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Construction of Unified Global 3D Cloud Fields

Combining Multiple Satellite Products and AI/ML-Derived Environmental Data

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with

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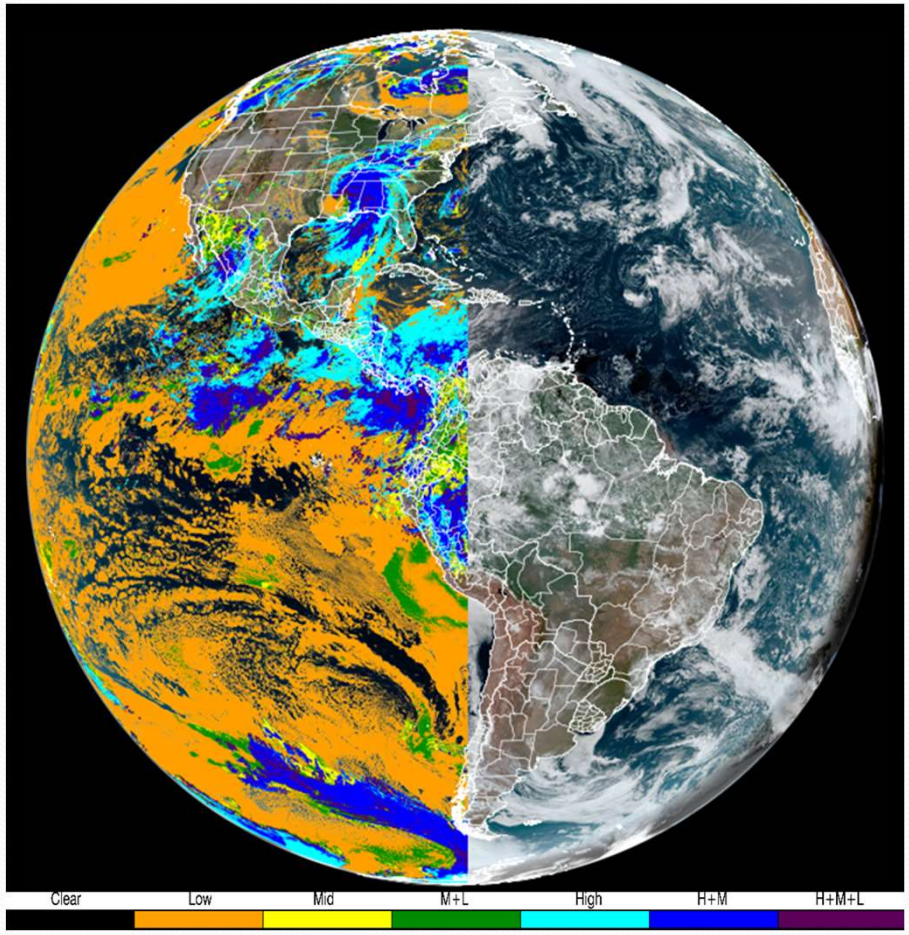
M. Foster, C. Phillips, S. Wanzong (University of Wisconsin-Madison / CIMSS)
M. Surratt, C. Camacho (NRL)

Satellite Imagery and Cloud Data

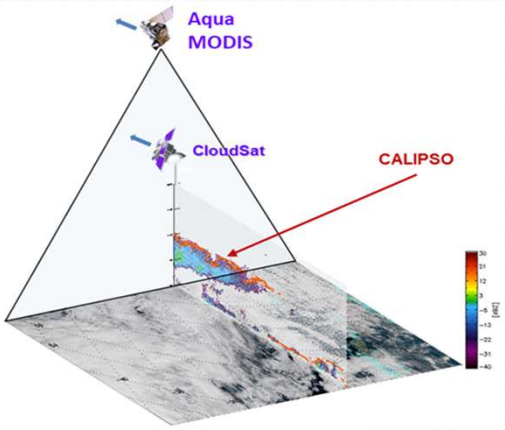


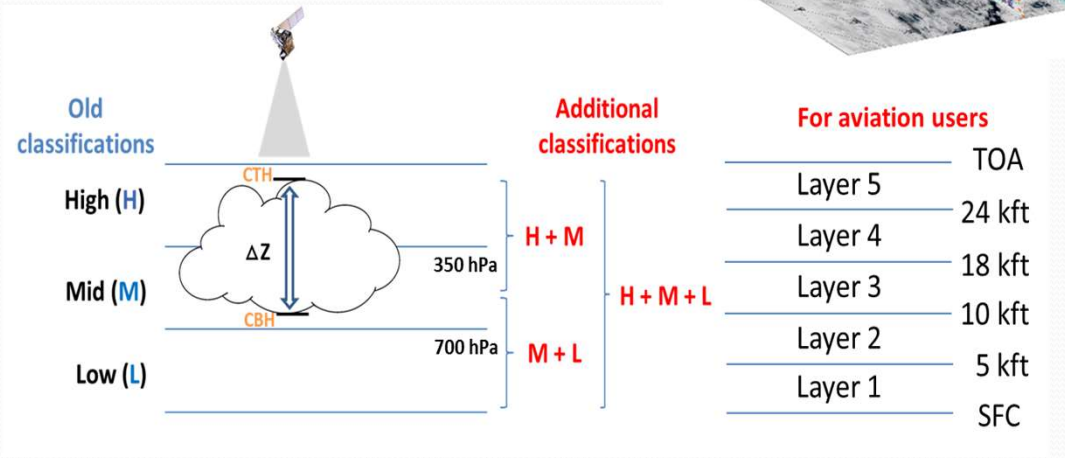
- Knowledge of 3D cloud structures is important for weather/climate studies
- Satellites have provided valuable cloud observations. But the information from conventional sensors (passive radiometers such as ABI and VIIRS) is often limited to 2D cloud top views
- Our goal is to extend the benefit of satellite cloud data into the vertical dimension for aviation users

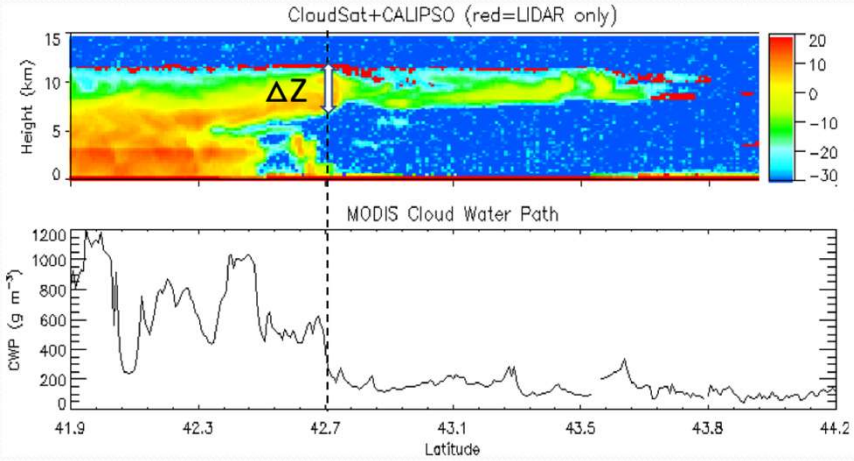
Satellite-Based Cloud Base/Layer Algorithms

