

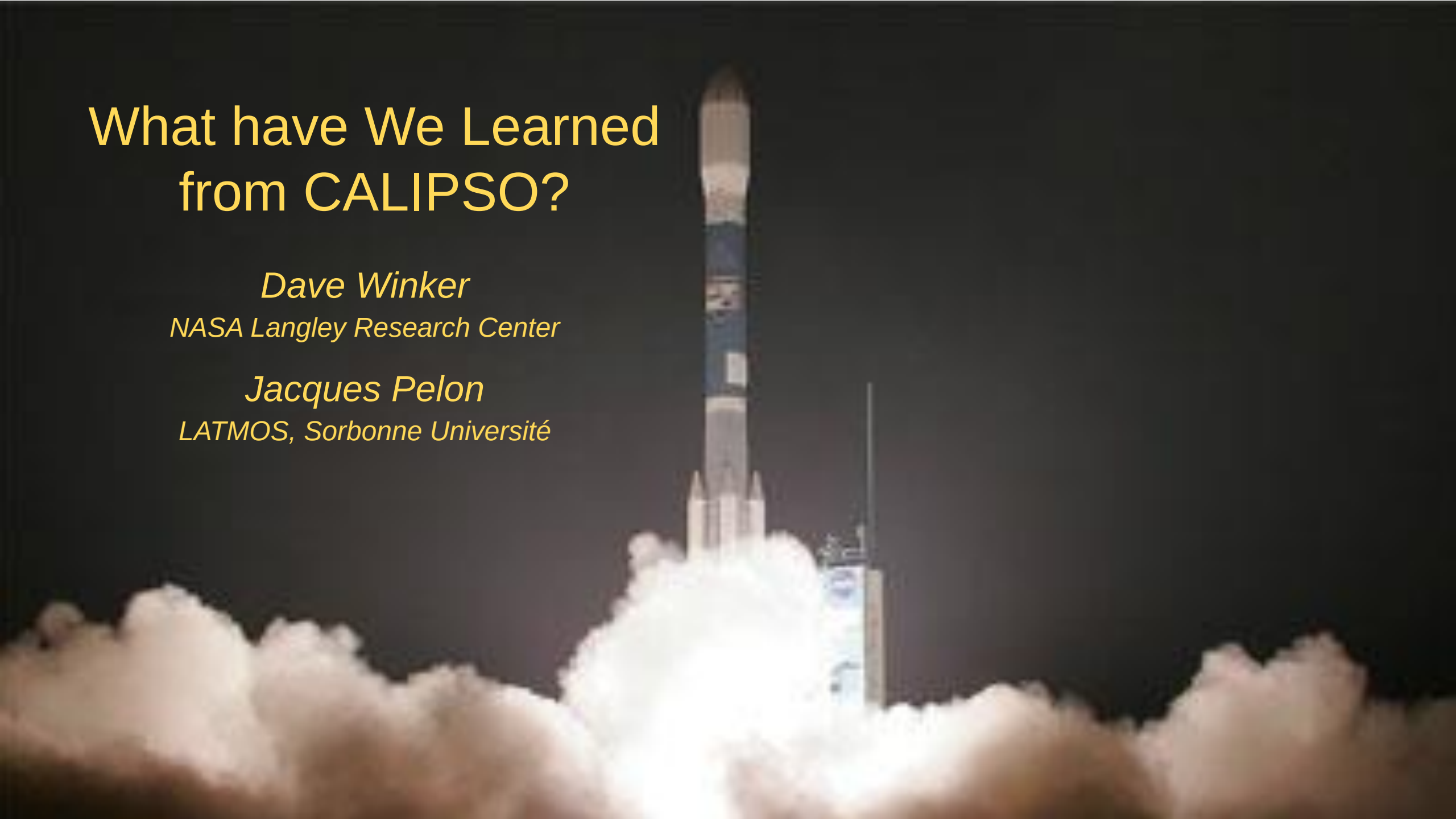
What have We Learned from CALIPSO?

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LATMOS, Sorbonne Université



Going Back in Time: December 1968

Iconic photograph of Earth
by astronaut Bill Anders
from Apollo 8, the first
spacecraft to circumnavigate
the Moon.



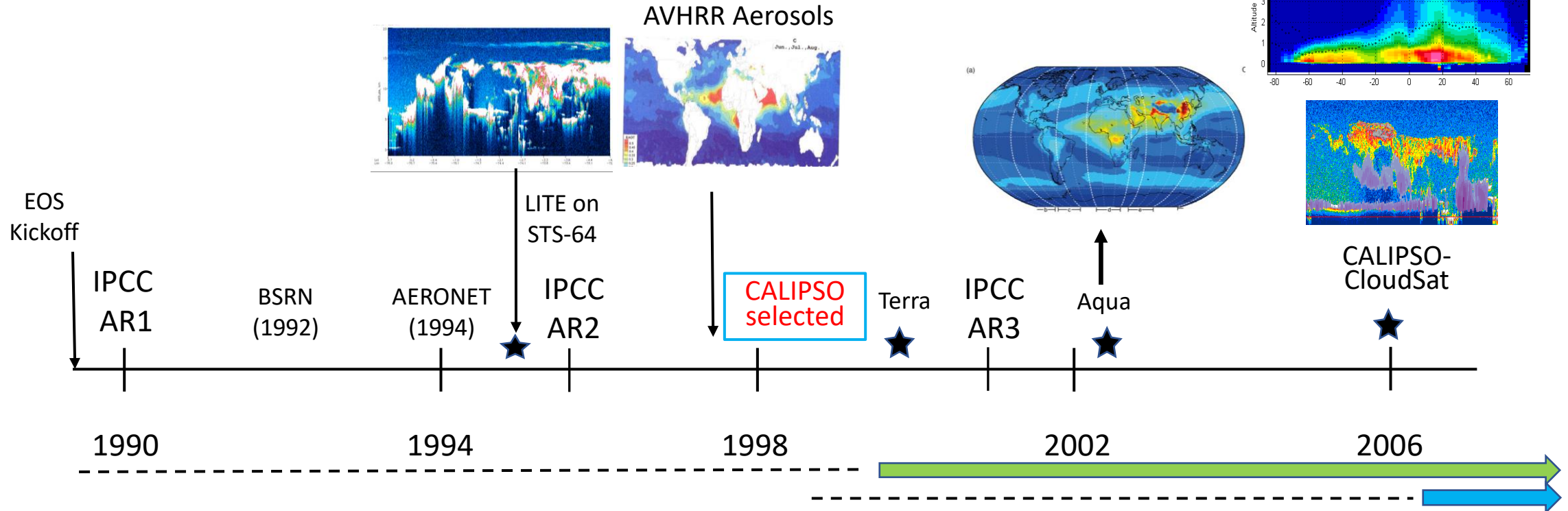
Image Credit: NASA



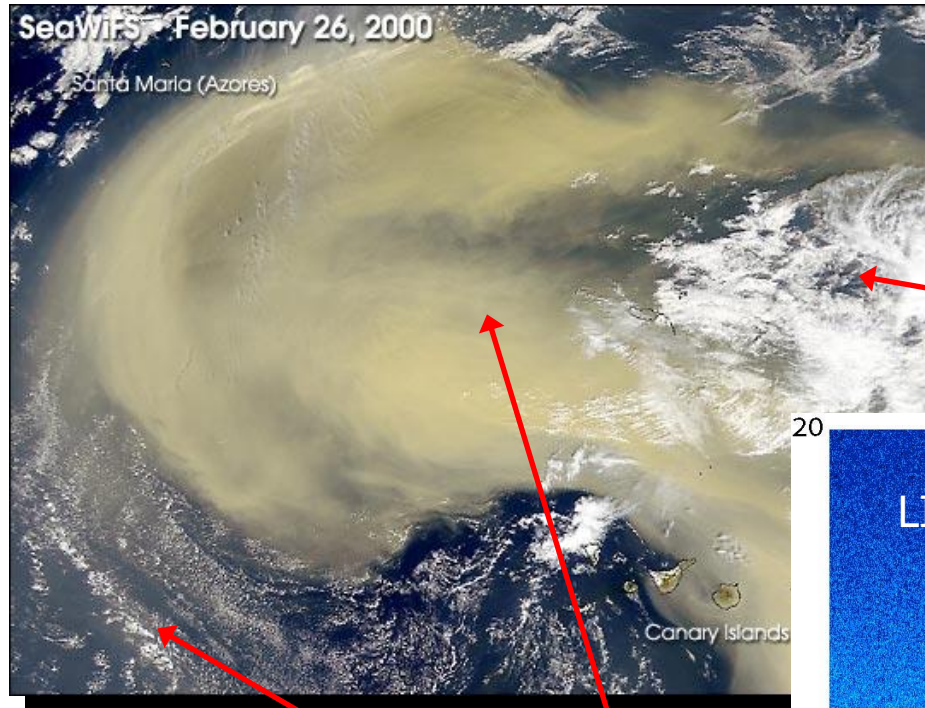
Historical Perspective



An explosion of interest in climate in the 1980's led to formation of the IPCC and advances in both satellite sensors and ground networks



