Investigating the dynamics of thermally driven up-slope flows

Analysis of data from measurements in the Inn Valley (Austria) and comparison with a simple model

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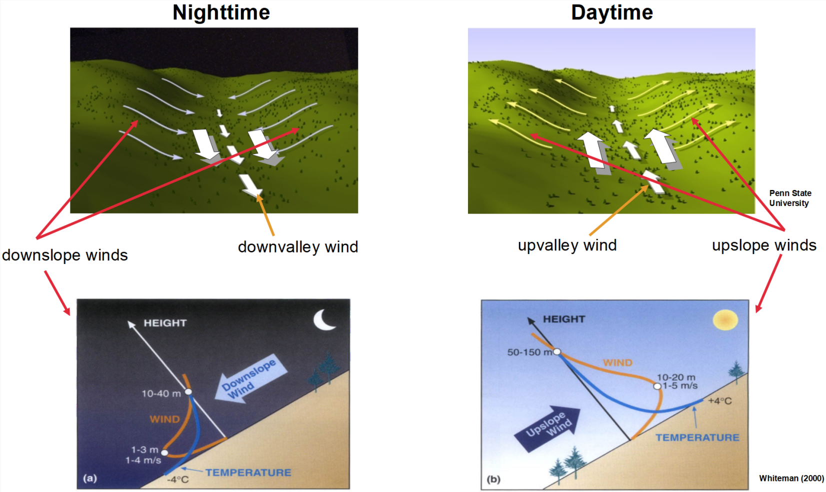
Introduction

Thermally-driven winds

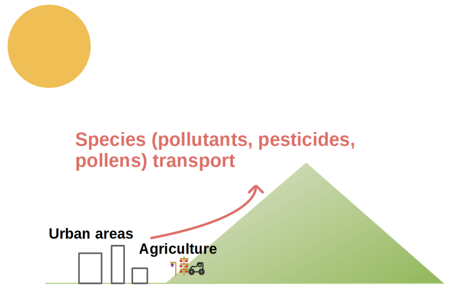
→ Originate from the daytime heating/nighttime cooling of sloping surfaces (more details on transition in Farina et al. 2021, EGU21)

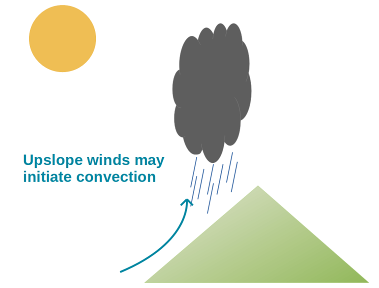
→ Mostly occur during clear-sky summer days characterized by weak synoptic forcing



Why to study upslope flows

- Better understanding of the soil-atmosphere exchange processes and of the surface energy budget over complex terrain
- Improvement of existing parameterizations of turbulent fluxes over complex terrain
- Modelling of species transport along slopes (e.g pollutants)
- Optimal convection initiation conditions from thermals

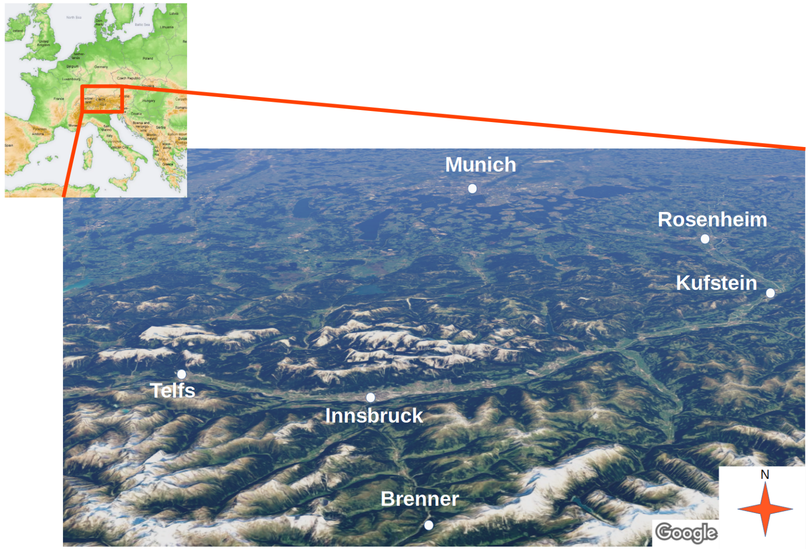




Analysis of data from measurements in the Inn Valley (Austria)

The i-Box project (Rotach et al., 2017)

Inn valley $\rightarrow$ i-Box = Innsbruck-Box

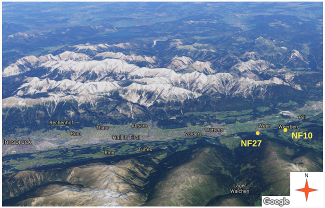


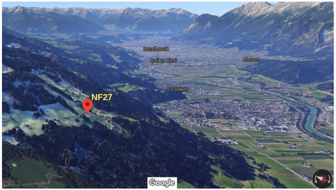
i-Box: 2 slope stations

Data processing: Stiperski et al. (2016)

