LASSO for Observations

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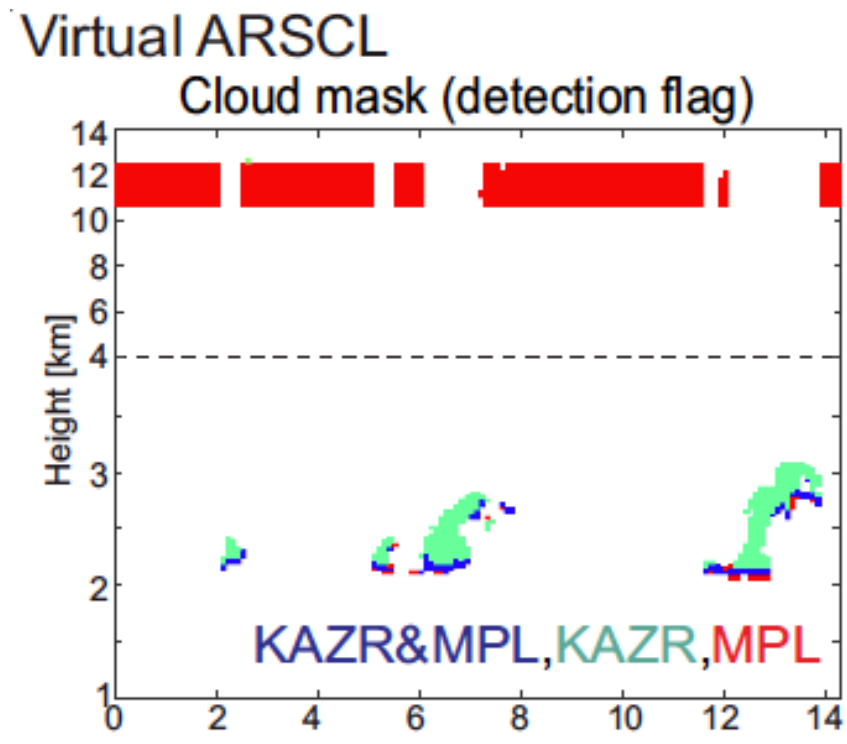
The LASSO project literally acts as a restrainer to observations. LASSO provided a detailed list of measurements required to accomplish the modeling objectives, which subsequently brought discipline to the observationalists and forced us to think in a creative way how to best address and satisfy the modeling needs in terms of measurements

Virtual ARSCL from WRF/LES

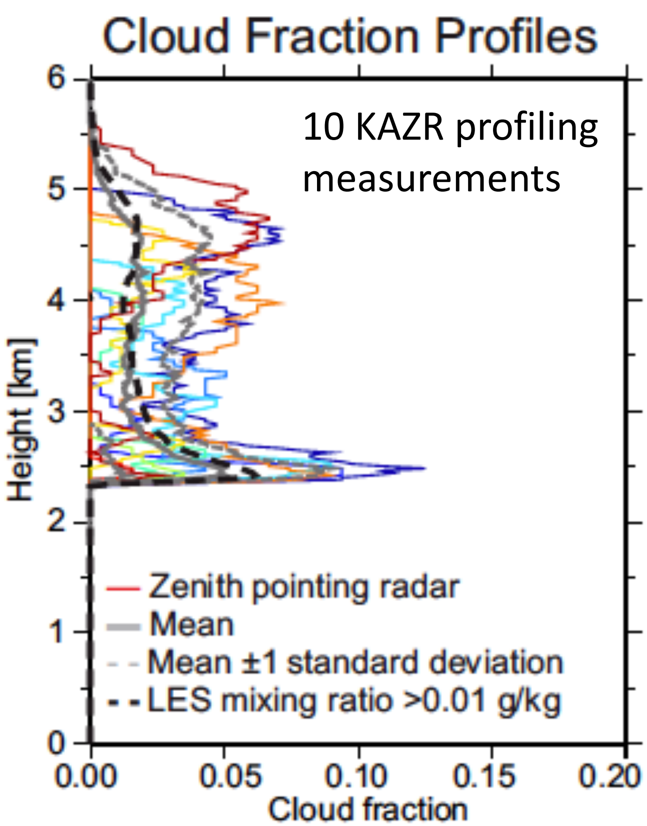
KAZR cannot detect cirrus clouds due to sensitivity issue.

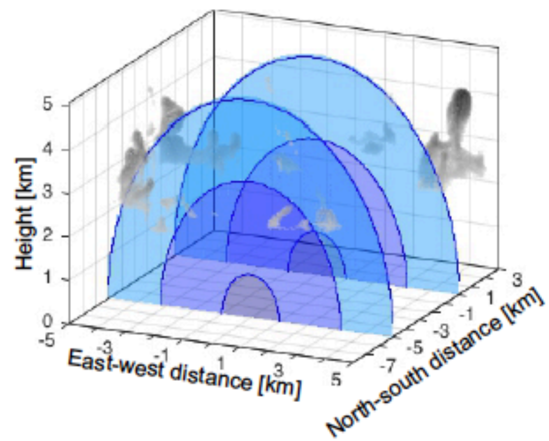
Ceilometer can well capture cloud base heights of cumulus convections.