Passive and Active Instruments are Complementary

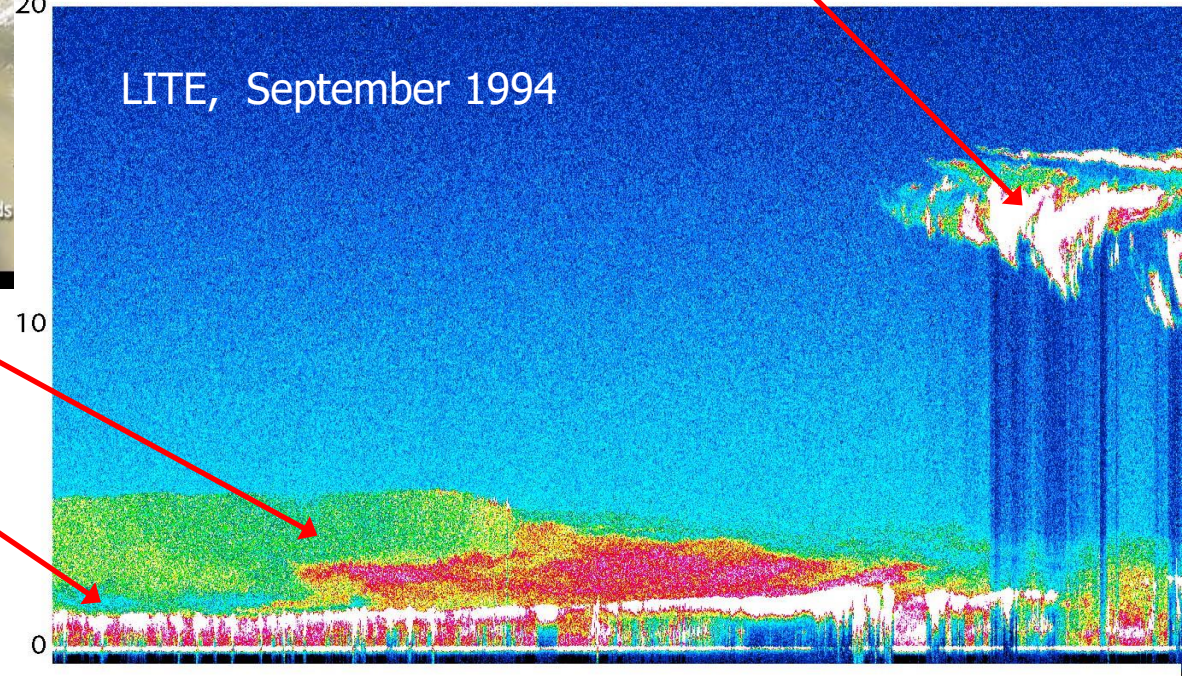


Passive sensors observe the horizontal distribution but little vertical information

Lidar observes vertical structure

Cirrus

LITE, September 1994



Dust

Low clouds

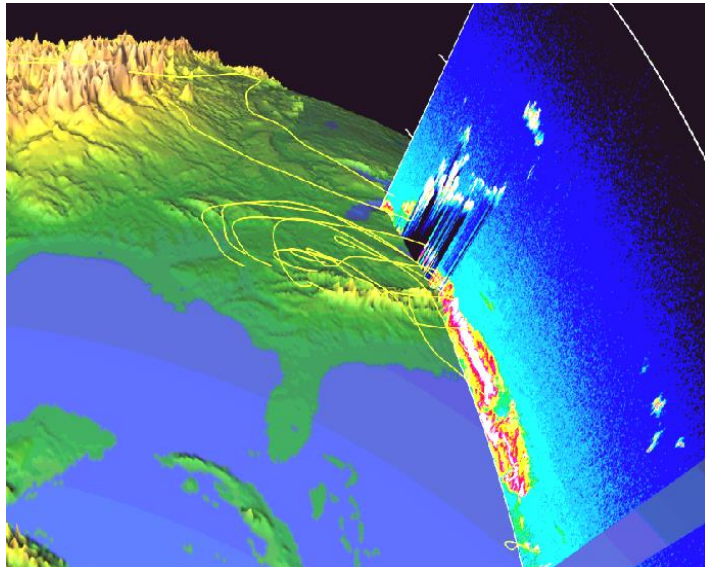


CALIPSO Science Objectives (c. 1998)



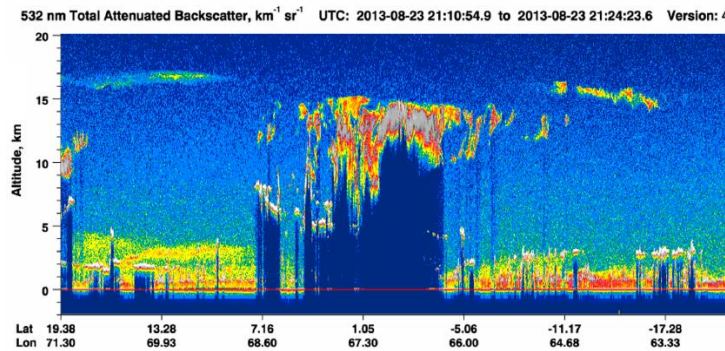
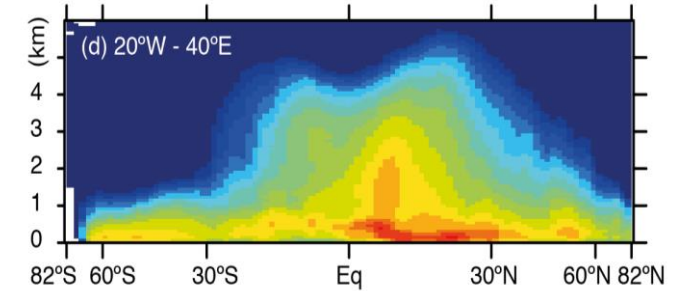
CALIPSO will fly in the A-train, providing observations to improve:

- Our understanding of the role of aerosols and clouds in the processes that govern climate responses and feedbacks
 - Direct and indirect aerosol effects
 - Cloud forcing and feedbacks

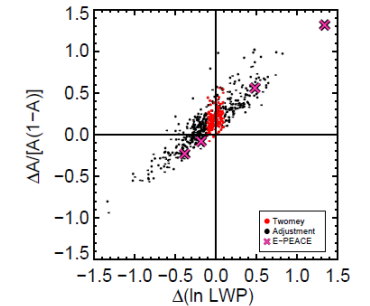
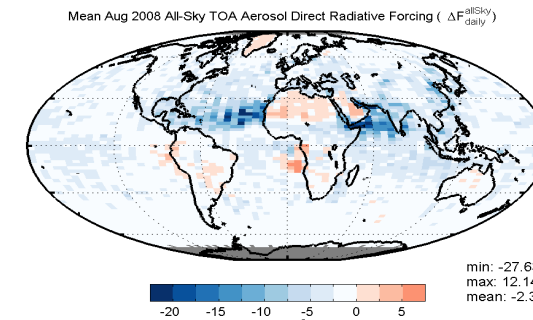


- The representation of aerosols and clouds in models of climate, air quality, weather, etc.
- Validation of other A-train sensors

First vertically-resolved
aerosol climatology

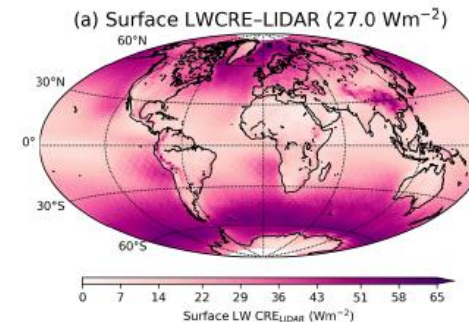


Aerosol direct and
indirect radiative effects

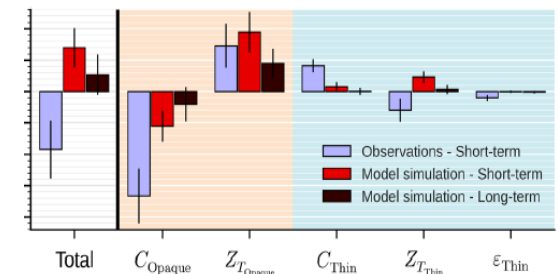


(Chen et al., 2012)

Cloud Radiative Effect
and Feedbacks



(Arouf et al., 2022)

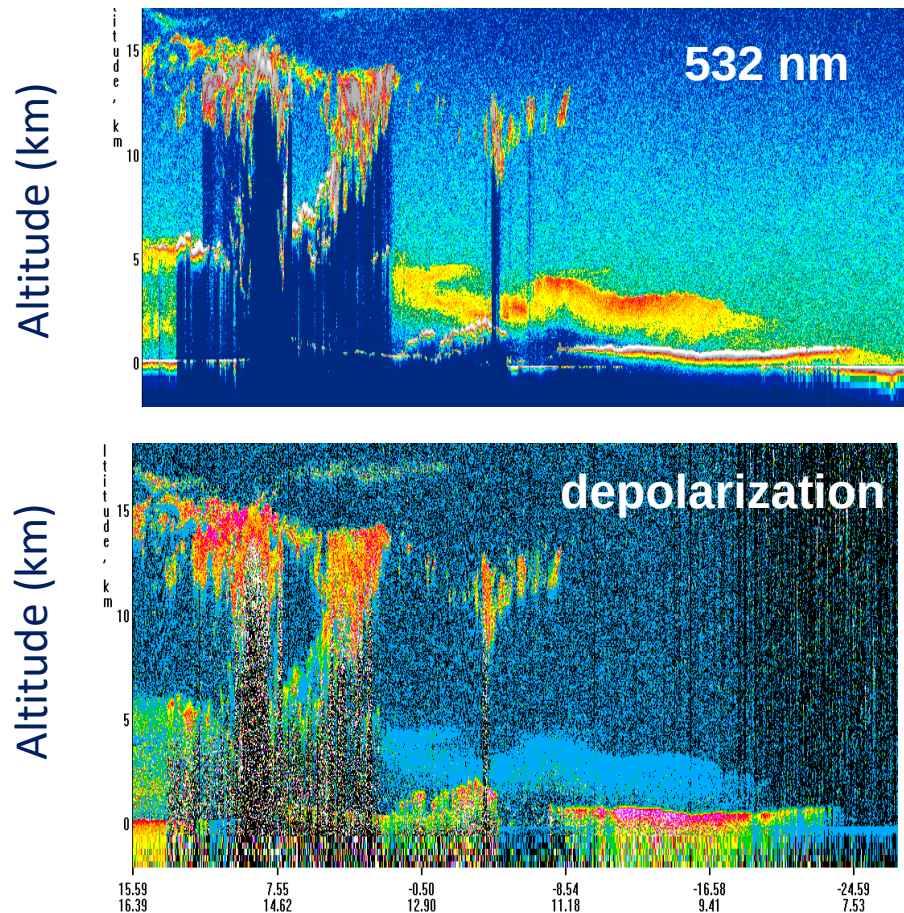


(Vaillant de Guelis et al., 2018)

