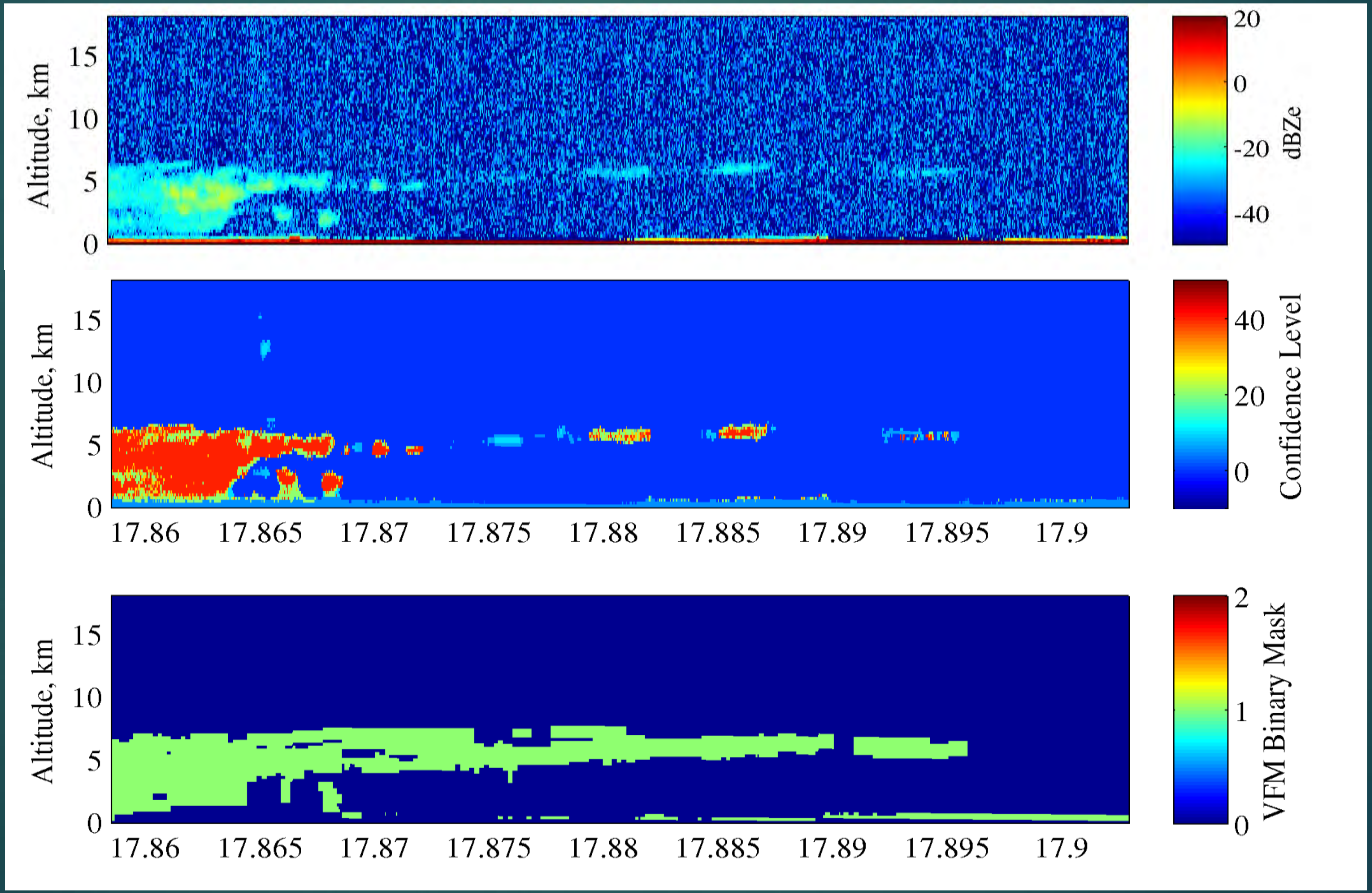
The Release 5 CloudSat Products: Upgrades of Relevance to UT Cloud Process Studies

TRISTAN L'ECUYER, ROGER MARCHAND, ZHIEN WANG, JAY MACE, MIN DENG, KATHRYN SAUTER, YUN HANG, JULIET PILEWSKIE

2B-GEOPROF

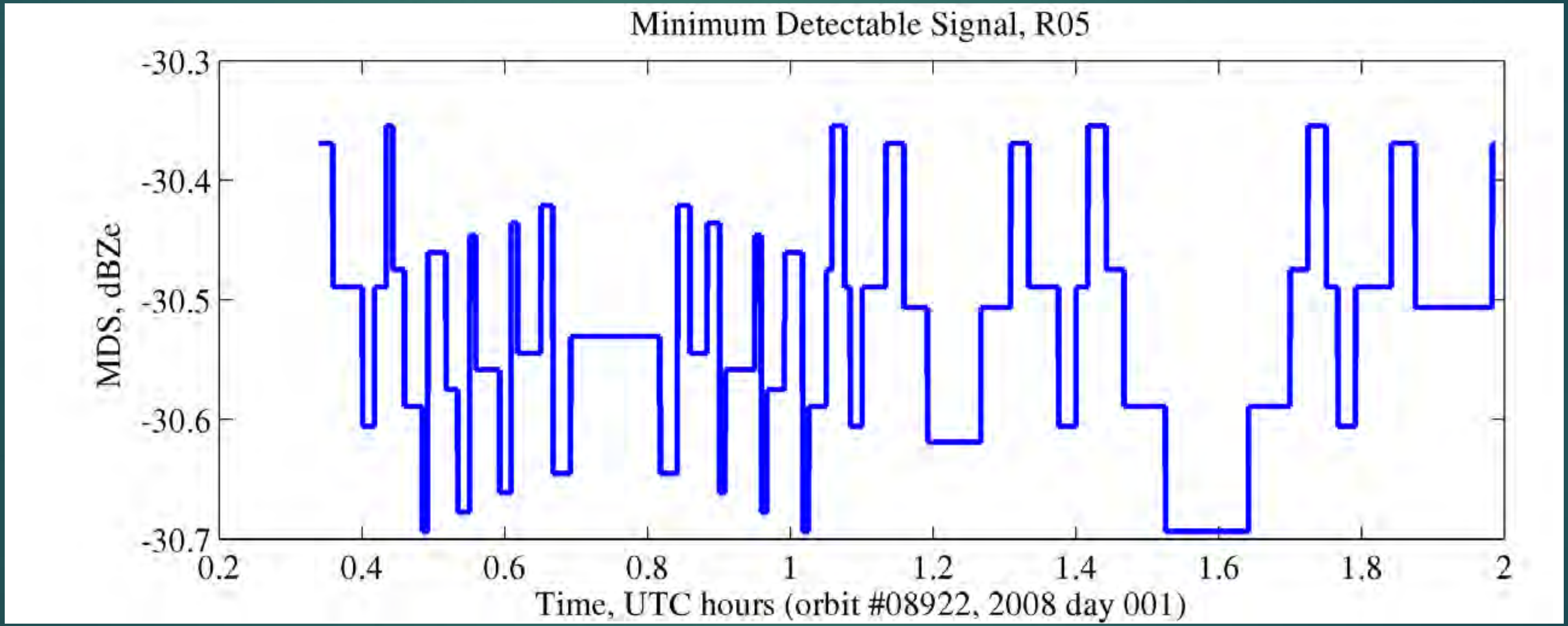


Altitude, km
15
10
5
0
20
0
-20
-40
dBZe
Altitude, km
15
10
5
0
17.86
17.865
17.87
17.875
17.88
17.885
17.89
17.895
17.9
40
20
0
Confidence Level
Altitude, km
15
10
5
0
17.86
17.865
17.87
17.875
17.88
17.885
17.89
17.895
17.9
2
1
0
VFM Binary Mask

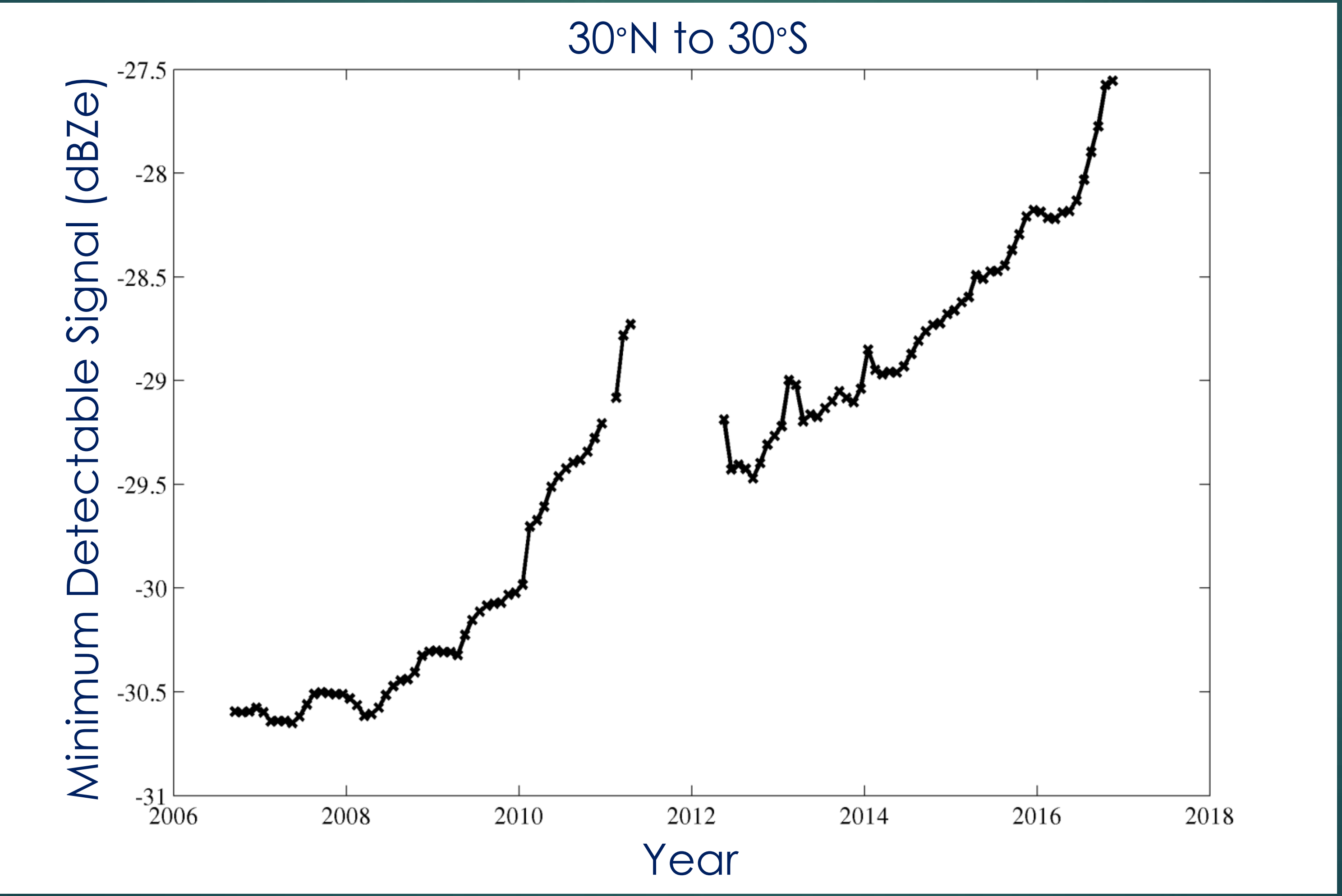
Status and Changes for R05

- Improved DEM, and minor changes to quality flags
- Reduced false detection rates
  - Primarily for low confidence detections
- Greatly improved clutter detection
  - Especially over land
- Extended through 2017
- Important new variable: Minimum Detectable Signal (MDS)
  - Important to track in longer-term studies of thin clouds

Minimum Detectable Signal

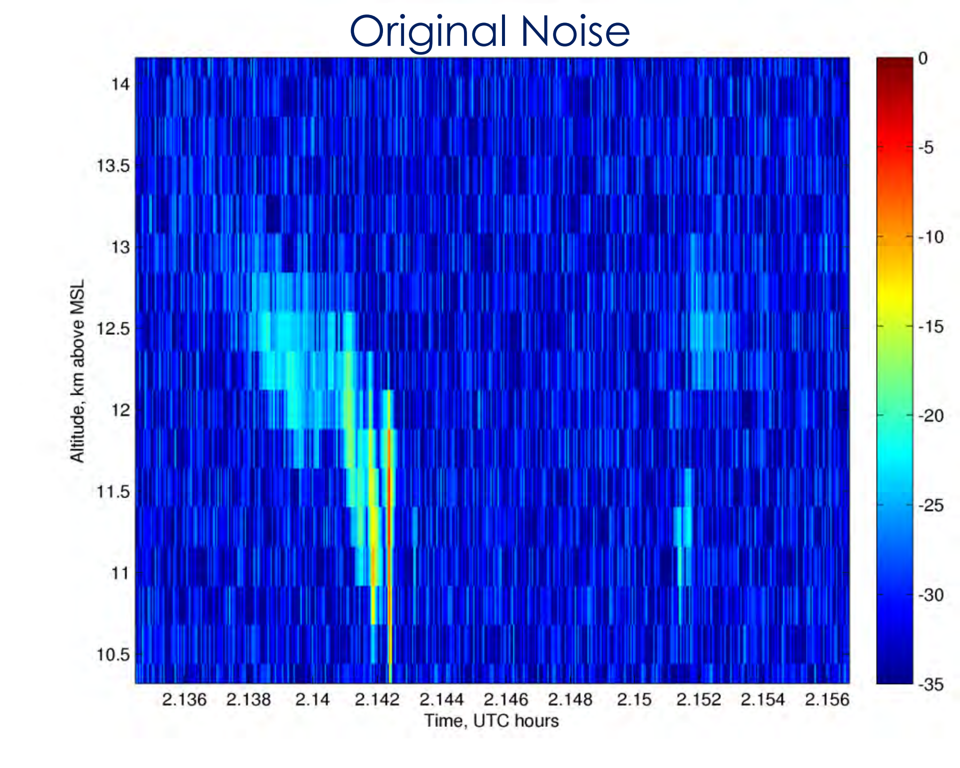


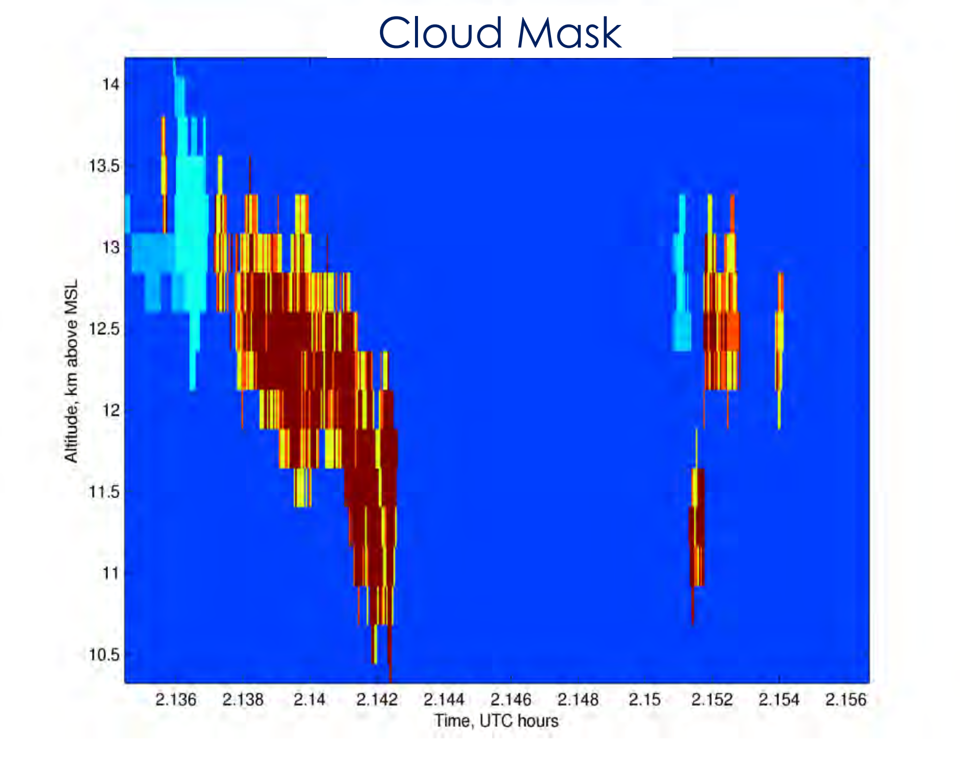
Time Evolution



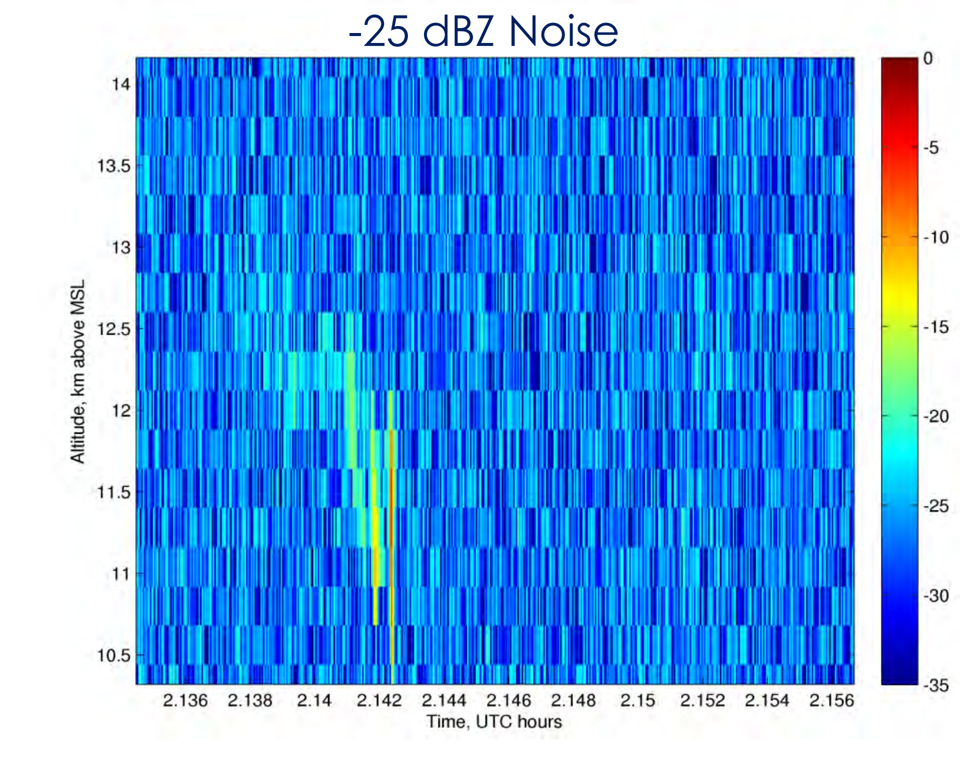
Decreased likelihood of detecting thin cirrus

