Cloud condensation nuclei closure during the Texas Air Quality Study of 2006

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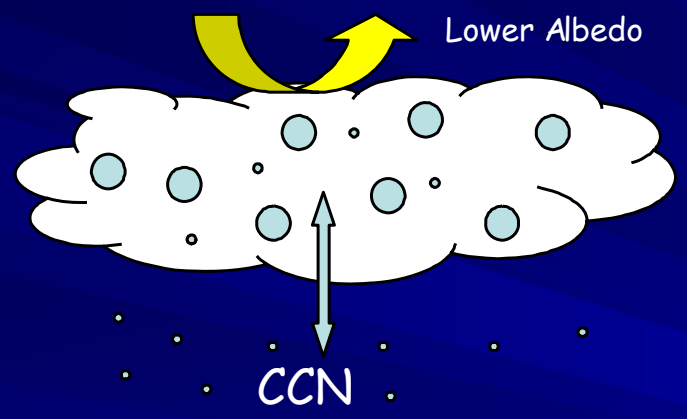
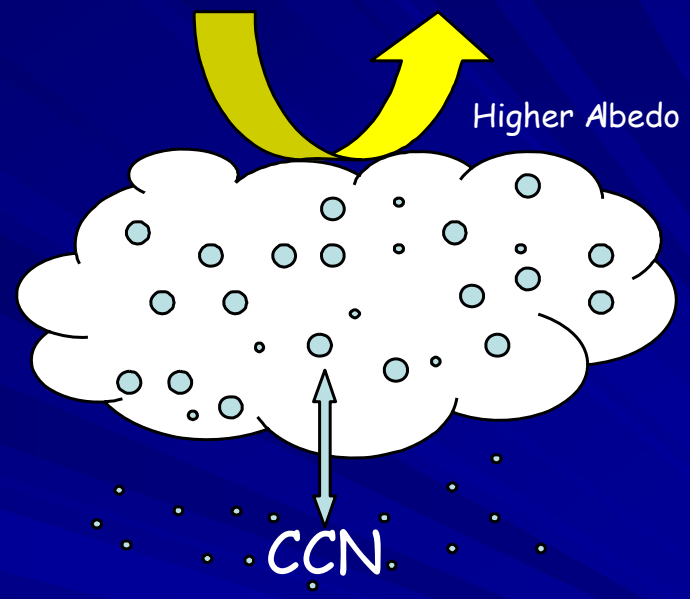
Humans affect clouds and hydrological cycle?

Yes! By changing the concentration of Cloud Condensation Nuclei (CCN) in the atmosphere. This phenomenon is known as the "**indirect climatic effect of aerosols**".



Clean Environment
(few CCN)



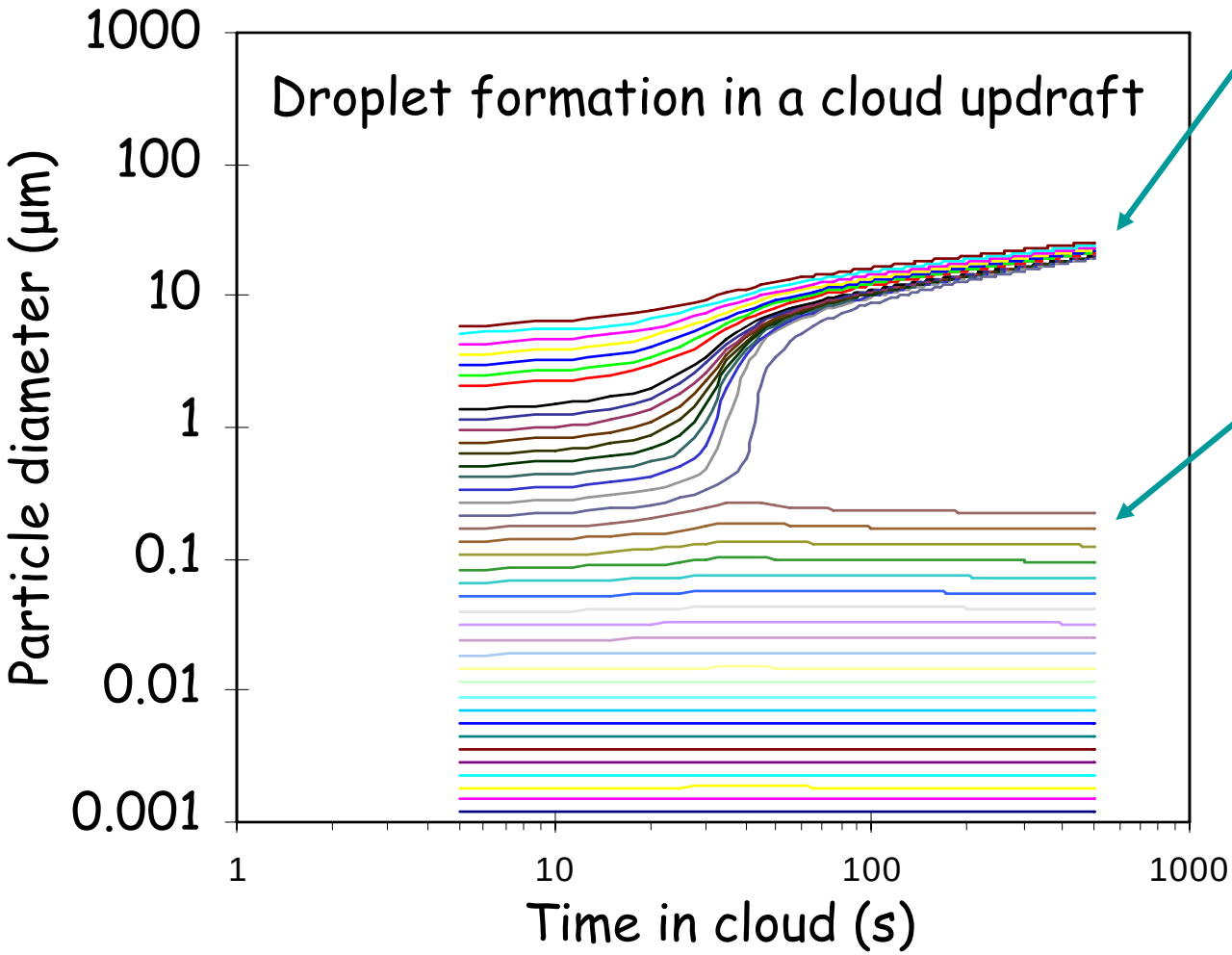
Polluted Environment
(more CCN)

Increasing particles tends to cool climate (potentially alot).

Climate models are the only tools for assessing the anthropogenic indirect effect, but this is very challenging.

CCN: The aerosol-cloud link

Each particle needs a certain level of water vapor concentration to grow to cloud droplet size (~10 μm).



Some particles become droplets (they **are** CCN)

…and some do not (they **are not** CCN)

Which particle properties controls this distinction?

- dry size
- composition
- surface tension

The aerosol is an evolving complex "soup" that's very hard to simulate

- **Primary emissions**

  automobiles, industry, domestic, vegetation, forest fires..

- **Secondary compounds**

  From oxidation of precursors (by O_3, H_2O_2, OH, NO_3, etc.)

  Reaction of volatile bases (NH_3) with acids to form NH_4NO_3, $(NH_4)_2SO_4$, etc…

Problems with GCM assessments of aerosol indirect effect

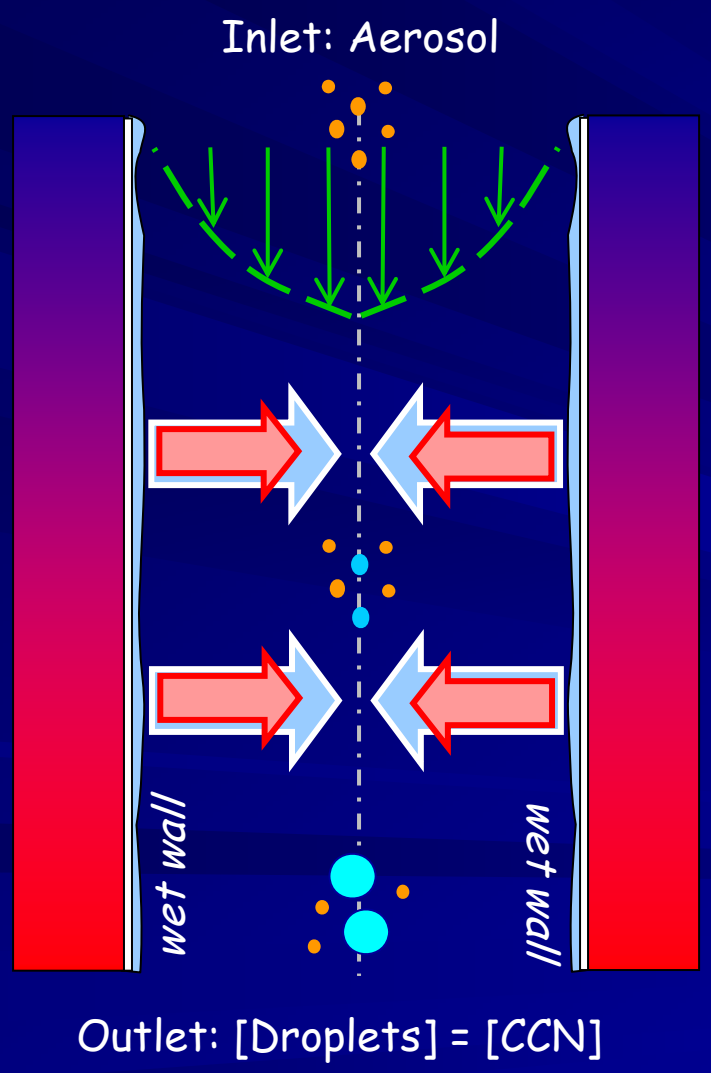
- Cloud formation happens at smaller spatial scales than global climate models can resolve, and must be parameterized.
- Aerosol-cloud interactions are complex; many processes are poorly represented, constrained and/or understood.
- Describing cloud formation explicitly in global models is VERY expensive. These calculations need to be simplified ("parameterized").
- Climate models provide limited information about clouds and aerosols.

Describing Aerosol/Cloud Processes on a Global Scale

- **How to simulate a process that we know/understand?**
  - Often extremely expensive to do it properly
  - Development of a simplified description by fitting the results of a benchmark model.
- **How do we simulate what we do not know?**
  - "The miracle of modeling"
  - Semi-empirical fits (e.g., cloud droplet concentration versus sulfate mass).
- **When is a model "good enough"?**
  - Model resolution (in space, in aerosol size, etc.)
  - Sub-grid processes, Numerical issues
- SIMPLFYING COMPLEXITY arises again and again….

