Use of Multiple Satellite Products in Assessing NOAA Global Forecast Model: Footprints of Aerosol-Cloud Interactions

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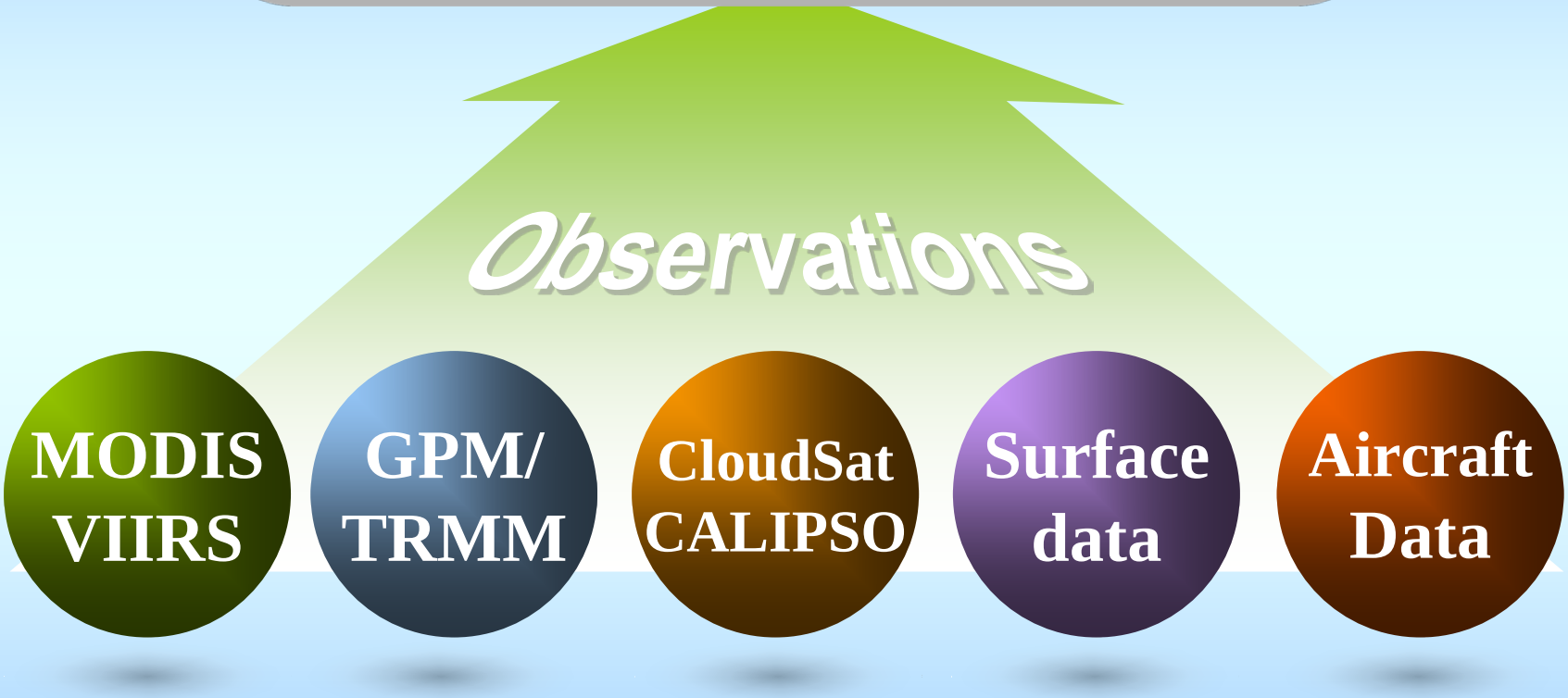
Theme 1

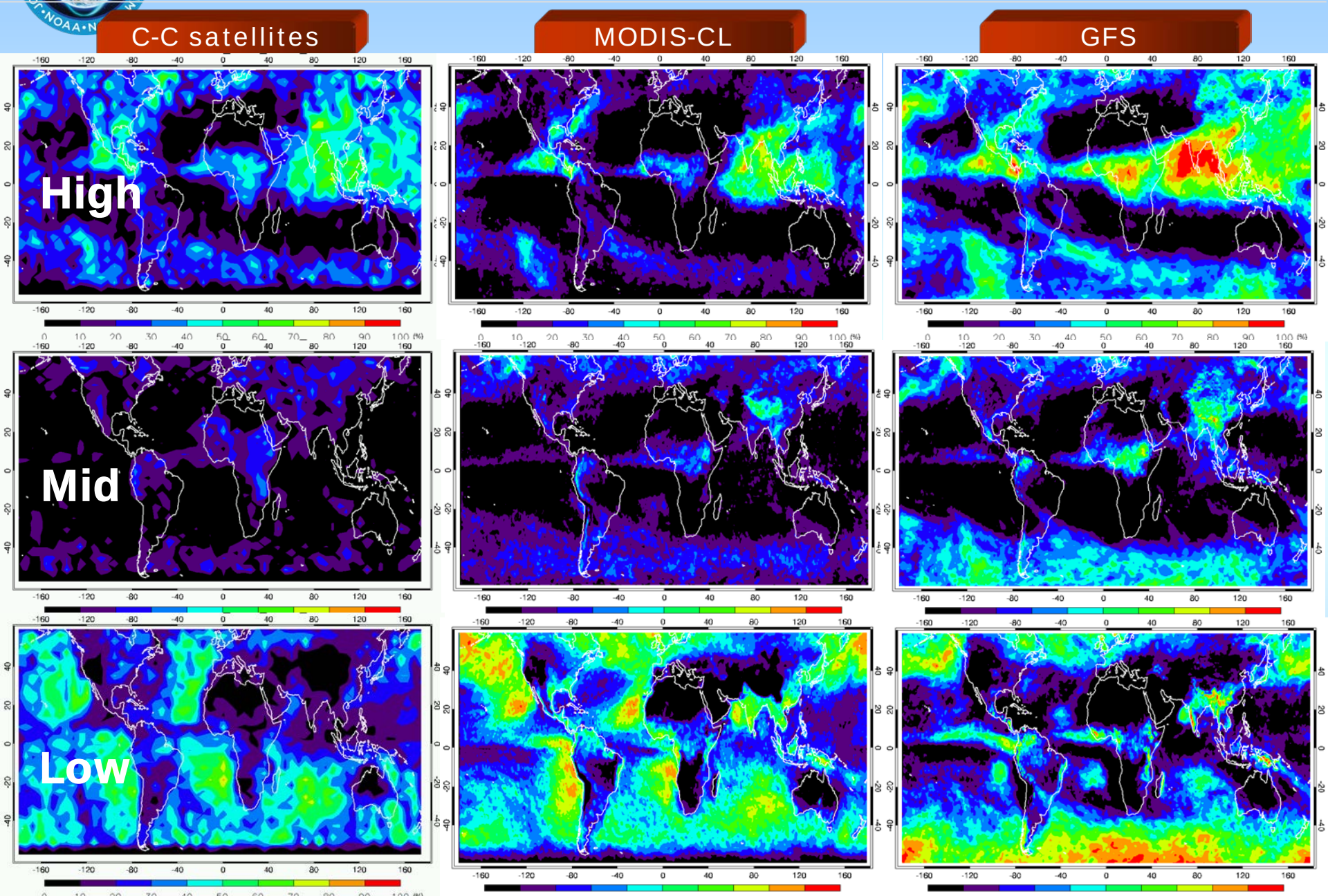
Conventional satellite products (column and cloud top quantities) deal with classical model problems

Evaluation of Model Performance



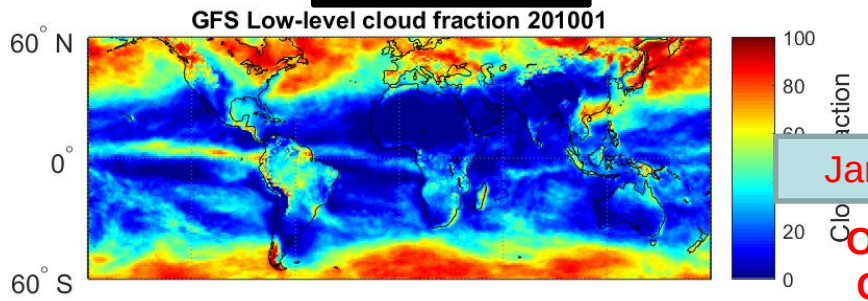
Comparison Cloud Fraction - July

Yoo and Li (2012, Climate Dyn)

