Cloud Properties: How much water is in a cloud?

presented by
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with guidance from
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Motivation

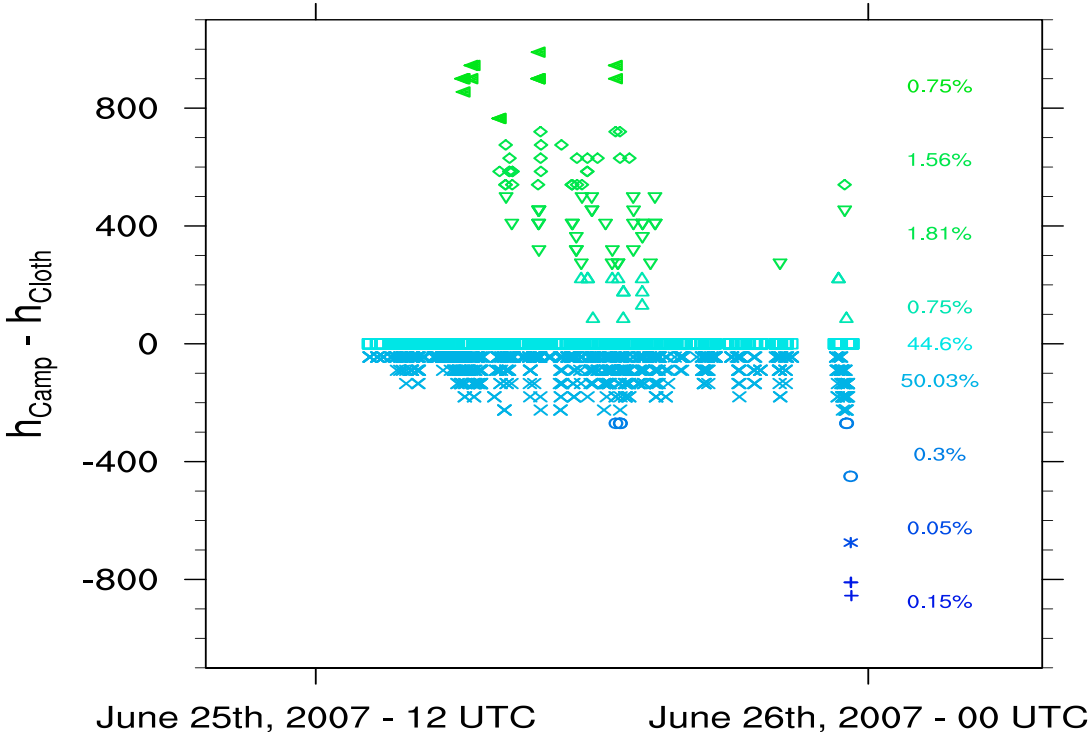
- Key for determining precipitation initiation
- Important interactions with solar and terrestrial radiation
- Models need to parameterize these processes, so to evaluate the parameterizations it is crucial to know cloud properties

Gathering the Data

- Active Remote Sensing of Clouds (ARSCL) data from June 25, 2007 from the Southern Great Plains (SGP) site
- Two cloud detection products based on radar and lidar observations with 10 second resolution (Clothiaux et al. 1998 and Campbell et al. 1998)
  - Cloud base height
  - Cloud top height
- Best estimate of LWP based on physical and statistical retrieval from MWR with ~30 second resolution (Gaustad et al. 2011)
- Radiosondes (0Z, 6Z, 12Z, and 18Z) to find horizontal wind at cloud base
- Total Sky Imager to see clouds throughout the day

Total Sky Imager from June 25, 2007

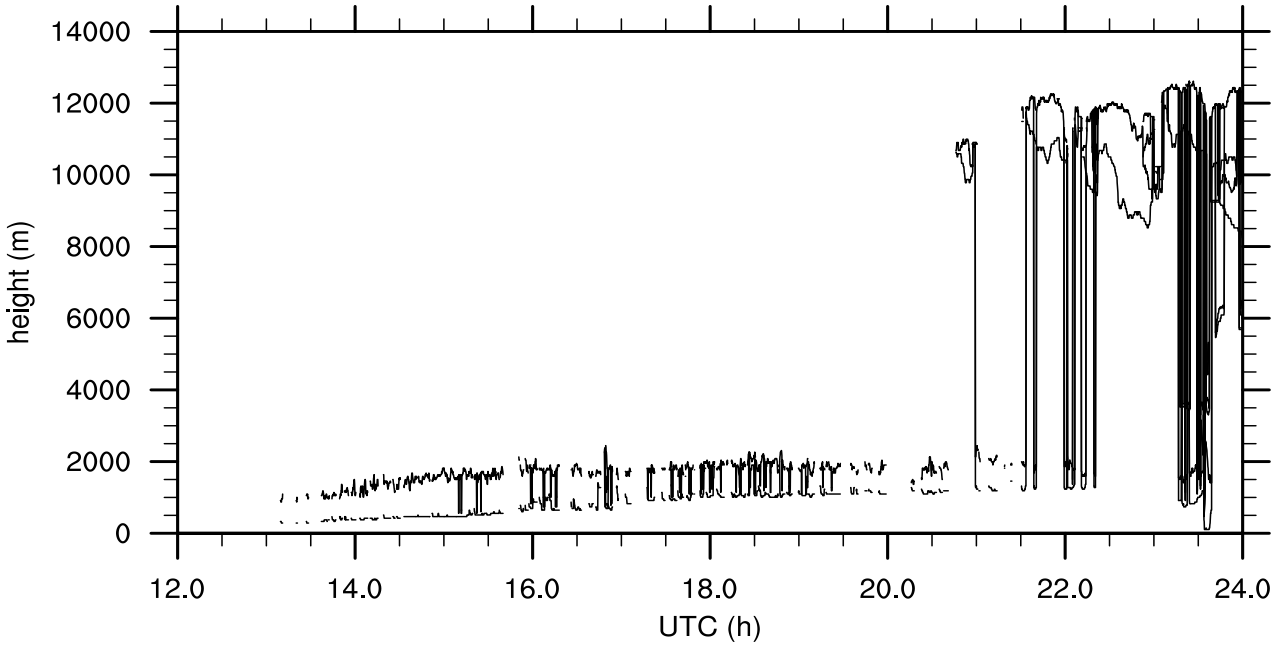
Cloud Height Retrievals



- Clothiaux et al. 1998 and Campbell et al. 1998
- In over 50% of cases Campbell retrieves shallower clouds
- For our study, we use Clothiaux et al. 2001

Gathering the Data

Step 1: Identify isolated liquid clouds and find cloud boundaries



- Identifying isolated, liquid clouds:
  - Throw out clouds with multiple layers
  - Throw out clouds above the meltinglevel (determined from interpolated radiosondes)
  - Throw out negative liquid water paths (LWP)

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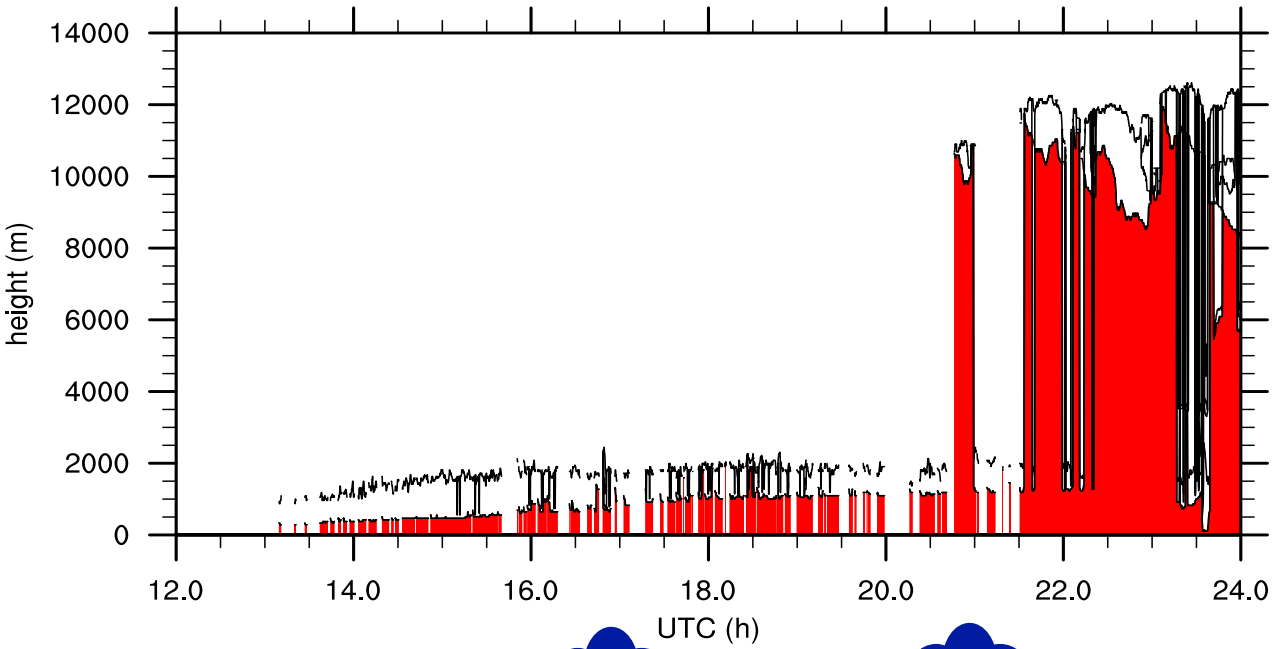

