A new Estimated Inversion Strength (EIS) based on the moist-air entropy.

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1) Motivations - Introduction.

Distinguishing between cumulus and well-mixed stratocumulus is an important component of the IFS boundary-layer scheme (`https://www.ecmwf.int/en/elibrary/18714-part-iv-physical-processes`.

Klein and Hartmann (1993) showed empirically that the stratus cloud cover increases with the "Lower Tropospheric Stability" of the atmosphere defined as LTS$=\;\theta_{700\mathrm{hPa}} - \theta_{\mathrm{surf}}$ (namely the difference in dry potential temperature $\theta = T\,(p_0/p)^{0.2857}$ between the level 700 hPa and the surface, where $p = 1000$ hPa).

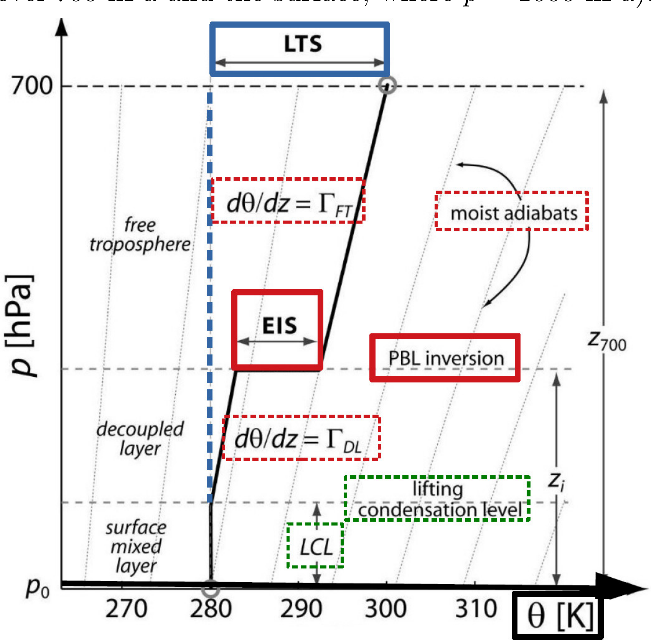

Figure 1: *The same Fig.1 of WB06 with coloured boxes.*

Wood and Bretherton (2006, WB06) defined a revised formulation of the inversion strength called the "Estimated Inversion Strength" (EIS) that is a better predictor for the stratus cloud cover than the LTS. If a cloud is detected in an unstable boundary layer, a threshold value of about 7 K is adopted for distinguishing whether it is a stratocumulus (EIS $>$ 7) or a shallow cumulus (EIS $<$ 7).

The definition EIS $=$ LTS $- \,\Gamma_m^{850}\,(z_{700} \,-\,$ LCL) depends both on the mean vertical lapse rate Γ_m^{850} (computed at 850 hPa) and the difference in the height of the 700 hPa and Lifting Condensation levels. It is clearly shown in Fig. 1 that EIS<LTS.

Figs. 2 shows the large impact of the thresholds EIS $>$ 8 or EIS $>$ 10 in the IFS on the mean model bias of the net shortwave radiation at the top of the atmosphere compared to observations by changing the low cloud cover and the optical thickness.

