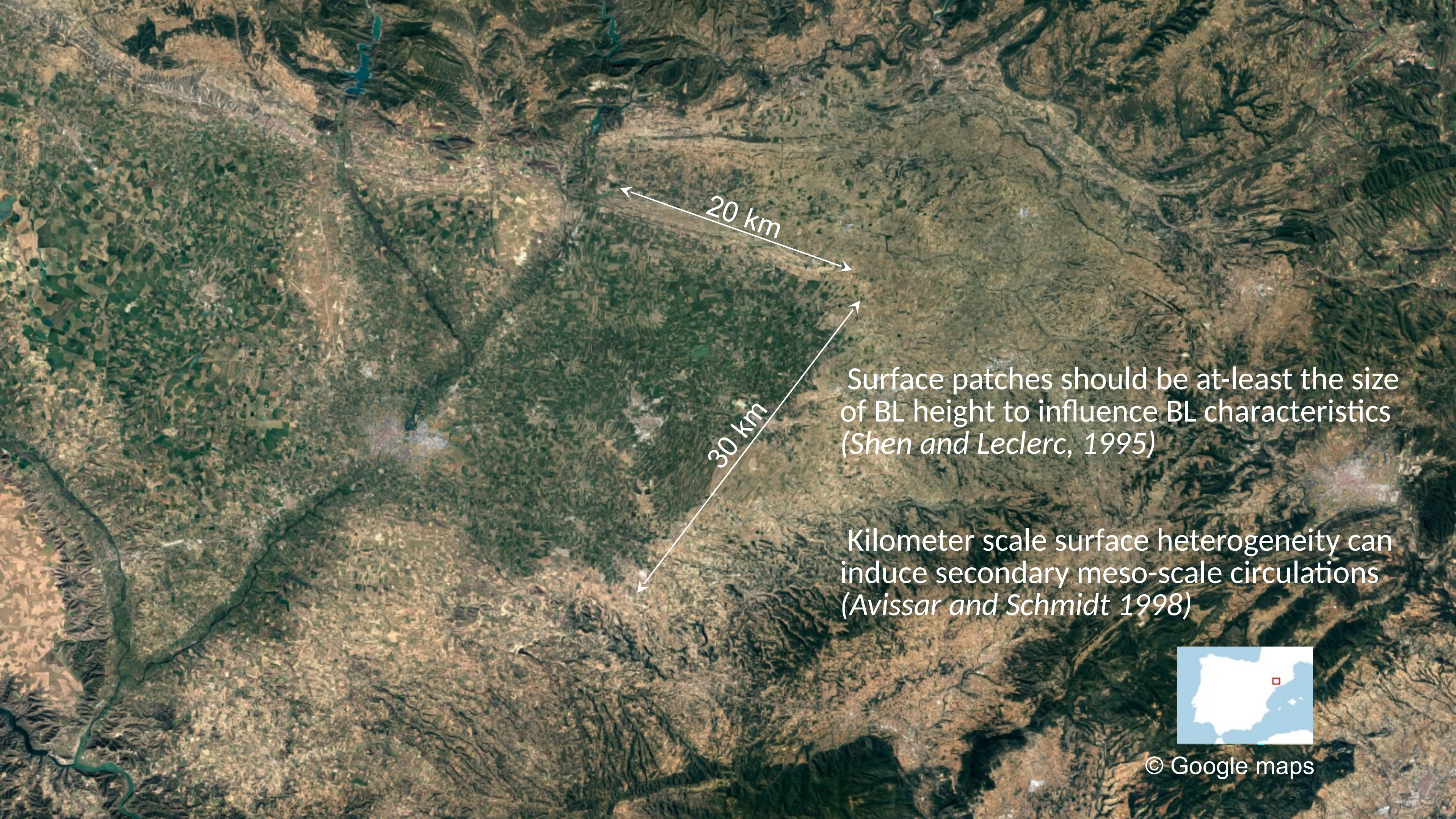
Characterictics of turbulence observed in the low troposphere over the LIAISE highly-contrasted area

Emmeline FRANCOIS (Master student then)
Guylaine CANUT (CNRM), Marie LOTHON (LAERO)

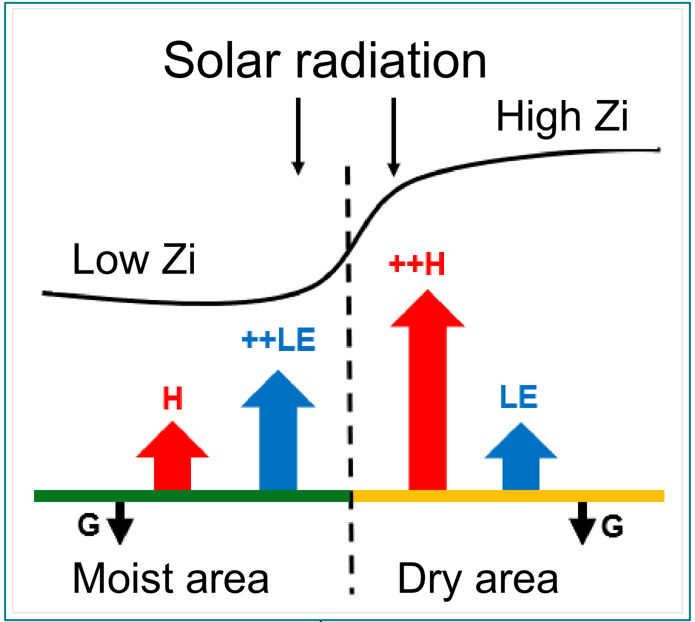

20 km
30 km
Surface patches should be at-least the size of BL height to influence BL characteristics
(Shen and Leclerc, 1995)
Kilometer scale surface heterogeneity can induce secondary meso-scale circulations
(Avissar and Schmidt 1998)
© Google maps

Introduction

CBL = Convective Boundary Layer

Zi = CBL depth

H : Sensible Heat Flux
LE : Latent Heat Flux



⇒ Which turbulent processes involved over two very contrasted surfaces ?

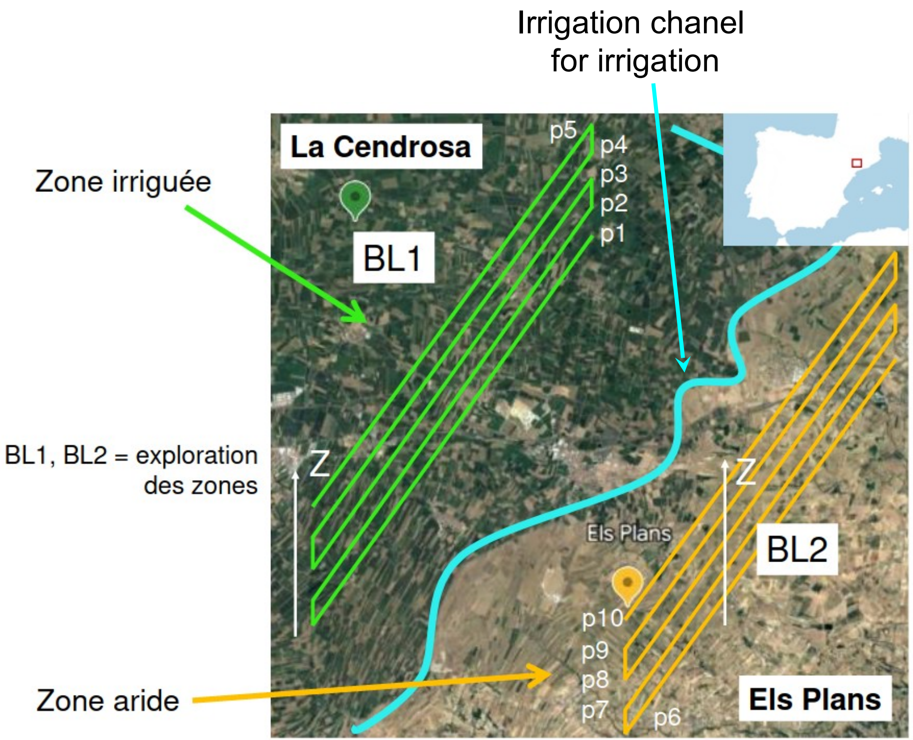
Outline

- ➢ The observations used
- ➢ Evolution of the CBL over the 8 IOPs
- ➢ CBL turbulent structure over the two contrasted surfaces

Period of interest and observations used

Period of interest : 8 POI
(15, 16, 17, 20, 21, 22, 27 et 28 July 2021)

Area of interest : La Cendrosa & Els Plans



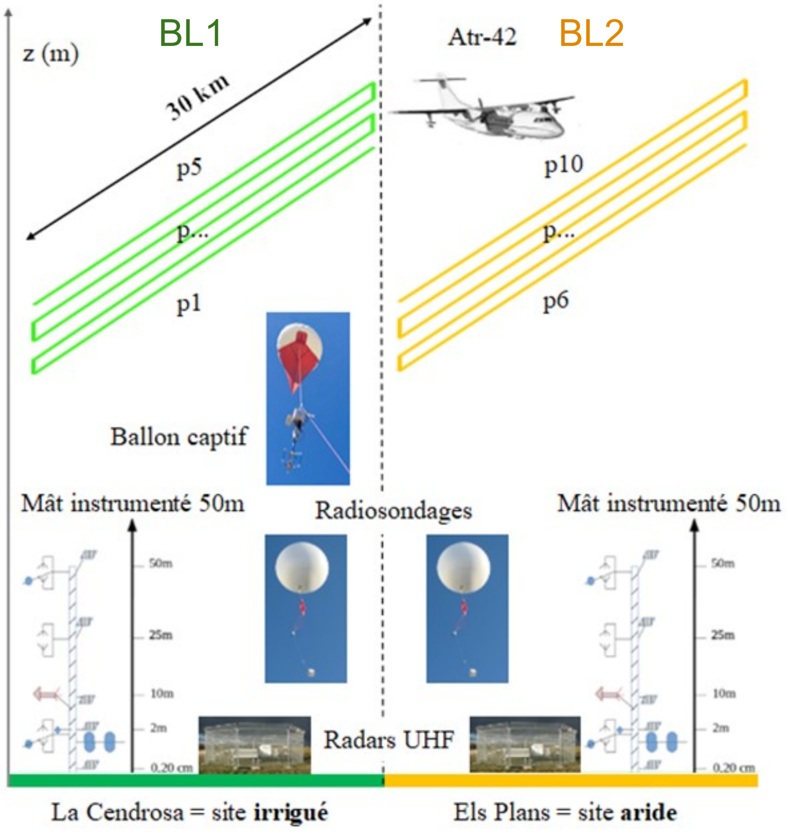
Period of interest and observations used

Period of interest : 8 POI
(15, 16, 17, 20, 21, 22, 27 et 28 July 2021)

Area of interest : La Cendrosa & Els Plans

Instrumentation used :

- Instrumented towers (50m)
- UHF wind profilers
- Tethered balloon (only et La Cendrosa)
- Radiosoundings
- ATR-42 aircraft (flights 11h-15h UTC)



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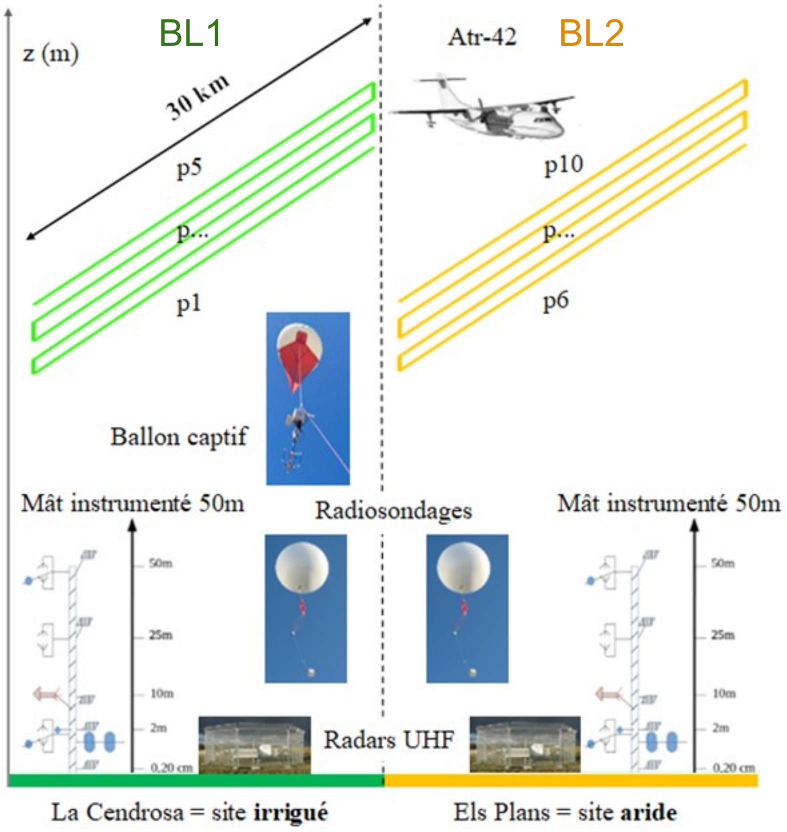
- Radiosoundings
- ATR-42 aircraft (flights 11h-15h UTC)

Access to measurements or estimates of :
- Temperature, Moisture, Wind
- At high frequency → Turbulent moment, fluxes
- Radiation

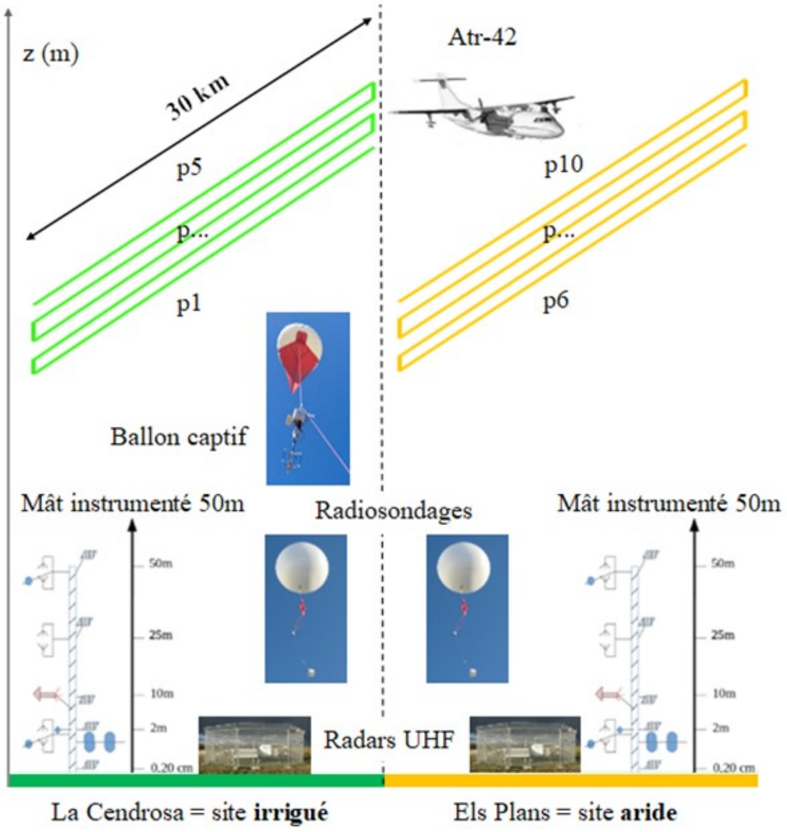


Période d'intérêt et moyens disponibles pour l'étude

Period of interest : 8 POI
(15, 16, 17, 20, 21, 22, 27 et 28 July 2021)

Area of interest : La Cendrosa & **Els Plans**

Objective ⇒ To study the vertical structure of turbulence from instrumental synergy based on the 8 IOPs



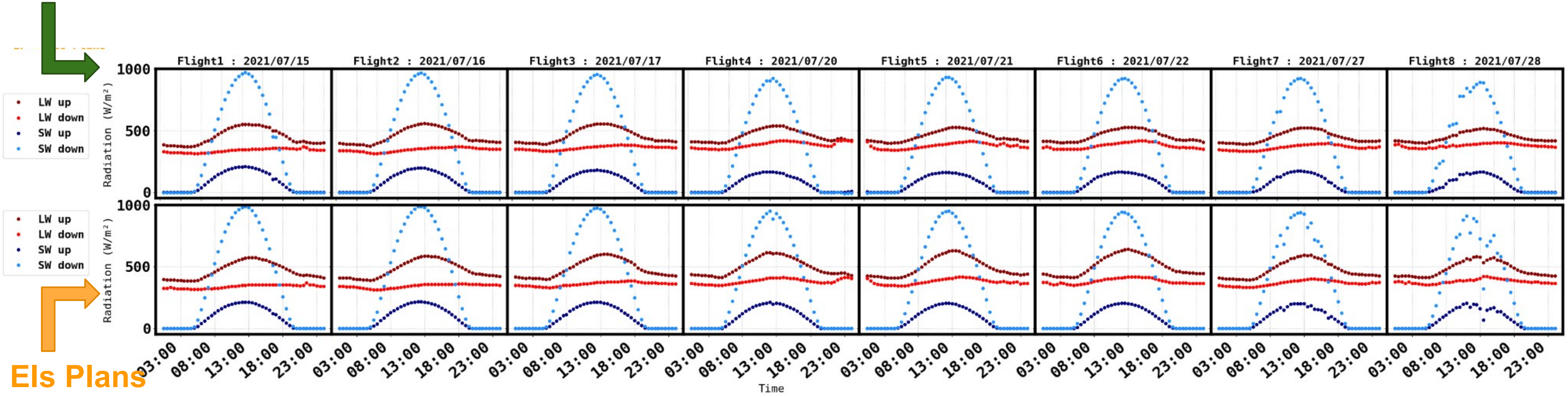
Evolution of the CBL over each surface

Evolution of the CBL over each surface

LC = La Cendrosa
EP = Els Plans

Time series of radiation components ($W.m^{-2}$) from 50 m towers (top)

La Cendrosa



Els Plans

⇒ conditions of dry convection are similar all days

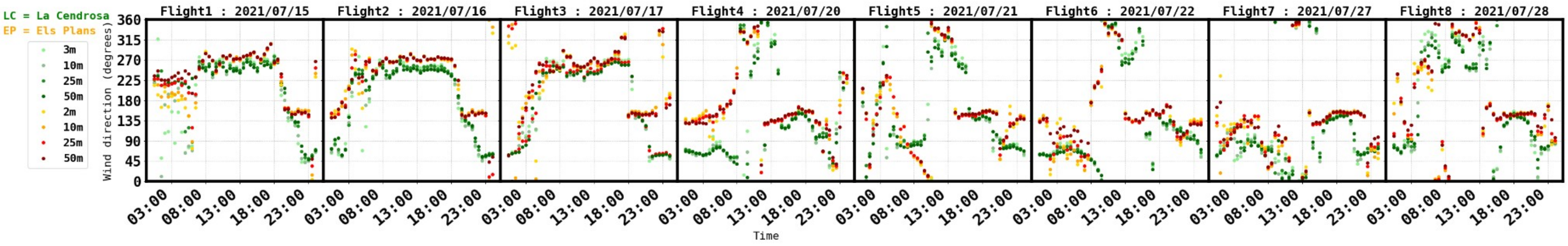
→ similar forcing of radiation from one day to the other

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Time series of wind direction (degrees) from 50 m towers

Color convention for all figures!



