NATURE AND CHARACTERISTICS OF WEAK AND INTENSE KATABATIC FLOWS

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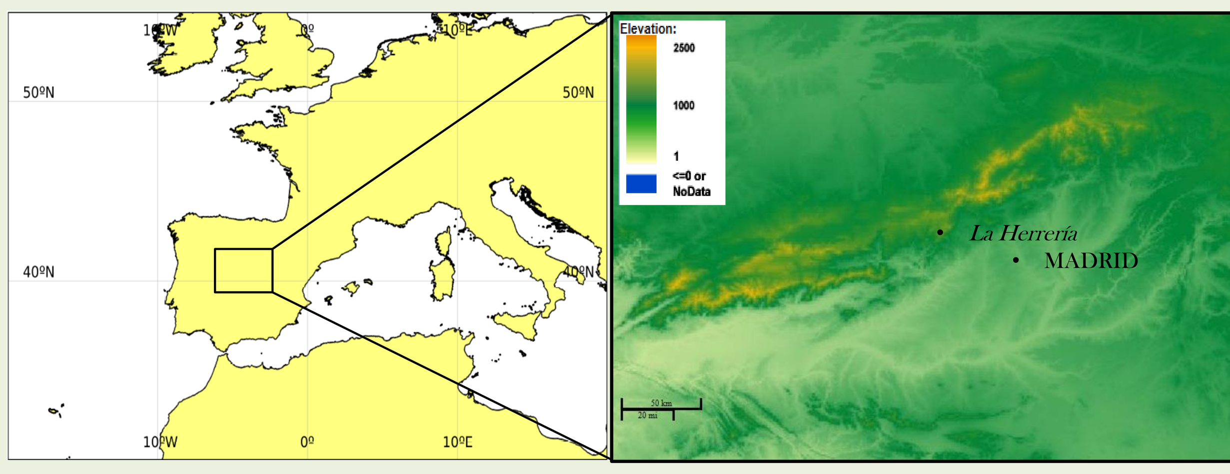
1. LA HERRERÍA

This anaylisis is performed in *La Herrería Forest*, located at the foothill of the Guadarrama Mountain Range (Spain), at around 50 km from the city of Madrid.



Summers are particularly dry and warm in this region. The surface energy balance is therefore moisture limited!

2. OBSERVATIONS

In this work we use 10-minutal meteorological measurements carried out during an intensive summer campaign in 2017 (22/06 – 26/09).

Picture of the 10-m meteorological fixed tower at La Herreria Forest during Summer 2017. La Herreria is part of the Guadarrama Monitoring Network (GuMNet; www.ucm.es/gumnet/).

Main measurements used in this study:

Variable	Height (m, agl)	Instrument
Air temperature	3, 6, 10	Aspirated thermometer
Wind speed	3, 6, 10	Cup anemometer
Wind direction	10	Wind Vane
Turbulent fluxes	4, 8	IRGASON
Rain	surface	Pluviometer
Soil Moisture	-0.05	Reflectometer
Soil-heat flux	-0.05	Heat-flux plate
Radiation components	2	4-component radiometer

3. KATABATIC DETECTION

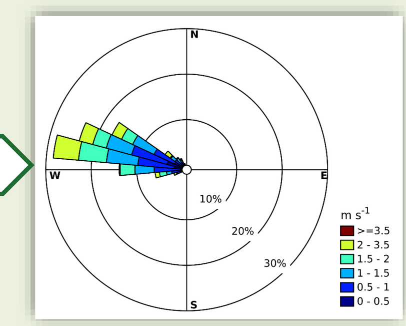
We apply an objective and systematic **algorithm** to the observational data in order to select the events that fulfil **katabatic-event criteria:**

