Mechanisms controlling air-sea CO_2 exchange in the Baltic Sea

UPPSALA UNIVERSITET

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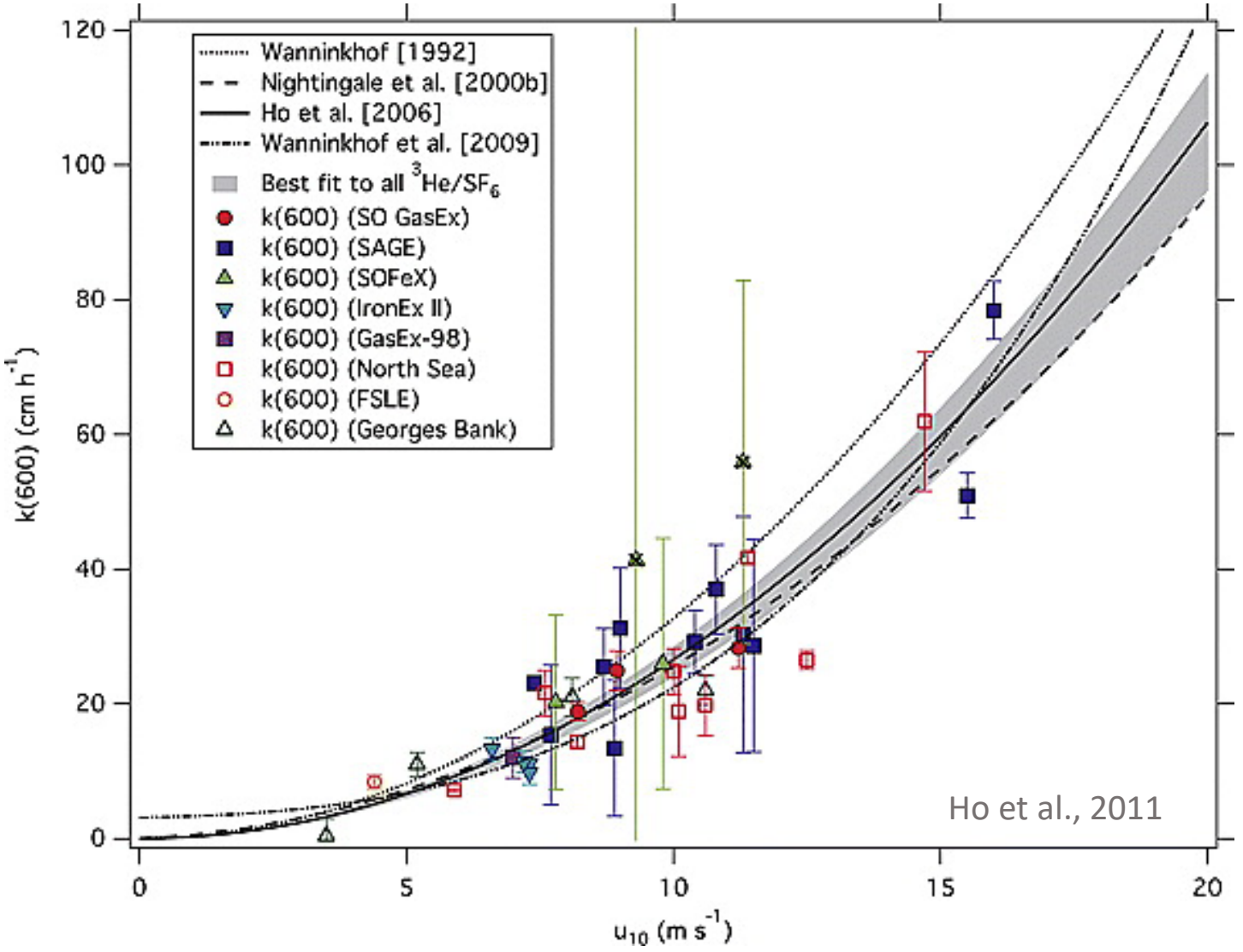
8th International Symposium on Gas Transfer at Water Surfaces, Plymouth, UK

IN CONTEXT

- Large uncertainties in global FCO_2 are associated with k
- Wind speed accounts for ~80% of the variability in k
- At local and regional scales the variability in k is larger



Ho et al., 2011

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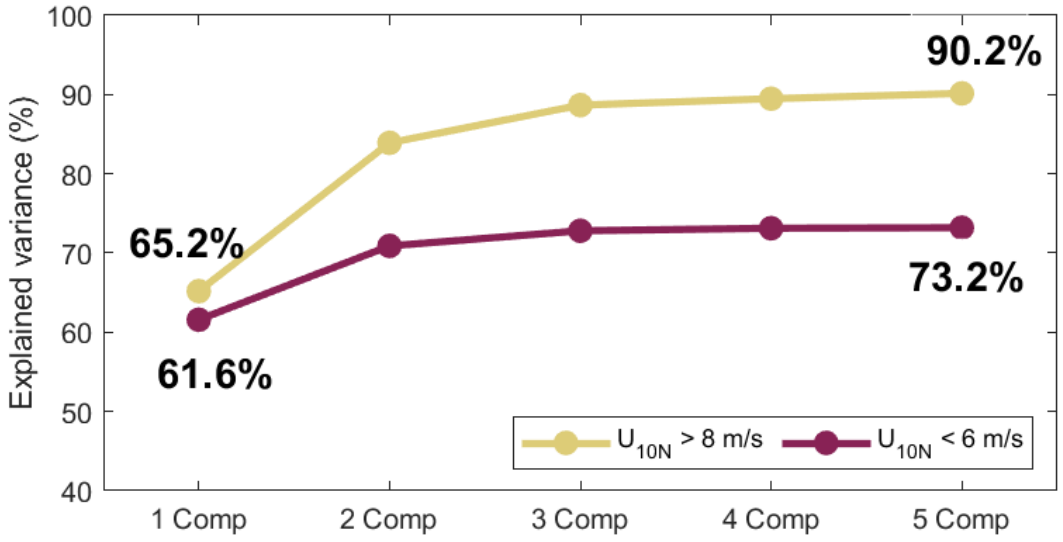
Partial Least Squares (PLS) Analysis



What else can we learn about the variability?

We use 9 years of in-situ data from the Östergarnsholm station in the Baltic Sea:

- CO_2 fluxes from eddy covariance
- Water pCO_2 measurements
- Monitoring of atmospheric and water-side conditions

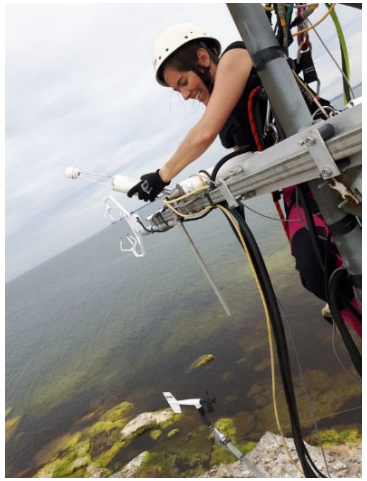
OBJECTIVES

- Study the behavior of the air-sea CO_2 fluxes in the marine environment
- Explore the effect of forcing mechanisms on the CO_2 fluxes

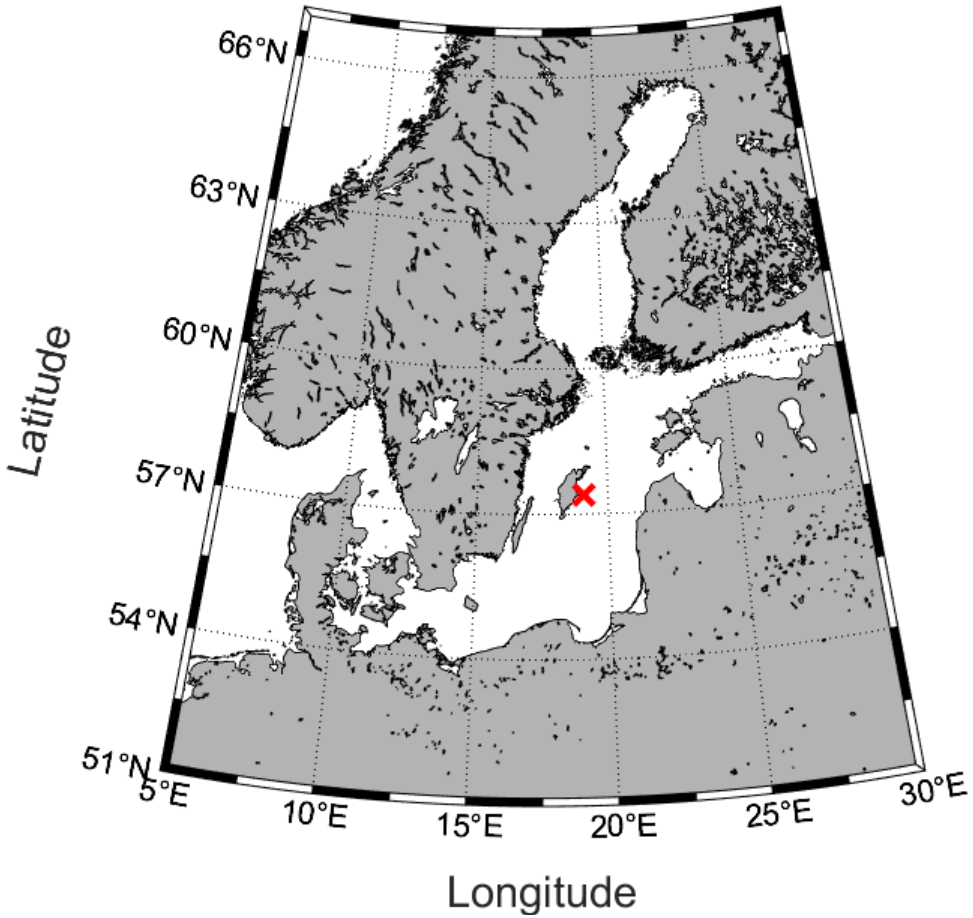
THE BALTIC SEA

AND THE ÖSTERGARNSHOLM STATION



WHY TO STUDY THE BALTIC SEA?



Coastal and marginal seas are an essential piece of the global carbon cycle. A better **understanding of the contributions and variability of the air-sea CO_2 fluxes** in these regions is necessary.

