Later today: Kaisa Kraft - Multiplatform detection of filamentous cyanobacteria blooms in the Baltic Sea

Utö Atmospheric and Marine Research Station: Physical, chemical and biological drivers of **diurnal carbon cycle** in the coastal region

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Motivation: time of the sampling may matter i.e. why fixed-location flow-through systems are needed

Carbon dioxide (CO_2)

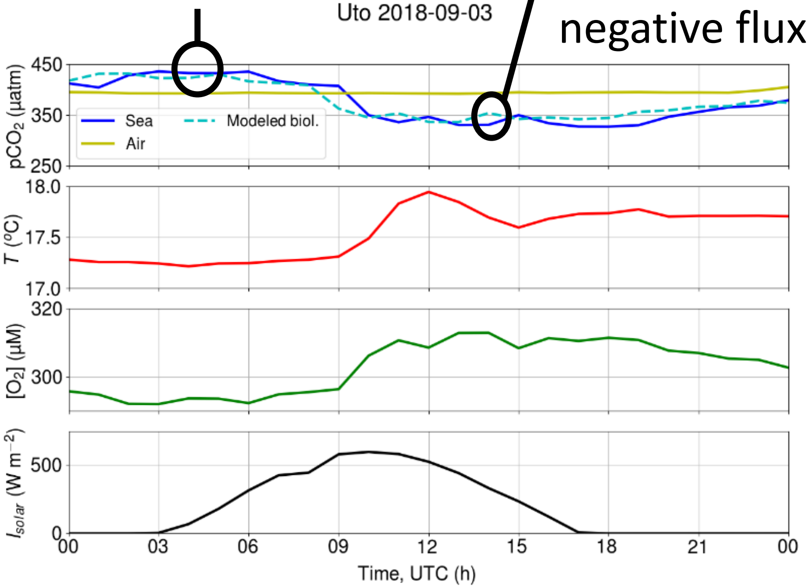
- Important greenhouse gas
- Generates ocean acidification
- Oceans are generally CO_2 sinks, whereas coastal seas are diverse systems

