Convective boundary layer depth and structure from UHF wind profilers

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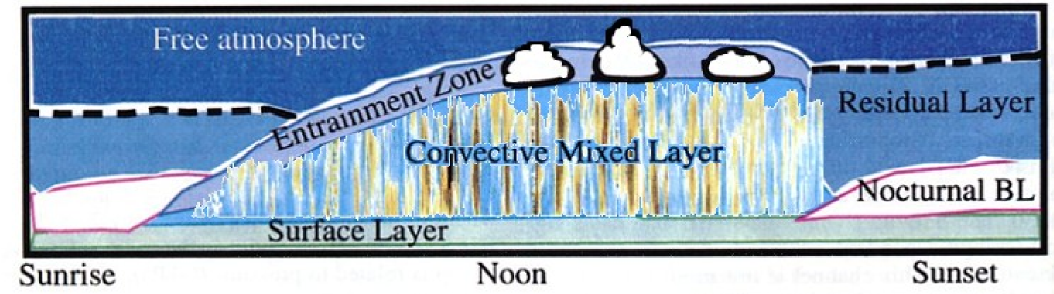
Motivation and context

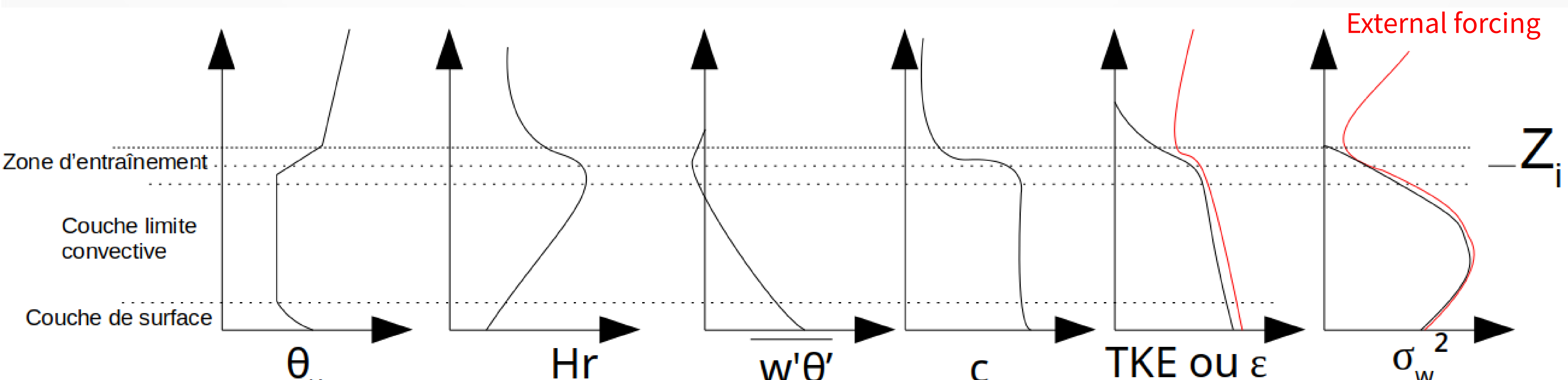
- The wish at LAERO-P2OA (Permanent multi-instrumented site) to improve our UHF-based Zi estimates, in order to be able work on long term series (> 20 years)
- The complex structure of the convective boundary layer observed in LIAISE, and the interest of estimating the various interfaces of the low troposphere...
- … to understand the interaction between boundary layers developped over contrasted surfaces

CBL depth definitions



Different approaches lead to different definitions :

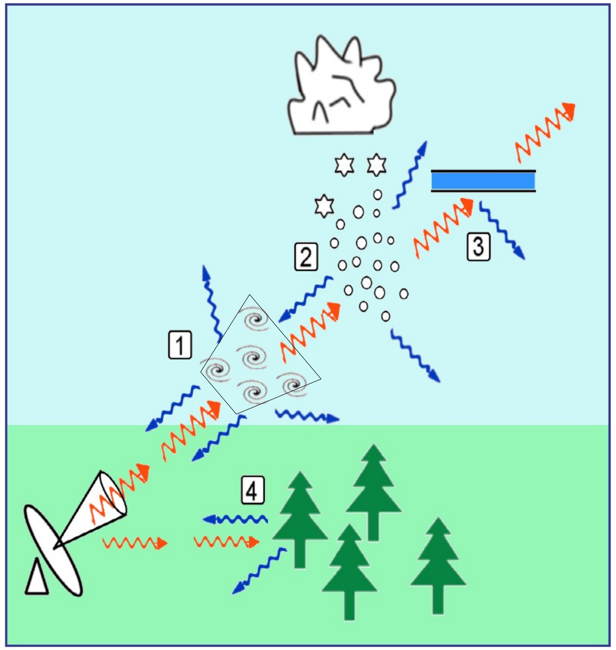
- **Thermodynamical :** Zi is the height at which one finds
  - A large positive gradient of potential temperature
  - A large negative gradient of humidity, a maximum of relative humidity
  - A minimum of buoyancy flux
- **Distribution of tracers :** Zi is the height at which the scalar concentration drastically decreases
- **Turbulence intensity :** Zi is the height at which Turbuent Kinetic Energy (TKE) or TKE dissipation rate (ε) falls



[Zhang, 2020] : Research progress on estimation of the atmospheric boundary layer height. Journal of Meteorological Research

How the UHF WP can see it ?

- **U**ltra **H**igh **F**requency Radar Wind Profiler (Degreane®)
- Electromagnetic waves backscatterd by air dielectrical discontinuities**, within a volume (75 m** verticale resolution, 8 deg beam aperture**)**
- σ_w^2 (vertical velocity variance) **and ε** (Turbulent Kinetic Energy Dissipation rate) deduced from Doppler spectral width
- C_n^2 (air refractive index structure coefficient of) calculated from reflectivity
- C_n^2 increases with temperature/moisture fluctuations or gradients within the volume



Local maximum of C_n^2 at Zi

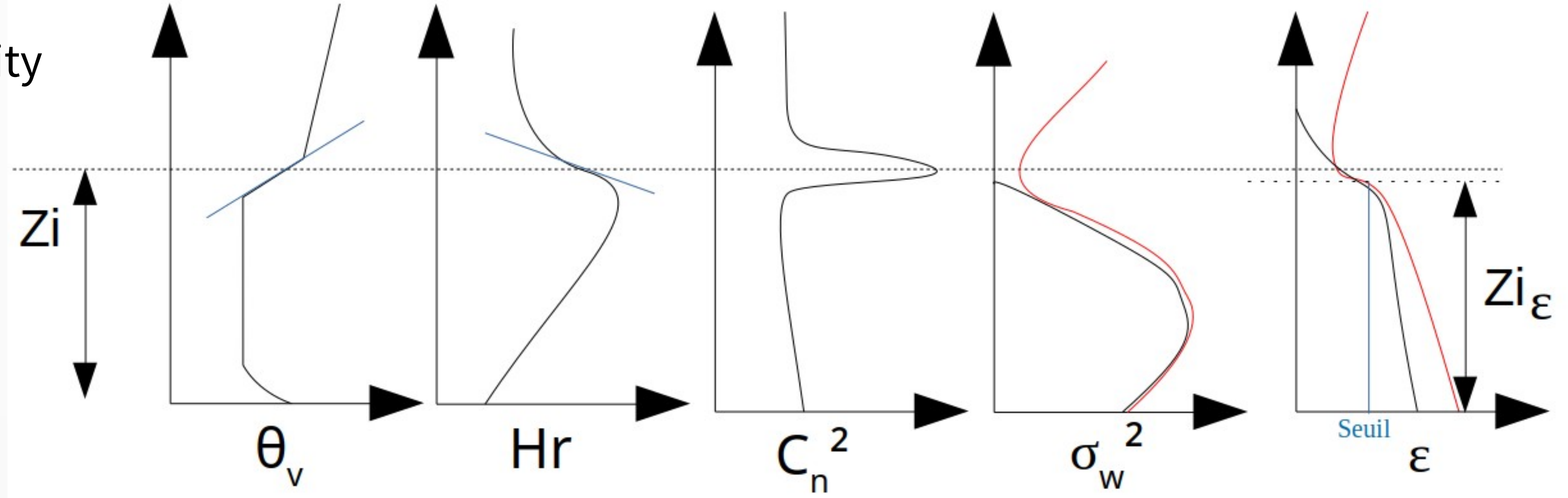
→ Typical method follows temporal continuity of lowest local maximum

