Toulouse, 22th of March 2013

On the use of moist entropy in moist turbulence.

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METEO FRANCE

Contents

1) ***Motivations**: a wish to use the 2nd Law and Moist Entropy "s", because it is the quantity that the moist-turbulence want to see well-mixed ?*

2) ***Opportunities**: Marquet (2011) = a writing of "s" as $s_{ref} + c_{pd} \ln(\theta_s)$*

3) ***The aim of this talk**: EFB closure working days + the note of V. Masson*
→ *a comparison of turbulent fluxes of "s" either i) computed directly or ii) computed indirectly with the Betts variables (θ_l, q_t) ?*

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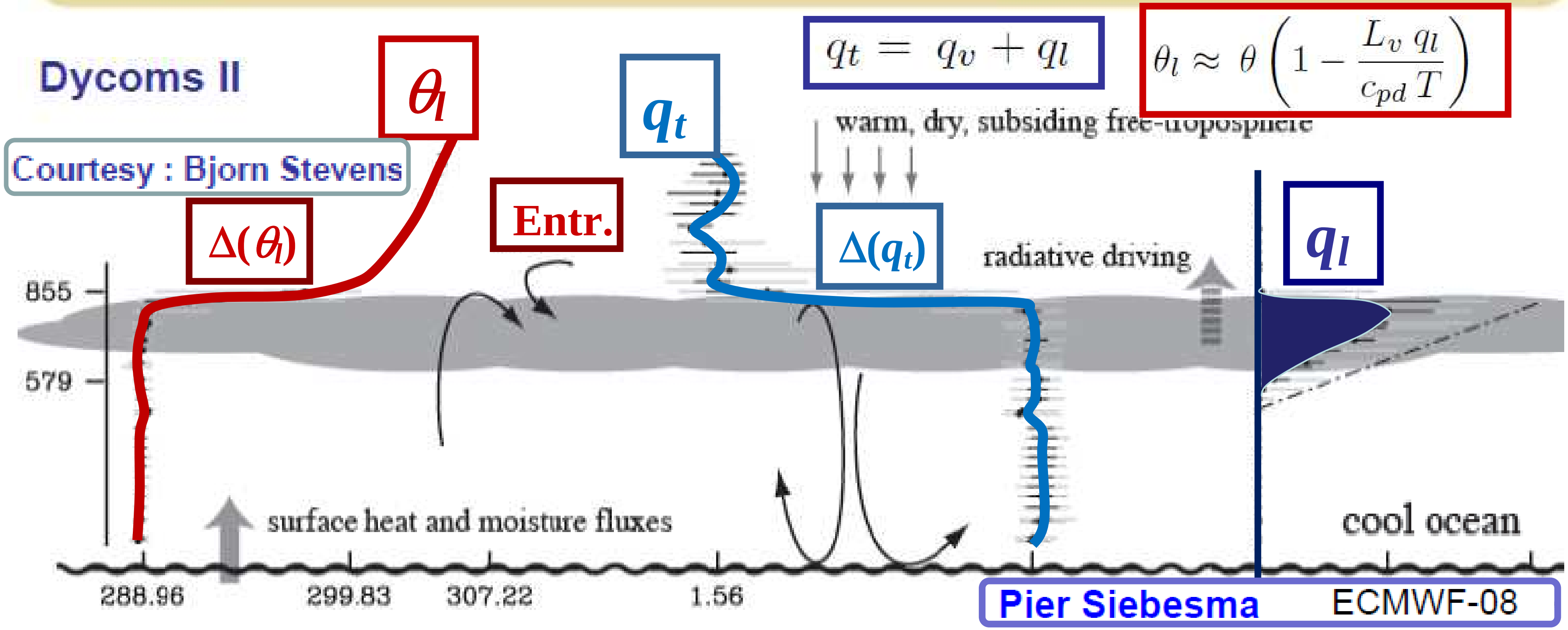
→ a comparison of turbulent fluxes of "s" either i) computed directly or ii) computed indirectly with the Betts variables (θ_l, q_t) ?