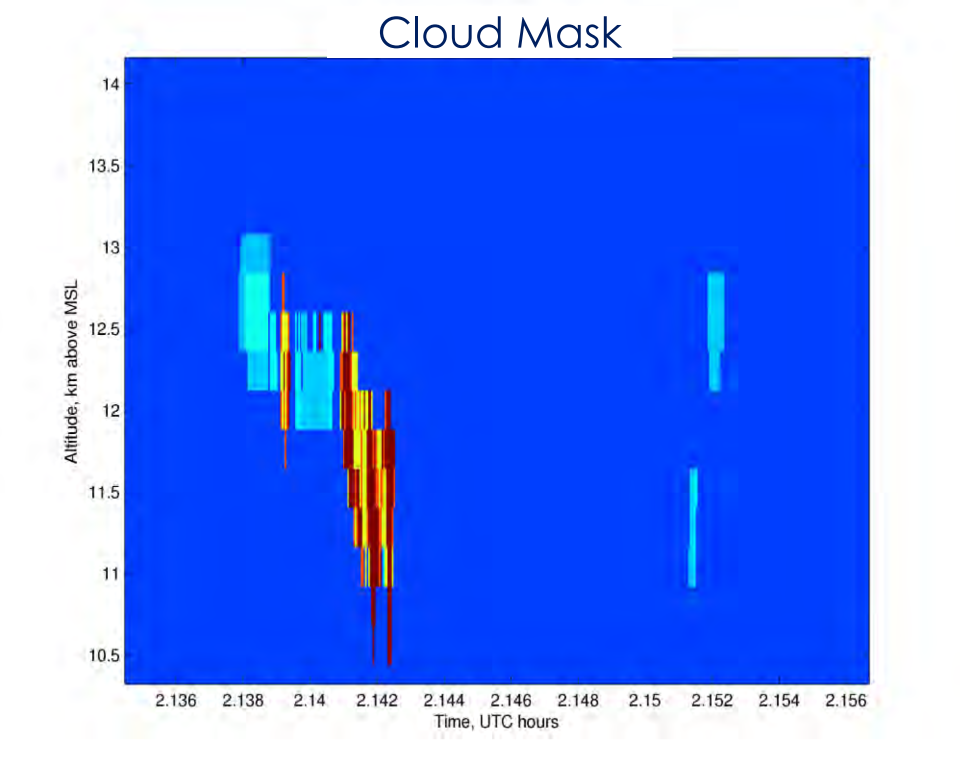
Example: Original





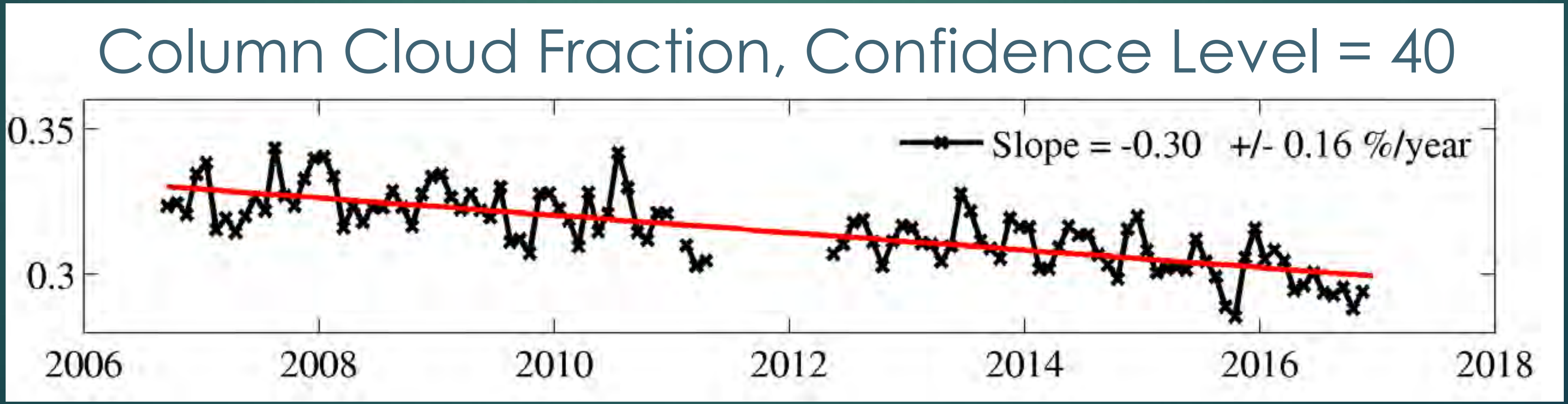
-25 dBZe Equivalent Noise





Impact on Trends

- Caution is required when analyzing trends
- If not properly accounted for, the decrease in sensitivity with time causes an artificial trend in cloud fraction
- This is mitigated by including lidar (GEOPROF-lidar)
- A '*Constant Sensitivity*' GEOPROF product is being developed

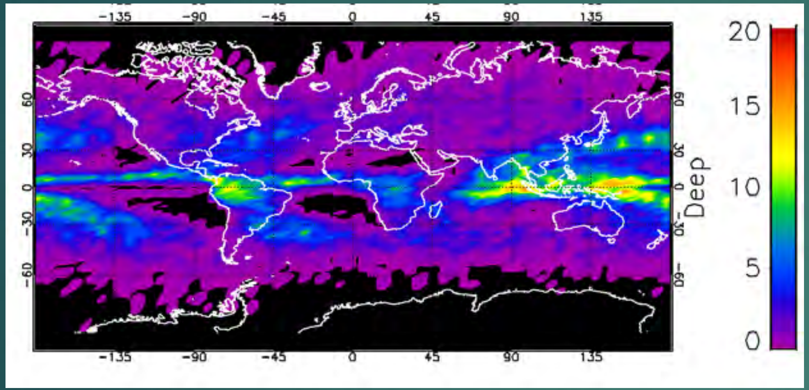


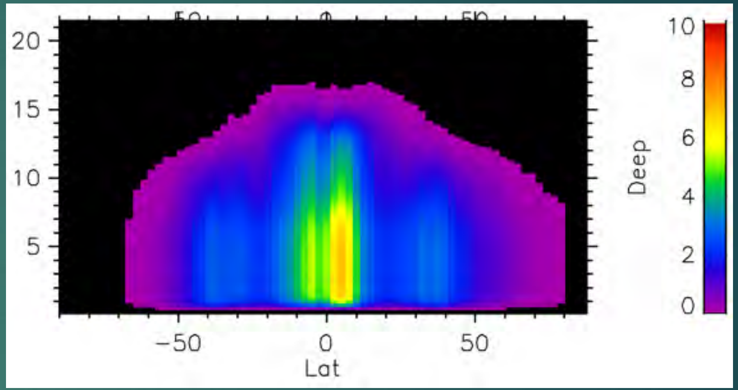
2B-CLDCLASS

- Provides vertical structure-based cloud classification including deep convective and cirrus clouds
- Refined deep convective cloud identification
  - Non-precipitating deep layers are moved to As
  - Extend precipitating clouds in high latitude → Ns
  - Weak precipitation clouds are not classified as deep convective clouds
- Add a temperature limitation for Ac
- Changes in the classifications of boundary layer clouds over Antarctica

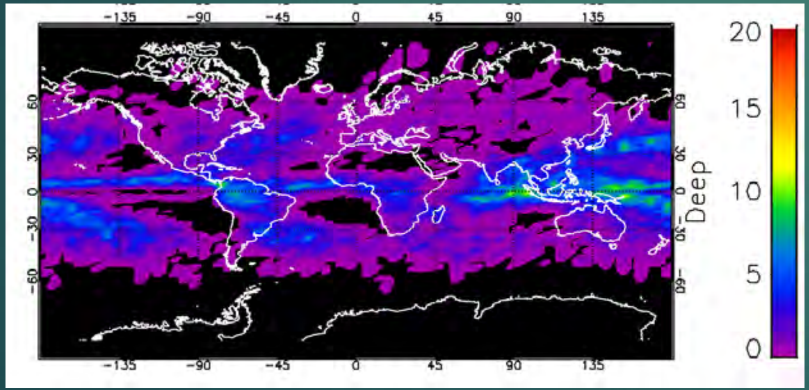
Deep Convection

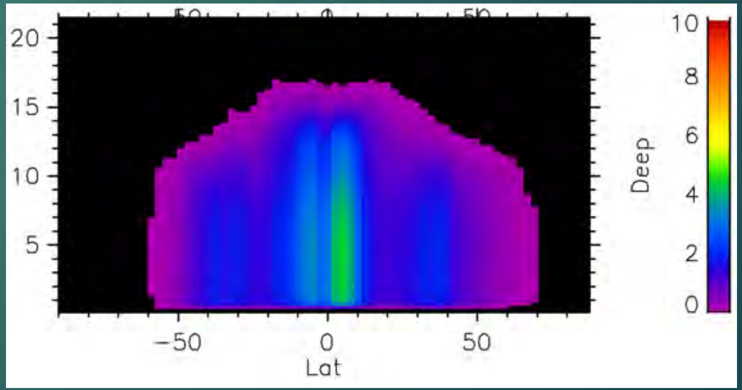
R04





R05

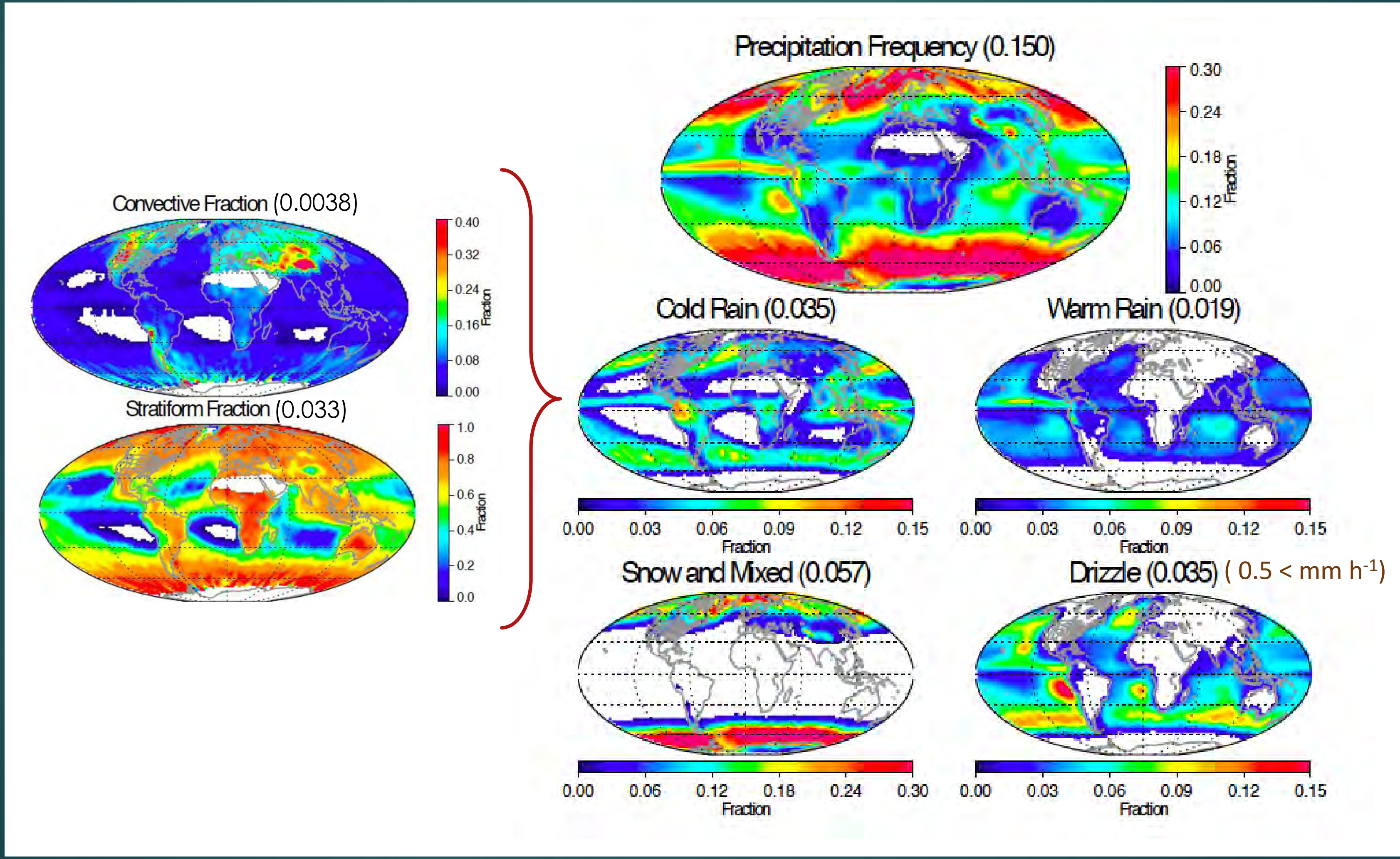




2007

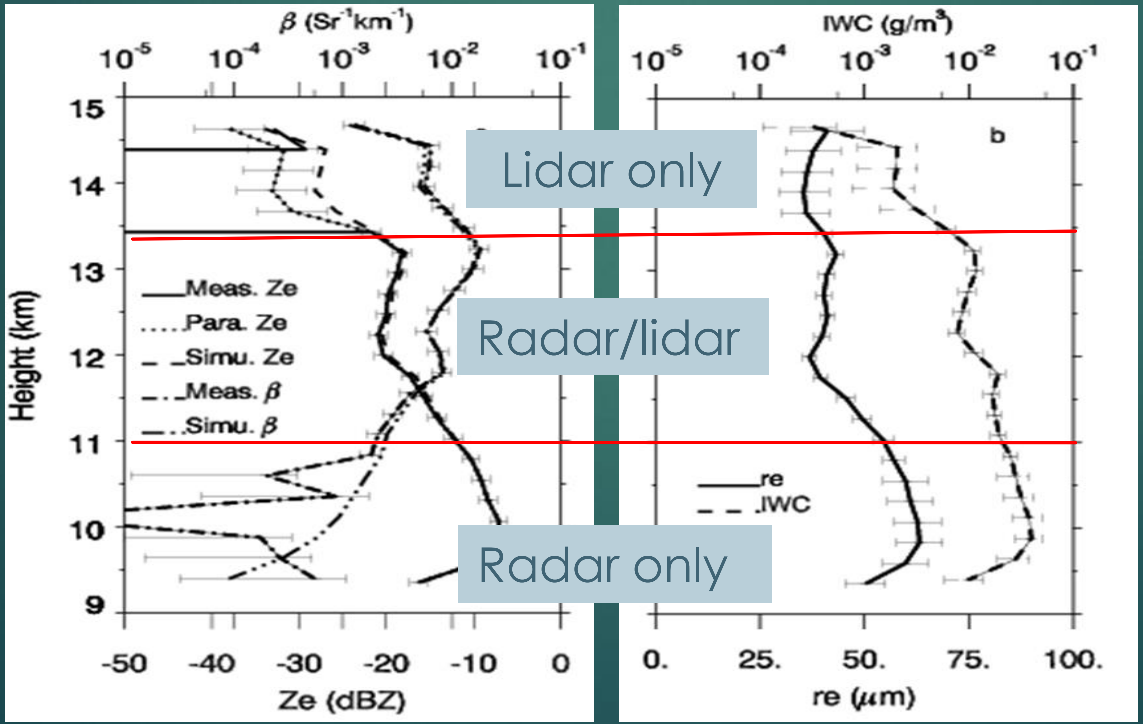
Precipitation Classification

2007-10 mean from 2C-PRECIP-COLUMN



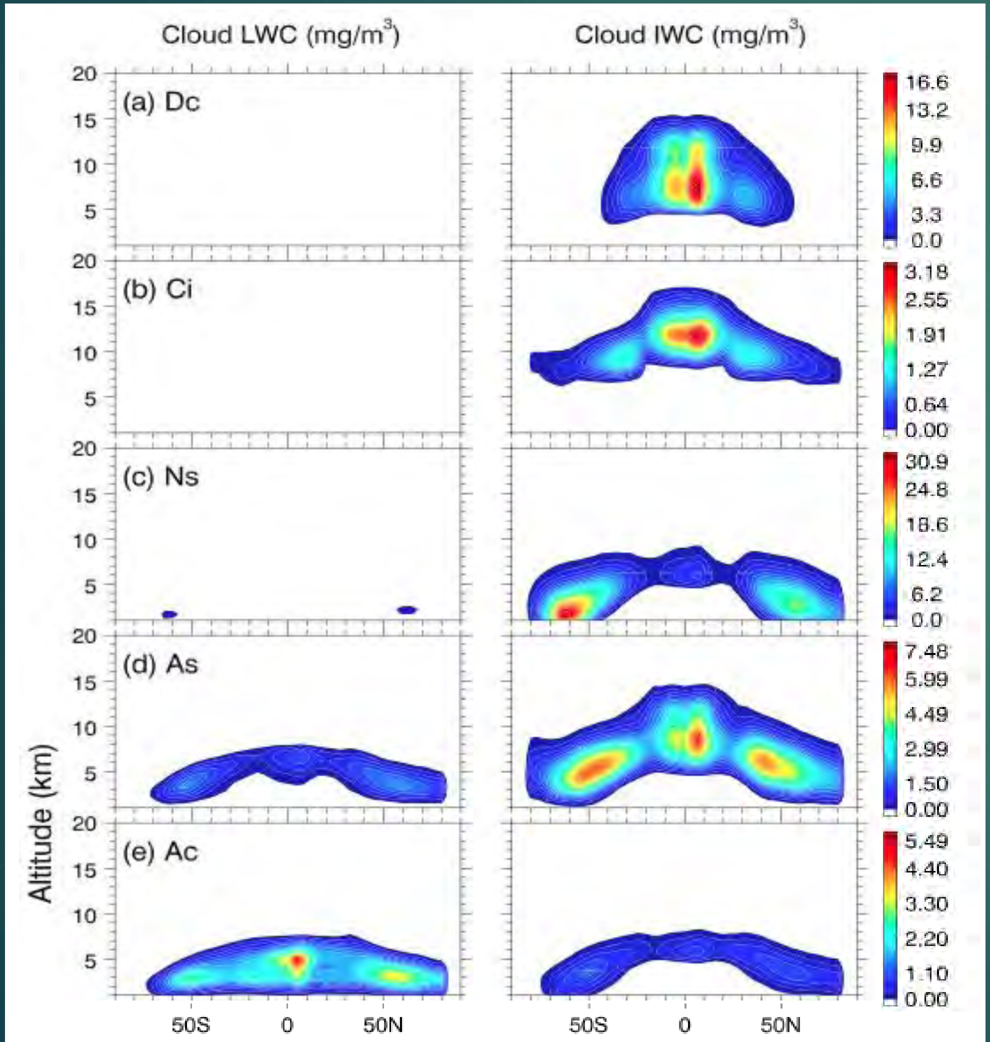
2C-ICE

- 2C-ICE is a validated operational algorithm to derive ice cloud microphysical properties from profiles of CPR Z and CALIPSO attenuated backscatter.
- Prior data derived from ARM Raman lidar and millimeter radar data
- Results compare very well against in situ observations from the SPARTICUS field campaign and agree reasonably well with DARDAR



- Deng, M., G. G. Mace, Z. Wang, and H. Okamoto, (2010) J. *Geophys. Res.*, **115**, D00J15, doi:10.1029/2009JD013104.
- Deng, M., Mace, G.G.; Wang, Z.; and Lawson, R. Paul (2013) *Journal of Applied Meteorology and Climatology* **52**, 1014-1030.
- Deng, M., Mace GG, Wang Z, Berry E. (2015) *Journal of Geophysical Research Atmospheres* **120,**12198-12208. doi:10.1002/2015JD023600.