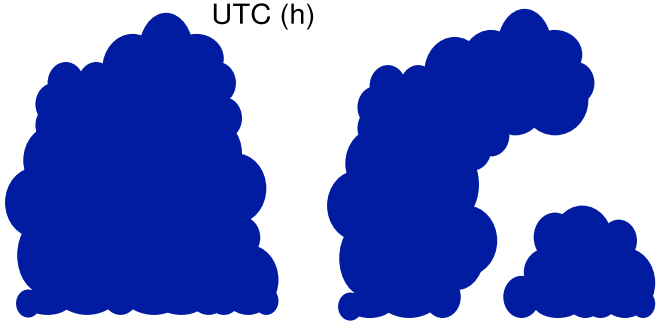

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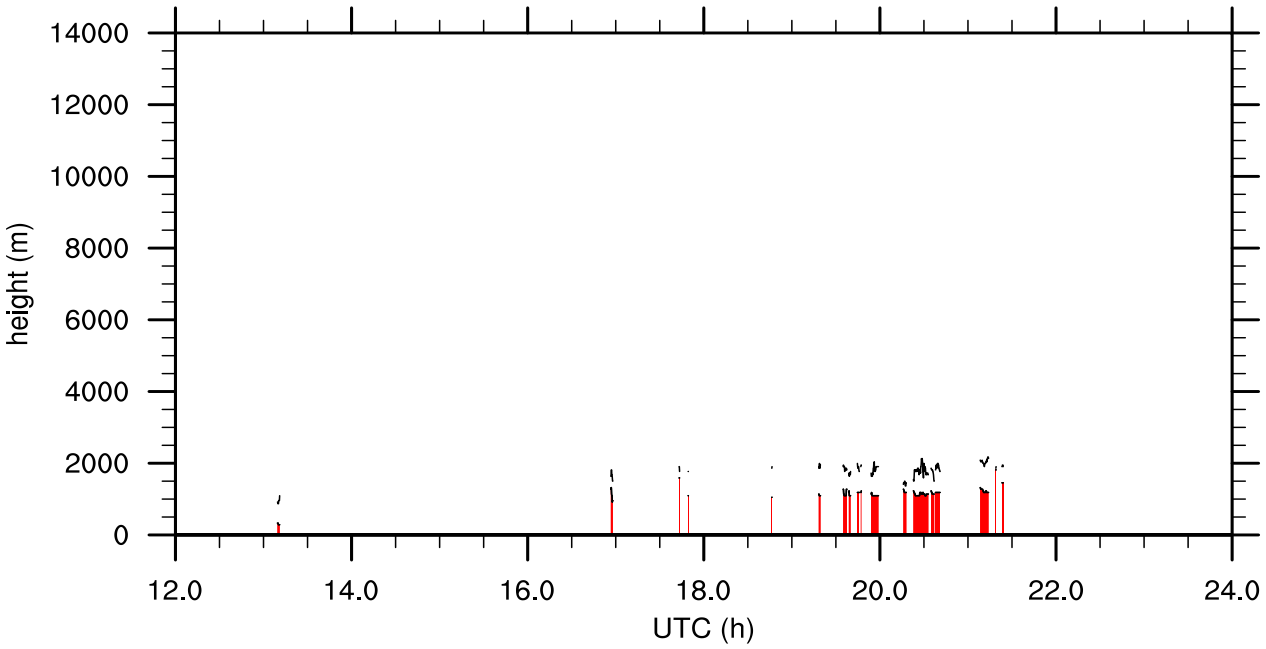

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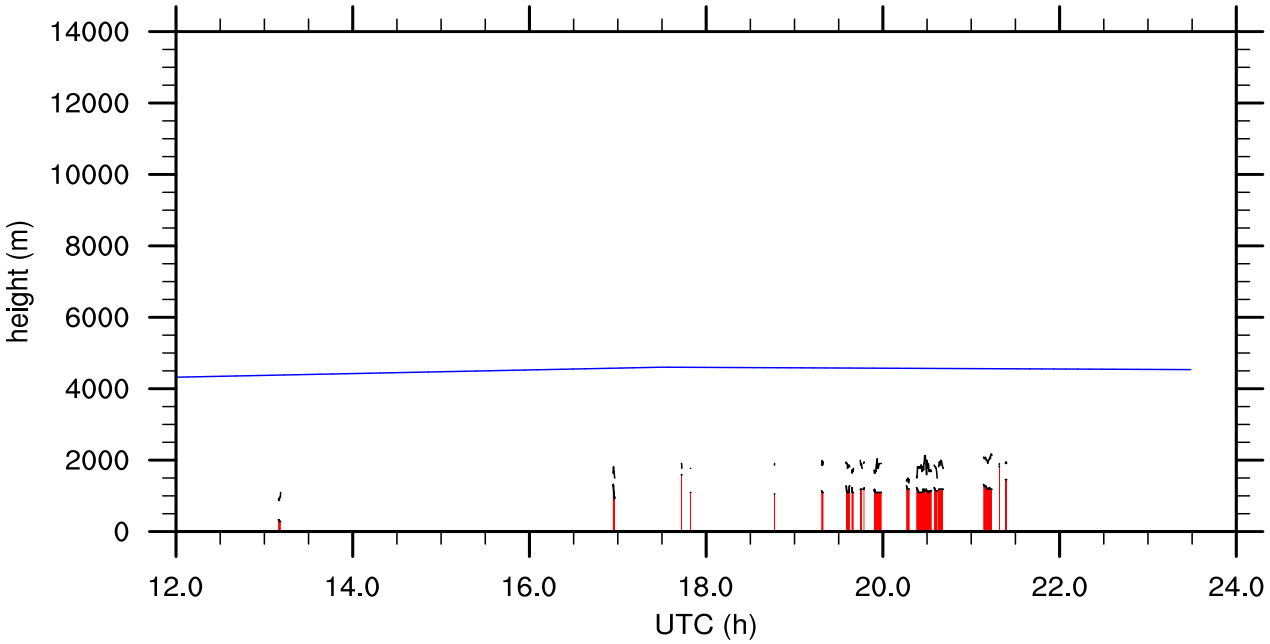

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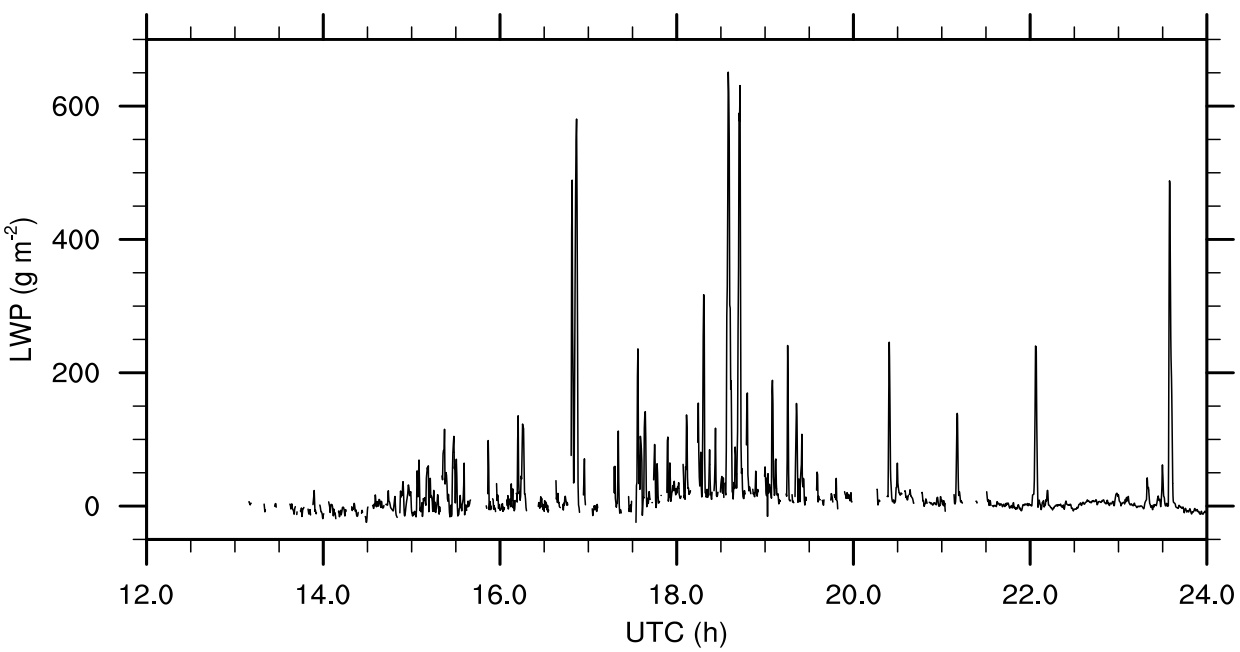