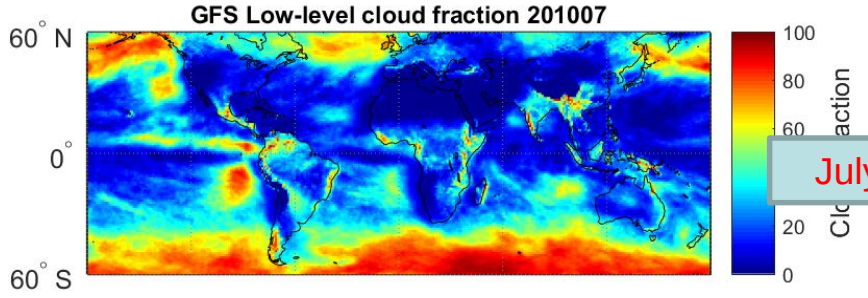


Comparison of Low Clouds from GFS & MODIS

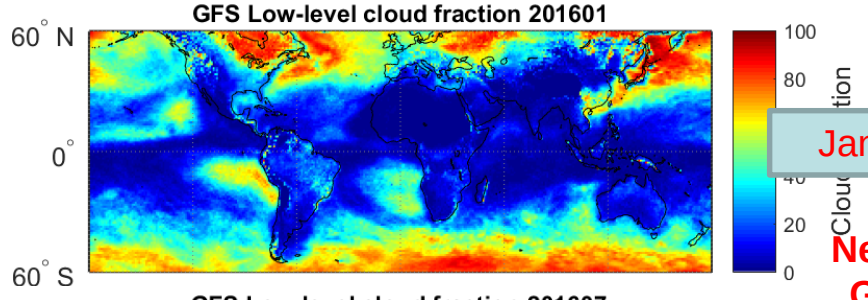
GFS



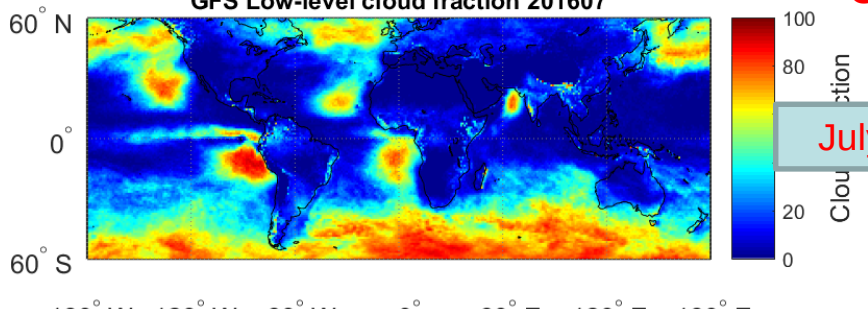
Jan 2010



July 2010

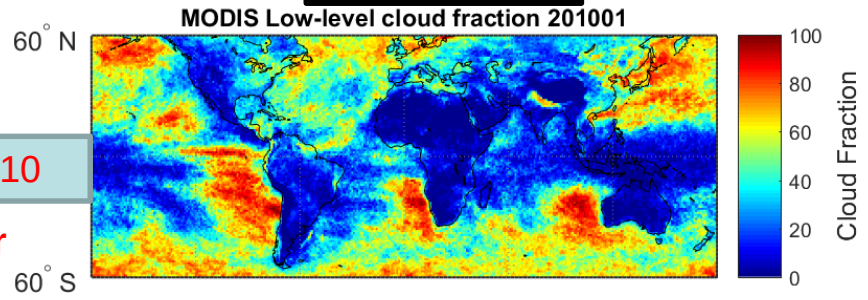


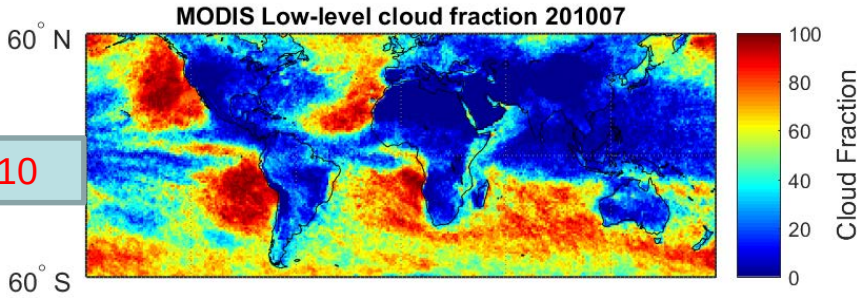
Jan 2016

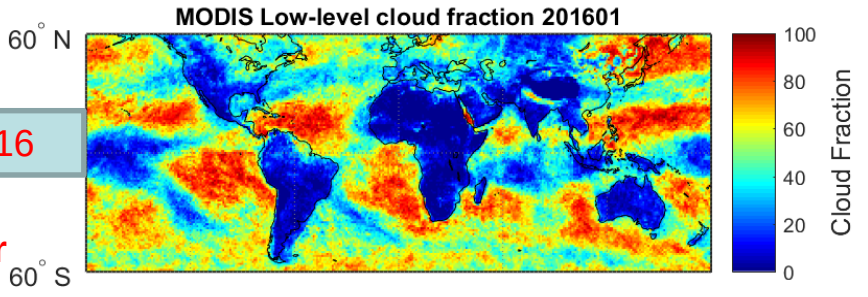


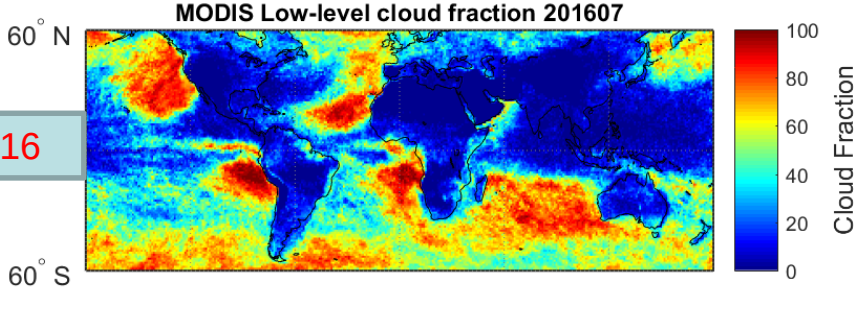
July 2016

MODIS



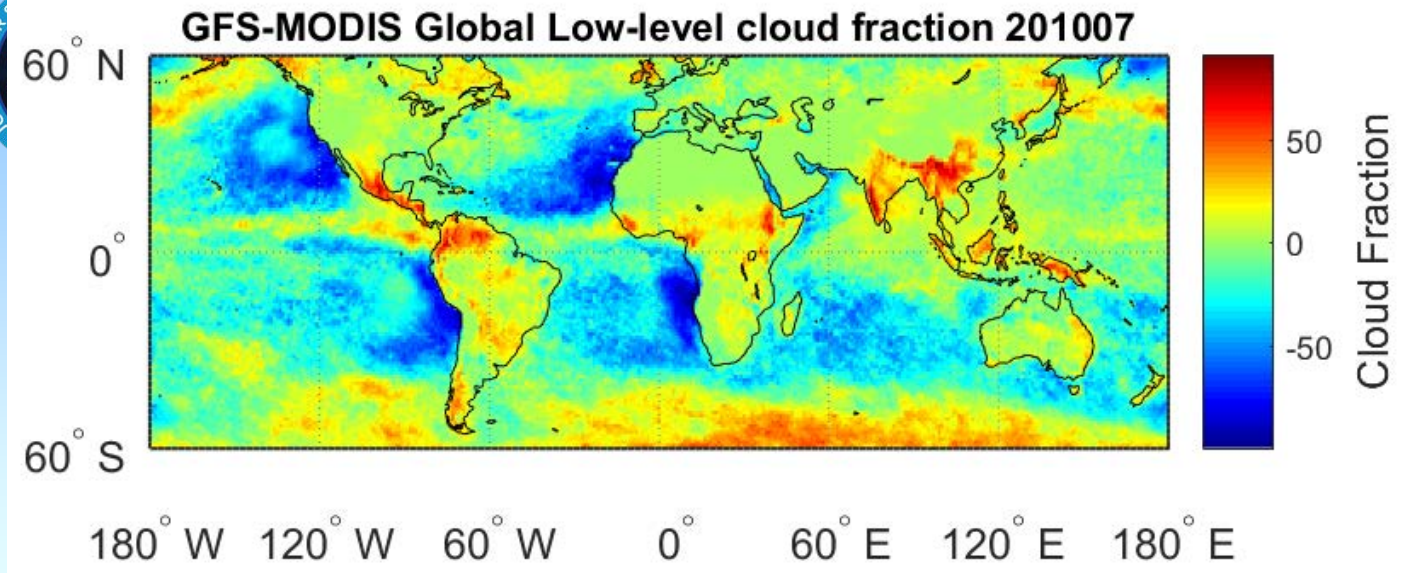


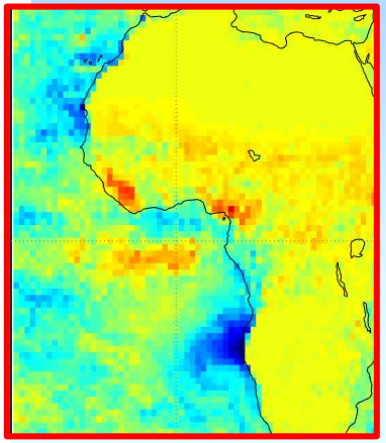


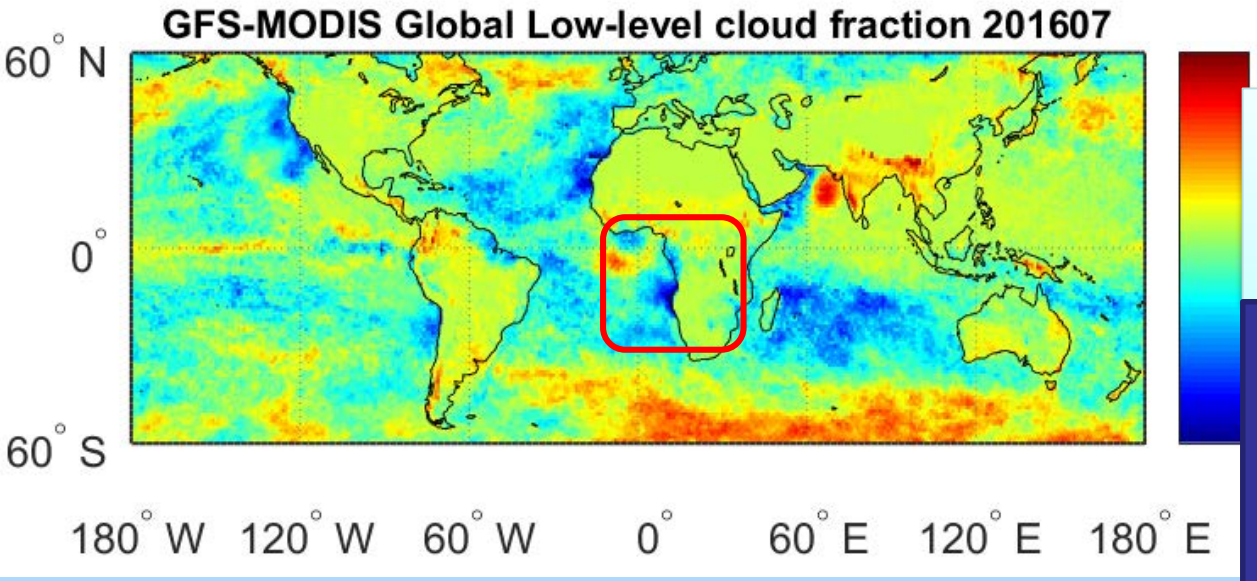


Older GFS

Newer GFS





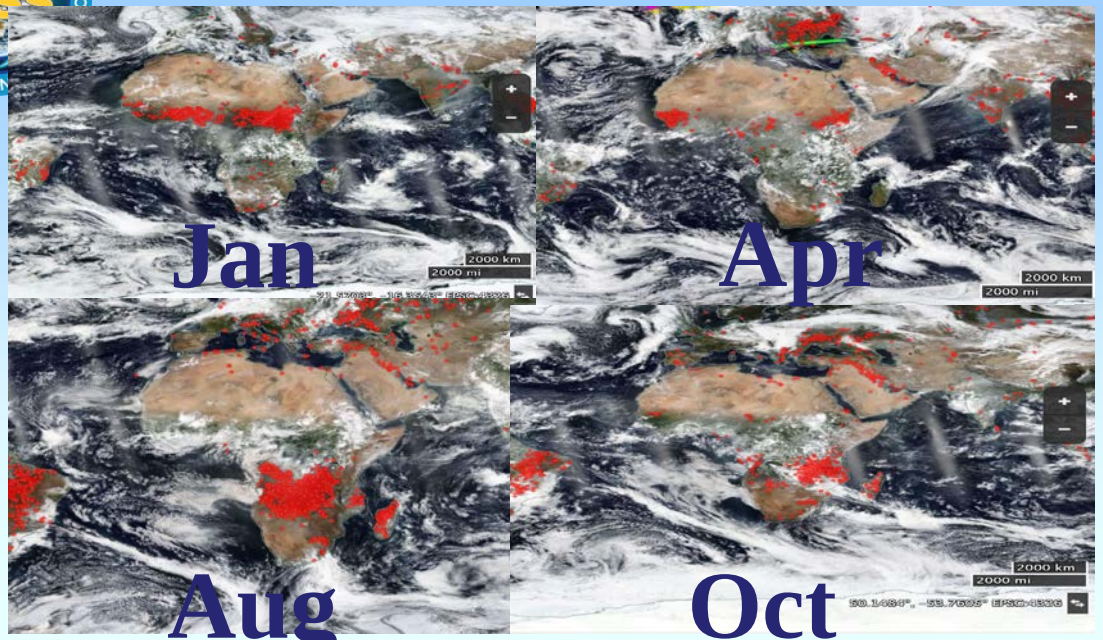


Is it possible the negative bias might related to the biomass burning aerosols ?

Many observations and modeling studies show that absorbing aerosols above the marine stratocumulus clouds tends to increase the cloud cover.