4) Improvements: liquid water / ice? … Cloud-Cover & subgrid / Sommeria-Deardorff / PDF ? … N^2 / M(C) / JFG ?

5) Improvements: more complicated : 3D-turbulent schemes? ... TOMS ?

6) Other ideas: "TPE" is in fact the APE of Lorenz ←→ EXERGY-Norm?

On the use of moist entropy in moist turbulence ?



Marine Strato-cumulus are paradigm of the moist turbulence, with θ_l and q_t often used as mixing variables (the so-called Betts' variables)

why θ_l and q_t ? *because* (θ_l , q_t) *is more homogeneous than* (θ , q_v) (impact of q_l)

On the use of moist entropy in moist turbulence ?

Moist turbulence: the so-called **Betts' (1973)** variables θ_l and q_t / often used as mixing variables

1) Total water content :

$$q_t \; = \; q_v \; + \; q_l \; + \; q_i$$

2) Liquid-water potential temperature:

$$\theta_l \; = \; \theta \; \exp\left(- \, \frac{L_{vap} \, q_l + L_{sub} \, q_i}{c_{pd} \, T} \right)$$

3) Optionally approximated by:

$$\theta_l \; \approx \; \theta \; \left(1 \; - \; \frac{L_{vap} \, q_l + L_{sub} \, q_i}{c_{pd} \, T} \right)$$

$$\exp(x) \approx 1 \, + \, x$$

On the use of moist entropy in moist turbulence ?

1) **Specific moist-air entropy:** Marquet (QJ-2011),
+ Marquet and Geleyn (QJ-2013)
+ Marquet QJ-2013 (a,b, submitted) → variable θ_s

$$s \; = \; s_{ref} \, + \, c_{pd} \, \ln(\theta_s)$$

s_{ref} and c_{pd} constant

2) Complete value:

$$\theta_s \; = \; (\theta_s)_1 \left(\frac{T}{T_r}\right)^{\lambda \, q_t} \left(\frac{p}{p_r}\right)^{-\kappa \, \delta \, q_t} \left(\frac{r_r}{r_v}\right)^{\gamma \, q_t} \frac{(1+\eta \, r_v)^{\kappa \, (1+\delta \, q_t)}}{(1+\eta \, r_r)^{\kappa \, \delta \, q_t}}$$

3) Approximation:

$$(\theta_s)_1 \; = \; \theta \, \exp\left(- \, \frac{L_{vap} \, q_l + L_{sub} \, q_i}{c_{pd} \, T}\right) \exp\left(\Lambda_r \, q_t\right)$$

4) Impact of the Third law :

$$\Lambda_r \, = \, (s_v^0 - s_d^0)/c_{pd} \approx 5.87$$

5) Optionally approximated by :

$$(\theta_s)_1 \; \approx \; \theta \, \left(1 \, - \, \frac{L_{vap} \, q_l + L_{sub} \, q_i}{c_{pd} \, T} \, + \Lambda_r \, q_t\right)$$

Betts' variable : $\theta_l \; \approx \; \theta \, \left(1 \, - \, \frac{L_{vap} \, q_l + L_{sub} \, q_i}{c_{pd} \, T}\right)$

Comparisons $(\theta_s)_1$

$\leftarrow\rightarrow$ [θ_l ; θ_v ; θ_E ; …] ?

≈ "constant" profiles and

≈ no (or small) top-PBL jump

$(\theta_s)_1$ different from all other Pot. Temp.

