Turbulent flow in the inner layer of a katabatic jet along a steep alpine slope

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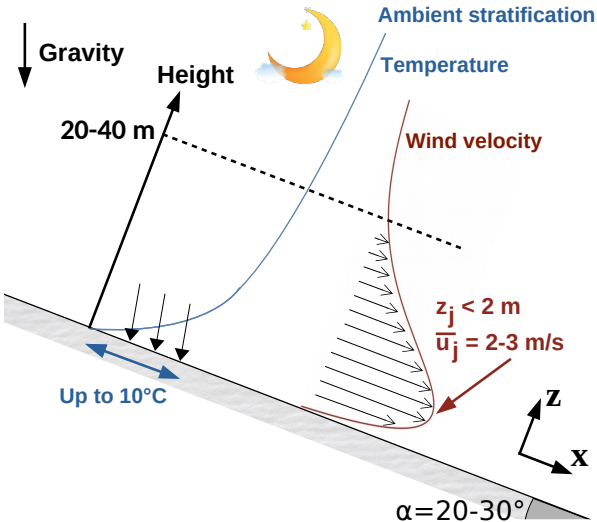
Katabatic wind process



Negative radiative budget

$$R_n^{night} = LW_{received} - LW_{emitted} < 0$$

$\Downarrow$

Surface temperature cooling

$\Rightarrow$ Temperature gradient

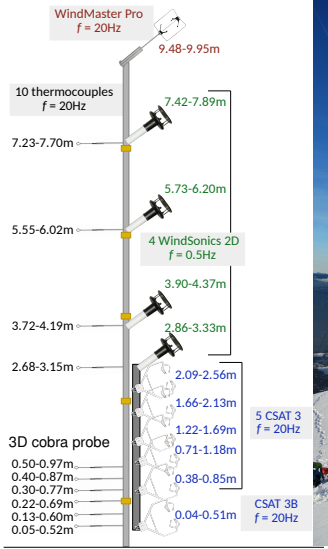
$\Rightarrow$ Air cooling / densification

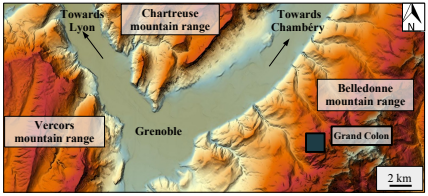
$\Downarrow$

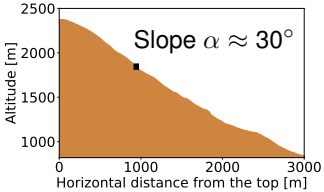
Downslope flow

$\Rightarrow$ Turbulent mixing

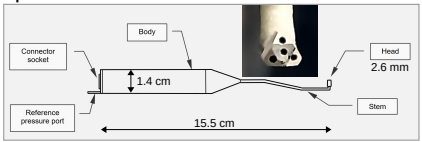
Measurement setup





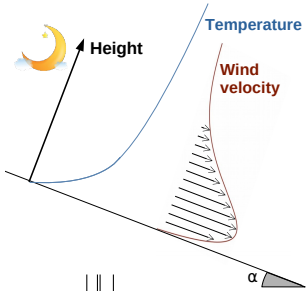


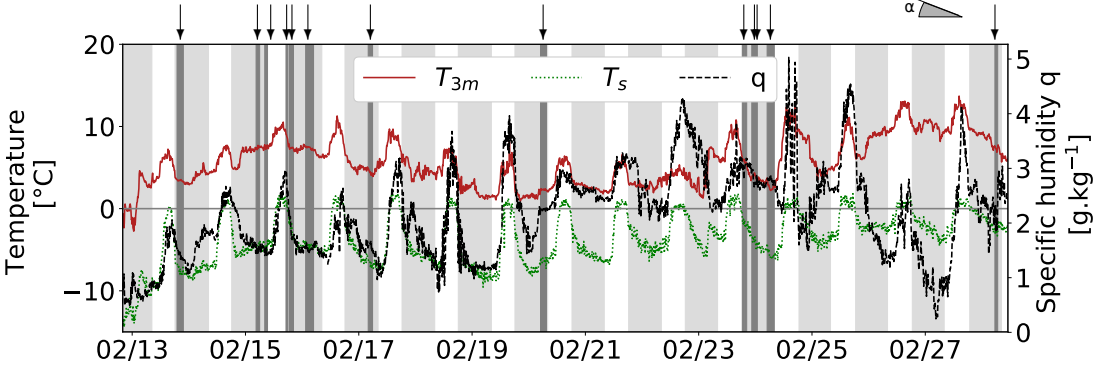
'Cobra' 3D pitot tube *TFI*
pressure transducers: $f = 1250$ Hz



