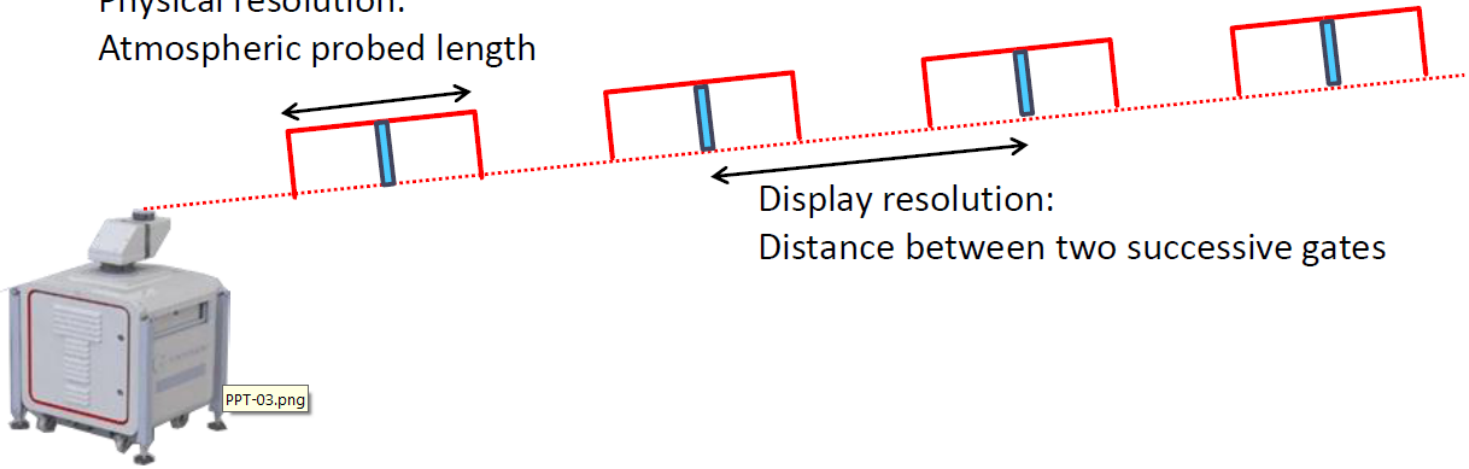
LIDAR Doppler principle (4)



- ✓ The moving aerosols induce an optical frequency change of the backscattered LASER pulse: Doppler effect.
- ✓ The Doppler shift is proportional to the radial wind speed.
- ✓ A radial wind speed V_r of 1m/s induces a Doppler shift of about 1,3MHz

