Crewed and Uncrewed Aircraft Measurements

Summary presentation Project X-Wakes

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

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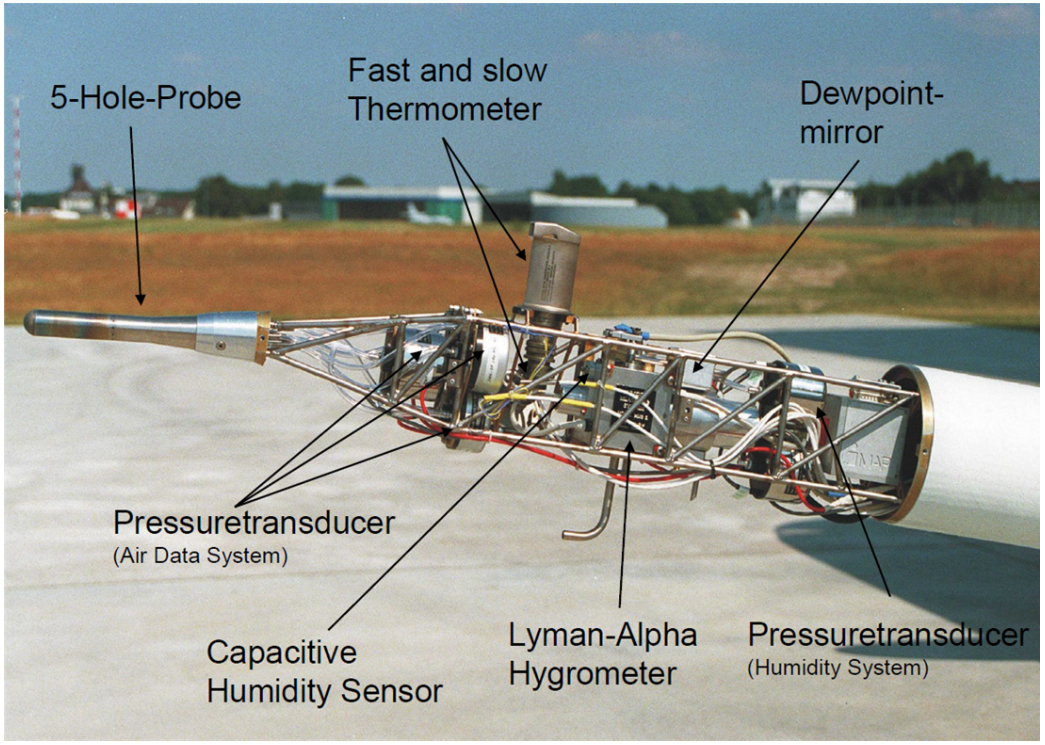
Fraunhofer IWES
ForWind Center for Wind Energy Research
Bremen Hannover Oldenburg

Observational Method Crewed Research Aircraft



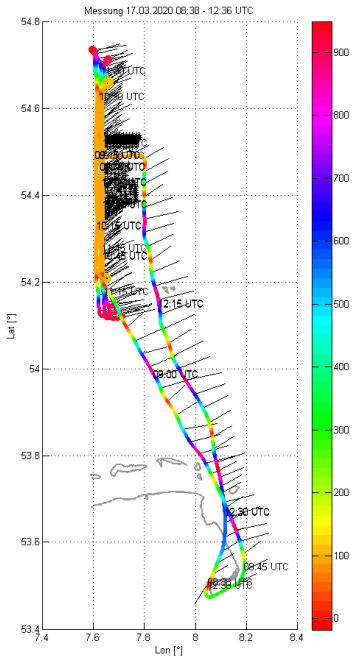
Research Aircraft DO-128 (D-IBUF) and Cessna Cessna F406 (D-ILAB) operated by the TU Braunschweig

Instrumentation of the nose boom:
wind speed/ turbulence (5 hole probe), temperature, humidity

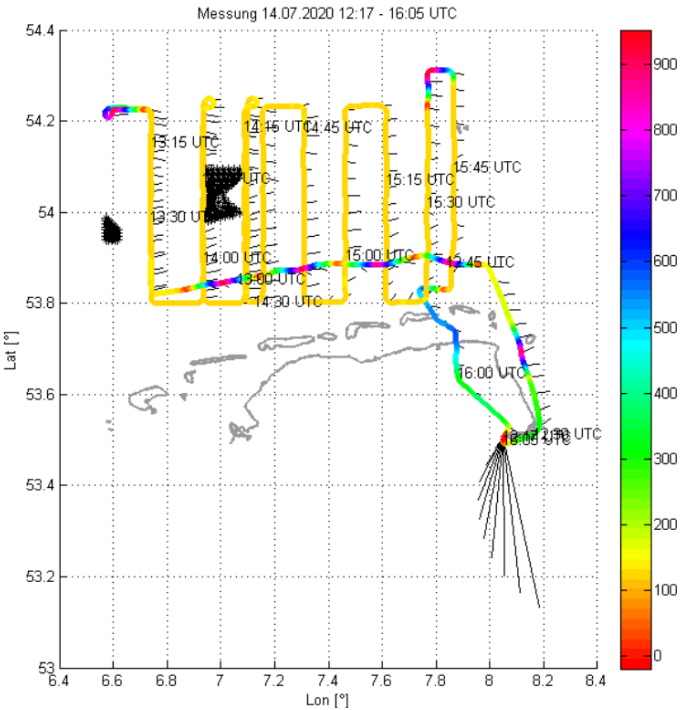
Flight Strategies

49 measurement flights in total performed by the TU Braunschweig, **3** different flight strategies

