CFMIP / GCSS / EUCLIPSE meeting

Exeter, UK. 8th of June,2011

Computations of the Moist Entropy for Stratocumulus and Cumulus from observations and simulations.

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Contents

1) ***Motivations*** **:** ***2nd Principle / Moist Entropy***

2) ***Result*** **:** ***a formula for the Moist Entropy /*** $s \rightarrow \theta_S \rightarrow (\theta_S)_1$

3) ***Applications-1*** ***: Sc = FIRE-I / … / compare*** $(\theta_S)_1 \leftrightarrow \theta_l \; \theta_E$ …

4) ***Applications-2*** ***: Sc & Cu ; EUCPLISE ; ASTEX ; …***

5) ***Other results*** ***: Fluxes …***

6) ***Conclusion*** **-** ***Outlook***

Contents

1) ***Motivations* : *why studying the 2nd Principle / Moist Entropy?***

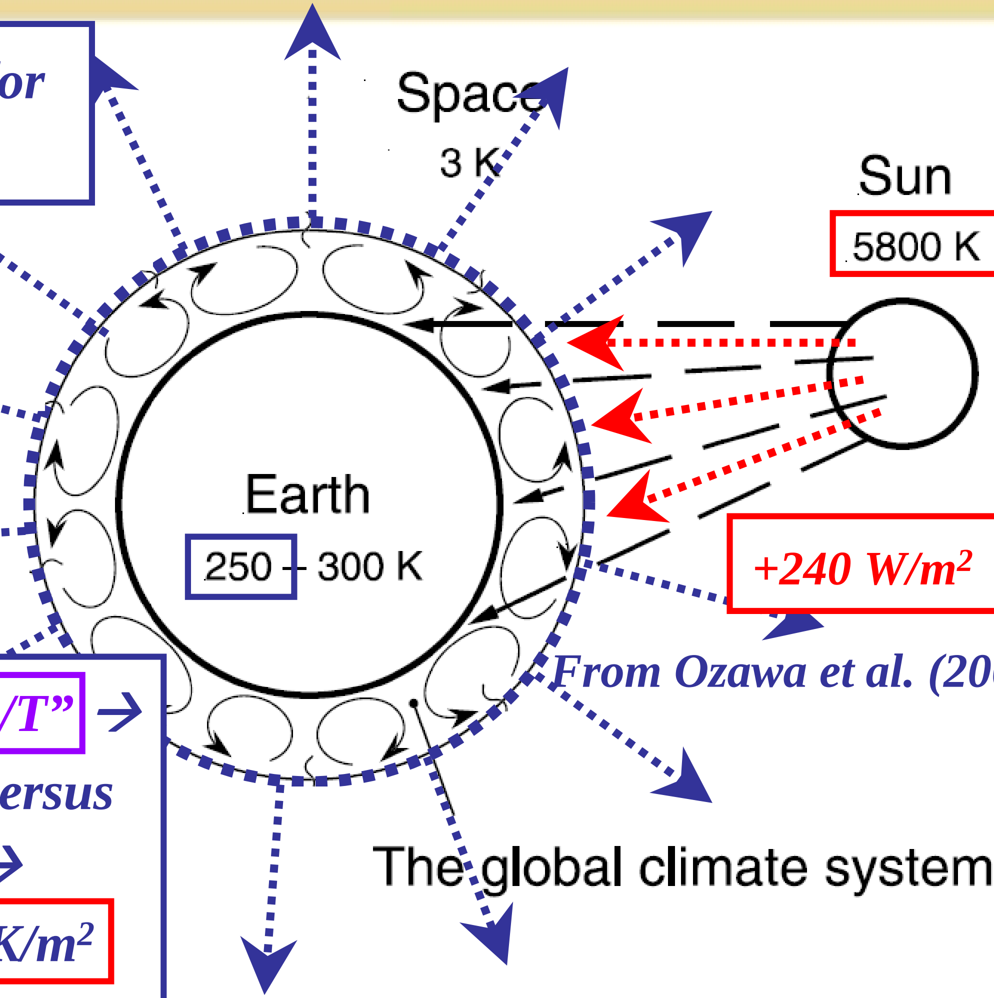
Motivations

Which kind of budget for the Earth?

1) A closed budget for energy (or enthalpy) : F = +/- 240 W/m²

–240 W/m²

→ a monitoring of these 2 budgets?



+240 W/m²

From Ozawa et al. (2003)

The global climate system

2) An imbalance for entropy : "F/T" →
–240/250 = – 940 mW/K/m² versus
+ 240/5800 = +40 mW/K/m² →
a net production of 900 mW/K/m²
by Atm. Surf. Oceans …

Motivations

Which kind of budget for the Earth?

1) A closed budget for energy :

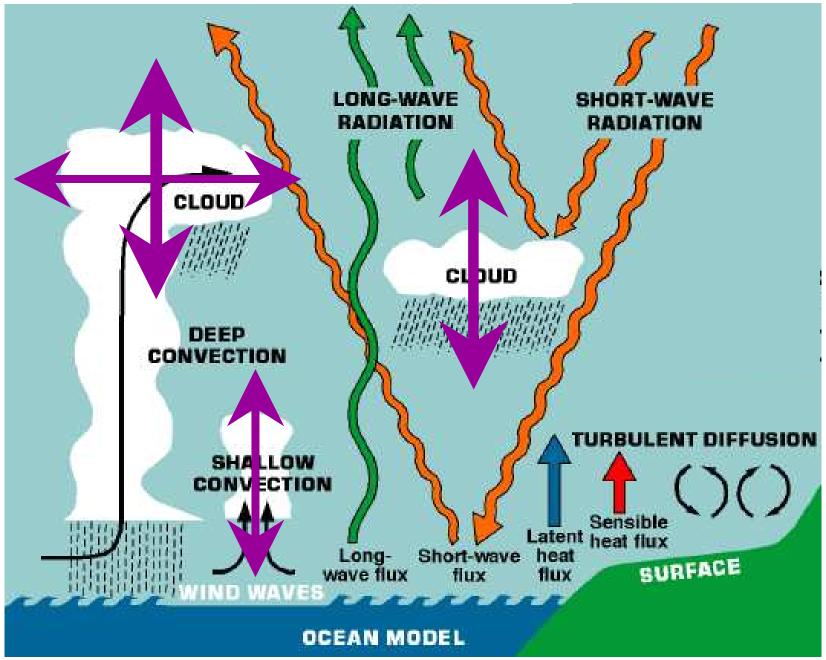
dE/dt = 0 ➔ E = Cste

2) An imbalance for entropy :

dS/dt > 0 ➔ $d^2S/dt^2 = 0$? … but S ??

← a monitoring of these 2 budgets

IFS DOCUMENTATION ECMWF



Changes in height / depth of clouds →

changes in energy and entropy budgets…

A way to select the tuning of SCM/GCM?

(i.e. to get the right E with the right S ?)

But budget of entropy = difficult to compute!

Hypothesis: wrong budget → wrong values of energy and/or entropy … If reference values exist (obs. / analysis ?), then …

→ compute the variables (energy and entropy) and check their realism ?

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Contents

1) *Motivations* : why studying the 2nd Principle / Moist Entropy?