Resolutions ? Physical VS Display resolutions

Physical resolution:
Atmospheric probed length



Display resolution:
Distance between two successive gates

Physical resolution < Display resolution

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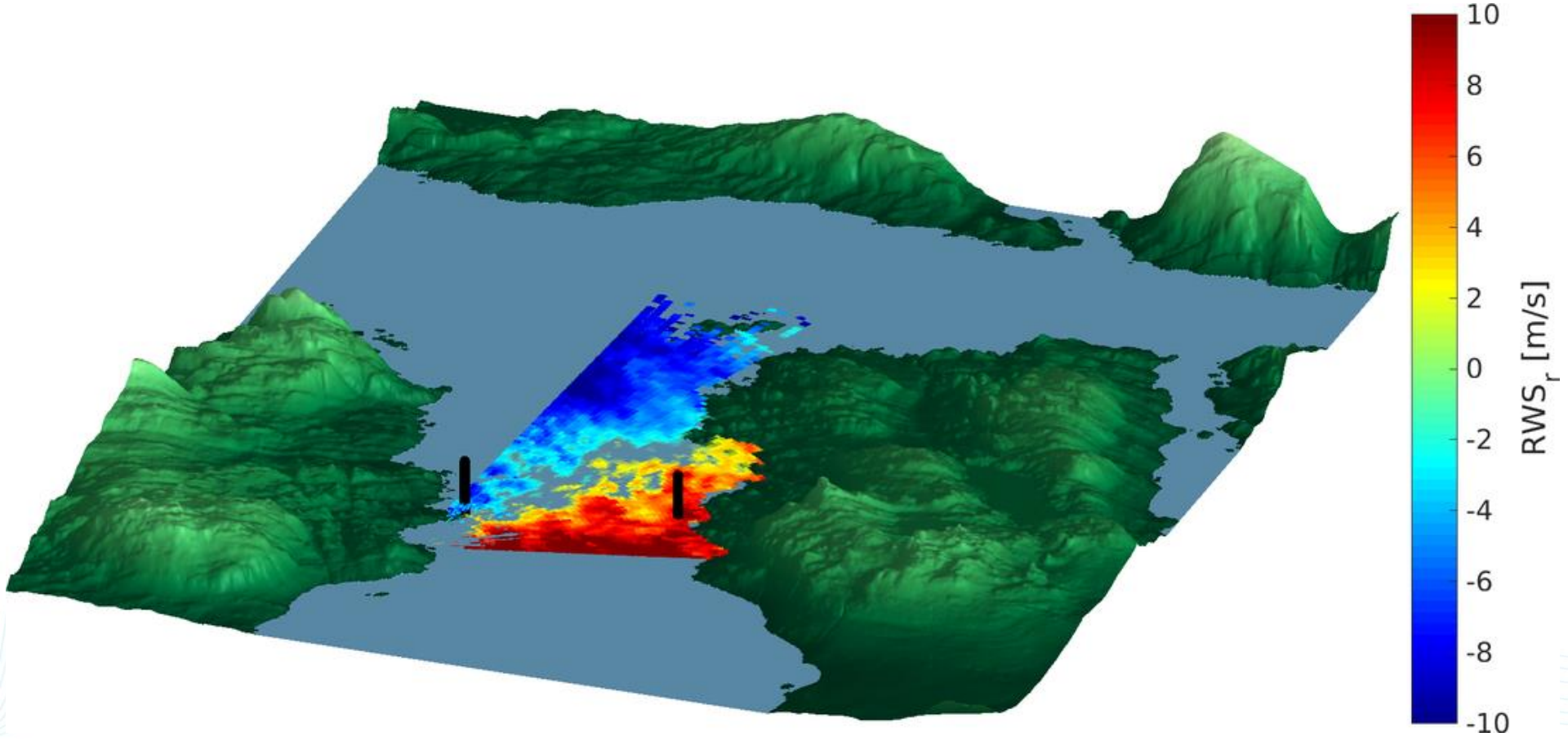
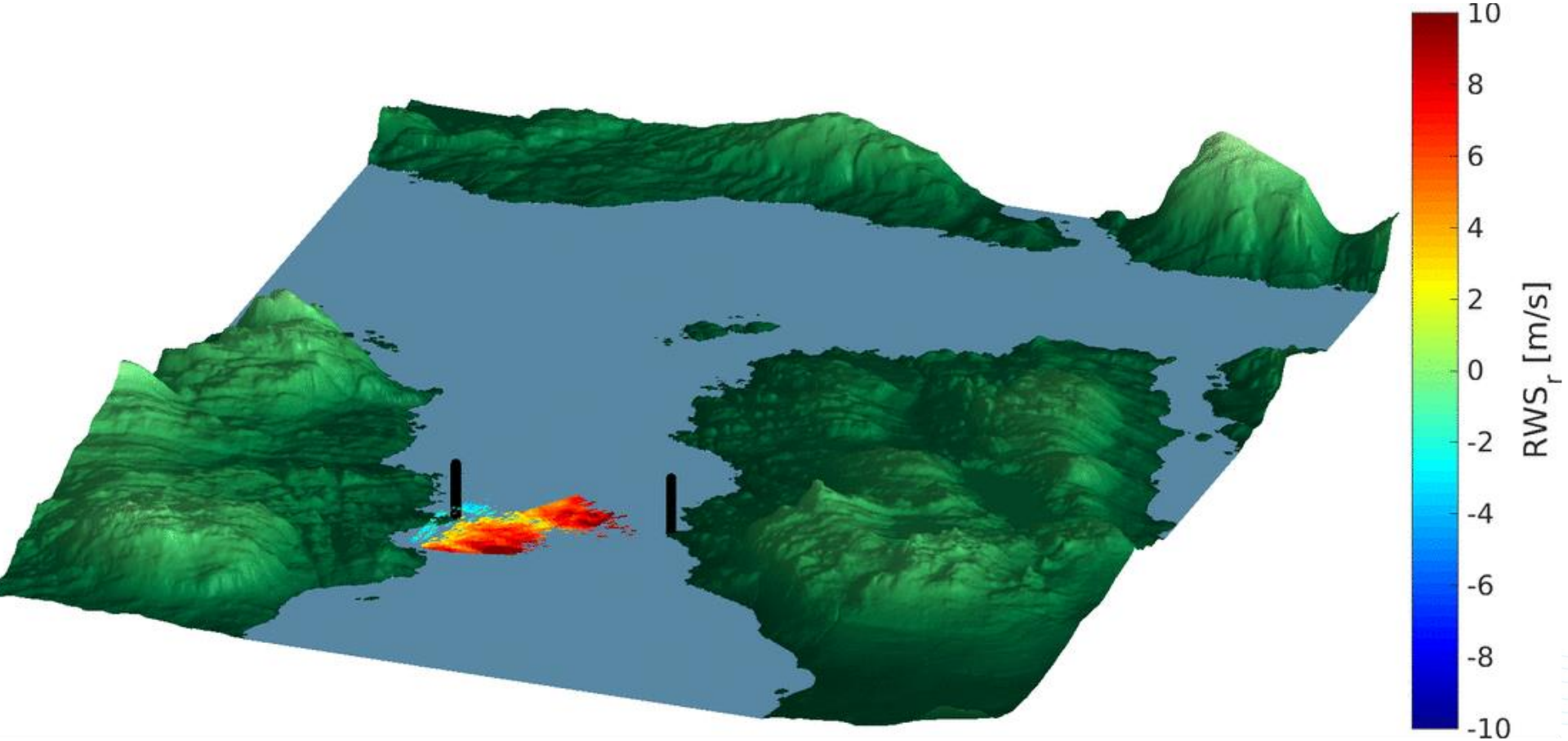
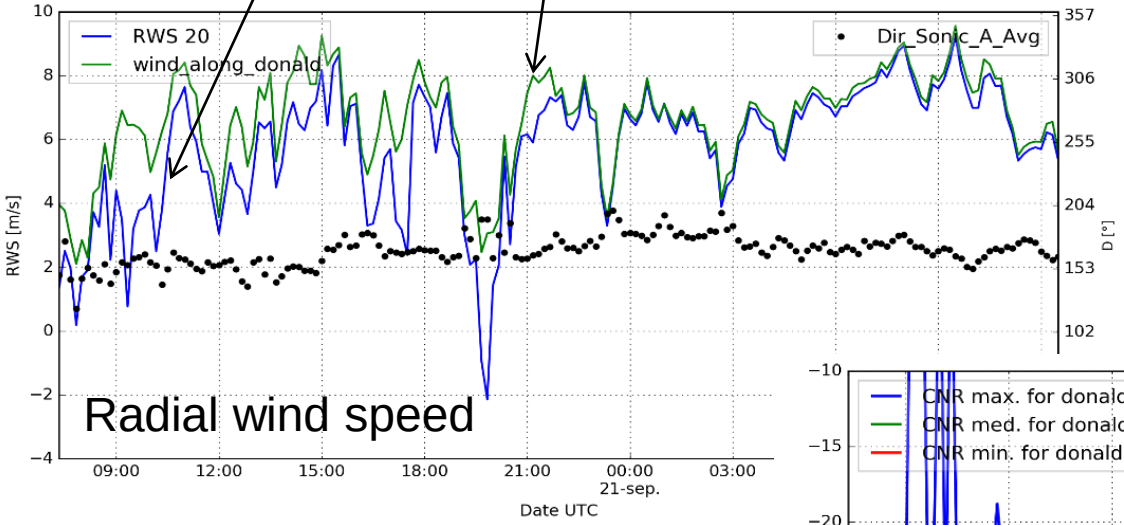
Example – Radial wind speed from one LIDAR

