Harvesting wind energy in Greenland and exporting it as electricity or energy-rich molecules

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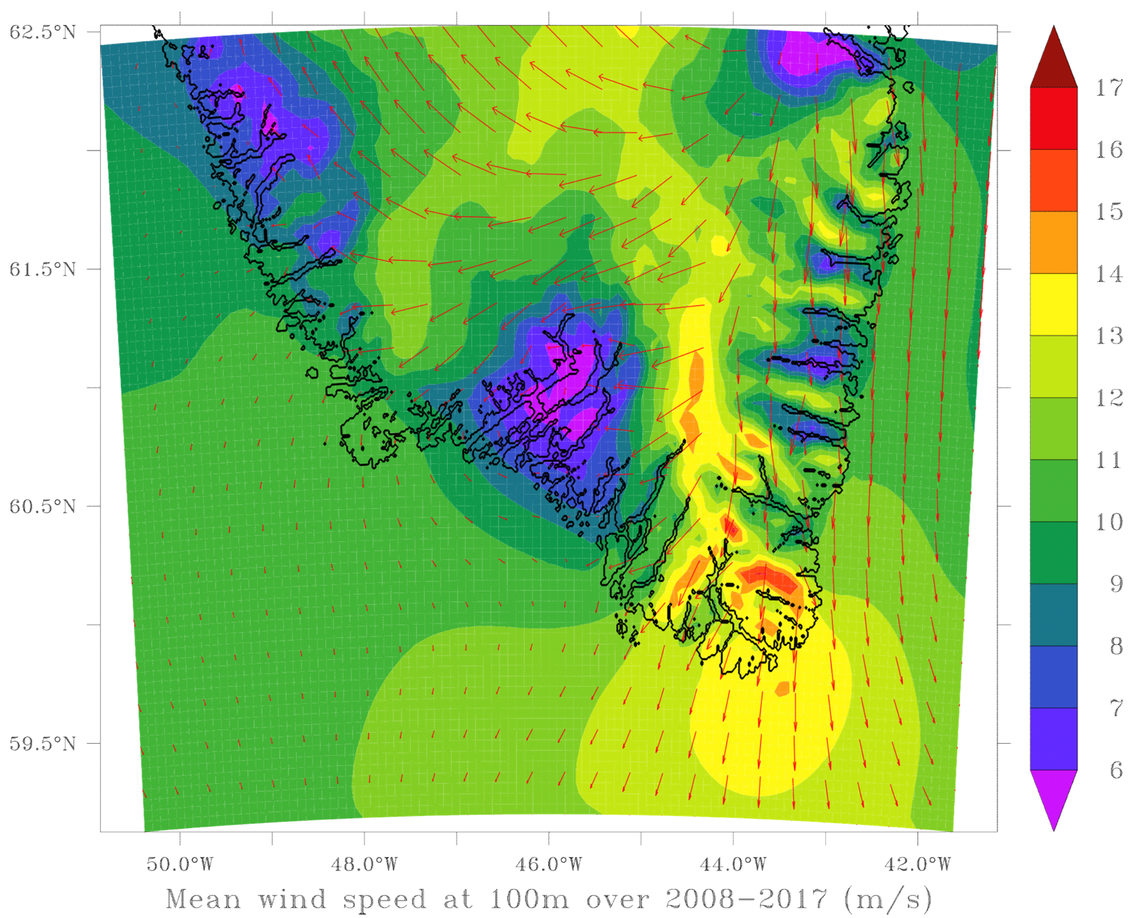
Why harvesting wind energy in the southeast Greenland is a good option?



1. Consistently strong winds.

2. Decorrelation with European wind patterns.

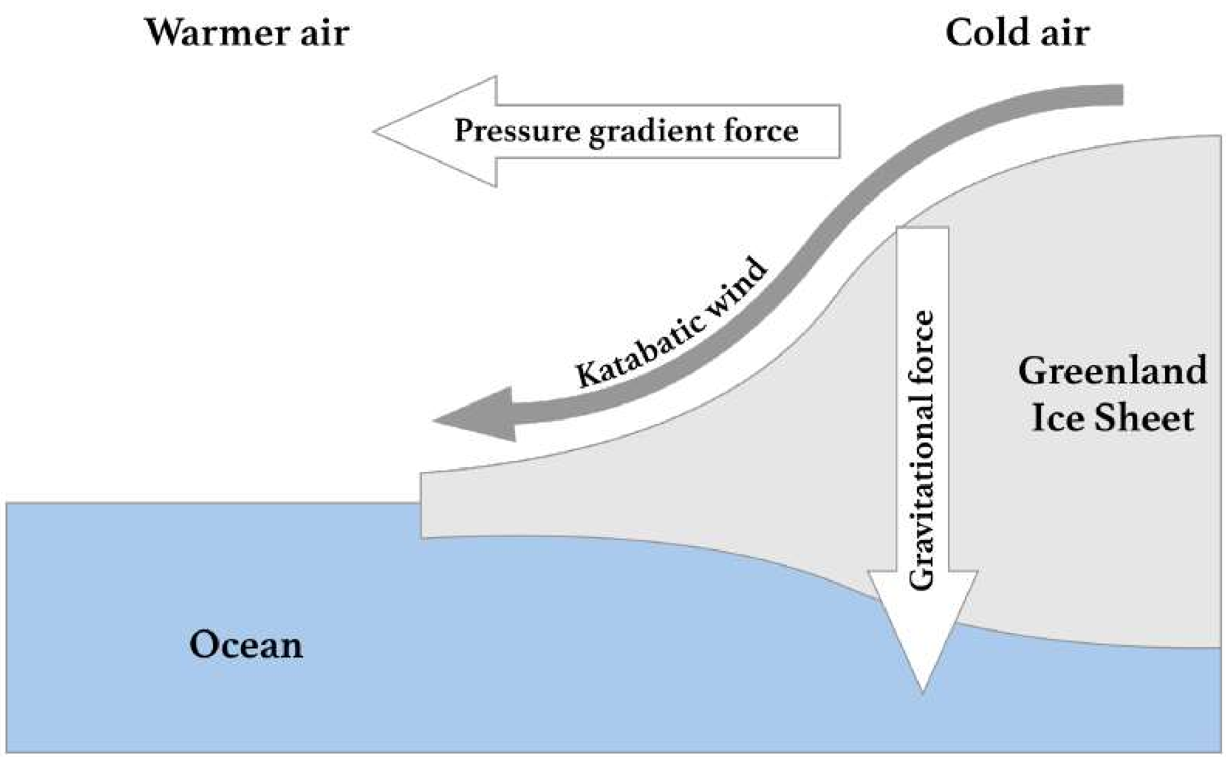
3. Huge areas. No NIMBY issues.