Hochhaueser (NF 27)

Elevation	1009 m
Slope angle	27°
Slope orientation	1°
Measurement points	1.5 and 6.8 m
Instrumentation	CSAT3





Weerberg (NF 10)

Elevation	930 m
Slope angle	10°
Slope orientation	314°
Measurement points	6.2 m
Instrumentation	CSAT3

Criteria for selecting slope wind days

Lehner et al. (2019) - identification of days with valley winds in the Inn valley:

- weak synoptic pressure-forcing from ERA-Interim data
- clear-sky index

Criteria tested on slope winds:

→ Performs well for the selection of days characterized by thermally-driven winds

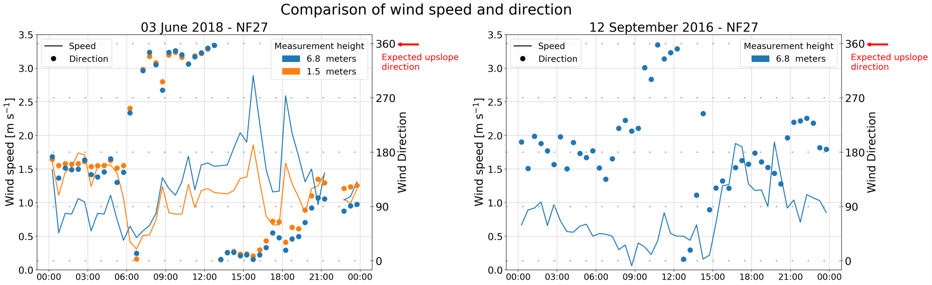
→ Not selective enough for detecting only days with clear, unmasked, occurrence.

→ Seems that slope winds are more connected to seasonality (e.g. incoming radiation)

Application of criteria for NF27

Selected 2014	Observed	Selected 2015	Observed	Selected 2016	Observed	Selected 2018	Observed
16 September	🔴	05 June	🟢	26 August	🟢	03 June	🟢
17 September	🔴	04 July	🟢	27 August	🟡	16 June	🟢
28 September	🔴	06 August	🟢	31 August	🟢	20 June	🟢
		12 August	🟢	08 September	🟡	30 July	🟢
		29 August	🟢	10 September	🟡	16 August	🟢
		08 September	🟡	12 September	🟡	17 August	🟢
				13 September	🔴	18 August	🟡
				26 September	🔴	19 August	🟢
				27 September	🔴	20 August	🟢
						21 August	🟢
						27 September	🔴

No	🔴
Partially	🟡
Yes	🟢



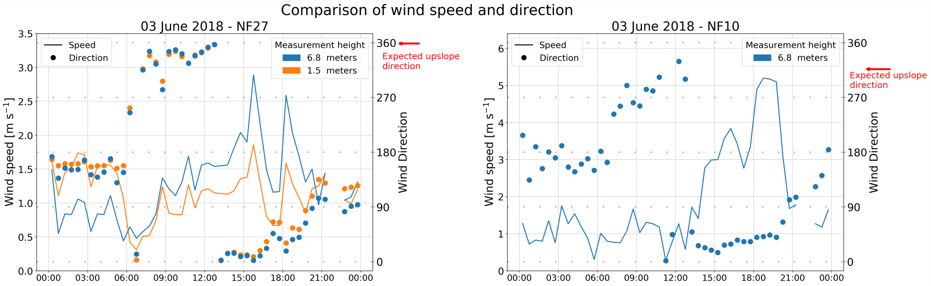
Comparison of stations for a "good day"

3rd of June 2018: day with clear development of upslope wind in station NF27

- Two stations just a few km away one from the other
- Slight change in the slope orientation (NF27 - 1° vs. NF10 - 314°) and slope angle (NF27 - 27°, NF10 - 10°)

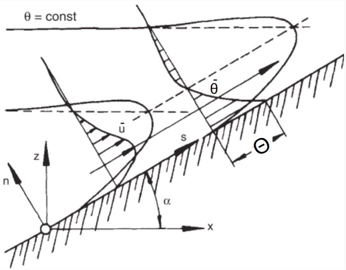
- Clear upslope development just in station NF27
- Prevalent daytime direction in NF10: up-valley

$\rightarrow$ **Under which conditions valley winds override slope winds?**



Comparison with a simple analytical model

Time dependent analytical model: Zardi and Serafin (2015)



Zardi and Serafin (2015), adapted from Schumann (1990)