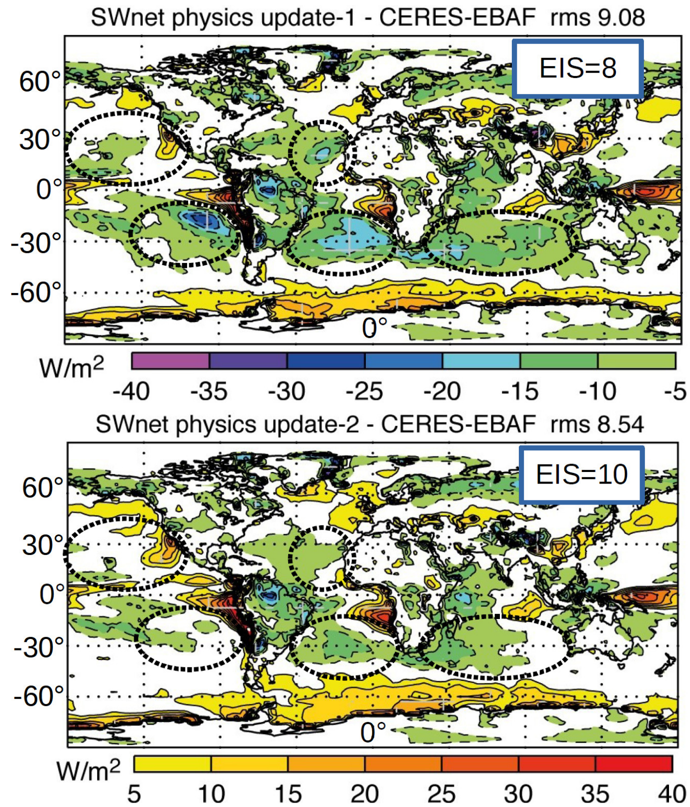

Figure 2: *The impact of the threshold for EIS on the bias of net short-wave for IFS forecasts compared to the CERES-EBAF climatology. Thresholds: EIS>8 (top) and EIS>10 (bottom)*

However, the definition of EIS is complex (it depends on the saturation conditions via Γ_m^{850}) and non-linear (product of "Γ_m^{850}" with "$z_{700} -$LCL") and is likely not suitable for more stable boundary-layer conditions over land. Therefore we evaluated the application of the moist-air entropy variable defined in Marquet (2011, M11).

2) Use of the moist-air entropy MSE.

The specific absolute moist-air entropy (s) is defined in M11 in terms of an entropy potential temperature θ_s so that $s = s_0 + c_{pd}\,\ln(\theta_s)$, where $s_0 \approx 1139$ kJ/K/kg and $c_{pd} \approx 1004.7$ kJ/kg are two constant terms. In order to get a quantity more linear than θ_s, it is possible to use as a proxi the "moist entropy static energy" S_m defined by Eq.73 of M11, but generalized to the ice-liquid conditions, to give

$$S_m \;=\; c_{pd}\,(1 + 5.87\,q_t)\;T \,-\, L_v\,q_l \,-\, L_s\,q_i \,+\, g\,z\,, \quad (1)$$

where z is the height (in m), $g \approx 9.80665$ m/s^2 the acceleration of gravity, L_v and L_s the latent heats of vaporization and sublimation, and $q_t = q_v + q_l + q_i$, q_v, q_l and q_i are the total water, water vapour, liquid water and ice specific contents, respectively. The new large coefficient 5.87 is the key parameter that allow θ_s or S_m to represent the absolute entropy.

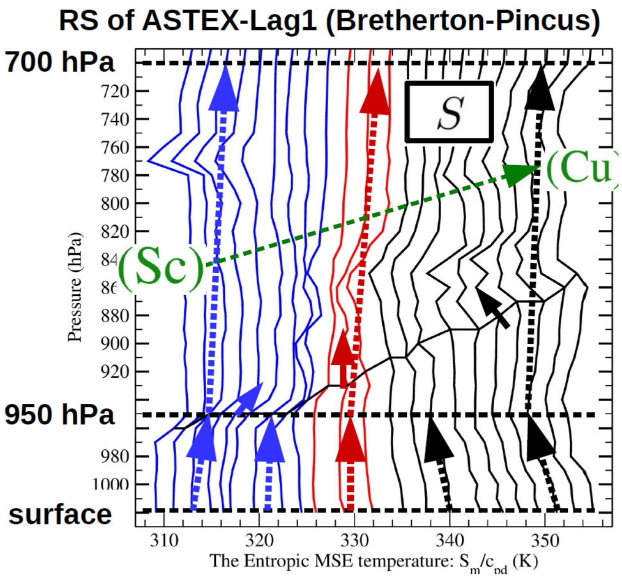

Figure 3: *Plots of vertical profiles of $S = S_m/c_{pd}$ (K) for the first ASTEX Lagrangian experiment (see the main text).*

Vertical soundings of the first ASTEX Lagrangian experiment (Bretherton and Pincus, 1995, de Roode and Duynkerke, 1997) have been used in Fig. 3 to compute the profiles of $S = S_m/c_{pd}$ for stratocumulus boundary-layers (left, in blue) and for cumulus boundary-layers (right, in black). The red profiles correspond to the transition between the regimes. (see: `http://www.atmos.washington.edu/~breth/astex/lagr/README.hourly.html`)

An interesting feature depicted by the solid arrows (and the dashed ones between the surface to the level 950 hPa) is that the transition from stratocumulus toward cumulus regimes occurs for constant values of S_m in the vertical from the surface to about 850 hPa, including across the top-PBL entrainment region. These results were already shown in M11, where a CTEI criterion was built with the simple hypothesis $\partial\theta_s/\partial z \approx 0$ corresponding to $\partial S_m/\partial z \approx 0$ at the top of the PBL.

