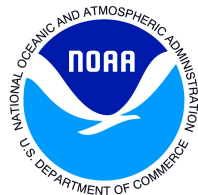


# Measuring Water Vapor and Temperature Advection and Studying the Evolution of the CBL using Mixing Diagrams

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# Introduction

Many important quantities depend on spatial gradients of the kinematic and thermodynamic fields:

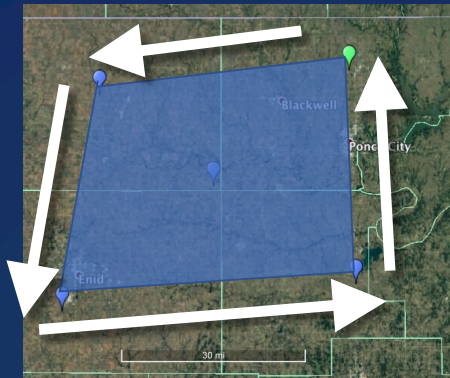
- Divergence
- Vorticity
- Advection

We can calculate this at SGP using Green's Theorem:

$$\oint P dx + Q dy = \iint \left( \frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) dA$$

The right-hand side of this equation looks a lot like the definitions of these quantities.

If we can use observations to approximate the left-hand side, we can get advection and similar properties.



1. Define a polygon with observations at the vertices
2. Find the average values of temp and winds along each side.
3. Calculate numerator term for each side
  - Move counterclockwise! It's direction dependent!
4. Sum the terms for all sides
5. Divide by the area of the polygon

Parameter	P	Q	Equation
Vertical Vorticity	$u$	$v$	$\zeta = \frac{dv}{dx} - \frac{du}{dy} \approx \frac{\Sigma(\bar{u}\Delta x + \bar{v}\Delta y)}{A}$
Divergence	$-v$	$u$	$D = \frac{du}{dx} + \frac{dv}{dy} \approx \frac{\Sigma(\bar{u}\Delta y - \bar{v}\Delta x)}{A}$
Moisture Advection	$-q v$	$q u$	$-\mathbf{V} \cdot \nabla q = -\left(u \frac{dq}{dx} + v \frac{dq}{dy}\right) \approx \frac{-\Sigma \bar{q}(\bar{u}\Delta y - \bar{v}\Delta x)}{A}$

# Applying to SGP Observing Network

ARM SGP network provides profiles of  $T$ ,  $w$  (from AERI) and  $u, v$  (from Doppler lidar).

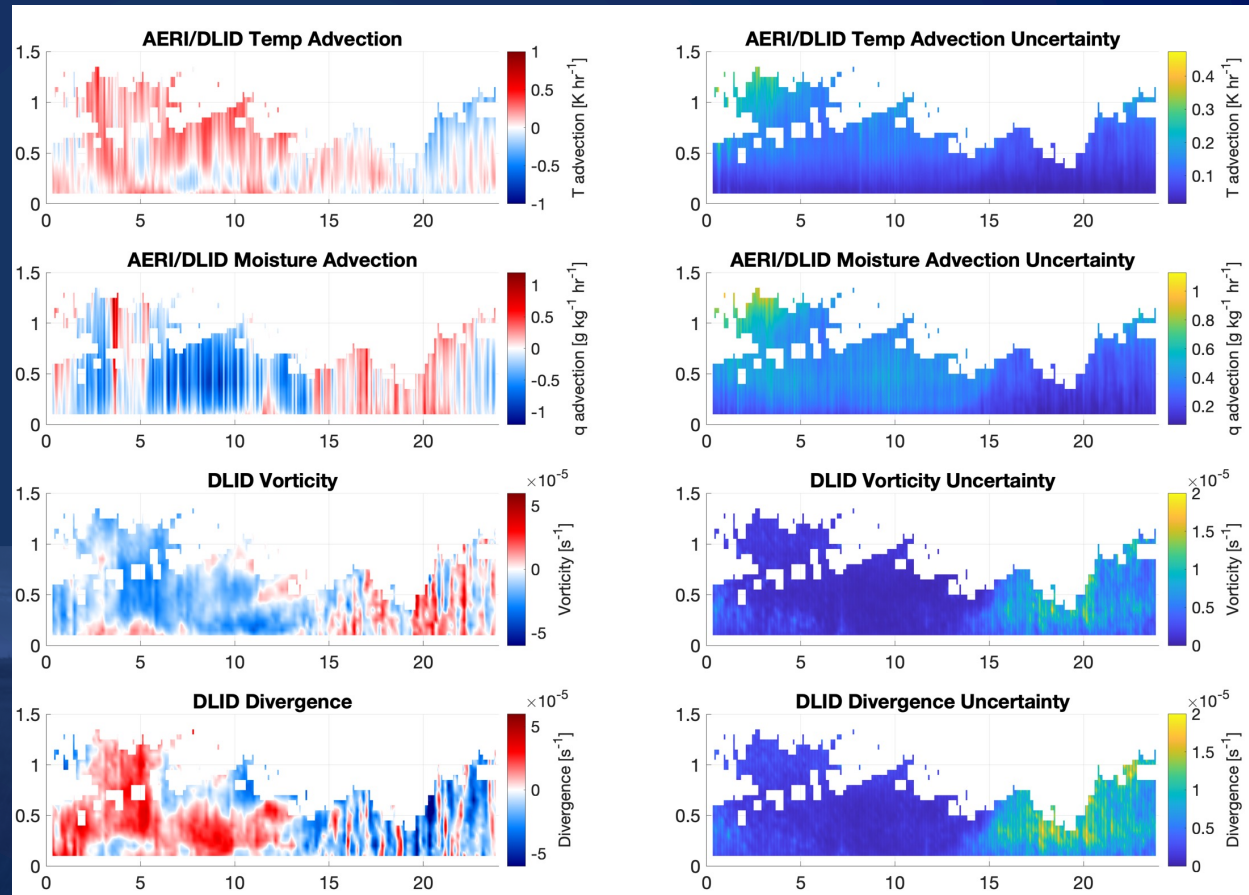
Use these to get time-resolved profiles of advection.