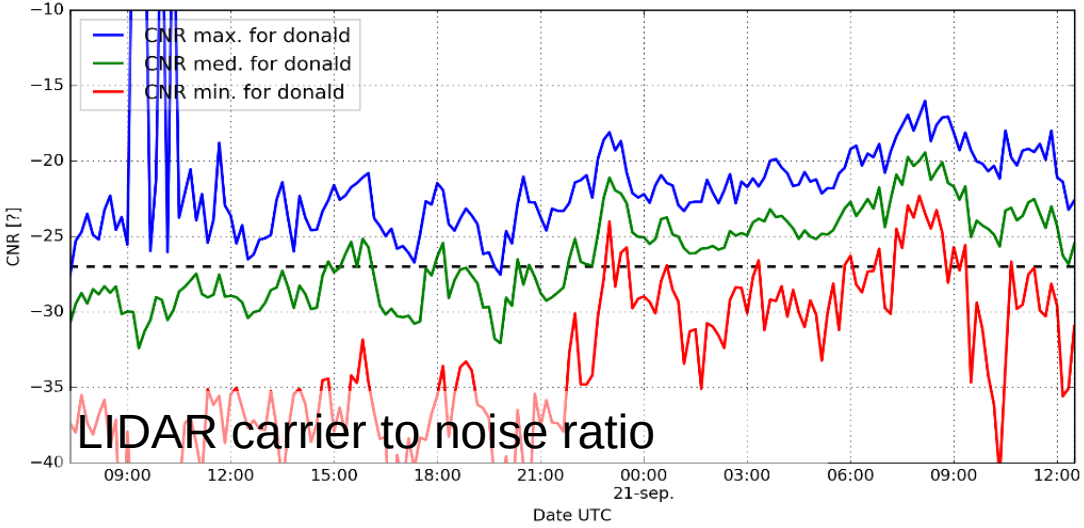


Example – Radial wind speed from one LIDAR



LIDAR vs mast





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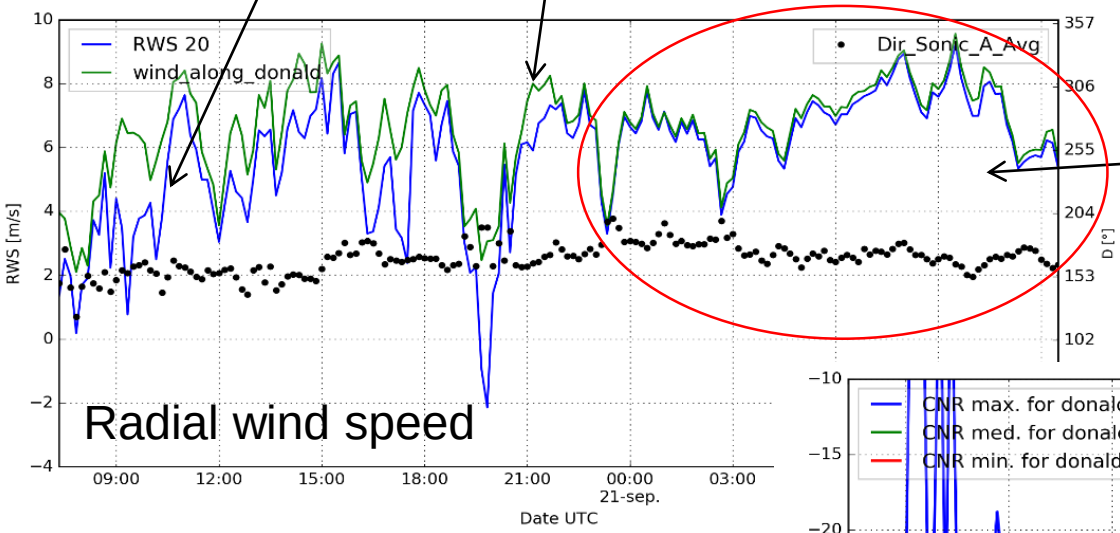
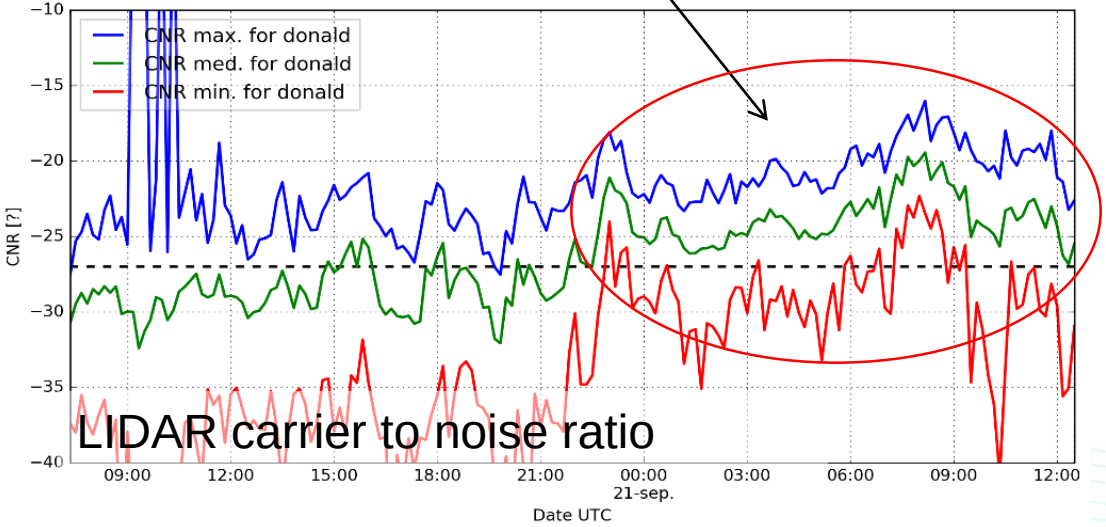
LIDAR vs mast