Angevine et al 1994 and many others

Decrease of local min of σ_w^2 and ε

→ Another method detects summit of the turbulent layer (threshold)

Jacoby-Koaly et al 2002, Nilsson et al 2016



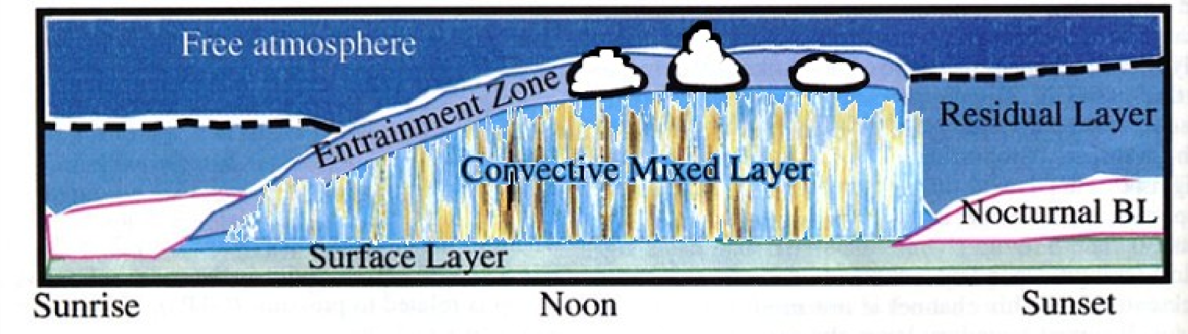
Proposed new algorithm

<u>Motivation : Challenges raised with previous methods</u>

- Upper inversions can be stronger than CBL top inversion, and lead to a maximum of Cn2
- Morning and afternoon transitions tricky (often may catch residual inversions)
- Temporal continuity is not always sufficiant to deal with those
- Cases with clouds, complex structure lead to erroneous estimates

<u>→ A new approach :</u>

- Combine C_n^2 local maximum and σ_w local minimum with a new parameter :



$$NP_x = \frac{\left[C_n^2 / \overline{C_n^{2\ profil}} \right]}{\left[\sigma_w^x / \overline{\sigma_w^{x\ profil}} \right]}$$

(NP_3 and NP_0 used here)

→ search for local maximum of NP_x

→ possibly consider a secondary local maximum

- Specific search of the « first Zi estimates » of the day (on first gates)
- Growth rate threshold (375 m since last estimate)
- Use of Zi_ε for first Zi estimate or adjustment of NPx local max choice

- Search Zi within : 225m => 3 000m
- Period of interest : from sunrise to sunset, out off rain and fog
- Use of median filters

From measured variables to Zi estimates

Input variables	C_n^2, σ_w, ε, and w	2 min	Main input variables
	H	30 min	t_{init} assessment (optional)
	RH	1 s	Fog occurrence estimation (optional)
Filtered variables	C_n^2, σ_w, and ε	5 min	
Calculated variables	NPx and Z_{i_ε}	5 min	Key intermediate variables
	t_{init}	1 d	Key CBL growth starting variables
Auxiliary variable	CBH	1 min	Configuration optimization
Final variables	$Z_{i_{\text{NP3}_{\text{std}}}}$	5 min	Best estimate
	$Z_{i_{\text{NP0}_{\text{std}}}}$, $Z_{i_{\text{NP0}_{\text{sup}}}}$, and $Z_{i_{\text{NP0}_{\text{sub}}}}$	5 min	Complementary estimates
	QF	5 min	Quality assessment

Configuration of detection criteria

Criterion number	Parameter	Value	Comments
1	Integration time	5 min	
2	Time median filter C_n^2	Three points	$\sim$ 6 min
3	Time median filter ε	Three points	$\sim$ 6 min
4	Time median filter σ_w	Four points	$\sim$ 8 min
5	Height median filter C_n^2	Zero points	0 m
6	Height median filter ε	Zero points	0 m
7	Height median filter σ_w	Three points	225 m
8	Growth limit	375 m	between two effective assignments
9	Relative humidity limit at 2 m	90 %	
10	NPx value limits	NPx profile mean	
11	Secondary maximum NPx value limit	90 % before and 50 % after 10:00 UTC	criterion no. 10 applied
12	Z_{i_ε} option	True	to exceed the growth limit

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9	Relative humidity limit at 2 m	90 %	
10	NPx value limits	NPx profile mean	
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12	Z_{i_ε} option	True	to exceed the growth limit

Optional→ different estimates

« Zi » estimates : heights of several interfaces

Different estimates made by CALOTRITON traduce the potential complexity of the low troposphere, and existence of several interfaces :

- **Zi_{ε} : par intensité de la turbulence**
- **Zi_{NPx} ($Zi_{NP0 <=> Cn^2}$ et Zi_{NP3}) thermodynamique :**
  - **$Zi_{NP3 « std »}$:** « standard configuration » with x=3 → « Best estimate »
  - **$Zi_{NP0 « std »}$:** « standard configuration » with x=0 → Close to older approach
  - **$Zi_{NP0 « sup »}$:** Without crit. 9-10-11 & t_{init} → Enables to catch residual inversions
  - **$Zi_{NP3 « sub »}$:** Without crit. 11 → Enables to catch internal BL