A new EIS index is then defined as follow:

$$\text{EIS}_{\text{new}} = \text{Max}\,(S_{700} - S_{950}\ ;\ S_{950} - S_{\text{surf}})\ . \qquad (2)$$

The respective two moist entropy differences intend to reflect: i) the typical boundary-layer structures over water, with cloud base typically around 950 hPa; and ii) also more shallow boundary-layers over land in higher latitudes or during transitions.

Figs. 4 show the old (top) and new (bottom) EIS index computed for a run of the operational IFS model. The present criteria EIS > 8 for delimiting strong stable stratocumulus is replaced by the new one $\text{EIS}_{\text{new}} > 6$, with cumulus regimes delimited by $\text{EIS}_{\text{new}} < 1$. The new formulation more clearly delimits the boundary-layer transitions in the subtropical anticyclones, exhibits finer and more marked filaments and shows a clear distinction between nighttime and daytime boundary-layer stability over land..

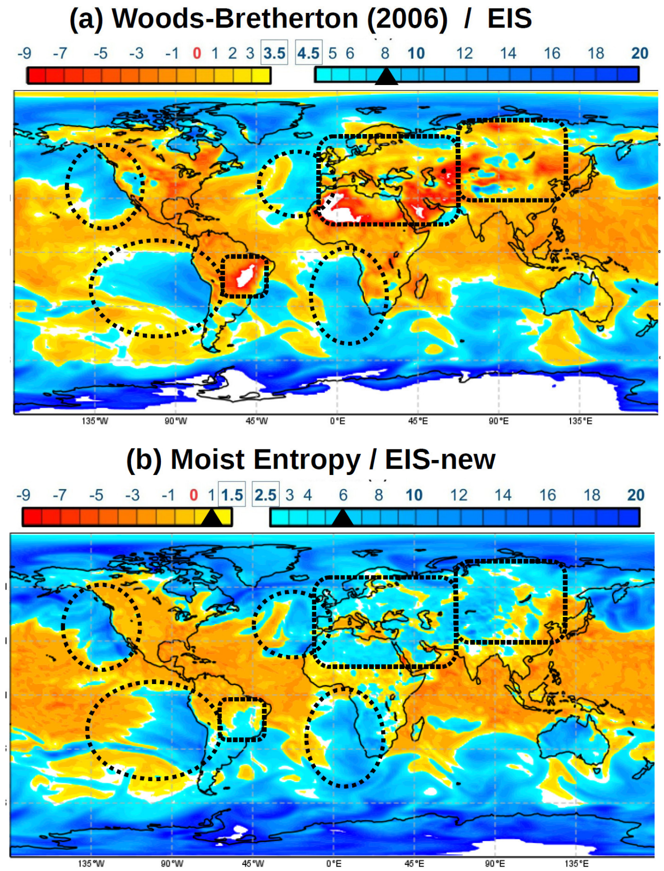

Figure 4: *Old (top) and new (bottom) EIS computed with IFS.*

3) Conclusions.

It is shown in this note that it is possible to use the proxi $S = S_m/c_{pd}$ of the moist-air entropy $s(\theta_s)$ to build a new EIS index based on the hypothesis of a transition between stratocumulus and cumulus regimes occurring for zero (or small) vertical changes of S, S_m and $s(\theta_s)$.

The new EIS index is simpler and more linear than the one derived in WS08 and is planned for introduction in IFS cycle 48r1 (2020) in the context of a larger moist physics upgrade.

References

• Bretherton, C. S. and Pincus, R. (1995). Cloudiness and marine boundary layer dynamics in the ASTEX lagrangian experiments. Part I: Synoptic setting and vertical structure. *J. Atmos. Sci.*, **52**: 2707–2723.

• Klein, S. A. and Hartmann, D. L. (1993). The seasonal cycle of low stratiform cloud. *J. Climate*, **6**: 1587–1606.

• Marquet P. (2011). Definition of a moist entropic potential temperature. Application to FIRE-I data flights. *Q. J. R. Meteorol. Soc.*, **137**: 768–791. `https://arxiv.org/abs/1401.1097`

• Wood R, Bretherton C. S. (2006). On the relationship between stratiform low cloud cover and Lower-tropospheric stability. *J. Climate*, **19**: 6425–6432.