Evolution de la CLA au-dessus de chaque surface

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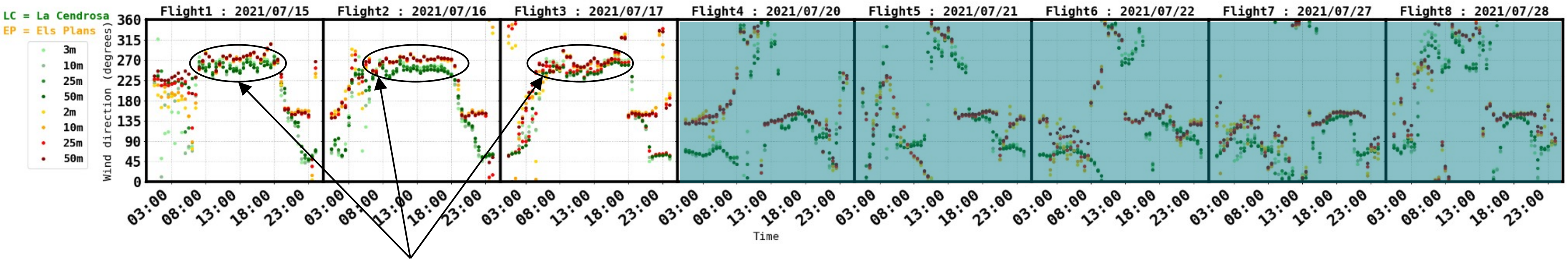
Time series of wind direction (degrees) from 50 m towers

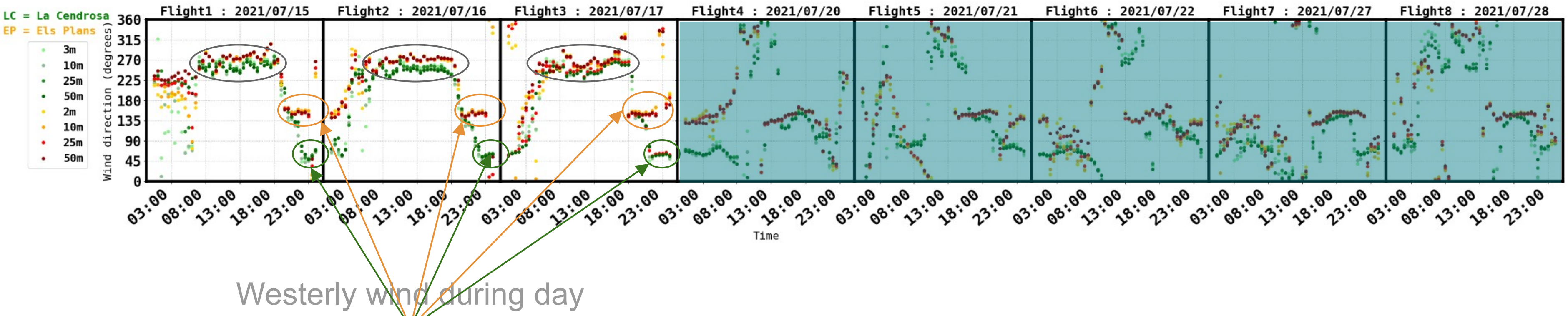


Westerly wind during day

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Time series of wind direction (degrees) from 50 m towers



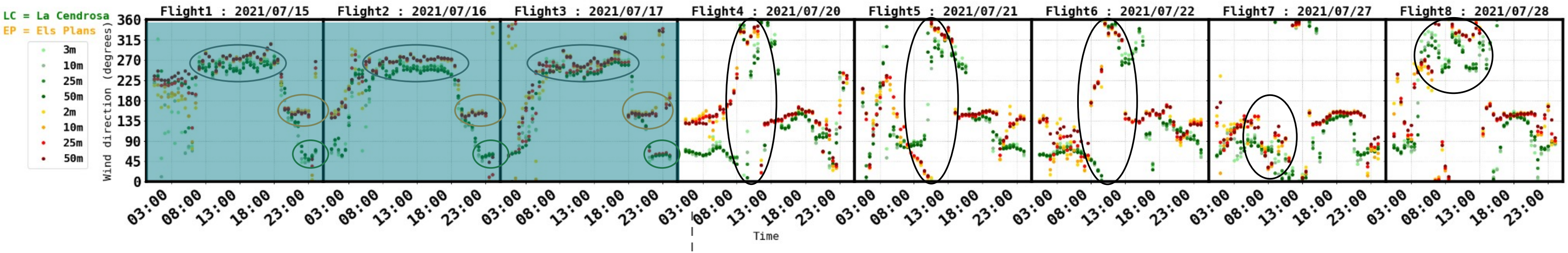
Wind veering during nightime
Different according to surface

- ⇒ Southerly Els Plans
- ⇒ North-Easterly at La Cendrosa

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Time series of wind direction (degrees) from 50 m towers



Vent d'Ouest en journée

Changement de direction la nuit selon la surface

⇒ Sud à Els Plans

⇒ Nord-Est à La Cendrosa

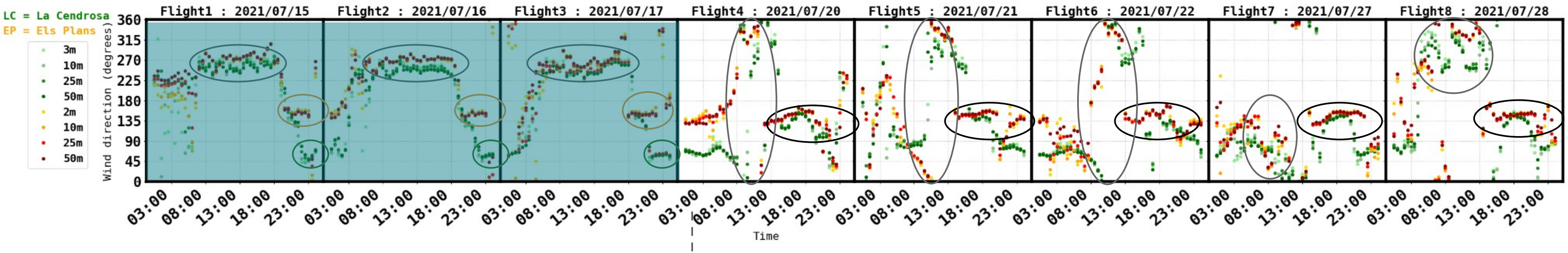
Wind direction more variable during the day (weak) :

⇒ Northerly during morning

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Time series of wind direction (degrees) from 50 m towers



Vent d'Ouest en journée

Changement de direction la nuit selon la surface

⇒ Nord-Est à La Cendrosa

⇒ Sud à Els Plans

Wind direction more variable during the day (weak) :

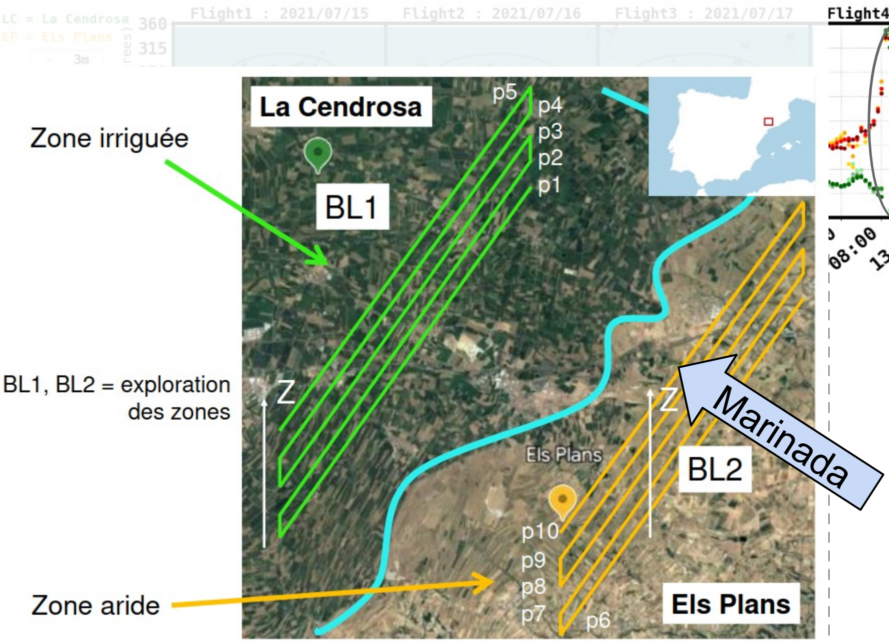
⇒ Northerly during morning

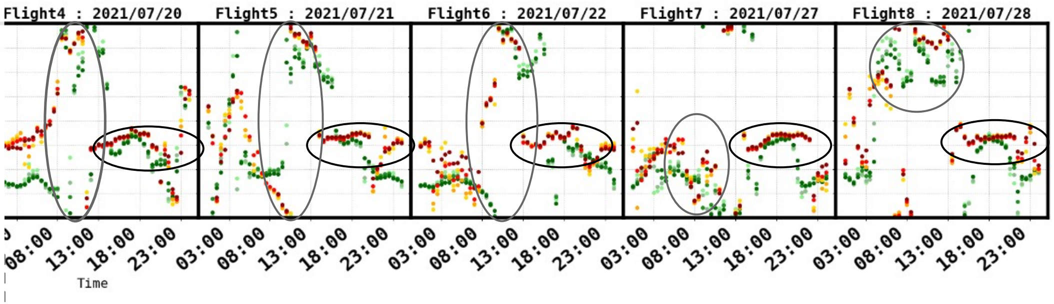
⇒ Then veering Southeasterly around 1300 UTC: Arrival of La Marinada

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Time series of wind direction (degrees) from 50 m towers





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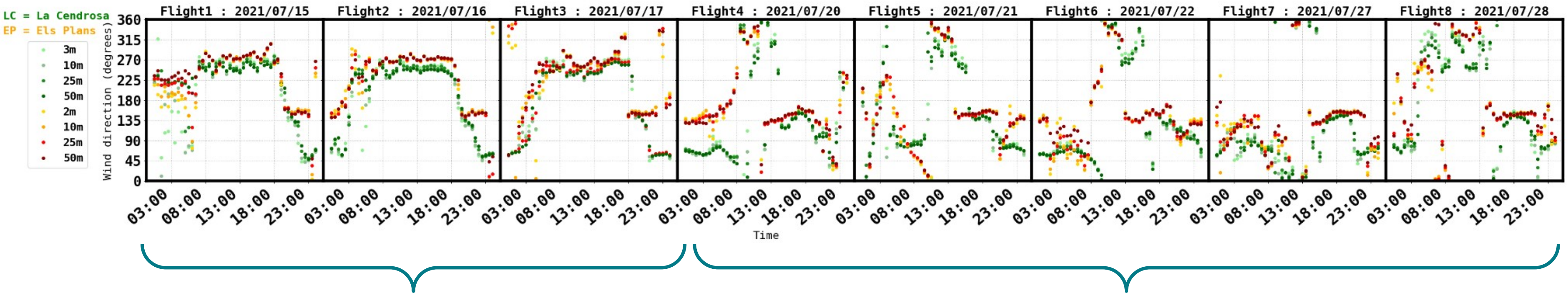
Time series of wind direction (degrees) from 50 m towers



from **15/07/21 to 17/07/21**

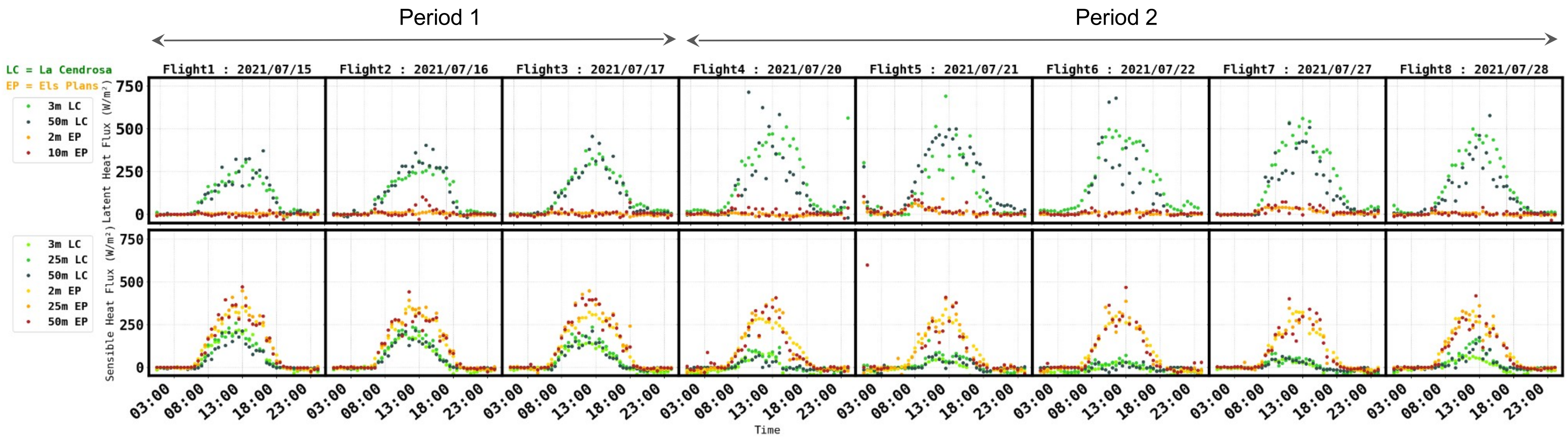
from **20/07/21 to 28/07/21**

⇒ Distinction of two periods according to wind direction daytime evolution

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

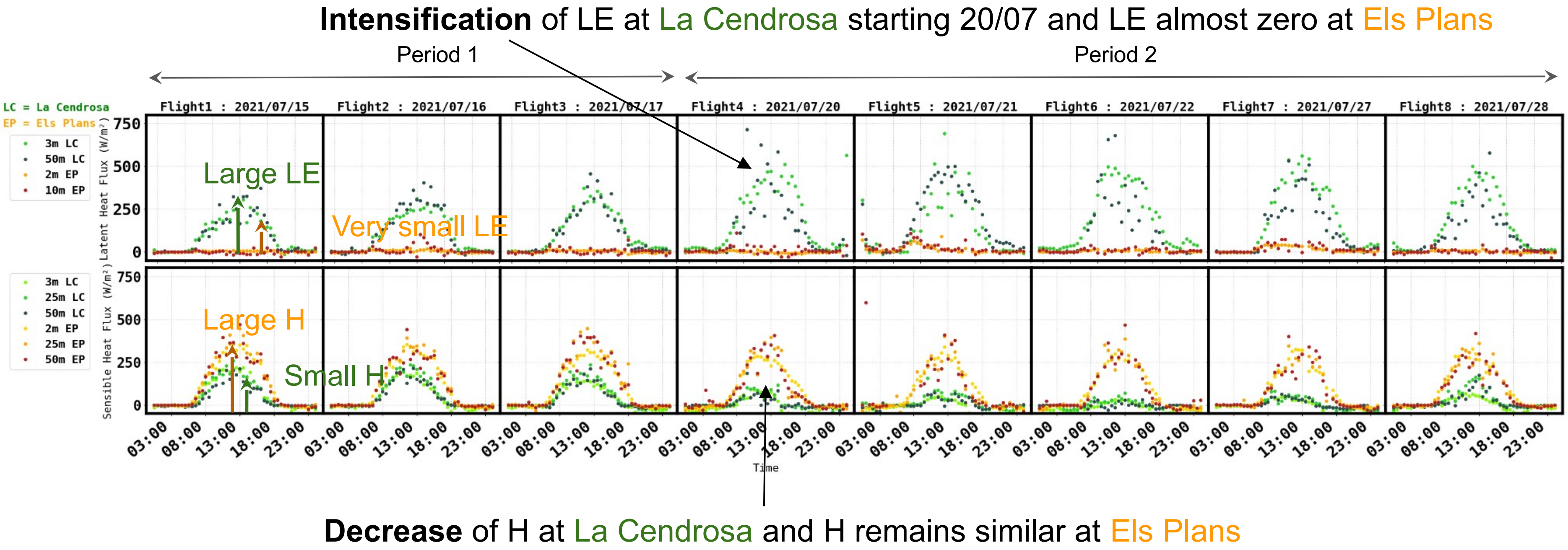
Time series of **latent heat flux LE (top)** and **sensible heat flux H (bottom)** in W/m², from 50 m towers



Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Série temporelle mât des flux de **chaleur latente LE (en haut)** et **sensible H (en bas)** en W/m²



