Controls on the water vapor isotopic composition near the surface of tropical oceans and role of boundary layer mixing processes

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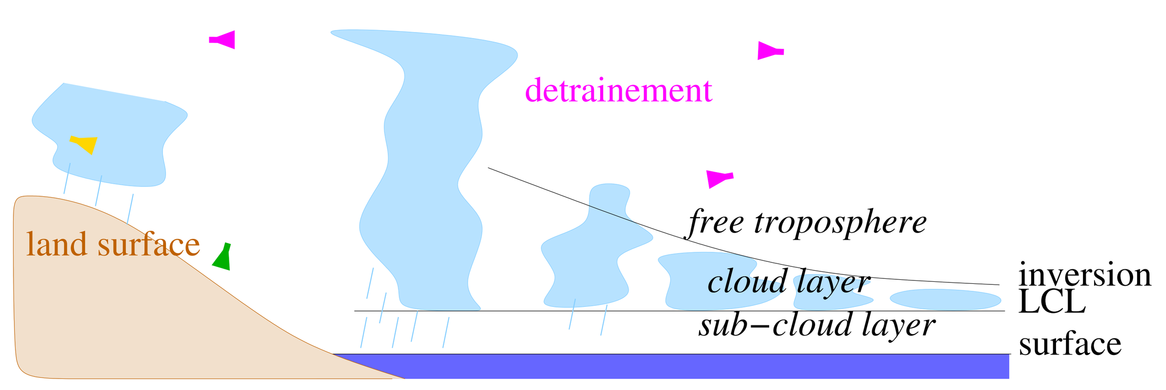
Introduction

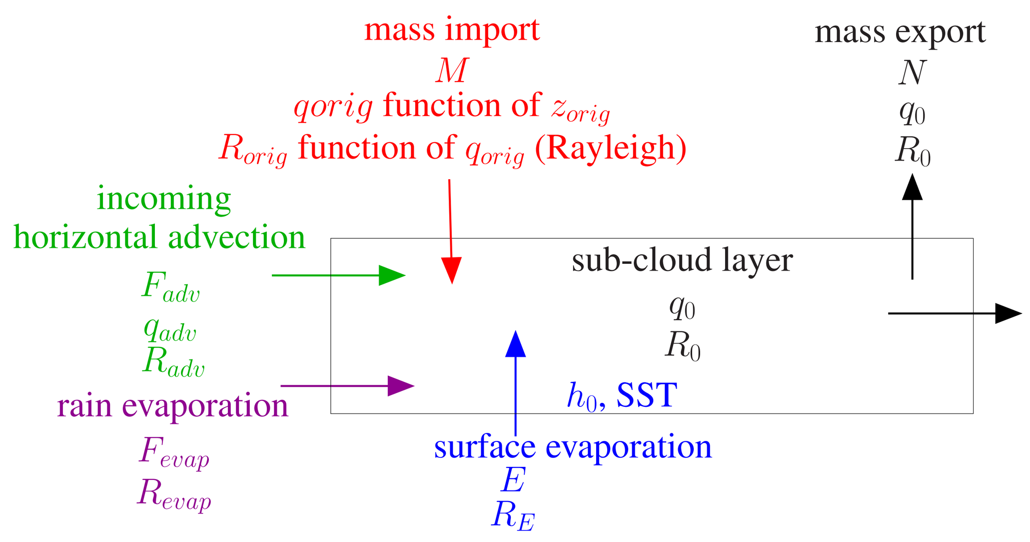
Understanding what controls the water vapor isotopic composition of the sub-cloud layer (SCL) over tropical oceans (δD_0) is a first step towards understanding the water vapor isotopic composition everywhere in the troposphere. We propose an analytical equation that predict δD_0 based on a simple box model.



