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Understanding the influence of soil moisture and surface water fluxes on extreme convective precipitation events during summer in South Norway

Laura Ehrnsperger, Mareile Wolff, Bikas Bhattarai, Vegar Kristiansen 20.09.2023

Project framework

- Eddy covariance (EC) flux station at Søråsfeldet, Ås, NMBU field site for Bioclimatic Studies (BIOKLIM)

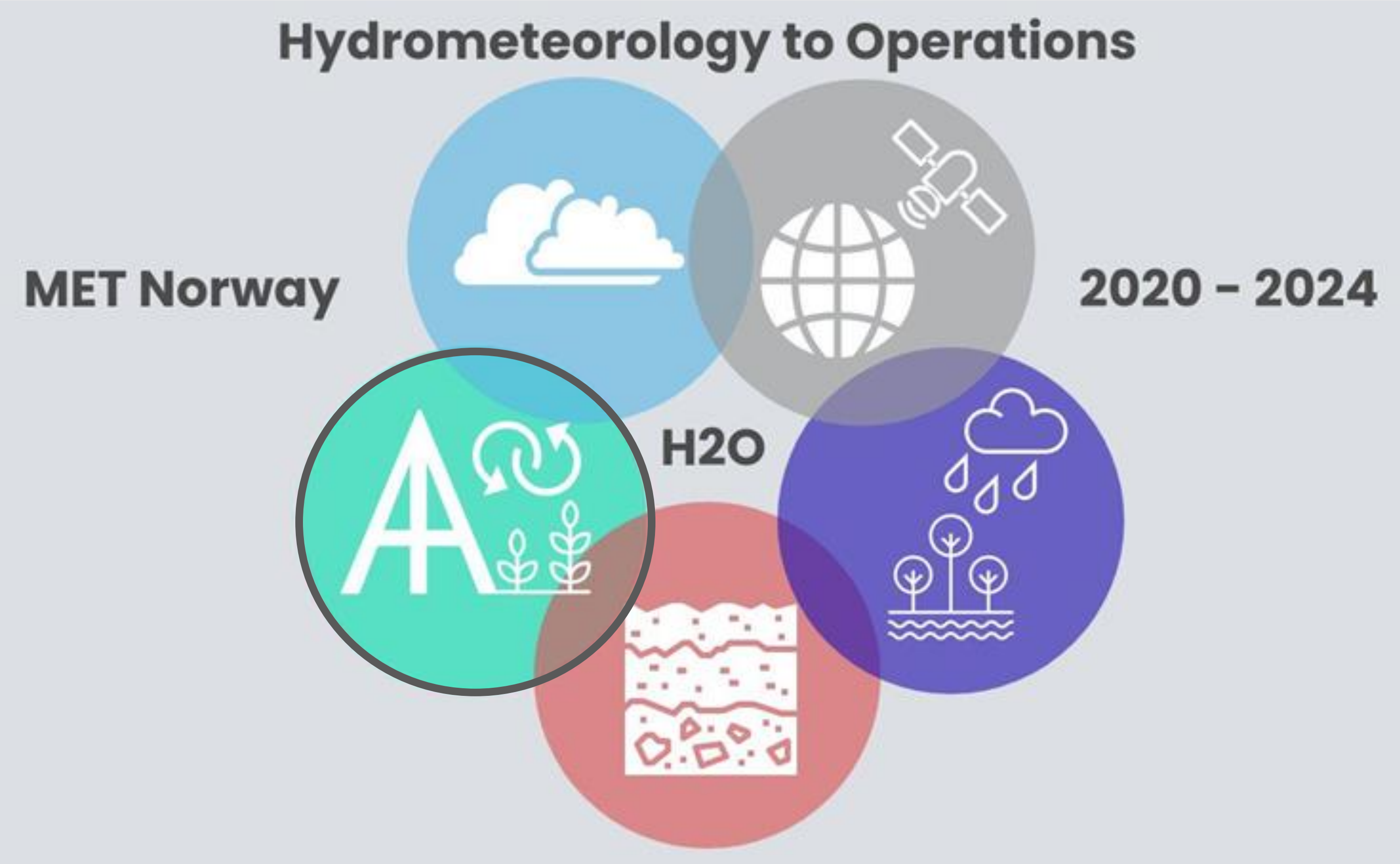
- EC and soil measurements are part of the Hydrology to operations (H2O) project by MET Norway

- Continuous EC flux measurements of sensible and latent heat fluxes, H_2O and CO_2 from June 2021 – present

Fig. 1: View over field site with EC tower in the middle.

Hydrometeorology to operations (H2O) project

Study influence of surface conditions on convection and extreme precipitation events and enhance model predictions of convective precipitation



Experimental site at Ås

Mostly flat, homogenous terrain with grassland and agricultural crops

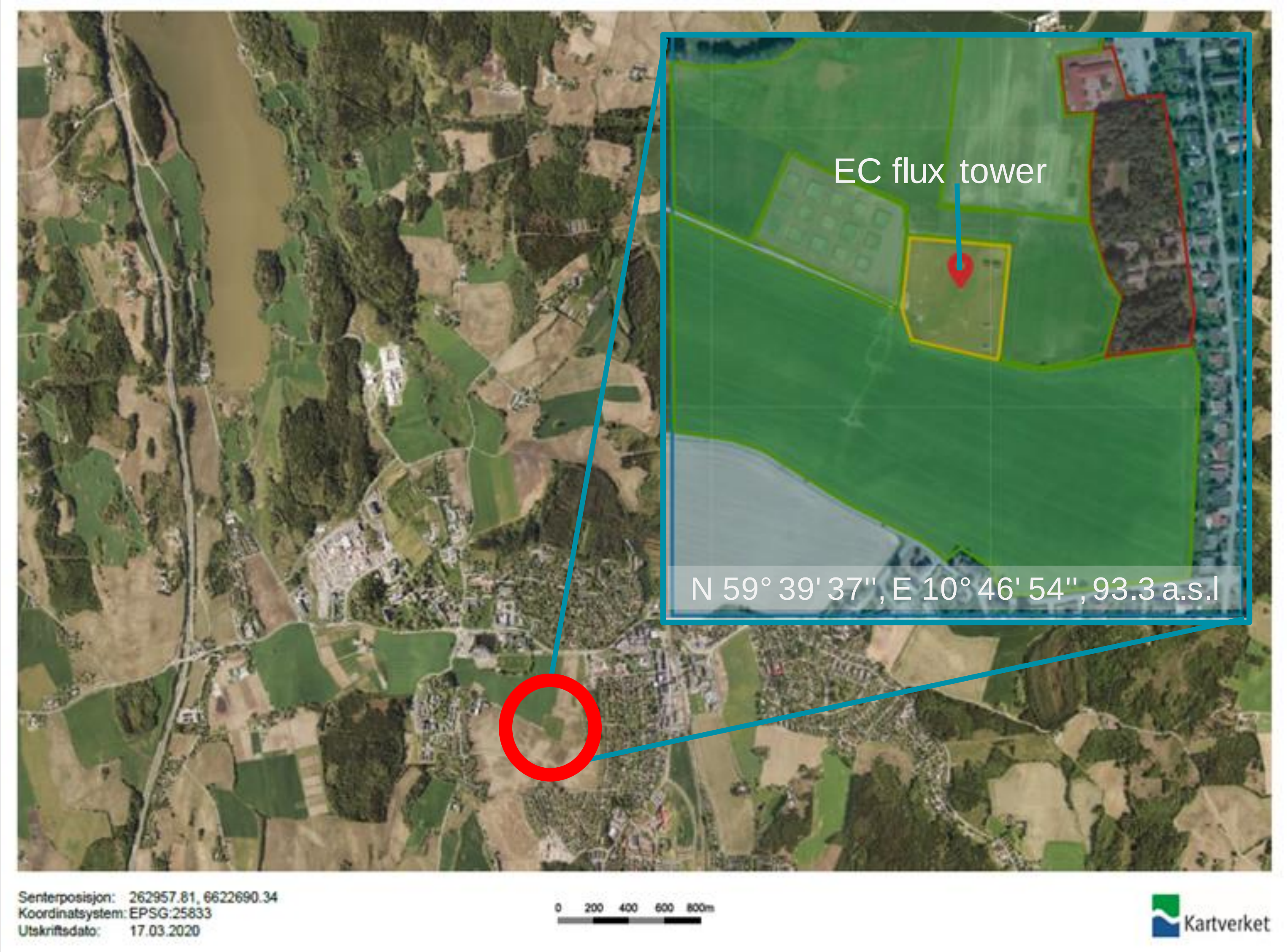


Fig. 2: Satellite image of field site area with zoomed in landuse map. Source: Kartverket

Experimental site at Ås

Container for radiosonde launch

IoT soil moisture sensor

10 m tower with EC sensors

Soil measurement field

Additional automatic weather station within main flux footprint

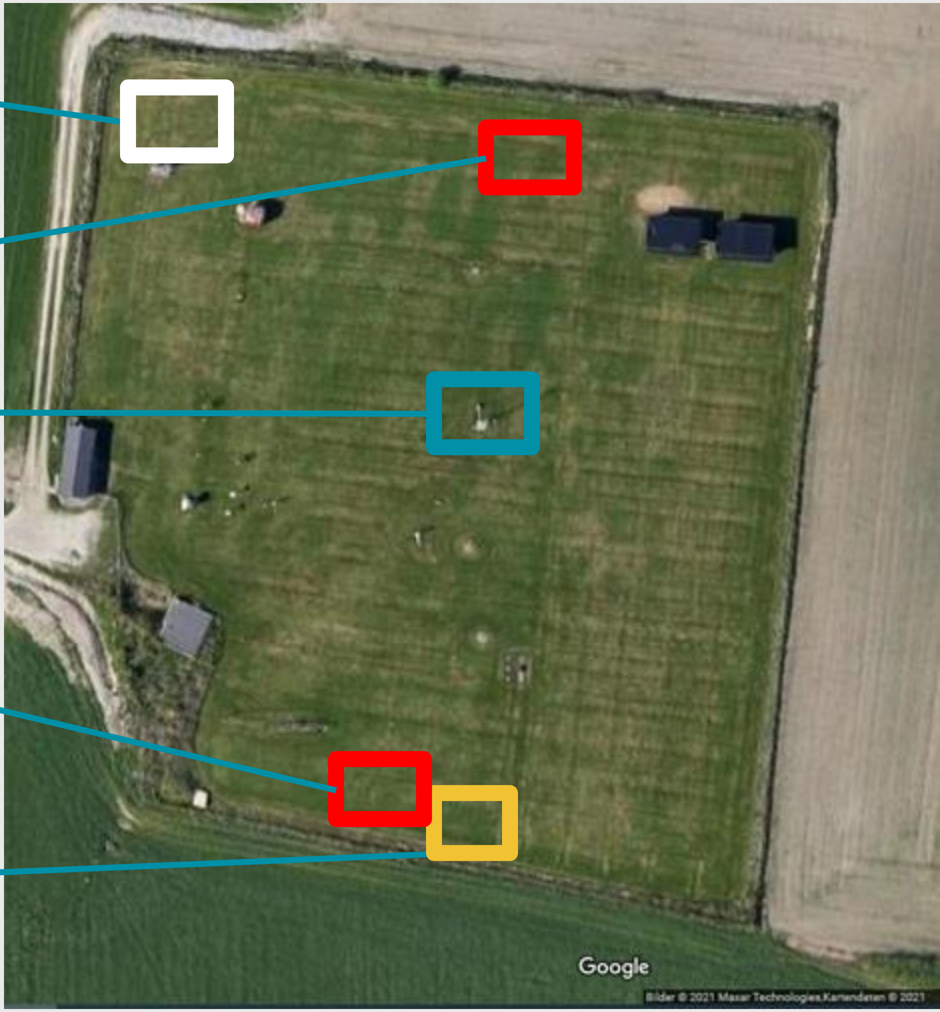


Fig. 3: Satellite picture of the measurement site Source: Google Maps

Measurements at Ås

Dualpol weatherradar at Hurum (C-band)

- Wind speed and wind direction (10 m)
- Air temperature (2 m)
- Relative humidity
- Grass minimum temperature
- Soil temperatures and ***soil moisture*** in six depths
- Radiation (global radiation, PAR, diffuse radiation, UV, radiation balance, sunshine duration, albedo, LW, full solar spectra)
- Atmospheric pressure
- Soil heat fluxes
- Precipitation
- Snow depth
- All sky camera (installed March 2023)
- ***Radiosonde (during campaign weekly and event-based)***

Fig. 7: Biometeorological measurements at the field site, EC tower in the background.

Eddy covariance flux setup

- High-resolution EC measurements (10 Hz)
- EC system with open-path infrared gas analyzer (IRGA) LICOR LI-7500 and 3-D sonic anemometer Gill WindmasterPro
- Installation at 6 m height
- In situ flux calculation at 30 min resolution with SmartFlux system

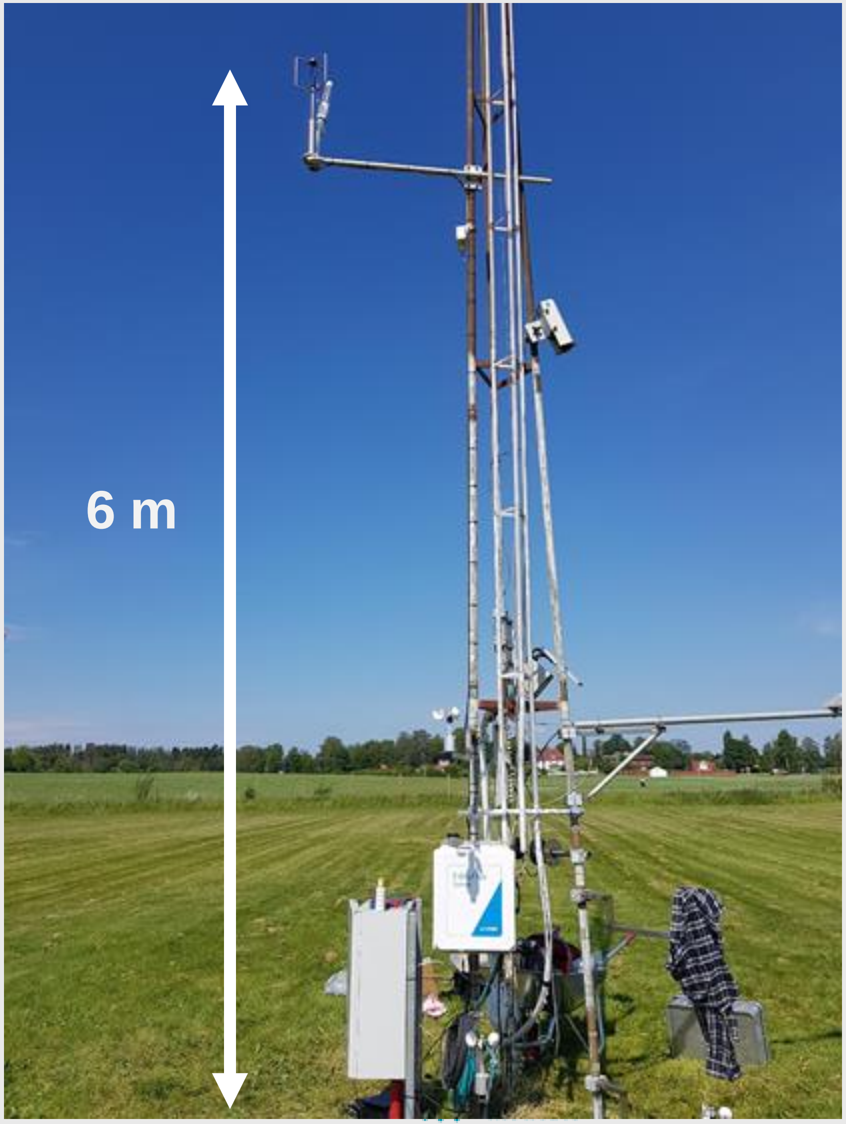


Fig. 4: EC system at 6 m height at the meteorological tower.

