Carbon Cycle Reliance on Planetary Boundary Layer Processes

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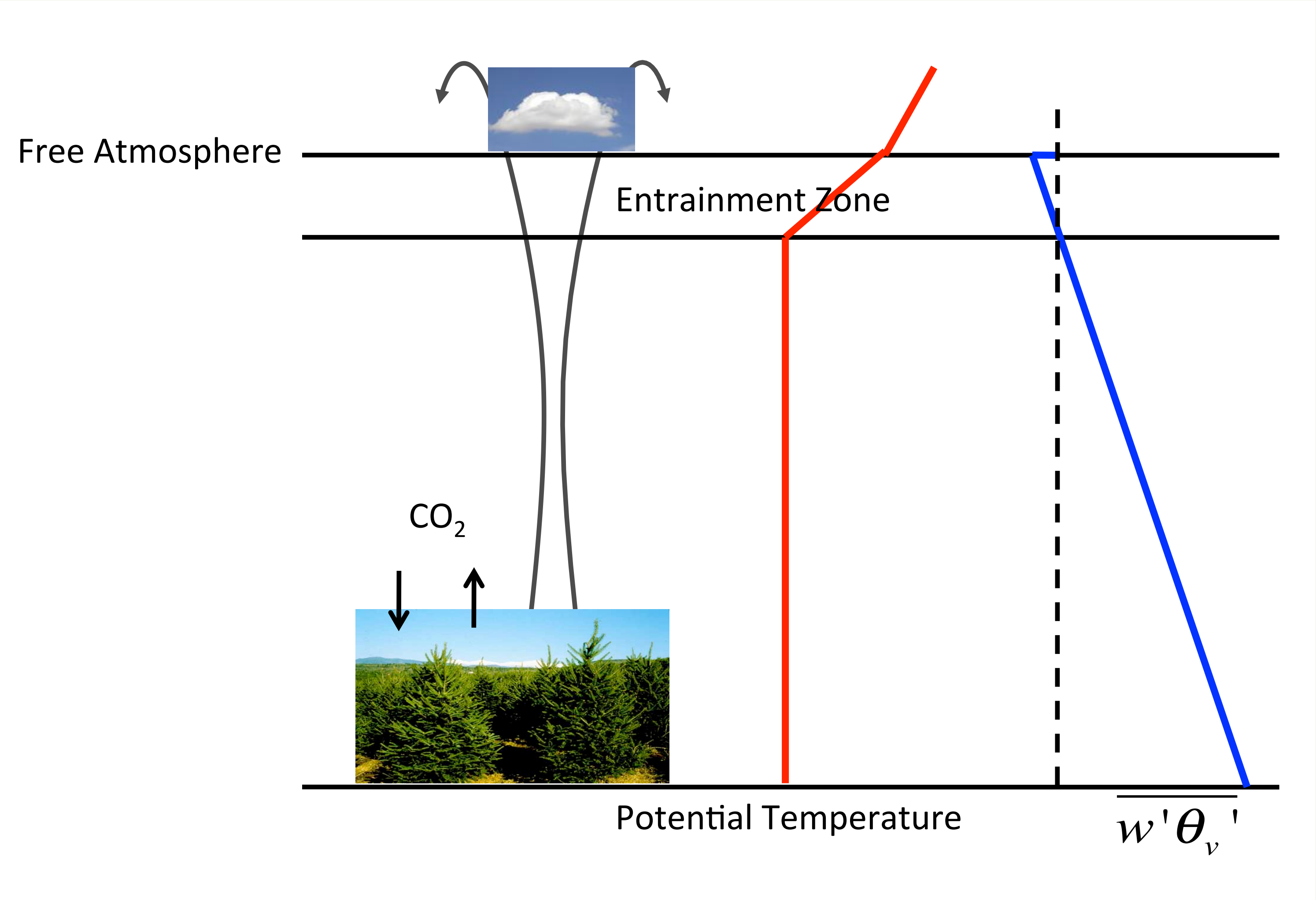
Introduction and Motivation

- Planetary boundary layer (PBL)
  - Turbulent layer closest to the Earth's surface
- Determines surface fluxes of heat, moisture, momentum
- Interacts with clouds, radiation, convection, aerosols, pollutants
- Transport of water vapor and momentum
- Scalar quantities (CO_2, H_2O, heat) diluted by depth of the PBL

