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Wind farm wake effects at the Alpha Ventus offshore wind farm

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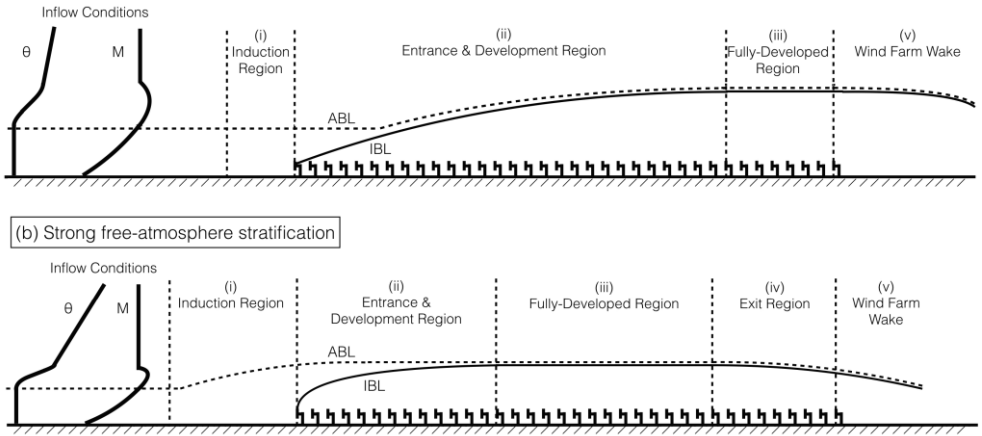
Motivation

The presence of wind farms close to each other influences the operation of downstream wind farms:

- Increase of roughness length (especially in flat terrain or offshore)
- Decrease of kinetic energy in the wind
- Introducing forces in the boundary layer due to the thrust of operating turbines
- Increased mixing in the boundary layer due to the rotation of the blades



Taken from: Wu et al. Flow Adjustment Inside and Around Large Finite-Size Wind Farms, Energies, 2019

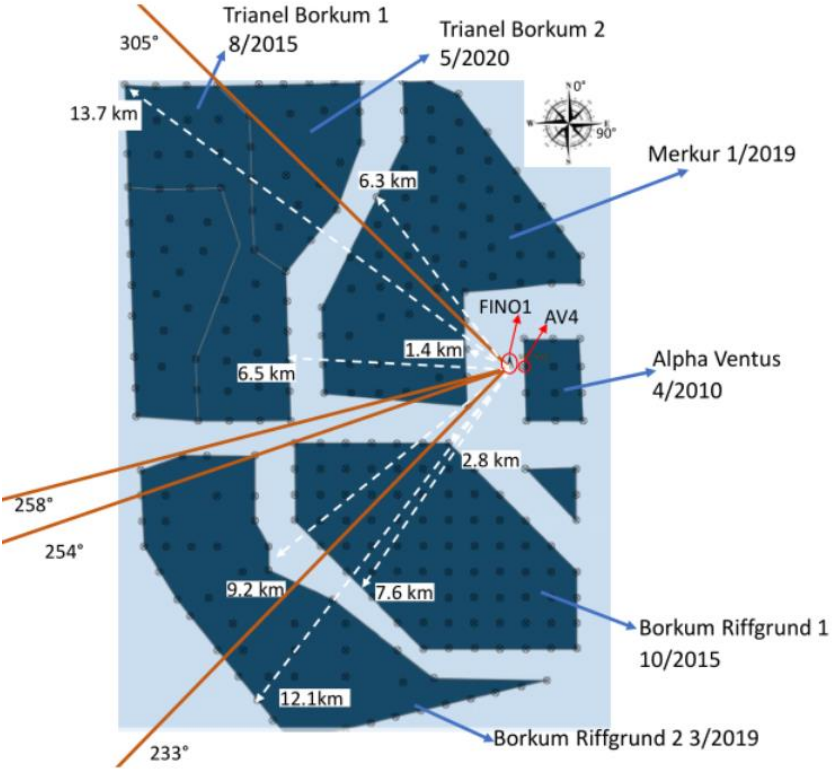
Motivation

- Neglecting these effects can have both **technical and financial impacts** leading to reduced energy production and increase fatigue consumption!
- Currently both industry and academia are focusing on quantifying and modelling wind farm wake effects

Using met mast data from FINO1 and turbine data from the Alpha Ventus farm we investigate **how the local conditions and the response of the wind turbines have evolved** from the period when AV was the only wind farm operating in the region to the period where close by wind farms are operating

Site and measurement setup description

Alpha Ventus site



FINO1 met mast operating since 2004

2010-2014: AV is the only farm
2015-2018: TB1 and BR1 are operating
2019-now : MRK, BR2, TB2 operating