4. Ideally located half way between Europe and the US.

5. Optimum flagship project for accelerating the building of the **global grid**.

Winds in southeast Greenland

In the southeastern part of Greenland, general circulation winds (driven by the Sun's energy) create katabatic winds.



Katabatic winds are the result of heat transfer processes between the cold ice cap and the warmer air mass above it.

When the air mass temperature is higher than that of the ice sheet, the former is cooled down by radiation, thus the air density increases forcing it down the sloping terrain.

The flow of katabatic winds is driven by gravity, temperature gradient and inclination of the slope of the ice sheet.

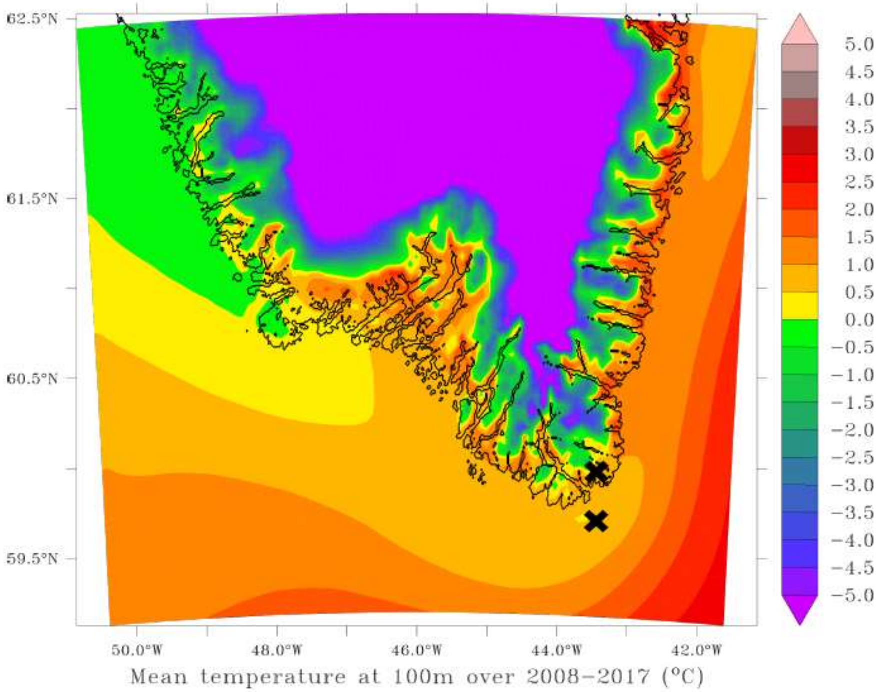
Data acquisition for our analysis

We have relied on data reanalysis to reconstruct wind signals from the past in situ and satellite observations.

The regional MAR (Modèle Atmosphérique Regional) model was used for data reanalysis over Greenland. This model can accurately represent physical processes in Greenlandic regions, including katabatic winds. Boundary conditions are determined by the ERA5 reanalysis model.

Hourly values of wind speed at 100 meters above ground level are generated using reanalysis models for the period 2008-2017.

Regions selection for our analysis

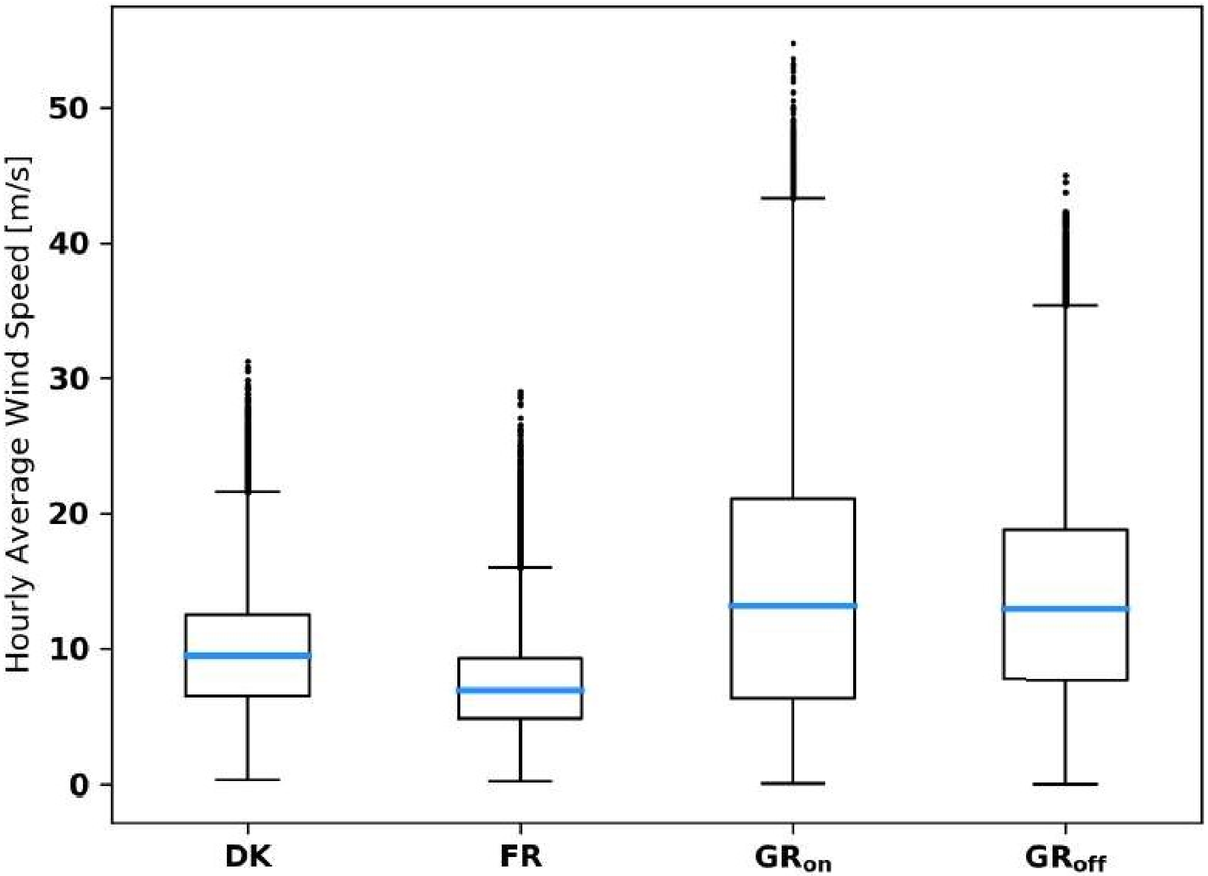


Two areas in Greenland: one offshore (GR_{OFF}) and one onshore (GR_{ON}).

