Diagnostics and Revision of the COSMO Surface Layer Formulation under Stable Conditions in horizontal homogeneous terrain

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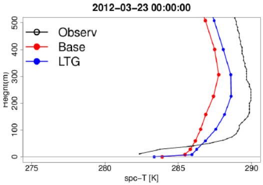
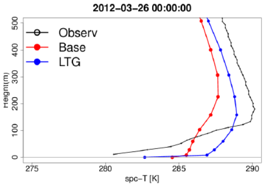
COSMO User Seminar 2016

Surface Layer (SL) scheme under stable stratification and above horizontal homogeneous terrain → the simplest case

- abundancy of measurements
- agreement with Monin-Obukhov similarity theory (MOST), under the limit of weak stability





The coupling of COSMO to a MOST based SL scheme produces relevant differences with respect to the operational case

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Outline

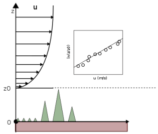
1. In which sense COSMO‘s SL scheme differs from MOST based schemes?

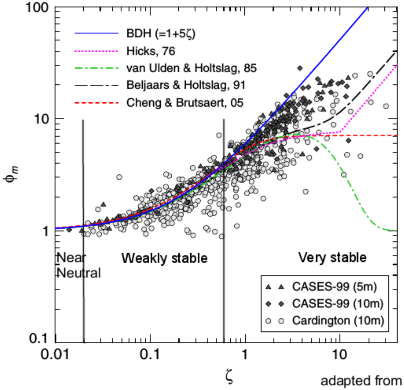
2. Is it possible to reduce COSMO‘s SL scheme to MOST based schemes?

3. Conclusions

Monin Obukhov approach (MOST)

$$\frac{d\overline{u}}{dz} = \frac{u_*}{kz}\phi_m(\xi) \qquad \frac{d\overline{\theta_v}}{dz} = \frac{\theta_*}{kz}\phi_h(\xi)$$

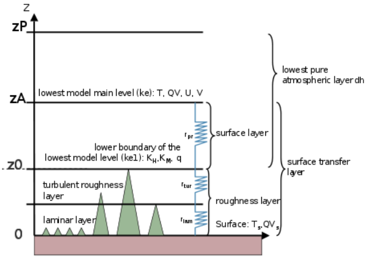




adapted from Luhar et al.2009

Fig. 6 Observed variation of the gradient stability function for momentum (ϕ_m) with the stability parameter ζ $(= z/L)$. A range of parameterisation curves as reported in the literature are also shown (see text for details)

COSMO's approach (Matthias Raschendorfer, DWD)



modified from Buzzi (2008)

Sublayers resistances:

$$r^{M,H} = \int_{z_1}^{z_2} \frac{dz}{K(z)^{M,H}} = \int_{z_1}^{z_2} \frac{dz}{l(z)U(z)}$$

Hypothesis on the inertial sublayer:

- it extends from z_0 to z_A
- $l(z) = kz$
- $U(z) = Az + B$ with B.C.:

$$U(z_P) = \frac{K_P^{TURB}}{l(z_P)} \text{ and } U(z_0) = \frac{K_0^{TURB}}{l(z_0)}$$

- Linear interpolation: the simplest ensuring that at neutrality $U(z) = u_*$ in agreement with MOST
- A and B follows from the turbulence closures at z_0 and z_P (not from empirical data)

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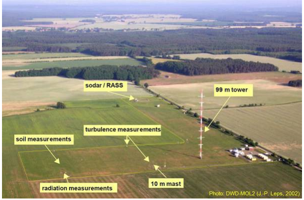
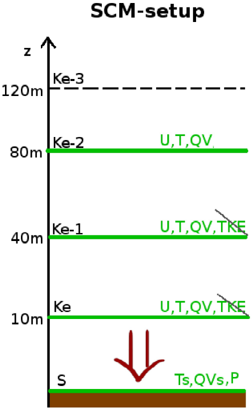
COSMO Single Column special setup

Single Column run forced with observations:

- avoid feedbacks due to vertical profiles errors
- simplest run to study the SL scheme