The new SC scheme does not destroy stratocumulus clouds off the west coasts of America and Africa as the old scheme does. (Han &Pan 2011)

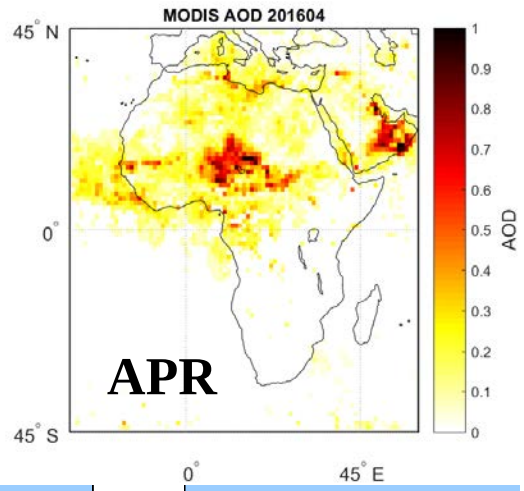
Fire and Thermal anomalies

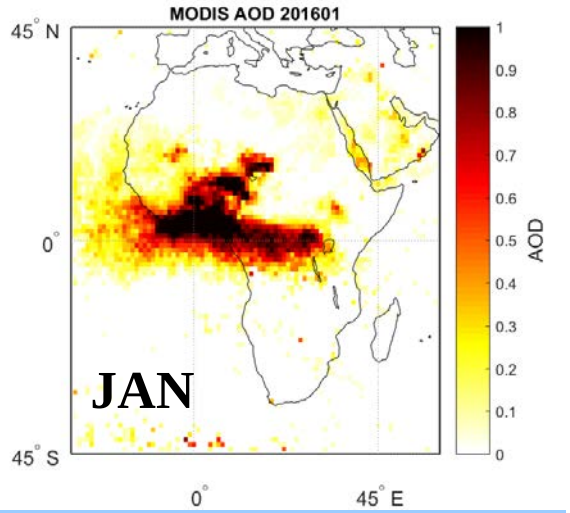


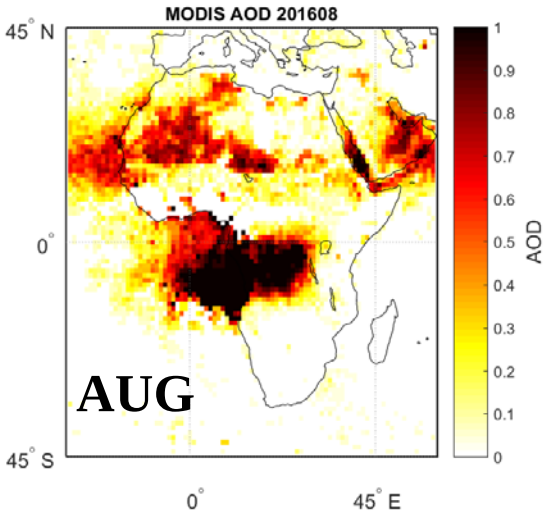
worldview.earthdata.nasa.gov/

Most biomass burning events occur during Aug (Jan) in the south(central) Africa but fewer during April.