- Operational part of the **NOAA Enterprise Cloud algorithms** (GOES ABI and JPSS VIIRS)

- CIRA developed a statistical cloud base height / cloud geometric thickness algorithm using NASA A-Train data
  (Noh et al.; Seaman et al. 2017)







$CBH = CTH - \Delta Z$ (CGT; Cloud Geometric Thickness)

where $\Delta Z = a(CWP)+b$ (a, b based on A-Train data)

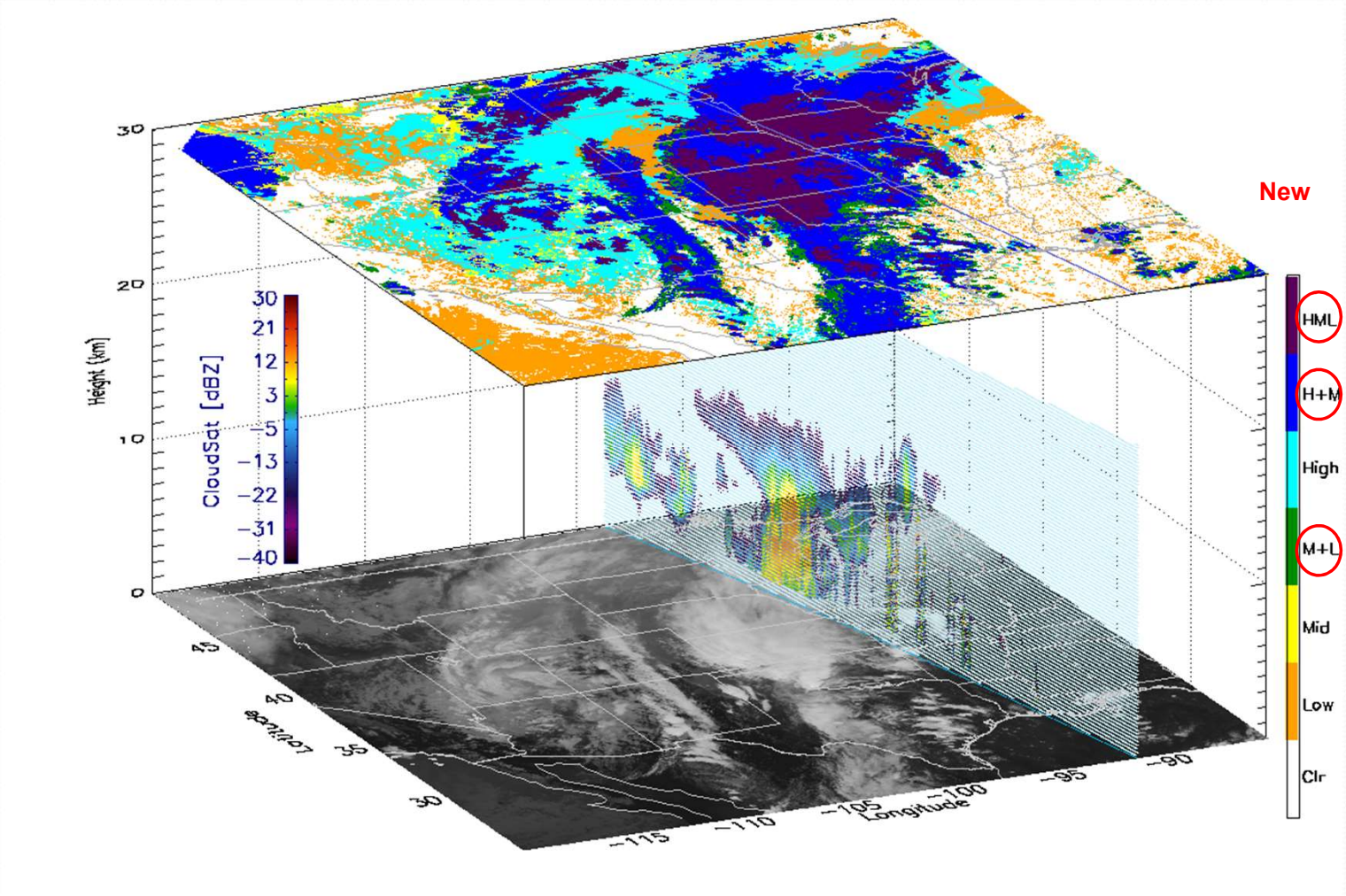
Optimal for single layers

+ supercooled liquid & convective cloud layer flags

Improvement of Cloud Cover Layers with Cloud Base

