What could we infer from lidar measurements during HILIAISE?

Focus on the convective boundary layer.

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Scientific objectives:

- address the issue of surface **scalar flux heterogeneity** (dry and irrigated region)
- address the issue of **scalar transport dissimilarity** (GHGs space mission interest)
- find advanced **model parametrizations** of transport processes for both convective and stable boundary layers in different climate regions (temperate and semi-arid in HILIAISE)

Path the way to a **3-D thermodynamic view** of the atmosphere that can match current/future Navier-Stokes equation simulation (LES, DNS…)

Instrumentation and site

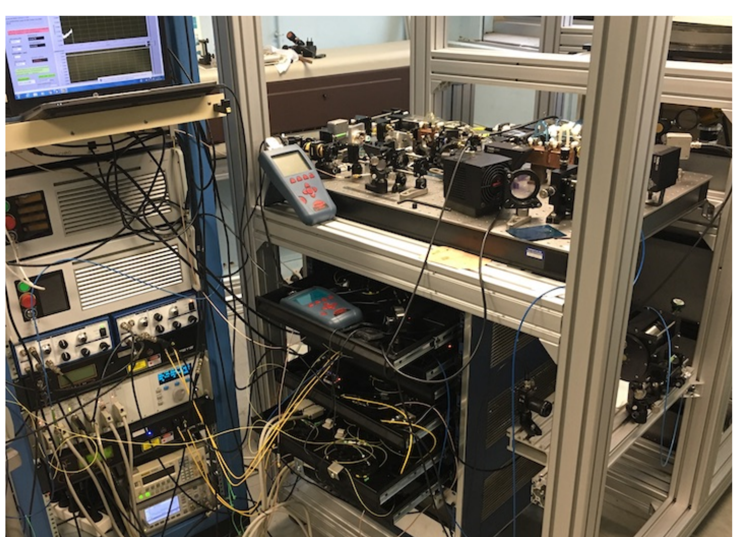
Site: El Plans (41.587, 1.0299)

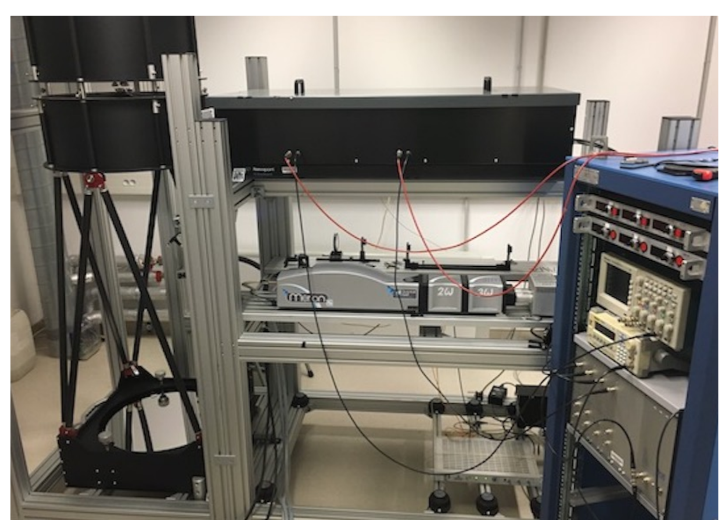
Period: 15-30 July 2021

Instrumentation:

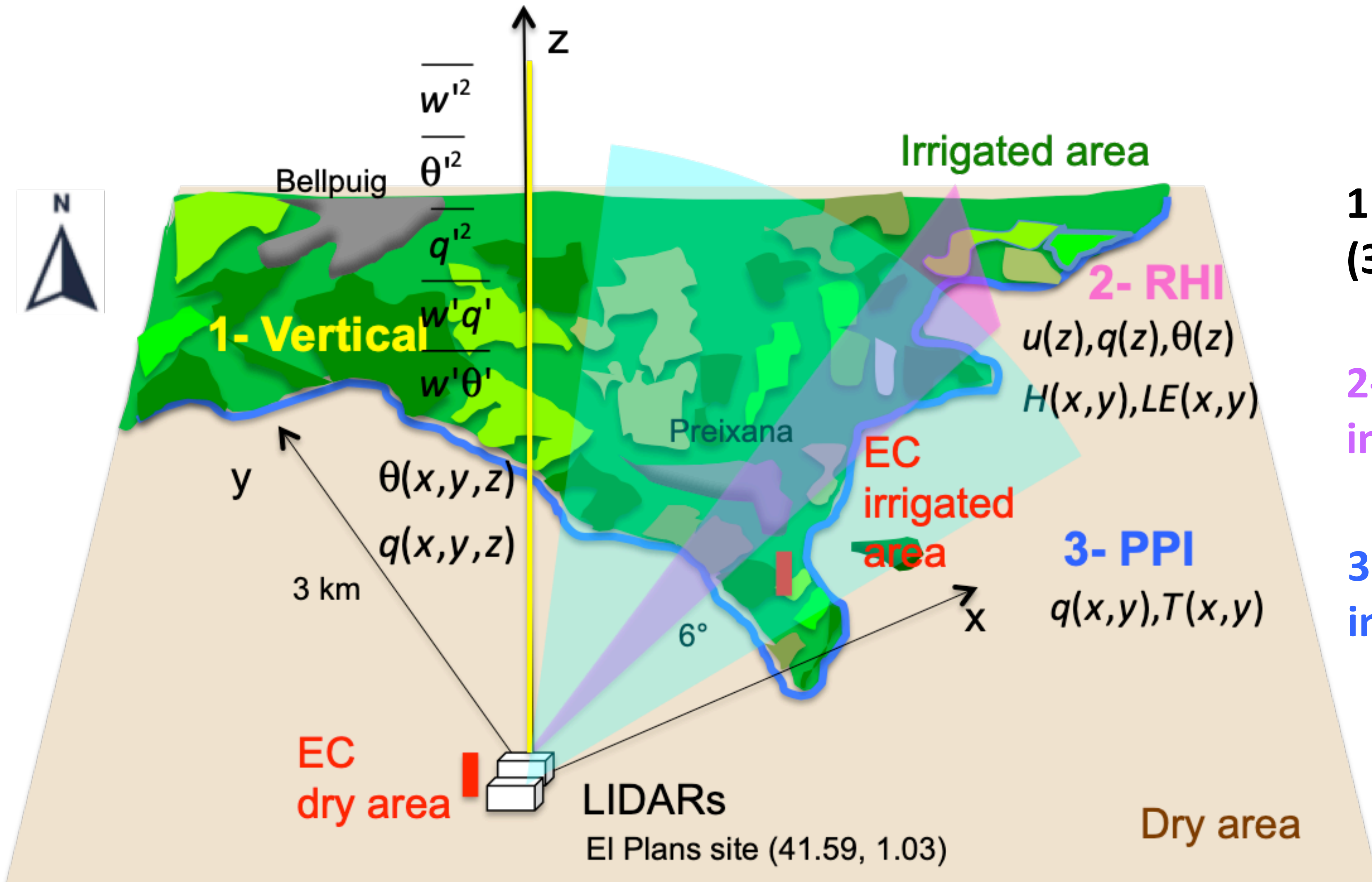
3D- lidars mobile station

- COWI : **CO_2 & wind** , Doppler and DIAL system at 2 µm
- TERA: **temperature & H_2O**, Raman lidar at 0.355 nm