Water Contents in High Clouds



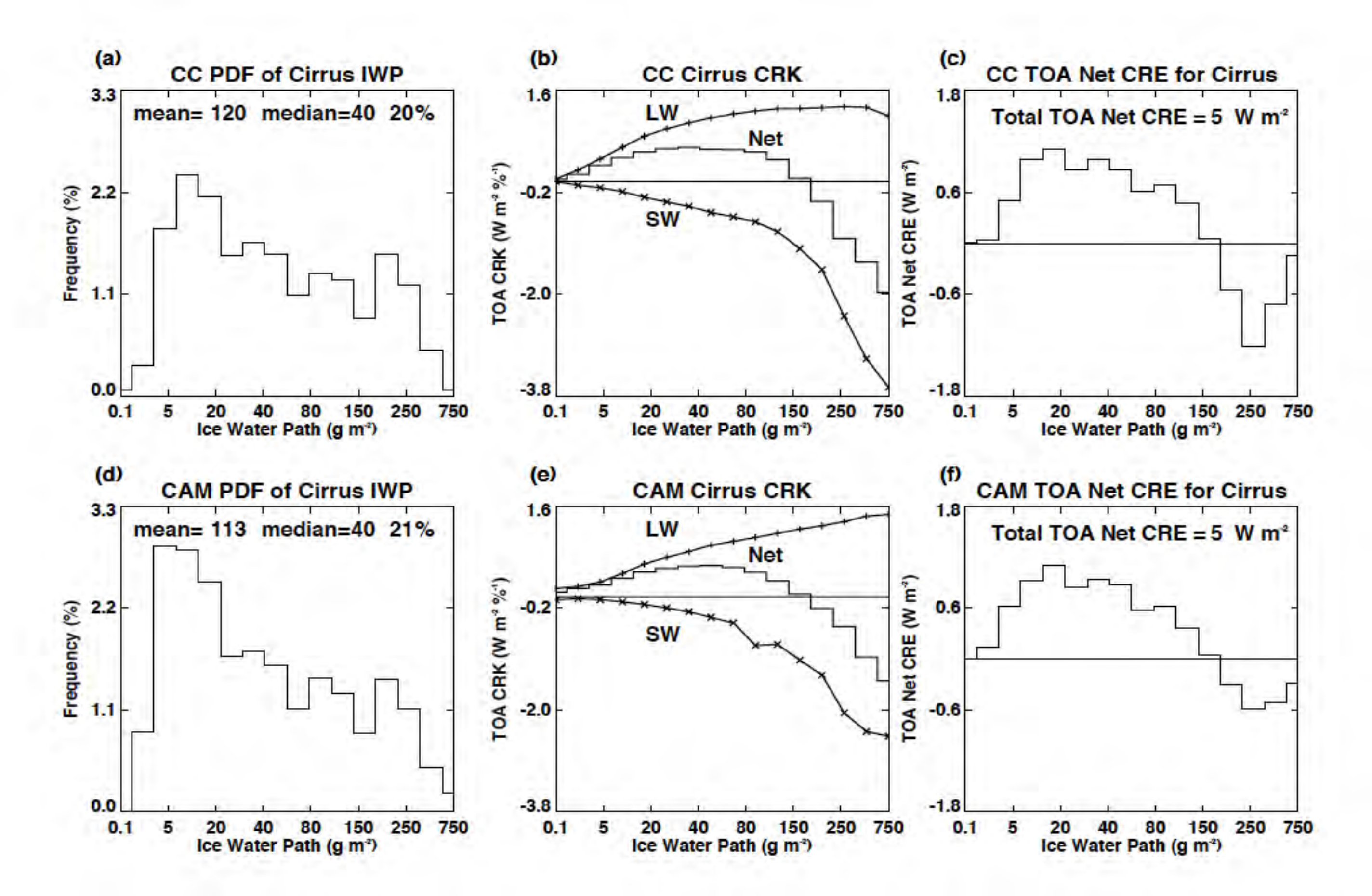
Ice clouds in Dc, Ci, Ns and As have high IWC.

As is ice dominant mixed phase cloud.

Ac is water dominant mixed phase cloud.

Huang, L., J. H. Jiang, Z. Wang, H. Su, M. Deng, and S. Massie (2015). *J. Geophys. Res.* **120**, 4196–4212, doi:10.1002/2014JD022779.

Role of Cirrus in Radiation Budget

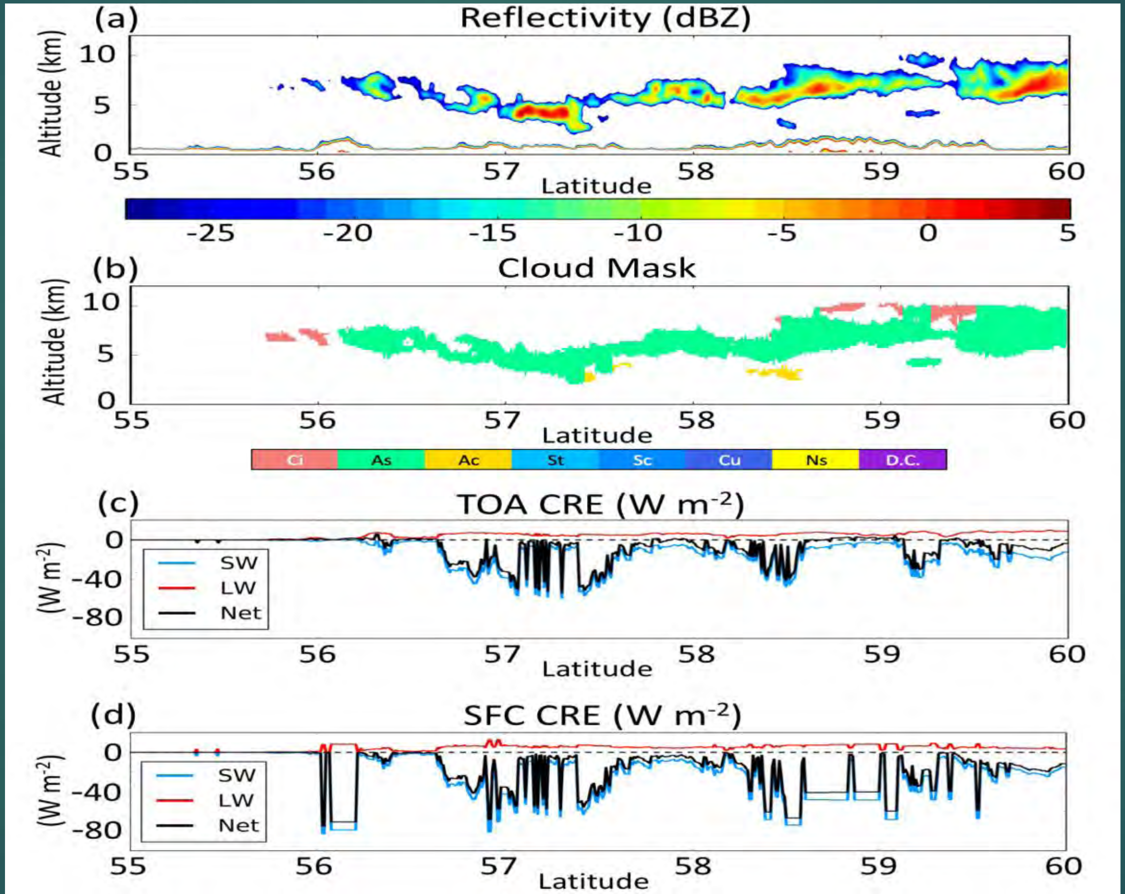


Observations

Model

- Cirrus in CAM force the tropical atmospheric column in a manner very similar to natural clouds (observed by CloudSat-CALISPO).

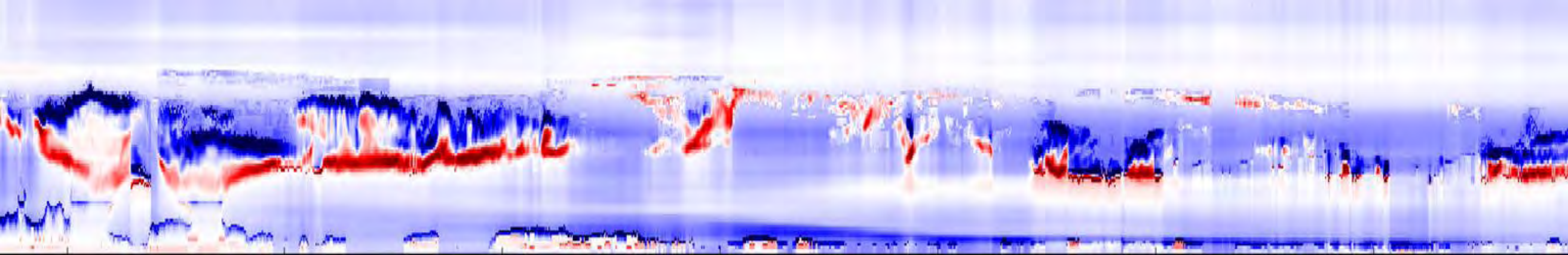
2B-FLXHR-lidar



- Synthesis of these changes to upstream products and new 2C-ICE radar-lidar ice cloud properties to derive fluxes and heating rates consistent with CloudSat, CALIPSO, MODIS, and AMSR-E

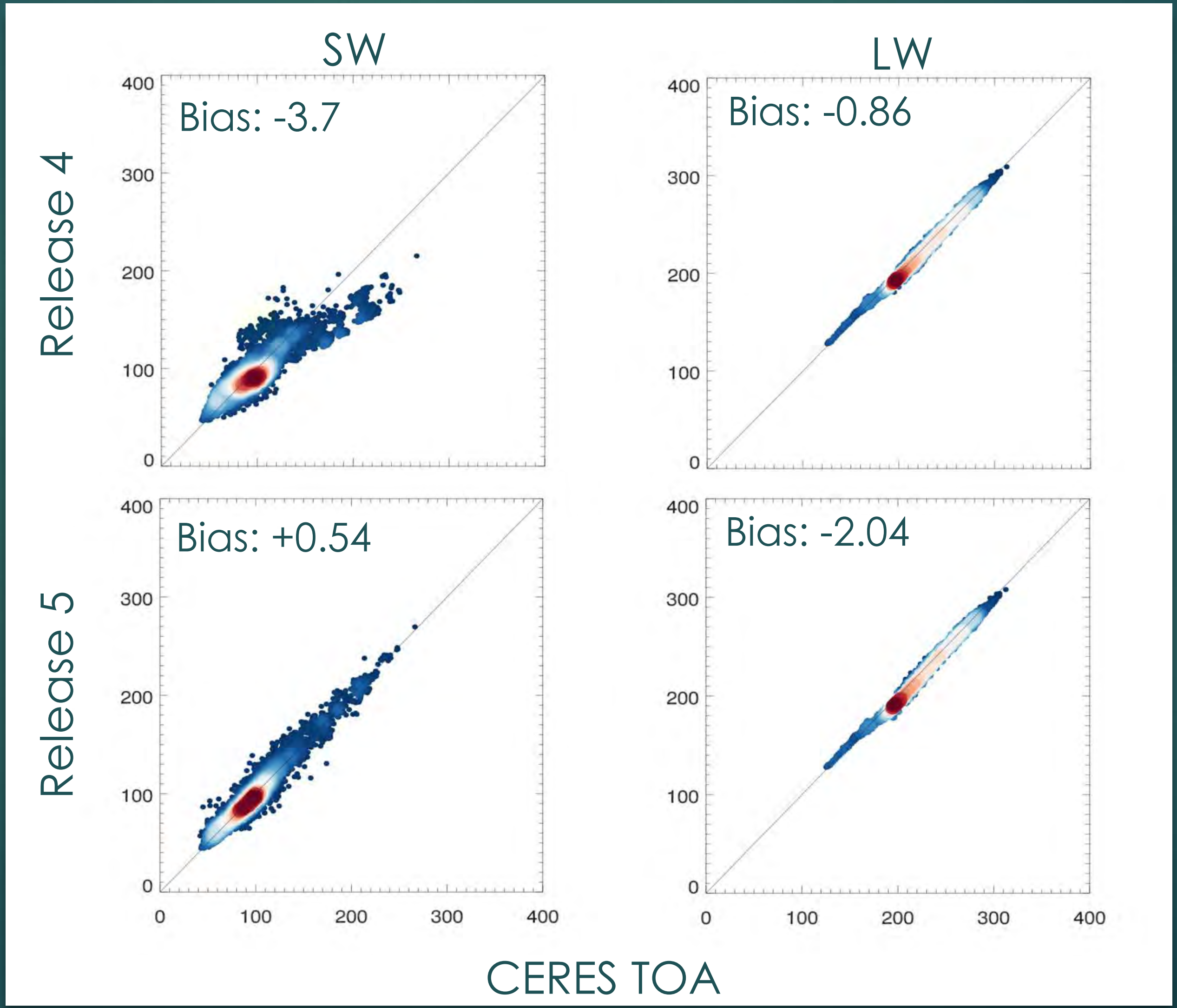
2B-FLXHR-Lidar

- Improved surface albedo
- Spectrally-varying surface emissivity
- New 2C-ICE ice property retrievals
- Explicit representation of mixed-phase clouds
- CALIPSO V4 aerosol observations
- TOA fluxes now output at 100 km
- Output vertically resolved visible and LW cloud optical depth



All-sky TOA Fluxes vs. CERES

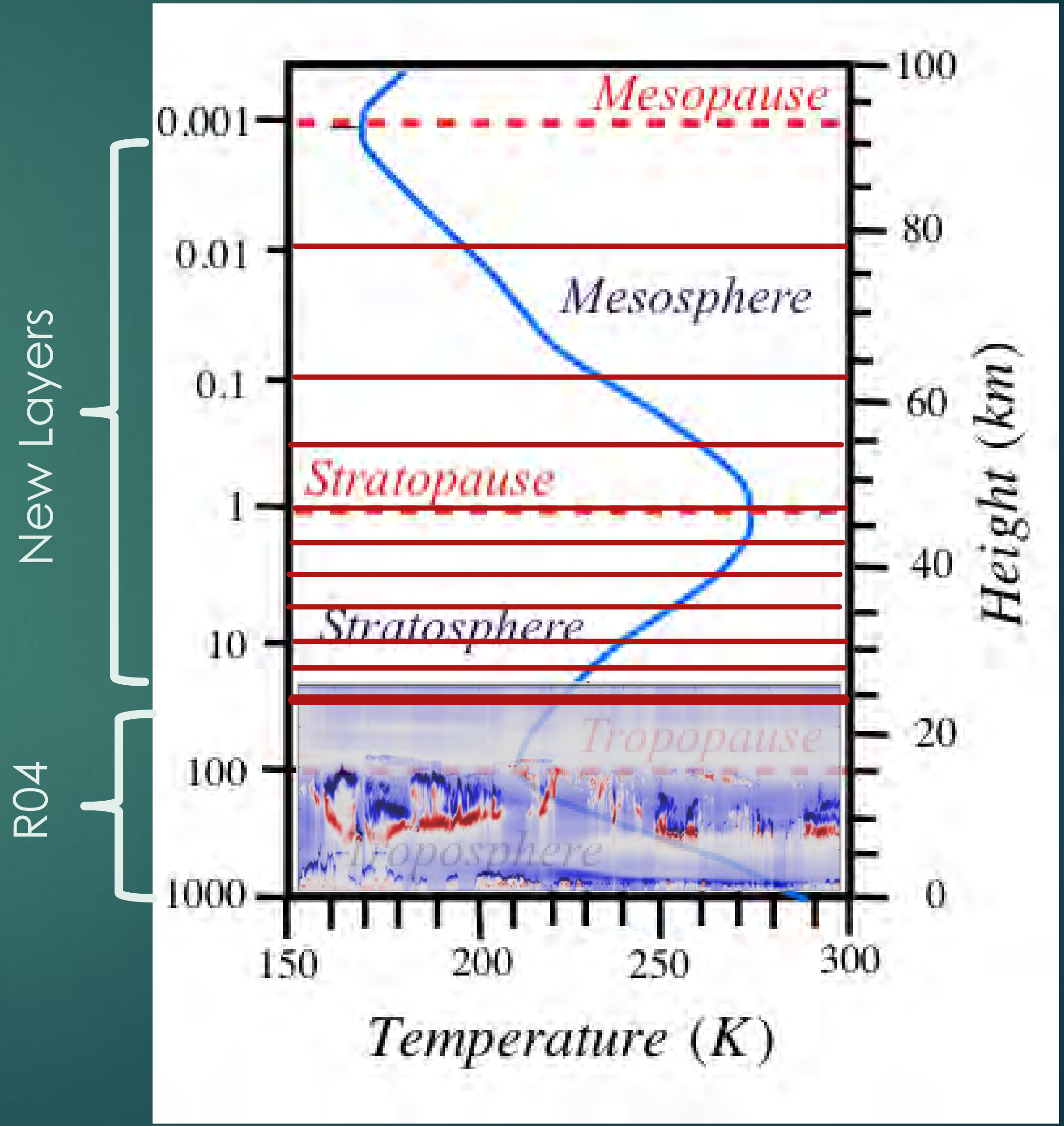
2009



Extrapolated TOA Fluxes

- Previously, 'top of atmosphere' radiative estimates were limited by the extent of the CloudSat profile ~25 km.

