DEEP MOIST CONVECTION INFERRED FROM CONSERVED VARIABLE PROFILES

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ATM651 TA lecture
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Outline

- First law of thermodynamics: conservation of energy
- Conserved variables in adiabatic processes: theta, theta_e, DSE, MSE
- Why do we need conserved variables? Rising parcel as a simple plume/convection
- Moist static energy diagram : A diagram based on energy and mass

  \- Advantages and information inferred from the MSE diagram
- Notebook: MSE diagram with near real-time sounding data

The first law of thermodynamics for a Lagrangian parcel of air

$$C_p \frac{dT}{dt} - \alpha \frac{dP}{dt} = \frac{dQ}{dt}$$

Enthalpy change

Rate of work done to the environment

Diabatic heating sources, i.e., *radiation* and *latent heat release*

- Assume that there is **no diabatic** source during its motion → the whole process is called the **"adiabatic"** process, and we have a new form of our 1st law

$$C_p \frac{dT}{dt} - \alpha \frac{dP}{dt} = 0$$

- And it will be even better to have

$$\boxed{\frac{d}{dt}(M) = 0}$$

A CONSERVED VARIABLE

How to get M and what it really is

$$C_p \frac{dT}{T} - R\frac{dp}{p} = \frac{dQ}{T}$$

dQ=0

$$\frac{dT}{T} - \frac{R}{C_p}\frac{dP}{p} = 0$$

$$\theta = T\left(\frac{p_0}{P}\right)^{\frac{R}{C_p}}$$

$$d\ln\theta = d\ln T - \frac{R}{C_p} d\ln(p) = 0$$

Following the adiabatic process, dQ=0 →dθ=0

$$\boxed{\frac{d}{dt}(M) = \frac{d}{dt}(\theta) = 0}$$

potential temperature

In this case, our conserved variable is the **potential temperature (K)** and we like it because of the familiar unit.

- But any other form? Instead of conservation of temperature?

How to get M and what it really is

dQ=0

$$\boxed{C_p \frac{dT}{dt} - \alpha \frac{dP}{dt} = \cancel{\frac{dQ}{dt}}} + \boxed{\frac{dp}{dz} - \rho g = 0} \Rightarrow \boxed{C_p \frac{dT}{dt} + g\frac{dz}{dt} = 0}$$

Hydrostatic balance

$$\boxed{\frac{d}{dt}(M) = \frac{d}{dt}(C_p T + gz) = \frac{d}{dt}(S) = 0}$$

Dry static energy

In this case, our conserved variable is the **dry static energy, S (J/kg)** and it really tells what conserved is the energy.

- Now we confirm that **potential temperature** and **dry static energy** are conserved during the adiabatic process.
- What makes a parcel of air more interesting/complicated? Water vapor!

How to get M and what it really is: considering the moist process

Now considering the latent heat release during the phase change $dQ = -Ldq_v$

$$\boxed{C_p\frac{dT}{T} - R\frac{dp}{p} = \frac{dQ}{T}} \quad -L\frac{dq_v}{T}$$

$$+ \quad \boxed{C_p\frac{d\theta}{\theta} = C_p\frac{dT}{T} - R\frac{dp}{p}} \quad \Rightarrow \quad \boxed{C_p\frac{d\theta}{\theta} = -L\frac{dq_v}{T}}$$

with the approximation $\frac{d\theta}{\theta} = -\frac{L}{C_p}d(\frac{q_v}{T})$ $\Rightarrow$ $\boxed{\theta_e = \theta\exp(-\frac{Lq_v}{C_pT})}$

Equivalent potential temperature

Similarly, by several steps, we can also prove that

$$\boxed{\frac{d}{dt}(M) = \frac{d}{dt}(\theta_e) = 0}$$

How to get M and what it really is: considering the moist process

Now considering the latent heat release during the phase change dQ = -Ldq$_v$

dQ = -Ldq$_v$

$$C_p \frac{dT}{dt} - \alpha \frac{dP}{dt} = \frac{dQ}{dt} \quad + \quad \frac{dp}{dz} - \rho g = 0 \quad \Rightarrow \quad \frac{d}{dt}(C_p T + gz + Lq_v)$$