Observation set-up

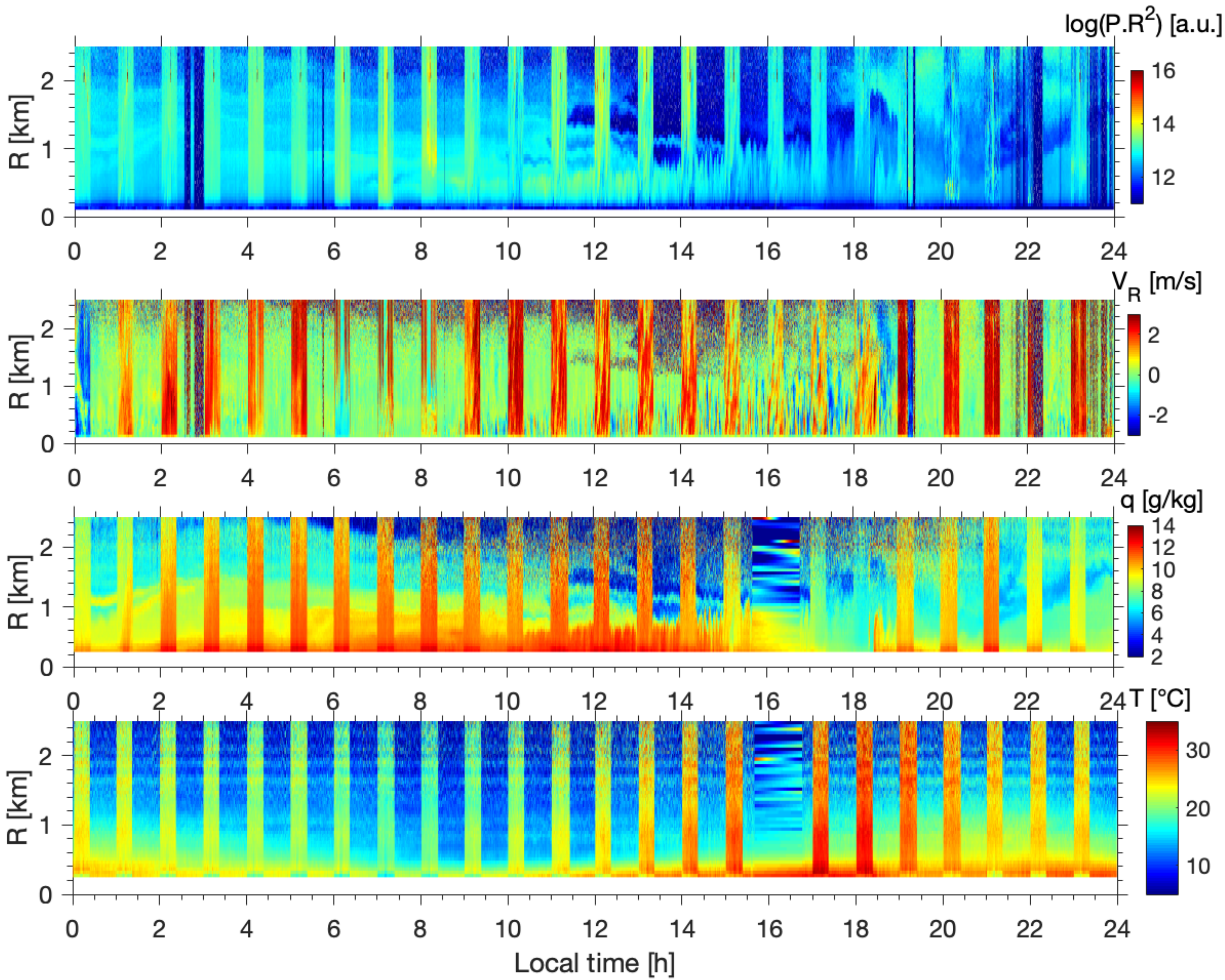


1 -Vertical mode (35 min – 0.2-12 km)

2- RHI mode: range height indicator (20 min – 0-100m)

3 –PPI mode: plane polar indicator mode (5 min - ~10m)