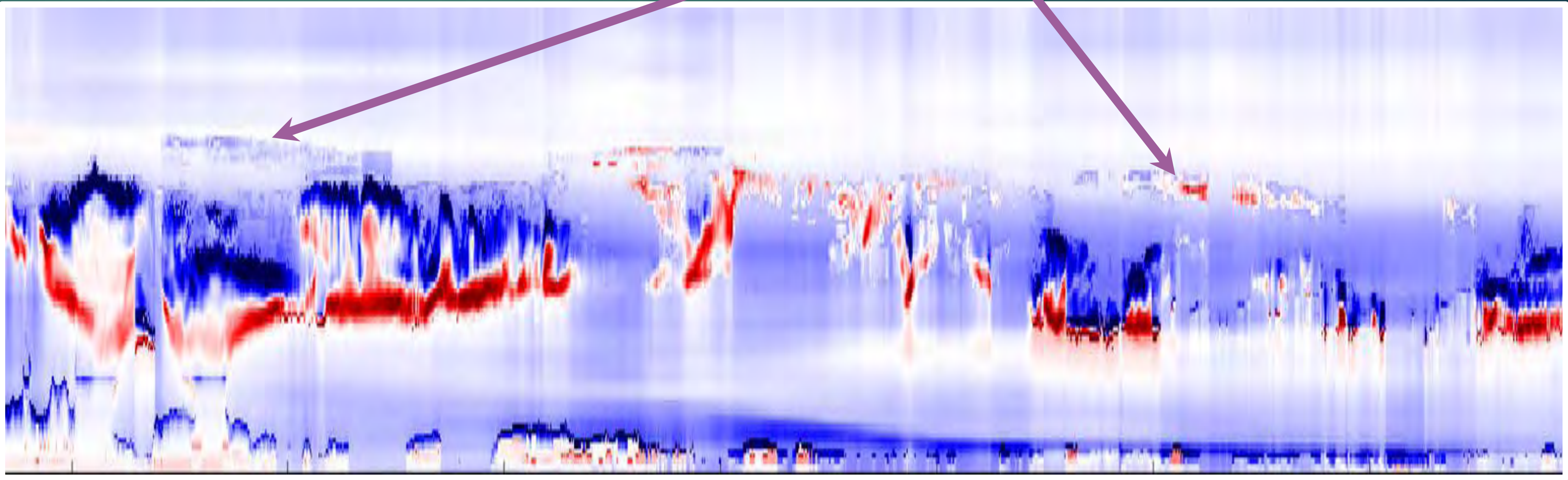
- ECMWF properties (ozone, temperature, humidity) are now use to extend profile to 100 km to provide estimates of true TOA fluxes.



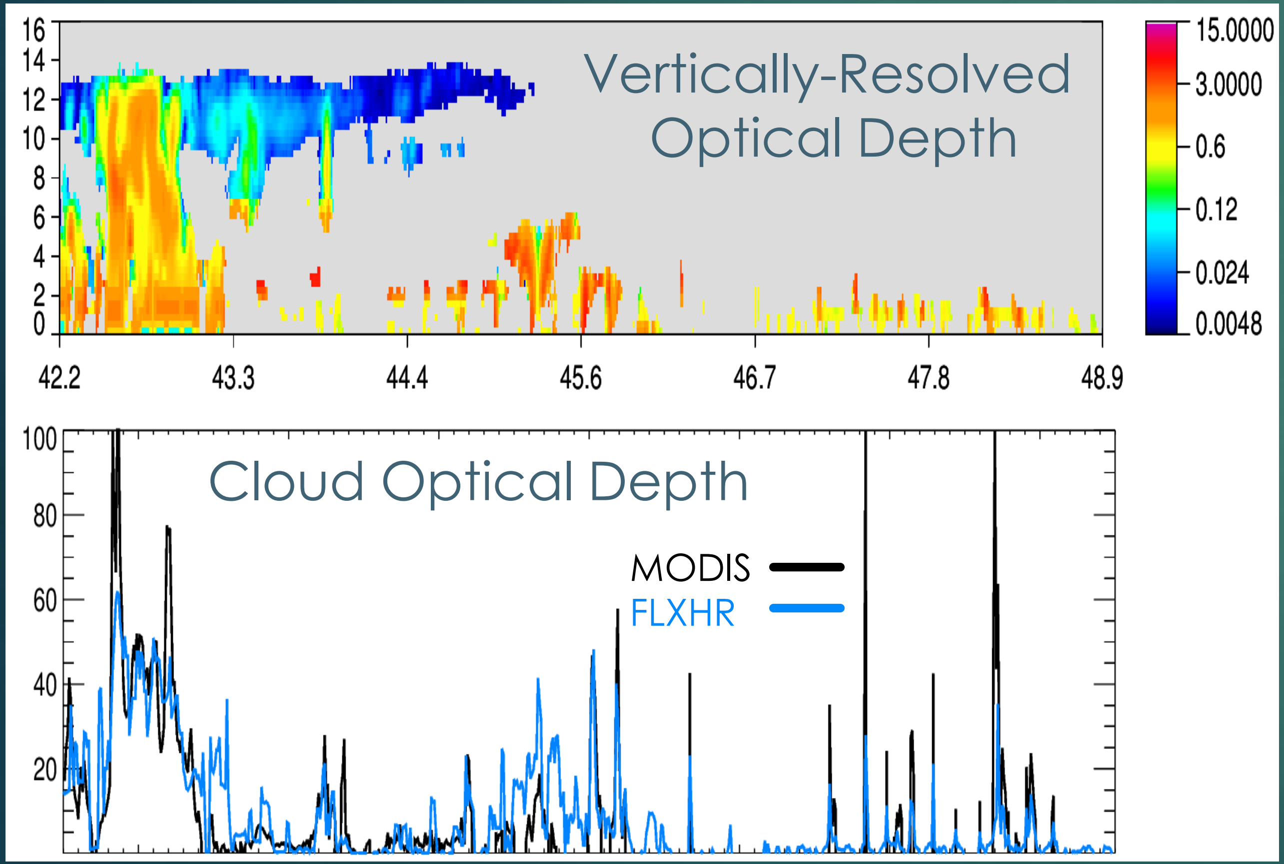
Improved Ice Cloud Microphysics from 2C-ICE

- To better represent cirrus properties, retrieved ice water content and effective radius from 2C-ICE are adopted.

Better representation of cirrus structure

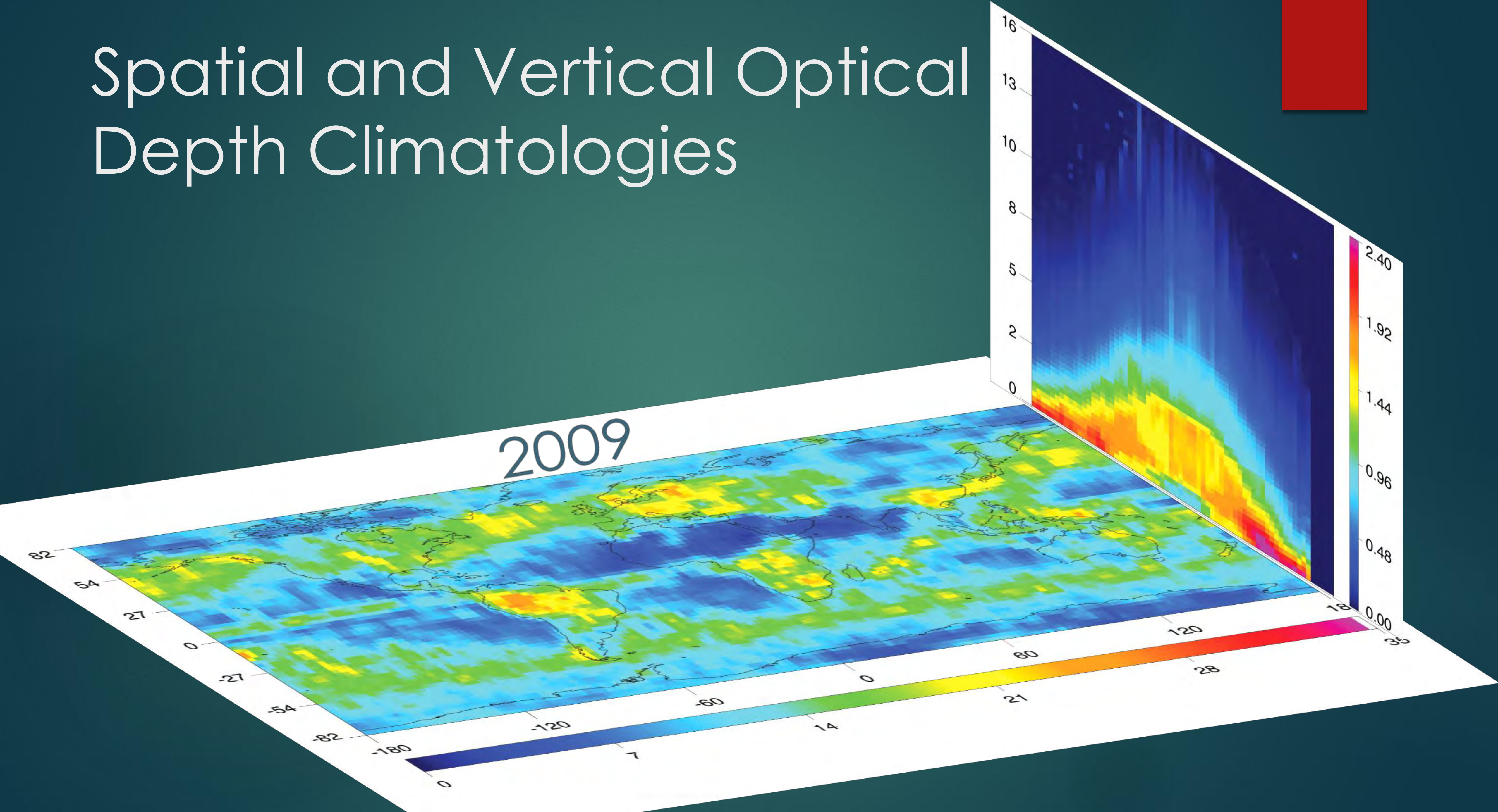


New Output Field: Vertically-Resolved Cloud Optical Depth



- We now include cloud optical depth in each bin as an output
  - Visible optical depth (Blue Band)
  - IR optical depth (LW window)
- Facilitates evaluation against passive sensors and new science applications
- Column-integral compares well with MODIS for single-layered clouds.
- Reveals possible under-estimates in multi-layered clouds

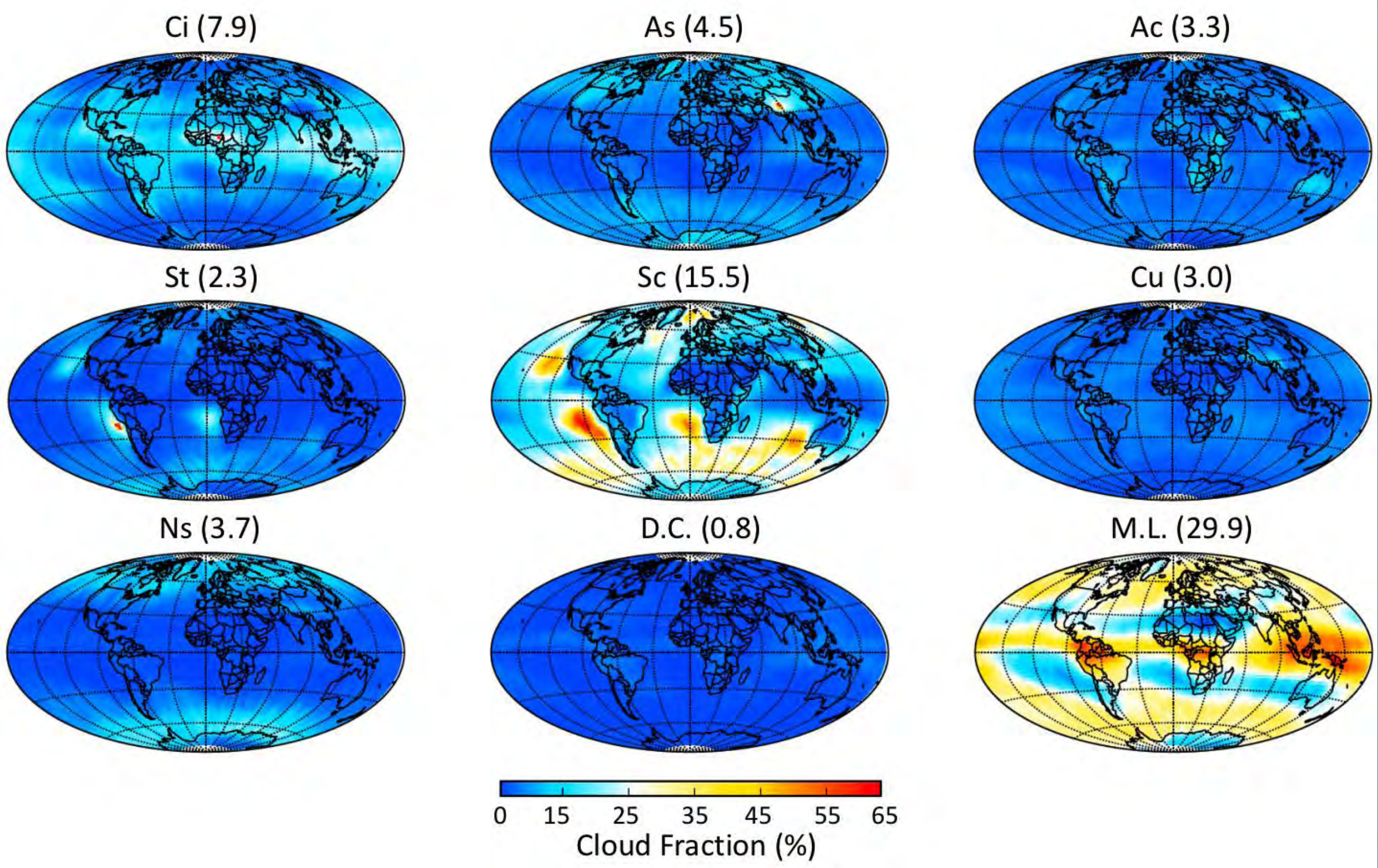
Spatial and Vertical Optical Depth Climatologies



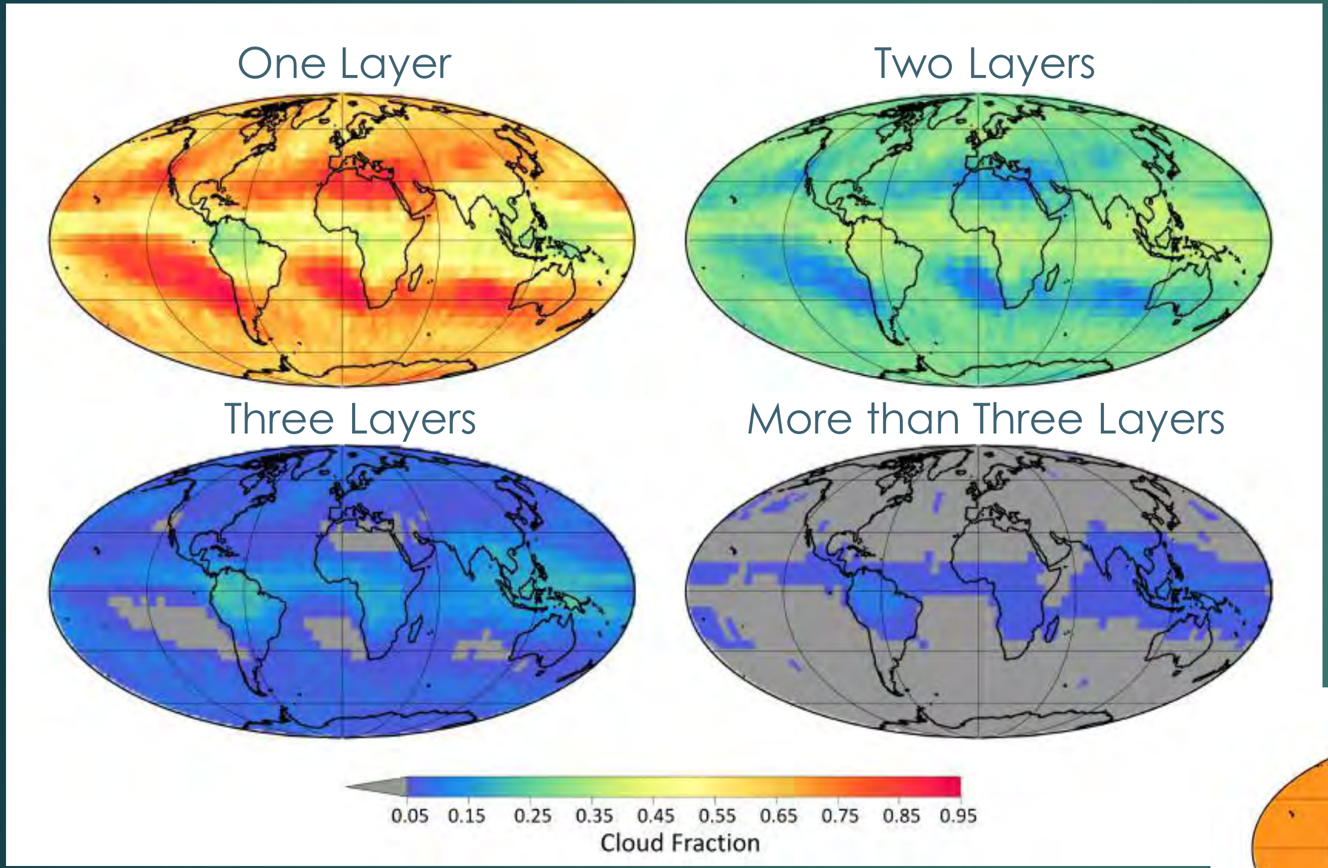
Application to UT Cloud Process Studies

Where Are UT Clouds Observed?