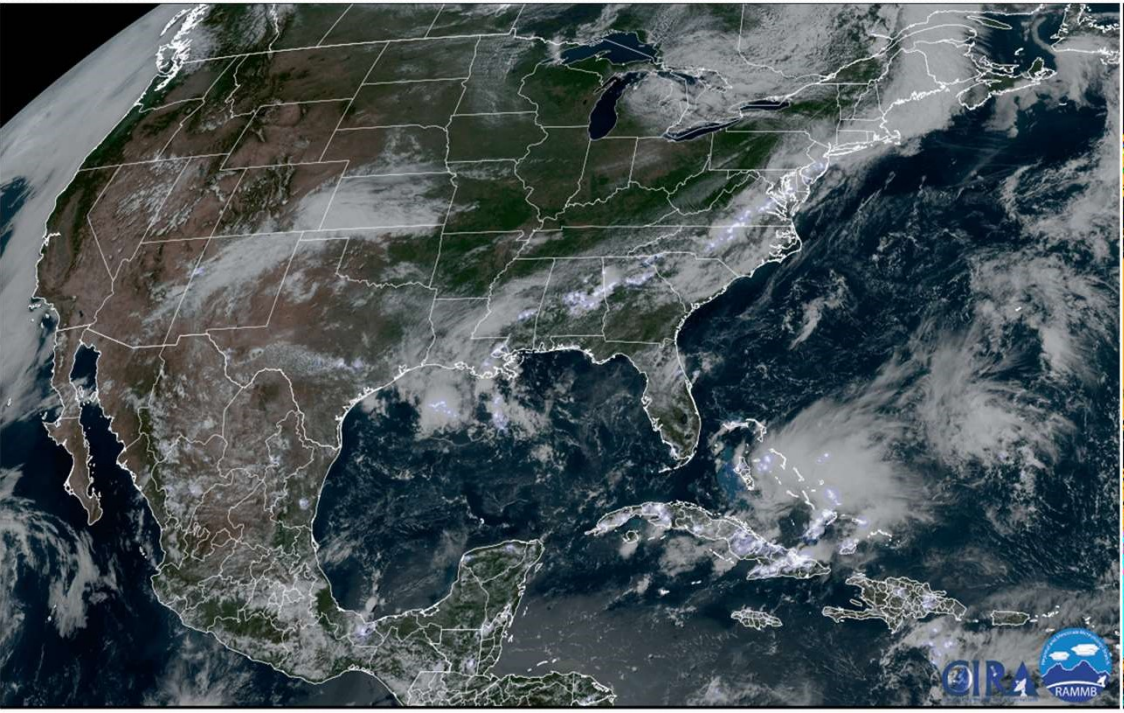
GOES-16 ABI

Applicable to both GEO and LEO



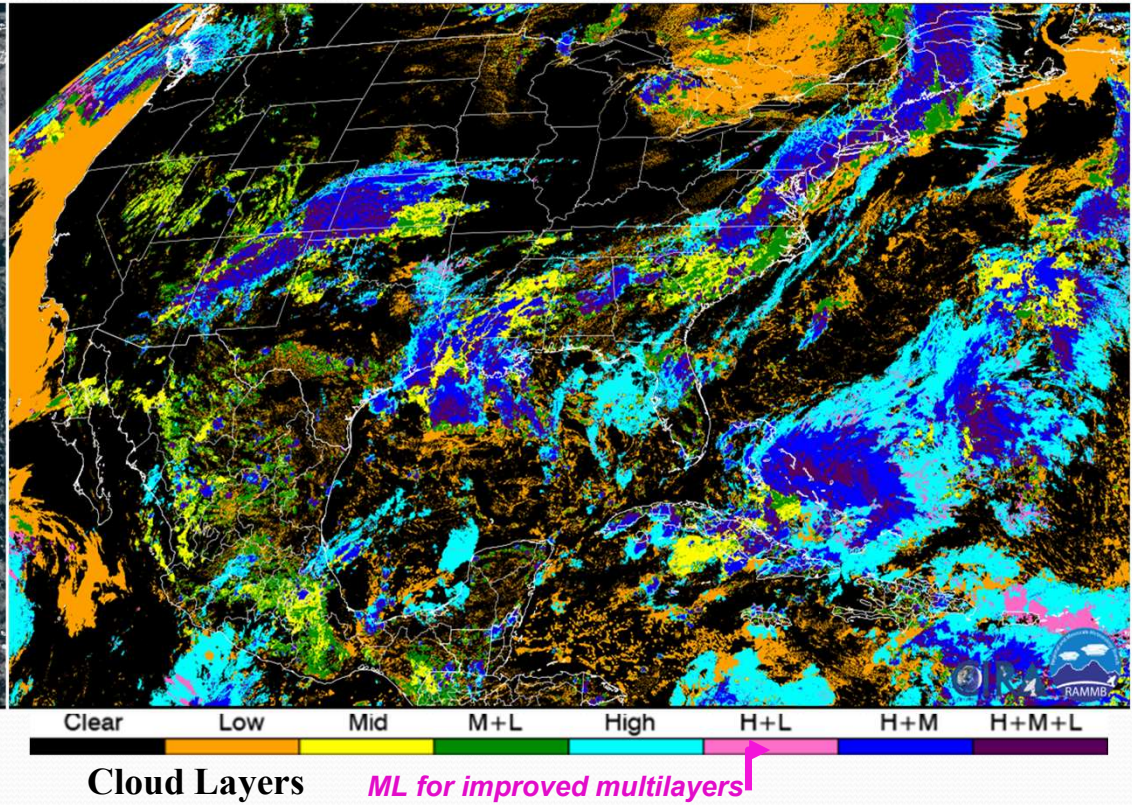
Improved Multilayer Clouds with ML/AI

- AI model trained with ABI data and NWP humidity using 'truth' from CloudSat radar and CALIPSO lidar
- Applicable to both polar and geostationary satellite sensors



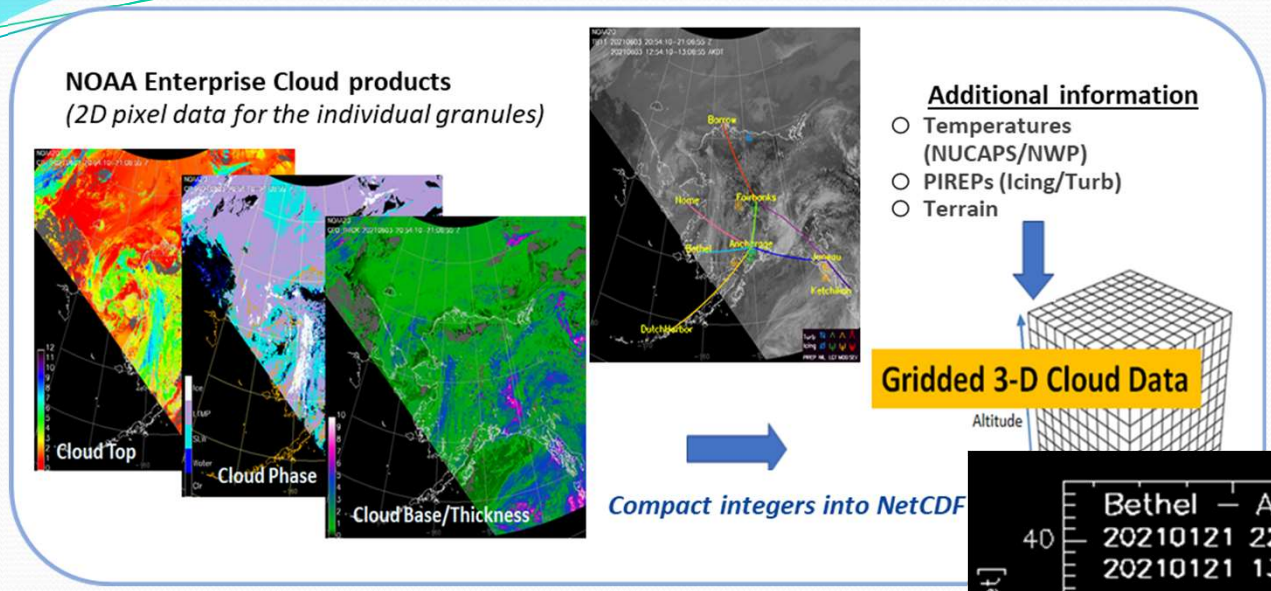
GOES-16 ABI GeoColor with GLM overlay (L2 group energy)
1851 – 1951 UTC (every 10 min) 27 June 2022

CIRA's SLIDER (http://rammb-slider.cira.colostate.edu)