Wind Farm Name	WT nominal power [MW]	Rotor diam. [m]	Total WT	OEM	Operation begins	Min. distance to FINO1 [km]	Azimuth sector [deg]
Alpha Ventus [AV]	5	126/116	12	Senvion/Adwen	4/2010	0.4	30-170
Merkur [MRK]	6	150	66	GE	1/2019	1.4	230-40
Trianel Borkum 1 [TB1]	5	116	40	Adwen	8/2015	6.5	255-305
Trianel Borkum 2 [TB2]	6.25	152	32	Senvion	5/2020	6.7	260-325
Borkum Riffgrund 1 [BR1]	4	120	78	Siemens	10/2015	2.8	155-255
Borkum Riffgrund 2 [BR2]	8	164	56	Vestas	3/2019	9.2	170-260

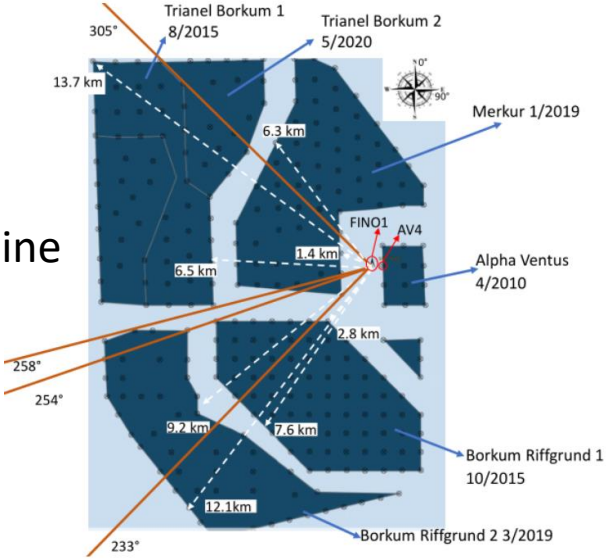
Site and measurements description

Measurements from the period **2010-2019**

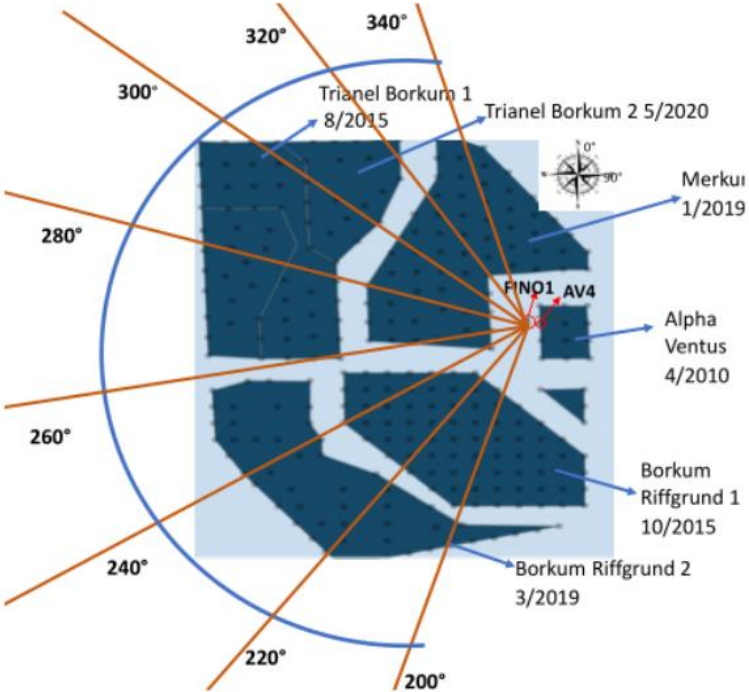
Wind speed and TI from: 40:10:100 m cup anemometers
Wind direction: 90 m vane (hub height)
SCADA and tower bottom loads from the 5 MW Senvion AV4 turbine