Box model

The box model extends [Merlivat and Jouzel, 1979]closure and builds on [Benetti et al., 2015]. Assumptions are:

- steady state
- $r_{orig} = q_{orig}/q_0$ where q_{orig} is a function of z_{orig}, the altitude at which the air originates.
- R_{orig} is a function of q_{orig} following Rayleigh distillation: $R_{orig} = R_0 \cdot r_{orig}^{\alpha_{eff}-1}$
- R_{evap} follows [Craig and Gordon, 1965] as a function of R_{oce}, $\alpha_{eq}(SST)$, α_K and h_0.
- Horizontal advection is characterized by $\phi = F_{adv} \cdot q_{adv}/E$ and $\beta = R_{adv}/R_0$.
- Rain evaporation is characterized by $\eta = F_{evap}/E$ and $R_{evap} = \alpha_{evap} \cdot R_0$.



We get :

$$R_0 = \frac{R_{oce}}{\alpha_{eq}} \cdot \frac{1}{h_0 + \alpha_K \cdot (1 - h_0) \cdot \left((1+\eta) \cdot \frac{1 - r_{orig}^{\alpha_{eff}}}{1 - r_{orig}} - \eta \cdot \alpha_{evap} + \phi \cdot (1 - \beta) \right)} \quad (1)$$

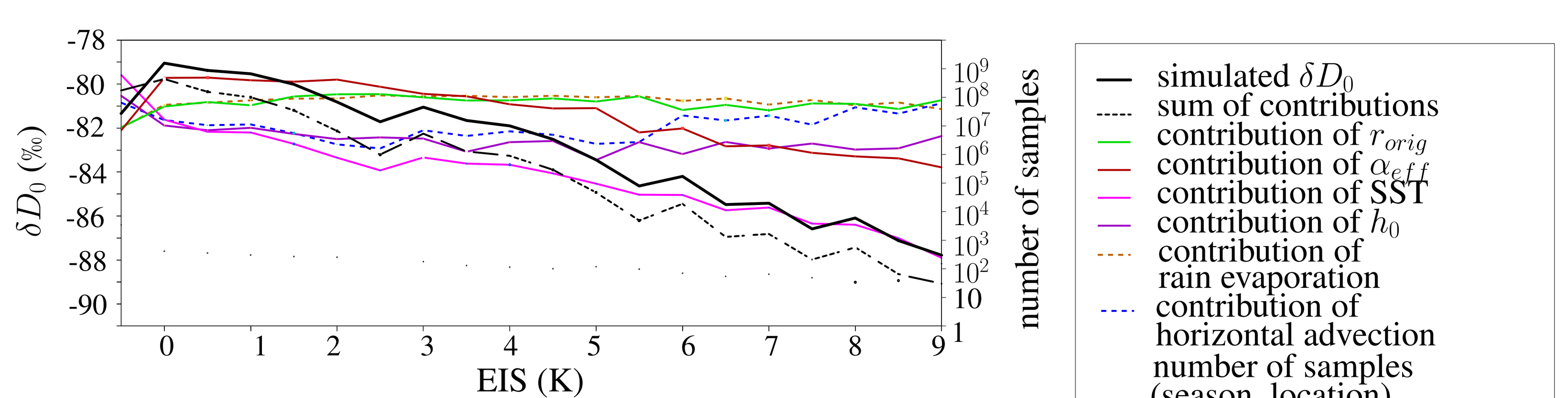
If $r_{orig} = \eta = \phi = 0$, we get [Merlivat and Jouzel, 1979] closure.

