High resolution simulation of the nocturnal boundary layer using the WRF and COSMO models: a comparative study

-Nocturnal Surface Layer simulated by COSMO-

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Motivation

Surface Layer (SL) Scheme

- Interaction between the Land Surface scheme and the Atmosphere Dynamics by surface fluxes
- Provide info of the profiles within SL → diagnose of variables at the observational level

Nocturnal Surface Layer

- weakly stable regime (continuous character, cloudy sky, significant wind shear near-surface, high surface fluxes)
- very stable regime (intermittent character, clear sky, less wind shear near-surface, low surface fluxes) → uncertainties in giving a general parameterization

Purpose: Overview of COSMO surface layer scheme performance compared to experimental data in a land site and to literature approaches.

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1. Surface Layer (SL) Schemes
    - Monin-Obhukov Similarity Theory
    - COSMO approach
2. Model set up and case study
3. COSMO's SL scheme performance in homogeneous terrain
4. COSMO's SL scheme performance in heterogeneous terrains
5. Conclusions

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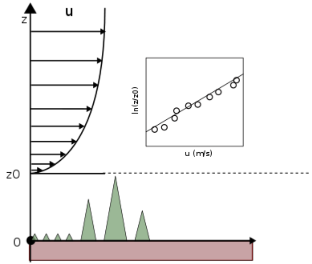
Monin-Obhukov Similarity Theory (1954)



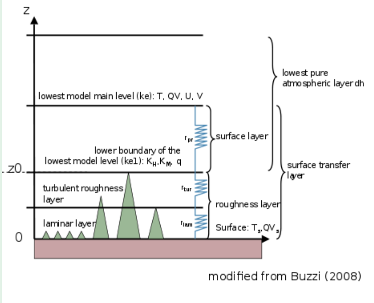
1. defines *scales* for the SL based on the constant surface fluxes (u_*,θ_*,L_{mo})
2. $\frac{kz}{u_*}\frac{\partial u_a}{\partial z} = \phi_m(\frac{z}{L_{mo}}), \frac{kz}{\theta_*}\frac{\partial \theta_a}{\partial z} = \phi_h(\frac{z}{L_{mo}})$
3. surface fluxes are derived integrating them over z

from Bellprat(2012)

- widely used to compute the surface turbulent fluxes, also in NWP models (eg. WRF, ..)
- similarity functions ($\phi_{m,h}$) needs to be determined empirically
- uncertainties in very stable regimes (large scatter in observations, 'self-correlation' problem)

COSMO approach (M. Raschendorfer)

1) SL sublayers



modified from Buzzi (2008)

Concept applied in urban meteorology (Rotach et al. 2001, Fisher et al. 2005)

$$
\begin{aligned}
r_{tot}^{M} &= r_{lam}^{M} + r_{roug}^{M} + r_{turb}^{M} \\
r_{tot}^{H} &= r_{lam}^{H} + r_{roug}^{H} + r_{turb}^{H}
\end{aligned}
$$

2) Solution *TKE* equation at model level ke1

from Mellor and Yamada (1982), in order to derive the diffusion coefficients $K_{M,H}^{ke1}$

$$\text{Surface fluxes} \propto \frac{K_{M,H}^{ke1}}{(r_{tot}^{M,H})}$$

Reduced dependency on empirical data.. But, how do the fluxes behave??

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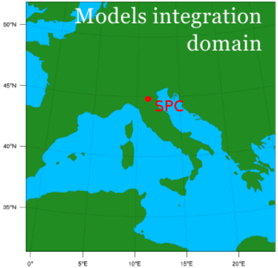
Model set up and case study

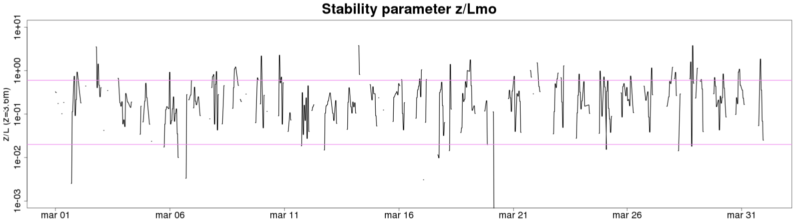
COSMO configuration:

- 30 runs 48h long (first 24h spinup)
- COSMO-DE namelist setting (2.8km horiz. resolution x 50 vert. level)
- IC and BC: ECMWF operational analysis (16km horiz. resolution)

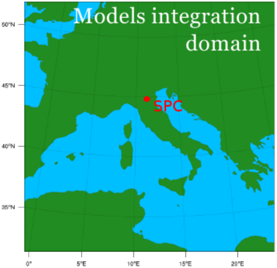


Site: San Pietro Capofiume (SPC) in Po Valley, Italy. Flat grassland - crop area.

