Uncrewed Aircraft Systems (UAS) for in-situ measurements across an air-sea interface

Dariusz B. Baranowski

Michał Brennek, Michał Chiliński, Michał Ciuryło, Piotr Flatau, Robert Grosz, Daniel Kępski, Szymon Malinowski, Beata Latos, Jerome Schmidt, Wojciech Szkółka

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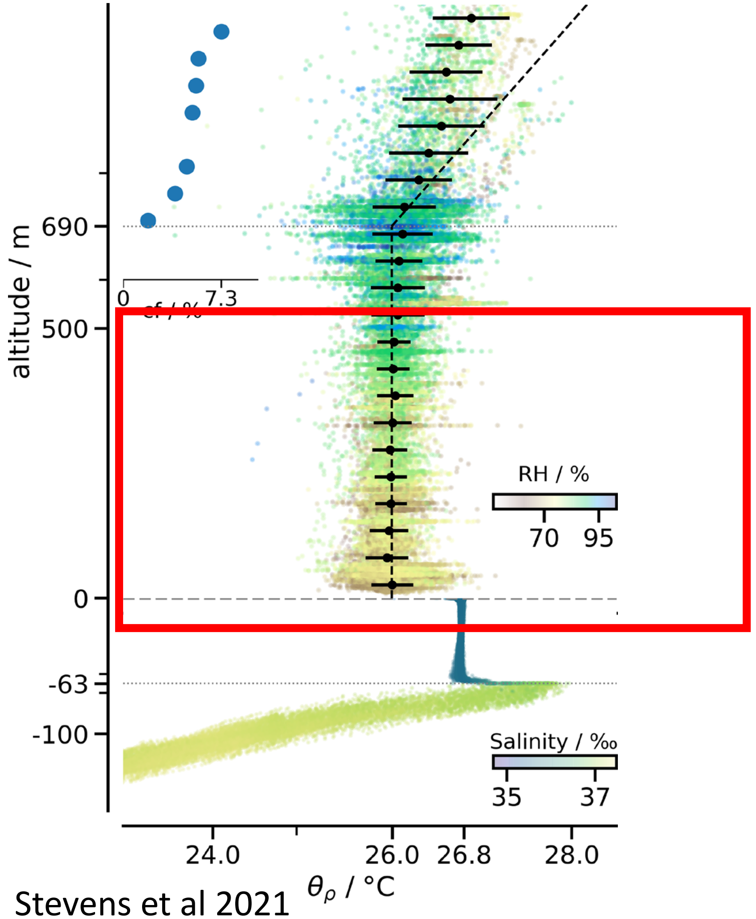
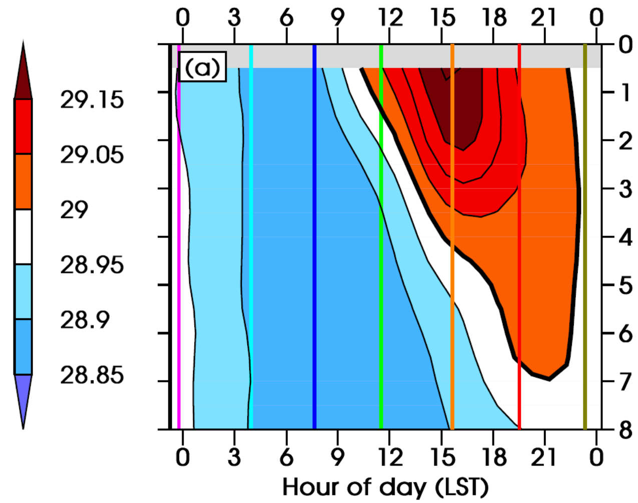


Stevens et al 2021



Matthews et al 2014

Opening remarks

- This is going to be a report on a work-in-progres
- I want to talk about what motivates measurements across an air-sea interface, how we contribute to do better and what else we can be doing better
- A large numer of people contributed to this work thus far
- So far, this research has been hitch-hiking on other projects (NCN funded Harmonia – PI Szymon Malinowski, OPUS – PI Aleksander Pietruczuk, OPUS – PI Darek Baranowski), but luckily this is going to change a little bit.

Outline

- Motivation (skewed towards global tropics)
- Limitation of canonical measurements approaches
- UAV observations in the lower PBL and across air-sea interface during three ship-borne campaigns
- Outlook ……. or where I want to go with this…

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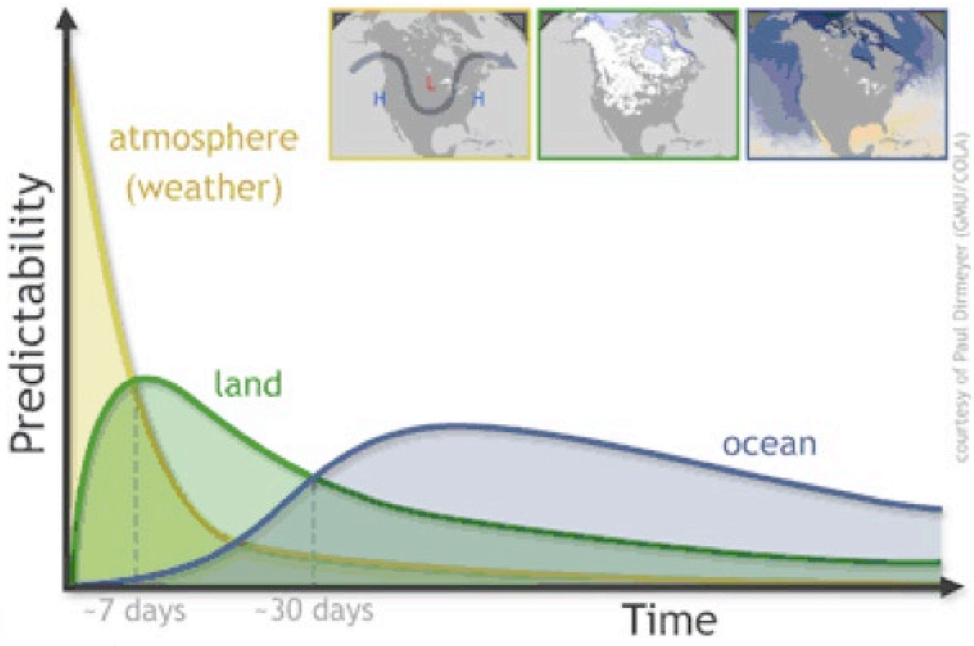
Motivation

Earth system and its predictability



Importance of the state of the ocean for weather predictability increases with the lead time, but there relevant atmospheric processes which are highly sensitive to **short term variations in ocean properties as well**!

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Motivation

Convection over ocean dependent on short-term SST variations

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE **On the cumulus diurnal cycle over the tropical warm pool**

10.1002/2015MS000610

James H. Ruppert Jr.[1,2] and Richard H. Johnson[1]

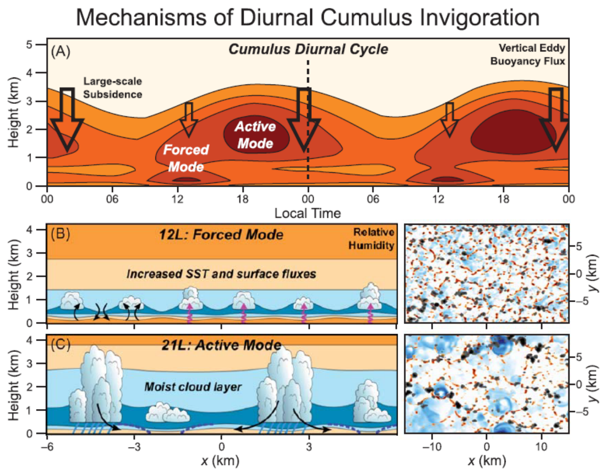


Figure 17. Conceptualized forcing mechanisms of the cumulus diurnal cycle—both the "forced" and "active" modes—over the tropical warm pool. (a) Time-height series of vertical eddy buoyancy flux (cf. Figure 13a; smoothed to emphasize robust features), with large-scale subsidence indicated by the open arrows. (b and c, left) Schematized cloud scenes in the *x-z* plane at (b) 12L and (c) 21L, including relative humidity (shaded; warmer colors indicate drier air), surface fluxes (magenta arrows), eddy circulation (black arrows), cold pools (blue-dashed lines), and rainfall (light-blue lines). (b and c, right) Corresponding maps in the *x-y* plane of negative θ' at 25 m (blue), upward motion at 225 m (red), and cloud (gray-black) (directly from model output; cf. Figure 6).

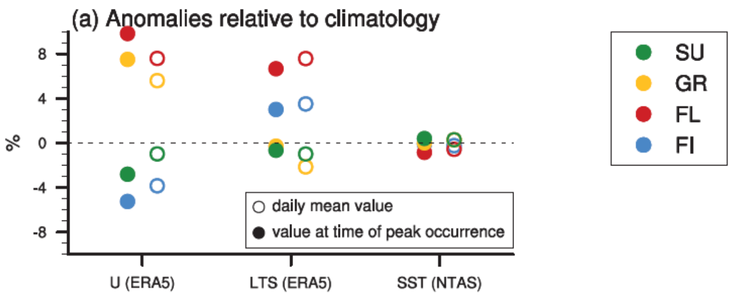
Diurnal SST increase drives daytime convection

Received: 13 January 2021 | Revised: 9 April 2021 | Accepted: 28 April 2021 | Published on: 9 June 2021
DOI: 10.1002/qj.4103
Quarterly Journal of the Royal Meteorological Society

RESEARCH ARTICLE

On the daily cycle of mesoscale cloud organization in the winter trades

Jessica Vial[1] | Raphaela Vogel[1] | Hauke Schulz[2]



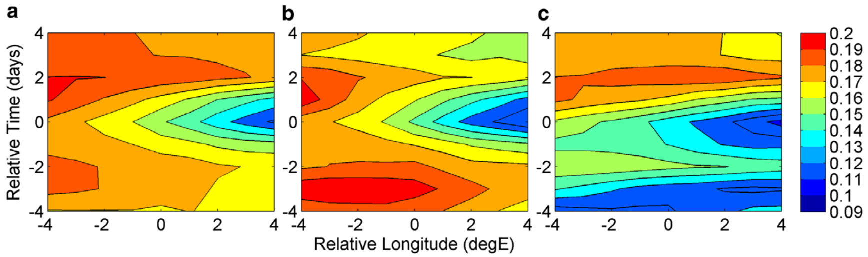
Mesoscale organization of shallow convection appears to be dependent on small variations in environmental conditions (*)

Clim Dyn (2017) 49:2991–3009
DOI 10.1007/s00382-016-3487-7

Multiple and spin off initiation of atmospheric convectively coupled Kelvin waves

Dariusz B. Baranowski[1,2] · Maria K. Flatau[3] · Piotr J. Flatau[4] · Jerome M. Schmidt[3]

Amplitude of the diurnal cycle



Increased diurnal SST variability prior to „multiple" initiations of convectively coupled Kelvin waves.