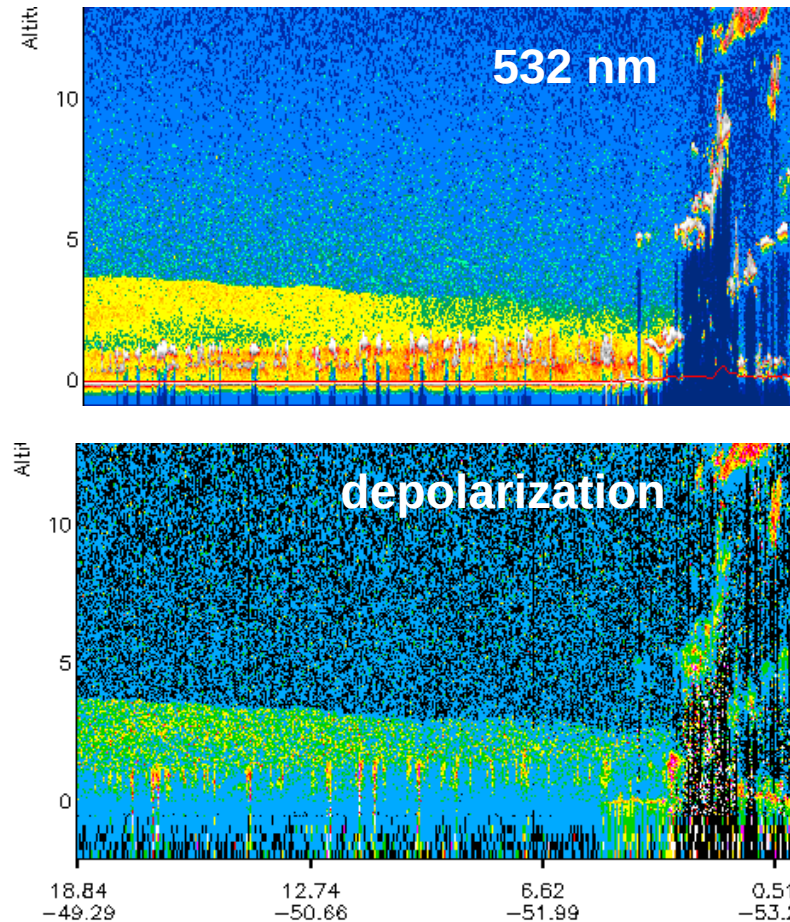
A CALIOP Advance over LITE: Important Capabilities from Lidar Depolarization

Discrimination of Aerosol Type

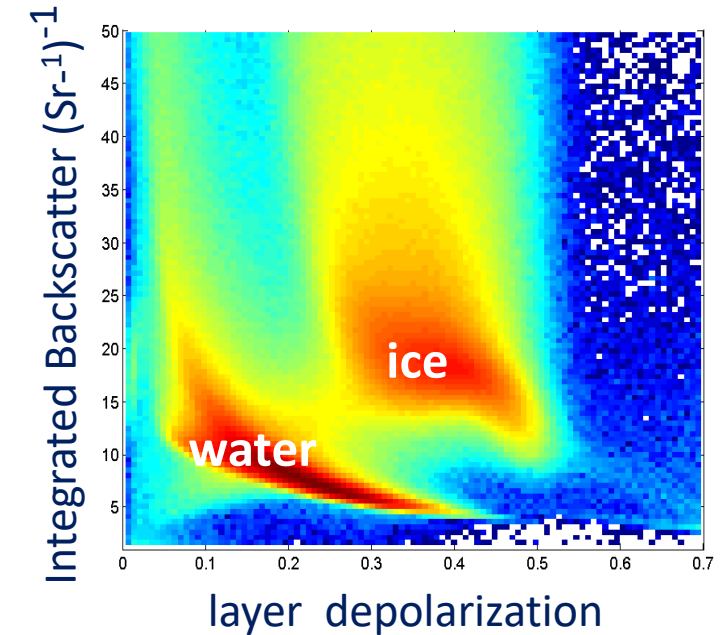
Smoke



Sahara Dust



Vertically resolved
cloud ice-water phase





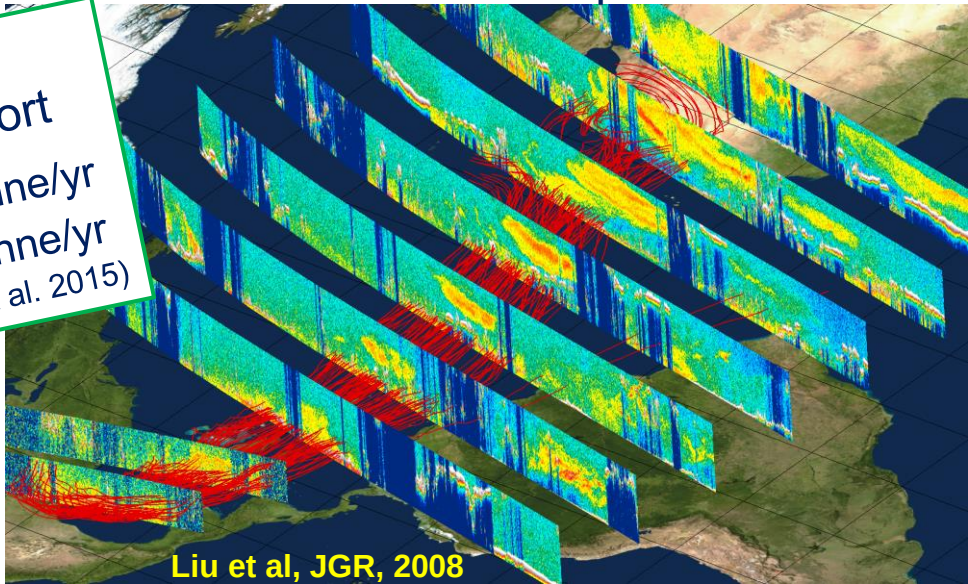
New Aerosol Capabilities



Aerosol Transport

Mass
Aerosol Transport
15°W: 0.18 Mtonne/yr
35°W: 0.13 Mtonne/yr
(Yu et al. 2015)

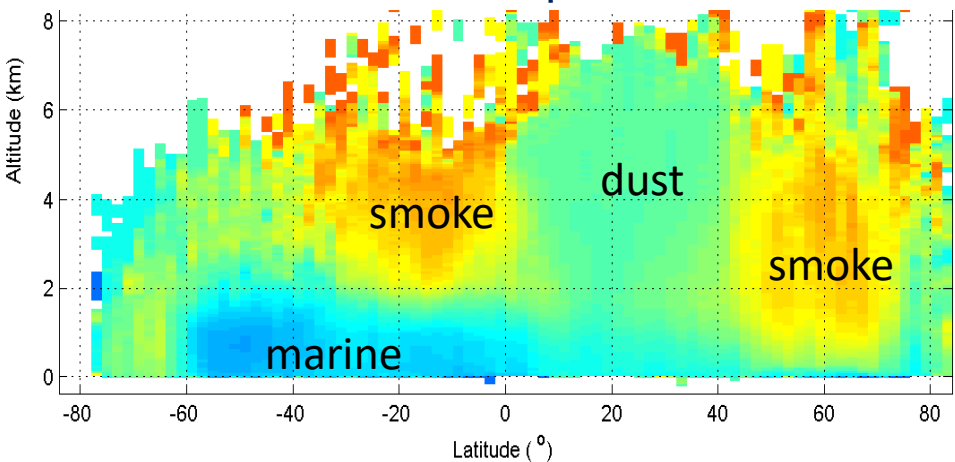
Sahara dust
outbreak, Aug 2007



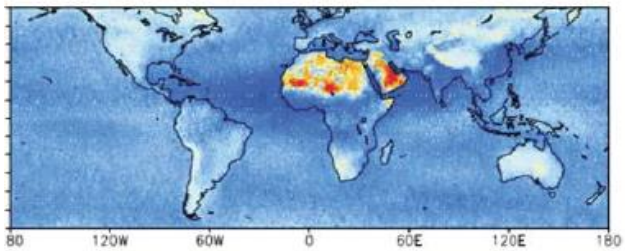
Liu et al, JGR, 2008

Aerosol Composition

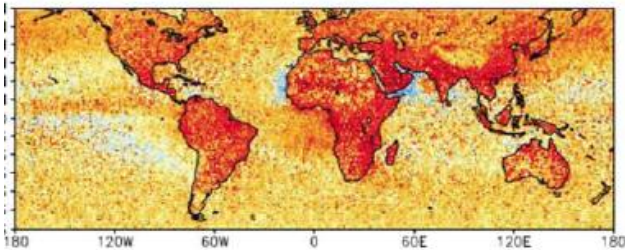
Zonal mean
distribution of
aerosol types, JJA



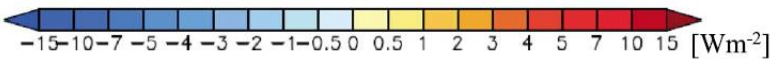
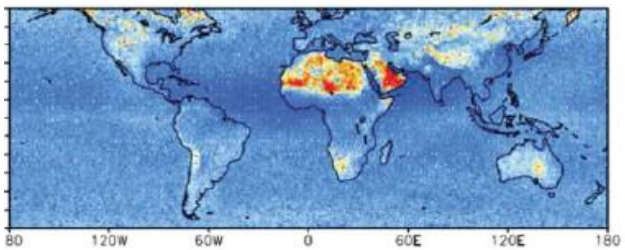
Aerosol Radiative Effects Clear-sky case