Radial wind speed

Good signal



LIDAR carrier to noise ratio

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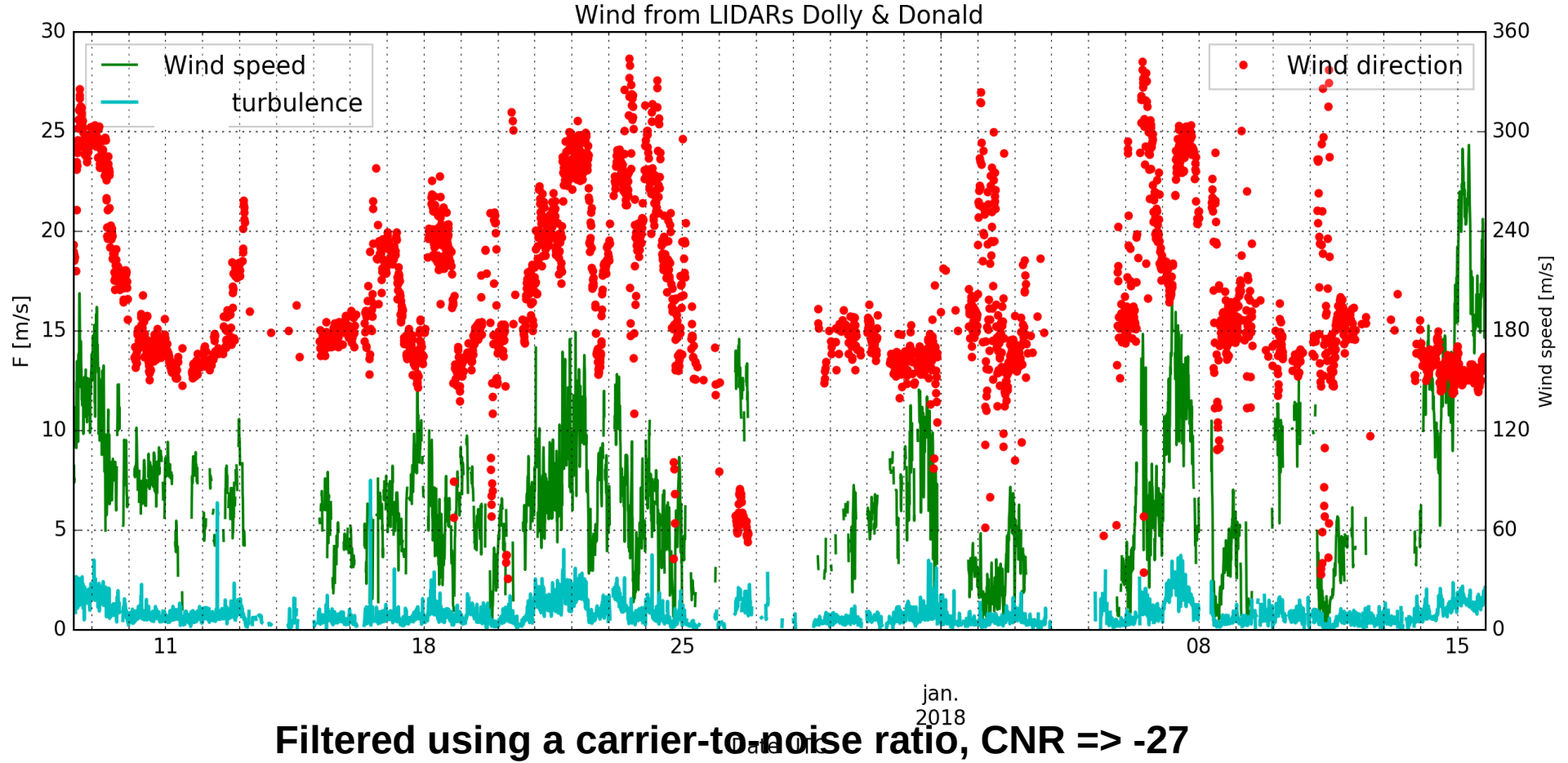
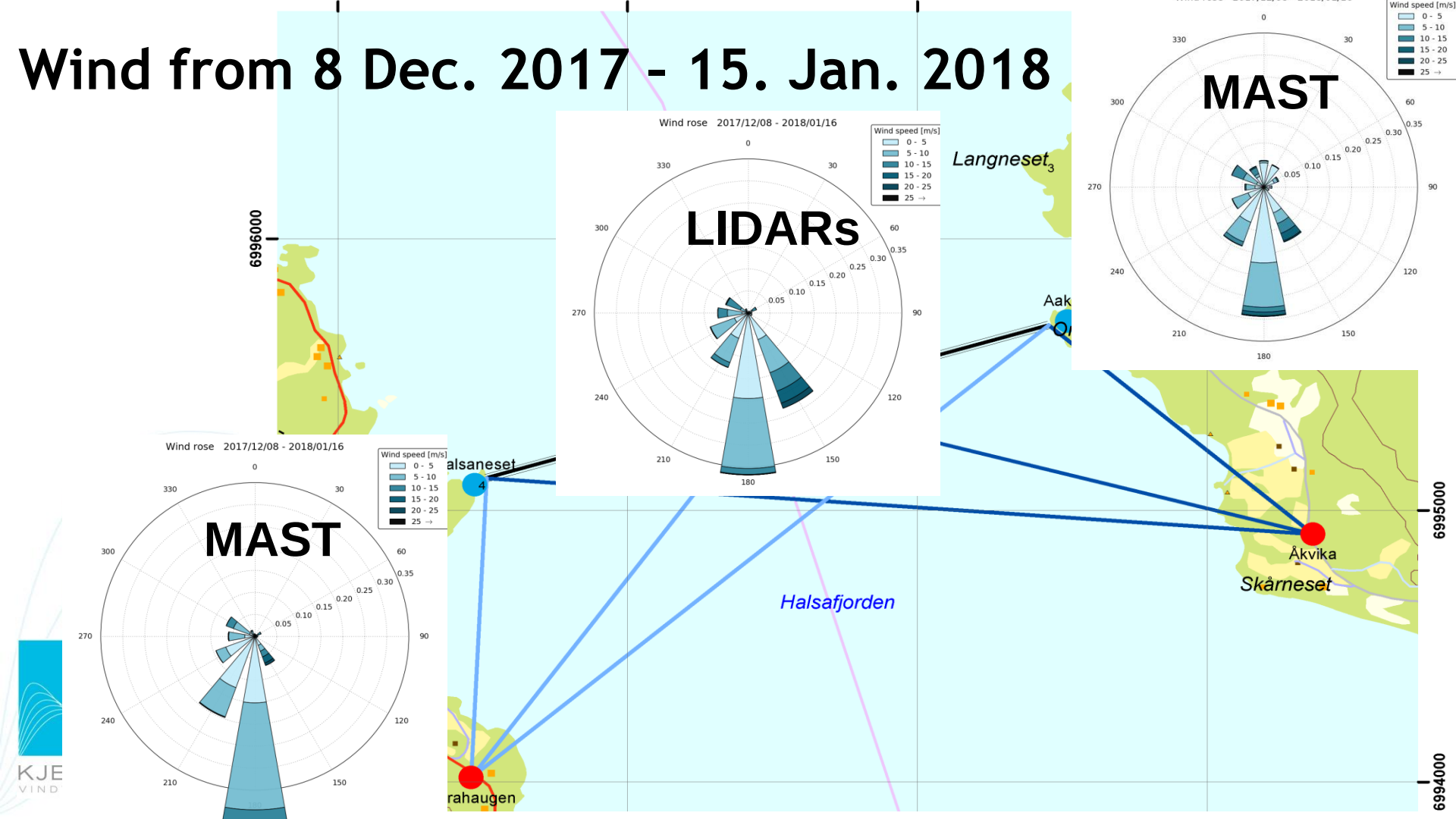
Wind observed at bridge location at middle of fjord