What about uncertainty?

Each AERI and Doppler lidar observation includes a  $1\sigma$  uncertainty.

Use a Monte Carlo Approach:

- Generate perturbed profiles (vertically correlated for AERI)
- Calculate the mean (left) and standard deviation (right) of the desired parameters





# What is the ideal spacing?

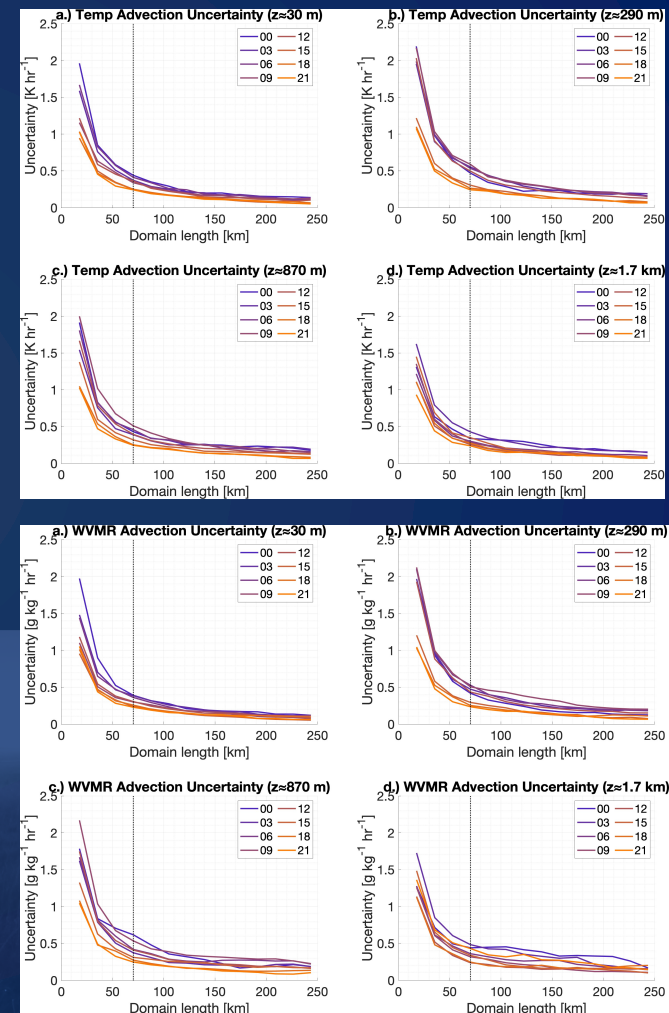
Uncertainty in the observations has a bigger effect when the domains are small, as there is little difference between the observing sites

- A 0.5 K error in a T observation will have a massive impact on advection when sites are already within 0.5 K.
- As domain grows, natural differences also grow and uncertainty has less of an impact.