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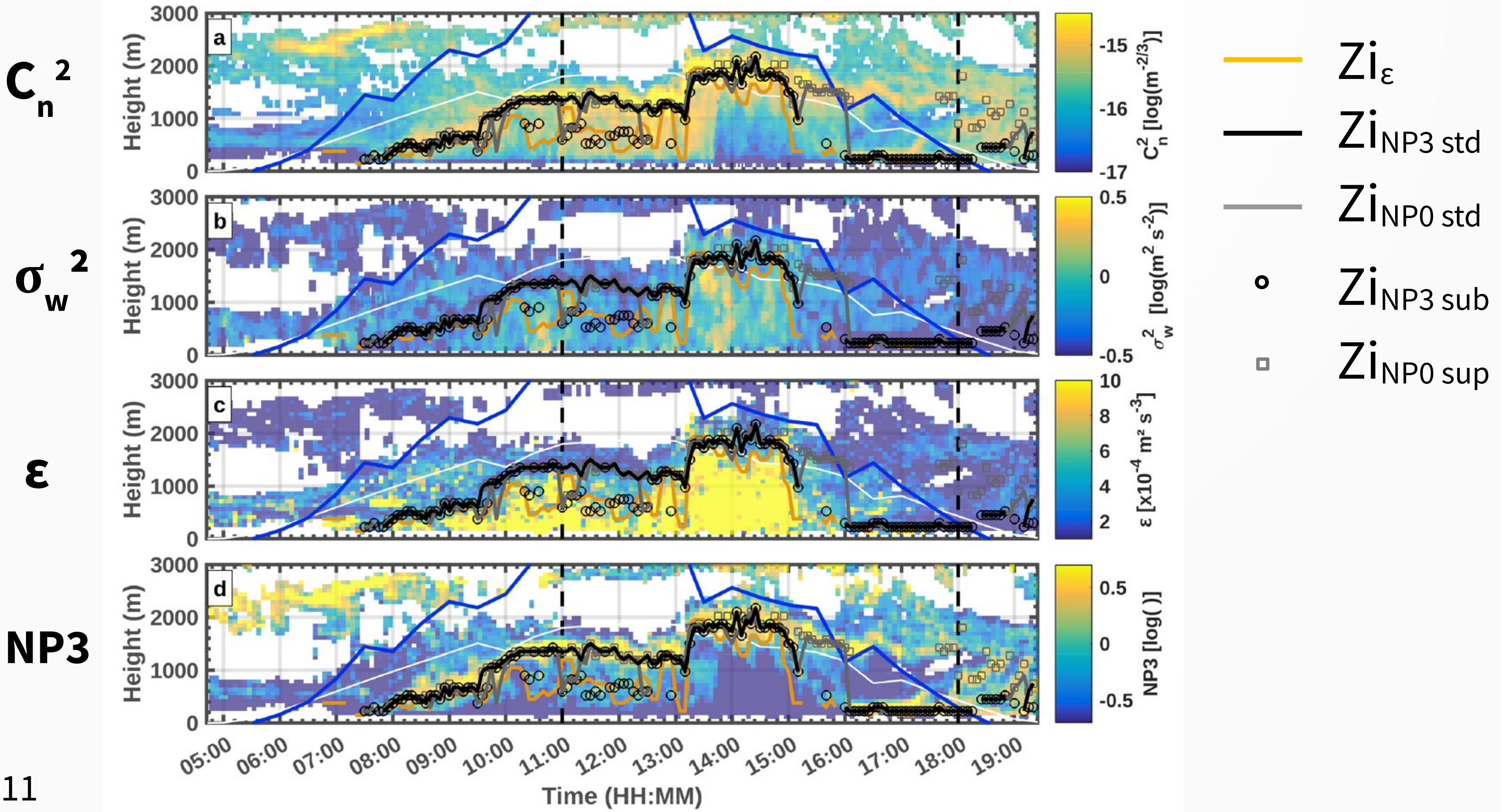
A **flag system** is applied to further qualify the resulting estimates, and help using them

QF =1, 2, 3, 4 **according to the consistency of those 4 different estimates** between each other

Ex : QF = 1 → All are equal → High confidence, « simple » CBL.

QF = 5 → All are different → Low confidence of the « Best estimate », High complexity documented by the 4 estimations.