Above-cloud case

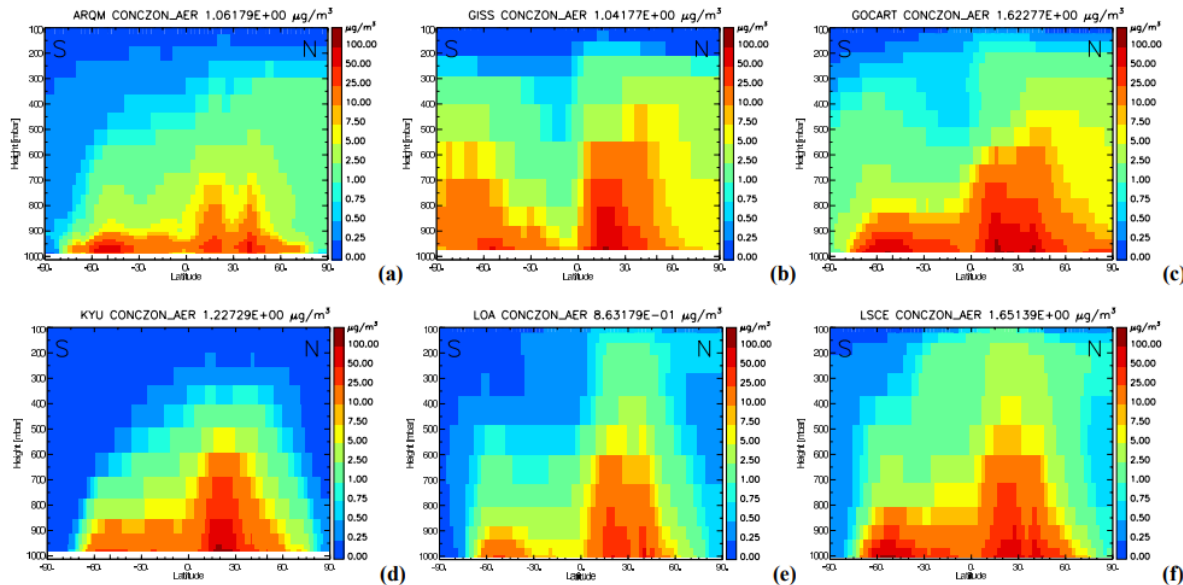


Below-cloud case



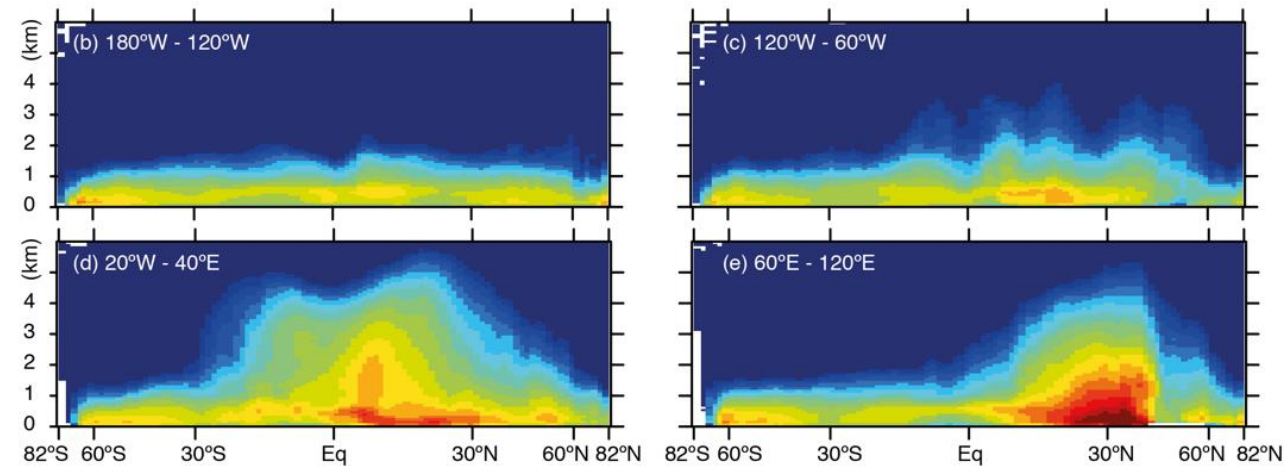
(Oikawa et al. 2018)

Until CALIOP there were no global observations to constrain aerosol vertical distribution in models and simulated zonal distributions varied widely



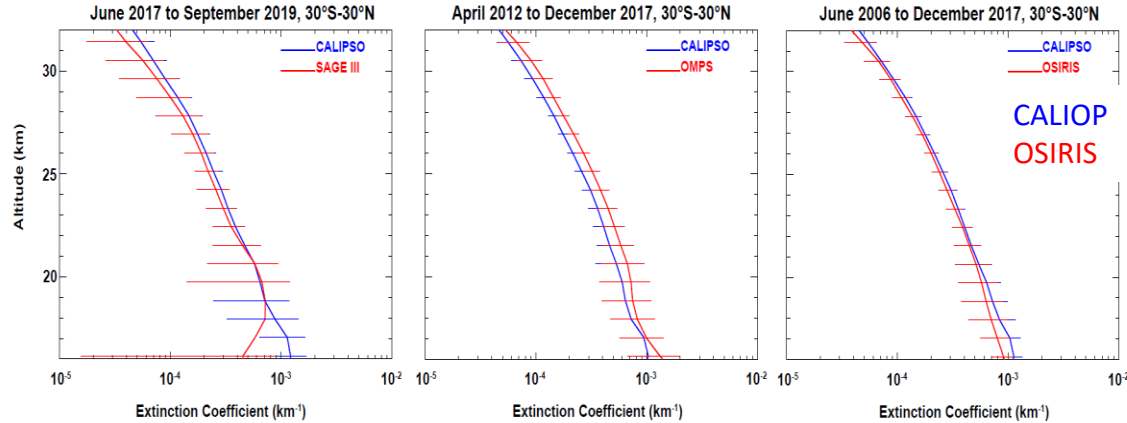
Zonal mean aerosol mass concentration from six global aerosol models (Textor et al. 2006)

For the first time, CALIOP provided observational constraints on global aerosol vertical distribution

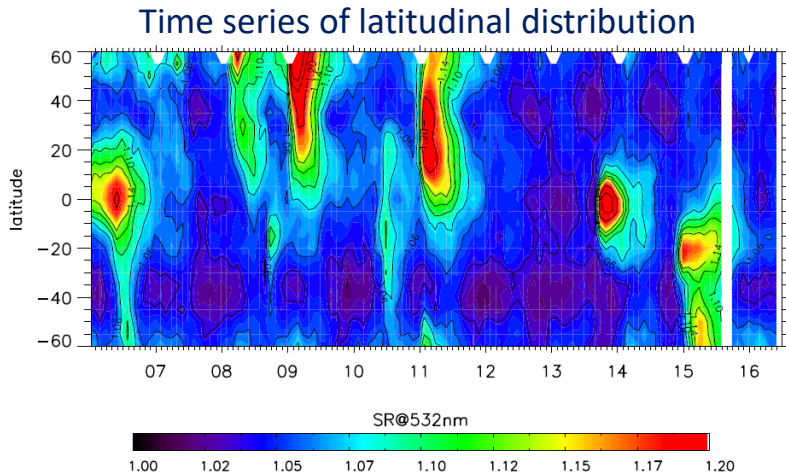


(IPCC AR5, 2013)

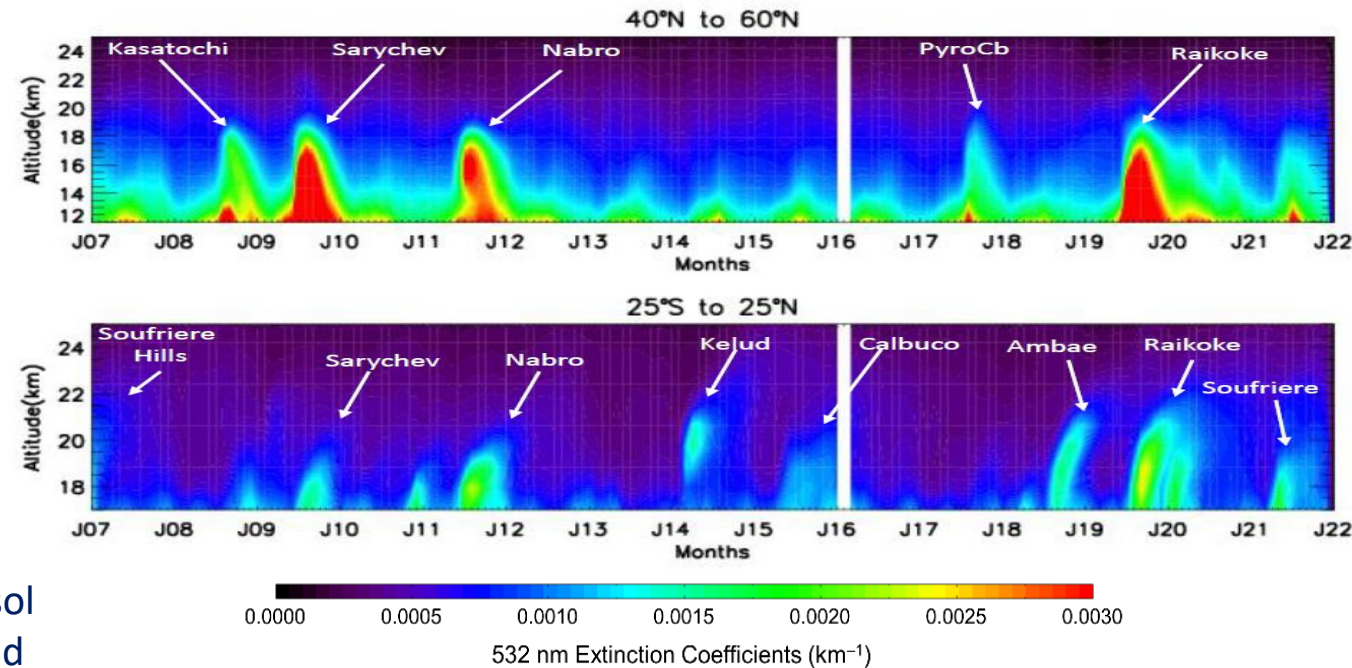
- CALIOP nighttime 532 nm stratospheric profiles are averaged on a 5° by 20° lat-lon grid
- Aerosol extinction profiles are retrieved and reported as monthly means on a 3D global grid



Zonally averaged CALIPSO extinction coefficient profiles compared to SAGE III-ISS, OMPS, and OSIRIS (Kar et al. 2019)



Evolution of aerosol between 10 km and 35 km



Time-height cross sections of CALIOP stratospheric aerosol extinction, Jan 2007 to Dec 2017 (Kar et al., 2019)