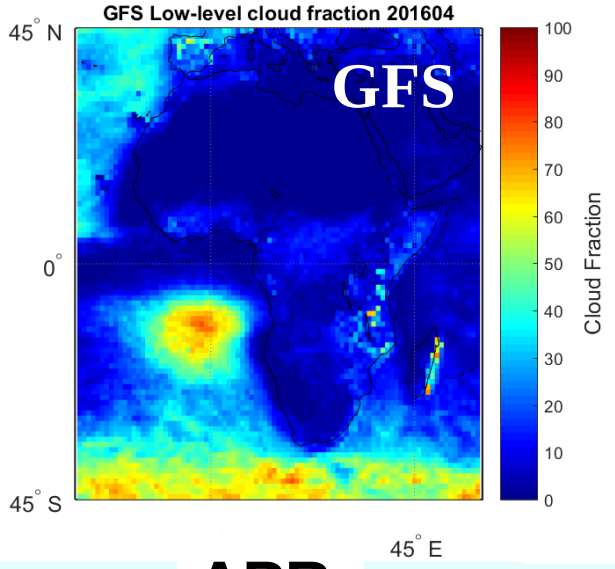
MODIS monthly AOD

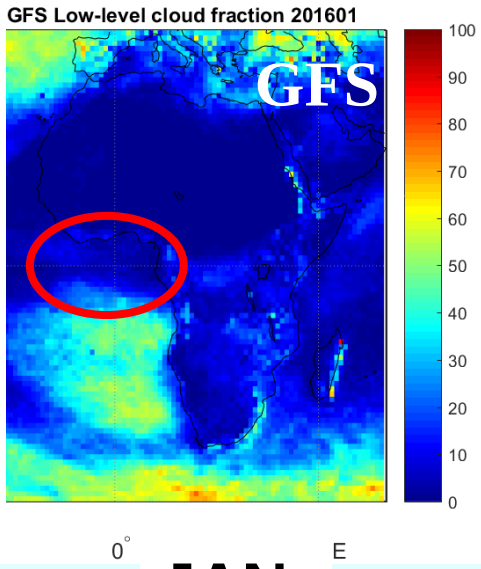


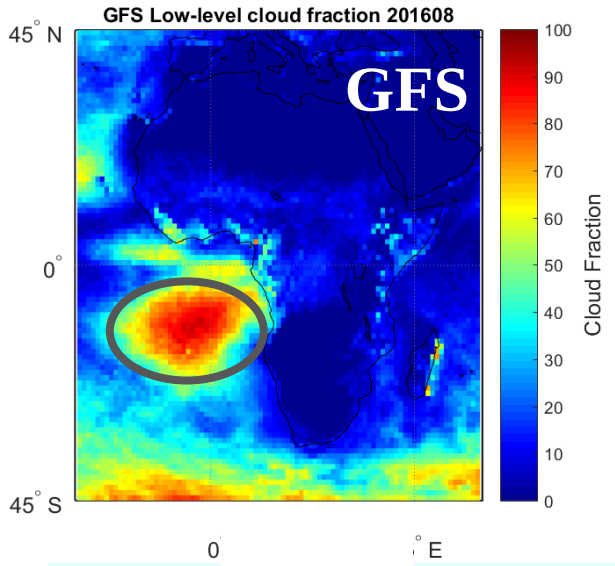




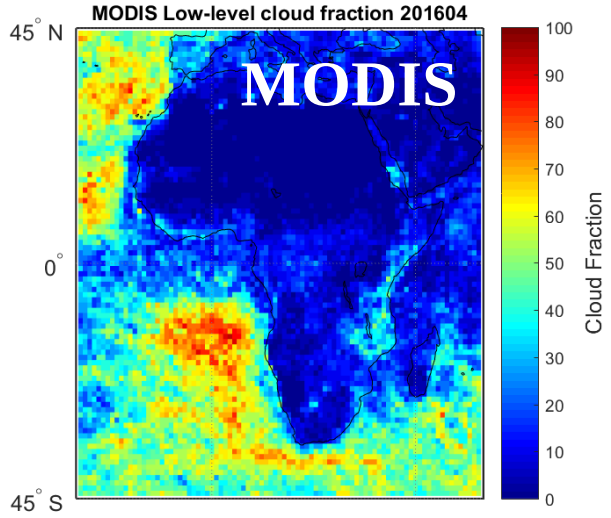
Low-level cloud fraction

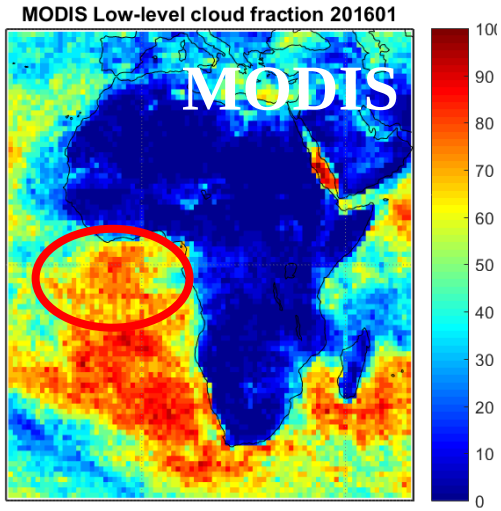


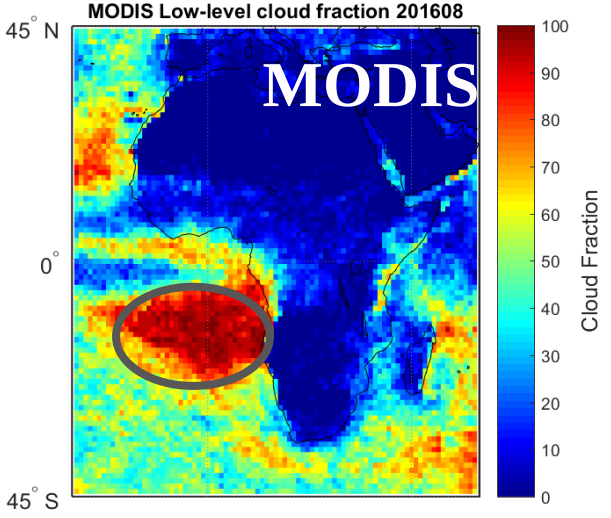




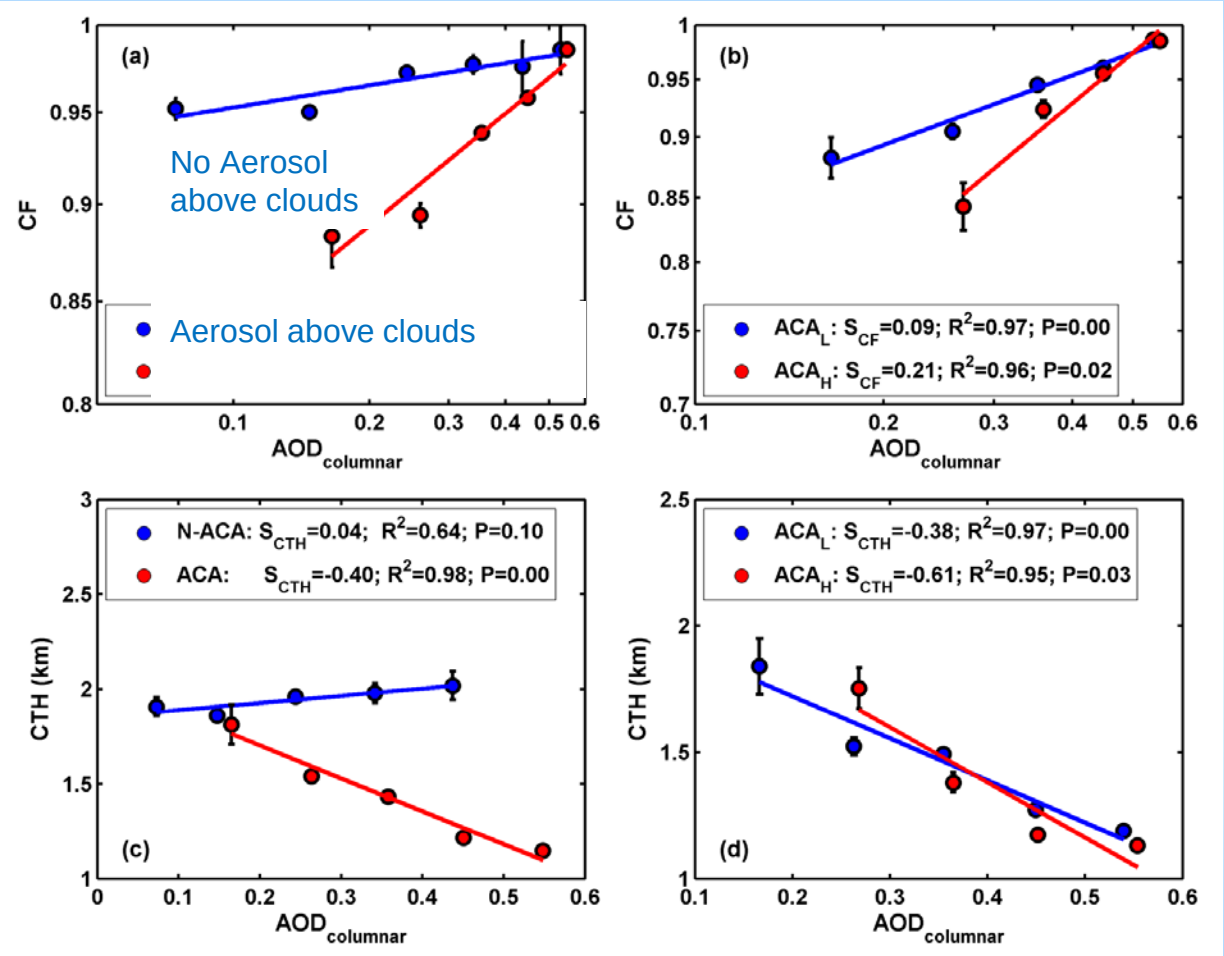
APR **JAN** **AUG**







Change of Cloud Fraction with Aerosol from CloudSat, CALIPSO, MODIS



- Significant increase in CF for both cases;
- Stronger increase in CF for ACA (ACA_H) than N-ACA (ACA_L) cases;
- For N-ACA cases, CTH increases slightly, while for ACA cases, CTH significantly decreases;
- Stronger increase in CF for ACA_H than ACA_L cases

Liu and Li (2017, in preparation)

Theme 2

Un-conventional satellite products (cloud base and vertical profile) have the potential in dealing with *future* model problems

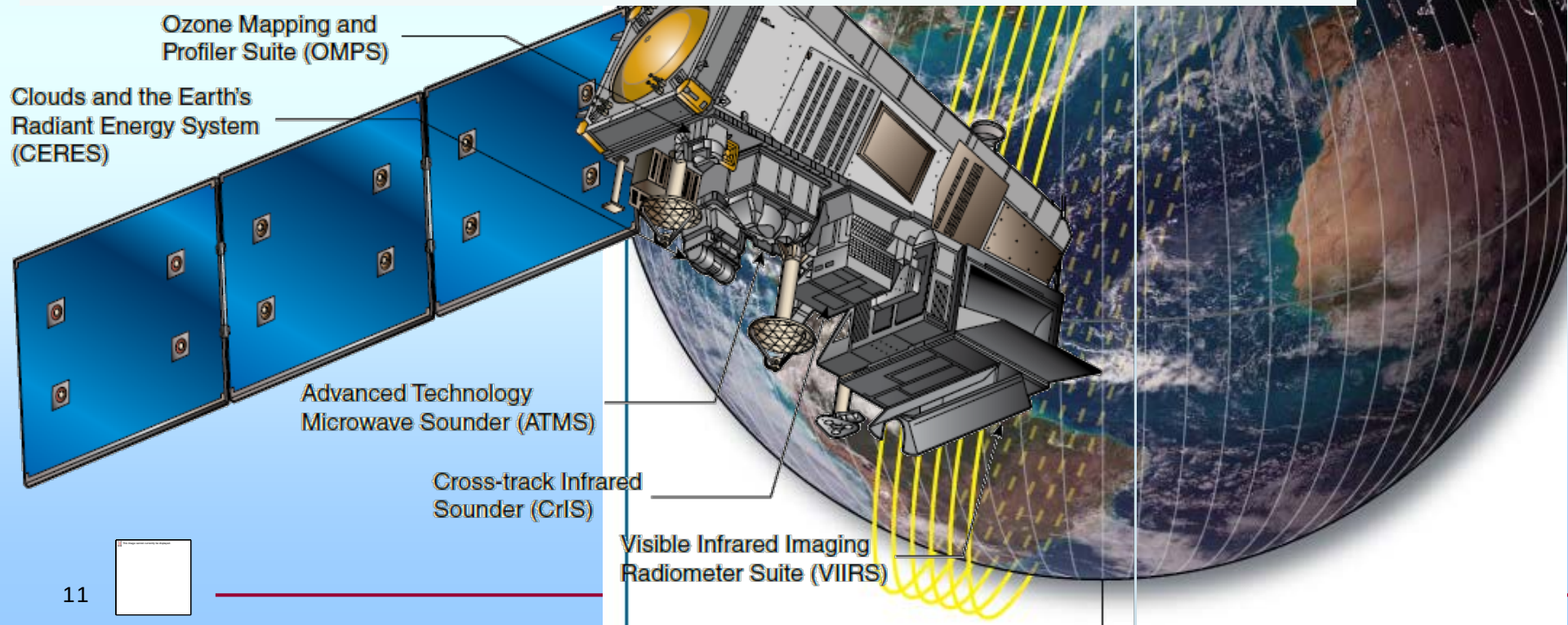
NPP: Building a Bridge to a New Era of Earth Observations

Solutions

Launched on 26/10/2011

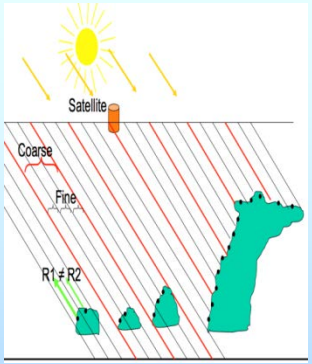
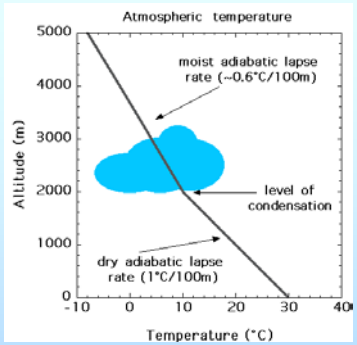
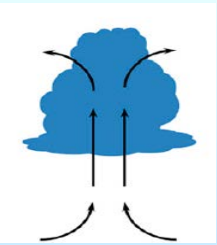
Suomi/NPP
VIIRS Imager
375 m thermal resolution

This made it possible to retrieving N_a and W_b

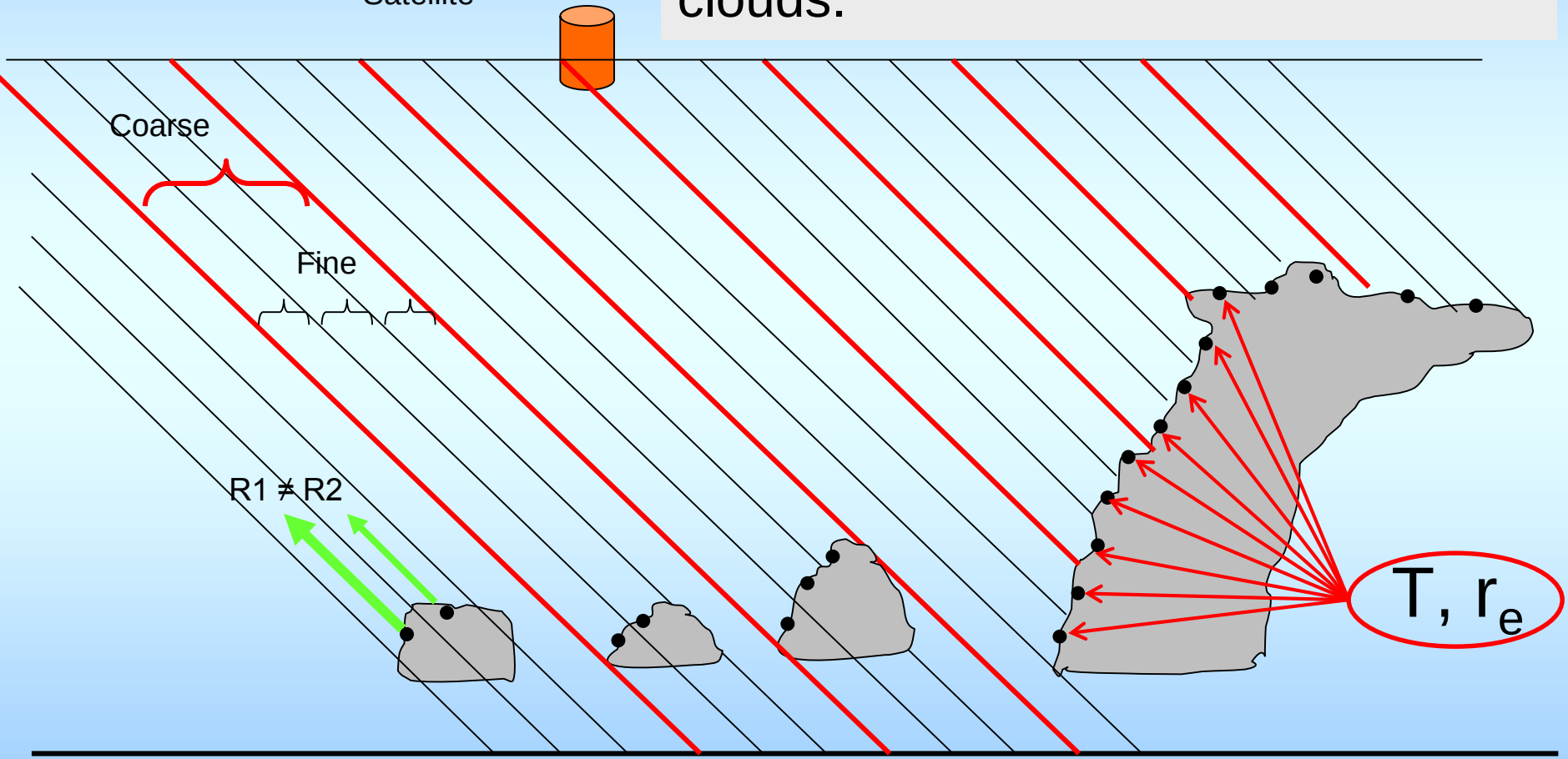


New Satellite Sensor, Novel Algorithms Unconventional Products

- Generation of new remote sensing products and quantify their uncertainties for operational application
- Demonstration of their potentials to improve the weather forecast if the information can be ingested into the system.