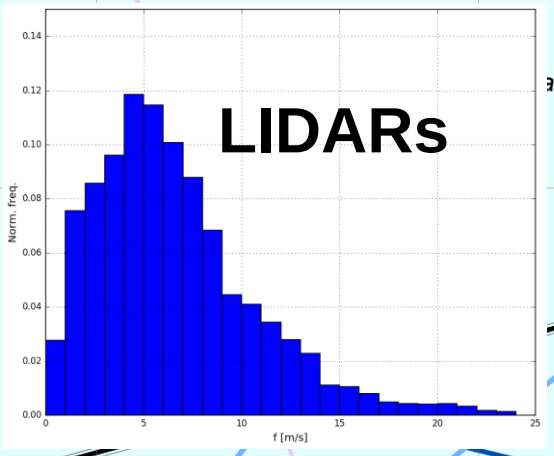


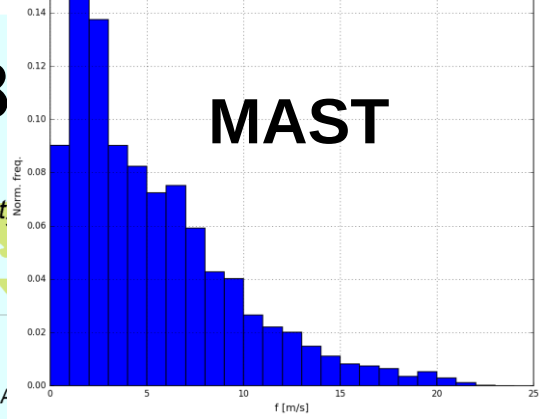
Filtered using a carrier-to-noise ratio, CNR => -27