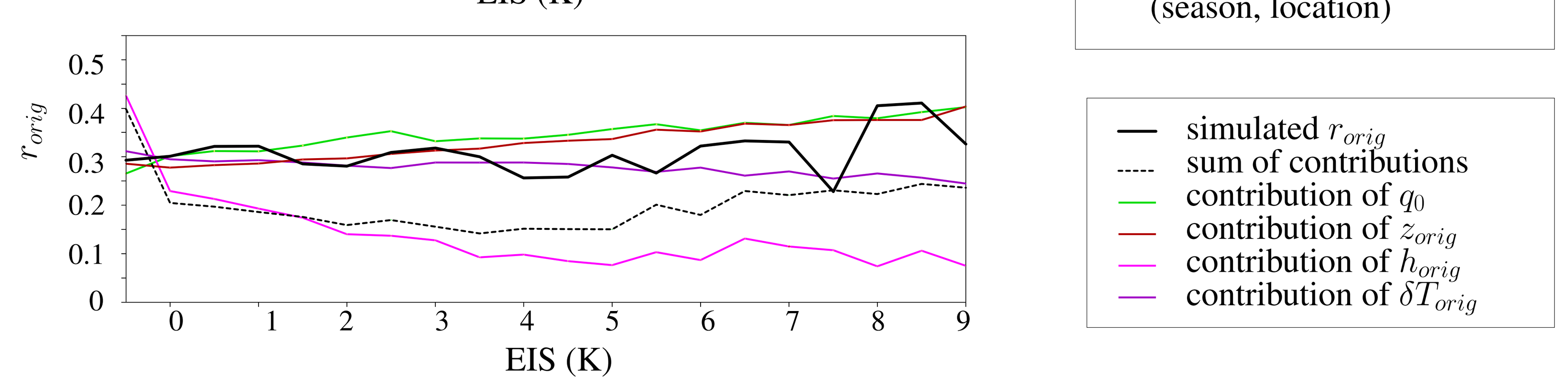
$\Longrightarrow$ An important property of Eq. 1 is that R_0 does not depend on the strength of mixing/entrainement M, but on z_{orig}, which reflects the processes underlying this mixing/entrainement.

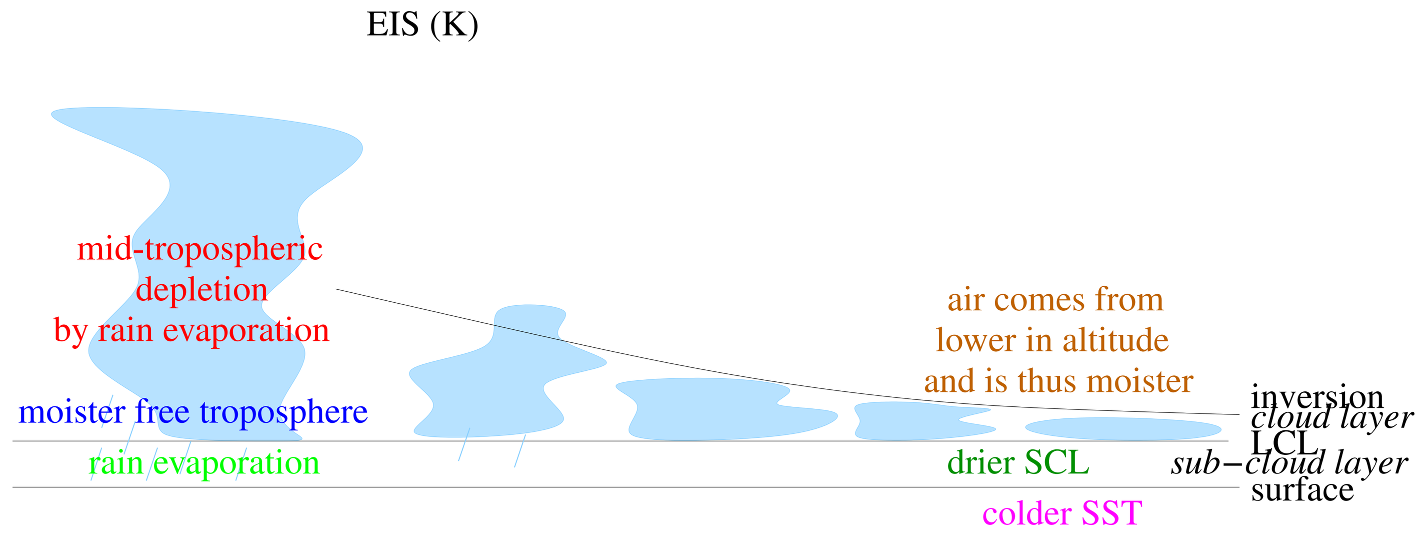
What controls the spatial and seasonal variations in δD_0?