Temperatures too high for the sea to freeze or for there to be permanent ice onshore.

Two areas in Europe: one offshore wind farm in Denmark (DK) and one on-shore wind farm in France (FR).

Wind ressource assessment

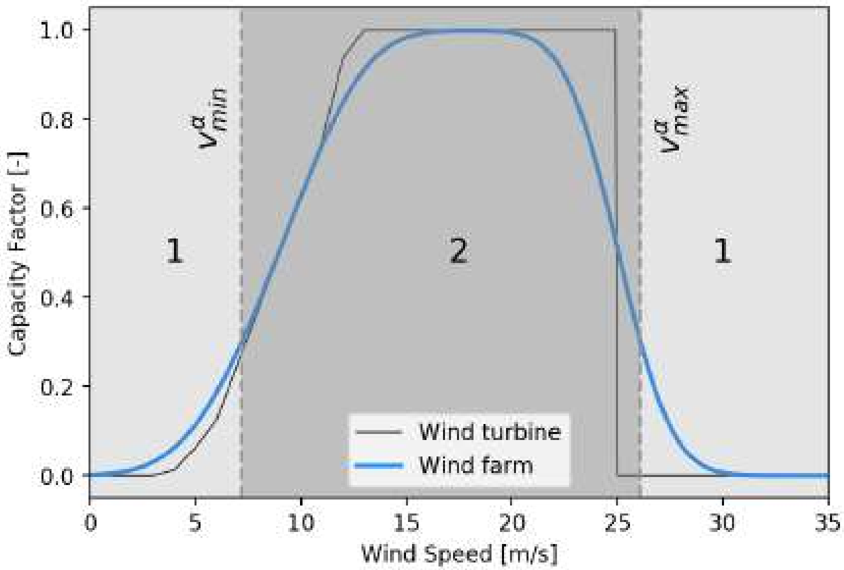


There are higher mean wind speeds in Greenland than in the two European locations.

Distribution of wind speeds are more assymetric for GR_{off} and GR_{on} than for DK and FR.

The high standard deviations of the wind speeds in Greenland do not correspond to a high turbulence intensity, but to the strong influence of seasonality of the local natural resource.

Load factors of the wind farms



Single turbine and wind farm transfer functions. Example of a wind farm power curve aggregation based on multiple aerodyn SCD 8.0/168 units.

DK	FR	GR_{on}	GR_{off}
0.55	0.32	0.50	0.59

Capacity factors for the different locations.

v_{cut}^{out} (m/s)	**DK**	**FR**	**GR$_{\mathbf{on}}$**	**GR$_{\mathbf{off}}$**
25	0.55	0.32	0.50	0.59
Highest wind speed observed	0.56	0.33	0.66	0.69

Capacity factors versus cut-out wind speed for the wind turbines.

Important remarks for manufacturers of wind turbines willing to tap into the Greenland wind energy market:

1. Wind turbines capable of operating with higher cut-out speed lead to significantly higher load factors in Greenland.

2. It may also be interesting to design wind turbines with greater capabilities in terms of power output for higher wind speeds (i.e., turbines having a higher rated output speed).

Critical time windows for studying the complementarity of wind production

In a power system, a window of duration δ is said to be critical for a set of locations if the average power generated in those locations over the time window is below a fraction α of the installed capacity.

Conjecture: The export of wind energy from Greenland to Europe would reduce to zero the number of these long, critical periods of time during which Europe would be unable to rely on wind energy to cover a significant amount of its energy needs (or more generally renewable energy - a phenomenon known as Dunkelflaute in German).

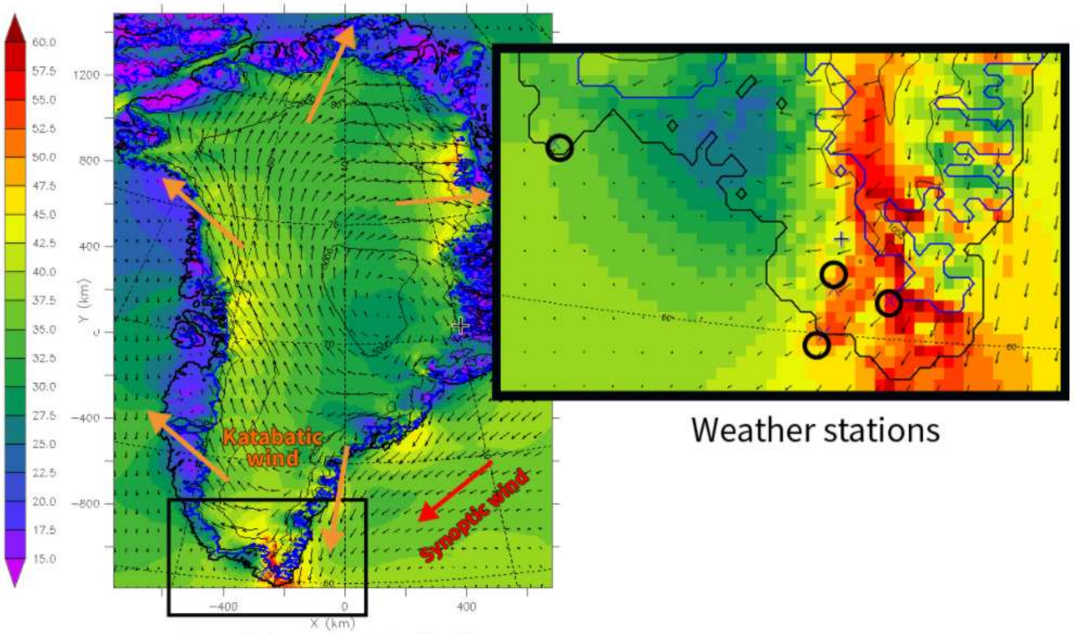
Occurrence of critical time windows

δ \ α	20%	30%	40%	50%	60%	70%
	0.11	0.18	0.27	0.35	0.44	0.53
1	**0.14**	**0.19**	**0.25**	**0.30**	**0.35**	**0.42**
	0.02	*0.04*	*0.07*	*0.11*	*0.17*	*0.23*
	0.10	0.18	0.27	0.35	0.45	0.54
6	**0.12**	**0.18**	**0.24**	**0.30**	**0.37**	**0.44**
	0.01	*0.04*	*0.07*	*0.11*	*0.17*	*0.25*
	0.08	0.16	0.26	0.36	0.48	0.59
24	**0.06**	**0.12**	**0.19**	**0.28**	**0.39**	**0.53**
	0.01	*0.02*	*0.06*	*0.11*	*0.20*	*0.32*
	0.01	0.06	0.18	0.38	0.58	0.77
168	**0.00**	**0.01**	**0.06**	**0.18**	**0.43**	**0.75**
	0.00	*0.00*	*0.01*	*0.08*	*0.26*	*0.58*

« Probability » of occurrence of critical time windows when using as set of locations: the two European locations (black); the Greenland sites (green) and all four locations (blue).

