Cloud Ceiling Estimates from Satellite

W. Smith, D. Spangenberg, S. Sun-Mack, P.Minnis

Climate Science Branch
NASA Langley Research Center

Who we are and what we do: SatCORPS

(Satellite Cloud Observations and Radiative Property retrieval System)

Global near real-time and historical cloud and surface parameters derived from Satellite imager data

- Primarily support climate studies
  - Cloud properties needed to compute Earth's radiation budget, to understand their effects and trends (NASA CERES Program)
  - VIIRS, MODIS polar orbiting imager's critical climate instruments
  - Global GEO imager data used to capture diurnal cycle
- GEO cloud properties now available for and utilized in a variety of Weather applications *(various stages of development and NWS demonstration)*
  - Aircraft icing (SLW, HIWC), Convection (OT's), NWP, solar energy…

DATA ACCESS: https://satcorps.larc.nasa.gov

GOAL: Accurate and consistent cloud retrievals in time and space

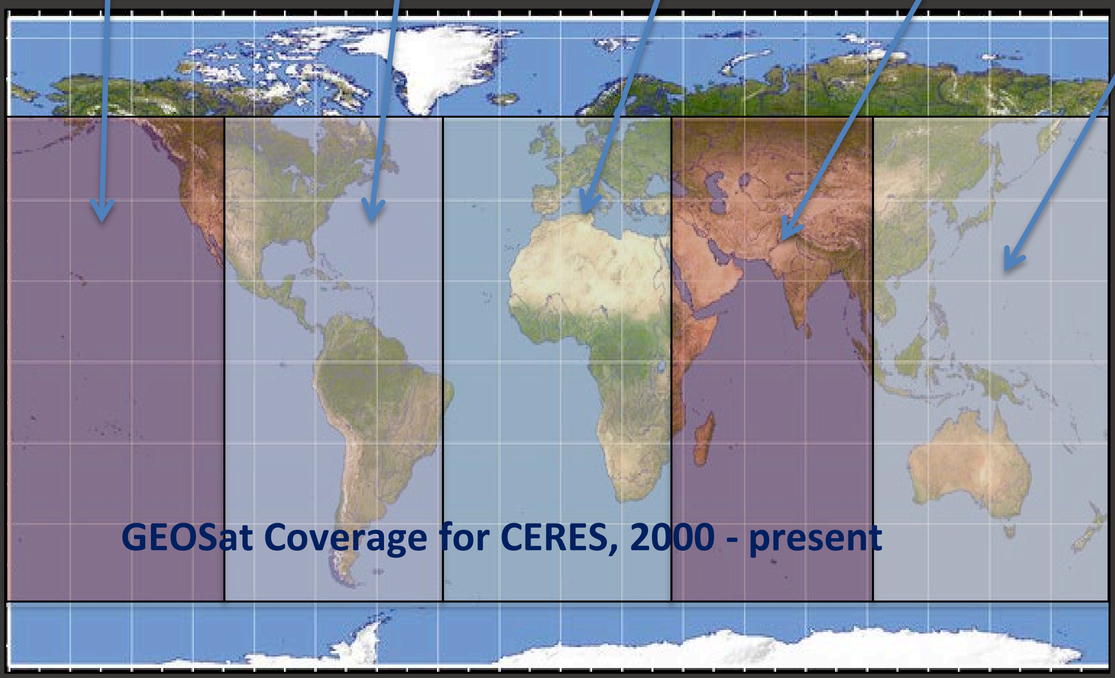
GOES-10
01/00 – 05/06
GOES-11
06/06 – 07/11
GOES-15
08/11 - now

GOES-8
01/00 – 03/03
GOES-12
04/03 – 07/13
GOES-13
08/13 – now
GOES-16
11/16 - now

MET-7*
01/00 – 03/04
MET-8
04/04 – 03/07
MET-9
04/07 – 12/12
MET-10
01/13 - now

MET-5*
01/00 – 12/06
MET-7*
01/07 – 12/16
MET-8
01/17- now

GMS-5*
01/00 – 04/03
GOES-9
05/03 – 06/05
MTSAT-1R
07/05 – 06/10
MTSAT-2R
07/10 – 06/15
HIMAWARI-8
06/15 - now



Three generations of GEOSat's

- Different spectral channels and response functions
- Different resolutions
- Different impacts from sfc & atmosphere

Achieving consistent retrievals among satellites a significant challenge

Weather and climate requirements quite different!