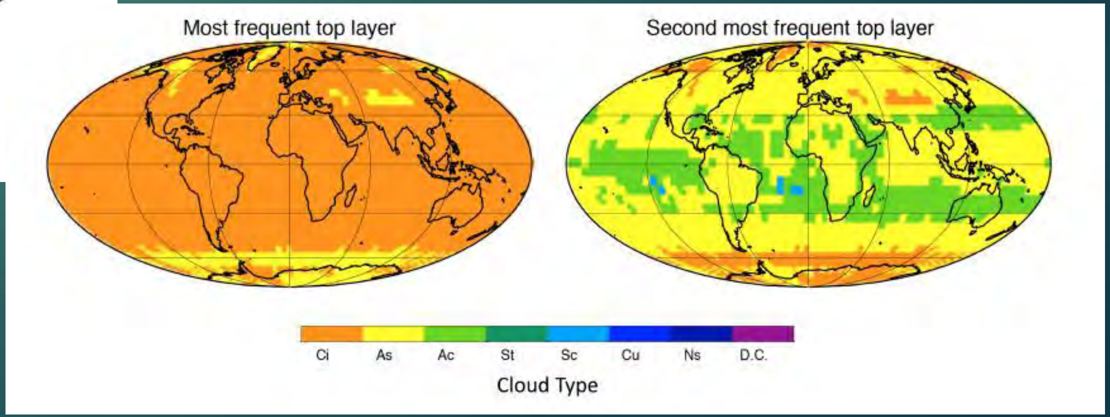
- CloudSat and CALIPSO observe single-layer high clouds 16.9% of the time
- They observe high clouds as part of multi-layered systems nearly twice as often (29.9% of the time)



Composition of Multi-Layer Clouds

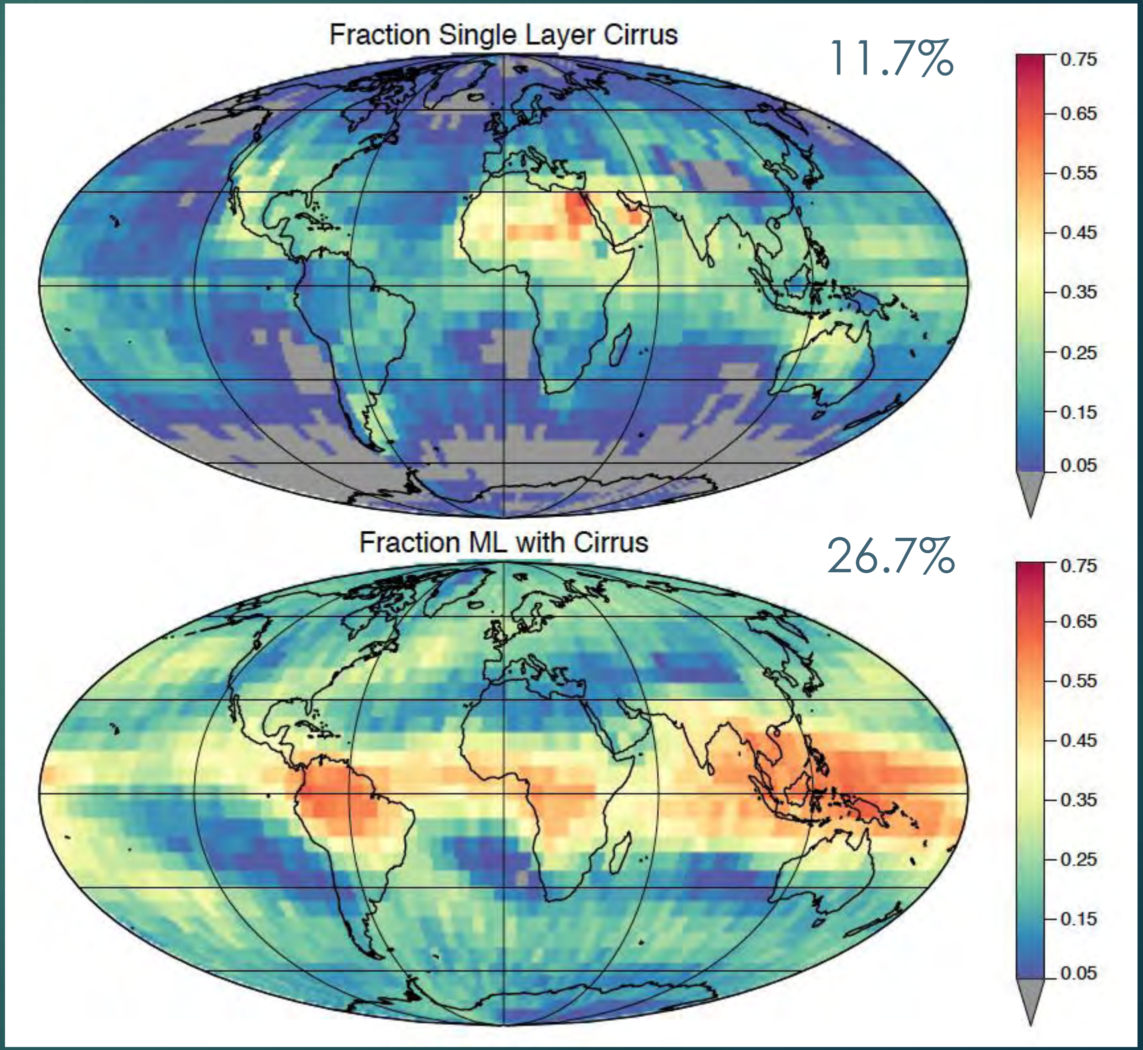


- More than 40% of cloudy pixels contain multiple cloud layers.
- Cirrus clouds are by the most frequent top layer in such profiles

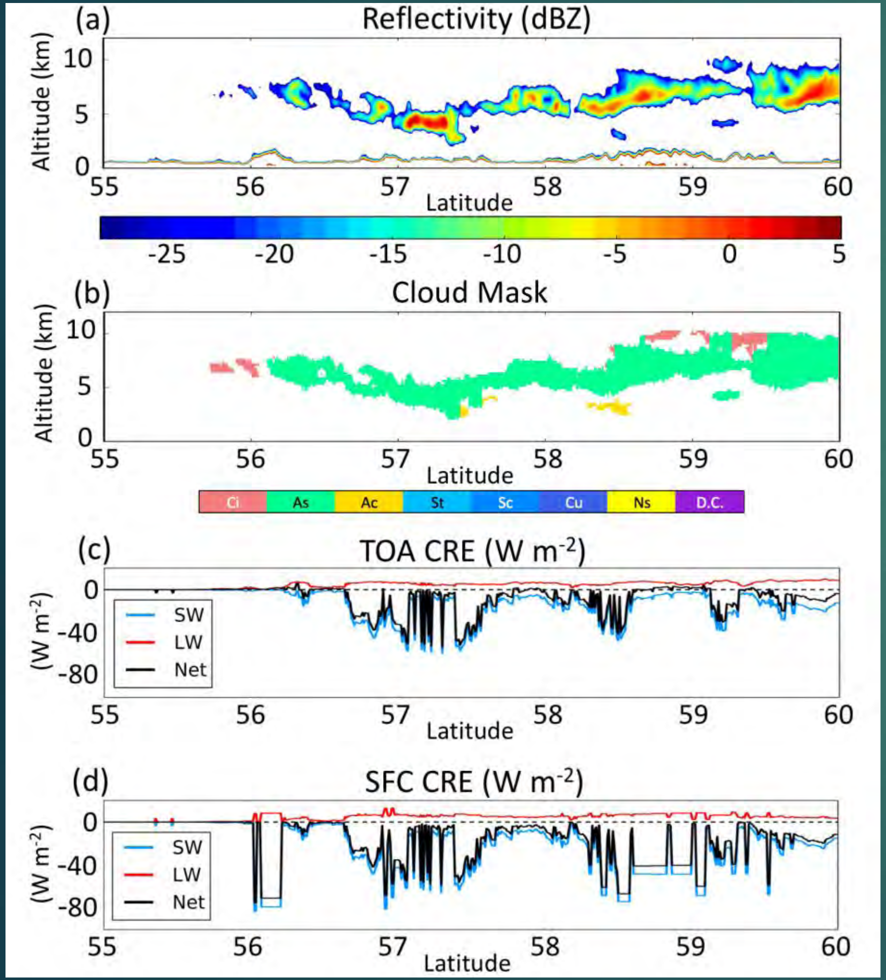


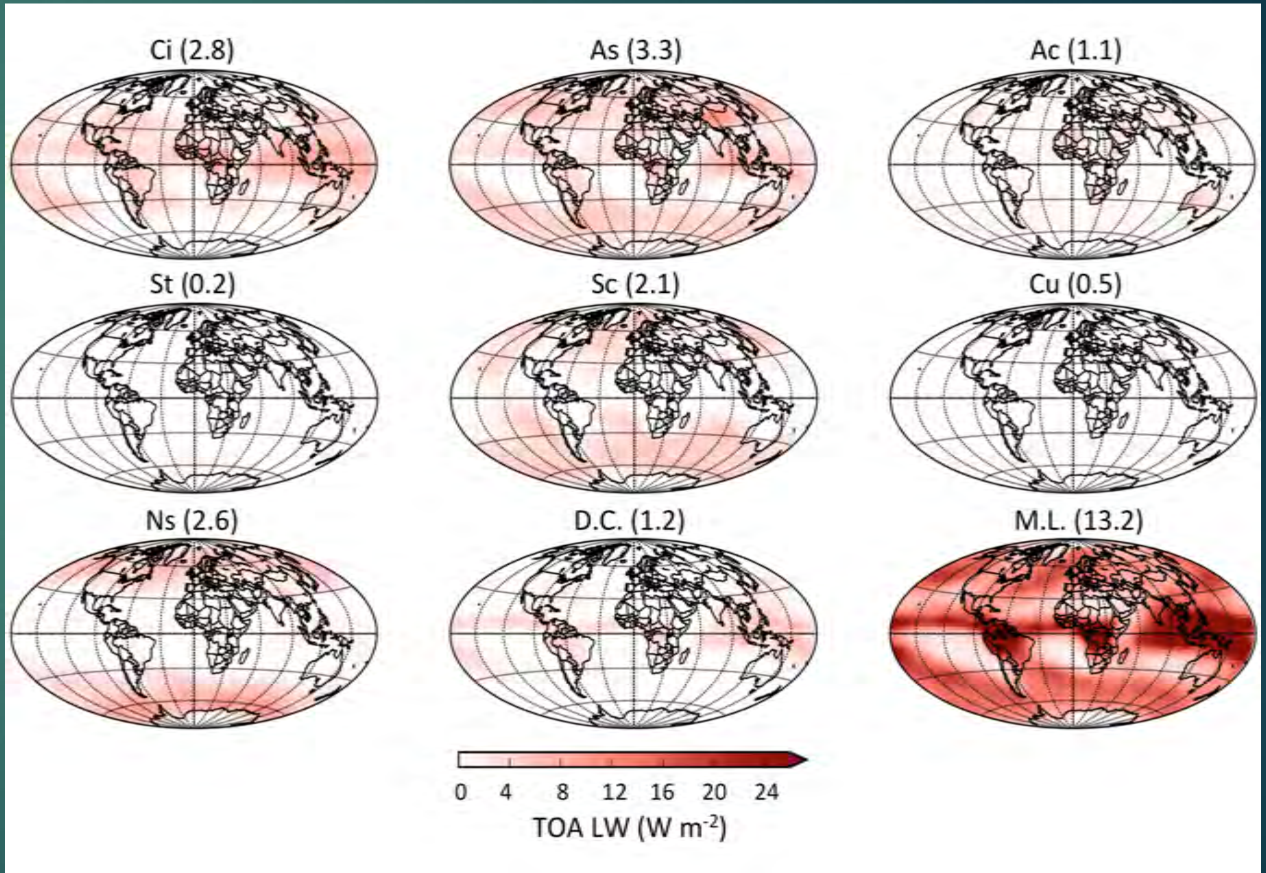
Cirrus in Multi-layer Cloud Systems

- More often than not, cirrus are observed with another cloud layer (often St or Sc) below them.
- More than 2/3 of cirrus profiles (69%) have low-level clouds beneath them.
- This significantly influences their radiative effects.



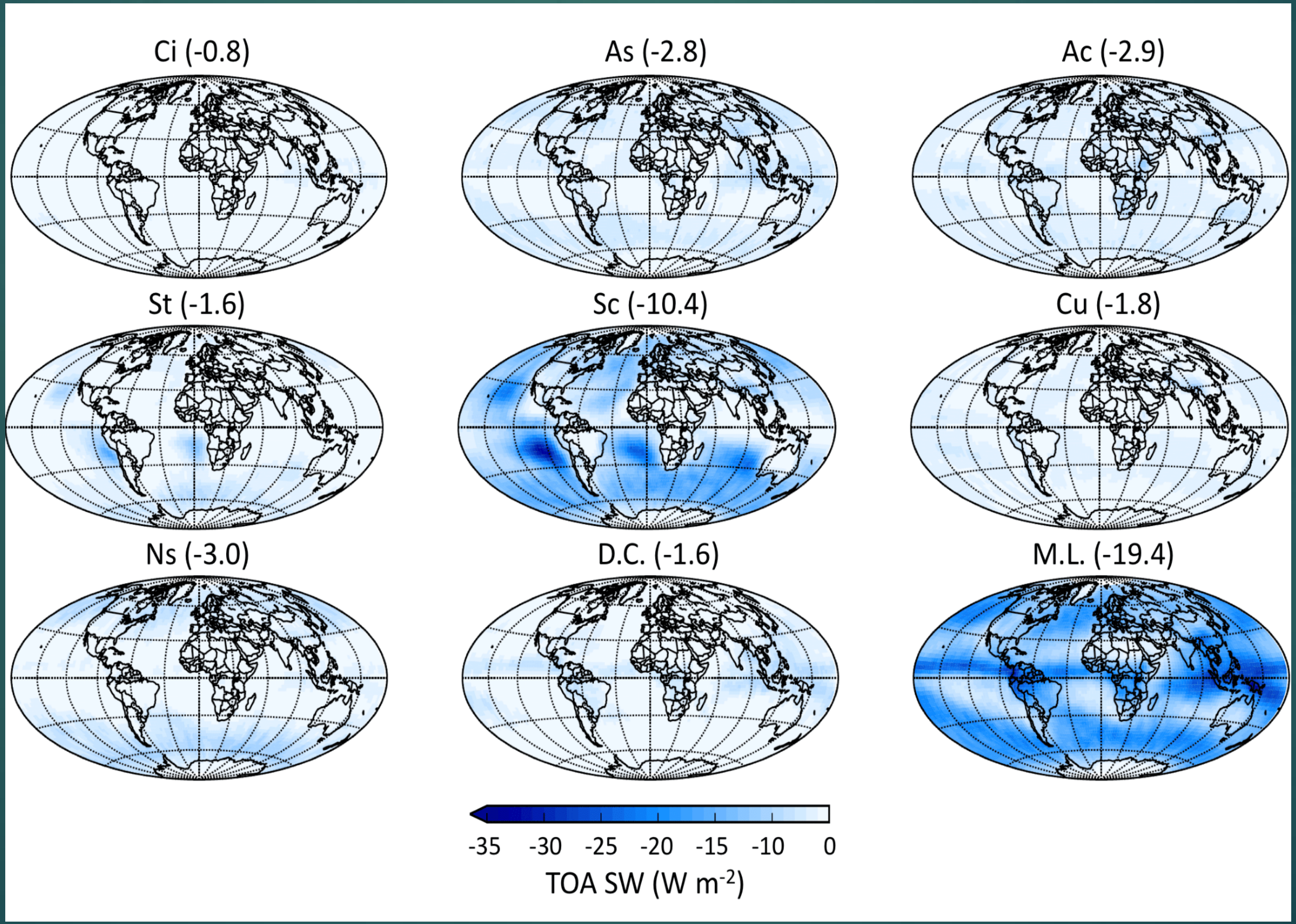
What are their Radiative Impacts?