Results : example of 27 July 2021, Els Plans



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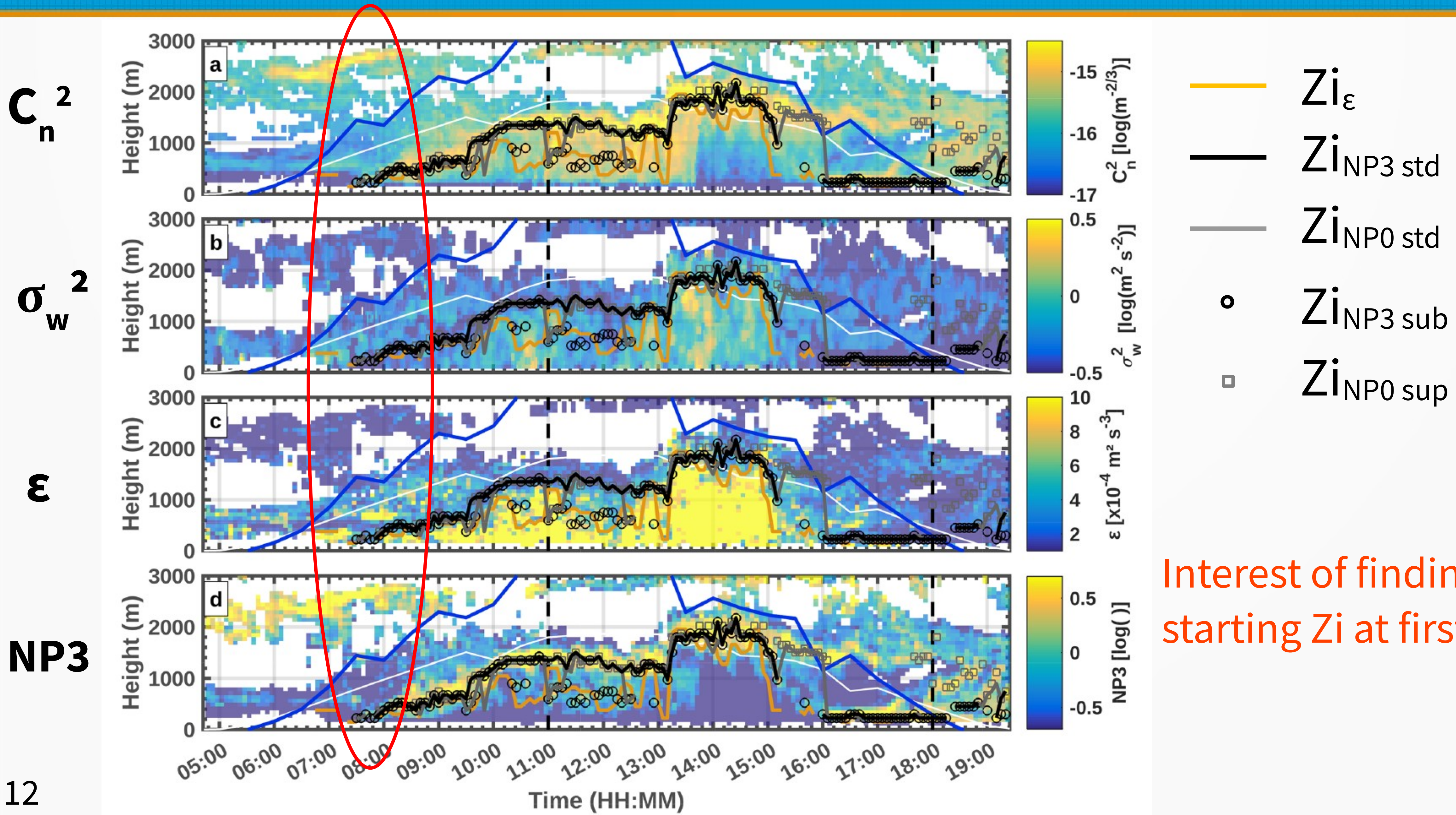
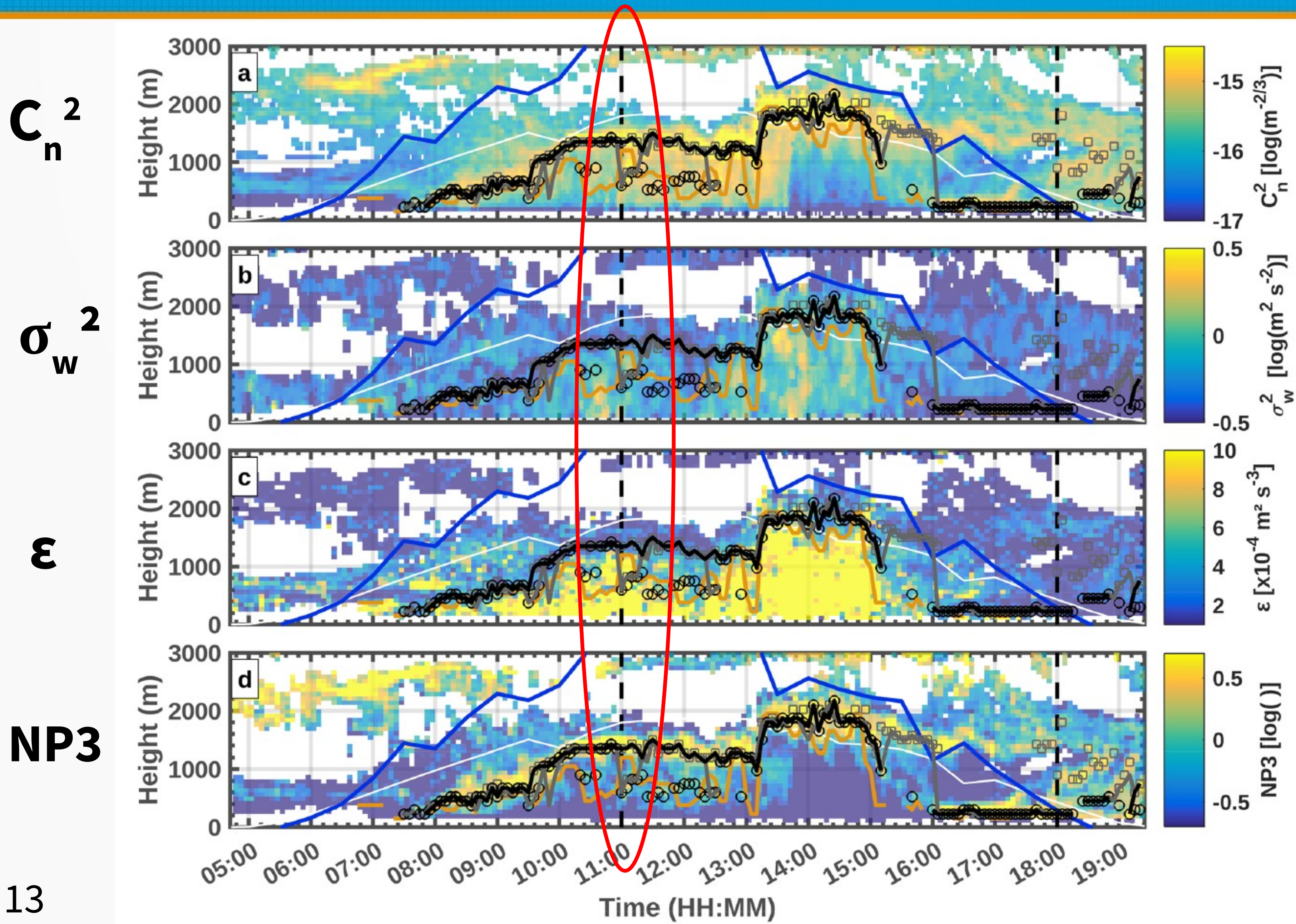
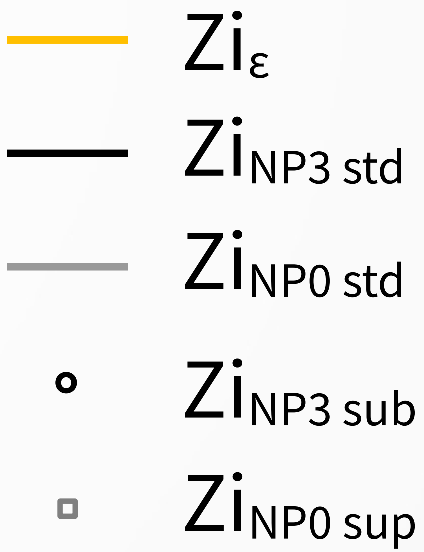


Interest of finding a starting Zi at first gates

Results : example of 27 July 2021, Els Plans

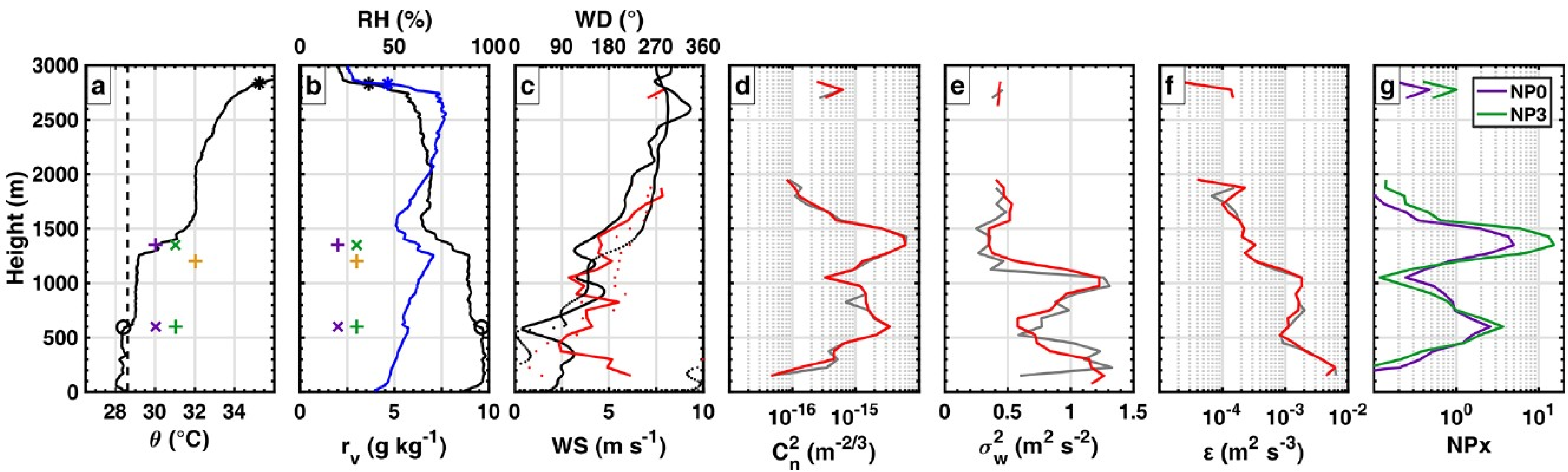




- Detected internal boundary layer
- Advection from the East (consistent with thinner CBL at La Cendrosa)

Results : example of 27 July 2021, Els Plans

Radiosounging at Els Plans - 27 July, 1100 UTC.