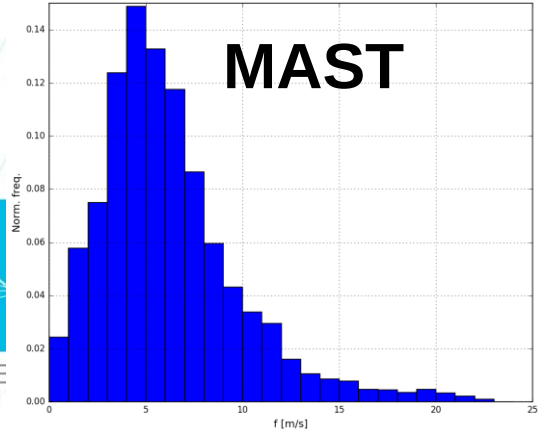
Wind from 8 Dec. 2017 - 15. Jan. 2018



Wind from 8 Dec. 2017 - 15. Jan. 2018







Halsaneset

Halsafjorden

Åkvika

Skårneset

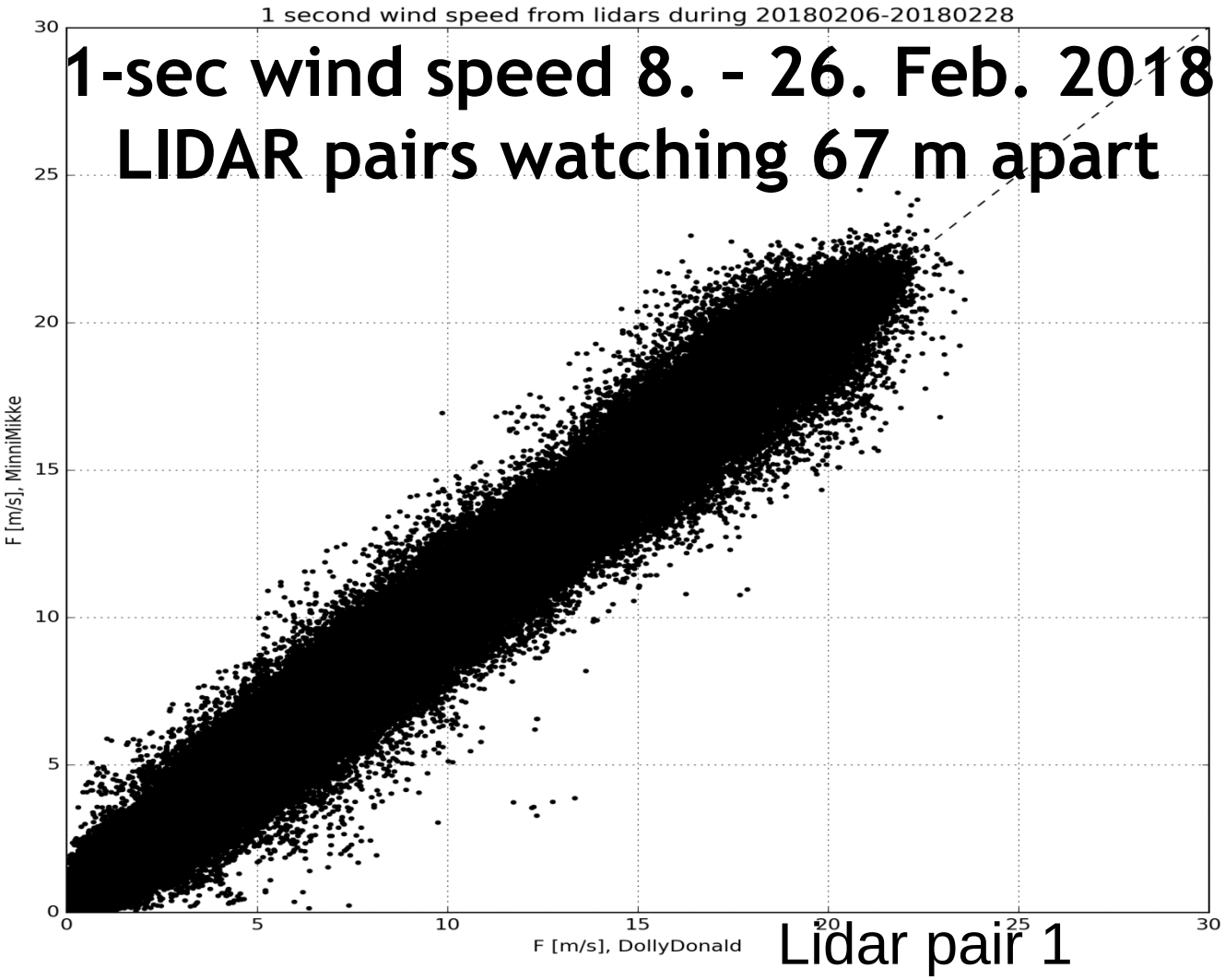
Ørneset

6996000

6995000

6994000

1-sec wind speed 8. - 26. Feb. 2018
LIDAR pairs watching 67 m apart



Lidar pair 2

Lidar pair 1

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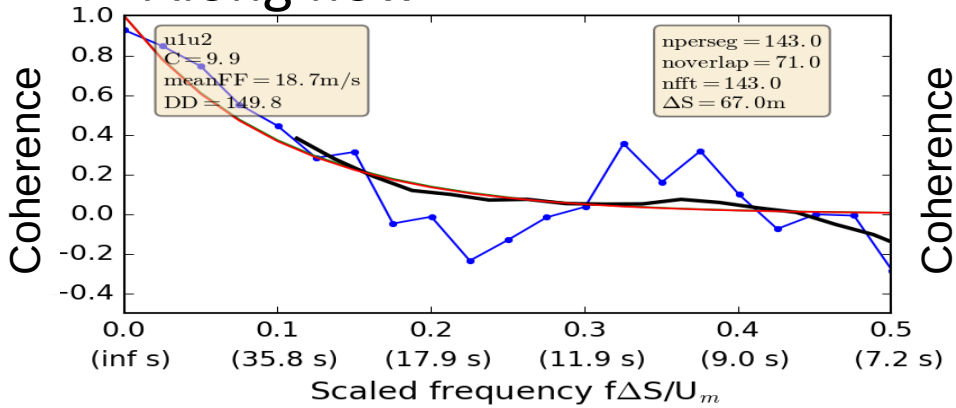
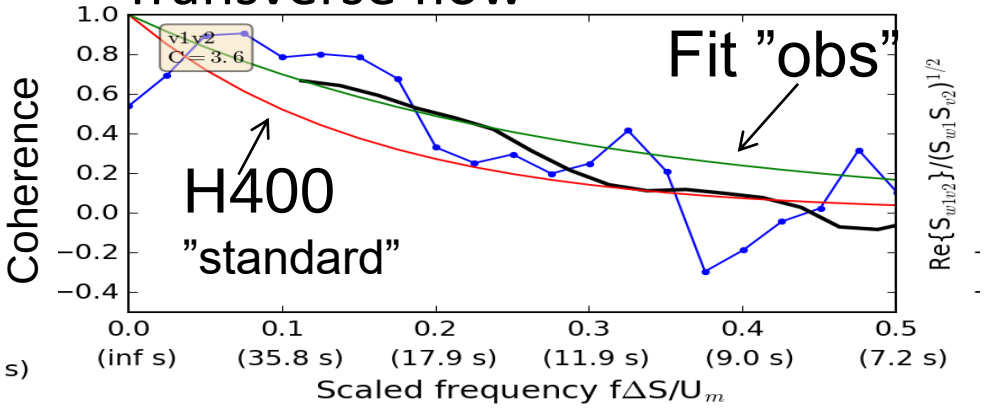
Co-coherence – coherent variations in flow at 2 locations
Horiz. separation **67 m**, 20 min. period, perp. to bridge.

Along flow



Transverse flow



Co-coherence according to handbook H400 (Davenport model)

$$\rho_{ws,j}(f,\Delta S_j) = \frac{Re\left[S_{ws_1 ws_2}(f,\Delta S_j)\right]}{\sqrt{S_{ws_1}(f)\cdot S_{ws_2}(f)}} = exp\left(-C_{ws,j}\frac{f\,\Delta S_j}{v_m(z)}\right)$$