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Motivation
Two hats

- Atmosphere cares only about SST
  - We neglect effect of ocean dynamics on SST variability
  - Atmospheric models with prescribed or slab SST

- Ocean cares only about surface fluxes
  - We neglect effect of atmospheric dynamics on energy and momentum fluxes
  - Ocean models forced with prescribed atmospheric forcing

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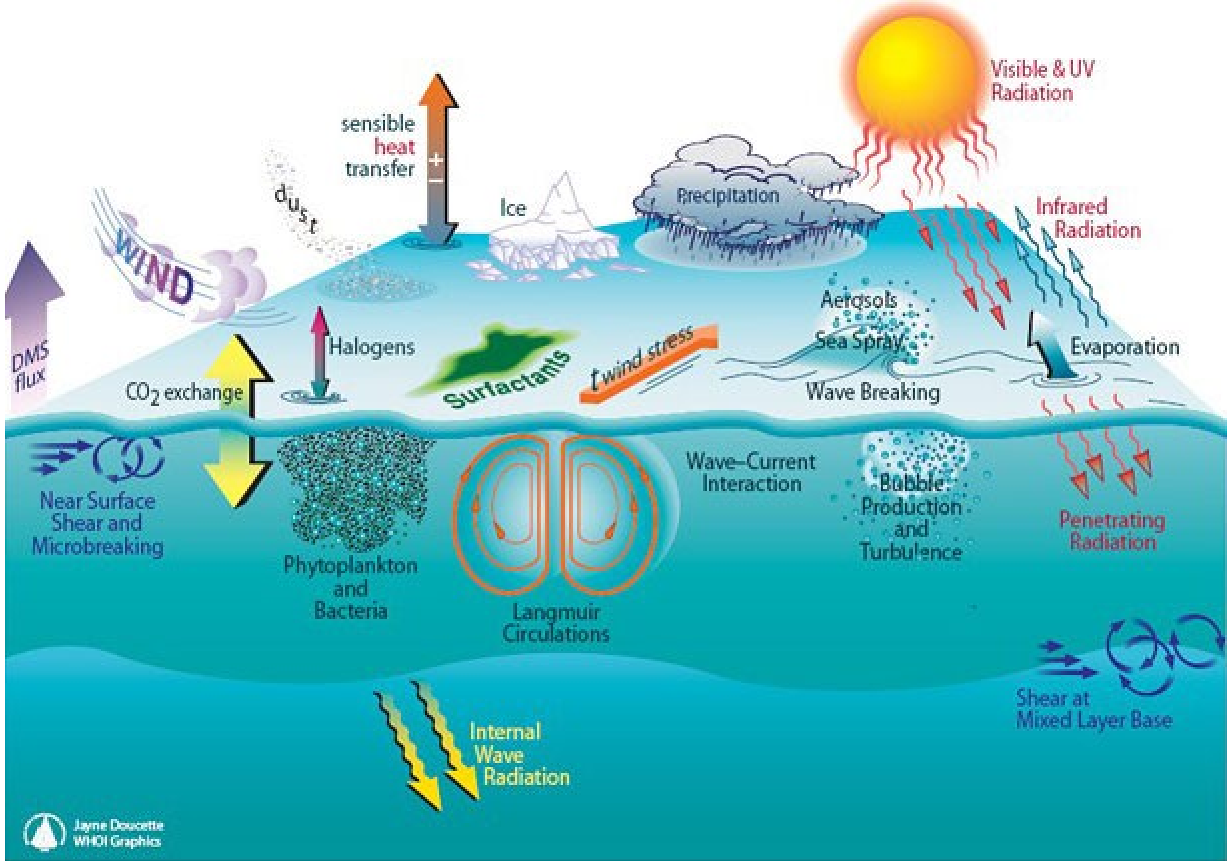
Motivation
Or is it one hat?

Interactions between atmosphere and ocean are **fully coupled** processes.

Changes to one environment will modity surface fluxes and force adjustment in the other environment and so on…

<u>DOES IT MATTER?</u>



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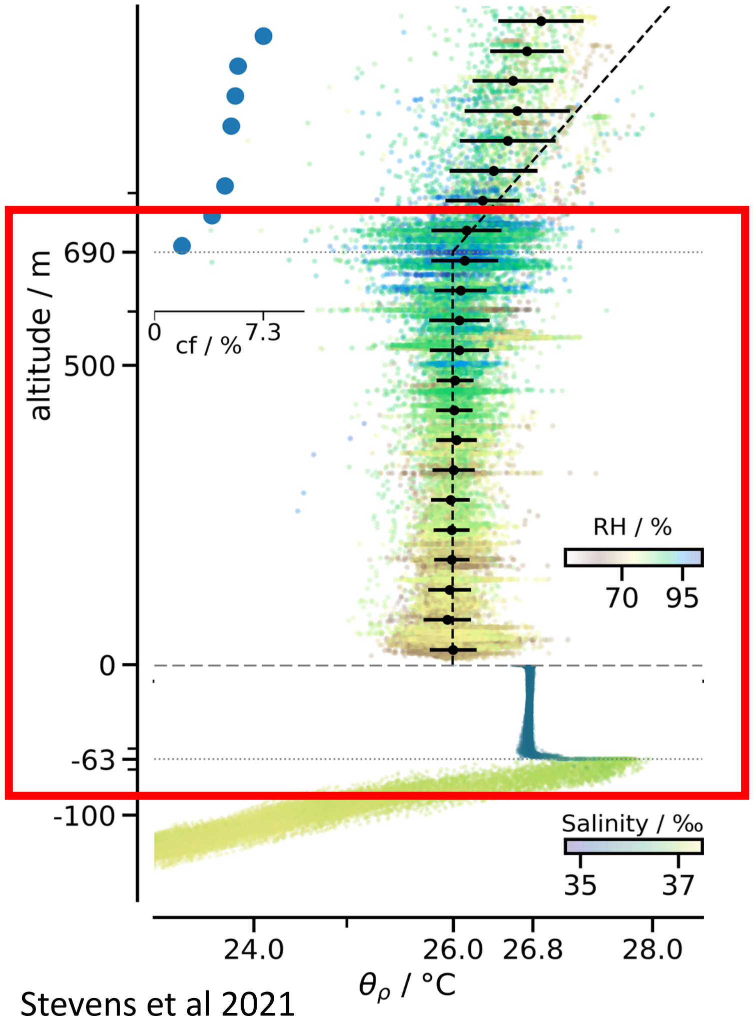
Motivation

Atmopshere-ocean transition zone

- We need to go beyond air-sea interface and consideration of surface fluxes only
- The <u>atmosphere-ocean transition zone</u> is a conceptual framework that considers processes **directly** influencing air-sea interface and surface fluxes.
- The atmosphere-ocean transition zone extends roughly from the bottom of oceanic mixed layer to the top of the atmospheric boudary layer



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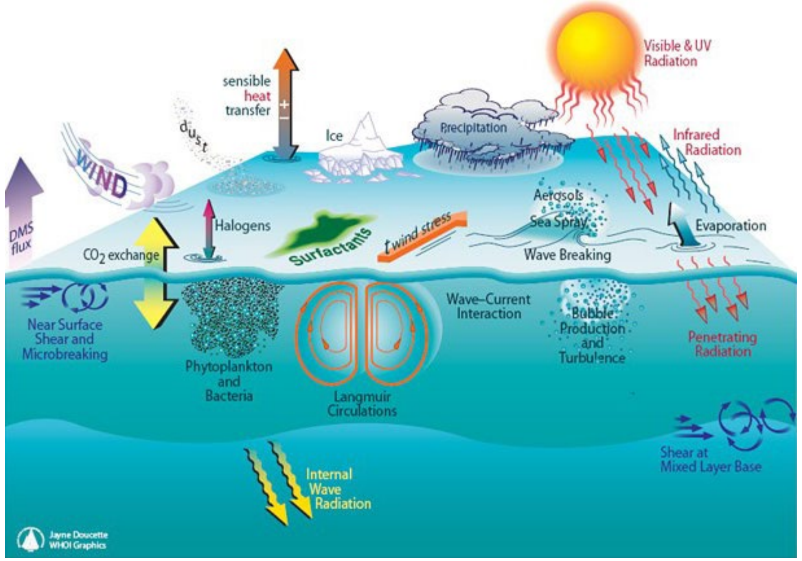

Consideration of physical (bio-chemical) processes within the atmosphere-ocean transition zone allow desciption of the coupled environment.

Applies to measurements and modeling.

Requires profiles!

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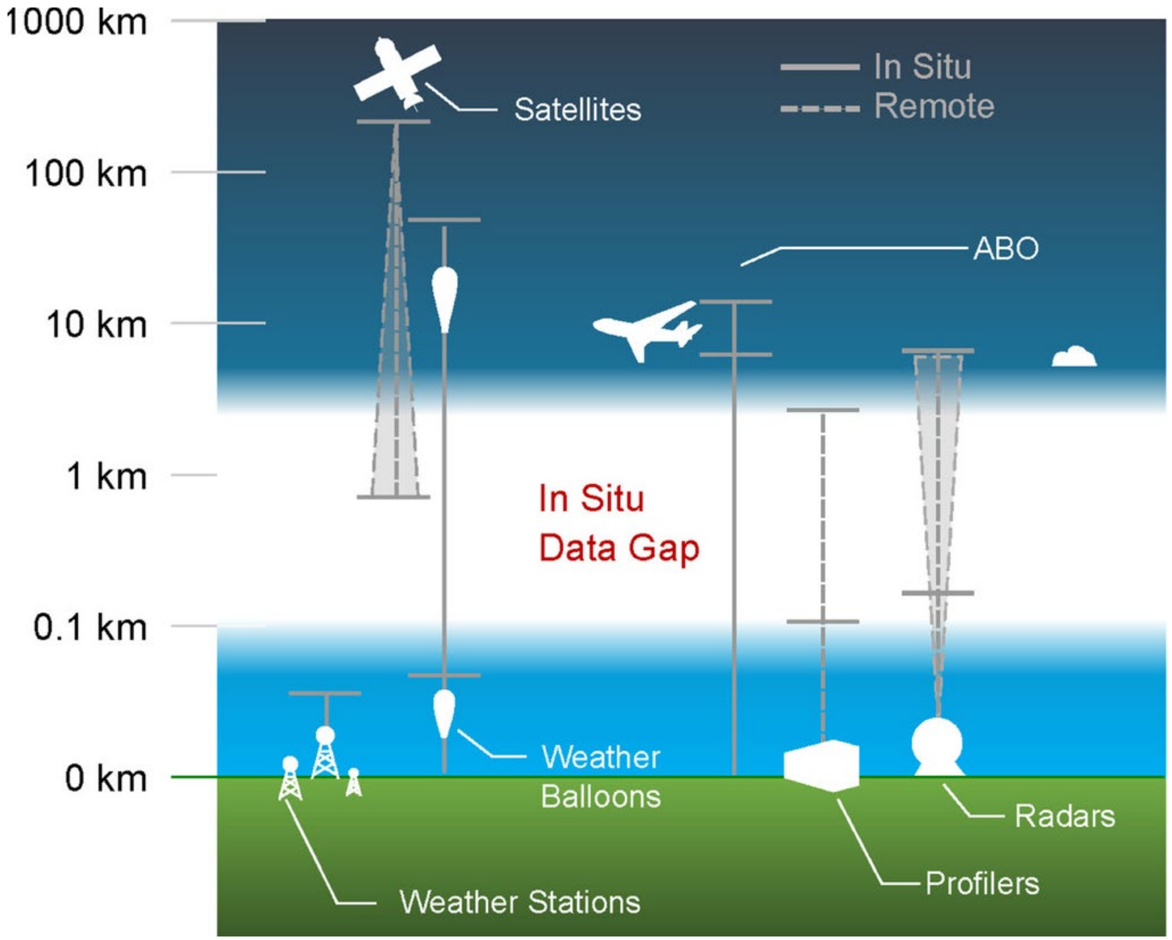
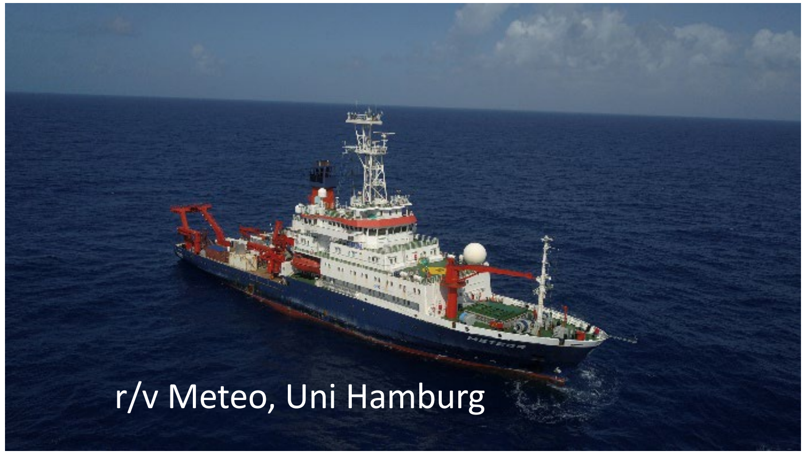
Atmosphere-ocean transition zone

Measurement constrains

- Limited profiling options in the atmospheric boundary layer, even over land
- Data gap exacerbated over oceans
- Ship-borne measurements contrains to the platform (big structure), balloons and remote sensing