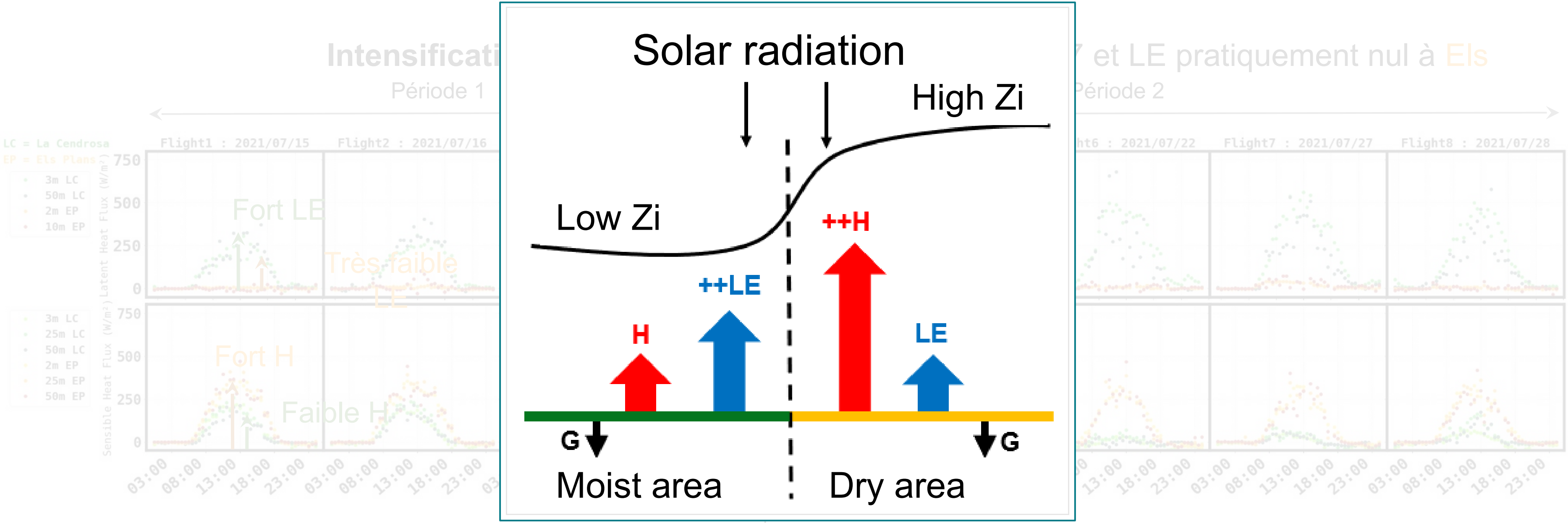
Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Série temporelle mât des flux de **chaleur latente LE (en haut)** et **sensible H (en bas)** en W/m²

Intensificati… et LE pratiquement nul à Els

Période 1 — Période 2

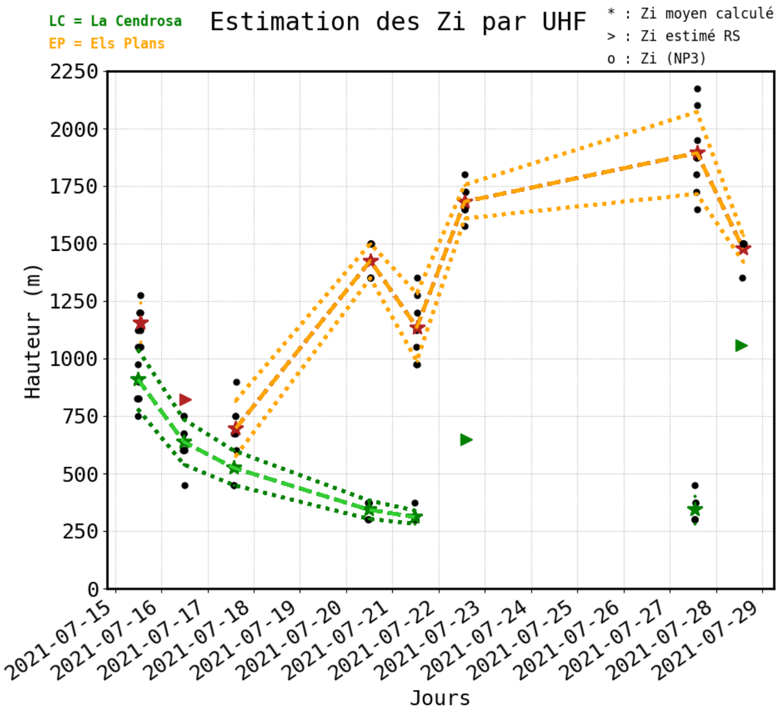


Affaiblissement du H à La Cendrosa et H similaire à Els Plans

Evolution de la CLA au-dessus de chaque surface

LC = La Cendrosa
EP = Els Plans

Estimation of Zi over each surface, based on CALOTRITON algorithm (*Philibert et al. 2024*)



⇒ CBL depth increases over the arid area

⇒ Thin CBL over the moist area

--★-- averaged Zi over the duration of the ATR exploration over La Cendrosa

· · · · Standad deviation

--★-- Averaged Zi over the duration of the ATR exploration over Els Plans

· · · · Standard deviation

Subjectives estimates

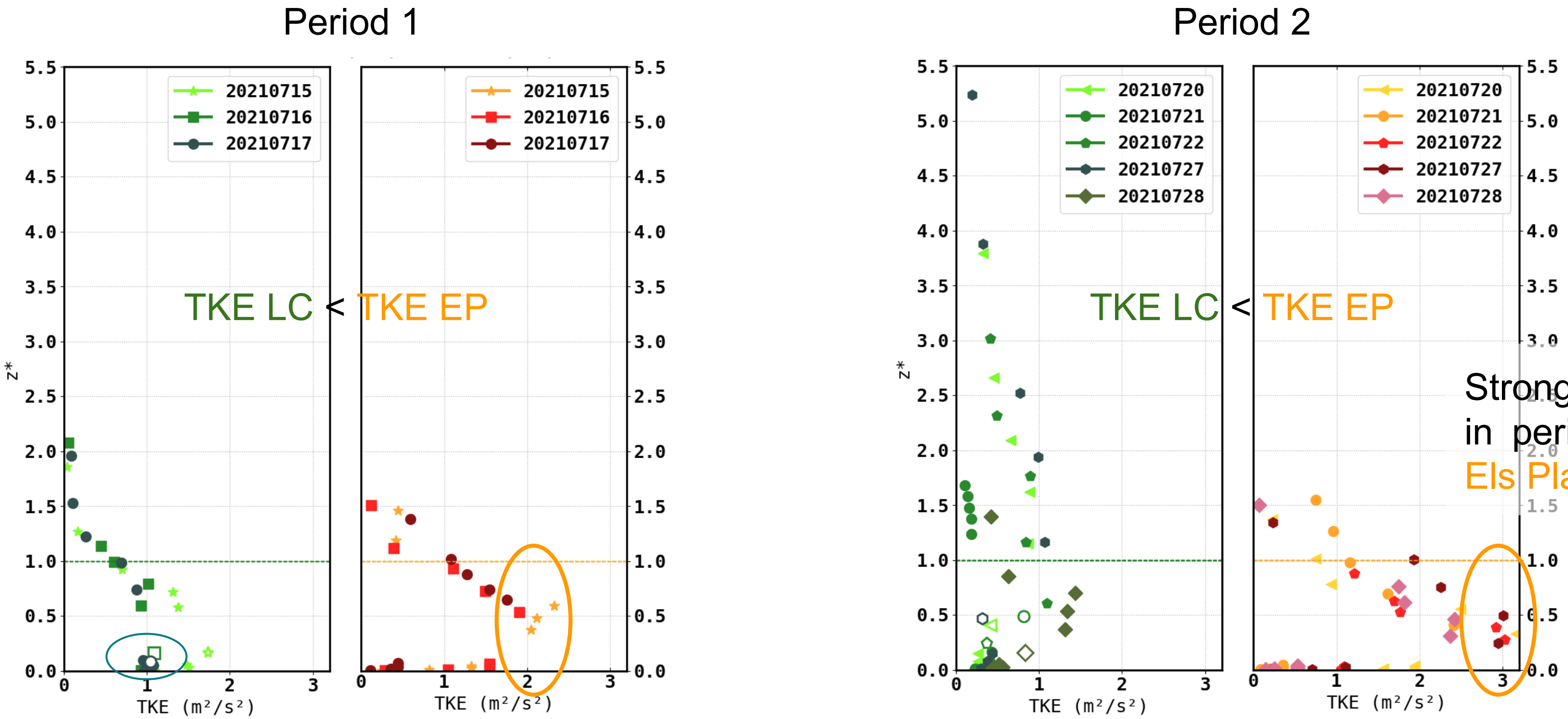
Turbulence observed over the contrasted surface

Turbulent Kinetic Energy

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

!! Height is normalized by Zi !!



Stronger TKE in period 2 at Els Plans

Tethered balloon

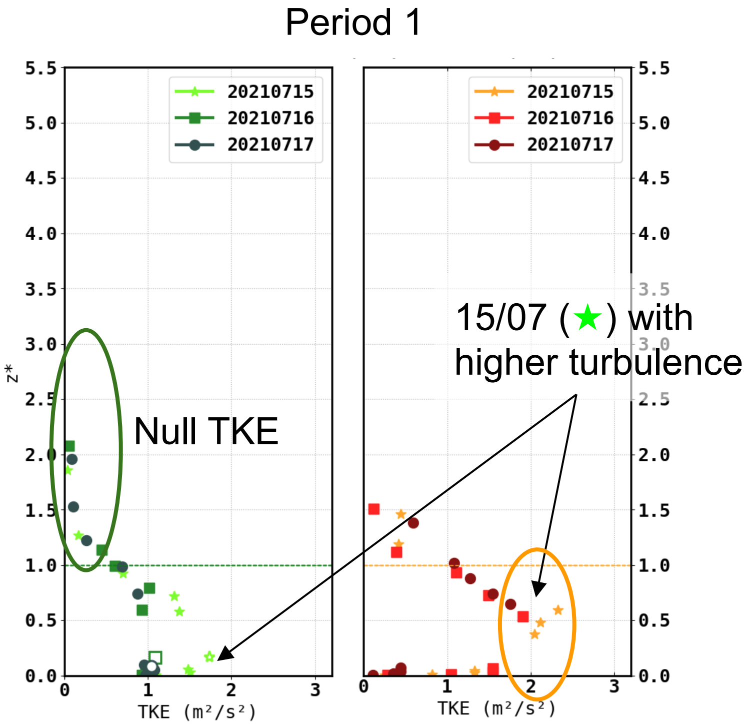
Distinction in two periods confirmed here

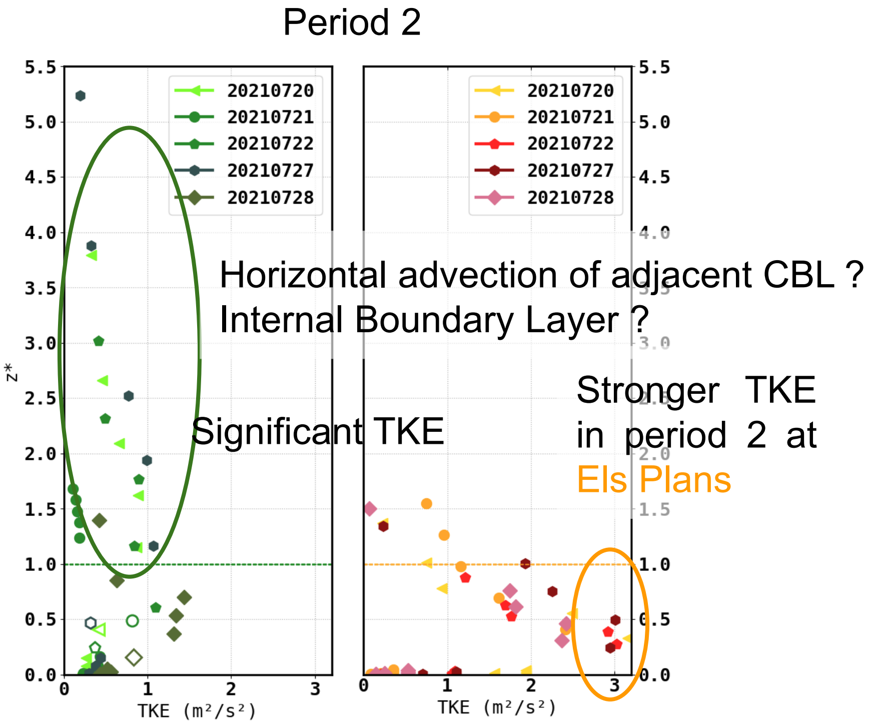
Turbulent Kinetic Energy

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

!! Height is normalized by Zi !!

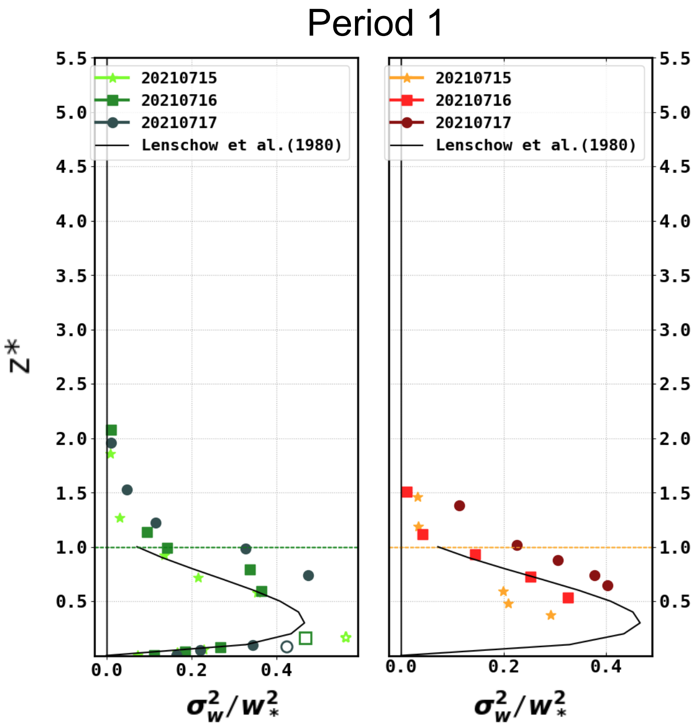


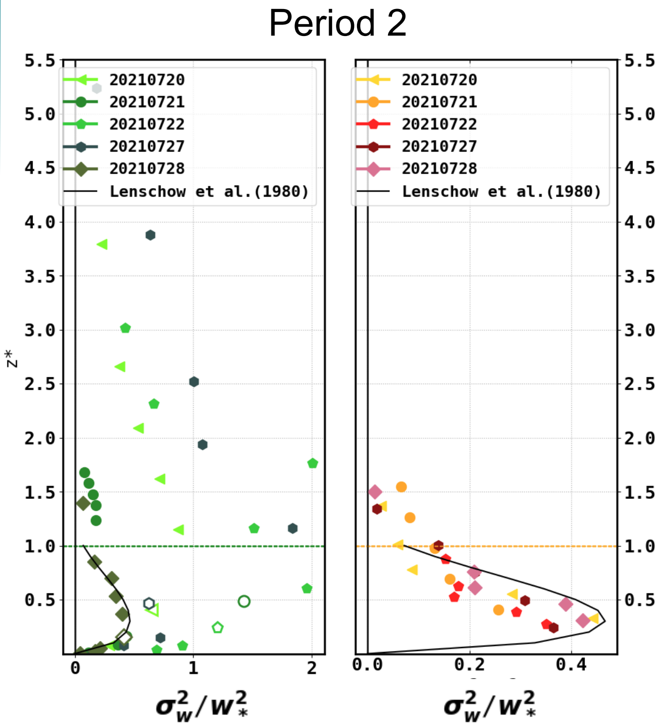


Normalized vertical velocity variance

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans





Convective velocity scale

$$w_* = \left(\frac{gZ_i}{\bar{\theta}}\overline{(w'\theta')_s}\right)^{\frac{1}{3}}$$

Lenschow et al (1980)

⇒ takes into account updraft from ground and downdrafts from CBL top

Maximum ~0,4 z_*

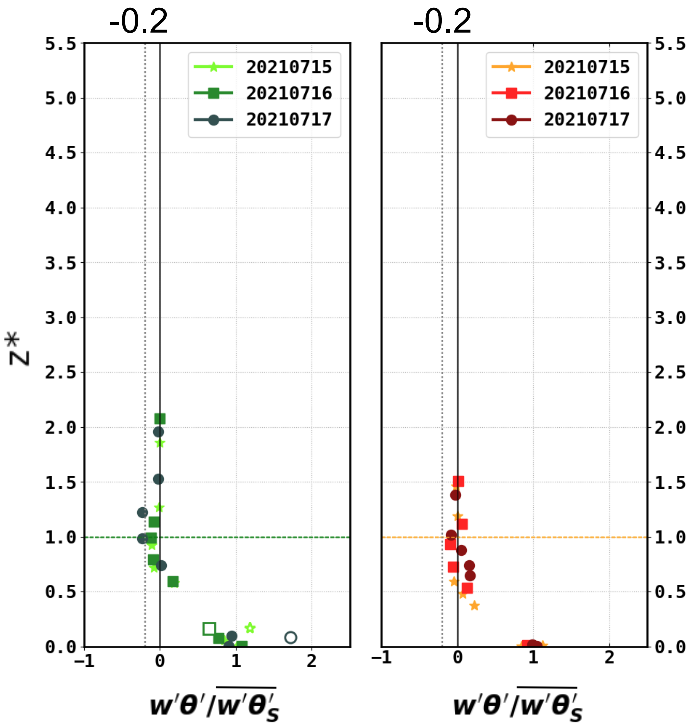
Typical profile of σ^2_w

Normalized heat vertical transport

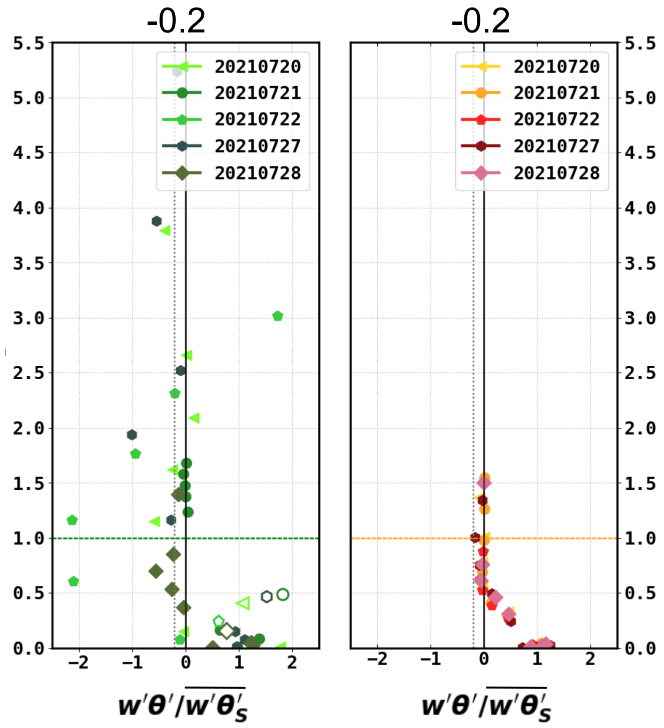
Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Period 1



Period 2



Scattered profiles
(sensible heat flux close to zero!)