Results show that the number of critical windows drops when connecting an electricity supply to mainland Europe from Greenland.

Katabata project



Weather stations

Mean wind speed at 100m (km/h)

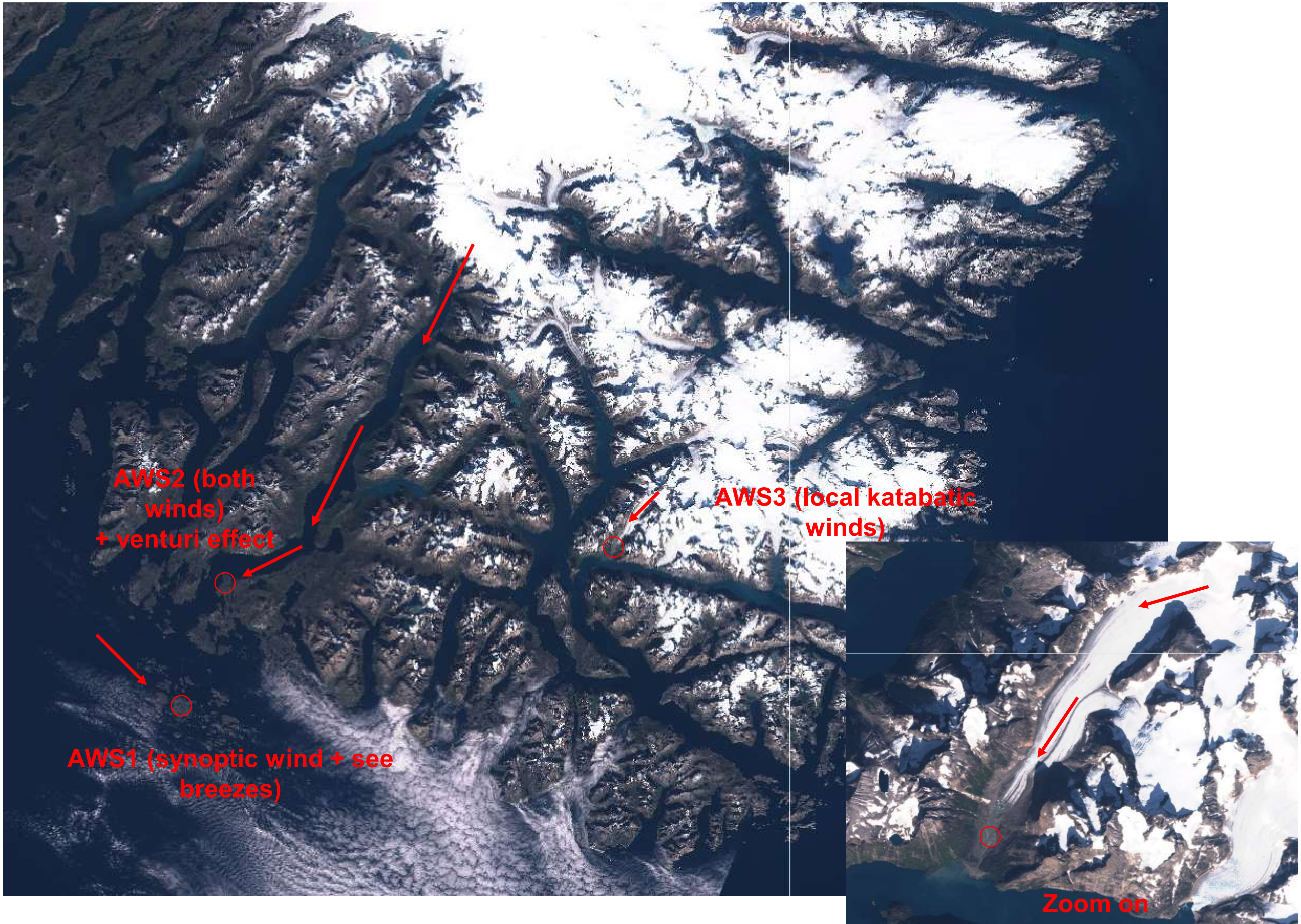
Goal of the project: installing three weather stations in the south-east of Greenland. The wind in this area has never been properly measured before!

The numerical model (MAR) needed to be validated in this area with measured wheather data.

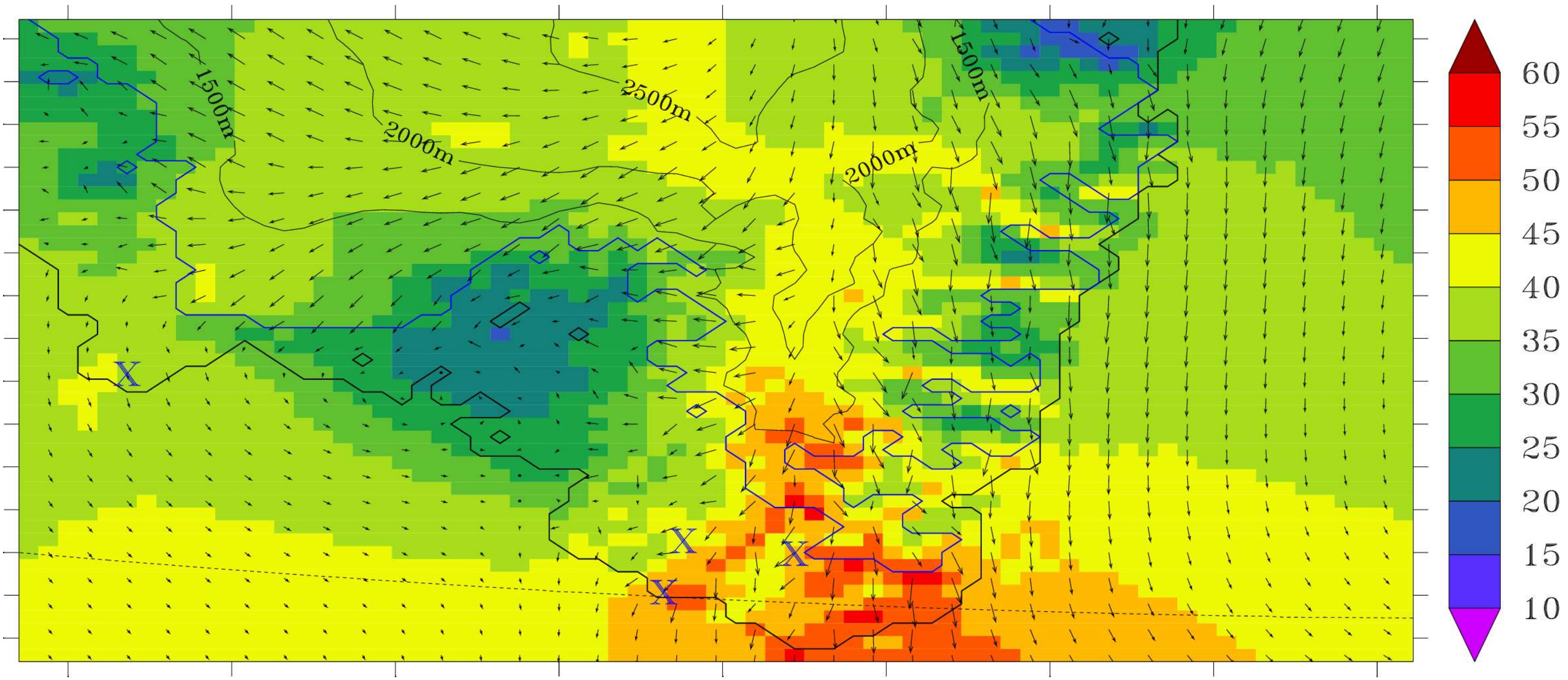
The team: Prof. Xavier Fettweis, Dr. Michaël Fonder and Prof. Damien Ernst