Pinto et al 2021



r/v Meteo, Uni Hamburg

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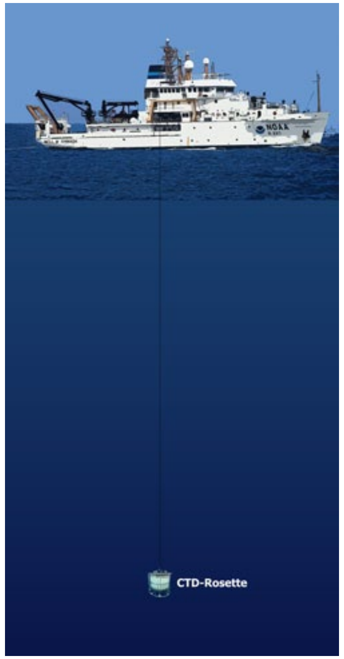
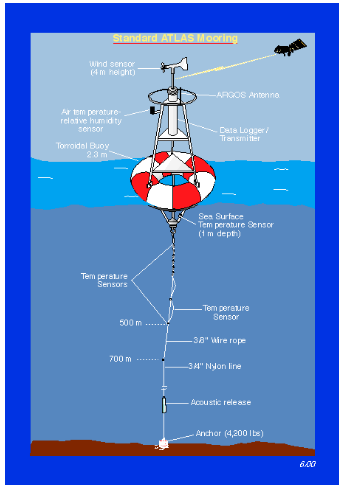
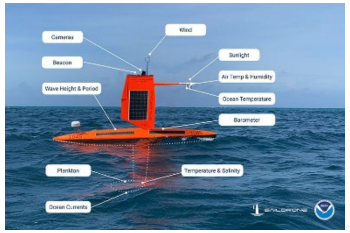
Atmosphere-ocean transition zone
Measurement constrains

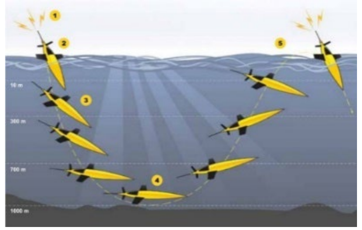


Typical ocean profiling does not extend to the atmosphere and rarely close to the air-sea interface

- Shipborne
  - CTD → blind in the top several (~10) meters
  - XBT/XCTD → can measure within the top layer but affected by platform's presence
- Autonomous
  - Argo floats → most switch off around 5m depth
  - Moorings → typically poor vertical resolution but, they <u>can have surface measurements</u>
  - Gliders → can measure to near top layer, but no surface component
  - surface vehicles/saildrones → both atmosphere and ocean but no profiles
- Satellites → good for surface,
  bad for subsurface







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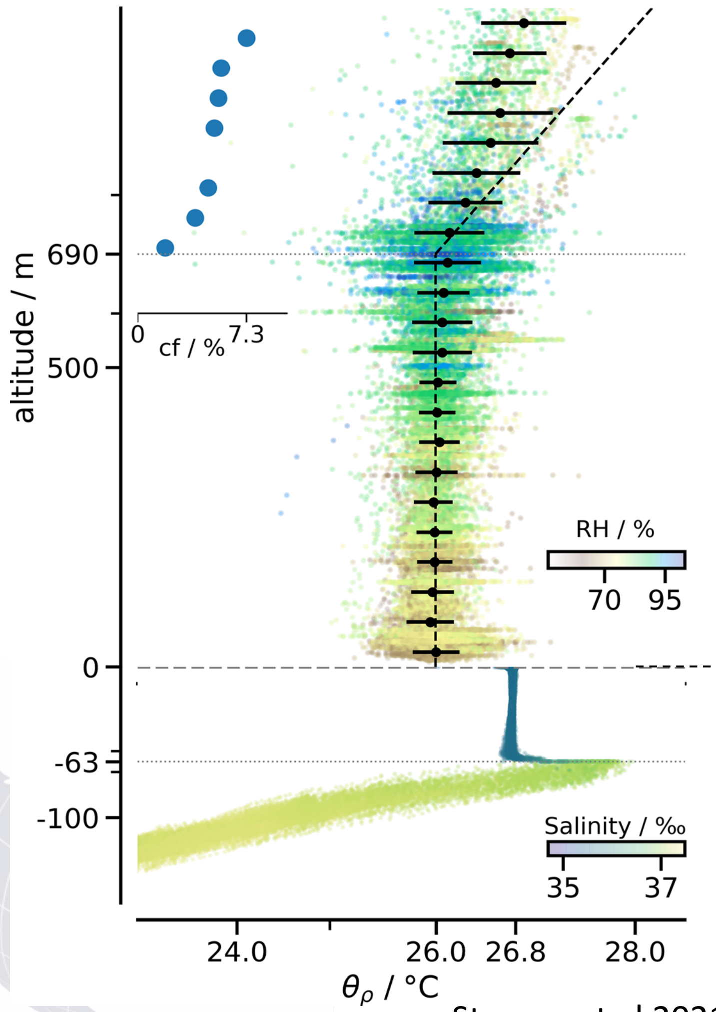
Atmosphere-ocean transition zone

Measurement constrains



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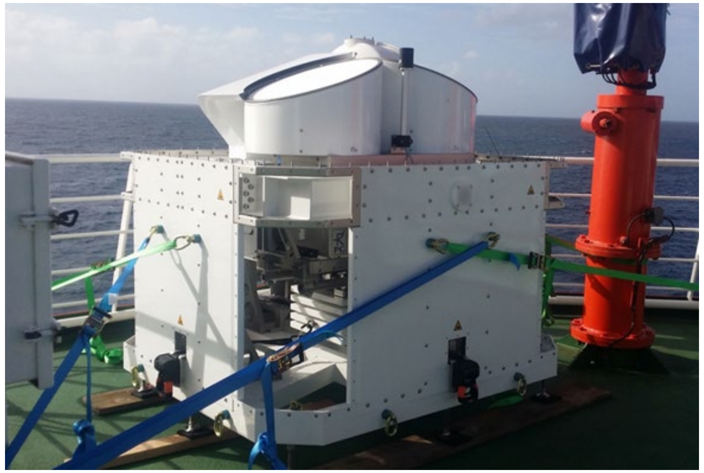
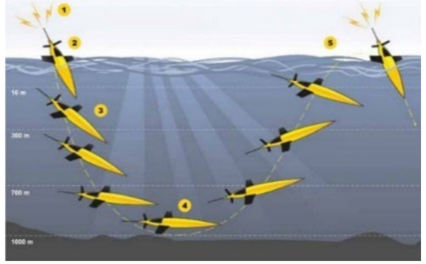
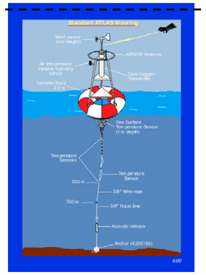
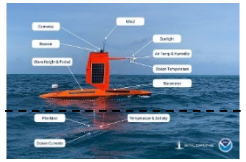




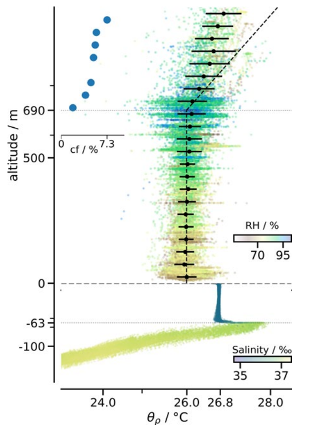




Atmosphere-ocean transition zone
Measurement constrains

- Assessing interactions between atmosphere and ocean require measurement of appropriate properties (momentum, energy, etc.) across an interface between air and water
  - **Profiles of respective properties across an air-sea interface**
- Autonomous measurements largely restricted to a single environment
- Ship-borne measurement limited by disturbances due to a vessel's presence in both atmospheric and oceanic environemnts

<u>SOLUTION</u>: **UAVs with atmosphere and ocean measuring capabilities launched from a ship for measurements across an air-sea interface in an environment undisturbed by the vessel**



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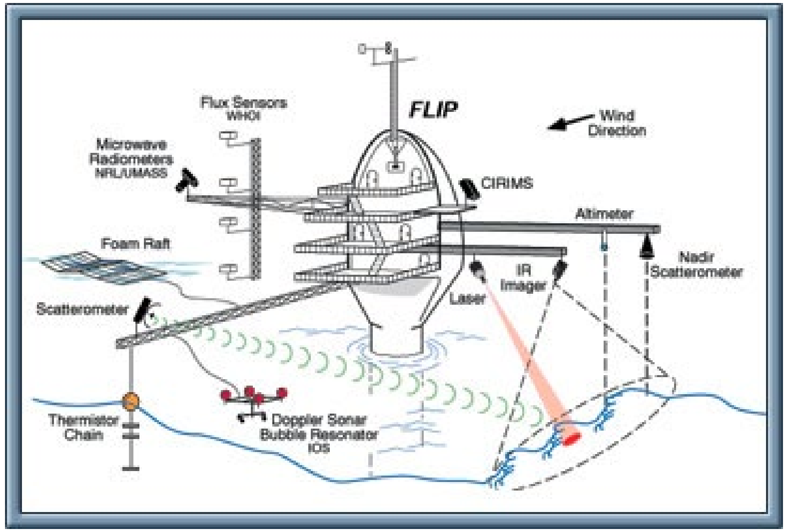
Profiling across the air-sea interface is not necessary a new idea…

- R/P Flip (launched in 1962) possess capability of instantuous, collocated measurements across air-sea interface at multiple levels



- But there is only one Flip plus $$$$ to operate it
  This approach is not scalable

Atmosphere-ocean transition zone

UAV measurments

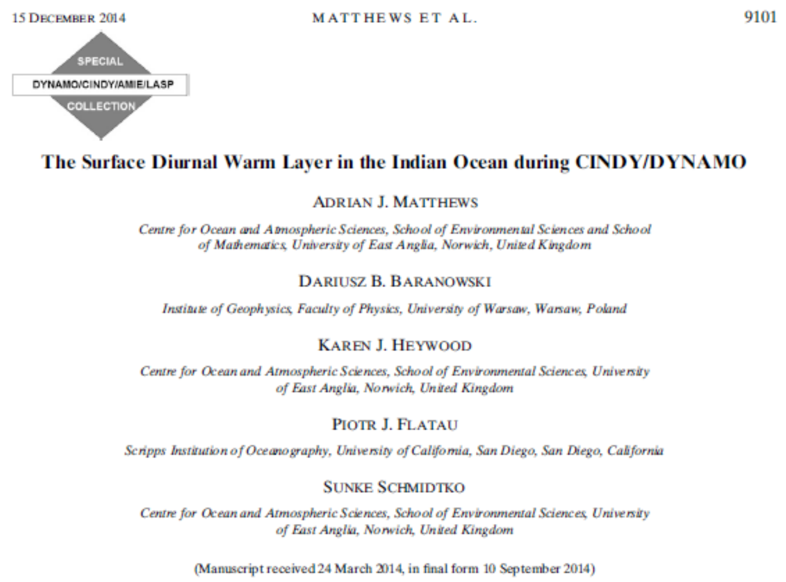
- Goal – perform measurements that span across the air-sea interface, that is between ~10m below the surface to ~500m above it.

- Perform measurements in a vicinity to a research vessel (logistics, cross-calibration) but in an environment not disturbed by it

- Cover the part of atmosphere-ocean transition zone under-sampled by other methods

- Direct goal: can we measure coupled atmosphere-ocean environment during occurence of diurnal warm layers?