However, as domain grows, we are dividing by a larger and larger area, so signal goes to 0.

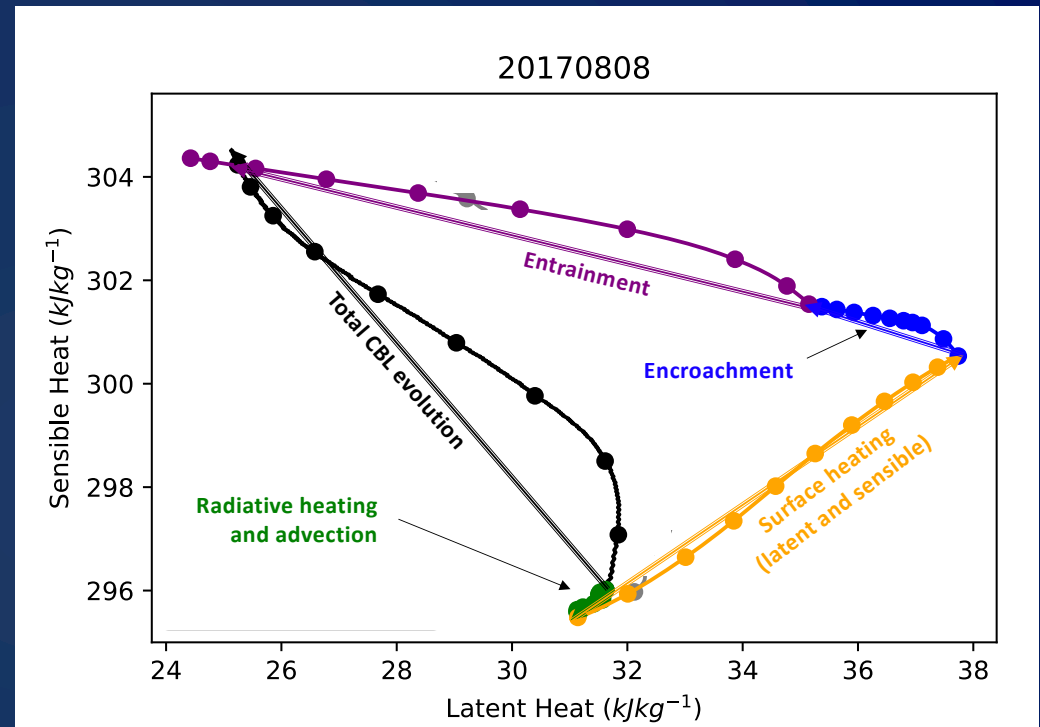
Use Monte Carlo sampling of HRRR analyses to determine interplay between site location and instrument error.

The SGP Boundary Facility network (dashed vertical line, approx. 70 km apart) lies in the “sweet spot” between low error yet significant value to the signal.