2) ***Result*** **: a formula to compute Moist Entropy /** $s \rightarrow \theta_s \rightarrow (\theta_s)_1$

Computations of $s \rightarrow \theta_s \rightarrow (\theta_s)_1$

Definition of a moist entropy potential temperature: application to FIRE-I data flights

Q. J. R. Meteorol. Soc. 137: 768–791, April 2011 A

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Budget of entropy is difficult to compute :
$$\rho\, T \frac{d\, s}{dt} = \rho \left(\dot{Q}_i + \dot{D} \right) - \rho \left[\mu_k \frac{d_i\, q_k}{dt} \right] - \boldsymbol{J}_k \,.\boldsymbol{\nabla}(h_k) - T\, s_k\, (\boldsymbol{\nabla}.\, \boldsymbol{J}_k)$$

Hauf & Höller (1987)

Entropy = state function → computable at any point:
$$s = q_d\, s_d + q_v\, s_v + q_l\, s_l + q_i\, s_i$$

q_d	$s_d = (s_d)_r + c_{pd} \ln(T/T_r) - R_d \ln[\,p/(p_d)_r\,]$
q_v	$s_v = (s_v)_r + c_{pv} \ln(T/T_r) - R_v \ln[\,e/e_r\,]$
q_l	$s_l = (s_l)_r + c_l \ln(T/T_r)$
q_i	$s_i = (s_i)_r + c_i \ln(T/T_r)$

become active!

The aim:

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

$$s \leftrightarrow \theta_s \,?$$

$$s_{ref} = \text{Cste}$$
$$c_{pd} = 1004.7 \text{ J K}^{-1} \text{ kg}^{-1}$$

Computations of $s \rightarrow \theta_s \rightarrow (\theta_s)_1$

MOIST ENTROPIC POTENTIAL TEMPERATURE

$\forall \; (T_r, p_r, r_r)$!

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

$$s_{ref} \approx 1138.56 \text{ J K}^{-1} \text{ kg}^{-1}$$

$$\theta_s \equiv \theta \exp(\Lambda \, q_t) \exp\left(- \frac{L_v \, q_l + L_s \, q_i}{c_{pd} \, T} \right) \times \left(\frac{T}{T_r} \right)^{\lambda \, q_t} \left(\frac{p}{p_r} \right)^{-\kappa \, \delta \, q_t} \times \left(\frac{r_r}{r_v} \right)^{\gamma \, q_t} \frac{(1 + \eta \, r_v)^{\kappa (1 + \delta \, q_t)}}{(1 + \eta \, r_r)^{\kappa \, \delta \, q_t}}$$

$(\theta_s)_1$

leading term

≈ 1

θ_s ***complicated*** ?

in fact "similar" to HH87, M93 or E94, except ...

Computations of $s \rightarrow \theta_s \rightarrow (\theta_s)_1$

The leading term :

$$(\theta_s)_1 = \theta_l \; \exp[\, \Lambda \, q_t \,]$$

Generalization / mixing of the 2 Betts variables:

$$\theta_l = \theta \; \exp\left(- \frac{L_v \, q_l}{c_{pd} \, T} \right)$$

$$q_t = q_v + q_l$$

+ absolute values of partial entropies →

$$\Lambda = [\, (s_v)_r - (s_d)_r \,] \, / \, c_{pd} \approx 5.87$$

The 3rd Law …

If needed :

$$(\theta_s)_1 \approx \theta_l \left(1 + \Lambda \, q_t \right)$$

$$(\theta_s)_1 \approx \theta \left(1 + \Lambda \, q_t - \frac{L_v q_l}{c_{pd} T} \right)$$

Contents

3) Applications. A new formula : seek for new consequences ?

new physical properties ? → a need of validations against observations : Strato-cumulus FIRE-I ; $(\theta_s)_1$ ←→ [θ_l ; θ_E ; …]

Marine Stratocumulus = a paradigm of moist turbulence

"black body radiator"

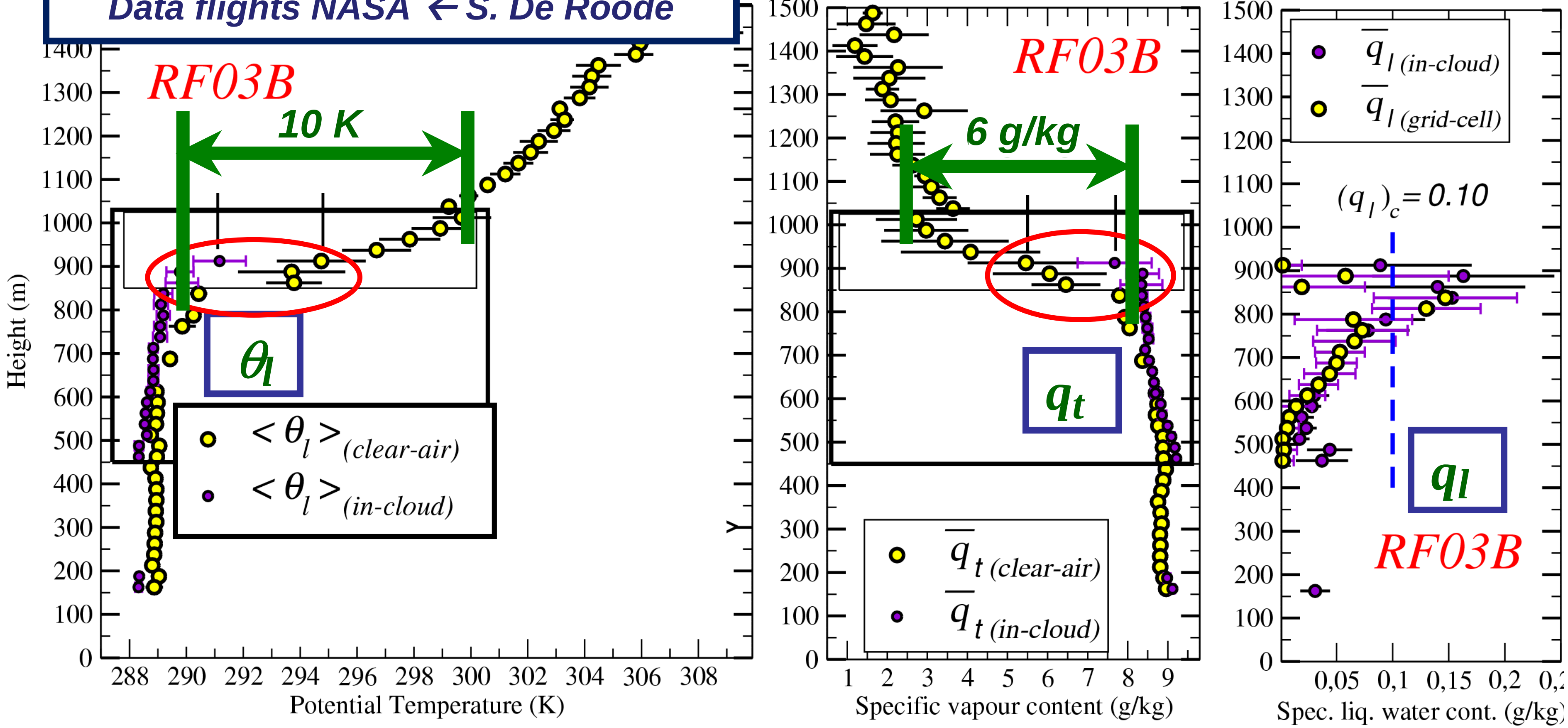
→ *test of a possible "Mixing In Moist Entropy" ?* **(MIME)**

Because "adiabatic & reversible" → **Moist Entropy = Cste**

(from 2nd Principle)

Applications / FIRE-I : [θ_l ; q_t ; q_l] RF03B-hom.