$\overline{w'\theta'_S}$: mean surface fluxbetween 2m & 50m (tower)

Sensible heat flux :

$H = \rho * C_P * w'\theta'$

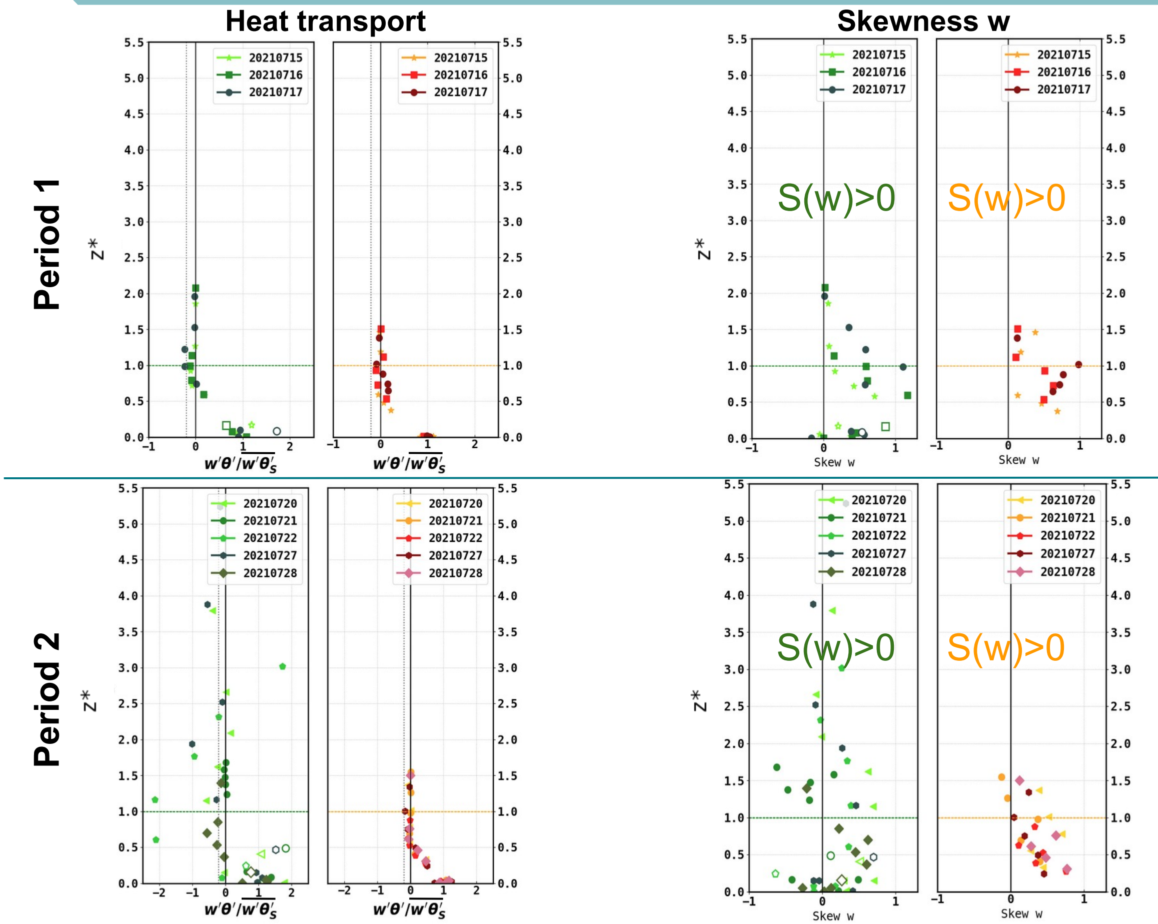
0.2 : typical entrainment rate

⇒ Typical profiles

Normalized heat vertical transport and skewnesses

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

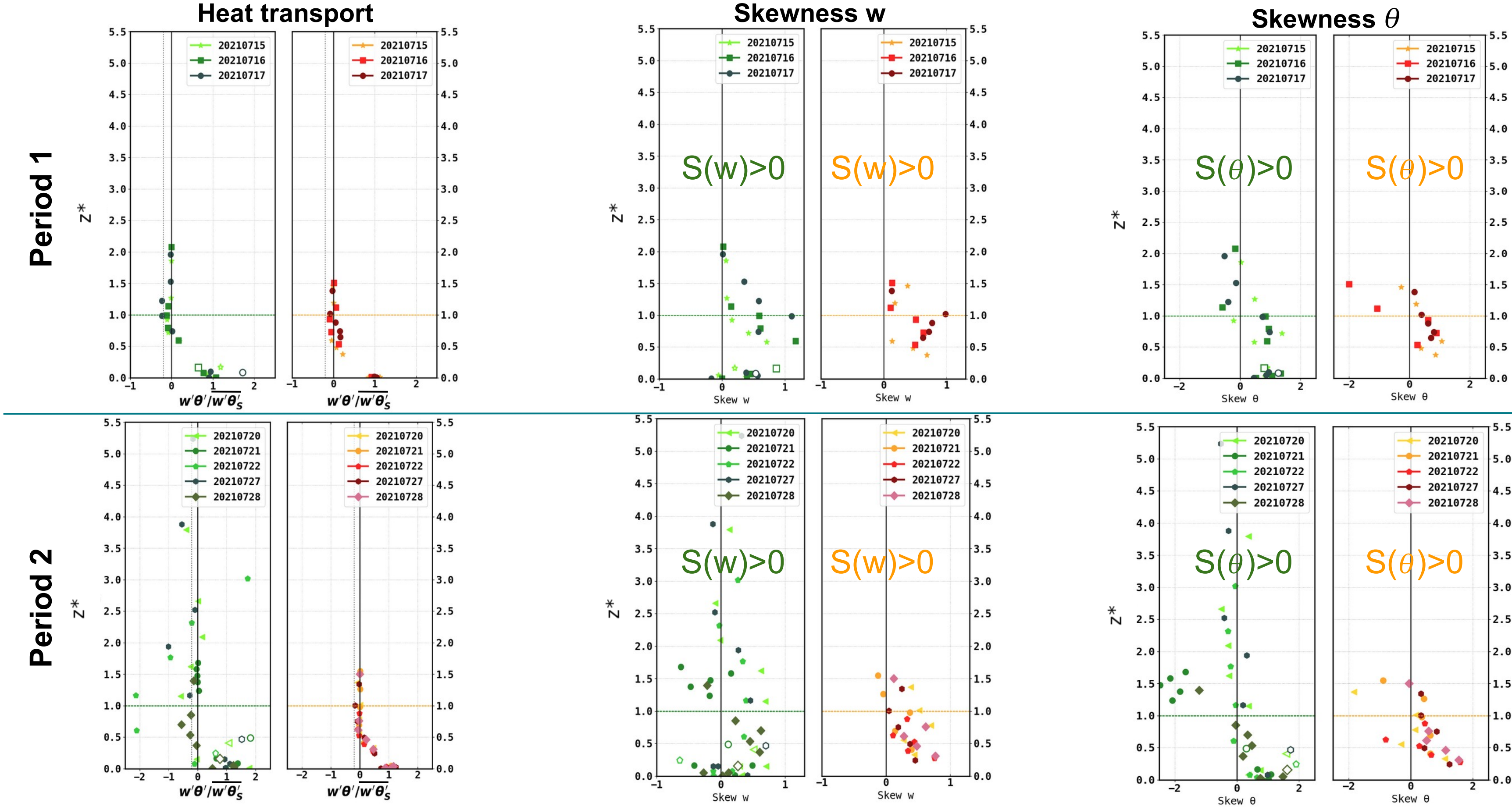


Skewness → sign of largest fluctuations

Normalized heat vertical transport and skewnesses

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans



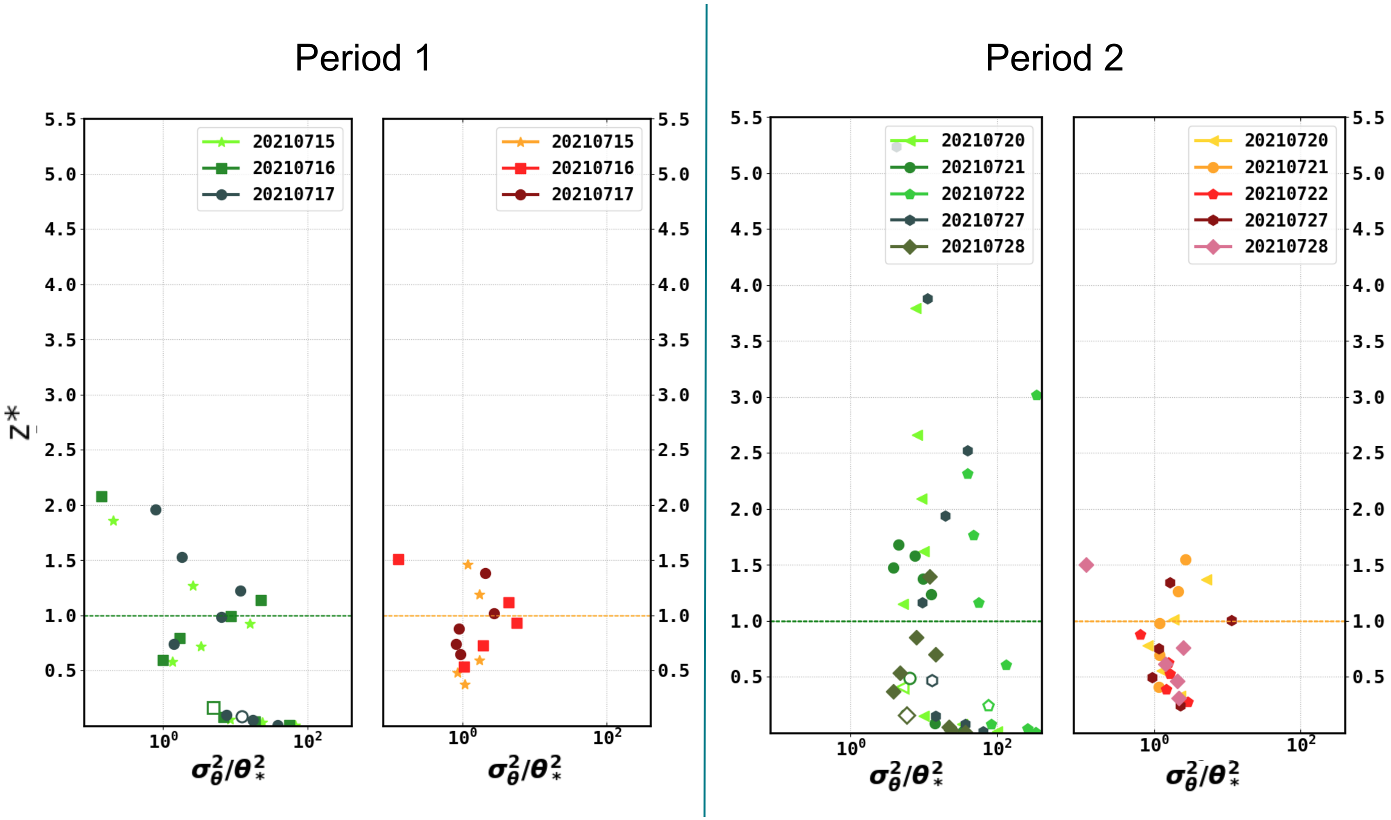
Normalized temperature variance

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Potential temperature scale

$$\theta_* = \frac{(\overline{w'\theta'})_s}{w_*}$$

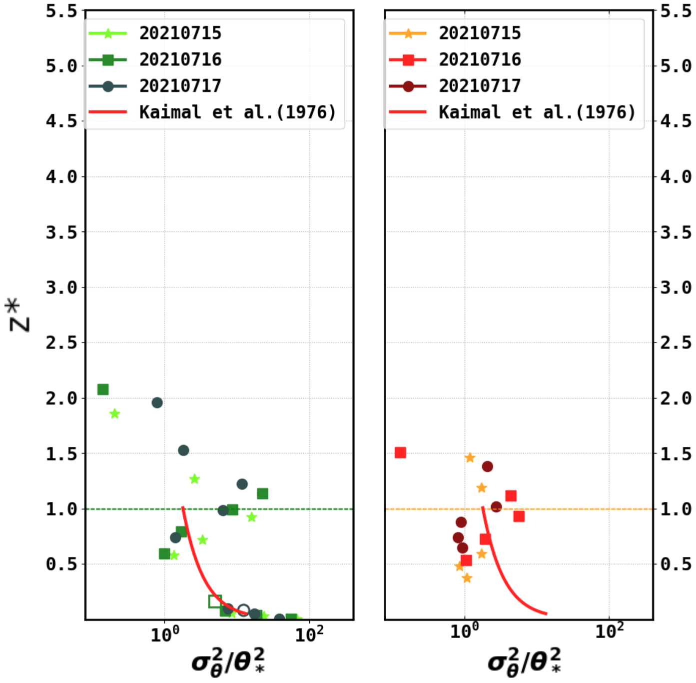


Normalized temperature variance

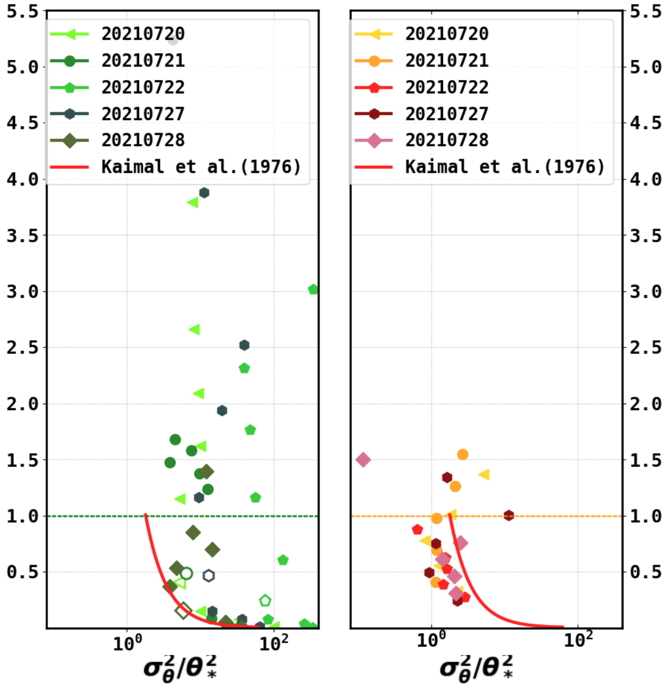
Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Period 1



Period 2



Kaimal et al (1976)

⇒ takes account of free convection
(valid up to 0.1 Zi)

Normalized temperature variance

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
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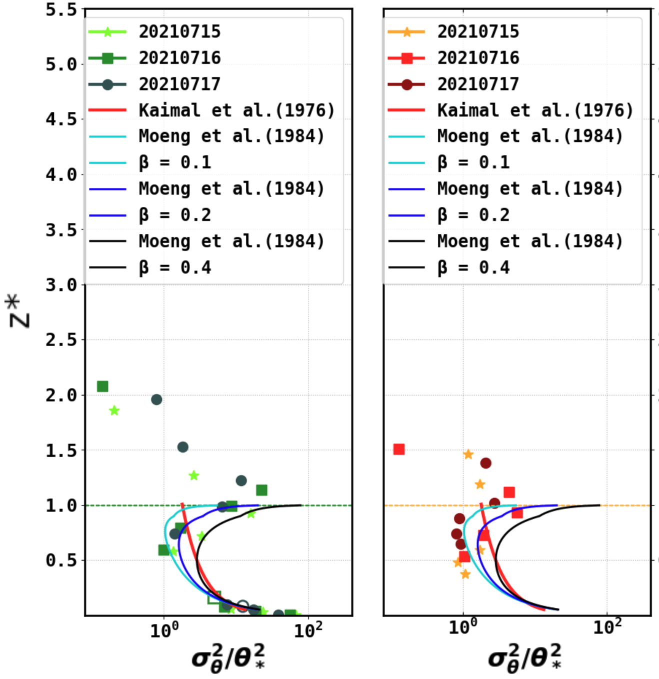
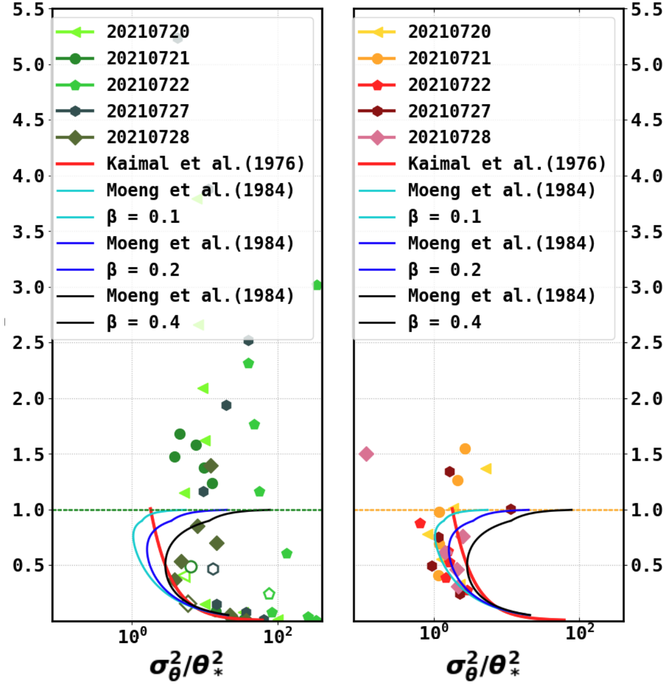
Period 1



Period 2



Kaimal et al (1976)

⇒ takes account of free convection
(valid up to 0.1 Zi)