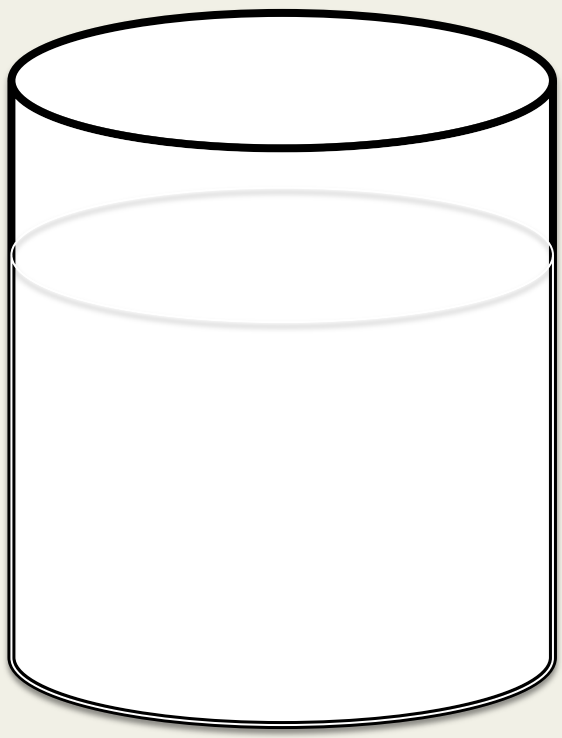
Stull, 1988; Beljaars and Betts, 1993

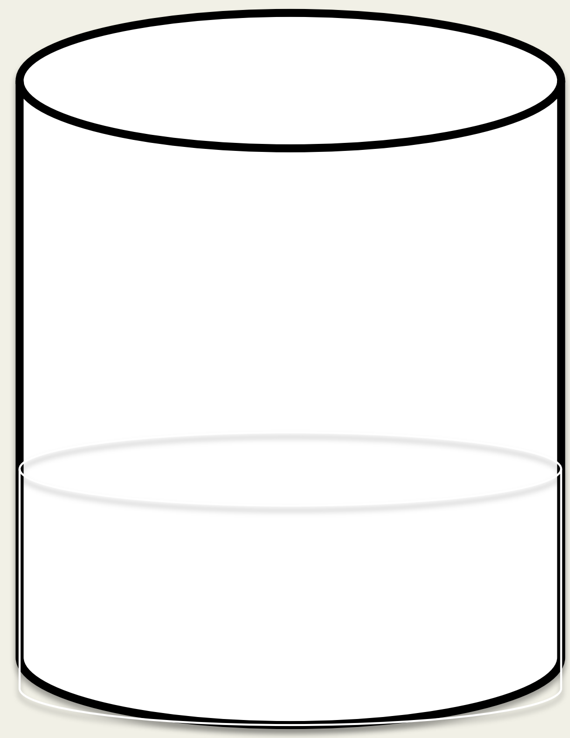
Idealized



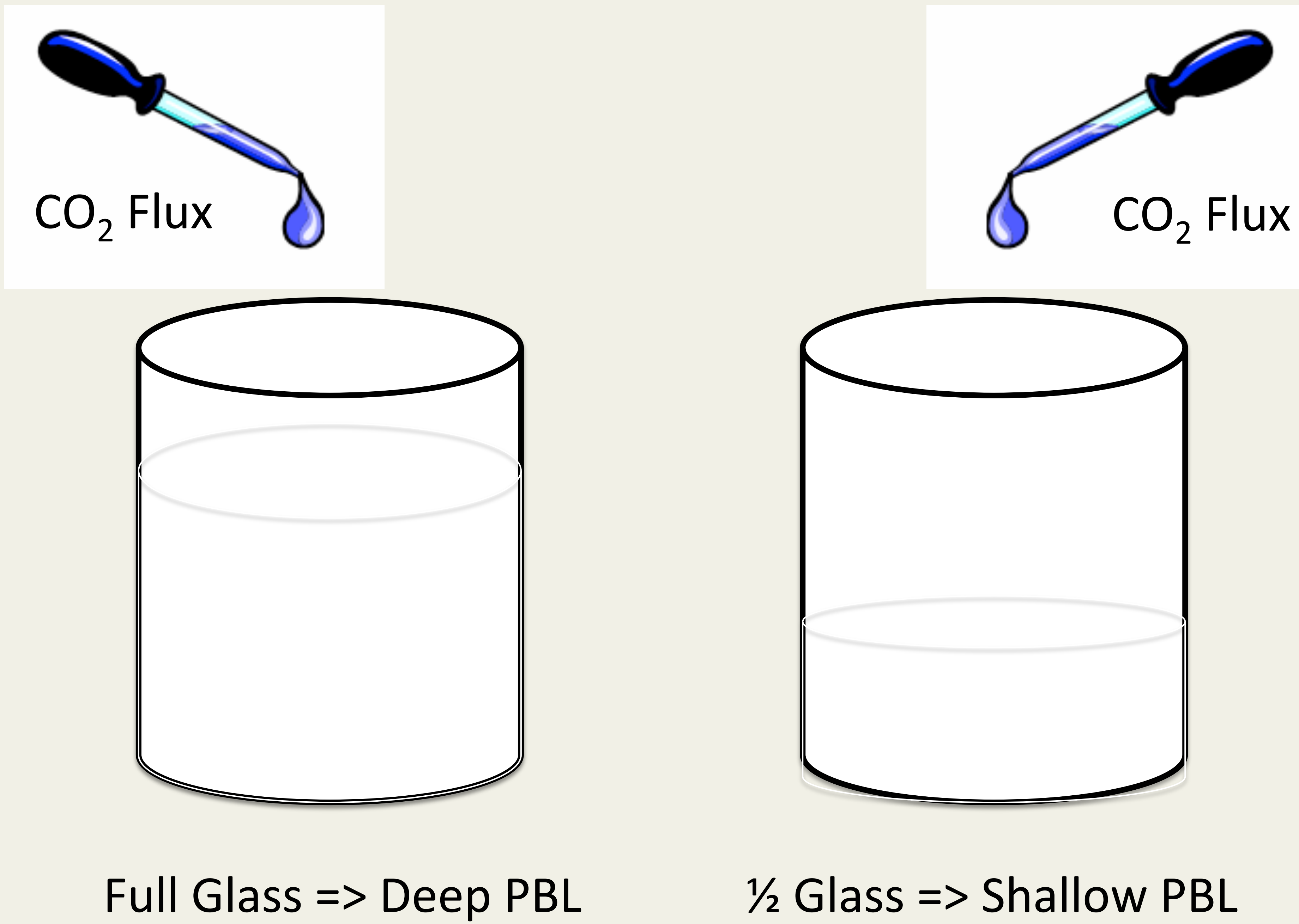
Free Atmosphere
Entrainment Zone
CO_2
Potential Temperature
$\overline{w'\theta_v'}$

Another way to look at this



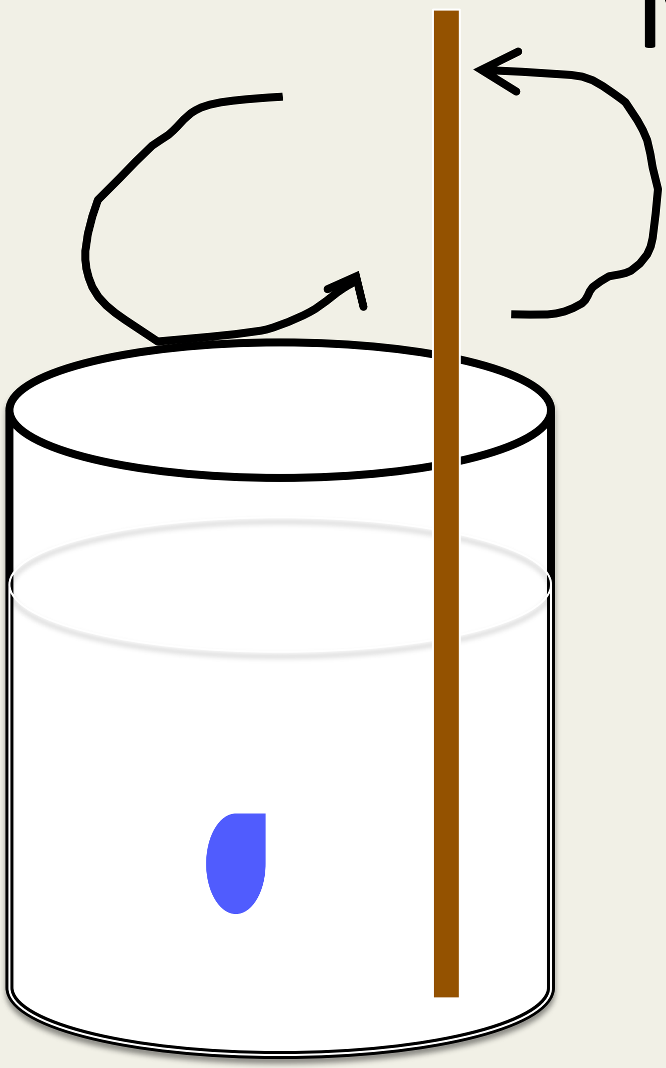


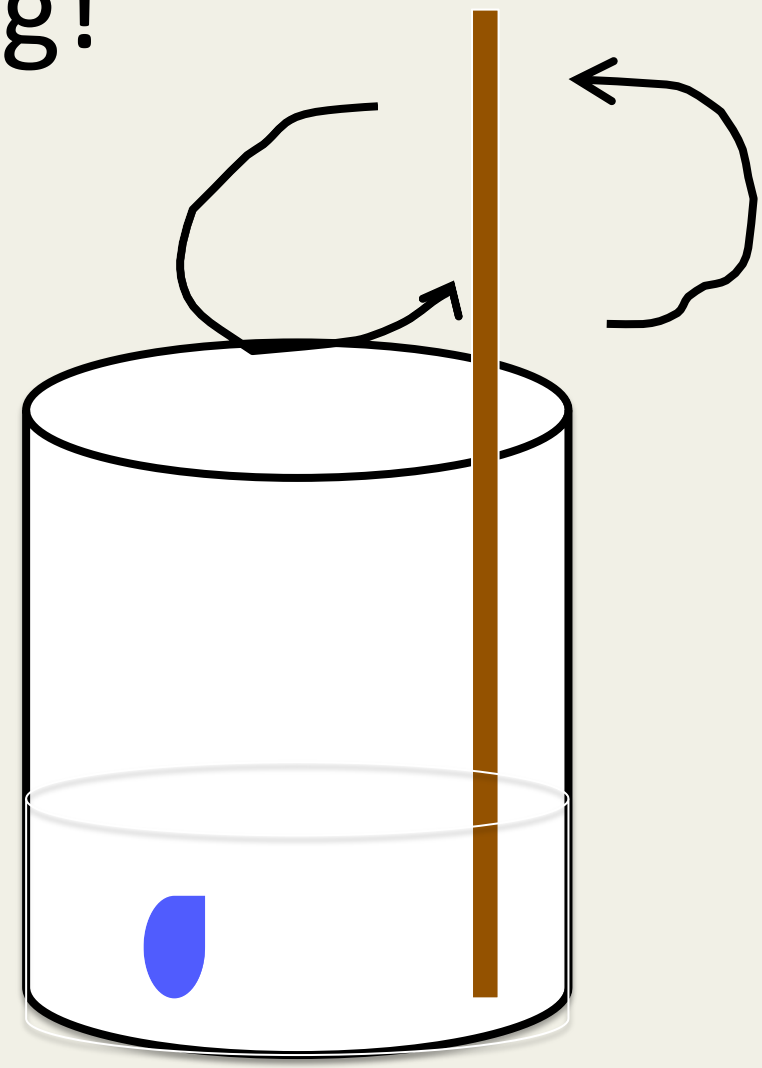
Full Glass => Deep PBL ½ Glass => Shallow PBL



CO_2 Flux
CO_2 Flux
Full Glass => Deep PBL
½ Glass => Shallow PBL

Mixing!