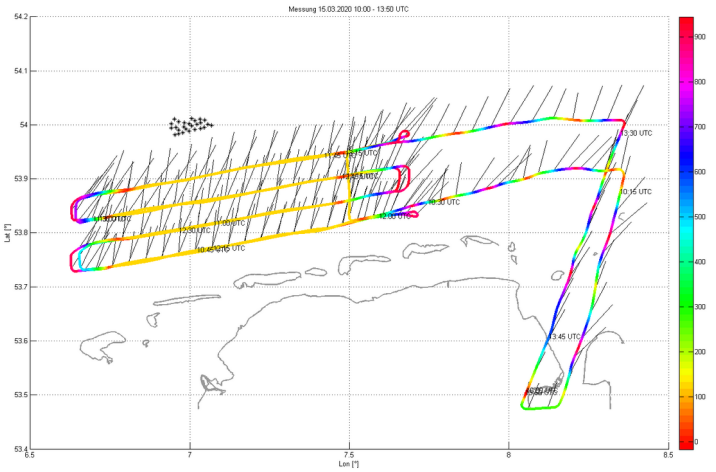
Global Blockage Effect



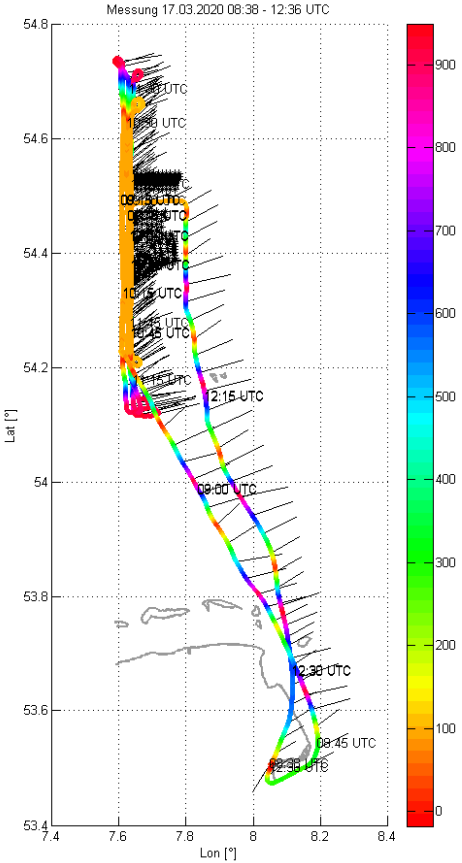
Interwakes

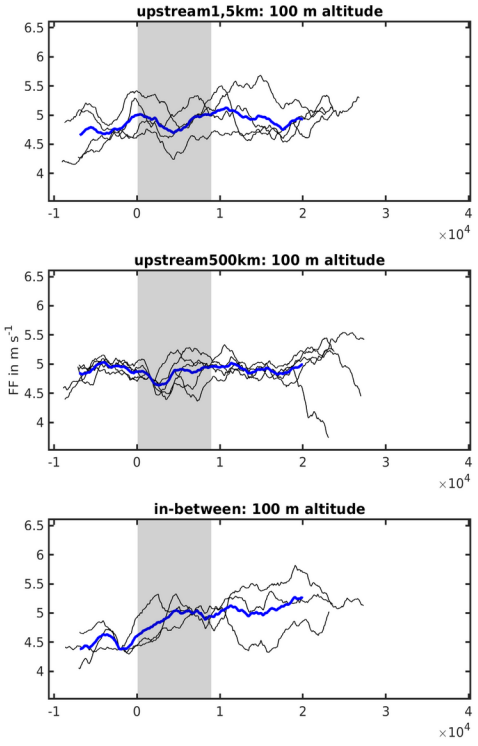


Coastal Effects

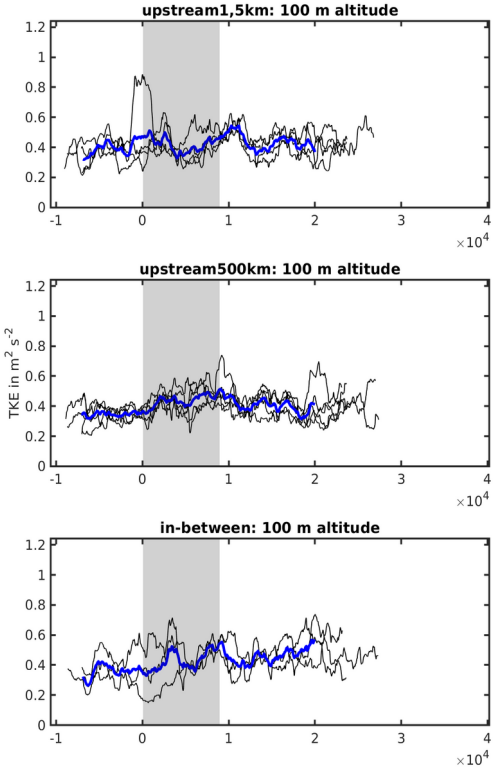


Global Blockage Effect

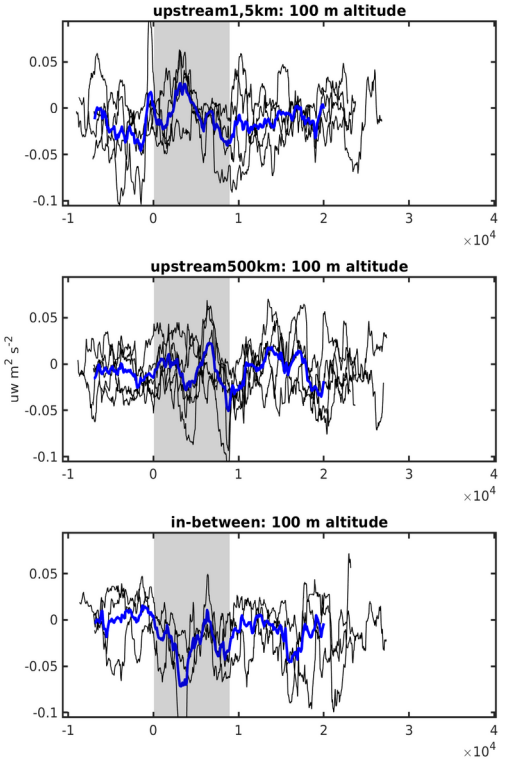




Wind speed

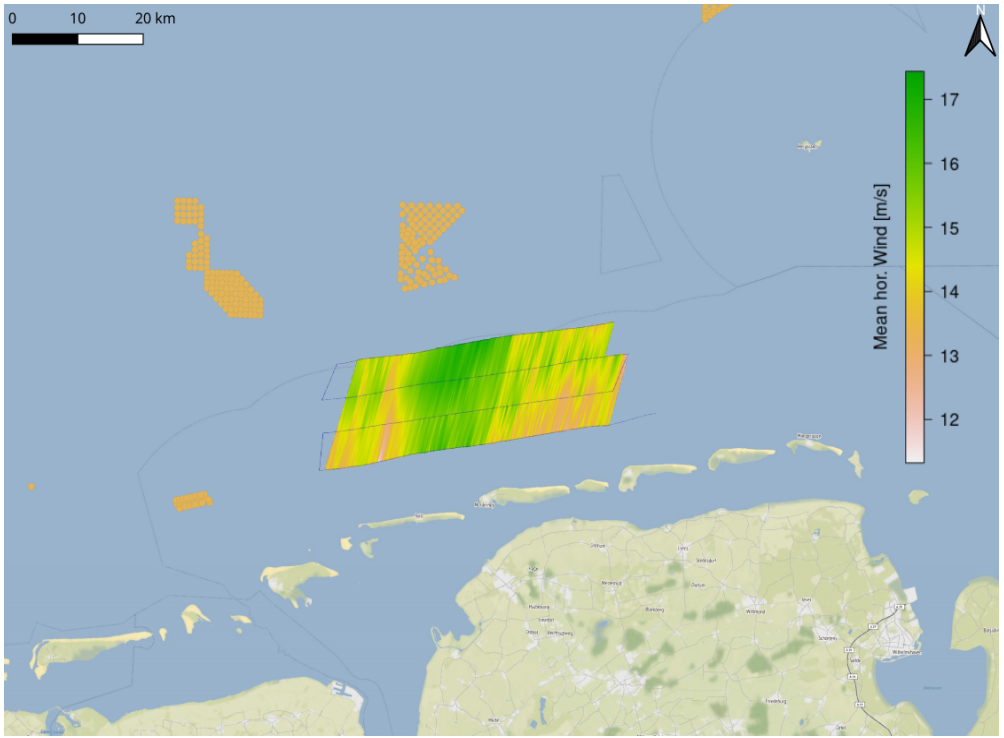


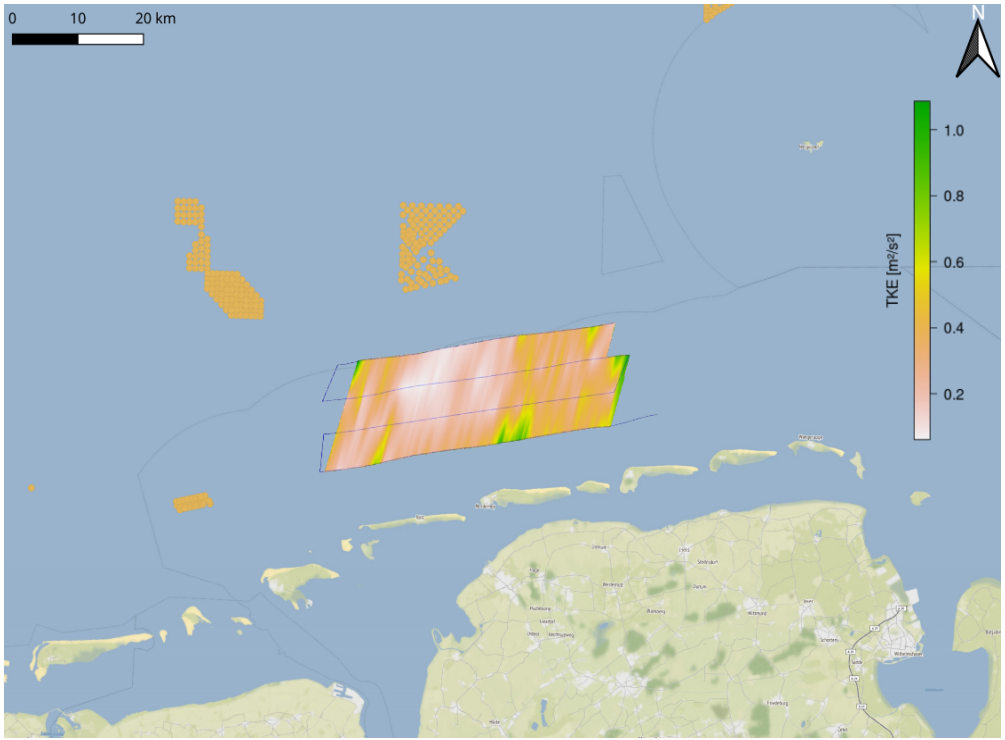
Turbulence kinetic energy



Momentum flux

Measurements – coastal effects





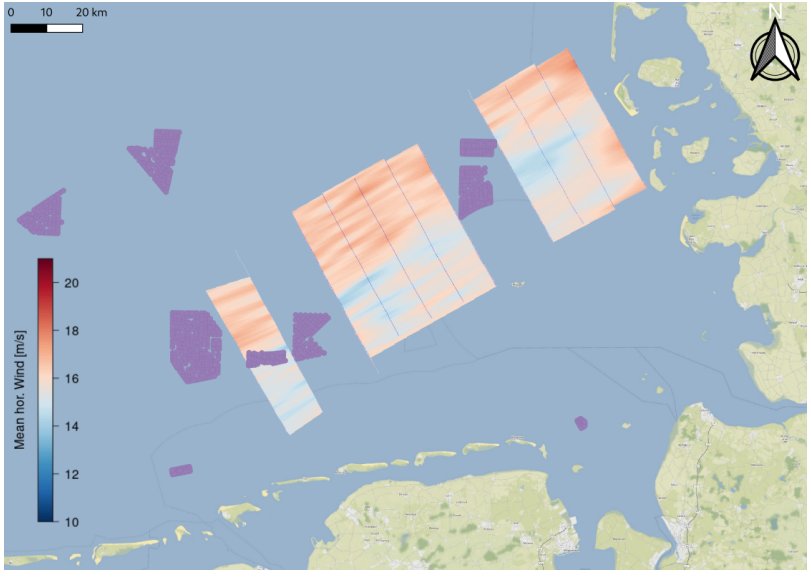
Flight No.2, 15.03.2020: Mean wind speed and direction: 14 m/s, 190°, stable stratification

More on coastal effects at **11:50 by Astrid Lampert** (TU Braunschweig): Coastal influence on wind speed in the North Sea based on wind lidar, airborne measurements and ERA5 data

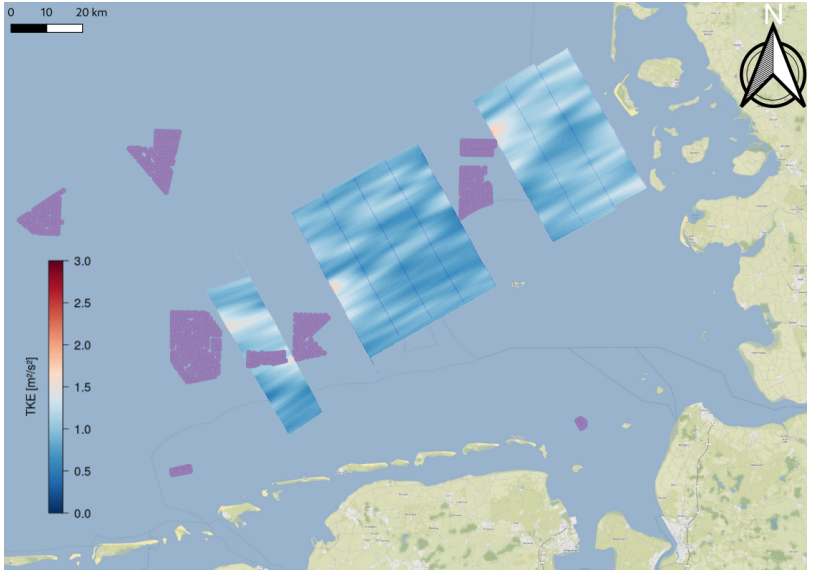
Measurement of Interwakes Effects

Example Flight 35:

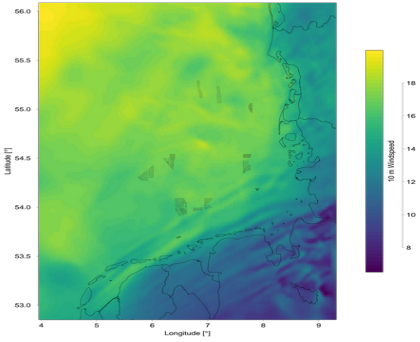
mean wind speed



turblence kinetic energy



WRF validation

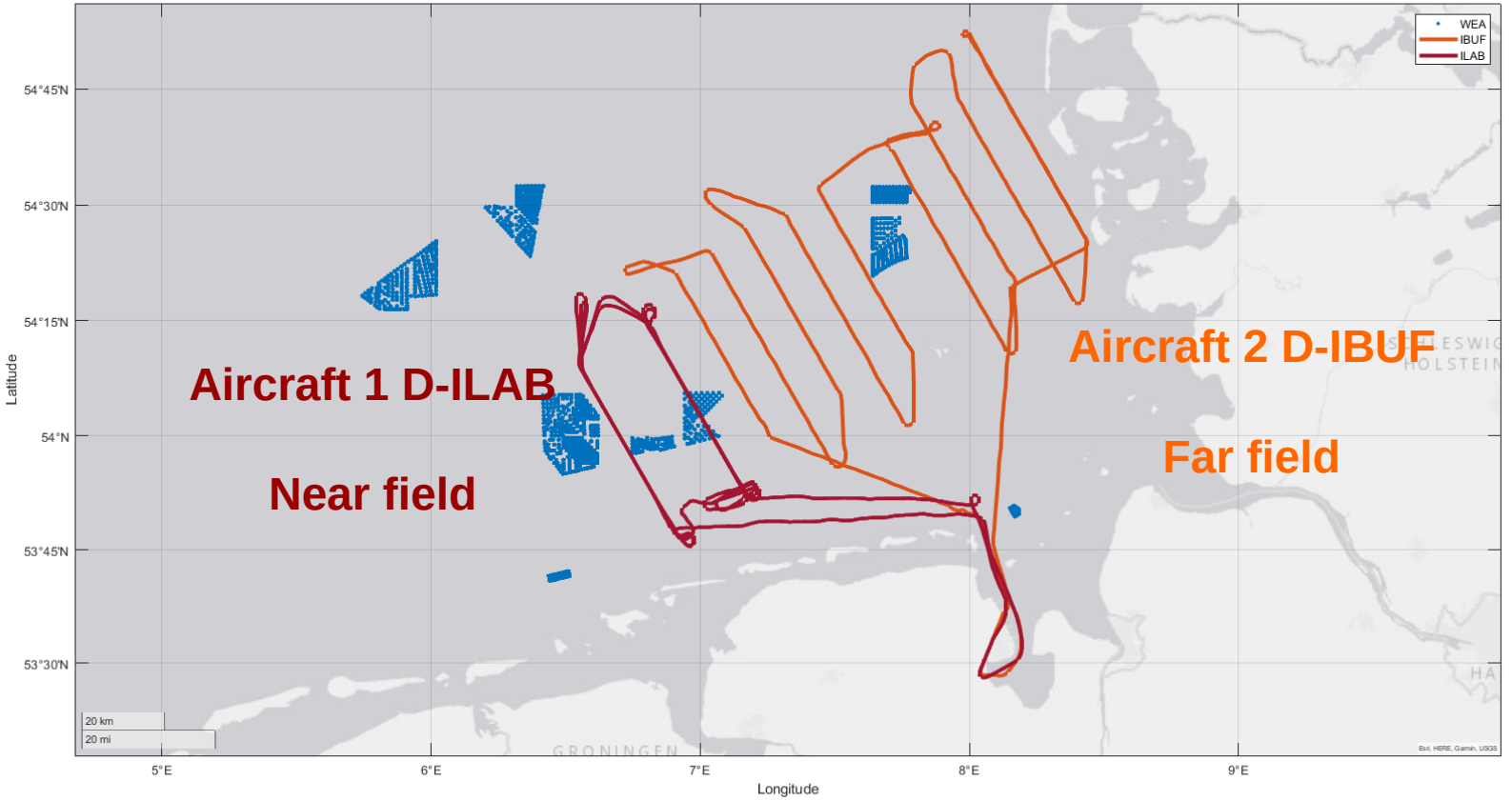


More on Interwakes: **13:50-14:10**
Kjell zum Berge (Tübingen) - Comparison of Modelled Cluster Wakes to Aircraft Data in the German Bight

Overview of wake measurement flights

Flight ID	Date	Flight Pattern	Wind Speed [m/s]	Wind Dir [°]	Stability
12 (IBUF)	6/29/2020	G240	15	230	neutral
17 (IBUF)	7/3/2020	G260	10	240	stable
19 (IBUF)	7/14/2020	G270	7	270	stable
23 (IBUF)	7/23/2020	G240	10	225	stable
24 (IBUF)	7/24/2020	G270	10	270	neutral up to 200 m
26 (IBUF)	7/28/2020	G260	13	250	slightly stable
30 (IBUF)	9/24/2020	G240	17	230	neutral up to 300 m
35 (IBUF)	4/8/2021	G240	15	240	neutral
38 (IBUF)	4/13/2021	G000	11	300	stable
39 (IBUF)	4/13/2021	G000	10	300	slightly stable
40 (IBUF)	4/14/2021	G000	7	330	neutral up to 300 m
41 (IBUF)	4/14/2021	G000	6	330	stable
44 (IBUF/ILAB)	**7/27/2021**	**G240**	**10**	**240**	**slightly stable**
46 (IBUF/ILAB)	**7/29/2021**	**G240**	**17**	**240**	**neutral**
47 (IBUF/ILAB)	7/29/2021	G245	17	245	neutral up to 700 m
48 (IBUF/ILAB)	7/30/2021	G240	10	240	slightly stable
49 IBUF	11/09/2021	G240	8	200	neutral up to 350 m

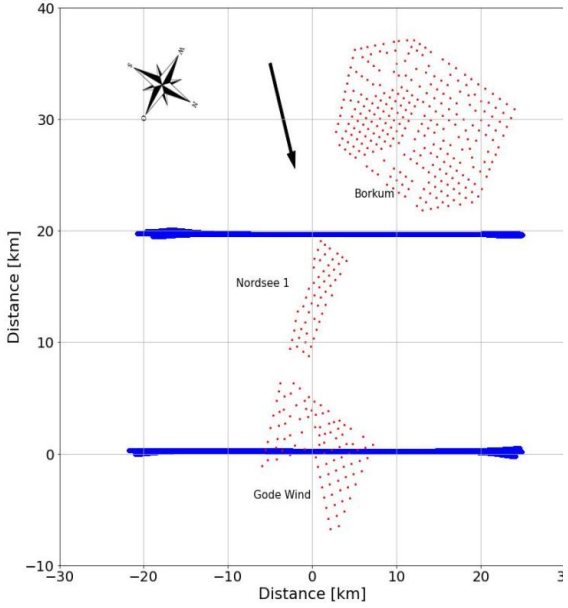
Flights with both aircraft D-IBUF and D-ILAB

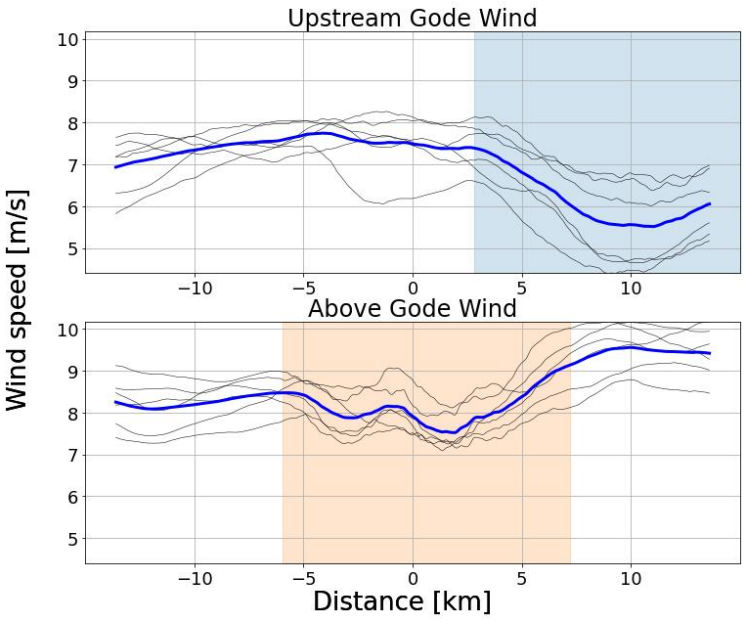


- 2 flights during (slightly) **stable**
- 2 fights during **neutral** conditions