What do Satellite Imager Cloud Retrievals Provide?

<u>**Standard Cloud Retrievals (most imagers)**</u>

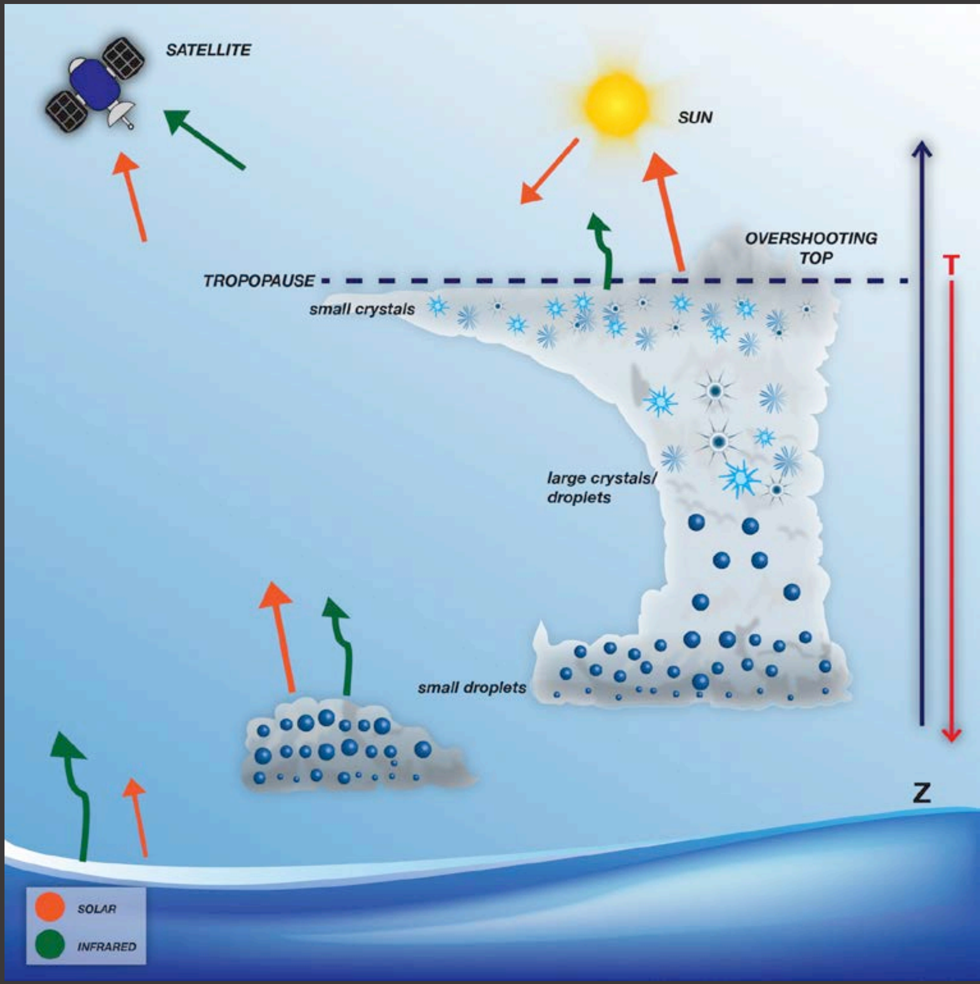
Channels: 0.65, 3.7, 10.8, 12.0 µm

(e.g. GOES since 1995 over U.S.)