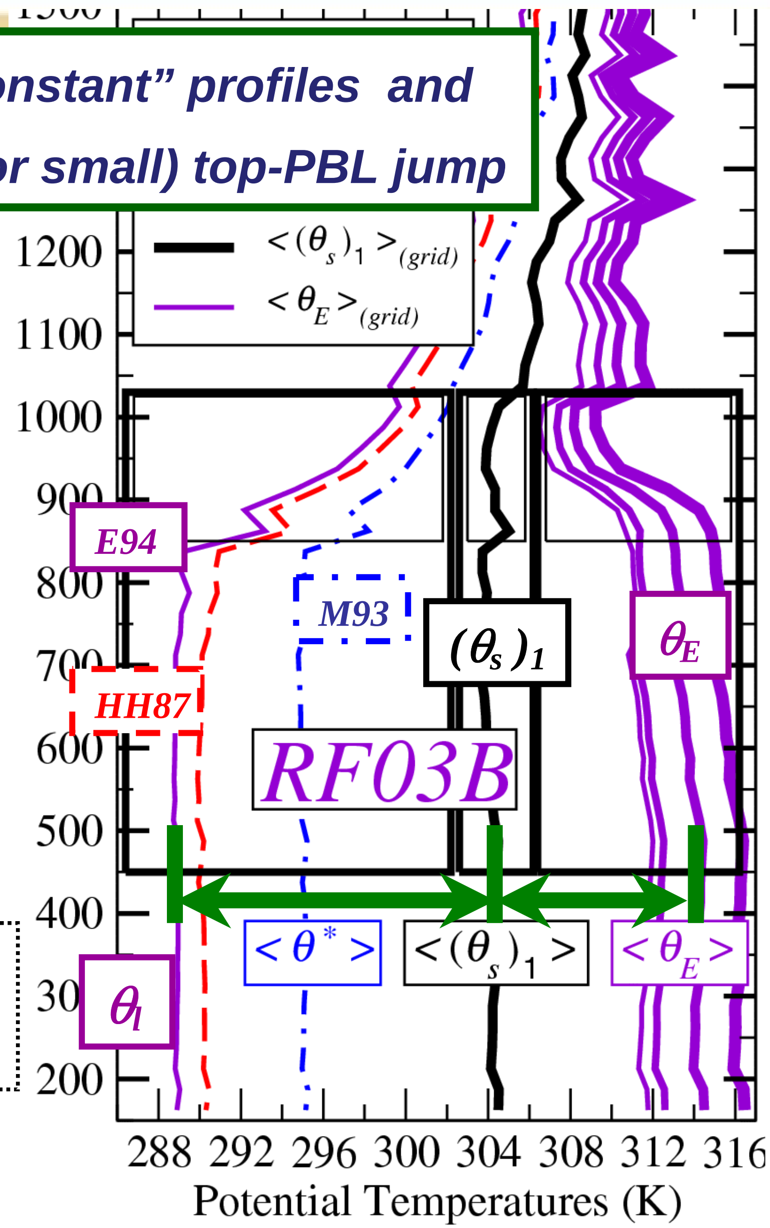
$(\theta_s)_1 \approx$ 2/3 - 1/3 between θ_l & θ_E