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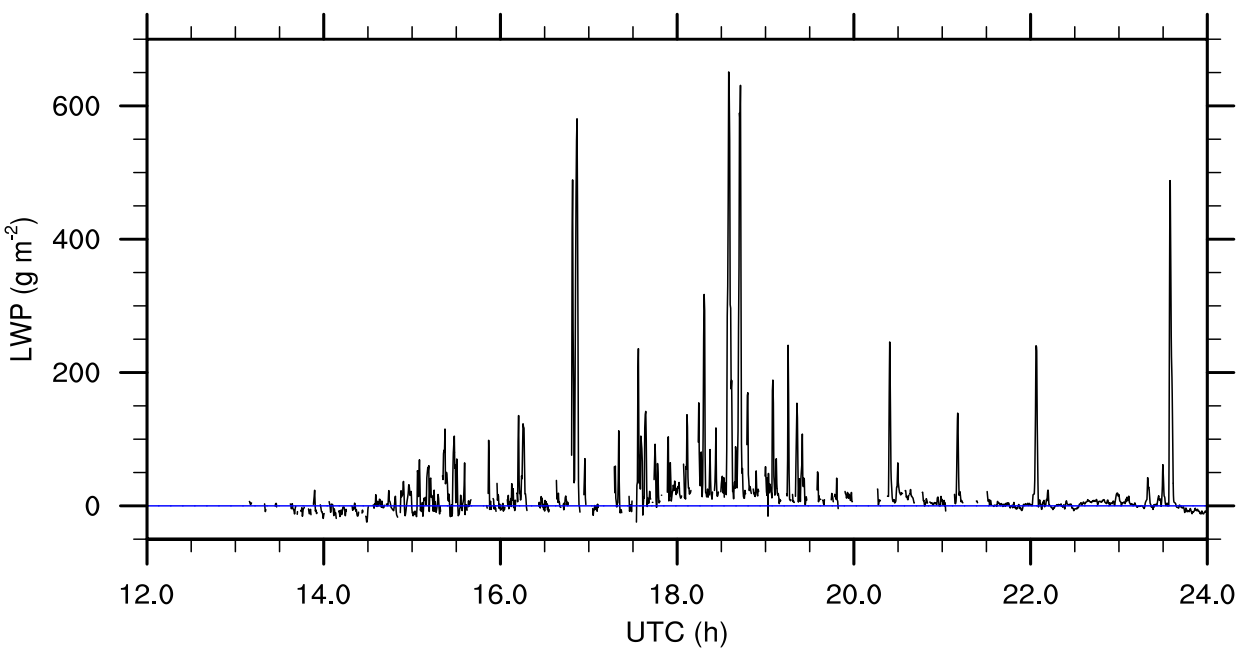

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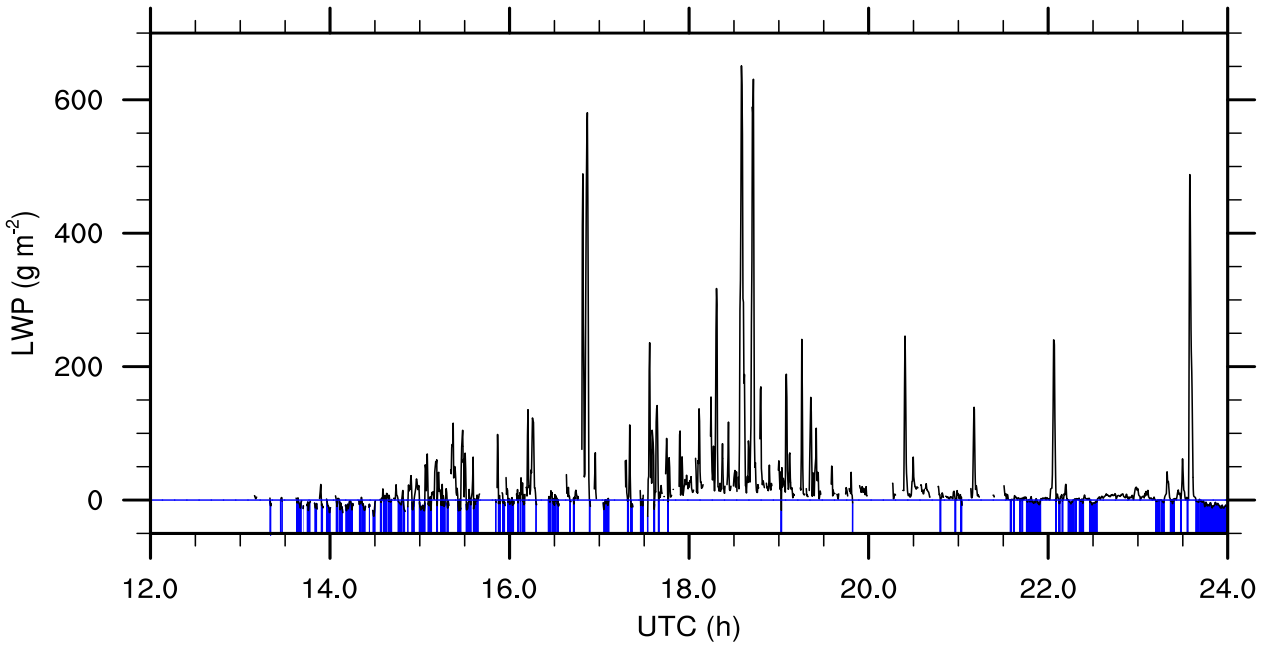

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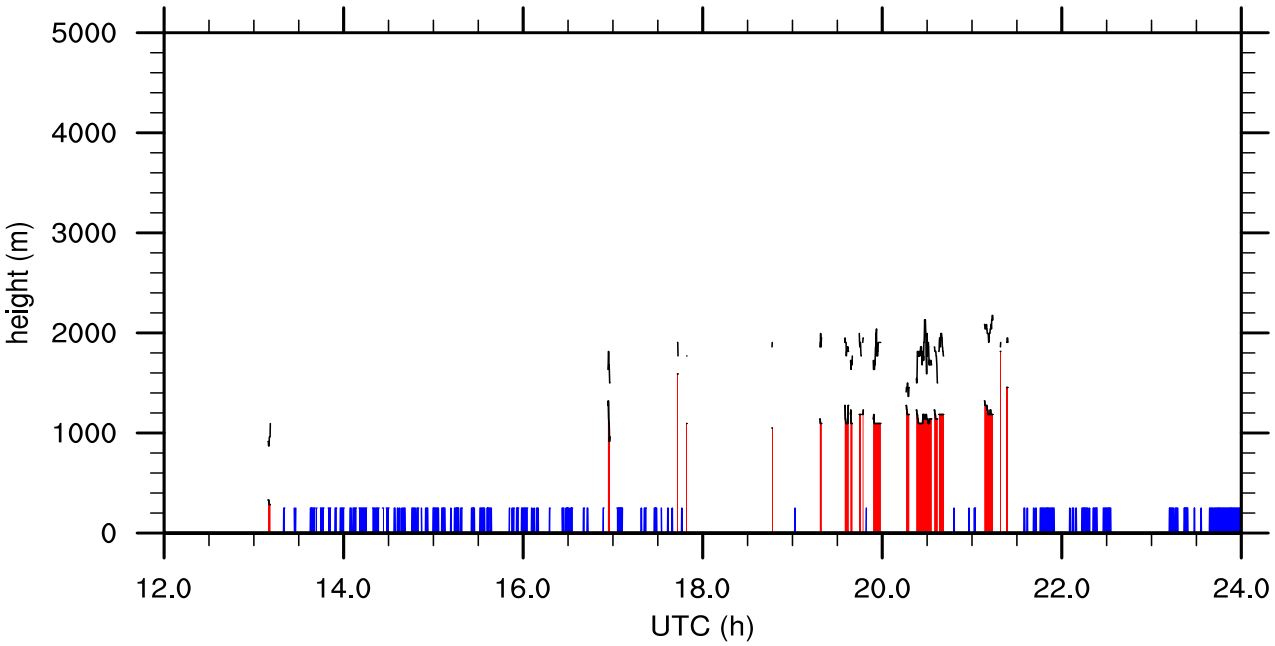

