# The estimate and scaling of mass and energy fluxes from three different ecosystems in the Trentino Alto Adige/South Tyrol region (Italy): Preliminary results from the Wheat Project.

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Fondazione Caritro
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# The Wheat Project

**Final goal**: Improve the estimate of turbulent fluxes of heat and water vapor over complex mountainous areas.

**Approach**: Identification of appropriate flux–variance similarity relationships.

**Dataset** (2010–2018): eddy-covariance data from 3 long–term research infrastructures at:

- **Apple orchard** ($240\,\mathrm{m\,ASL}$);
- Coniferous forest ($1349, \mathrm{m\,ASL}$);
- **Alpine grassland** ($1553\,\mathrm{m\,ASL}$).

Apple orchard (courtesy L. Montagnani)

Coniferous forest (courtesy L. Belelli Marchesini)

Alpine grassland (courtesy L. Belelli Marchesini)

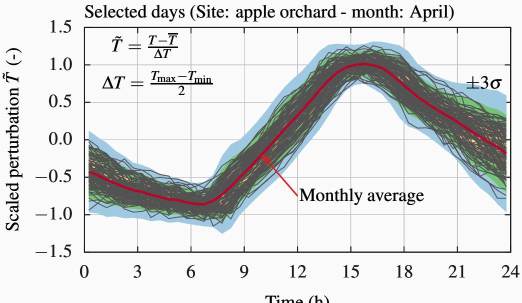
# Working dataset: selection criteria and data preprocessing

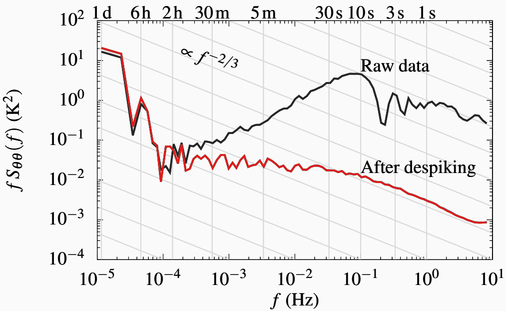
**Averaged data**:

1. No gaps;
2. Sunny days with similar temperature cycles;

**High–frequency data**:

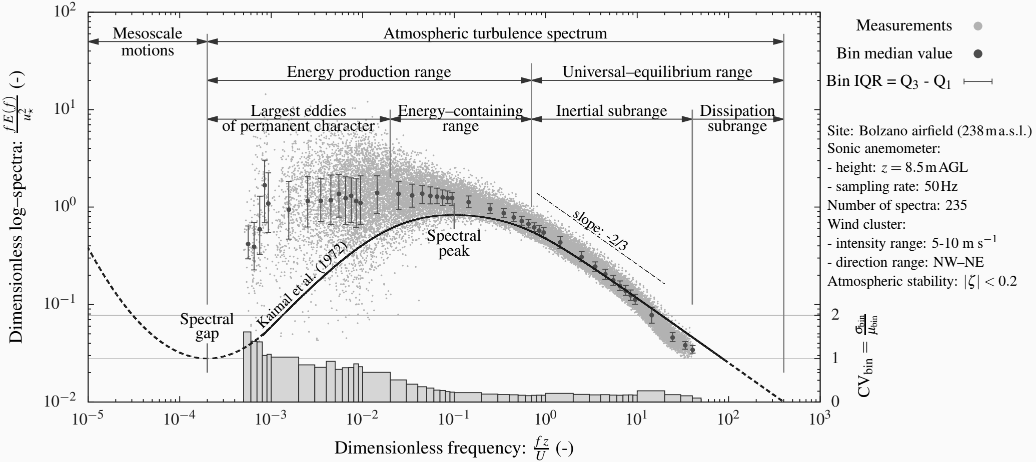
3. After despiking procedure, no days with corrupted spectra;
4. Consecutive days: at least 2.



# Separation criterion

Recursive digital filter with a time–scale of quasi–isotropic turbulence (Falocchi et al., 2018, 2019).