Diurnal warm layers


15 December 2014 MATTHEWS ET AL. 9101

SPECIAL DYNAMO/CINDY/AMIE/LASP COLLECTION

The Surface Diurnal Warm Layer in the Indian Ocean during CINDY/DYNAMO

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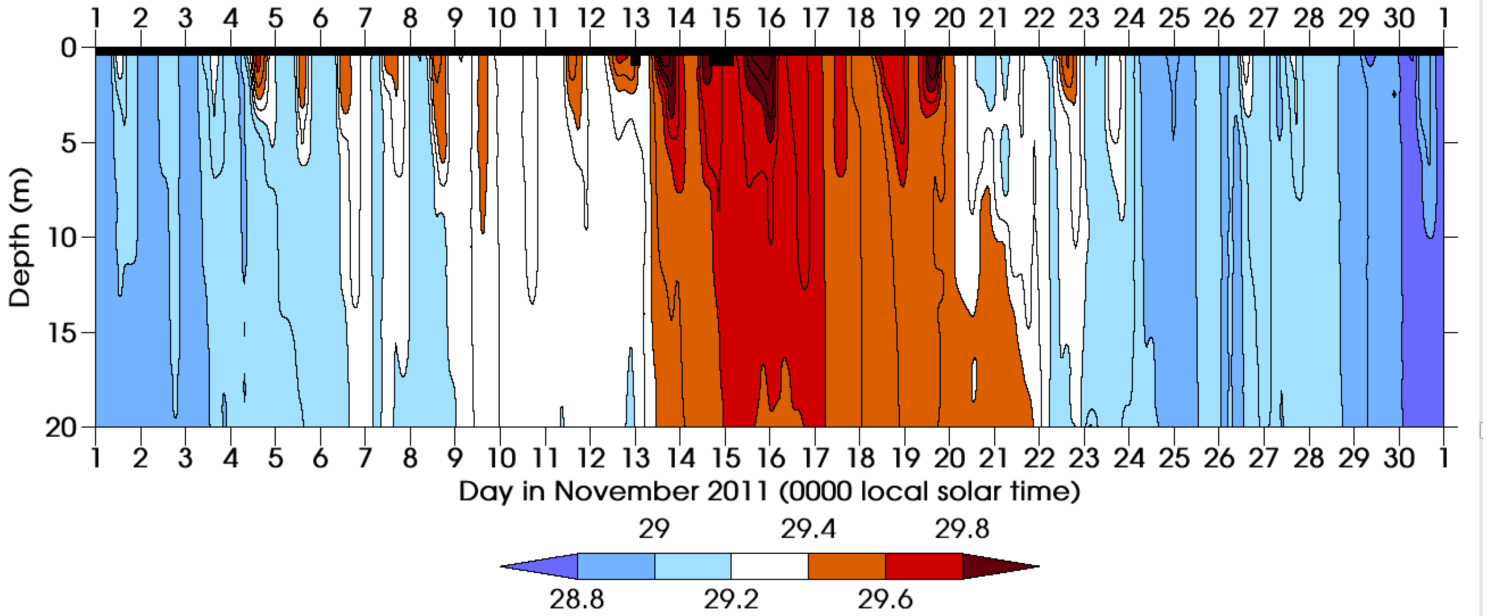
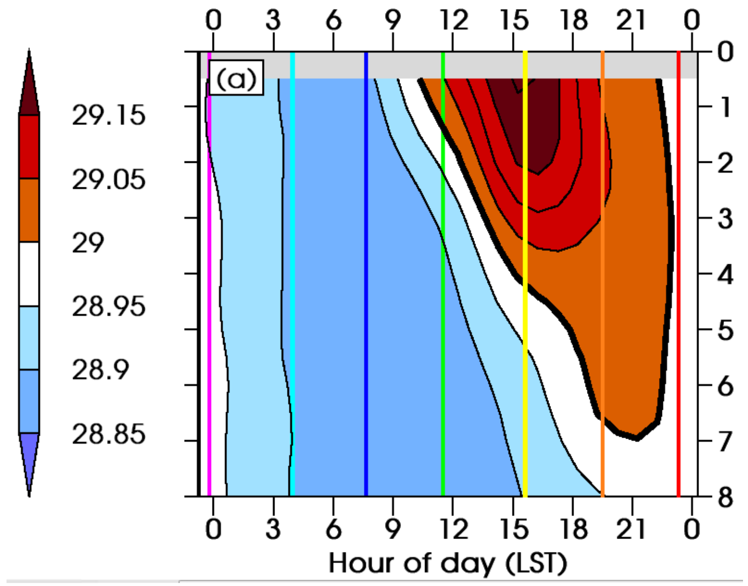
(Manuscript received 24 March 2014, in final form 10 September 2014)





Daytime increase of the SST in the top layer of the ocean.

Due to nocturnal mixing there is no memory of the WL from a day before

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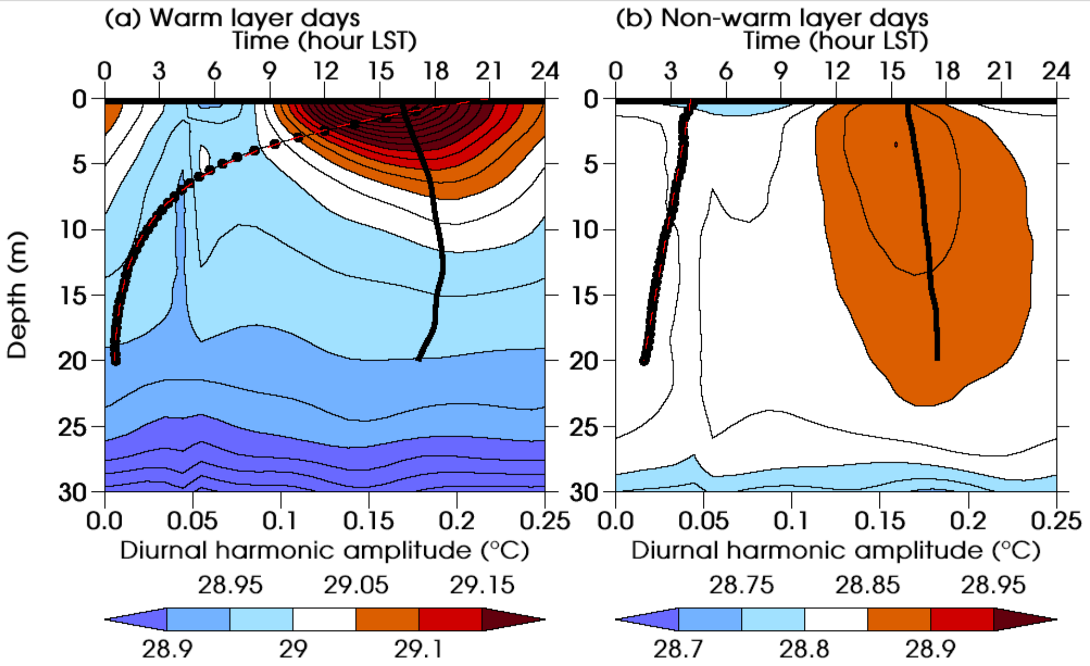
Diurnal warm layers

Warm layer days vs no warm layer days

- Warm layers days exhibit exponential temperature profile following solar absorption profile
  - Maximum achieved around 15LST
  - At later hours, cooling and entrainment driven mixing of WL

- No warm layer days show linear temperature profile with much smaller amplitude near the Surface
  - Shortwave radiation being mixed more evenly throughout a thicker layer



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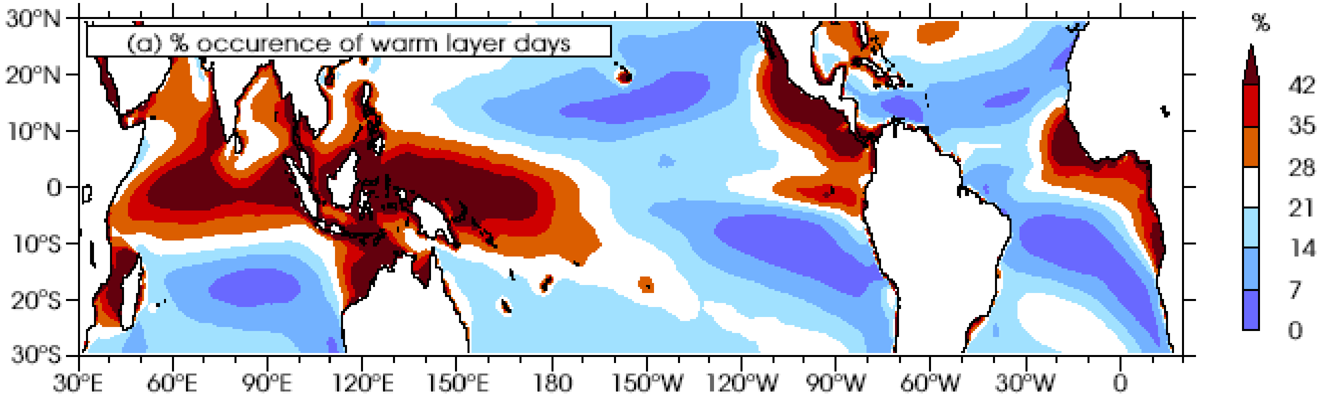
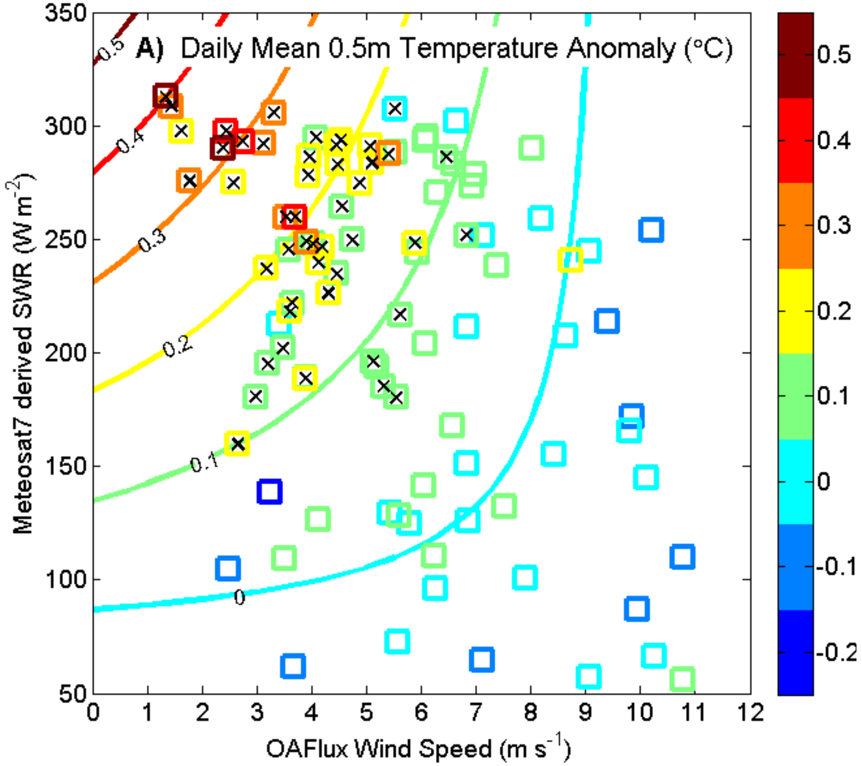
Diurnal warm layers
Drivers

- Warm layers appear to be primarily driven by atmospheric conditions: surface wind speed and shortwave radiation at the ocean surface
  - Low wind speed and high insolation favor development of a warm layer

- We can derive a simple diagnostic model





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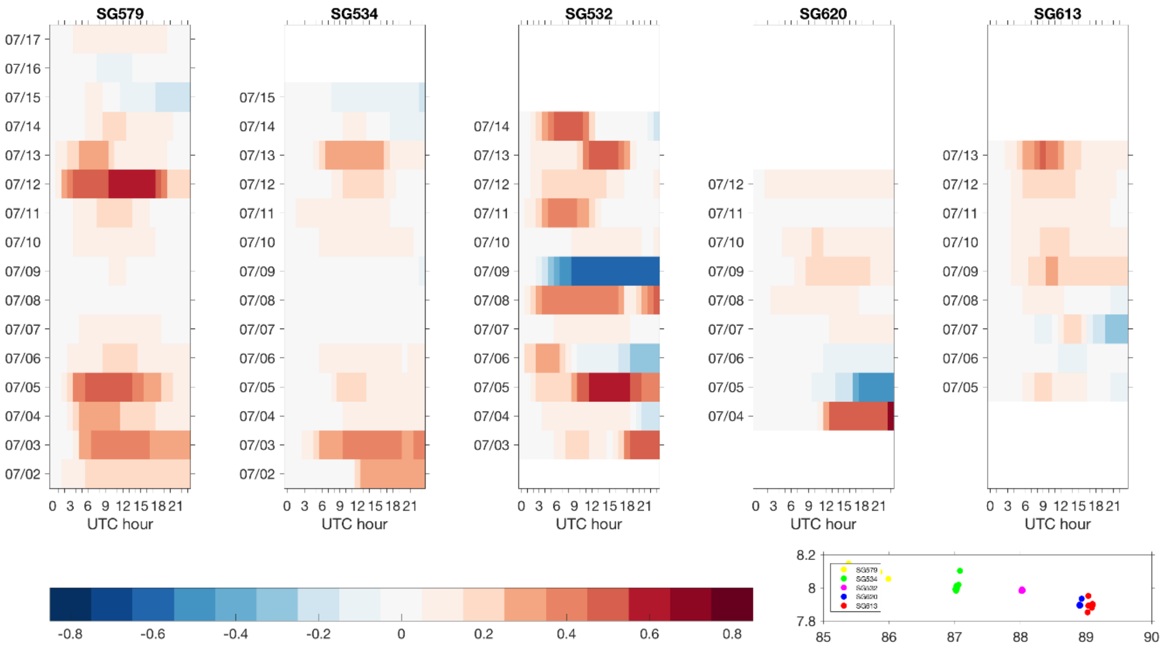
Diurnal warm layers