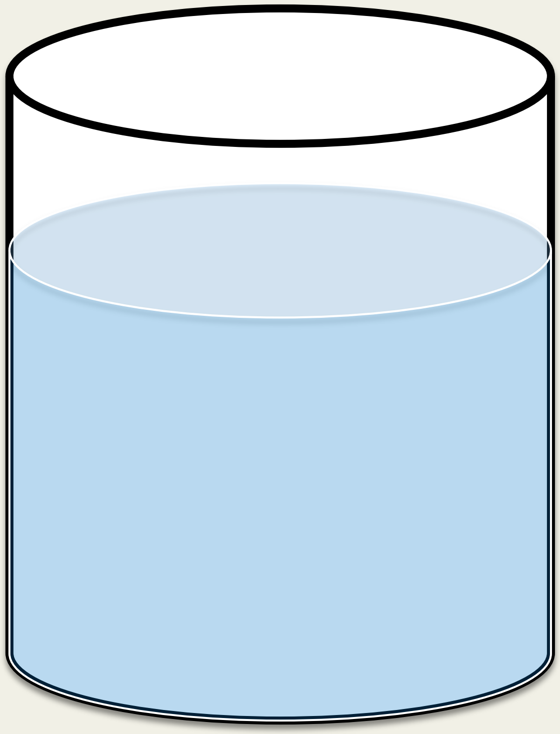




Full Glass => Deep PBL

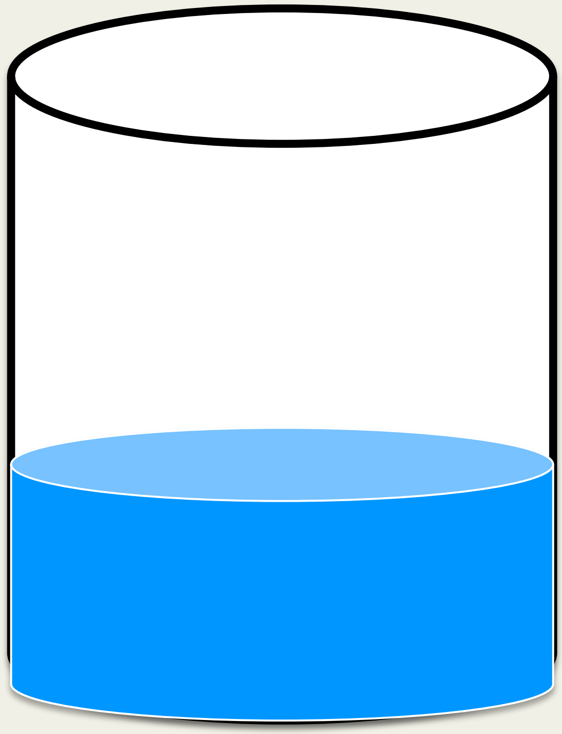
½ Glass => Shallow PBL

Small Impact



Full Glass => Deep PBL

Large Impact



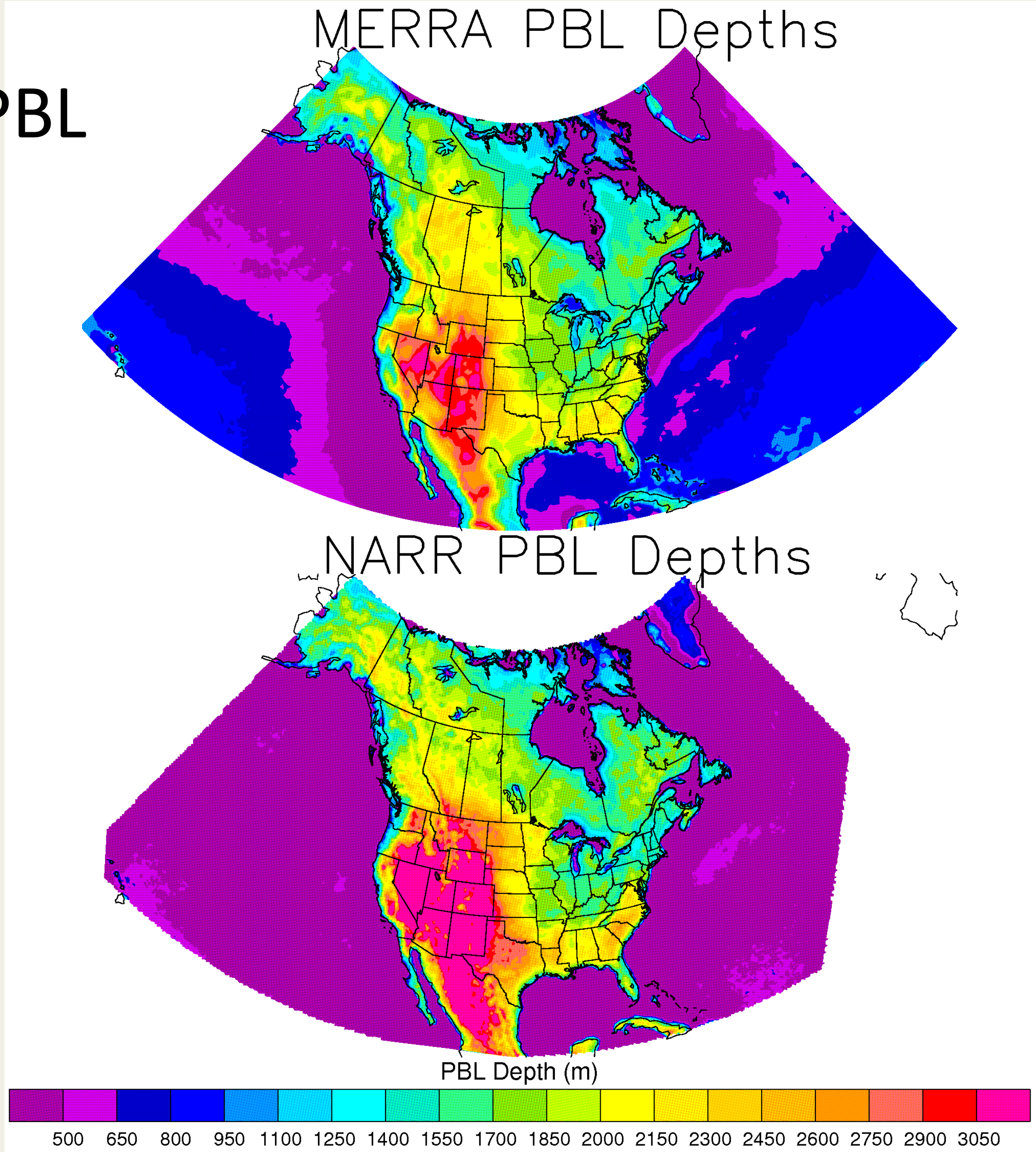
½ Glass => Shallow PBL

- PBL depth - hard to observe
- Generally 1-2 km above the ground
- Wind profilers and aircraft
  - Expensive
  - Limited spatially and temporally
- Radiosondes launched at the wrong times (0 and 12 UTC)
  - Measure only one point in space/time and may differ from average by up to 40%

Angevine et al., 1994

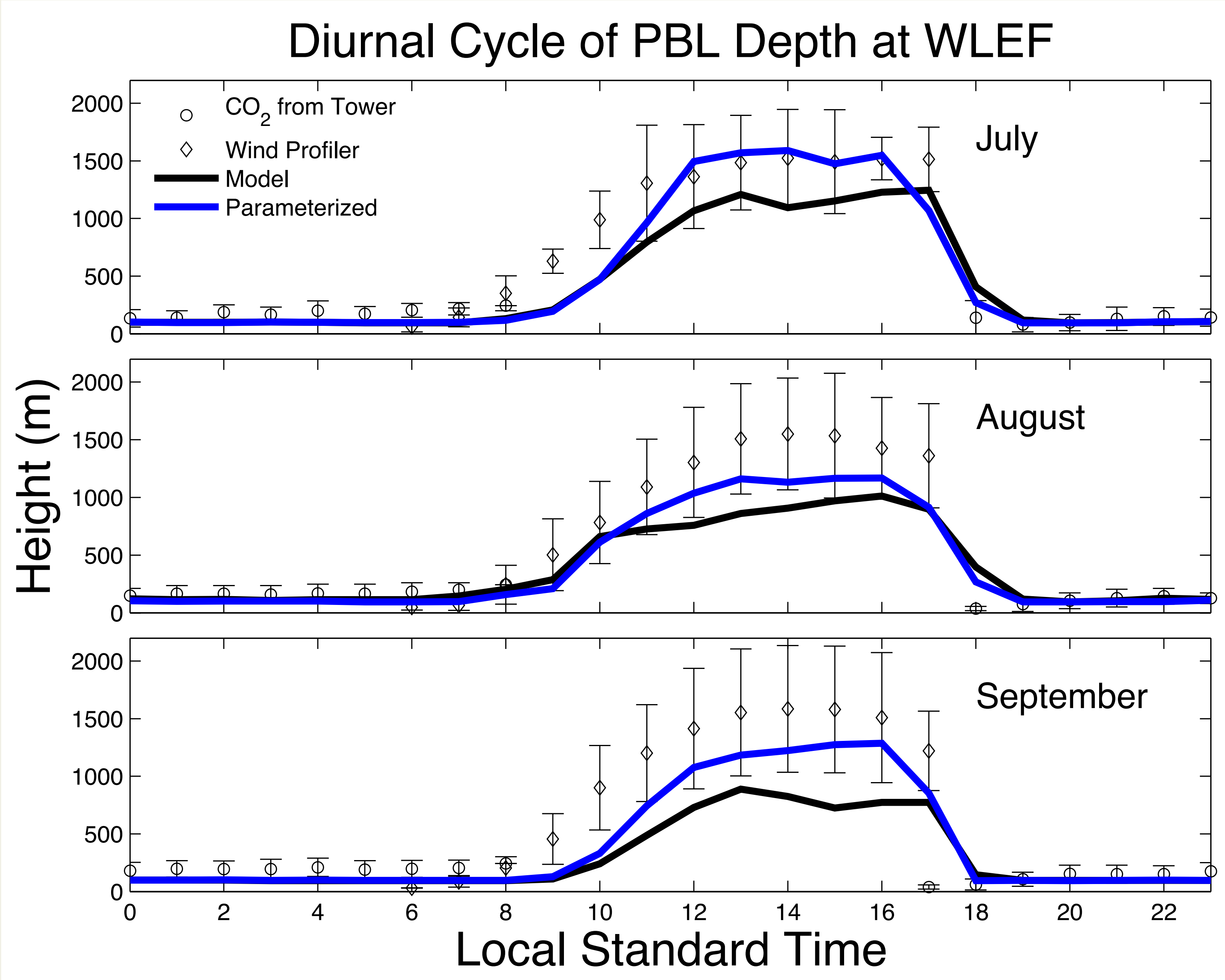
What happens when we try to model PBL depth?

