# Towards a local similarity framework for scalar turbulence in very complex terrain

E.Sfyri, M.W. Rotach, I. Stiperski, F. Obleitner

Institute for Meteorology and Geophysics

universität innsbruck

## Introduction

- **Monin-Obukhov similarity theory (MOST)**
  Valid in principle for Horizontally Homogeneous and Flat surfaces (HHF)
- **Similarity**
  - Can solve the closure problem in conservation equations
  - Also necessary in complex terrain
  - Applied in numerical models
  - Useful in hydrology, air-quality applications etc.
- **Research question**: MOST or local scaling in complex terrain?

**Table 1:** Main characteristics of the i-Box measurement sites.

| Sites | Name | Slope (°) | Levels | Tower Height (m) | Elevation (m) | Orientation |
|---|---|---|---|---|---|---|
| Kolsass | CS-VF0 | 0 | 3 | 16.93 | 545 | Valley floor |
| Terfens | CS-SF8 | 8 | 2 | 12 | 575 | South-facing |
| Eggen | CS-SF1 | 1 | 1 | 6,6 | 829 | South-facing |
| Weerberg | CS-NF10 | 10 | 1 | 7 | 930 | North-facing |
| Hochhäuser | CS-NF27 | 27 | 1 | 6.8 | 1009 | North-facing |
| (*) Arbeser | CS-MT21 | 21 | 1 | 4 | 2020 | Mountain-top |

## Research method

- **Experimental data**
  - From 5 **i-Box** sites (Fig.1; table 1)
  - 17 months (8/2013-12/2014)
- **Post-processing method**
  - Double Rotation/Multiple despiking
  - High quality criteria (Stiperski and Rotach, 2015)
  - Additional humidity filter: weak signal periodicity → discarded signal<50mV
- **Similarity considerations**
  - MOST: Universal functions
  - Local scaling: individual best-fit functions
  - General formulation for temperature and humidity variance for stable and unstable :

$$\frac{\sigma_x}{x_*} = \alpha(1 + b|\zeta|)^c \qquad \textbf{(a)}$$

  - MOST: c=-1/3 (for ζ<0) and c ≈0 (for ζ>0)
  - Local (e.g. Nadeau et al. 2013 ):c=-1/3 (for ζ<0) and c ≈0 (for ζ>0)