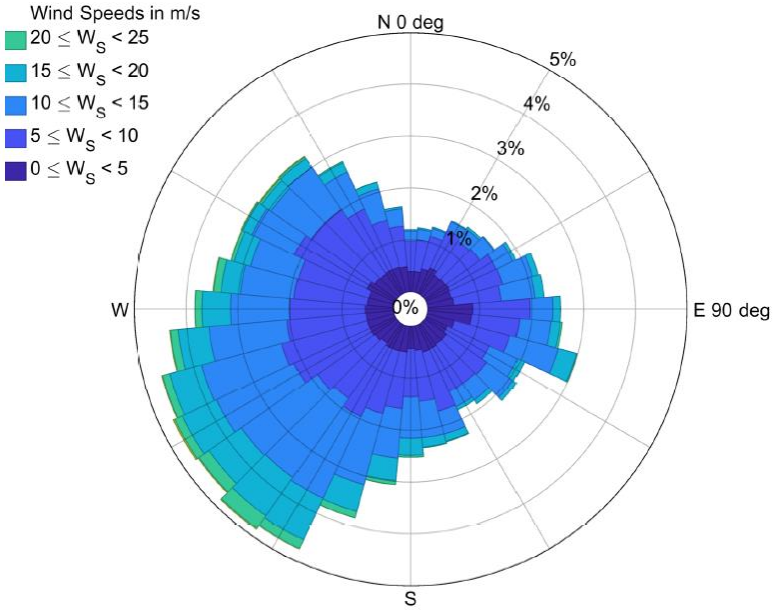
Correction and data cleaning:

- Data quality flags
- Availability of data in the 10 min
- Thresholds for statistics
- Strain gauge calibration
- Turbine not curtailed
- Alignment of turbine with mast and reduced yaw action
- ….