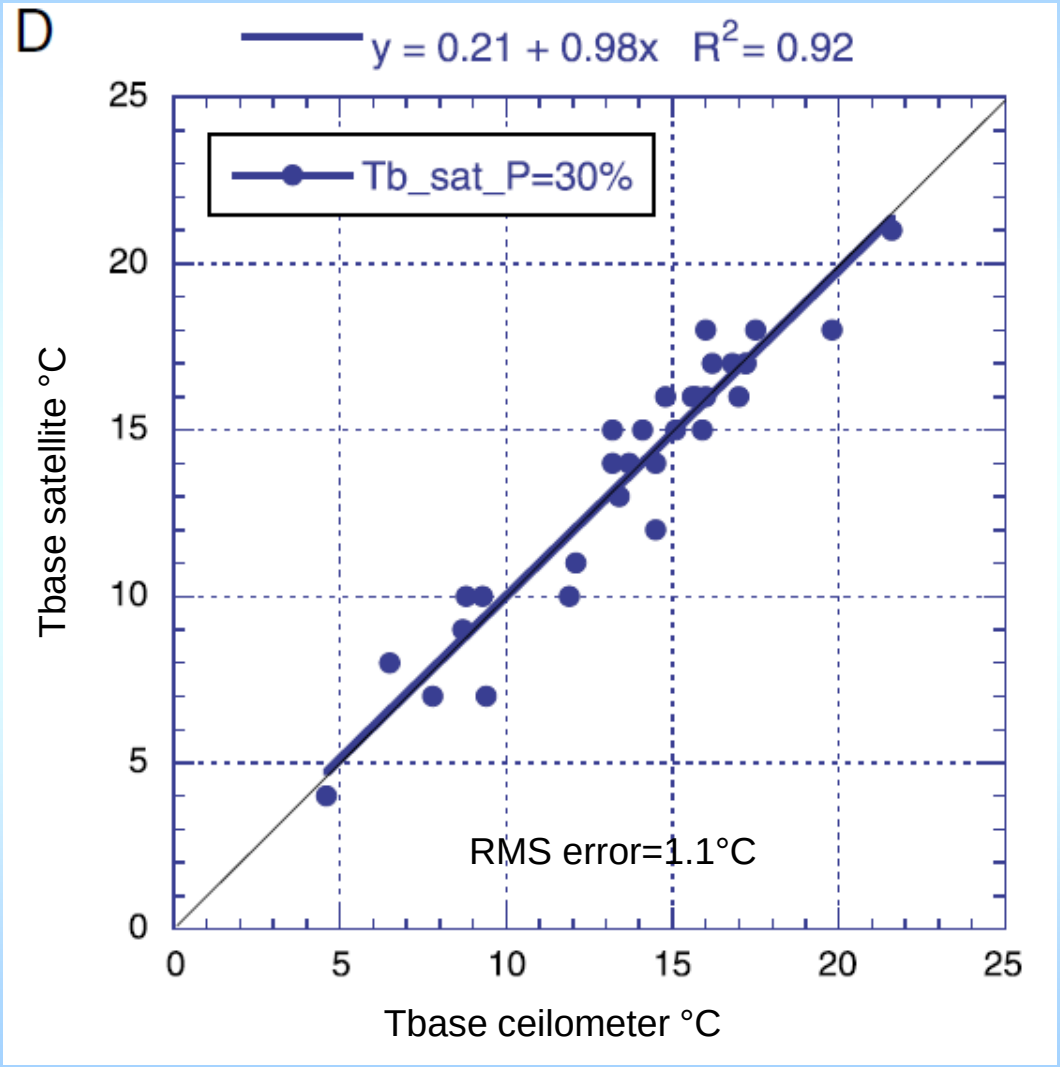
cloud base temperature	*cloud base height*	*PBL water vapor mixing ratio*	*cloud base updraft speed*
 *cloud base temperature is defined as warmest cloudy pixel (Zhu et al. 2014)*	 $H_b = (T_a - T_b)/9.8$	*With a relative humidity of 100% at cloud base height, the T_b can be used to compute the water vapor mixing ratio at cloud base. To retrieve the w_{BL}, we assume a well-mixed BL with fixed water vapor mixing ratio(Zhu et al. 2014)*	 $W_b = 0.20 * [H_b(1 + 0.25V)(T_s - T_a)]^{1/2} + 0.26$ *(Zheng et al., 2015, JAS)*

High spatial resolution is required to resolve the vertical structure of convective clouds. Lower resolution misses all but largest and deepest clouds.



Measurement concept for T-r_e based CCN retrievals

Retrieval of cloudbase height from VIIRS



Zhu et al. (2014, GRL)

Retrieval of Cloud Base Updraft

Algorithm development

Cloud base temperature, height, boundary layer moisture:

Zhu et al., GRL, 2014
Zheng and Rosenfeld, GRL, 2015

Cloud base updrafts:

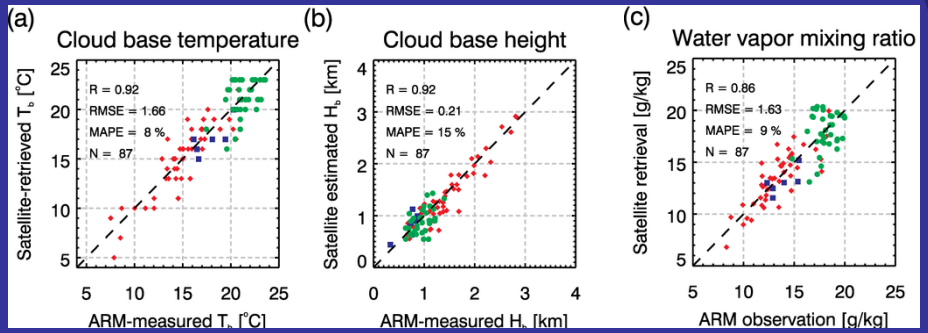
(1) Temperature gradient method: *Zheng et al., JAS, 2015*

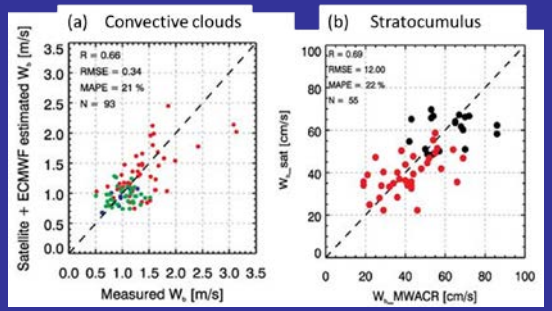
(2) **Cloud base height method**: *Zheng and Rosenfeld, GRL, 2015*

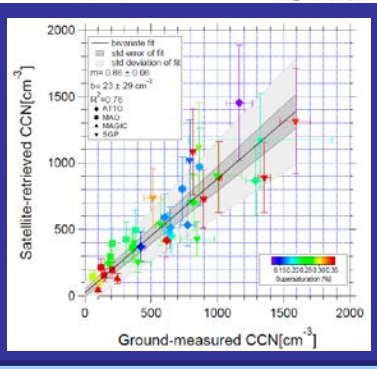
(3) **CTRC method**: *Zheng et al., GRL, 2016,*

CCN (Cloud condensation nuclei):
D Rosenfeld, Youtong Zheng, et al., PNAS, 2016

Ground-based validation



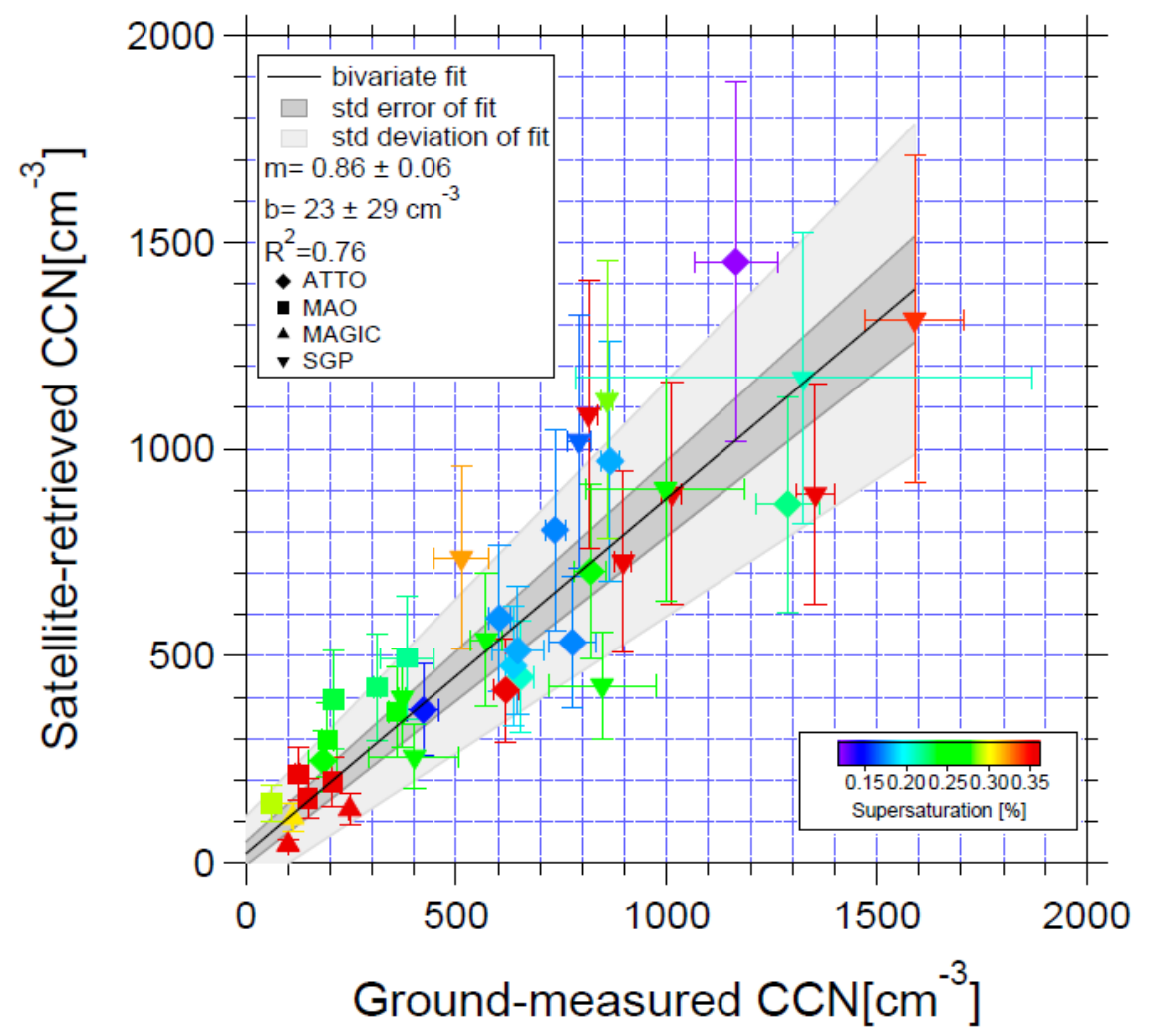




Satellite retrieval of cloud condensation nuclei concentrations by using clouds as CCN chambers

Daniel Rosenfeld[a,1], Youtong Zheng[b,c,d], Eyal Hashimshoni[a], Mira L. Pöhlker[e,f], Anne Jefferson[g], Christopher Pöhlker[e], Xing Yu[h], Yannian Zhu[d,h], Guihua Liu[h], Zhiguo Yue[h], Baruch Fischman[a], Zhanqing Li[b,c,d], David Giguzin[a], Tom Goren[a], Paulo Artaxo[i], Henrique M. J. Barbosa[i], Ulrich Pöschl[e,f], and Meinrat O. Andreae[e]