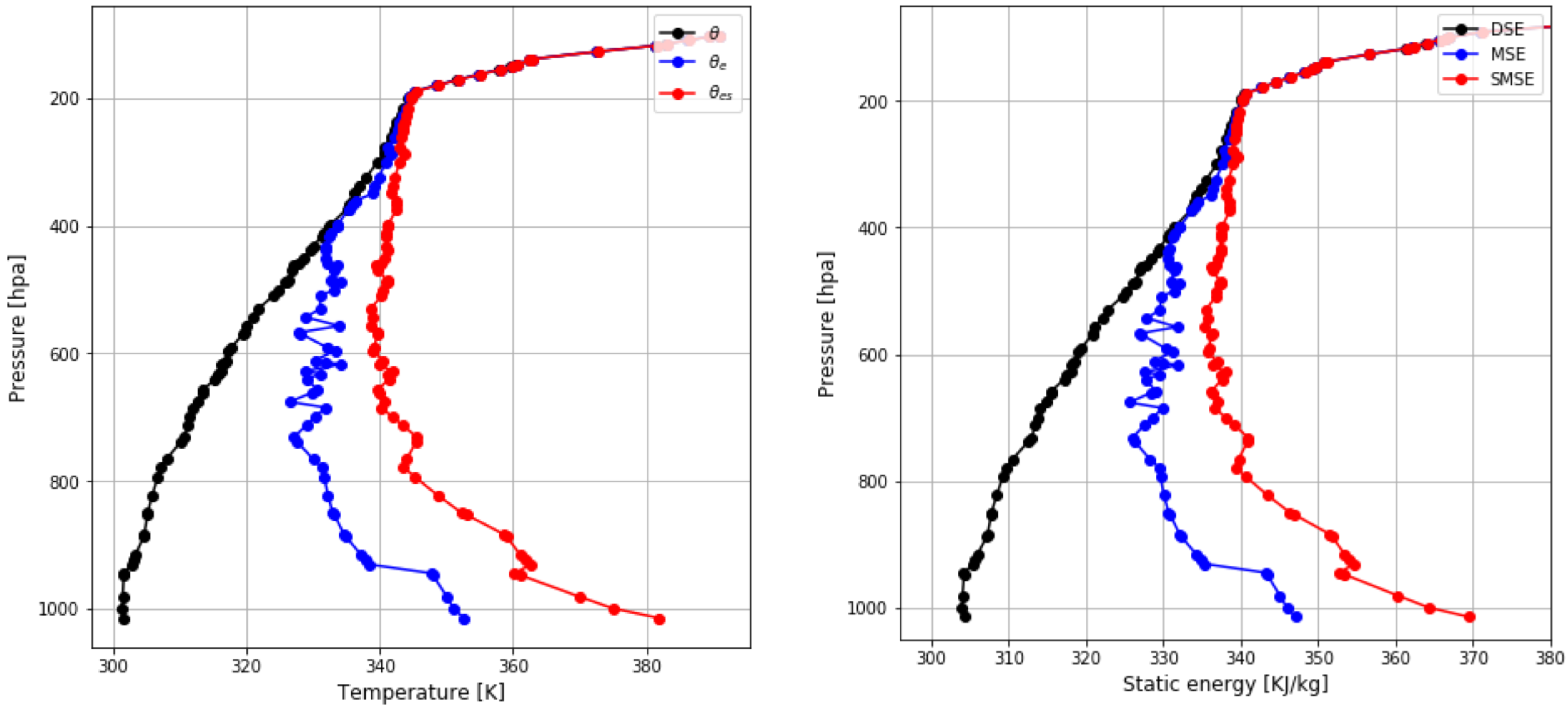
$$\boxed{\frac{d}{dt}(M) = \frac{d}{dt}(C_p T + gz + Lq_v) = \frac{d}{dt}(h) = 0}$$

Moist static energy

- Now we confirm that **equivalent potential temperature** and **moist static energy** are conserved during the moist adiabatic process.