Data flights NASA ← S. De Roode

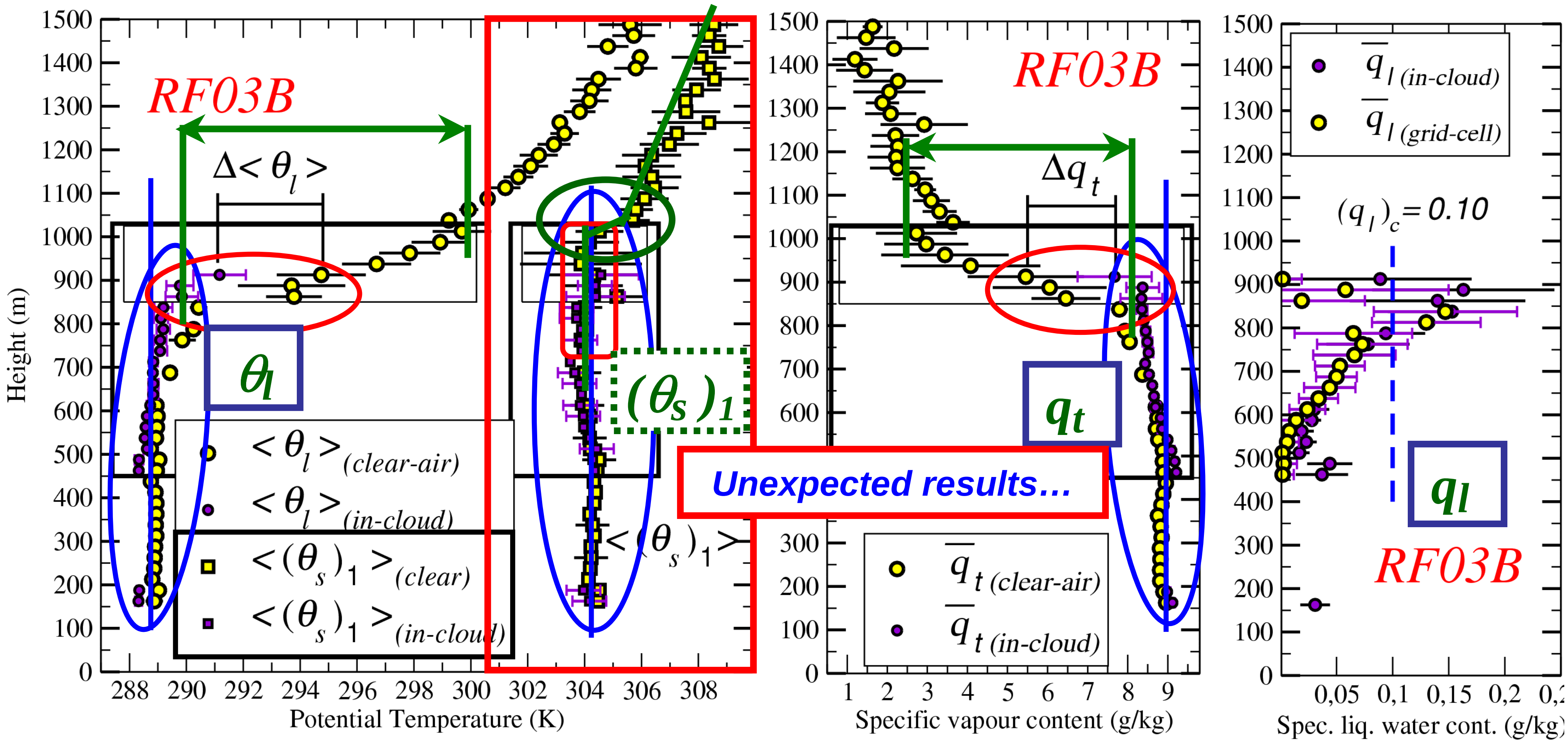


Same results as Roode & Wang (2007)

"clear-air" ≠ "cloud" (entrain. region)

Large jumps in θ_l and q_t (entrain. region)

Applications / FIRE-I : [θ_l ; q_t ; q_l] RF03B-hom.



$(\theta_s)_1$ constant with z

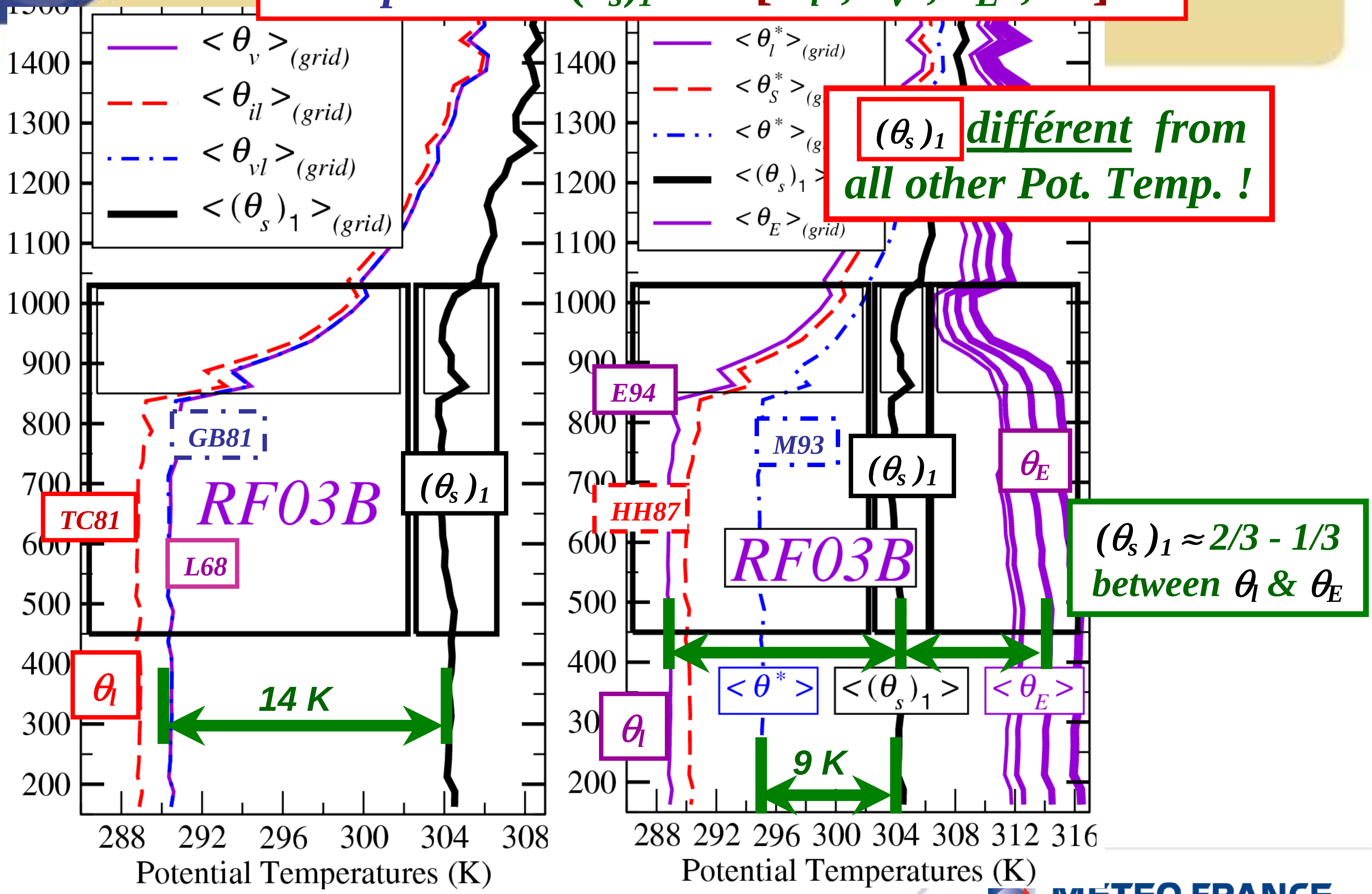
"clear-air" = "cloud" ! for $(\theta_s)_1$

No jump in $(\theta_s)_1$!