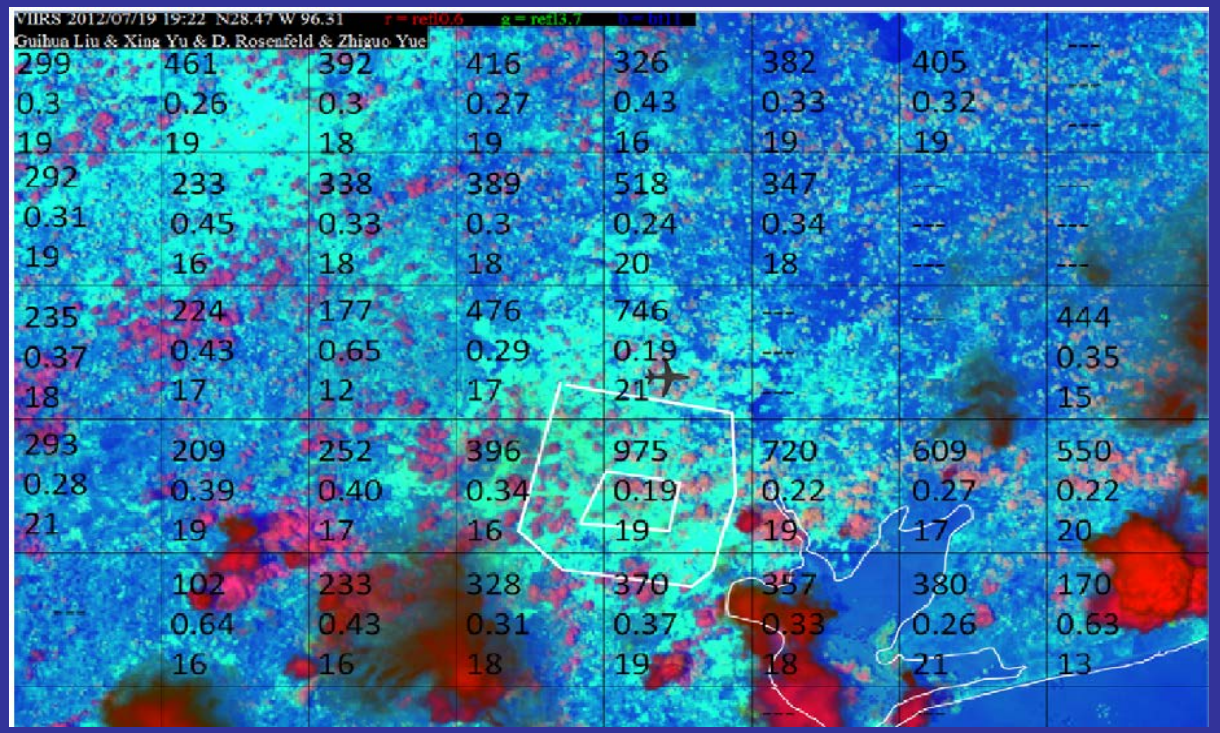
PNAS PNAS PNAS



COLLOQUIUM PAPER

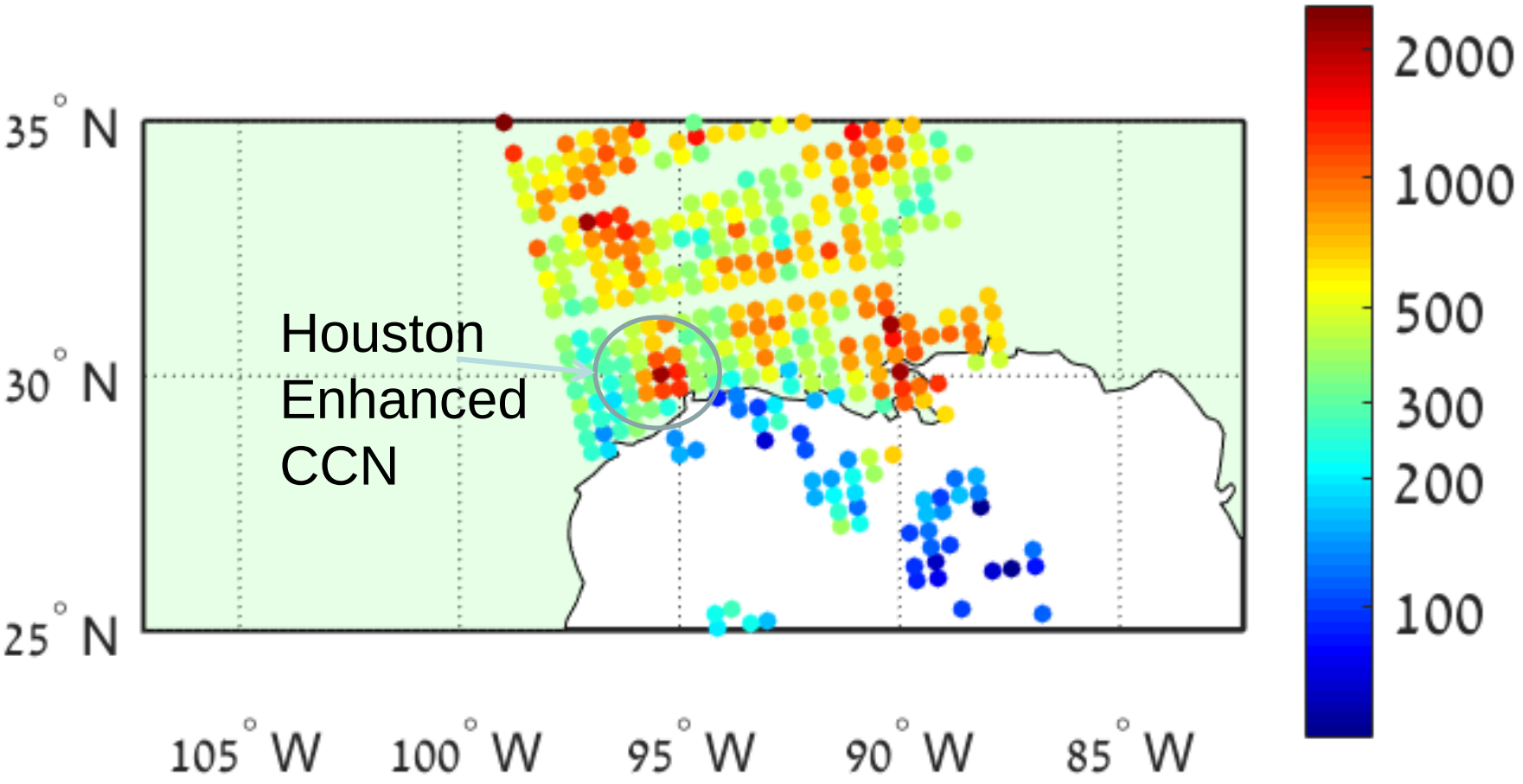
Progress on Meeting Objectives (3/3)

Application to aerosol-cloud interactions



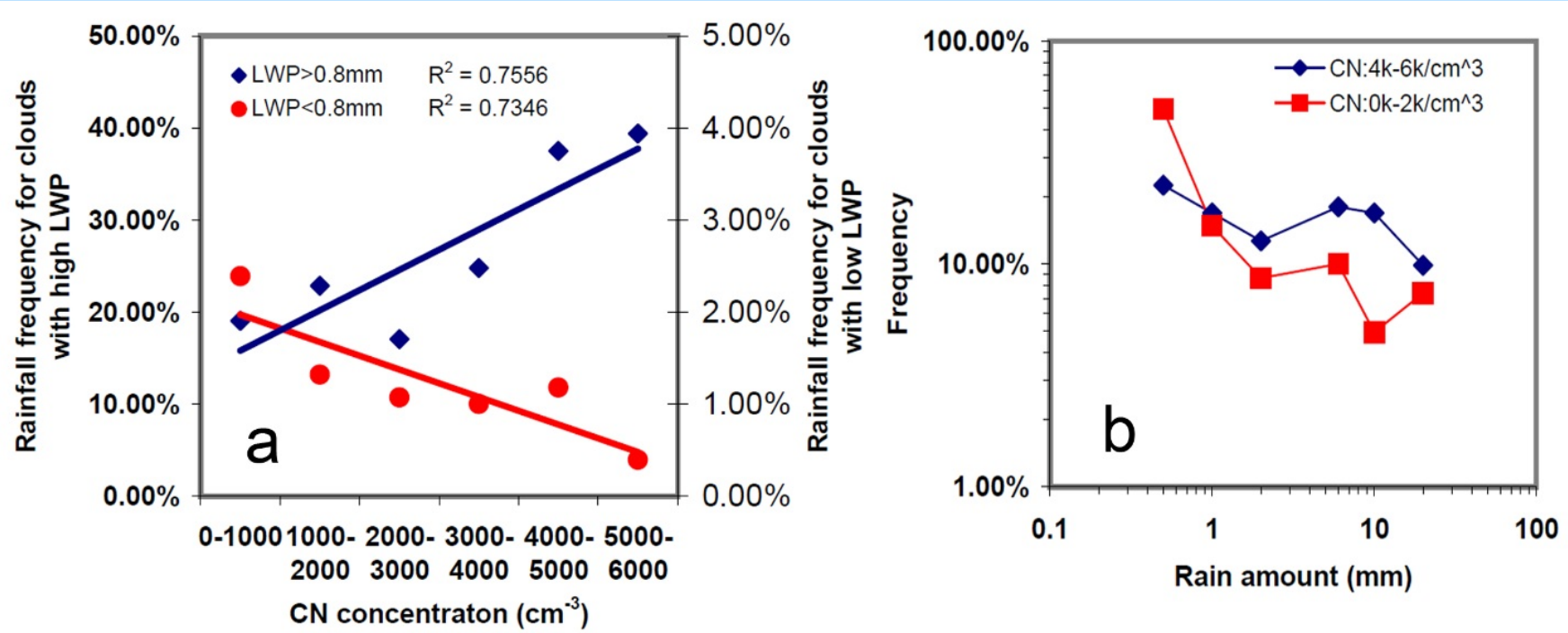
The numbers in each area are, top: CCN (cm^{-3}); middle: *S* (%), bottom: cloud base temperature (°C). Unstable clean tropical air mass flows northward (upward in the image) from the Gulf of Mexico. The Houston urban effect is clearly visible by more than tripling the CCN concentrations over Houston

Satellite retrieved CCN [mg^{-1}]



What can the new products of cloud base height, updraft and CCN help weather and climate studies ?