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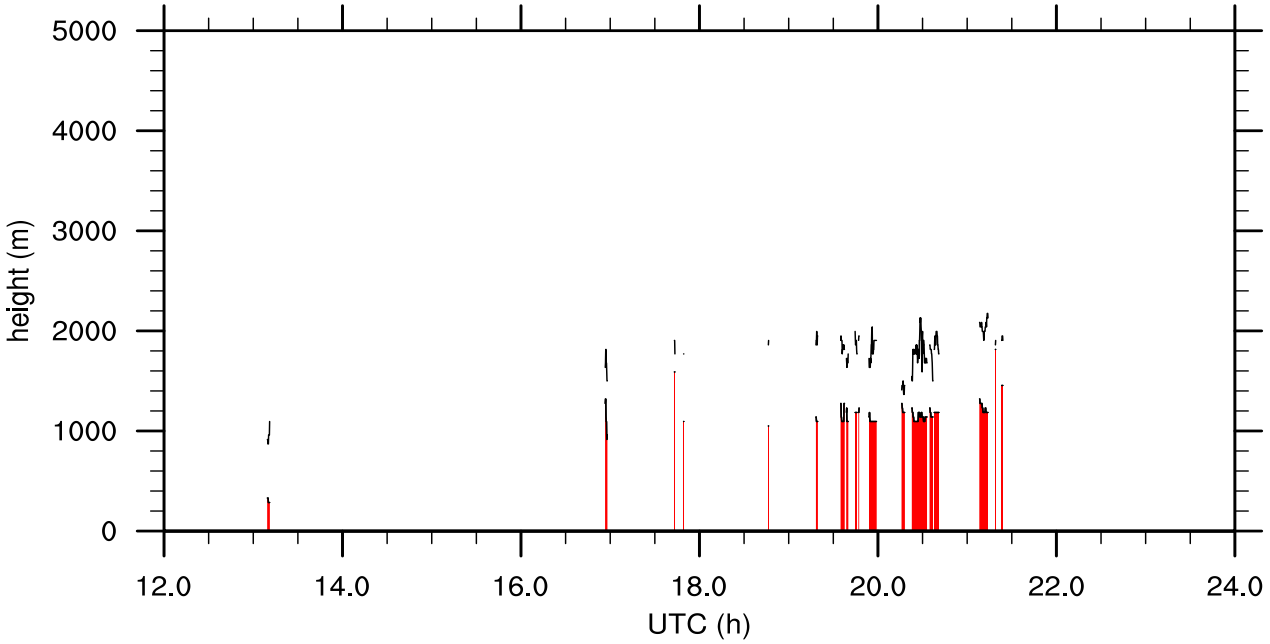

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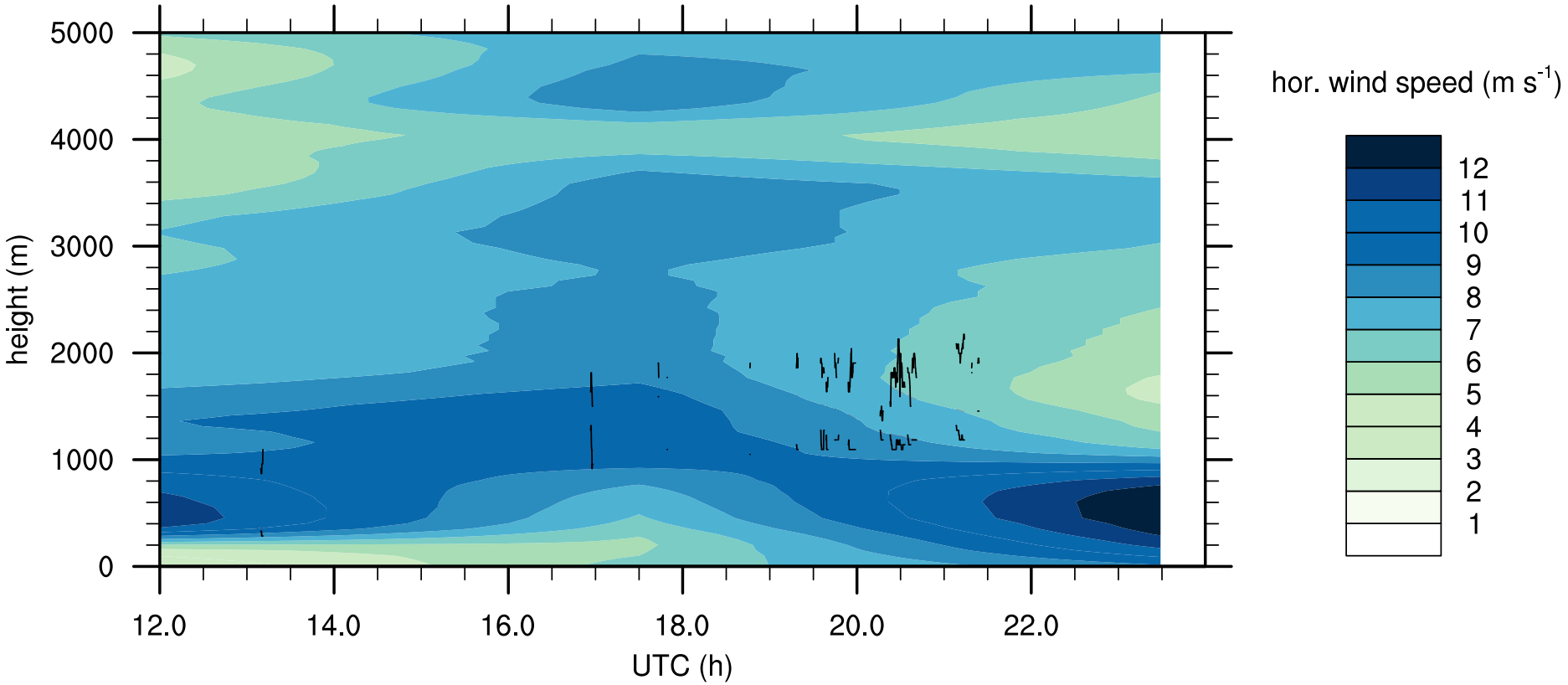
Gathering the Data

Step 2: Estimate horizontal extent of clouds

$$\Delta x = u \cdot \Delta t$$



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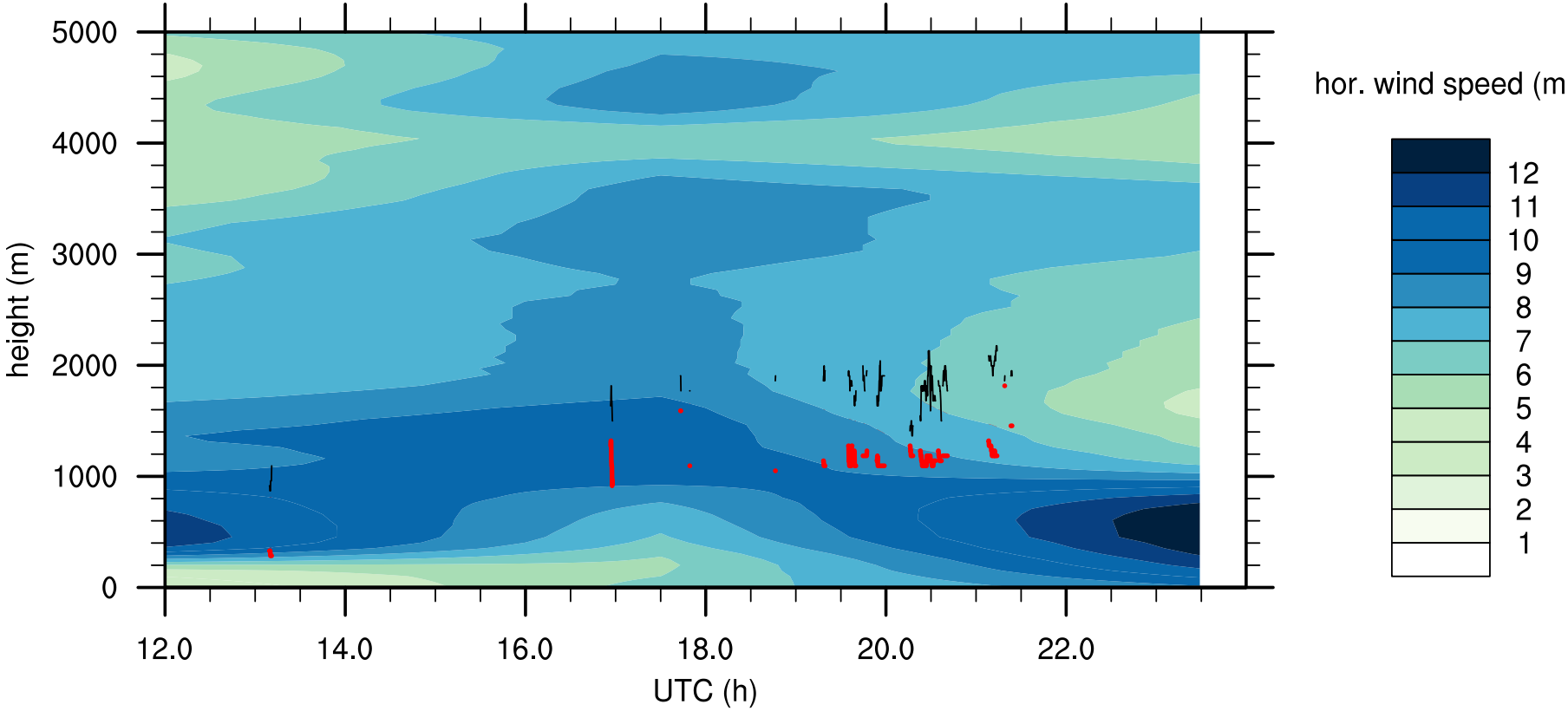
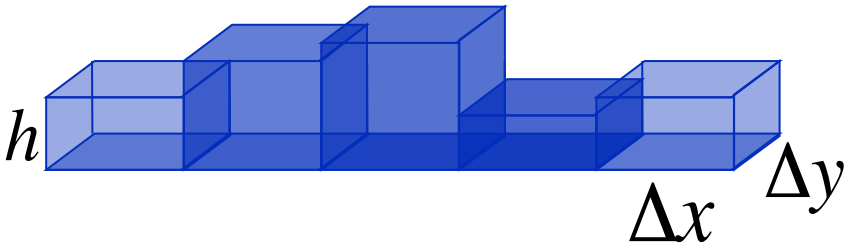