MPL can capture cumulus cloud bases and cirrus clouds, but not detect cirrus when cumulus cloud existed at lower altitudes due to attenuation

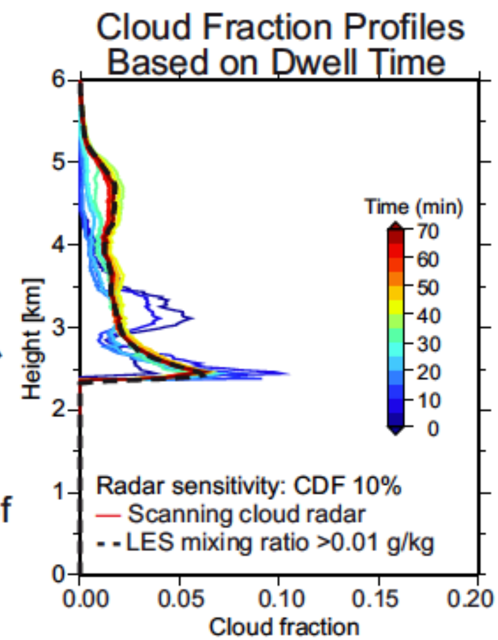


Cloud Fraction Profile (CFP) Estimation





Blue lines: Sensitivity isolines of -50, -40, and -36 dBZ



Oue, M., P. Kollias, K. W. North, A. Tatarevic, S. Endo, A. M. Vogelmann, and W. I. Gustafson Jr. (2016), Estimation of cloud fraction profile in shallow convection using a scanning cloud radar, Geophys. Res. Lett., 43, 10,998–11,006

ENTRAINMENT IN CUMULUS CLOUDS

- cumulus entrainment regulates cloud evolution
  - climate model are very sensitive to entrainment parameterization

- thorough quantitative understanding of entrainment is essential but remains elusive
  - inability to directly observe cumulus entrainment rates (Blyth (1993))

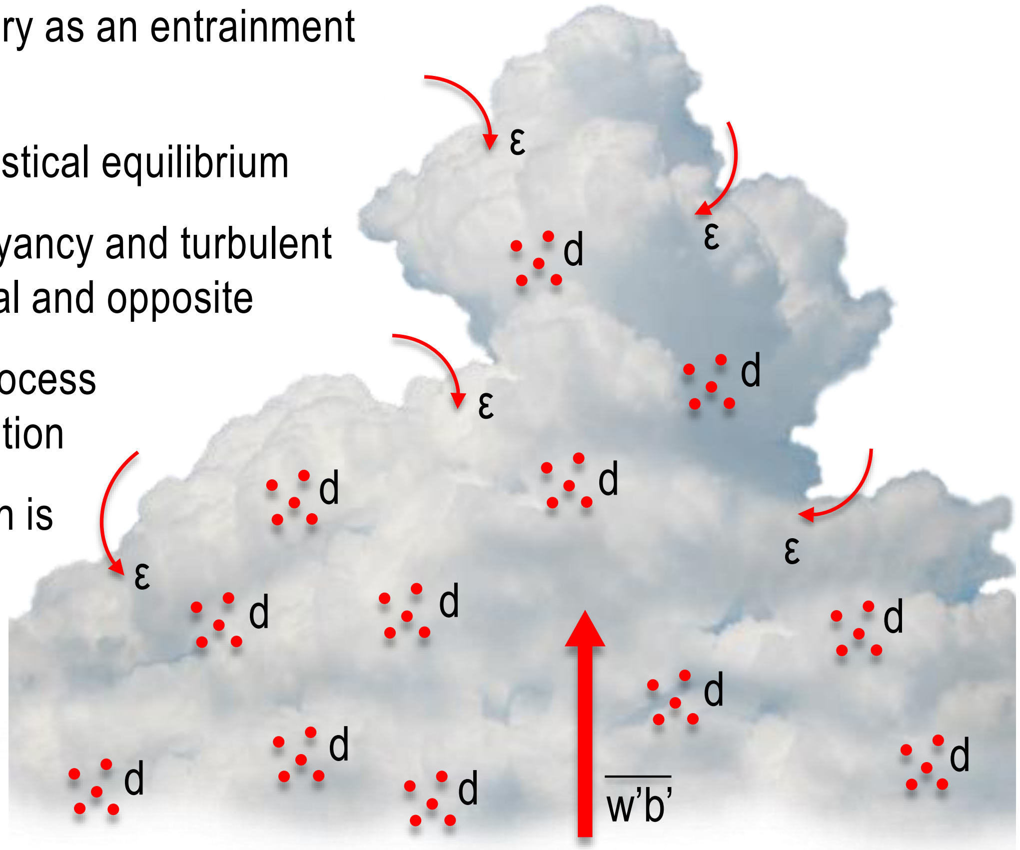
- multiple approaches to retrieve bulk fractional entrainment rates have been developed (e.g., Jensen and Del Genio (2006), Lu et al. (2012), Wagner et al. (2014))
  - these retrieval have not been verified observationally or numerically