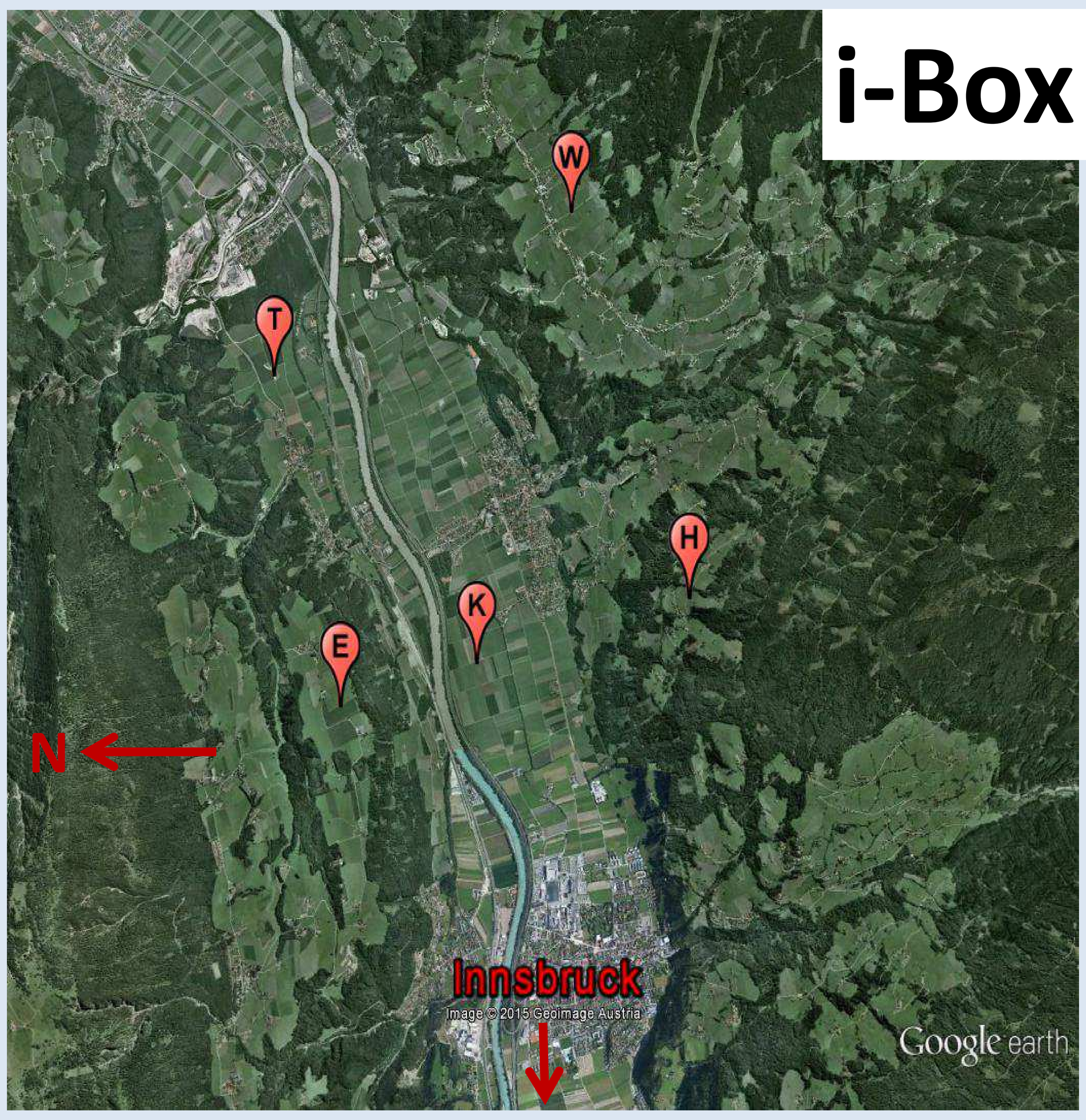


**Fig. 1:** The i-Box area in the Inn Valley and the 6 i-Box sites , Kolsass (K), Terfens (T), Eggen (E), Weerberg (W) and Hochhauser (H).