Air-sea flux of CO_2

- Depends on the partial pressure (pCO_2) difference in sea and water

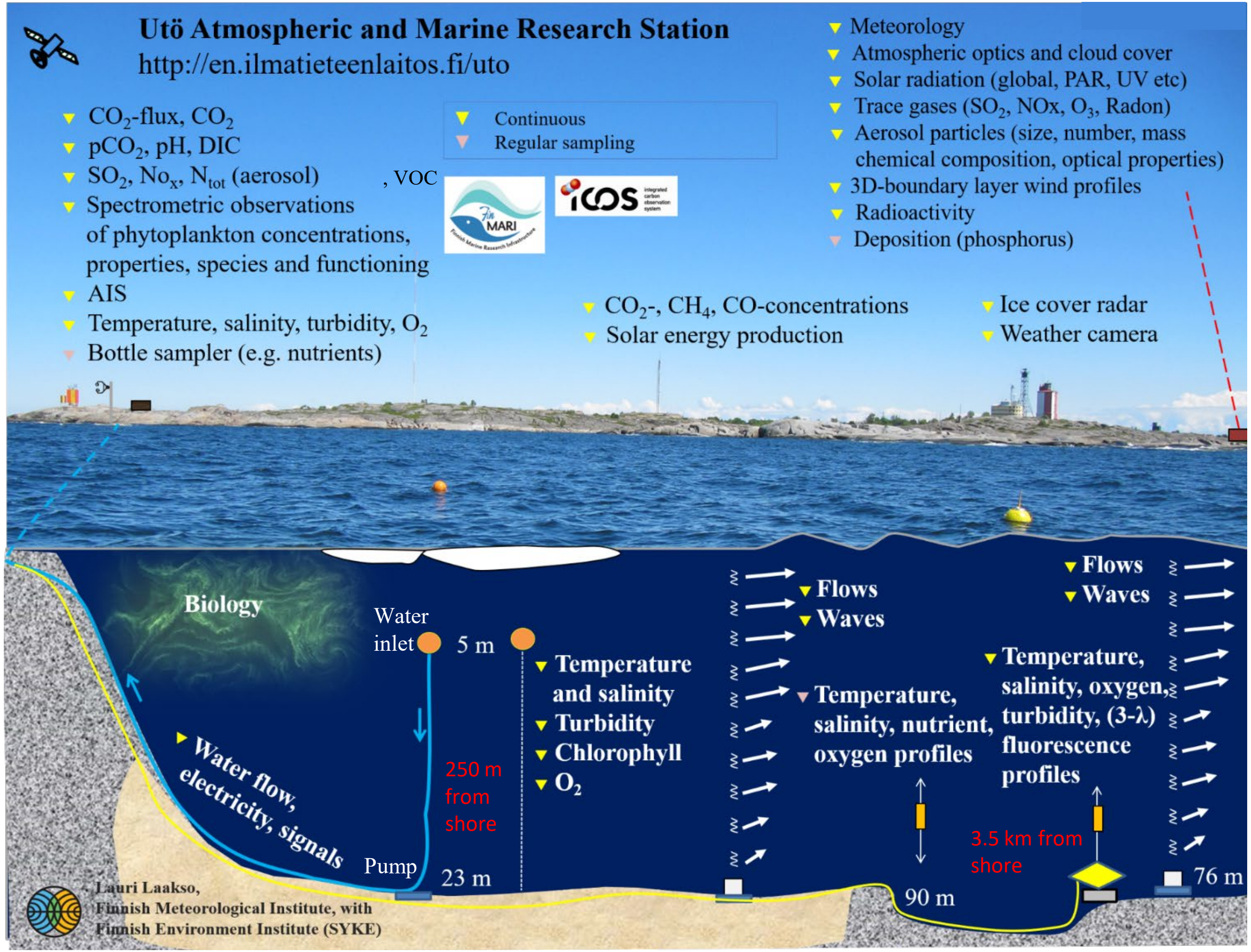
Sample in morning: positive flux

Sample in afternoon: negative flux



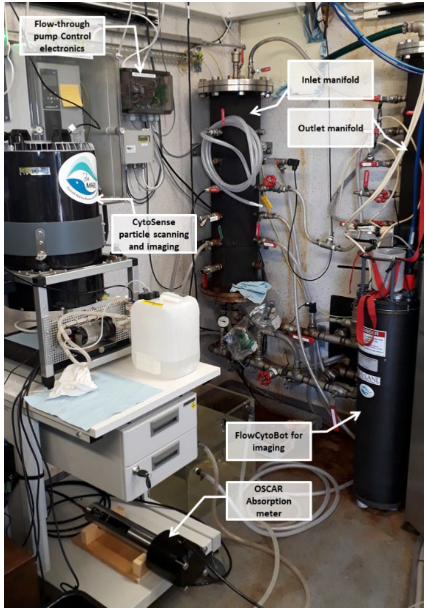
Aims of the study

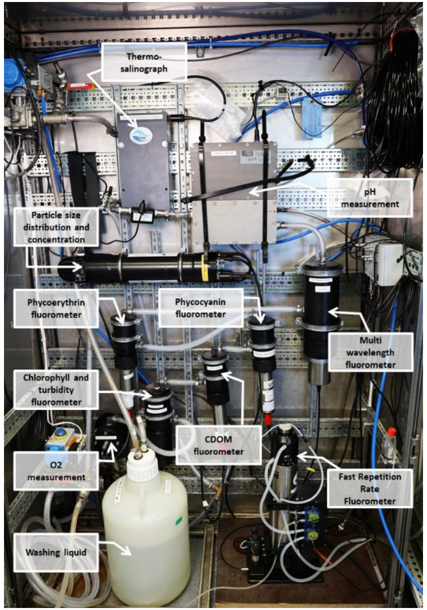
- **Determine the magnitude of the *p*CO_2 daily variability at Utö during different seasons**
- **Determine the driving processes behind this variability**
  - Biological transformations
  - Temperature changes
  - Air-sea exchange of carbon
  - (Upwelling is omitted as it is random in time)
- **Assess the possible error introduced if *p*CO_2 is sampled only once a day**