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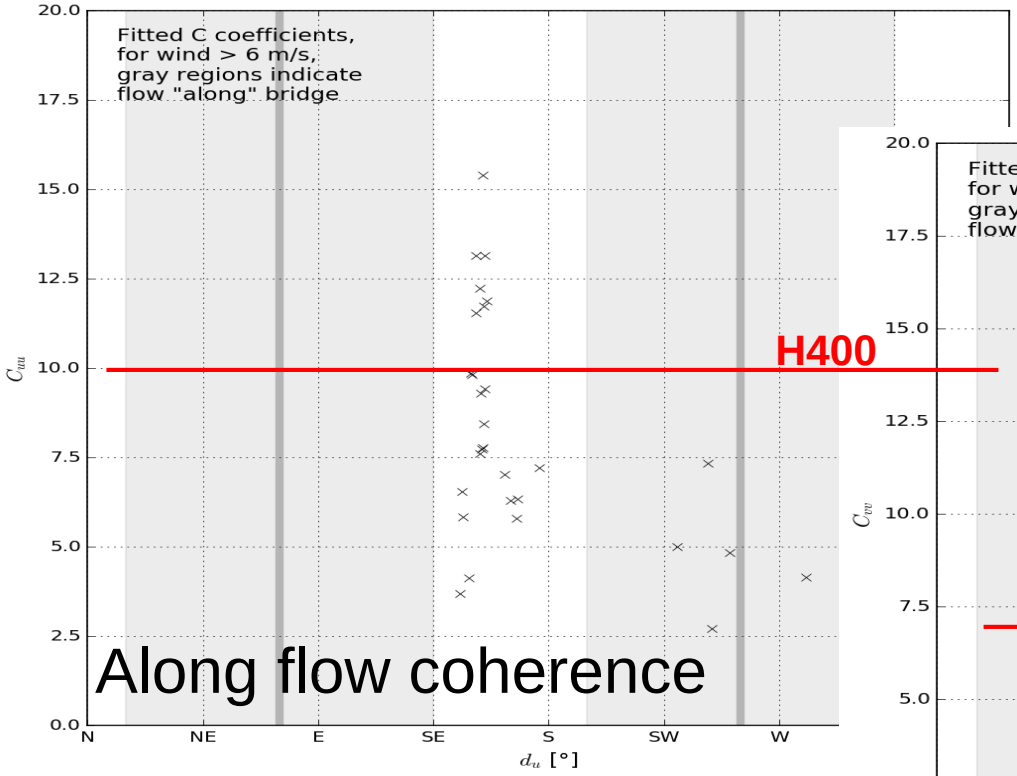
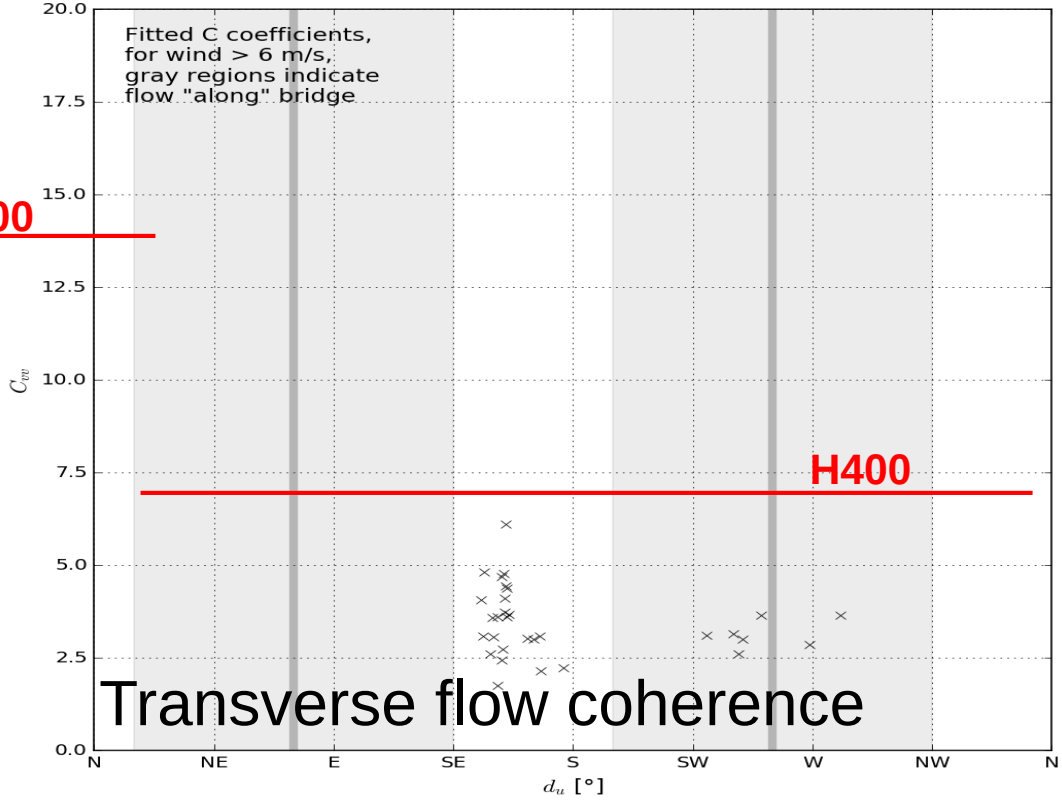
Coherence parameter vs. wind direction





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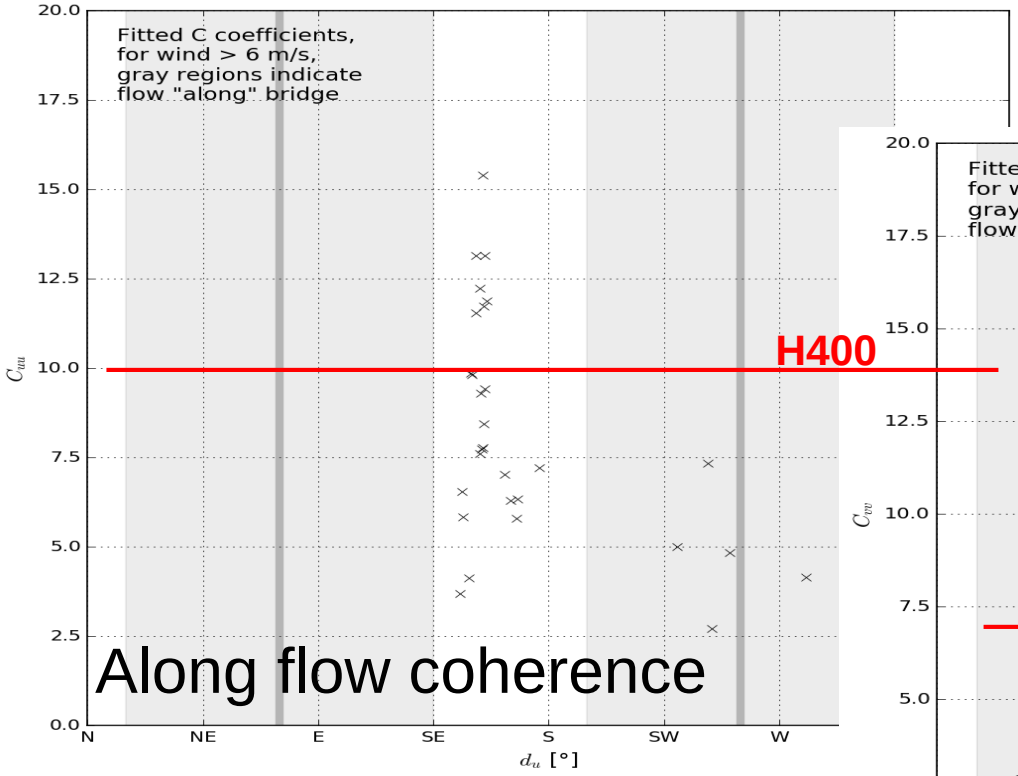
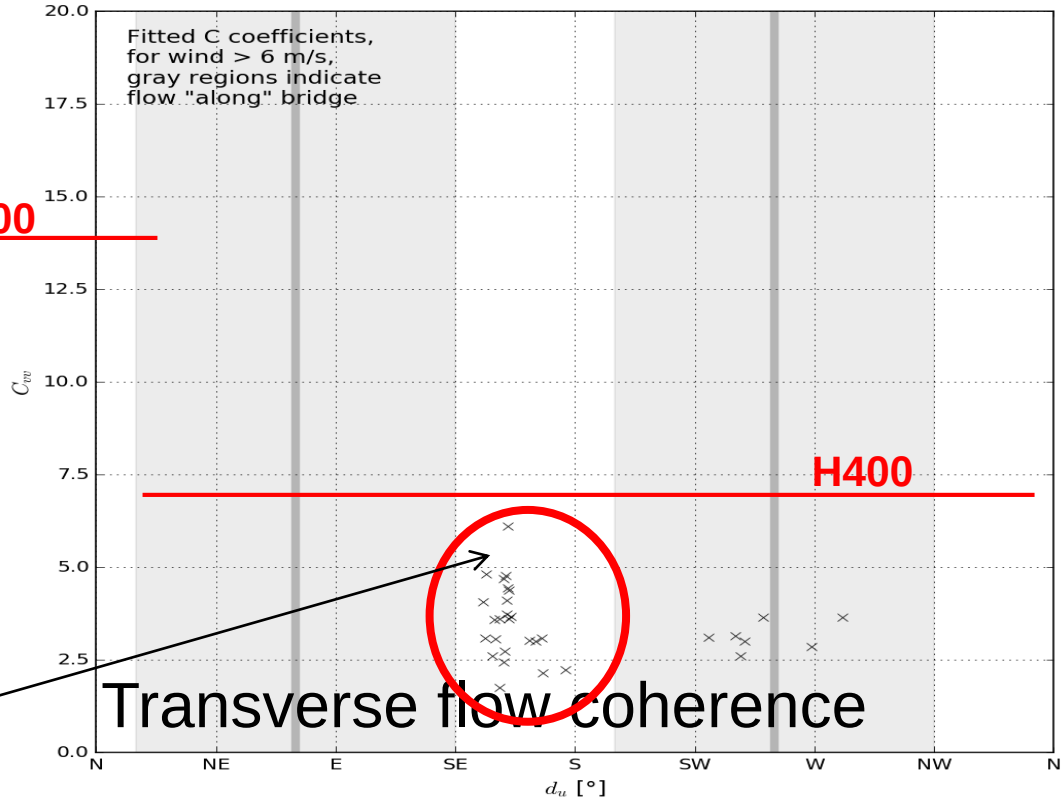
Coherence parameter vs. wind direction