UHF-based Zi estimates :

x Zi NP0 std x Zi NP3 std + Zi ε

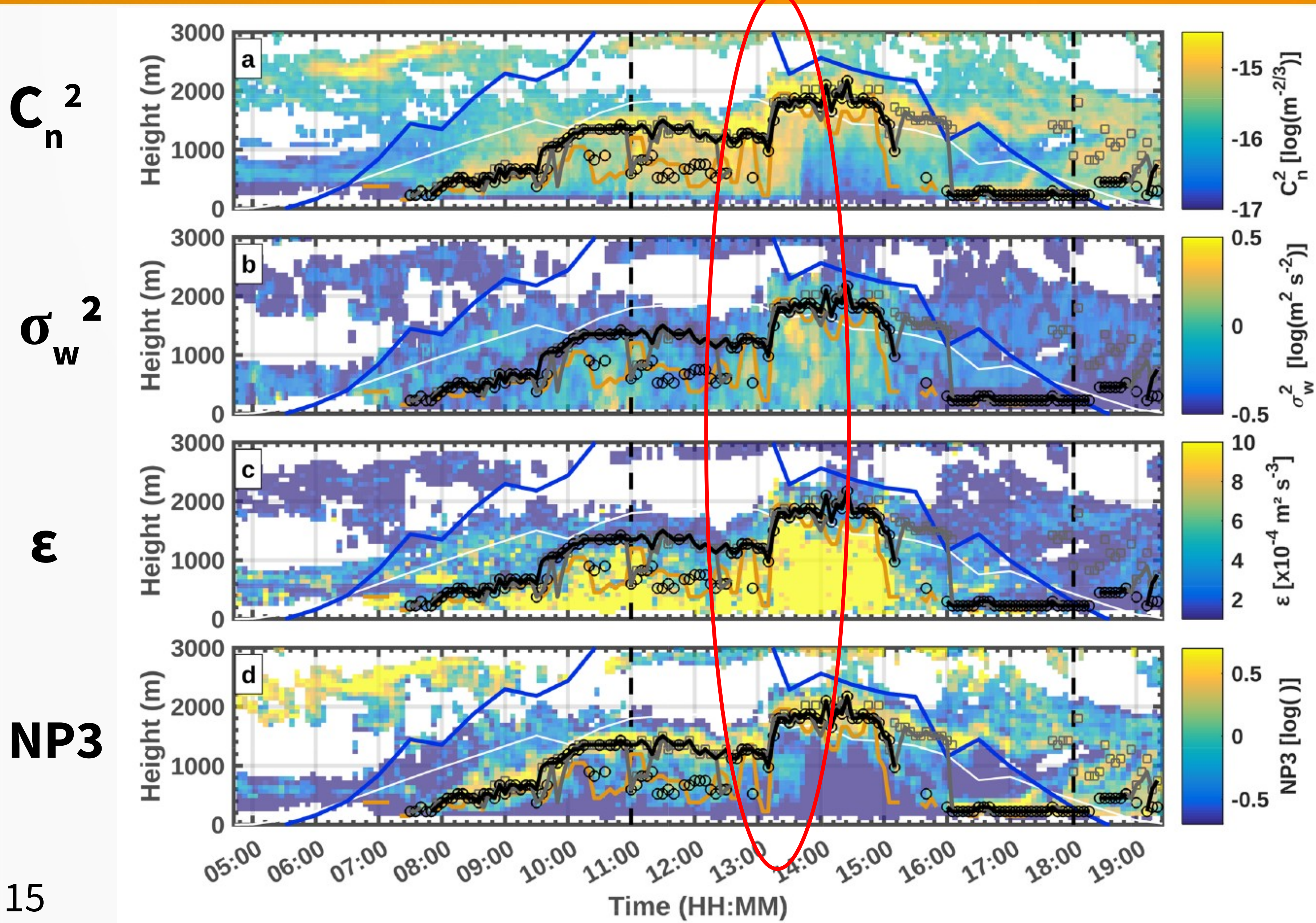
+ Zi NP0 sup + Zi NP3 sub

In-Situ-based Zi estimates :

o Parcel method

★★ Temperature and moisture gradient methods

Results : example of 27 July 2021, Els Plans



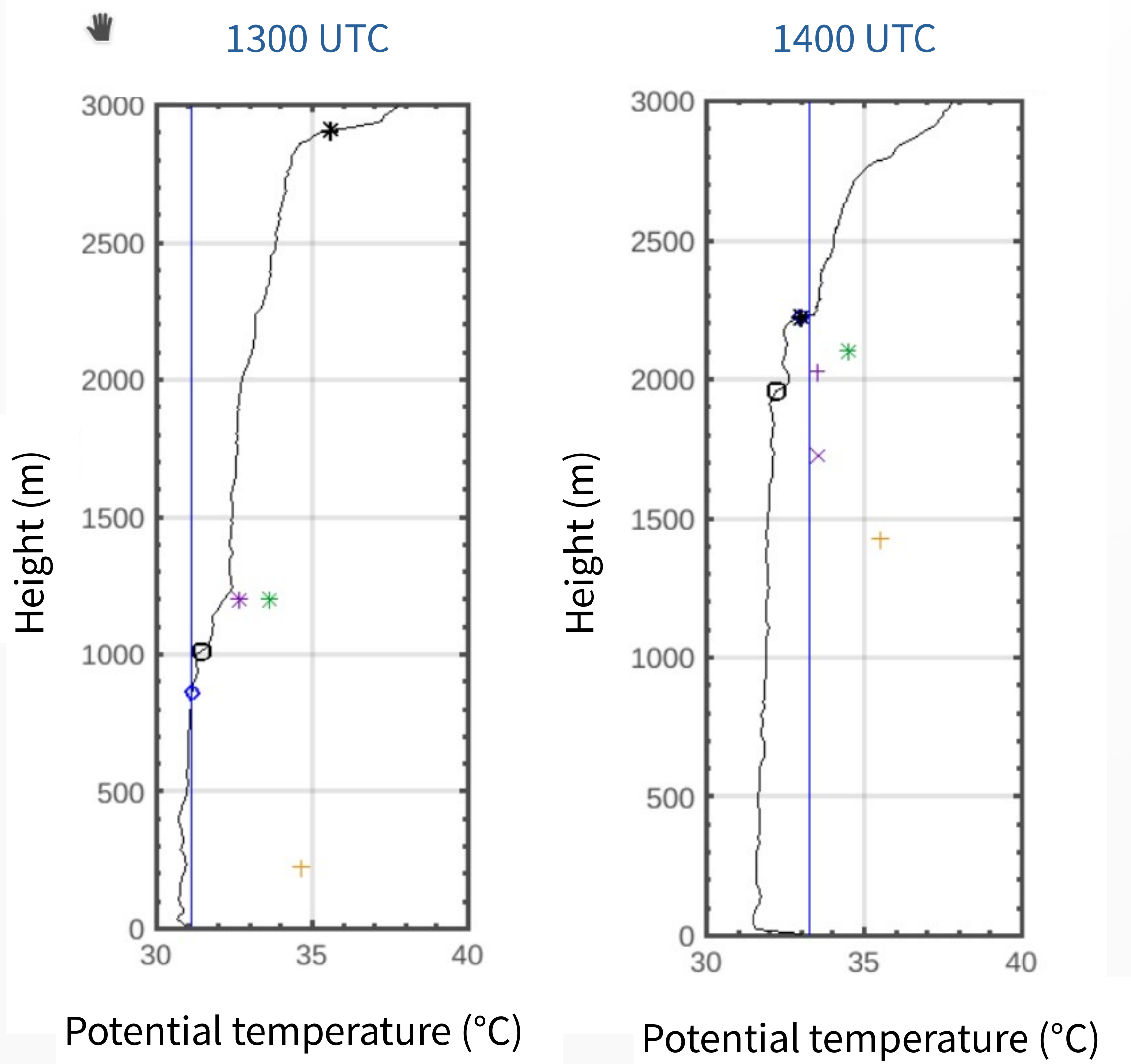
- Zi_{ε}
- $Zi_{NP3\ std}$
- $Zi_{NP0\ std}$
- $Zi_{NP3\ sub}$
- $Zi_{NP0\ sup}$