Utö Atmospheric and Marine Research Station
http://en.ilmatieteenlaitos.fi/uto
CO2-flux, CO2
pCO2, pH, DIC
SO2, Nox, Ntot (aerosol)
, VOC
Spectrometric observations of phytoplankton concentrations, properties, species and functioning
AIS
Temperature, salinity, turbidity, O2
Bottle sampler (e.g. nutrients)
Continuous
Regular sampling
Meteorology
Atmospheric optics and cloud cover
Solar radiation (global, PAR, UV etc)
Trace gases (SO2, NOx, O3, Radon)
Aerosol particles (size, number, mass chemical composition, optical properties)
3D-boundary layer wind profiles
Radioactivity
Deposition (phosphorus)
CO2-, CH4, CO-concentrations
Solar energy production
Ice cover radar
Weather camera
Biology
Water inlet
5 m
Temperature and salinity
Turbidity
Chlorophyll
O2
Water flow, electricity, signals
250 m from shore
Pump
23 m
Flows
Waves
Temperature, salinity, nutrient, oxygen profiles
90 m
Flows
Waves
Temperature, salinity, oxygen, turbidity, (3-λ) fluorescence profiles
3.5 km from shore
76 m
Lauri Laakso, Finnish Meteorological Institute, with Finnish Environment Institute (SYKE)

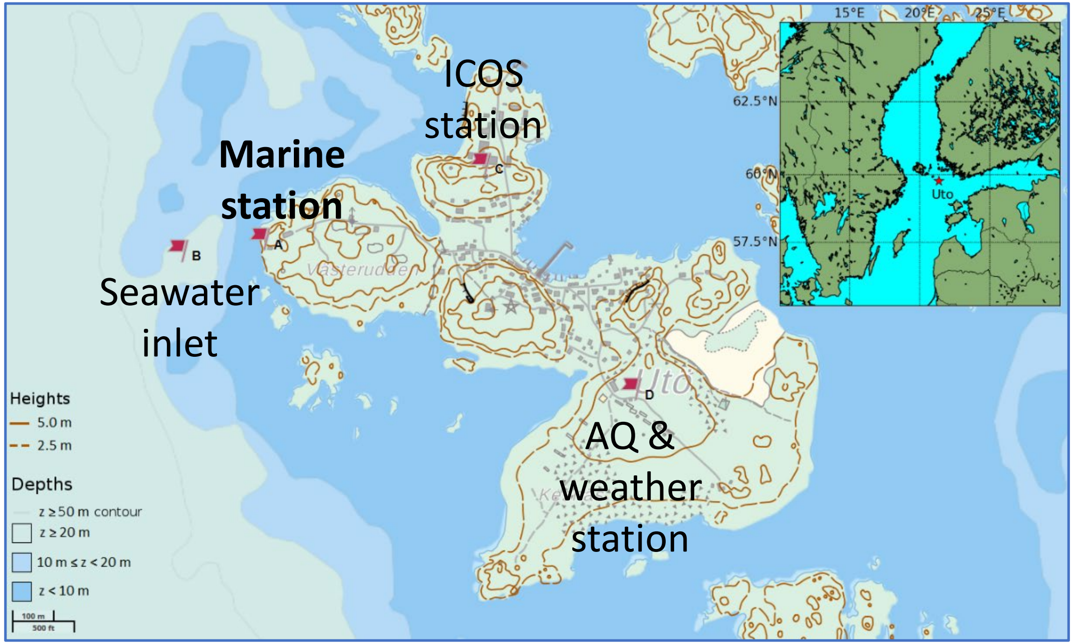

E1
E2
D
F
G
C
B
A
H
I


Flow-through pump Control electronics
Inlet manifold
Outlet manifold
CytoSense particle scanning and imaging
FlowCytoBot for imaging
OSCAR Absorption meter


Thermo-salinograph
pH measurement
Particle size distribution and concentration
Phycoerythrin fluorometer
Phycocyanin fluorometer
Multi wavelength fluorometer
Chlorophyll and turbidity fluorometer
CDOM fluorometer
O2 measurement
Fast Repetition Rate Fluorometer
Washing liquid