- What's more? If qv = 0, MSE → DSE and θ_e → θ, so they are also conserved in both dry and moist adiabatic processes!

Vertical profiles of mentioned variables



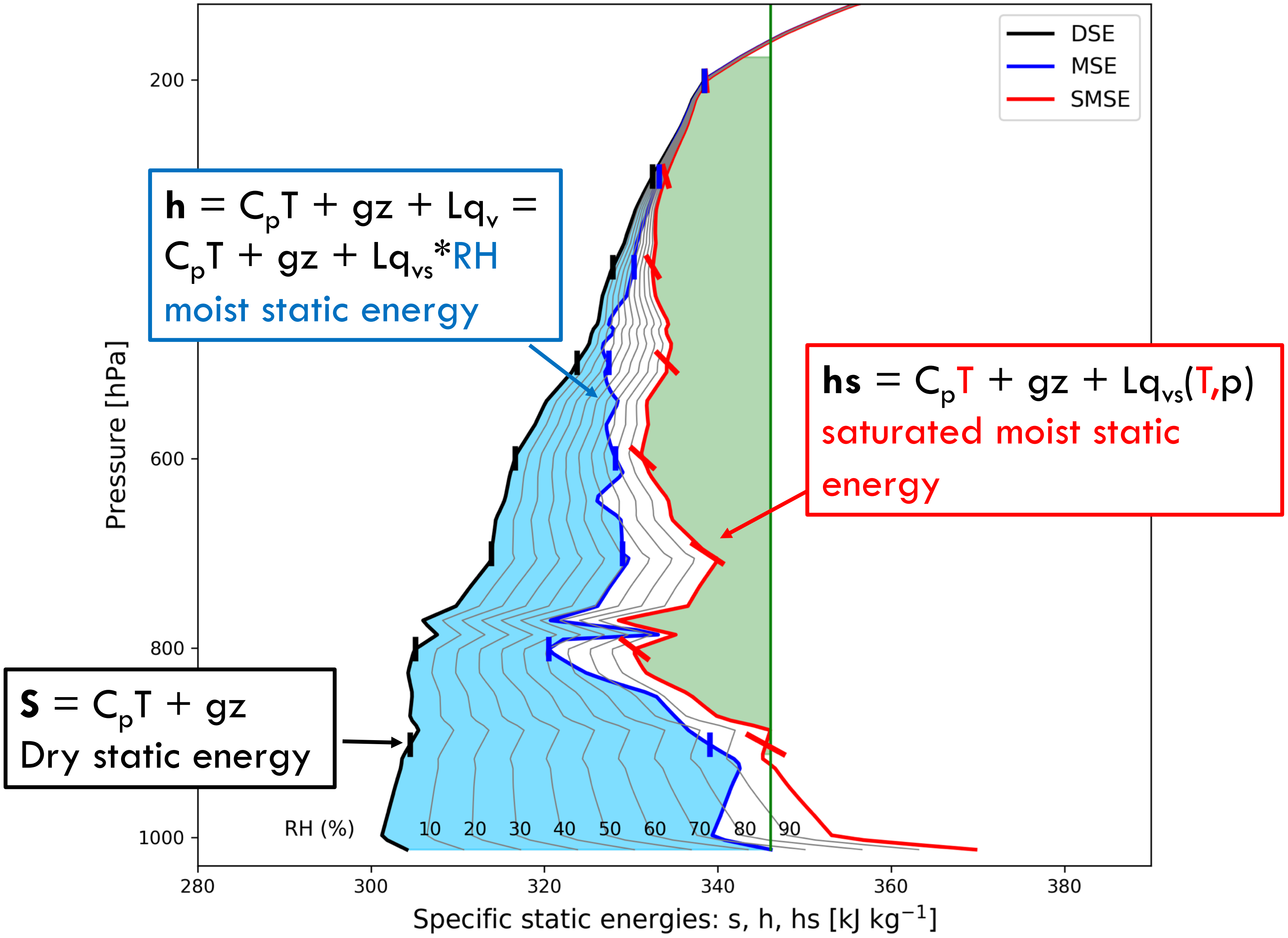
Almost identical in their vertical structures and in differences between curves, so we prefer static energy profiles because of its lovely unit