Filter	Criteria	Description
1	Weak large-scale winds	$V_{850} < 6$ m s^{-1}
2	Days without synoptic cold fronts	$(\Delta\theta_{e,850}/\Delta t) > -1.5$ºC/6h
3	Non-rainy events	pp < 0.5 mm/day
4	Minimum persistence in the katabatic direction	WD ϵ $[240 - 330]_{2h}$

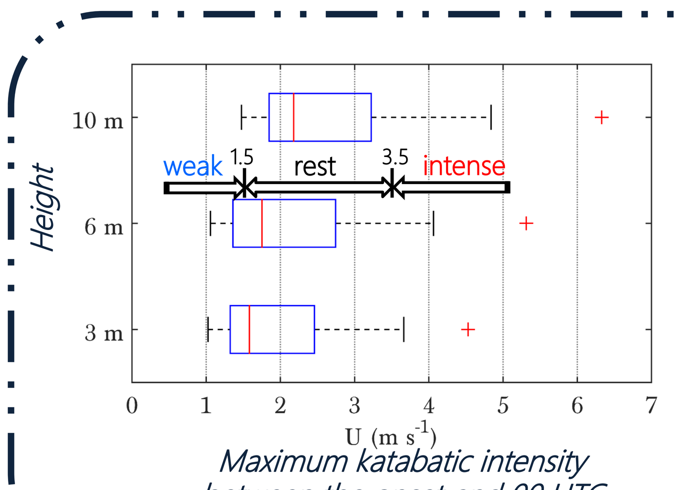
It is based on the algorithm for selecting sea-breeze events from Arrillaga et al. (2018).

We find **40/94** katabatic events meeting the requirements from the algorithm.

Wind rose at 6 m over 2 h after the katabatic onset.



MOTIVATION



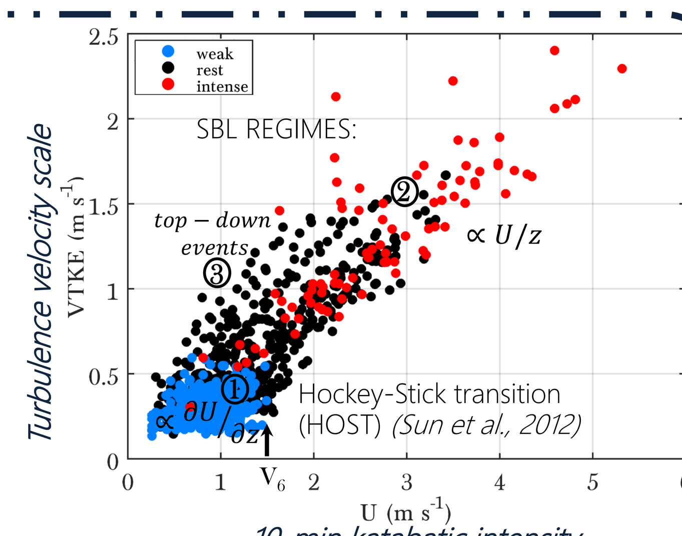
Maximum katabatic intensity between the onset and 00 UTC

1. WE CLASSIFY KATABATICS INTO 3 GROUPS ACCORDING TO THEIR MAXIMUM INTENSITY AT 6 M.

WHICH ARE THE FACTORS PRODUCING DIFFERENT INTENSITIES?