More on the Katabata project: https://www.katabata-project.uliege.be/cms/c_5654602/en/katabata-project

Location of the weather stations



Winds at those locations



Mean Wind Speed at 100m (km/h). Location of the weather stations indicated by the symbol X

Vaisala's AWS310 stations

Description of AWS310 stations:

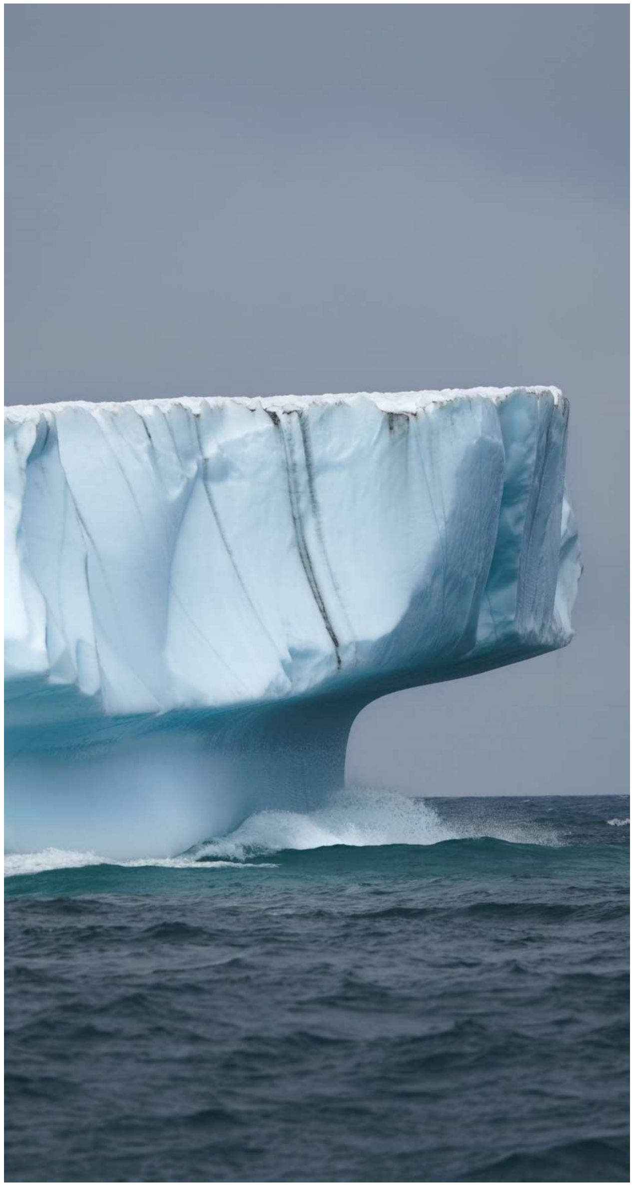
- 4 sensors:
  i. Anemometer for wind speed
  ii. Weathervane for wind direction
  iii. Thermometer
  iv. Humidity sensor
- Satellite antenna for data transfer
- 10m mast with three guy wires
- Battery with photovoltaic panel for lengthy operations in complete autonomy

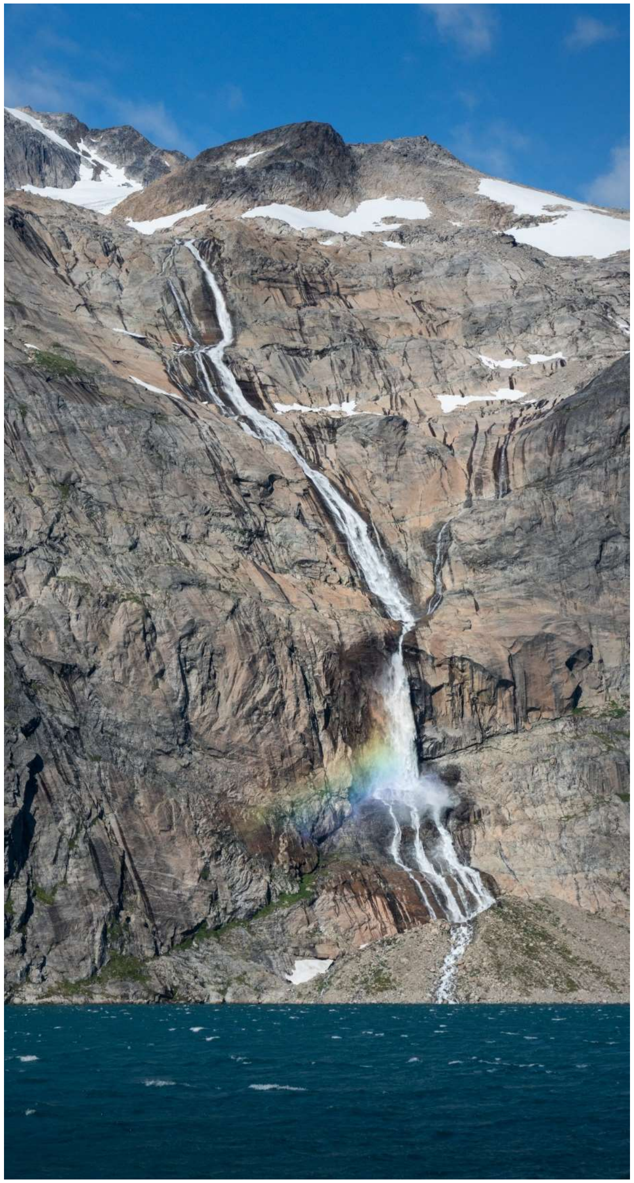
Our AWS310s are also synonyms for an epic delivery:

- Packages weighing more than 350kg for a total volume of 2m³ divided into seven boxes for each station
- A total delivery delay of three months

Departure from Saint-Malo

Arrival in Greenland

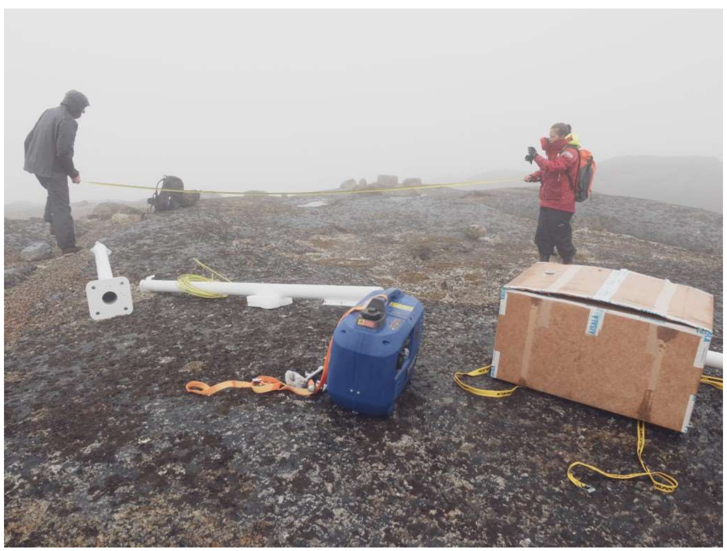




Installing a station is easier said than done!

Installing a station is a challenging task:

- Planning all details on the boat
- Transferring everything ashore
- Finding the right spot for the station
- Getting everything on site
- Starting the installation, hoping for the best
- Dealing with unpredictable weather



Photos © Julien Fumard

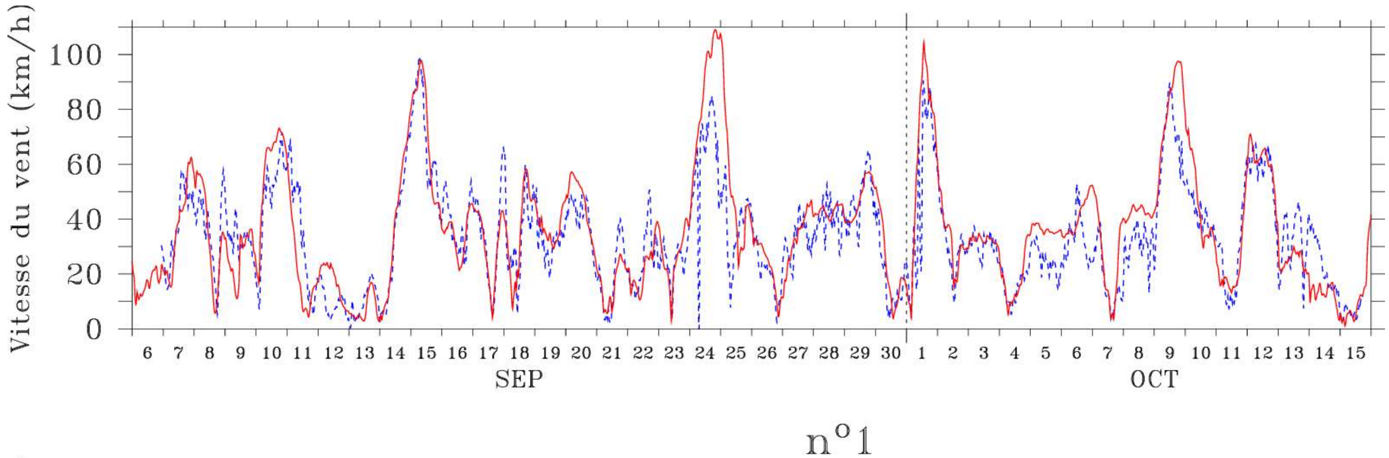
Finalising the installation of Station 1

First comparison: MAR vs observations

1 observation every 20m from 6 SEP 2020 to 15 OCT 2020.