Life can never be that simple

- Prognostic model does not account for ocean dynamics
- BoBBLE 2016 observations (gliders) reveal that under relatively uniform atmospheric conditions, local diurnal SST response can differ
- Potenial impact of oceanic mesoscale variability
- Atmospheric conditions assessed based on reanalysis / flux products



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Diurnal warm layers

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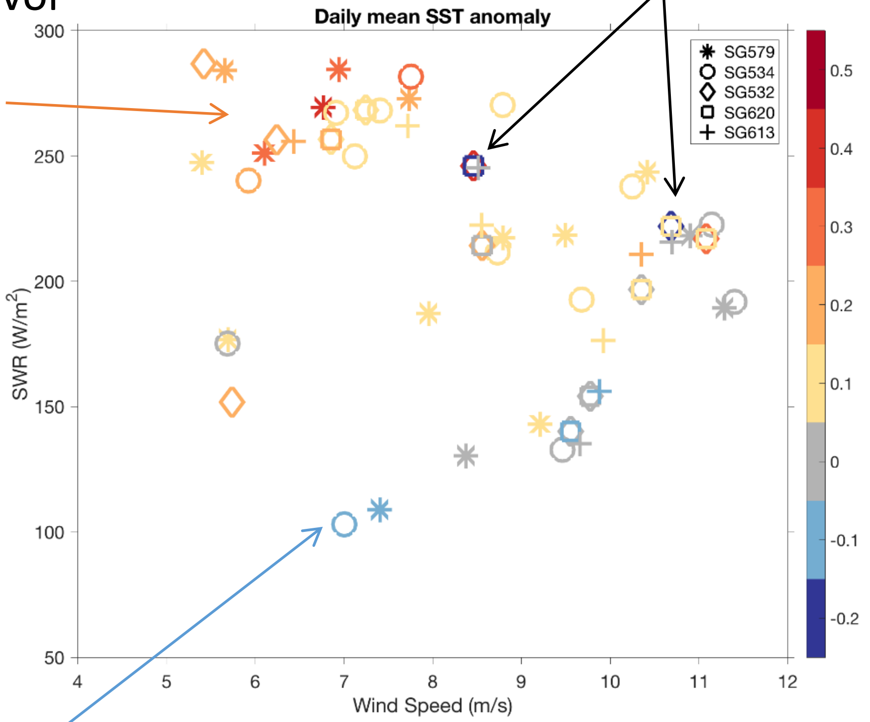
High insolation and weak winds favor warm layer development

Disagreement between gliders for moderate winds and insolation conditions



High winds and low solar radiation associated with cooling

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A short recap

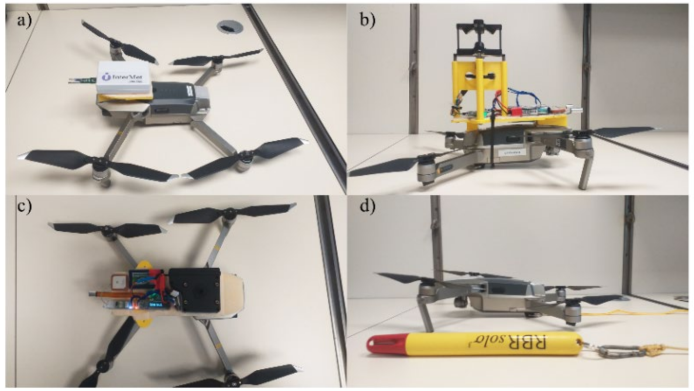
- Warm layers can be important for atmospheric processes because they temporarily „limit" heat capacity of the ocean by trapping solar radiation in the top few metres (rather evenly dirstribute to across oceanic mixed layer) of water
- Standard measurements can't assess near surface regions on the both sides of the air-sea interface
- We want to attempt that with UAVs

UAV set up(s) and operations

- Small Uncrewed Aerial Vehicles (UAV), specifically multi-rotor UAV can be launched and recovered from research vessels and equipped with dual atmospheric and oceanic measurement capability.

- Single flight is about 10min
  - Multiple (2-3) T/RH profiles up to 500m
  - A single winds/aerosol profile up to 500m
  - Multiple (2-4) to of the ocean sampling (0-15m) in undisturbed conditions ~100m away from a vessel
  - A semi-simultaneous profile across an air-sea interface

- We use various payloads



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UAV ocean deployments on research vessels

- 3 research cruises since 2020

- r/v Meteor M161 Jan-Mar 2020 (EUREC4A)
  - 128 atmospheric (T/RH) profiles at 62 stations
  - 2 ocean profiling stations

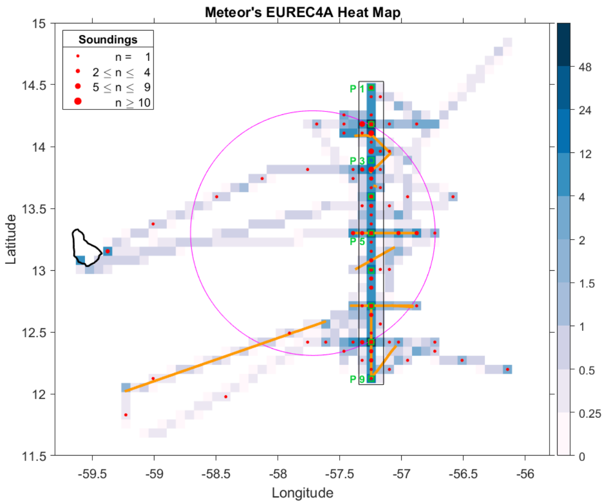
- r/v Maria S Merian MSM112-2 Nov 2022
  - 39 atmospheric profiles at 20 stations
  - 5 wind profiling stations, 1 aerosol profiling station, all T/RH
  - 4 ocean profiling stations

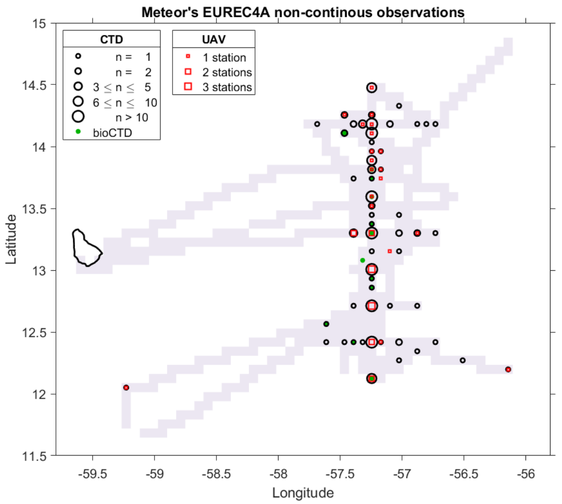
- r/v Maria S Merian MSM114-2 Jan-Feb 2023
  - 137 atmospheric profiles at 50 stations
  - 23 wind profiling stations, 26 aerosol profiling stations, all with T/RH
  - 28 ocean profiling stations

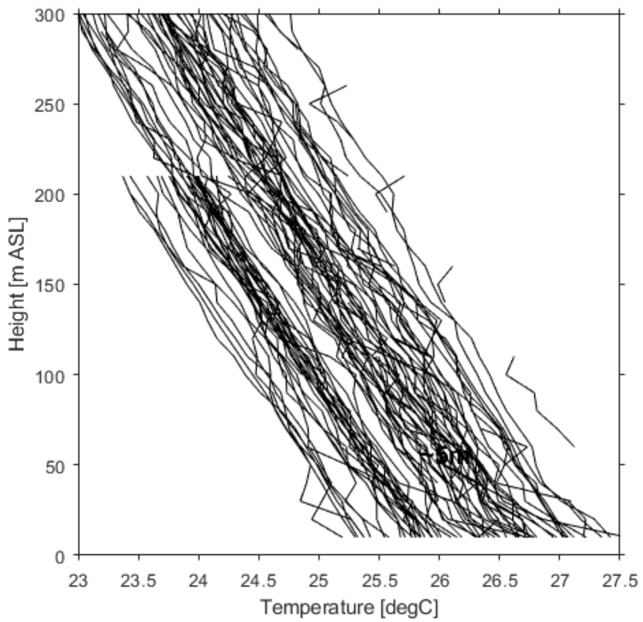
UAV measurements

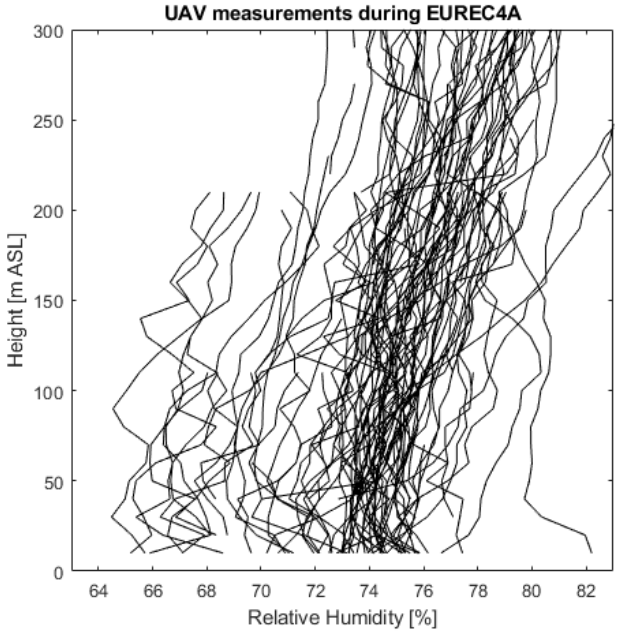
EUREC4A

- Most measurements along the 57.25W line, between 12N and 14.5N
- All atmospheric measurements conducted with iMet-XQ2 temperature, humidity, pressure data logger
- Ability to monitor spatio-temporal variability in atmospheric conditions









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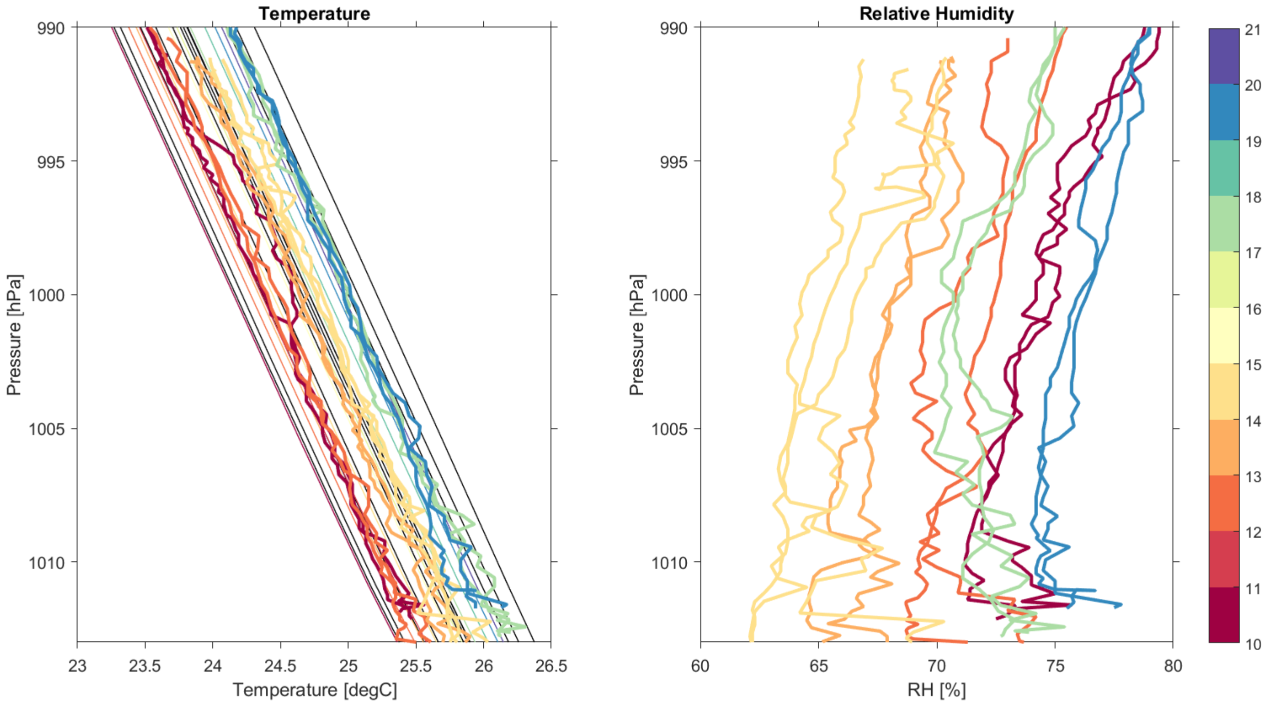
UAV measurements
EUREC4A: Jan 23, 2020 case