- **Mask (detection)**
- **Phase at top**
- **Effective droplet/crystal size (cloud top)**
- **Effective Temp, height, pressure**
- **Optical thickness**

Minnis et al., TGRS, 2011

Cloud top height and optical depth provide a vertical dimension – potential to infer the geometric thickness and base height or ceiling



What do Satellite Cloud Retrievals Provide?

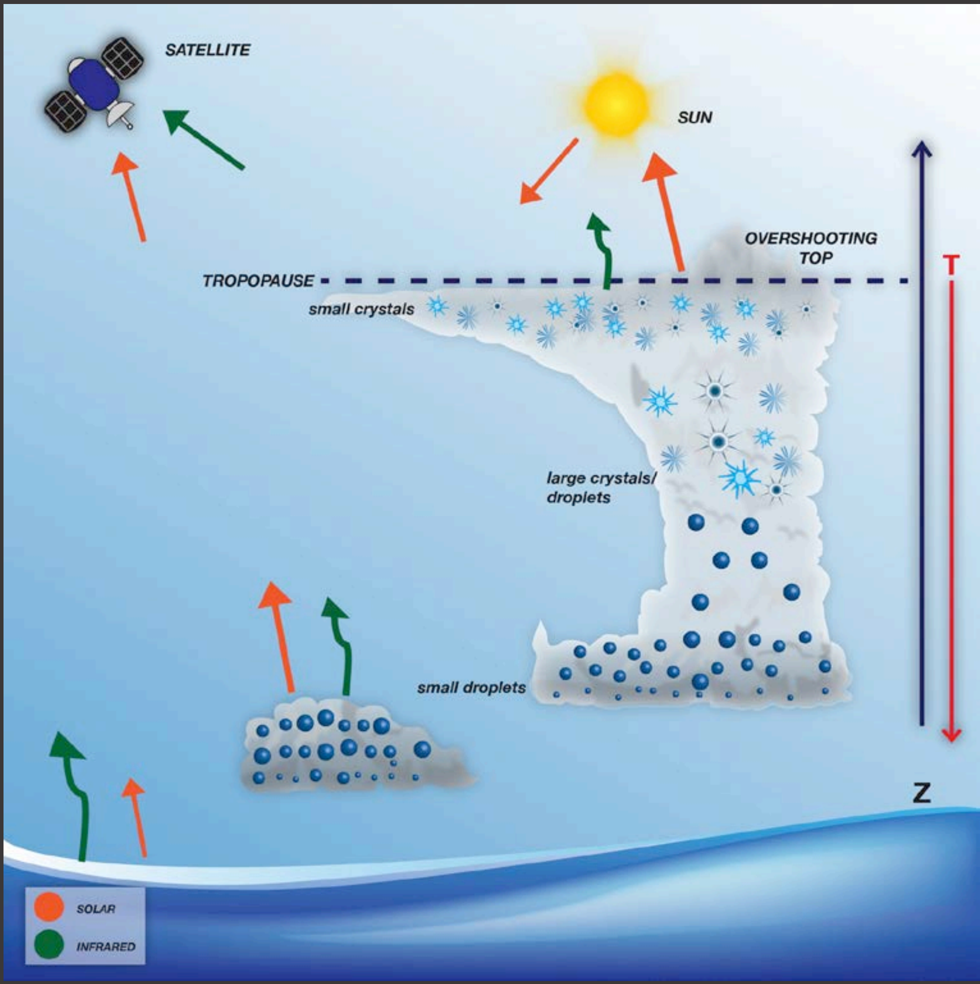
<u>More recent capabilities</u>

Additional channels on newer imagers:
MODIS/SEVIRI/VIIRS/Himawari/GOES-R
1.38, 1.2, 1.6, 2.1, 6.7, 13.3 µm

- **Improved cloud detection**
- **Improved retrievals over snow**
- **Multilayer retrievals (cirrus over stratus)**
- **Improved cloud heights**
- **Effective radius profiles - info on cloud vertical structure**
- **More information at night**

<u>Derived products</u>

- **Cloud top height, thickness, base height**
- **Liquid or Ice Water Path**
- **Ice & liquid water content profiles (4D)**
- **Icing, HIWC, OT's**