❑ Why conserved variables? Rising parcel as plume/convection

- The traditional concept of convection starts from the parcel theorem which assumes there is no mass exchange between an parcel and its environment.
- The parcel theorem determines how buoyant the air parcel will be and its destination (neutral buoyancy) by knowing state variables (T,q,P…) during the rising process.

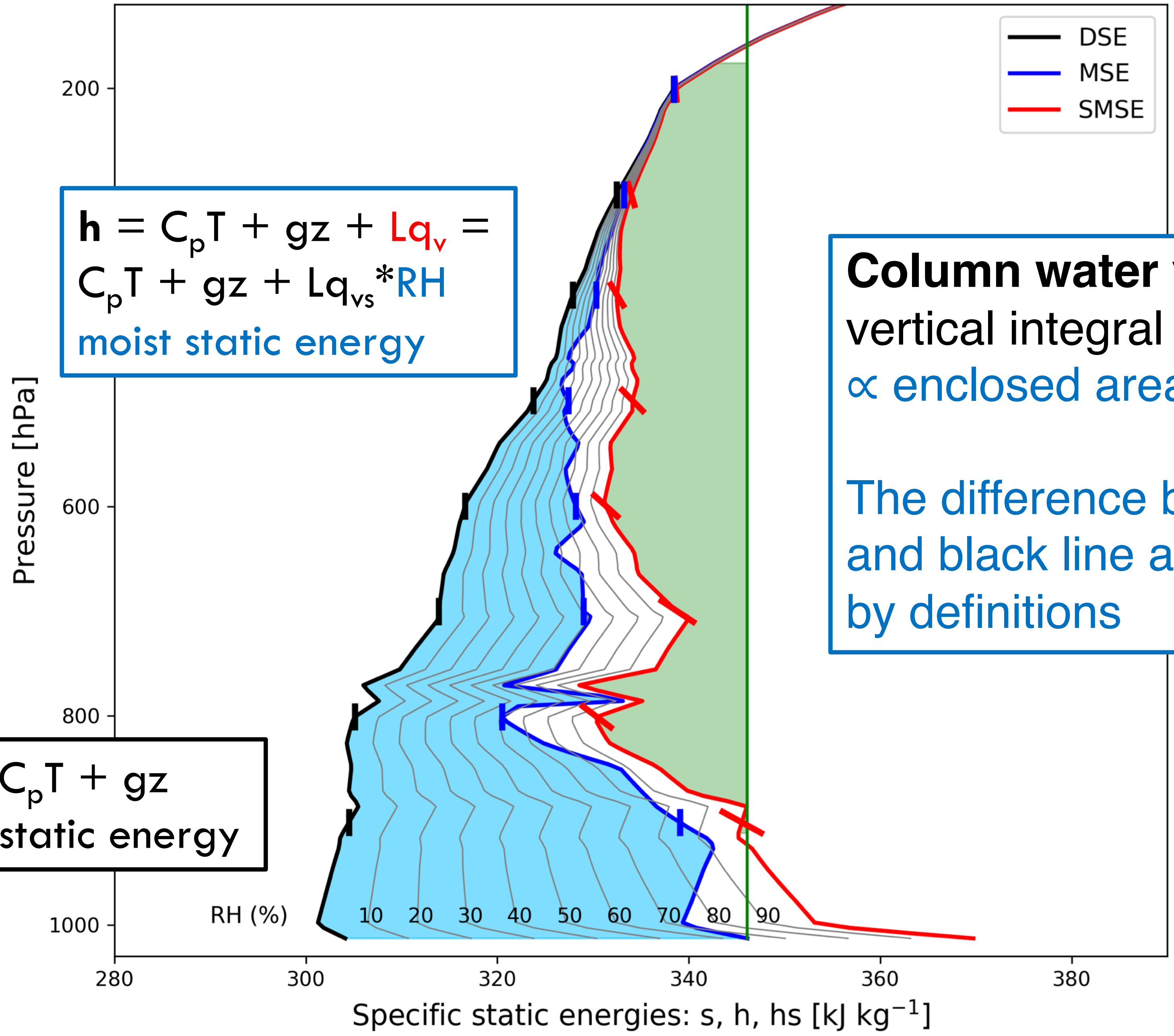
A conserved variable can just allow us to describe a rising moist parcel by
- following the adiabatic process. no mass exchange
- estimating required state variables based inferred from the conserved value
- considering the phase change of water