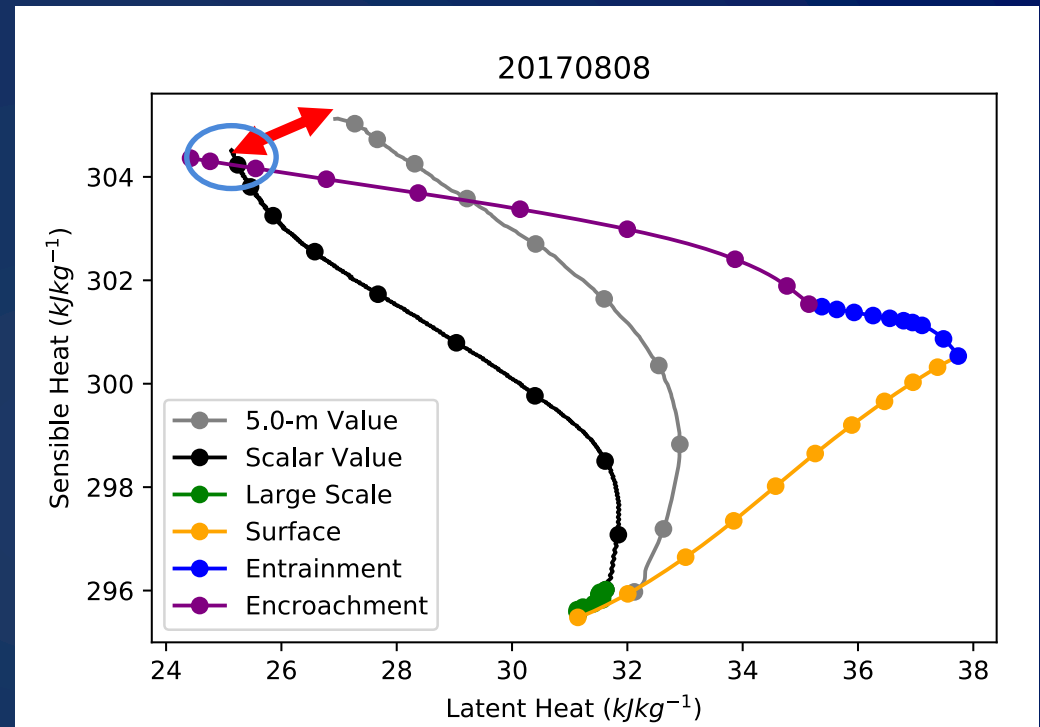
# Mixing Diagrams

- Mixing diagram approach to study energy and moisture budget evolution in the CBL pioneered by Betts (1992)
- Santanello et al. (2009) showed utility of the approach to evaluate models