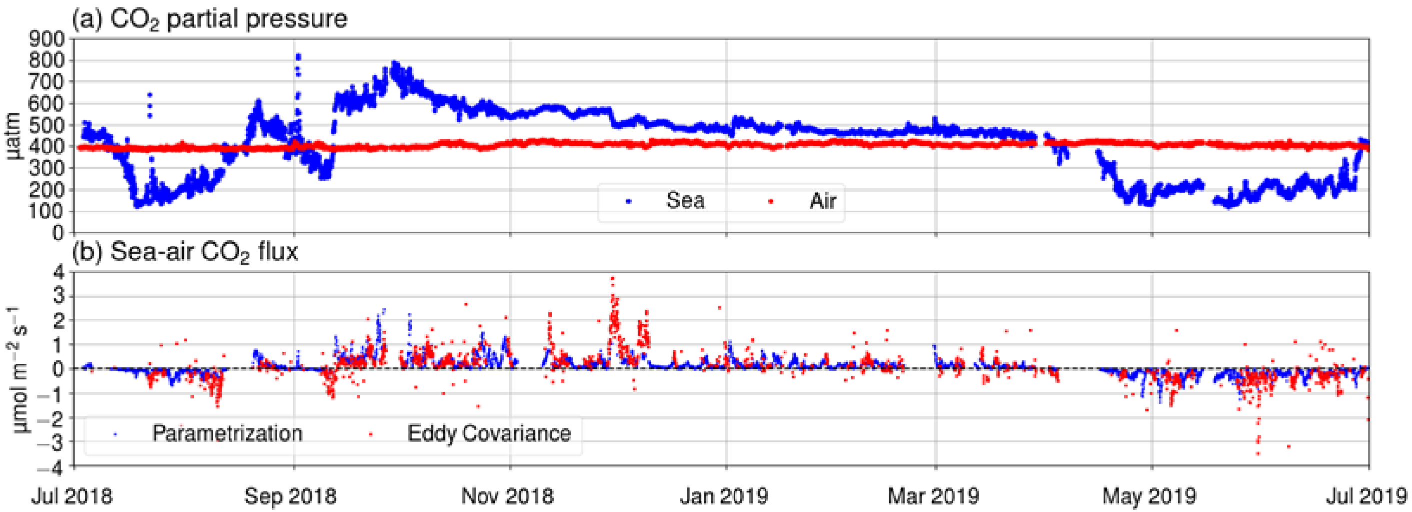
Utö Atmospheric and Marine Research Station
and its continuous inorganic carbon measurements

- **Located in the southern Archipelago Sea**
- **Flow-through system**
  - Sunburst SuperCO_2 for pCO_2:
    - Showerhead equilibrator
    - Infrared gas analyzer
- **Eddy covariance flux tower**
  - Direct measurement of air-sea exchange of CO_2
- **ICOS ATM station**
  - Atmospheric CO_2



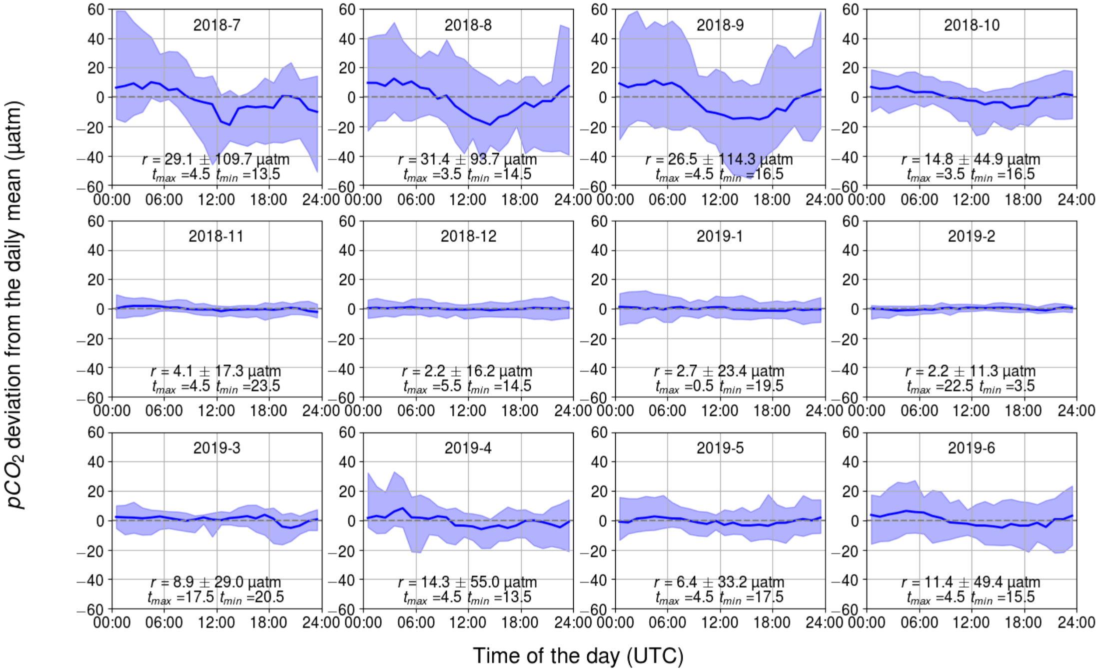
pCO_2 annual cycle during the study period 2018–2019