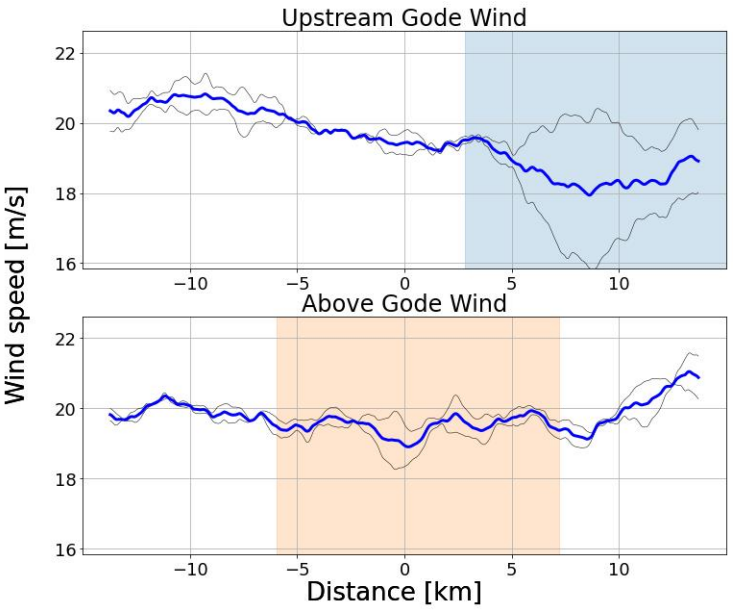
Wind speed in the near field

slightly stable



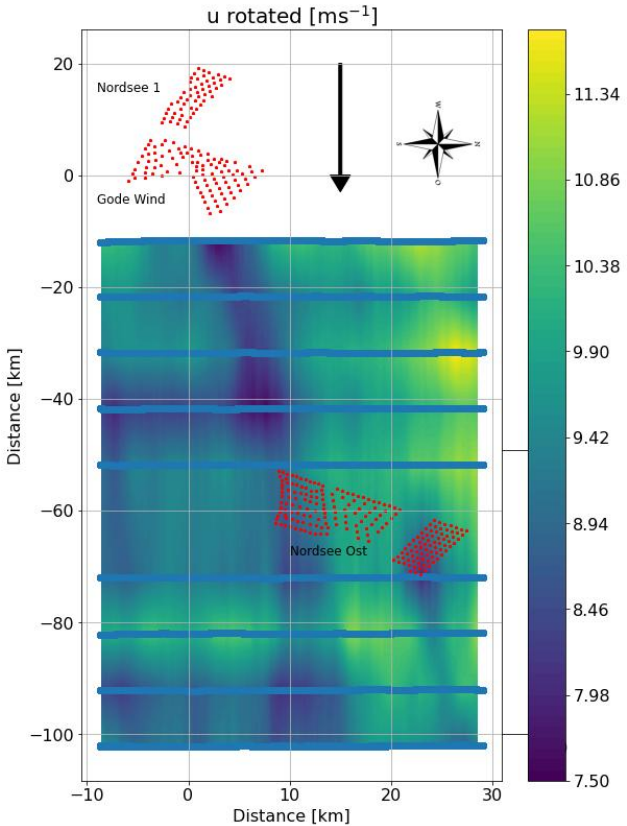


neutral

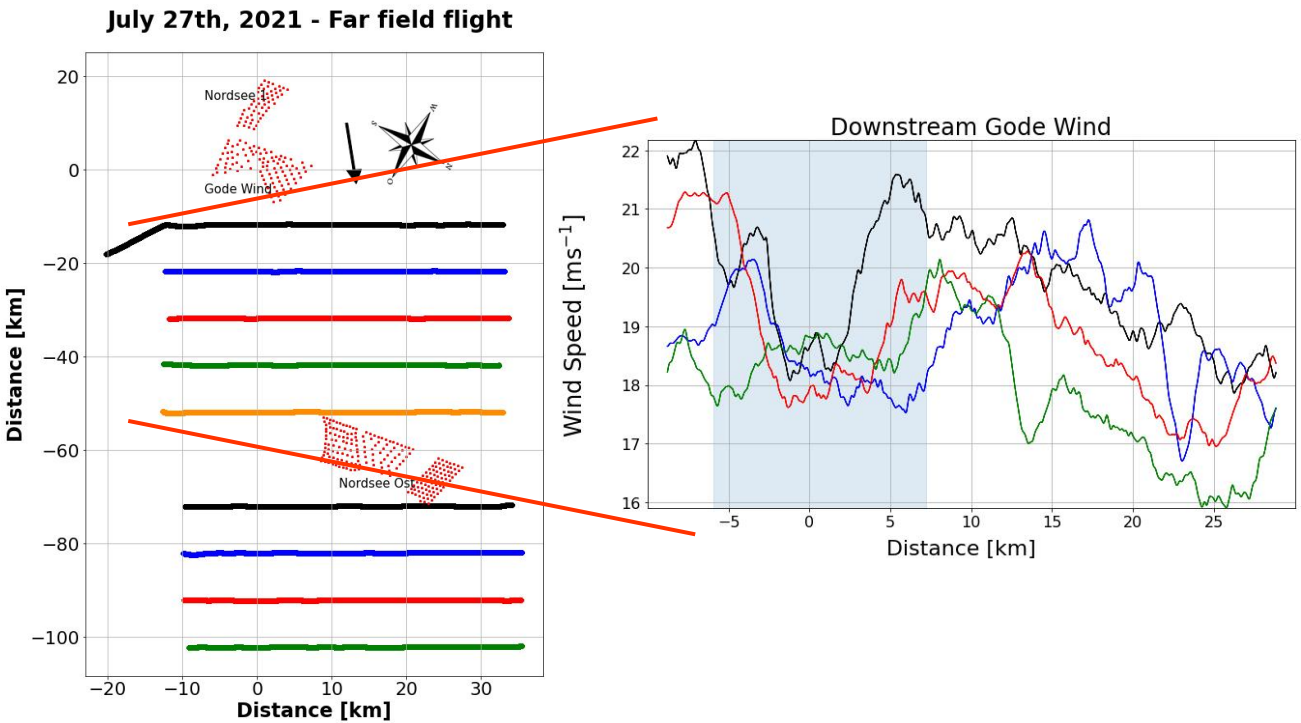


Wind speed in the far field

slightly stable



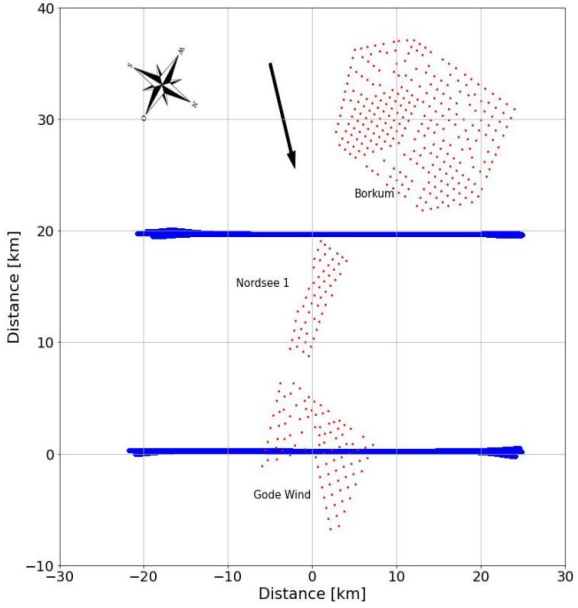
neutral

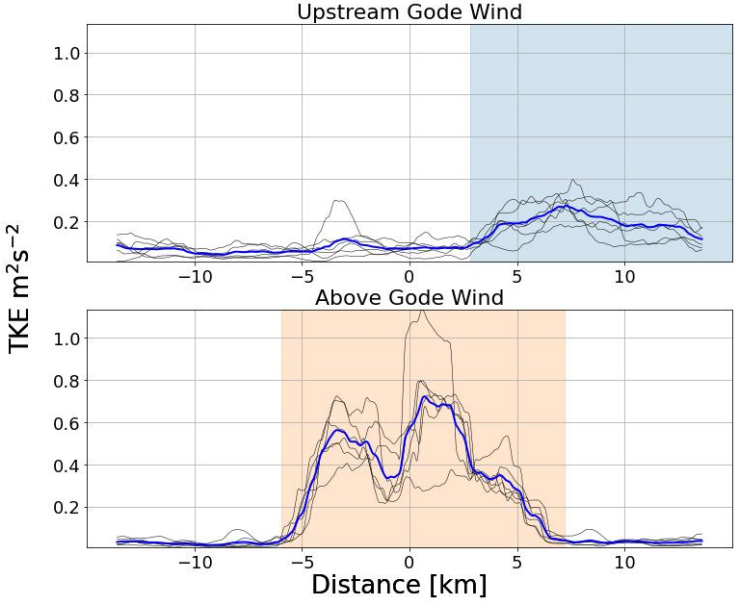


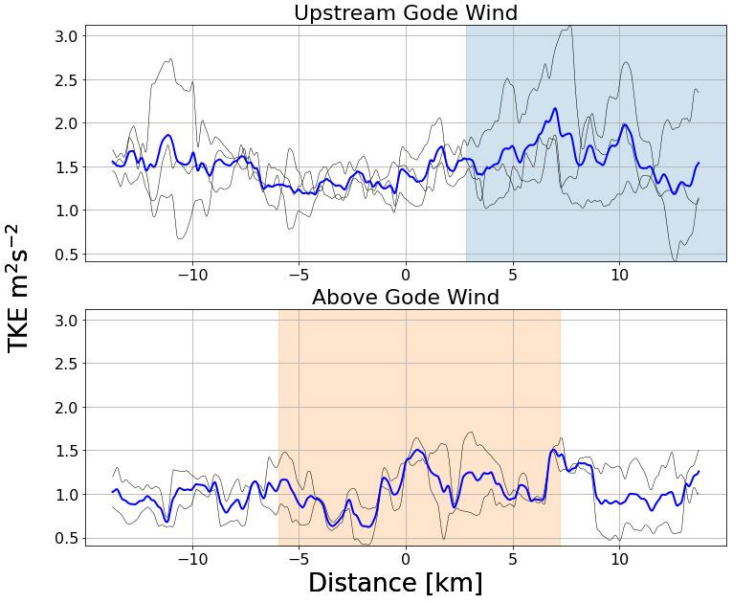
Turbulence kinetic energy (TKE) in the near field