Moeng et al. (1984)

β = 0,1 → weak
β = 0,2 → typical
β = 0,4 → strong

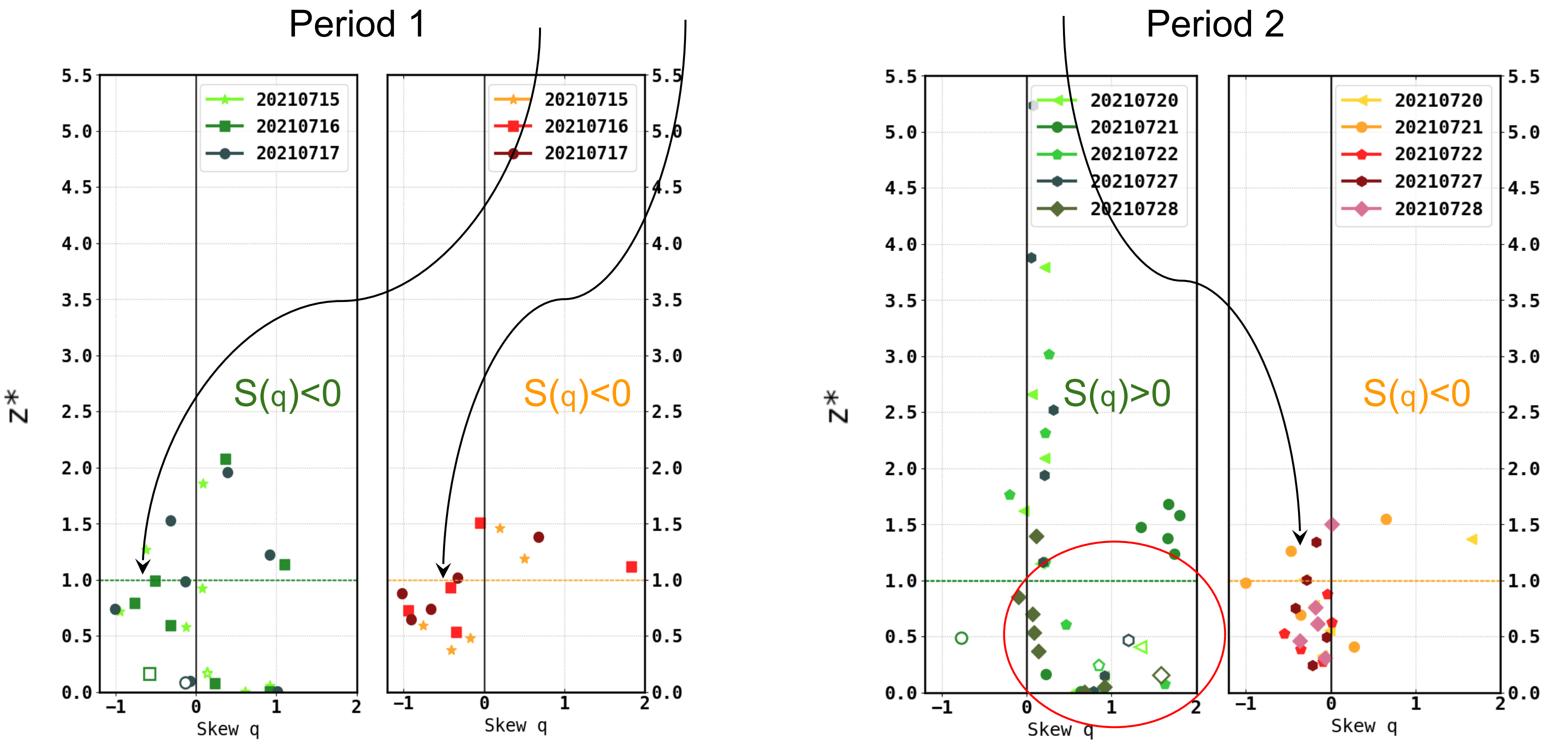
⇒ takes account of varying entrainment rate

Moisture Skewness

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

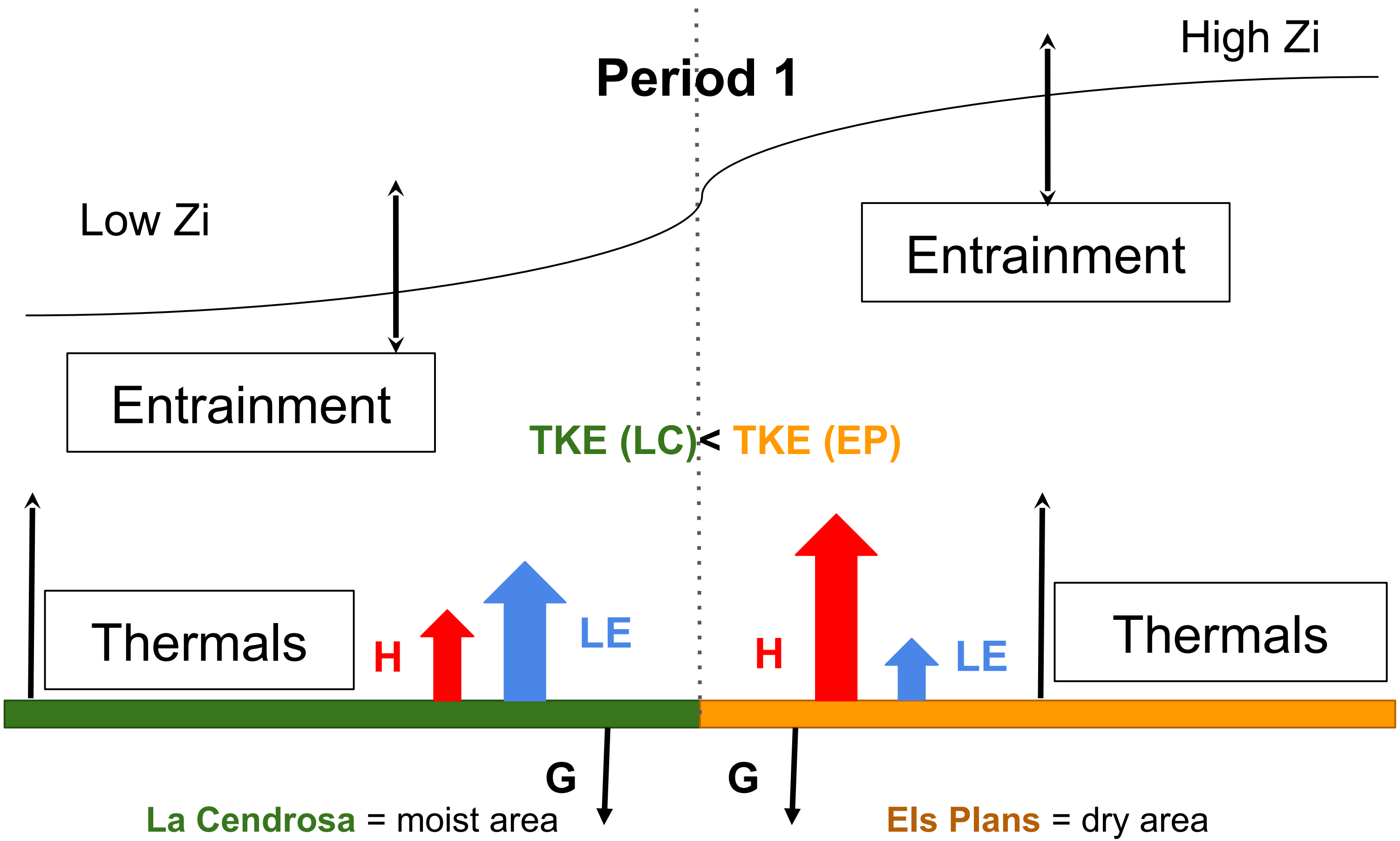
Entrainment (Druilhet et al. (1983))



Summary Scheme

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans



La Cendrosa = moist area

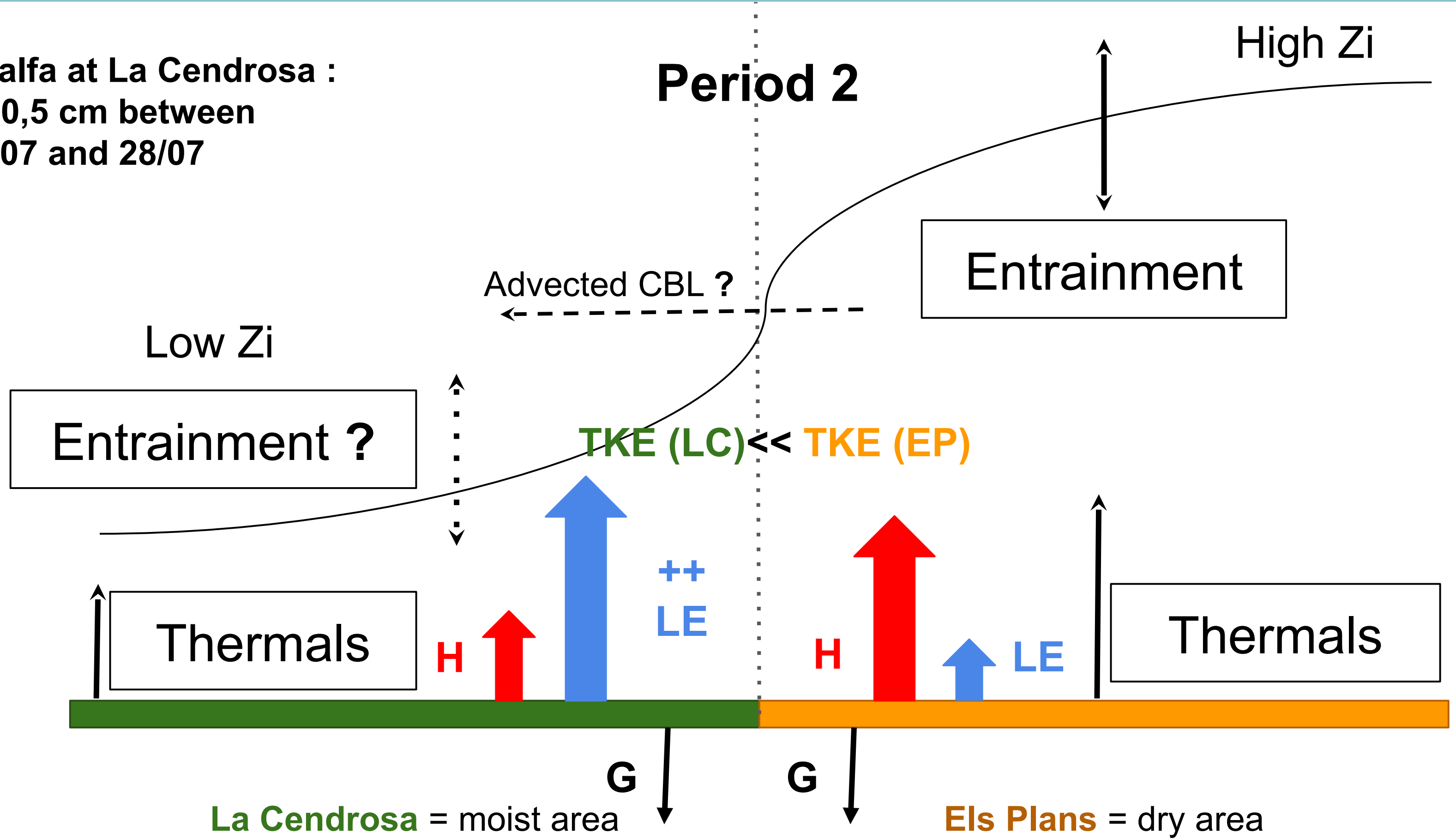
Els Plans = dry area

Summary Scheme

Zi EP ~ [750 m ; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Alfalfa at La Cendrosa :
+ 50,5 cm between
15/07 and 28/07



Conclusion and perspectives

Conclusion :

- A really nice dataset to explore turbulence over the surface heterogeneity induced by irrigation and the interactions between different CBL
- A statistical study (Variances, Covariances et Skewness) → important for the study of turbulent processes
- Very typical CBLs over each surface, with interesting comparison with empirical laws found in the litterature
- The distinction of 2 periods within the 8 IOPs showed consistent profiles within each period, but the study of moist area is challenging during the second period

Conclusion et perspectives

Perspectives :

- Explore the horizontal transports of momentum and heat and spatial variability → Detect potential circulations between the two areas
- Make use of the transverse legs from one area to the other → nice transitions from low to very high turbulence
- Use numerical simulation → with the irrigation scheme proposed by CNRM/GMME/surface in Meso-NH


Thank you for you attention !

References

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- Moeng, C., and J. C. Wyngaard, 1984: Statistics of Conservative Scalars in the Convective Boundary Layer. J. Atmos. Sci., 41, 3161–3169, https://doi.org/10.1175/1520-0469(1984)041<3161:SOCSIT>2.0.CO;2
- Philibert et al., 2023 : A layer convective boundary layer height estimation algorithm from UHF wind profiler data. Sub. To ACP

Appendices

Normalisation des profils par Z_i

LC = La Cendrosa
EP = Els Plans

Vols à différentes hauteurs selon les jours et la zone étudiée

Hauteurs de couches limites différentes

↓

Difficulté de comparaison

↓

Normalisation : $z_* = \frac{z}{Z_i}$

z_* = hauteur réduite

z = hauteur de la mesure

Z_i = hauteur de couche limite

⇒ situer les processus dans la CLA

TKE = Energie Cinétique Turbulente ($m^2.s^{-2}$)

LC = La Cendrosa
EP = Els Plans

⇒ Quantifie l'intensité de la turbulence (m^2/s^2)

$$TKE = \frac{1}{2}(\sigma_u^2 + \sigma_v^2 + \sigma_w^2)$$

Dynamique (cisaillement de vent) : σ_u^2, σ_v^2

Thermique : σ_w^2

Fluctuations :

$$x' = x - \bar{x}$$

Variances :

$$\sigma_x^2 = \frac{1}{N}\Sigma(x-\bar{x})^2 = \overline{\Sigma(x')^2}$$

Covariances

$$\overline{x'y'} = \frac{1}{N}\Sigma\big((x-\bar{x})*(y-\bar{y})\big) = \overline{\Sigma(x'*y')}$$

Palier avion 6 min, 25 Hz
⇒ 9 000 échantillons

TKE = Energie Cinétique Turbulente ($m^2.s^{-2}$)

LC = La Cendrosa
EP = Els Plans

⇒ Quantifie l'intensité de la turbulence (m^2/s^2)

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$$\sigma_x^2 = \frac{1}{N}\Sigma(x-\bar{x})^2 = \overline{\Sigma(x')^2}$$

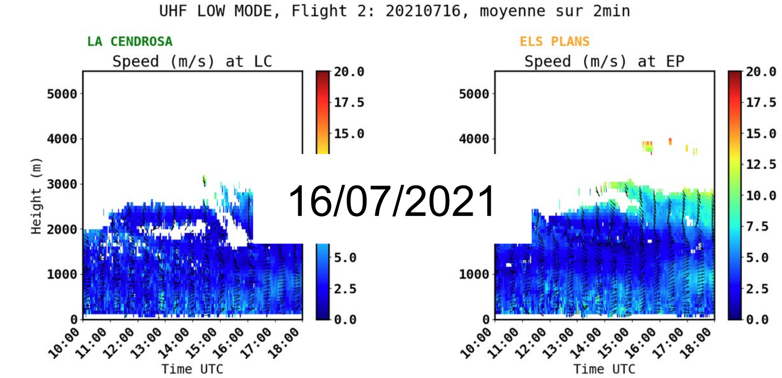
Covariances

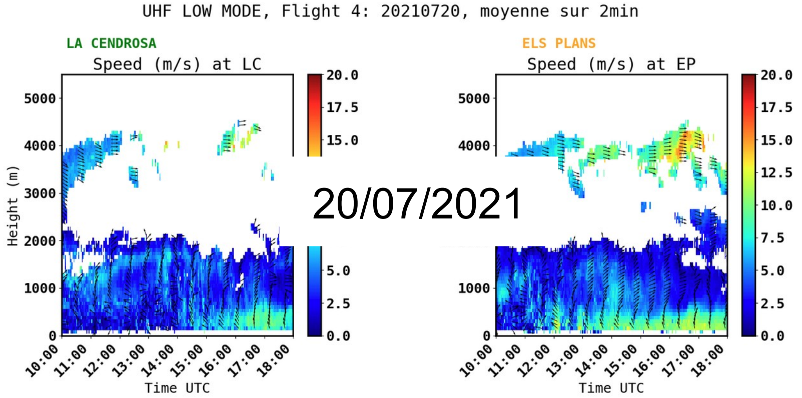
$$\overline{x'y'} = \frac{1}{N}\Sigma\big((x-\bar{x})*(y-\bar{y})\big) = \overline{\Sigma(x'*y')}$$

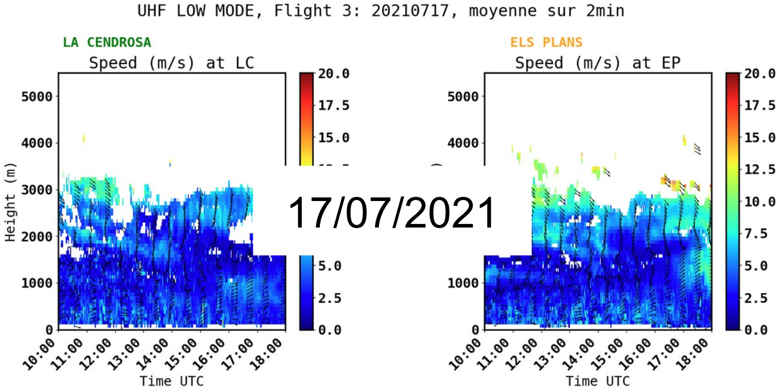
Coupe hauteur temps du vent par le radar UHF (Low Mode, 2 min)