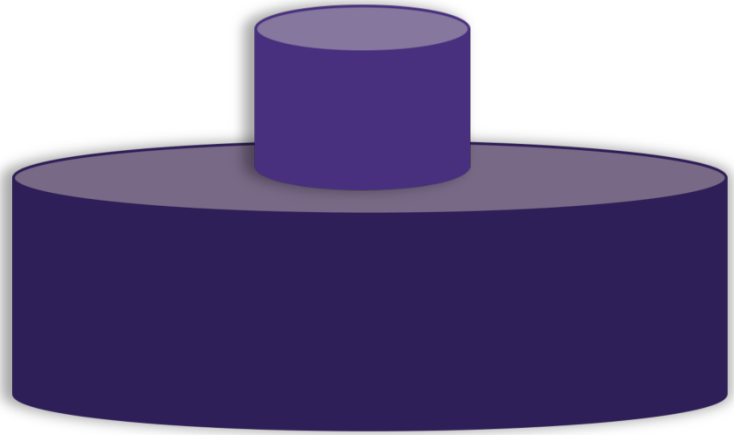
Gathering the Data

Step 2: Estimate horizontal extent of clouds

Column Clouds

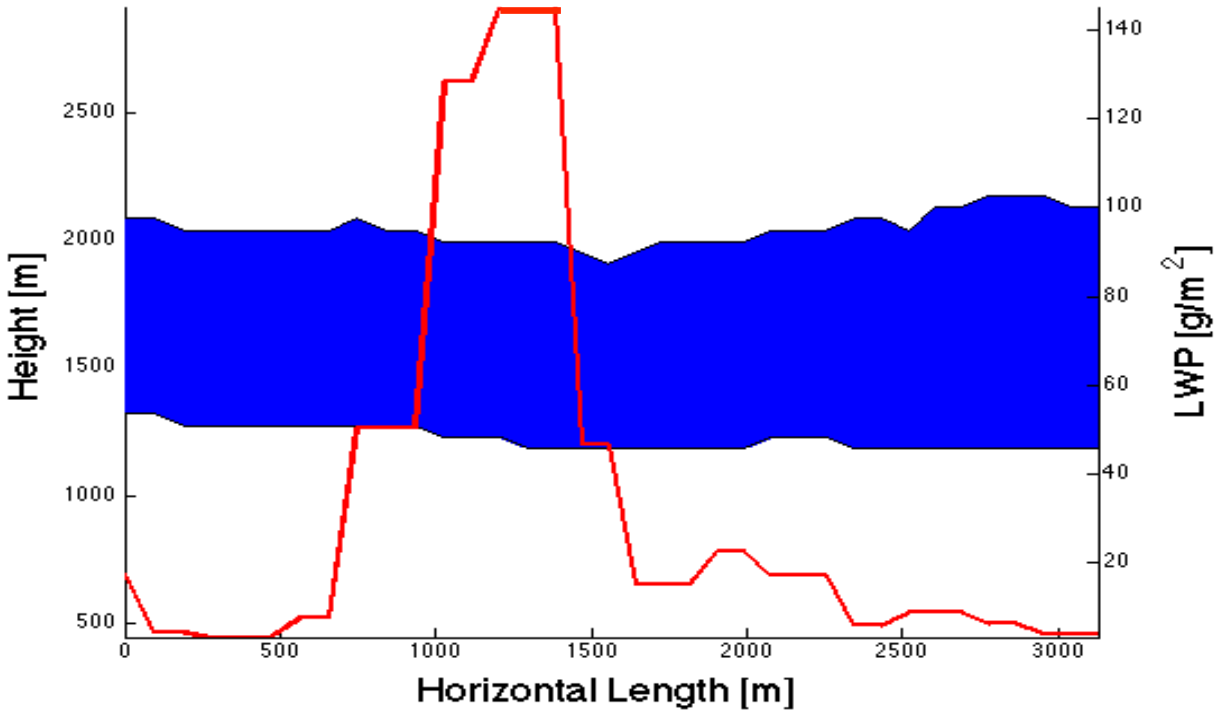


Circle Clouds



Gathering the Data
Step 3: Identify LWP of these isolated liquid clouds

- Match interpolated LWP to every 10 seconds with cloud thickness



Gathering the Data

Step 4: Estimate volume, water amount and latent heat of clouds

- Volume:

$$\frac{\pi}{4}\sum_{i=1}\frac{Z(i)+Z(n_{total}+1-i)}{2}\left[((n_{total}-2(i-1))\Delta x)^2-((n_{total}-2i)\Delta x)^2\right]$$

- Water Amount:

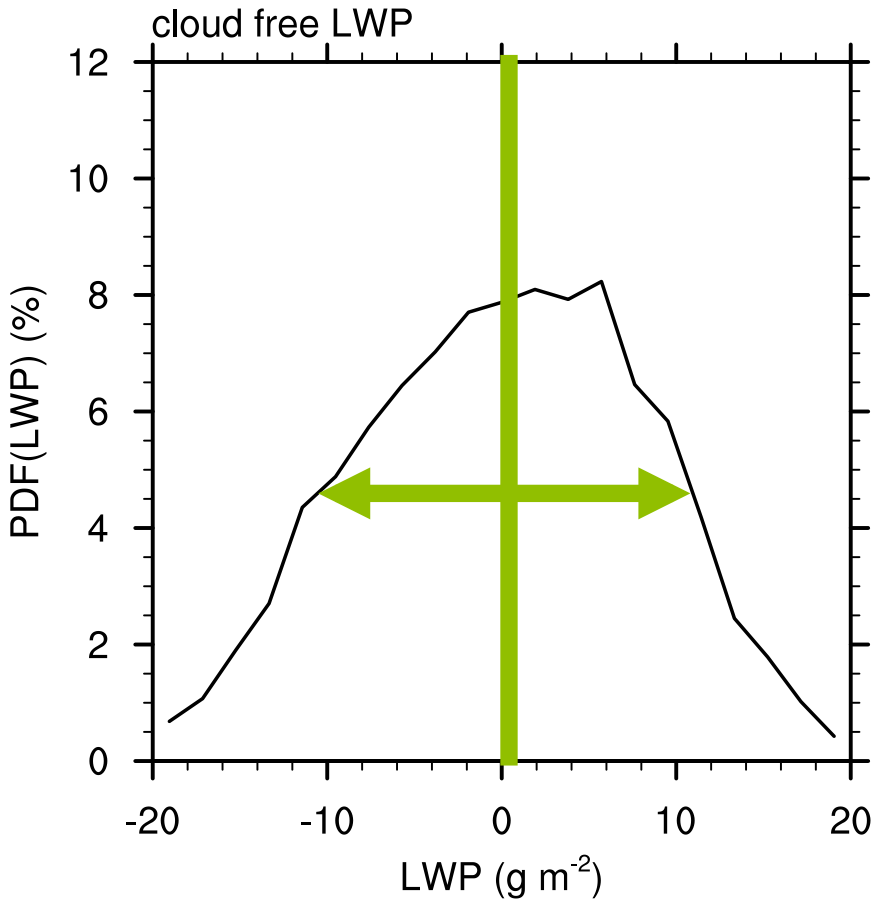
$$\frac{\pi}{4}\sum_{i=1}\frac{LWP(i)+LWP(n_{total}+1-i)}{2}\left[((n_{total}-2(i-1))\Delta x)^2-((n_{total}-2i)\Delta x)^2\right]$$

- Latent Heat Contained in Each Cloud:

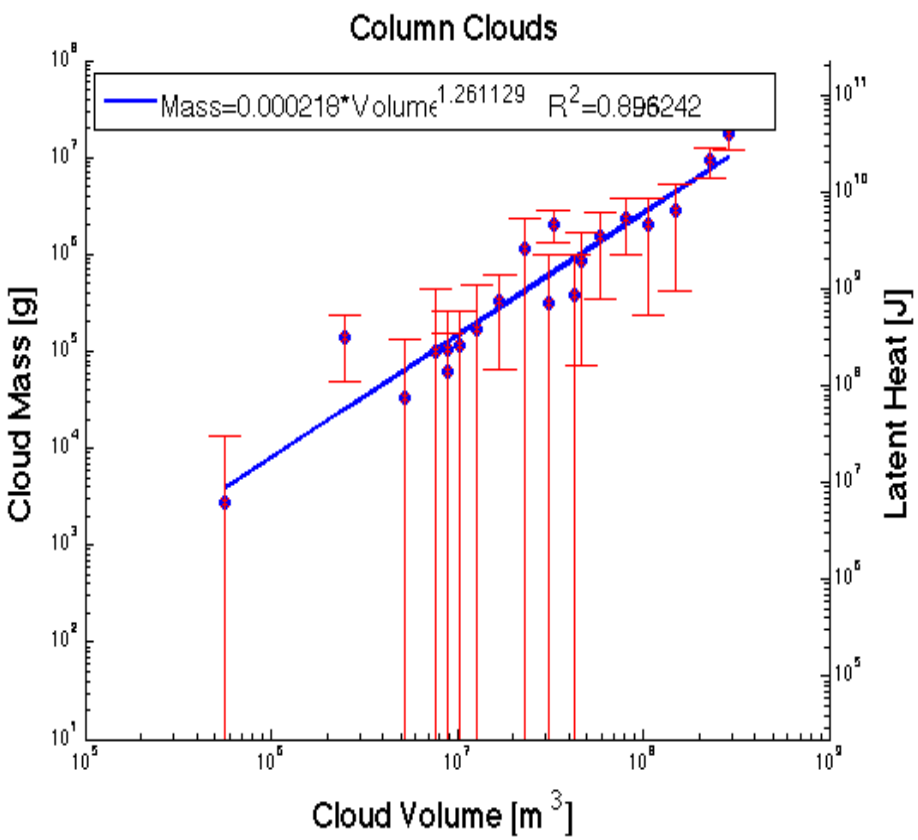
$$LH_{cloud}=L_v\cdot water_{cloud}$$

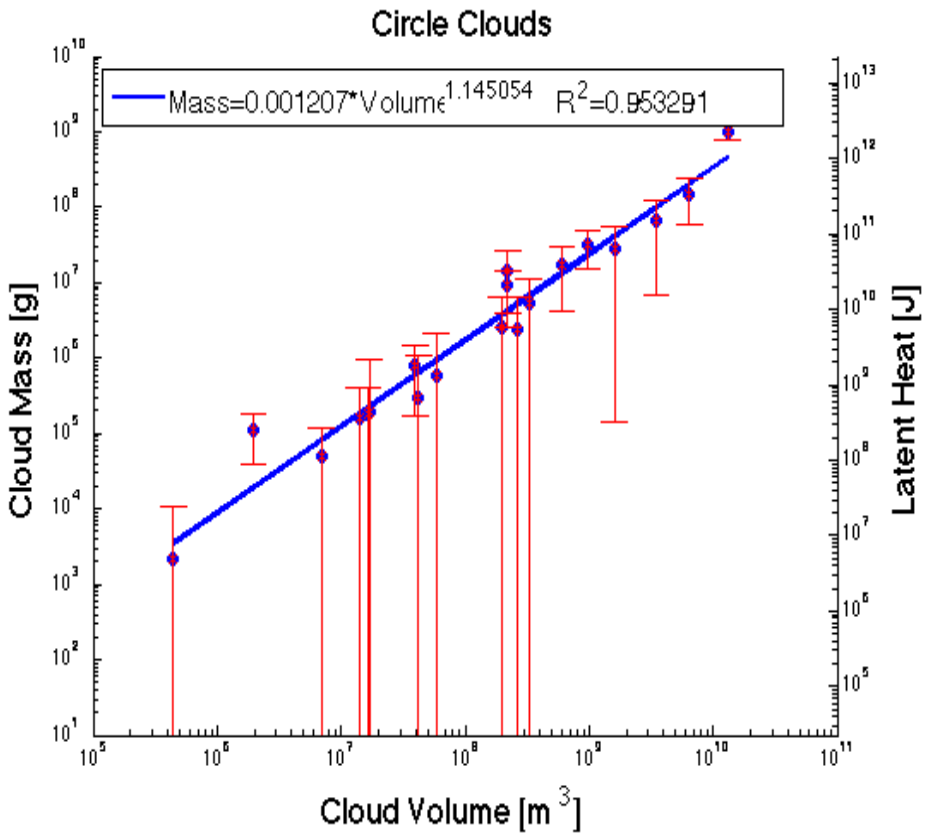
$$L_v=2.26\ x\ 10^6\ J/kg$$

LWP Uncertainty



Results

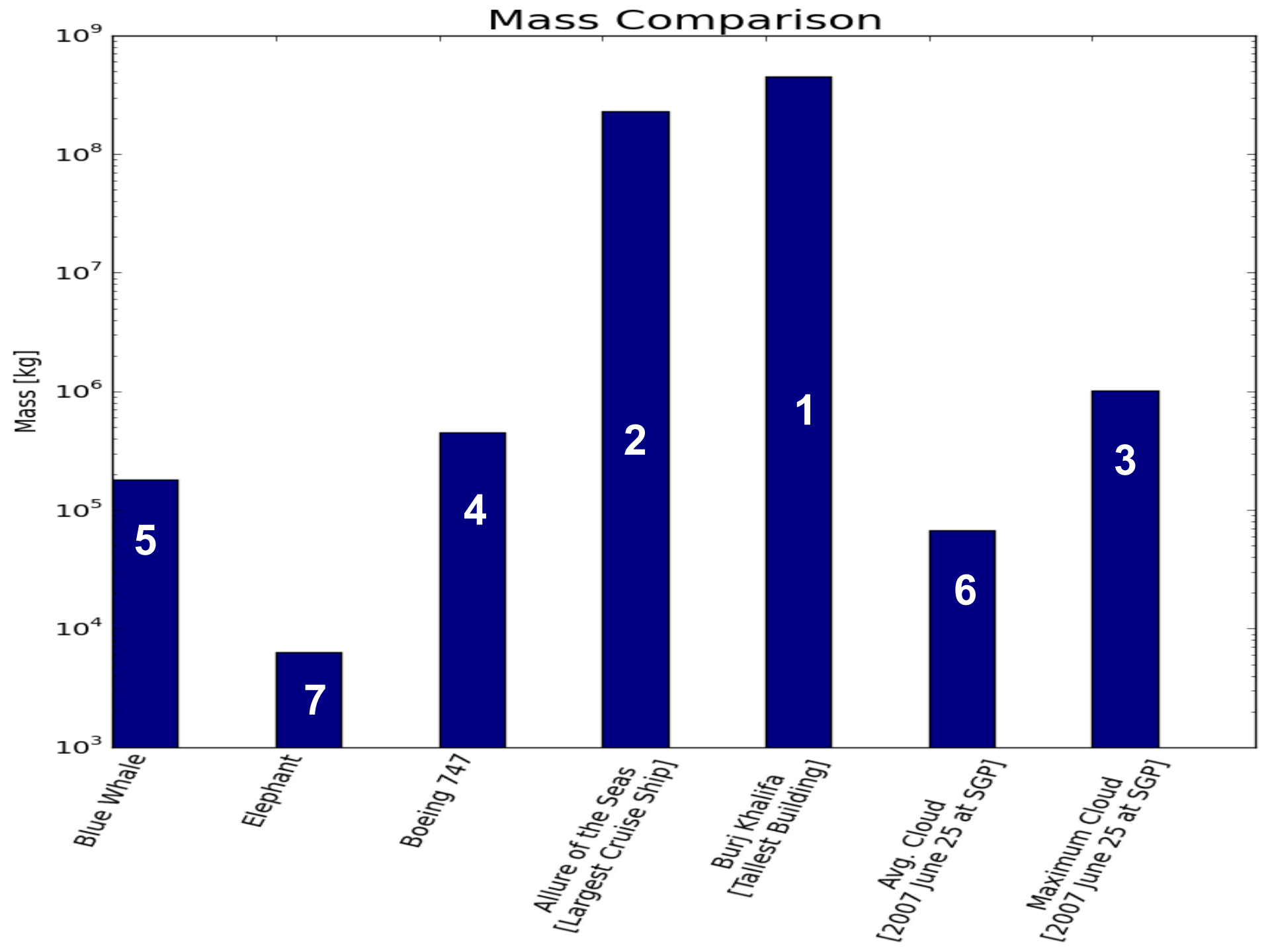

Column Clouds
Mass=0.000218*Volume^1.261129 R^2=0.896242
Cloud Mass [g]
Latent Heat [J]
Cloud Volume [m^3]


Circle Clouds
Mass=0.001207*Volume^1.145054 R^2=0.953291
Cloud Mass [g]
Latent Heat [J]
Cloud Volume [m^3]

How much mass is contained in a shallow cumulus cloud?