Summer sink Winter source Spring sink



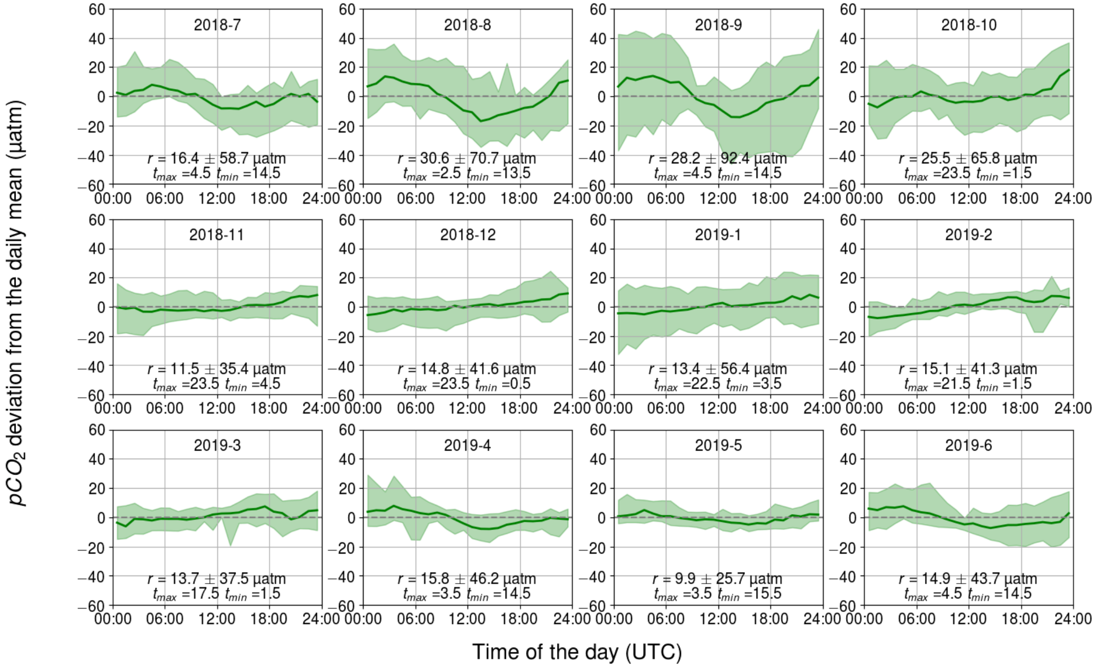
Observed diurnal pCO$_2$ variation

- Winter:
  - Low variation, monthly median amplitude less than 4 µatm
- Spring-Autumn:
  - Sinusoidal form
    - A minimum in afternoon
    - A maximum in night
  - Monthly median amplitude up to 30 µatm