- We use an AMIP-type LMDZ simulation ([Risi et al., 2010]) and diagnose all variables from it.
- We calculate z_{orig} so that R_0 predicted by Eq. 1 matches simulated R_0.
- We decompose the simulated δD_0 into different contributions based on equation 1.
- We further decompose r_{orig} into different contributions based on:

$$r_{orig} = \frac{h(z_{orig}) \cdot q_s(\bar{T}(z_{orig}) + \delta T(z_{orig}), P(z_{orig}))}{q_0}$$



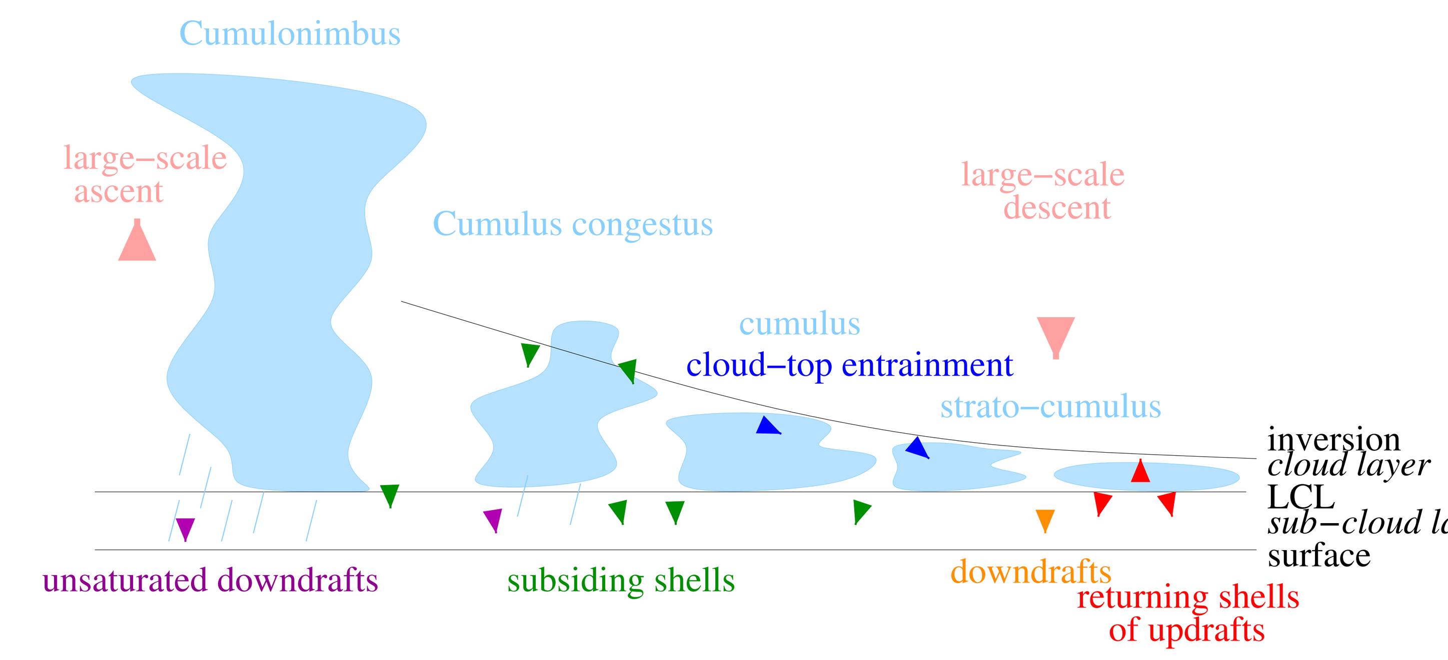


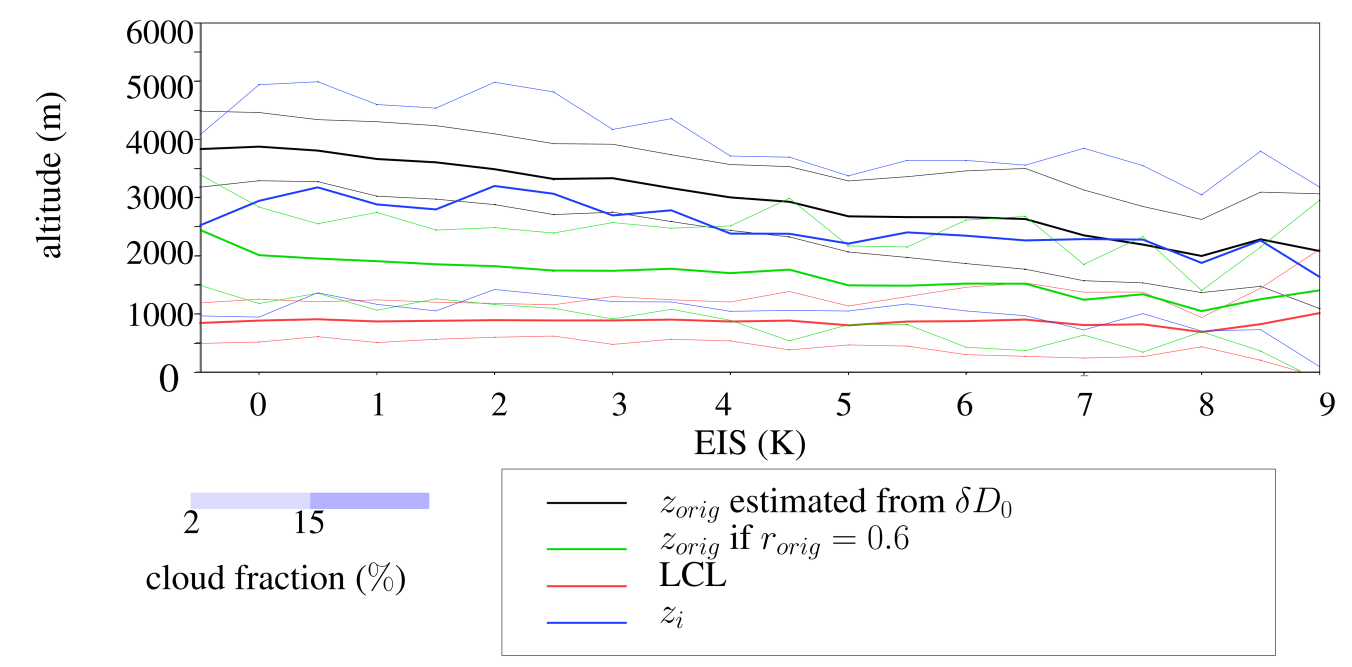


$\Longrightarrow$ δD_0 variations are mainly controlled by mid-tropospheric depletion and rain evaporation in ascending regions, and by SST and z_{orig} in subsiding regions.

Could δD_0 measurements help estimate z_{orig} and thus discriminate between different mixing processes?

z_{orig} estimates from δD_0 simulated by LMDZ are consistent with our knowledge of mixing processes: air comes from just above the inversion in strato-cumulus regions ([Faloona et al., 2005, Davini et al., 2017, Mellado, 2017, Brient et al., 2019]), from higher in altitude from trade-wind cumulus clouds [Jonas, 1990, Heus and Jonker, 2008, Park et al., 2016]) and even higher in deep convective couds ([Zipser, 1977, Glenn and Krueger, 2014, Thayer-Calder and Randall, 2015]).