$$\theta_v \;=\; \theta\;(1 + \delta\, q_v - q_l - q_i)$$

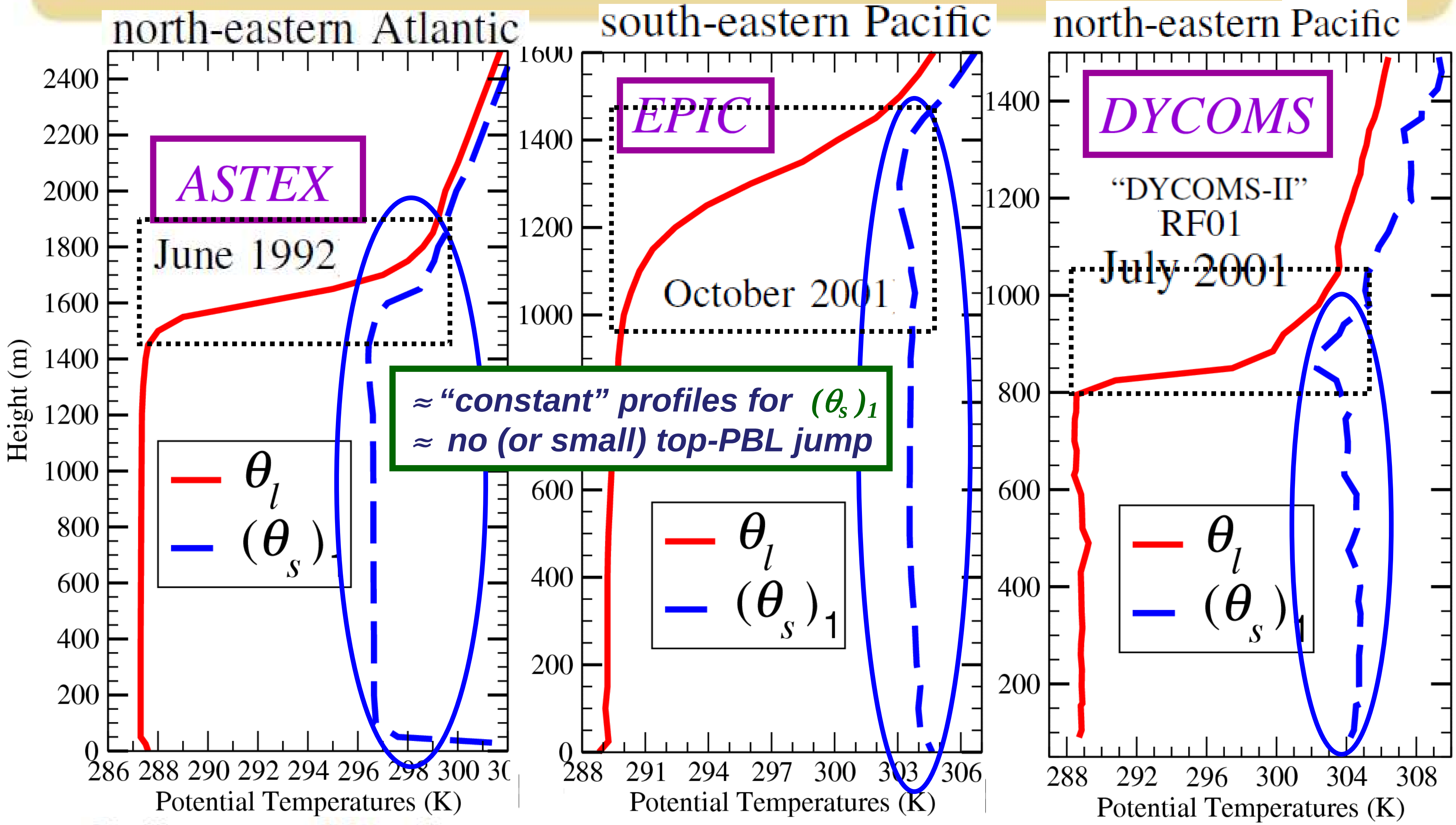
$$\theta_e \;\approx\; \theta\left(1 + \frac{L_{vap}\, q_v}{c_{pd}\, T}\right) \qquad \delta \approx 0.608$$

$$(\theta_s)_1 \;\approx\; \theta\left(1 - \frac{L_{vap}\, q_l + L_{sub}\, q_i}{c_{pd}\, T} + \Lambda_r\, q_t\right)$$

$$L_{vap}/(c_{pd}\, T) \approx 9 \qquad \Lambda_r \approx 6$$



FIRE-I RF03B → 02B-04B-08B : OK ! … and :



Cuijpers and Bechtold (1995) — Bretherton et al. (2004) — Zhu et al. (2005)

On the use of moist entropy in moist turbulence ?