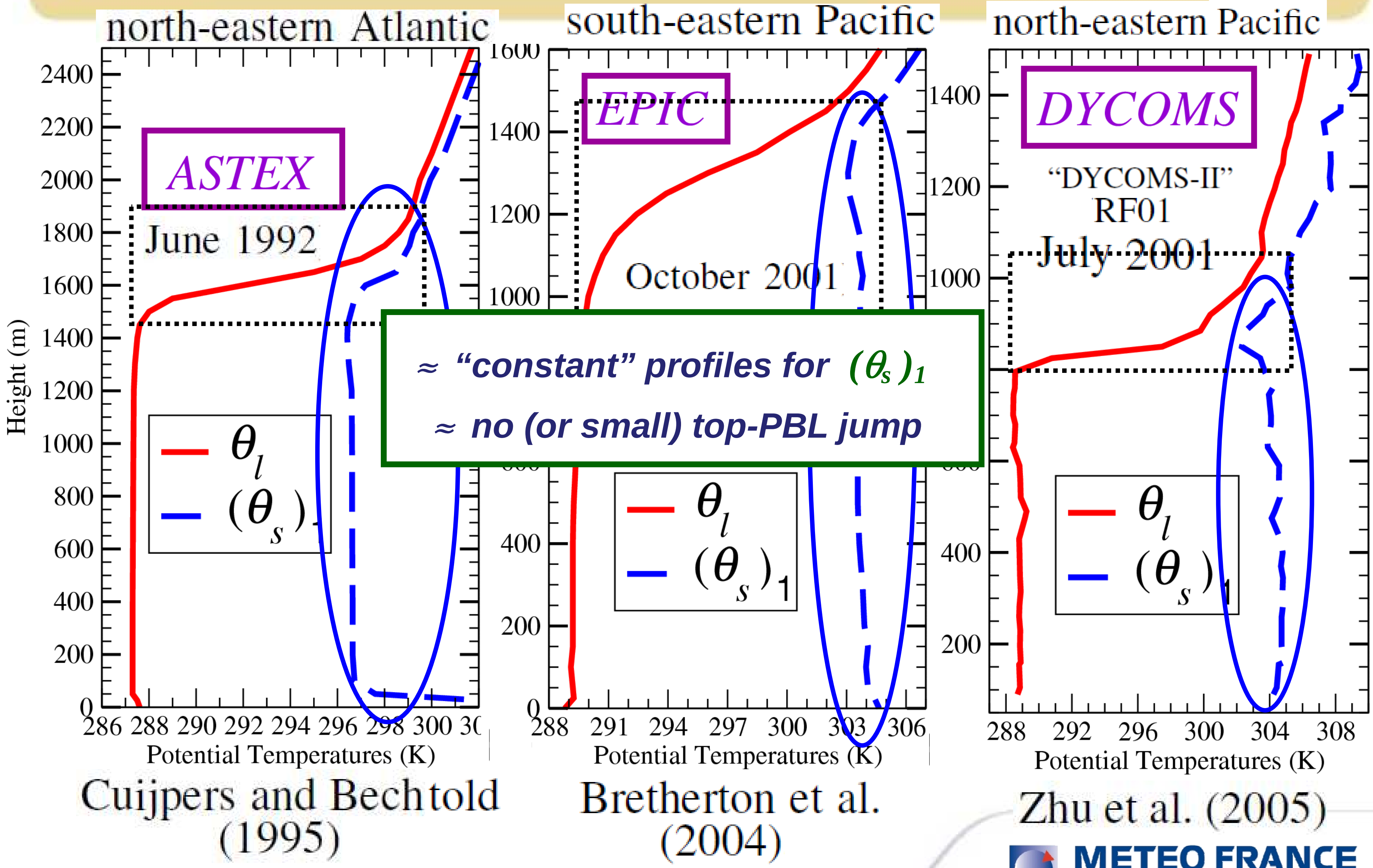
$$s = s_{ref} + c_{pd} \ln(\theta_s)$$

$$(\theta_s)_1 = \theta_l \exp[\Lambda q_t]$$

Comparisons $(\theta_s)_1$ ←→ [θ_l ; θ_v ; θ_E ; …] ?



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



≈ "constant" profiles for $(\theta_s)_1$

≈ no (or small) top-PBL jump

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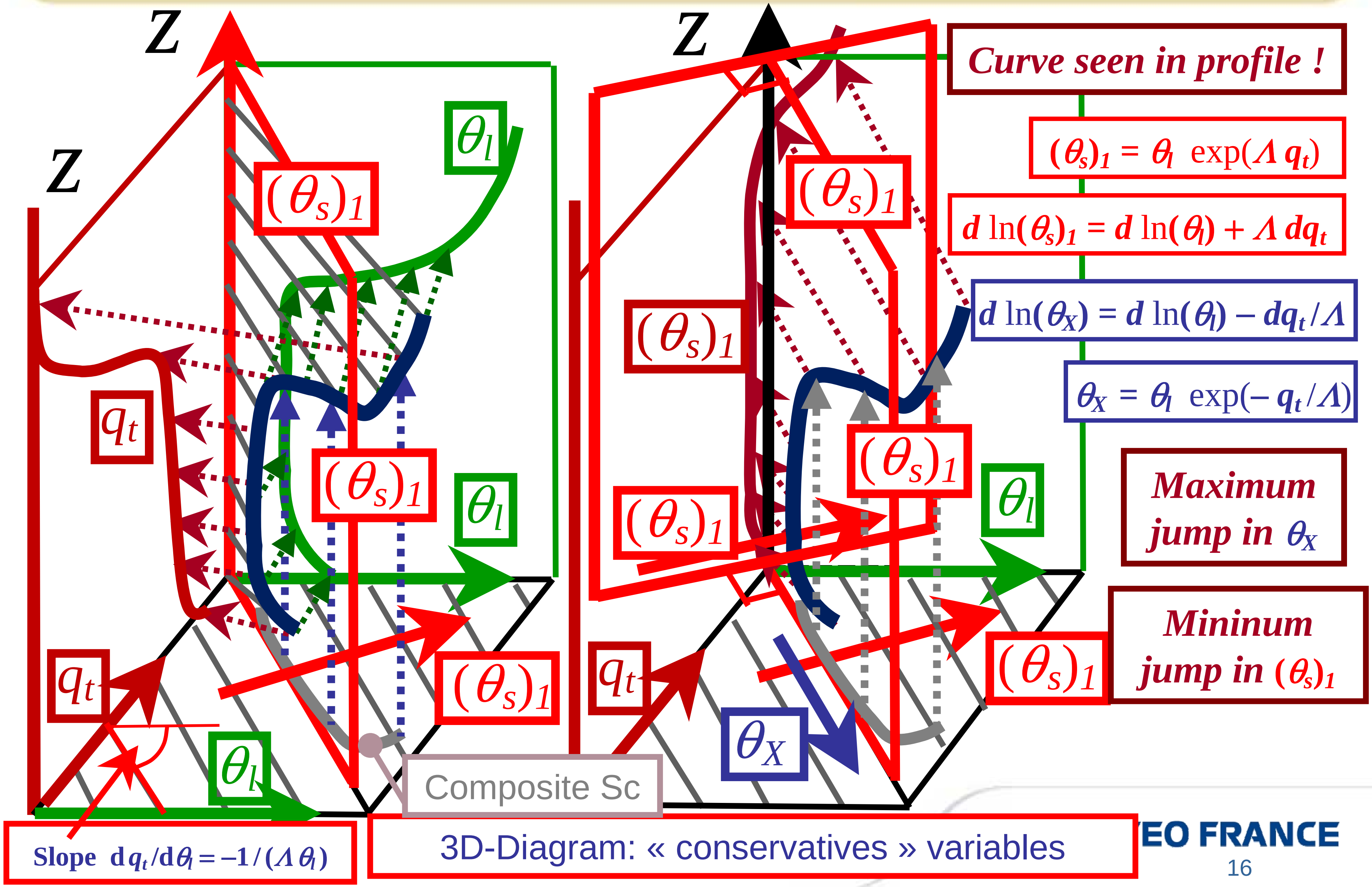
3) Applications. A new formula : is there new consequences ? new physical properties ? If yes, a need of validations against measurements : Strato-cumulus FIRE-I ; $(\theta_s)_1$ ←→ [θ_l ; θ_E ; …]

Marine Stratocumulus = a paradigm of moist turbulence

→ a mixing in moist entropy ?