Measuring CCN: a key source of data

Goal: Generate supersaturation, expose CCN to it and count how many droplets form.

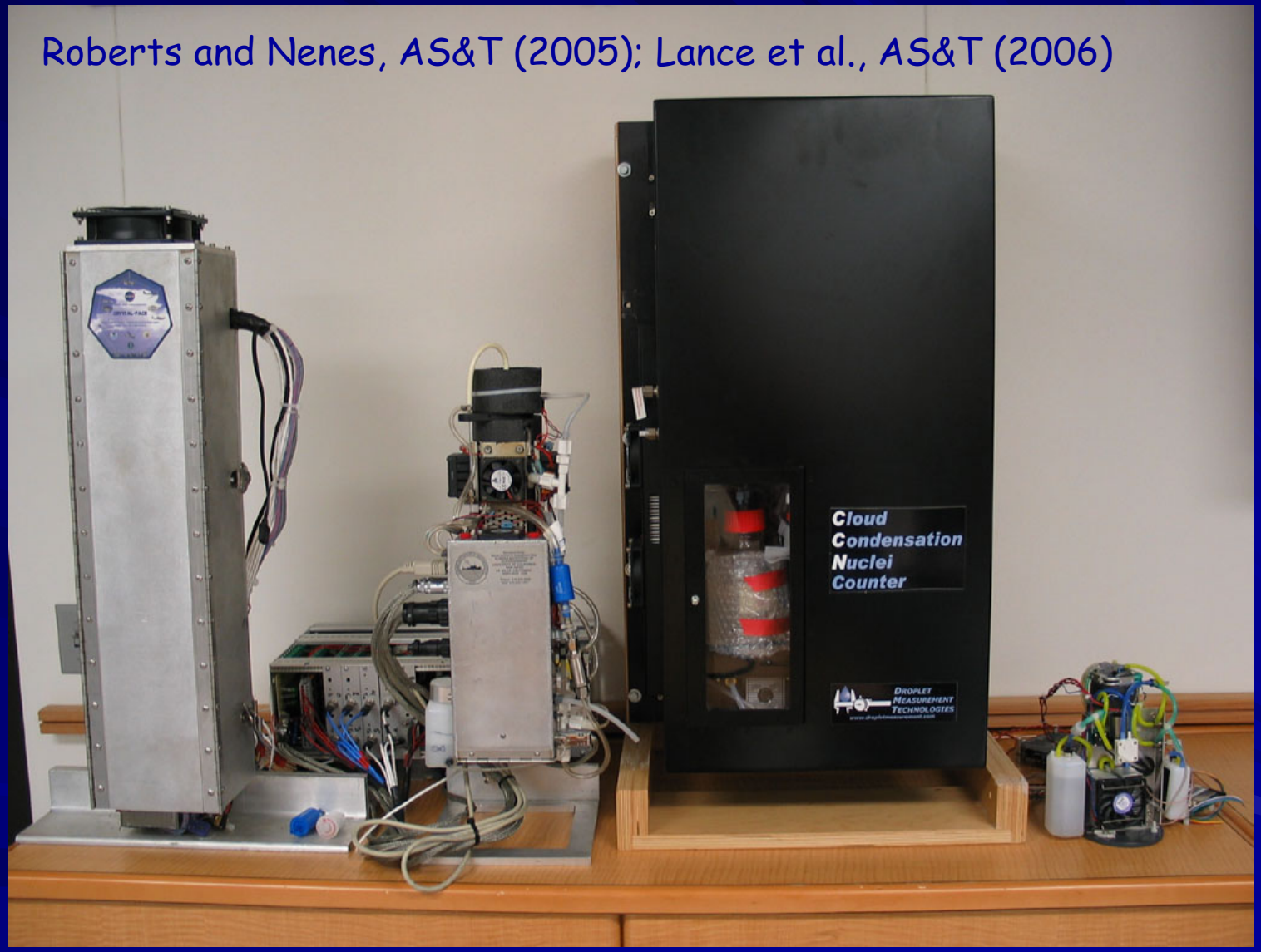


Our Method: Take a metallic cylinder, wet its walls. Cool one end, heat the other, and flow air through it.

- Wall saturated with H_2O. Linear temperature gradient.
- H_2O mass diffuses more quickly than heat and arrives at centerline first.
- The flow is supersaturated with water vapor at the centerline.
- Flowing aerosol would activate some into droplets.

Streamwise Thermal Gradient Chamber

scale = 1 m



1st version
April 2002

2nd version
January 2003

DMT
July 2004

mini version
August 2006

CCN "CLOSURE"

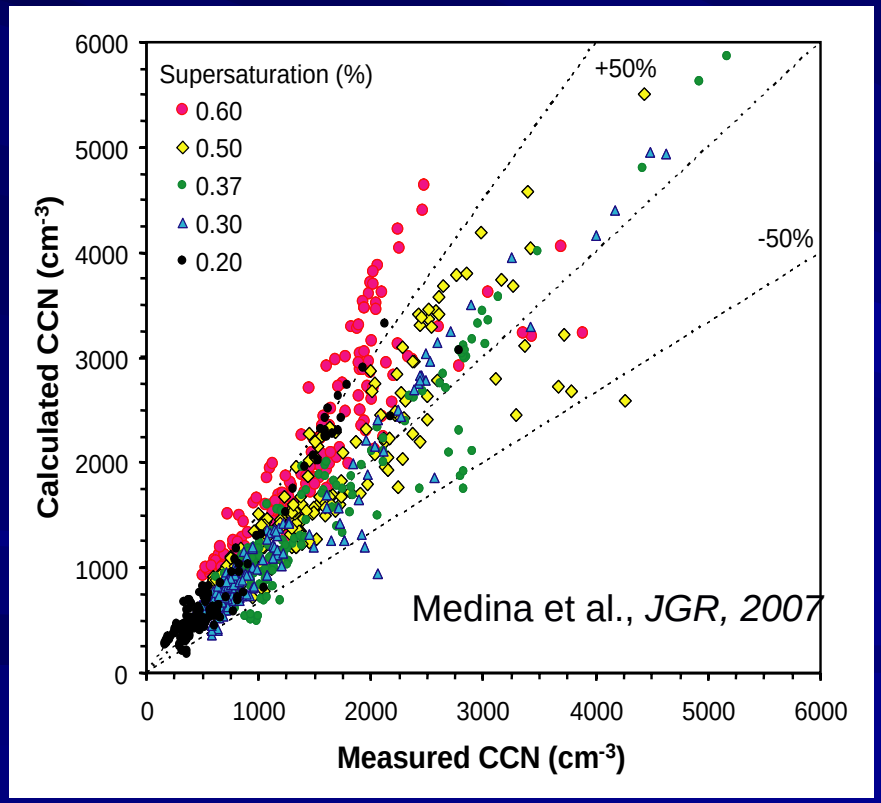
CCN MEASUREMENTS ⟷ CCN PREDICTIONS

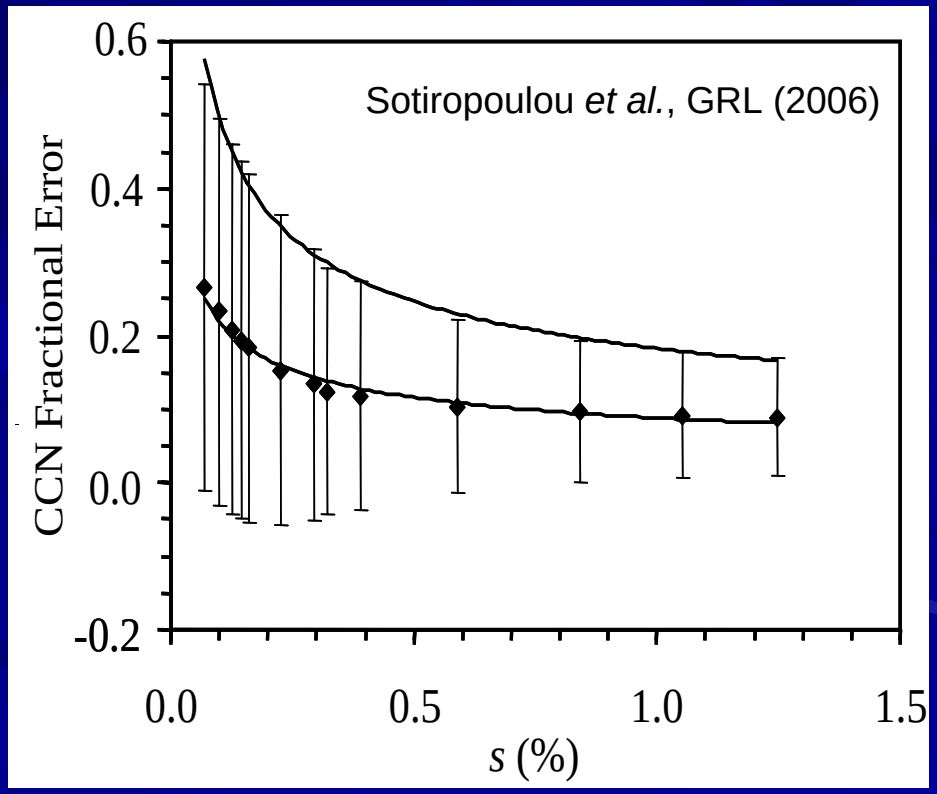
CCN Closure Study tests our theoretical understanding of CCN activation (droplet formation). Determine the "right" simplifying assumptions

Quantifying CCN prediction error for ambient aerosol allows a quantitative assessment of indirect forcing uncertainty.

CCN closure: how is it done?