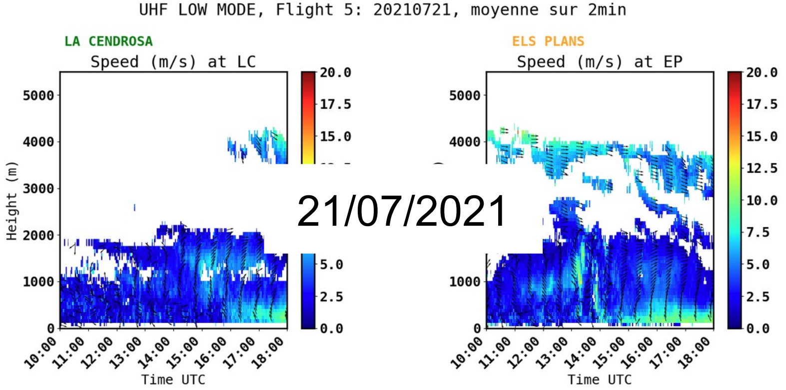
LC = La Cendrosa
EP = Els Plans

La Cendrosa | Els Plans | La Cendrosa | Els Plans



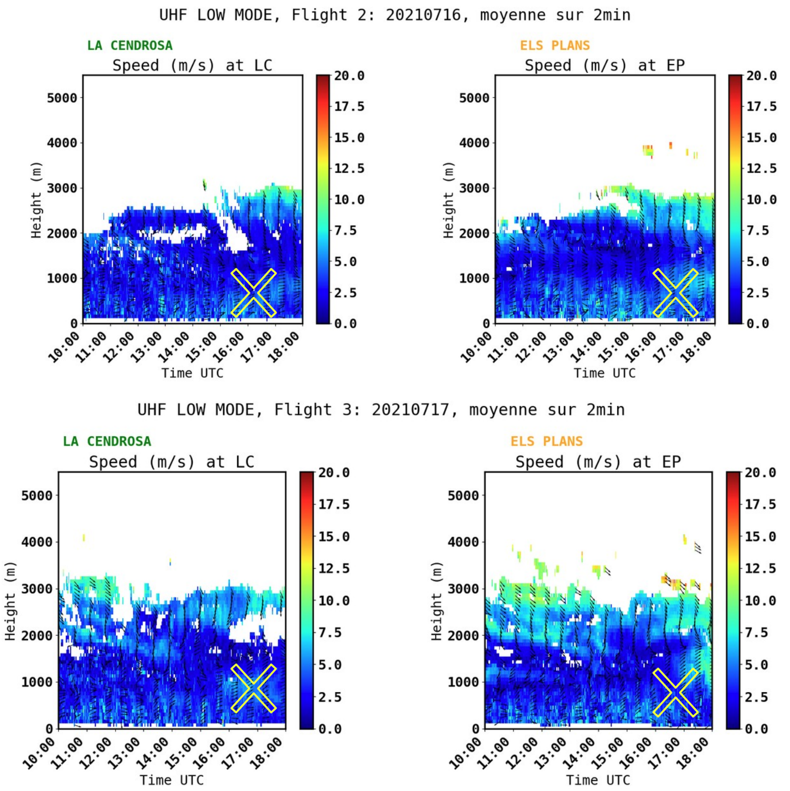




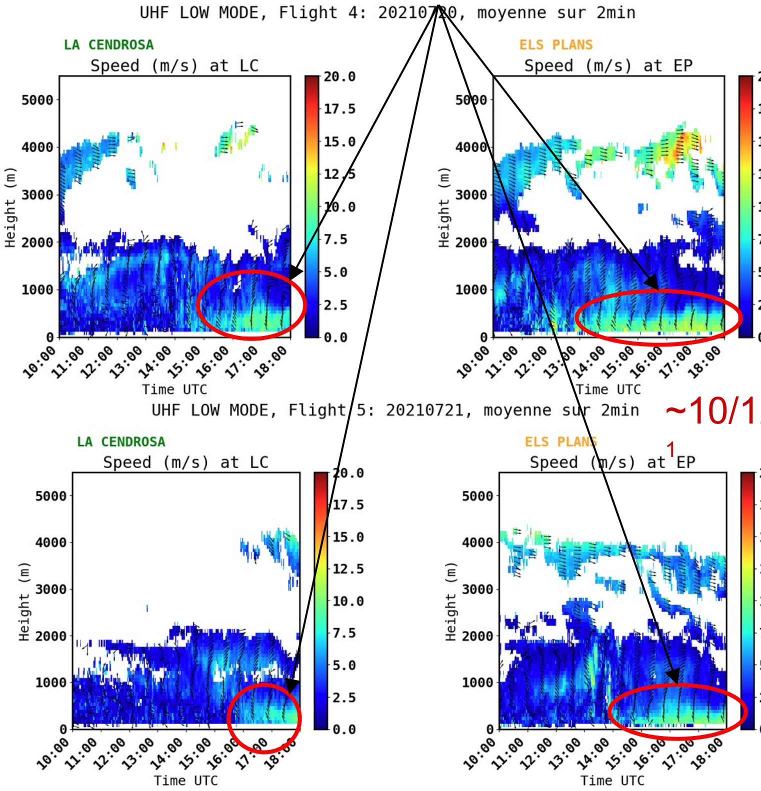


Coupe hauteur temps du vent par le radar UHF (Low Mode, 2 min)

LC = La Cendrosa
EP = Els Plans



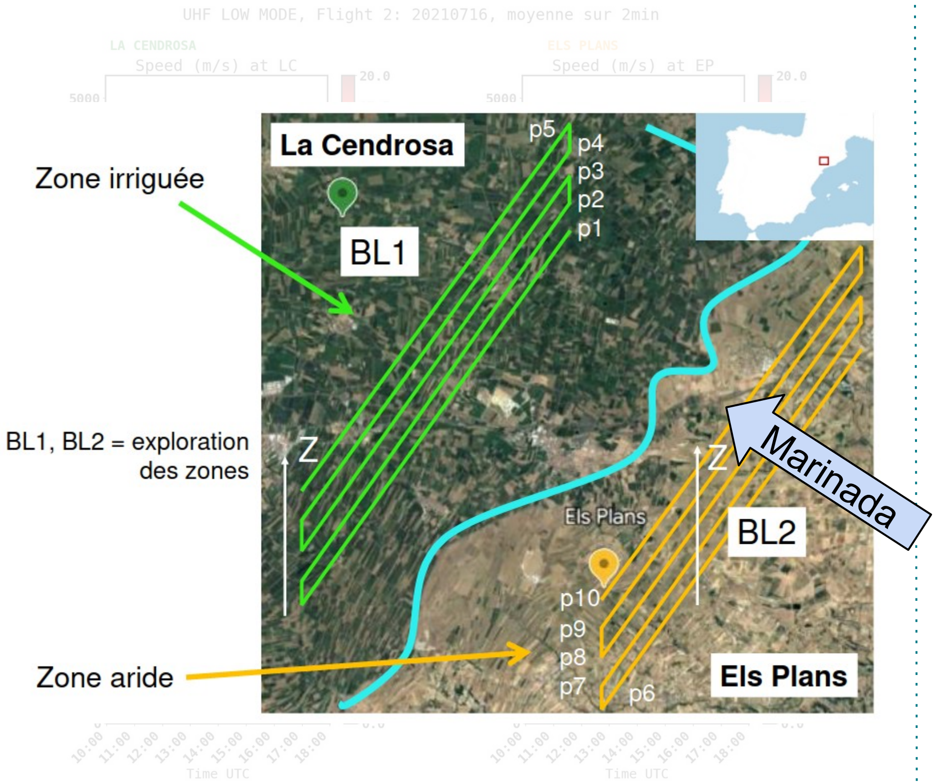
Arrivée de la Marinada plus tôt à EP qu'à LC



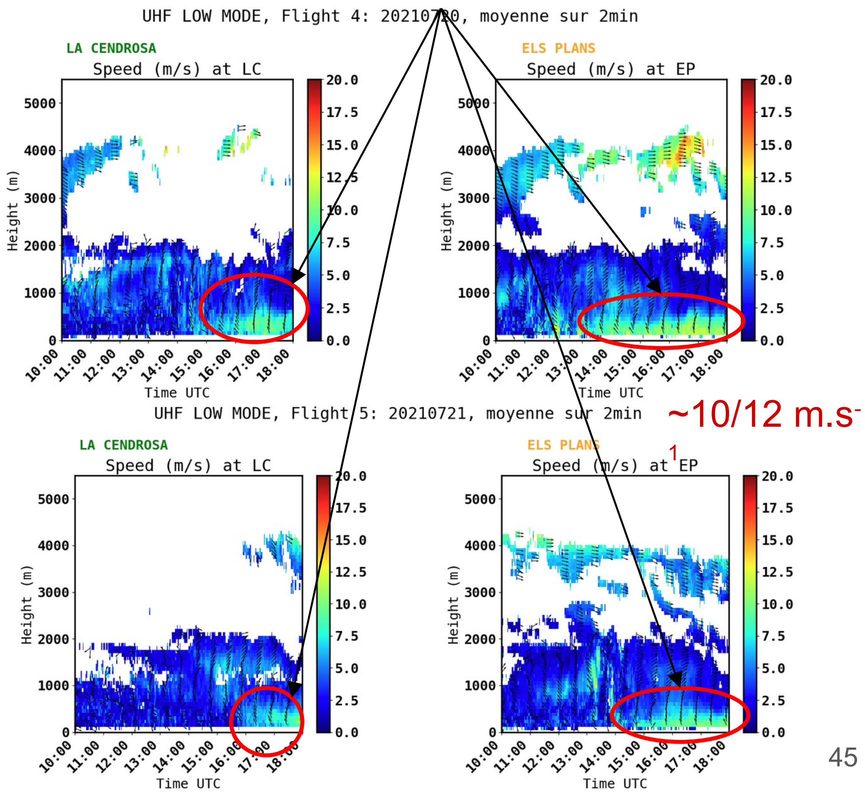
~10/12 $m.s^{-1}$

Coupe hauteur temps du vent par le radar UHF (Low Mode, 2 min)

LC = La Cendrosa
EP = Els Plans



Arrivée de la Marinada plus tôt à EP qu'à LC



Coupe hauteur temps du vent par le radar UHF (Low Mode, 2 min)

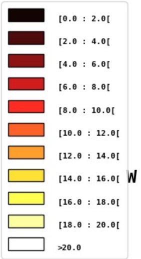
LC = La Cendrosa
EP = Els Plans

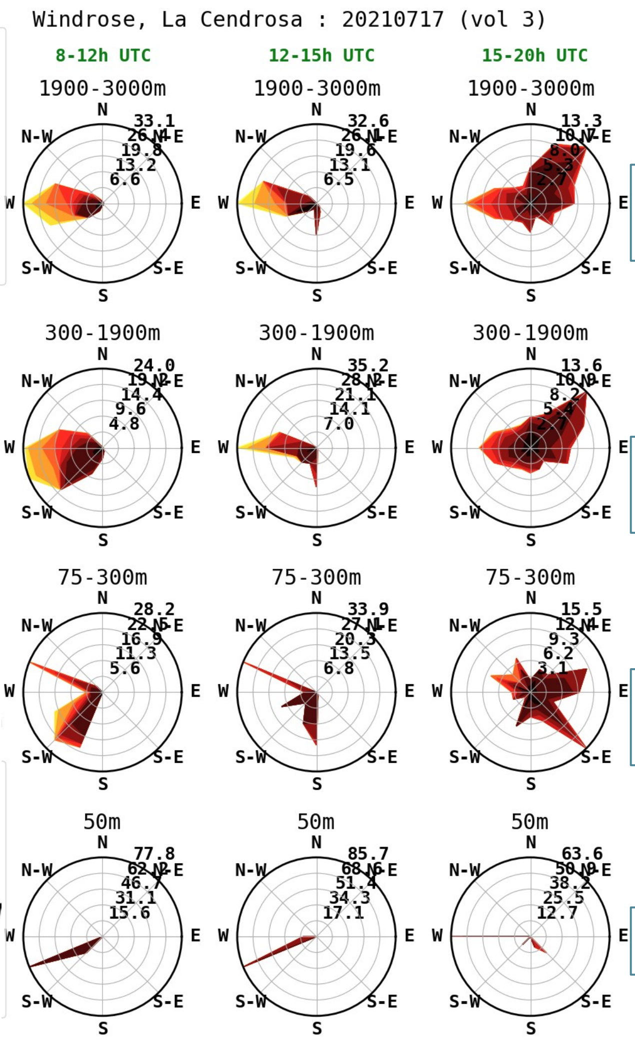
Estimation de Zi par l'algorithme CALOTRITON (Philibert et al. (2023))

$$NP_x = \frac{[C_n^2 / \overline{C^2{}_n^{profil}}]}{[\sigma_w^x / \overline{\sigma^x{}_w^{profil}}]} \quad (3.1)$$

(3.1) : Avec C_n^2 le coefficient de structure d'indice de réfraction de l'air, σ la variance de la vitesse verticale, et x l'ordre de l'équation. x = 3 représente la meilleure estimation (Philibert et al. (2023)). Les lignes représentent un opérateur de moyenne, qui permet d'adimensionaliser NP3.