The 1D-scheme of Masson (2013):

$$\overline{w'\theta'} = -K_\theta \frac{\partial \Theta}{\partial z} + \Gamma_\theta E_\theta \overline{(\theta')^2} + \Gamma_\theta E_q \overline{\theta' q'}$$

$$\overline{w'q'} = -K_q \frac{\partial Q}{\partial z} + \Gamma_q E_\theta \overline{q'\,\theta'} + \Gamma_q E_q \overline{(q')^2}$$

$$\theta = \Theta + \theta'$$

$$q = Q + q'$$

Mean + eddies

First-order fluxes

Exchange-coeff. + Grad.

Second order fluxes

$$K_\theta = \frac{L}{C_{p\theta}\sqrt{e}} \overline{(w')^2} \qquad \Gamma_\theta = \frac{2}{3}\,\beta \frac{L}{C_{p\theta}\sqrt{e}}$$

$$K_q = \frac{L}{C_{pq}\sqrt{e}} \overline{(w')^2} \qquad \Gamma_q = \frac{2}{3}\,\beta \frac{L}{C_{pq}\sqrt{e}}$$

$$\beta = g/\Theta$$

Constants: $C_{p\theta}$ and C_{pq}

On the use of moist entropy in moist turbulence ?

$$\theta_l = \theta \, ,$$
$$\theta_v = \theta \; (1 + \delta \, q_v) \, ,$$
$$\theta_s \approx \theta \; (1 + \Lambda_r \, q_v) \, .$$

$$\delta \approx 0.608 \quad \Lambda_r \approx 5.87$$

1) under-saturation approximation

$$\overline{w' \, \theta'_v} = E_\theta \; \overline{w' \, \theta'} + E_q \; \overline{w' \, q'_v}$$

2) Buoyancy fluxes? (Betts' variables)

$$E_\theta = 1 + \delta \, Q$$
$$E_q = \delta \, \Theta$$

$$\overline{w' \, \theta'_s} = (1 + \Lambda_r \, Q) \; \overline{w' \, \theta'} + (\Lambda_r \, \Theta) \; \overline{w' \, q'_v}$$

$$\overline{w' \, \theta'_v} = E^\star_\theta \; \overline{w' \, {\theta_s}'} + E^\star_q \; \overline{w' \, q'_v}$$

3) Buoyancy fluxes? (moist entropy)

$$E^\star_\theta = \frac{1 + \delta \, Q}{1 + \Lambda_r \, Q}$$
$$E^\star_q = \Theta \left(\delta - \frac{\Lambda_r}{1 + \Lambda_r \, Q} \right)$$

On the use of moist entropy in moist turbulence ?

1) A direct use of the Moist Entropy in 1D-turbulent scheme: $\theta_l \rightarrow \theta_s$?

$$\left(\overline{w'\,\theta'_s}\right)_1 \;=\; -\,K_s\,\frac{\partial \Theta_s}{\partial z} + \Gamma_s\,E^{\star}_{\theta}\;\overline{(\theta'_s)^2} + \Gamma_s\,E^{\star}_{q}\;\overline{\theta'_s\,q'_v}$$

2) Flux of Moist Entropy indirectly computed from Betts' variables (what is presently done)

$$\theta_s \;\approx\; \theta\;(1 + \Lambda_r\,q_v)$$

$$\left(\overline{w'\,\theta'_s}\right)_2 \;=\; (1 + \Lambda_r\,Q)\;\overline{w'\,\theta'} + (\Lambda_r\,\Theta)\;\overline{w'\,q'_v}$$

$$\overline{w'\theta'} \;=\; -\,K_\theta\,\frac{\partial \Theta}{\partial z} + \Gamma_\theta\,E_\theta\,\overline{(\theta')^2} + \Gamma_\theta\,E_q\,\overline{\theta' q'}$$

$$\overline{w'q'} \;=\; -\,K_q\,\frac{\partial Q}{\partial z} + \Gamma_q\,E_\theta\,\overline{q'\,\theta'} + \Gamma_q\,E_q\,\overline{(q')^2}$$

On the use of moist entropy in moist turbulence ?