But how (and why?) the large jumps in q_t and θ_l may disappear with $(\theta_s)_1$?

Thermodynamic Diagrams (Gibbs) …reversible adiabats ?



3D-Diagram: « conservatives » variables

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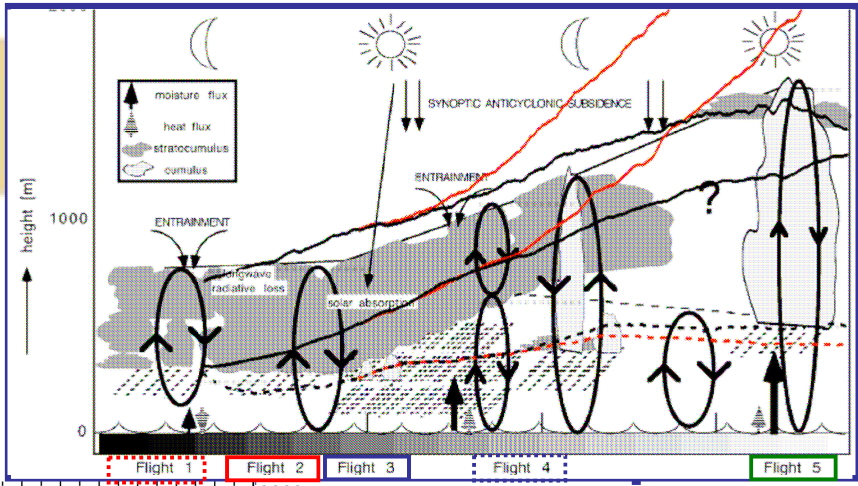
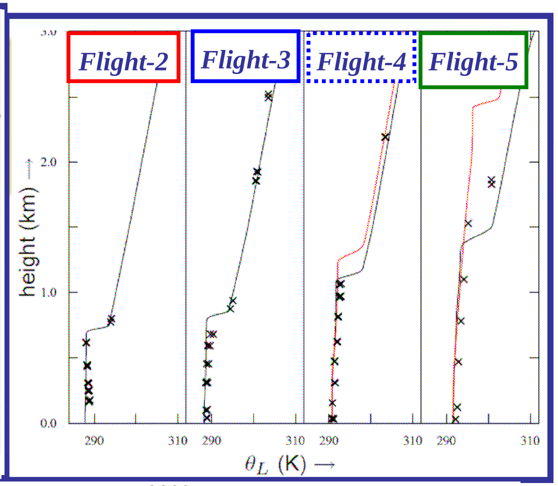
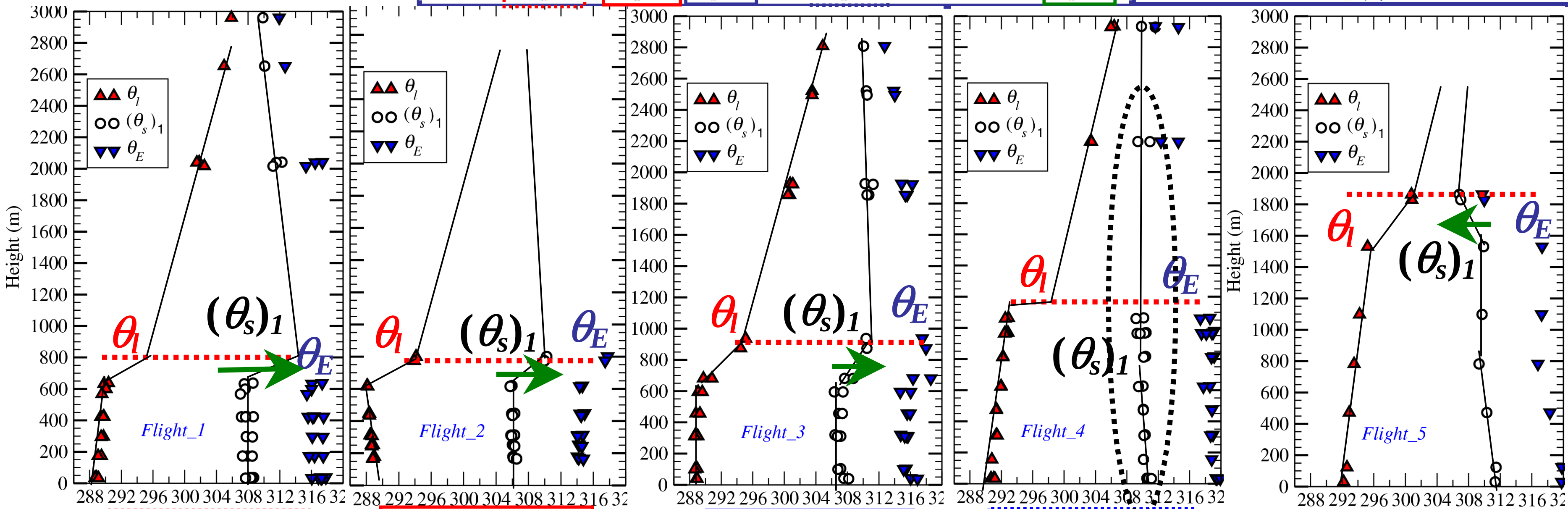
ASTEX first Lagrangian

De Roode and Dussen (Keystone, 2010)