Atmospheric stability and convective events

- Atmospheric stability parameter ζ [-]:

The parameter ζ is a dimensionless measure for dynamic atmospheric stability. Dynamic atmospheric stability takes both buoyancy and shear-generated turbulence into account, while static atmospheric stability is only considering buoyant motions.
ζ [-] can be calculated using the measurement height z and the Obukhov length L using the following formula:

$$\zeta = z / L$$

Negative values indicate unstable conditions, values between - 0.05 and 0.05 neutral conditions and positive values > 0.05 mark stable atmospheric stability.

- Free convective events: Most convective clouds are driven by positive buoyancy, with virtual temperature greater than the environment
  - **Convection driven by wet surface**
  - **Convective events over dry surface**

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Convective triggering potential and HI_{low} humidity index

- Convective triggering potential CTP [J/kg]: Measure for stability within 1 – 3 km of boundary layer (BL) (Findell and Eltahir 2003a, 2003b). Calculated by integrating the area between the actual atmospheric profiles and the moist adiabatic lapse rate. The higher the CTP, the more turbulence.

  High positive CTP = conditions close to dry adiabatic lapse rate

  - ➢ **Convective triggering favored over dry soils**

  Slightly positive CTP = close to moist adiabatic lapse rate

  - ➢ **Convective triggering favored over wet soils**

  Negative CTP = atmosphere is stable, no convection

- HI_{low} surface moisture index [K]: Measure for surface moisture = sum of dewpoint depressions in two heights within the BL:

$$HI_{low} = (T_{air\ 950\ hPa} - T_{d\ 950\ hPa}) + (T_{air\ 850\ hPa} - T_{d\ 850\ hPa})$$

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Convection and surface conditions

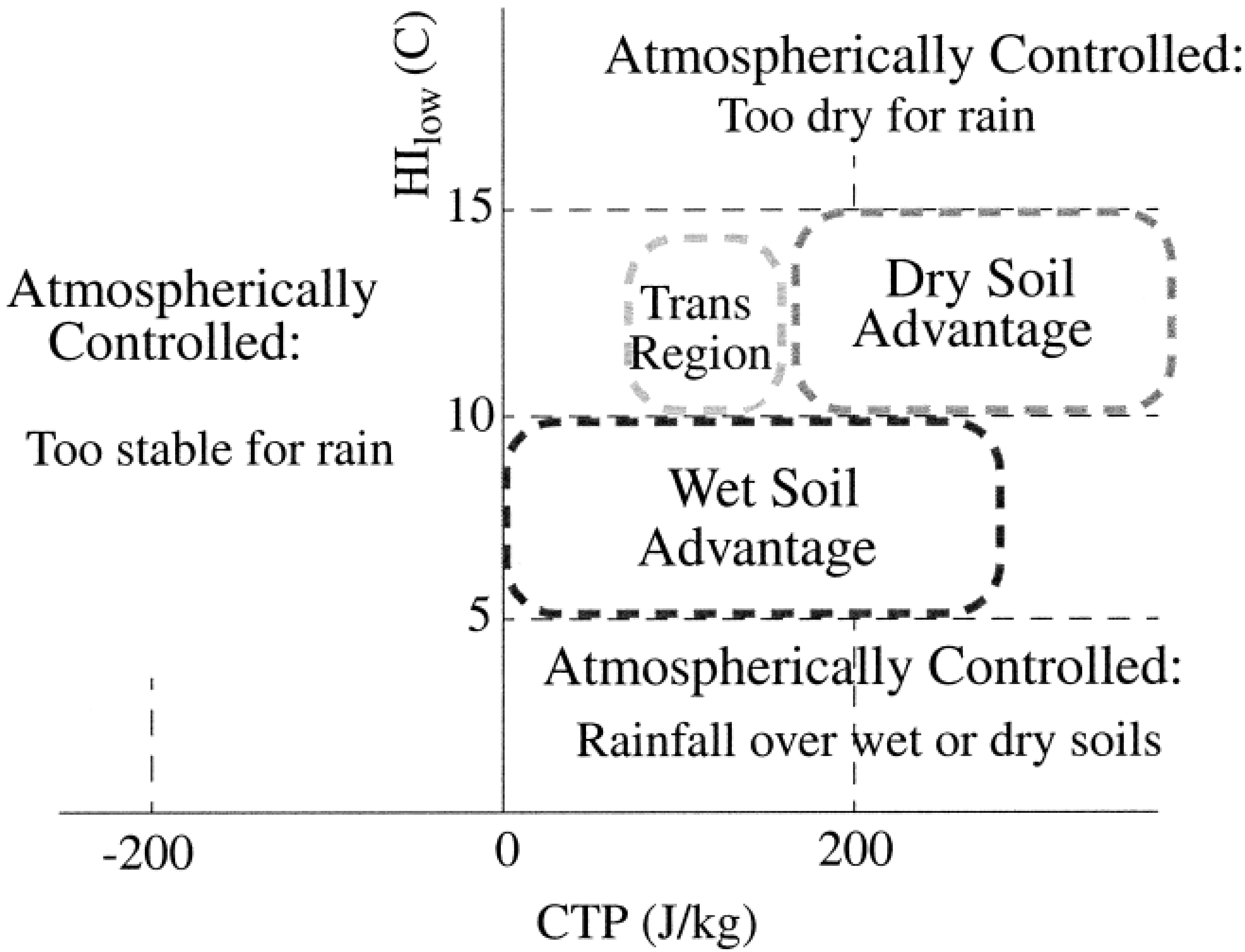


FIG. 1. The CTP-HI$_{low}$ framework for describing atmospheric controls on soil moisture–rainfall feedbacks. Only when the early-morning atmosphere has CTP > 0 J kg^{-1} and 5 < HI$_{low}$ < 15°C can flux partioning at the surface influence the triggering of convection. (Fig. reprinted from Findell and Eltahir 2003b.)

Fig. 5: Graphical representation of CTP-HI$_{low}$ indices. Reprinted from Findell and Eltahir (2003b).

Latent heat (LE) flux summer/fall 2022

- Latent heat fluxes are dominant over sensible heat fluxes (H) when water is abundant
- Higher LE fluxes during early summer due to higher water availability
- During the day often positive fluxes
  - ➢ **Latent heat is transported from the ecosystem into the atmosphere**

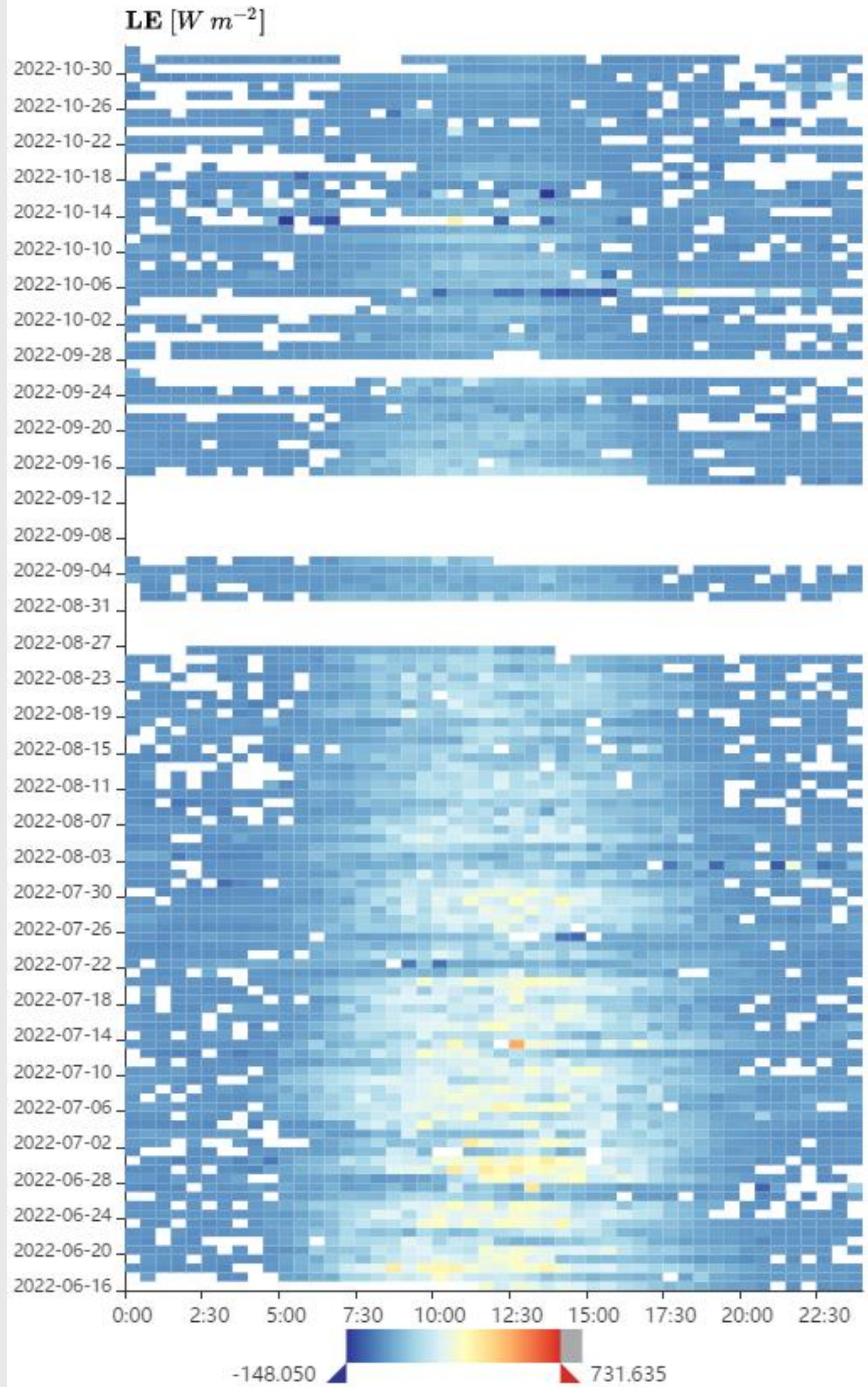
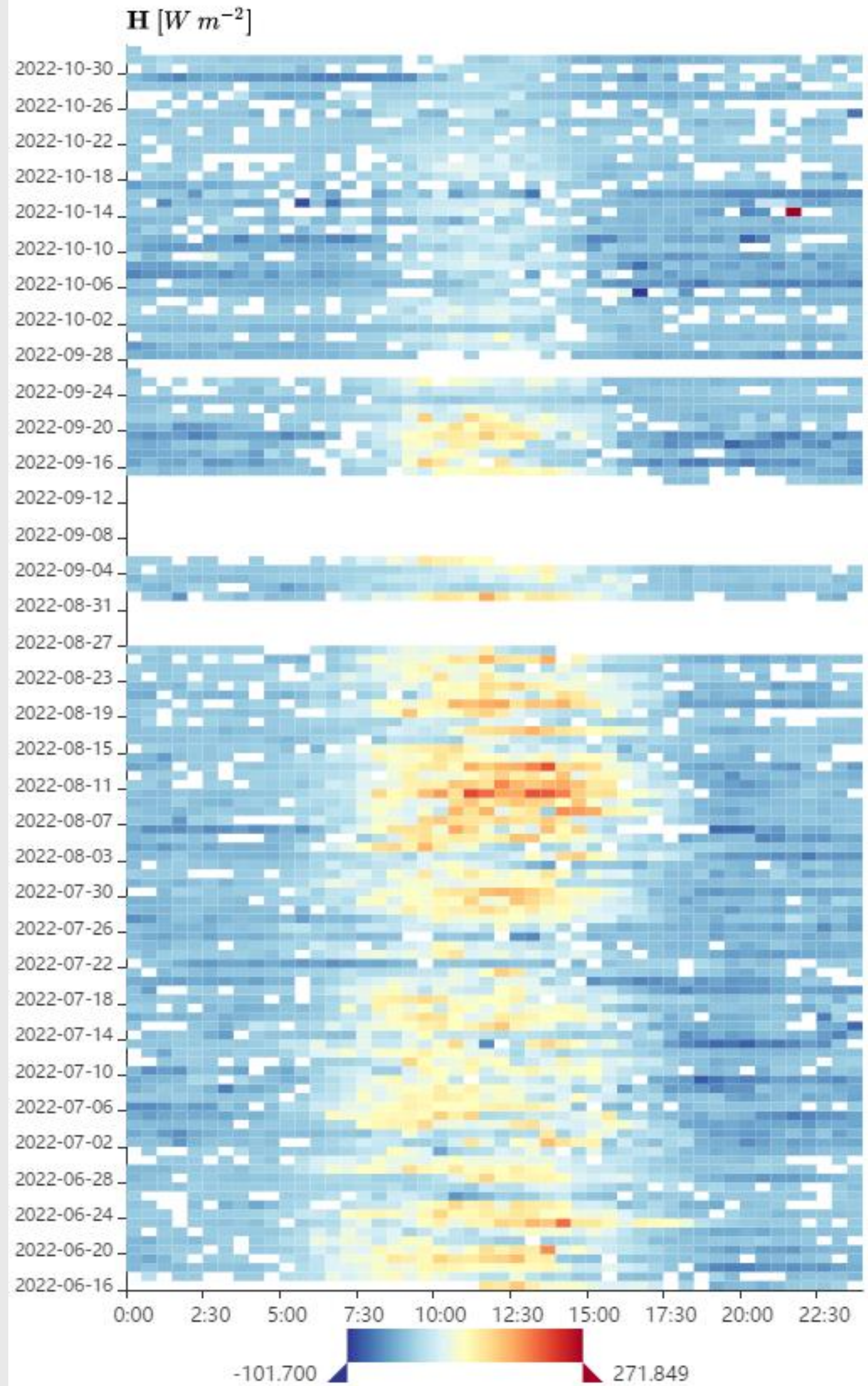


Fig. 6: 30 minute fluxes of latent heat from June 2022 to October 2022.