Observations: one month at Lindenberg



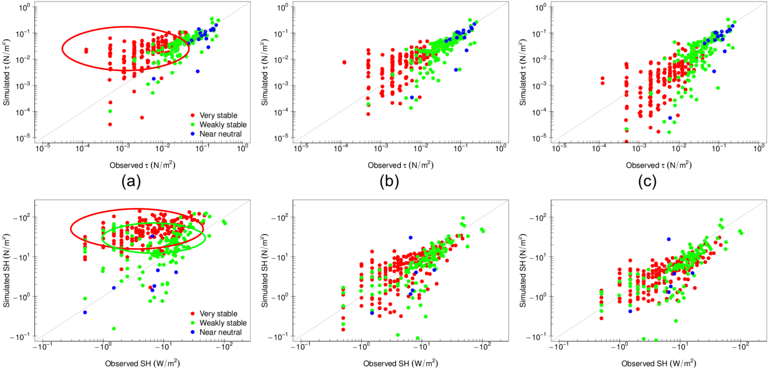


- Very stable
- Weakly stable
- Near neutral

COSMO "Base"	Louis et al.(1982) "LTG"	Cheng and Brutsaert (2005) "CB05"

τ

SH



(a) (b) (c)

(d) (e) (f)

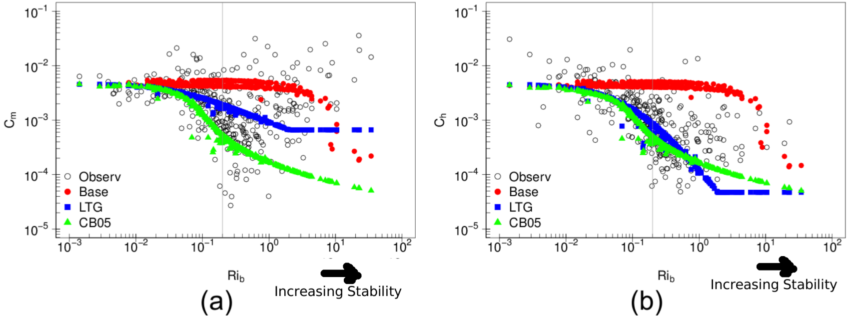
Overestimation of the surface fluxes under stable stratification

Transfer coefficients

Surface fluxes:

$$\tau = \rho \underline{C_m} |U_{ke}|^2$$
$$SH = -\rho c_p \underline{C_h} |U_{ke}| (\theta_{ke} - T_s)$$

C_m C_h

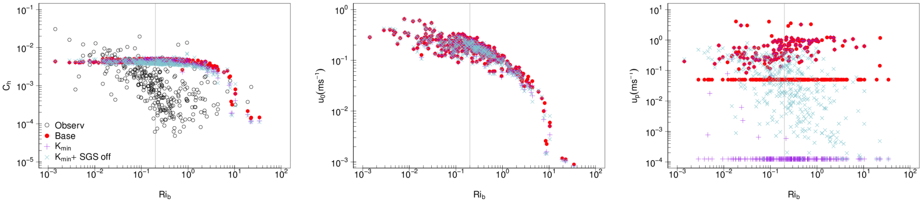


COSMO's SL weaker stability dependency of $C_{m,h}$ with respect to MOST

Long tail removal

Effect of the long tail turbulence closure?
NB: COSMO's SL scheme is strongly dependent on the turbulence closure!

C_h $U(z_0)$ $U(z_P)$



(a) (b) (c)

=> No, turbulence-enhancing measures impact only above SL

Theoretical modification

Hypothesis on the inertial sublayer:

- $K(z) = l(z)U(z)$
- $l(z) = kz$
- $U(z) = Az + B$

However, away from the neutral case $K_{MOST} = \frac{l(z)u_*}{\phi(\xi)}$. Thus:

1. the analogy $K(z) = K_{MOST}$ corresponds to $U(z) = \frac{u_*}{\phi(\xi)}$
2. in stable case: $\phi(\xi) = 1 + \beta\xi$ (Businger et al., 1971)
3. $U(z) = \frac{u_*}{1+\frac{\beta}{L_{MO}}z} \rightarrow U(z) = \frac{A}{1+Bz}$

   with B.C.: $U(z_P) = \frac{K_P^{TURB}}{L(z_P)}$ and $U(z_0) = \frac{K_0^{TURB}}{L(z_0)}$