Example of measurements



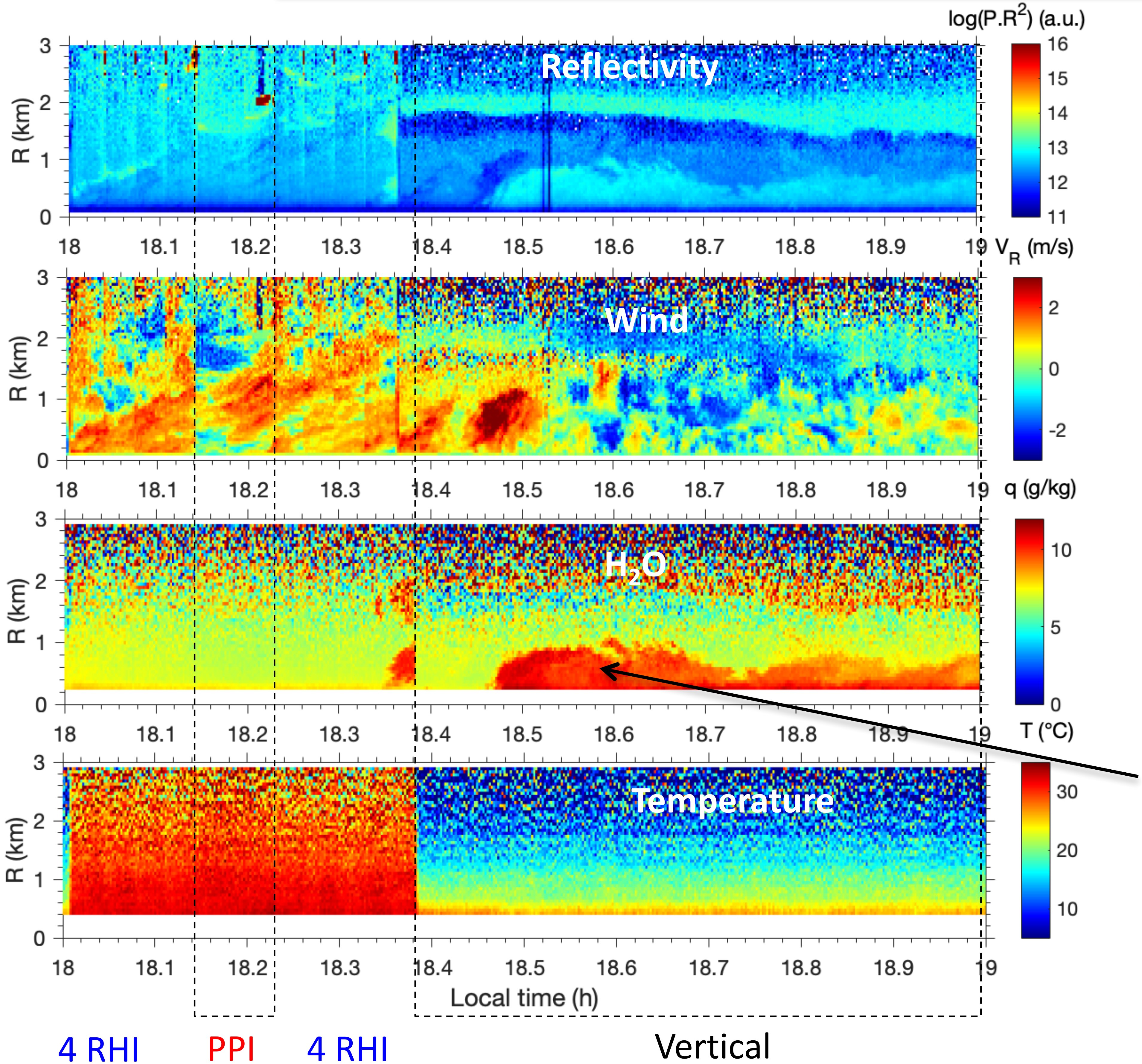
lidar reflectivity at 2 µm

radial wind speed

Specific humidity

Temperature

Example of 1h of measurements



Time resolution: 8 s
Space resolution: 50 m

RHI: fixed azimut – vertical cross-section of the atmosphere 0-6° at 0.05°/s

PPI: fixed elevation - horizontal cross-section of the atmosphere 30° at 0.1°/s

sea breeze event
cold and humid layer that propagates close to the ground

Products (1/2)

	Units	Resolution	Correction	Comments
Lidar reflectivity 355, 2051 nm Radial wind speed Temperature Specific humidity	a.u. m/s K g/kg	8s, 50 m	no no yes RS no	- space resolution can be changed for temperature and specific humidity and not for wind speed 6 min/ 7.5 m - overlap/ bias correction for temperature

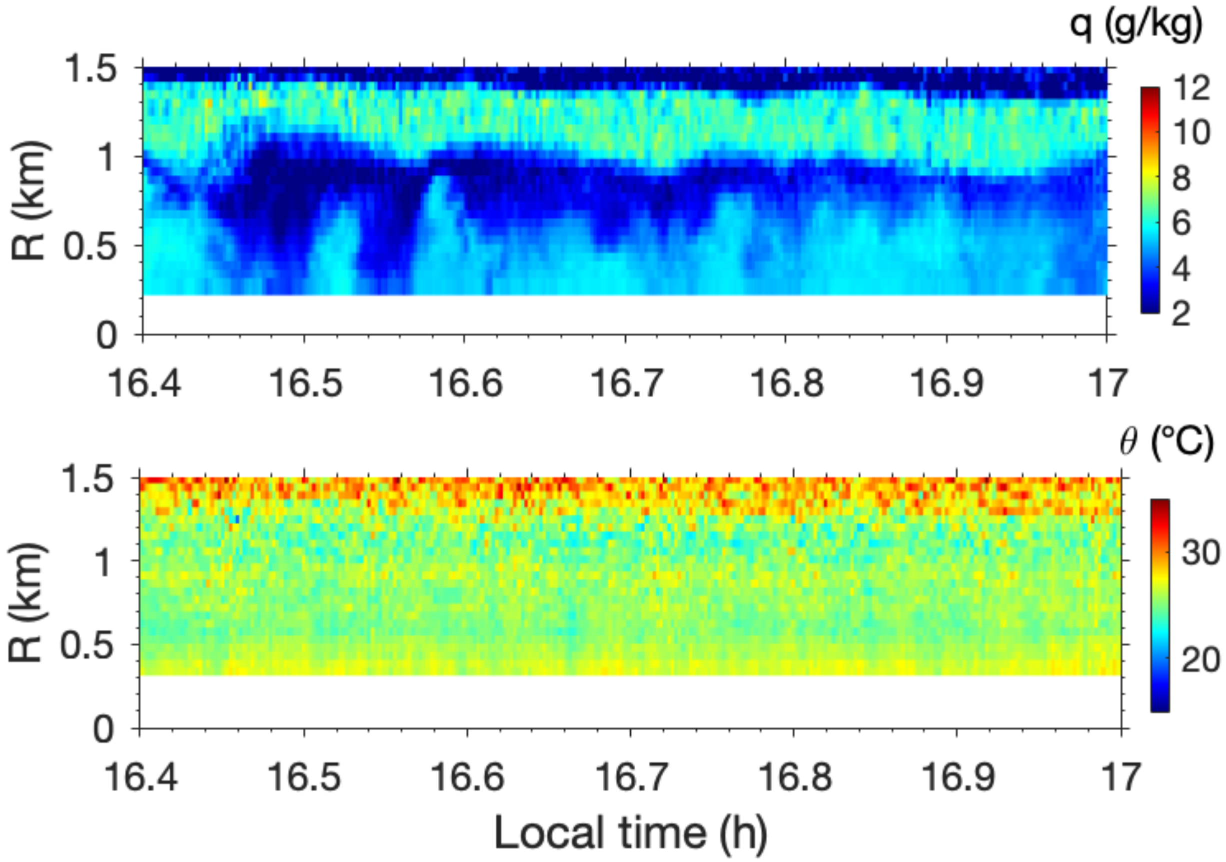
1-VERTICAL	Units	Resolution	Correction	Comments
z_i w* NBV -> Ri	m	1h, 50m		-zi: using minimum sensible heat flux (≠ lidar reflectivity or potential temperature) -w*: using in situ surface sensible heat flux - Ri: using UHF wind shear measurements
Second-order moments variances: $\overline{\theta'}^2, \overline{q'}^2, \overline{w'}^2$ covariances, flux $\overline{w'\theta'}, \overline{w'q'}, \overline{q'\theta'}$ Third order moments…	… K.m/s, g/kg.m/s	1h, 50m	no	typical vertical period: 9.4 -10 h instrumental and sampling uncertainty
Along wind integral scales horizontal vertical	s m	1h, 50m 1h, 500m*	no	integral scales should be larger than 8s (horizontal) and 50 m (vertical) * depend on data vertical resolution
Turbulent kinetic energy dissipation rate and destruction rates		1h, 50 m	no	using variance and integral scale

Products (2/2)