slightly stable

neutral

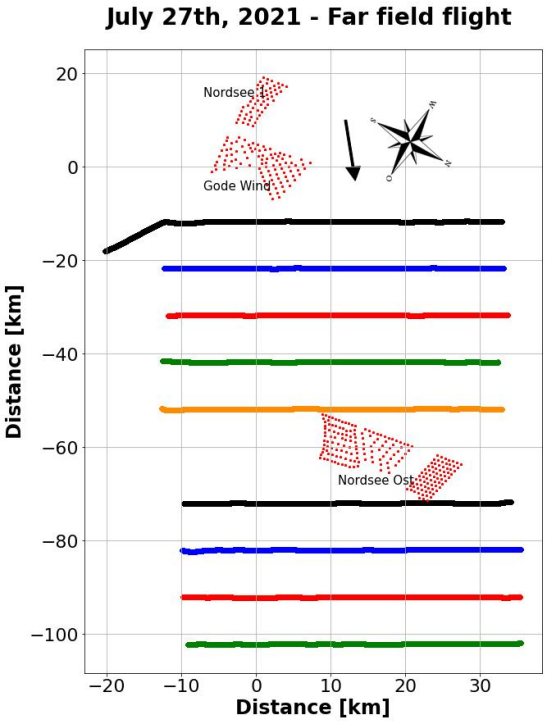


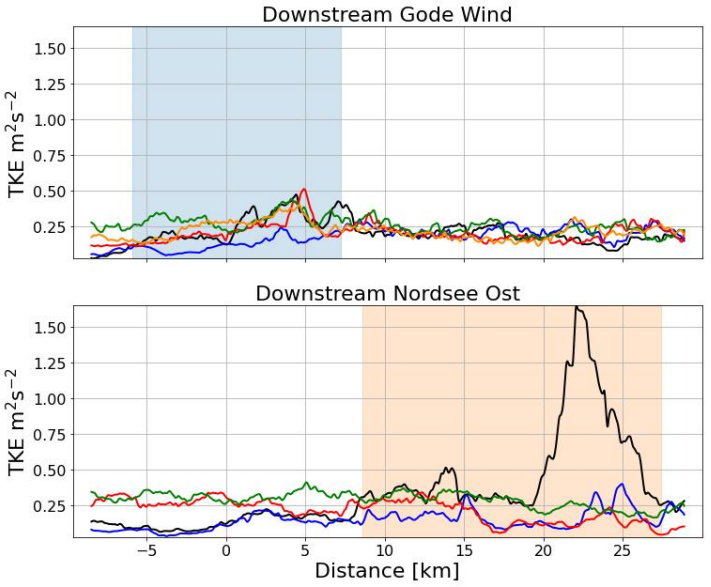




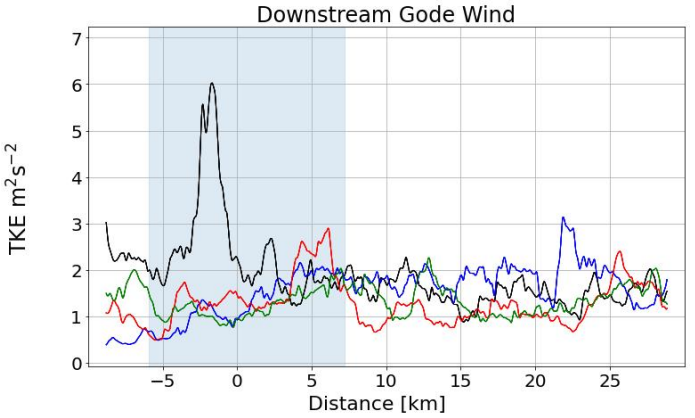
Turbulence kinetic energy (TKE) in the near field