13 katabatic events

- Wind in the downslope direction
- Positive temperature gradient
- Velocity profiles $\sim$ wall jet



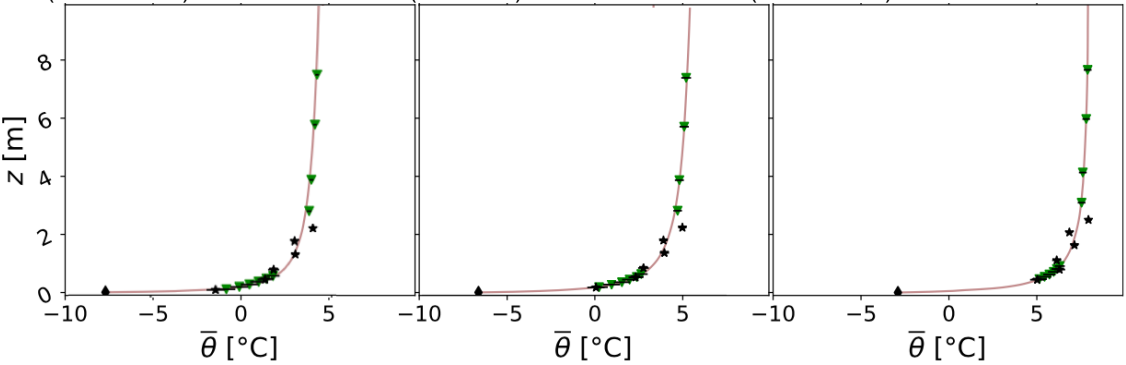


Potential temperature profiles $\overline{\theta}$

February 13, 2019
(19h-21h40)

February 17, 2019
(4h-5h45)

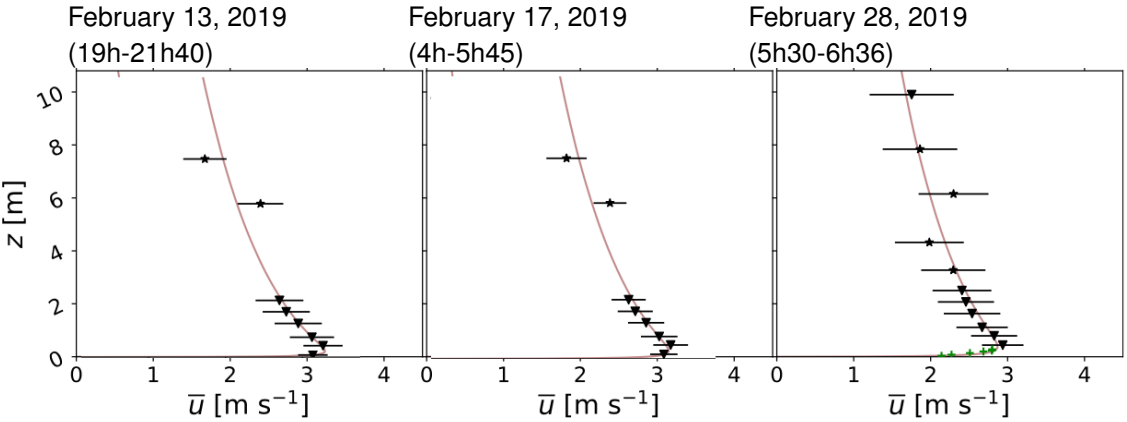
February 28, 2019
(5h30-6h36)



Thermocouples (green), sonic anemometers (black), Prandtl model (red)

Charrondière et al., BLM (2022) https://doi.org/10.1007/s10546-021-00644-y
Charrondière et al., JFM (2022) https://doi.org/10.1017/jfm.2022.281

Along the slope velocity $\overline{u}$



sonic anemometers (black), cobra pitot (green), Prandtl model (red)

Charrondière et al., BLM (2022) https://doi.org/10.1007/s10546-021-00644-y
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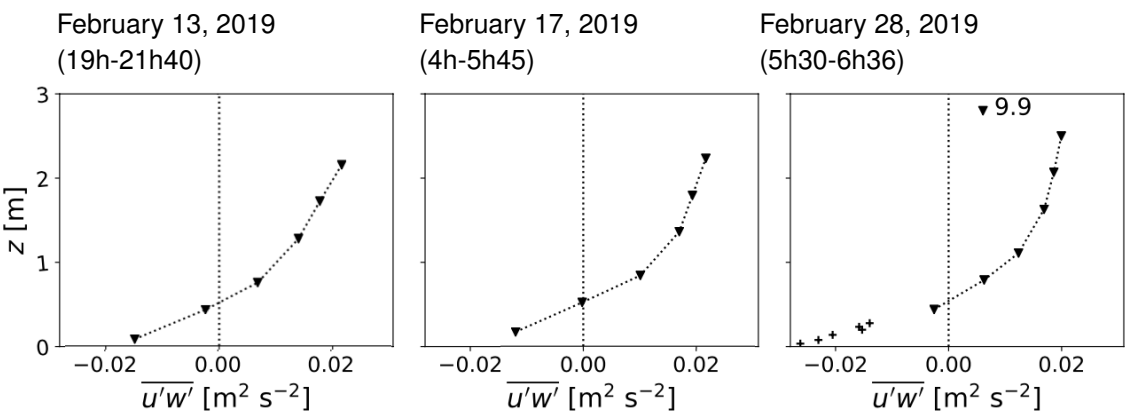
Momentum turbulent flux