1) The present method: Betts' variables (θ_l, q_v)

$$
\begin{aligned}
\left(\overline{w'\,\theta'_s}\right)_2 \; = \;
& - K_\theta \, (1 + \Lambda_r\, Q) \, \frac{\partial \Theta}{\partial z} - K_q \, (\Lambda_r\, \Theta) \, \frac{\partial Q}{\partial z} \\
& + \Gamma_\theta \, (1 + \delta\, Q)\, (1 + \Lambda_r\, Q)\, \overline{(\theta')^2} \\
& + \Gamma_\theta \, (\delta\, \Theta)\, (1 + \Lambda_r\, Q)\, \overline{\theta'\, q'_v} \\
& + \Gamma_q \, (1 + \delta\, Q)\, (\Lambda_r\, \Theta)\, \overline{q'_v\, \theta'} \\
& + \Gamma_q \, (\delta\, \Lambda_r\, \Theta^2)\, \overline{(q'_v)^2} \, .
\end{aligned}
$$

2) Direct use of (θ_s, q_v) moist entropy variable

$$
\begin{aligned}
\left(\overline{w'\,\theta'_s}\right)_1 \; = \;
& - K_s \, (1 + \Lambda_r\, Q) \, \frac{\partial \Theta}{\partial z} - K_s \, (\Lambda_r\, \Theta) \, \frac{\partial Q}{\partial z} \\
& + \Gamma_s \, (1 + \delta\, Q)\, (1 + \Lambda_r\, Q)\, \overline{(\theta')^2} \\
& + \Gamma_s \, (\delta\, \Theta)\, (1 + \Lambda_r\, Q)\, \overline{\theta'\, q'_v} \\
& + \Gamma_s \, (1 + 2\,\delta\, Q)\, (\Lambda_r\, \Theta)\, \overline{q'_v\, \theta'} \\
& + \Gamma_s \, (\delta\, \Lambda_r\, \Theta^2) \left[1 + \left(\frac{\Lambda_r\, Q}{1 + \Lambda_r\, Q} \right) \right] \overline{(q'_v)^2}
\end{aligned}
$$

$$K_s = K_\theta = K_q$$

$$C_{ps} = C_{p\theta} = C_{pq}$$

$$\Gamma_s = \Gamma_\theta = \Gamma_q$$

3) From the ← first line

4) New terms with the use of (θ_s, q_v) moist entropy variable

5) Conclusion: different formulations...

On the use of moist entropy in moist turbulence ?

2) Not for these LES →

$$\overline{w'q'} = -K_q \frac{\partial Q}{\partial z}$$

$$\overline{w'\theta'} = -K_\theta \frac{\partial \Theta}{\partial z}$$

1) Is this relevant?