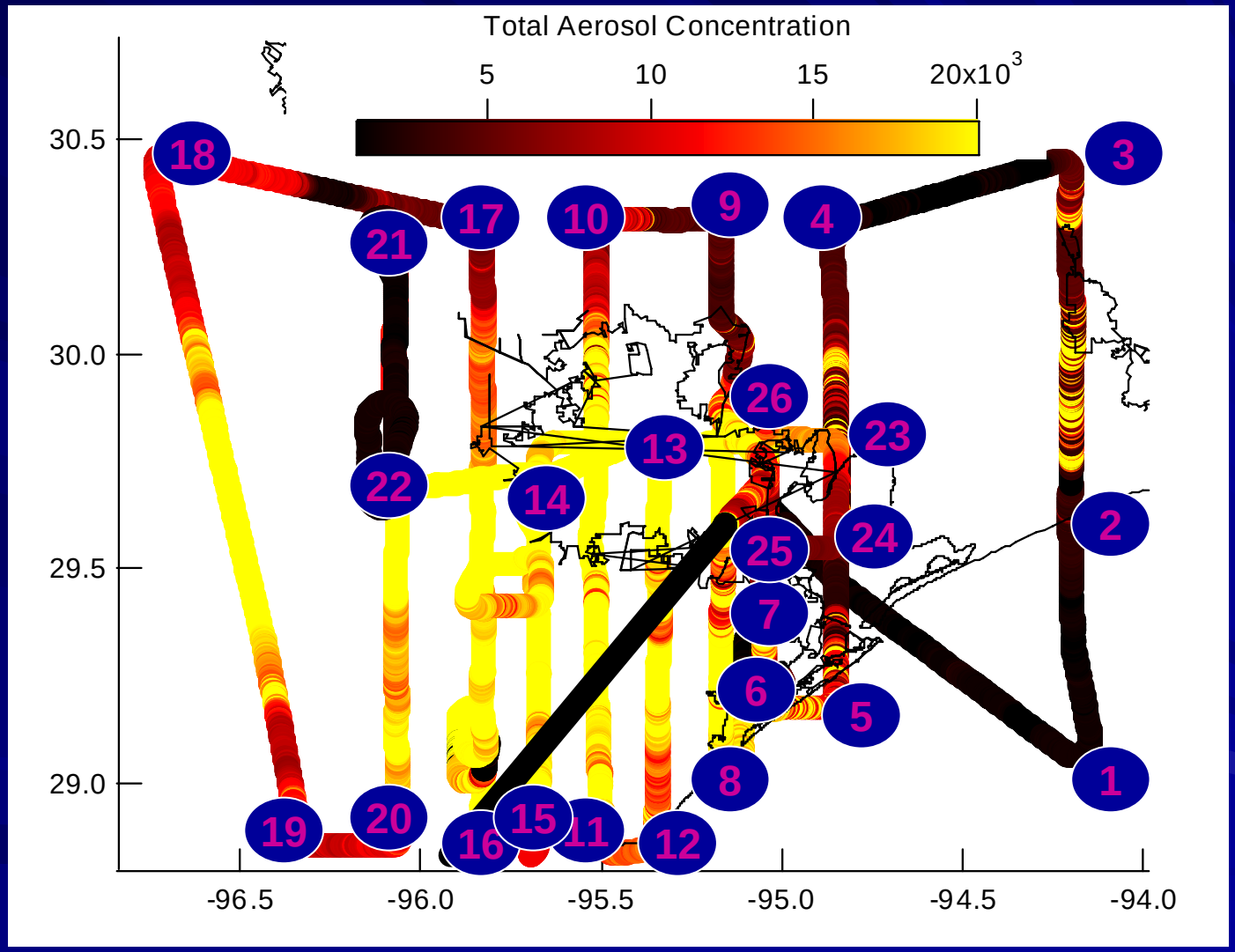
- Measure aerosol size & composition (PILS, AMS) .
- "Plug" into Köhler theory and predict CCN concentrations.
- Compare with measured CCN (0.1-0.3% supersaturation) and assess closure.





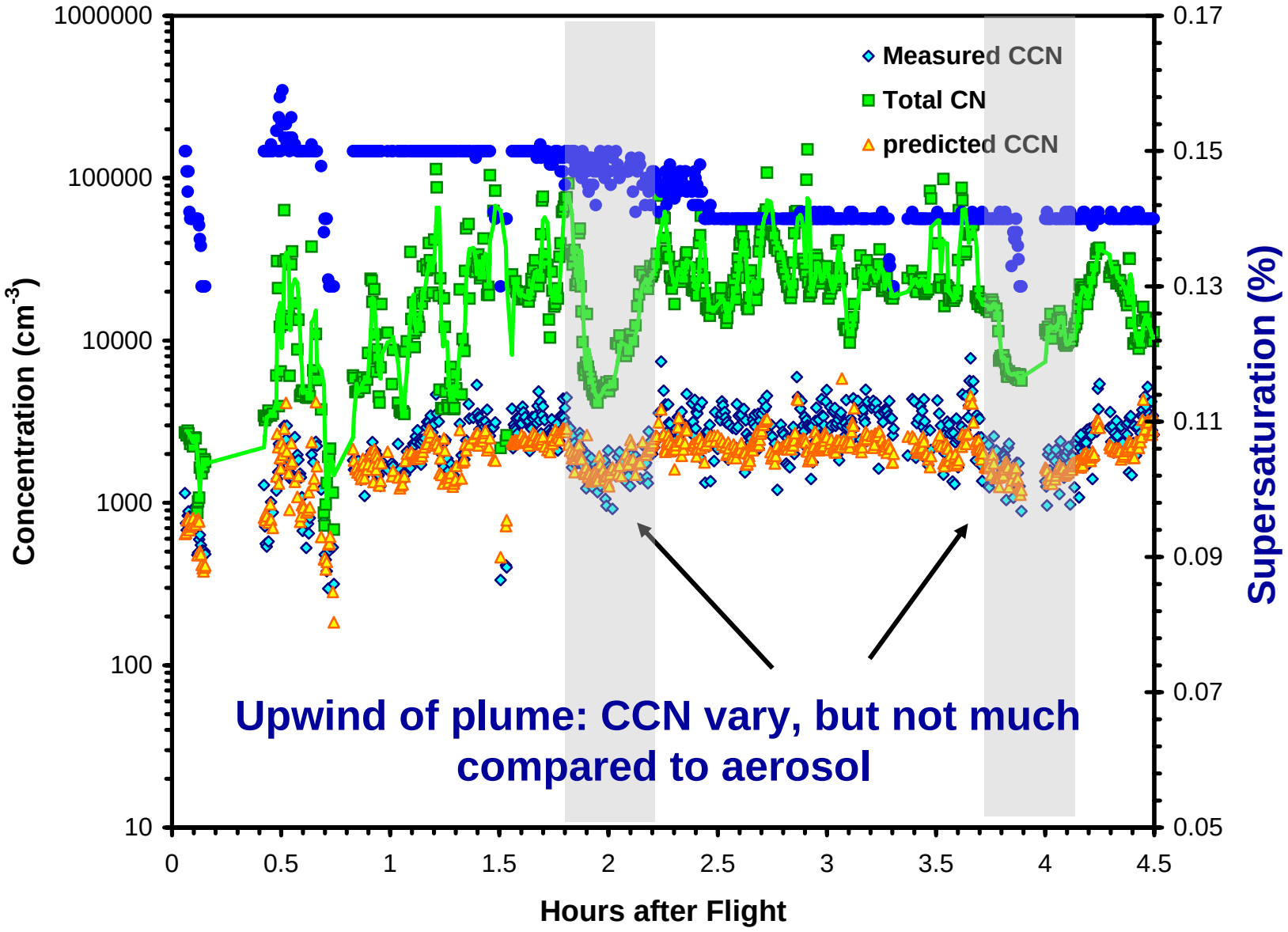
Closure from Thompson Farm during ICARTT 2004

September 20: Beaumont Port Arthur, Houston Urban, Parish PP, Isolated refineries…