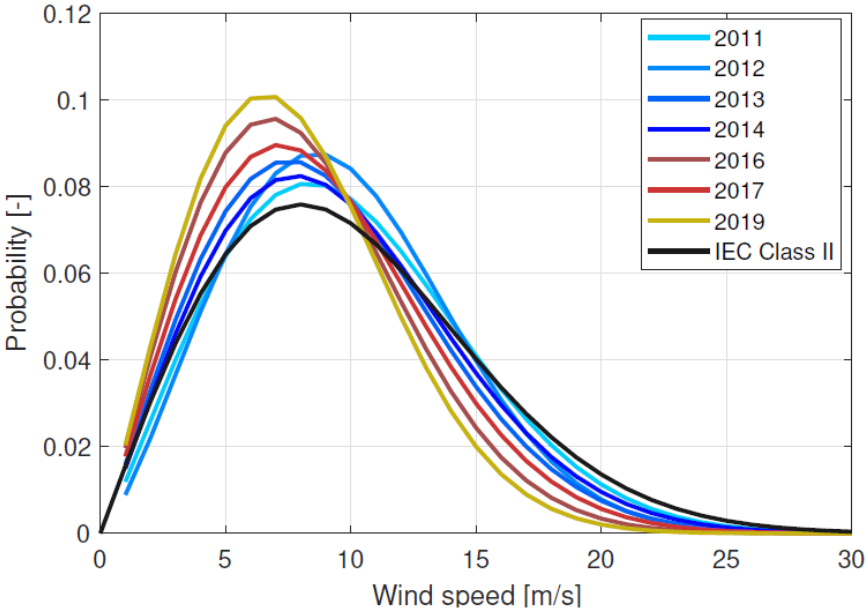
Wind rose and sectors





Results

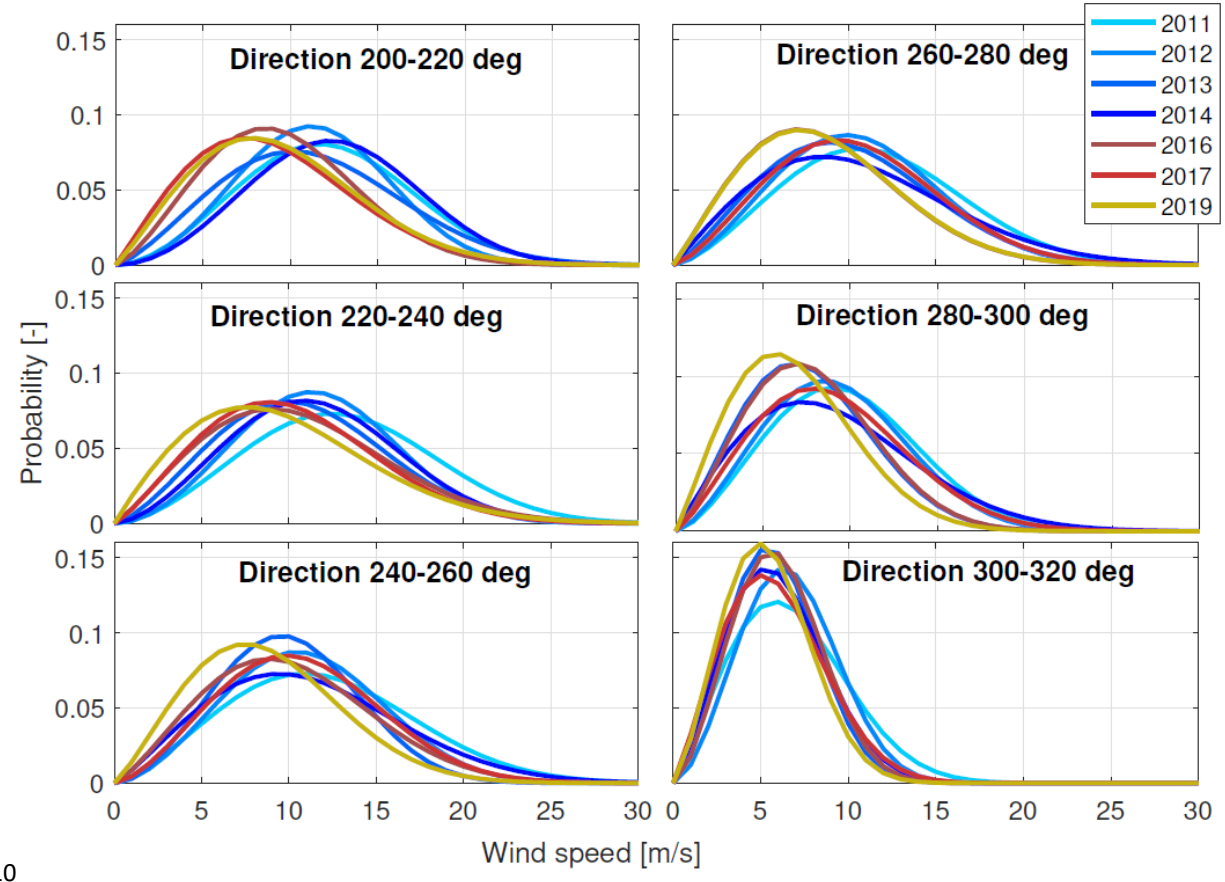
Weibull distributions fits and AEP

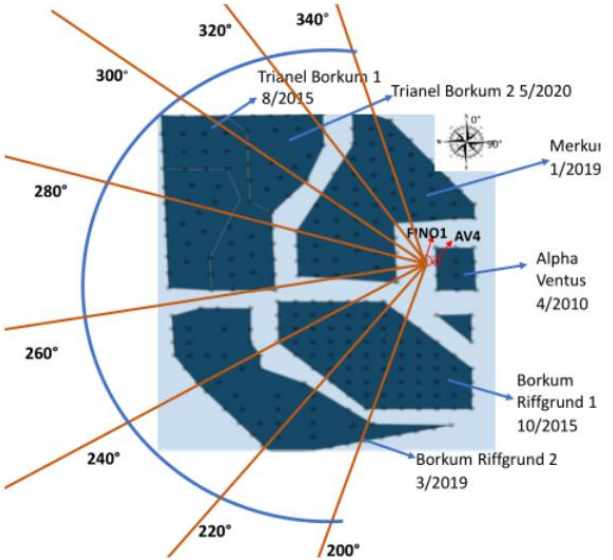


- Reduction in wind speed distributions much higher than the inter annual variability
- Mean theoretical AEP reduced by 18% with TB1 and BR1
- AEP reduction by 25% when all farms started operating