sonic anemometers (triangles), cobra pitot (plus)

Charrondière et al., BLM (2022) https://doi.org/10.1007/s10546-021-00644-y
Charrondière et al., JFM (2022) https://doi.org/10.1017/jfm.2022.281

Momentum budget along the slope

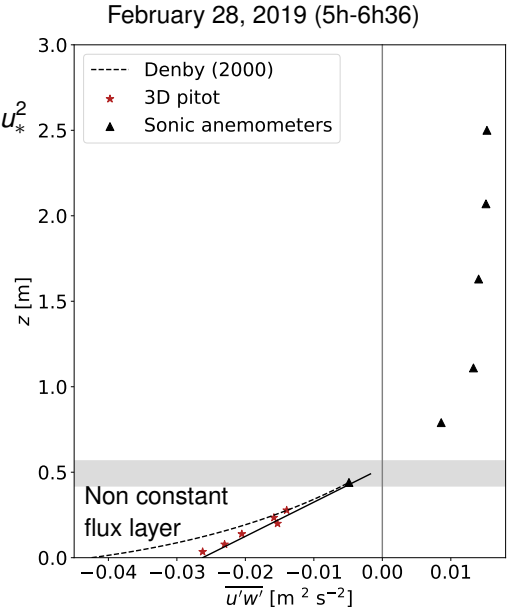
$$\underbrace{\frac{\partial \overline{u}}{\partial t}}_{\text{Inertia}} + \underbrace{\overline{w}\frac{\partial \overline{u}}{\partial z}}_{\text{Advection}} + \underbrace{\frac{\partial \overline{u'w'}}{\partial z}}_{\substack{\text{Divergence of} \\ \text{the turbulent} \\ \text{momentum flux}}} \approx \underbrace{-g\frac{\overline{\theta_s} - \theta_a}{\theta_a}\sin\alpha}_{\text{Katabatic forcing}} = a u_*^2$$

Denby (2000)

Non constant flux profile

$$-\overline{u'w'} = u_*^2(1 - az) = \left(\kappa z \frac{\partial \overline{u}}{\partial z}\right)^2$$

Charrondière et al., BLM (2022)
Charrondière et al., JFM (2022)



Momentum budget along the slope

$$\underbrace{\frac{\partial \overline{u}}{\partial t}}_{\text{Inertia}} + \underbrace{\overline{w}\frac{\partial \overline{u}}{\partial z}}_{\text{Advection}} + \underbrace{\frac{\partial \overline{u'w'}}{\partial z}}_{\substack{\text{Divergence of} \\ \text{the turbulent} \\ \text{momentum flux}}} \approx \underbrace{-g\frac{\overline{\theta_s} - \theta_a}{\theta_a}\sin\alpha}_{\text{Katabatic forcing}} = a u_*^2$$

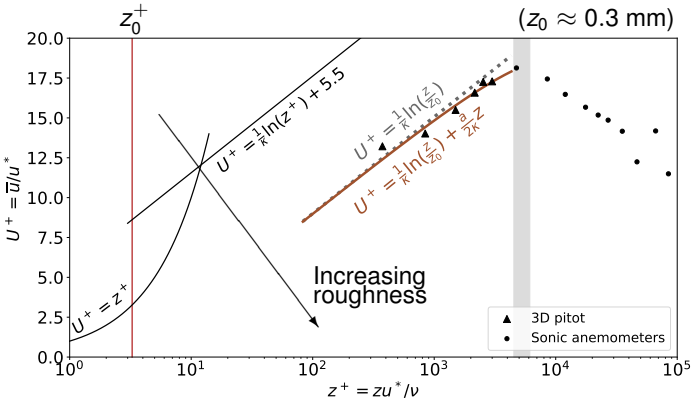
Denby (2000)

February 28, 2019 (5h-6h36)