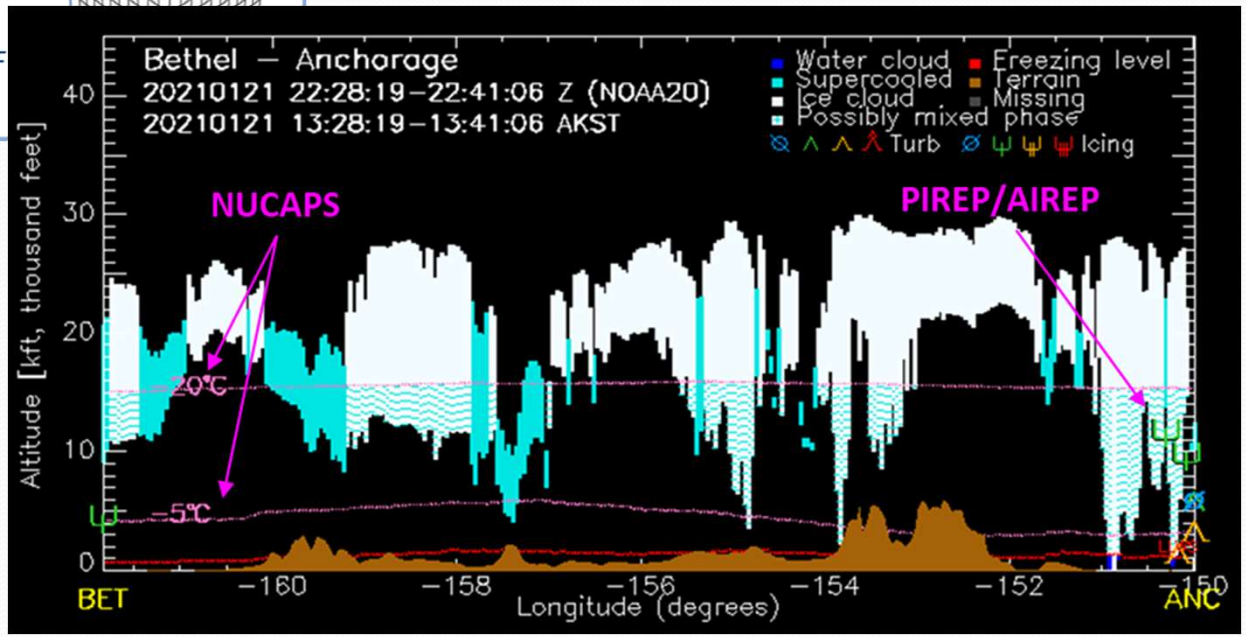
(Haynes et al. (2022 JTECH)

Gridded 3D Cloud Data for Aviation

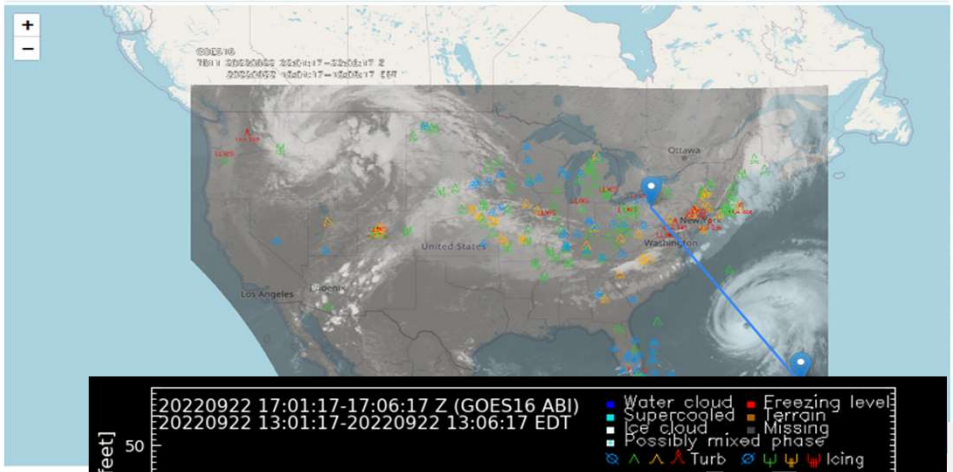


- 3D gridded cloud data using NOAA Enterprise satellite cloud products, leveraging CIRA's JPSS/GOES research

- A comprehensive package to extend the benefit of satellite data into the vertical dimension for users: ***Cloud Cross-sections***