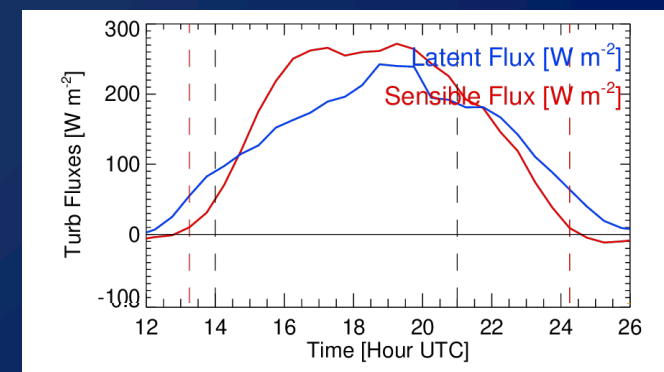
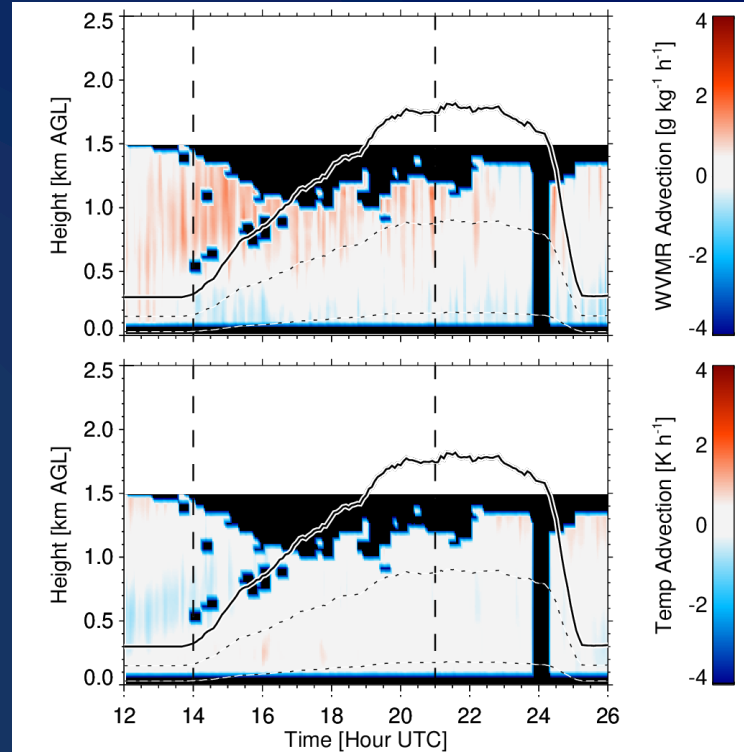
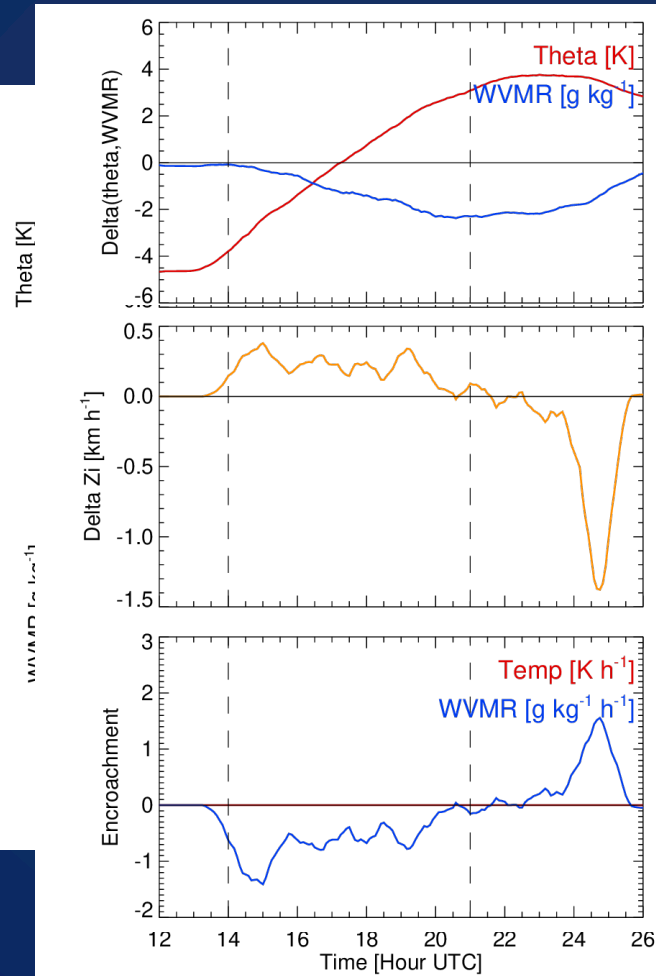
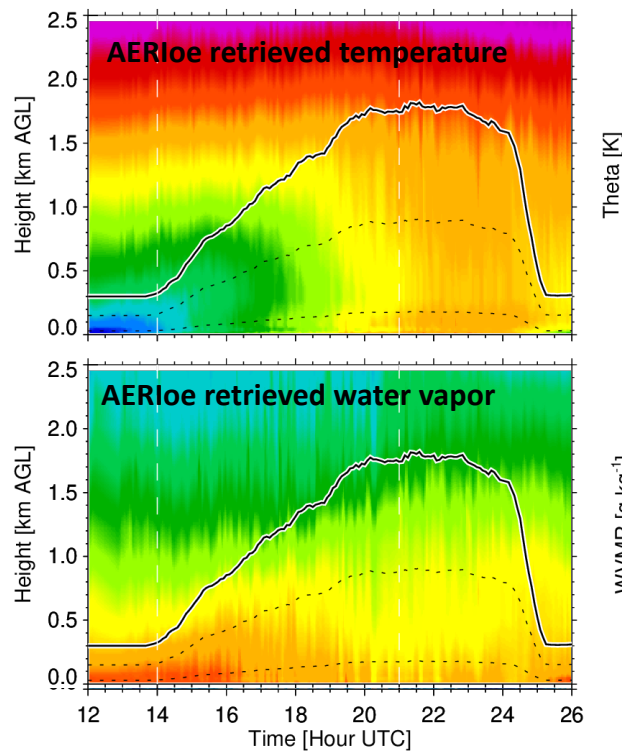
# Mixing Diagrams

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- Santanello et al. (2009) showed utility of the approach to evaluate models
- Used Micro-HH LES model
- Forced with ARM's "variational analysis"(VARANAL) product
- Large-scale from VARANAL includes advection and radiative heating
- Historically, estimate "Entrainment" as the residual; however, residual is actually both entrainment and encroachment
- Able to compute encroachment directly from observations (and model)