- Rapid growth (beyond threshold)

« Authorized » thanks to the use of Zi_{ε}

Results : example of 27 July 2021, Els Plans

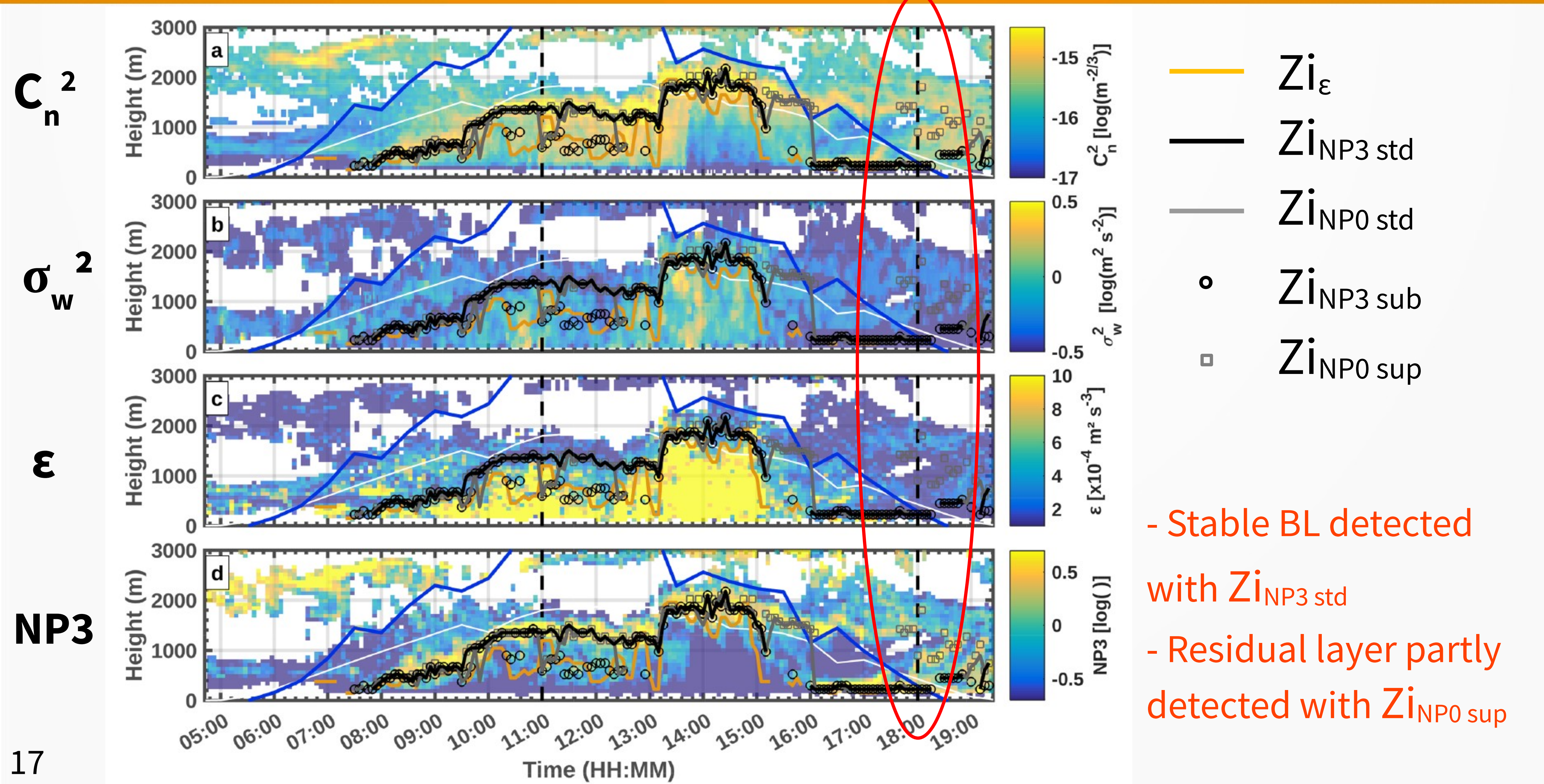
Radiosounging at Els Plans - 27 July, 1300 and 1400 UTC



- Rapid growth (beyond threshold)

« Authorized » thanks to the use of Zi_{ε}

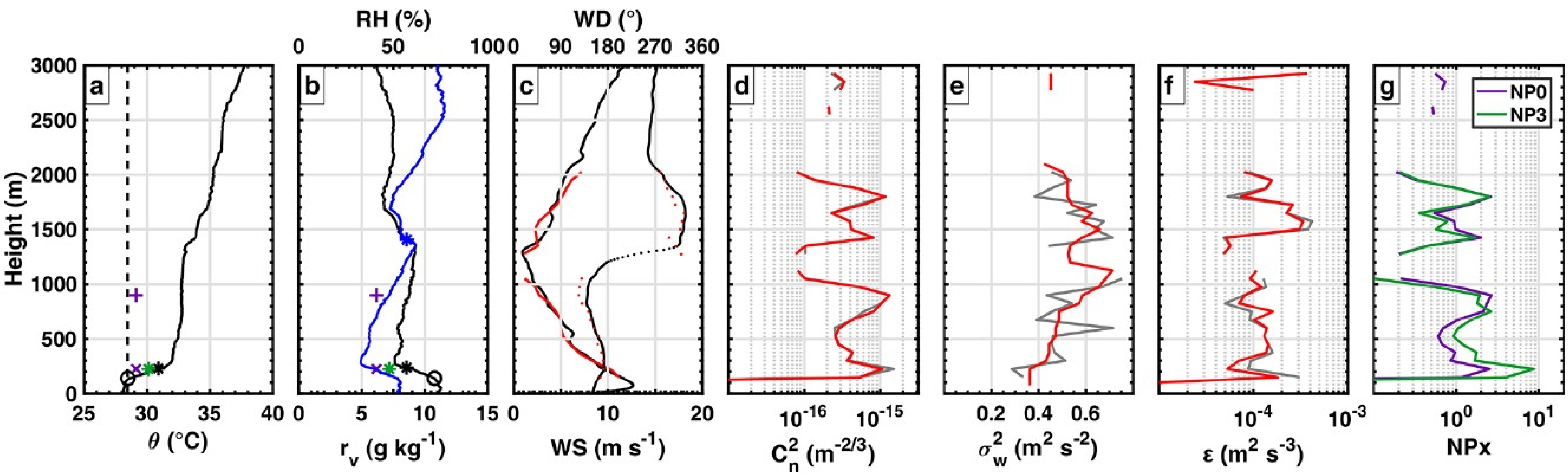
Results : example of 27 July 2021, Els Plans