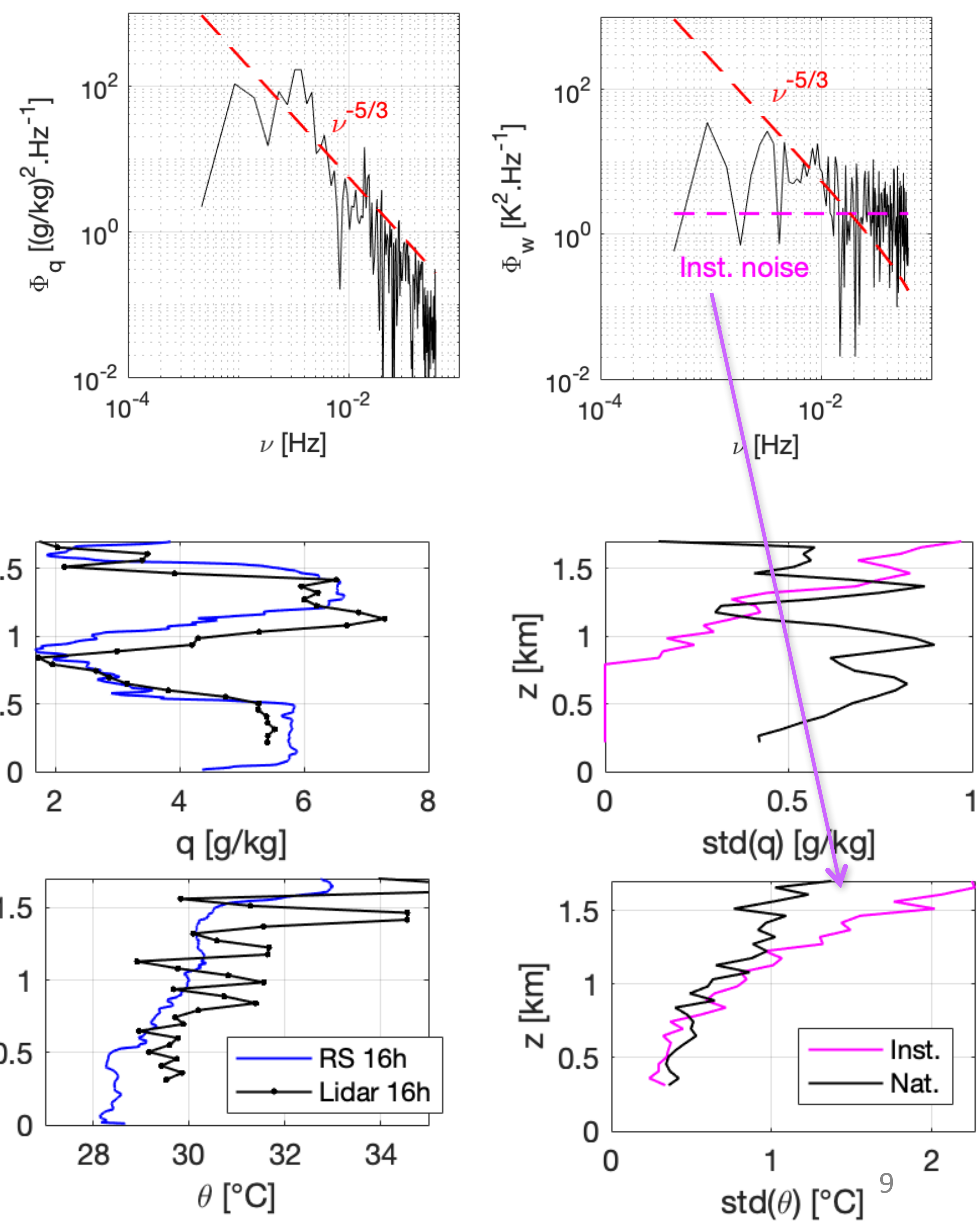
2-RHI (vertical cross section)	Units	Resolution	Correction	Comments
Range resolved (50 m) low altitude (0-100m @ 1 km) vertical profiles reflectivity, V_R, T, q		7m @ 1 km 2 min	no	8 RHI / hour vertical resolution depends on the distance 8 s -> 0.4° -> 7 m @ 1 km
Range resolved surface fluxes heterogeneity using MOST		1h, 250 m	no	needs for u*, L_{MO} estimated by 1) in situ EC station, 2) RHI wind profile (wind direction from PPI), 3) PPI integral scales

3-PPI (horizontal cross section)	Units	Resolution	Correction	Comments
Low altitude (~10m), 30°, 2D map reflectivity, V_R, T, q		50m x 14m @ 1 km 5 min	no	1 map/ hour - horizontal resolution depends on the distance - altitude depends on terrain height 8 s -> 0.8° -> 14 m @ 1 km
Wind speed direction as a function of distance		50 m, 5 min		1 profile/ hour
Along wind and cross wind integral scale		5 min	no	- needs for horizontal wind direction as a function of distance - can be used for u* and L_{MO} estimates

Precision and bias



at z=0.4 km - 8s – 50 m



→ Instrumental standard deviations

8 s – 50 m

w: < 0.1 m/s

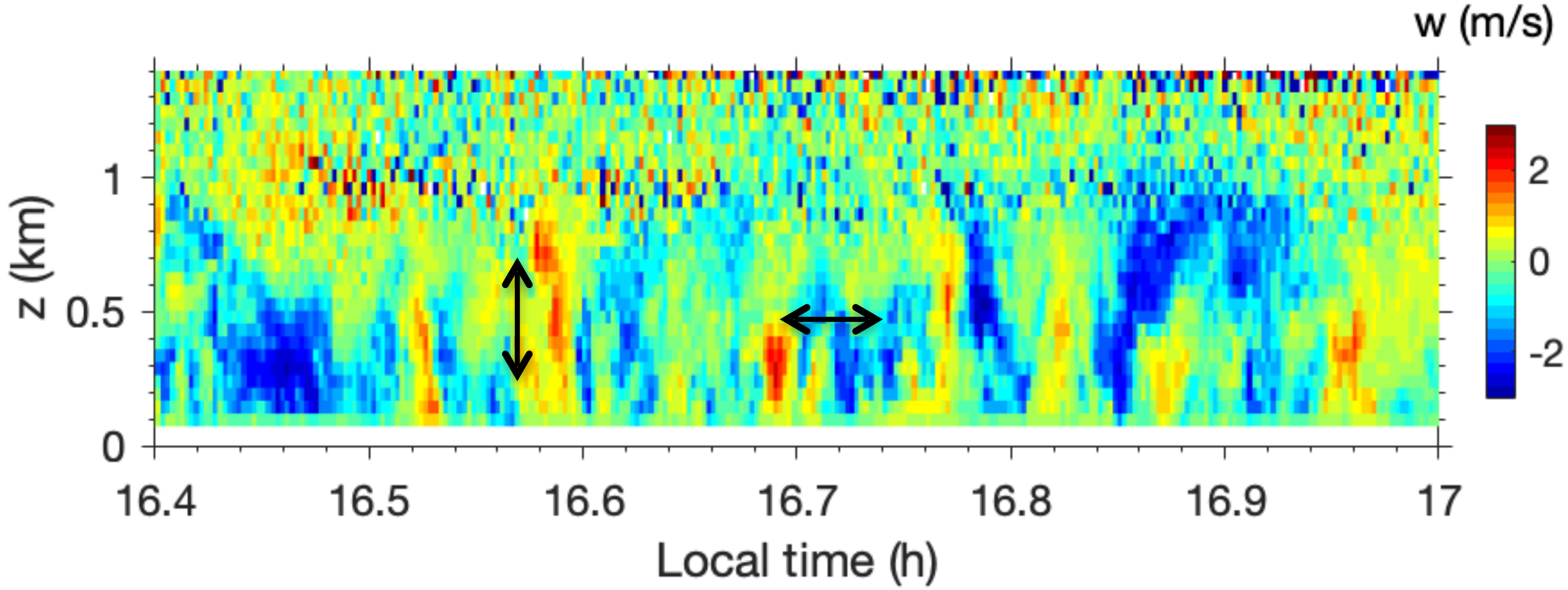
q: < 0.1 g/kg

T: < 0.7 °C @ 1 km

→ Comparaison with RS show **bias and overlap correction** issue for temperature

→ Temperature natural fluctuations ~ 0.4 K (**1.5 ‰**)