17/07/21



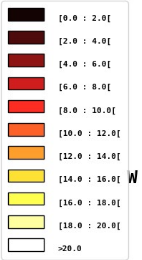


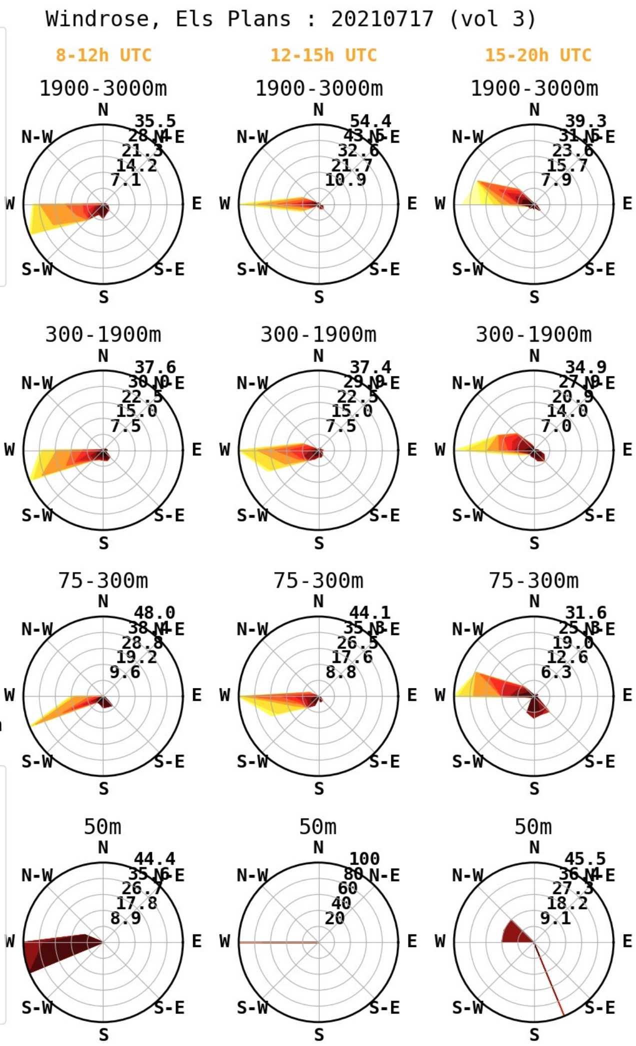
3000 - 1900m

1900 - 300 m

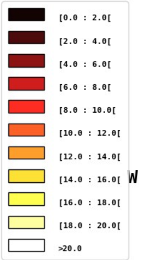
300 - 75 m

50 m

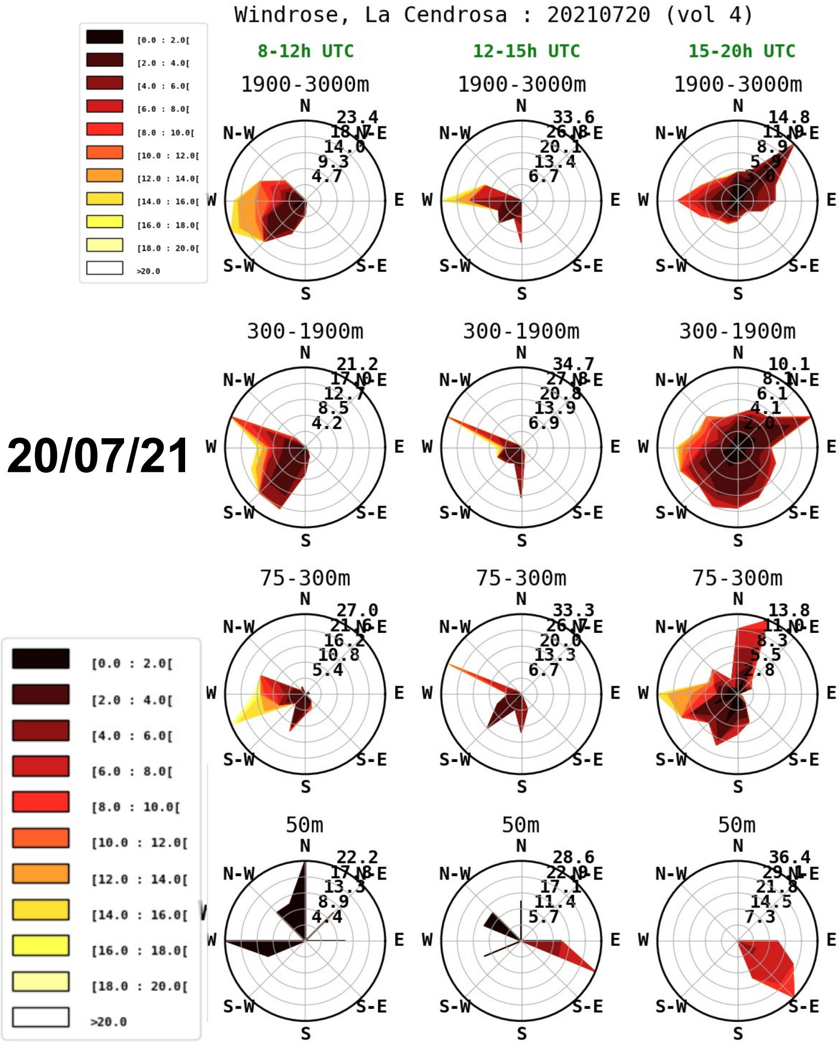




Légende 50m



20/07/21

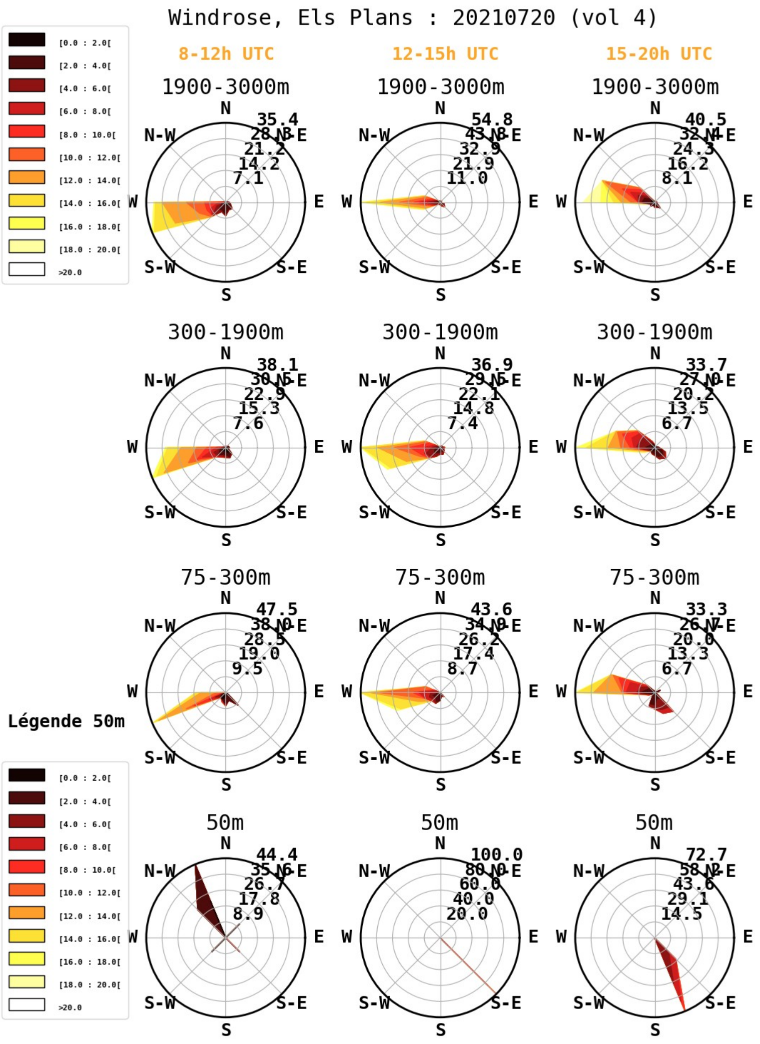


3000 - 1900m

1900 - 300 m

300 - 75 m

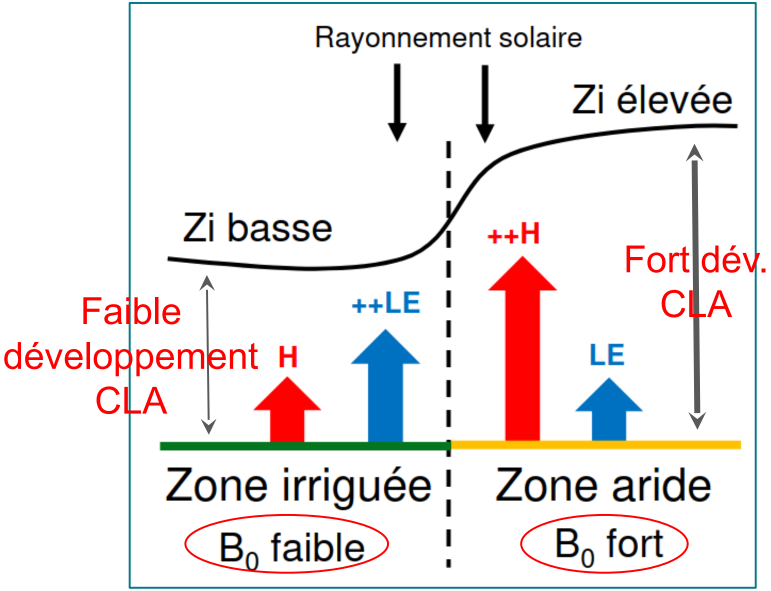
50 m



Rapport de Bowen

LC = La Cendrosa
EP = Els Plans

- Les flux de chaleur latente LE (en haut) et sensible H (en bas) en W/m²



Caractérisation des échanges entre le sol et la partie d’atmosphère juste au-dessus

Rapport de Bowen :

$$B_0 = \frac{H}{LE}$$

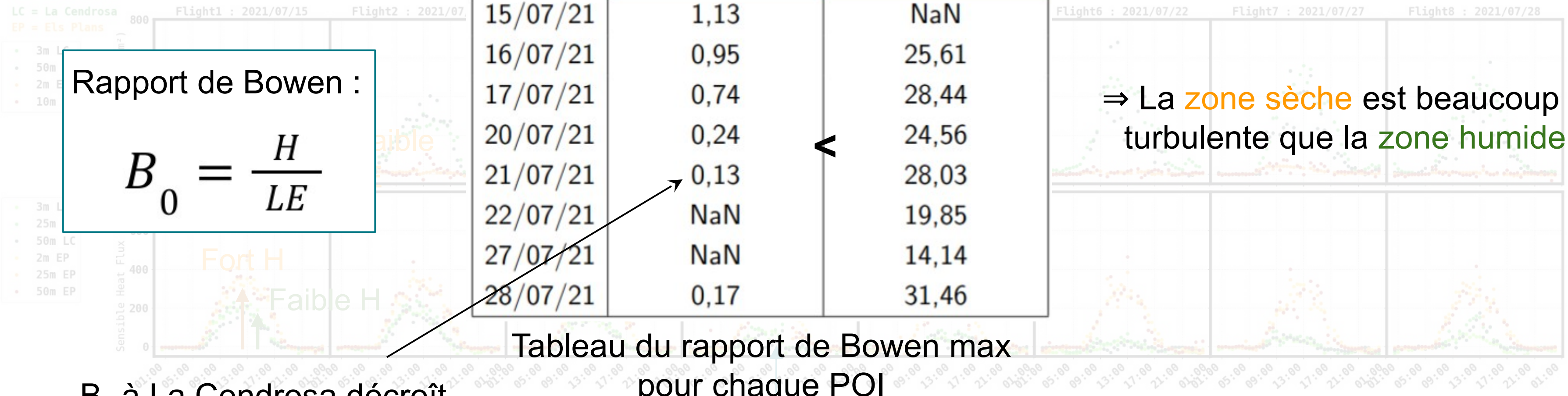
CLA = Couche Limite Atmosphérique
Zi = hauteur de la CLA
H : Flux de chaleur sensible
LE : Flux de chaleur latente

Rapport de Bowen

LC = La Cendrosa
EP = Els Plans

- Les flux de chaleur latente LE (en haut) et sensible H (en bas) en W/m²

Intensification du LE à La Cendrosa et H pratiquement nul à Els Plans



Dates	B0 max 3m BL1	B0 max 3m BL2
15/07/21	1,13	NaN
16/07/21	0,95	25,61
17/07/21	0,74	28,44
20/07/21	0,24	24,56
21/07/21	0,13	28,03
22/07/21	NaN	19,85
27/07/21	NaN	14,14
28/07/21	0,17	31,46

<

Tableau du rapport de Bowen max pour chaque POI

Rapport de Bowen :

$$B_0 = \frac{H}{LE}$$

B_0 à La Cendrosa décroît

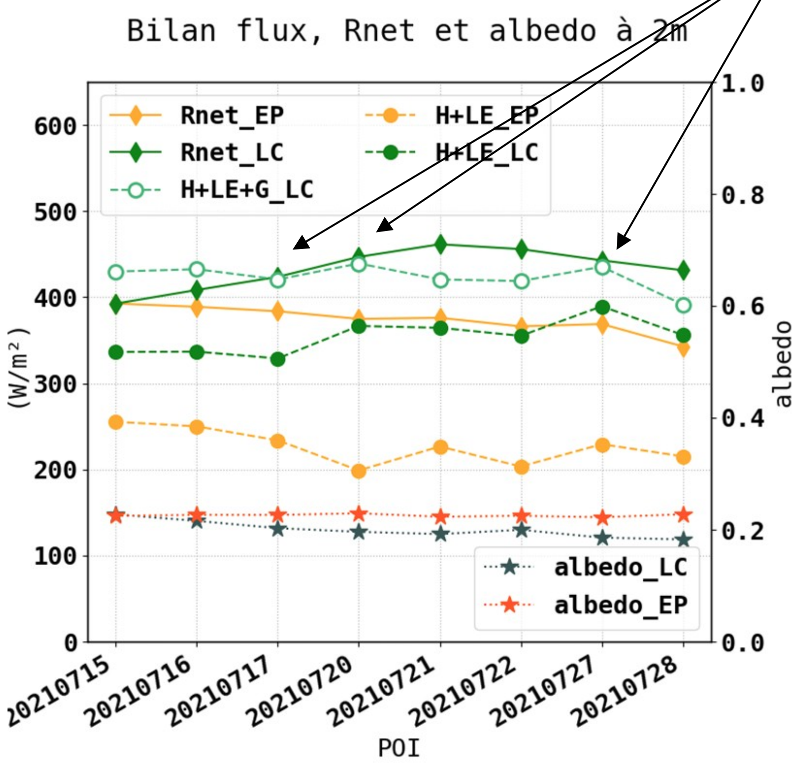
⇒ La zone sèche est beaucoup + turbulente que la zone humide

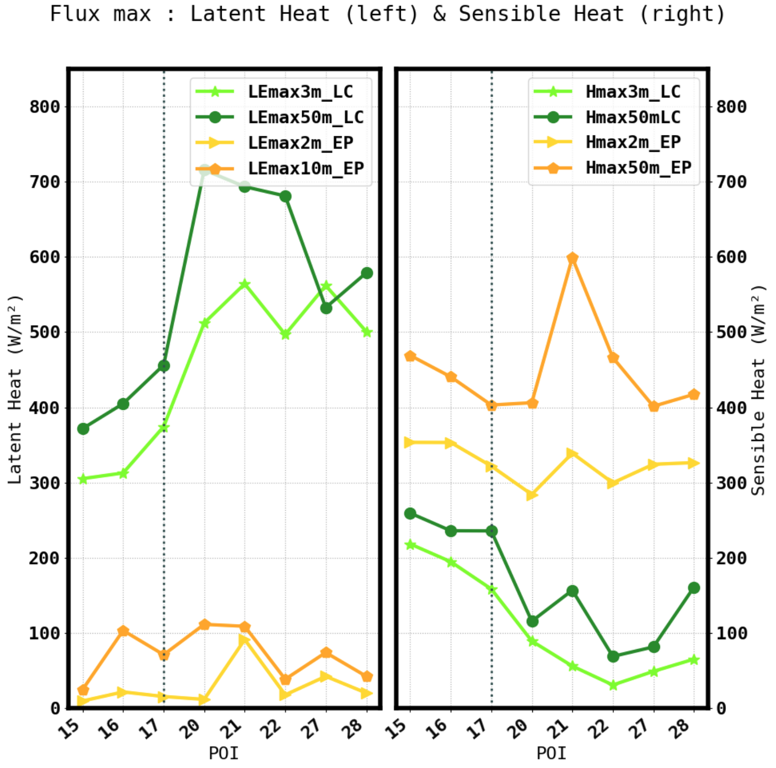
Affaiblissement du H à La Cendrosa et constance du H à Els Plans

Bilan énergie moyen, Rnet moyen, albédo moyen (à gauche) et Flux max (à droite)

LC = La Cendrosa
EP = Els Plans

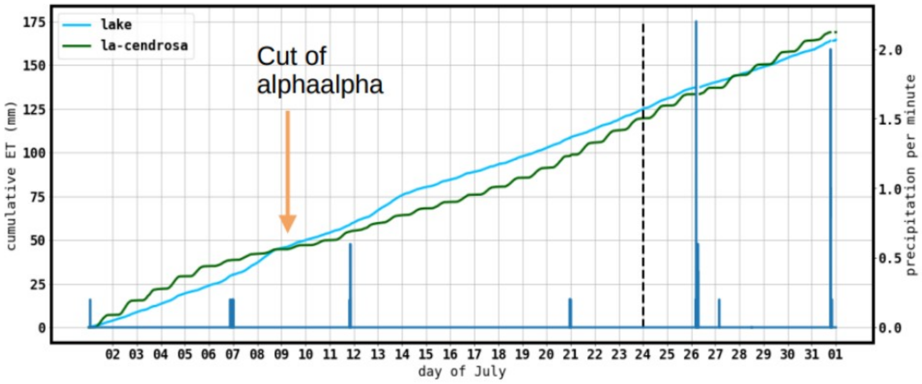
Fermeture du bilan pour 3 jours à LC





Taux évapotranspiration sur le lac Ivars

LC = La Cendrosa
EP = Els Plans

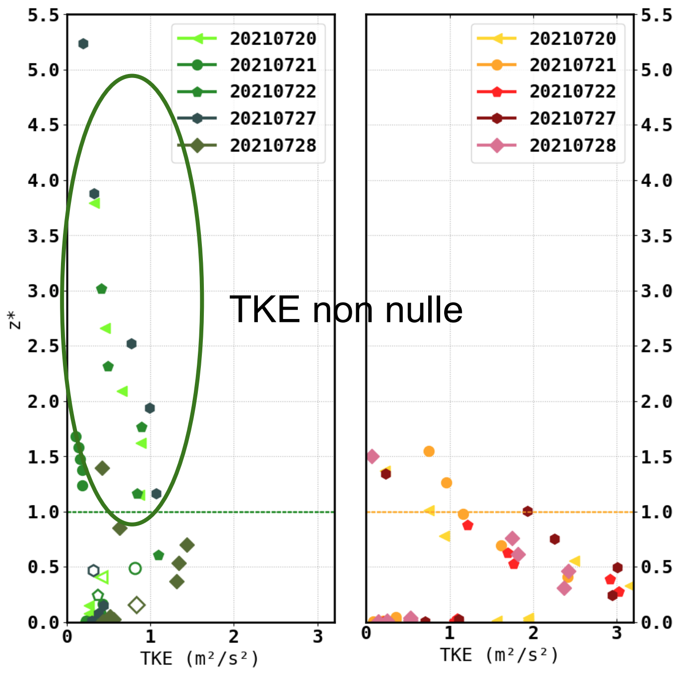


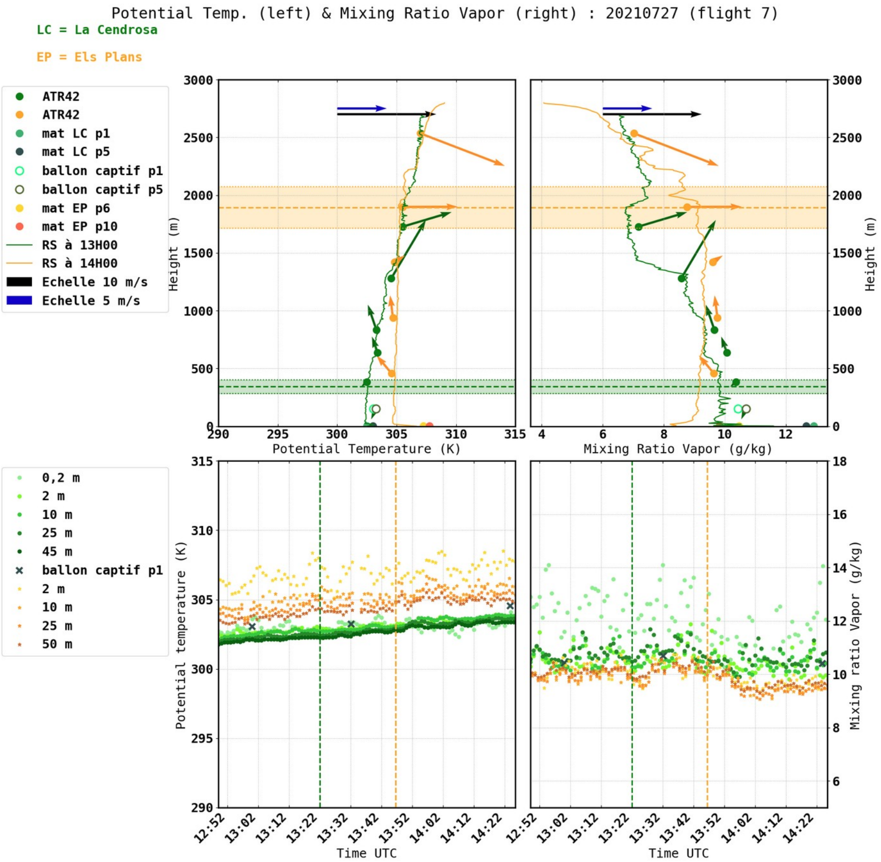
Canut et al. (2023), Surface energy balance and thermodynamic measurements over a mobil platform on Lake Ivars during the LIAISE field campaign. [Poster]. Workshop Gewex, Lerida, Espagne.