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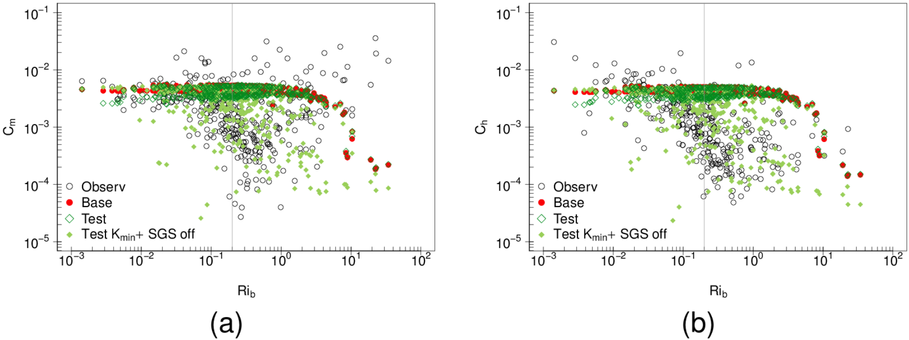

Hyperbolic interpolation allows :

- the reduction of $C_{m,h}$ under stable conditions
- the SL to react to changes in the upper layers

Results

Good news:
Yes, it is possible to reduce the COSMO SL to the MOST in stable stratified cases and above horizontal homogeneous surfaces if the hyperbolic interpolation is used

Bad news:
Effects are visible only by reducing the turbulence-enhancing measures, which are still necessary to keep high the large scale scores (Holtslag et al, 2013)

Which effect on a COSMO simulation?
A firts attempt:reduce the turbulence-enhancing measures in horizontal homogeneous regions and plug in the hyperbolic interpolation

Profiles-COSMO simulation

Good agreement between:

- COSMO Hyp.Int. (reduced mixing-enhanced measures + hyperbolic interpolation)
- COSMO LTG (reduced mixing-enhanced measures + LTG scheme based on MOST)

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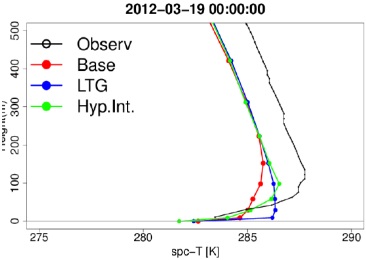

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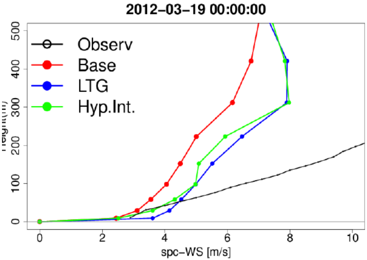

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Summary

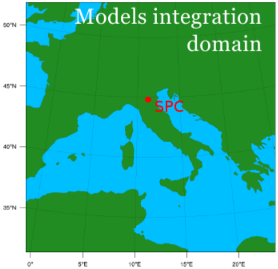
In horizontal homogeneous terrains:

1. Overestimation of surface fluxes in stable stratified conditions
2. Weak stability dependency of the transfer coefficients
3. Reason: missing agreement with MOST when stratification becomes stable
4. Solution: modification of the velocity scale profile in the constant flux sub-layer (hyperbolic interpolation)
5. It is possible to reduce the COSMO' SL scheme to MOST but the mixing-enhancing measures mask the effect.

Thank you for your attention!!

COSMO configuration:

- 3 parallel runs:
  - COSMO (as operational)
  - LTG (with reduced mixing-enhanced measures for homogeneous terrain)
  - Hyp. Int. (with reduced mixing-enhanced measures for homogeneous terrain)
- 30 runs 48h long (first 24h spinup)
- IC and BC: ECMWF operational analysis (16km horiz. resolution)

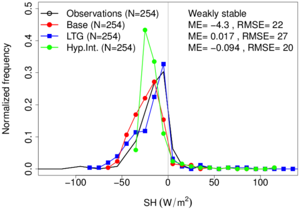


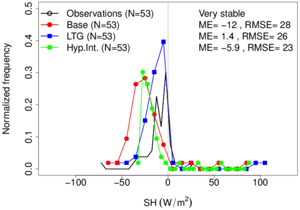
Site: San Pietro Capofiume (SPC) in Po Valley, Italy. Flat grassland - crop area.

Surface Fluxes-COSMO simulation

Weakly Stable | Very Stable

SH





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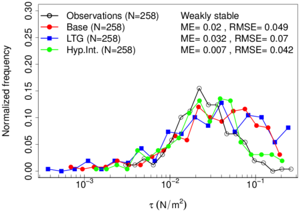

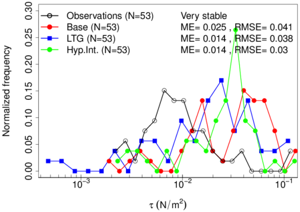

- Overestimation of fluxes by COSMO reduced by Hyp.Int and LTG
- Hyp. Int. always improves with respect to Base and LTG