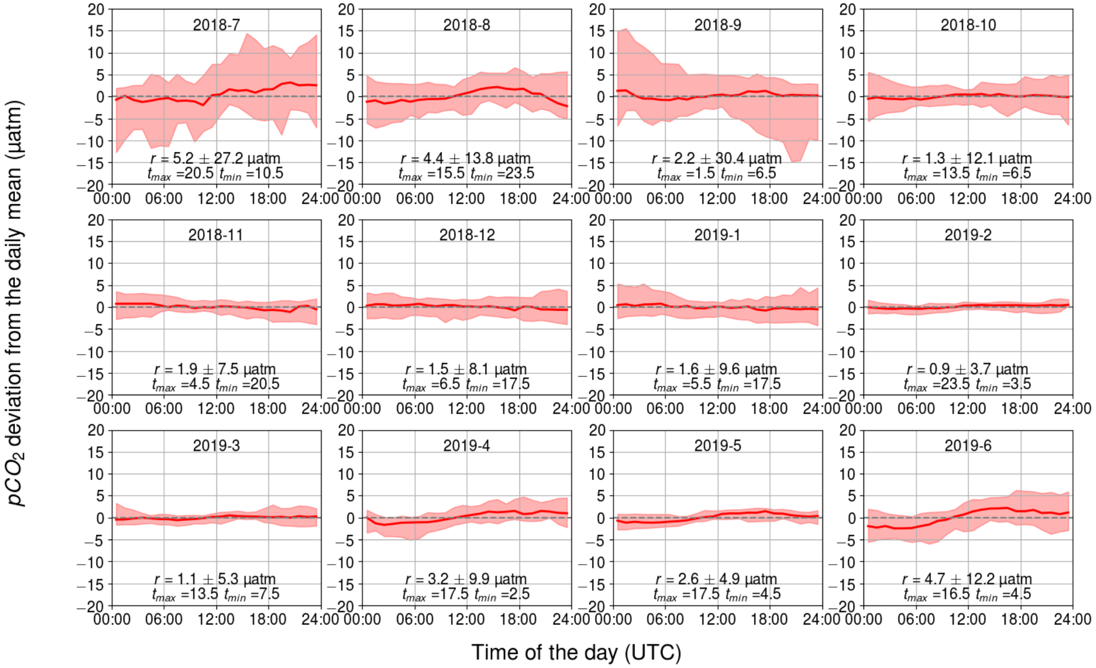
Biological pCO_2 diurnal variability

- **Calculated using continuous oxygen data**
  - We assumed common oceanic ratio between oxygen and carbon
- **Closely similar sinusoidal signal during productive season as observed from direct pCO_2 measurement**
  - ➢ Most pCO_2 diurnal signal is driven by biological transformations



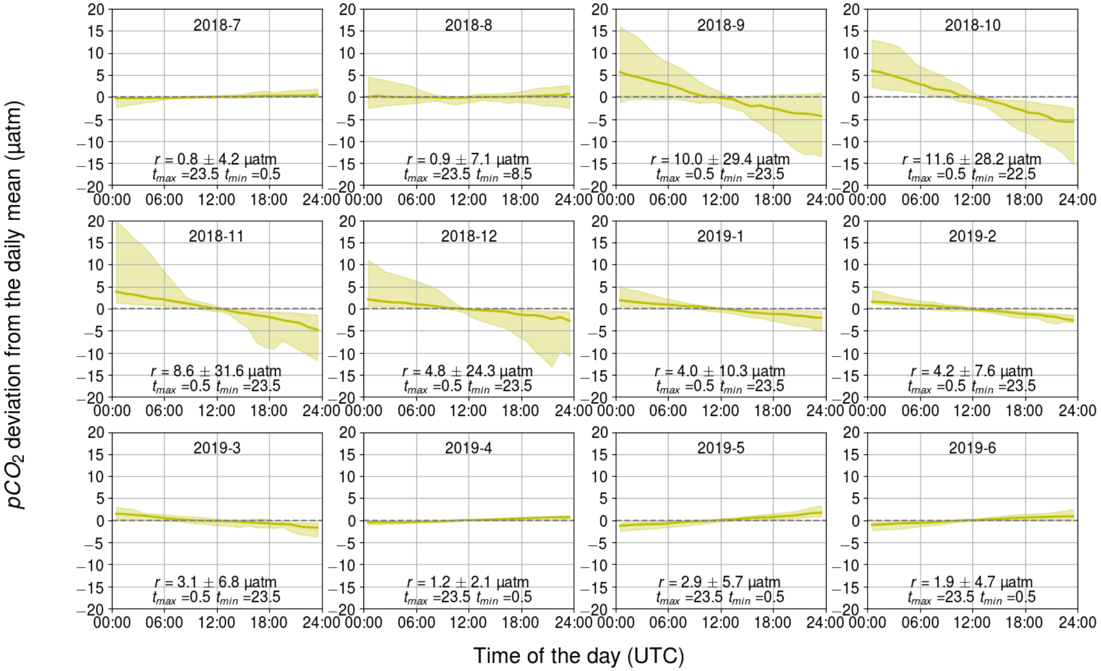
pCO$_2$ diurnal variability generated by the temperature changes