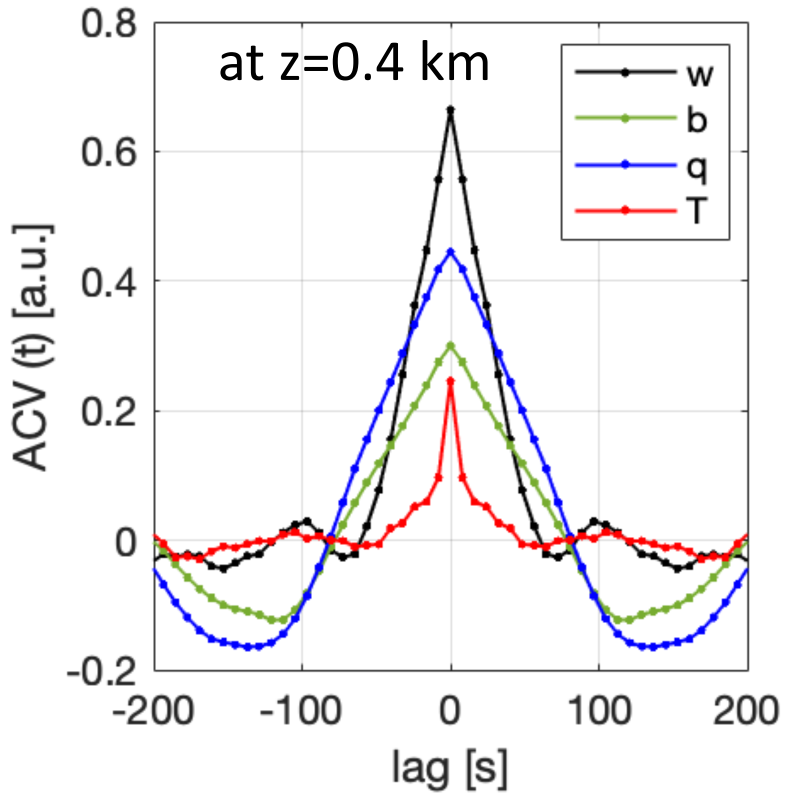
Turbulent scales and lidar time/space resolution

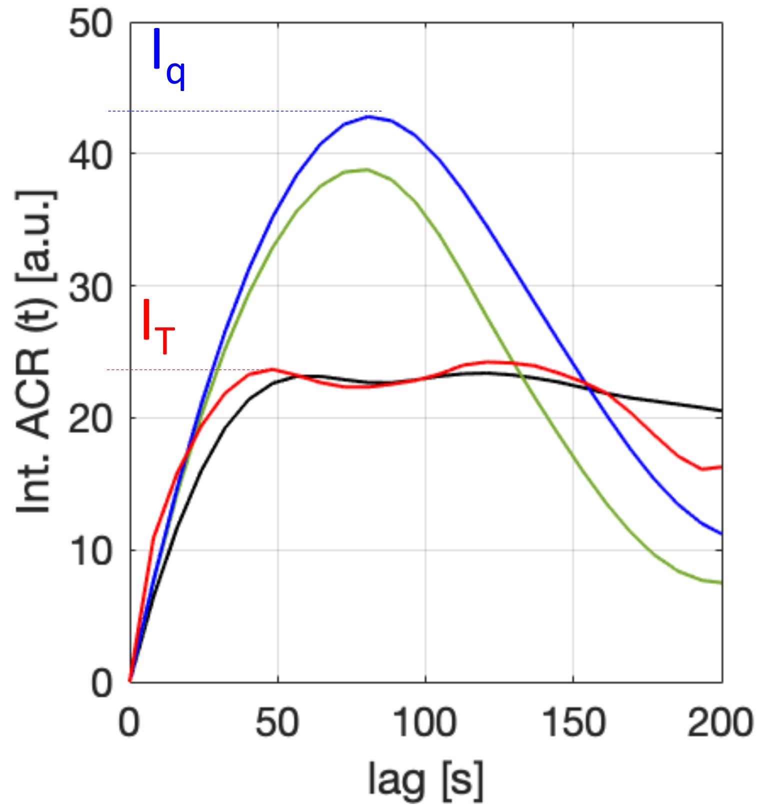


Spatial / temporal coherent structures

Integral scale:

$$I = \max\left(\int_0^{\infty} ACR(x)\,dx \right)$$





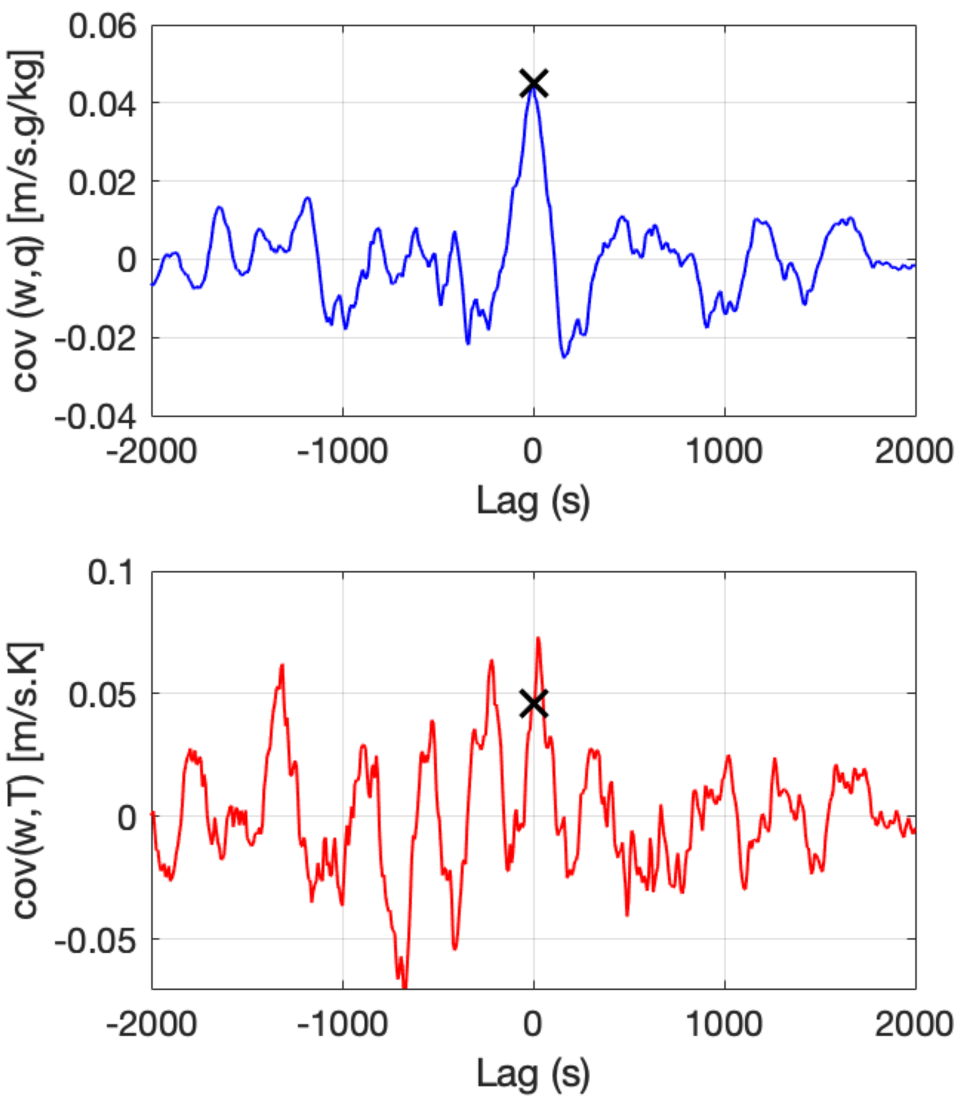
→ Similar length scale for wind and temperature ~ 25 s