Flight-1 / RF05
Electra / 92-06-12

Flight-2 / A209
UKMRF / 92-06-13

Flight-3 / RF06
Electra / 92-06-13

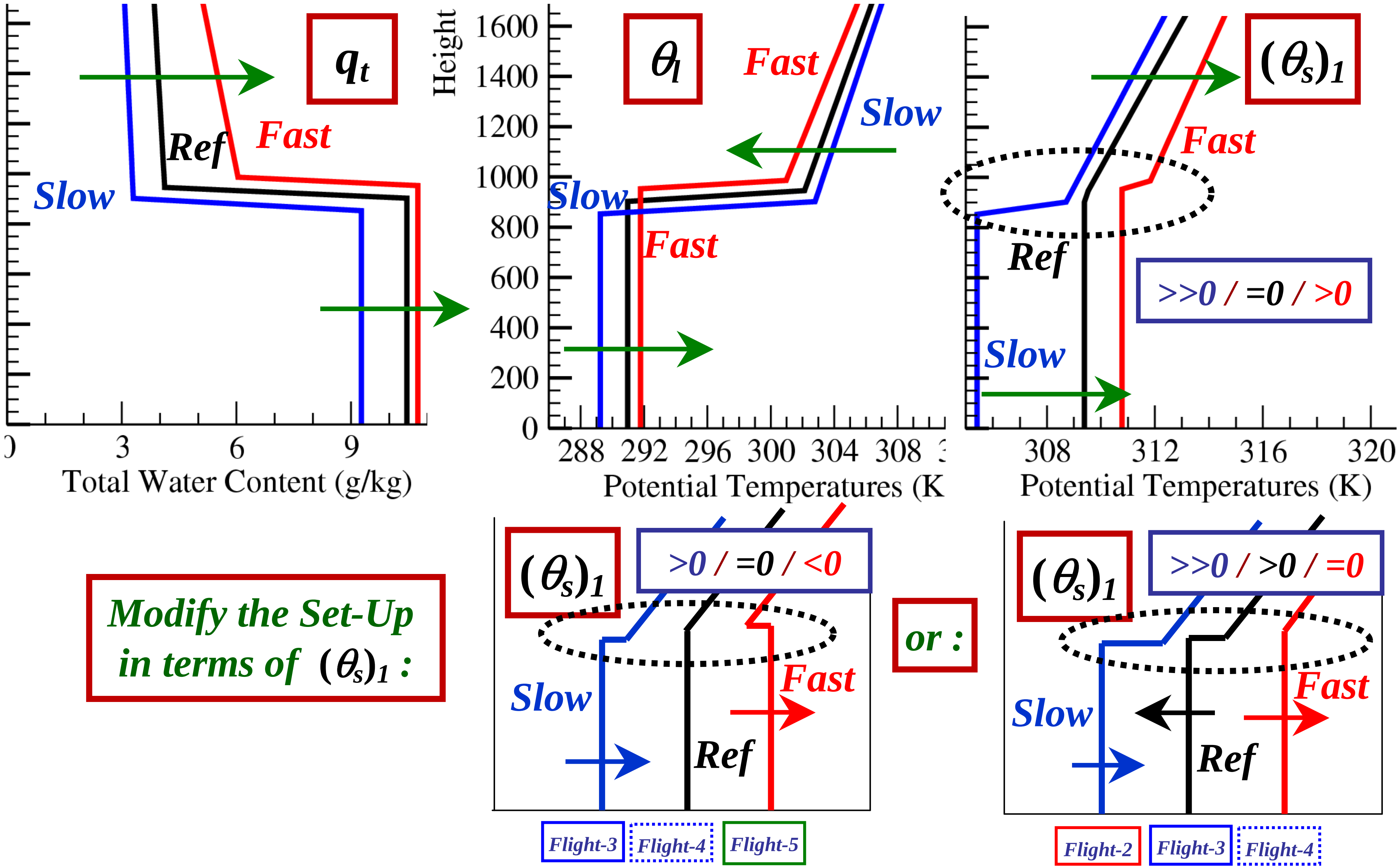
Flight-4 / RF07
Electra / 92-06-13

Flight-5 / A210
UKMRF / 92-06-13

Transition : Sc → Cu in terms of θ_l, $(\theta_s)_1$ and θ_E ?

Lagrangian Composite Cases

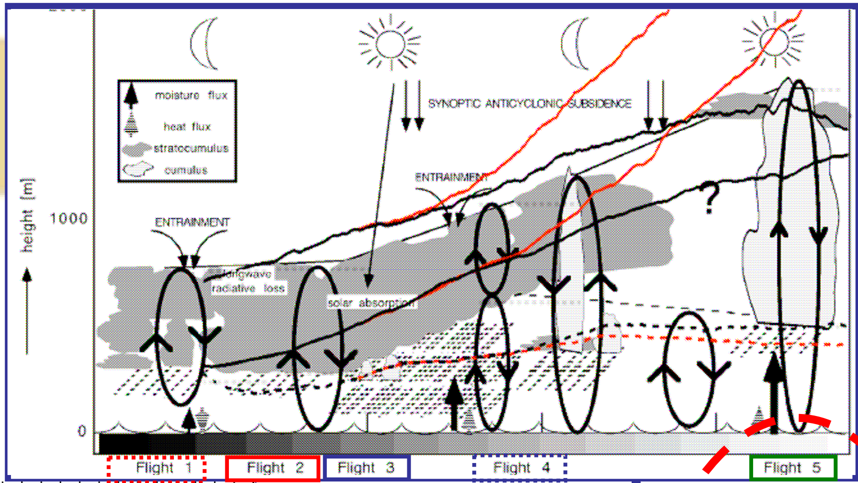
Sandu and Stevens

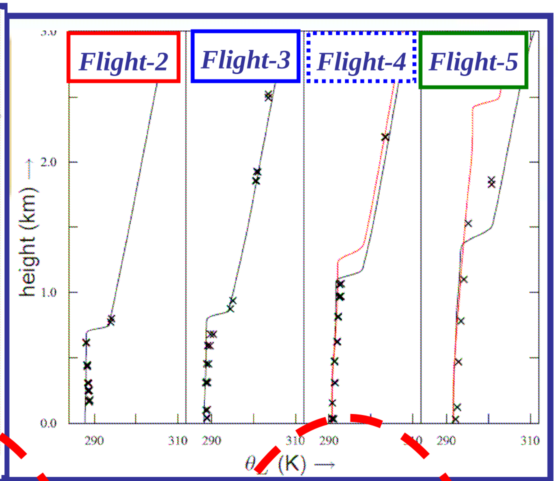


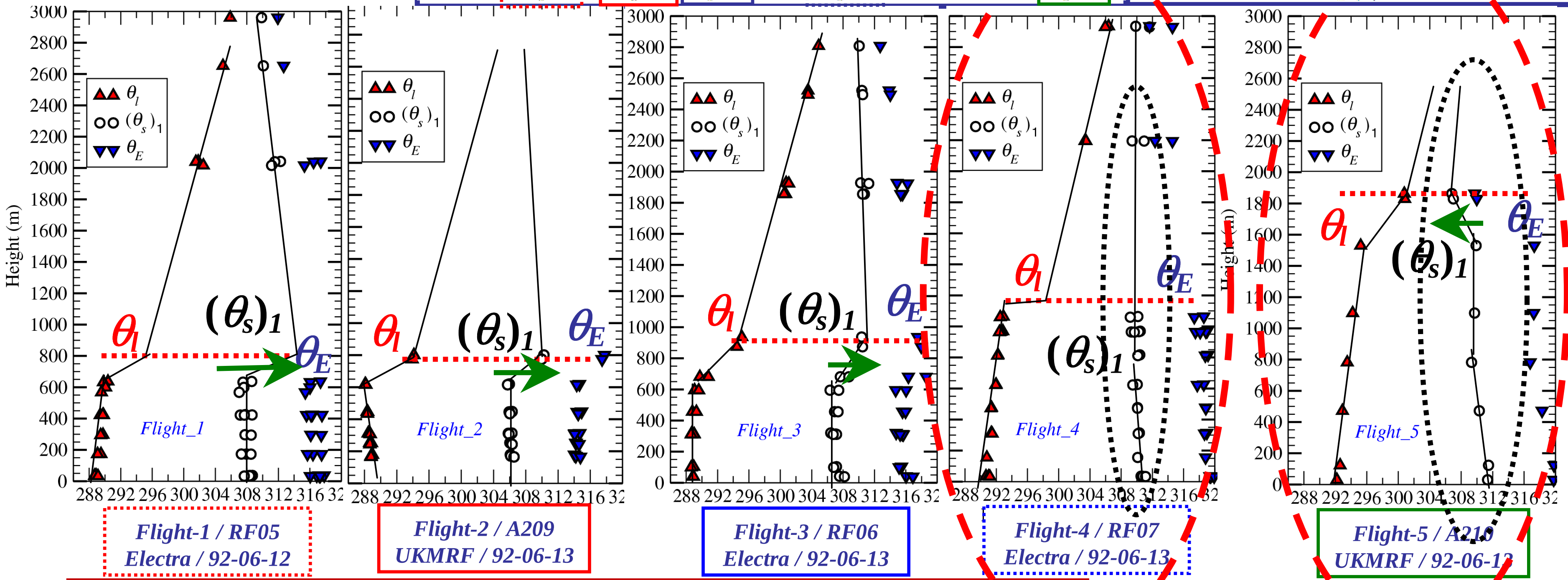
Modify the Set-Up in terms of $(\theta_s)_1$:

ASTEX first Lagrangian

De Roode and Dussen (Keystone, 2010)







Transition : Sc → Cu in terms of θ_l , $(\theta_s)_1$ and θ_E ?