slightly stable



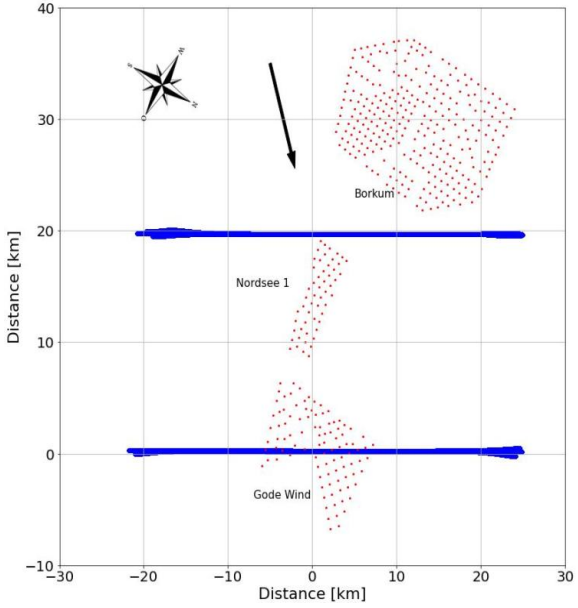


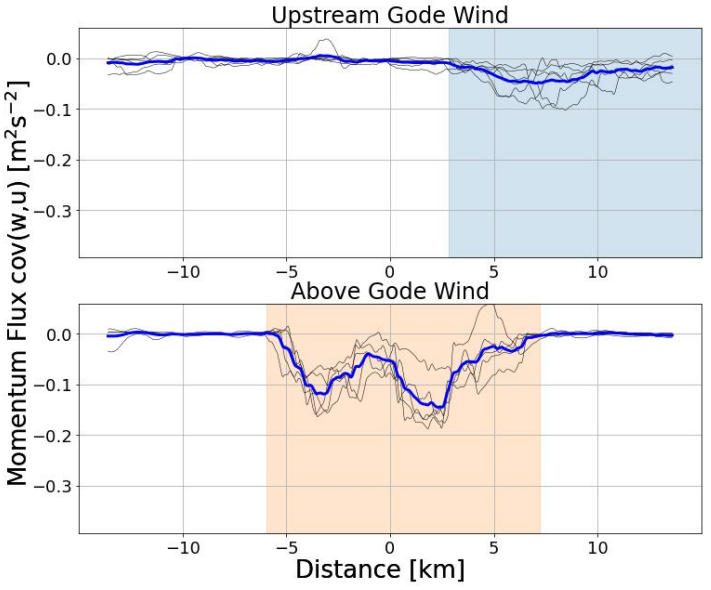
neutral



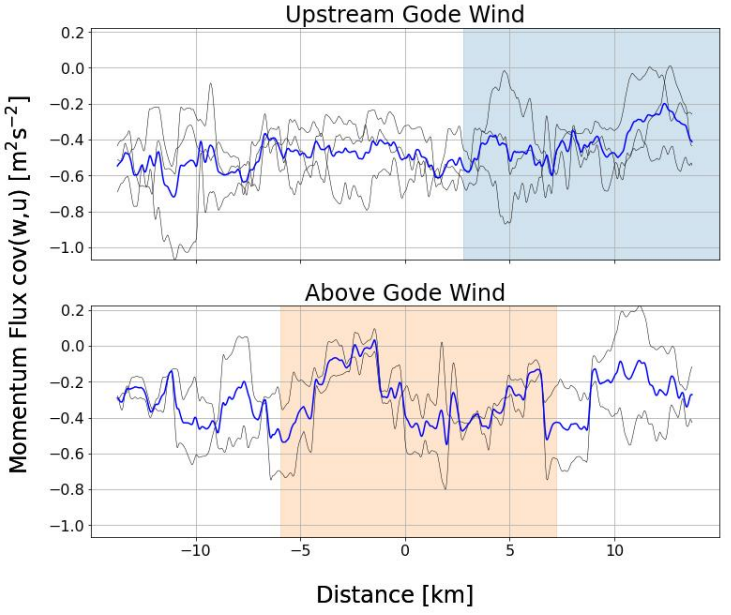
Momentum flux in the near field

slightly stable



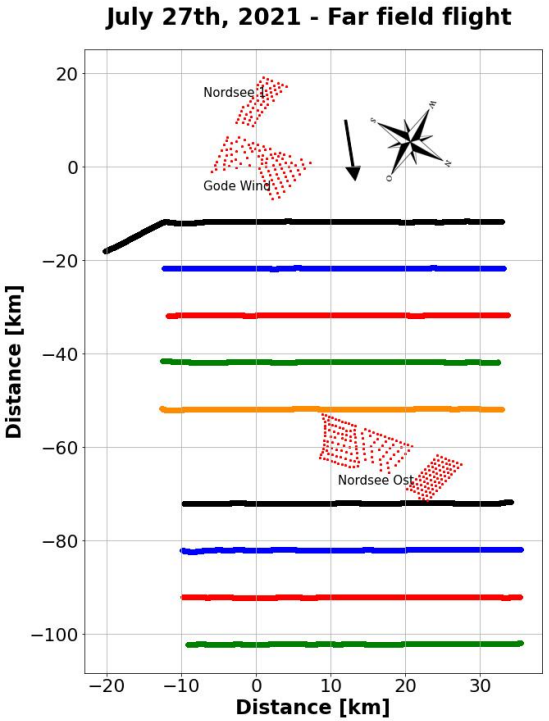


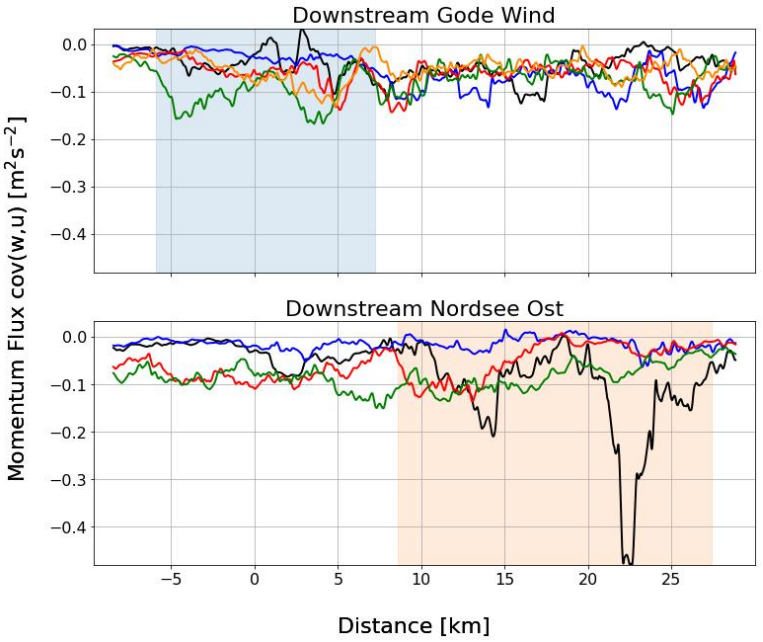
neutral



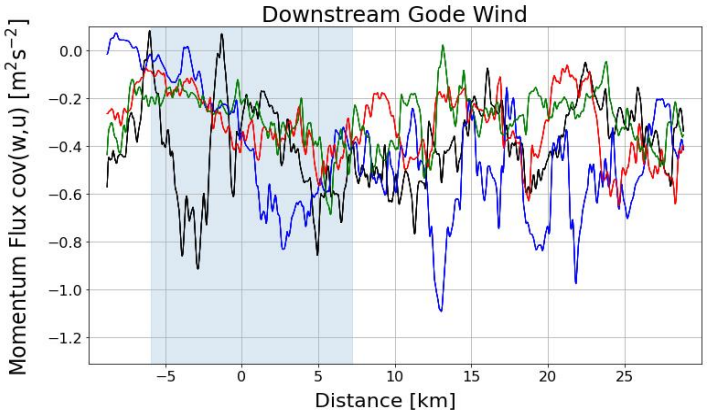
Momentum flux in the far field

slightly stable



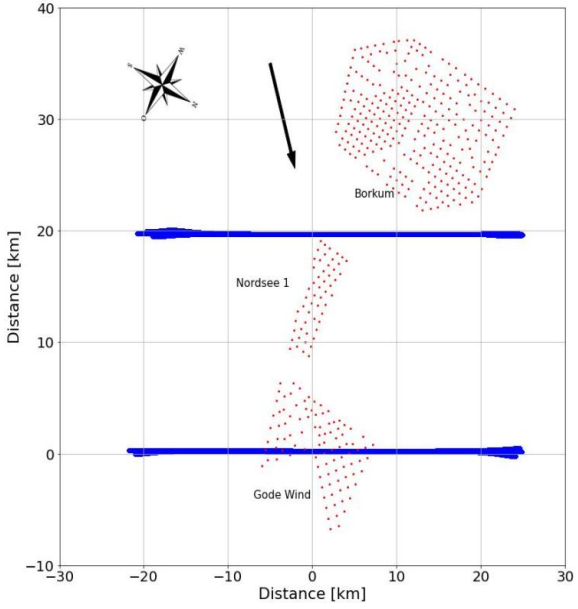


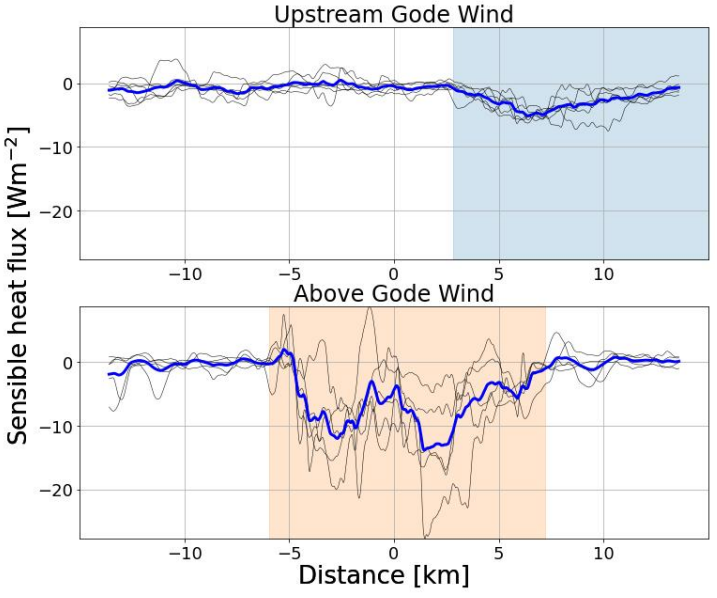
neutral



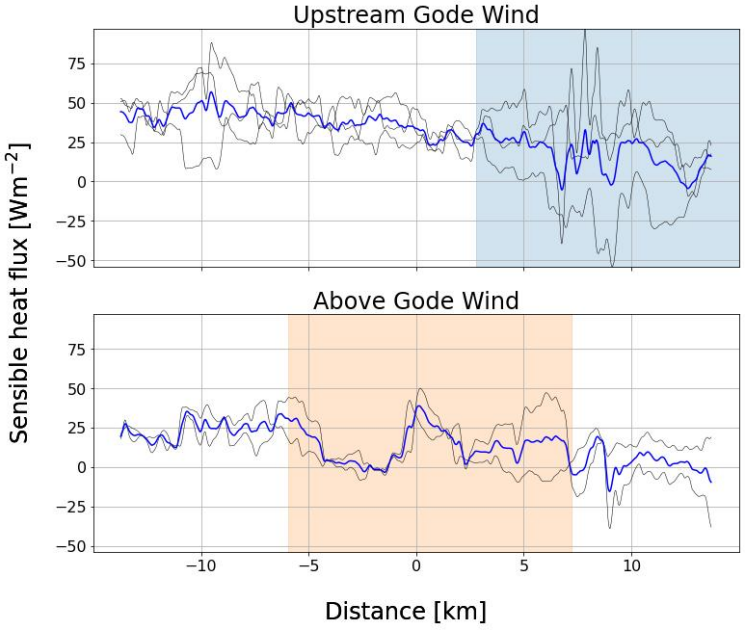
Sensible heat in the near field

slightly stable





neutral



SAR Validation with UAS

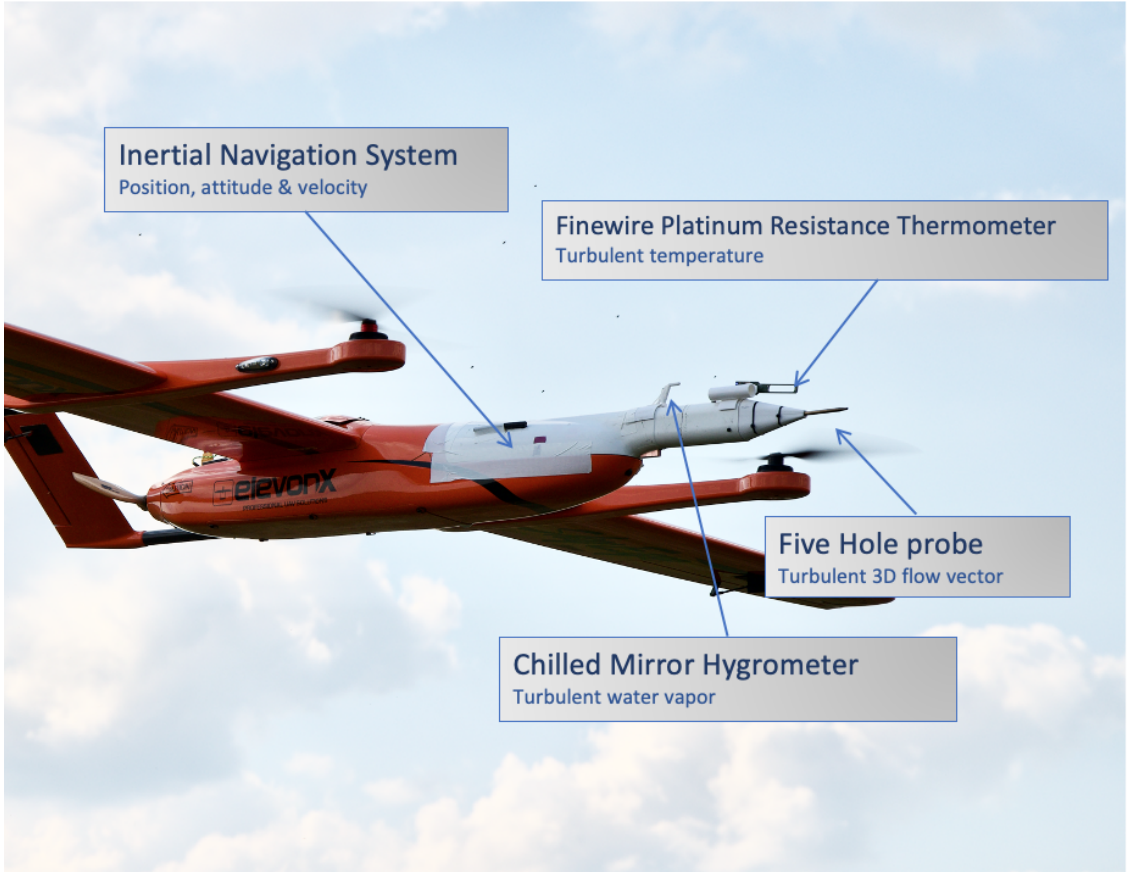
Project requirements

- Large area ~ 10 km^2
- Low altitude
- True offshore conditions

Realization

- Vertical takeoff and landing
- Flying Beyond Visual Line of Sight
- Video telemetry
- LTE link
- Laser altimeter
- > 100 pages in legal documents
- according to new EU law
- 160 km² restricted airspace
- Collaboration with Fraunhofer IFAM