- **Blue Whale:** largest animal ever known to lived; weighs in at **181,000 kilograms** (Source: animals.nationalgeographic.com)
- **African Elephant:** largest land animal; weighs in at **6,350 kilograms** (Source: animals.nationalgeographic.com)
- **Boeing 747-8F:** maximum takeoff weight is **447,700 kilograms** (Source: boeing.com)
- **Allure of the Seas:** world's largest cruise ship; weight of **228,897,079 kilograms** (Source: royalcaribbean.com)
- **Burj Khalifa:** world's tallest building; weight of **453,592,370 kilograms** (Source: great-towers.com)

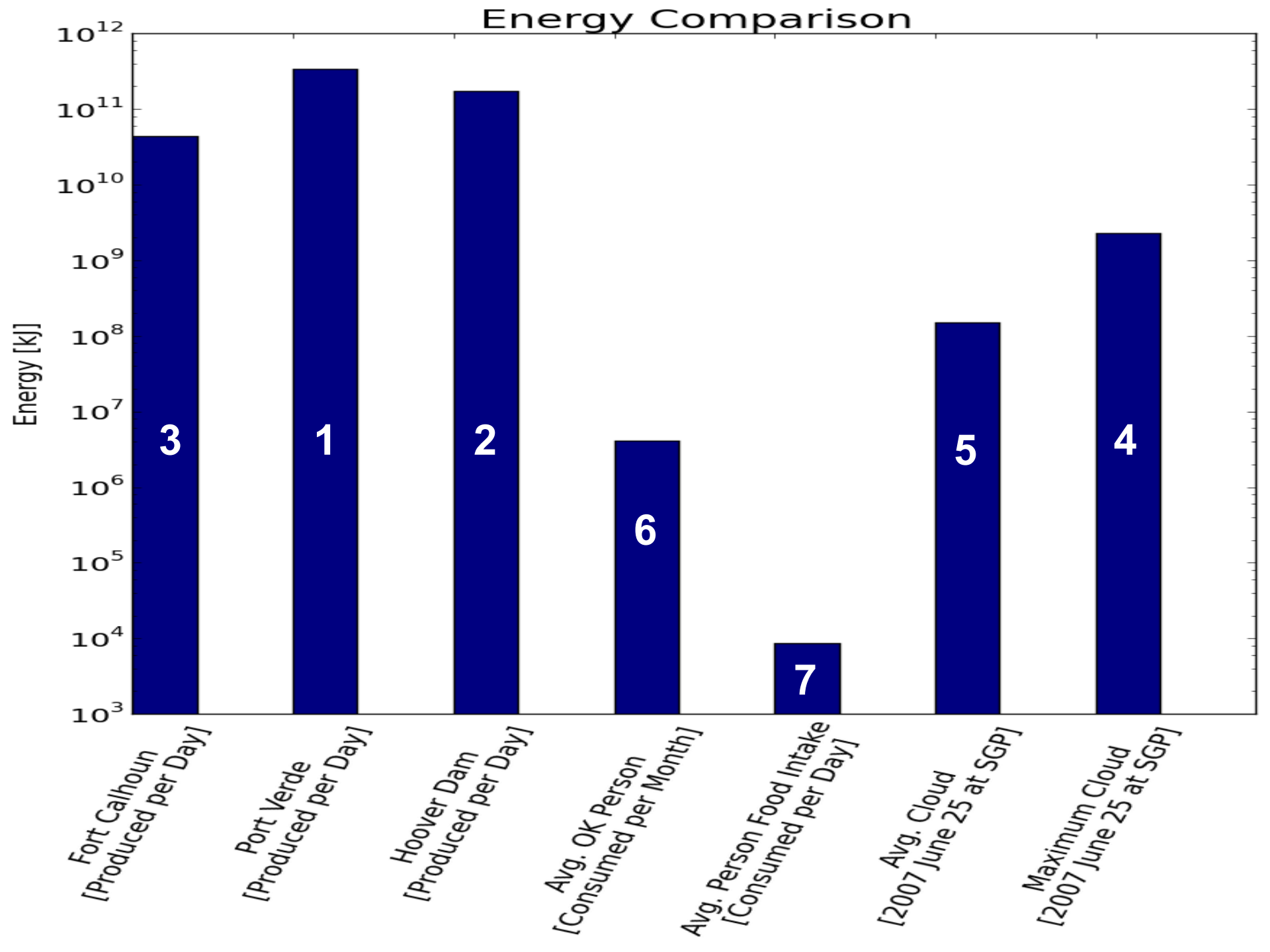
How do these compare to the mass contained in a cloud?!? Any guesses?


Mass Comparison
Mass [kg]
10^9
10^8
10^7
10^6
10^5
10^4
10^3
5
7
4
2
1
6
3
Blue Whale
Elephant
Boeing 747
Allure of the Seas [Largest Cruise Ship]
Burj Khalifa [Tallest Building]
Avg. Cloud [2007 June 25 at SGP]
Maximum Cloud [2007 June 25 at SGP]

How much energy is contained in a shallow cumulus cloud?

- **Fort Calhoun:** smallest generating capacity nuclear power plant in US; generates 12,048 megawatt-hours over 24 hours or **43,372,800,000 kilojoules** (Source: eia.gov)
- **Port Verde:** largest generating capacity nuclear power plant in US; generates 94,488 megawatt-hours over 24 hours or **340,156,800,000 kilojoules** (Source: eia.gov)
- **Hoover Dam:** provides to nearly 8 million people; can produce 48,000 mWh over 24 hours or **172,800,000,000 kilojoules** (Source: powerauthority.org)
- **Monthly Consumed Power for the Average Oklahoman:** In 2013, residential electricity consumption averaged 1,132 kilowatt-hours per month or **4,075,200 kilojoules per month** (Source: electricitylocal.com from U.S. Energy Information Administration (2012))
- **Daily Food Consumption for the Average Person:** The average person should consumed **8,700 kilojoules per day**. (Source: mydailyintake.net)

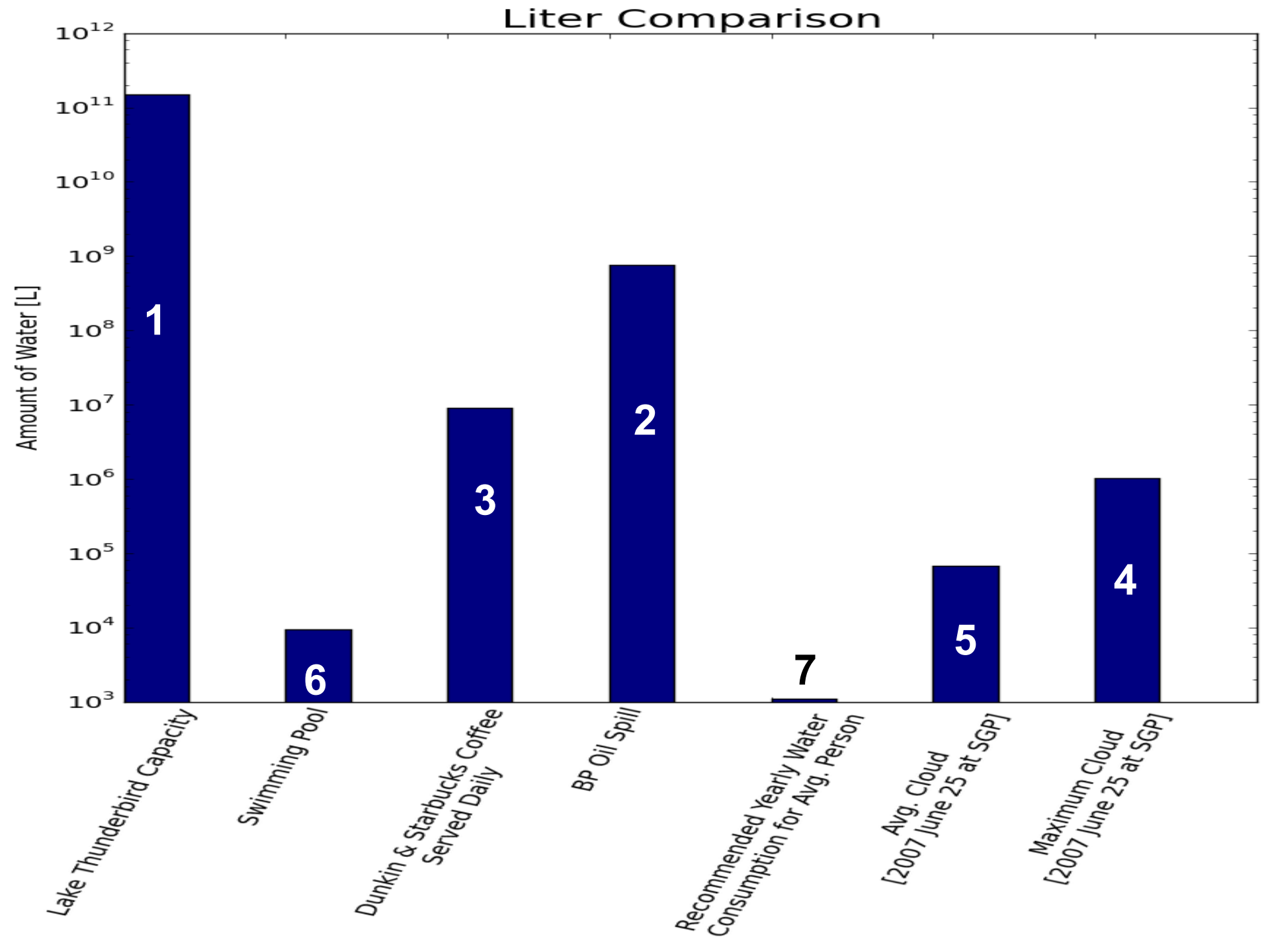
How do these compare to the energy contained in a cloud?!? Any guesses?