Cloud Ceiling Estimates from Satellite

Basic approach (current)

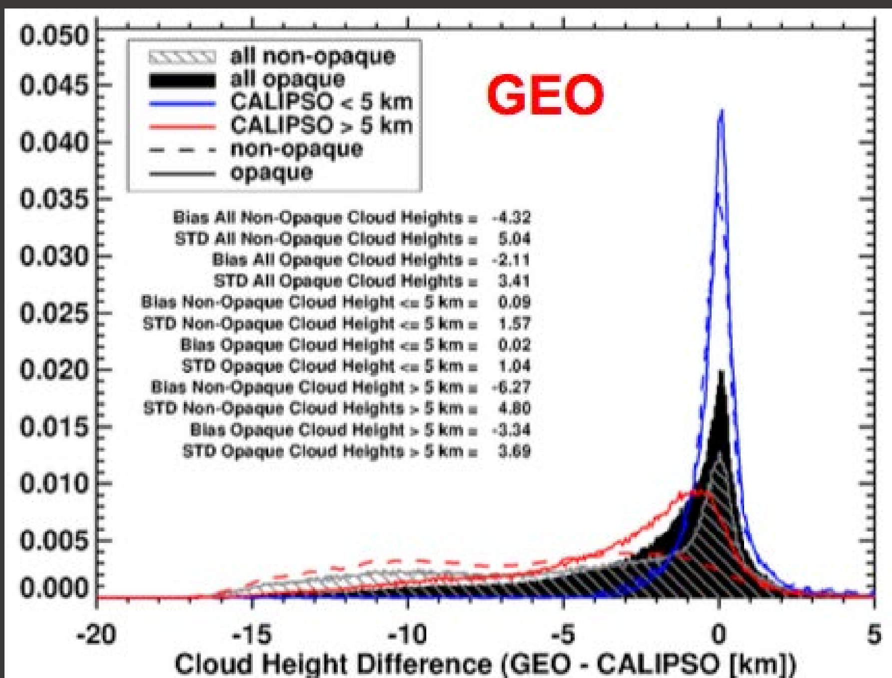
1. Infer cloud geometric thickness from other retrieved parameters (satellite only)
   - parameterized as function of cloud T, COD, Re, phase
   - One empirical fit each for ice and water clouds
2. Subtract thickness from CTH to estimate CBH:
   - CTH also challenging
     a) Satellite sensitive to radiative top (lower than physical top for ice clouds)
     b) Satellite measures temperature (must infer height from T-profile)
        - Boundary layer inversions not well characterized (NWP), can lead to large errors wne converting satellite cloud temperature to height
   - Empirical methods employed to estimate physical CTH