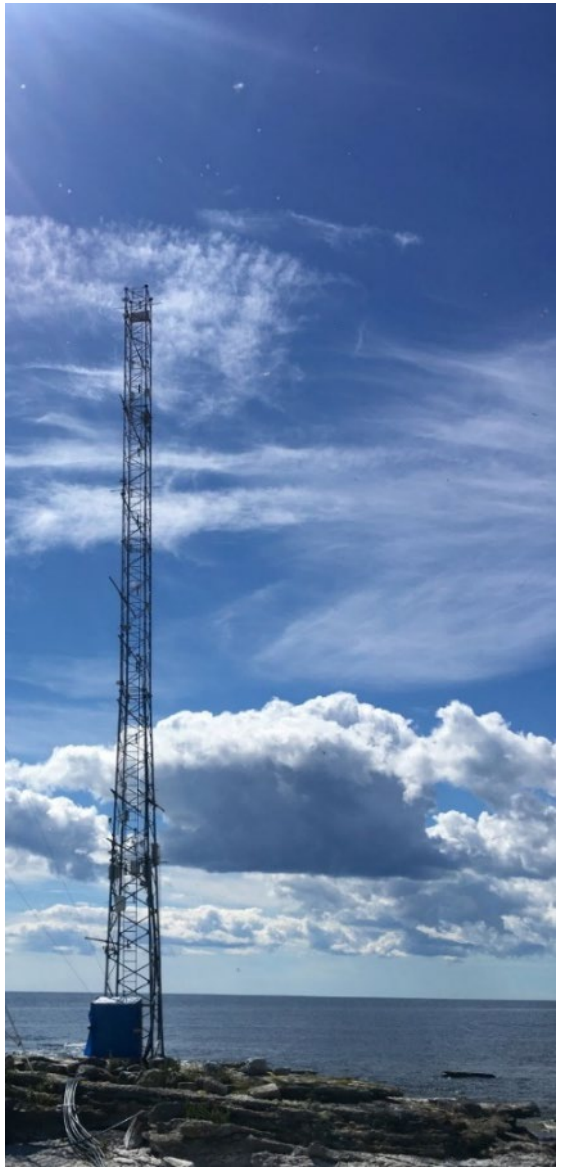
The Baltic Sea:

- Dynamic carbon system with large spatio-temporal variability
- Available research addressing the variability of the elements of the carbon system
- Test field relevant to other environments
- **The Östergarnsholm station for long-term monitoring and research**

THE ÖSTERGARNSHOLM STATION

The land-based tower is instrumented to study the **marine atmospheric boundary layer** and **air-sea interaction processes.**

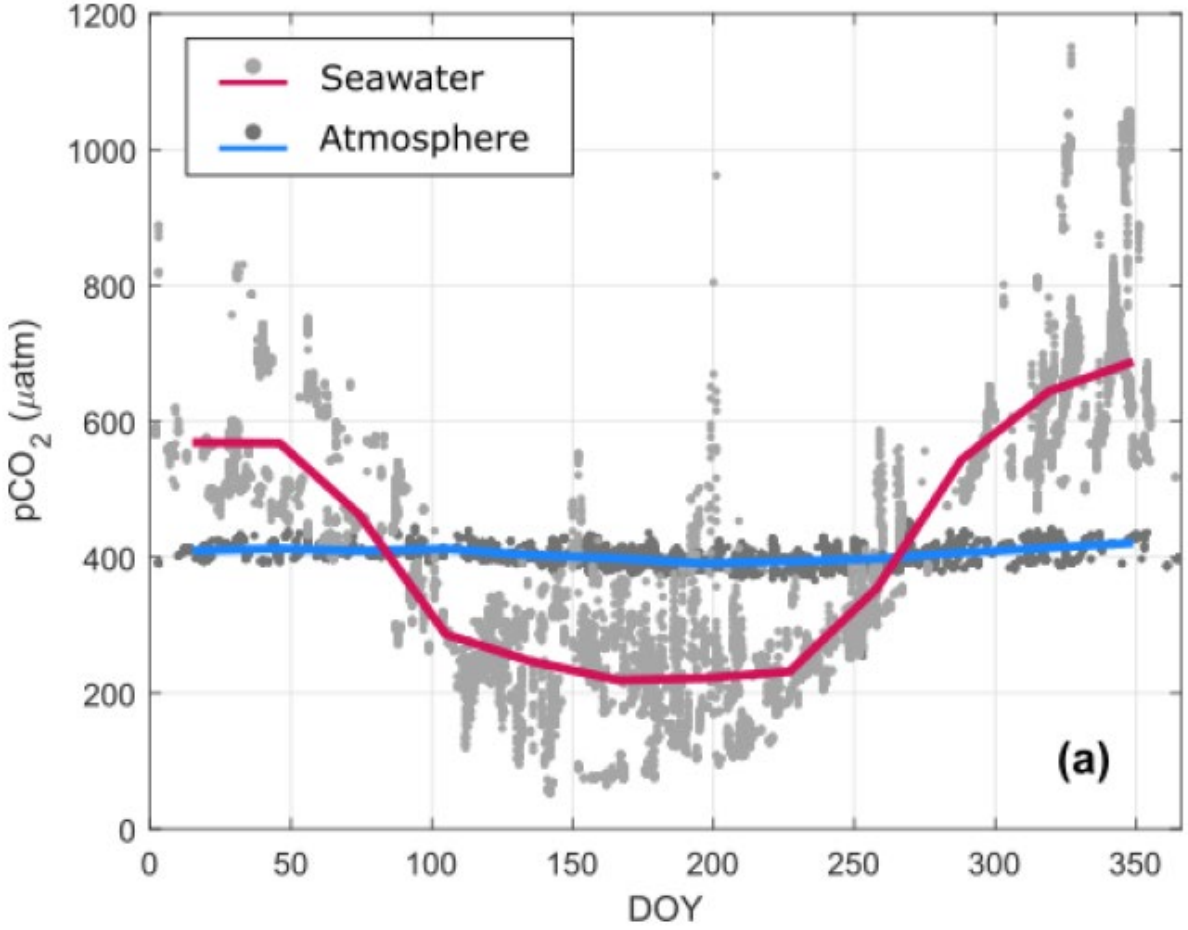
- Meteorological station + flux tower
- Coastal station → open sea + coastal conditions
- Complementary water-side observations



RESULTS

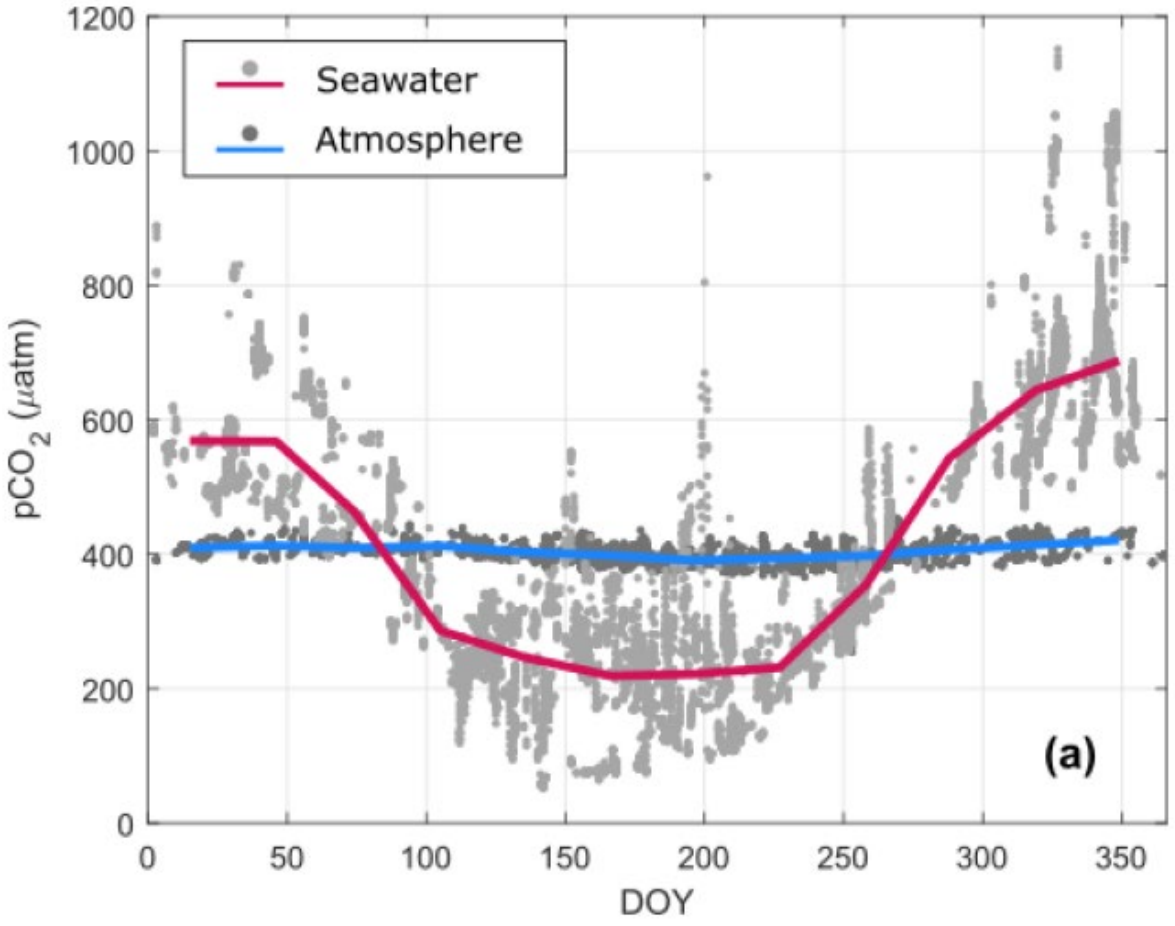
THE SEASONAL FCO_2 VARIABILITY AND GAS EXCHANGE CONTROL MECHANISMS

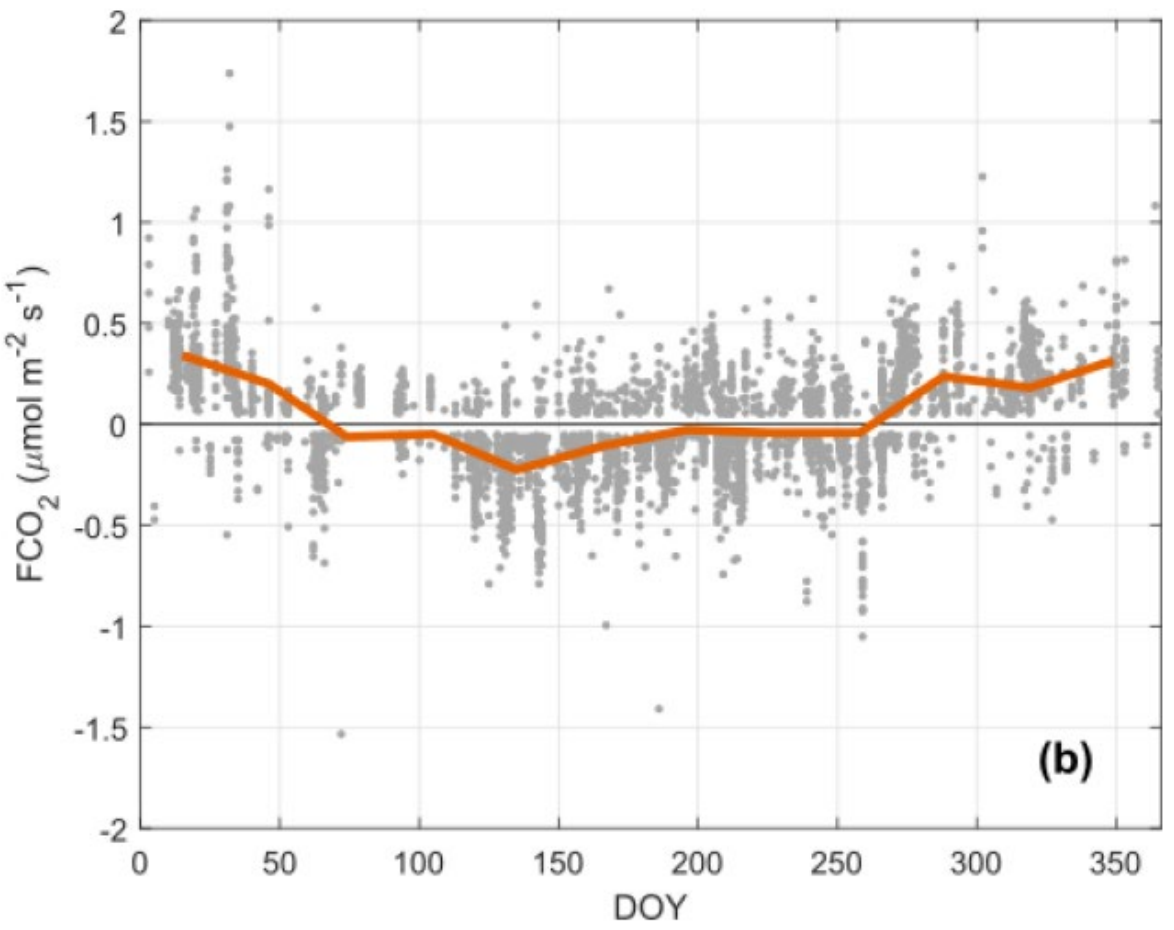
THE SEASONAL VARIABILITY OF FCO_2



- The variability in ΔpCO_2 is driven by changes in the water-side pCO_2
- Increasing trend in the atmospheric pCO_2
- Increasing amplitude in the seasonal cycle of seawater pCO_2