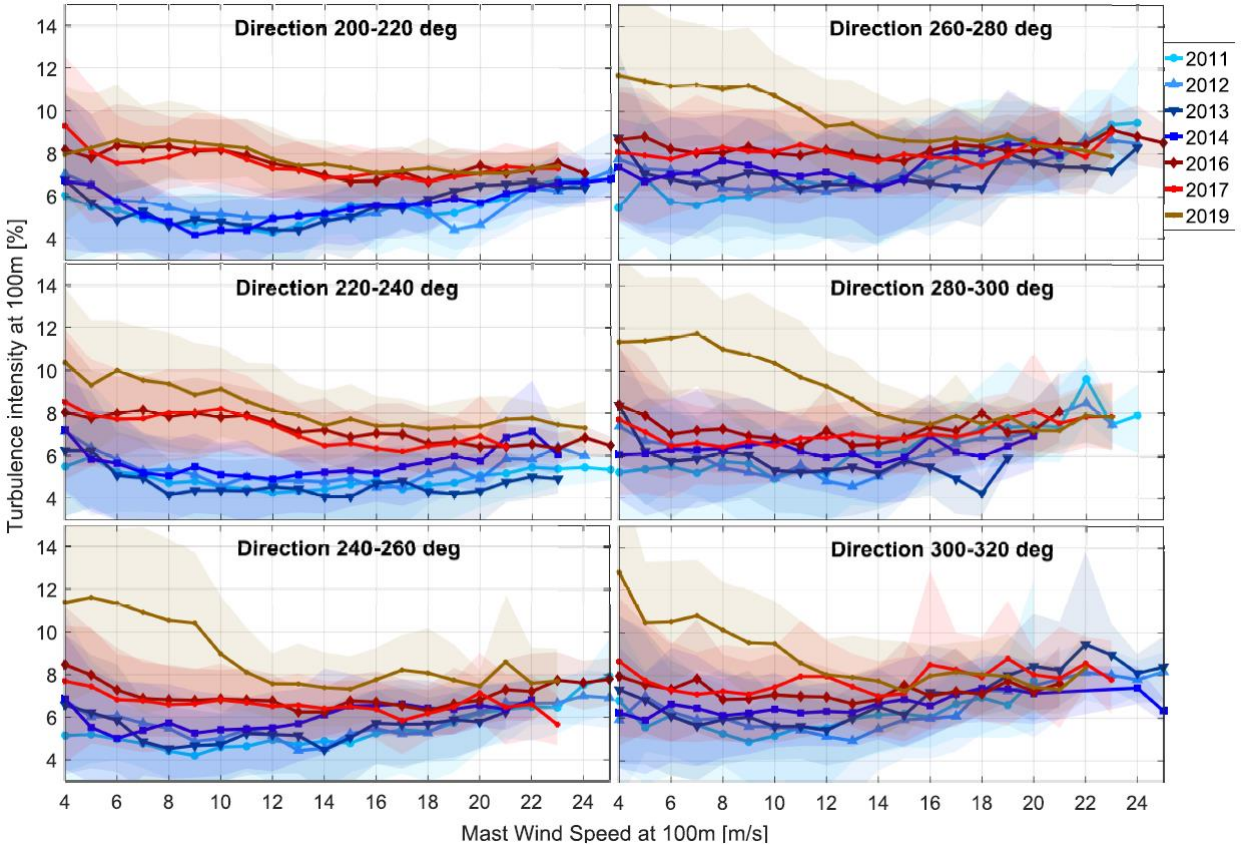
Year/Class	Weibul k parameter	Weibul C parameter	Theoretical AEP [GWh]	Mean AEP [GWh]	STD AEP [GWh]	Operating Farm
2011	2.06	10.75	19.6	18.7	0.92	AV
2012	2.20	10.47	19.4			AV
2013	2.05	9.93	17.6			AV
2014	2.01	10.36	18.5			AV
2016	2.07	8.89	15.1	15.2	1.25	AV,TB1,BR1
2017	2.02	9.52	16.5			AV,TB1,BR1
2019	2.10	8.46	14.0			AV,TB1,BR1,MRK
IEC class II	2.00	11.30	19.5	-	-	-