# Separation criterion: Time scale of quasi–isotropic turbulence

**Concept**: the anisotropy analysis of turbulence is applied in the frequency domain.

**Dimensionless anisotropic tensor**:

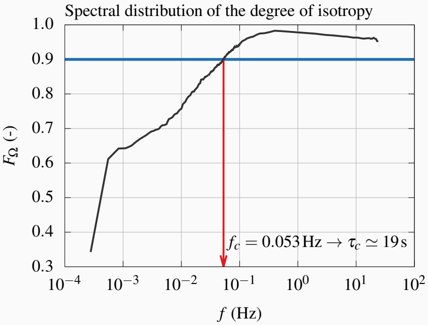
$$\mathbf{b} = \frac{1}{2\,\mathrm{TKE}} \underbrace{\begin{bmatrix} \overline{u_1' u_1'} & \overline{u_1' u_2'} & \overline{u_1' u_3'} \\ \overline{u_2' u_1'} & \overline{u_2' u_2'} & \overline{u_2' u_3'} \\ \overline{u_3' u_1'} & \overline{u_3' u_2'} & \overline{u_3' u_3'} \end{bmatrix}}_{\text{Reynolds stress tensor}} - \frac{1}{3}\mathbf{I}_3$$

**Choi & Lumley (2001)**:
degree of isotropy: $F_b = 1 + 27\,\mathrm{III} + 9\,\mathrm{II}$

**In the frequency domain**:

$$\overline{u_i' u_j'}(f) = \int_{+\infty}^{f} S_{ij}(f')\mathrm{d}f' = \mathrm{Og}_{ij}(f)$$

$$F_\Omega(f) = 1 + 27\,\mathrm{III}(f) + 9\,\mathrm{II}(f)$$




Time scale of quasi–isotropic turbulence:

$$\tau_c = f_c^{-1} : F_\Omega(f_c) = 0.9$$

(Falocchi et al., 2019)

# MOST theoretical background

**Standard deviations**:

- Wind speed components ($i = u,\ v,\ w$): $$\frac{\sigma_i}{u_\star} = \phi_i\left(\zeta\right), \qquad u_\star = \sqrt[4]{\overline{u'w'}^2 + \overline{v'w'}^2}$$
- Scalar quantities ($s$): $$\frac{\sigma_s}{|s_\star|} = \phi_s\left(\zeta\right), \qquad s_\star = \frac{\overline{w's'}}{u_\star}$$

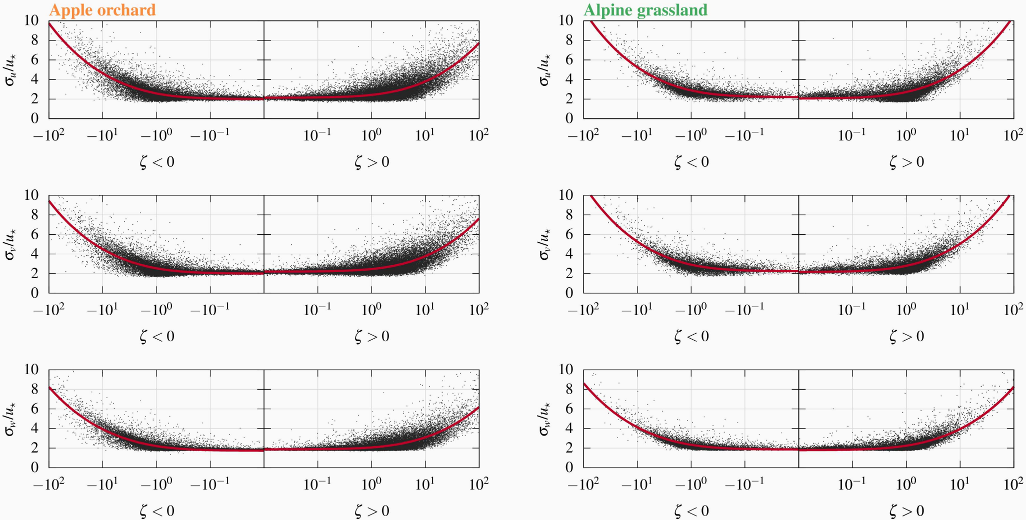
**Coefficients of correlation**:

- Vertical fluxes of temperature ($\theta$): $$\frac{\overline{w'\theta'}}{\sigma_w\sigma_\theta} = \frac{\overline{w'\theta'}}{\sigma_w\sigma_\theta}\cdot\frac{u_\star}{u_\star} = \frac{u_\star}{\sigma_w}\cdot\frac{|\theta_\star|}{\sigma_\theta} = \pm\frac{1}{\phi_w\left(\zeta\right)\phi_\theta\left(\zeta\right)}$$
- Vertical fluxes of specific humidity ($q$): $$\frac{\overline{w'q'}}{\sigma_w\sigma_q} = \frac{\overline{w'q'}}{\sigma_w\sigma_q}\cdot\frac{u_\star}{u_\star} = \frac{u_\star}{\sigma_w}\cdot\frac{|q_\star|}{\sigma_q} = \frac{1}{\phi_w\left(\zeta\right)\phi_q\left(\zeta\right)}$$

Stability parameter: $\zeta = \dfrac{z-d}{L}$ Obukhov length: $L = -\dfrac{u_\star^3\overline{\theta_v}}{\kappa g\overline{w'\theta_v'}}$

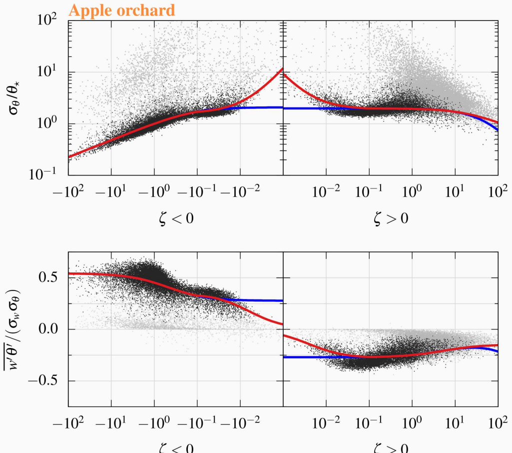
# FV relationships for the wind speed components $u$, $v$, $w$

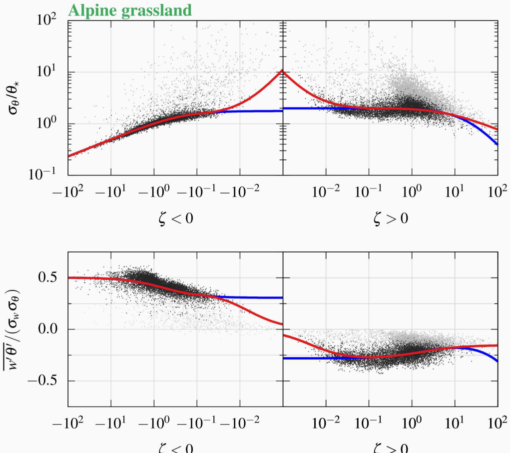
$$\frac{\sigma_i}{u_\star} = \phi_i(\zeta) = a_i\,(1 + b_i|\zeta|)^{1/3}$$



# FV relationships for the potential temperature ($\theta$, $|H_S| > 7\,\mathrm{W m^{-2}}$)

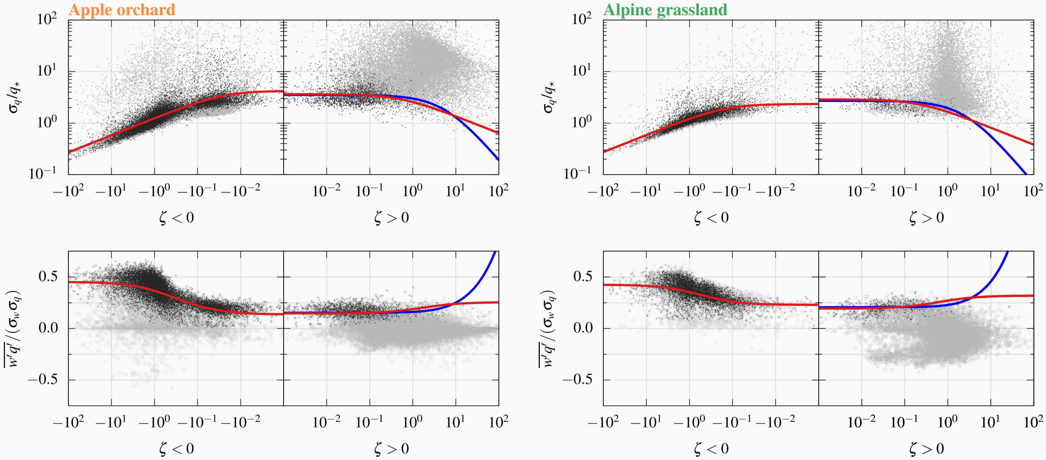
$$\frac{\sigma_\theta}{\theta_\star} = \phi_\theta(\zeta) = \begin{cases} a_\theta\,(1+b_\theta|\zeta|)^{-1/3}, & \text{if } \zeta < 0 \\ a_\theta\,(1+b_\theta|\zeta|)^{-1}, & \text{if } \zeta > 0 \end{cases} \quad \text{and} \quad \phi_\theta(\zeta) = \begin{cases} a_\theta\,(1+b_\theta|\zeta|)^{-1/3}, & \text{if } |\zeta| > 0.1 \\ a_\theta + b_\theta|\zeta|^{-1}, & \text{if } |\zeta| \le 0.1 \end{cases}$$