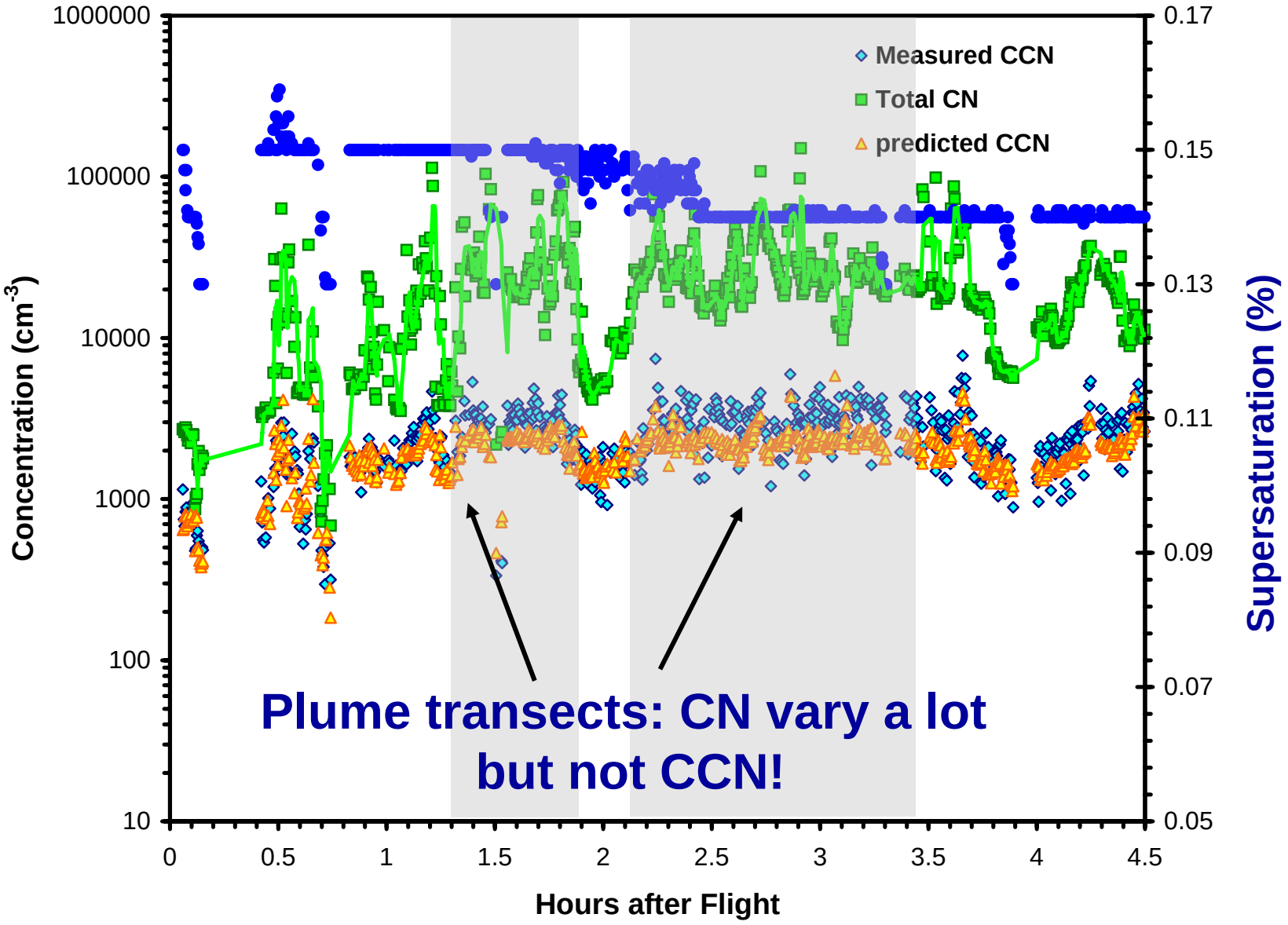


CCN instrument is operated at ~ constant supersaturation

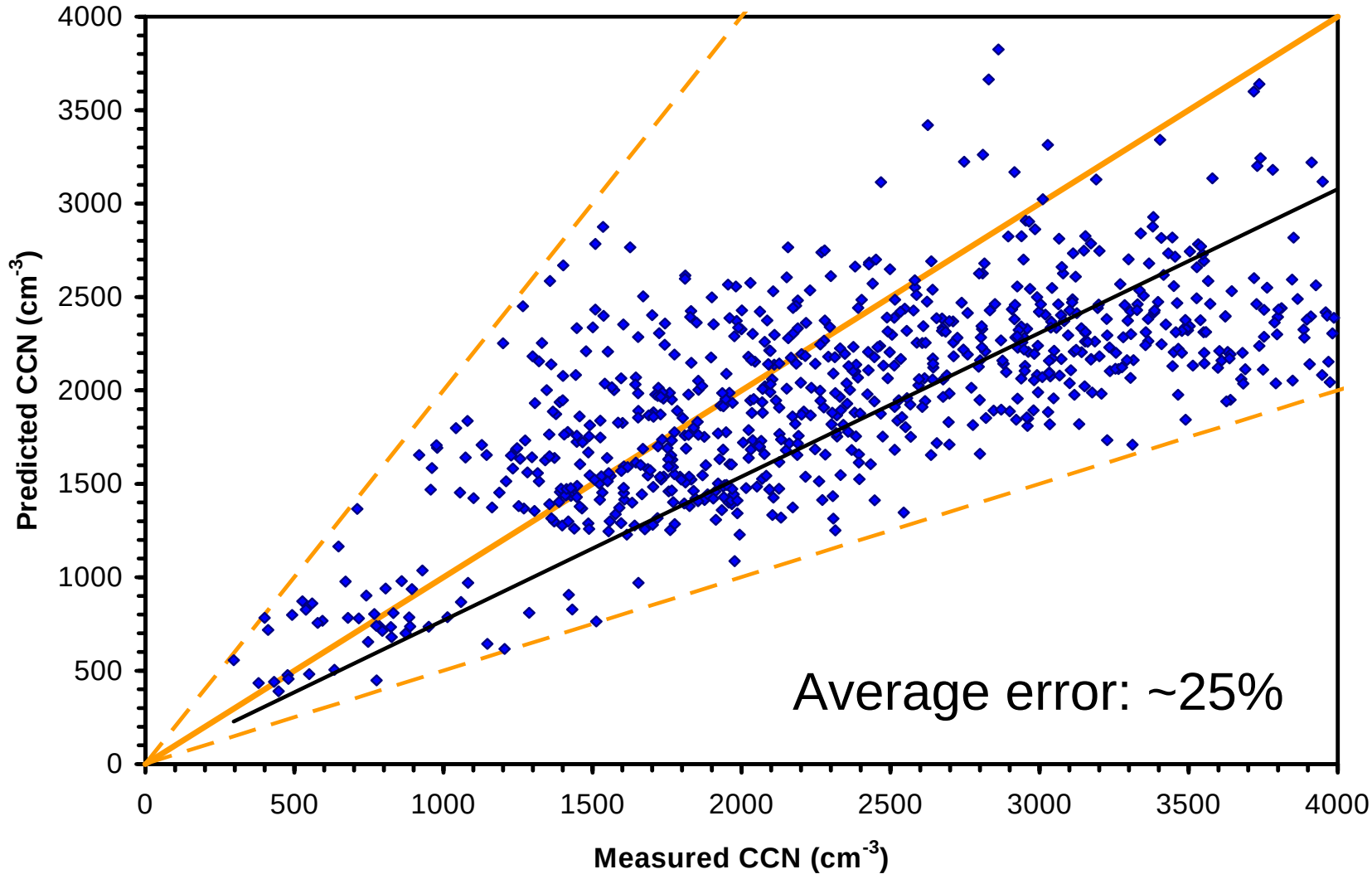
September 20 Flight



September 20 Flight



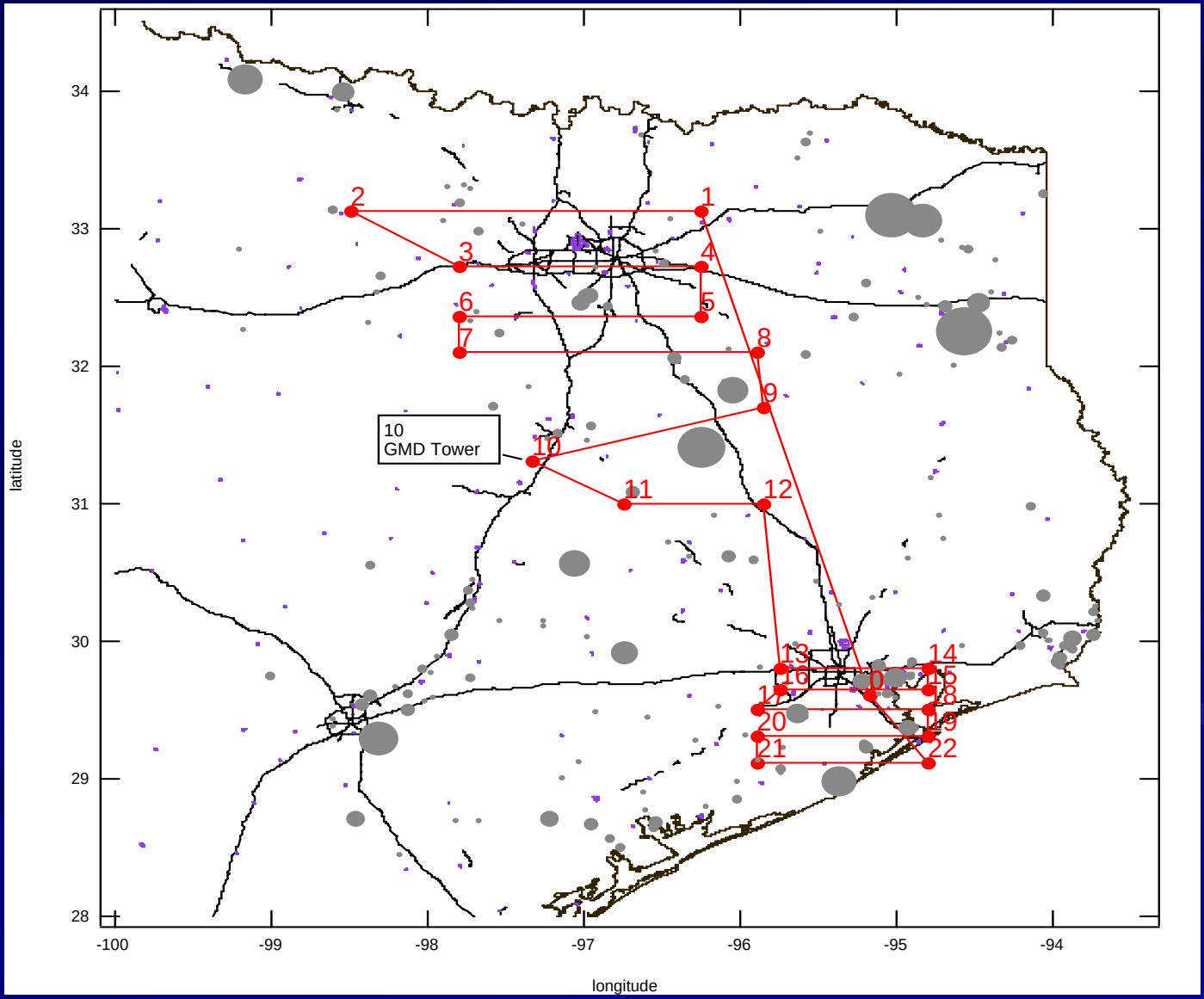
CCN Closure "scatterplot"