Wind measured at 10m

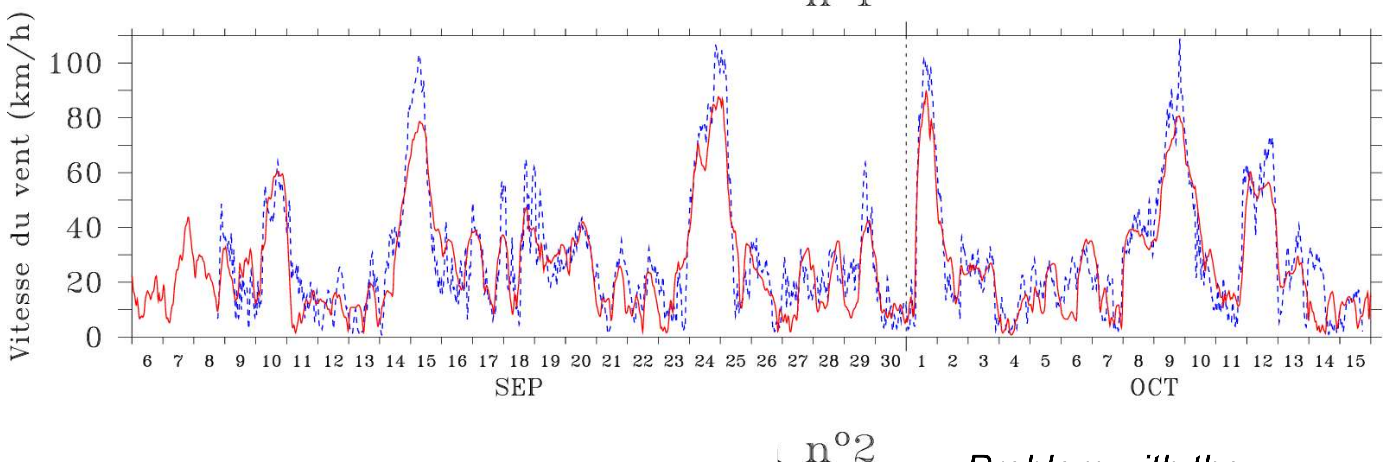
AWS1



Correlation: 0.87
Bias=+2.4km/h
RMSE=11km/h

Mean: 34±20km/h

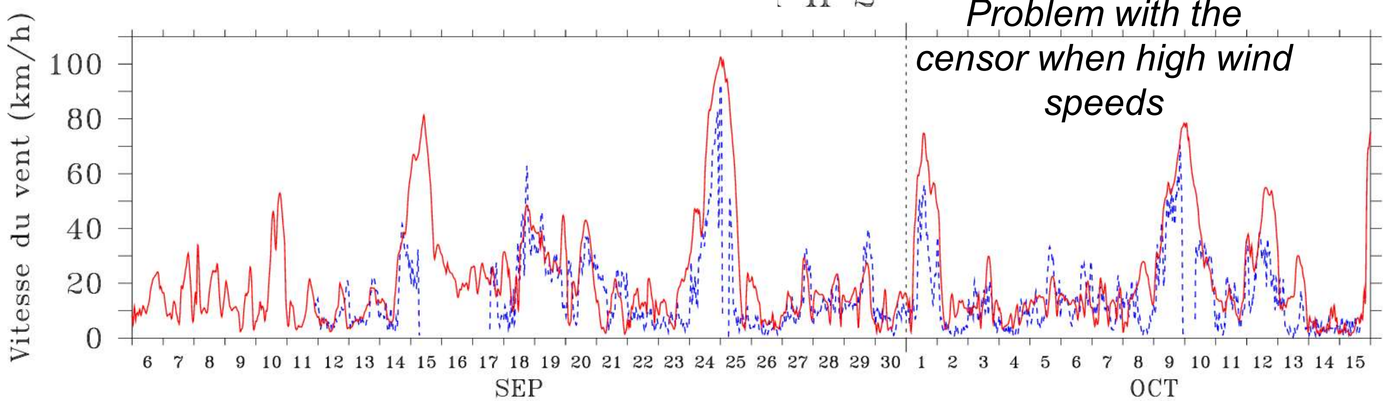
AWS2



Correlation: 0.9
bias=-2km/h
RMSE=10km/h

Mean: 29±23km/h

AWS3

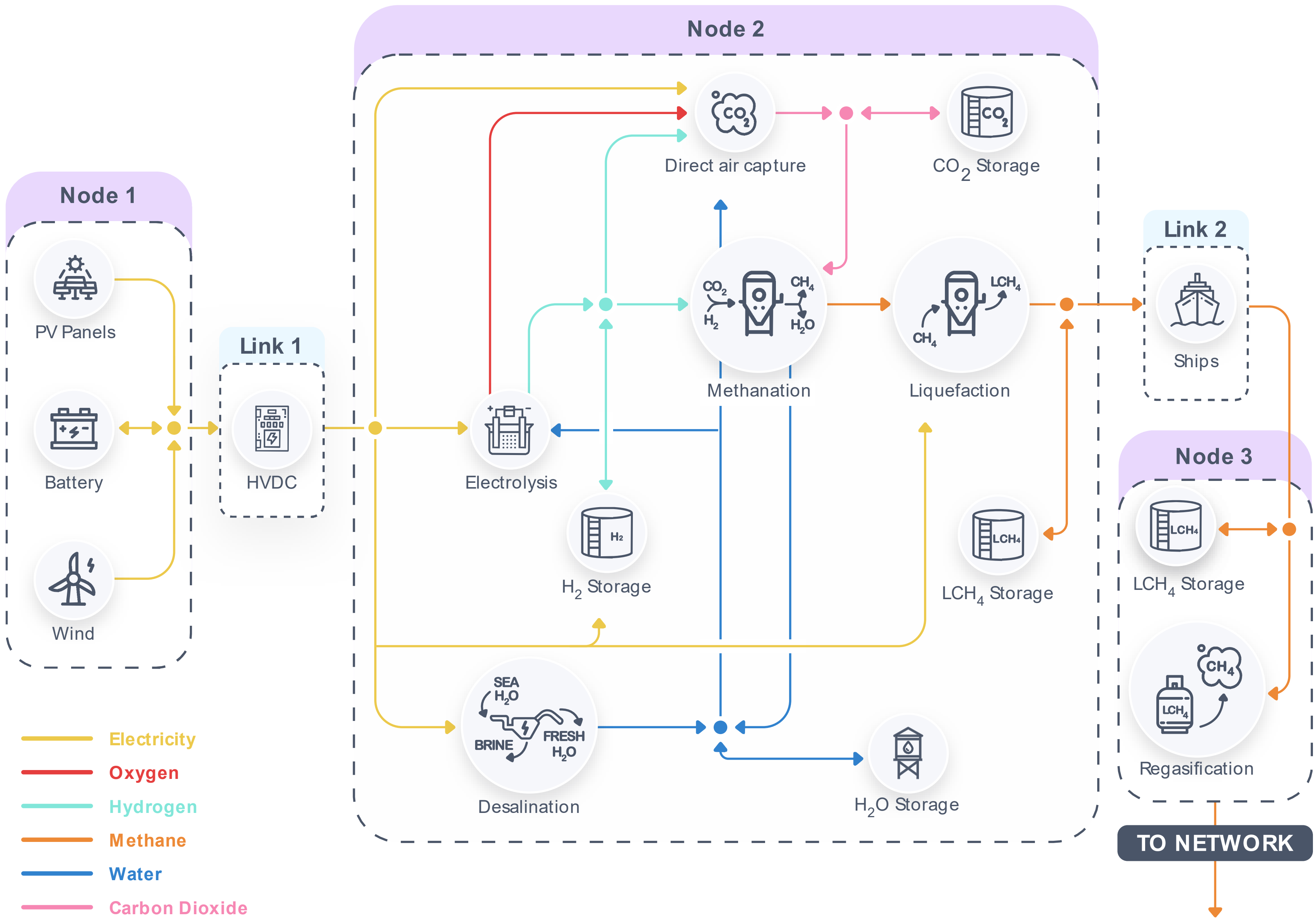


Correlation: 0.86
bias=+4km/h
RMSE=11km/h

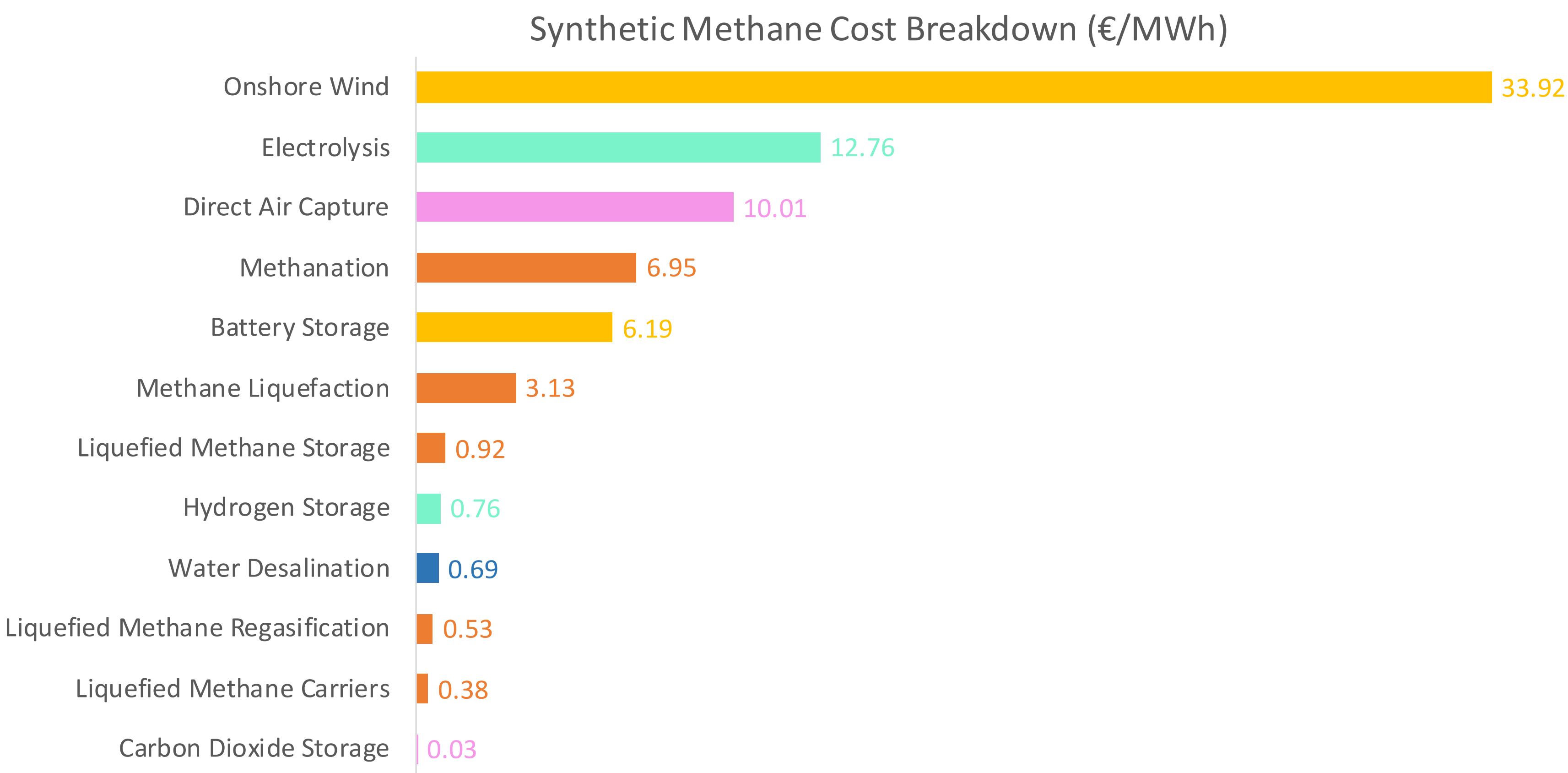
Mean: 17±17km/h

MAR is able to simulate spatial and temporal variability at the three stations.

Remote renewable energy hub for carbon-neutral fuel production



Remote renewable energy hub in Greenland: cost breakdown



Methane comes at a price 76.4 €/MWh in Zeebrugge (WACC 0%).

Pros and cons of carbon-neutral energy-rich molecules to export this energy

Pros

Molecules can be used to power loads that are difficult to electrify (airplanes, etc.).

They can exploit existing downstream infrastructure (gas networks, heating systems, etc.).

Hubs are easier to develop than large-scale intercontinental electrical connections.

The byproducts of hubs, such as heat and pure water, can be exploited locally.

Cons

Exporting this energy in the form of energy-rich molecules generally results in greater losses than when it is repatriated in the form of electricity.

You still depend on imports for your energy supply.

Artist representation of a remote energy hub located in Greenland.

References

Chatzivasileiadis, S., Ernst, D., & Andersson, G. (2013). *The global grid*. Renewable Energy, 57, 372-383. doi:10.1016/j.renene.2013.01.032