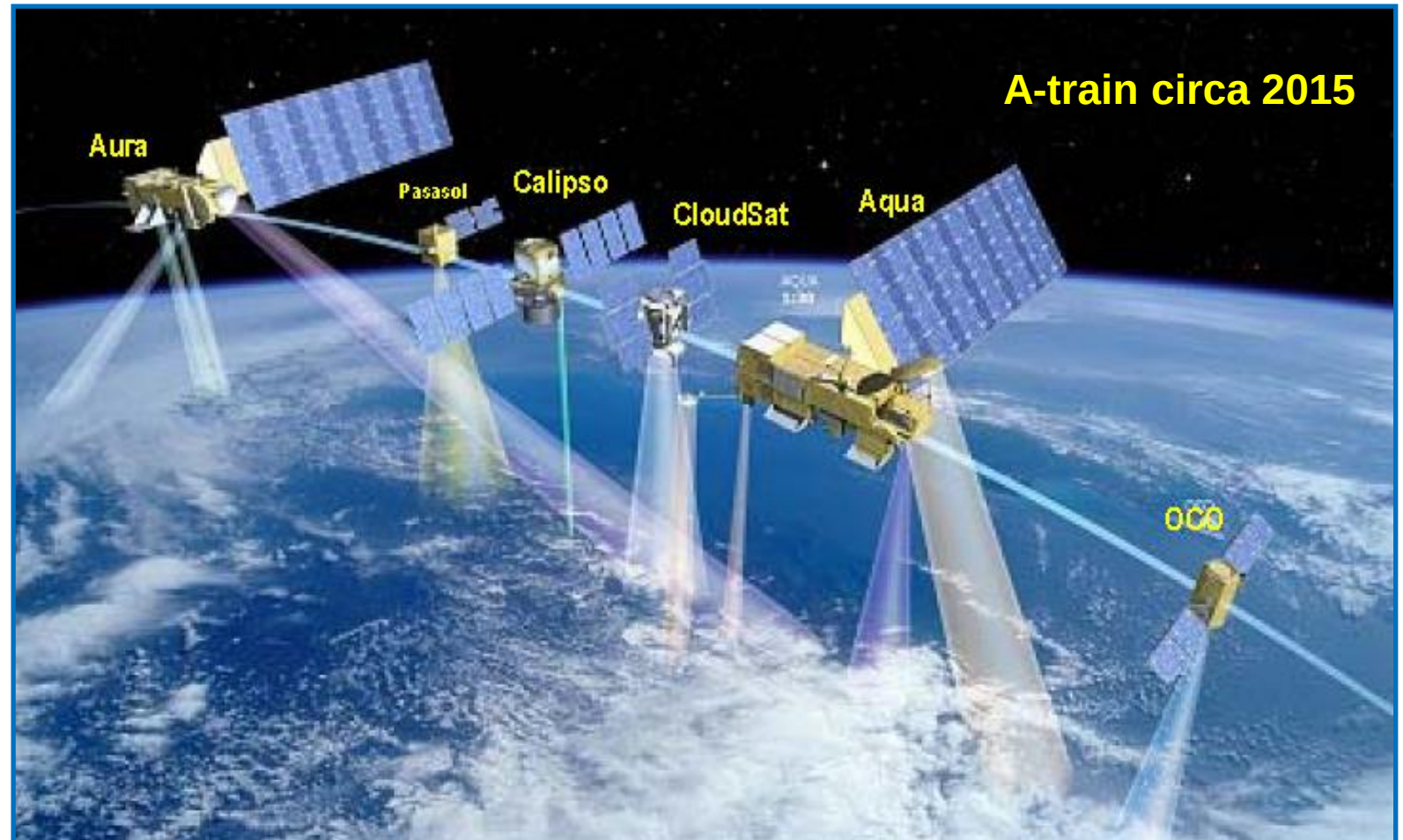


Synergies!

CALIPSO & CloudSat teamed in mid-1990's and originally planned to fly with Aqua (MODIS & CERES) and then the A-train happened



CALIPSO and CloudSat, 2006



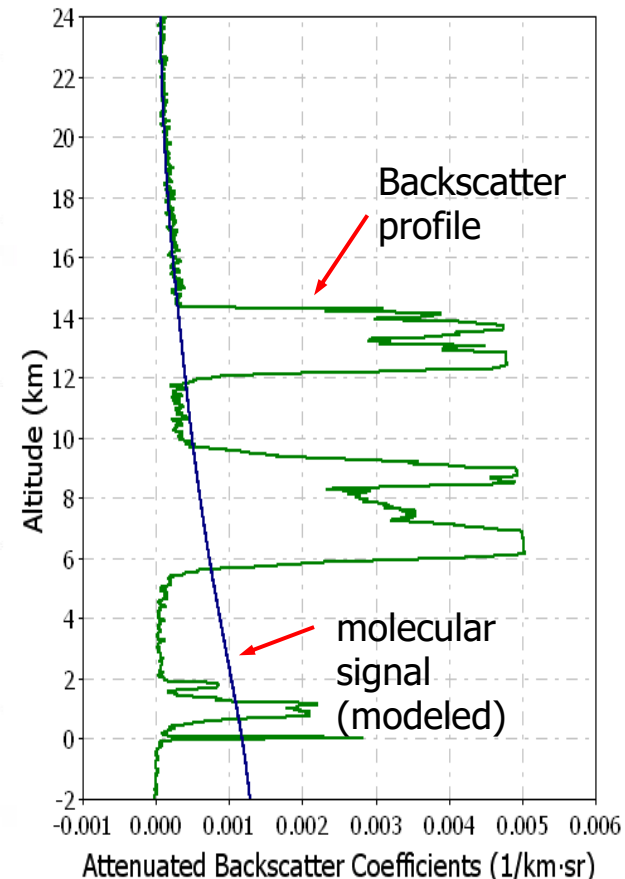
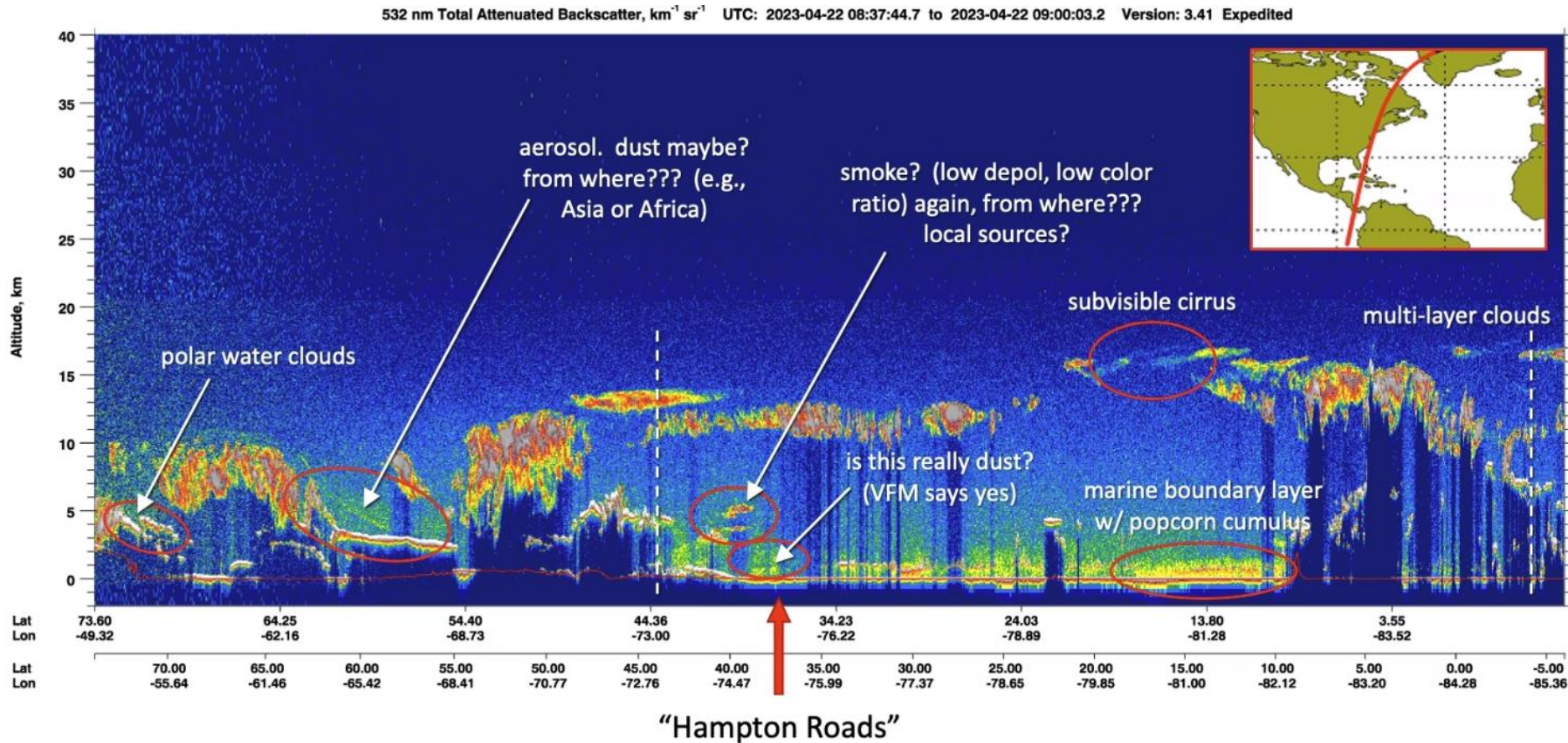


Lidar Shows “What You’re Looking At”



- Passive retrievals are based on simplified models of atmospheric vertical structure
- Errors result when these assumptions are violated
- Lidar provides scene identification

... and measures
precise boundaries:

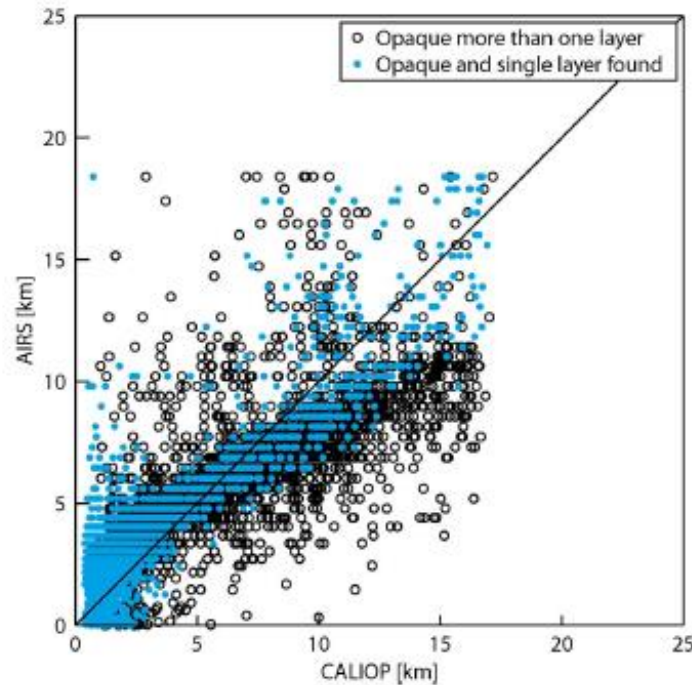




CALIPSO Widely Used to Evaluate and Improve Passive Cloud Retrievals

Evaluation of MODIS cloud mask/cloud heights:

- MODIS low-cloud heights biased by PBL temperature inversions
- Cirrus heights biased in multi-layer situations



(Di Michele et al., 2013)