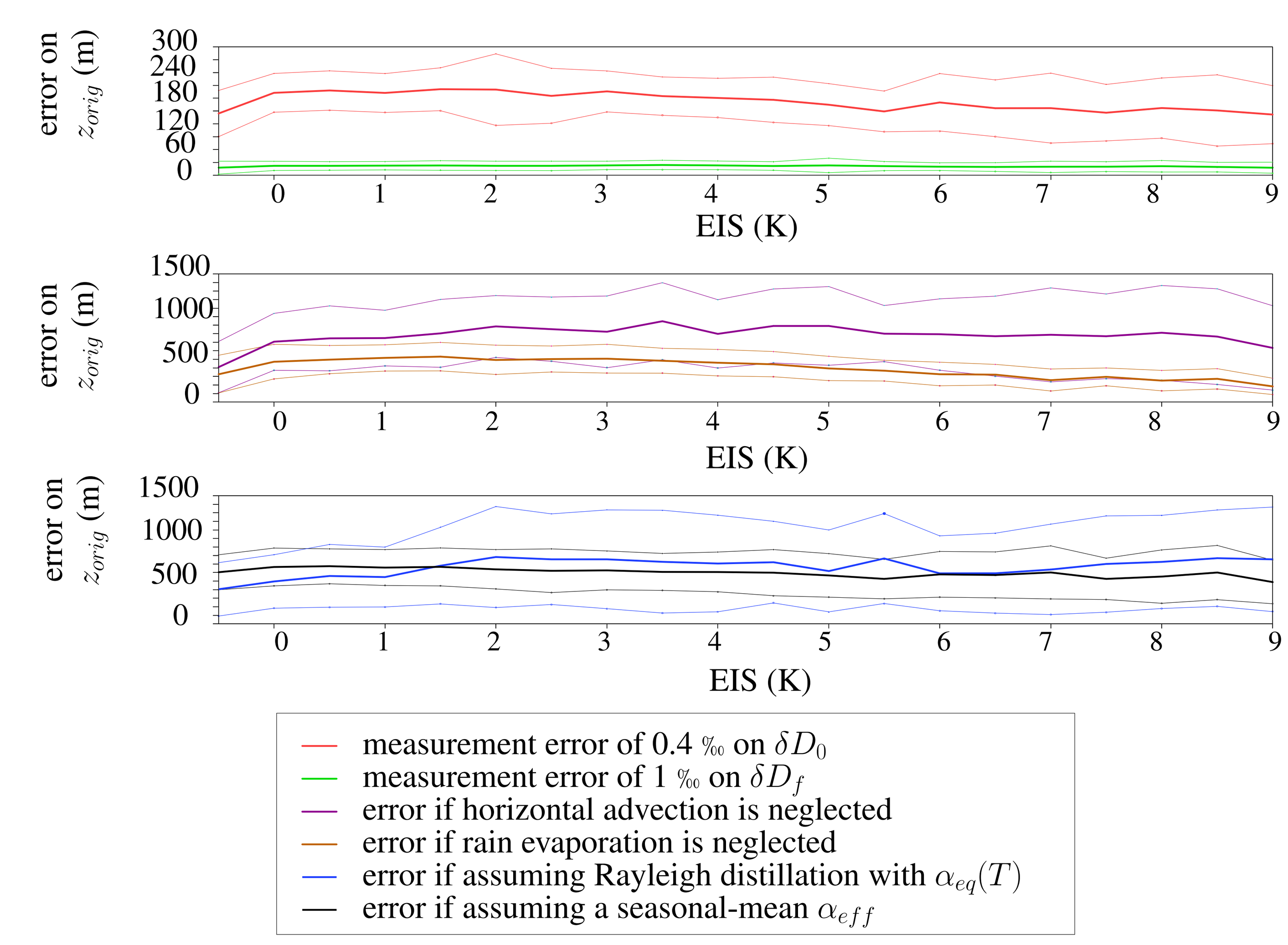




For δD_0-based estimates of z_{orig} to be useful, we need a precision that is better than what we already know of mixing processes: a few hundred meters in deep convective regions and smaller than 20 m in stratocumulus regions. We quantify the different sources of uncertainties on z_{orig}.

$\Longrightarrow$ To reach a useful precision, we would need:

- daily measurements of δD in the mid-troposphere
- accurate measurements of δD_0 (down to 0.1 ‰ in the case of stratocumulus clouds, which is currently difficult to obtain).
- information on the horizontal distribution of δD to account for horizontal advection effects
- full δD profiles to quantify the uncertainty associated with assuming that δD profiles follow Rayleigh distillation.
- Innovative techniques to quantify the effect of rain evaporation, which is an issue in all regimes, even in stratocumulus clouds.



Perspectives

- water tagging to check z_{orig} estimate in LMDZ
- compare with observations: e.g. EUREC4A campaign (e.g. [Bony et al., 2017])
- Large-eddy simulations (e.g. [Moore et al., 2014]) to investigate processes

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