→ Larger length scale for densities (particles, H2O) ~ 40 s

Time and space average of lidar measurements have to be lower than temporal and space integral scales of turbulence respectively to avoid biases in statistical calculations (Flux, moments)

Lidar eddy-covariance flux estimates

Cross covariance

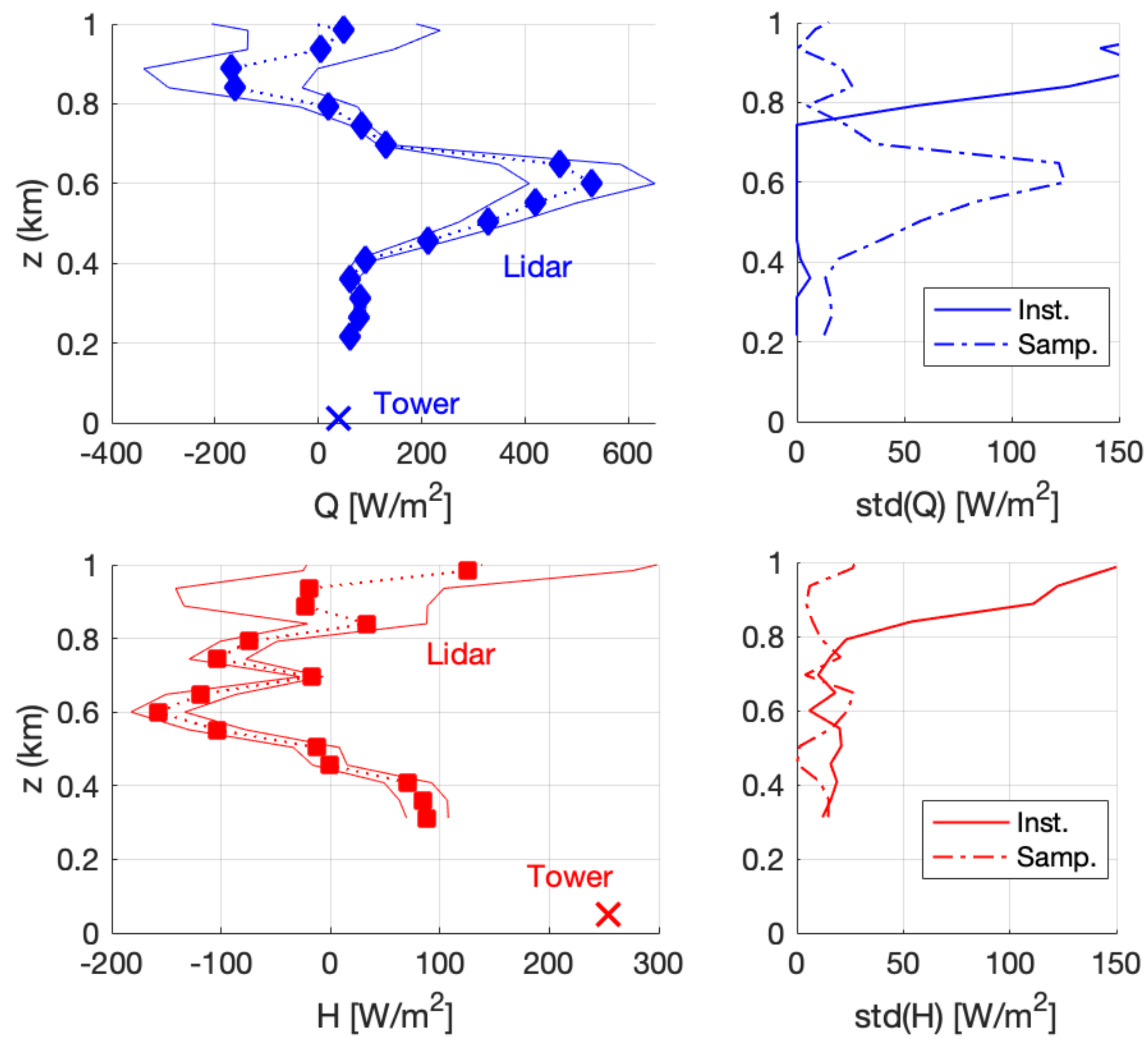


$$Q = L_v . \overline{w'q'}$$

$$H = \rho_a . C_p \overline{w'T'}$$

Lidar flux profiles

Error

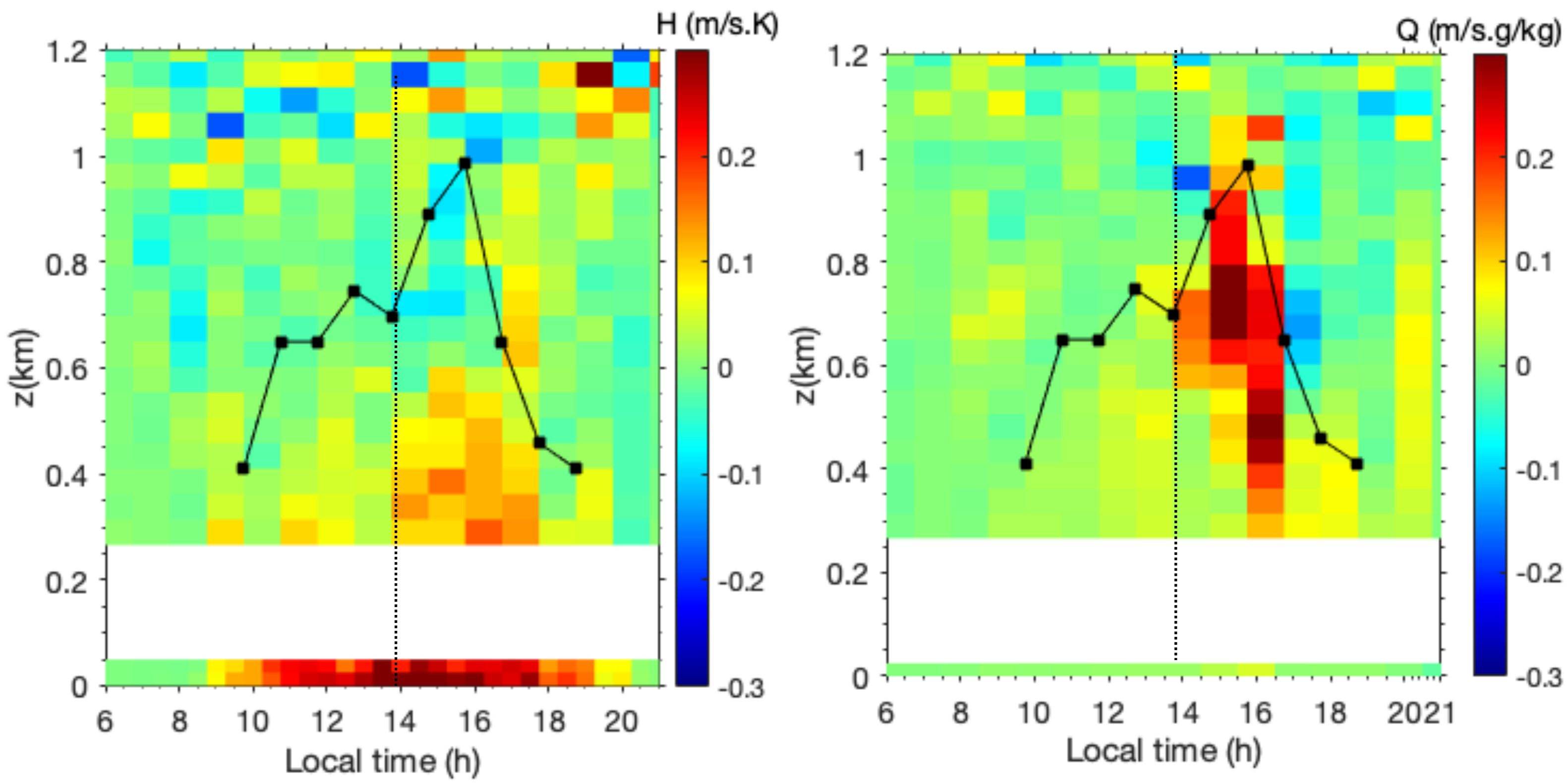


(Giez 1999; Gibert, 2011; Behrendt 2019)