- Sunny, midday PBL depths
- June, July, and August
- 2006-2010
- Qualitatively similar
- Very different quantitative results!



Case Study

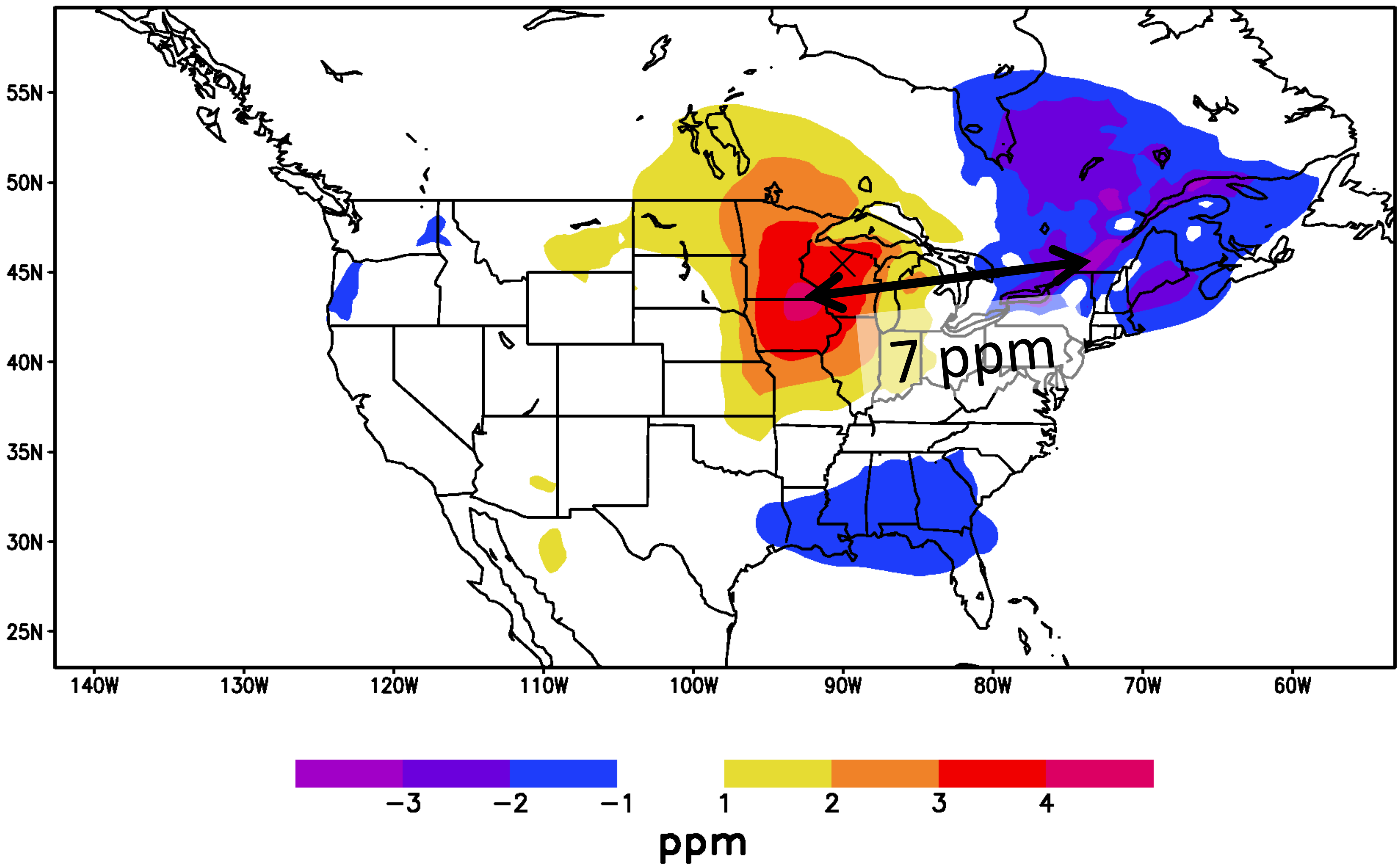
- July – September 1999
- Fully 3D Model
- Nudged lateral boundary conditions
- 4 month spin-up, 3 months analyzed
- North America domain with 40 km grid intervals
- Initialized from observational data