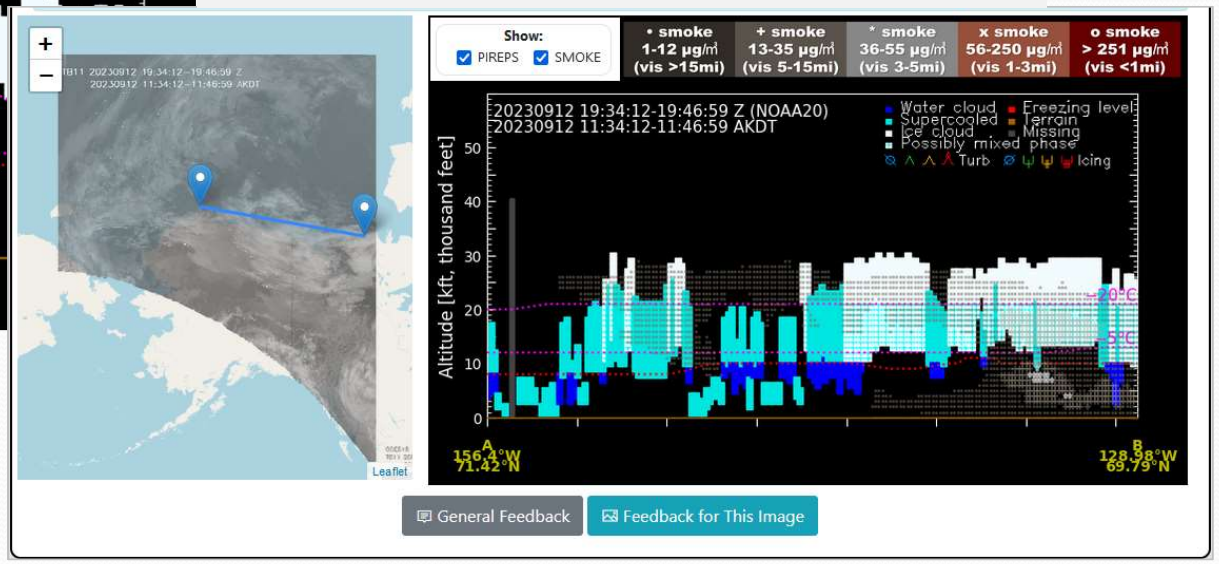


Gridded 3D Cloud Data for Aviation

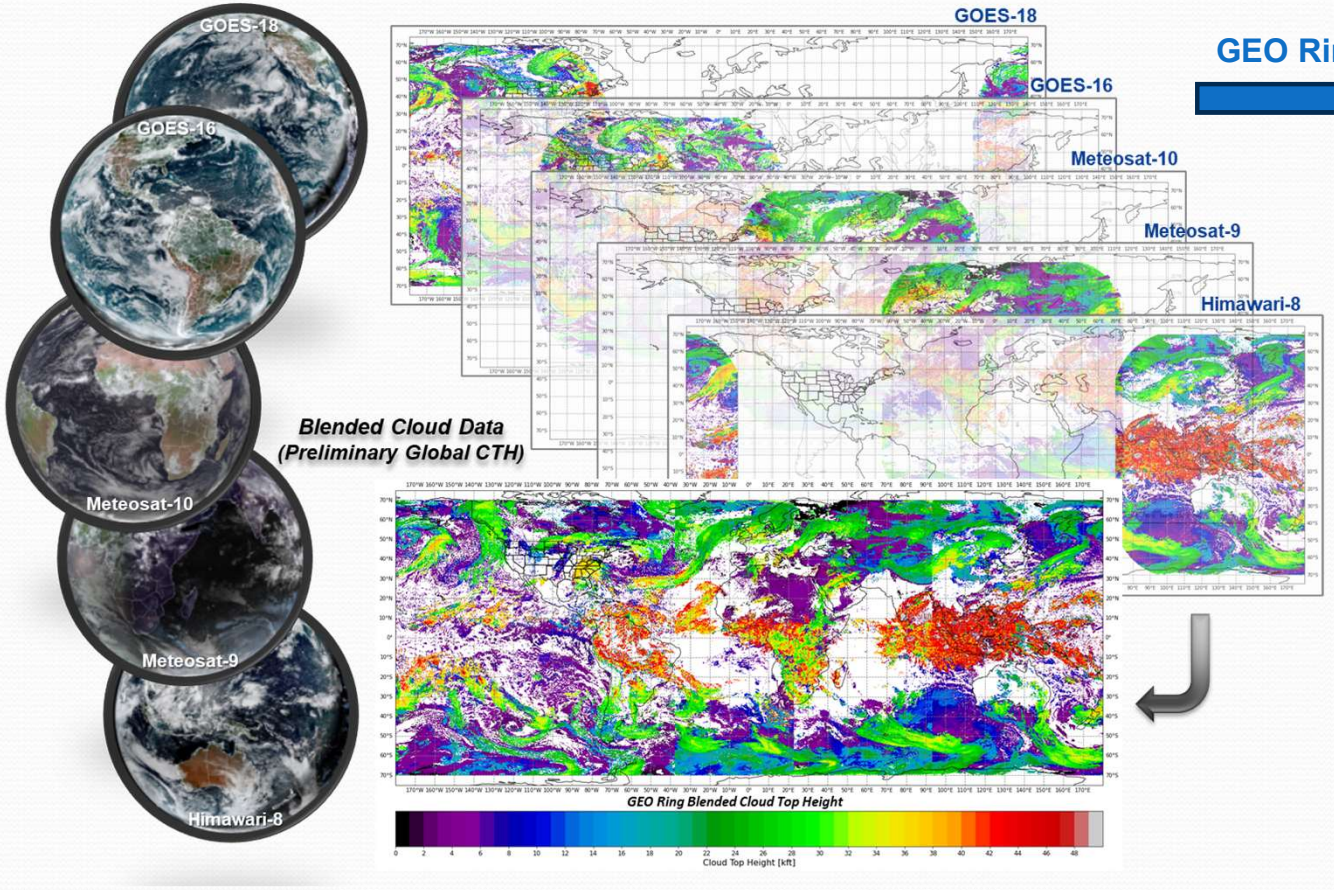


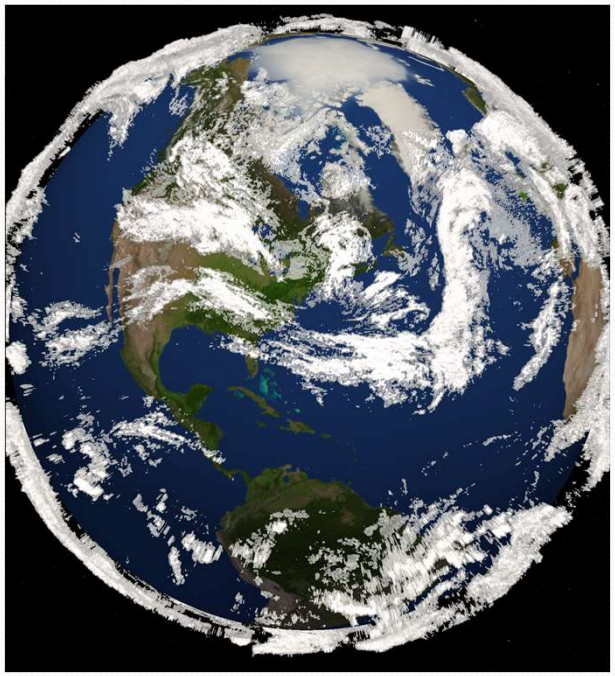
- *CIRA's aviation website for custom cloud cross-sections: https://aviation.cira.colostate.edu*
- Active user engagement in support of NOAA Aviation Initiative efforts
- Continue to improve the products based on user feedback
- smoke data addition – *HRRR model*

Updated with the smoke visibility information



Expansion Toward Global 3D Cloud Data





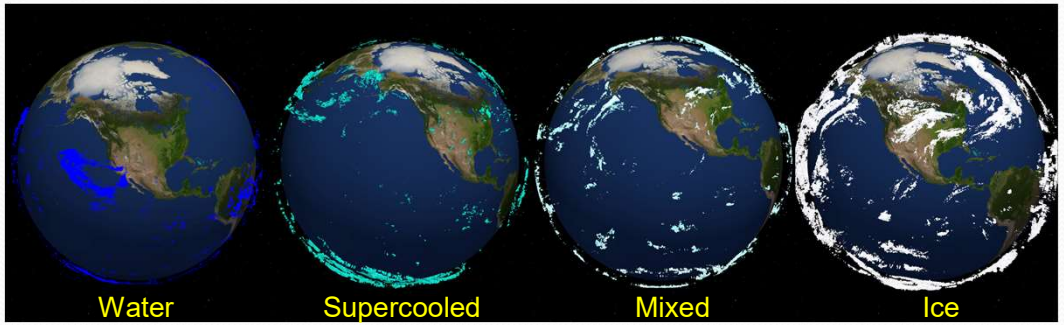
CIRA's OVERCAST:

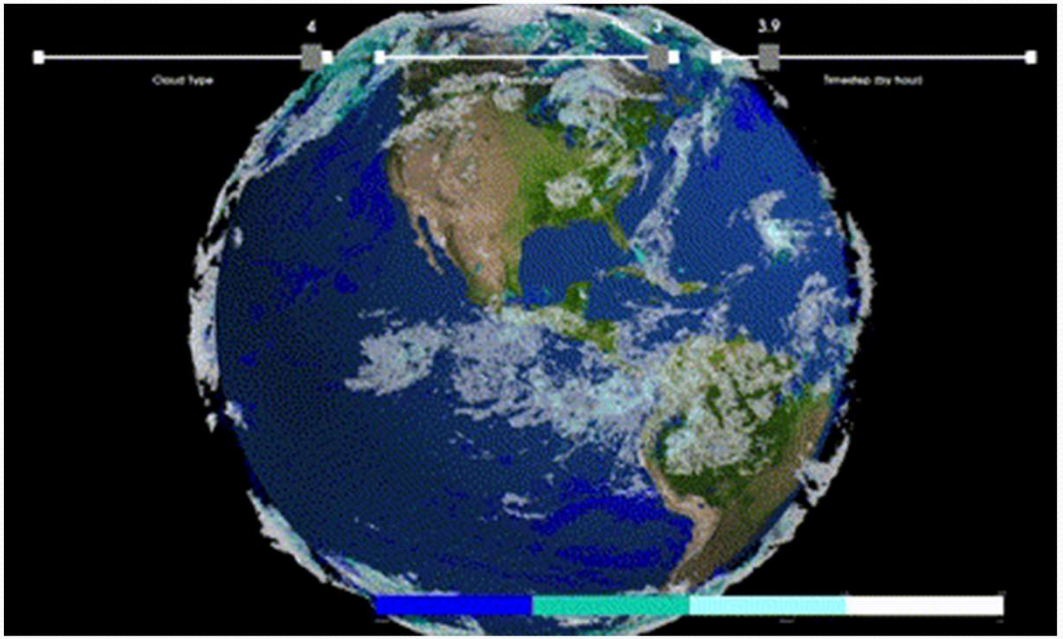
A Satellite-Based 3D Global Cloud Field Analysis + Time

Generate quantitative global, near real-time 3D satellite cloud analysis based on:	• Interfaces with NOAA Enterprise Cloud algorithms (CLAVR-x) • ***Cloud Geometric Thickness*** (developed using NASA A-Train data, operational at NOAA) • Combines physical retrievals and Machine Learning for advanced 3D-blended product Hidden layer estimation, Ice/Water profile estimation
A global cloud analysis rendered via:	• Geostationary + polar-orbiting satellite sensors (ABI, AHI, SEVIRI/FCI, VIIRS, AVHRR), blended at seams • Nowcasting to advent and evolve the 3D cloud field forward in time • Potentially expand to other cloud/environmental fields
Be mindful of the past, present, and future of global cloud data development activities in parallel:	• WWMCA (World Wide Merged Cloud Analysis) by Air Force Weather • ISCCP-NG (International Satellite Cloud Climatology Product—Next Generation)

Gridded 3D Cloud Data

- Our current, *experimental near real-time product* features
  - *GOES-16 & 18, Meteosat-9 & 10, and Himawari-9 (work in progress: MTG and GK-2A)*
  - 0.02 × 0.02° coverage from GEO-ring sensors, between 70° N/S latitude
  - 250 m vertical resolution
  - Produced hourly (target: 10-15 min)
- Cloud vertical extent mask, including cloud phase
- Polar orbiters and additional AI/ML products: coming soon





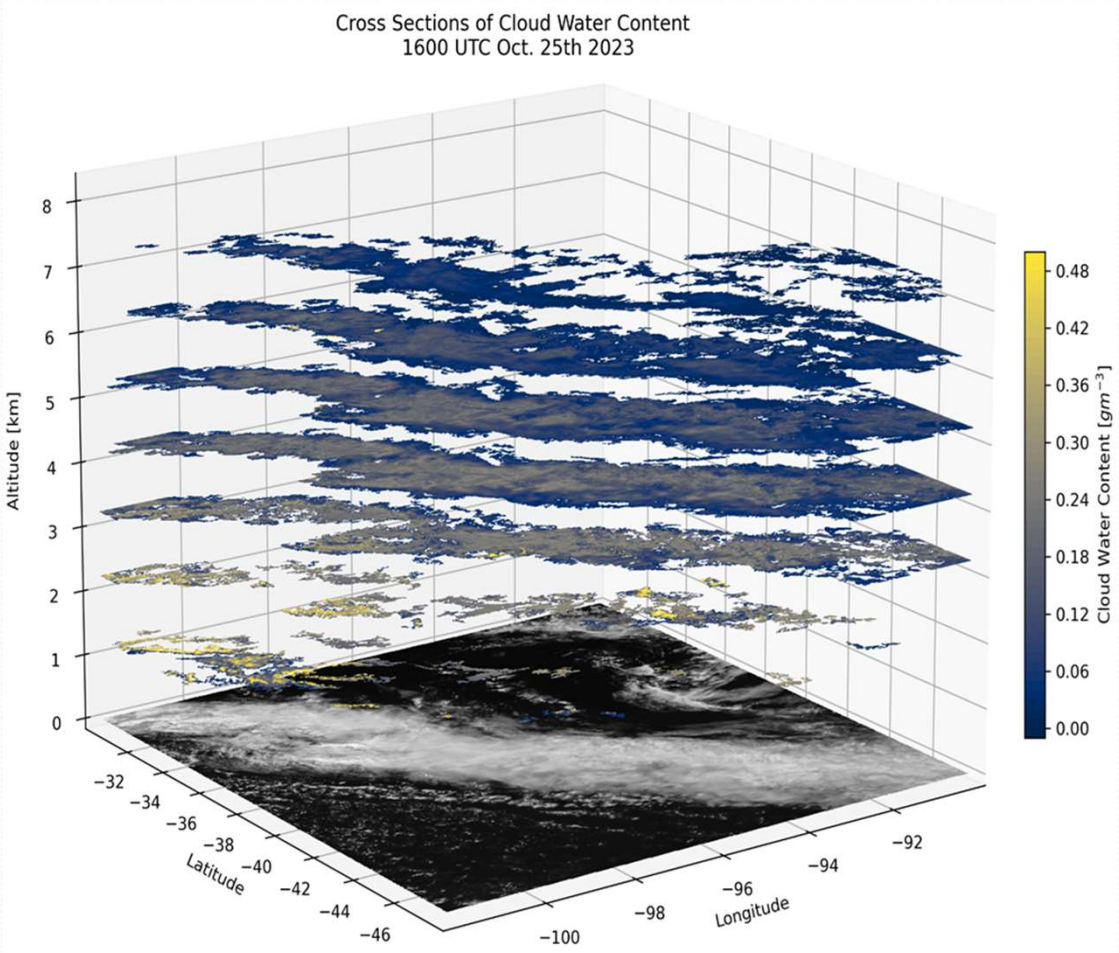
Credit: Evan Rose

AI-based Cloud Water Profile Estimation

- NASA CloudSat radar offers detailed **vertical profiles of cloud water content**
- Building a neural network to estimate the shape of the cloud water profile based on VIIRS/ABI observations matched with CloudSat