September 20 Flight

Very high CCN concentrations

September 25: Dallas, Houston Urban Parish PP, Big Brown and Limestone PPs



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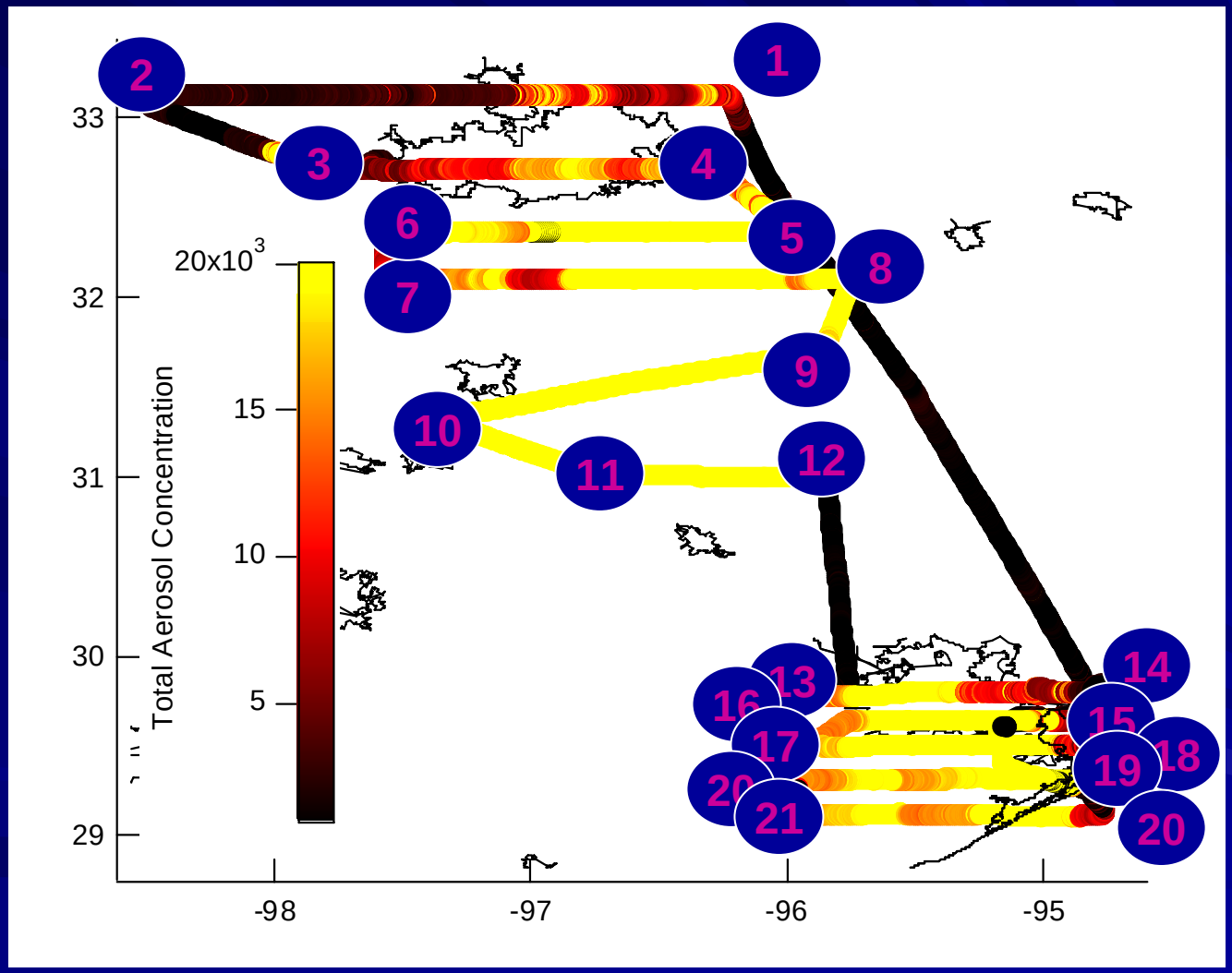
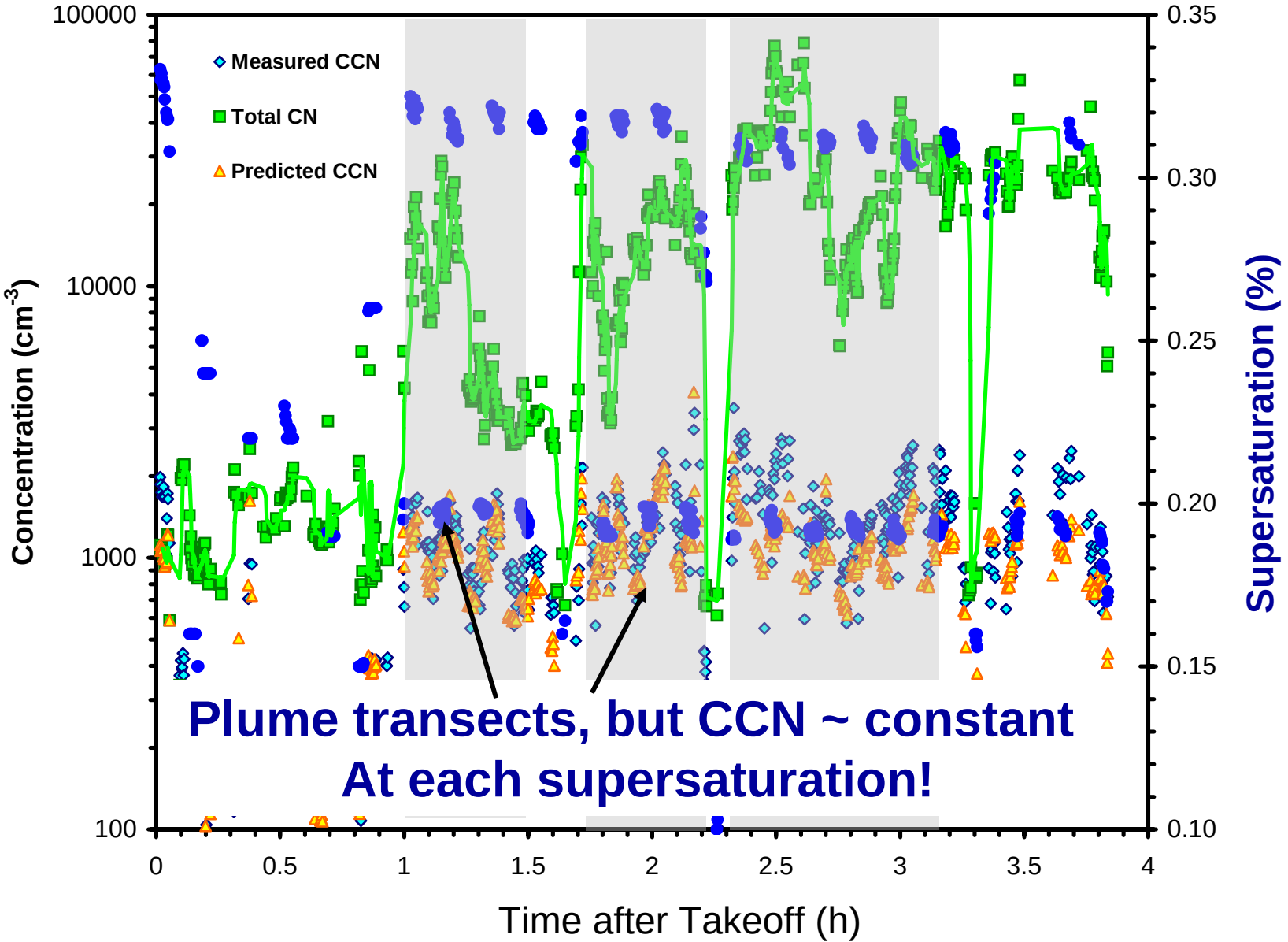
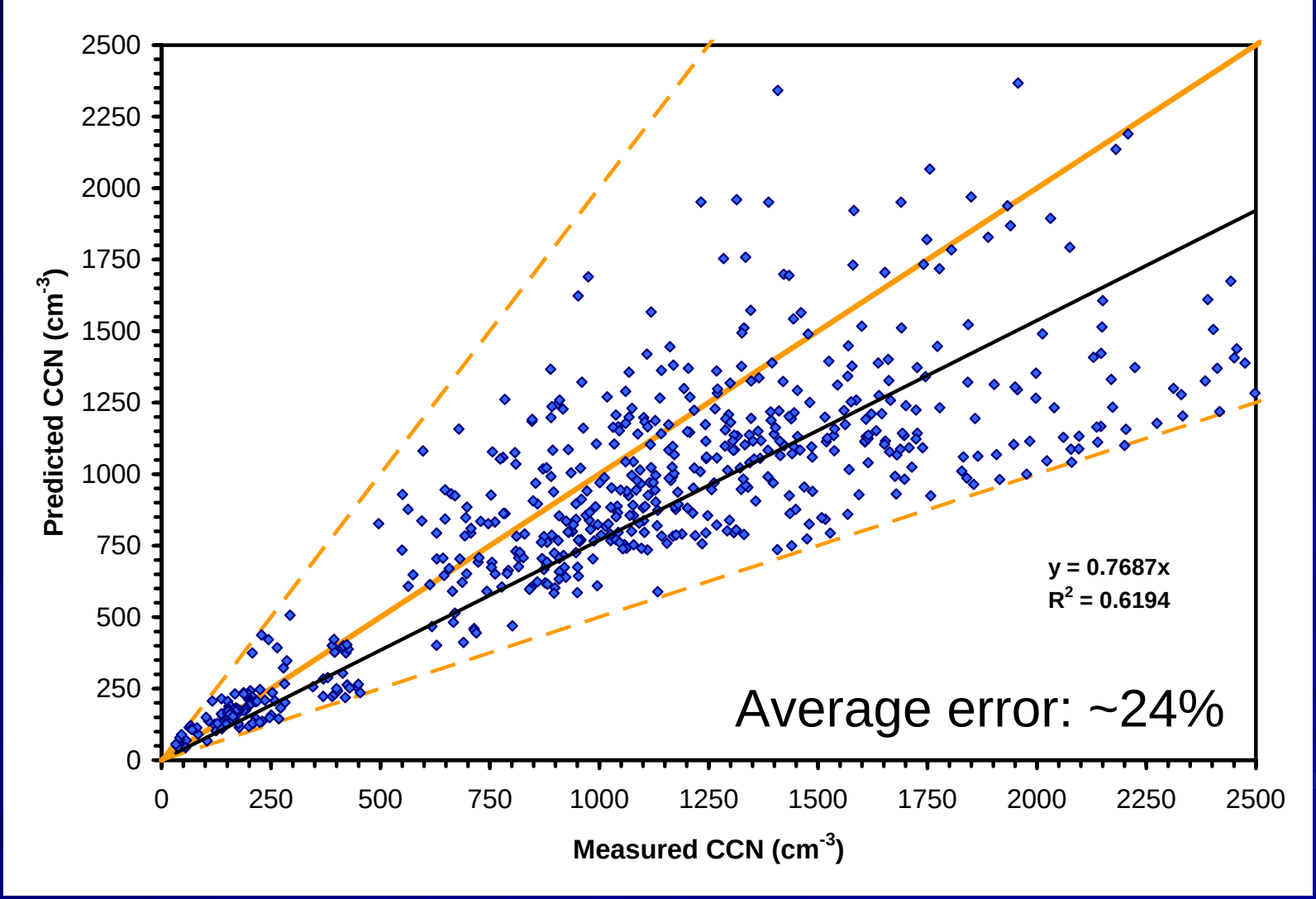