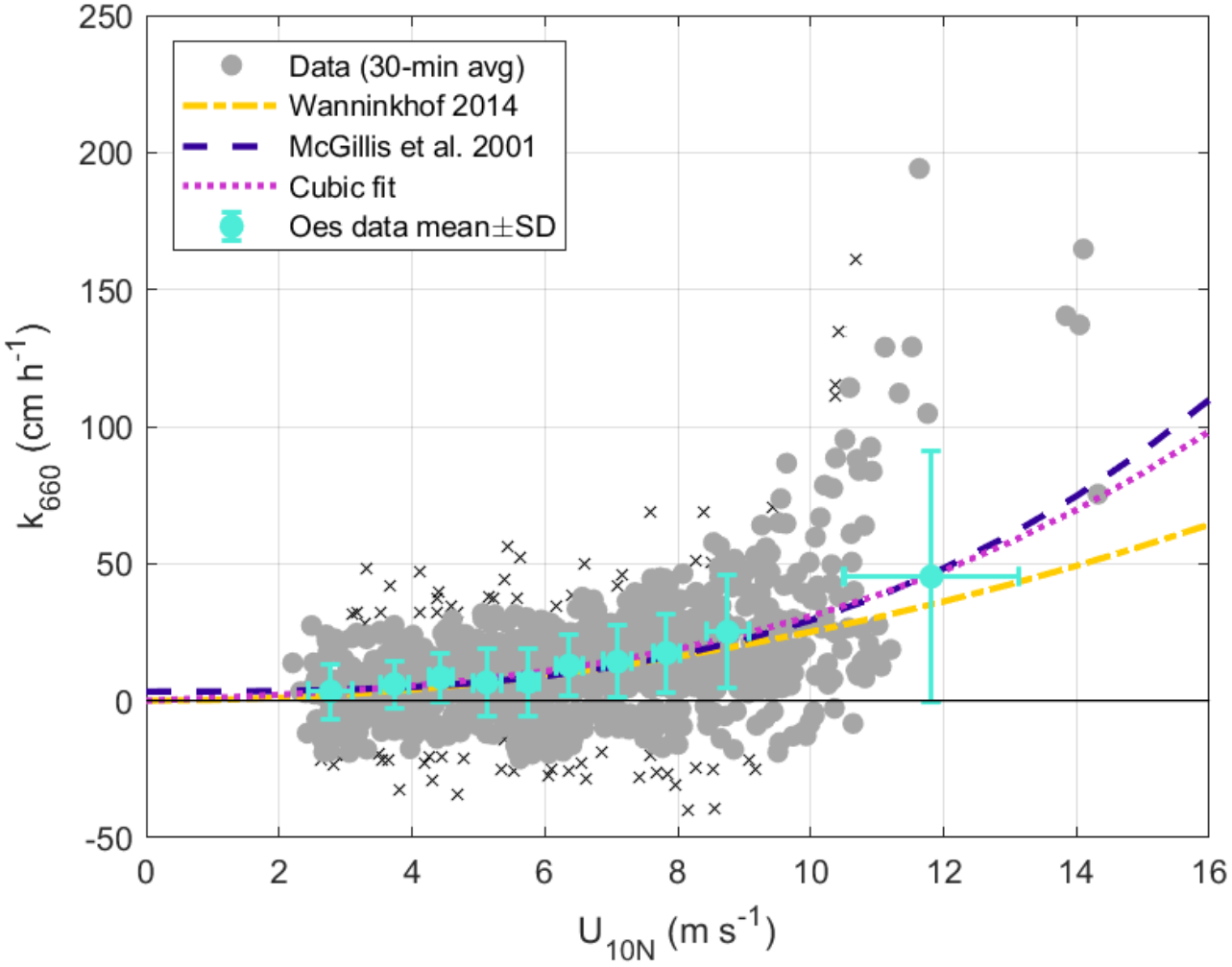
THE SEASONAL VARIABILITY OF FCO_2





THE GAS TRANSFER VELOCITY (k_{660})

- Our data shows good agreement with wind-based parameterizations
- Understanding the effect of other mechanisms will improve our ability to explain the flux variability



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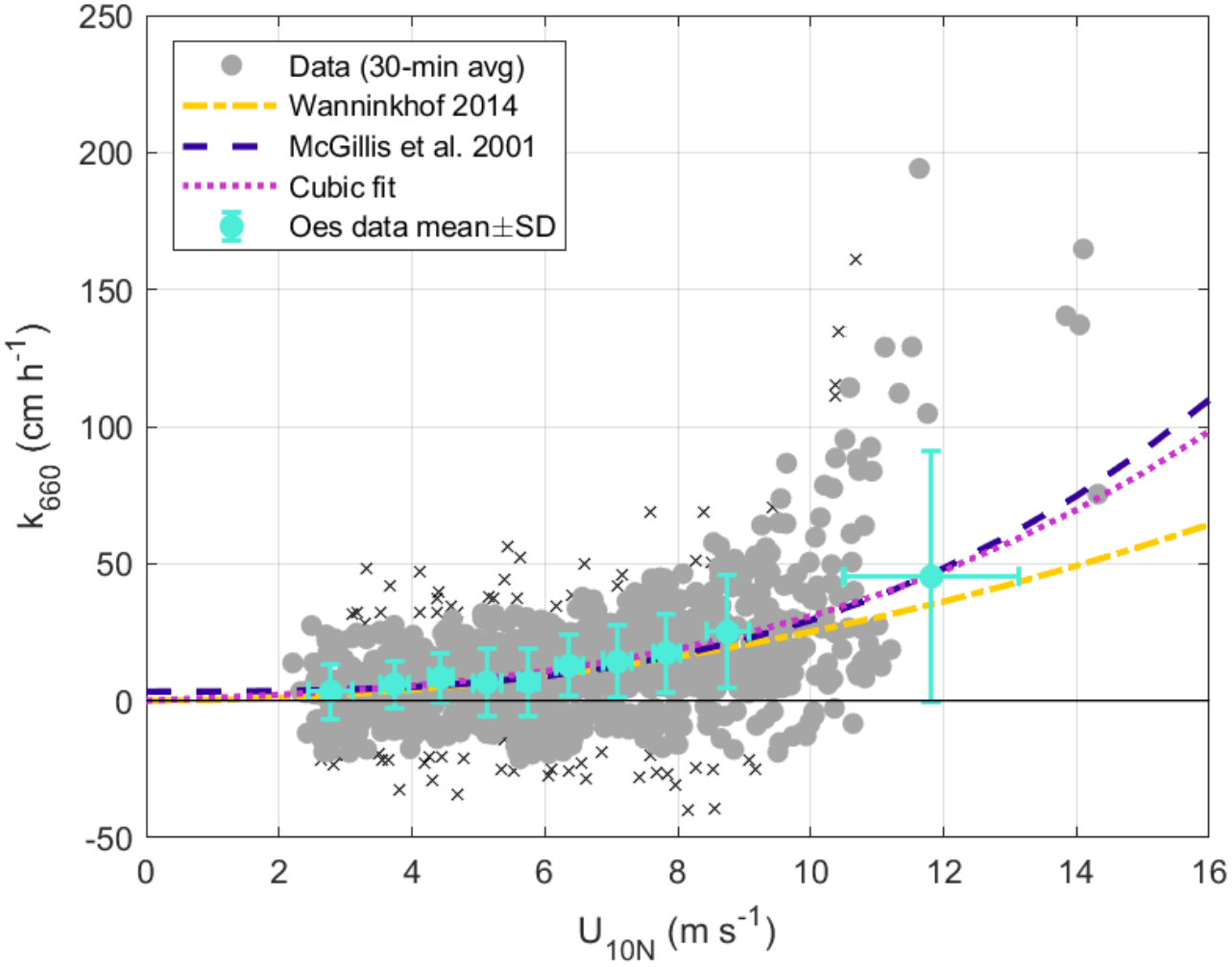
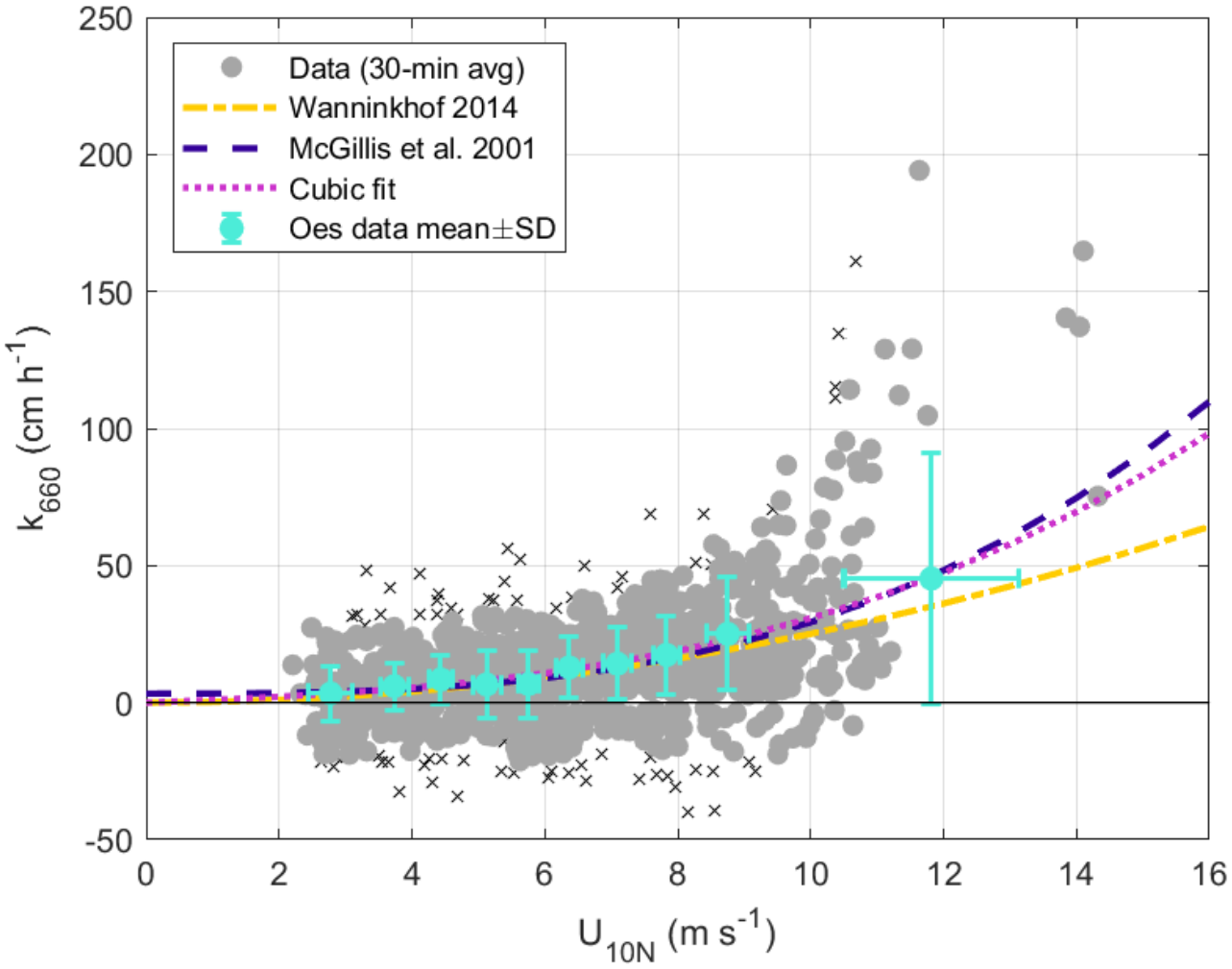
If everything fails…
USE THE WIND SPEED



HOW TO EXPLAIN THE REST OF THE VARIABILITY?

Residual gas transfer velocity:

$$k_r = k_{660} - k_{wind}$$



HOW TO EXPLAIN THE REST OF THE VARIABILITY?