- many positives benefits of improved entrainment retrievals
  - climatologies to constrain climate models
  - verification for LASSO simulations

TKE SIMILARITY THEORY BASED APPROACH

- based on a similarity hypothesis by Grant and Brown (1999) and Grant and Lock (2004)
  - our idea: using TKE similarity theory as an entrainment retrieval method
  - shallow-cumulus ensemble in statistical equilibrium
  - rate of TKE production due to buoyancy and turbulent dissipation are approximately equal and opposite
- view entrainment as an intermediate process between energy production and dissipation
- assume fixed fraction of TKE production is available for entrainment and is ultimately dissipated

$$\varepsilon = A \frac{w^*}{m_b} \frac{1}{z_{cld}}$$

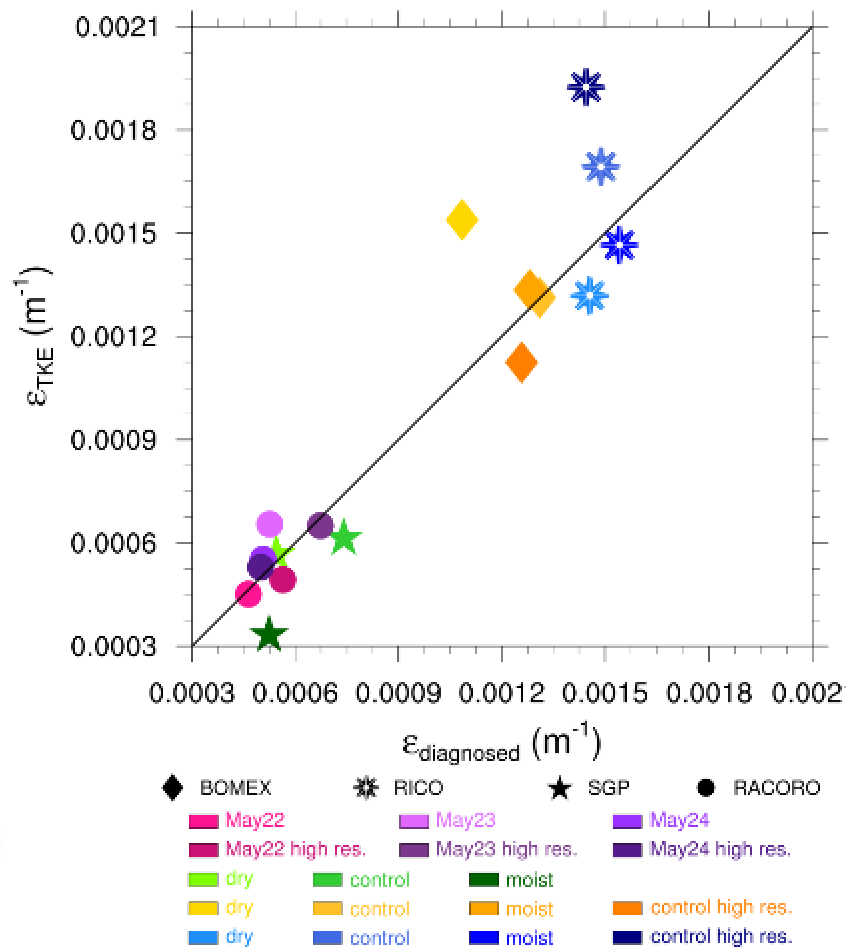


LARGE EDDY SIMULATION AS OSSES

- multiple observationally constrained shallow cumulus cloud field
  - maritime cases: BOMEX and RICO (Siebesma et al. (2003) and vanZanten et al. (2011), respectively)
  - continental cases: SGP and RACORO (Brown et al. (2002) and Endo et al. (2014), respectively)
- increase sampling by conducting control, dry and moist versions of BOMEX, RICO and SGP
- we use OSSEs for first-ever numerical verification of proposed entrainment retrievals
- compare pseudo-retrieval using two different methods (TKE and modified Jensen and Del Genio)
  - perfect observations assumption
- verification against mean bulk-plume entrainment rates over central 500 m of cloud layer

COMPARING RETRIEVAL METHODS

- diagnosed bulk-plume entrainment rate vs TKE similarity theory based entrainment rates
- captures key sensitivities found in the different cases
  - mean error: 14%
  - less entrainment over land than over the ocean
  - slightly increased entrainment for RICO compared to BOMEX
- out-performs parcel-based method by Jensen and Del Genio
  - higher deviation and mean error: 30%



INDIVIDUAL SAMPLING POINTS

- in reality information about a cloud field are only available at individual points (compare Oue et al., 2016)
  - How many sampling points are necessary to represent the bulk entrainment rate for a cloud field?

- we used described LES as OSSEs with perfect observation assumption for individual sampling points analysis
- example comparison for the BOMEX control simulation using TKE similarity theory based entrainment method

	Domain avg.	5 sampling points	10 sampling points
ε (km^{-1})	1.309	1.038 ± 0.263	1.333 ± 0.957

- clouds must be sufficiently well sampled for bulk entrainment retrievals to be accurate