2. KATABATIC INTENSITY IS ASSOCIATED WITH DISTINCT REGIMES IN THE STABLE BOUNDARY LAYER (SBL)

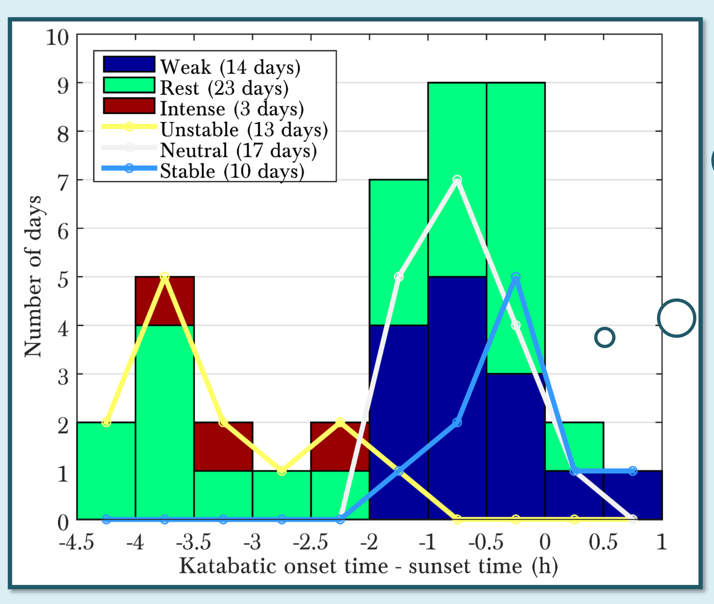
HOW DOES THE INTERACTION BETWEEN KATABATICS AND TURBULENCE OCCUR?



10-min katabatic intensity

4. NATURE

4.1) Close relationship between katabatic intensity & thermal stratification at the onset



THERMAL STRATIFICATION: $\Delta\theta_V = \theta_v(10m) - \theta_v(3m)$

Unstable: $(\Delta\theta_v)_{onset} < -0.2\ K$

Neutral: $-0.2\ K \leq (\Delta\theta_v)_{onset} \leq +0.2\ K$

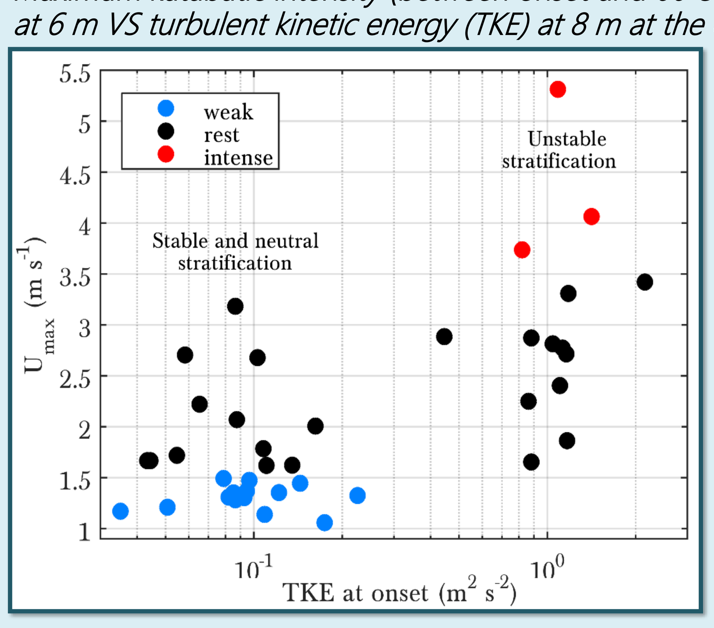
Stable: $(\Delta\theta_v)_{onset} > +0.2\ K$

Early onset (prior to 2h before sunset) → Unstable stratification → Intense (& few *rest*) katabatics

Late onset (after 2h before sunset) → Neutral/Stable stratification → Weak (& most *rest*) katabatics

4.2) Thermal stratification at the katabatic onset is directly linked to turbulence.

Maximum katabatic intensity (between onset and 00 UTC) at 6 m VS turbulent kinetic energy (TKE) at 8 m at the onset



WE FIND TWO GROUPS:

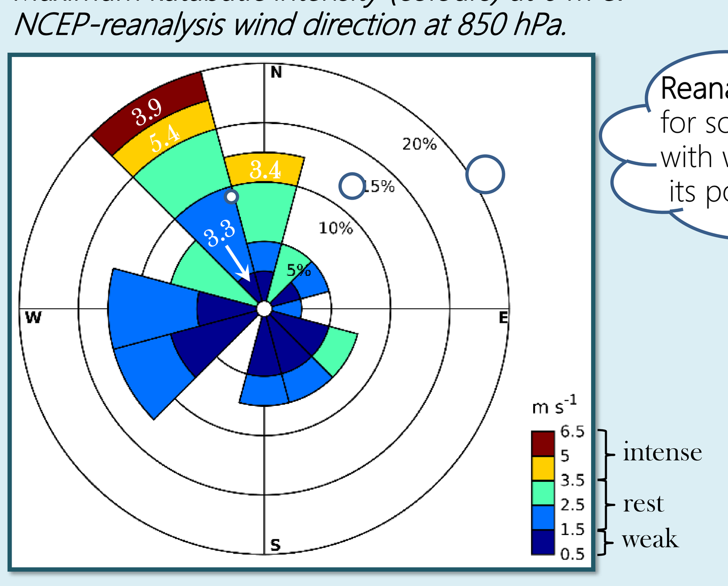
(1) TKE ~∝ 0.1 m^2 s^{-2} → Neutral/Stable stratification (WEAK AND SOME *REST* KATABATICS)

(2) TKE ~∝ **1** m^2 s^{-2} → Unstable stratification (INTENSE AND SOME *REST* KATABATICS)

TURBULENCE INTENSITY AT THE ONSET MODULATES THE SUBSEQUENT KATABATIC INTENSITY → IT IS EXPLAINED BY THE COMPLEX INTERACTION BETWEEN KATABATICS AND TURBULENCE

4.3) Which are the factors that induce an earlier or later onset of katabatic flows?

Maximum katabatic intensity (colours) at 6 m & NCEP-reanalysis wind direction at 850 hPa.



Reanalysis wind speed at 850 hPa for some events is indicated with white labels to show its possible influence.

We explore the influence of synoptic-wind direction and soil moisture (Fitzjarrald, 1984; Banta & Gannon, 1995).

Since it is generally weak, its influence is negligible

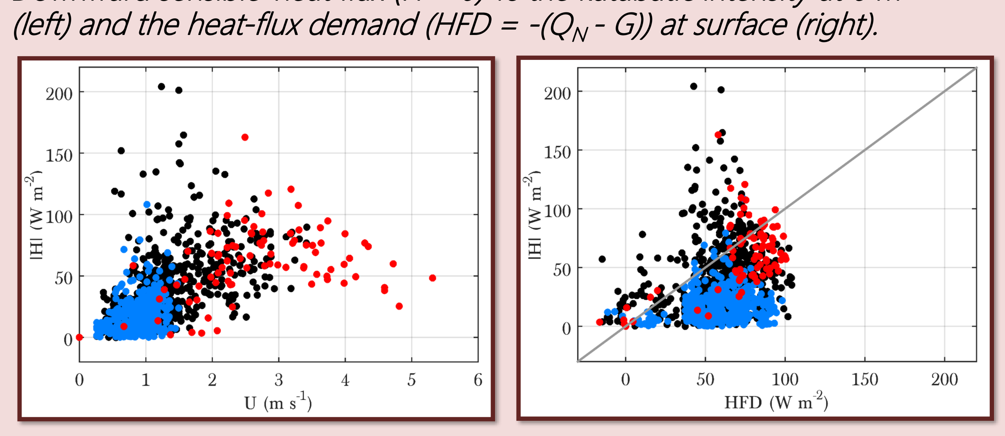
N-NW SYNOPTIC WIND + SOIL MOISTURE < 0.06 m^3 m^{-3} → INTENSE KATABATICS

W-SW / S-SE SYNOPTIC WIND or N-NW SYNOPTIC WIND + SOIL MOISTURE > 0.06 m^3 m^{-3} → WEAK KATABATICS

5. INTERACTION WITH TURBULENCE

5.1) Downward sensible heat flux and surface energy balance

Downward sensible-heat flux (H < 0) vs the katabatic intensity at 6 m (left) and the heat-flux demand (HFD = -(Q_N - G)) at surface (right).