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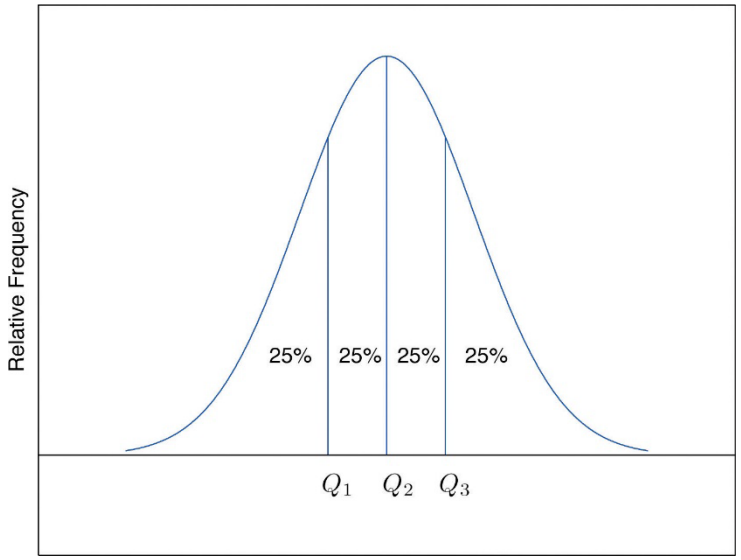
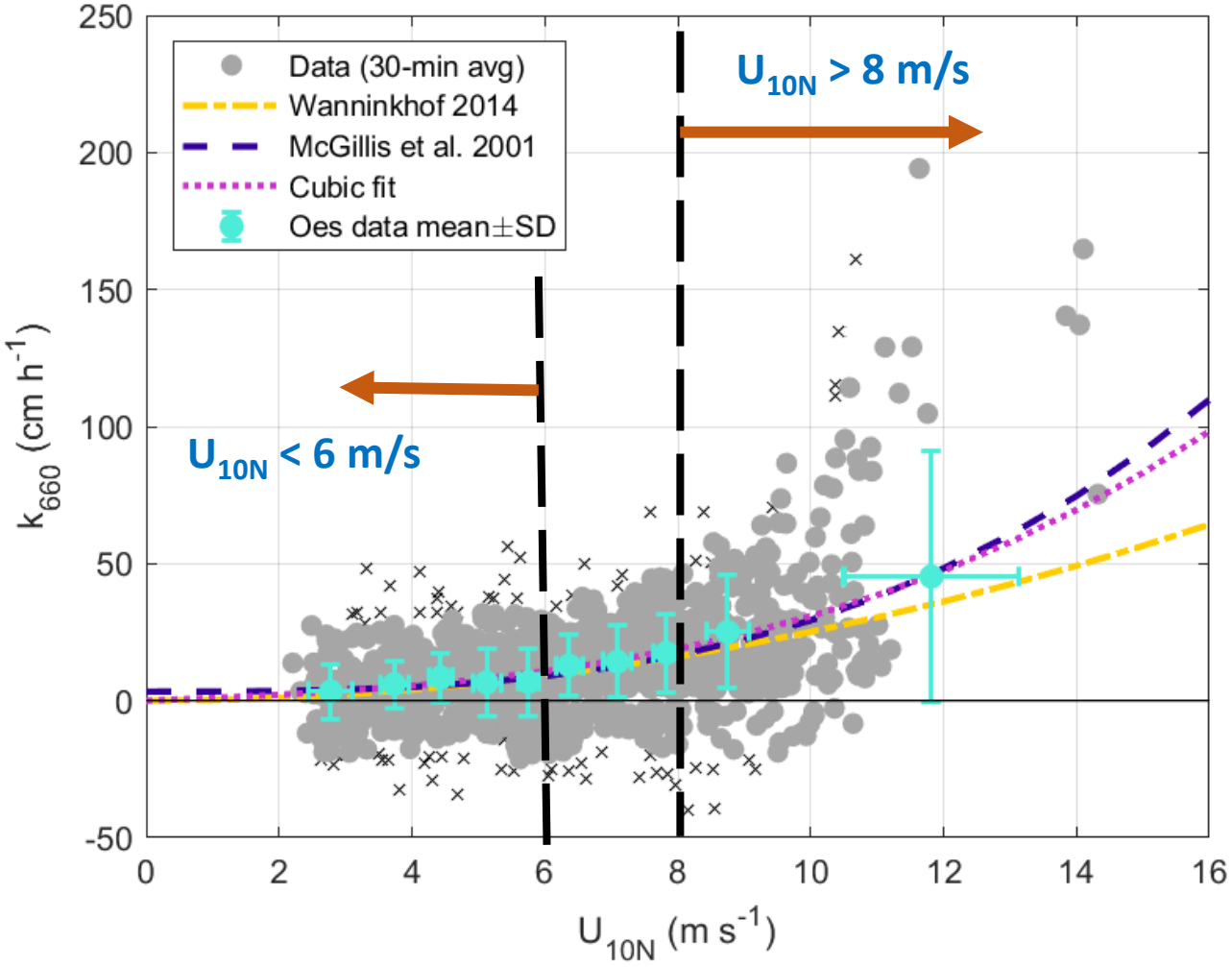
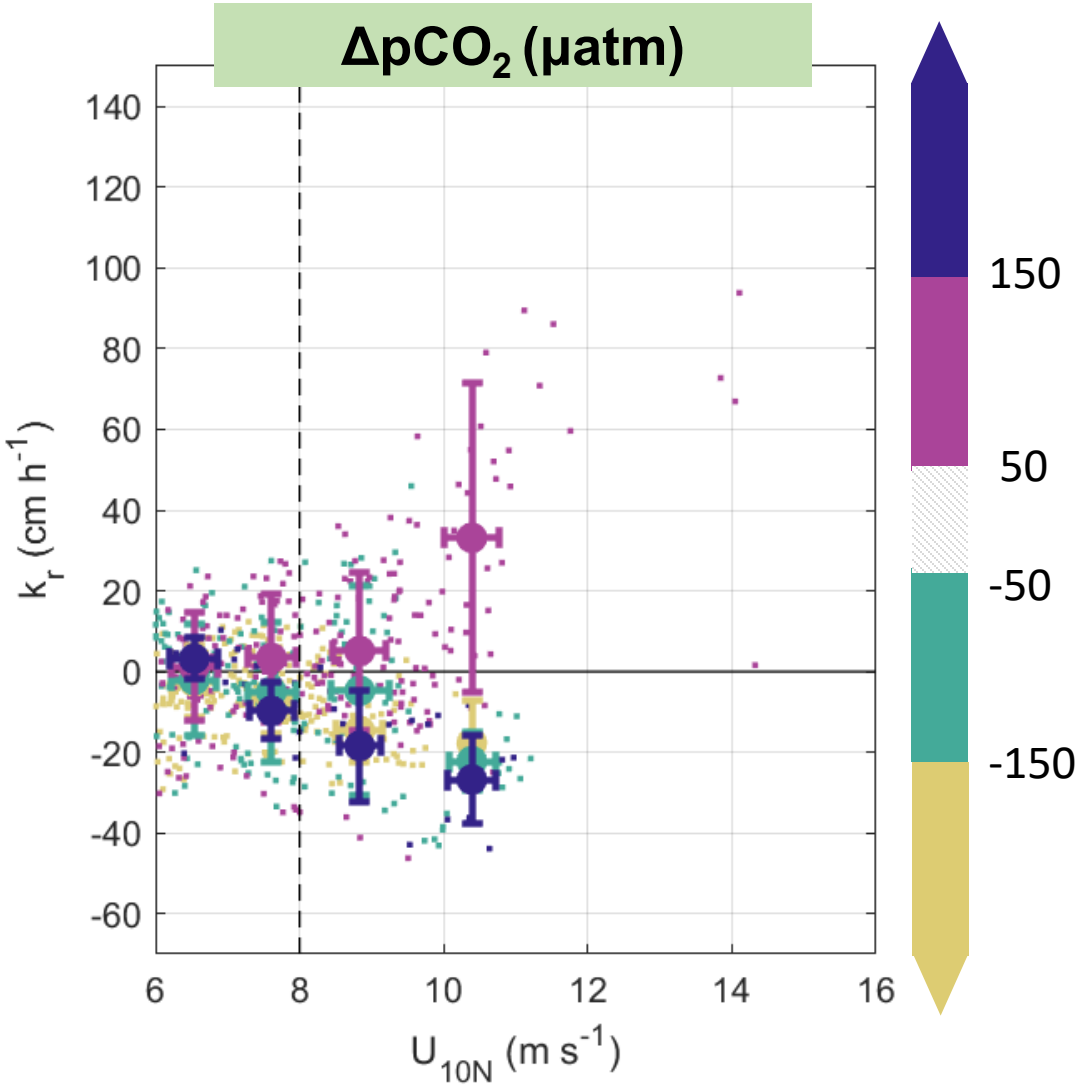
Each variable is divided in quartiles:





THE GAS TRANSFER VELOCITY

High wind speed conditions (U_{10N} > 8 m/s)



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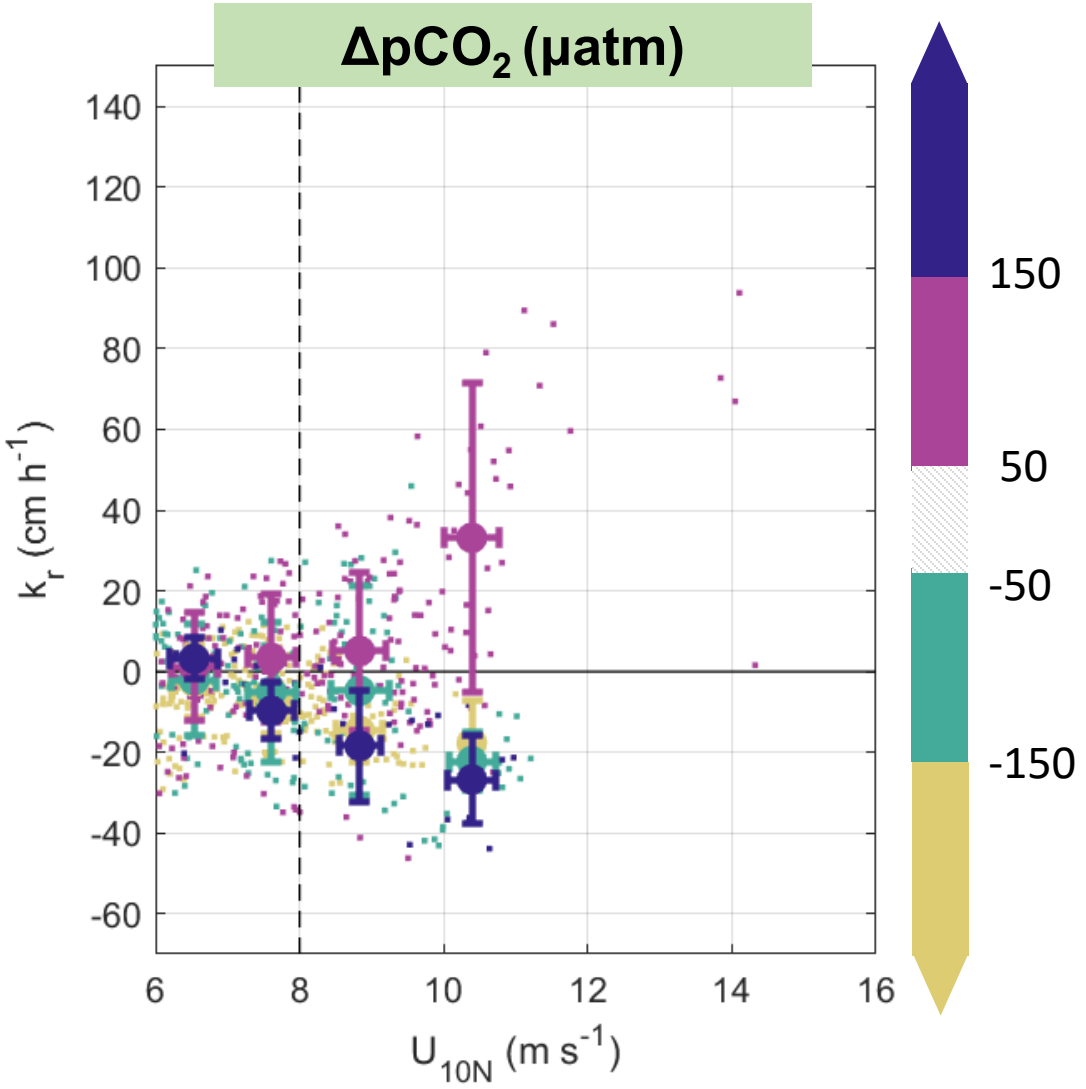