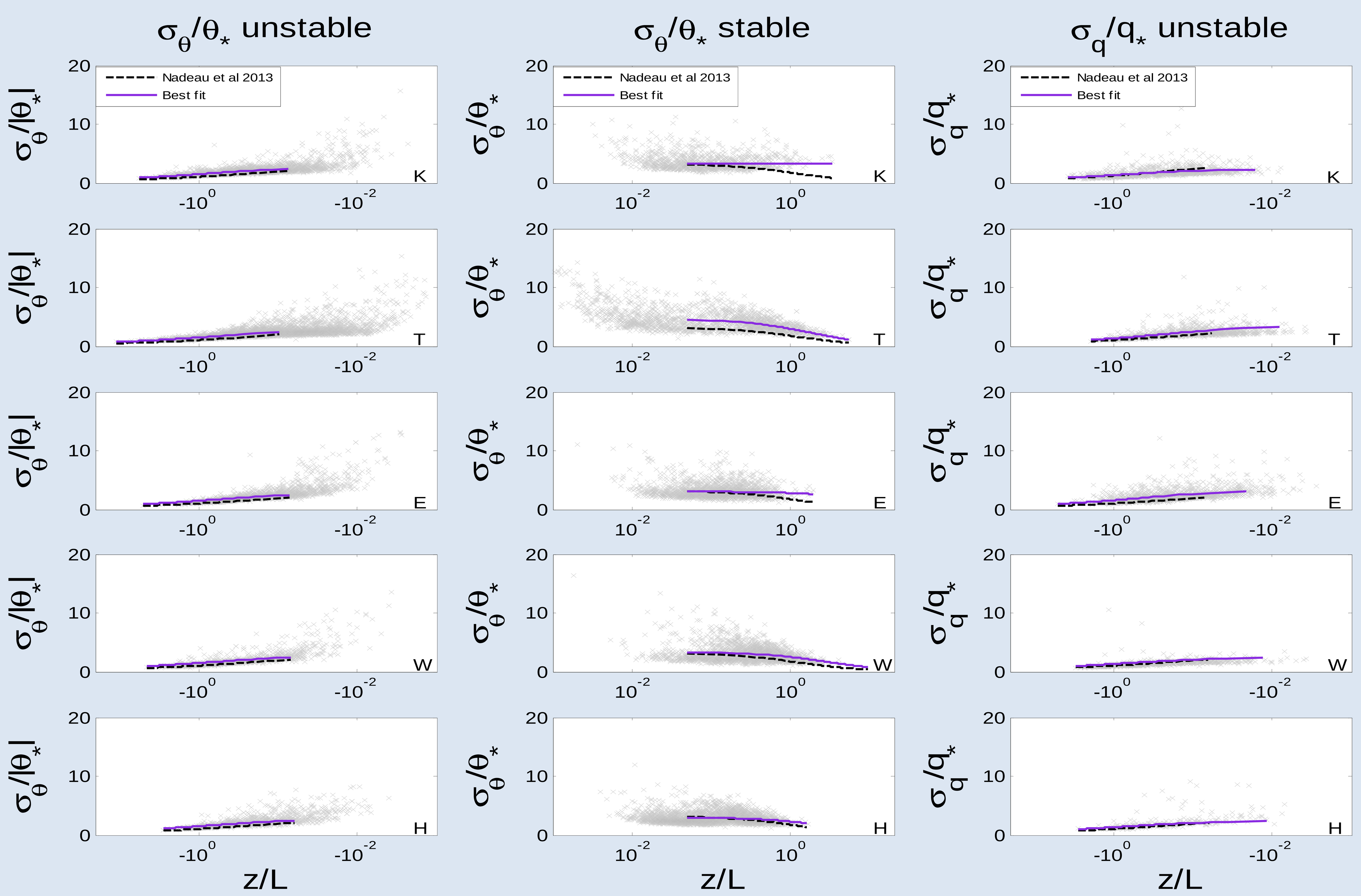


**Figure 3** : Scaled standard deviation of temperature and humidity with the stability parameter ζ=z/L, for ζ<0 (unstable) and ζ>0 (stable), for Kolsass (K), Terfens (T), Eggen (E), Weerberg (W) and Hochhauser (H). The best-fit curve for every data set and the curve fit of Nadeau et al (2013) are shown, until ζ=0.05 (only for temperature variance) in order to exclude the large scatter in near-neutral conditions.

## Results of temperature variance

**unstable**

- Local scaling can be applied : similarity functions (Table 2)
- The -1/3 exponent is successful : small root-mean-square errors (**RMS**)
- No neutral limit (Fig. 3) (Tampieri et al. 2009)
- No general complex terrain formulation is found (yet?)

**stable**

- **Larger scatter** than unstable (Fig. 3)
- Again in near-neutral limit the similarity functions diverge (Tampieri et al. 2009)
- The **-1 exponent** is not successful at all stations
  - The flat sites (Kolsass and Eggen) present very small exponent
  - Slope dependence of the exponent?

## Results of humidity variance

**unstable**

- Large scatter (Fig. 3)
- The **-1/3 exponent** seems to be successful
- Near-neutral: finite value approached
- No general complex terrain formulation

**stable**

- **Large scatter** for all i-Box sites (Fig. 5) in accordance to previous literature (e.g. Moraes et al. 2005)
- Local scaling does not seem to apply: no regularities

**Table 2:** Coefficients of best-fit similarity functions for temperature variance and RMS, with respect to best fit curve and from literature curve (Nadeau et al. 2013), for the 5 i-Box sites, for ζ>0 and ζ<0.