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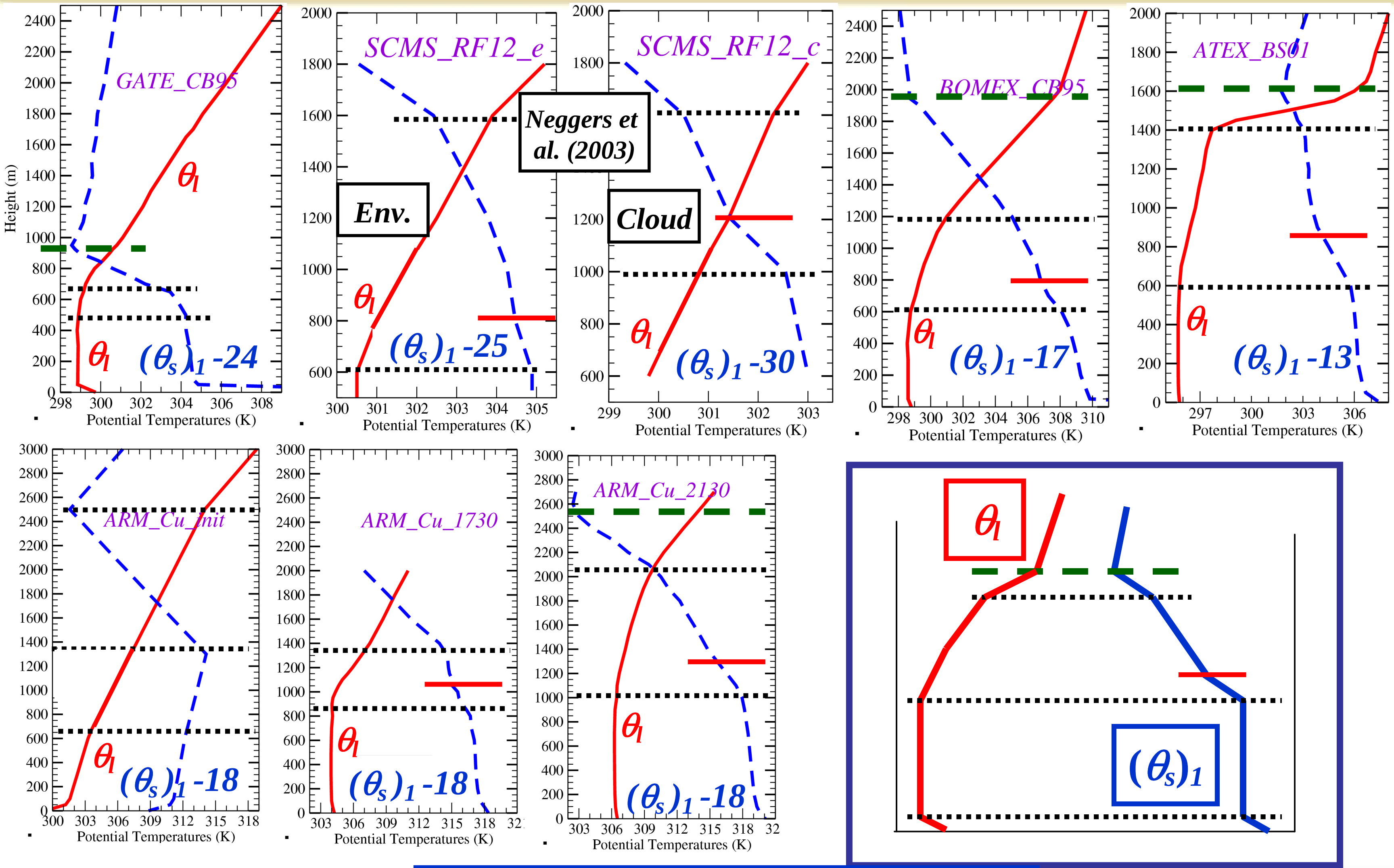
Various Cumulus profiles ?

data pick-up from articles, set-up …



Composite Cumulus pattern ? ↑

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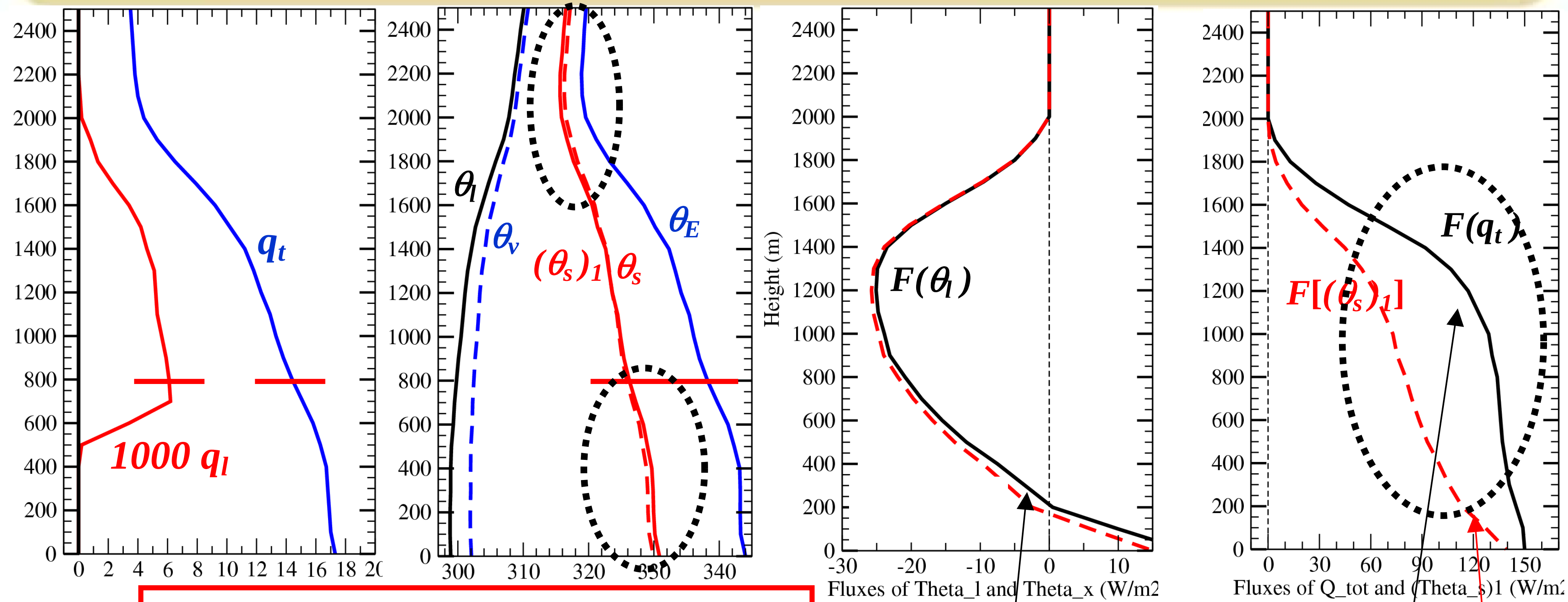
BOMEX-Cu (θ q_v q_l)

Siebesma et al. JAS-2003



pattern of $F[(\theta_s)_1] \approx F(q_t)$
and $\approx$ 60 to 90 % of it ?