McGrath-Spangler and Denning, 2010

Case Study

CO_2

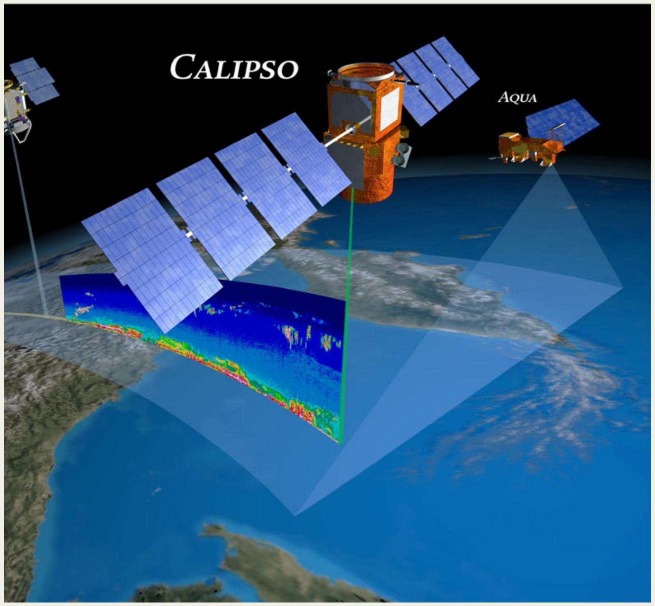


McGrath-Spangler and Denning, 2010

Case Study

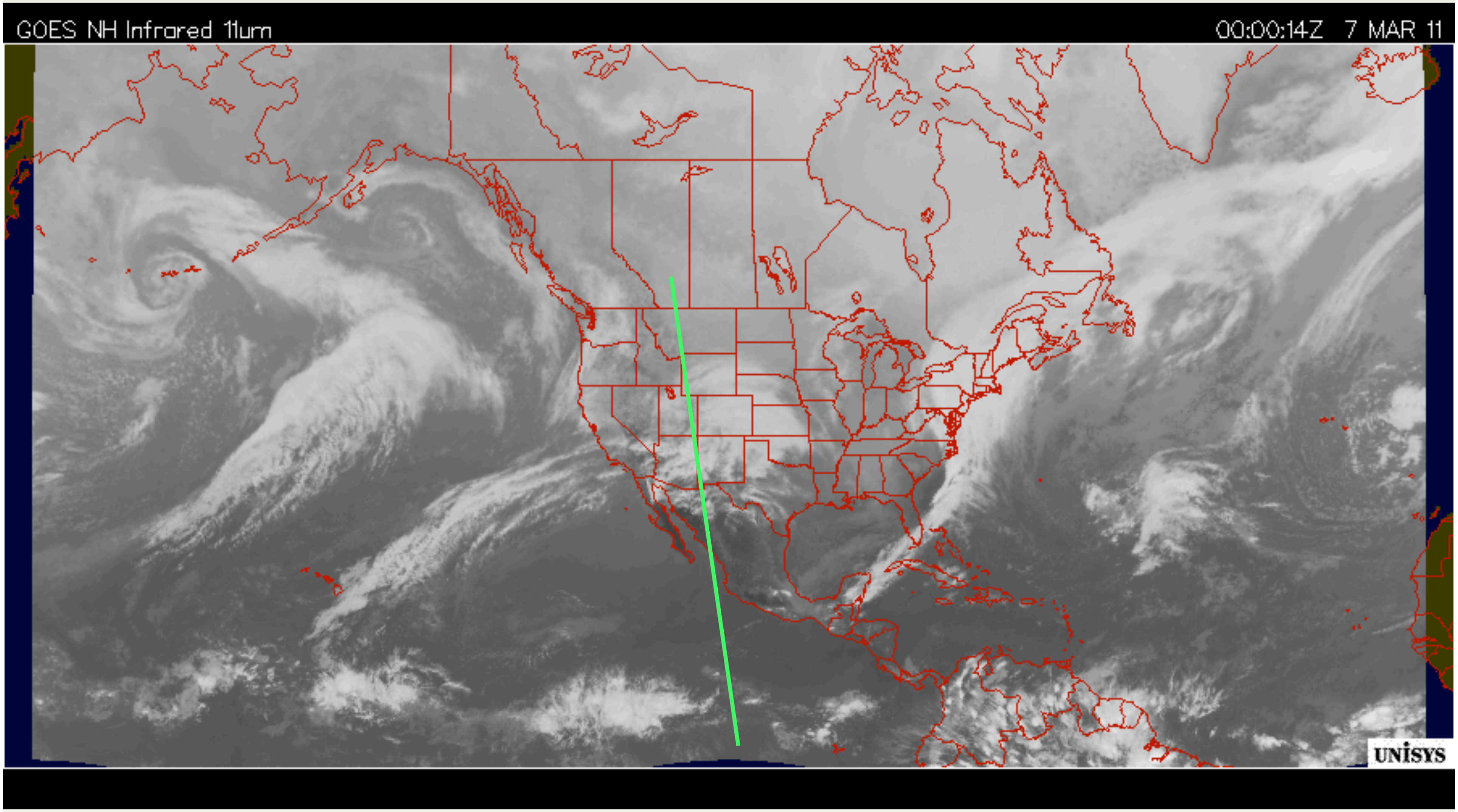
PBL Depth from Space

- Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observations (CALIPSO)
- Launched April 2006, First light June 2006
- Part of the Afternoon (A-train) constellation of satellites

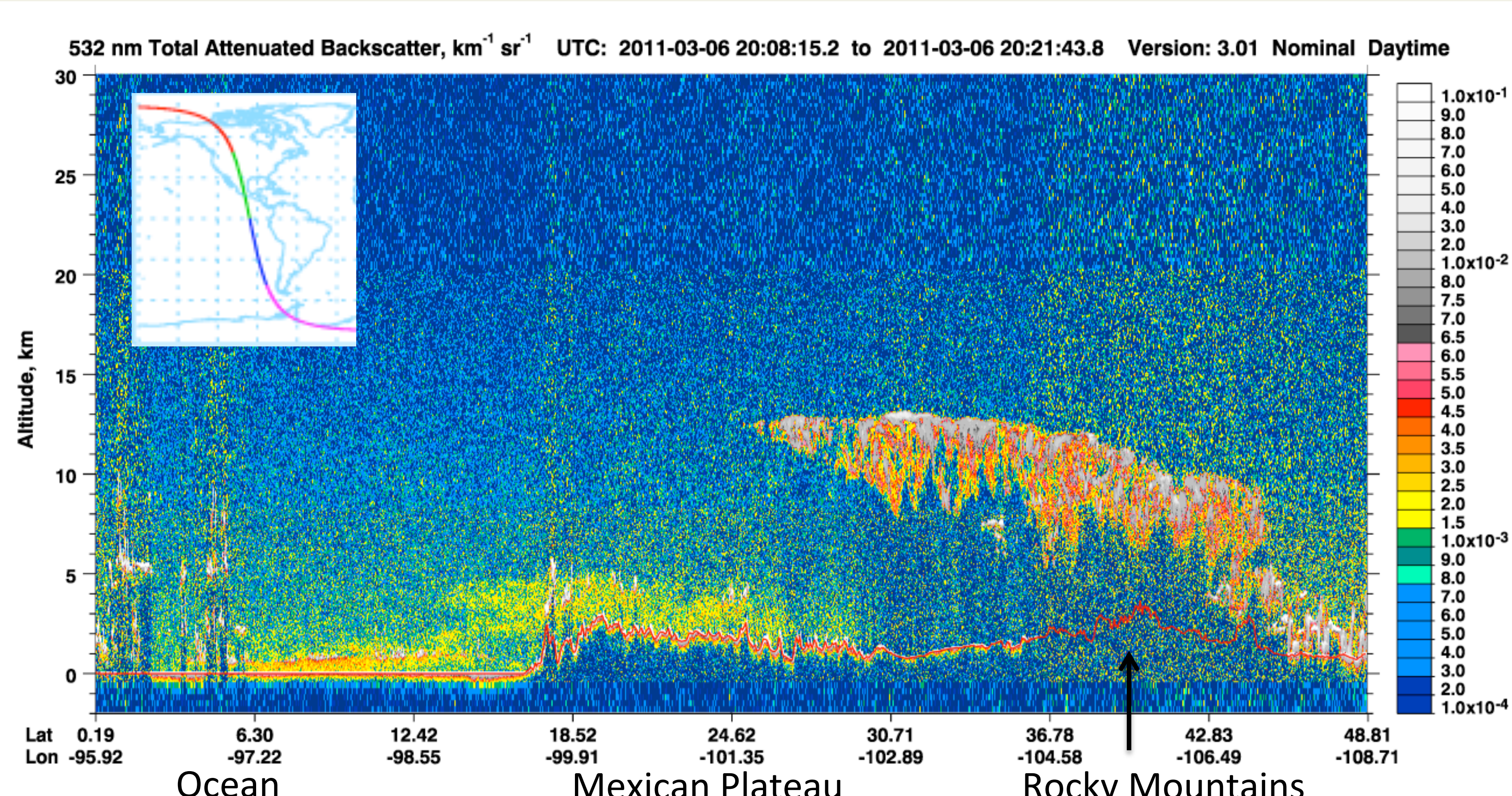


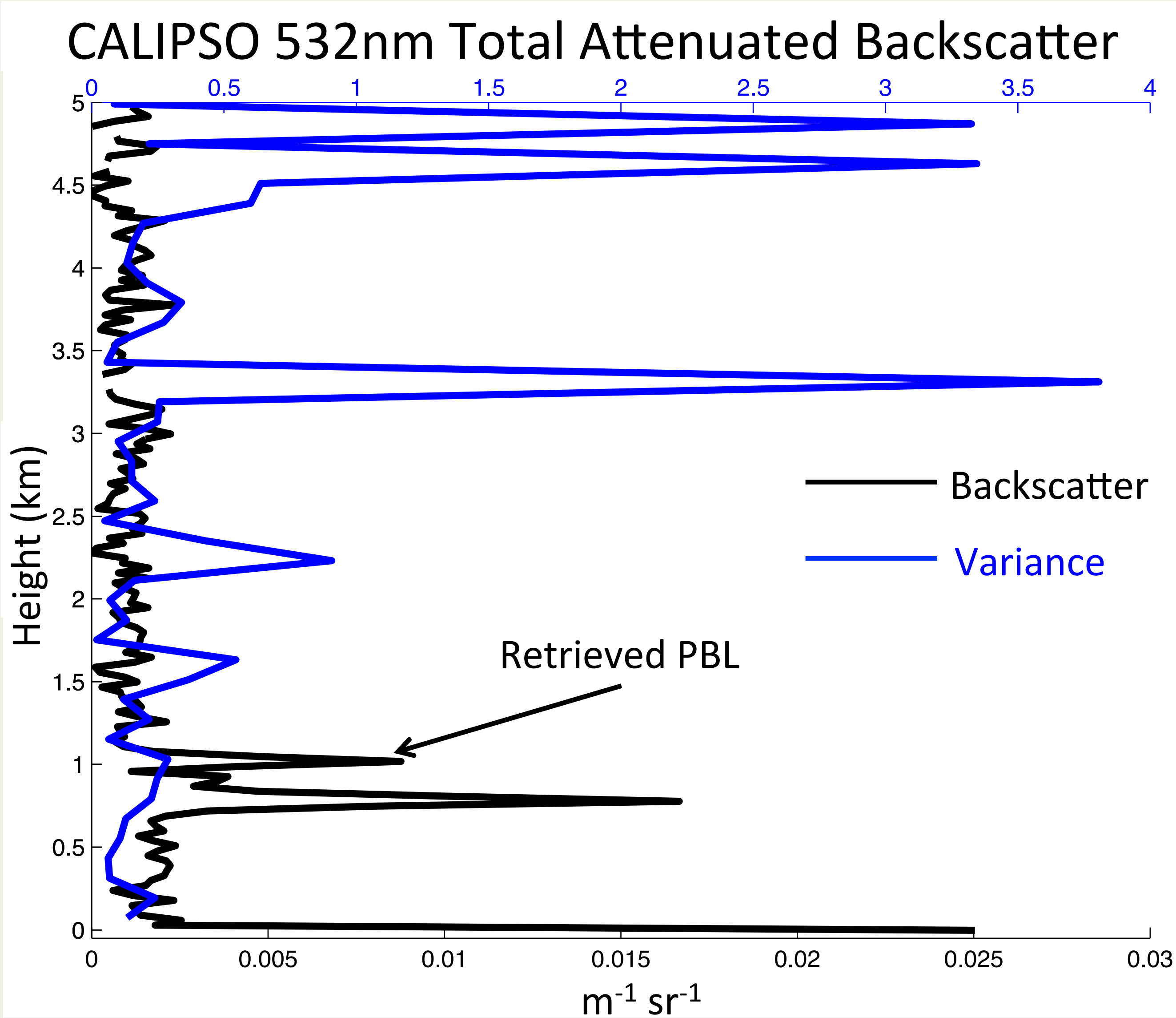
e.g. Winker et al., 2007

- Method developed by Jordan et al. (2010)
  - Local maximum in LIDAR 532 nm backscatter collocated with a maximum in the variance in the backscatter
- Search only between 250 m and 5 km AGL and reject profiles attenuated by thick clouds