- Ability to monitor diurnal evolution of atmospheric conditions
- Observations in a „single" location
- Multiple profiles at each station provide more observations
  - Robustness
  - Short-term variability
- Good overall agreement with ERA-5, but reanalysis profiles are smoother



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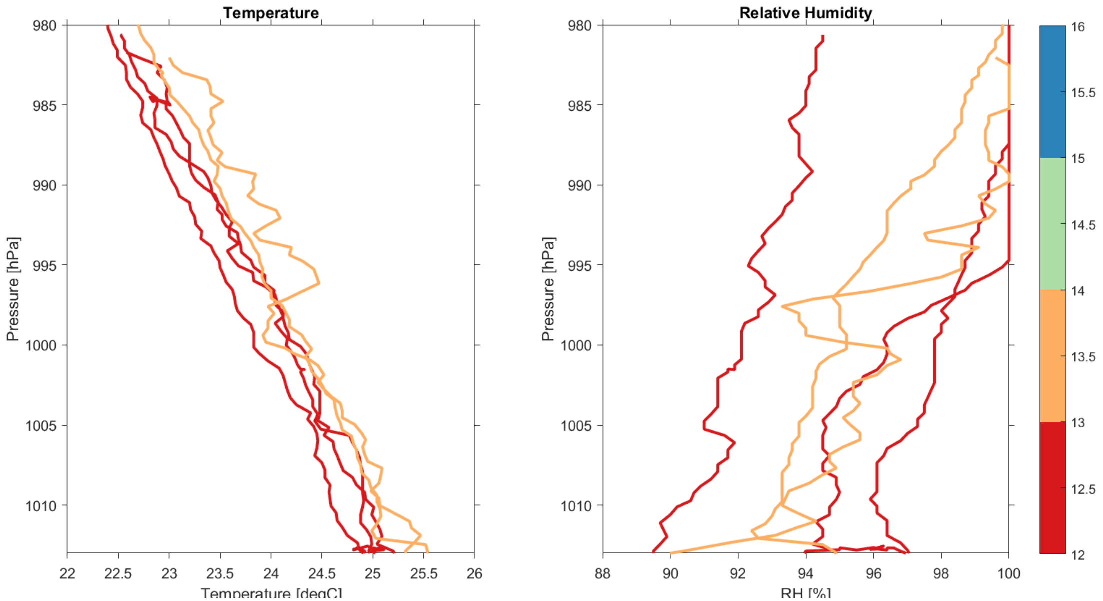
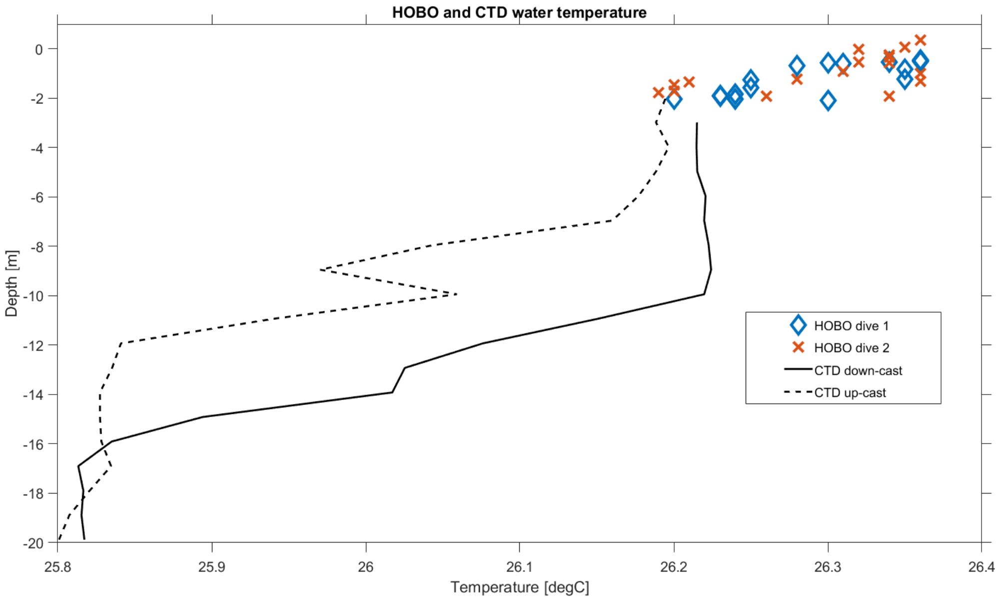
UAV measurements

EUREC4A: Feb 21, 2020

- First attempt at profiling atmosphere and ocean at the same station
- High insolation, wind ~5m/s
- Reveal stratification within top 5m of the ocean
- Clear difference from the CTD data





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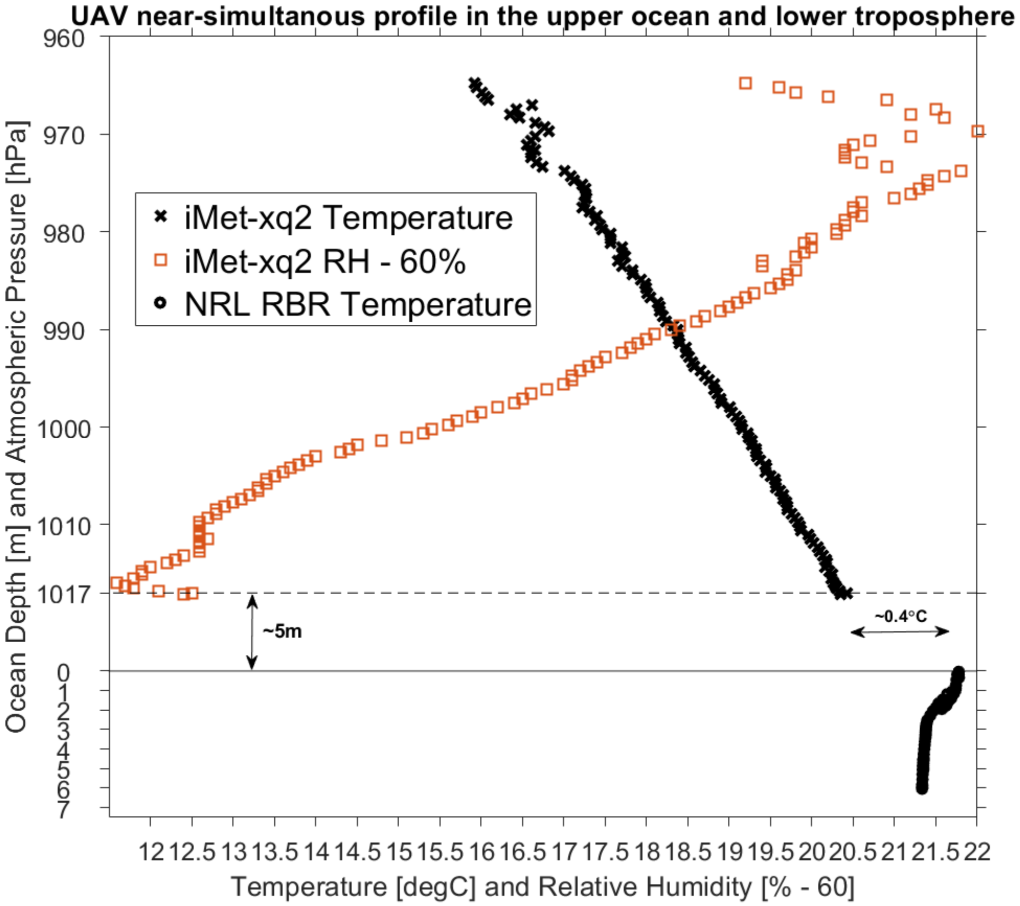
UAV measurements

EUREC4A: Feb 26, 2020

- The near-simultanuous profile across an air-sea interface
  - We are able to measure across an air-sea interface
  - Small gap (~5m) due to waves and spray production
  - Near surface humidity gradients observed
  - Discontinuity in temperature profile across an air-sea interface can be assessed

- **Multiple observations throughout a day can show if/how diurnal warming at the ocean's surface interacts with atmospheric boundary layer**



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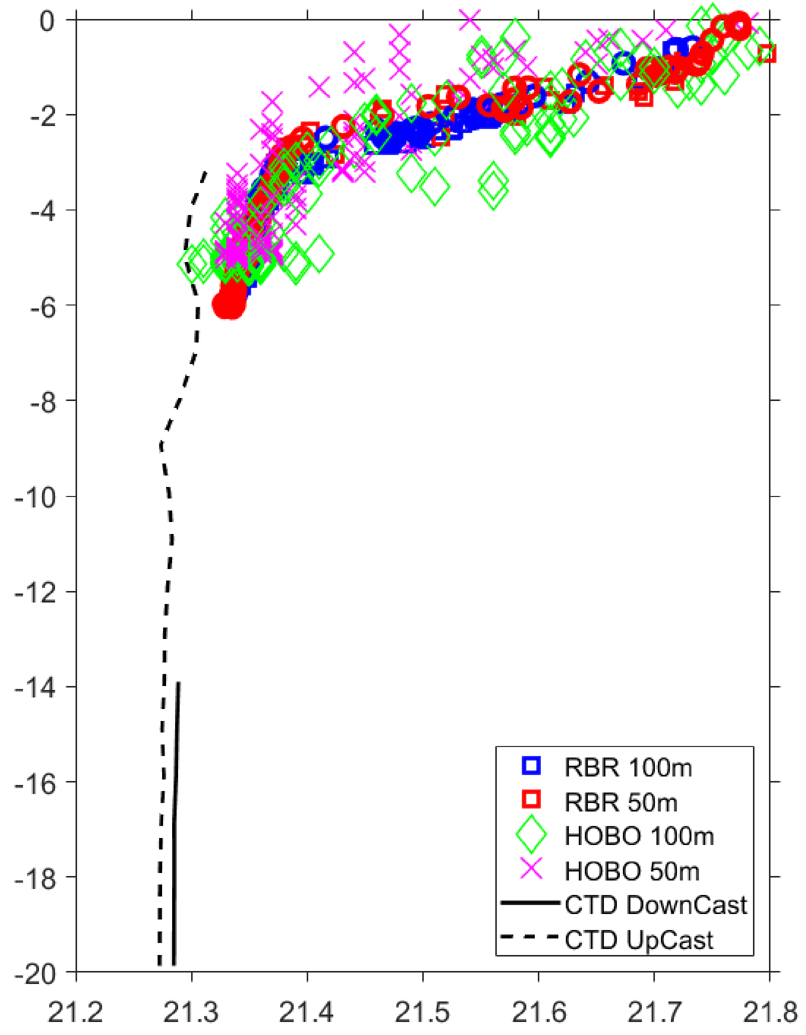
UAV measurements

Ocean profiles

- Two ocean temperature sensors
  - RBR: temperature and pressure (depth)
  - HOBO: temperature and salinity
  - RBR: higher frequency, higher response rate