Stronger coherence than prescribed by handbook

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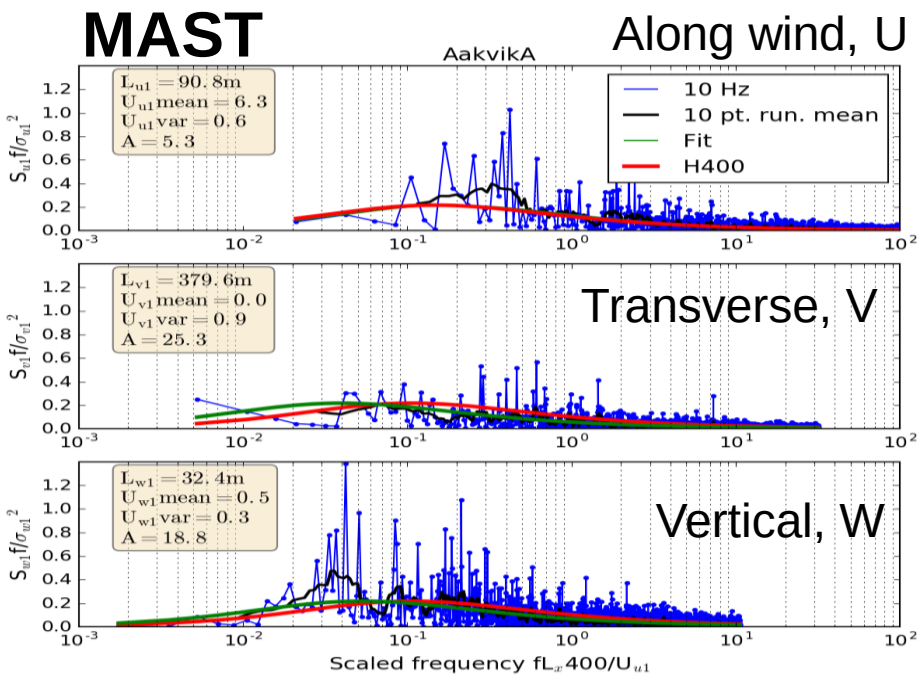
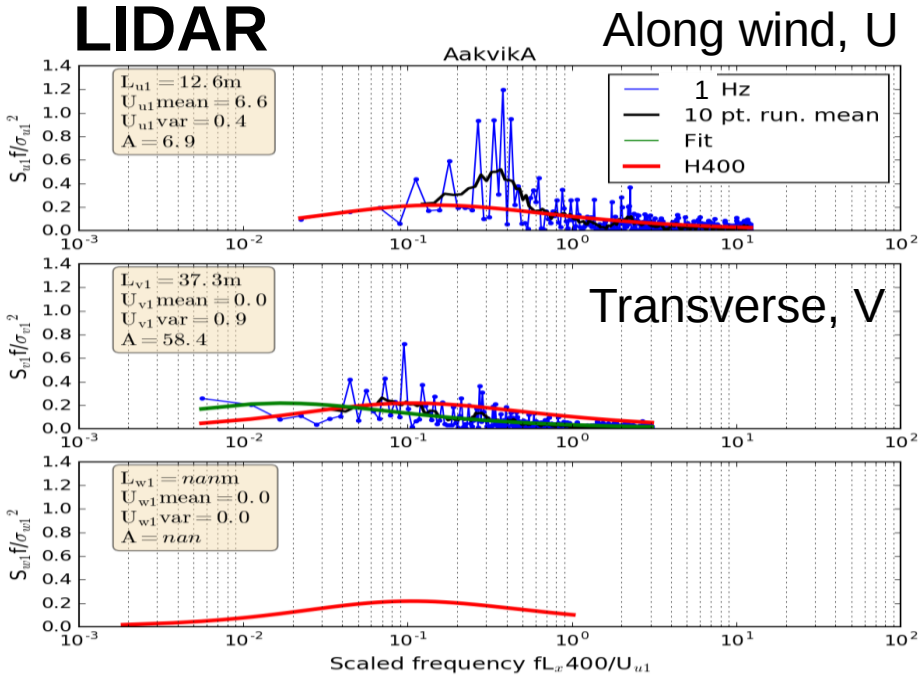
Example turbulence spectra - Mast vs LIDAR

1 Hz / 10 Hz temporal resolution, 20 min period, **50.3 m.**





Concluding remarks

• First results and examples from from four LIDARs observing atmospheric flow in Halsafjorden since autumn 2017.

• The synchronized LIDARs are a part of the extensive observation campaign pertaining to the ferry-free E39 project.

• Detailed description of key parameters of atmospheric flow away from the shore, here surrounded by complex orography

Acknowledgments

Important contributions and expert advice from:

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•Jasna Bogunovic Jakobsen and Etienne Francois Cyprien Cheynet from the University in Stavanger