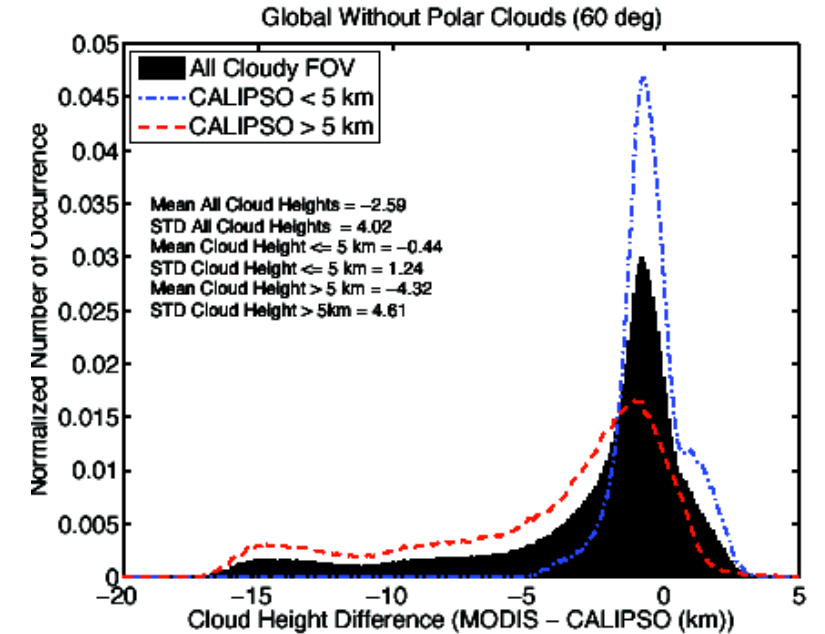
CALIOP cloud heights vs. AIRS

AIRS height retrievals biased for:

- Non-opaque cloud
- Multi-layer cloud



CALIOP comparisons improved height assignments of AIRS AMVs



(Holz et al. 2008)

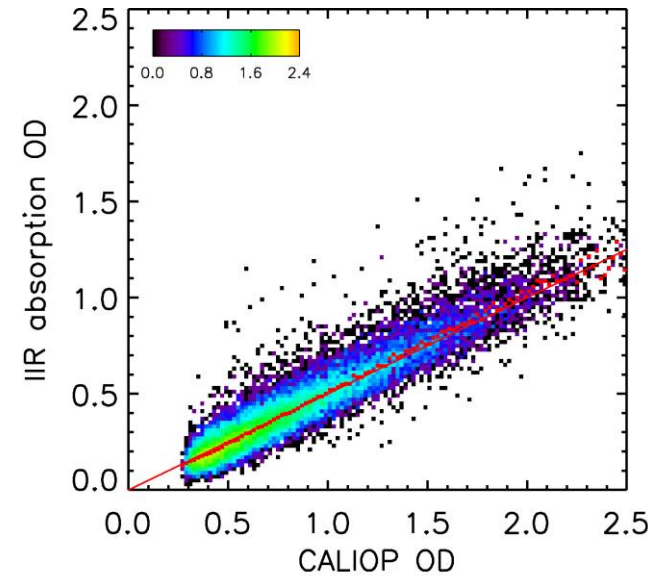
CALIPOP constraints on IIR retrievals

- 1) improve over standard retrievals
- 2) allow retrievals of new properties

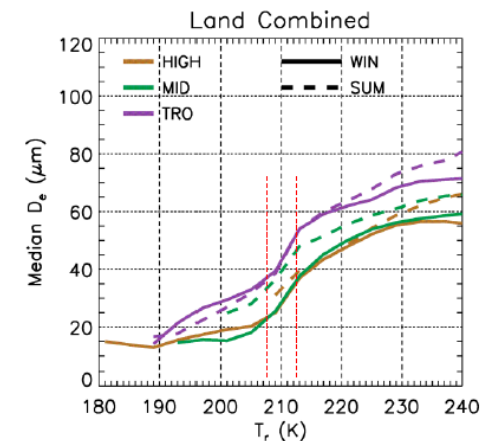
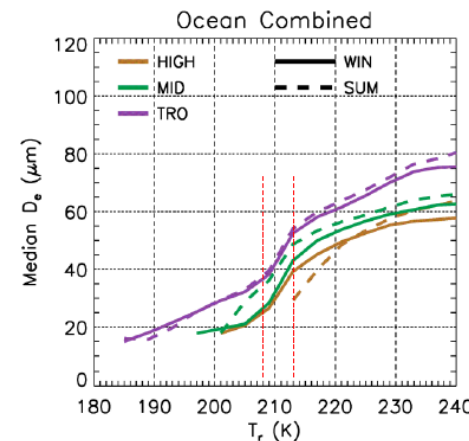
Infrared retrievals of cirrus involve assumptions which are poorly constrained

CALIPOP observations provide:

- Scene identification:
 - single/multiple cloud layers
 - clear-sky columns
- Improved cloud-free IR radiances
- Accurate cloud heights

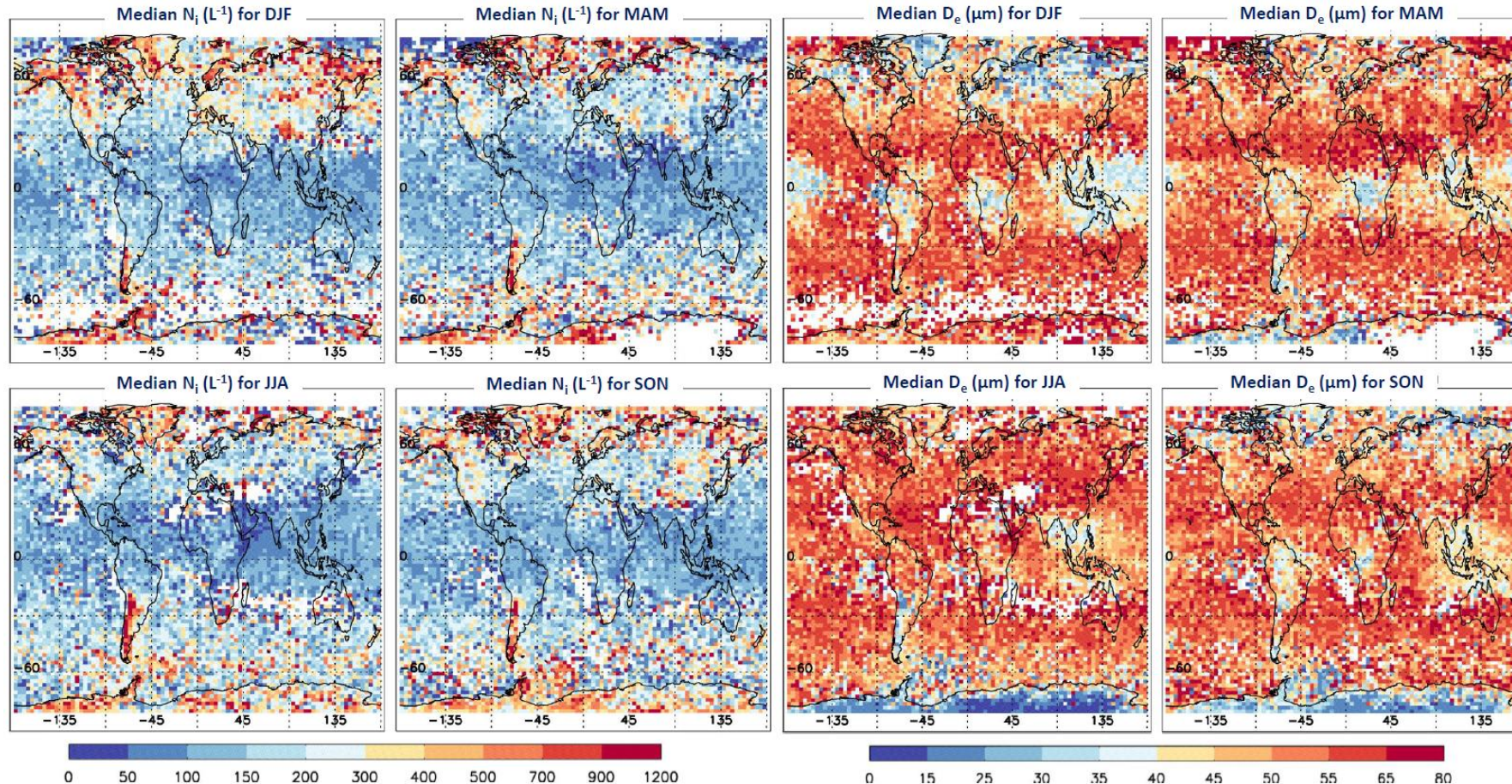


IIR cirrus optical depth retrievals vs CALIPOP “constrained” retrievals



(Mitchell and Garnier, 2022)

New Information on Cirrus Formed *in situ*: Ice Crystal Size and Concentration



- Low D_{eff} and high N_i over **the Andes** are linked to homogeneous formation
- Evidence of **polar** stratospheric clouds in winter