CCN instrument is operated at ~ 3 supersaturations

September 25 Flight



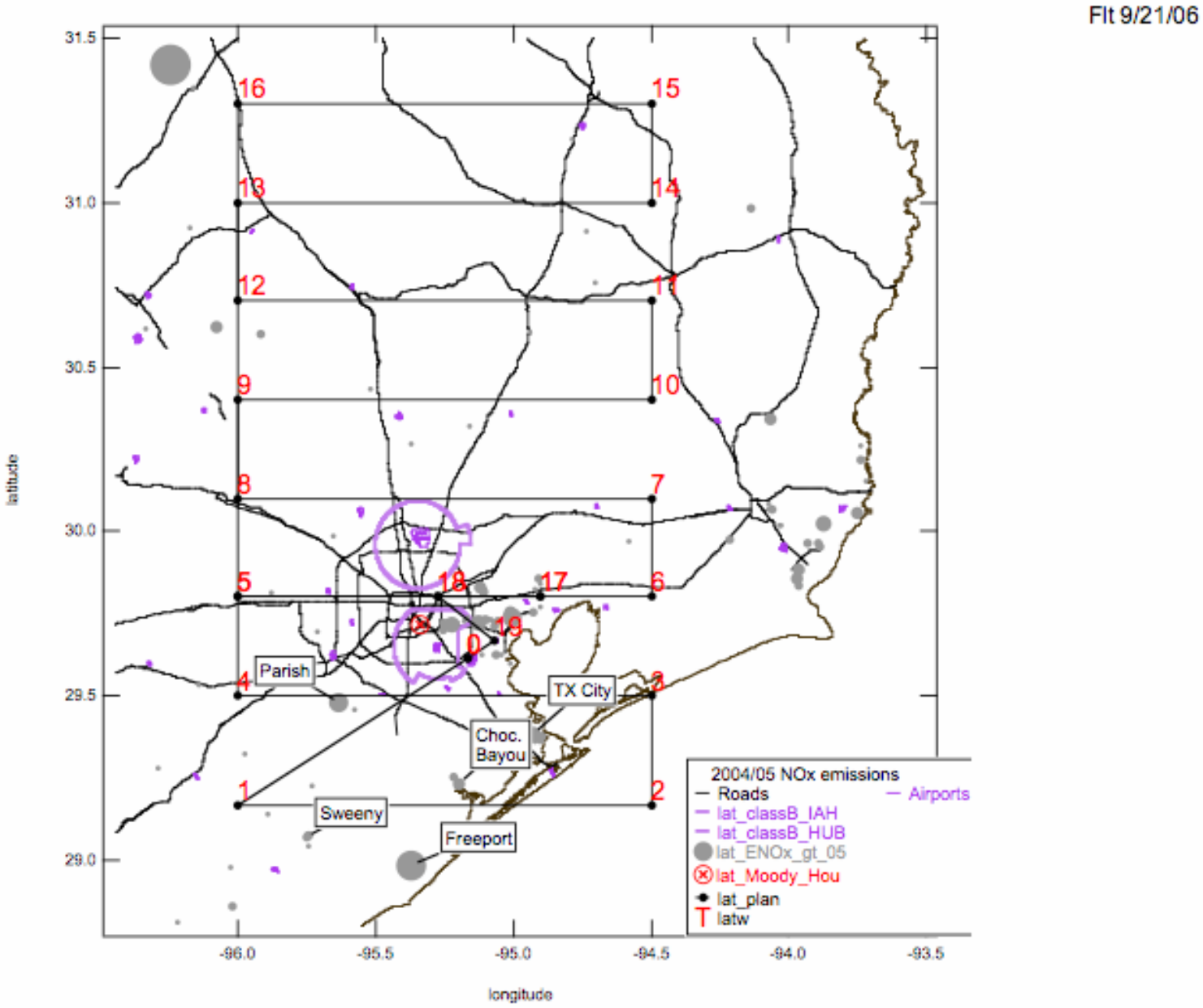
CCN Closure "scatterplot"