UAS of type MASC-V



basic meteorology turbulence:

- 3D wind vector
- temperature
- humidity

→ turbulence and turbulent fluxes

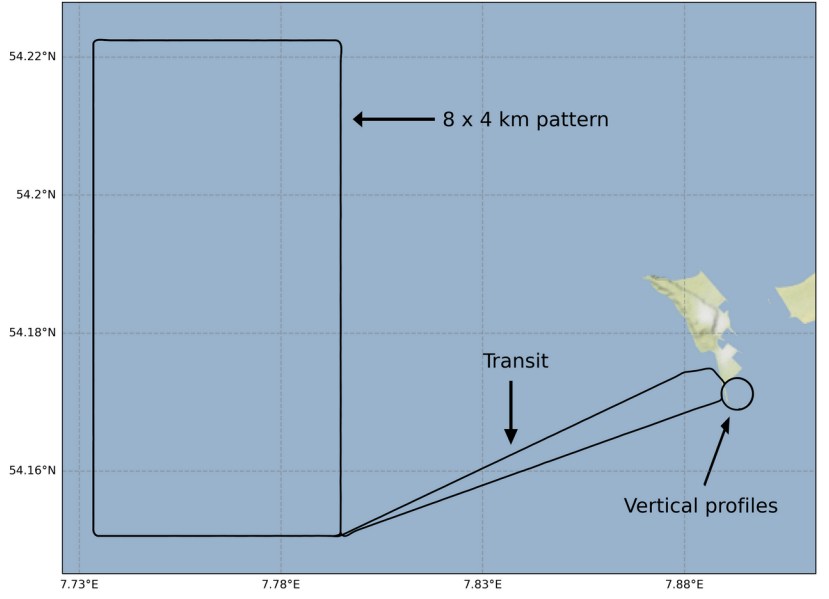
optional / modular:

- Aerosol particles
- CO2 concentration
- charge distribution

Aerial SAR Validation Measurements

No	Date	Launch (UTC)	Ldg. (UTC)	W.-speed (30 m)	W.-dir. (30 m)	Comment
1	14.09.21	13:00	13:44	6	E	Test flight with boat visual observer
2	17.09.21	16:52	17:52	7	N	SAR validation 8 x 4 km rectangle
3	20.09.21	12:49	13:44	2.5	E	Racetrack pattern - Heligoland wake
4	22.09.21	06:23	07:18	6.5	W	
5	22.09.21	08:10	09:04	8	W	

Flight track
17.09.2021



In collaboration with Fraunhofer IFAM & Testzentrum für maritime Technologien @Heligoland

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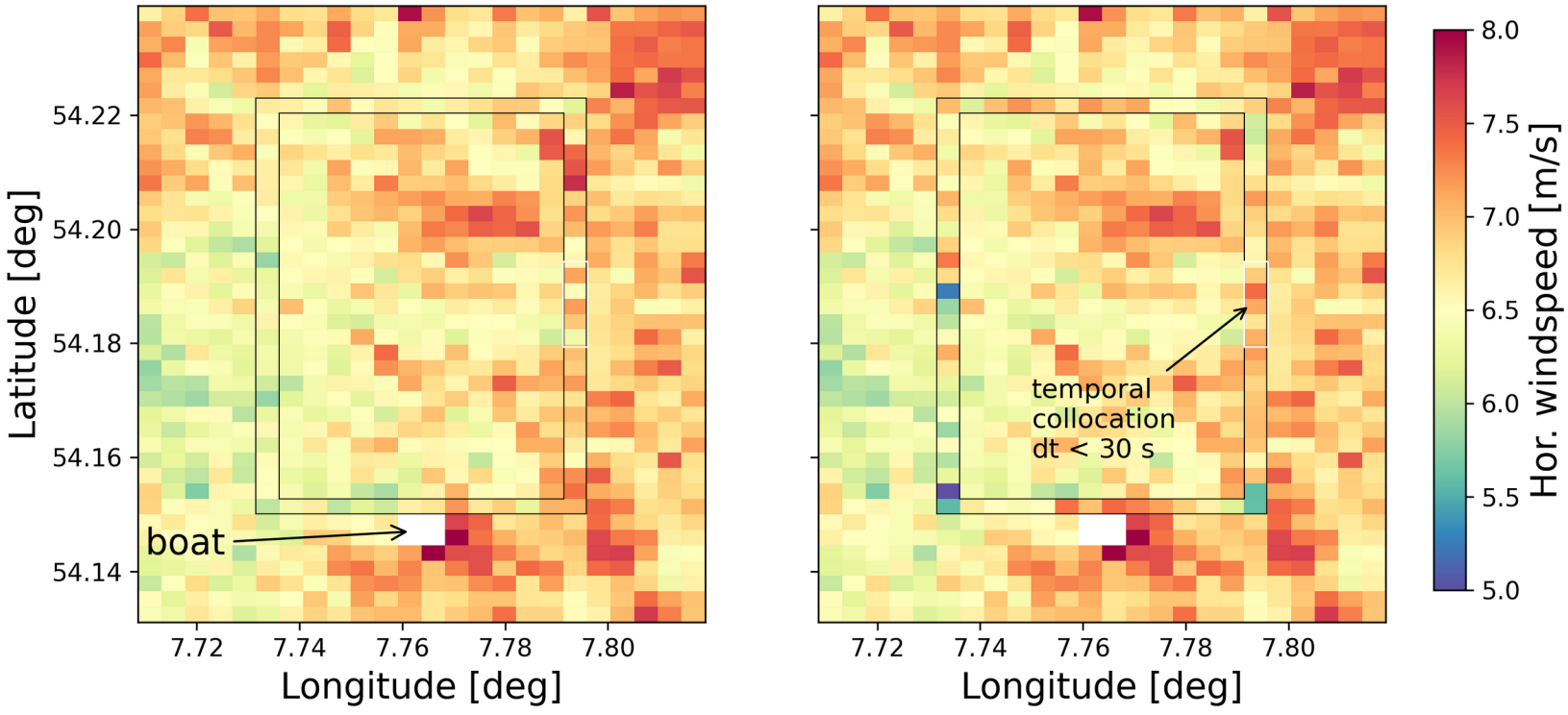
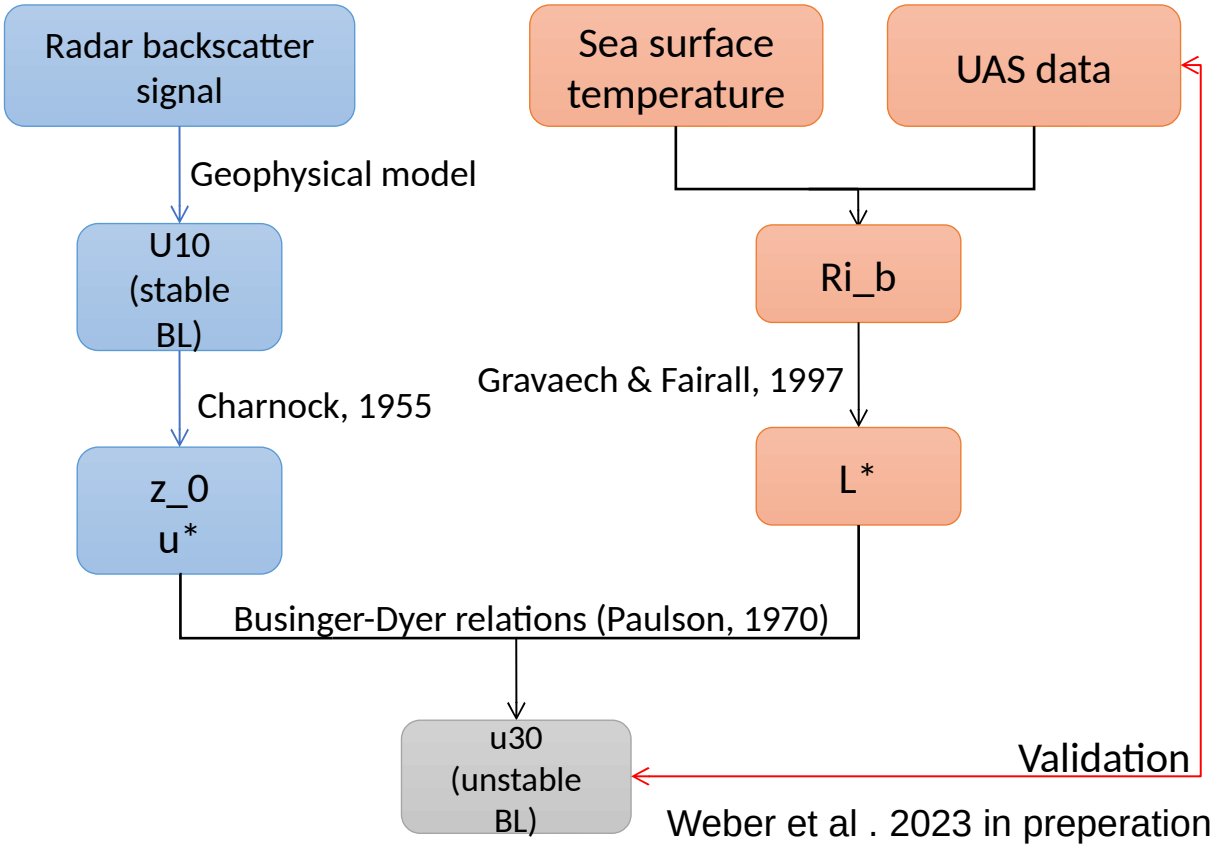
SAR vs UAS comparison