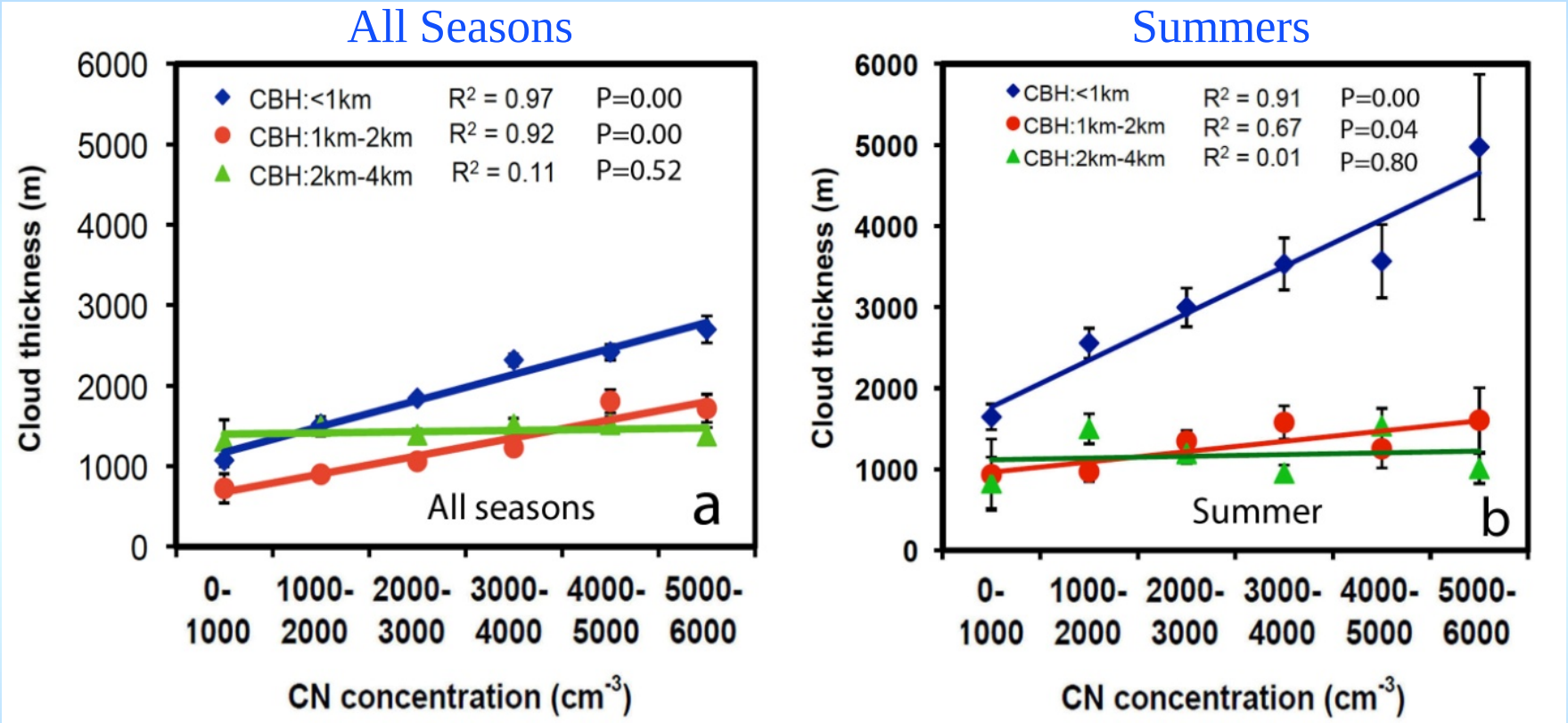
Effect of CCN on Rainfall frequency



1. **For low LWP, rainfall occurrence is suppressed by aerosols (30-50%)**
2. **For large LWP, rainfall frequency is increased by aerosols (50%)**
3. **Light rain is suppressed by aerosols, heavy rain is enhanced !**

Li et al. (2011, Nature-Geoscience)

The Effect of Cloud Base Height on Aerosol-Cloud Interactions



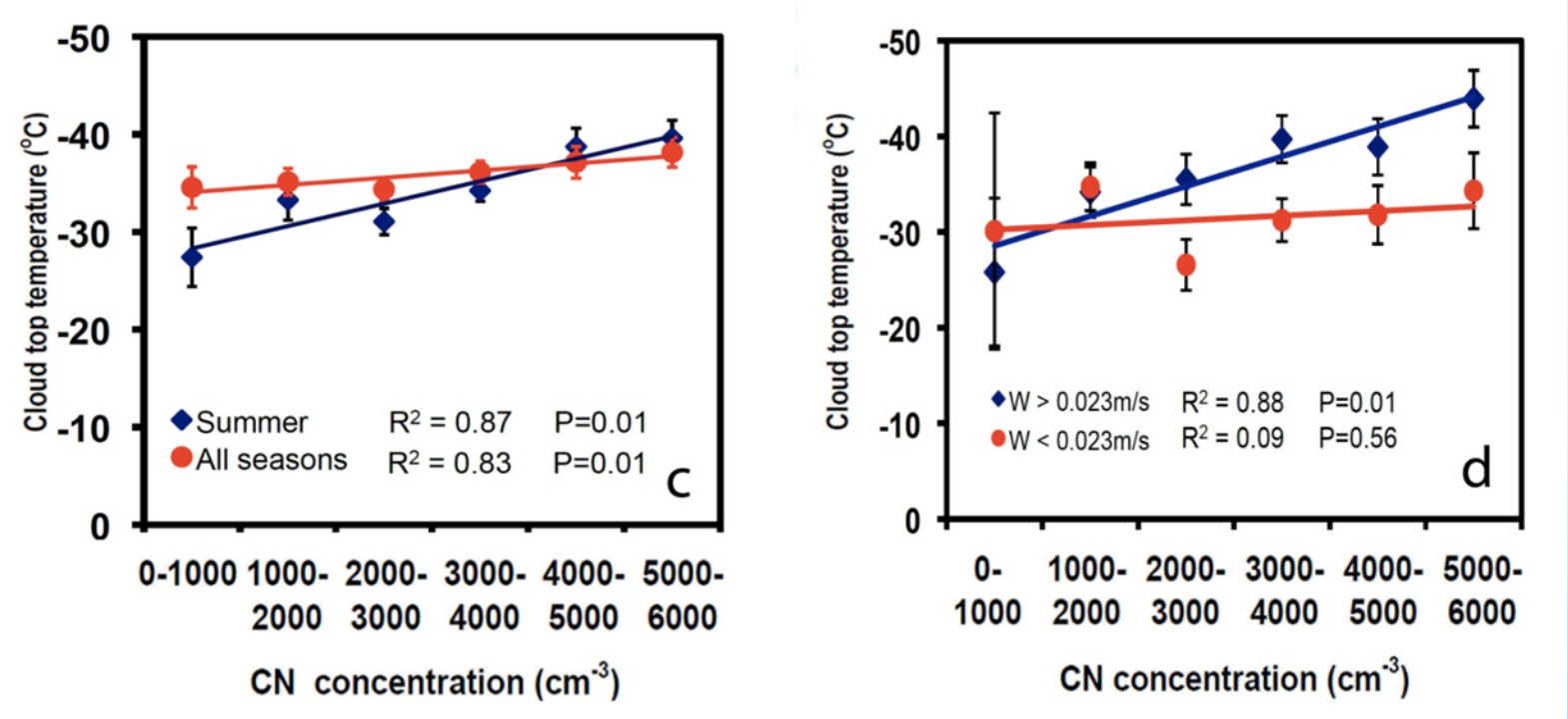
For low clouds (<1km), cloud thickness increases by a factor of 2!
For high clouds (>2km), cloud thickness is not affected at all!.

Li et al. (2011, Nature-Geoscience)

The effect of updraft speed

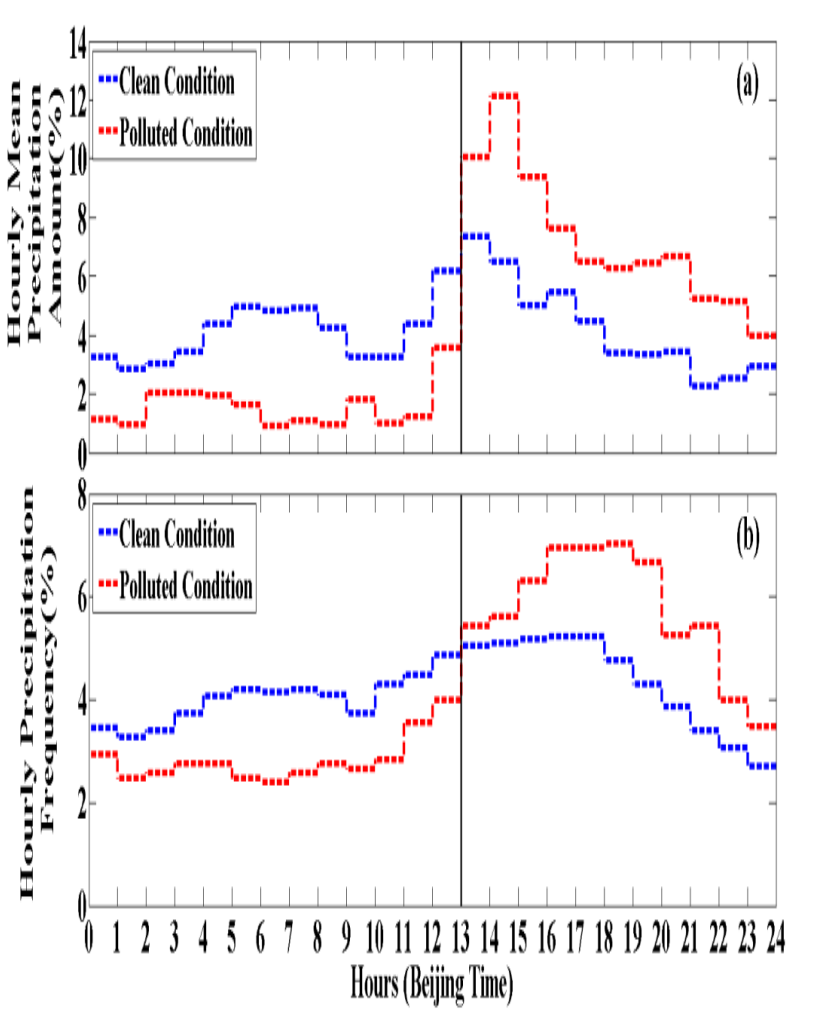
Summer vs All-season

Strong vs Weak Vertical Wind

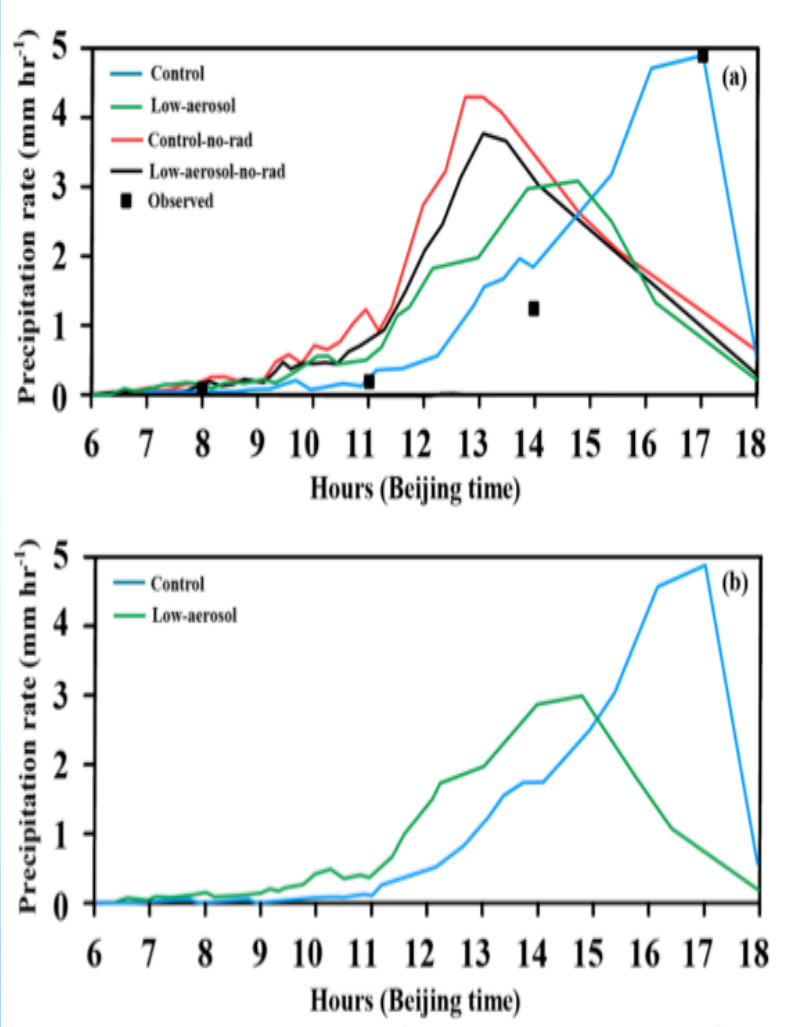


Aerosols have the strongest impact on convective clouds, especially for the invigorated clouds!