→ **significant noise contribution** for w'T' (maximum is not clearly seen in cross-covariance, integral of co-spectrum is not directly applicable like for in situ data)

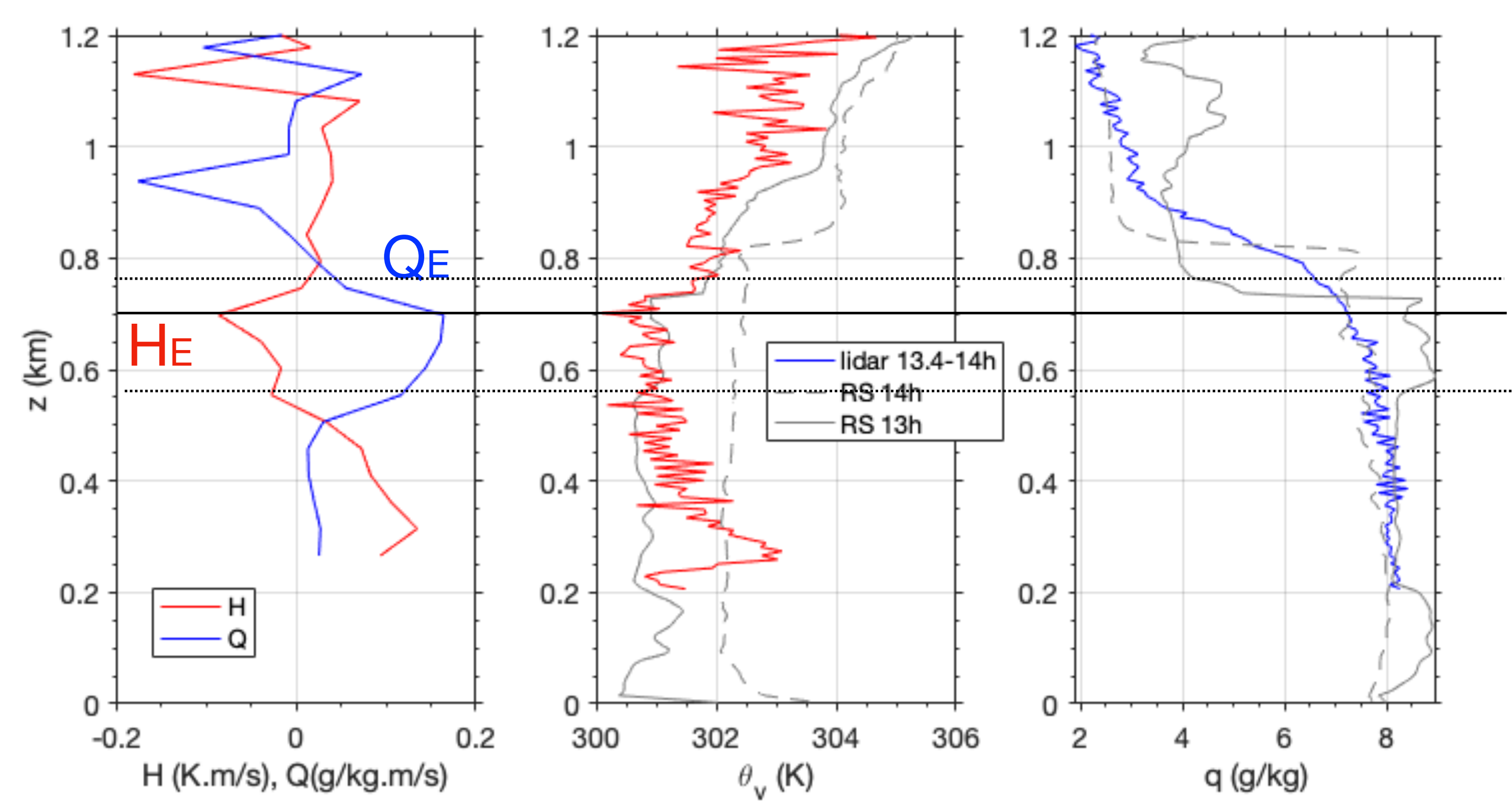
→ **time synchronization** (lidars acquisition, scanning devices) is **necessary**

Flux profiles - 2021/07/16 case



- RS gives an instantaneous profile vs lidar provides a mean in time (LES gives a ensemble mean) - ergodicity issue?
- RS profile is not vertical as the balloon moves horizontally
- Mean gradient in temperature and water vapour seems to follow different laws (advection issue for water vapour)