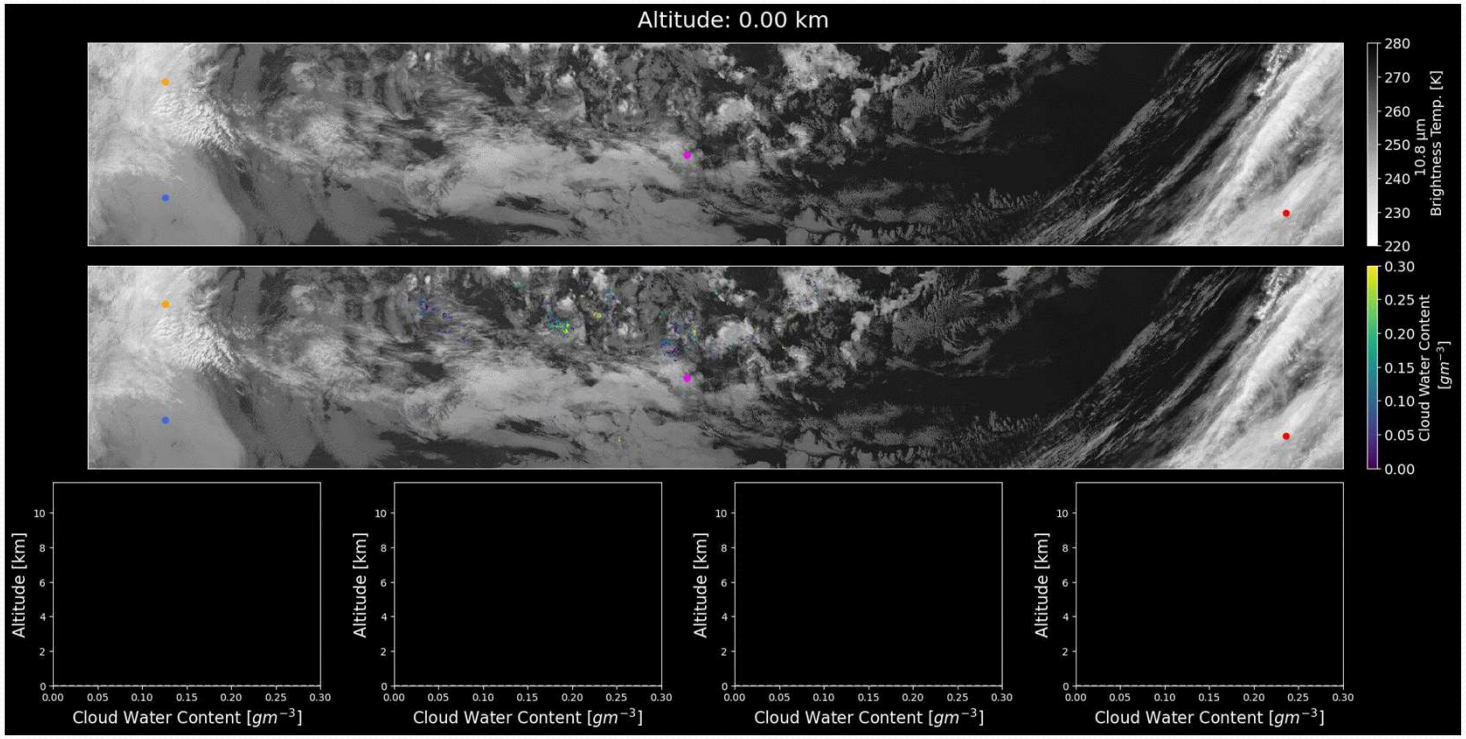
- ***To complete the 3D cloud structure information***
- ***Potentially to help improve cloud visibility information and aircraft icing potential detection***

(Chuck White et al.)



GOES-16 ABI cross sections of cloud water content displayed on top of 0.65 µm reflectance (25 October 2023)