Minnis et al, 2008, GRL   Sun-Mack et al, 2014, JAMC

Cloud Ceiling Estimates from Satellite

Cloud top height uncertainties

Lidar data (CALIPSO) used to ground truth imager CTH estimates



Lidar highly sensitive to cloud

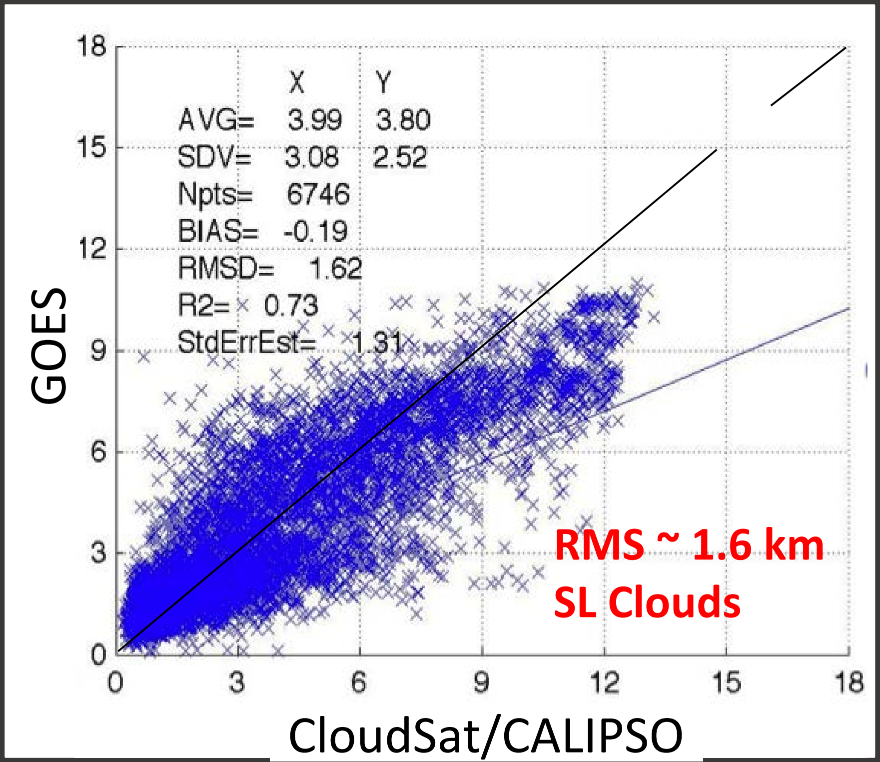
Overall Summary
(excludes very thin clouds)

Cloud Type	BIAS (km)	RMS (km)
SL Ice (thick)	0.03	1.2
SL Ice (thin)	- 0.8	2.0
SL Water	0.05	0.8
All ice clouds	-2.5	4.0

- **Low level water cloud and thick ice cloud top heights nearly unbiased**
- **Cirrus CTH uncertainty 1-2 km**
- **Largest uncertainties found in ML cloud conditions (~3-5 km)**

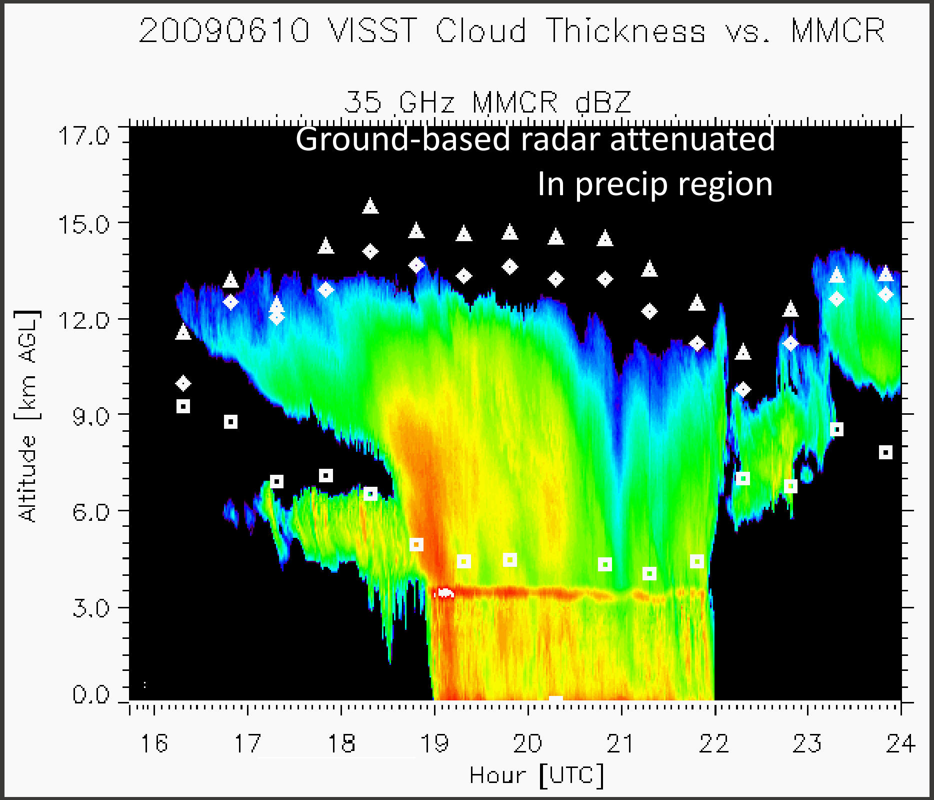
Ice Cloud Thickness from CloudSat, CALIPSO & GOES