Sensible heat (H) flux summer/fall 2022

- Higher H fluxes during late summer due to lower water availability
- Daytime H fluxes driven by buoyancy
  - ➢ **Driving free convection**
- Nighttime H fluxes show radiative loss



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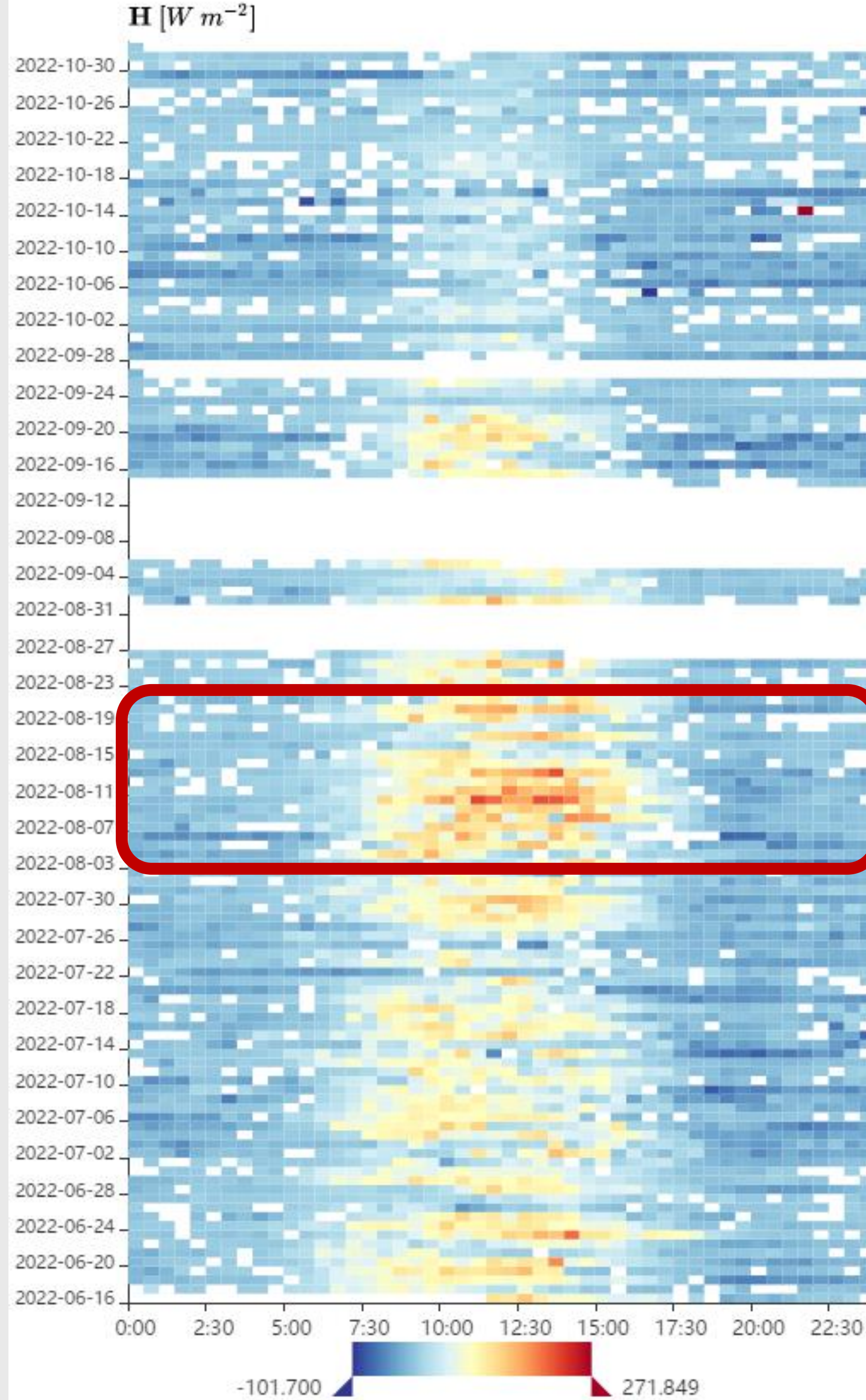

Fig. 8: 30 minute fluxes of sensible heat from June 2022 to October 2022.

Convective events August 2022

- 02/08/2022 – 16/08/2022
- Convection is occurring during early morning until early afternoon
  - ➢ **Possibly leading to convective precipitation in the afternoon**
- Neutral conditions mostly in the afternoon
- Stable conditions in the evening and night

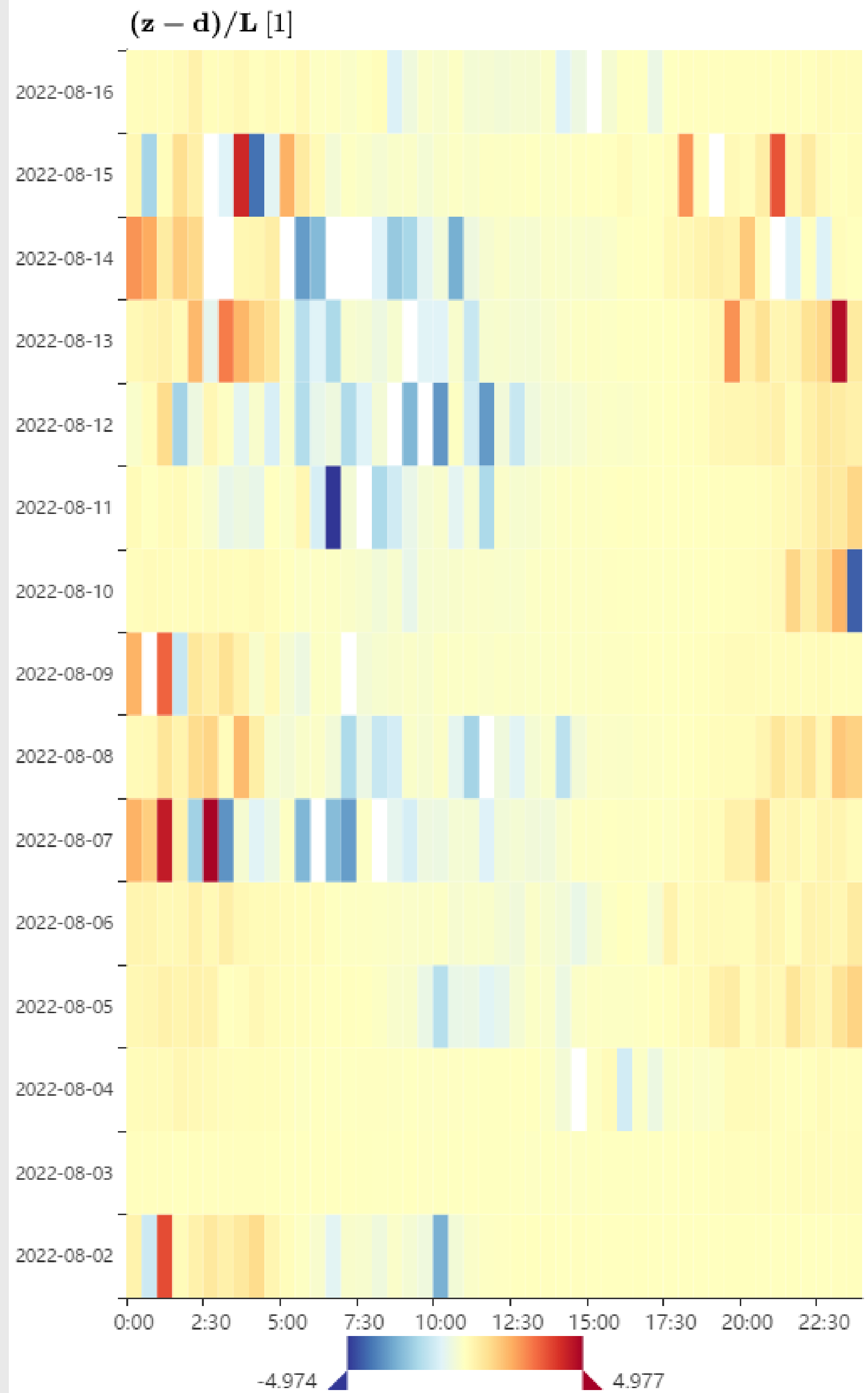

Fig. 9: 30 minute average of atmospheric stability parameter for period in August 2022.

Convective events 2022

- 02/08/2022 – 16/08/2022
- High H fluxes after instable morning conditions
- Dry convective conditions due to limited water supply near the surface

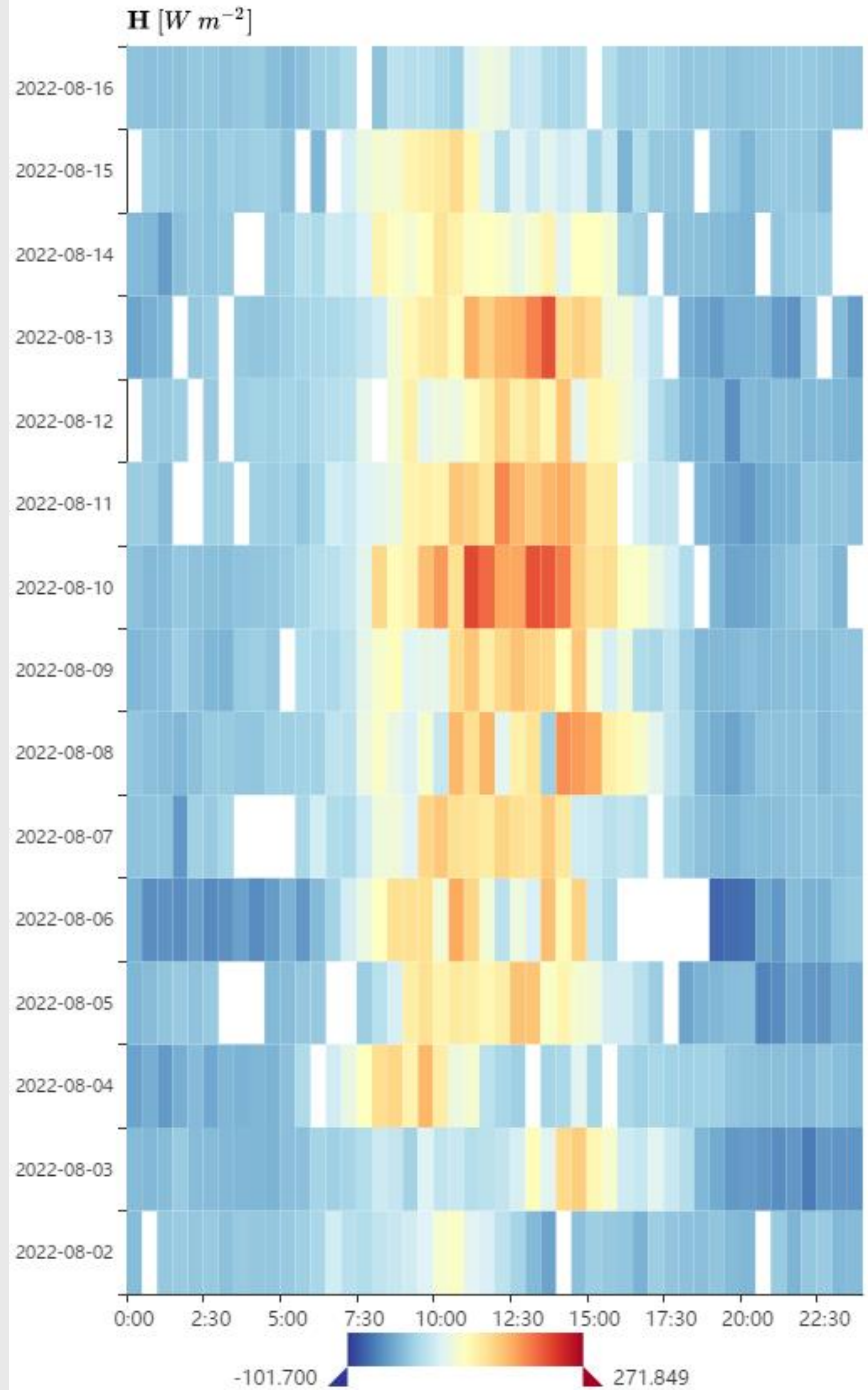

Fig. 10: 30 minute average of sensible heat fluxes for period in August 2022.

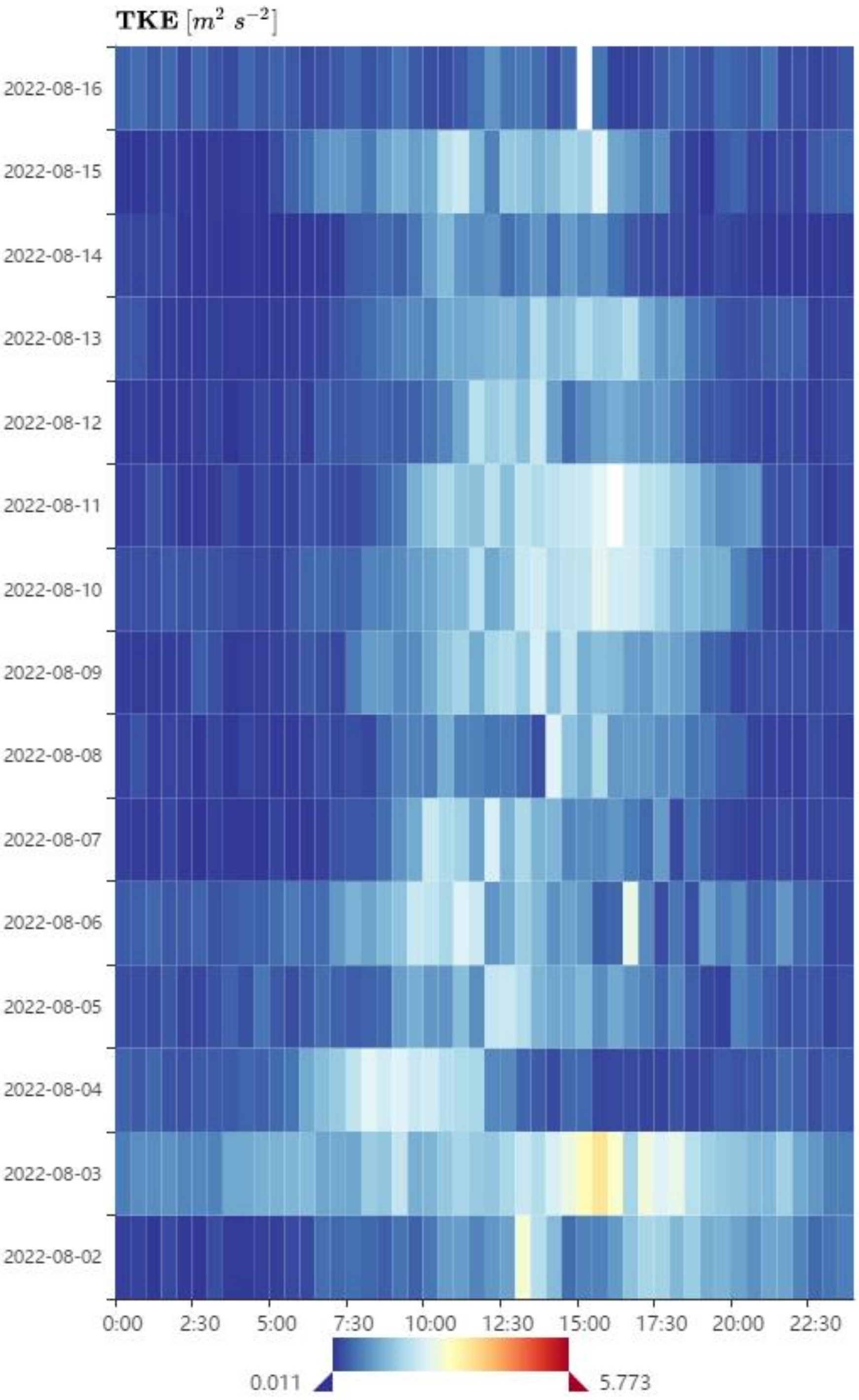

Fig. 11: 30 minute average of turbulent kinetic energy for period in August 2022.