Period: synoptical quiescent, no snow at the surface



Model set-up and case study



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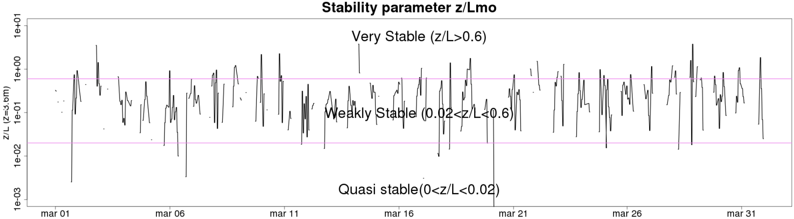

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Fluxes: sensitivity to observed stability

Friction velocity

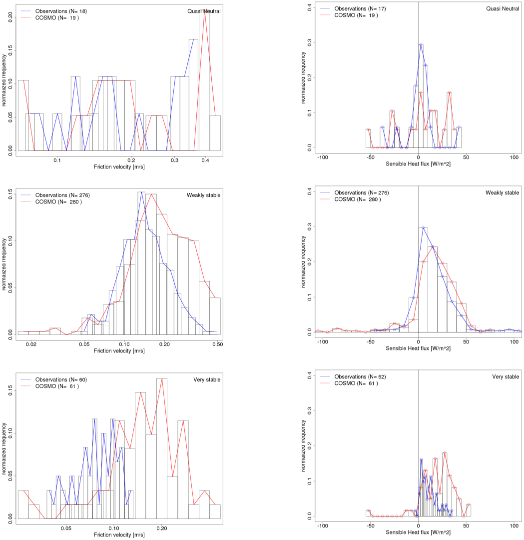
Sensible heat flux

🟦 Observations
🟥 COSMO

Quasi Neutral

Weakly Stable

Very Stable



The more the regime is stable, the more COSMO tends towards higher values of fluxes!

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Component testing of fluxes

Fluxes definition:

$$\begin{aligned} \tau &= \rho u_*^2 = \rho C_m U_a^2 \\ H &= -\rho c_p u_* T_* = -\rho c_p C_h U_a (T_a - T_g) \end{aligned}$$

with the transfer coefficients:

Monin Obhukov approach

$$C_{m,h} = \frac{k^2}{\left[ln(\frac{z}{z_0}) - \psi_m(\frac{z}{L})\right]\left[ln(\frac{z}{z_0}) - \psi_{m,h}(\frac{z}{L})\right]}$$

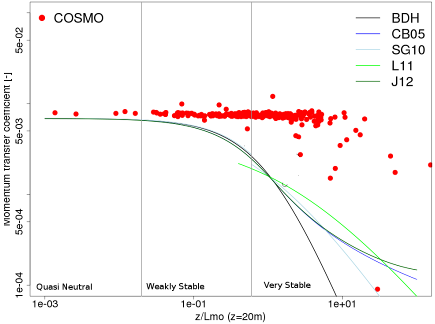
COSMO approach

$$C_{m,h} = \frac{K_{m,h}^{ke1}}{r_{m,h}^{tot} U_a}$$

Transfer coefficients

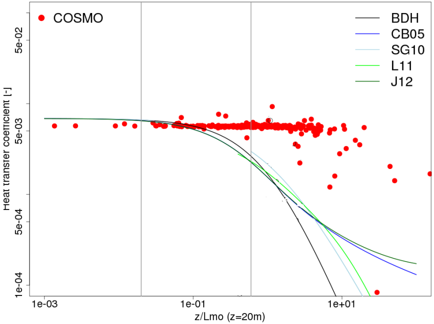
C_m

Stable regime



C_h

Stable regime



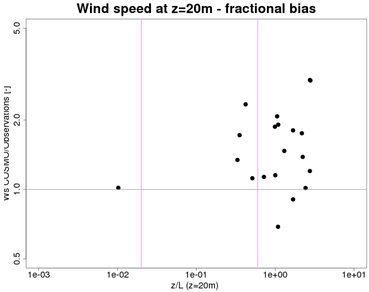
With increasing stability, COSMO keeps high $C_{m,h}$ compared to all the experimental curves, and it is not included in their range