Moist static energy diagram



$\mathbf{h} = C_pT + gz + Lq_v = C_pT + gz + Lq_{vs}*RH$

moist static energy

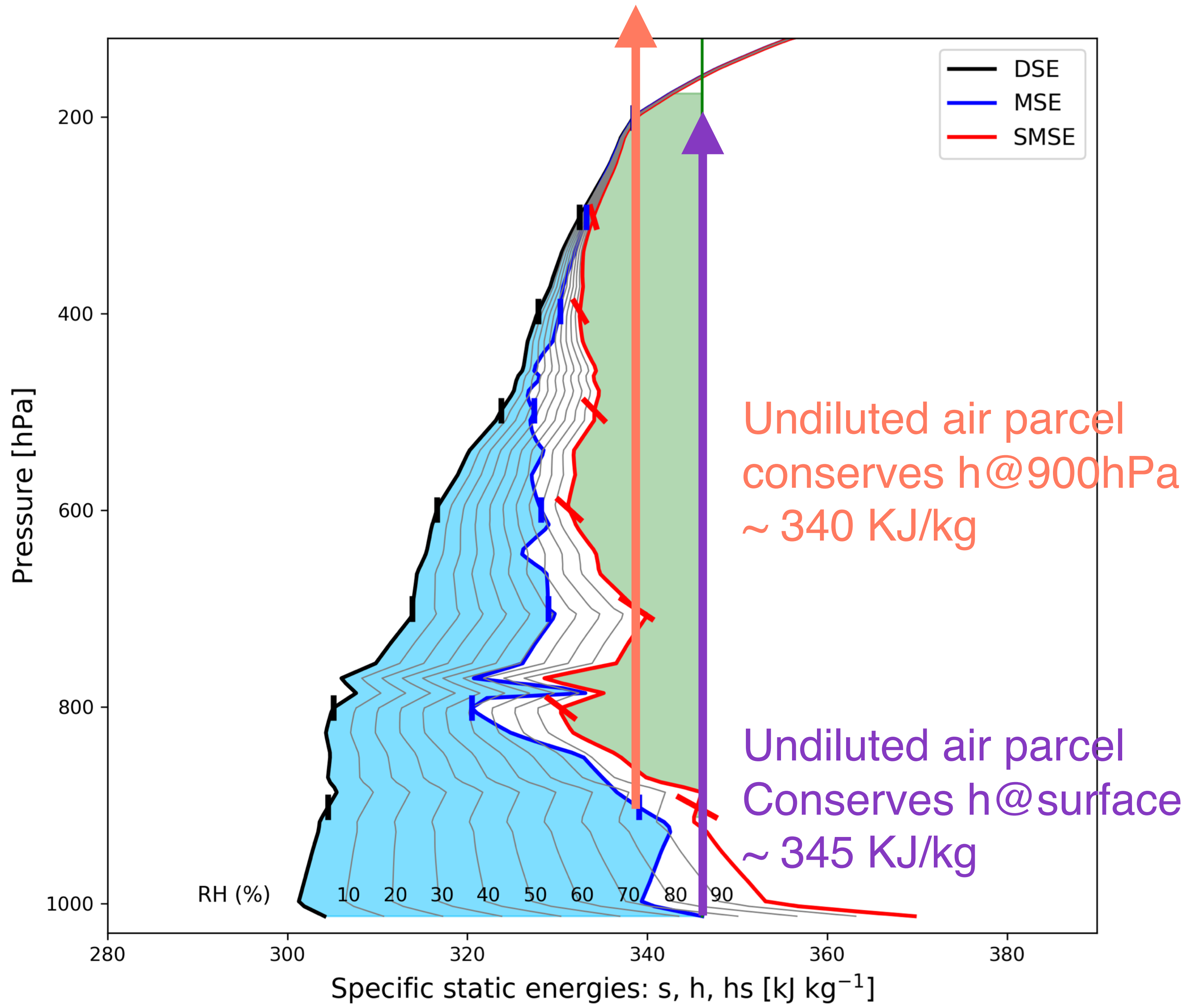


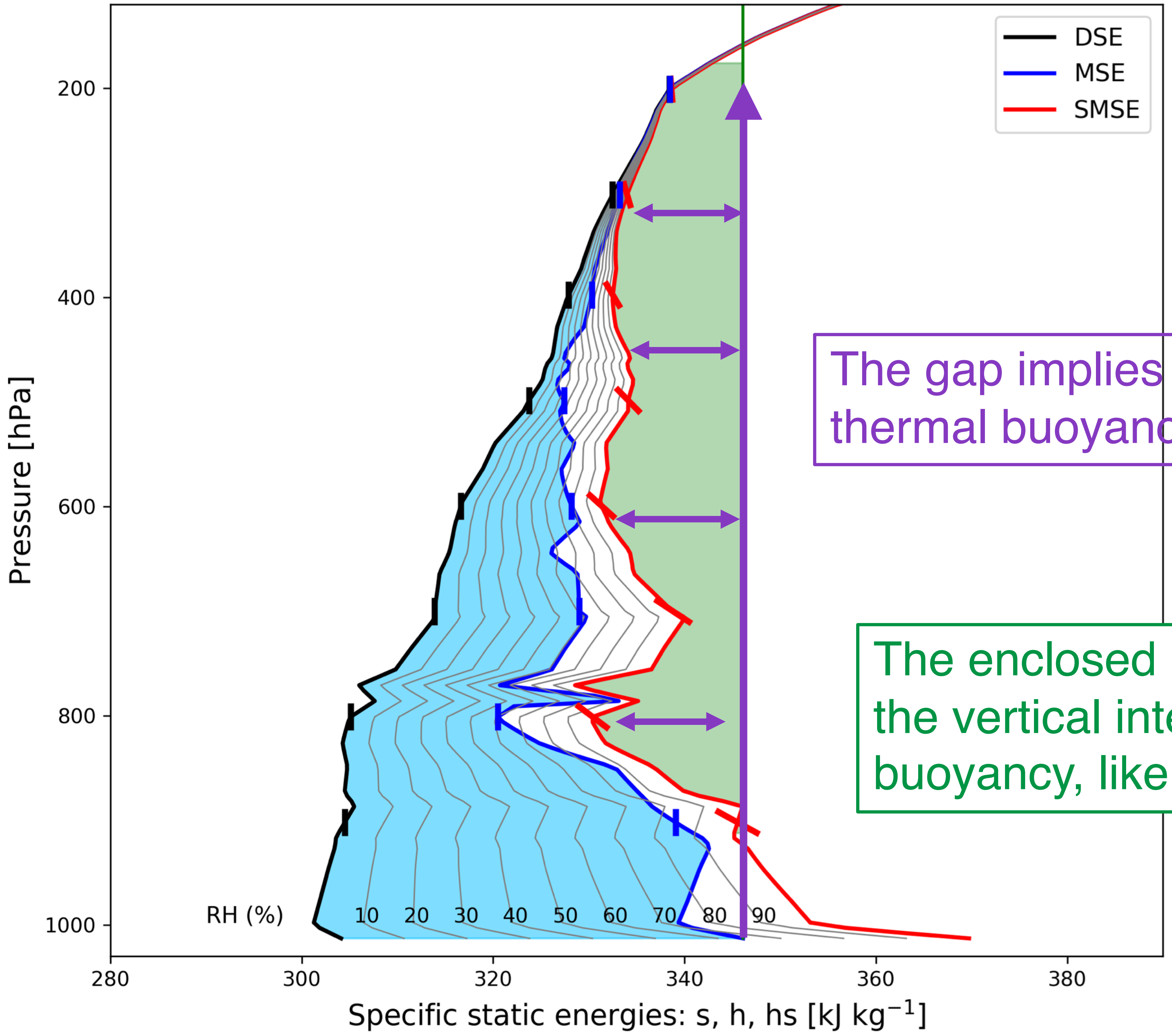
$\mathbf{S} = C_pT + gz$

Dry static energy

Column water vapor =
vertical integral of q_v
$\propto$ enclosed area

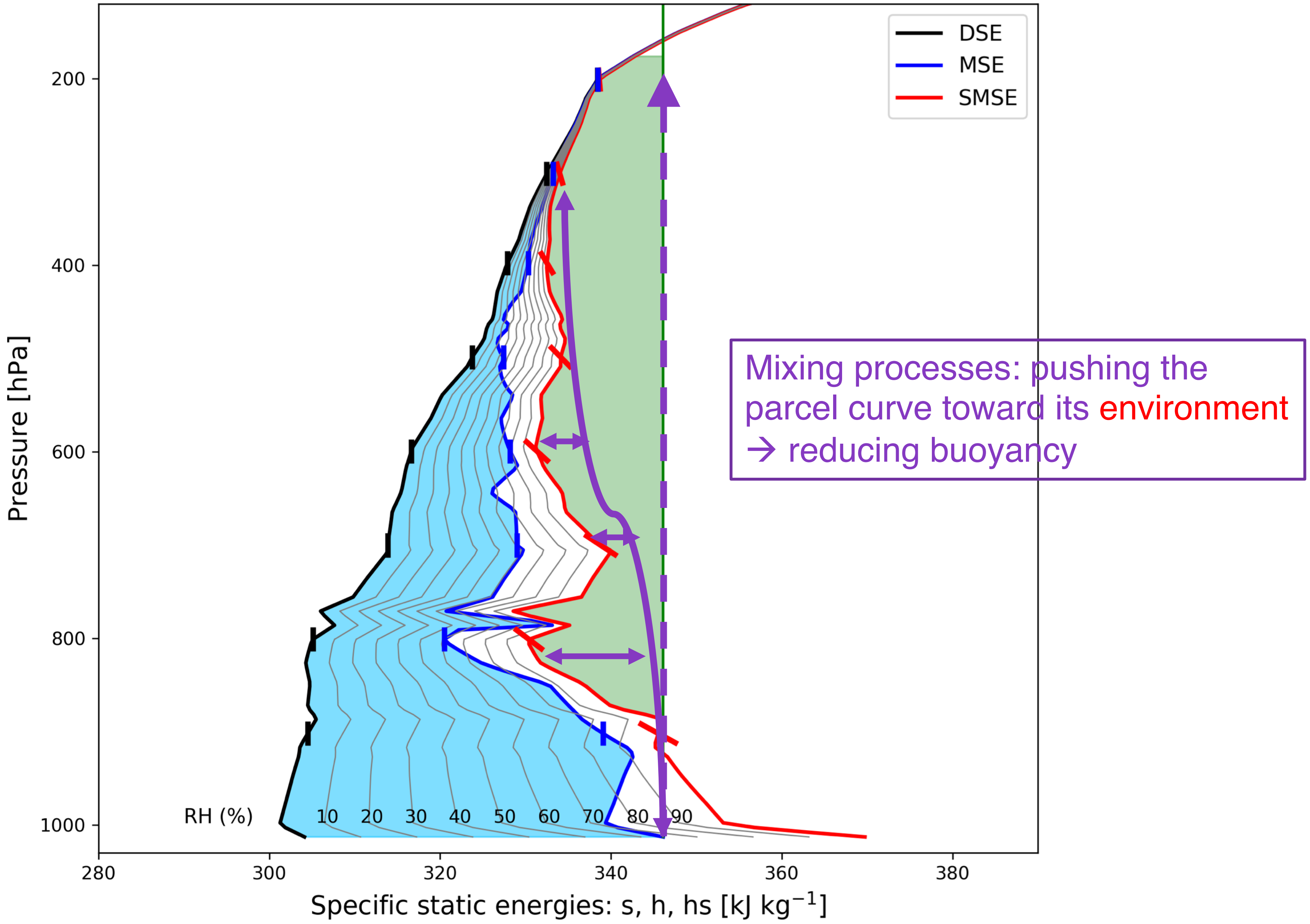
The difference between blue and black line attributes to q_v by definitions


DSE
MSE
SMSE
Pressure [hPa]
200
400
600
800
1000
RH (%)
10 20 30 40 50 60 70 80 90
280 300 320 340 360 380
Specific static energies: s, h, hs [kJ kg^{-1}]
Undiluted air parcel
conserves h@900hPa
~ 340 KJ/kg
Undiluted air parcel
Conserves h@surface
~ 345 KJ/kg



The gap implies the parcel thermal buoyancy, like (Tp-Tenv)