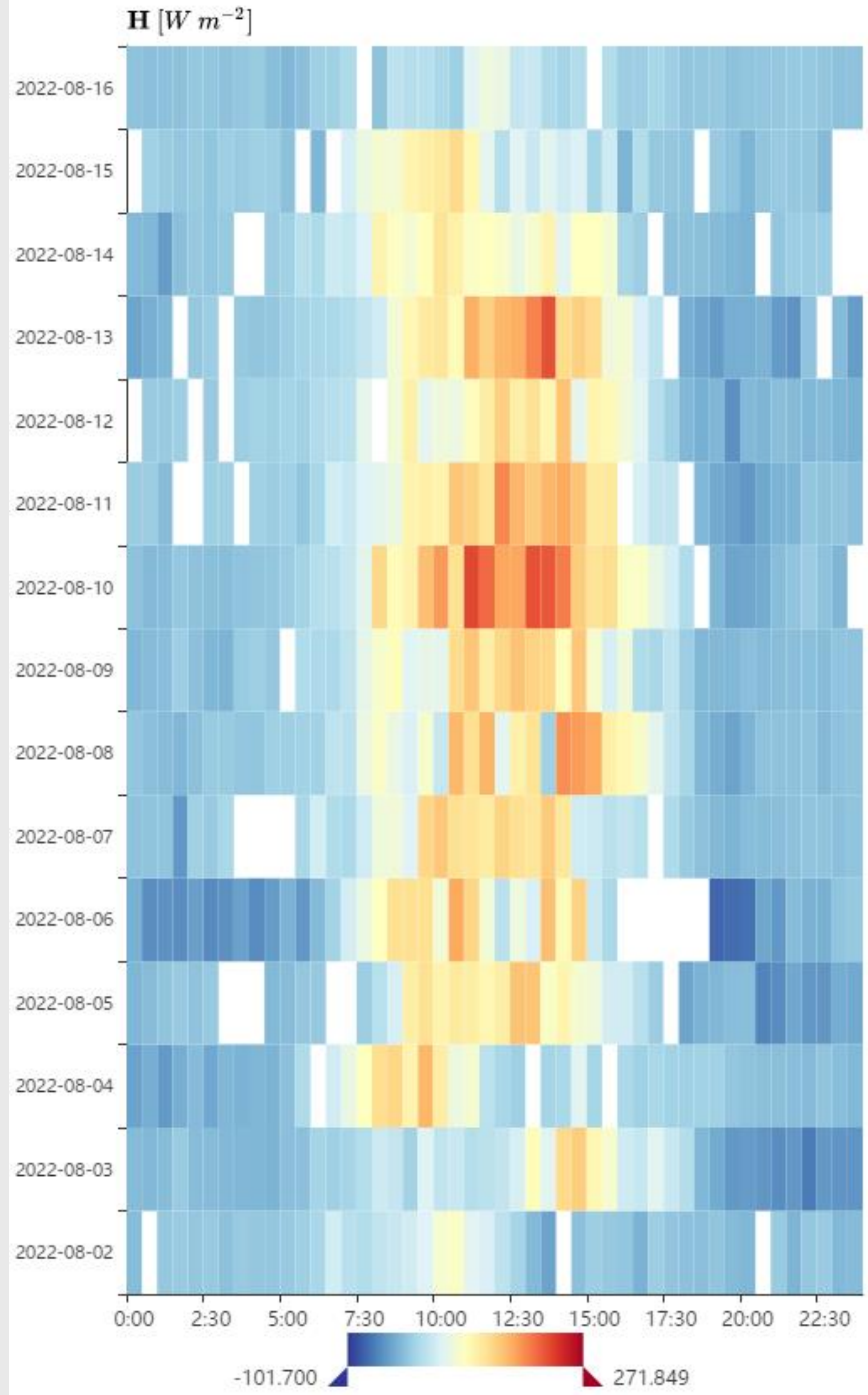

Fig. 12: 30 minute average of sensible heat fluxes for period in August 2022.

Surface moisture influence: Very dry conditions

- Drought period:
  15/05/2023 – 29/05/2023
- HI_{low} values: 18 – 20
- Convection is atmospherically controlled, influence of surface negligible

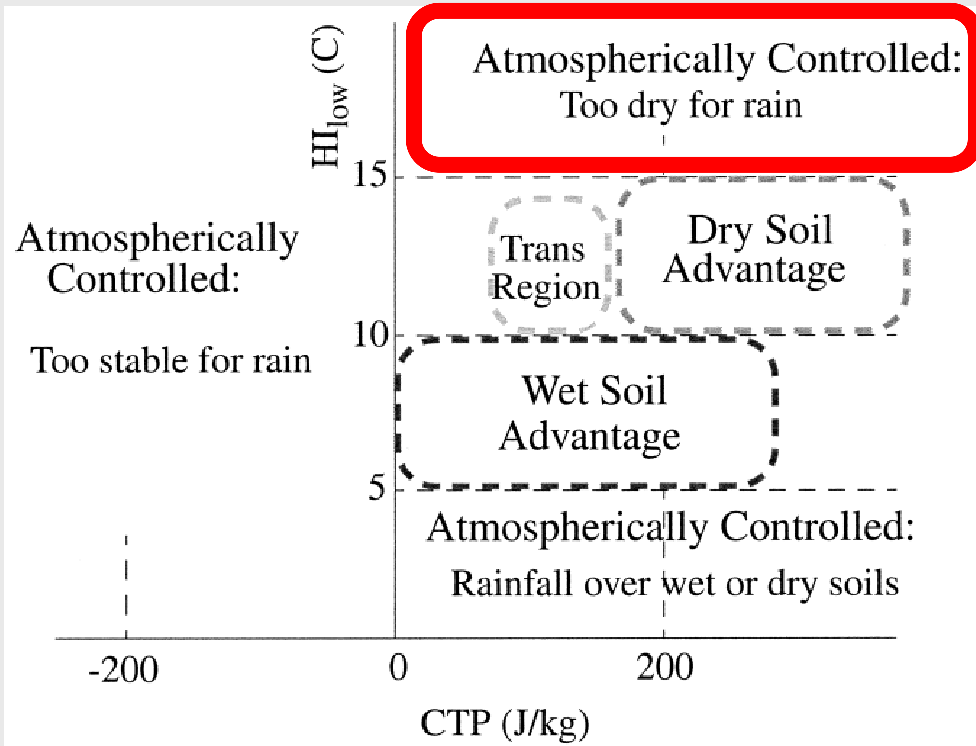

FIG. 1. The CTP-HI_{low} framework for describing atmospheric controls on soil moisture–rainfall feedbacks. Only when the early-morning atmosphere has CTP > 0 J kg^{-1} and $5 < HI_{low} < 15$°C can flux partioning at the surface influence the triggering of convection. (Fig. reprinted from Findell and Eltahir 2003b.)

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Convection during very dry conditions

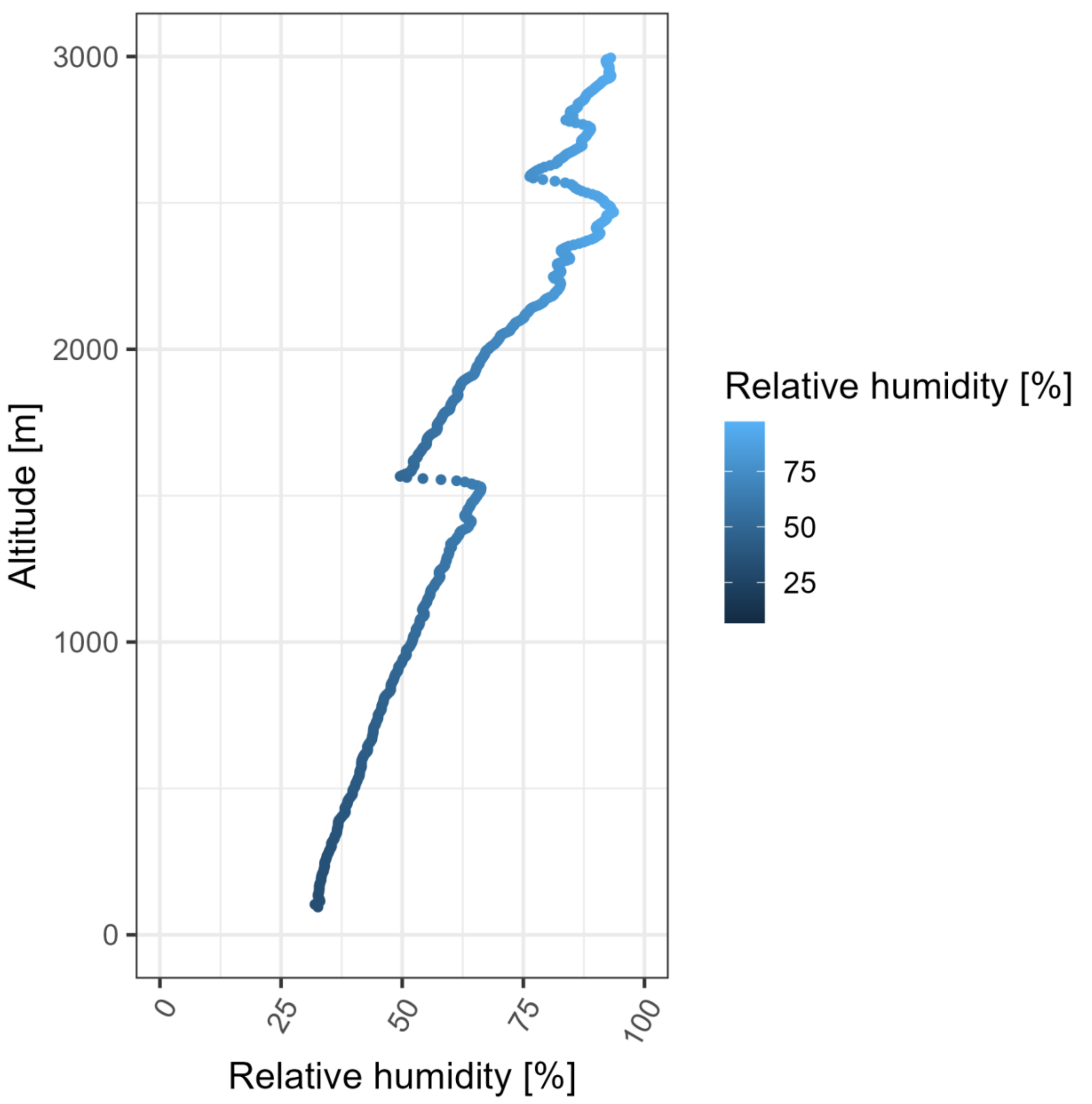

Fig. 13: Atmospheric vertical profile of RH between 1-3km height.

- Very dry surface conditions: 22/05/2023
- Very low RH near the surface, rapid increase with increasing altitude
- Atmospherically controlled: Too dry for precipitation
- Precipitation: 0 mm

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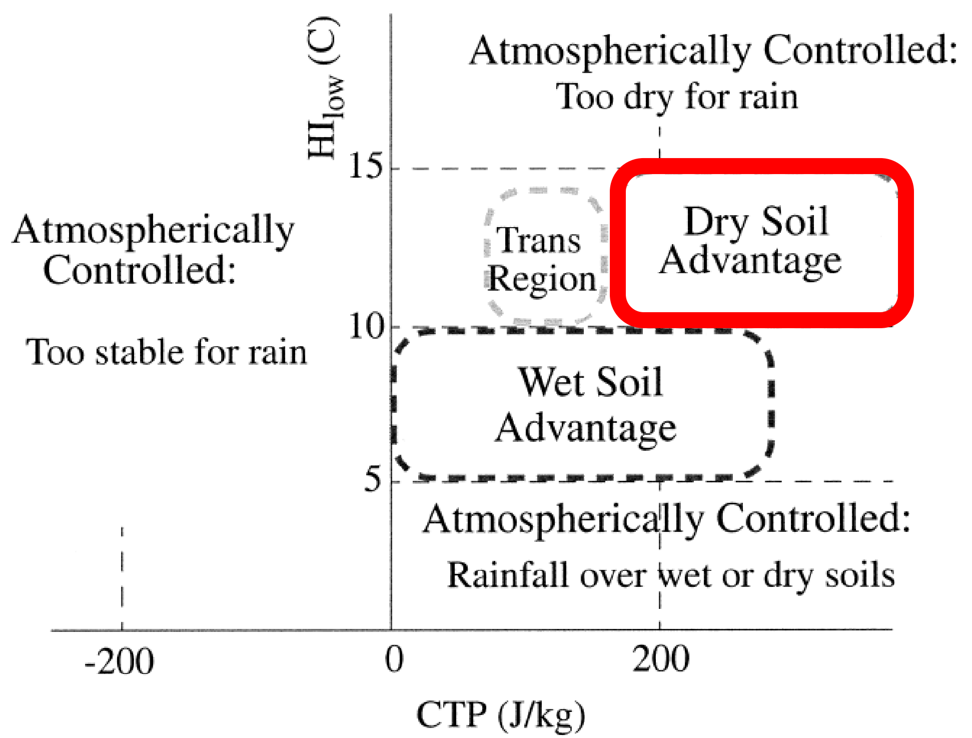
Surface soil moisture:
Convective events over dry soil

- Dry conditions:
  05/07/2021
- HI_{low} values: 12.33
- Convection favored over dry surfaces



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Convective events over dry surface

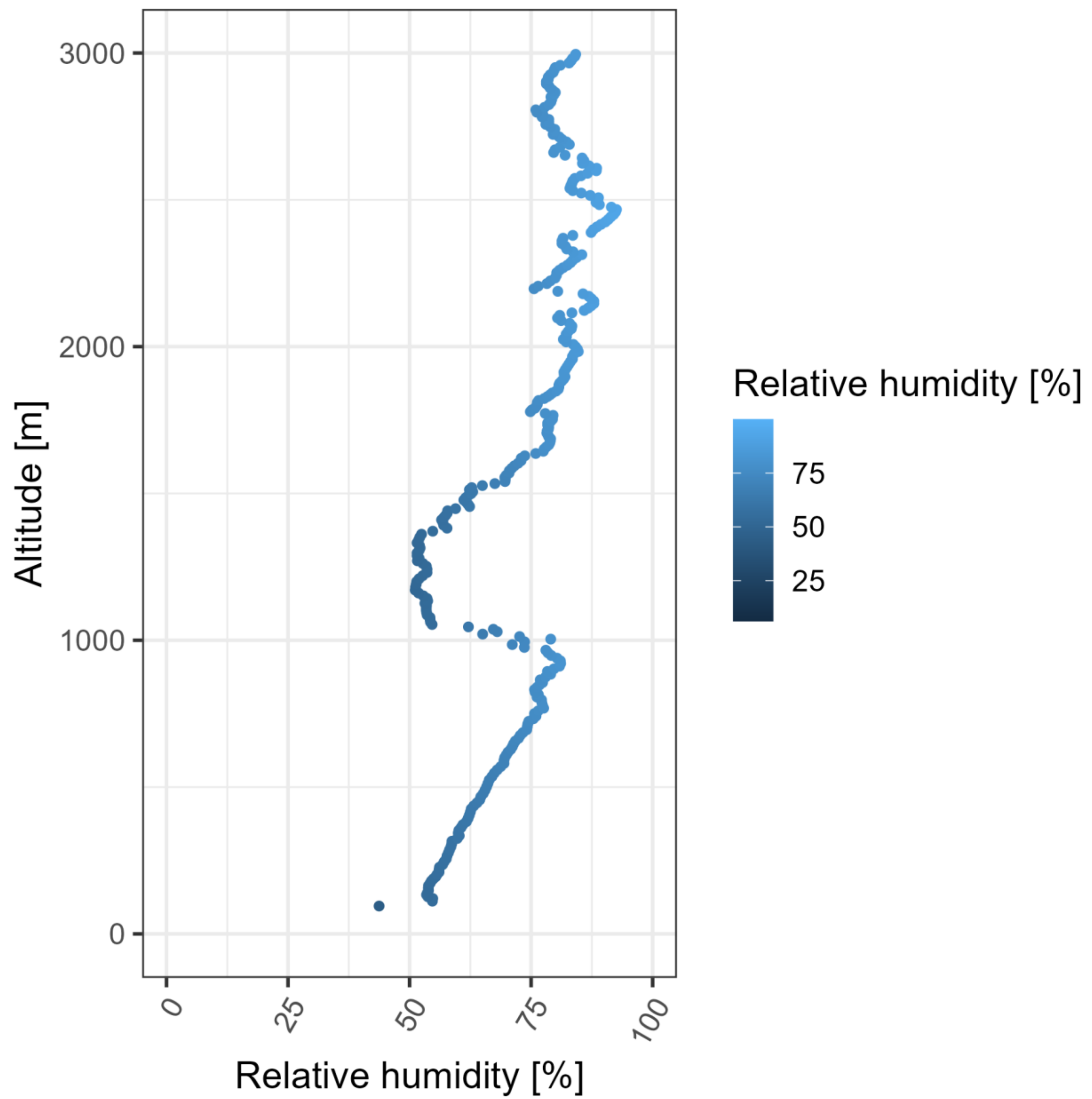

Fig. 14: Atmospheric vertical profile of RH between 1-3km height.