Diurnal Cycle of Rainfall from Deep Clouds Contrast between Clean & Dirty Air

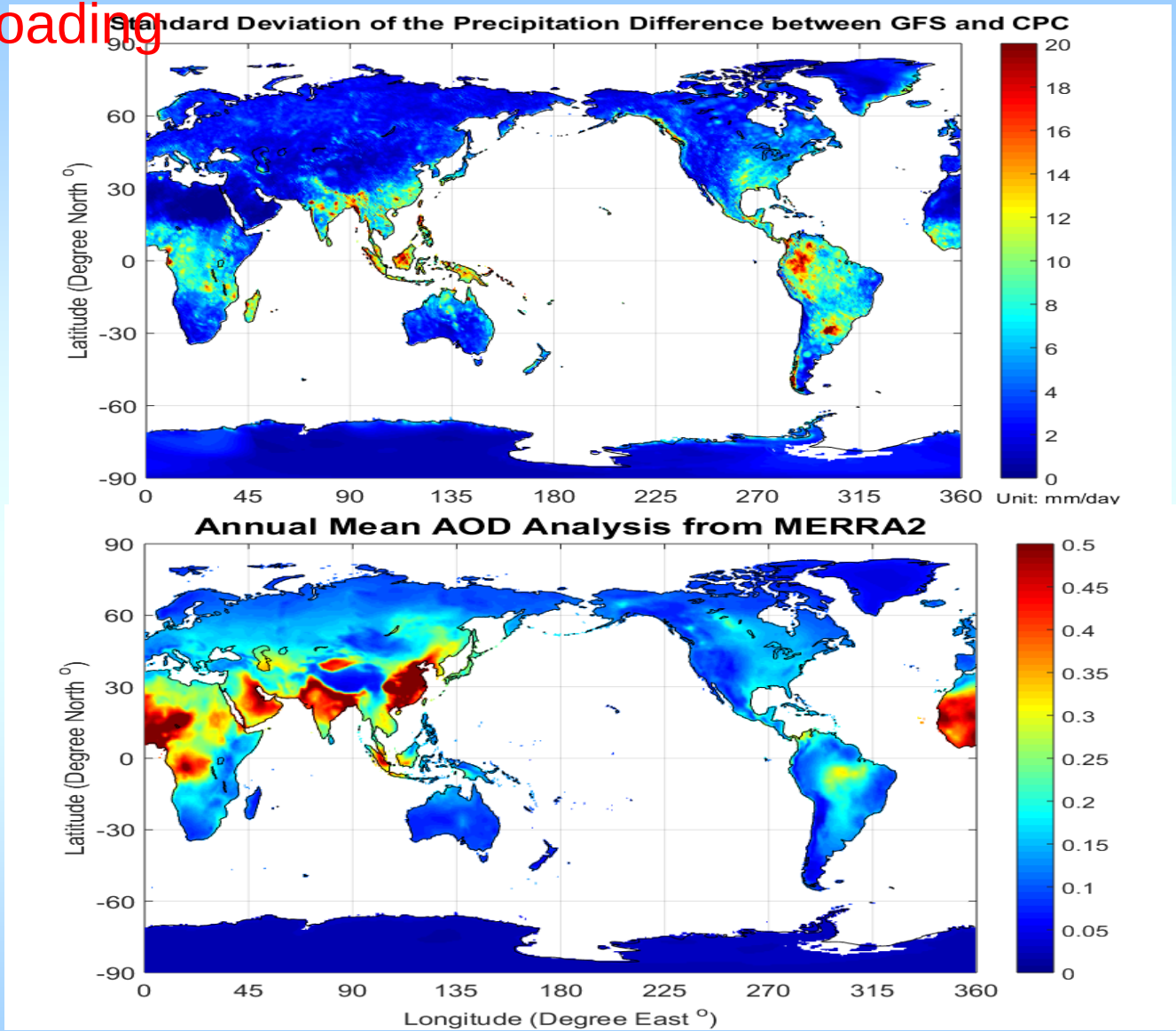


Guo et al. (2016, JGR)



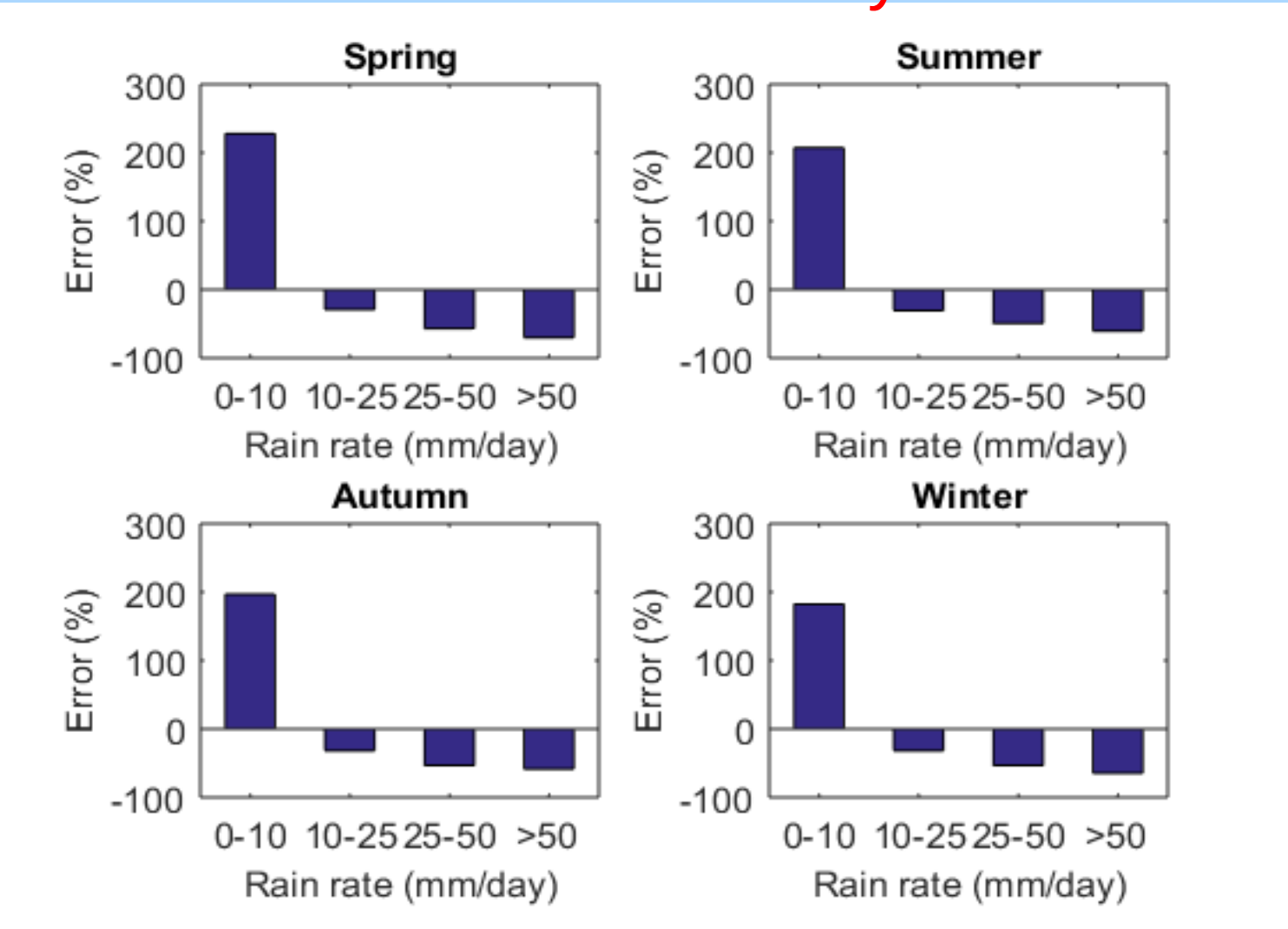
Lee et al. (2016, JGR)

GFS Precipitation Model Error and Aerosol Loading



Jiang et al. (2017, ACP)

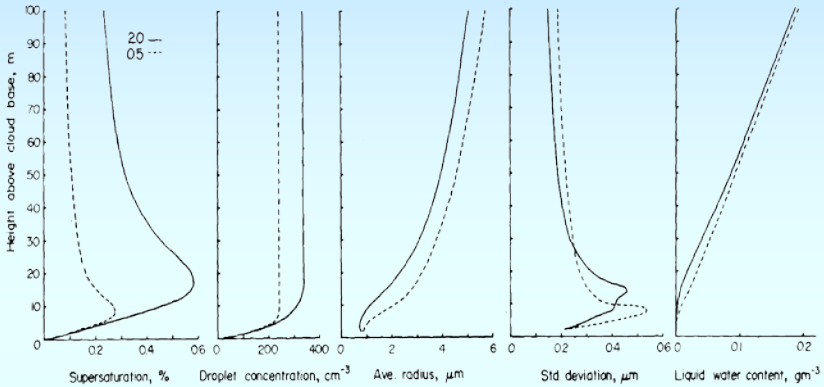
GFS overestimates light rain and underestimates heavy rain



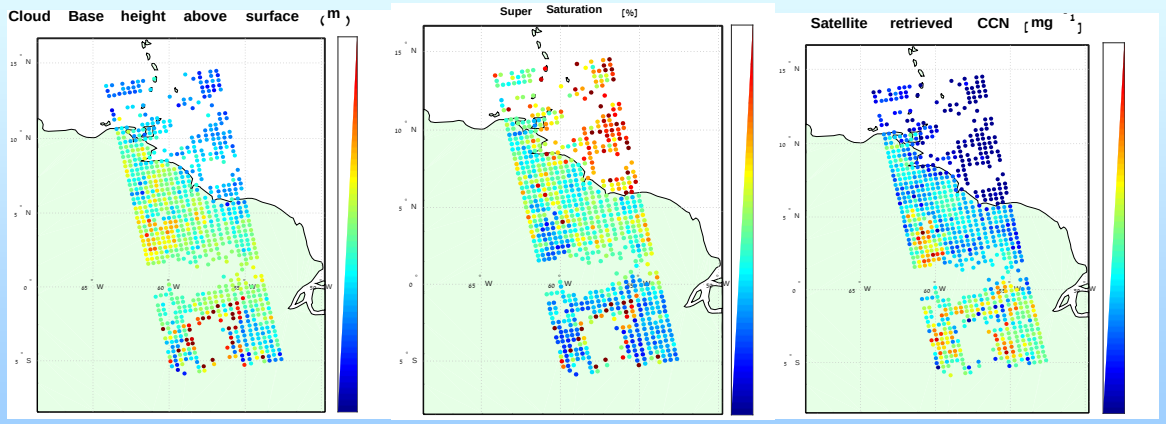
Jiang et al. (2017, ACP)

Looking Ahead

- **Data assimilation to improve NWP**
  - Impacts of updrafts on vertical structure and development of convective clouds



  - VIIRS-retrieved cloud base height, supersaturations and CCN in an automatic system.



Summary

- Satellite products have long been employed in improving weather forecast. It's time to go beyond the conventional approach.
- We have developed a suite of novel satellite methods to derive cloud base updrafts, temperature, height, boundary layer moisture and CCN.
- Pilot work is under way to demonstrate the potentials of the new products in improving weather forecast.
- A new approach of data assimilation for using the new products is yet to be developed when our methods are ready for generating semi-operational products.