Radu, D.-C., Berger, M., Fonteneau, R., Hardy, S., Fettweis, X., Le Du, M., Panciatici, P., Balea, L., & Ernst, D. (2019). *Complementarity Assessment of South Greenland Katabatic Flows and West Europe Wind Regimes*. Energy, 175, 393-401. doi:10.1016/j.energy.2019.03.048

Berger, M., Radu, D.-C., Fonteneau, R., Henry, R., Glavic, M., Fettweis, X., Le Du, M., Panciatici, P., Balea, L., & Ernst, D. (2020). *Critical Time Windows for Renewable Resource Complementarity Assessment.* Energy, 198. doi:10.1016/j.energy.2020.117308

Berger, M., Radu, D.-C., Fonteneau, R., Henry, R., Glavic, M., Fettweis, X., Le Du, M., Panciatici, P., Balea, L., & Ernst, D. (2020). *Critical Time Windows for Renewable Resource Complementarity Assessment*. Energy, 198. doi:10.1016/j.energy.2020.117308

Berger, M., Radu, D.-C., Detienne, G., Deschuyteneer, T., Richel, A., & Ernst, D. (2021). *Remote Renewable Hubs for Carbon-Neutral Synthetic Fuel Production*. Frontiers in Energy Research. doi:10.3389/fenrg.2021.671279

Lambin, C., Fettweis, X., Kittel, C., Fonder, M., & Ernst, D. (2022). *Assessment of future wind speed and wind power changes over South Greenland using the MAR regional climate model*. International Journal of Climatology. doi:10.1002/joc.7795

Dachet, V., Benzerga, A., Fonteneau, R., & Ernst, D. (2023). *Towards CO2 valorization in a multi remote renewable energy hub framework.* Proceedings of ECOS 2023 - The 36th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, Las Palmas, Spain.