- H (<0) is maximum for intermediate wind speed (1.5 – 3.5 m s^{-1}).
- We neglect the latent-heat flux (it is almost zero) in the surface energy balance and compare H vs HFD.
- The greatest negative energetic imbalance occurs for weak katabatics, which induces the formation of a very stable regime.

5.2) Regime transition from non-dimensional parameters

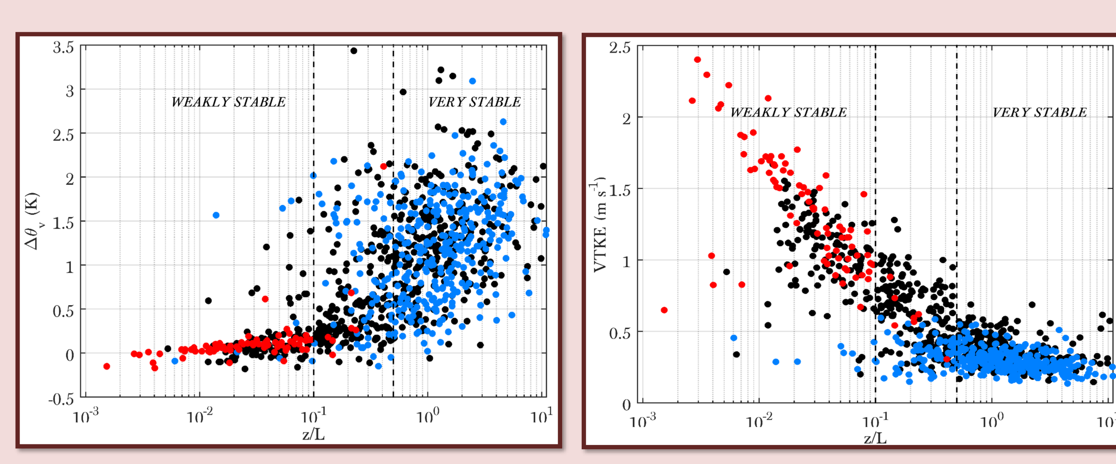
We characterise the regime transition from relevant non-dimensional parameters by representing thermal stratification $\Delta\theta_v$ and V_{TKE} as a function of one local and one non-local parameter: z/L and shear capacity (SC) respectively.

$$V_{TKE} = \sqrt{\frac{1}{2}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})}$$

This variable is used as a measure of turbulence intensity.

$$L = \frac{-u_*^3\theta_v}{\kappa g \overline{w'\theta_v'}}$$

Turbulent fluxes are calculated at 8 m agl, and so is z/L.



By using this local parameter we are unable to find a single value to separate the SBL regimes!

For instance, results are similar to *Mahrt et al. (1998)* at 10 m for the **regime transition**:

→ Weakly stable: 0.1 VS 0.065 *(Mahrt et al., 1998)*

→ Very stable: 0.5 VS 1 *(Mahrt et al., 1998)*

The **SC** compares the measured shear with the mínimum shear to maintain continuous turbulence, which is given by the heat-flux demand at surface (*van Hooijdonk et al., 2015*). We calculate it considering that turbulence depends on local shear when U < V_6 = 1.5 m s^{-1}, and on bulk shear when U > V_6 (HOST transition).