Turbulent velocity profile

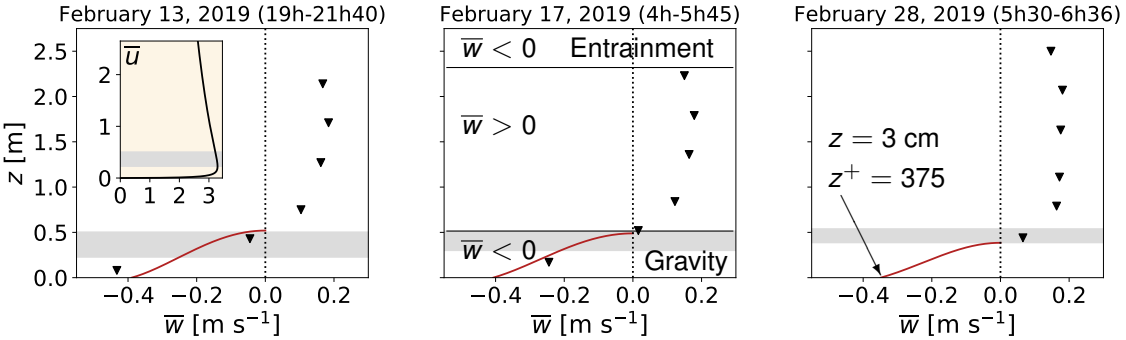
$$\overline{u}^+ = \frac{1}{\kappa}\ln\frac{z}{z_0} - \frac{a}{2\kappa}z + \beta\frac{z}{L_{MO}}$$

avec $\frac{1}{a} \approx 0.5m$ et $L_{MO} \approx 200m$



Charrondière et al., BLM (2022)
Charrondière et al., JFM (2022)

Normal to the slope velocity $\overline{w}$



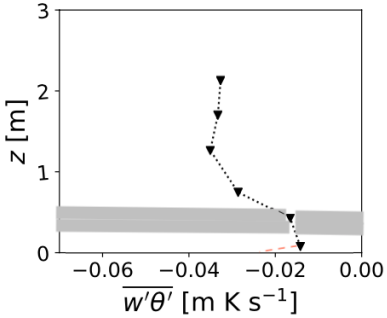
$$\underbrace{\frac{\partial \overline{w}}{\partial t}}_{\text{Inertia}} + \underbrace{1/2\frac{\partial \overline{w}^2}{\partial z}}_{\text{Advection}} + \underbrace{\frac{\partial \overline{w'^2}}{\partial z}}_{\substack{\text{Divergence of} \\ \text{the turbulent} \\ \text{velocity variance}}} \approx \underbrace{g\frac{\overline{\theta} - \theta_a}{\theta_a}\cos\alpha}_{\text{Katabatic forcing}}$$

Charrondière et al., BLM (2022)
Charrondière et al., JFM (2022)

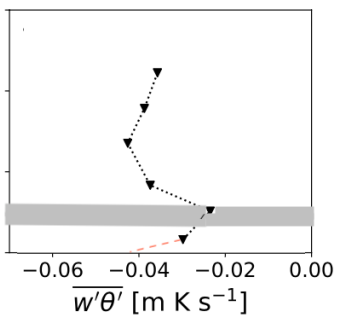
Potential temperature budget & turbulent sensible heat flux $\overline{w'\theta'}$

$$\underbrace{\frac{\partial \overline{\theta}}{\partial t}}_{\text{Inertia}} + \underbrace{\frac{\partial \overline{w'\theta'}}{\partial z}}_{\text{Flux divergence}} \approx - \underbrace{\overline{w}\frac{\partial \overline{\theta}}{\partial z}}_{\text{Advection}} - \underbrace{\overline{u}\frac{\partial \theta_a}{\partial z}\sin\alpha}_{\text{Ambient stratification effect}} > 0$$

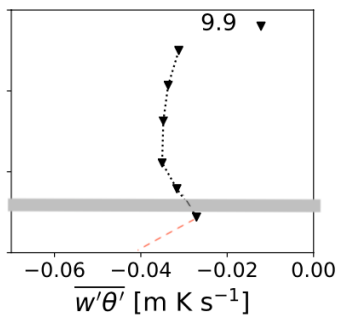
February 13, 2019
(19h-21h40)



February 17, 2019
(4h-5h45)



February 28, 2019
(5h30-6h36)



Conclusion & overlook

Katabatic jet along a steep slope

$\Rightarrow$ **Turbulent boundary layer in the inner layer**
– **non constant turbulent fluxes (gravity effect)**
– **log-lin law for the along the slope velocity**
– **normal to the slope velocity contribution** $10\%Uj$

$\Rightarrow$ **Data available on a zenodo repository**
– **https://doi.org/10.5281/zenodo.6546702**