Coupled equations for slope-normal profiles of along-slope wind speed ($\overline{u}$) and potential temperature ($\overline{\theta}$)

$$\frac{\partial \overline{u}}{\partial t} = \overline{\theta}\frac{N^2}{\gamma} sin(\alpha) + K_m \frac{\partial^2 \overline{u}}{\partial n^2}$$

$$\frac{\partial \overline{\theta}}{\partial t} = -\overline{u}\gamma sin(\alpha) + K_h \frac{\partial^2 \overline{\theta}}{\partial n^2}$$

N: Brunt-Vaisala frequency; γ: lapse rate; K_m: eddy viscosity; K_h: eddy heat diffusivity.

$$\overline{\theta}(0, t) = \Theta sin(\omega t + \psi)$$

$$K_m = K_h = K$$

Site parameters:

$$N = 0.01\, s^{-1} \qquad \alpha = 27^\circ \qquad N \sin\alpha = 0.0053\, s^{-1} \qquad \omega = 0.000076\, s^{-1}$$

$$N \sin\alpha > \omega \quad \rightarrow \quad Supercritical$$

Solutions are given by

$$\overline{u} = \frac{\Theta}{2}\frac{N}{\gamma}\left[e^{-n/l_+} cos\left(\omega t - \frac{n}{l_+} + \psi\right) - e^{-n/l_-} cos\left(\omega t + \frac{n}{l_-} + \psi\right)\right]$$

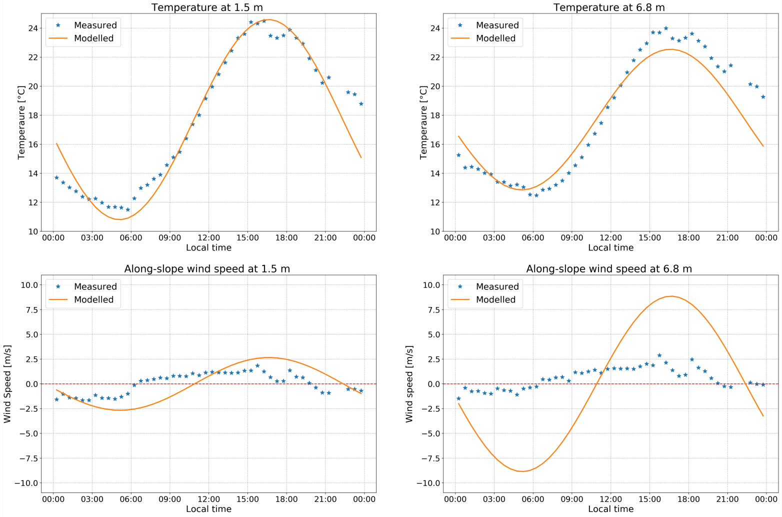
$$\overline{\theta} = \frac{\Theta}{2}\left[e^{-n/l_+} sin\left(\omega t - \frac{n}{l_+} + \psi\right) - e^{-n/l_-} sin\left(\omega t + \frac{n}{l_-} + \psi\right)\right]$$

Comparison with the analytical model

Model parameters are fitted in order to reproduce daily temperature evolution at both measurement points.

$\rightarrow$ Modelled surface temperature is derived

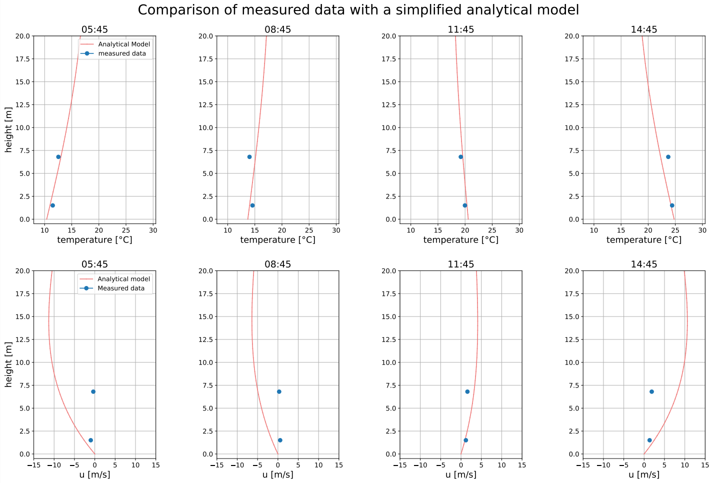
$\rightarrow$ Along-slope wind speed is then computed using the formula



Vertical profiles

- Modelled temperature profiles match with observations
- Modelled along-slope wind speed does not match both in magnitude and timing

→ An improved analytical model is required (e.g. improved boundary condition and/or turbulence closure)



Conclusions

Conclusions and perspective works

- Slope winds are still an open research topic
- Development of a new selection criteria for days with occurrence of pure slope winds
- Development of an improved analytical model with a more realistic surface boundary condition and an improved turbulence closure
- Analysis of second-order moments for the development of suitable parameterizations

Thank you for your attention!

Feel free to contact me at mattia.marchio@unitn.it for any questions or curiosity.

Bibliography

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