- **Benefits of using collocated temperature and depth measurements are apparent, but temperature measurement and UAV-based depth retrieval can provide a low-cost alternative**

Ocean Temperature measurements
Feb 26, 2020



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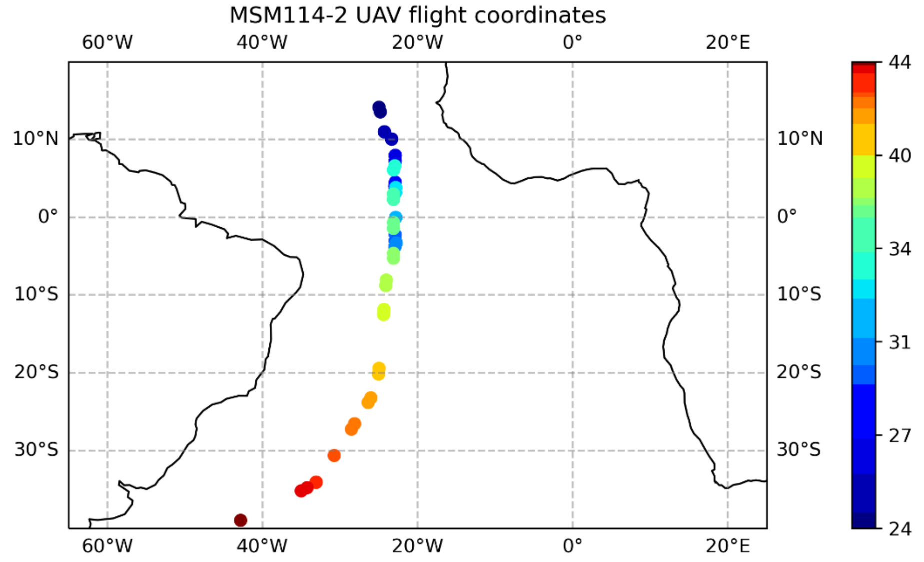
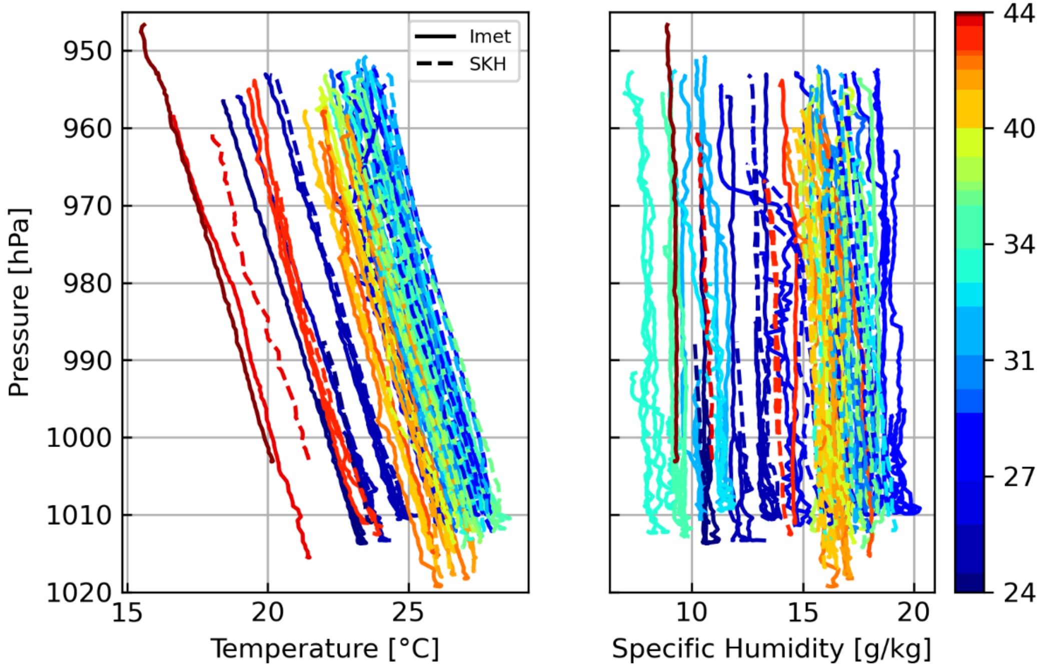
UAV measurements
MSM114-2

- Transect from Capo Verde to Chile with extra time in the Atlantic ITCZ
- Temperature variability mostly along the N-S transect
- Humidity variability within the Atlantic ITCZ is visible
- Two sensors (independent flights) quantitatively agree



MSM 114-2 UAV flights



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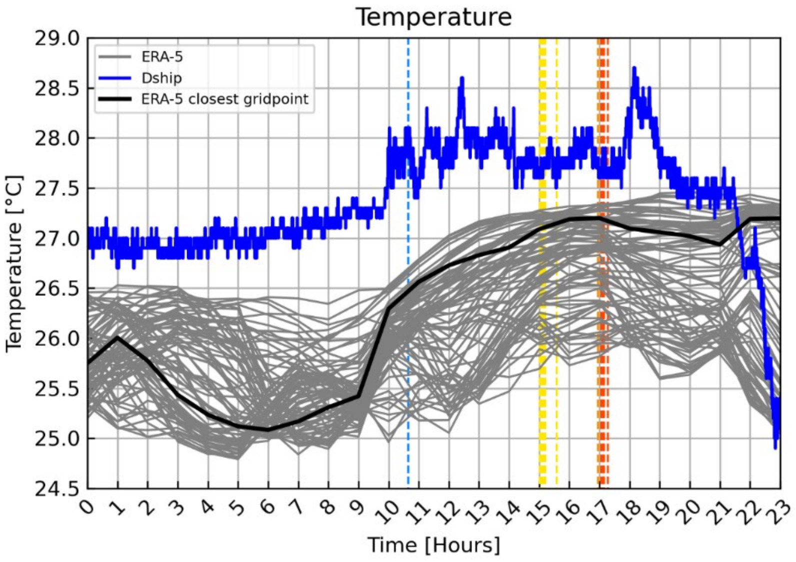
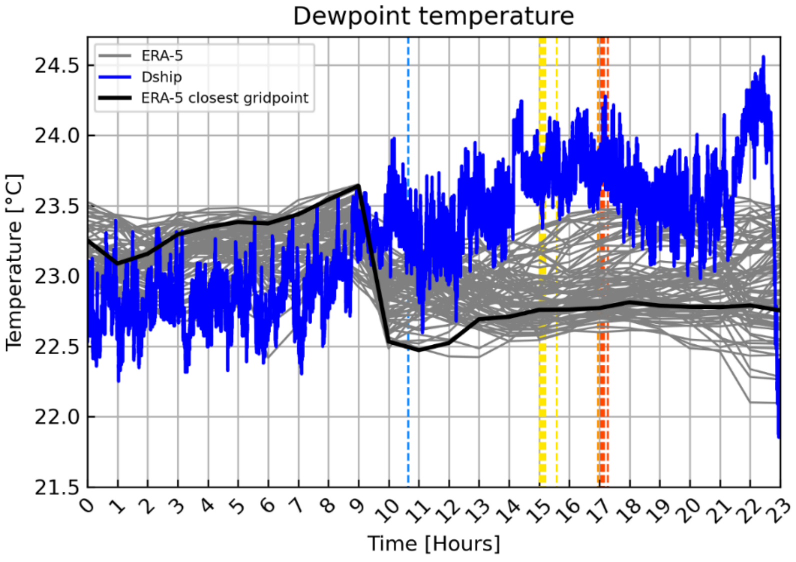
UAV measurements
MSM114-2: Jan 23, 2023

- Comparison between ship-borne AWS and ERA-5
- Cold bias throughout the day
- Different humidty (Td) tendency on a given day
- Vertical colored lines indicate UAV profiles





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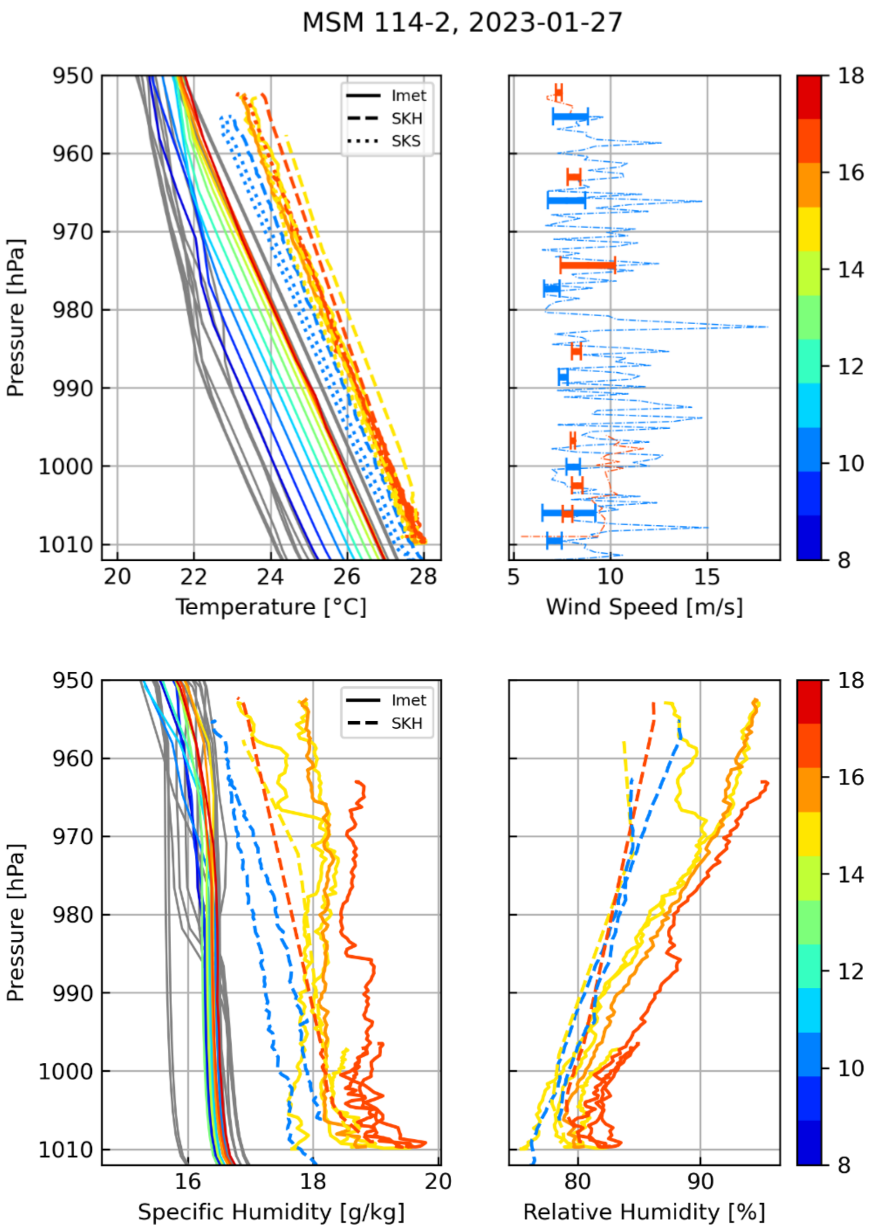
UAV measurements
MSM114-2: Jan 23, 2023

- UAV measuremetns (two sensors) agree with each other
- Clear diurnal evolution of the lower troposphere
- Wind speed profiles different than hoover measurements.
- ERA-5 shows cold/dry bias
- ERA-5 shows larger diurnal temperature variations and smaller diurnal humidity variations than UAV observations