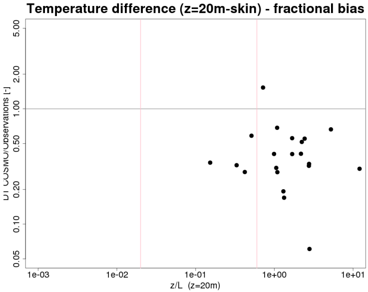
- BDH = Businger-Dyer-Hicks, 1976
- CB05 = Cheng Brutsaert, 2005
- SG10 = Sorbjan Grachev, 2010
- L11 = Luhar et al., 2011
- J12 = Jimenez et al., 2012 - **WRF**

Vertical difference in the SL

Fluxes definition:

$$
\begin{aligned}
\tau &= \rho u_*^2 = \rho C_m U_a^2 \\
H &= -\rho c_p u_* T_* = -\rho c_p C_h U_a (T_a - T_g)
\end{aligned}
$$


Wind speed at z=20m - fractional bias


Temperature difference (z=20m-skin) - fractional bias

- The overestimation of wind speed at 20m in the very stable regime enhances the overestimation of fluxes for stable regimes
- The ΔT underestimation is instead compensating the errors of the other terms in the sensible heat flux formulation

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COSMO's surface layer performance in heterogeneous surfaces

COSMO SL scheme includes a dependency on the features of the surface:

$$r_{lam}^{M,H}, r_{roug}^{M,H} \propto \left(\frac{z_0}{SAI}\right); r_{turb}^{M,H} = f(z_0, ...) \tag{1}$$

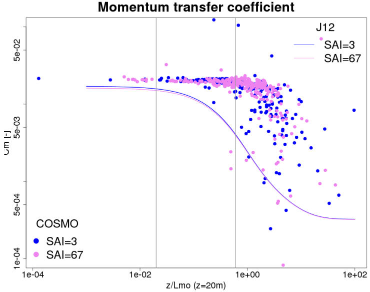
where z_0 is the roughness length (including: local roughness + subgrid scale variance) and *SAI* is the surface area index:

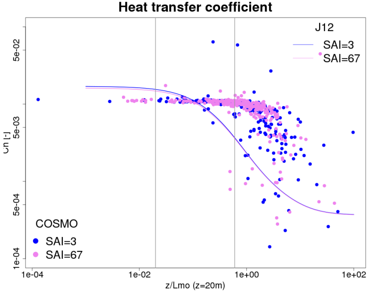
$$SAI = PL_{cov} LAI + C_{lnd} \tag{2}$$

PL_{cov} = plant coverage
LAI = leaf area index
C_{lnd} parameter from namelist (default=2)

Sensitivity of the transfer coefficients to *SAI*

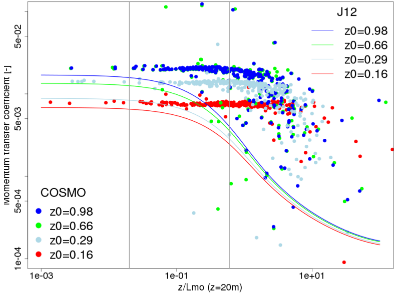
Select 2 gridpoints in COSMO domain with the same z_0 (z_0=0.90) but with different *SAI*: urban (*SAI*=3) and deciduos forest (*SAI*=67)





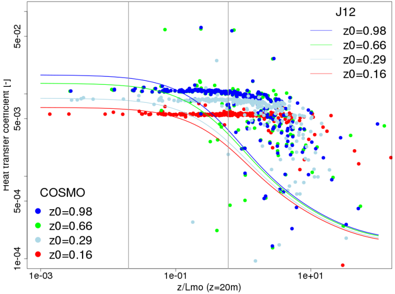
- C_m is independent on *SAI*: Sure! From namelist $rlam\_mom = 0 \rightarrow r^M_{lam}, r^M_{rough} = 0$
- C_h is independent too on *SAI* in stable cases. Hypothesis: in stable regime, the laminar and roughness layers for heat are not very active

Sensitivity of transfer coefficients to z_0



C_m

Stable regime



C_h

Stable regime

- the transfer coefficients increase for increasing z_0,
- different rate of increase with respect to WRF surface layer scheme, also in quasi-neutral regimes
- always higher values with respect ot WRF in weakly/very stable regimes

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Conclusions

Is COSMO Surface Layer scheme reliable on nocturnal surface fluxes simulation?

In homogeneous terrain (low z_0):

- Quasi stable regime: YES!
- Weakly/Very stable regimes: NO..fluxes are overestimated (combined effect of transfer coefficients and the wind value at the lowest model level, while the error of temperature vertical difference compensates)

In heterogeneous terrain (high z_0, SAI): - only looked at transfer coefficients! -

- Quasi stable regime: NO agreement with empirical curves at some z_0
- Weakly/Very stable regimes: NO.. always higher values with respect to empirical curves

Thank you for the attention!!