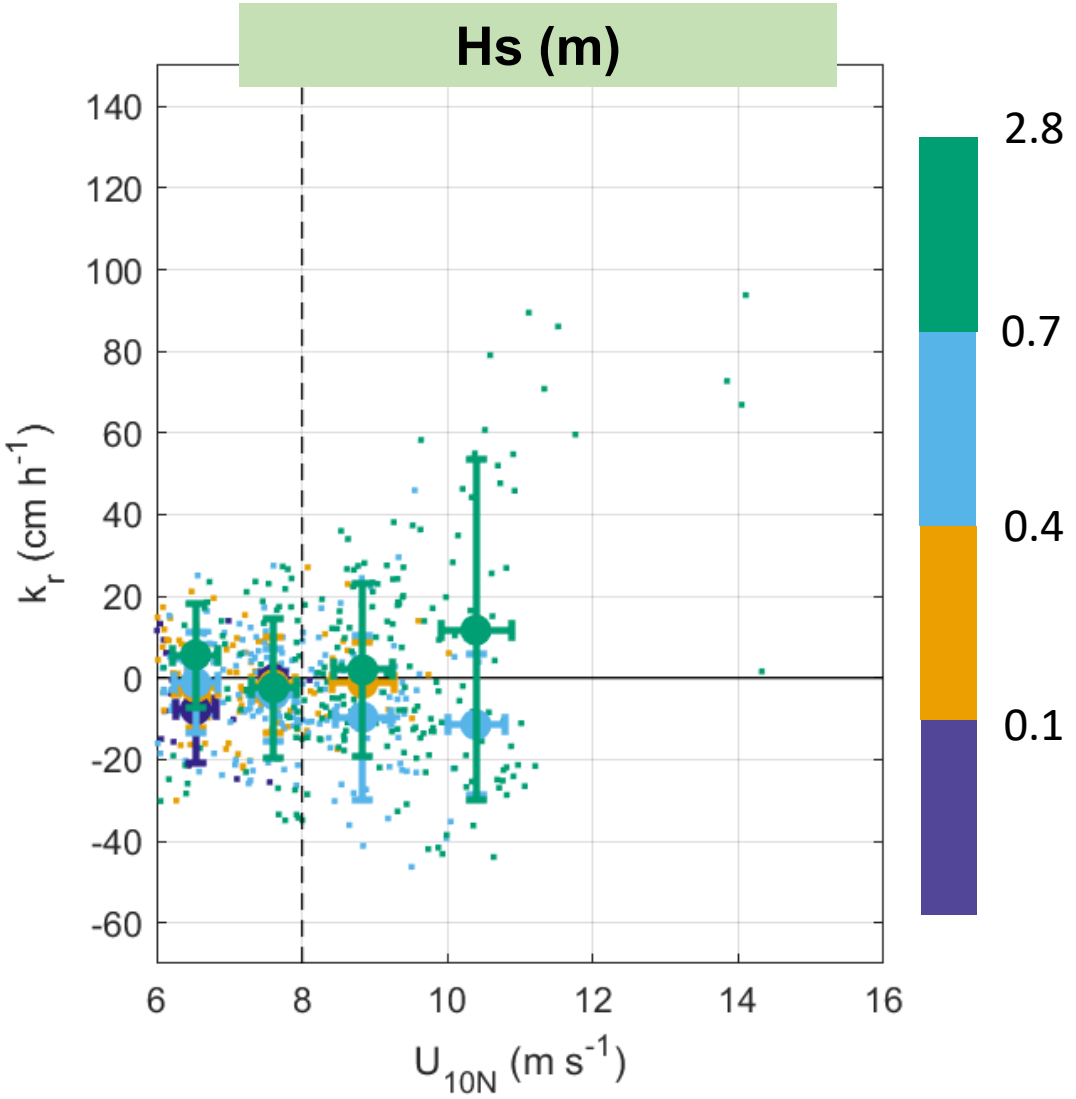

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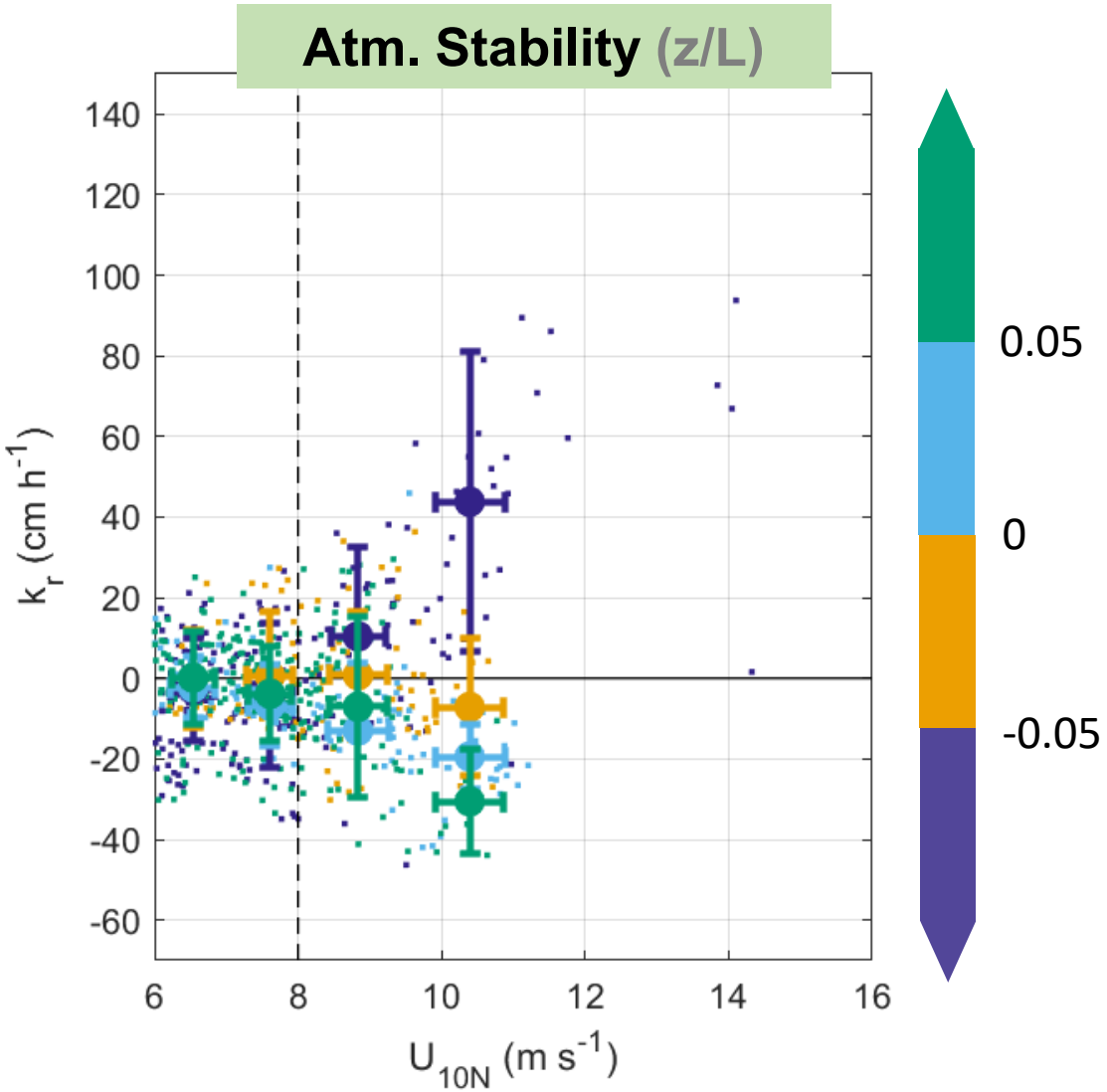

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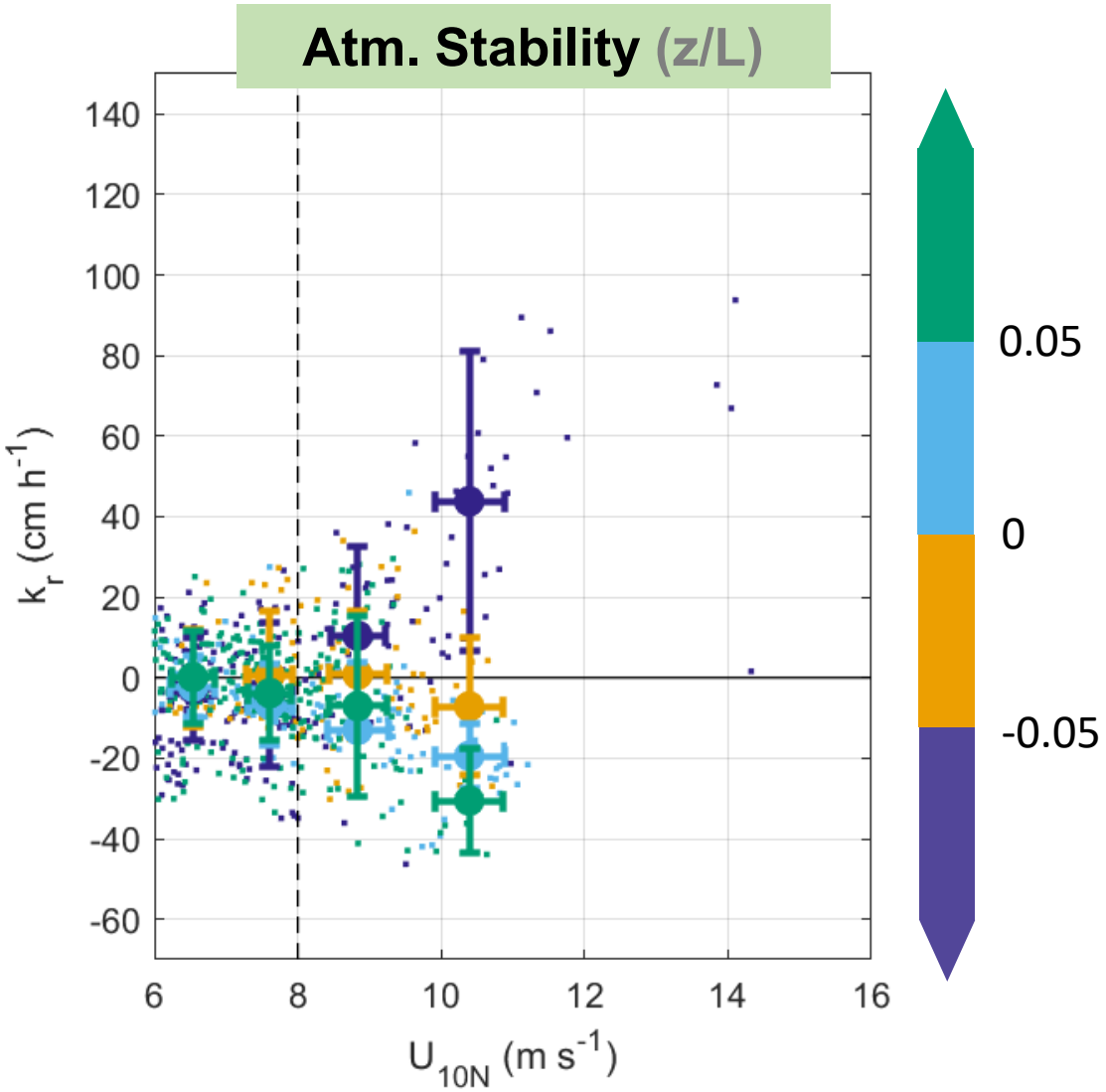