- Stable BL detected with $Zi_{NP3\ std}$
- Residual layer partly detected with $Zi_{NP0\ sup}$

Results : example of 27 July 2021, Els Plans

Radiosounging at Els Plans - 27 July, 1800 UTC



UHF-based Zi estimates :

x Zi NP0 std x Zi NP3 std + Zi ε

+ Zi NP0 sup + Zi NP3 sub

In-Situ-based Zi estimates :

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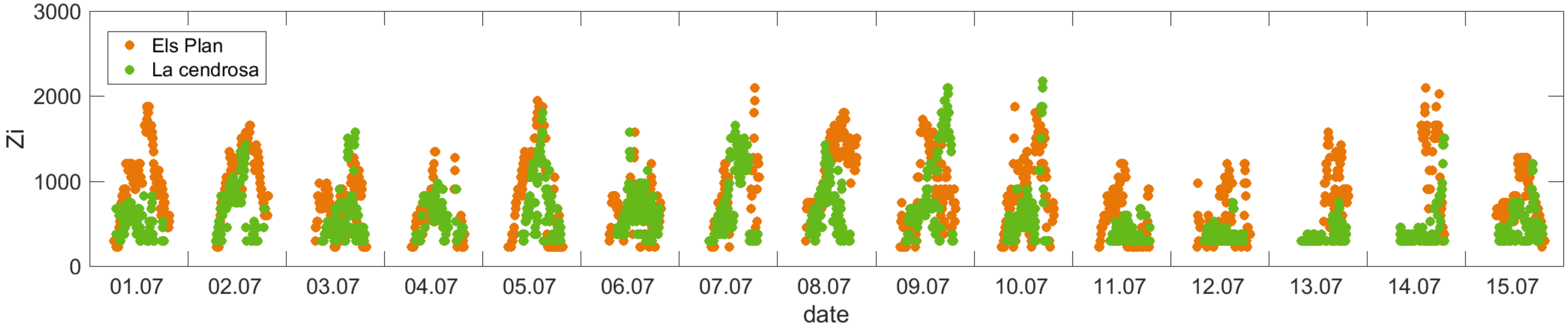
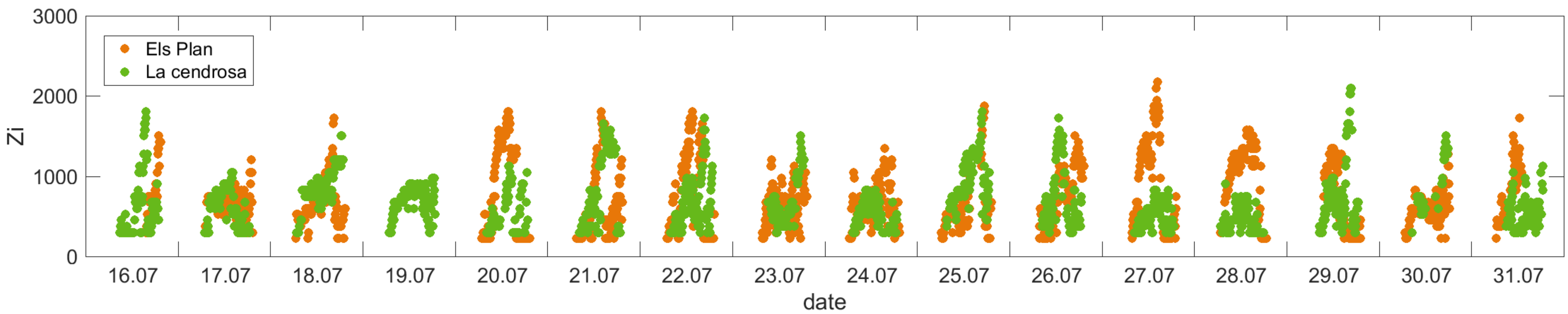
★★ Temperature and moisture gradient methods

Results : Time series of Zi
« Best estimates » through July month





Conclusion

- **Improvement** of UHF-WP-based algorithm for Zi detection
- This method allows to **document the complexity of the vertical structure** of the low troposphere (not reduce it to one single textbook CBL that is not always observed)
- **Developed and evaluated** with LIAISE (2021), BLLAST (2011), and P2OA (long term, Y> 2010) data, with the 2 UHF wind profilers and many soundings
- Some errors still remain during morning and evening transitions
- Zi estimates from UHF wind profiler are complementary to those obtained from in situ measurements
- Complex situation makes it tough for any algorithm and any observation system
- **Zi various estimates and quality flags are available** on the LIAISE database

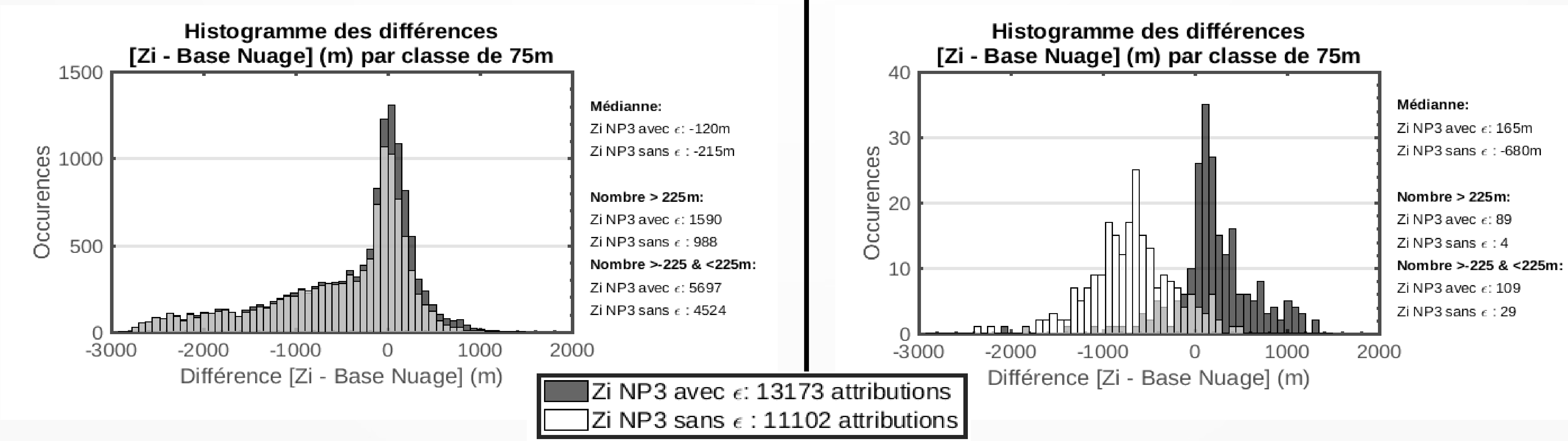
  Feedbacks welcome !
- CALOTRITON is descrived in details in Philibert et al 2024

Optimizing the algorithm criteria

Comparison of Zi estimates with cloud base height from P2OA ceilometer CT25K

All NP3 attributions with and without ε

~200 attributions with more than 225m difference



Autres histogrammes comparés :

Attributions par NPx, Valeurs de ε à hauteur de Zi, Différence Zi-Ziε, ...