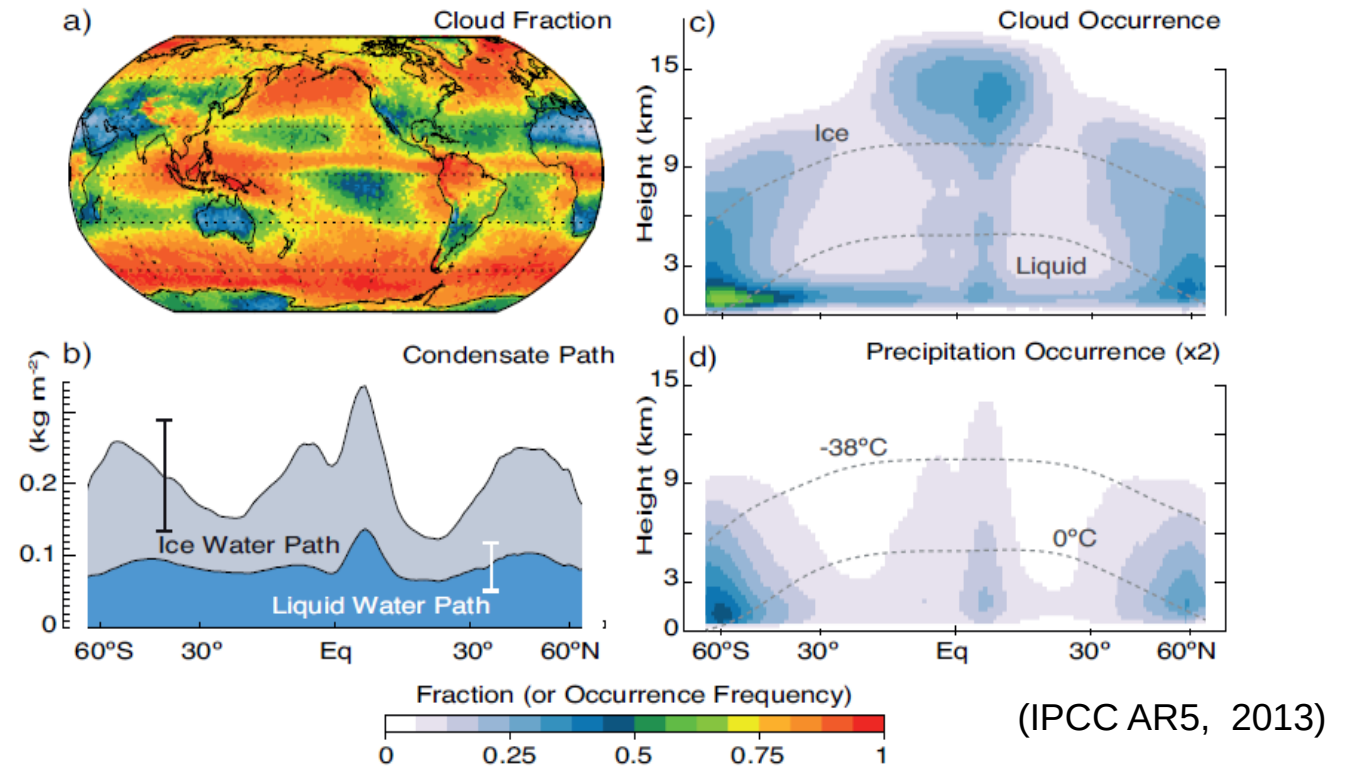
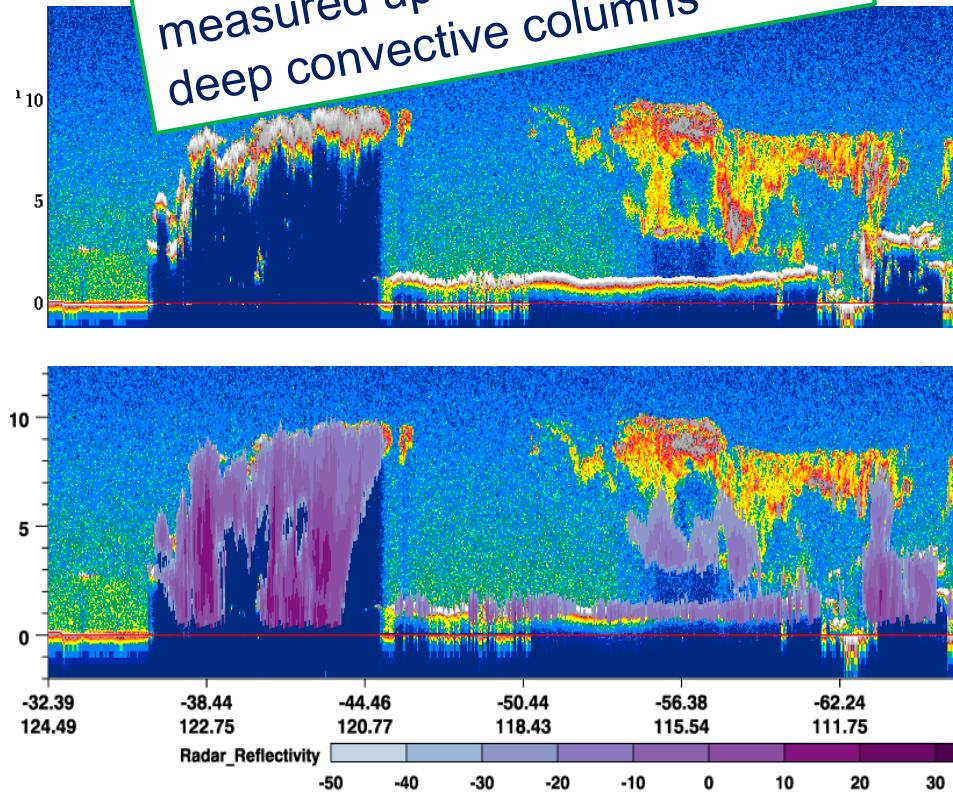
(Mitchell and Garnier, 2022)



CALIPOP + CloudSat: A new ability to Assess Clouds in the Climate System



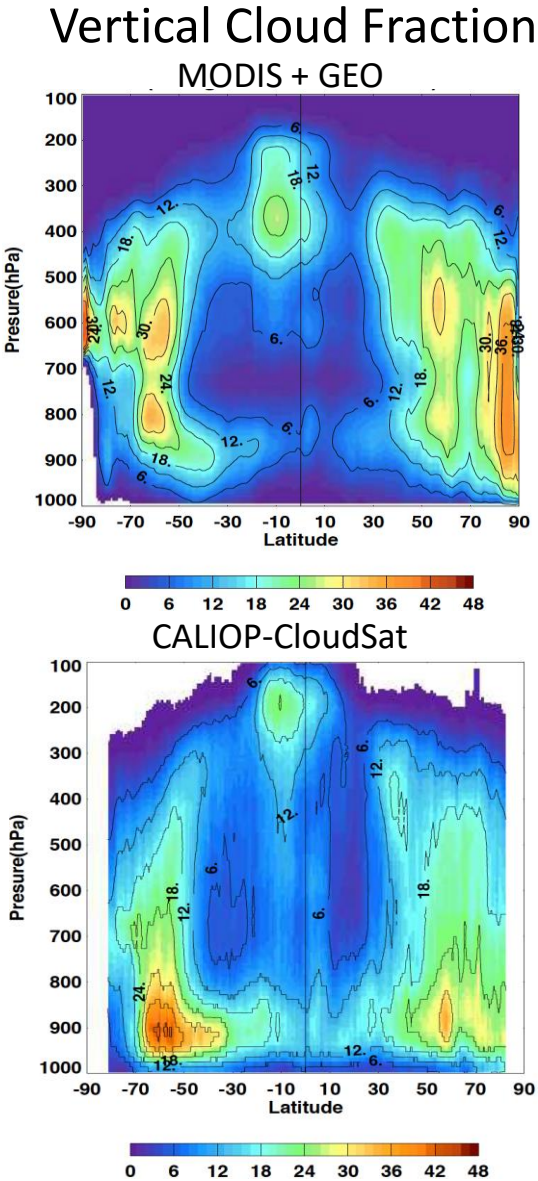
What does a cloud weigh?
We can measure it!
CloudSat+CALIPOP have
measured up to 1 kg/m² ice in
deep convective columns



“Active sensors show more clearly that low clouds are prevalent in nearly all types of convective systems, and are often underestimated by models. Cloud layers at different levels overlap less often than typically assumed in General Circulation Models ... New observations have led to revised treatments of overlap in some models, which significantly affects cloud radiative effects.”



Improved Estimate of LW Radiative Fluxes at Earth's Surface

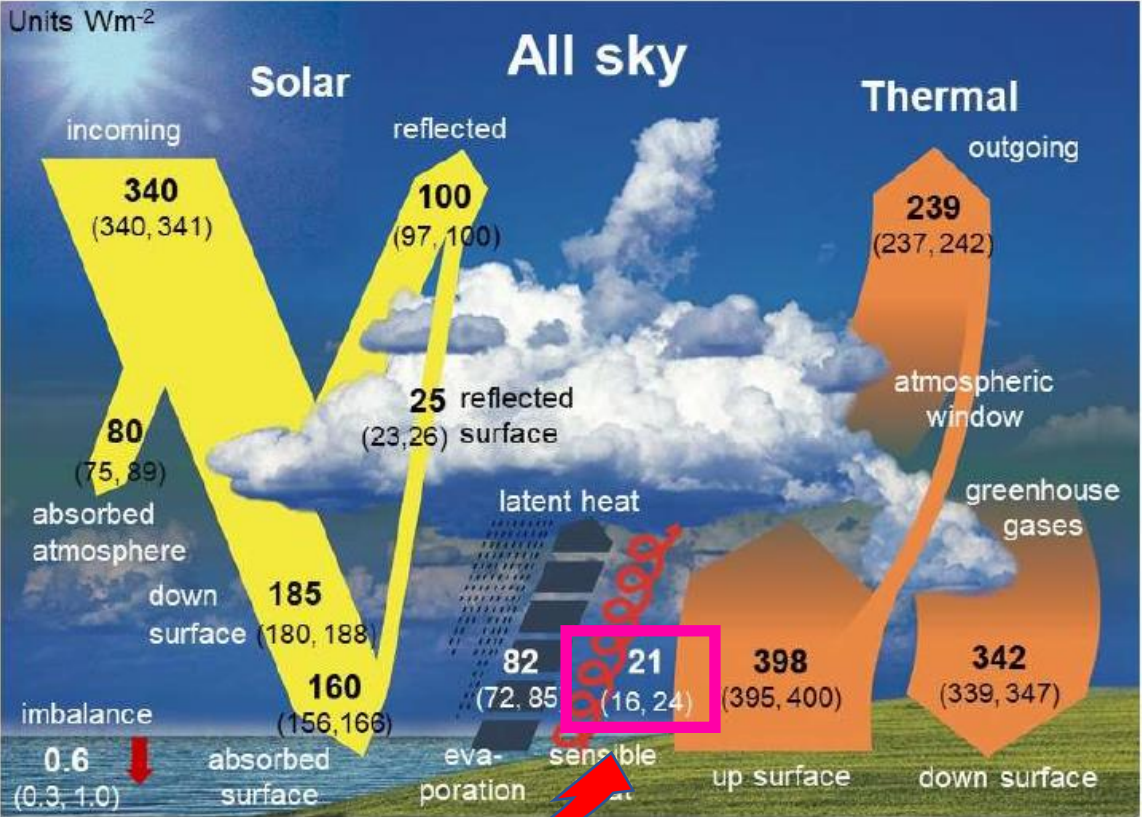


Cloud climatologies from passive sensors are 'top-heavy'

- Passive sensors only view tops of deep clouds
- View of lower clouds blocked by upper clouds