14h

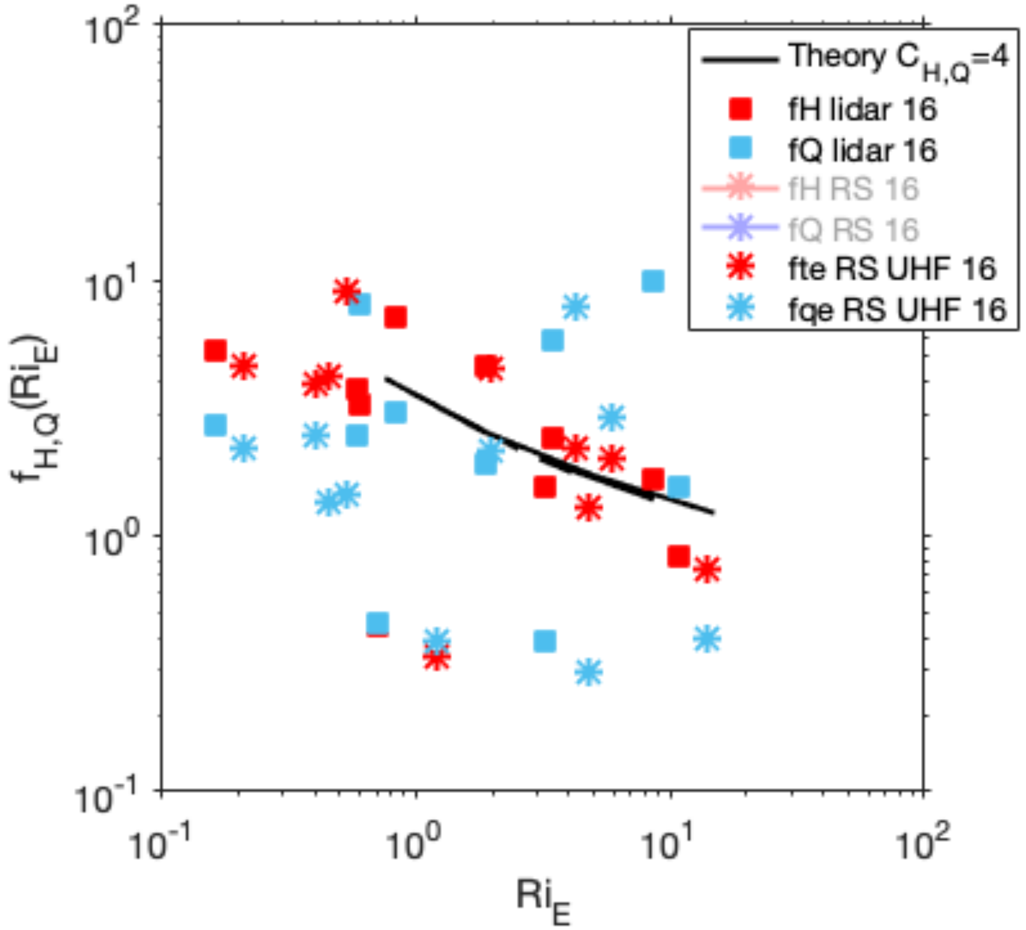


zi

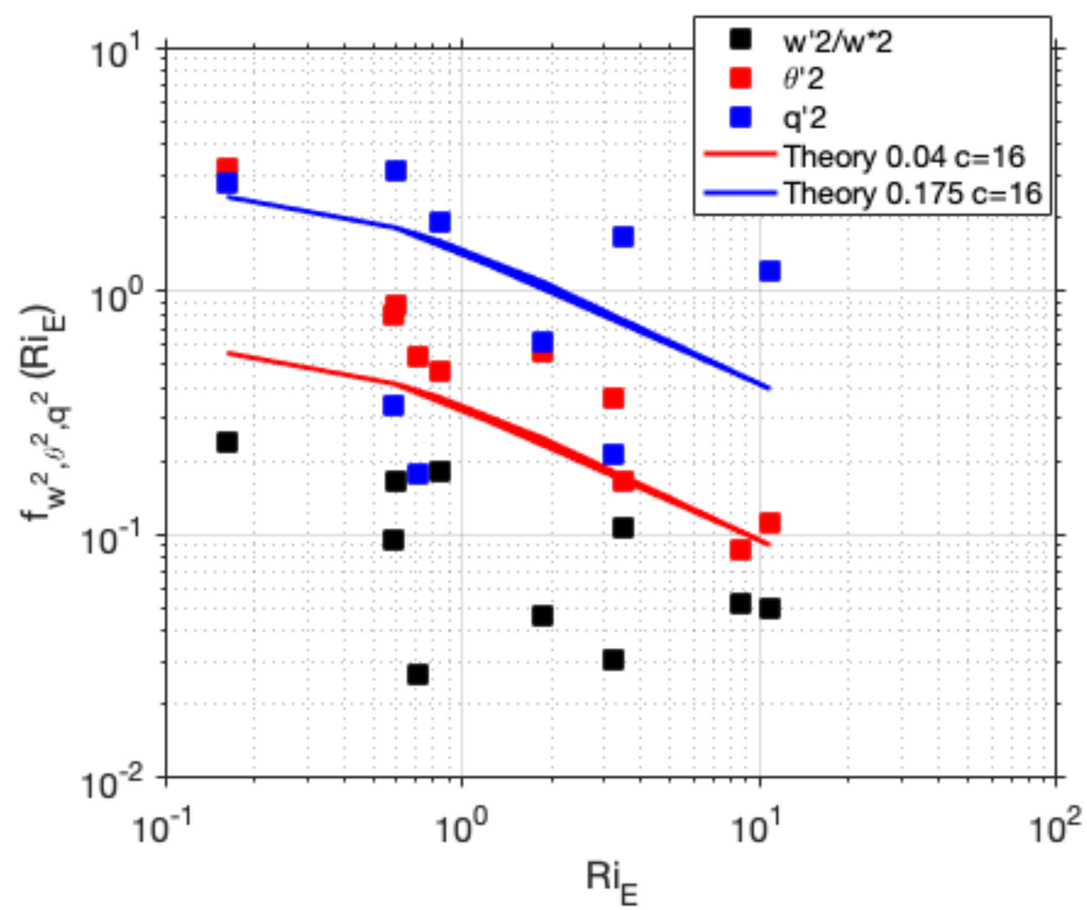
entrainment layer

Parametrization of the interfacial layer - 2021/07/16 case

Flux



Variances



$$H_E = -C_H w_*^2 \frac{\gamma_E}{N_E} f_H(Ri_E)$$

$$Q_E = -C_H w_*^2 \frac{g_E}{N_E} f_Q(Ri_E) \qquad f_{H,Q}(Ri_E) = \frac{1 + c_{H,Q}/Ri_E}{\sqrt{1 + 1/Ri_E}}$$

For the first time we have the opportunity to test parametrizations in the entrainment layer
Temperature seems to follow gradient Richardson based similarity law for flux and variance.
This seems to be more difficult for water vapour

(Sorbjan, BLM, 2005, 2006; Wulfmeyer, JAS, 2016)