CALIPSO/CloudSat ice cloud thickness vs GOES thickness April – June, 2008



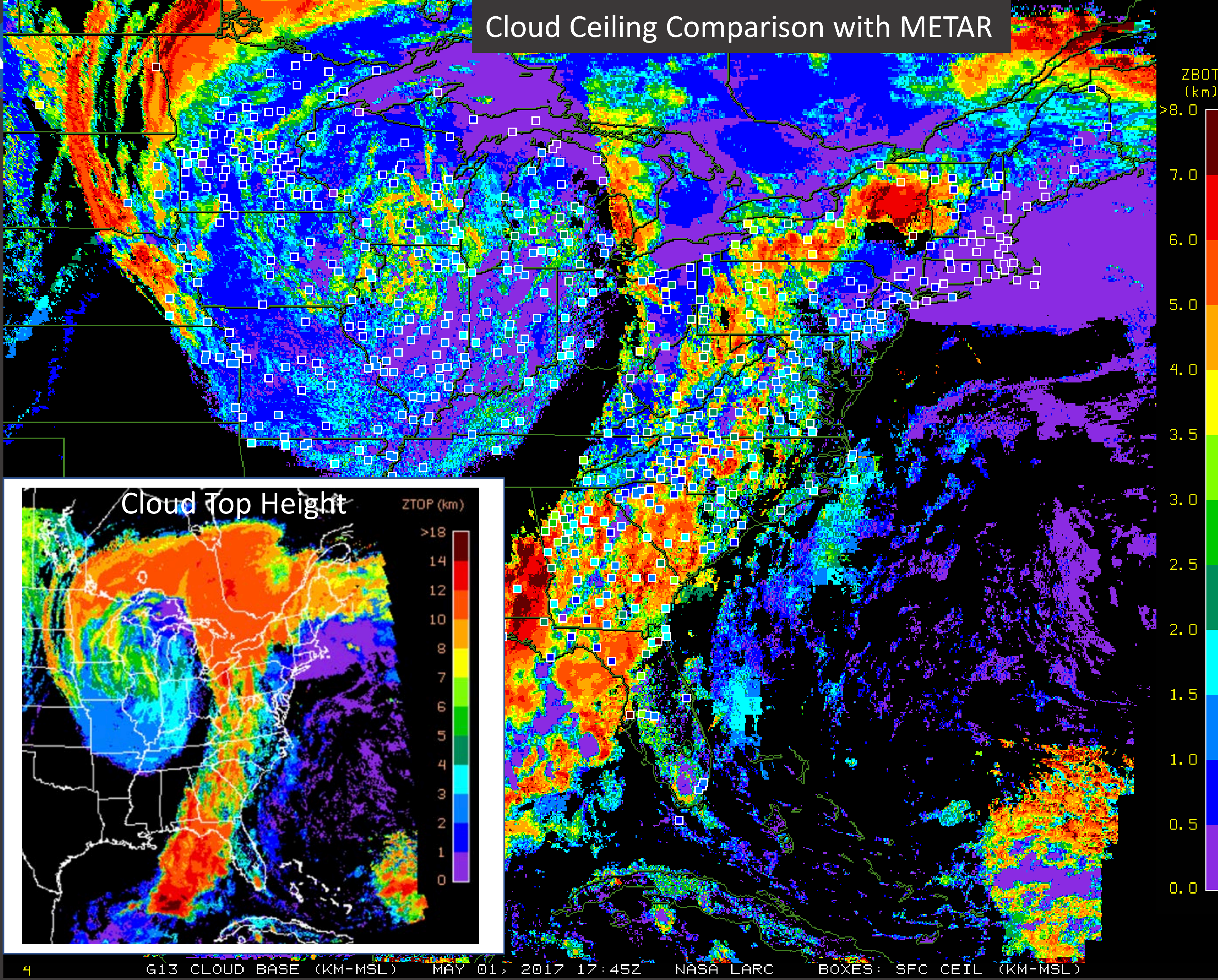
GOES DZ based on empirical fit to CALIPSO/CloudSat data from different year