Weibull distributions fits per sector

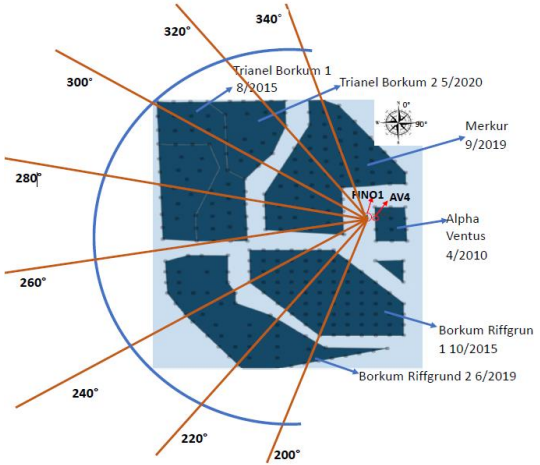




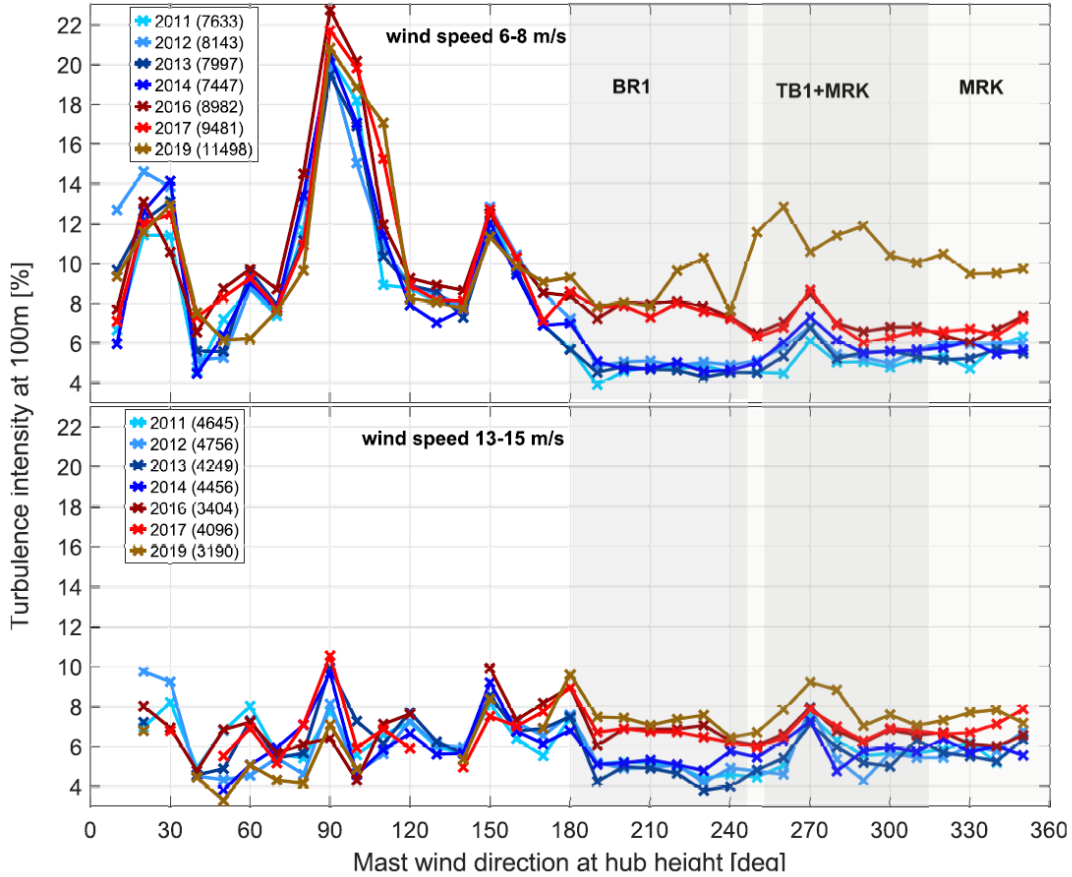
TI per wind speed and sector



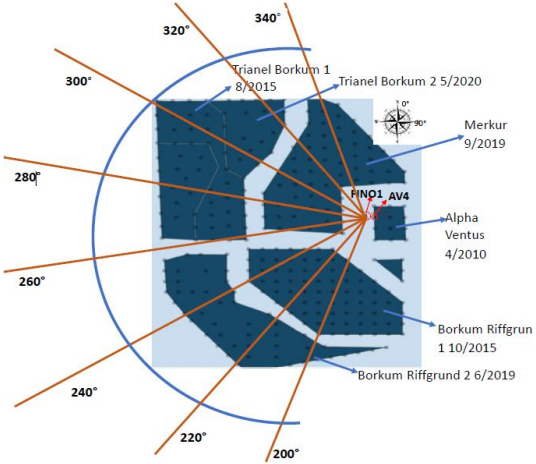
- BR1 (3km) has the most influence increase 30-40%
- TB1 (7km) no effect on TI
- MRK (1.5km) has the highest influence
- Effect on TI decreasing as speed increase