The enclosed area indicates the vertical integral of buoyancy, like CAPE


DSE
MSE
SMSE
Pressure [hPa]
200
400
600
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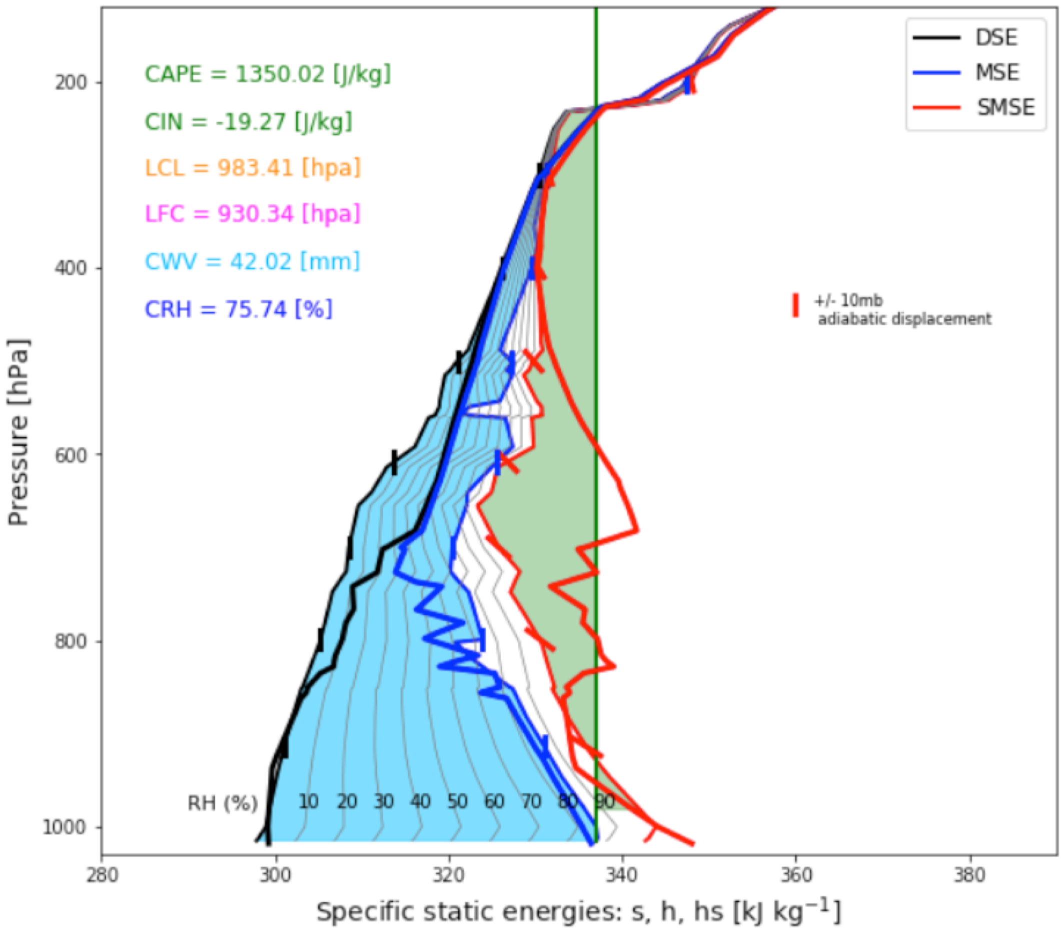
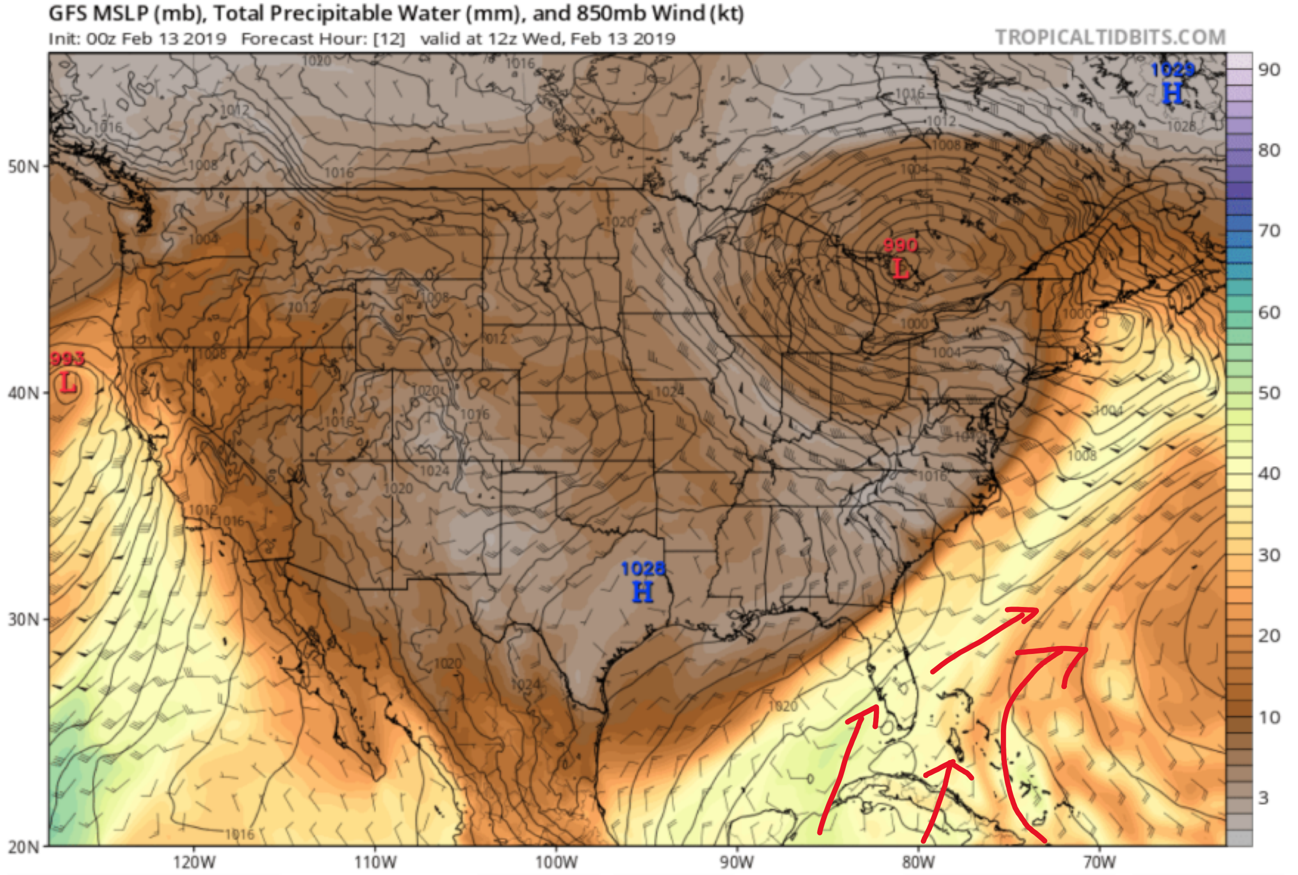
RH (%)
10 20 30 40 50 60 70 80 90
280 300 320 340 360 380
Specific static energies: s, h, hs [kJ kg^{-1}]
Mixing processes: pushing the parcel curve toward its environment
→ reducing buoyancy