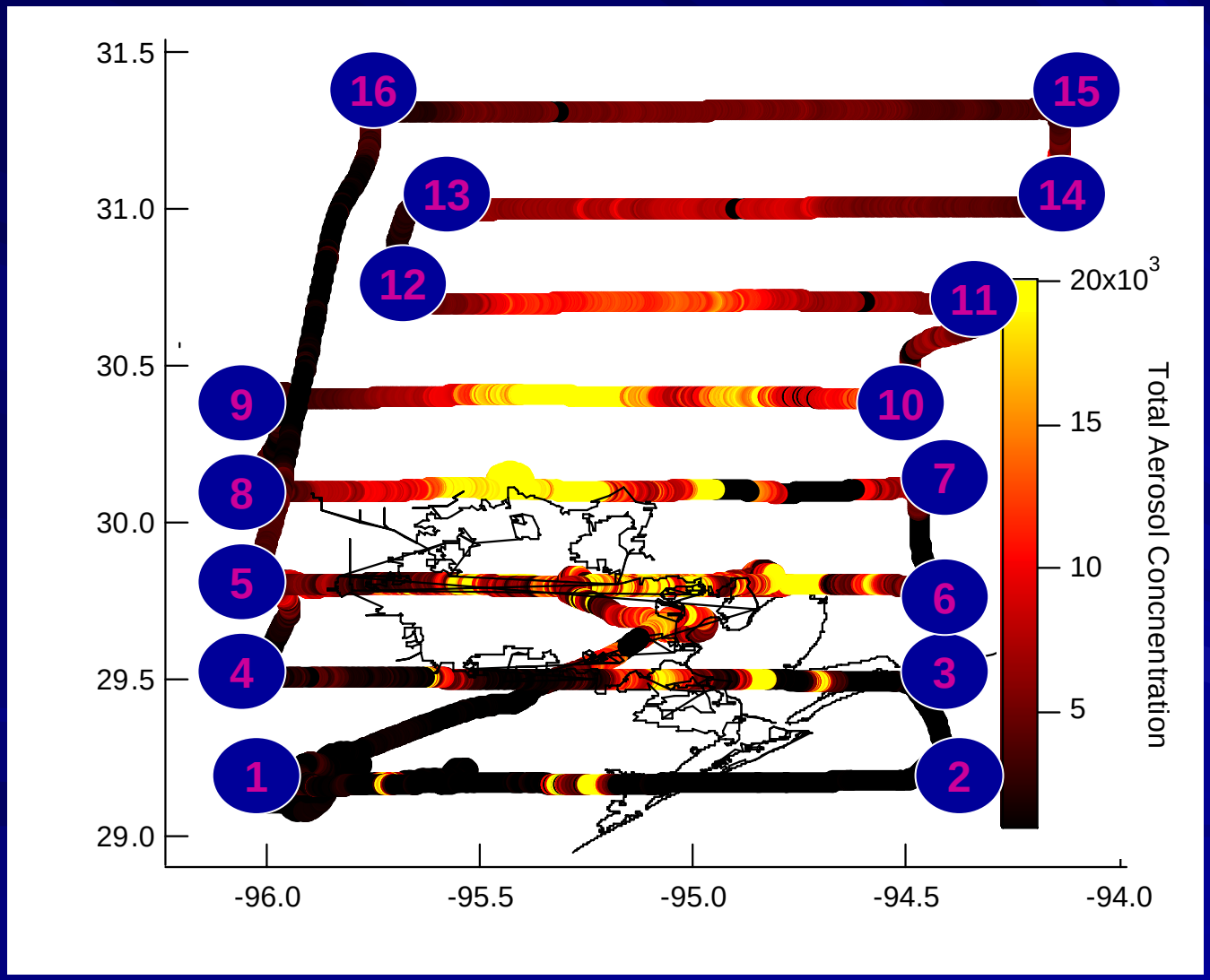
September 25 Flight

CCN concentrations in Dallas similar to Houston urban plume

September 21: Texas City, Houston Urban Plume

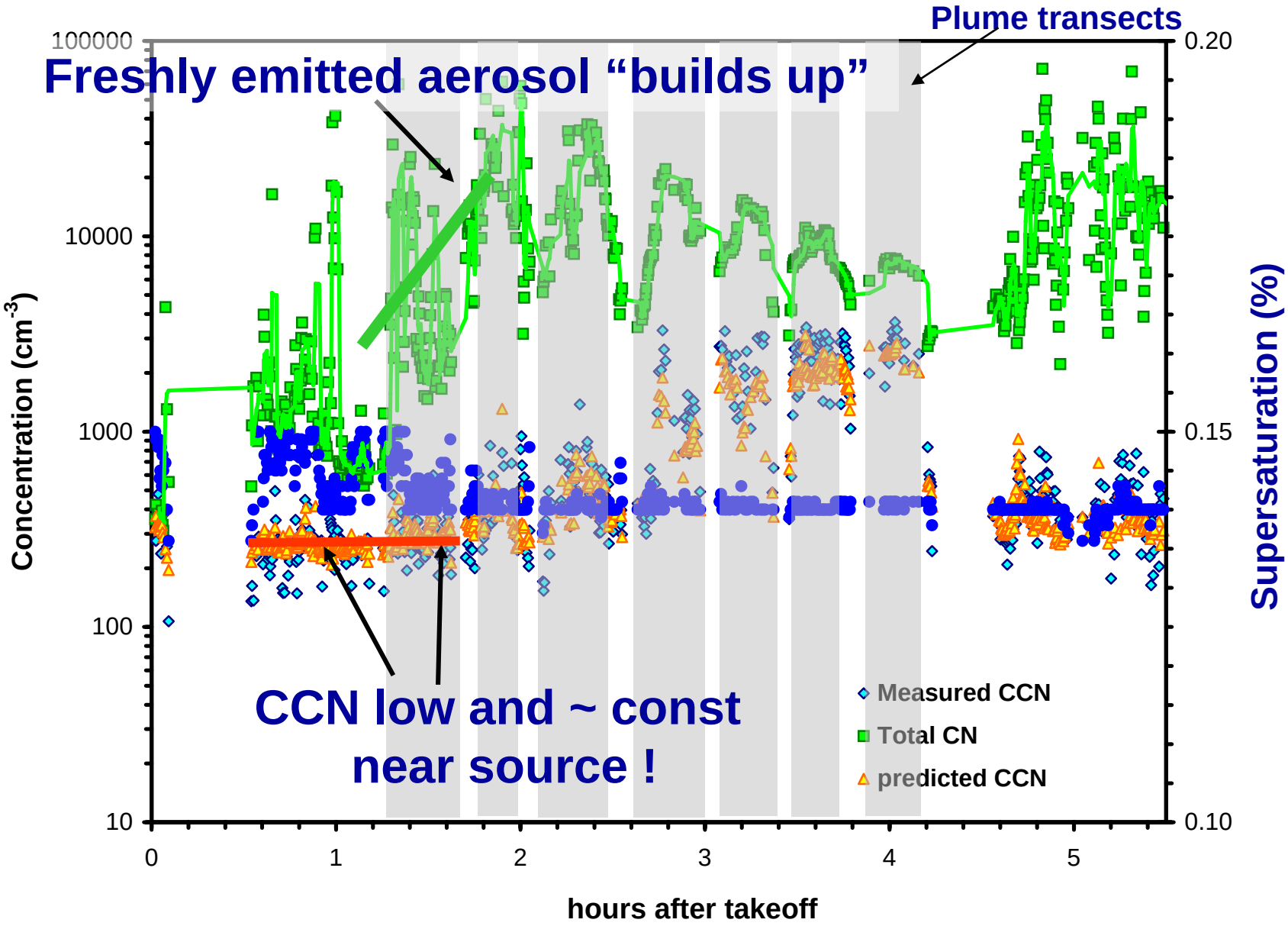


September 21: Texas City, Houston Urban Plume



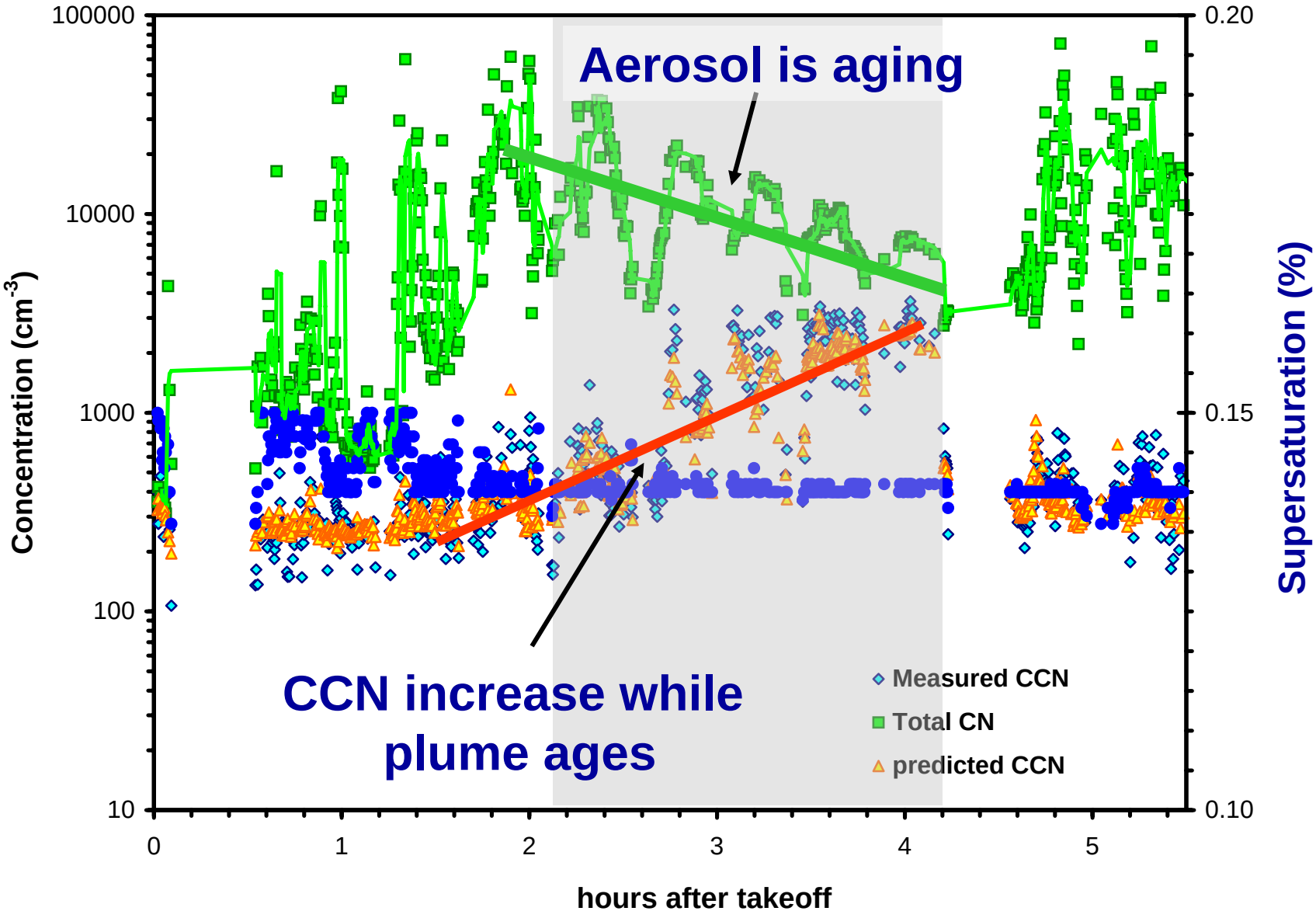
Flight progression

September 21 Flight



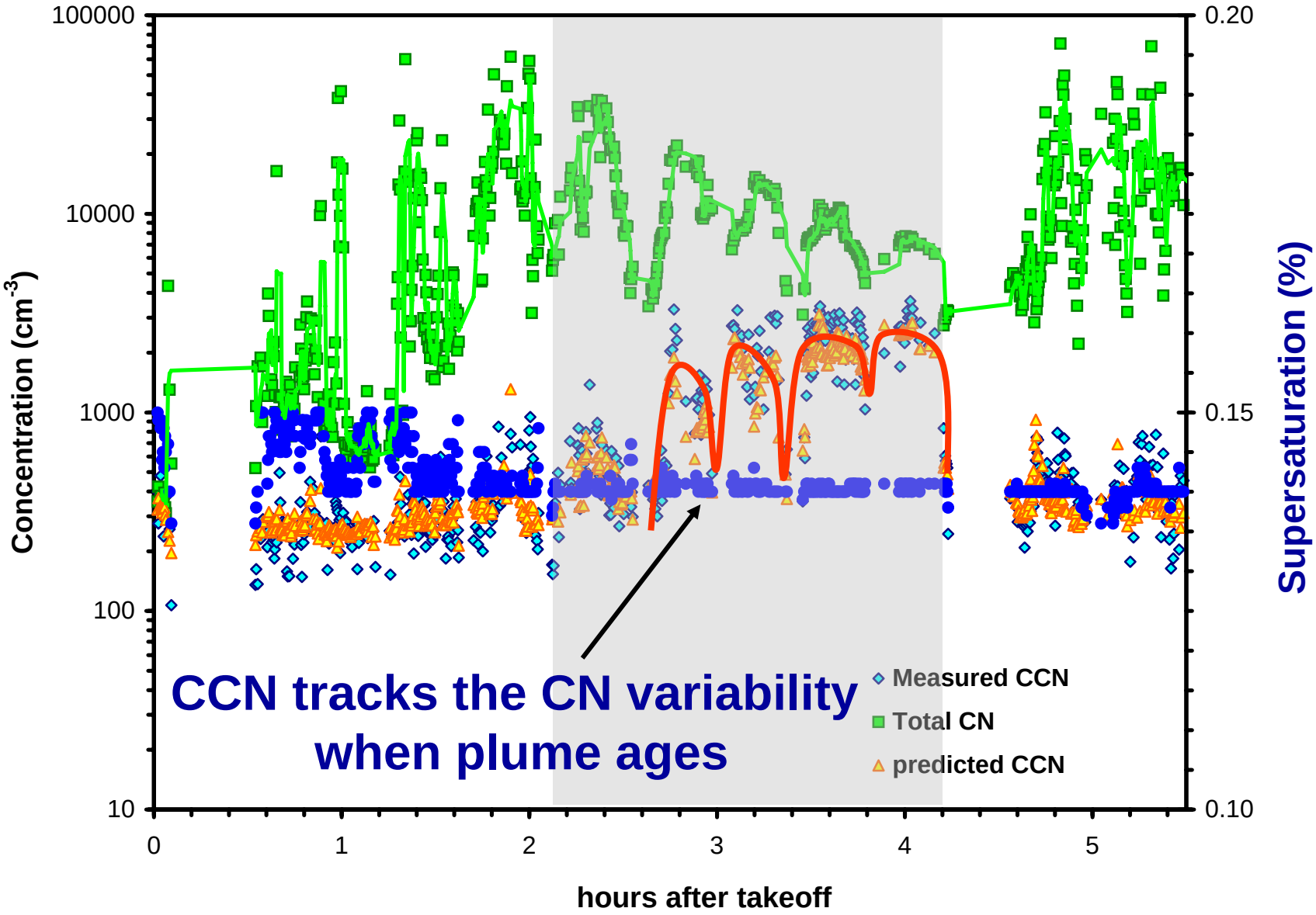
September 21 Flight

~ 100 km

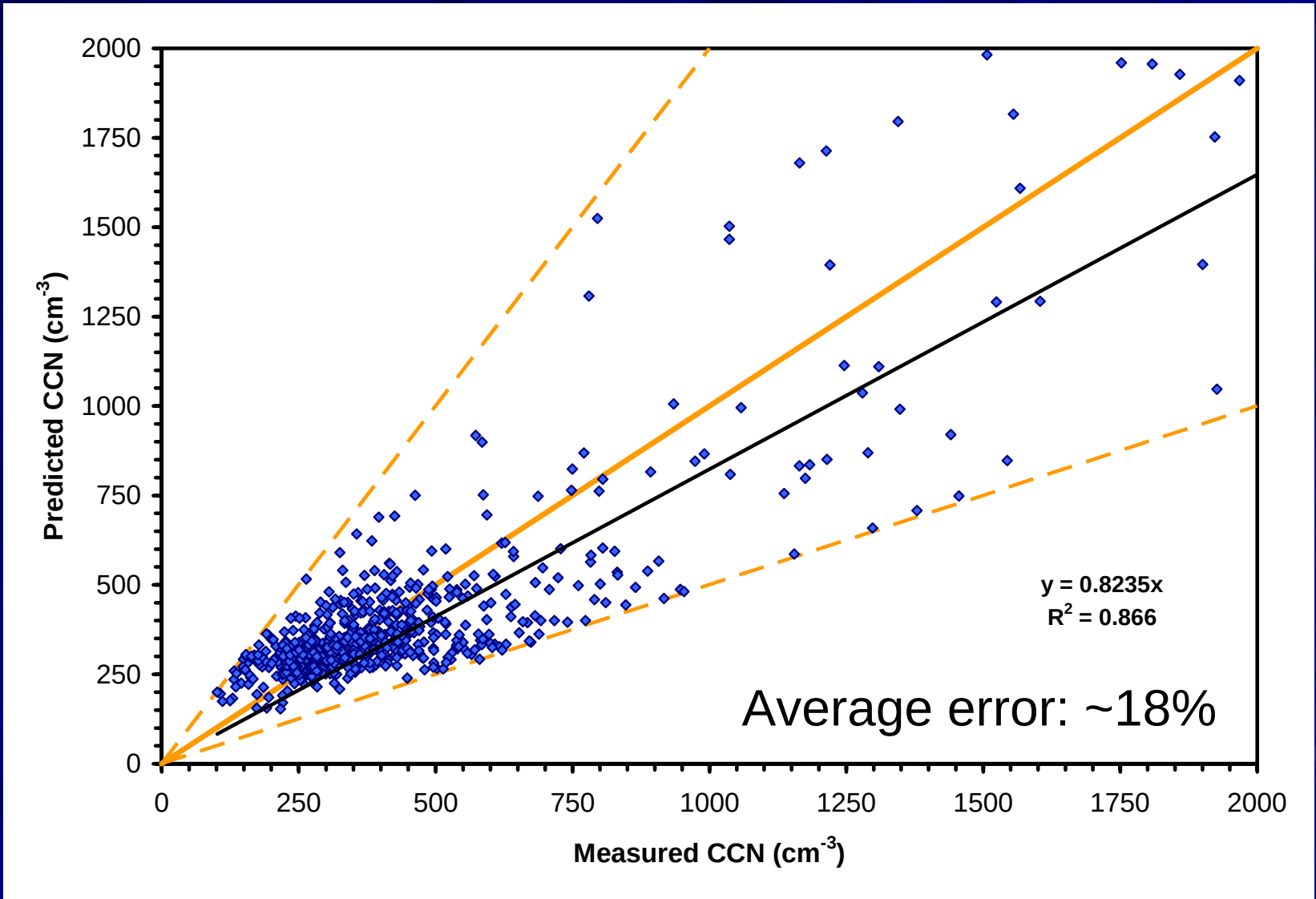


September 21 Flight

~ 100 km



CCN Closure "scatterplot"