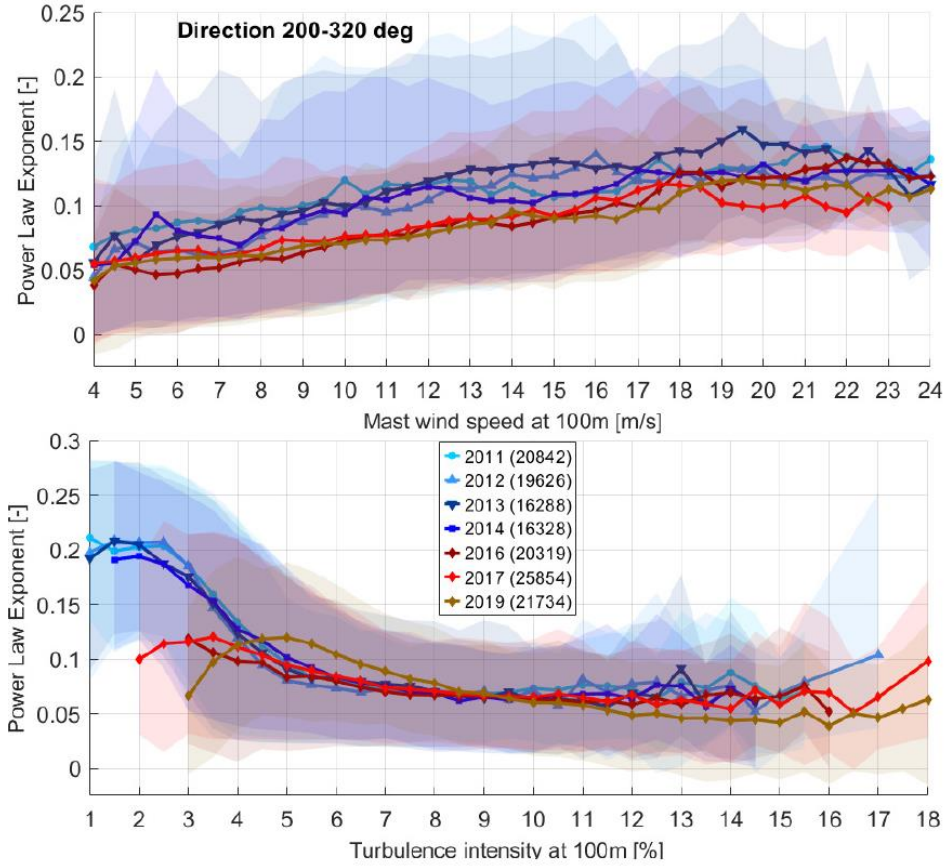
TI per direction



- Wake effects decrease as wind speed increases
- Sectors with no new farms 0-190 prove that what we see is actually wake effects

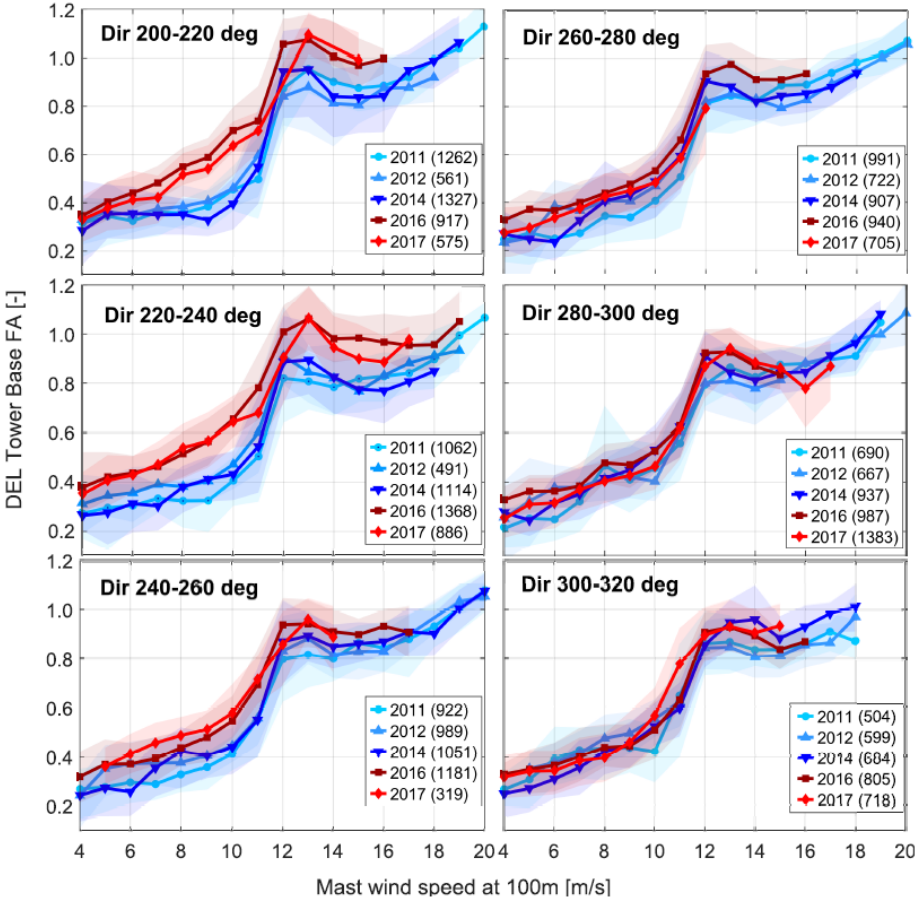


Effects on shear

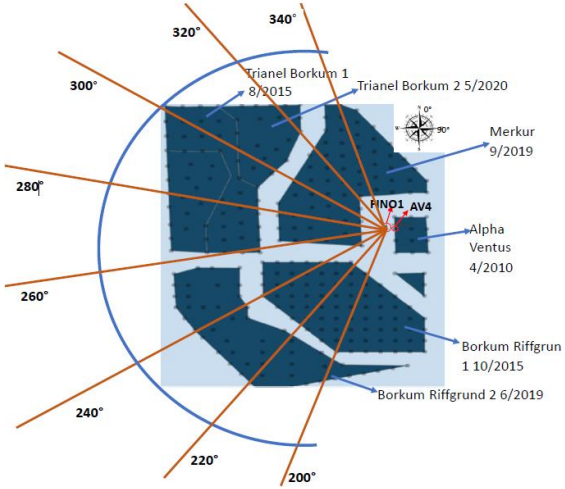


- Shear per wind speed is decreasing due to increased turbulence
- Stability difficult to define but also less influential on shear and TI as the wake interactions create mechanical mixing in the IBL