TKE non nulle et CLA interne

LC = La Cendrosa
EP = Els Plans

Période 2



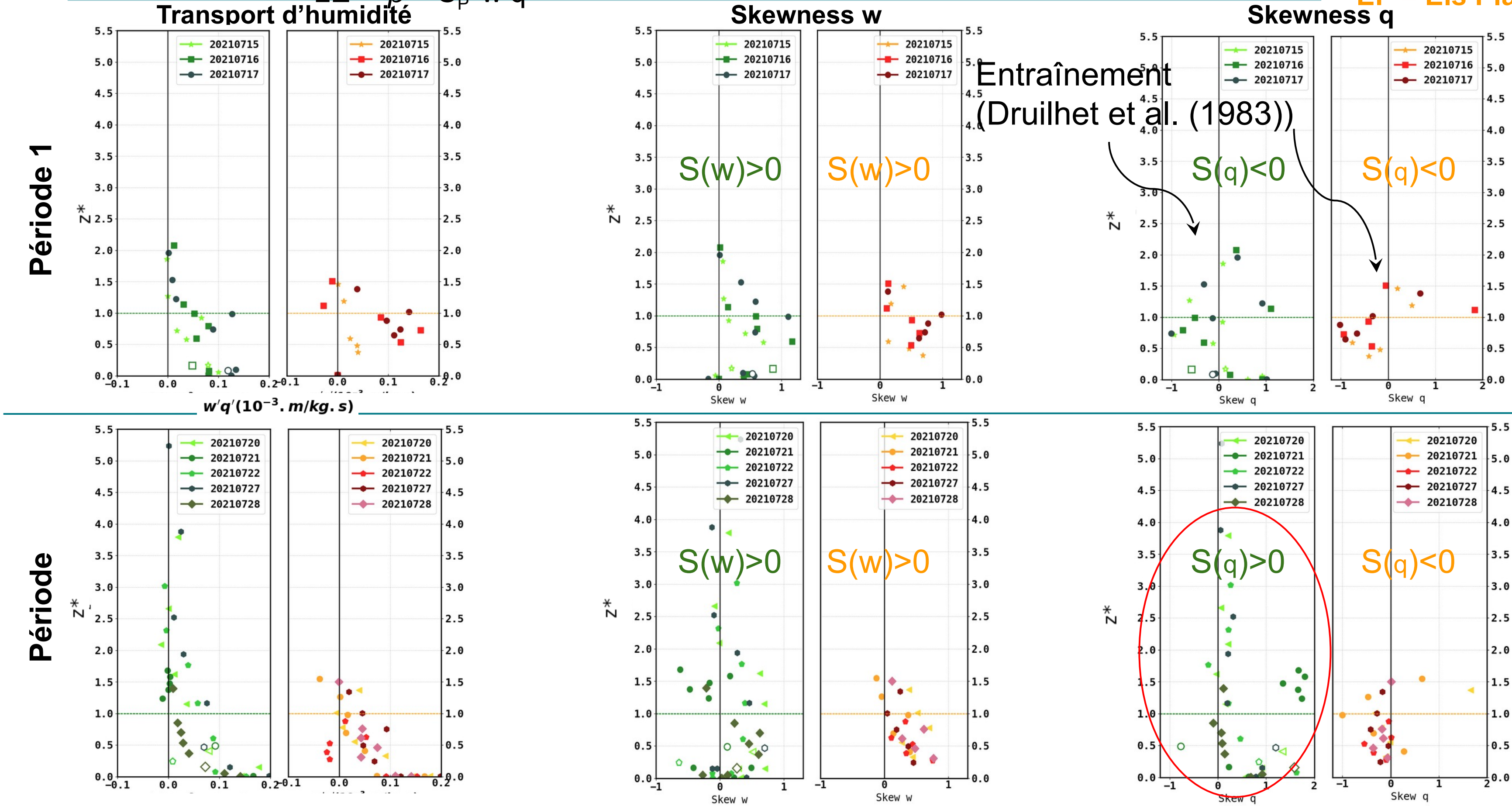


Transport d'humidité et Skewness de w et q

Chaleur latente : $LE = \rho * C_P * w'q'$

Zi EP ~ [750 m,; 2000 m]
Zi LC ~ [300 m ; 1000 m]

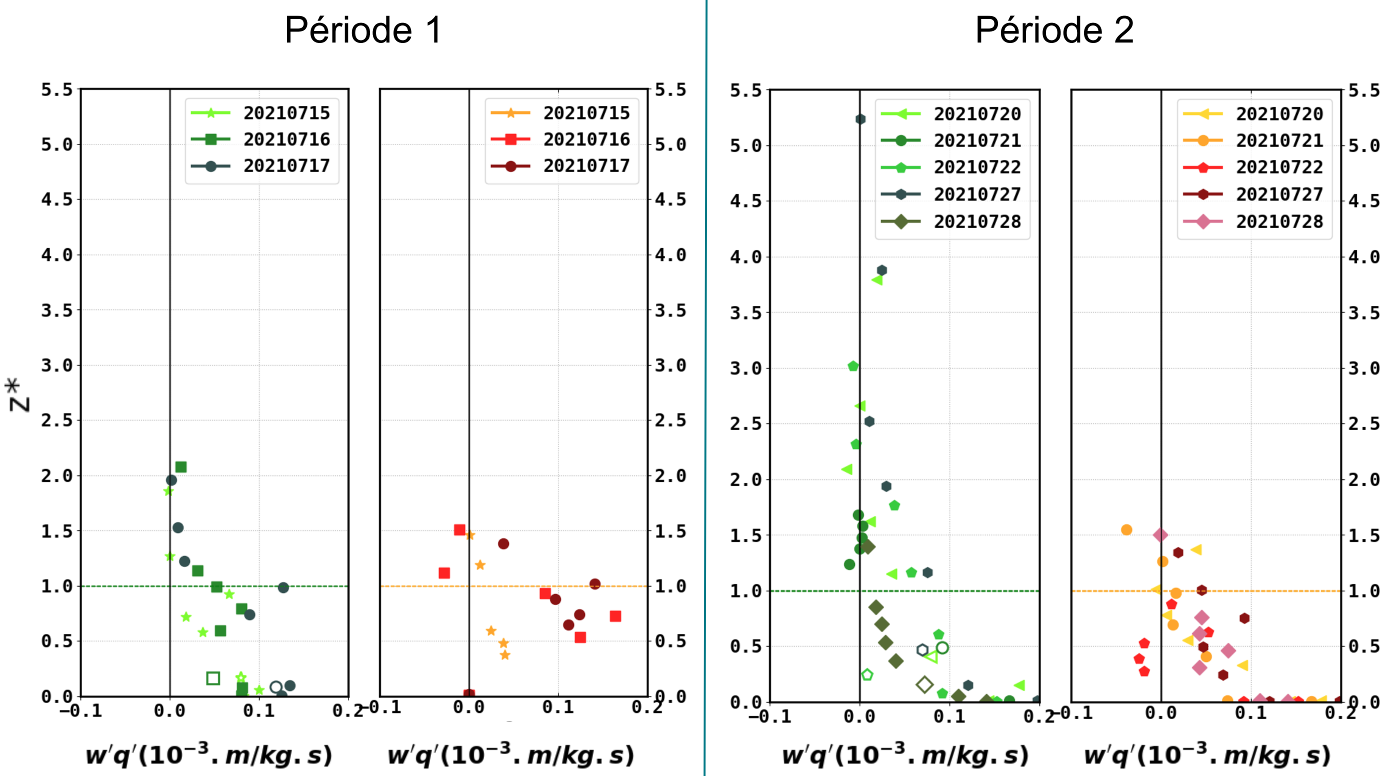
LC = La Cendrosa
EP = Els Plans



Transport d'humidité

Zi EP ~ [750 m,; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans



Chaleur latente : LE = ρ * C_P*w'q'

C_P : capacité calorifique de l'air sec à pression constante (~1004 $J.kg^{-1}.K^{-1}$)

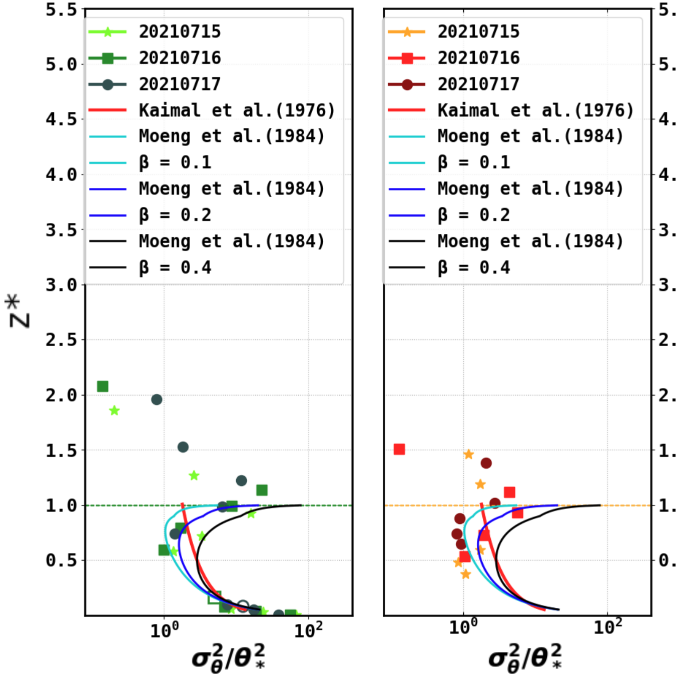
⇒ Profils typiques

Variance de la température potentielle normalisée par θ^2_*

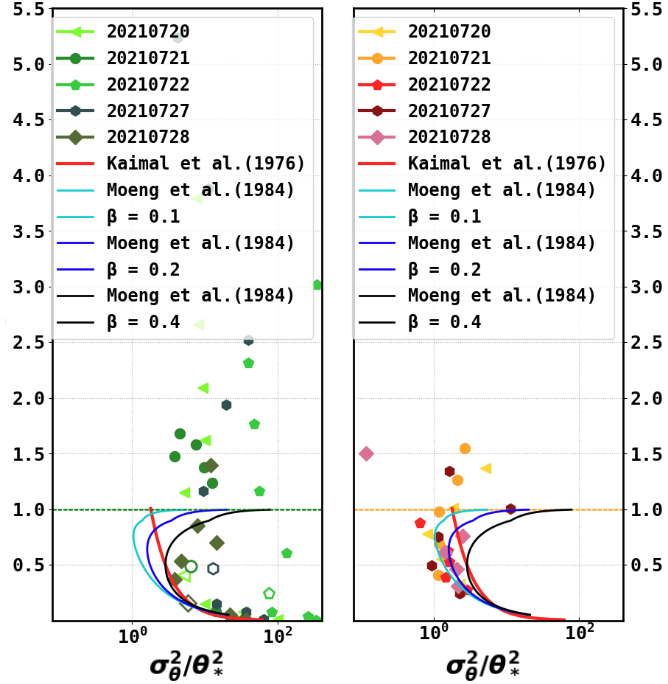
Zi EP ~ [750 m,; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Période 1



Période 2



Loi Kaimal et al. (1976)

⇒ prise en compte de la convection libre

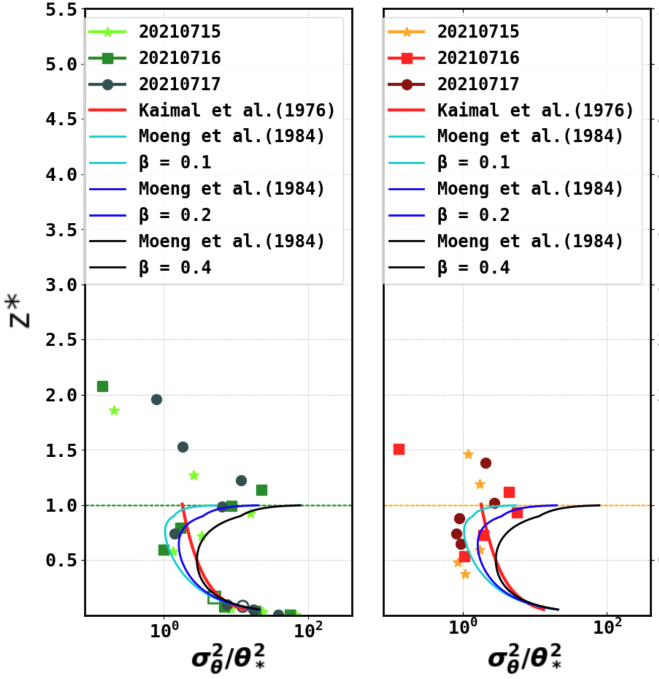
$$\frac{\sigma_\theta^2}{\theta_*^2} = 1{,}8 z_*^{-\frac{2}{3}}$$

Variance de la température potentielle normalisée par θ^2_*

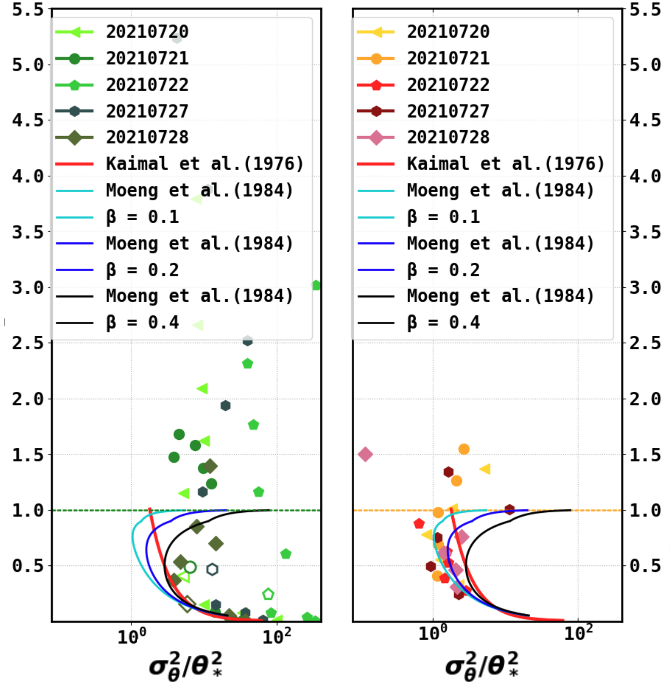
Zi EP ~ [750 m,; 2000 m]
Zi LC ~ [300 m ; 1000 m]

LC = La Cendrosa
EP = Els Plans

Période 1



Période 2



Loi Moeng et al. (1984)

- β = 0,1 → faible
- β = 0,2 → classique
- β = 0,4 → fort

⇒ prise en compte de l'entraînement

$$\frac{\sigma_\theta^2}{\theta_*^2} = f_b + 2\beta f_{tb} + \beta^2 ft$$

Avec $f_b = 0{,}47 z_*^{-\frac{5}{4}}$, f_{tb} qui vaut 1

$$f_t = 2{,}1(1 - z_*)^{-\frac{3}{2}} \quad pour\ z_* < 0{,}9\ Zi$$

$$f_t = 14(1 - z_*)^{-\frac{2}{3}} \quad pour\ z_* > 0{,}9\ Zi$$

Les premiers résultats : mesures en surface (mâts instrumentés)

LC = La Cendrosa
EP = Els Plans

La Cendrosa

Dates La Cendrosa	Vols	$\overline{Zi}$ BL1(m)	$\overline{\theta}$ (K)	$\overline{r_v}$ (g.kg⁻1)	B_0 (à 3m)	w_* (m.s⁻1)	θ_* (K)	$\overline{(w'\theta')}_S$ (K.m.s⁻1)	$\overline{(w'q')}_S$ (m.s⁻1).(g.kg⁻1)	Hauteur de la luzerne (cm)
15/07/21	1	909	289	8,3	1,1	1,72	0,098	0,17	0,083	17,4
16/07/21	2	638	291	10,1	1,0	1,4	0,093	0,13	0,081	22,6
17/07/21	3	525	292	11,0	0,7	1,24	0,09	0,11	0,13	28,2
20/07/21	4	343	295	9,6	0,2	0,73	0,048	0,035	0,14	39,9
21/07/21	5	311	294	11,2	0,1	0,76	0,058	0,044	0,17	40,9
22/07/21	6	650	295	9,5	NaN	0,52	0,013	0,0068	0,15	47,6
27/07/21	7	343	292	10,7	NaN	0,61	0,034	0,021	0,20	62,9
28/07/21	8	1057	294	12,0	0,2	1,38	0,055	0,076	0,14	67,9

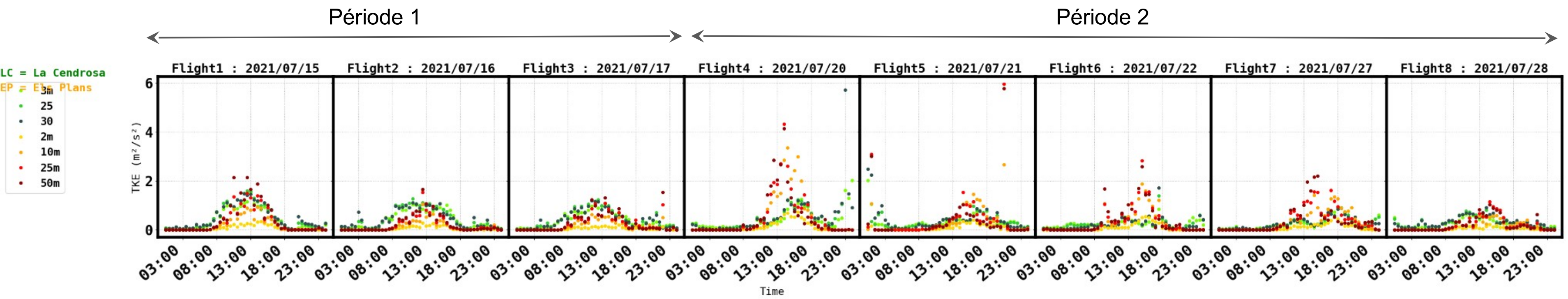
Els Plans

Dates Els Plans	Vols	$\overline{Zi}$ BL2(m)	$\overline{\theta}$ (K)	$\overline{r_v}$ (g.kg⁻1)	B_0 (à 3m)	w_* (m.s⁻1)	θ_* (K)	$\overline{(w'\theta')}_S$ (K.m.s⁻1)	Vent à 500 hPa (valable pour BL1 et BL2)
15/07/21	1	1157	291	8,0	NaN	2,4	0,15	0,36	N (faible)
16/07/21	2	824	292	10,7	25,6	1,97	0,14	0,28	NO (modérée)
17/07/21	3	696	294	12,5	28,4	1,76	0,14	0,24	NO (modérée)
20/07/21	4	1425	298	9,2	24,6	2,25	0,11	0,25	O (faible)
21/07/21	5	1136	297	10,5	28,0	2,3	0,15	0,37	NO (modérée)
22/07/21	6	1682	297	8,2	19,9	2,37	0,11	0,25	O (modérée)
27/07/21	7	1894	293	10,3	14,1	2,45	0,099	0,24	O (modérée)
28/07/21	8	1479	296	13,4	31,5	2,1	0,092	0,19	O (modérée)

Les premiers résultats : mesures en surface (mâts instrumentés)

LC = La Cendrosa
EP = Els Plans

- L'énergie cinétique turbulente = TKE (m^2/s^2)



période 1 → tke identique avec max à 13h
période 2 → différente avec un max le 20/07 et un décalage de du max de tke entre 13 et 17h

exemple du 17/07/2021

LC = La Cendrosa
EP = Els Plans