Cloud boundaries from GOES-12 over ARM SGP radar, 10 June 2009



- Triangle – physical top
- diamond – effective top
- square - base

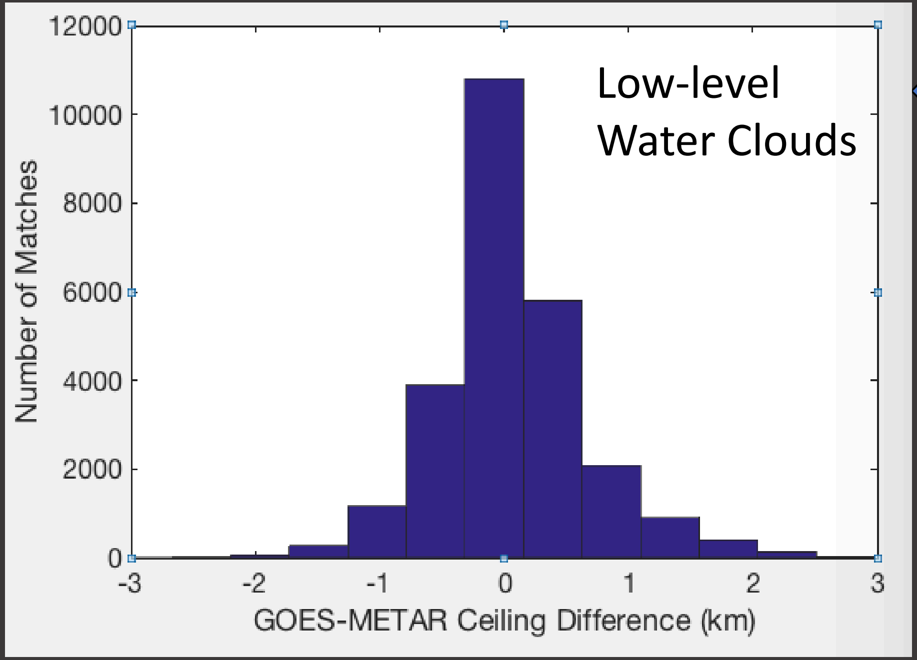
Cloud Ceiling Comparison with METAR



Cloud Ceiling Comparisons with Surface Obs

Cloud thickness estimated as function of optical depth, temperature, water-path, Reff & phase: cloud base height = top - thickness

Histogram, GOES-METAR



Satellite Cloud Base vs. METAR
Eastern USA: May-June, 2017

	RMS Error (km)	Bias (km)	Number of Matches
Water Cloud Base	0.53	0.06	25564
Ice Cloud Base	1.96	1.03	32155

- Base height error similar to top height error for water clouds
- Base height error larger for ice clouds (precip & ML clouds included)

Summary and Future Plans

Cloud ceiling estimates from satellite challenging – not directly observed

- Sufficient information content for some applications and for many clouds (e.g. single-layer, non precipitating cloud systems)
- Most useful in remote areas where no other information
- Unobscured low cloud ceilings and single layer cirrus are best
- Deep optically thick and multi-layer systems currently problematic
- CTH data assimilation in NWP improves predictions of ceilings<1000’ by 10%

Future work

- New multi-layer retrieval method (neural net) nearly complete – important to ID these clouds to improve the practical utility of satellite CBH
- Plan to test neural net method for cloud thickness (later this year)
- Potential to fuse ASOS observations and satellite method over CONUS
  - Goal to use satellite data to extend ASOS ceiling information to surrounding areas
  - Recent studies use MODIS to extend nadir CloudSat Radar obs along MODIS cross-track, i.e. 3-D cloud reconstruction (Barker et al. 2011, Miller et al. 2014, Ham et al. 2015)