# FV relationships for the specific humidity ($q$, $|H_E| > 10\,\mathrm{W\,m^{-2}}$)

$$\frac{\sigma_q}{q_\star} = \phi_q(\zeta) = \begin{cases} a_q\left(1 + b_q|\zeta|\right)^{-1/3}, & \text{if } \zeta < 0 \\ a_q\left(1 + b_q|\zeta|\right)^{-1}, & \text{if } \zeta > 0 \end{cases} \quad \text{and} \quad \phi_q(\zeta) = a_q\left(1 + b_q|\zeta|\right)^{-1/3}$$



# FV relationships: fitted coefficients

Wind speed components ($i = u, v, w$):

$$\phi_i(\zeta) = a_i\,(1 + b_i|\zeta|)^{1/3}$$

Temperature ($\theta$) and humidity ($q$):

$$\phi_i(\zeta) = \begin{cases} a_\theta\,(1 + b_\theta|\zeta|)^{-1/3}, & \zeta < 0 \\ a_\theta\,(1 + b_\theta|\zeta|)^{-1}, & \zeta > 0 \end{cases}$$

Proposed for temperature ($\theta$):

$$\phi_\theta(\zeta) = \begin{cases} a_\theta\,(1 + b_\theta|\zeta|)^{-1/3}, & \zeta < -0.1 \\ a_\theta + b_\theta|\zeta|^{-1}, & |\zeta| \leq 0.1 \\ a_\theta\,(1 + b_\theta|\zeta|)^{-1/3}, & \zeta > 0.1 \end{cases}$$

Proposed for humidity ($q$):

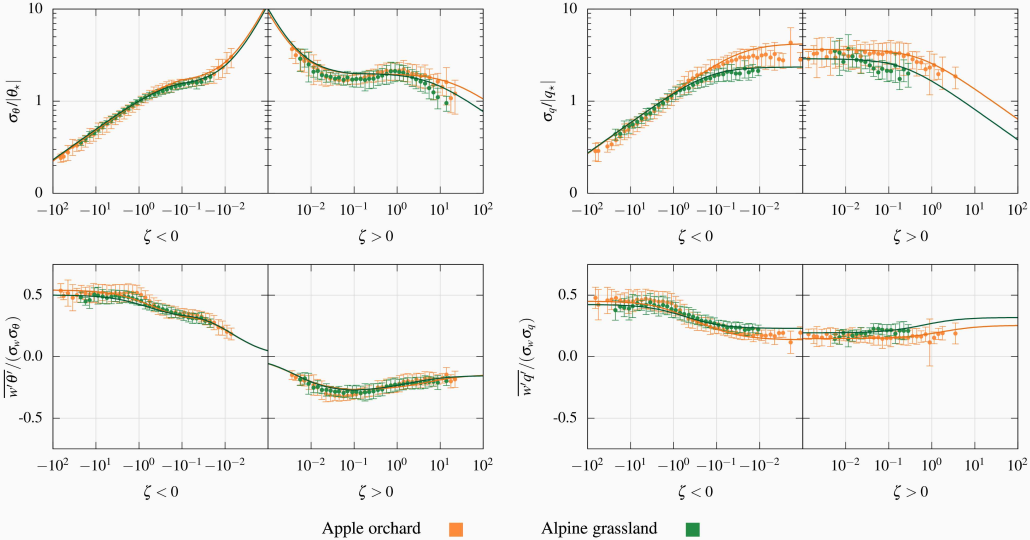
$$\phi_q(\zeta) = a_\theta\,(1 + b_\theta|\zeta|)^{-1/3}$$