What can be inferred from changes in profiles



Bold line→ current (Feb 12)
Thin line → one day after (Feb 13)



moister air brought from the south above ~900hPa
Cold air at the mid-levels carried by the storm

MSE diagram based on near real-time sounding

```python
from MSEplots import plots as mpt
from datetime import datetime
from siphon.simplewebservice.wyoming import WyomingUpperAir
```

Packages already in our ATM651 environment

Time string and station you pick

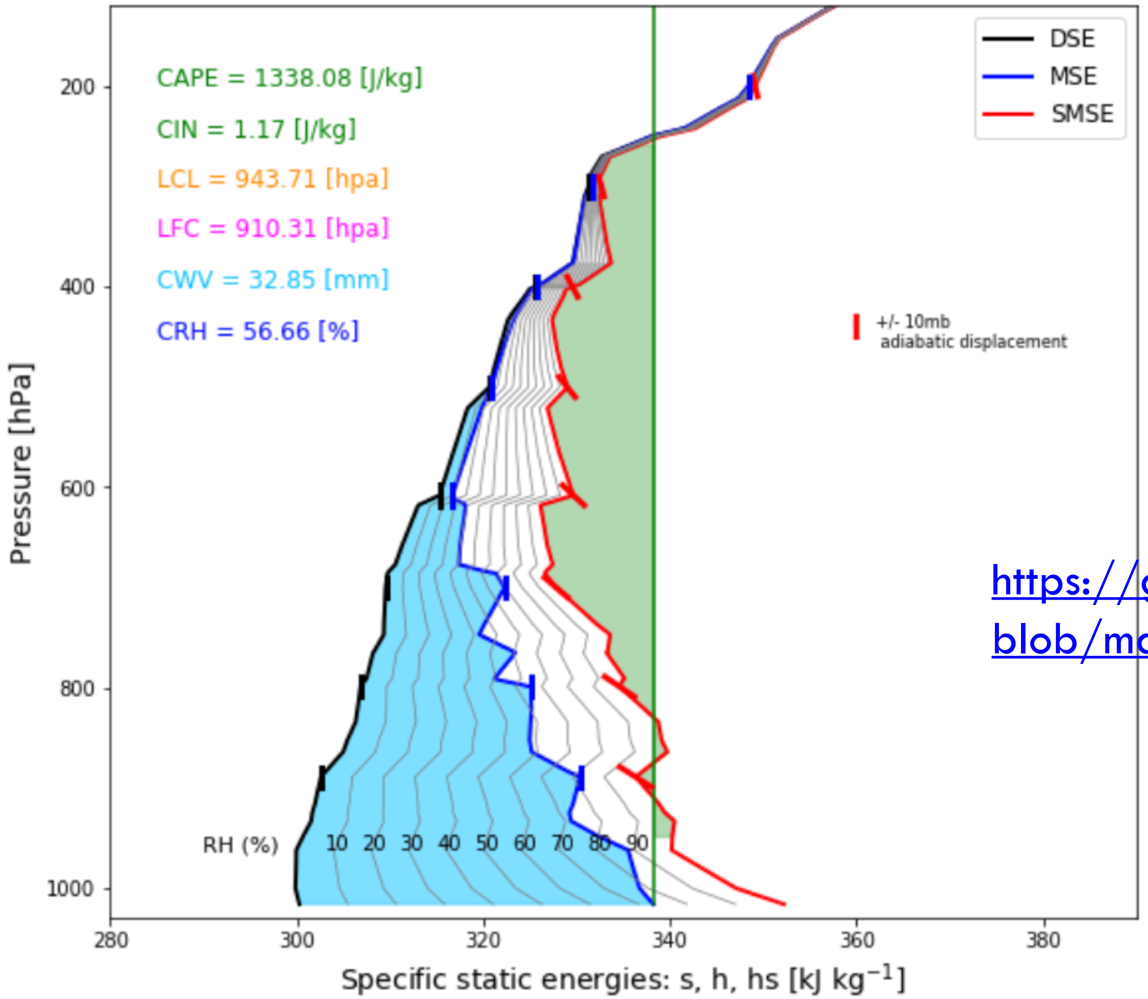
```python
# reading data prociding vertical profiles of T, Td, pressure
date = datetime(2019, 2, 13, 12) # cyclone in the north, bring
station = 'MFL'
```

```python
df = WyomingUpperAir.request_data(date, station)
pressure = df['pressure'].values
Temp = df['temperature'].values
Temp_dew = df['dewpoint'].values
altitude = df['height'].values

from metpy.calc.thermo import *
from metpy.units import units
q = mixing_ratio(saturation_vapor_pressure(Temp_dew*units.degC),pressure*units.mbar)
q = specific_humidity_from_mixing_ratio(q)
```

Plotting function

```
ax = mpt.msed_plots(p, T ,q , Z, h0_std=2000, ensemble_size=20, ent_rate=np.arange(0,2,0.05), entrain=False)
```



See how to add curves if you want to overlay curves at different times

https://github.com/ATMOcanes/ATM651_IntroAtmDynamics/blob/master/MSEdiagram_demo.ipynb