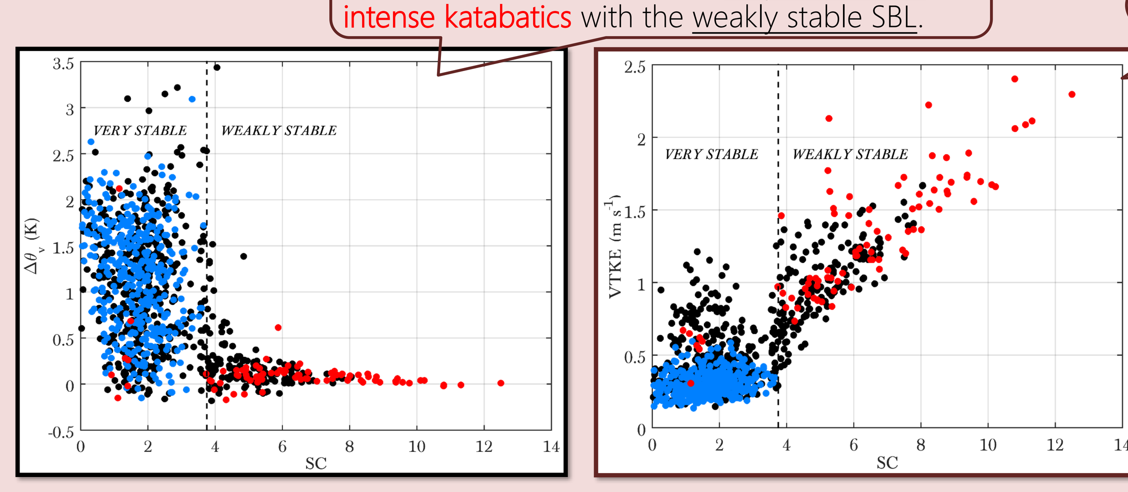
$$SC(U < 1.5\ m\ s^{-1}) = \left[\frac{\rho C_p(\kappa z)^2 \left(\partial U/\partial z\right)^3}{g/\theta_v\ |Q_N - G|}\right]^{\frac{1}{3}},$$

$$SC(U > 1.5\ m\ s^{-1}) = \left[\frac{\rho C_p(\kappa z)^2 \left(U/z\right)^3}{g/\theta_v\ |Q_N - G|}\right]^{1/3}$$

Local shear is calculated from fitting wind-speed measurements to a log-linear profile.

We consider a minimum HFD of 50 W m^{-2} to sustain continuous turbulence.

Except for very few 10-min values, weak katabatics are linked with the very stable SBL and intense katabatics with the weakly stable SBL.



This non-local parameter **predicts the regime transition** (SC~3.5) independently of the height *(van Hooijdonk et al., 2015)*.

THIS PARAMETER IS DEFINED BY IGNORING TRANSPORT TERMS IN THE TKE BUDGET, WHICH HOWEVER CAN BE IMPORTANT IN KATABATIC WINDS. STILL, WE ARE ABLE TO DEFINE THE REGIME TRANSITION FROM THE KATABATIC WIND SPEED.

6. FINAL THOUGHT

- WE HAVE LINKED THE SYNOPTIC WIND AND LOCAL SOIL-MOISTURE CONDITIONS, WITH KATABATIC INTENSITY AND THE ASSOCIATED SBL REGIMES FROM THEIR INTERACTION WITH TURBULENCE:

⇨ SYNOPTIC WIND IN THE KATABATIC DIRECTION + LOW SOIL MOISTURE → EARLY KATABATIC ONSET: UNSTABLE/CONVECTIVE STRATIFICATION → MODERATE TO HIGH TURBULENCE → BULK SHEAR INCREASES → SUBSEQUENT INTENSE KATABATIC → NEAR-NEUTRAL/WEAKLY STABLE SBL REGIME.

⇨ IF THE CONDITIONS ABOVE FOR THE SYNOPTIC WIND AND SOIL MOISTURE ARE NOT MET → LATER ONSET: NEUTRAL/STABLE STRATIFICATION → WEAK TURBULENCE + RADIATIVE LOSS NOT COMPENSATED → STABLE STRATIFICATION THAT SUPPRESSES TURBULENCE PRODUCTION (POSITIVE FEEDBACK) → WEAK KATABATIC PRODUCING A VERY STABLE REGIME.

7. REFERENCES

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8. ACKNOWLEDGEMENTS

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