Turb flux of θ_l

Turb flux of q_t
Turb flux of $(\theta_s)_1$

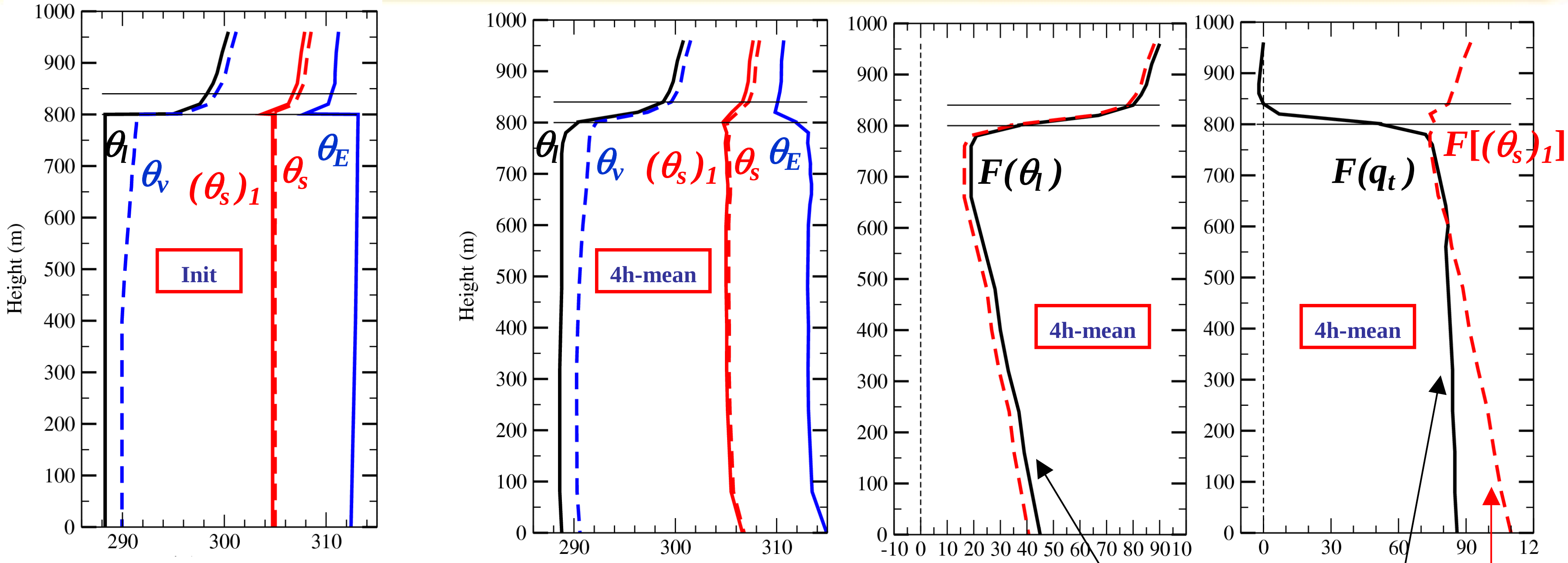
$$\overline{w'(\theta_s)'_1} \approx (1 + \Lambda\,\overline{q_t})\,\overline{w'\theta'_l} + \Lambda\,\overline{(\theta_s)_1}\,\overline{w'q'_t}$$

Same with ATEX-Cu (θ q_t q_l)

Stevens et al. JAS-2001

DYCOMS-II (RF02) Sc (θ_l q_t q_l)

Ackerman et al. (MWR-2009)



pattern of $F[(\theta_s)_1]$ $\approx$ *constant with z ?*

$\leftrightarrow$ $(\theta_s)_1$ *constant with z ?*

Total Flux of θ_l
+ Precip + Rad

Total flux of q_t
+ Precip
+ Flux of $(\theta_s)_1$

$$\overline{w'(\theta_s)'_1} \approx \left(1 + \Lambda\, \overline{q_t}\right) \overline{w'\theta'_l} + \Lambda\, \overline{(\theta_s)_1}\; \overline{w'q'_t}$$

Turbulent Fluxes : ($c_{pd}\, T + \phi$; $L_v\, q_v$; $L_v\, q_l$) variables ?

$$c_{pd}\,\frac{d\theta}{\theta} = \frac{1}{T}\, d\,(\,c_{pd}\,T + g\,z\,)$$

$$\frac{c_{pd}}{\overline{(\theta)}}\,\overline{w'\theta'} \approx \frac{1}{\overline{(T)}}\,\overline{w'(c_{pd}\,T' + g\,z')}$$

Stevens et al. (2003)

$$\frac{c_{pd}}{\overline{(\theta_l)}}\,\overline{w'\theta_l'} \approx \frac{1}{\overline{(T)}}\,\overline{w'S_l'}$$

$$S_l = c_{pd}\,T + g\,z - \overline{L_v}\,q_l$$

$$\overline{w'\,s'} \approx \frac{1}{\overline{(T)}}\,\overline{w'\,S_m'}$$

Flux of S_m

$$S_m = c_{pd}\,\left(T + \Lambda\,\overline{T}\,q_t\right) + g\,z - \overline{L_v}\,q_l$$

But how to go further ? What are the links between entropy and turbulence ?
A crude idea: to replace S ***or*** θ_l ***by*** S_m ***or*** $(\theta_s)_1$ ***? But what about*** q_t ***? ? ?***

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5) *Other results :* Fluxes …

6) ***Conclusion - Outlook***

Conclusions – 1/2

- *It is indeed possible to measure Moist Entropy* / $s \rightarrow \theta_s \rightarrow (\theta_s)_1$: *reversible moist adiabats ; small (no) Top-PBL jumps (Sc) ; CTEI ($k \approx 0.3$)* **; many thanks to S. de Roode, J.-L. Brenguier, J.-F. Geleyn…**

  (Q.J. R. Meteorol. Soc., Vol 137. April 2011 A, p.768-791)

- *Others interesting new properties: Emagram & R.S. ; LES outputs (EUCARII O. Thouron & J.L. Brenguier)*

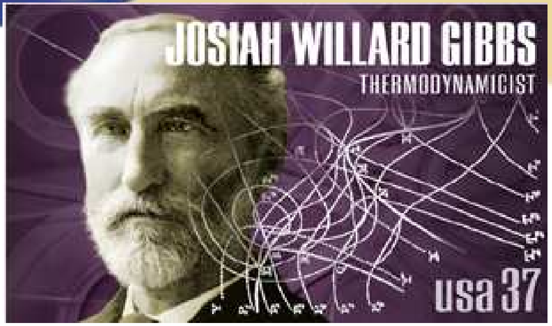
Conclusions – 2/2

- ***A proposal*: to use $(\theta_s)_1$ to prepare /analyse / validate CRM LES SCM NWP GCM ? ←→ measurements of (absolute) Moist Entropy … and (absolute) Moist Enthalpy ? (≠ M.S.E.)**

- ***ASTEX* & *EUCLIPSE*: constraints for Set-up and analyses of Output?**

- ***The future*: N R_i CAPE ... improve (present and next) turbulence & convection schemes … J.F. Geleyn (ECMWF nov. 2010 workshop ; COST actions) ; use of [$(\theta_s)_1$; θ_X] ?**

Thanks a lot / Questions ?



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

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« A Method of Geometrical Representation of the Thermodynamic Properties of Substances by Means of Surfaces » - Gibbs (1873)