- **Calculated as how much pCO$_2$ is changed if it is governed by temperature alone**
- **Relatively small effect**
  - Monthly median amplitude is less than 5 µatm in May-July
    - Sinusoidal form that partly compensates the biological component
- **However, some large variation in 10th and 90th percentiles in summer, up to 30 µatm**

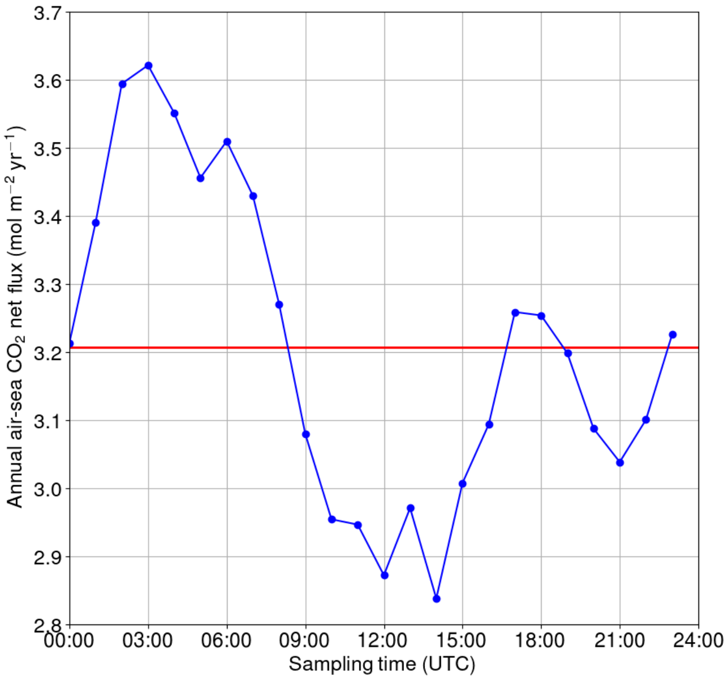


pCO_2 diurnal variability generated by the air-sea exchange of CO_2

- **Calculated from the flux data**
- **September-November close to 10 µatm daily change, when pCO_2 gradient is large and wind is high**
  - ➢ The estimate is sensitive to the mixed layer depth
- **December-August, less than 5 µatm monthly median amplitude**



Effect on the net air-sea CO_2 exchange



- The flux was calculated for the theoretical case, where only one measurement is considered for each day
- Highest effect during early hours and afternoon
  - Up to ±12 % effect on the net flux
- Could provide information on the error estimate of the voluntary observing ship measurements on strickly scheduled routes

Summary

- ***p*CO_2 diurnal cycle at Utö is mainly driven by biological processes with highest monthly median amplitudes of up to 30 µatm in Jul-Oct**
  - Other drivers generally smaller
    - However, single days can show large changes due to e.g. upwelling (not dealt here)
- **Sampling time may cause up to ±12 % error in the flux estimate**
- **Acknowledgments:**
  - FINMARI, JERICO RI, BONUS INTEGRAL, SEASINK and ICOS
- **More information:**
  - Honkanen et al.: **The diurnal cycle of *p*CO_2 in the coastal region of the Baltic Sea**, Ocean Sci., 17, 1657–1675, https://doi.org/10.5194/os-17-1657-2021, 2021.

New paper in preparation: 5 years data from a fixed ferrybox location