Energy Comparison
Energy [kJ]
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
3
1
2
6
7
5
4
Fort Calhoun [Produced per Day]
Port Verde [Produced per Day]
Hoover Dam [Produced per Day]
Avg. OK Person [Consumed per Month]
Avg. Person Food Intake [Consumed per Day]
Avg. Cloud [2007 June 25 at SGP]
Maximum Cloud [2007 June 25 at SGP]

How many liters of water are contained in a shallow cumulus cloud?

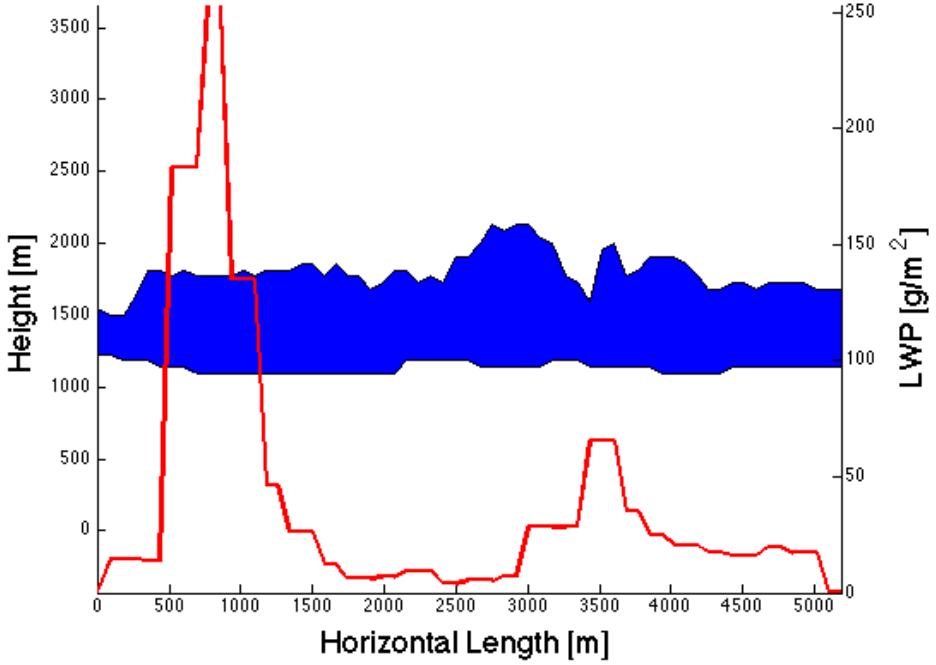
- **Capacity of Lake Thunderbird:** nearby lake that provides drinking water to Norman; capacity of 119,600 acre-feet or **147,524,427,770 liters** of water (Source: owrb.ok.gov)
- **Swimming Pool:** a five feet deep and 15 feet diameter circular swimming pool contains **9,342 liters** of water (Source: swimmingpool.com)
- **Coffee Served by Dunkin' Doughnuts and Starbucks a Day:** the two coffee serving chains serve 2,400,000 million gallons or **9,084,988 liters** of coffee a day (Source: tomlobaugh.com)
- ***Deepwater Horizon* Oil Spill (BP Oil Spill):** In April 2010, 200,000,000 gallons or **757,082,356 liters** of oil spilled into the Gulf of Mexico (Source: dosomething.org)
- **Recommended Yearly Water Consumption for the Average Person:** The average person should consumed 3 liters per day or **1095 liters** per year. (Source: mayoclinic.org)

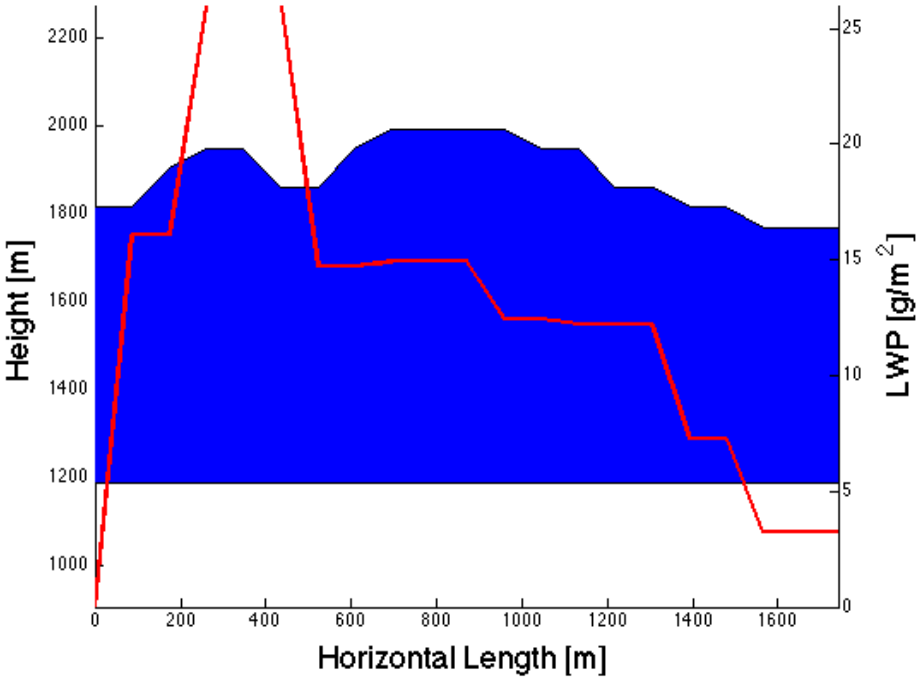
How do these compare to the liters contained in a cloud?!? Any guesses?


Liter Comparison
Amount of Water [L]
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
1
2
3
4
5
6
7
Lake Thunderbird Capacity
Swimming Pool
Dunkin & Starbucks Coffee Served Daily
BP Oil Spill
Recommended Yearly Water Consumption for Avg. Person
Avg. Cloud [2007 June 25 at SGP]
Maximum Cloud [2007 June 25 at SGP]

Conclusions

- Key to know cloud properties for precipitation, radiative processes, and model parameterization evaluation
- There is a relationship between cloud volume and cloud mass, and cloud volume and amount of latent heat (however there are uncertainties)
- The average shallow cumulus cloud weighs around 67 tons and contains 1.56 x 10^{11} joules!!


Height [m]
LWP [g/m^2]
Horizontal Length [m]


Height [m]
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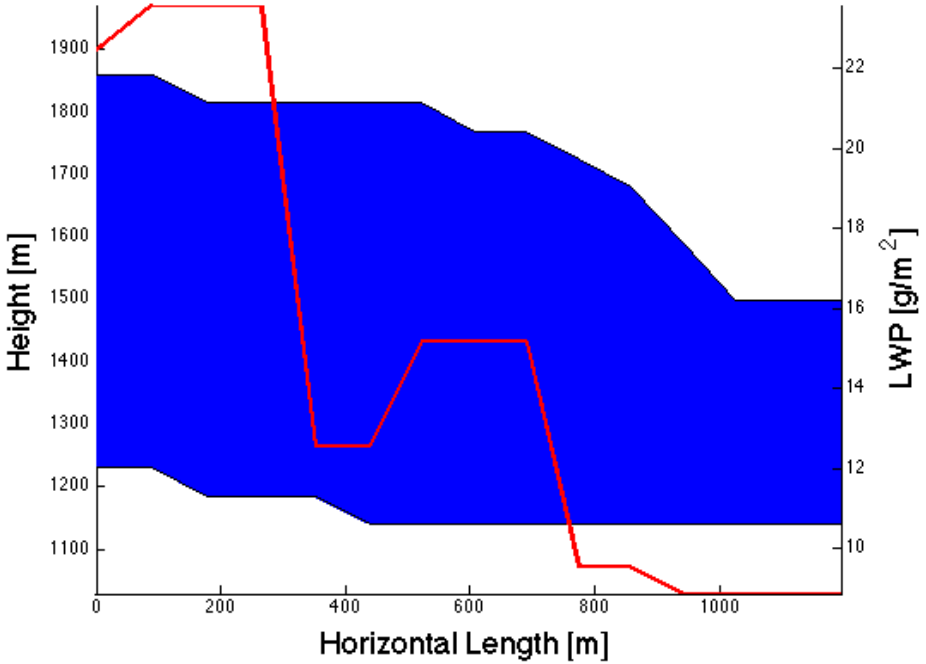
Height [m]
LWP [g/m^2]
Horizontal Length [m]