| | | Apple orchard | | | Alpine grassland | | |
|---|---|---|---|---|---|---|---|
| | | $a_i$ | $b_i$ | $R^2$ | $a_i$ | $b_i$ | $R^2$ |
| $u$ | U | 2.001 | 1.150 | 0.709 | 2.200 | 1.267 | 0.762 |
| $u$ | S | 2.141 | 0.464 | 0.670 | 2.053 | 1.342 | 0.644 |
| $v$ | U | 2.000 | 1.041 | 0.702 | 2.243 | 1.193 | 0.740 |
| $v$ | S | 2.199 | 0.411 | 0.678 | 2.155 | 1.191 | 0.691 |
| $w$ | U | 1.731 | 1.070 | 0.791 | 1.853 | 1.003 | 0.787 |
| $w$ | S | 1.868 | 0.357 | 0.694 | 1.787 | 0.983 | 0.701 |
| $\theta$ | U | 2.079 | 7.979 | 0.605 | 1.764 | 4.420 | 0.671 |
| $\theta$ | S | 1.985 | 0.017 | 0.007 | 1.995 | 0.041 | 0.048 |
| $\theta$ | NU | 1.518 | 0.010 | 0.040 | 1.492 | 0.010 | 0.136 |
| $\theta$ | NS | 1.622 | 0.007 | 0.230 | 1.630 | 0.008 | 0.436 |
| $\theta$ | S | 1.985 | 0.057 | 0.005 | 2.007 | 0.166 | 0.043 |
| $q$ | U | 4.232 | 38.898 | 0.237 | 2.352 | 6.370 | 0.376 |
| $q$ | S | 3.518 | 0.174 | 0.027 | 2.707 | 0.388 | 0.053 |
| $q$ | S | 2.890 | 4.404 | 0.077 | 3.644 | 1.871 | 0.035 |

U = unstable, S = stable

NU : $-0.1 \leq \zeta < 0$, NS : $0 < \zeta \leq 0.1$

# Comparisons:



# Conclusions

1. The mathematical form of the similarity functions for the standard deviations is crucial to properly scale the vertical turbulent fluxes;
2. The distributions of the correlation coefficients are a good testbed to check if the selected similarity functions are appropriate;
3. A unique scaling for the scalar fluxes, not site dependent, appear to be possible when turbulence is quasi–isotropic.
4. However, further investigations are required to:
   - refine the results for the fluxes of specific humidity;
   - investigate the increase of the correlation coefficients under unstable conditions;
   - extend the results to other complex–terrain sites.

Thank you for the attention.

# Data processing

- **Time window**: 30 min with overlap of 15 min;

- **Rotation**: double rotation;

- **Correction of scalar quantities**:
  - Sonic temperature: Schotanus et al. (1983);
  - Density fluctuations: Webb et al. (1983); Detto & Katul (2007);

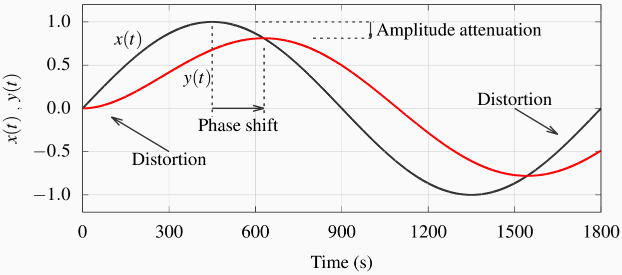
- **Separation criterion**:
  - Recursive digital filter (Falocchi et al., 2018) with a time–scale of quasi–isotropic turbulence (Falocchi et al., 2019).

# Separation criterion: Refinement of the McMillen (1988) recursive digital filter

- **McMillen (1988)**:

$$y_i = \alpha\, y_{i-1} + (1-\alpha) x_i$$

$x$: input data;
$y$: low–pass filtered data;
$\alpha = \alpha(\tau_c)$: recursion coefficient.




Previous refinements:

- **de Franceschi & Zardi (2003)**:
  → appropriate $\alpha = \alpha(\tau_c)$
  → phasing procedure.

- **Weigel & Rotach (2004)**:
  → phasing procedure.

- **Falocchi et al. (2018)**:
  → distortions
  → amplitude attenuation

  → Ideal–like filtering procedure
  ? Physically–based time–scale $\tau_c$.