- Dry surface conditions: 05/07/2021
- Intermediate RH near the surface, RH variant with altitude
- Diurnal precipitation: 2.9 mm
- Convection triggered due to buoyant motions

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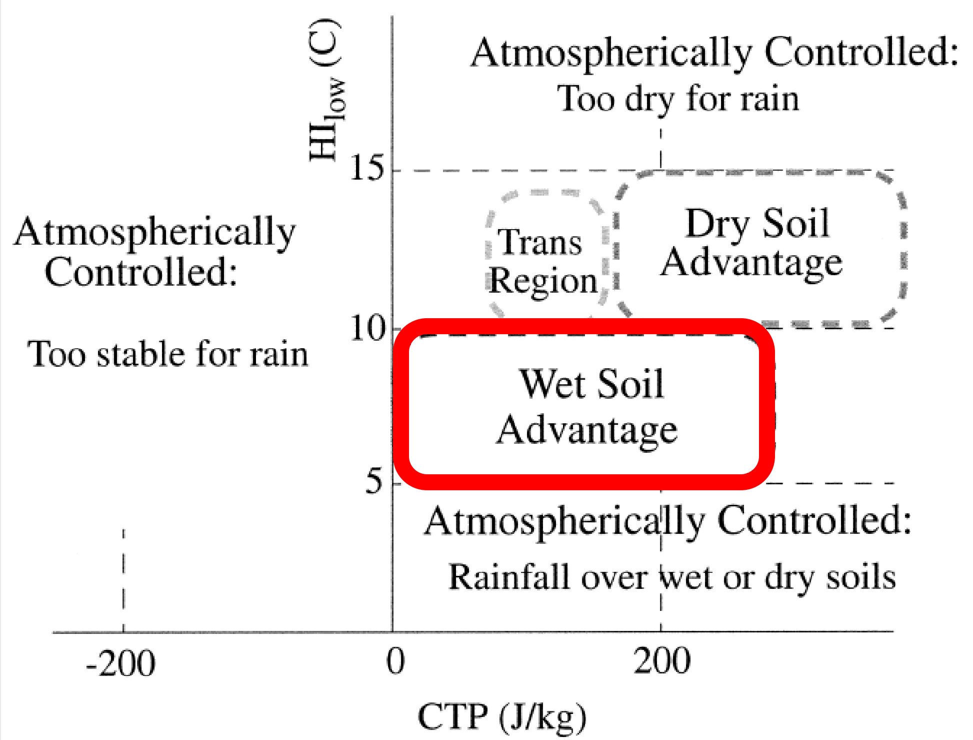
Convective events over wet surface

- Wet surface conditions: 27/06/2023
- HI_{low} values: 7.34
- Convection driven by wet surface conditions



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Convective events over wet soil

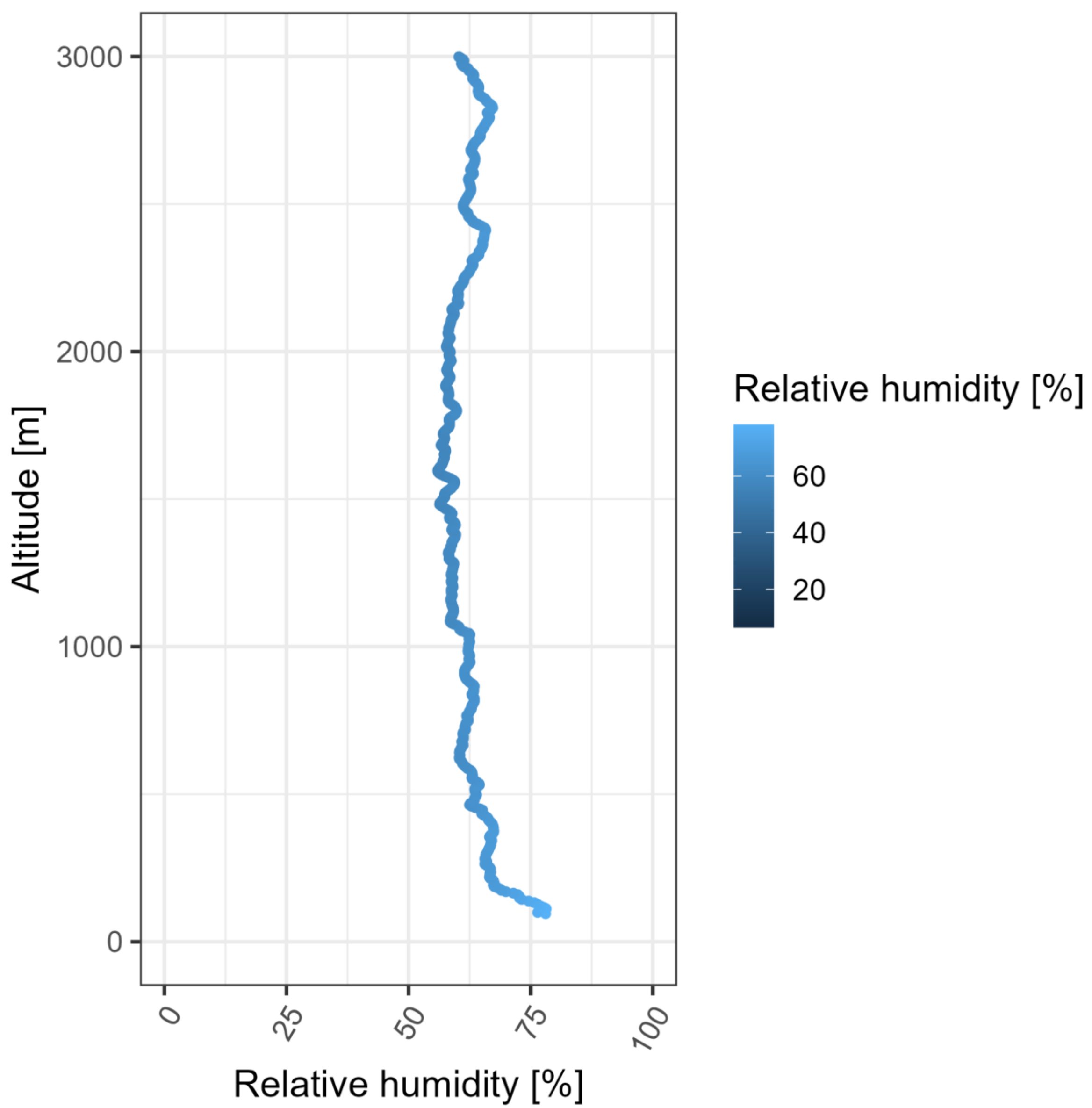

Fig. 15: Atmospheric vertical profile of RH between 1-3km height.

- Wet surface conditions: 22/06/2023
- Relatively constant RH within BL
- Diurnal precipitation: 7.8 mm
- Convection driven by latent heat flux

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Summary

- Latent heat flux dominant in early summer seasons when water is abundant, in late summer season H fluxes higher

- Convective events over both wet and dry surfaces occurred

➢ Highly variant conditions caused convection at Ås

- Outlook: Evaluate ratio of wet and dry convective events over three summer seasons 2021 – 2023

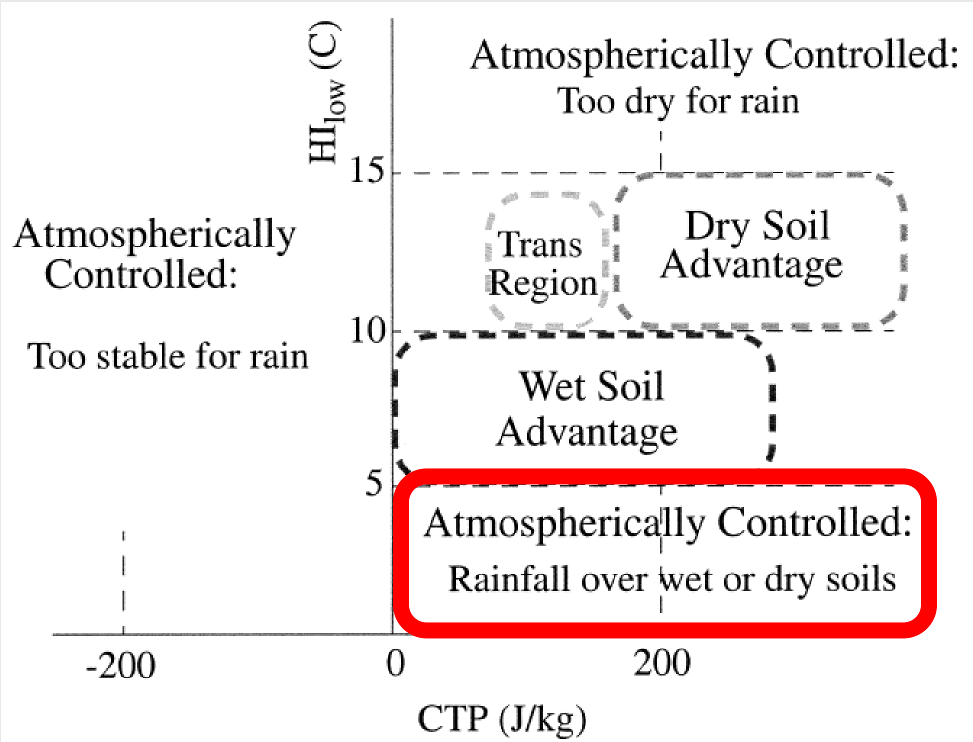
➢ Which convection driver is dominant in Southern Norway?

Thank you for your attention!

Open data policy at MET Norway –
We are happy to share our data!

Convective events: Very wet conditions

- Very wet surface conditions: 27/06/2023
- HI_{low} values: 0.8
- Rainfall independent from surface conditions



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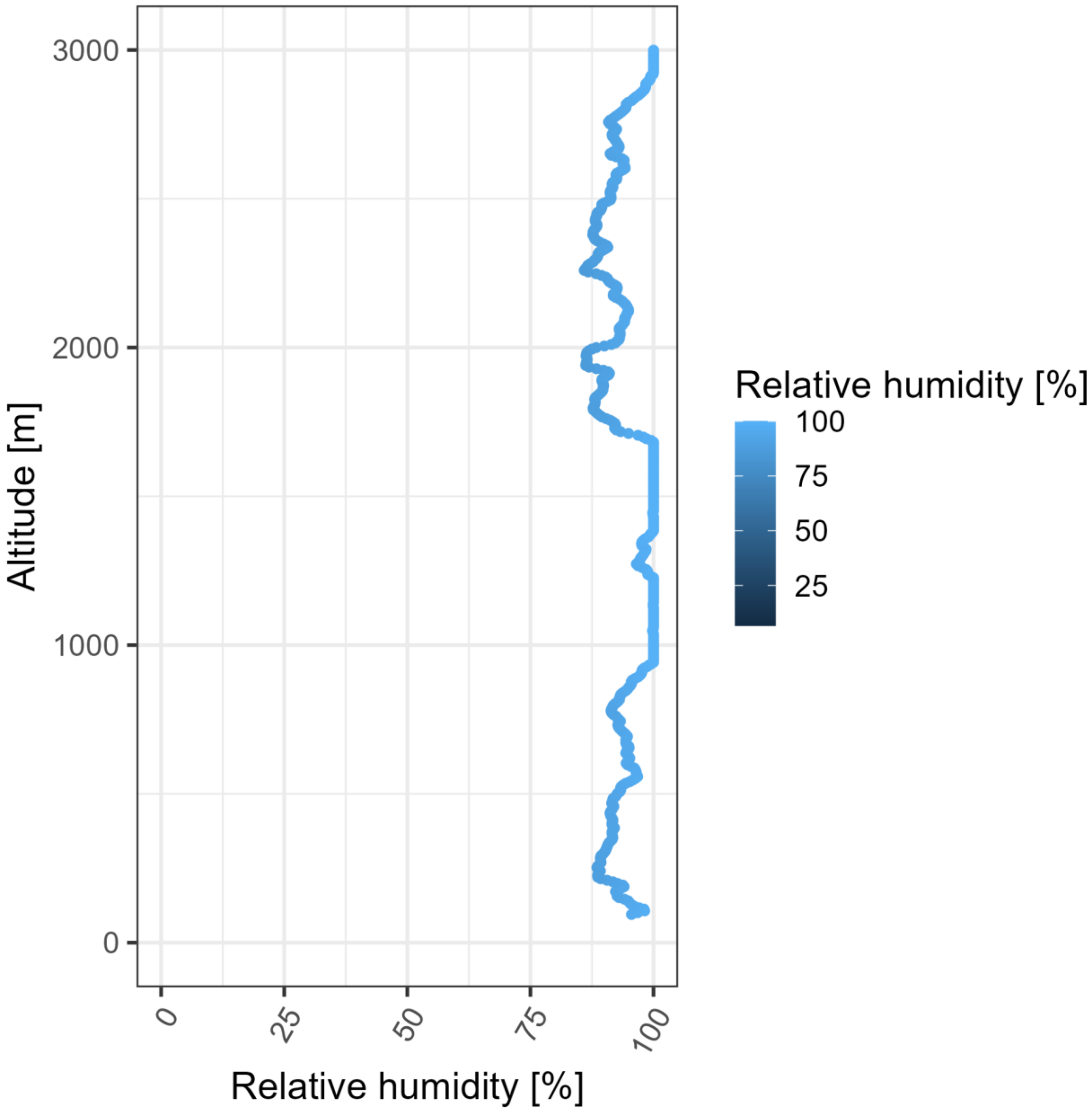
Convective events over wet soil



- Wet surface conditions: 27/06/2023
- Very humid conditions
- High, relatively constant RH within BL
- Diurnal precipitation: 7.6 mm
- Rainfall independent from surface conditions

Flux footprint

- Flux footprint during **neutral** conditions
- Major contributions from south and north due to the prevailing wind direction
- The main source area is covering the fenced field site (yellow area) and surrounding agricultural crops (green area)