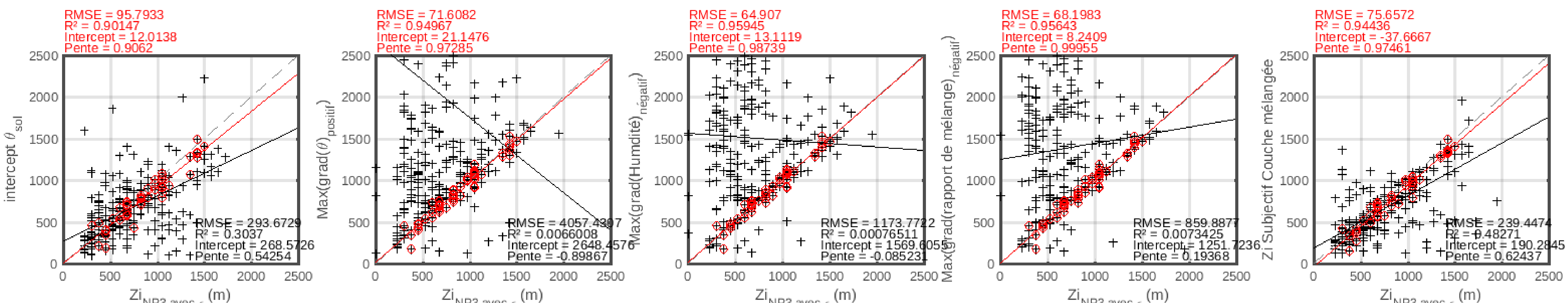
Comparison with in situ profiles

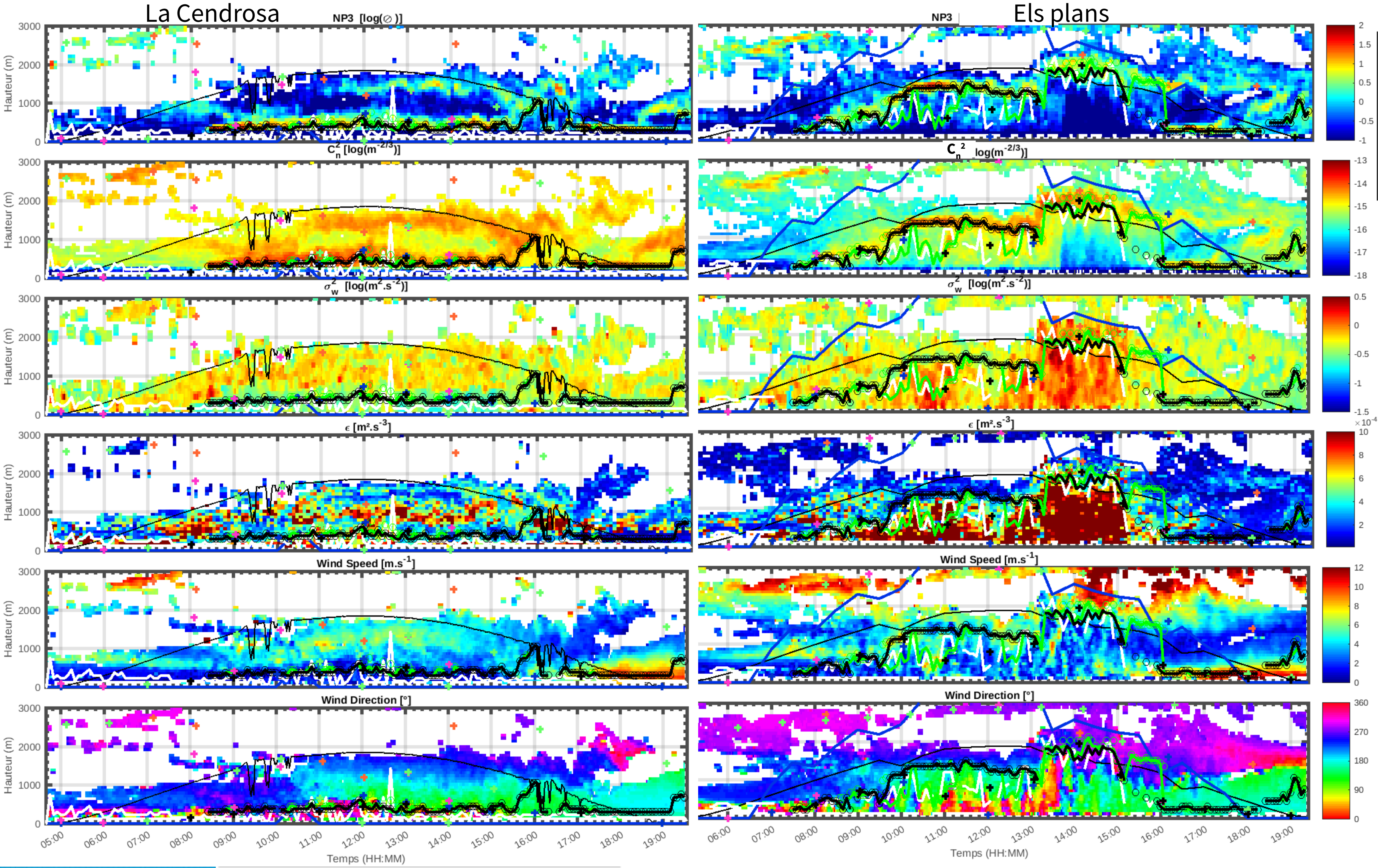
- Two intensive field campaigns, LIAISE and BLLAST :
  - LAERO UHF WP (site1 during BLLASTand at Els Plans during LIAISE)
  - CNRM UHF WP (site 2 during BLLAST and at La Cendrosa during LIAISE)
- Comparisons between in-situ-based Zi (drone & balloon) and UHF-NP3-based Zi estimates

  In-situ estimates : many techniques (θ & r_v gradients, parcel methode, maximum RH, subjective)

  – Black : all profiles

  – Red : only cases where in-situ estimates have less than 200 m diffference, & without Els Plans




La Cendrosa
Els plans
NP3 [log(⊘)]
NP3
C_n^2 [log(m$^{-2/3}$)]
σ_w^2 [log(m^2.s^{-2})]
ϵ [m².s^{-3}]
Wind Speed [m.s^{-1}]
Wind Direction [°]
Hauteur (m)
Temps (HH:MM)

- $Z_{i_{\mathrm{NP3}_{\mathrm{std}}}}$ is estimated with the standard configuration for NP3 as described in Table 4, which is considered to be the best set of attributions.

- $Z_{i_{\mathrm{NP0}_{\mathrm{std}}}}$ is estimated with the standard configuration for NP0 as described in Table 4.

- $Z_{i_{\mathrm{NP0}_{\mathrm{sup}}}}$ is estimated from NP0 as described in Table 4 but without applying criteria nos. 9, 10, and 11. With this configuration, the 375 m growth limit (no. 8) is applied between the Z_i searched for and the already allocated maximum Z_i. There is also no t_{init} restriction after sunrise. This configuration allows for the search for levels higher than the estimates made with a standard configuration, which may correspond to the top of a residual layer or to Z_i if the standard configuration assigns it to a TIBL top.

- $Z_{i_{\mathrm{NP3}_{\mathrm{sub}}}}$ is estimated from NP3 as described in Table 4 but without applying criterion no. 11. With this configuration, the NPx profile mean of the criterion no. 10 is replaced by the median, which gives lower values most of the time, mainly because of high values of C_n^2. This