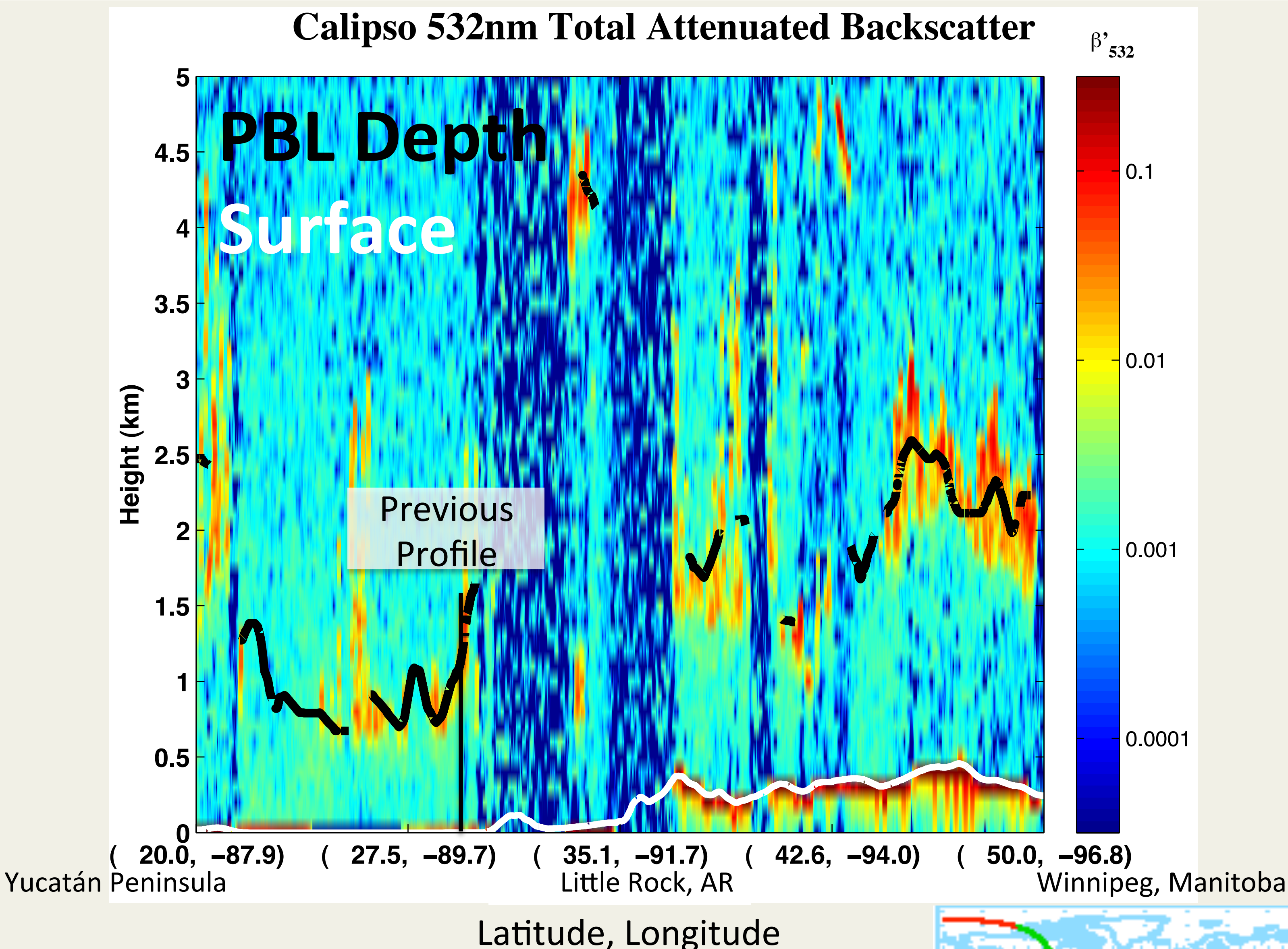

GOES NH Infrared 11um
00:00:14Z 7 MAR 11
UNISYS

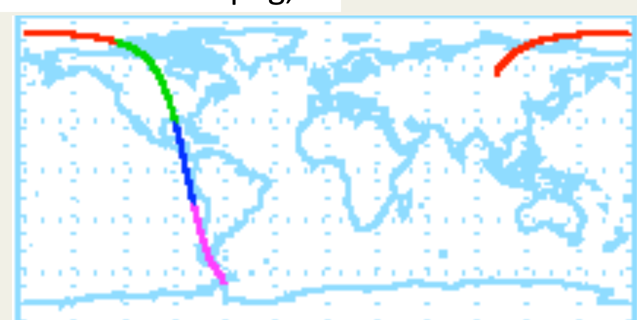
- CALIOP acquires 1.7 million laser shots every 24 hours