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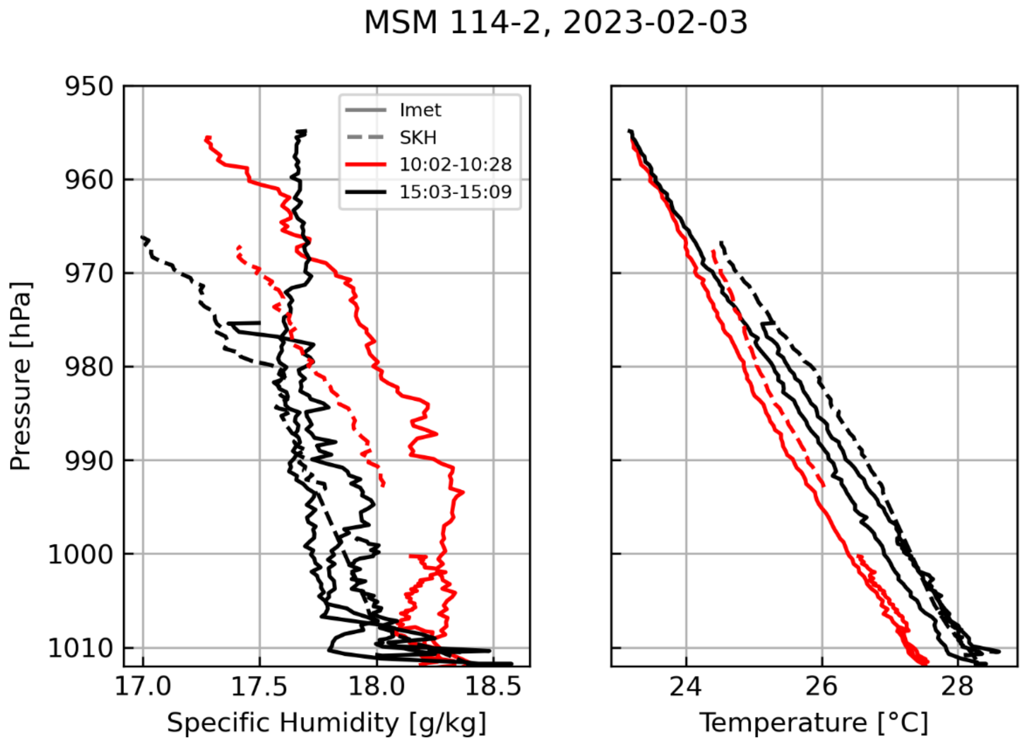
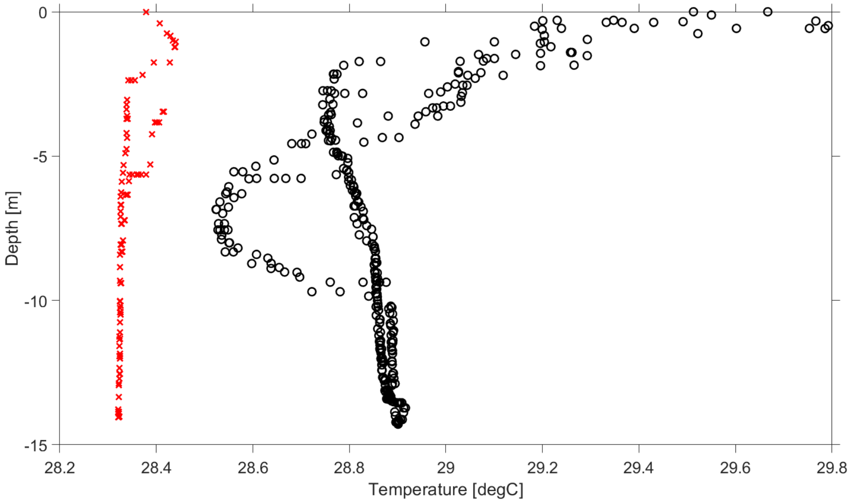
UAV measurements
MSM114-2: Feb 3, 2023

- Observations show warming of the ABL and drying above Surface layer
- Ocean measurements show changes in the mixed layer temperature and development of the warm layer throughout a day
- Measurements at two locations in slightly different (~0.5degC) ML conditions (ocean mesoscale filament or eddy)
- **Even UAV-based ocean sampling can distort WL!!!**





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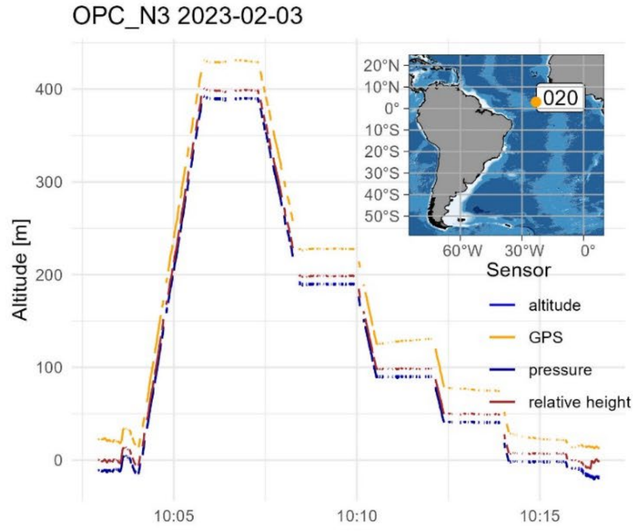
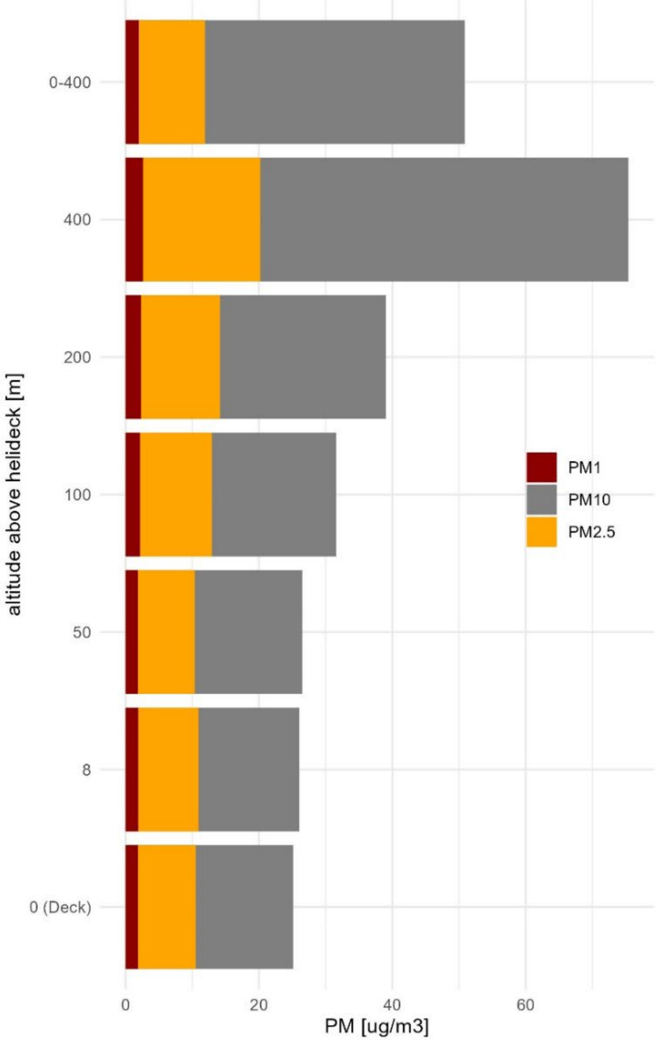
Honorable mention

Aerosol measurements on UAVs

- Optical particle counter - OPC N3
- PM_{10}, $PM_{2.5}$ and PM_1 profiles
- Values retrieved during hoovers
- Aerosol intake through extended sampling tube





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Lessons learned

- We can perform near-simultaneous profiles across an air-sea interface measuring air/water properties from 10m below the surface to 500m (or more) above it.
- UAV observations can’t cover the entire atmosphere-ocean transition zone, but provide opportunity for in-situ measurements in the critical region with a high repetition rate.
- Measurements are constrained by weather (rain, wind, swell) but most interesting things (for me!) happen at low-moderate wind conditions.
- Have to account for ocean mesoscale – UAV profiles do not provide the full picture
- More measurements (especially stationary) needed.

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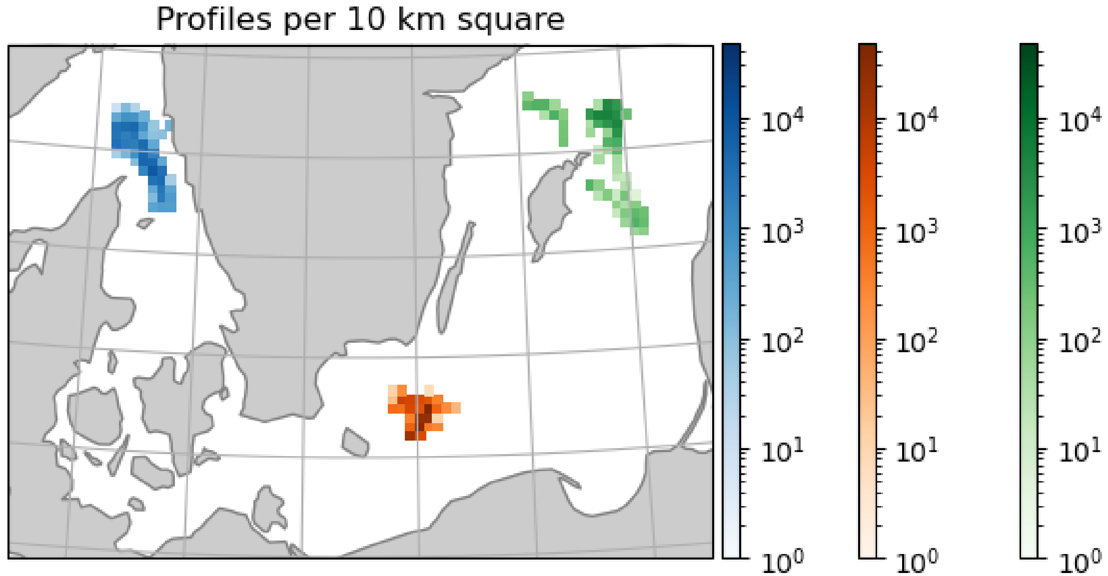
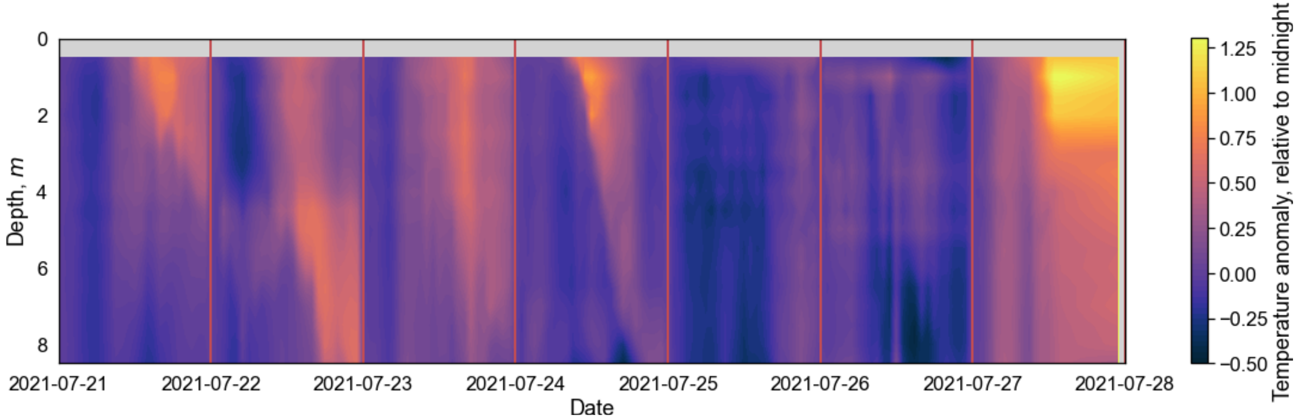
Future directions

- This line of reasearch will be supported over next 4 years with more measurements from research vessels as well as in coastal zone to come.
- Partnership with U Gothenburg and Voice of the Ocean Foundation to perform regular observations in the Baltic as well as some coordinated measurement campaigns
- Data quality and quality assurance protocols to be developed to mitigate exacerbated aging of sensors
- Full circle: I like to have depth measurement with my ocean temperature measurement
- More measurements (especially stationary) needed. A new grant (NCN Opus) devoted to UAV observations in coastal zone, marginal seas and ocean oceans.

Future directions

- Baltic has gliders and has **warm layers** as well!!!
- Gliders can provide information about the mesoscale variability, while ship-borne UAV measurements and Surface vehicle can monitor coupled variability across the air-sea interface
- Field campaign being planned for 2024.





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Thank you for your attention!

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