SAR u30

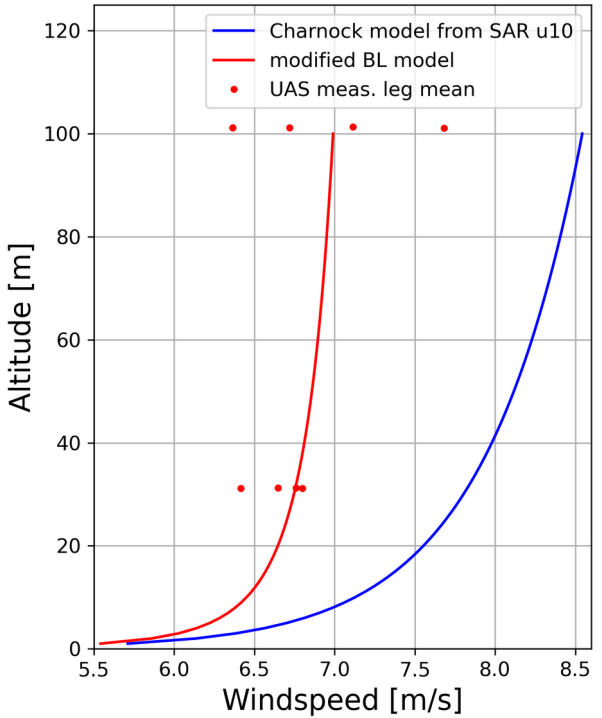
SAR u30 with UAS overlay

SAR wind reconstruction for unstable BL using UAS data



Weber et al . 2023 in preperation

Unstable conditions most frequent one occurring in the German Bight (Platis et al. 2022)



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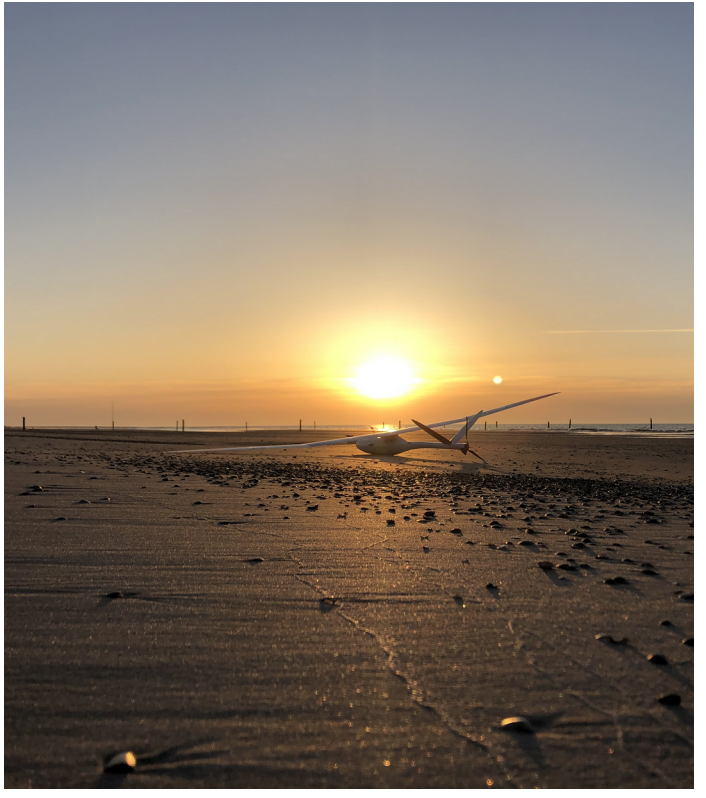
Conclusion UAS

Review

- UAV open new opportunities for offshore wind energy research
- In-situ measurement of turbulent and thermodynamic quantities
- Soundings (vertical profiles)
- Remote sensing SAR and numerical simulation validation
- BVLOS capabilities demonstrated

Outlook

- Close to wind farms
- Inside wind farms
- Single turbines (distances < ½ D)
- Sea spray measurements



Conclusion Crewed Aircraft

- 49 crewed measurement flights to study several effects and impacts of offshore wind farms in the German Bight
- First order statistics are visible in stable and unstable conditions, but extend longer under stable conditions
- Second order statistics effected by wind farms are significant observable under stable conditions above the wind farm and in regions closer to the wind farm
- In situ airborne data is used for model validation and improvements
- Data is available to the public

Airborne data available:
Rausch, Thomas; Bärfuss, Konrad; Hankers, Rudolf; Bitter, Mark; Feuerle, Thomas; Cremer, Matthias; Angermann, Maik; Füllgraf, Jonas; Lampert, Astrid (2023): **In-situ airborne measurements of atmospheric and sea surface parameters related to offshore wind parks in the German Bight**. PANGAEA, **https://doi.org/10.1594/PANGAEA.955382**

Questions?

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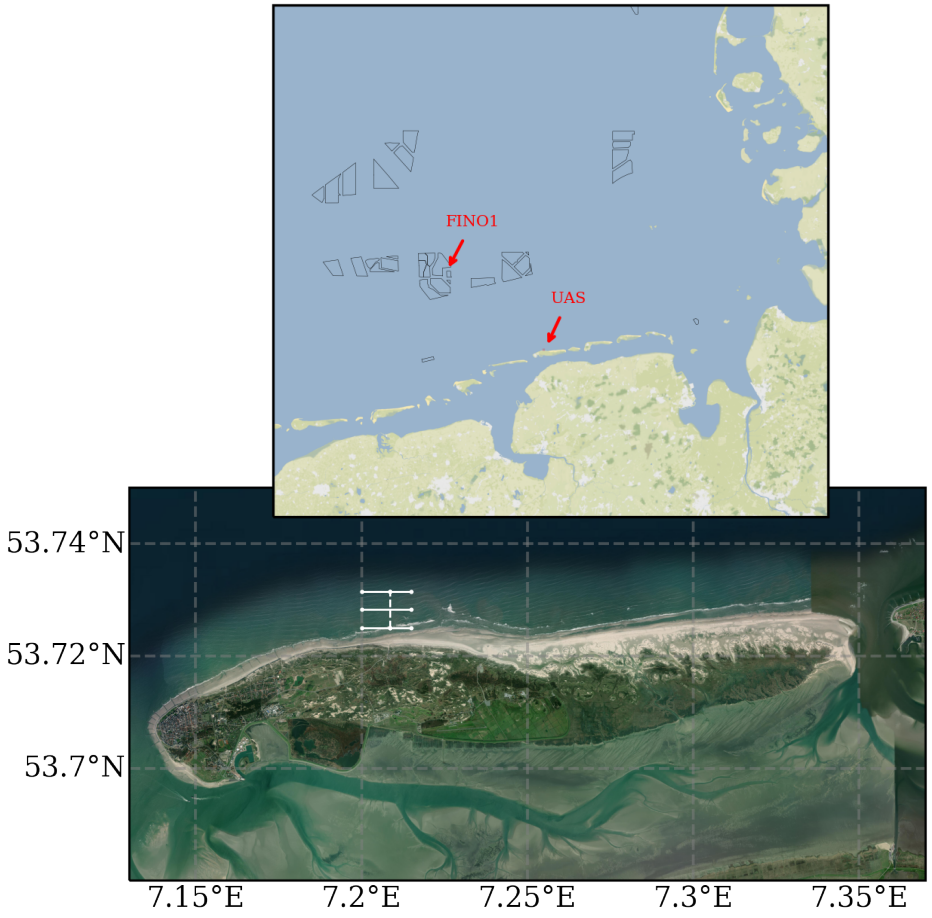
Flight Overview – Coastal Effects



4.1 September/October 2020

No	Date	Launch (UTC)	Ldg. (UTC)	W.-speed (120m)	W.-dir. (120m)
1	22.09.20	08:39	09:43	1.5	SW
2	23.09.20	05:07	06:15	8	SW
3	23.09.20	06:41	07:50	7.5	SW
4	25.09.20	10:03	10:41	3.5	S
5	28.09.20	13:33	16:06	3.5	S
6	30.09.20	12:24	13:33	7	S
7	30.09.20	14:11	15:19	6	SSO
8	01.10.20	11:26	12:41	7	SO

4.2 April 2021

No	Date	Launch (UTC)	Ldg. (UTC)	W.-speed (120m)	W.-dir. (120m)
9	15.04.21	06:42	08:07	2	NE
10	15.04.21	09:09	10:40	3	NE
11	17.04.21	05:59	07:36	3	N
12	17.04.21	08:17	09:47	3	N
13	18.04.21	09:12	10:35	4.5	NE
14	19.04.21	08:38	10:01	6	E
15	19.04.21	10:38	11:58	6	E
16	20.04.21	14:57	16:12	4.5	NE
17	20.04.21	16:45	18:15	4	NE
18	23.04.21	11:10	12:32	5.5	NW
19	23.04.21	13:14	14:34	5.5	NW
20	23.04.21	15:08	16:29	5.5	NW