September 21 Flight

Lower CCN concentrations

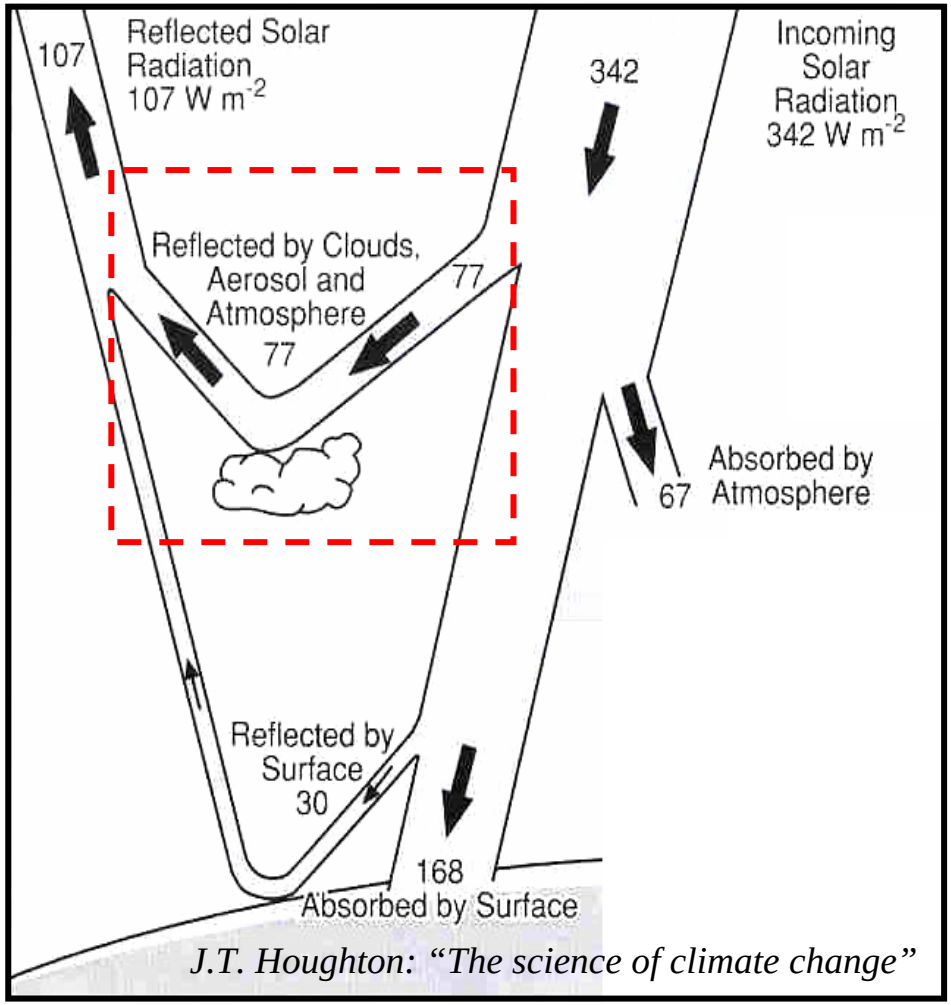
Some "take home" points

- Aerosol variability does not necessarily translate to CCN variability, especially close to source regions, where impacts are in small particles which do not act as CCN.
- This suggests that CCN levels may be controlled by "background" (or "aged") levels more than expected.
- As plumes age, CCN increase and covary with total CN. Ageing seen for the scale of a typical GCM grid cell.
- Assuming a uniform mixture of sulfate + insoluble captures most of the CCN variability (on average, to within 20-25%).
- This suggests that predicting CCN concentrations at low supersaturations typical of stratus/stratocumulus clouds (which includes the effect of aging) is not "hopeless". Good news for indirect effect modeling.

THANK YOU!

Earth's Albedo: controlling factor of "global dimming"

Clouds play a major role in determining albedo.



J.T. Houghton: "The science of climate change"

Facts:

- Clouds account for 50% of planetary reflectivity.
- Small changes in clouds yield large changes in global energy balance.
- Clouds are VERY dynamic
- **1%** increase in global cloud cover can counteract warming.

Consequence:

Understanding cloud formation is necessary for reliable climate change predictions.

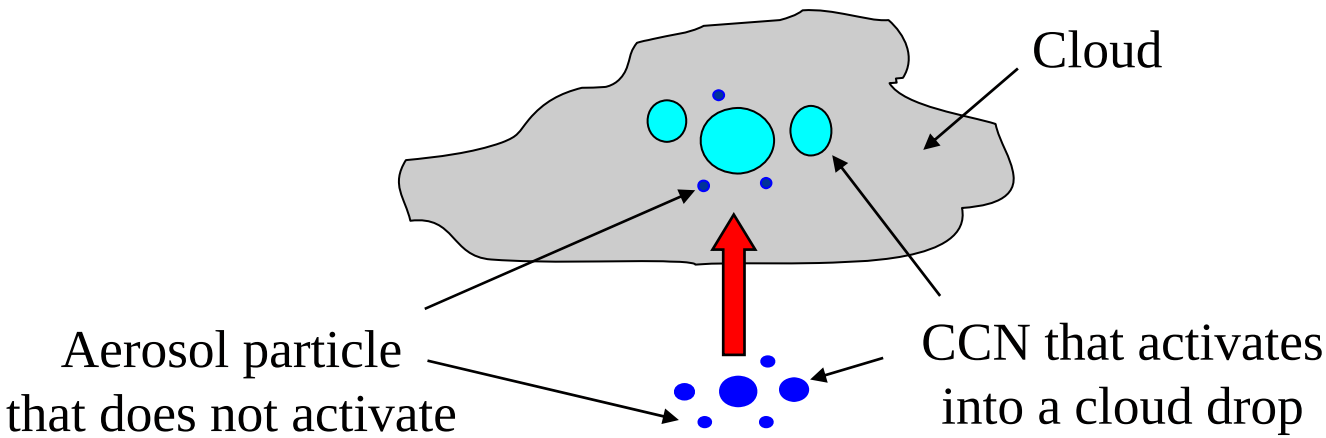
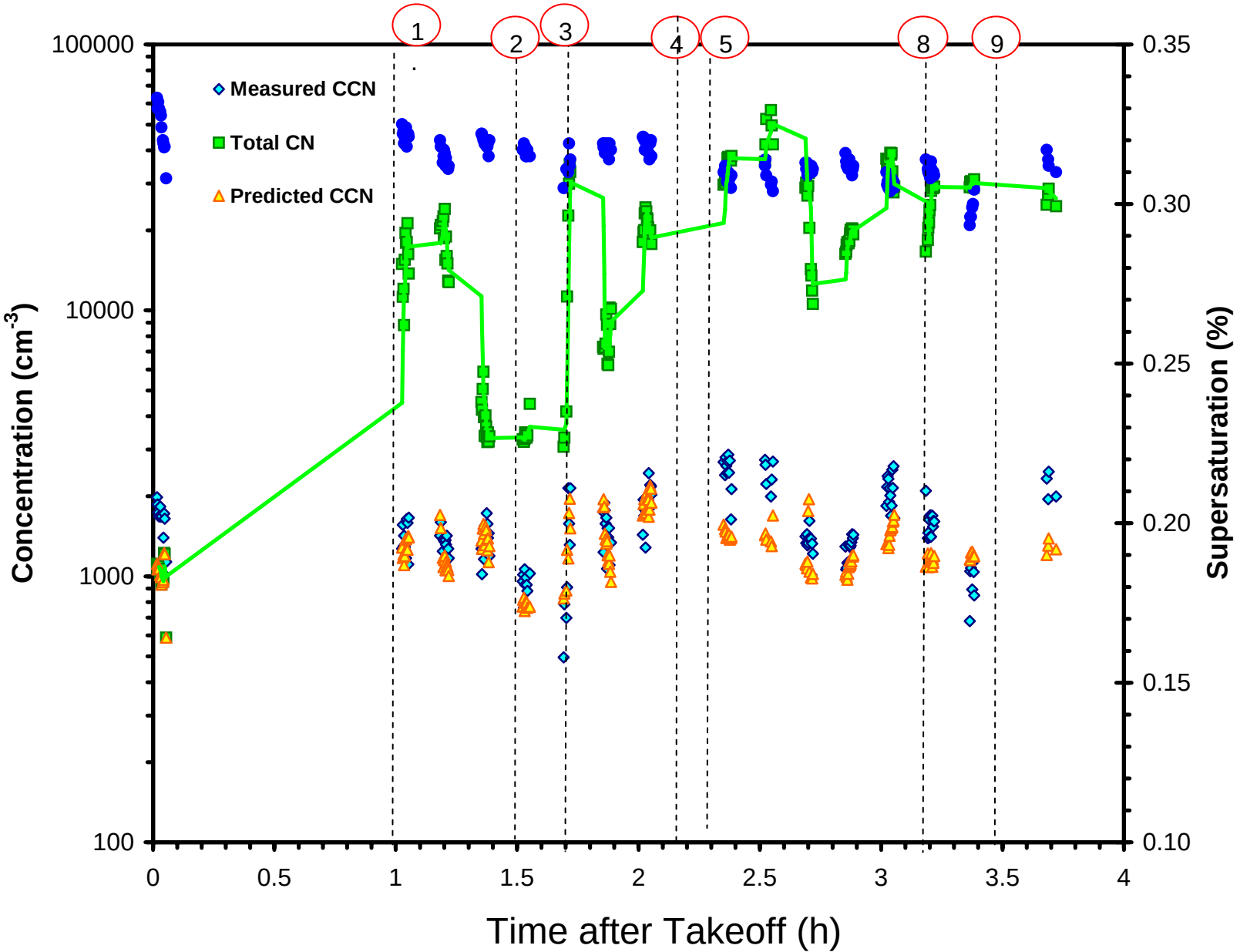
How do clouds form?

Clouds form in regions of the atmosphere where there is too much water vapor (it is “supersaturated”).

This happens when air is cooled (primarily through expansion in updraft regions and radiative cooling).

Cloud droplets form on pre-existing particles found in the atmosphere (aerosols). This process is known as *activation*.

Aerosols that can become droplets are called cloud condensation nuclei (CCN).



For High SS (0.29-0.35)