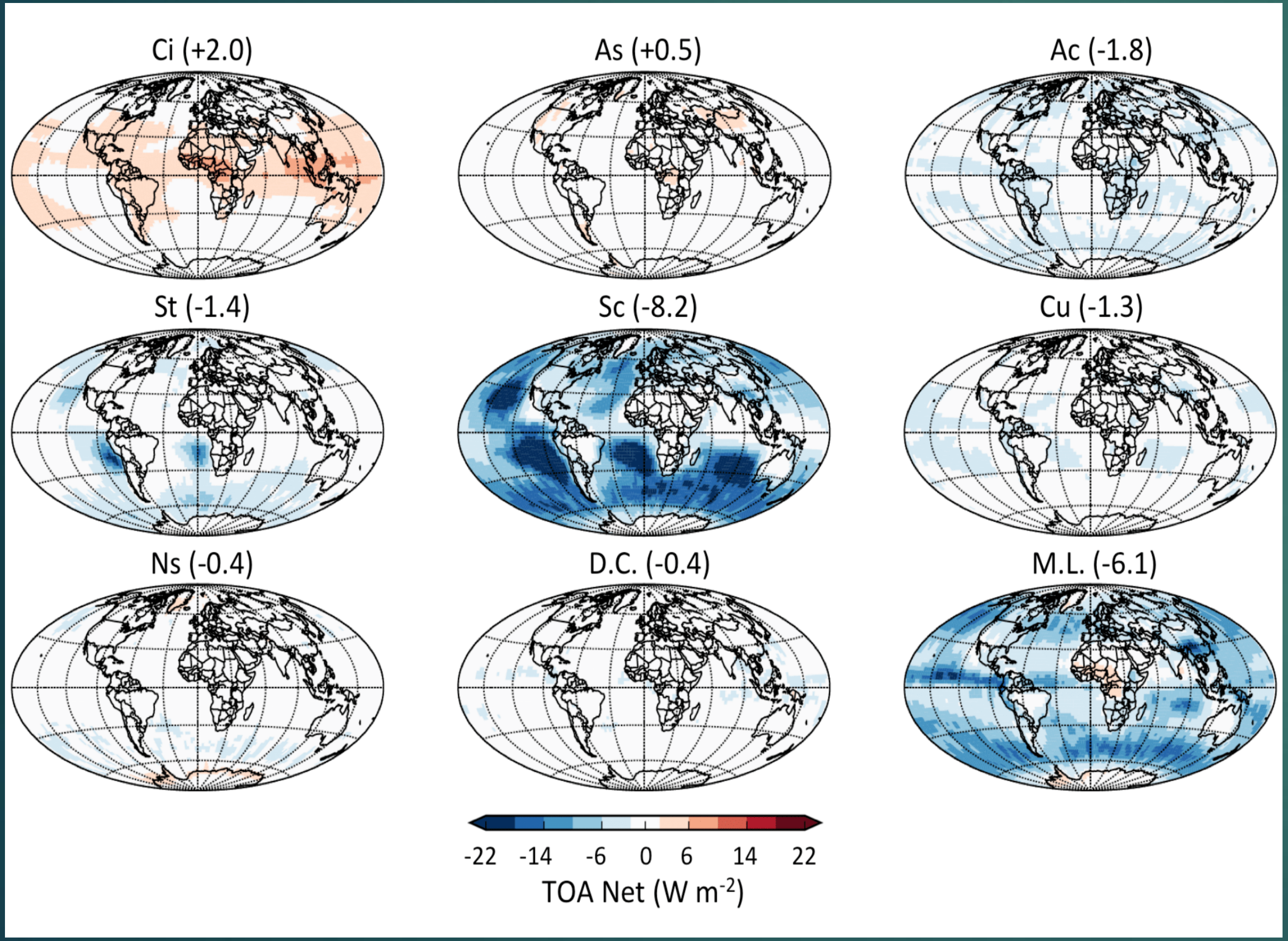


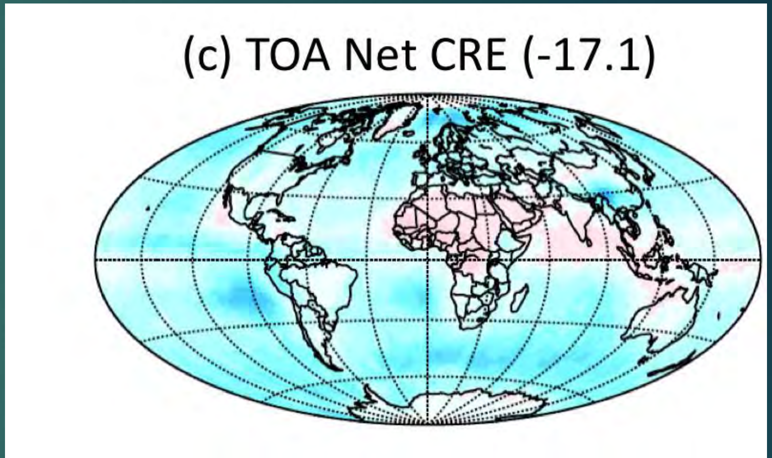
L'Ecuyer et al: submitting to *J. Climate* this week

SW Radiative Impacts

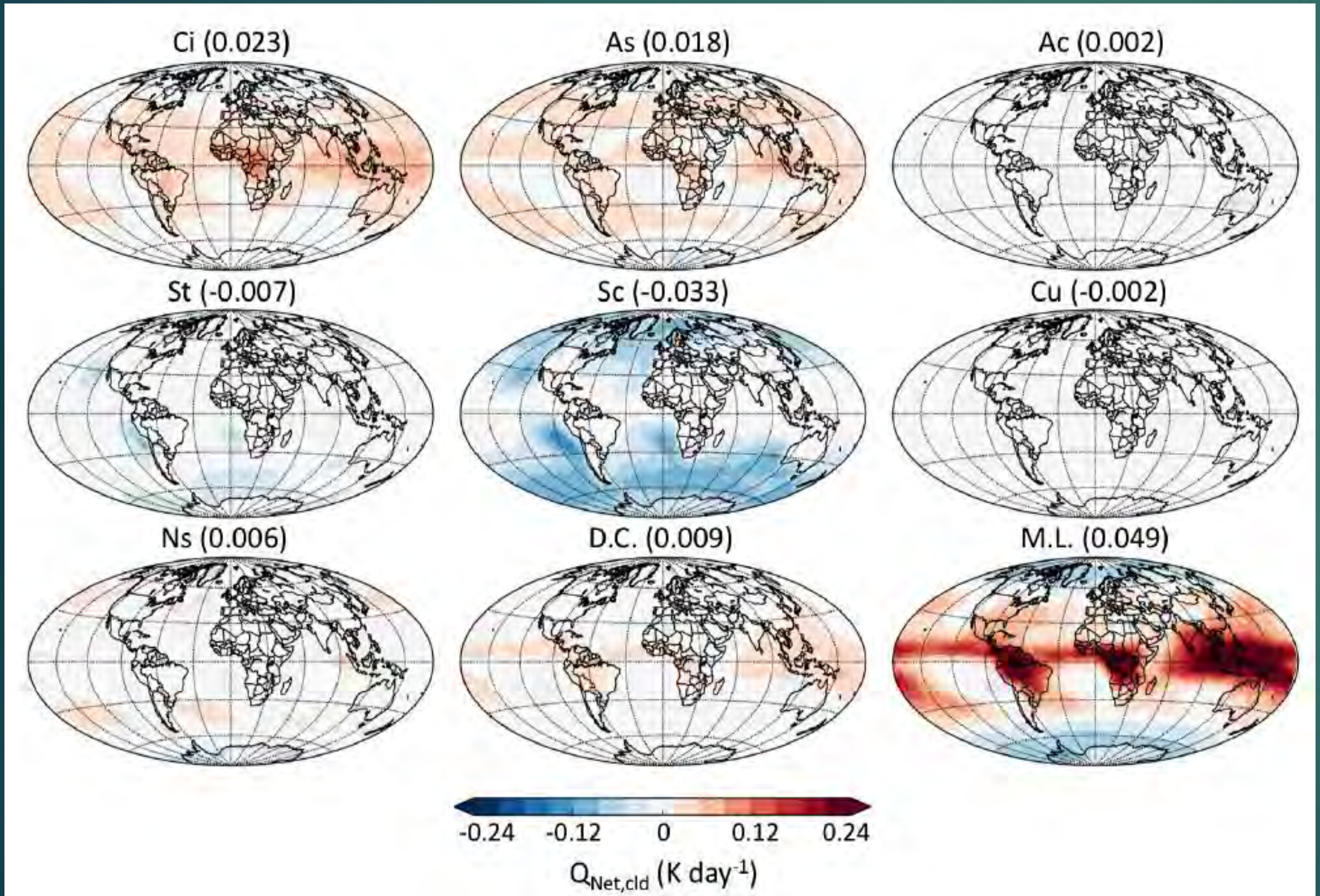


Net Radiative Impacts

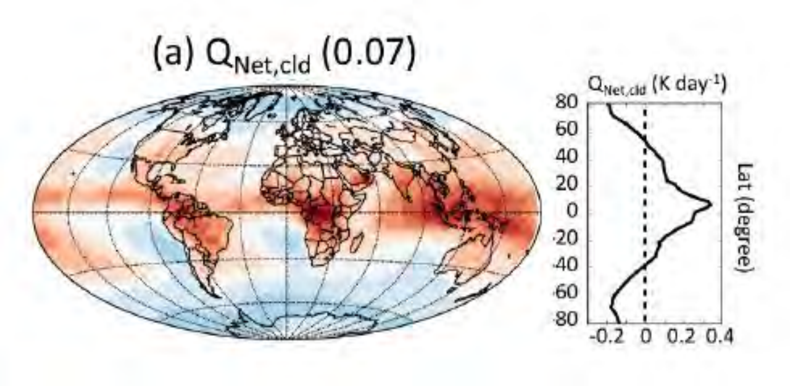




Likewise Multi-layer Clouds Dominate Atmospheric Heating



- Multi-layer clouds profile dominate atmospheric heating in the tropics
- Tropical heating from multi-layer clouds accounts for 1/3 of the observed hemispheric energy imbalance



Hang et al: submitting to *J. Climate* this week

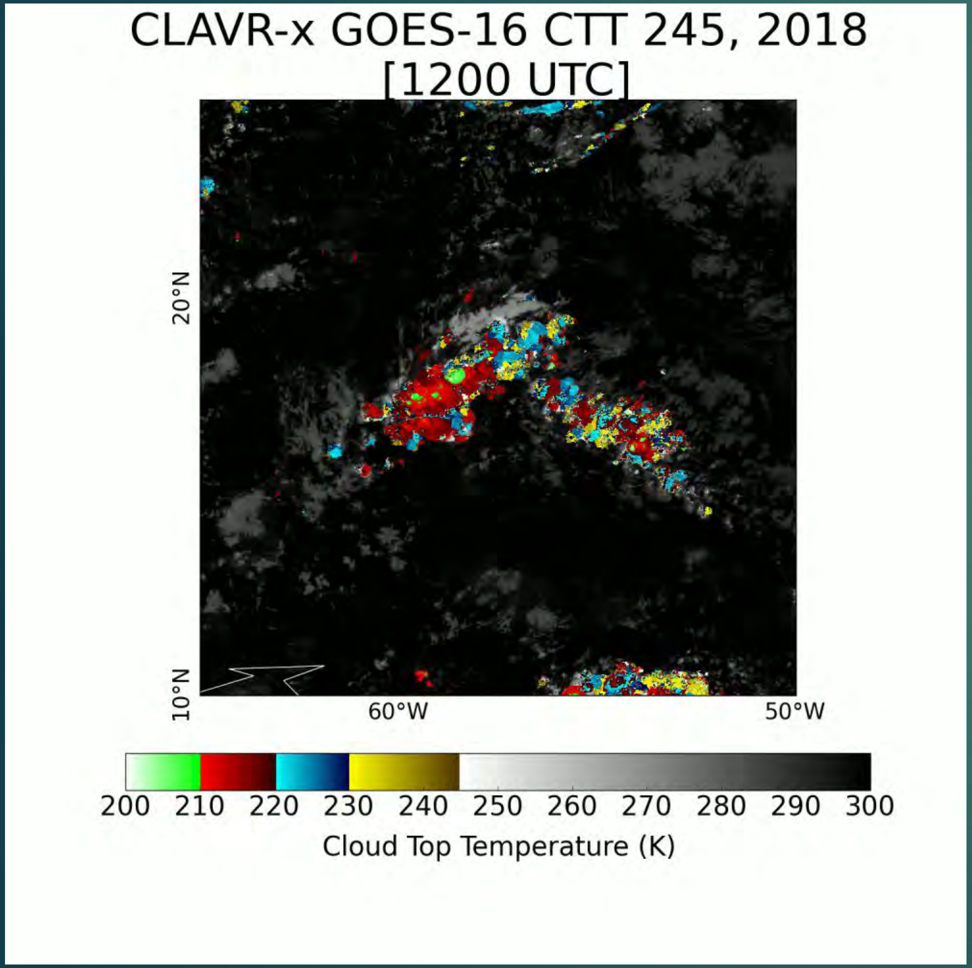
Summary

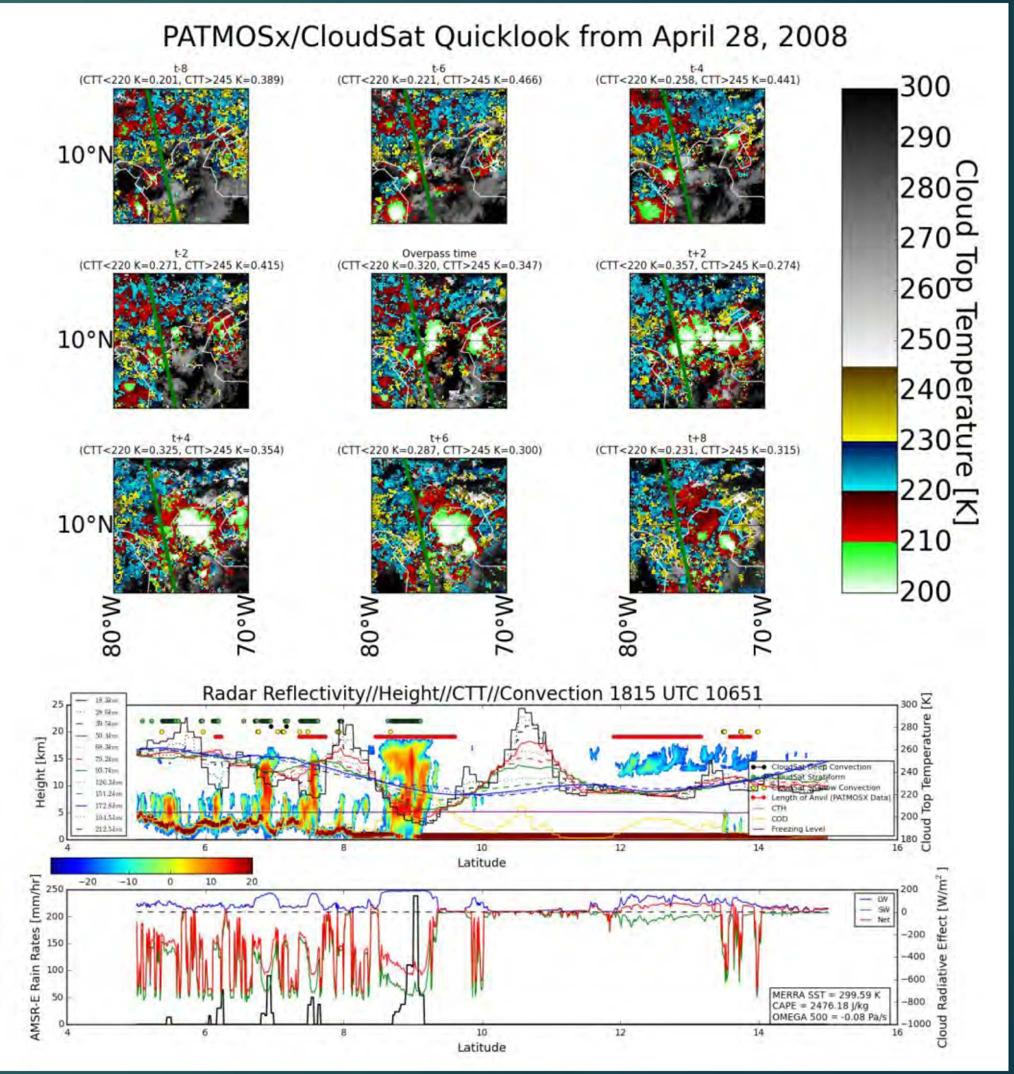
- The new Release 5 CloudSat products feature several advances that are especially relevant to upper-tropospheric cloud process studies.
  - 2C-ICE provides ice microphysical properties consistent with both CloudSat and CALIPSO that agree well with in situ observations
  - 2B-FLXHR-LIDAR will soon provide vertically-resolved optical depth in addition to the computed radiative fluxes
- More often than not, cirrus are found to have low clouds below them.
- Profiles with multiple cloud layers dominate both cloud radiative effects and atmospheric heating yet exhibit different radiative characteristics than single-layer clouds.
- Future: working on adding a time-dimension by coupling CloudSat/CALIPSO curtains to time-evolving geostationary cloud property retrievals

New Directions: Adding a Time-Dimension

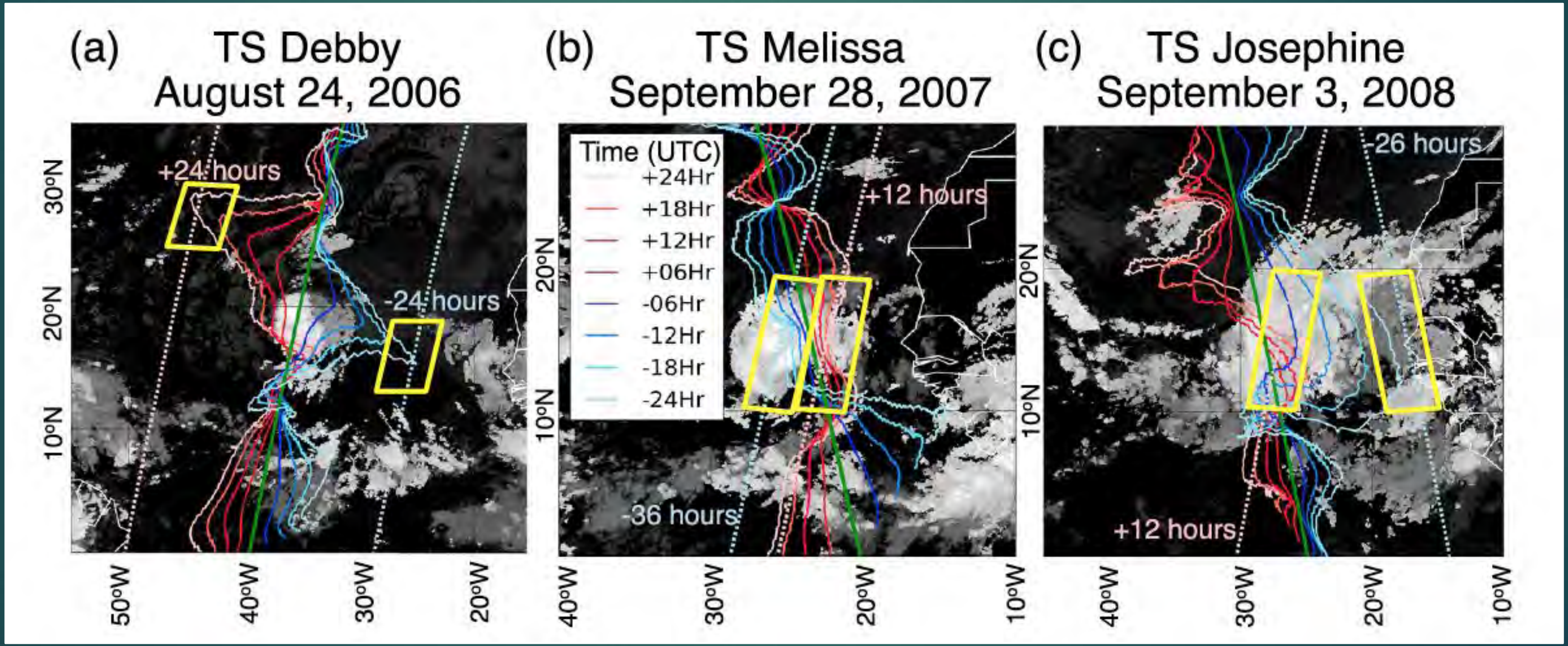
- This time focus on ‘ideas’ for advancing the goals of UTCC PROES
  - Will this meeting have more time for discussing how to advance this science as opposed to more isolated research summaries?
- Show some of the other influences of convection: dust advection
  - One message here ought to be that we can use collocations of polar orbiters and geostationary to examine processes. Others have used geo for lifecycle context and we’re doing the same (show example from Juliet)
  - We’ve also used geo to examine processes like dust lofting into UT and scavenging (show a few slides from Kate’s work); perhaps there’s value in applying similar techniques to study UT cloud evolution?