$$K_s = K_\theta = K_q$$

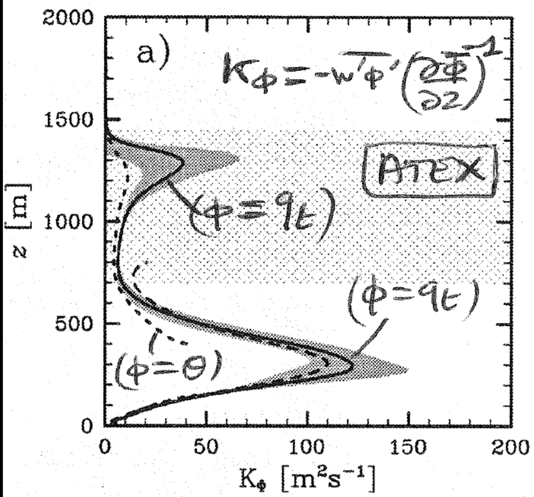
$$C_{ps} = C_{p\theta} = C_{pq}$$

$$\Gamma_s = \Gamma_\theta = \Gamma_q$$

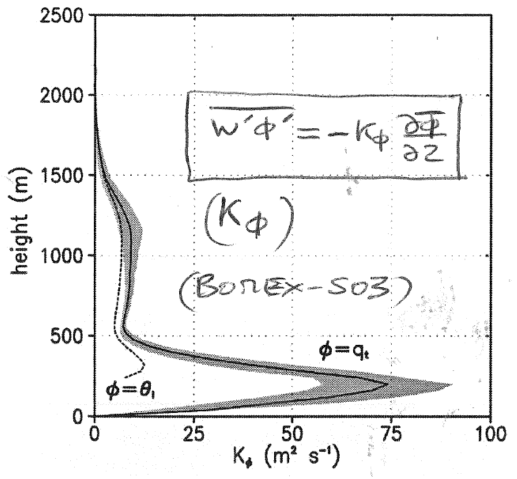
3) Not for the Drag-coef. (ECUME / SURFEX) →

$$C_H = \frac{u_* \theta_*}{U(\theta_a - \theta_s)}$$

$$C_E = \frac{u_* q_*}{U(q_a - q_s)}$$

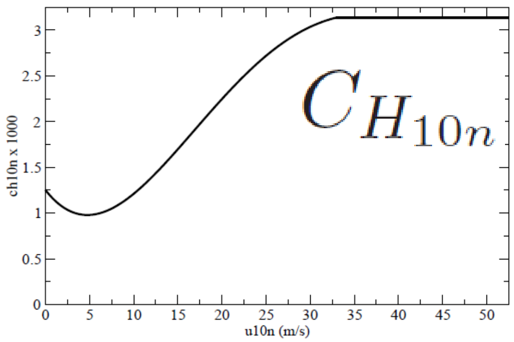


ATEX (Stevens et al, 2001)

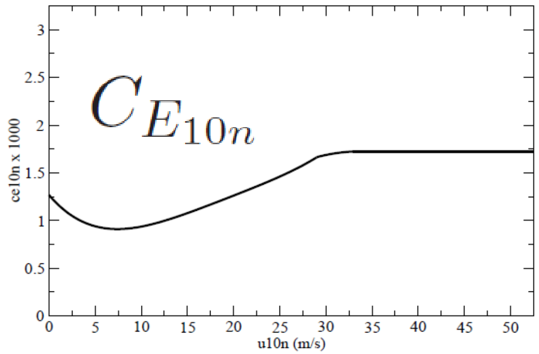


BOMEX (Siebesma et al, 2003)

SURFEX v7.2 - Issue n°2 - 2012



neutral heat coefficient



neutral evaporation coefficient

Conclusions

1) ***Motivations***: *a wish to use the* 2[nd] *Law and* ***Moist Entropy*** *"s", because it is the quantity that the* ***moist-turbulence*** *want to see* ***well-mixed*** *?*

2) ***Opportunities***: *Marquet (2011) = a writing of "s" as* $s_{ref} + c_{pd} \ln(\theta_s)$

3) ***The aim of this talk:***

→ *Turbulent fluxes of "moist entropy -* θ_s*" either computed* ***directly*** *or computed indirectly* ***with the Betts variables*** (θ_l, q_t) *?*

→ *Equivalent only if ...* $C_{p\theta} = C_{pq}$ *:* ***not realistic****?* ***consequences****? (rewind)*

→ *Other differences even if* $C_{p\theta} = C_{pq}$ *:* ***second-order fluxes / non-lin.***

Conclusion – Outlook

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Other ideas: *"TPE" is in fact the **Available Potential Energy** of Lorenz*

→ *There is no "moist APE" … (even MAE of Lorenz 1978-79 …)*

→ *"Exergy" = an alternative for APE with a **moist version** of it …*

→ *(total) **Moist Available Enthalpy Norm** (T, p_{surf}, q_v): a **new starting point**?*

`http://perso.numericable.fr/~pmarquet/`

Thank you … Questions ?