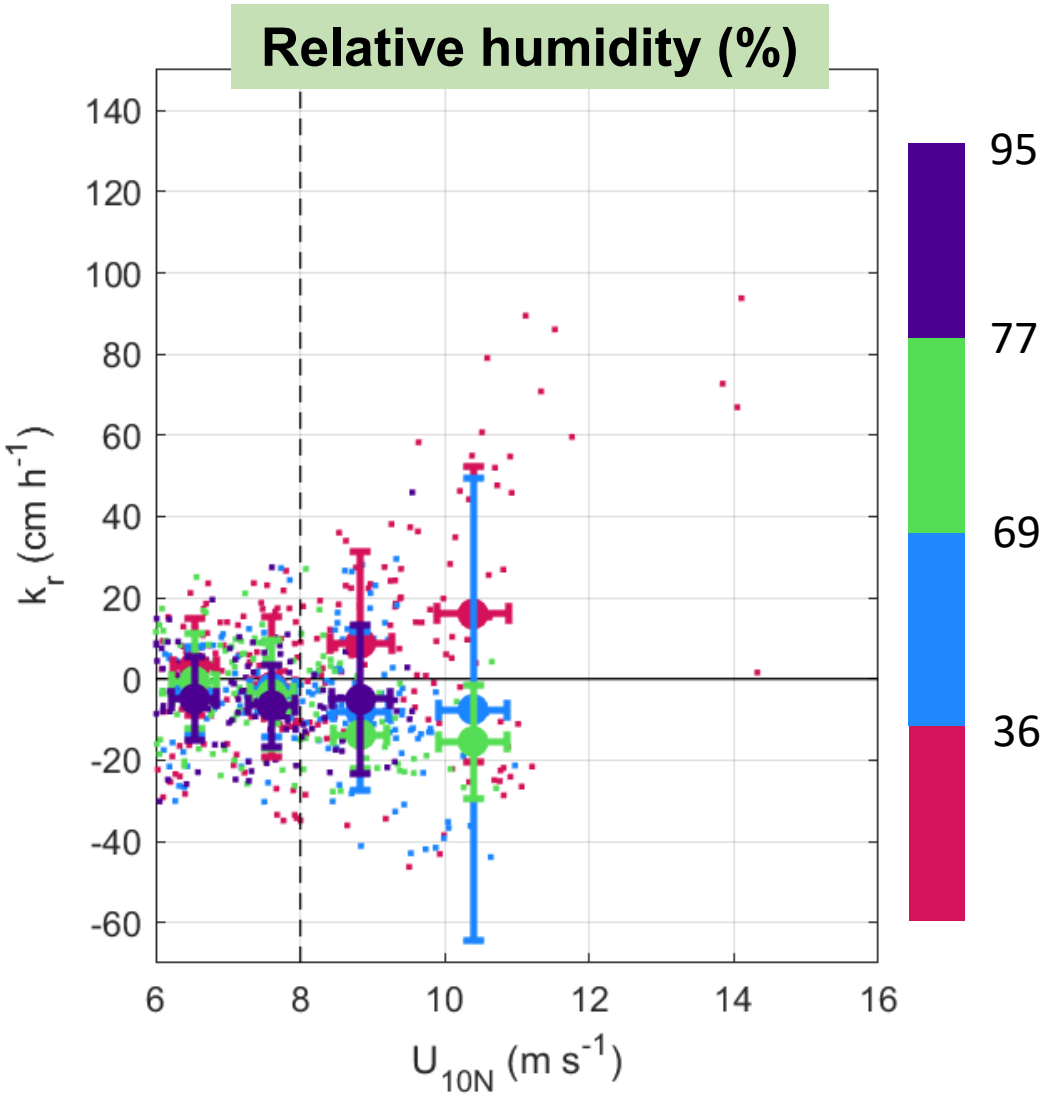

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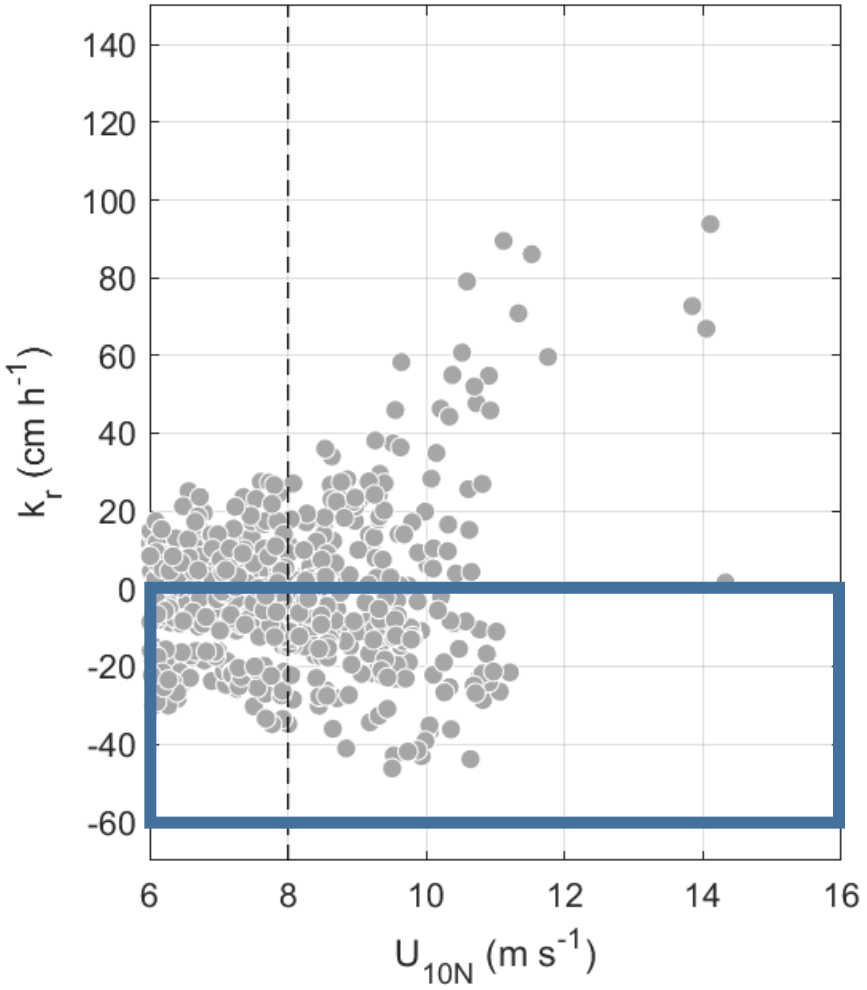
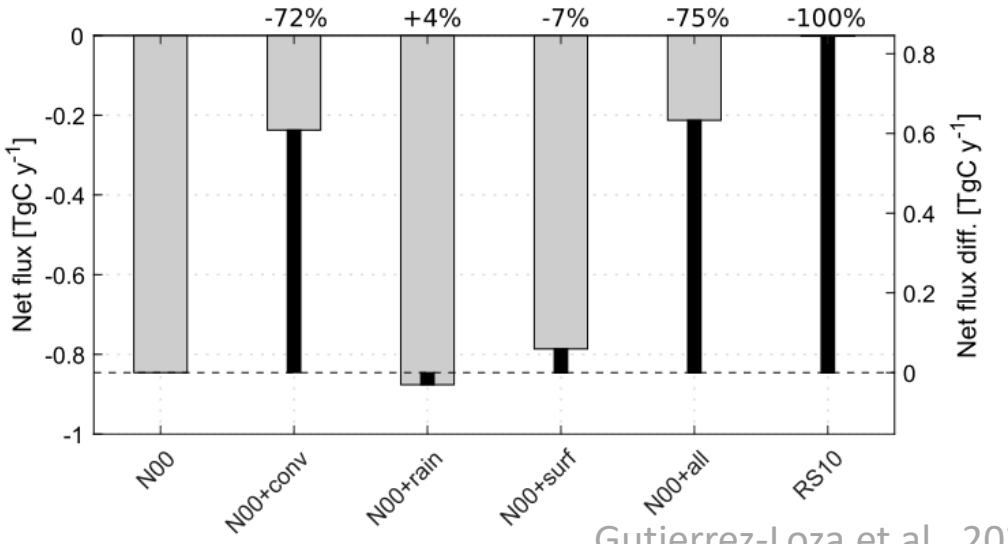


Follow (more-or-less) the story line:

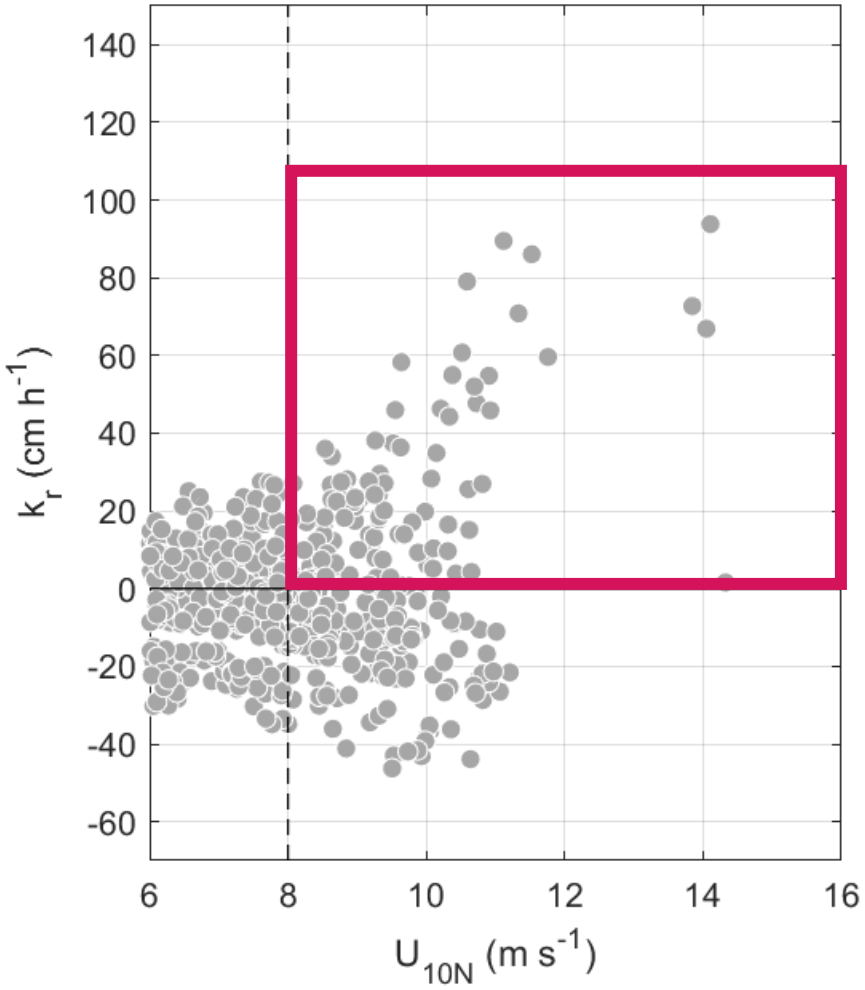
- Gas transfer velocities lower than k_{wind}
- Under a variety of conditions
- Still trying to dis-entangle the effect of the different mechanisms



Gutierrez-Loza et al., 2021

THE GAS TRANSFER VELOCITY

High wind speed conditions (U_{10N} > 8 m/s)