Adding The Time-Dimension



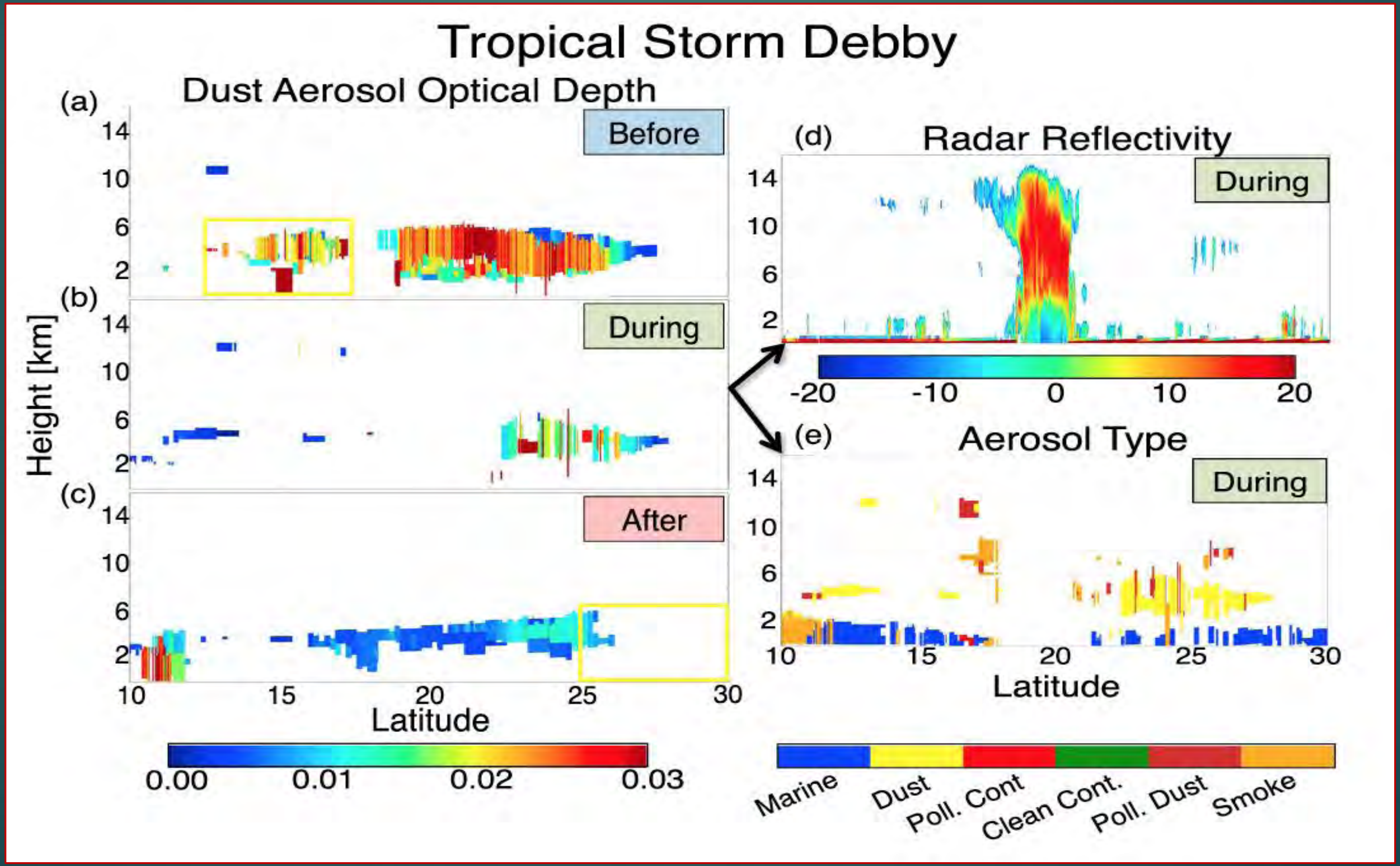


E.g. Convective Lofting of Saharan Dust



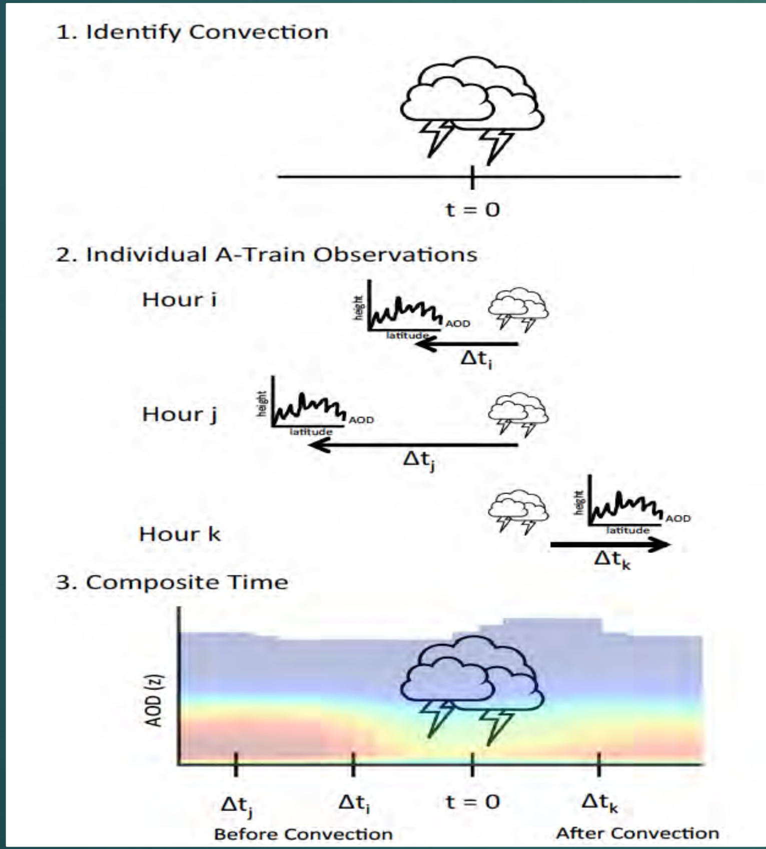
Sauter and L'Ecuyer, *Geophys. Res. Letters* (2017)

Dust Layer Evolution



Sauter and L'Ecuyer, *Geophys. Res. Letters* (2017)

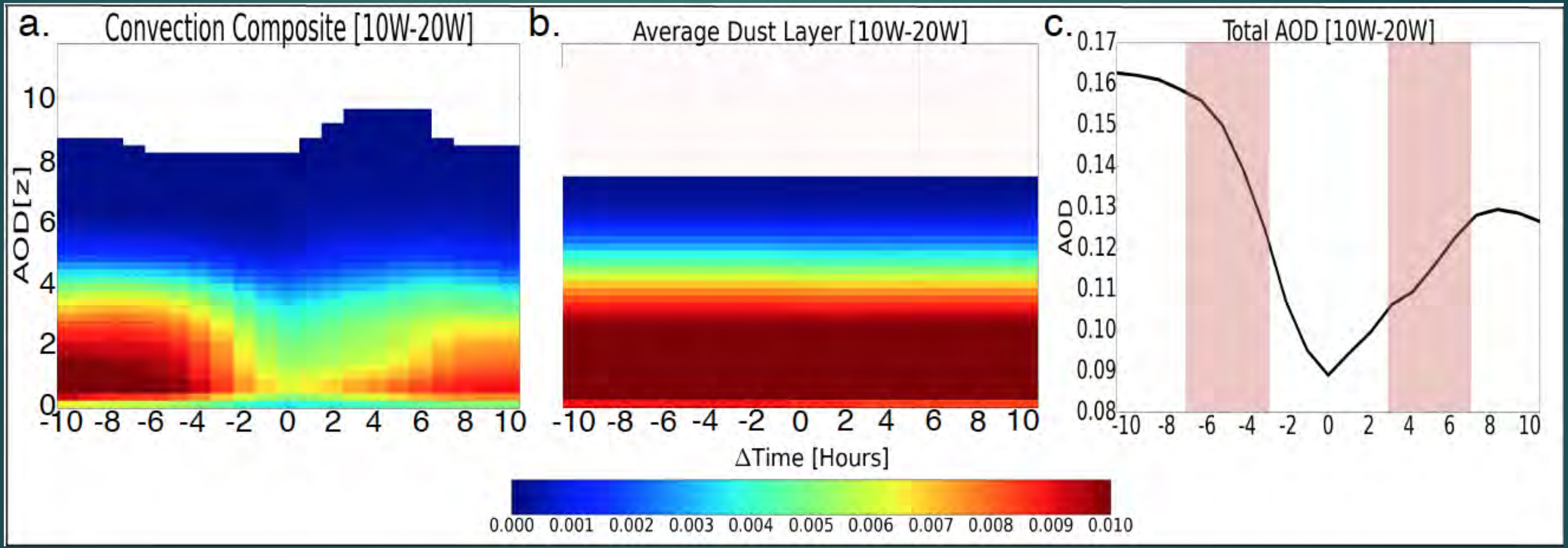
Composite Analysis



Sauter et al. in revision for *J. Geophys. Res.*

- Adapted from Masunaga, JAS, (2012)
- Match IR-based convection Meteosat and GOES (PATMOS-x) to cloud and AOD profiles from advected CALIPSO/CloudSat track
- Use time-difference to reconstruct the composite evolution of dust AOD over a typical convective lifecycle.

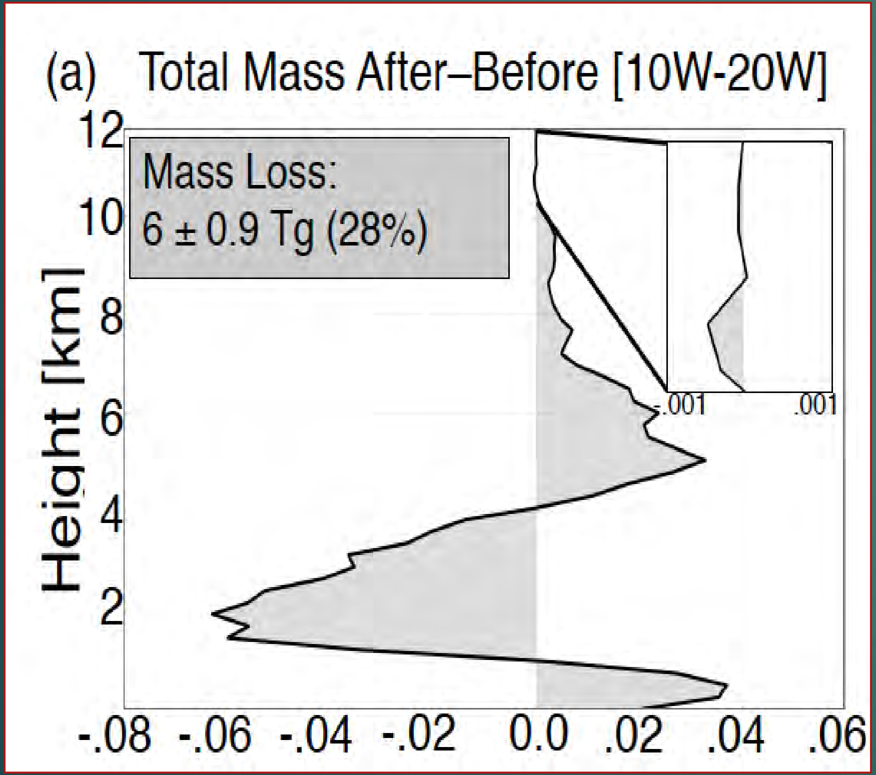
Influence of Convection

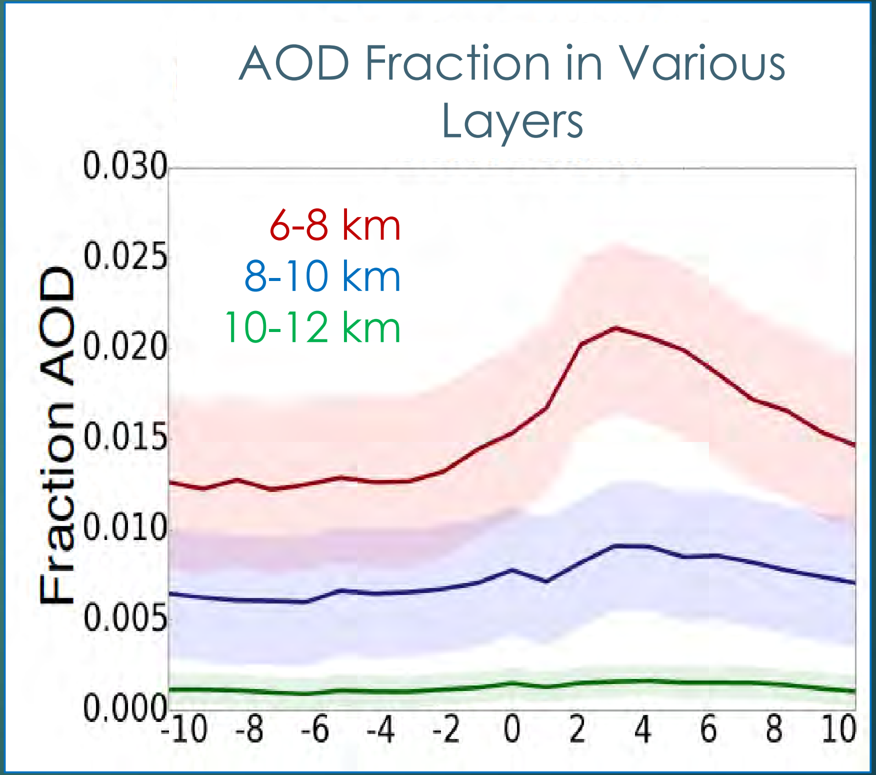


Sauter et al, *J. Geophys. Res.* (2018)

- Convection removes a total of 18 ± 6 Tg between 15∘W and 80∘W
- This represents 15% of the total deposition inferred from budget analyses

Vertical Redistribution



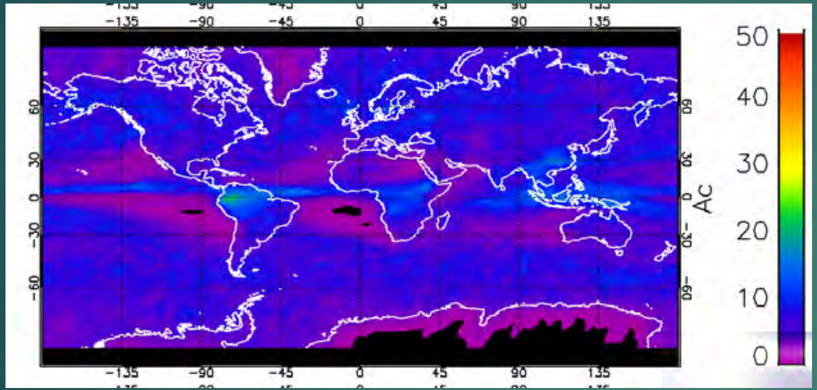


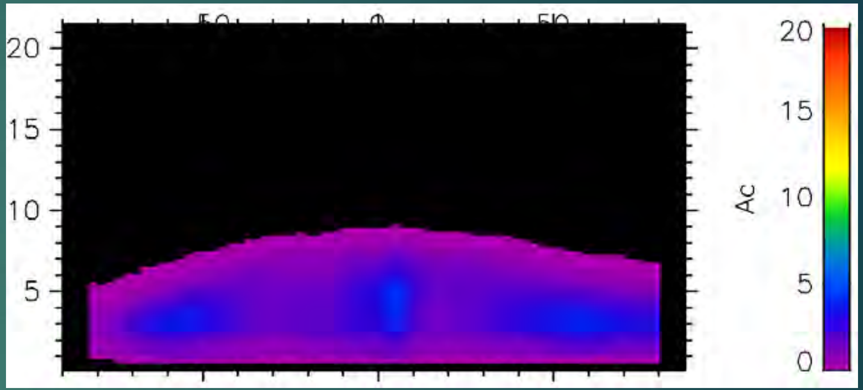
Sauter et al. in review for *J. Geophys. Res.*

Alto-Cumulus

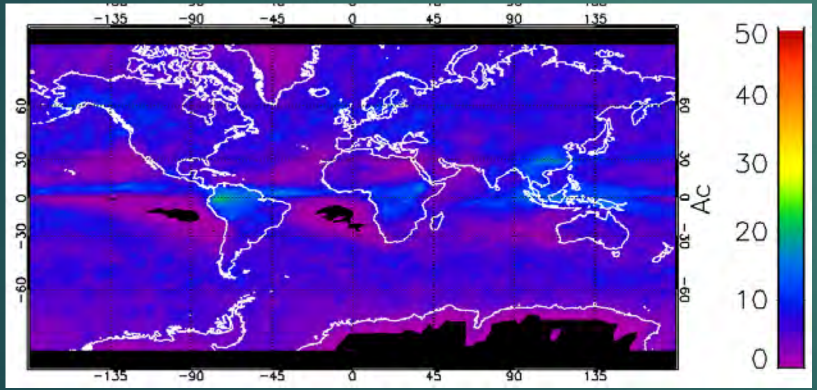
- Limit Ac to warmer than -35 °C – likely with supercooled water.