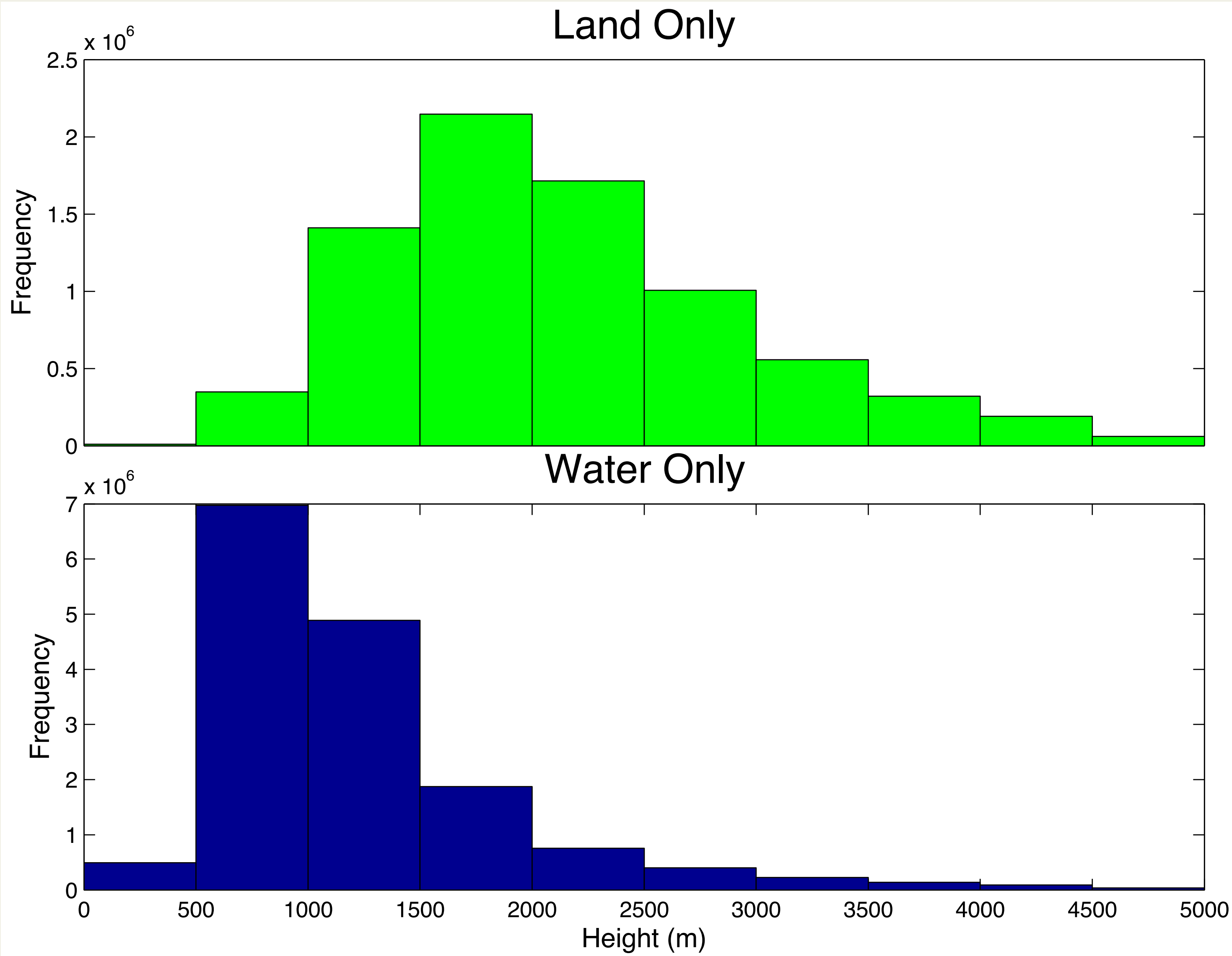




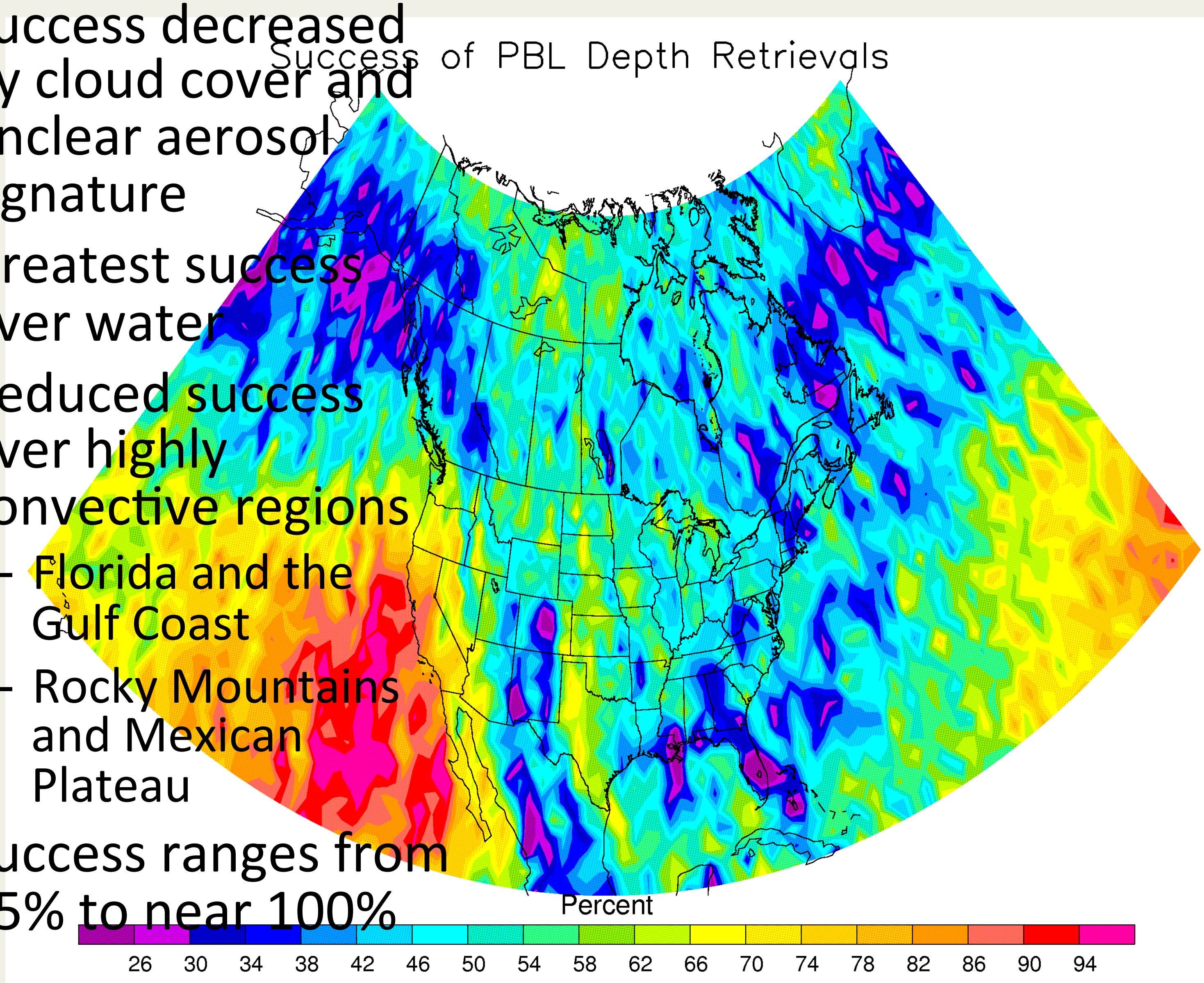
CALIPSO 532nm Total Attenuated Backscatter
0
0.5
1
1.5
2
2.5
3
3.5
4
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Height (km)
Backscatter
Variance
Retrieved PBL
0
0.005
0.01
0.015
0.02
0.025
0.03
m-1 sr-1


Calipso 532nm Total Attenuated Backscatter
β'532
0.1
0.01
0.001
0.0001
Height (km)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
PBL Depth
Surface
Previous
Profile
(20.0, −87.9) (27.5, −89.7) (35.1, −91.7) (42.6, −94.0) (50.0, −96.8)
Yucatán Peninsula
Little Rock, AR
Winnipeg, Manitoba
Latitude, Longitude

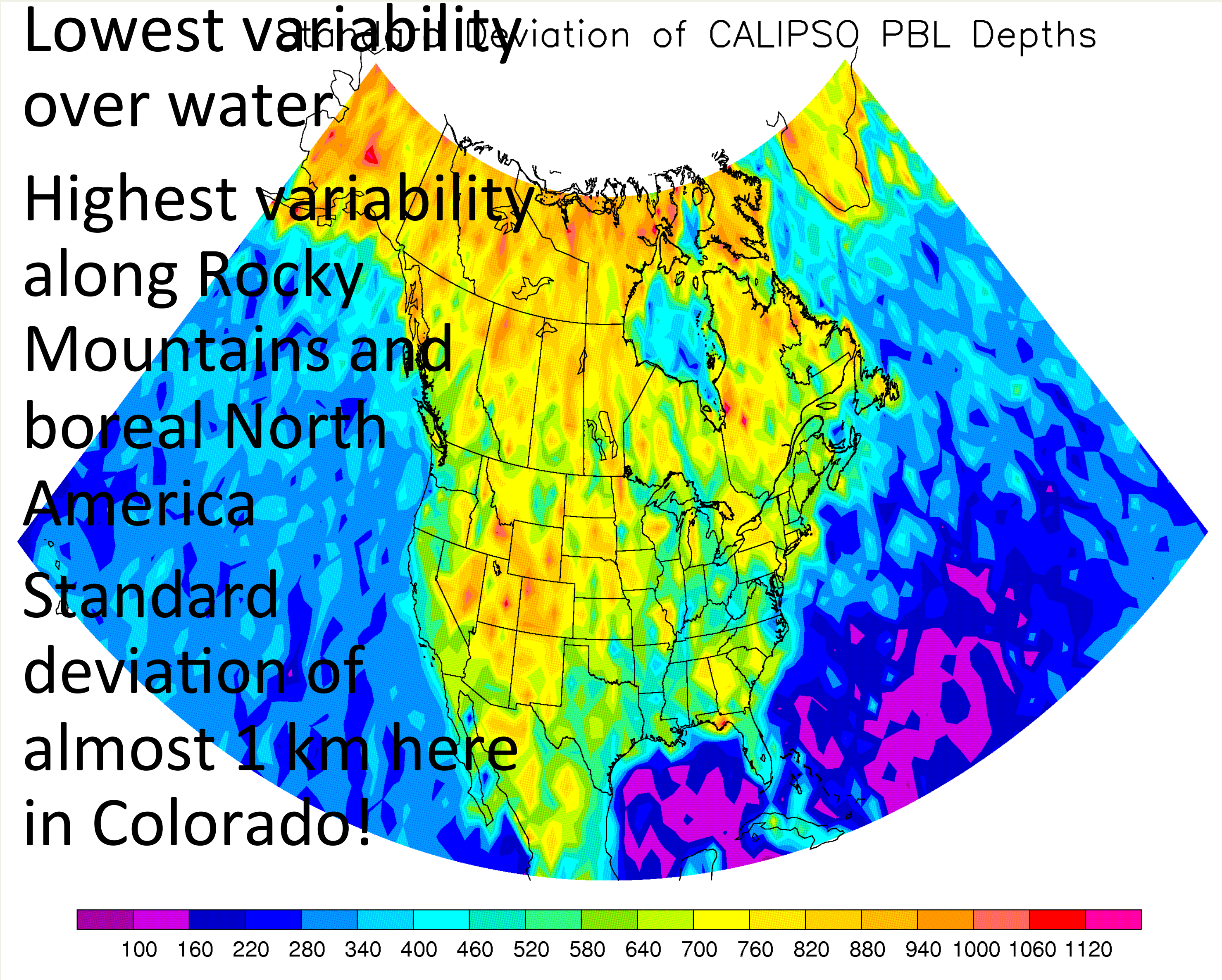



Land Only
x 10^6
2.5
2
1.5
1
0.5
0
Frequency
Water Only
x 10^6
7
6
5
4
3
2
1
0
Frequency
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Height (m)