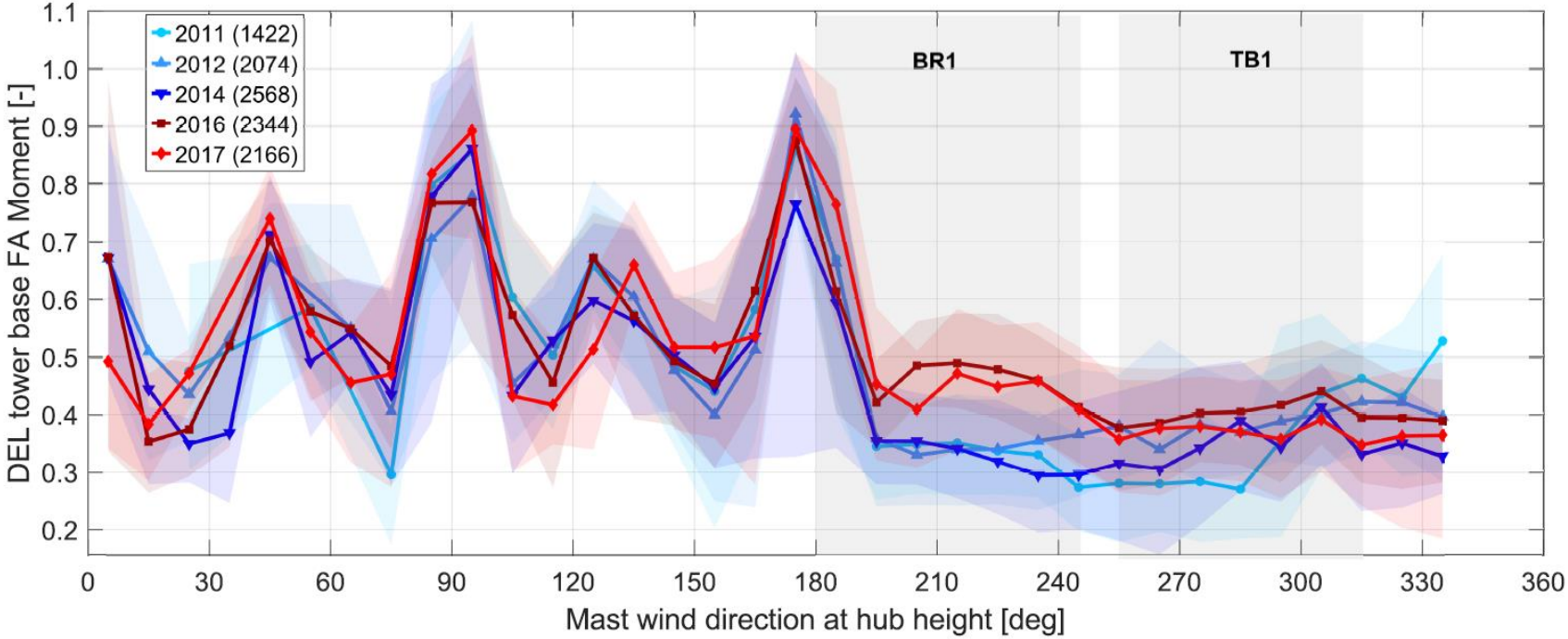
Tower bottom loads per speed and sector



- Increase of 20-50% in below rated speeds
- TB1 farm at 7km not influencing the loads



Tower bottom loads per directions wsp 6-8m/s



Conclusions

- The effects of farm wakes are clearly observed at FINO1 and the AV site
- The microclimate of AV was influenced mainly by the closest wind farms (<3km)
- Reduction on windspeeds observed leading to AEP reductions in the level of 20%
- Increase of TI correlated to park distances and wind speed
- Perceived shear is decreased mainly due to increased turbulence
- Increase in Tower FA loads 20-50%

Future steps:

Evaluate the economic impact in LCOE and the technical impact in terms of structural lifetime reduction

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Thank you for your attention!

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Generator speed std per speed and sector