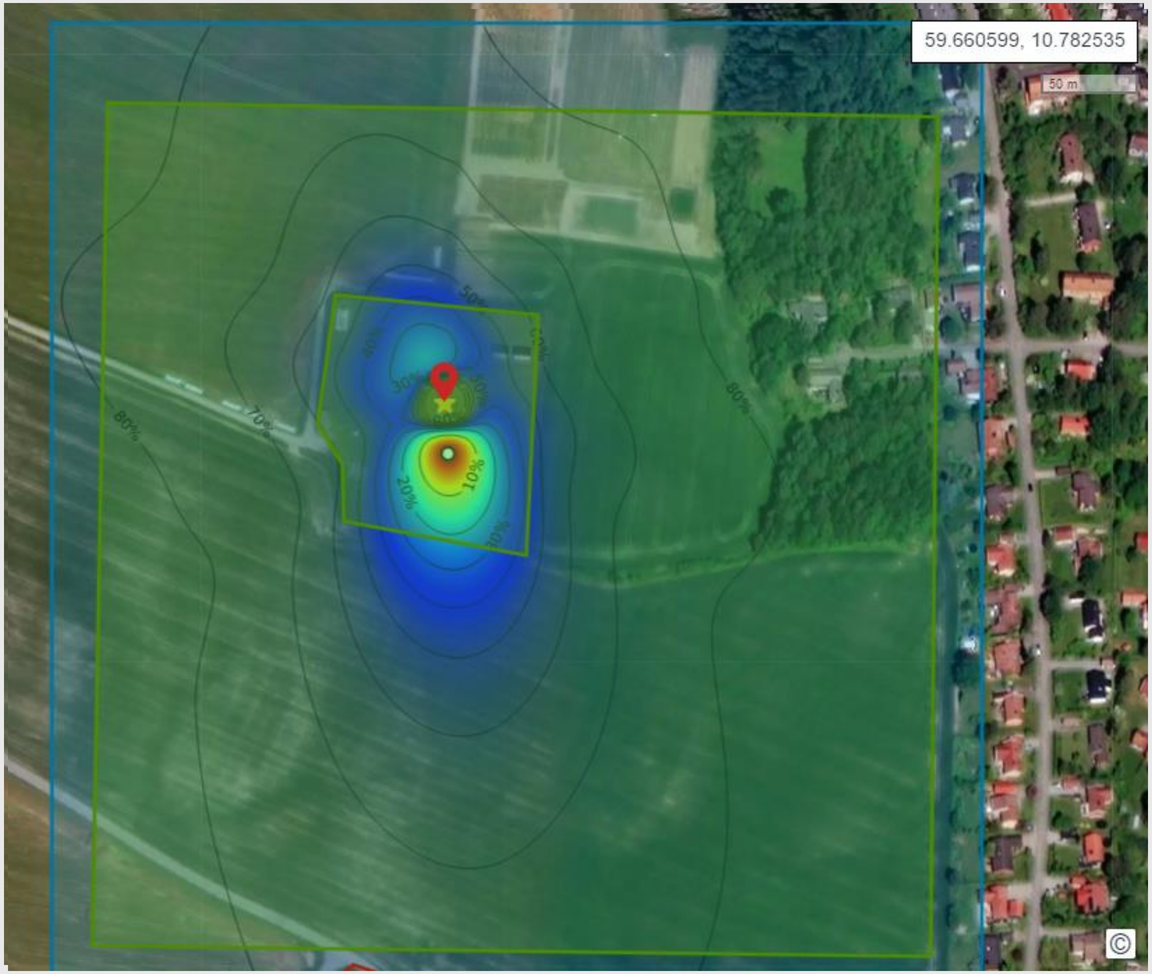


Fig. 16: Flux footprint for the summer season under unstable atmospheric stability.

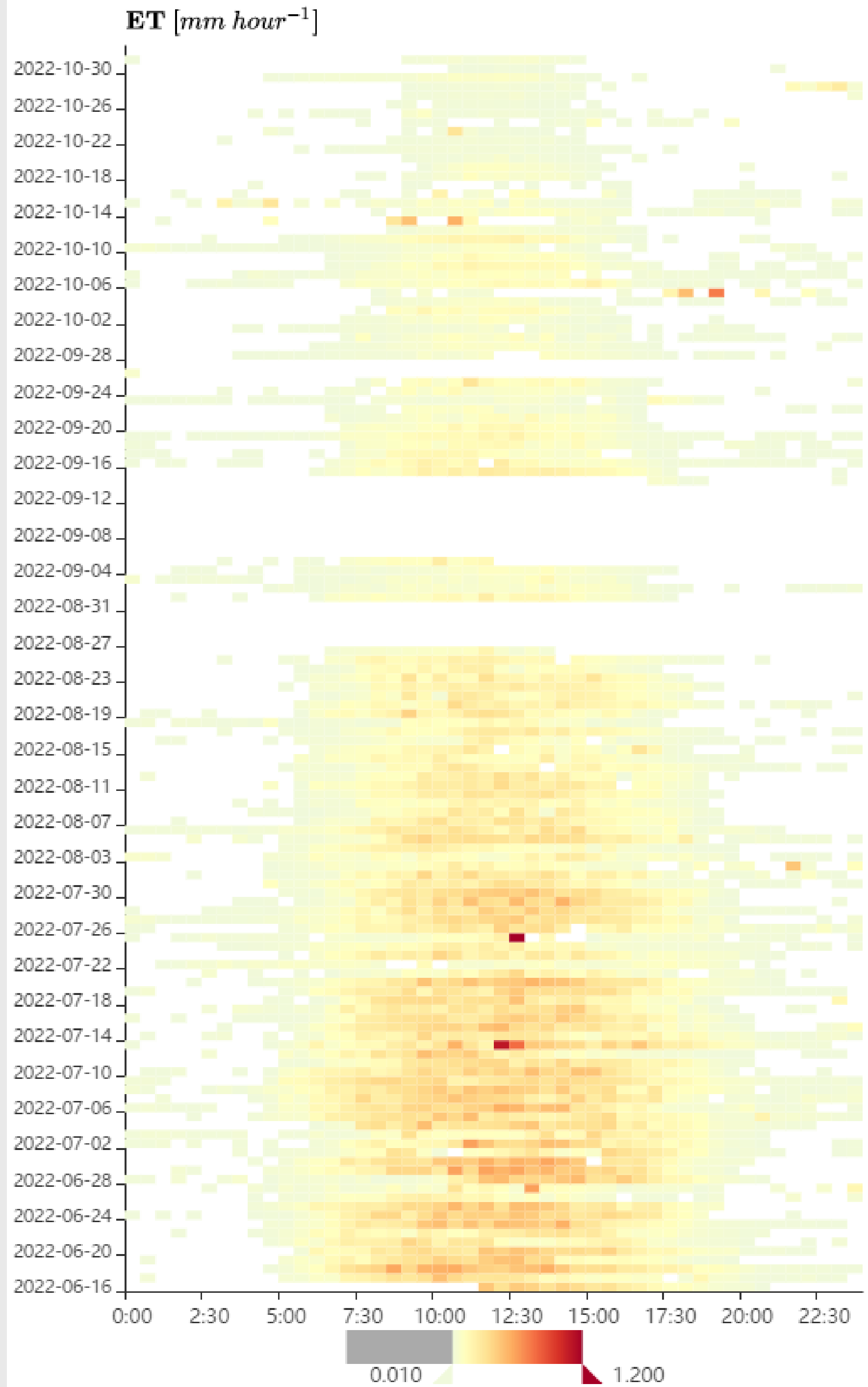
Flux footprint

- Flux footprint during **unstable** conditions
- Smaller local footprint
- The main source area is the short grass surrounding the flux tower (yellow area)

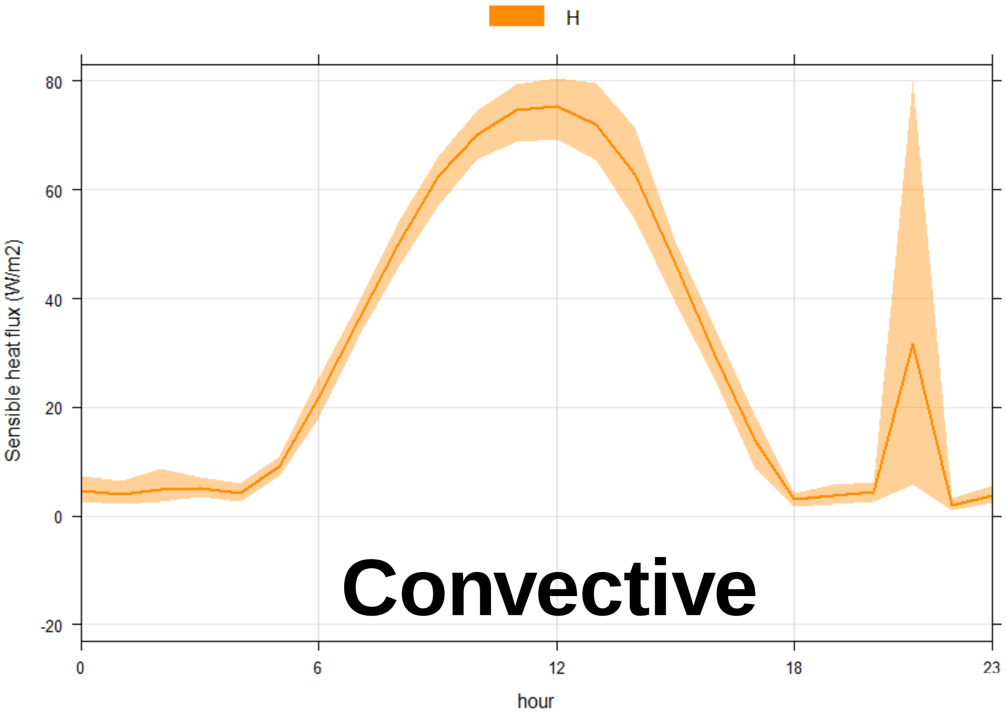
Fig. 16: Flux footprint for the summer season under unstable atmospheric stability.

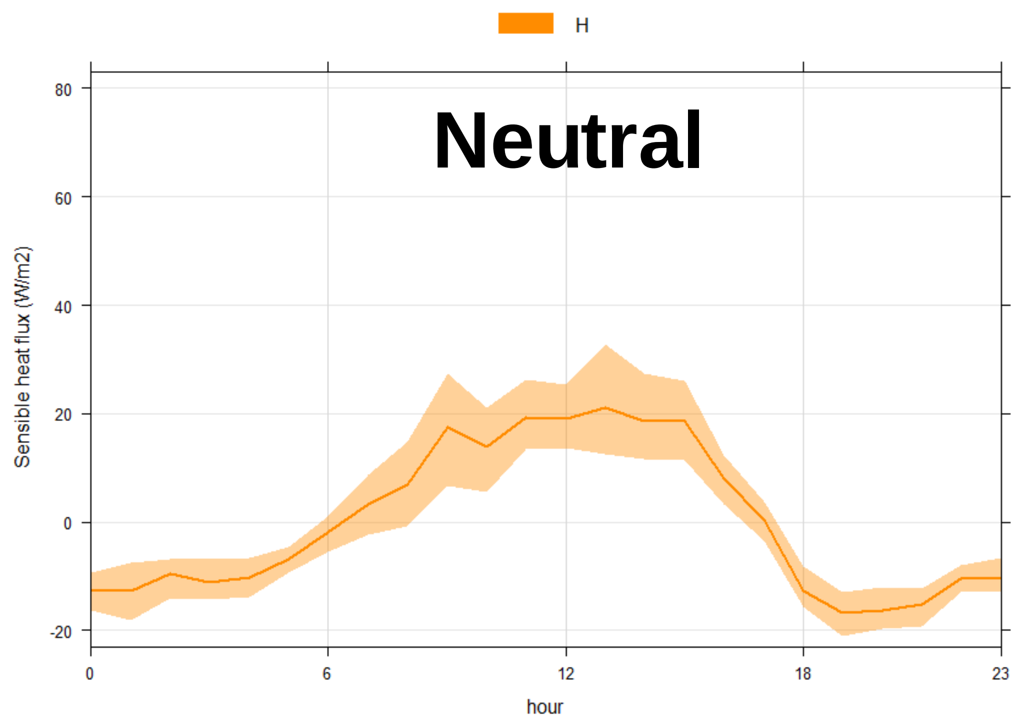
Evapotranspiration (ET) flux summer/fall 2022

- High ET fluxes in June and July showing abundant surface moisture
- Reduced ET fluxes in August despite high air temperatures



Sensible heat flux depending on atmospheric stability

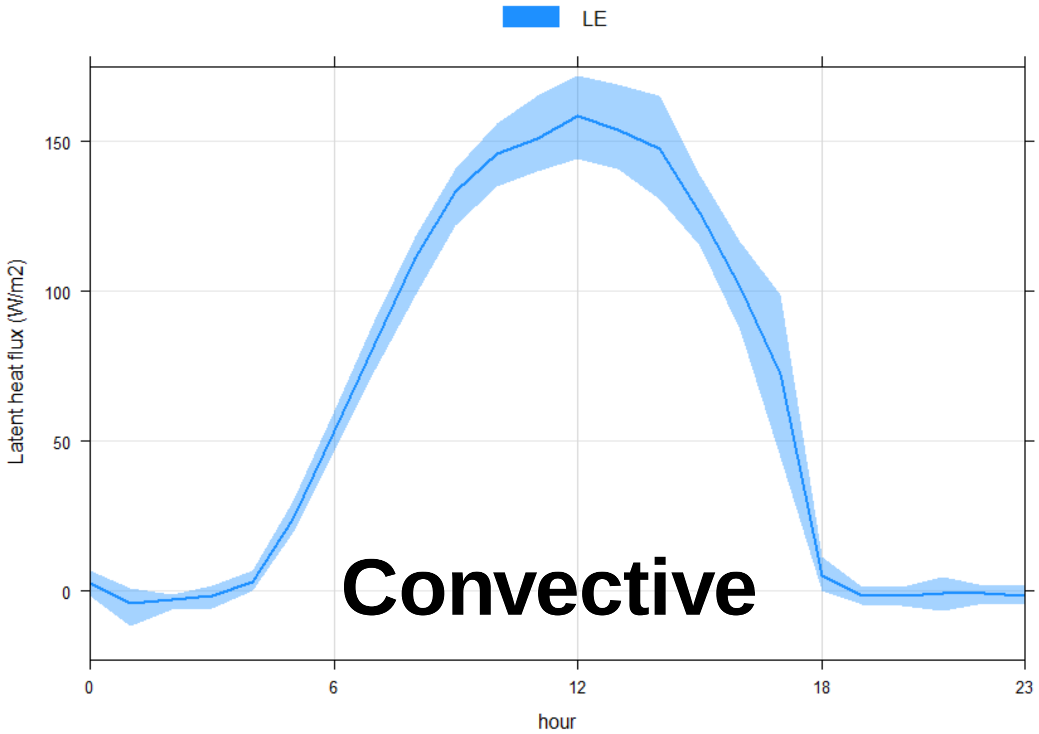




- Mean daily sensible heat flux H ~4x higher under convective conditions compared to neutral

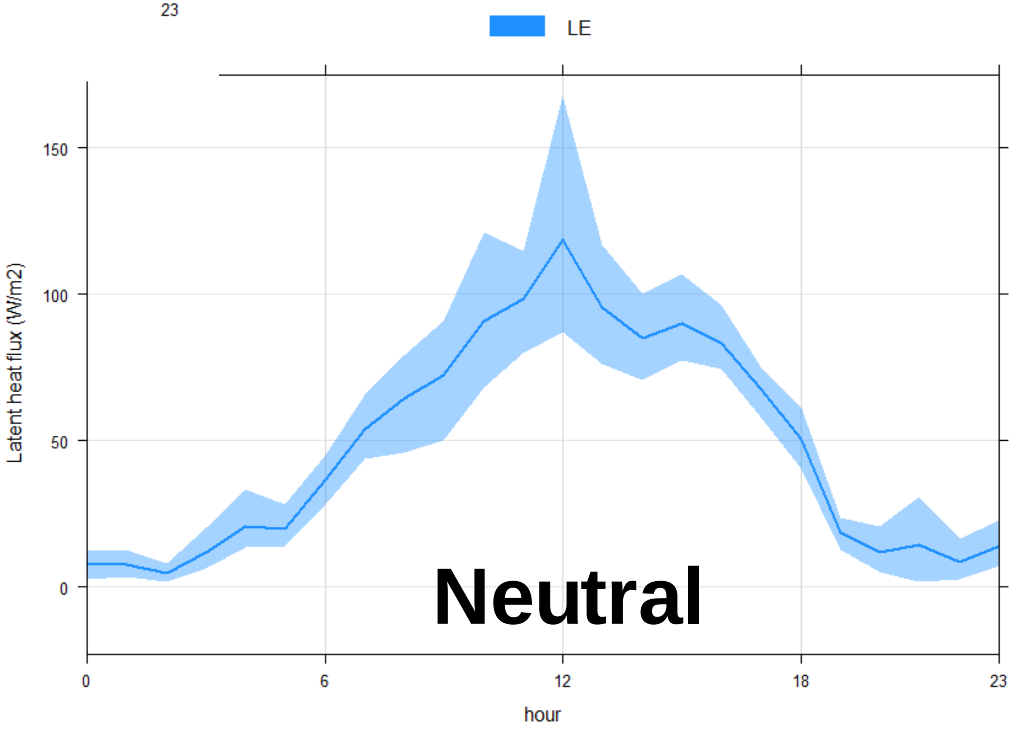
- Stability parameter zeta:
  - Convection: zeta < -0.05
  - Neutral: -0.05 < zeta 0.05