| i-Box sites | Fitting curves | | | | RMS (Nadeau et al. 2013) | | RMS (best fit ) | |
|---|---|---|---|---|---|---|---|---|
| | ζ<0 (unstable) | | ζ>0 (stable) | | ζ<0 unstable | ζ>0 stable | ζ<0 unstable | ζ>0 stable |
| | a | b | a | b | | | | |
| Kolsass | 2.66 | -4.67 | 3.34 | 0 | 0.4 | 1.79 | 0.19 | 1.2 |
| Terfens | 3.03 | -8.45 | 4.64 | 0.57 | 0.48 | 3.22 | 0.24 | 1.44 |
| Eggen | 5.81 | -99.75 | 3.06 | 0.01 | 0.5 | 1.18 | 0.24 | 1.06 |
| Weerberg | 5.74 | -100.73 | 3.37 | 0.35 | 0.43 | 1.71 | 0.26 | 1.42 |
| Hochhauser | 4.39 | -32.12 | 3.01 | 0.31 | 0.79 | 0.72 | 0.45 | 0.68 |
| Nadeau et al. 2013 | 2.67 | -16.29 | 3.22 | 0.83 | | | | |

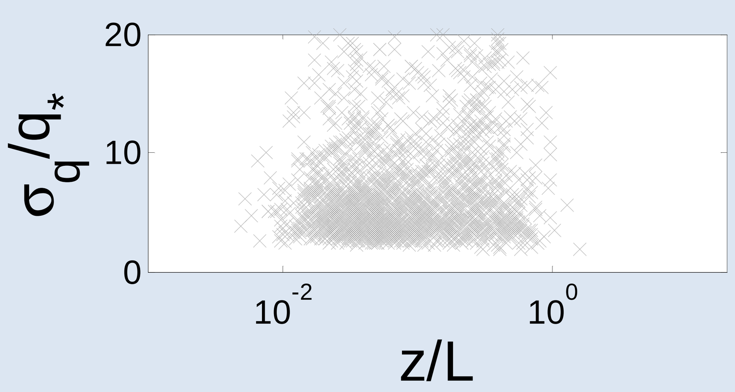


**Figure 4**: Scaled standard deviation of humidity with the stability parameter ζ=z/L, for ζ>0 (stable), for Hochhauser.

## Conclusions

- ✓ **Local similarity** can be applied at i-Box sites, for temperature (stable and unstable) and for humidity variance (unstable)
- ✓ **No universality** of the results (different functions than literature)
- ✓ The best-fit curve is in most of the cases higher than the Nadeau et al. (2013) curve
- ✓ **Site-to-site dependence** for temperature variance
- ✓ Temperature variance (stable): the **-1 exponent** is not valid in the flat i-Box sites
  - **Slope dependence**?
- ✓ **Similar curves** for i-Box sites in the case of humidity variance (unstable)
  - Can one local similarity function be applied in complex terrain?

## References

**Foken T., and Wichura B. 1996.** Agric. For. Meteor., 78, 83–105. **Moore, C. J., 1986.** Bound.-Layer Meteor., 37, 17–35. **Moraes O.L.L., Acevedp O.C., Degrazia G.A., Anfossi D., da Silva R., Anabor V. 2005.** AtmosEnvion 39: 3103-3112. **Nadeau D.F., Pardyjak E.R., Higgins C.W., Parlange M.B. 2013**. Boundary-Layer Meteorol, **147**, 401–419, DOI 10.1007/s10546-012- 9787-5. **Schotanus P., Nieuwstadt F.T.M., De Bruin H.A.R. 1983**. Boundary-Layer Meteorol, **26**, 81-93. **Stiperski I., Rotach M.W. 2015.** In press, Boundary-Layer Meteorol. **Tampieri F., Maurizi A., Viola A. 2009.** Boundary-Layer Meteorol 132:31–42. **Tillman, J. E. 1972**.J. Appl. Meteorol. 11:7S3 792. **Wyngaard J.C. 1973.** Workshop on Micrometeorology, Amer. Meteorol. Soc., Boston, 101-150. **Van Dijk A., Kohsiek W. DeBruin H.A.R. 2003.** *J Atmos Oceanic Tech*, **20**, 143-151.

Contact: eleni.sfyri@uibk.ac.at