- Low relative humidity
- Unstable atmospheric conditions
- Positive ΔpCO_2

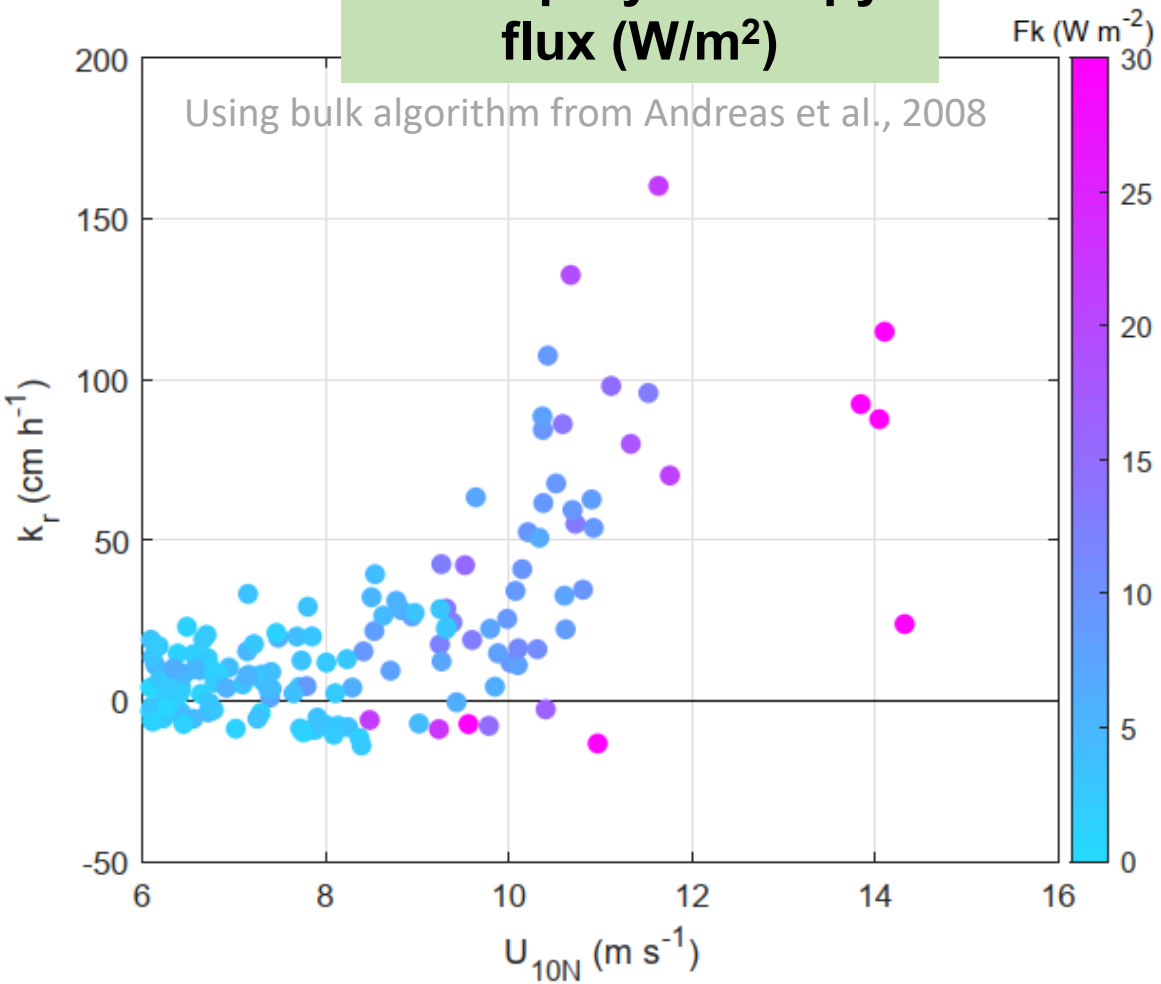
…only in winter

- Importance of capturing the seasonality
- Possible impact of atmospheric-side control mechanisms
- Asymmetric effect on FCO_2

THE GAS TRANSFER VELOCITY

High wind speed conditions (U_{10N} > 8 m/s)

Sea-spray enthalpy flux (W/m²)



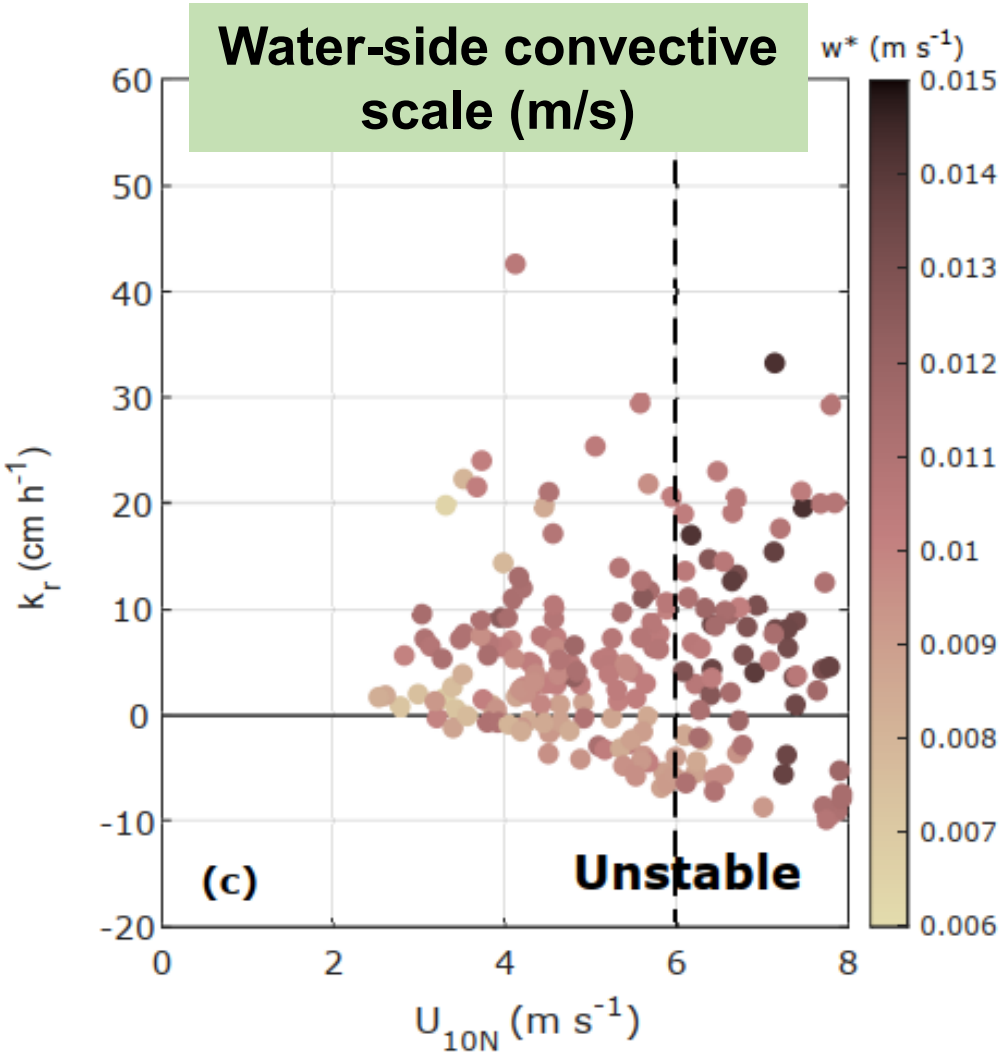
…maybe sea spray?

Can sea spray also enhance FCO_2 under particular atmospheric and oceanic conditions?...

THE GAS TRANSFER VELOCITY

Low wind speed conditions (U_{10N} < 6 m/s)

- Larger uncertainties
- Large heterogeneity at low mixing conditions (summer)
- Other relevant processes (e.g. surfactants)
- … water-side convection!



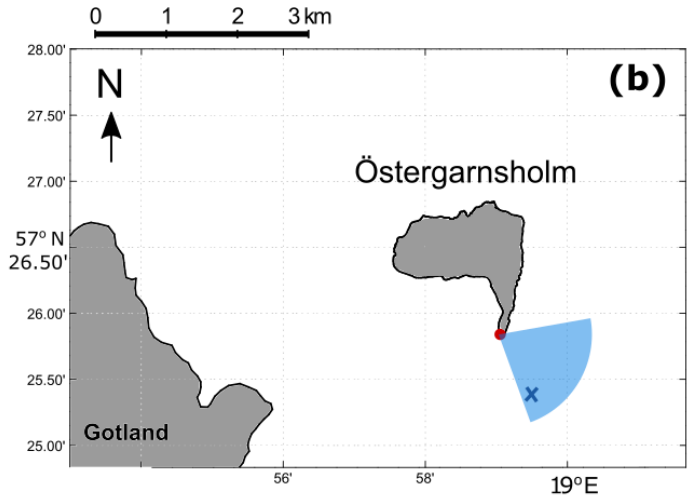
SUMMARY

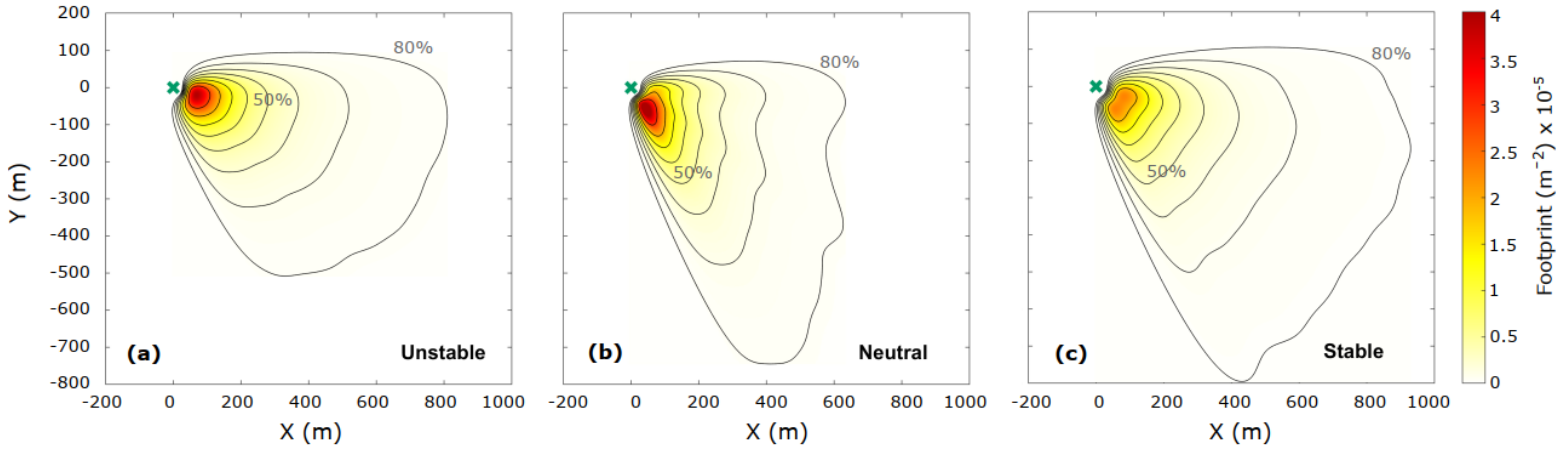
- These “long records” are a great monitoring effort that opens the possibility to study the effect of relevant mechanisms on FCO_2
- Wind-based parameterizations are able to represent the long-term averages of k in the study site…and potentially other coastal regions
- Winter-time conditions can promote large efflux events
- Possible (direct or indirect) effect of atmospheric conditions on FCO_2
- Asymmetric effect on FCO_2

Gutiérrez-Loza, L., Nilsson, E., Wallin, M. B., Sahlée, E., & Rutgersson, A. (2022). On physical mechanisms controlling air-sea CO_2 exchange. *Biogeosciences Discussions*, 1-24.