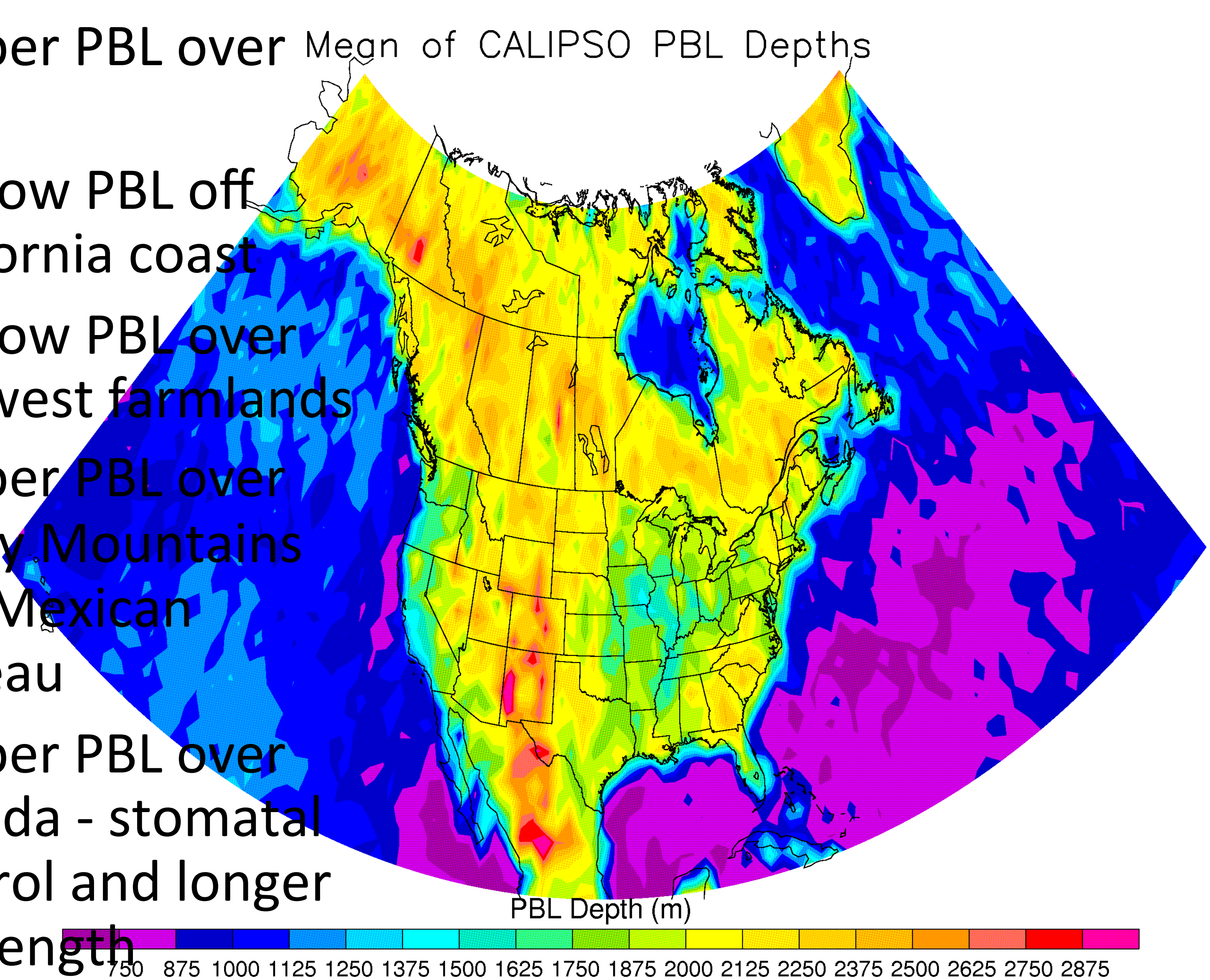
- Success decreased by cloud cover and unclear aerosol signature
- Greatest success over water
- Reduced success over highly convective regions
  - Florida and the Gulf Coast
  - Rocky Mountains and Mexican Plateau
- Success ranges from 15% to near 100%



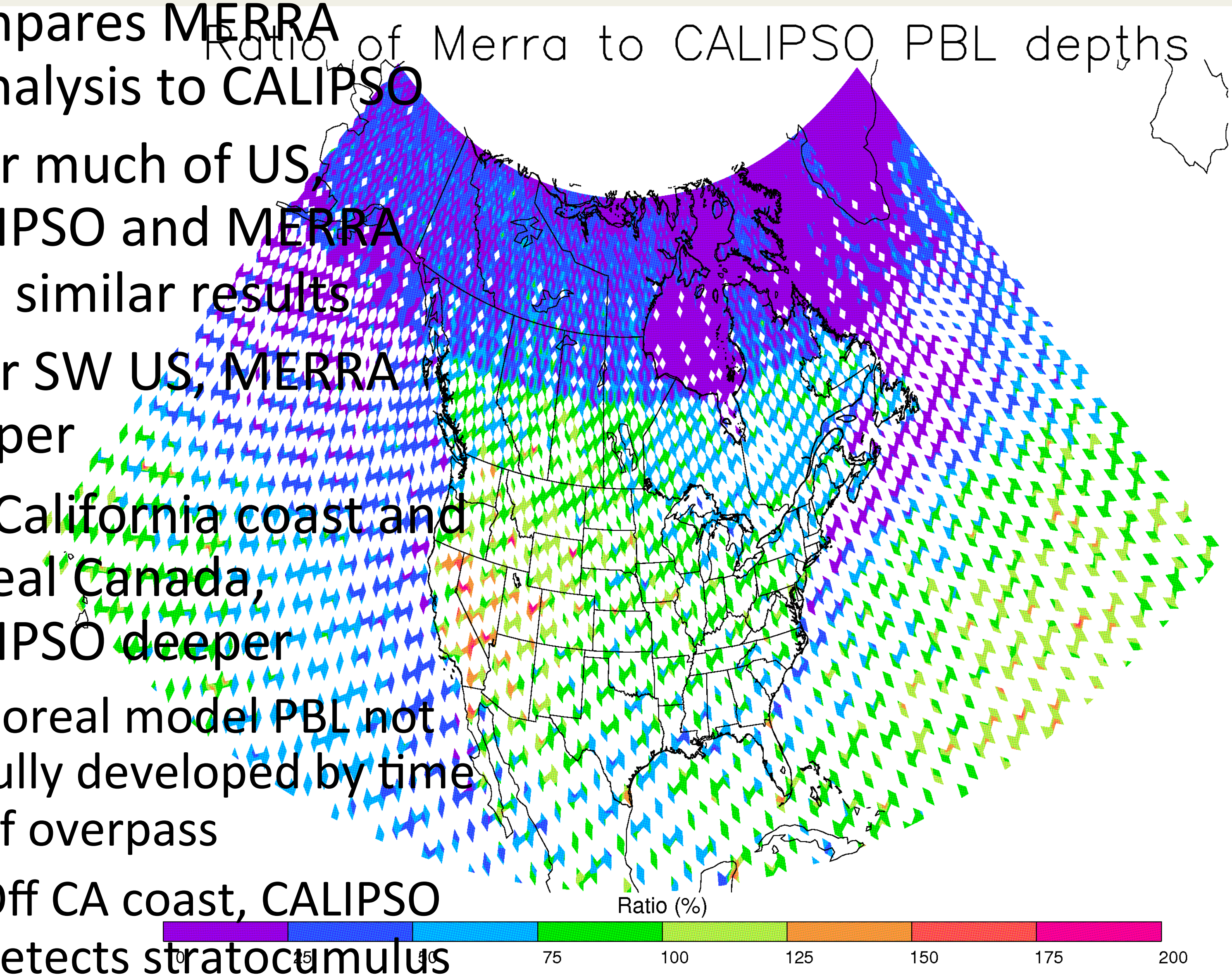
- Lowest variability over water
- Highest variability along Rocky Mountains and boreal North America
- Standard deviation of almost 1 km here in Colorado!



- Deeper PBL over land
- Shallow PBL off California coast
- Shallow PBL over Midwest farmlands
- Deeper PBL over Rocky Mountains and Mexican Plateau
- Deeper PBL over Canada - stomatal control and longer day length



- Compares MERRA reanalysis to CALIPSO
- Over much of US, CALIPSO and MERRA give similar results
- Over SW US, MERRA deeper
- Off California coast and boreal Canada, CALIPSO deeper
  - Boreal model PBL not fully developed by time of overpass
  - Off CA coast, CALIPSO detects stratocumulus cloud top



← CALIPSO is deeper MERRA is deeper →

Conclusions

- PBL depth is important for carbon budget studies, especially inversion studies
- Inaccurate PBL depths produce inaccurate CO_2 mixing ratios, even for perfect surface fluxes
- Millions of satellite observations can be used to determine PBL depth and constrain model simulations
- Initial estimates are qualitatively reasonable

- Success of the retrieval is greatest over subtropical oceans
- General success over land is about 50%
- Decreased success over Southwestern United States and convective regions
- Underprediction of PBL depths by reanalyses over oceans
- Overprediction by reanalyses over SW United States