Latent heat flux depending on atmospheric stability

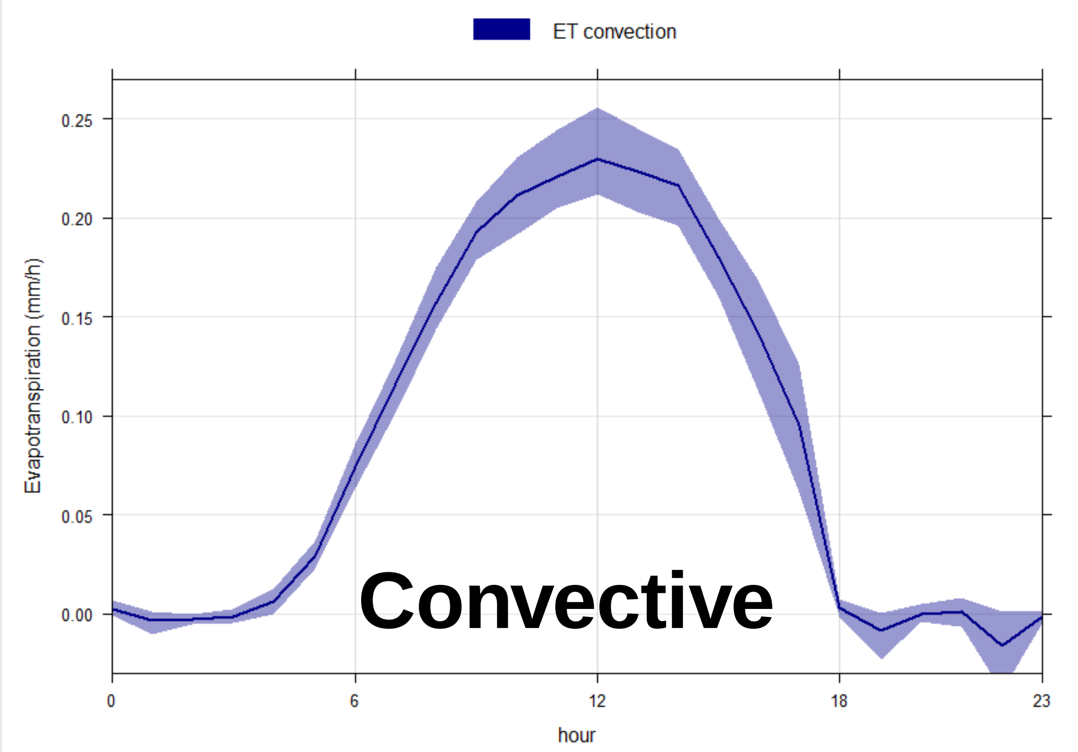


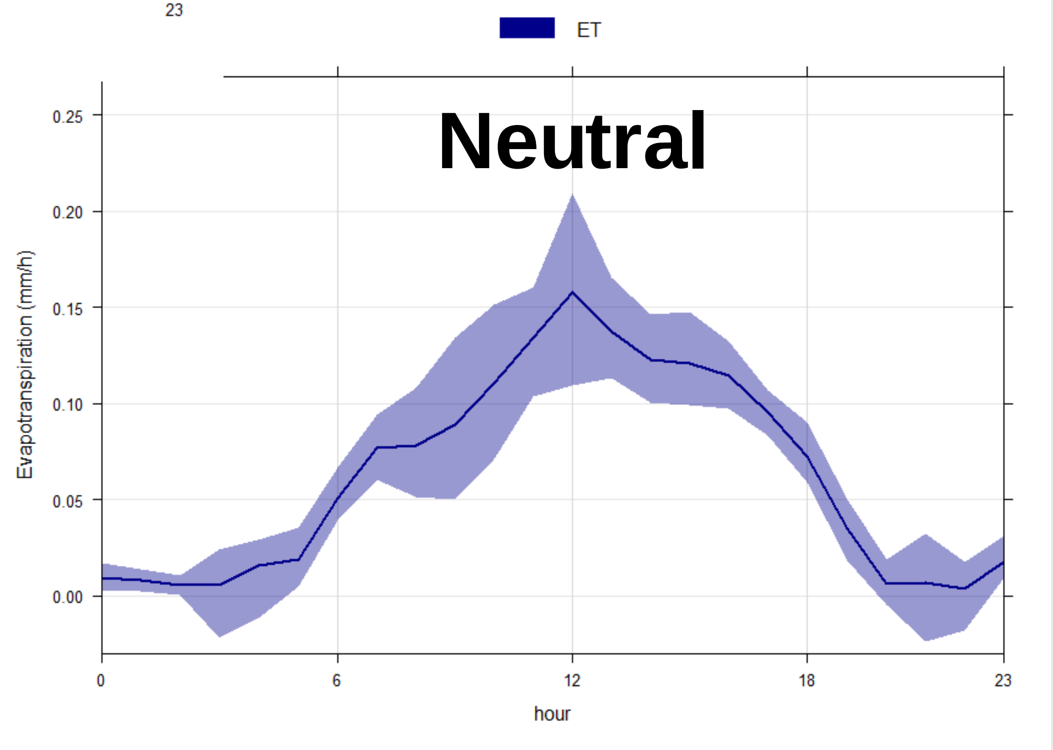
- Mean daily latent heat flux distinctively higher under convective conditions compared to neutral

- Stability parameter zeta:
  - Convection: zeta < -0.05
  - Neutral: -0.05 < zeta 0.05



Evapotranspiration depending on atmospheric stability





- Mean daily evapotranspiration distinctively higher under convective conditions compared to neutral

- Stability parameter zeta:
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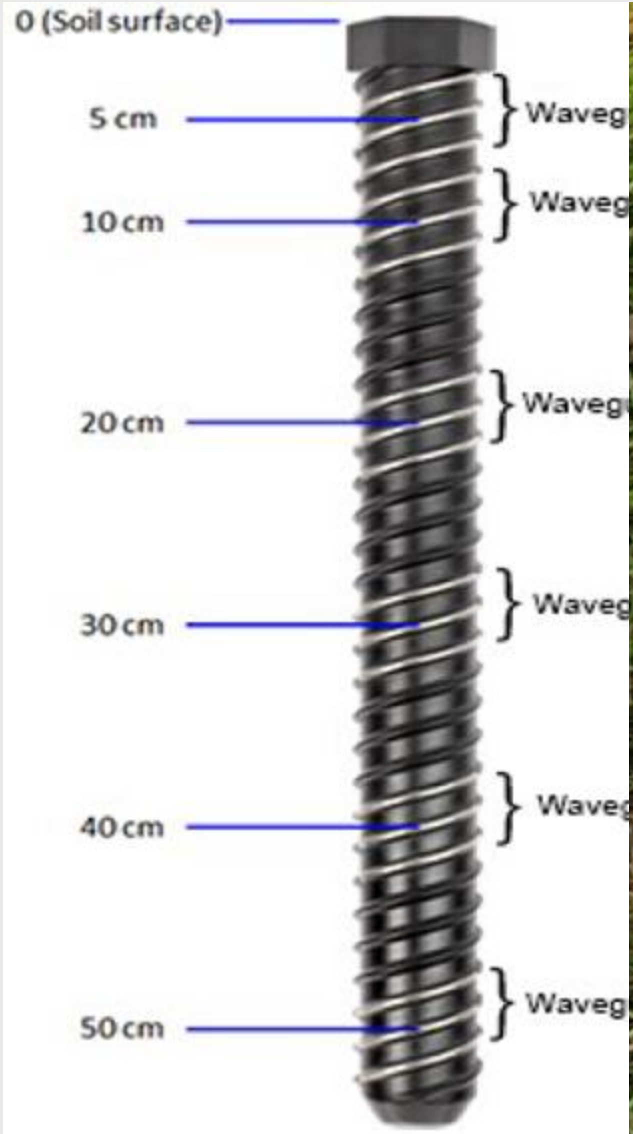
Soil moisture and temperature



Soil moisture

Figure 11: Satellite picture of the measurement site Source: Google Maps

Pan evaporation

Radiosonde and Radar

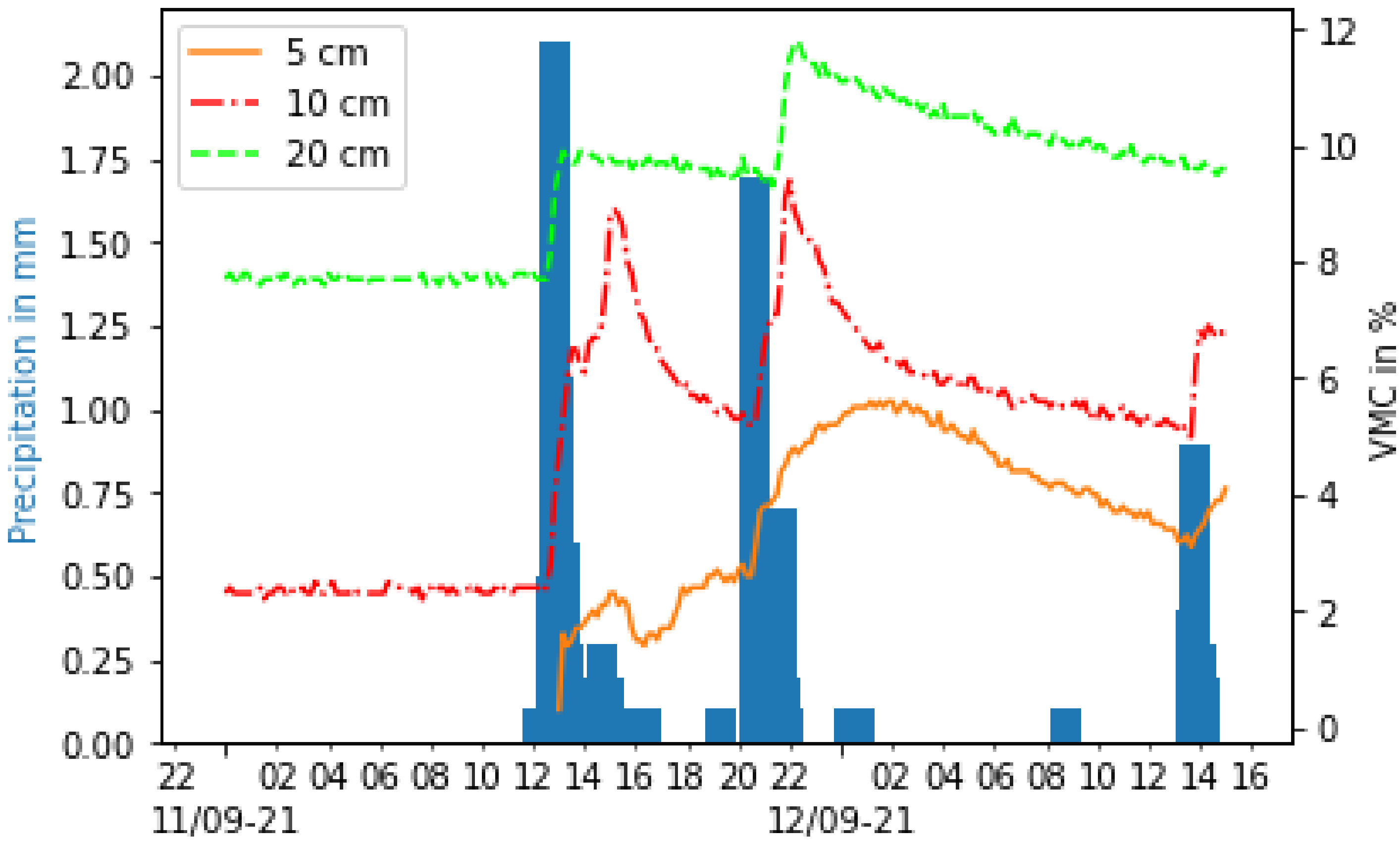
EC Data processing and QAQC

Corrections and QAQC procedures:

- Rotation method: Double rotation
- Detrend method: Block average
- Time lag detection method: Covariance maximization
- WPL correction to compensate for density fluctuations (specific for open-path IRGA)
- Quality flags following Foken and Mauder (2004)
- Footprint calculation following Kljun et al. (2004)

Fig. 8: Gill 3-D sonic anemometer and open-path LI-7500 gas analyser at 6 m height. Picture was taken during setup, the cables are fastened by now.

IoT sensors



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- 16/08/2022 17/08/2022 precipitation (seklima)

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Collaboration ideas

- **Carbon budget** of subarctic agricultural ecosystem under droughts
- **Energy balance closure** in general and during **winter** in Norway: Energy and matter fluxes during the cold season, with influence of moisture, snow cover, etc.