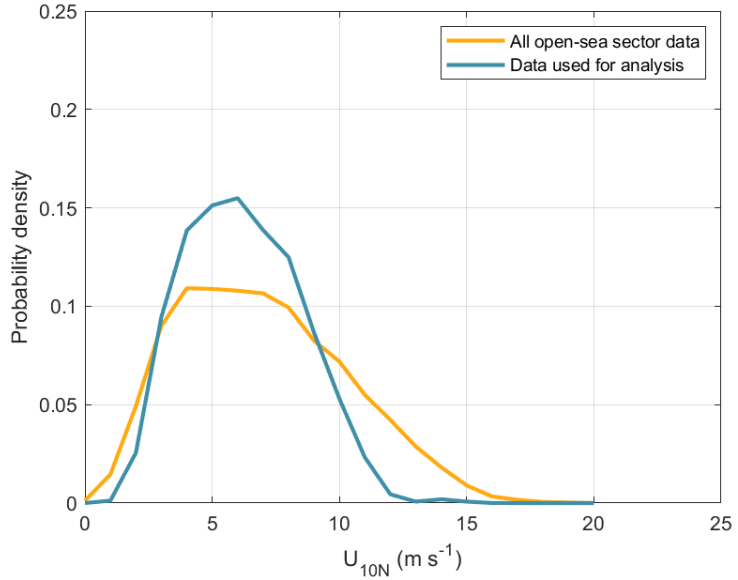
Thank you!

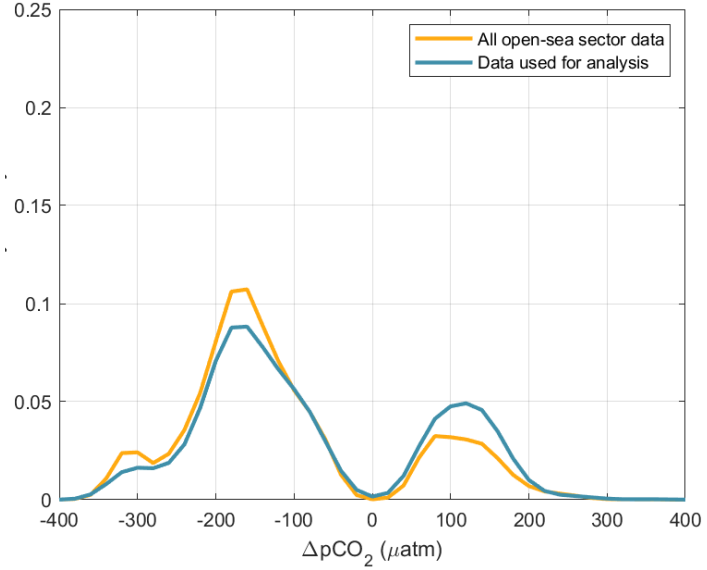
THE ÖSTERGARNSHOLM STATION AND MEASUREMENTS

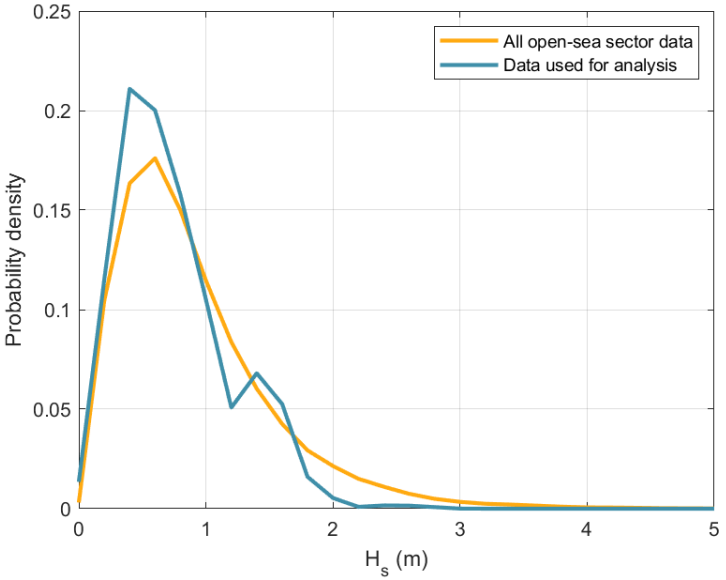


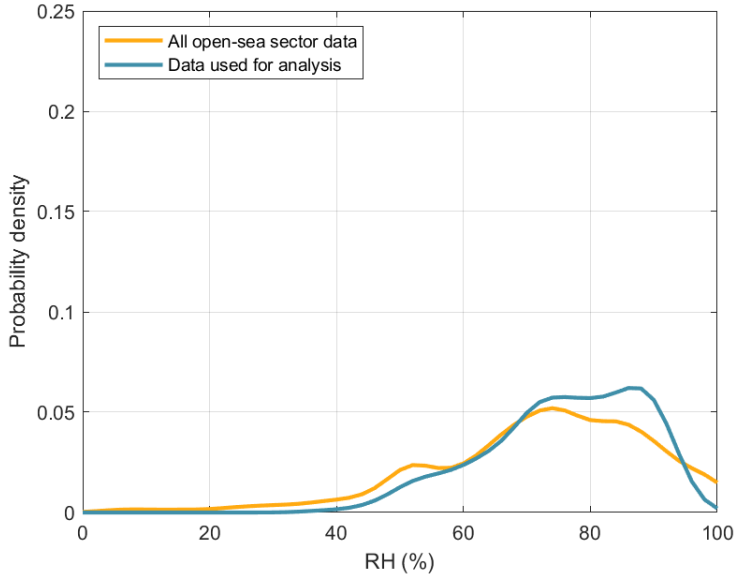


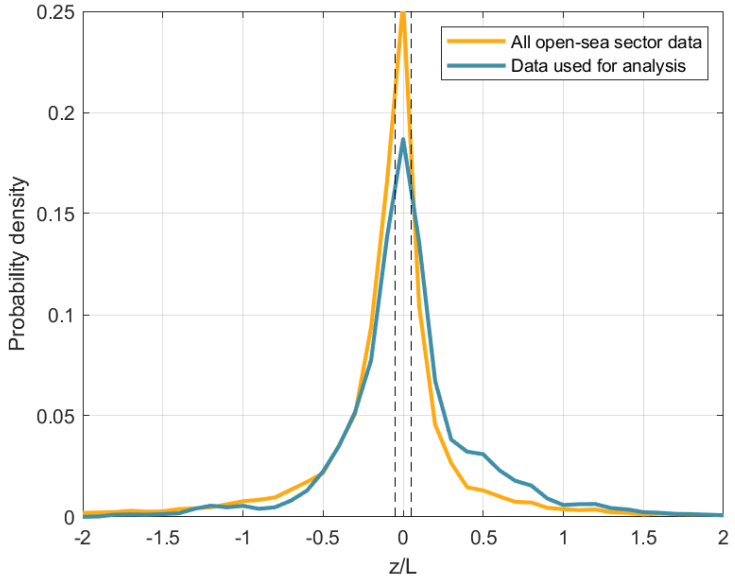
HISTOGRAMS

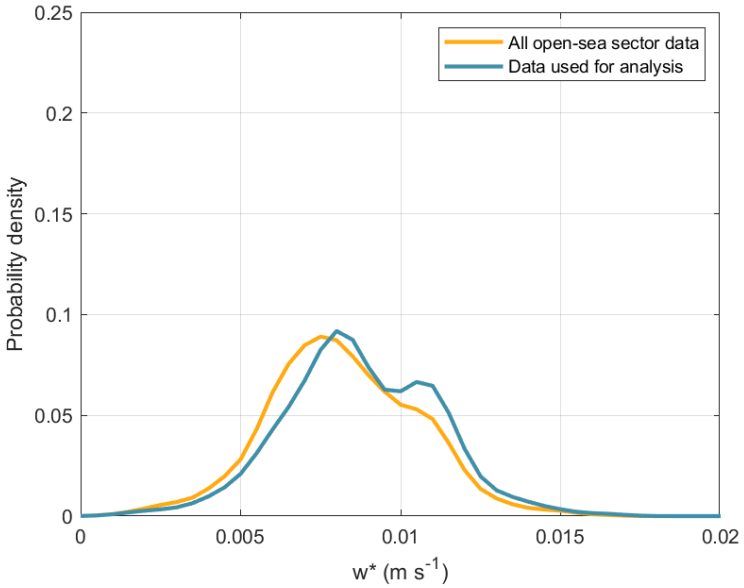

All open-sea sector data
Data used for analysis
Probability density
U_{10N} (m s^{-1})


All open-sea sector data
Data used for analysis
ΔpCO_2 (μatm)


All open-sea sector data
Data used for analysis
Probability density
H_s (m)


All open-sea sector data
Data used for analysis
Probability density
RH (%)

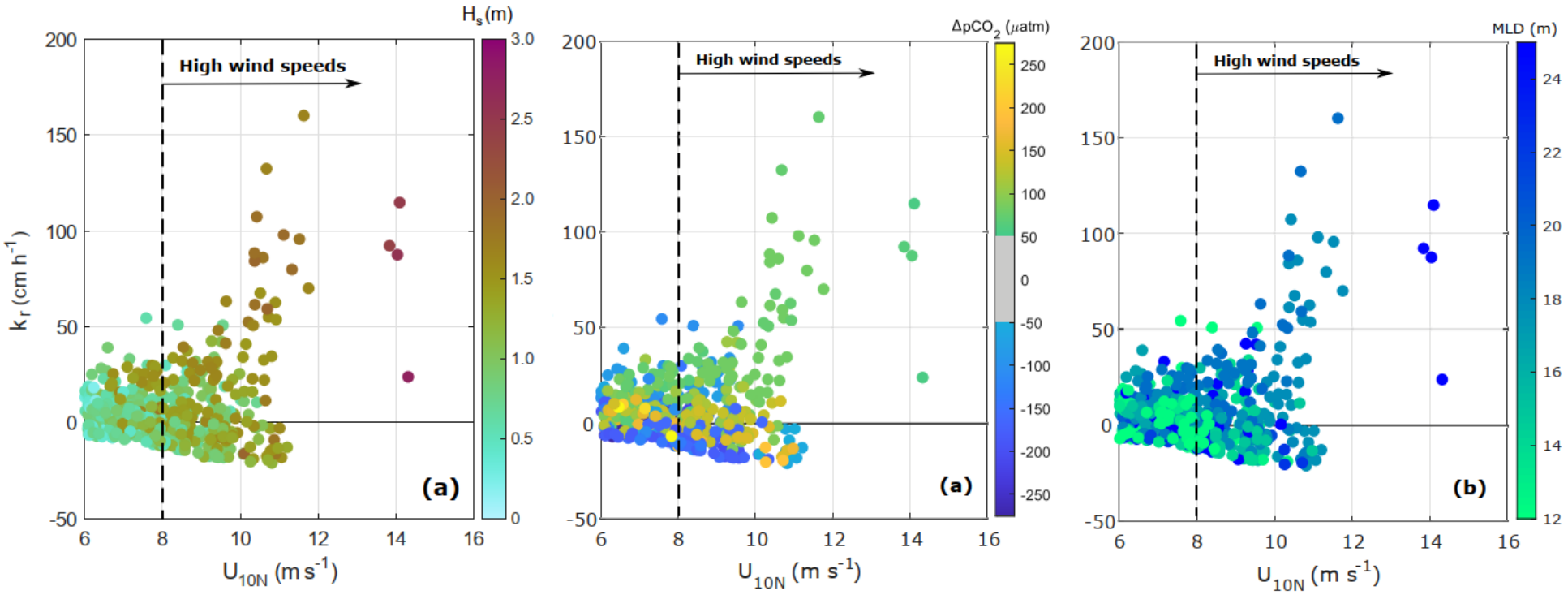

All open-sea sector data
Data used for analysis
Probability density
z/L


All open-sea sector data
Data used for analysis
Probability density
w* (m s^{-1})

THE GAS TRANSFER VELOCITY

High wind speed conditions

Water-side control mechanisms



- Higher (and younger) waves occur at high wind speed
- k_{660} follows the wind-based parameterization when ΔpCO_2 is large
- At lower ΔpCO_2, additional mixing is necessary

THE GAS TRANSFER VELOCITY

High wind speed conditions

- Atmospheric controls are to often taken into account
- Large k_{660} occur under unstable conditions when large enthalpy flux and low RH

Atmospheric control mechanisms