CALIOP+CloudSat observe the true vertical distribution of cloud

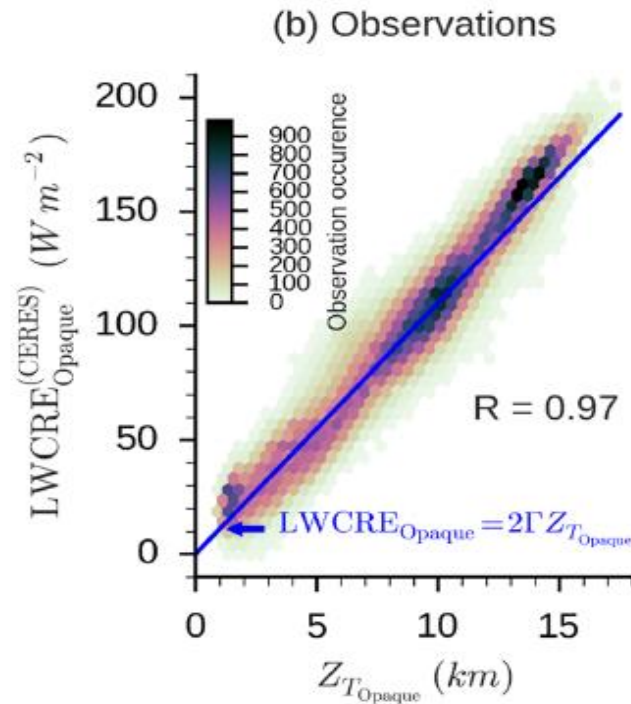
(Kato et al. 2019)



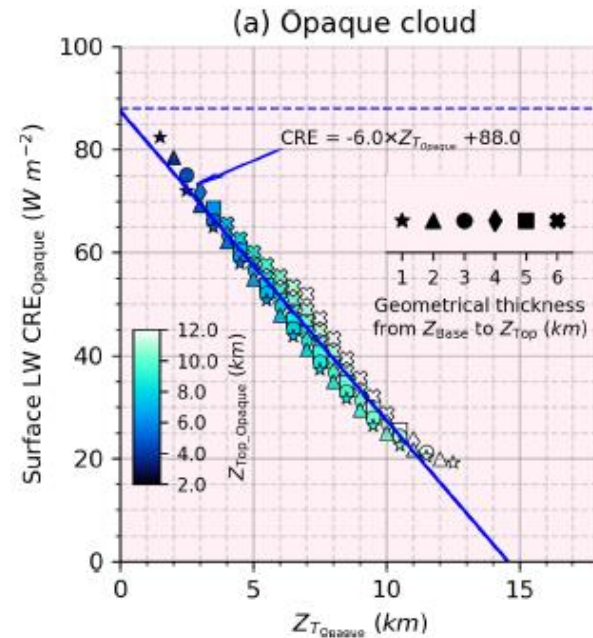
(IPCC AR6, Chapter 7)

C-C cloud observations led to an increase in the estimate of upward surface LW flux of $> 10 W/m^2$ and the first meaningful estimates of uncertainty

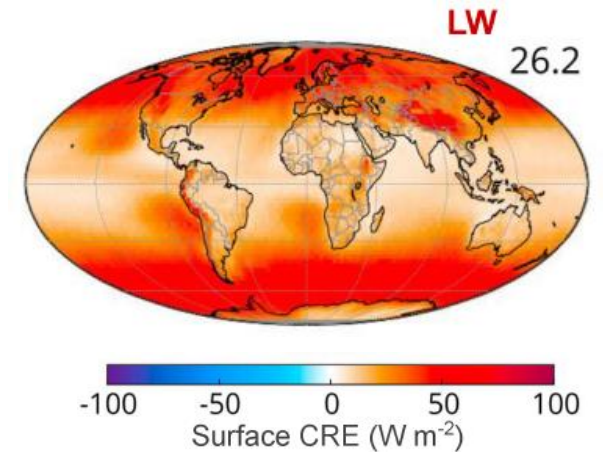
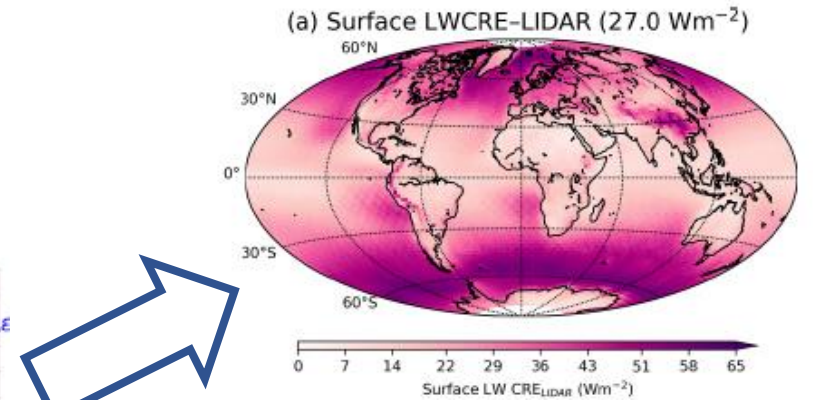
Recent extension of TOA flux retrieval has allowed estimates of the surface LW cloud radiative effect (CRE) from CALIOP alone



(Vaillant de Guelis et al., 2018)



(Arouf et al., 2022)



(Matus and L'Ecuier 2017)

What is Next after CALIPSO?

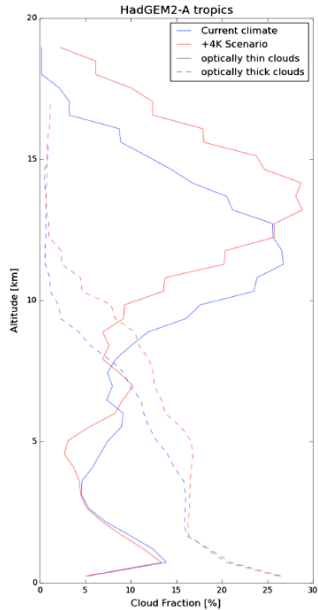
One image was taken by Apollo 17 (7 Dec 1972). The other is a recent computer simulation by a climate model running at kilometer-scale global resolution



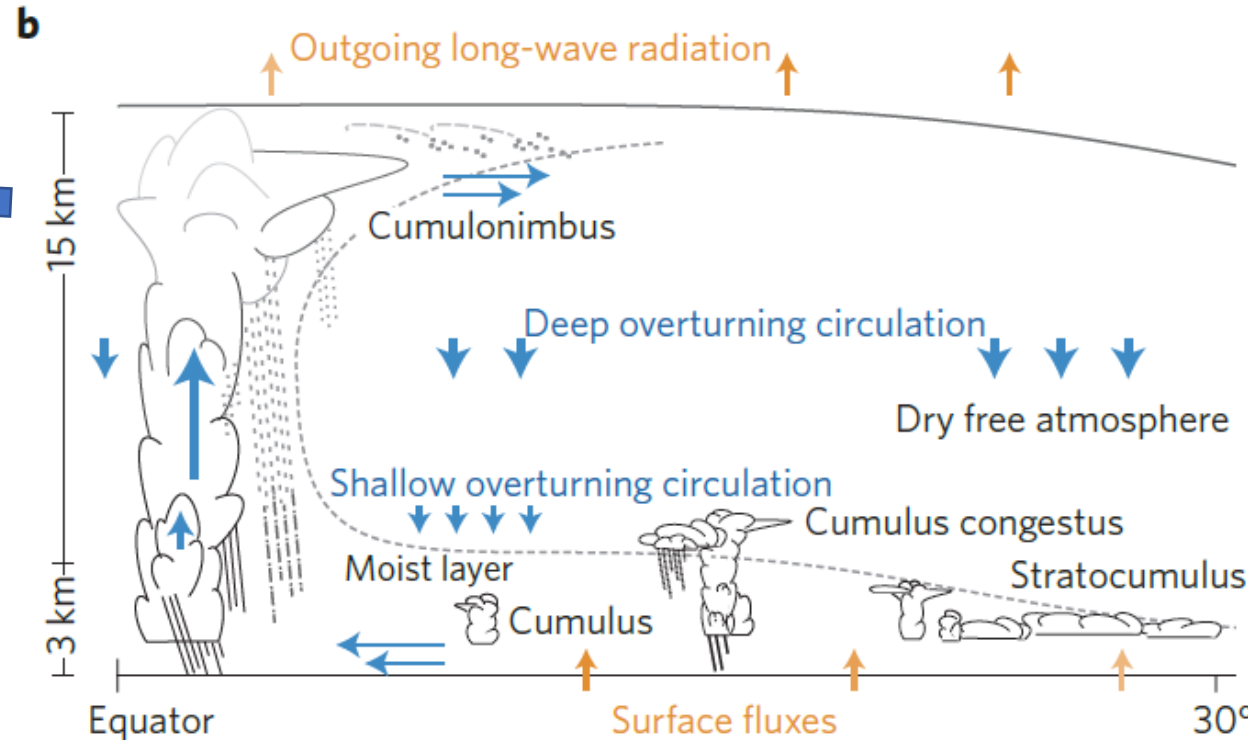


Multi-decade Records are Needed to Understand Climate change

CALIPSO has established a baseline



Cloud fraction profiles simulated by HadGEM2. Blue: current climate Red: +4K climate (Chepfer et al., 2014)

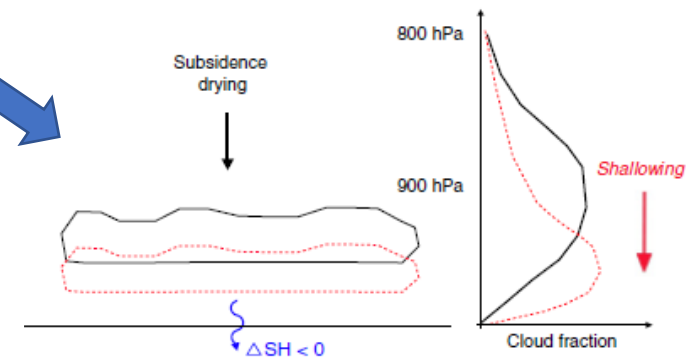


With warming climate:

- High clouds get higher
- Low clouds may thin, or thicken

How clouds change depends on microphysics and dynamics

Continued active observations are needed



(Brient et al., Clim Dyn, 2015)

Some of the largest uncertainties in predicting the climate response to rising GHG concentrations involve predicting how clouds will change, and the radiative impacts of these cloud changes.



... many thanks to the CALIPSO team

A cast of hundreds at NASA LaRC, CNES (Toulouse), Ball Aerospace (Boulder), SODERN (Paris), Aerospatiale (Cannes), and NASA GSFC