➢ Use eddy covariance energy and CO_2 fluxes and concentrations and link them to environmental and meteorological parameters

- **Trend of evapotranspiration** in the recent decades in SE Norway

➢ Use of long-term evaporation pan measurements at Ås verified by parallel EC flux data to investigate the trend in ET over the last decades

- **Biogenic emissions (BVOCs)** of agricultural and grassland ecosystems in a cold climate and their role in cloud formation and tropospheric ozone formation

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Atmospheric and LSM modelling

- Implement advanced land surface physics and hydrology in NWP models to improve the short-range forecasts
- More accurate initialization of the land surface through the uptake of Earth observations (EOs) benefits both short-range NWP and downstream hydrological forecast accuracy and reliability
- Coupled Earth system models need coupled data assimilation (CDA) systems to ensure consistency between the analysis updates in the different domains
- **Atmospheric model:** MetCoOp based on HARMONIE-AROME of ALADIN-LACE-HIRLAM

➢ PI Jostein Blyverket

- **Land surface model (LSM):** SURFEX for surface / soil modeling and hydrology

➢ Åsmund Bakketun and Helene Birkelund Erlandsen

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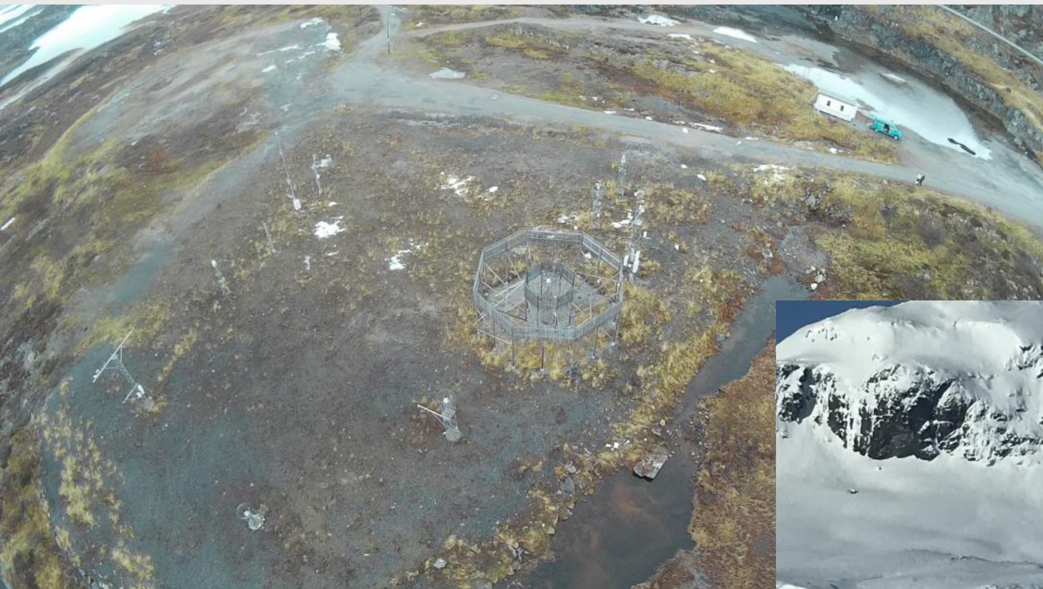
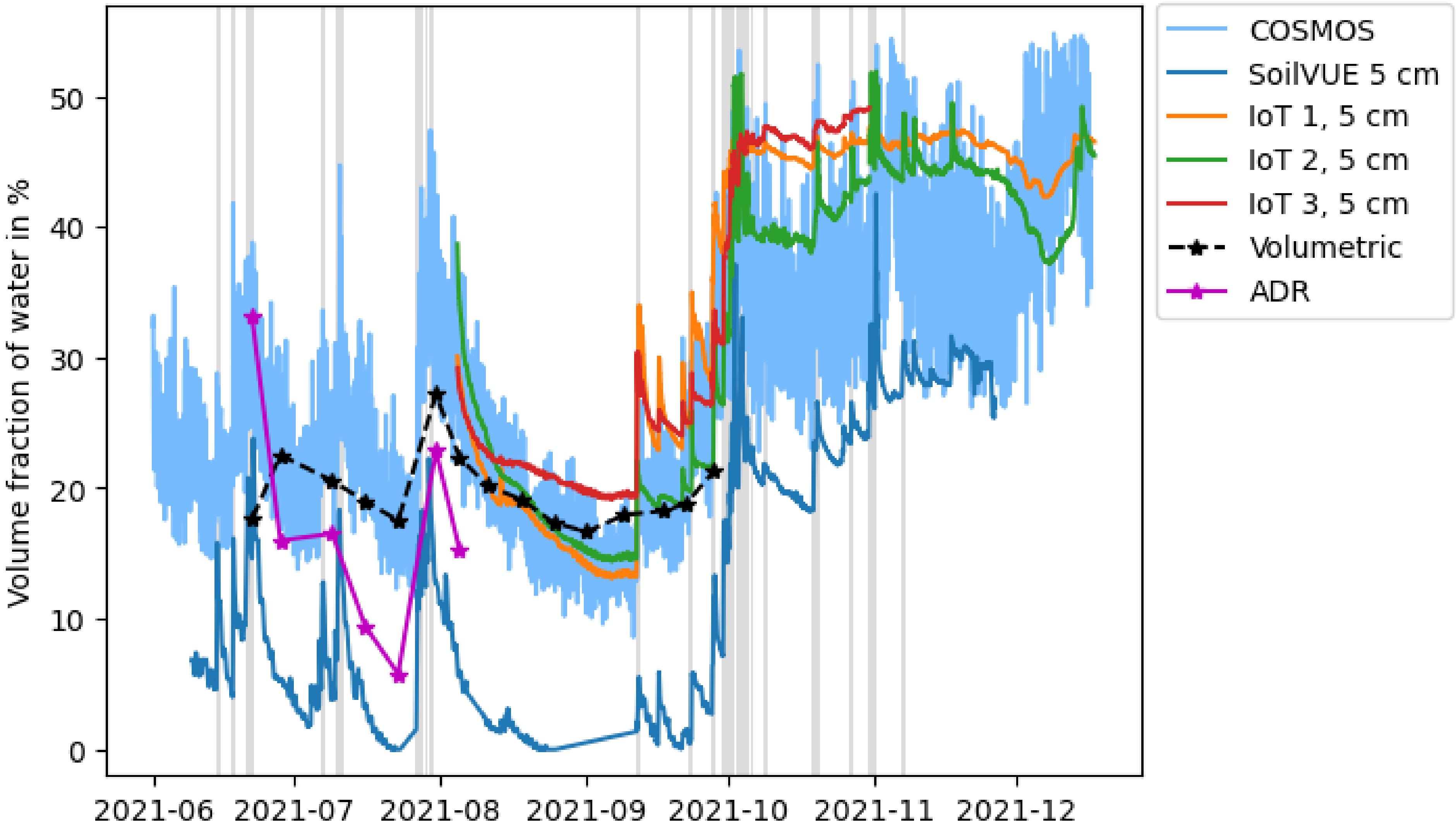
Collaboration ideas

Potential new EC measurement at Haukeliseter as addition to existing MET station (precipitation, snow, radiation, temperature, etc.)



Appendix and optional slides

Soil moisture in summer 2021



Collaboration ideas

- Carbon budget of subarctic agricultural / grassland ecosystem under droughts

➢ Use eddy covariance CO_2 fluxes and concentrations and link them to environmental and meteorological parameters

➢ Soil moisture data to estimate water limitation of the vegetation

➢ Possible cooperation with other flux sites like Hurdal or Finse

Collaboration ideas

- Energy fluxes and energy balance closure during subarctic winter in Norway: Energy and matter fluxes during the cold season, with influence of moisture, snow cover, etc.
- Grasslands and agriculture land use types underrepresented in subarctic and arctic studies.

➢ Use eddy covariance CO_2 fluxes and concentrations and link them to

➢ Use EC fluxes and NMBU facilities (e.g. radiation, temperature, cloud camera, snow measurements)

Collaboration ideas

- Trend of evapotranspiration in the recent decades in SE Norway – Is climate change visible?

- Shift from energy to water limited ecosystems apparent?

➢ Use of long-term evaporation pan measurements at Ås verified by parallel EC flux measurements (2 yr time series) to investigate the trend in ET over the last decades

Collaboration ideas

- Biogenic emissions of agricultural and grassland ecosystems in a cold climate: Investigate the influence of soil moisture and vegetation conditions on the emissions of biogenic volatile organic compounds (BVOCs) and their role in cloud formation and tropospheric ozone formation
- Maybe also in combination with extreme weather events as biogenic emissions can be also stress reactions of the vegetation.

➢ Sørasjordet site due with multitude of measurements of biometeorological measurements, radiosonde vertical profiling and EC flux measurements

➢ Possibility of additional equipment at the Sørasjordet flux tower to measure BVOCs and aerosols near the surface and use already available sensor like distrometer and cloud camera

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Ås site

- Atmospheric model: AROME Arctic
  - ➢ Jostein, Trygve, Stephanie

- Land surface modelling (LSM): SURFEX for surface / soil modeling and hydrology. External offline forcing
  - ➢ Åsmund Bakketun and Helene Birkelund

Meteorological characteristics

- Prevailing wind direction south, occasionally northerly winds
- Low precipitation during the summer field campaign 2021

June -September temperature and precipitation

TA 2021	TA normal	Precip 2021	Precip normal
15,8	14,6	284	342

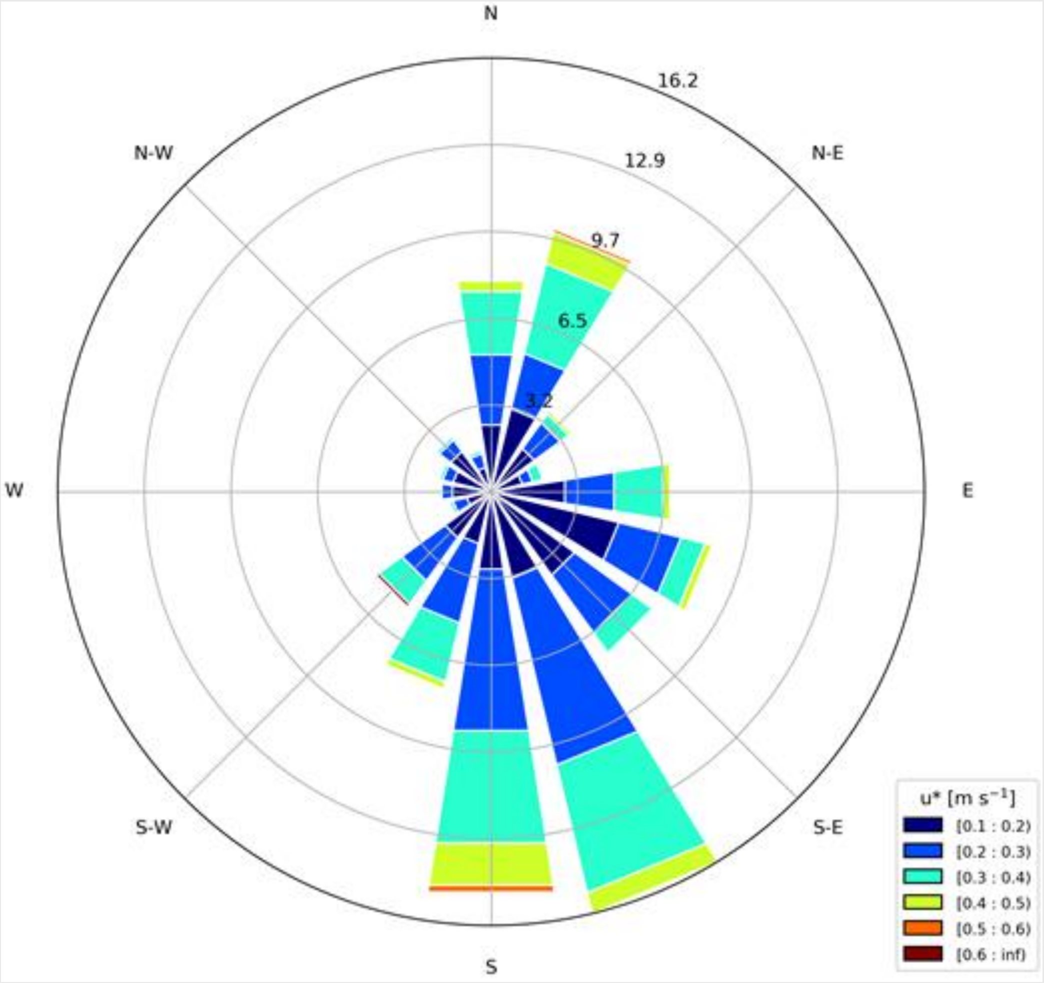

Fig. 5: Windrose with friction velocity and wind direction during 2021's summer field campaign.

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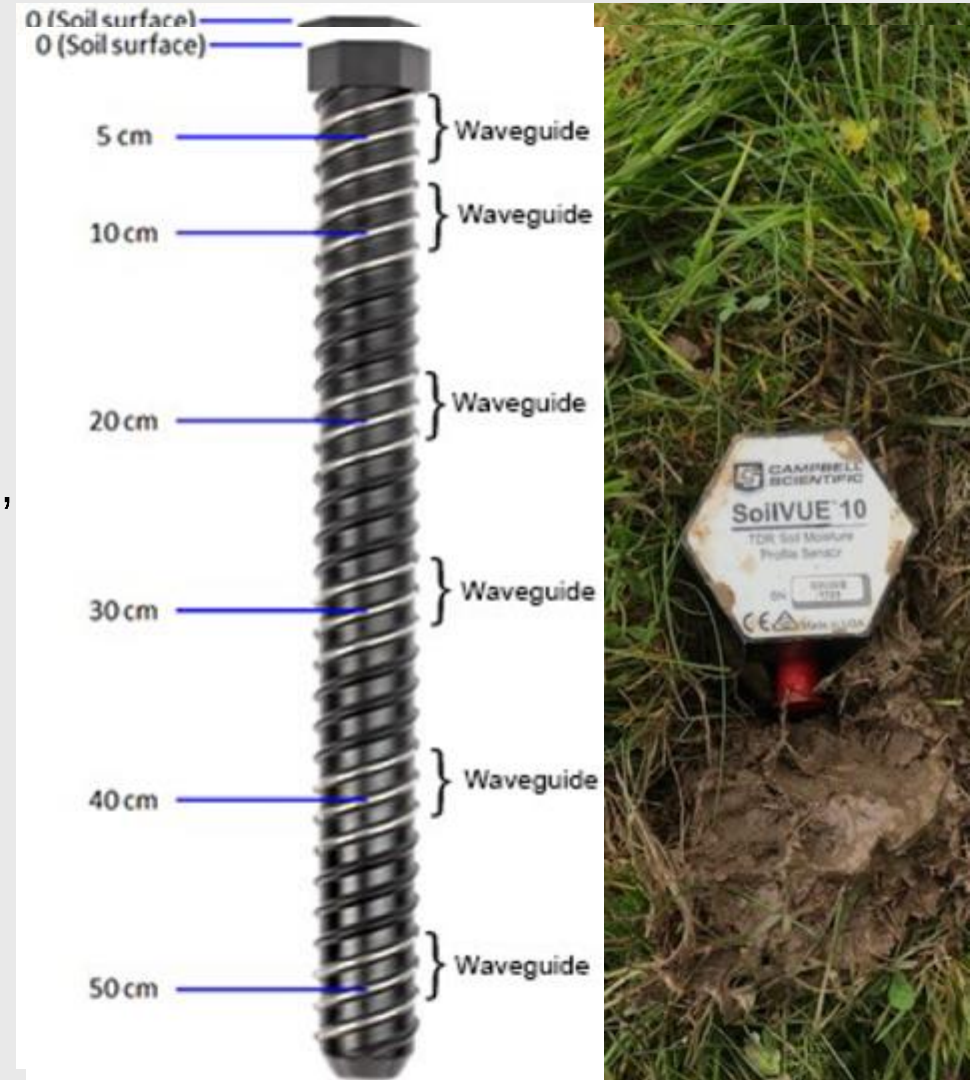
Additional measurements during summer field campaigns

Overview of measurements

- Fast-response eddy covariance (EC) measurements
- Continuous soil moisture, soil temperature and soil heat flux measurements
- Additional manual soil sampling with TDR sondes and soil cores at a high spatial resolution
- Radiosondes for vertical profiles
- Drones for spatial coverage and vertical profiles
- Citizen science observations for soil moisture and temperature
- EOs from satellite remote sensing

Soil moisture and soil temperature

- Continuous soil moisture and temperature measurements with SoilVUE10 along a vertical profile (100 cm)
- TDR method for soil moisture at 5 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, 75 cm and 100 cm
- Temporal resolution: 1 h



SoilVUE10, private

Soil moisture

- Manual soil moisture measurements
- TDR method for soil moisture near the surface (~10 cm)
- Gravimetric method using soil cores
- Temporal resolution: Weekly

Figure 9: TDR sonde Source: Manual Theta Probe

Figure 10: Bulk density core, stainless steel cylinder and hammer used for extracting soil cores Source: John Ballinger

Radiosondes

- Radiosonde launches upon request to get vertical profile of the atmosphere during extreme events

- Temporal resolution: Variable

Figure 12: Deployment of radiosonde container Source: private

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EC flux station at NMBU site in Ås