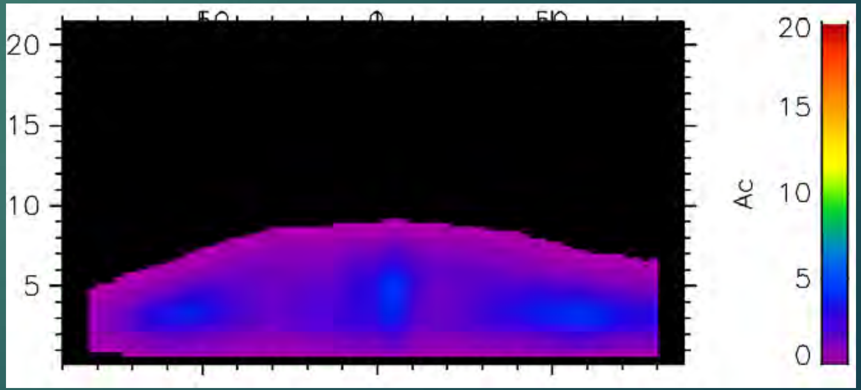
R04





R05





2007

Using A-Train observations to evaluate cloud occurrence and radiative effects of monsoon region clouds in the Community Atmosphere Model

Elizabeth Berry[1#], Gerald G. Mace[1] and Andrew Gettelman[2]
Submitted to Journal of Climate (October, 2018)

As presented to this GEWEX group in New York, Berry and Mace (2014) used 2C-ICE to establish that cirrus in the 20 g m^{-2} range are

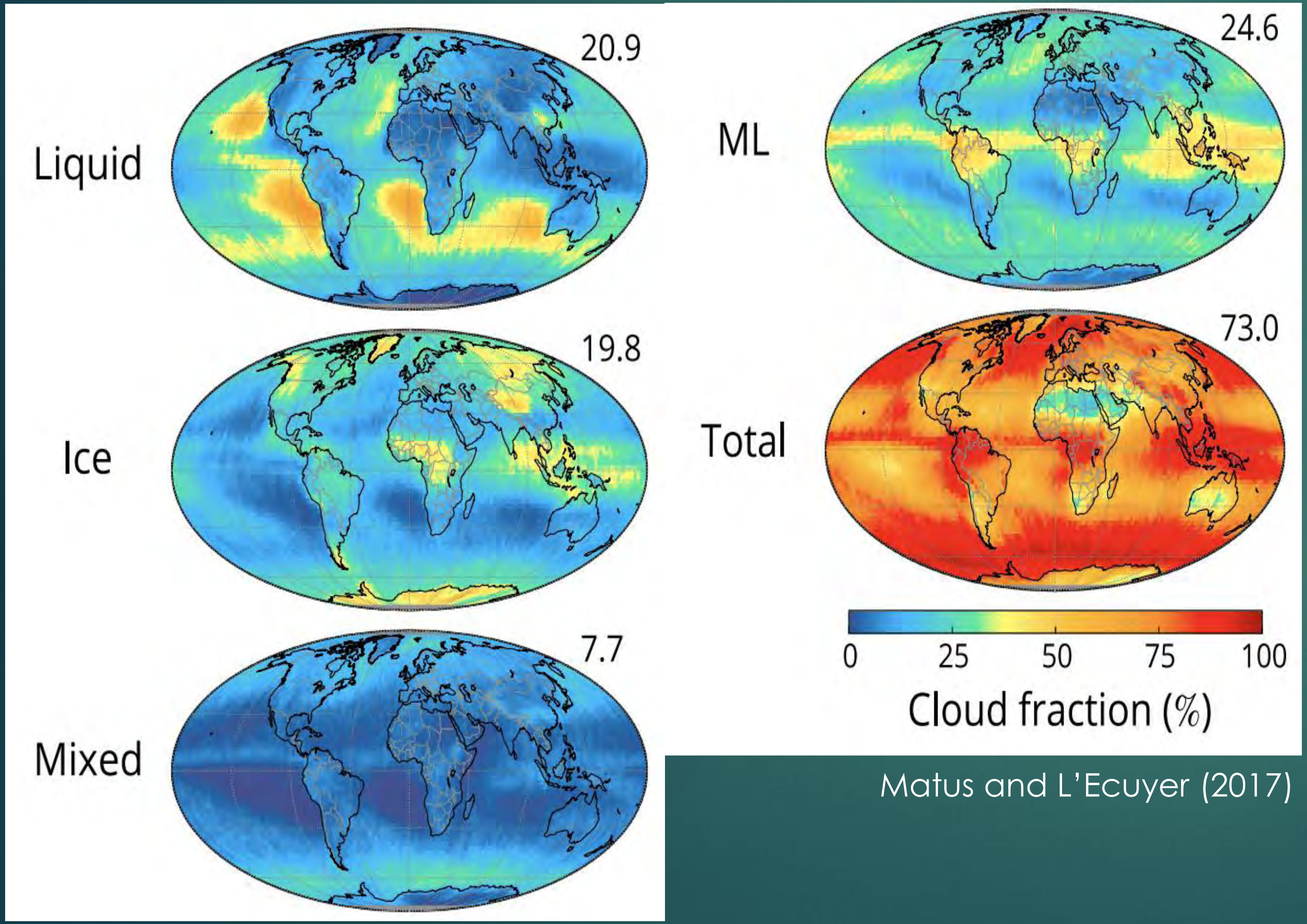
1. The ice clouds that are most important to forcing the tropical atmosphere from TOA
2. Mean IWP statistics is a poor metric for comparing TOA CRE of models and measurements – the median IWP is much more representative of the cirrus that are important to TOA CRE.

Question: In climate models, is heating by ice clouds in the tropical upper troposphere in any way similar to what is observed in nature?

In the last several years we have collaborated with Andrew Gettelman to use climate model output over SE Asia during two summer monsoon seasons:

- Model output sampled using methodology similar to Jakob and Klein (2000) as done in ISCCP simulator and COSP
- An evaluation methodology was developed that ensured near zero bias in computing TOA CRE from models and observations
- Adapted the radiative kernel methodology of Zelinka et al. (2012)

Role of Mixed-Phase Clouds in the Earth's Radiation Budget



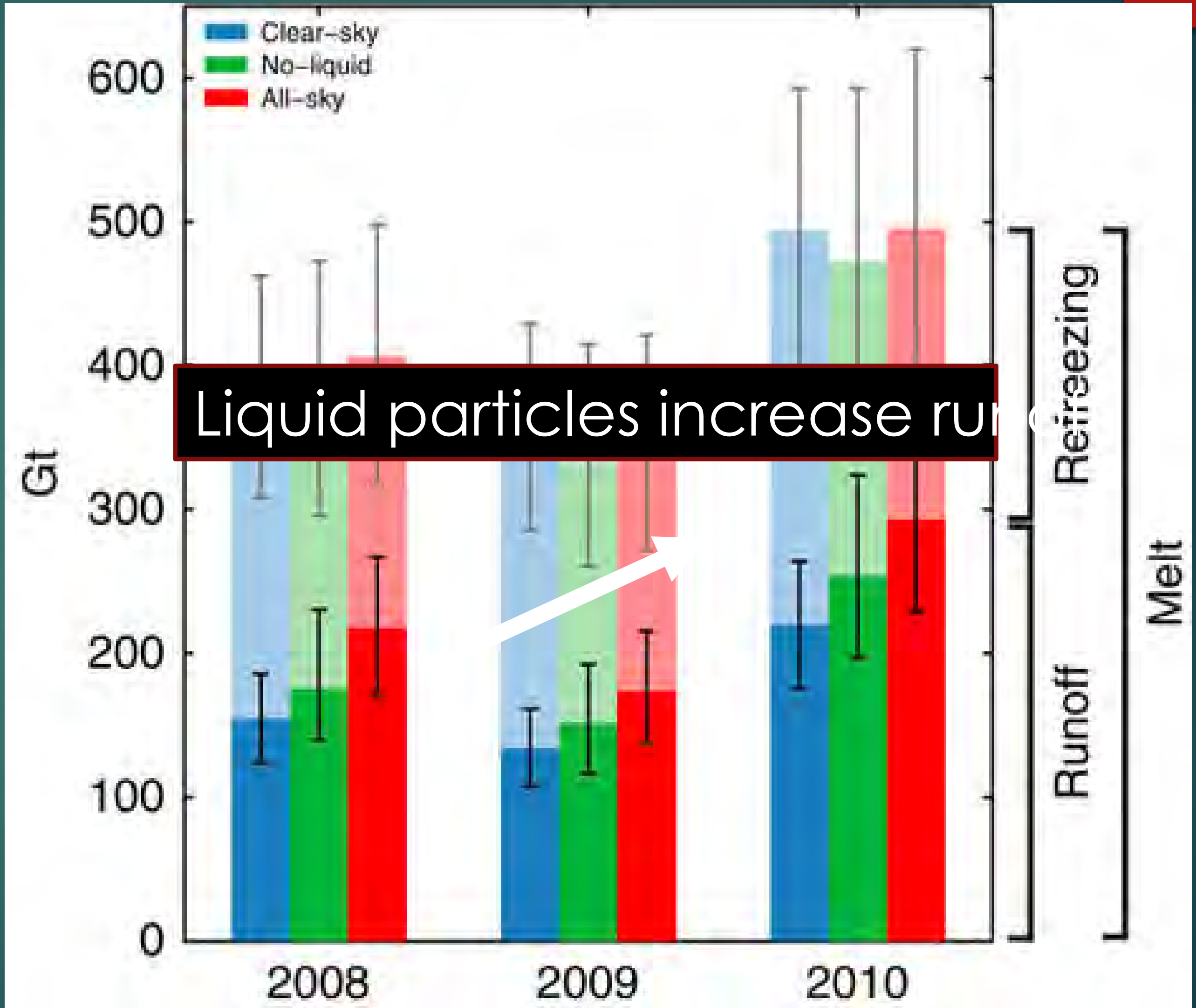
Matus and L'Ecuyer (2017)

- Mixed clouds make up a non-negligible amount to the total cloud occurrence (7.7%)
- The 2b-cldclass-lidar product provides information on the cloud phase. FLXHR adds liquid water when indicated.
- Methodology outlined in Van Tricht et al. (2016)

Mixed Phase Clouds: Application to surface mass balance

- Surface modeling demonstrate that the increased CRE results in about 25 Gt yr^{-1} of runoff after warming and sublimation effects are accounted for.
- Important across arctic as models underestimate liquid water in clouds.

(McIlhattan et al. 2017, J. Climate)



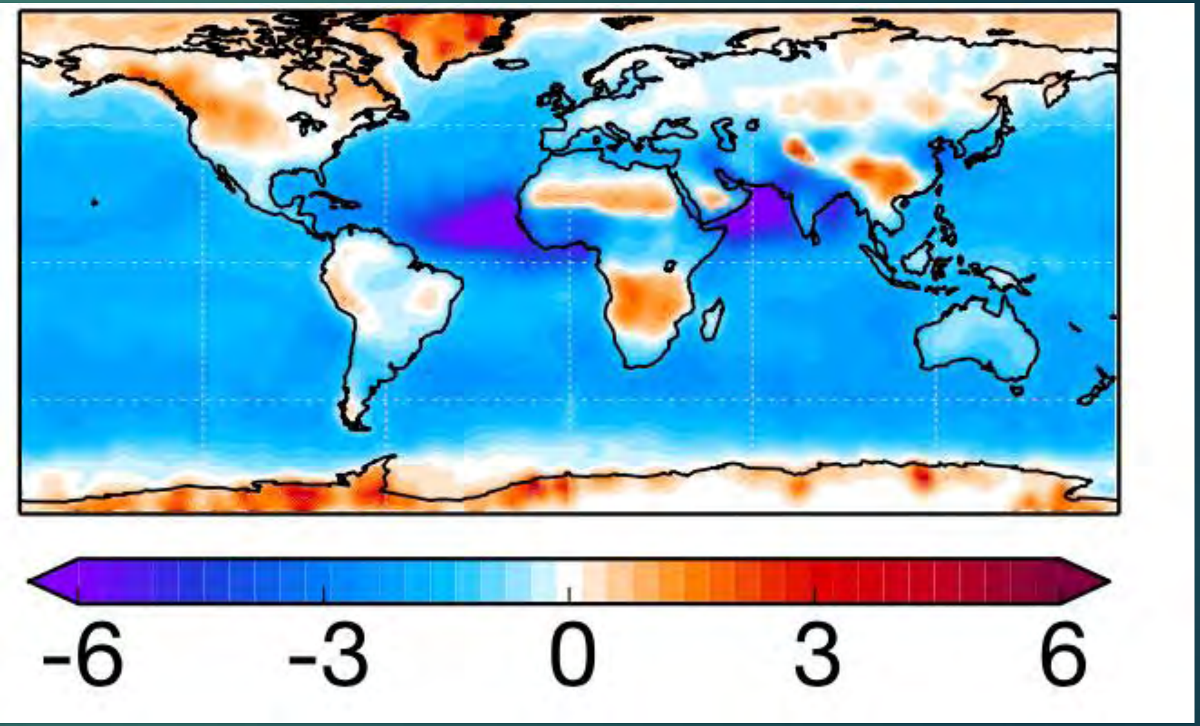
Van Tricht et al (2016), Nature Co

Update to V4 CALIPSO Aerosol

All-Sky Aerosol Direct Radiative Effect (ADRE): -1.6 W/m2

CALIPSO V4 drastically improves aerosol detection and subtyping

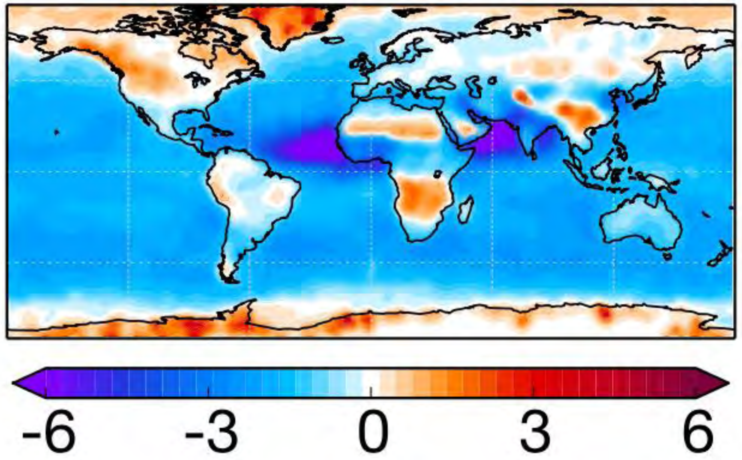
- The combined aerosol detection from CALIPSO combined with CloudSat cloud detection provides a true estimate of aerosol radiative impacts



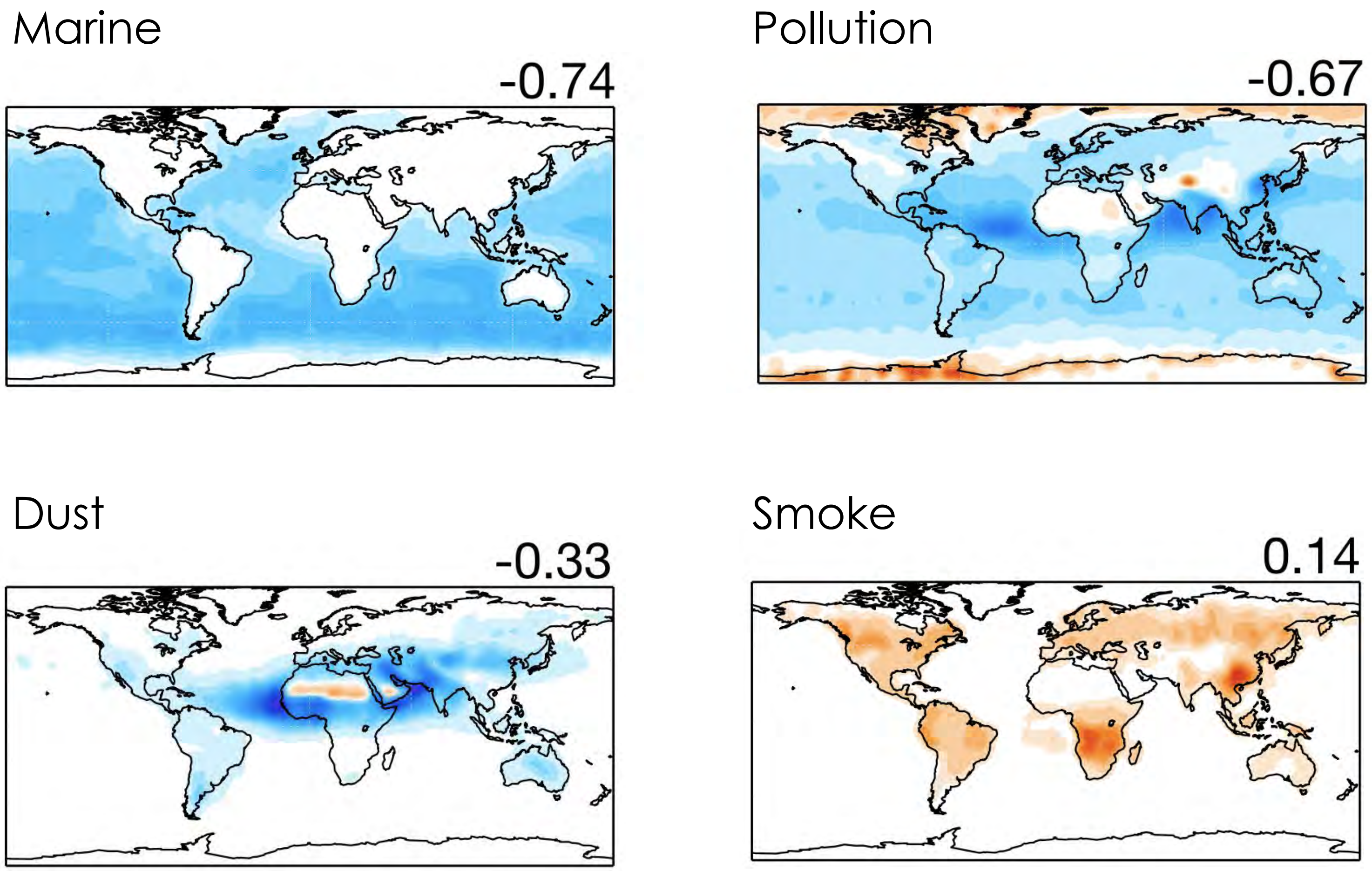
Matus et al., 2018; In Revision, GRL

Assessing ADRE From Distinct Aerosol Species

Total ADRE [redacted]



Aerosol type	DRE
Marine	−0.74 ± 0.1
Dust	−0.33 ± 0.4
Pollution	−0.67 ± 0.5
Smoke	0.14 ± 0.2
Total	−1.60 ± 0.6



Matus et al., 2018; In Revision, GRL