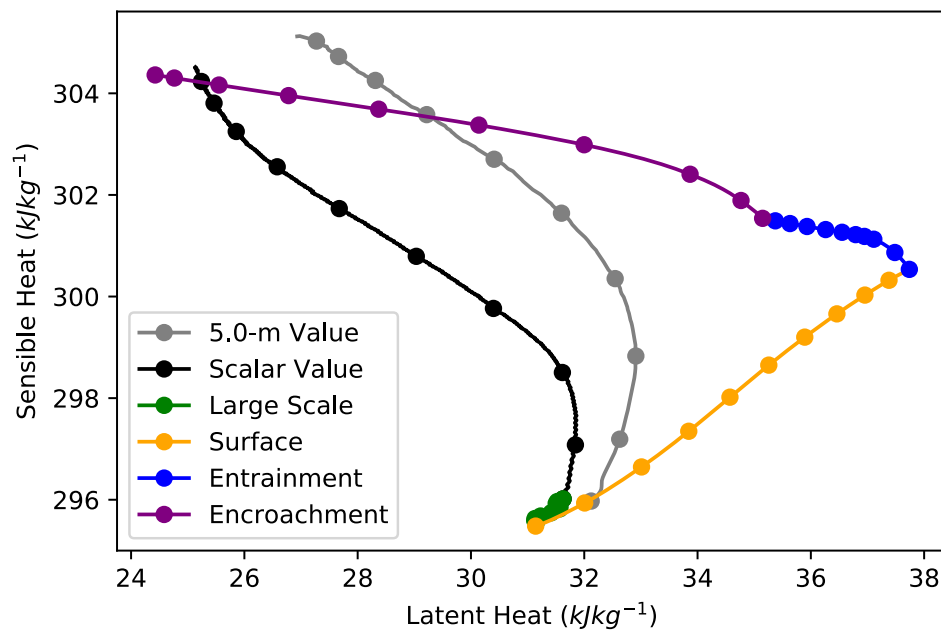
- Traditional "surface-level" obs do not close
- PBL-averaged  $T$  and  $q_v$  results in better closure
- Encroachment is a key term in the closure

# Mixing Diagrams – from Obs

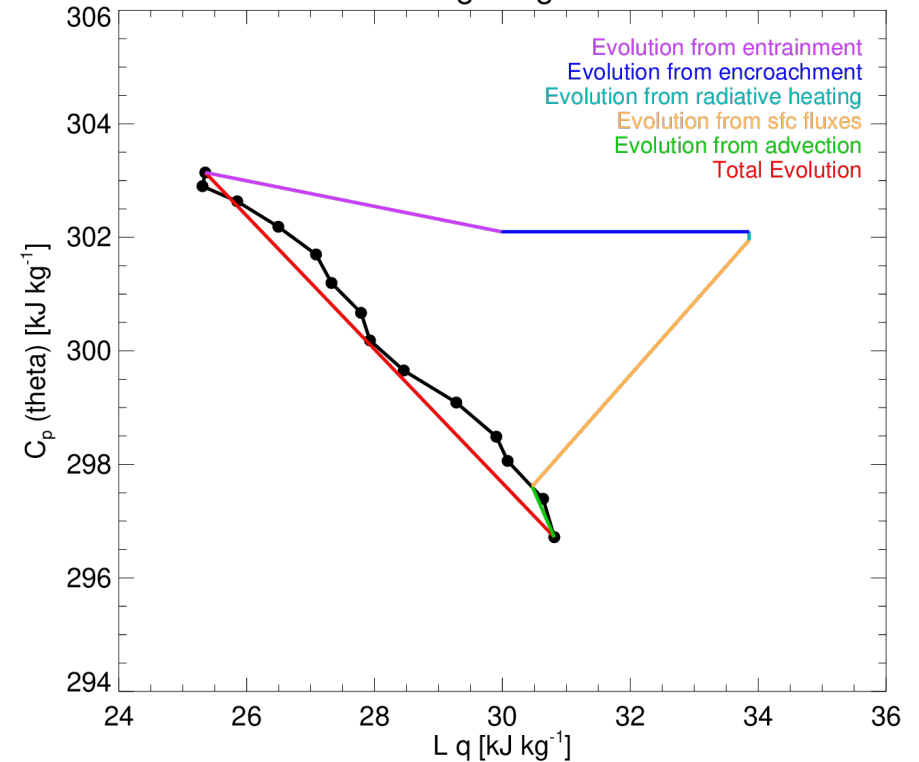


# Mixing Diagrams – from Obs

LES Mixing Diagram on 20170808



Observation Mixing Diagram on 20170808





## Next Steps

- Error analysis / propagation
  - Improved calculation of encroachment (to account for the AERloe's vertical resolution)
  - What is the uncertainty in the derived entrainment flux?
- Analysis of a large dataset at SGP to characterize how often, and under what conditions, advection is important
- Analysis of large dataset at SGP to evaluate CBL evolution within models against observations
  - Able to separate create separate classifications, and composite for each?
  - Generate statistics on entrainment flux
- Hope to extend the framework to the AMF deployment to the SEUS