AI-based Cloud Water Profile Estimation

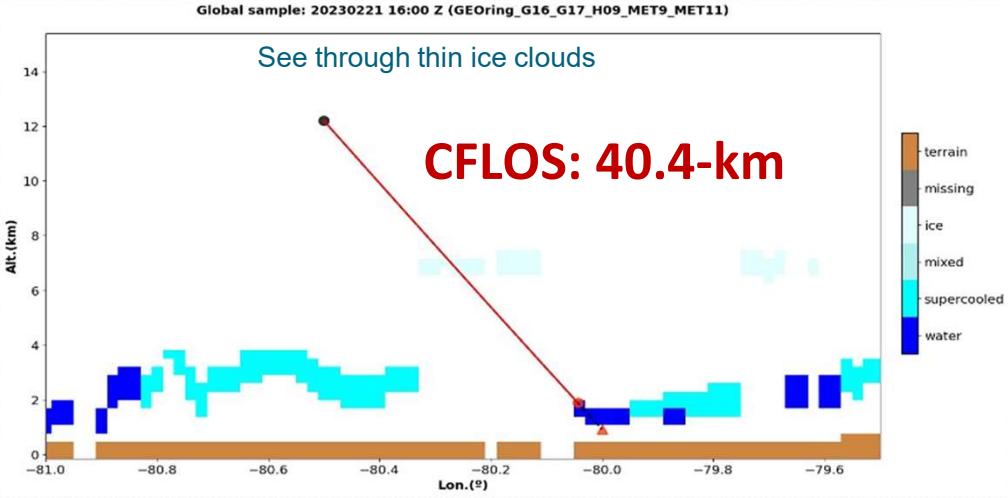


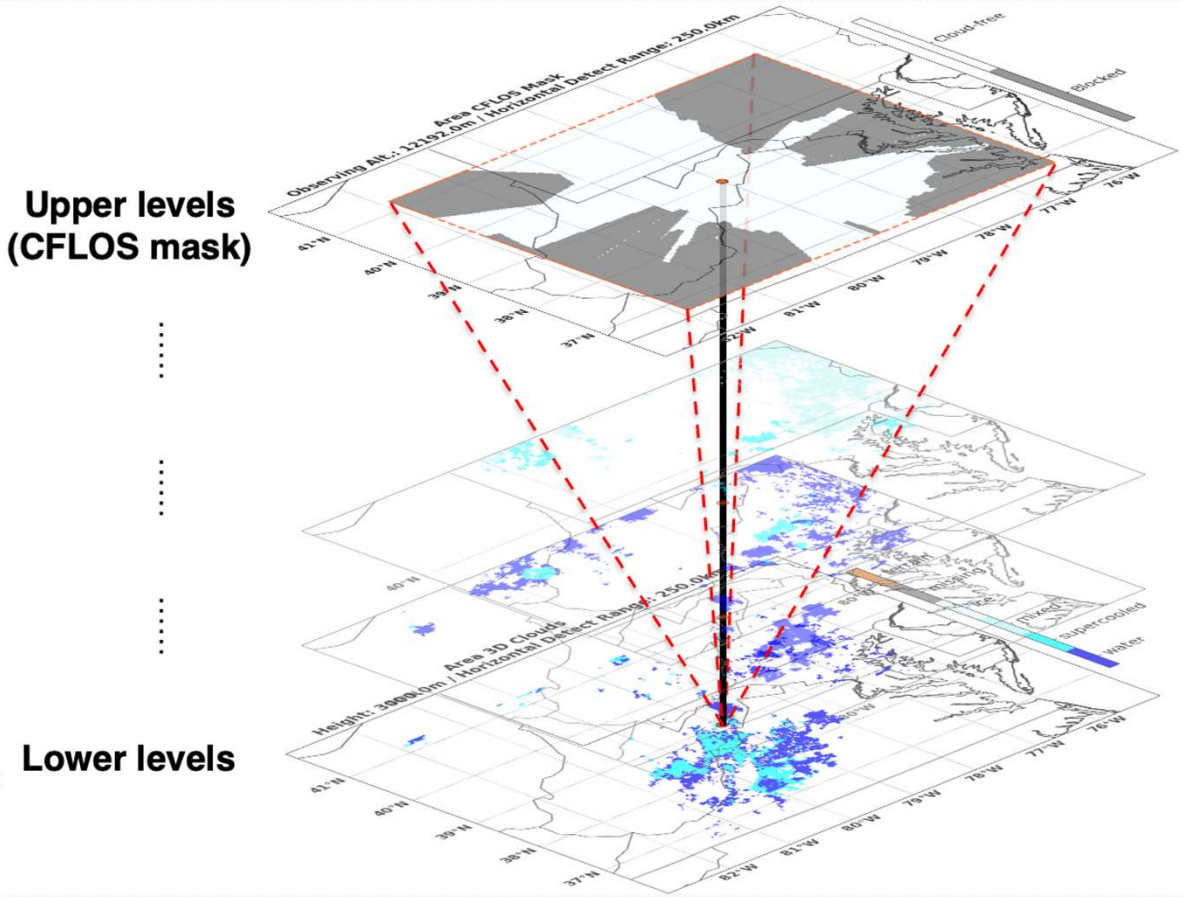
	Mean Profile	Cloud-Type LUT	CTH/CWP LUT	Neural Network
Earth Mover's Distance	0.74	0.69	0.70	0.60
Mean Absolute Error	0.046	0.043	0.044	0.039

Deterministic Cloud-Free Line of Sight (D-CFLOS)

(Hungjui Yu et al.)

- CFLOS is a tool to calculate the probability that a visible line-of-sight exists between an observer and a target potentially obstructed by clouds
- Help determine the safest altitude to fly while still maintaining a view of ground targets

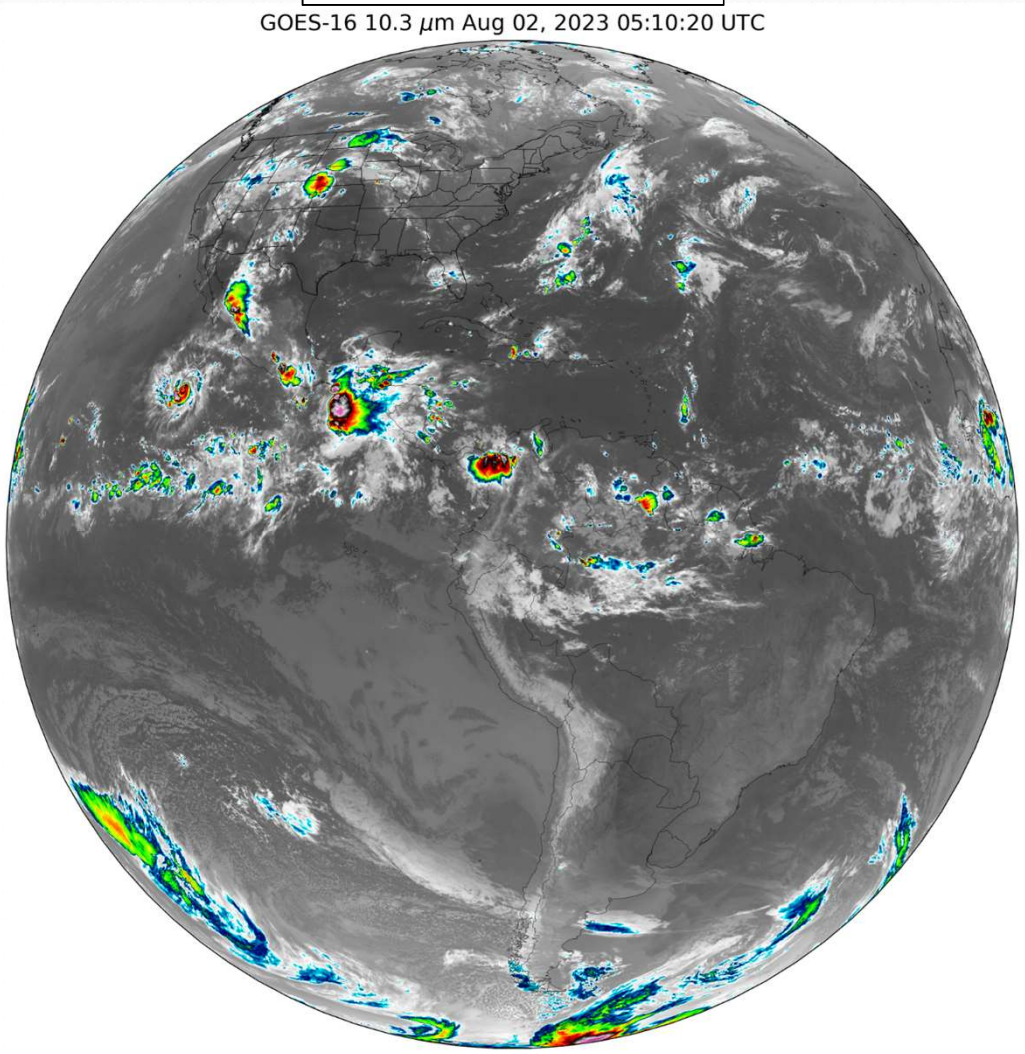




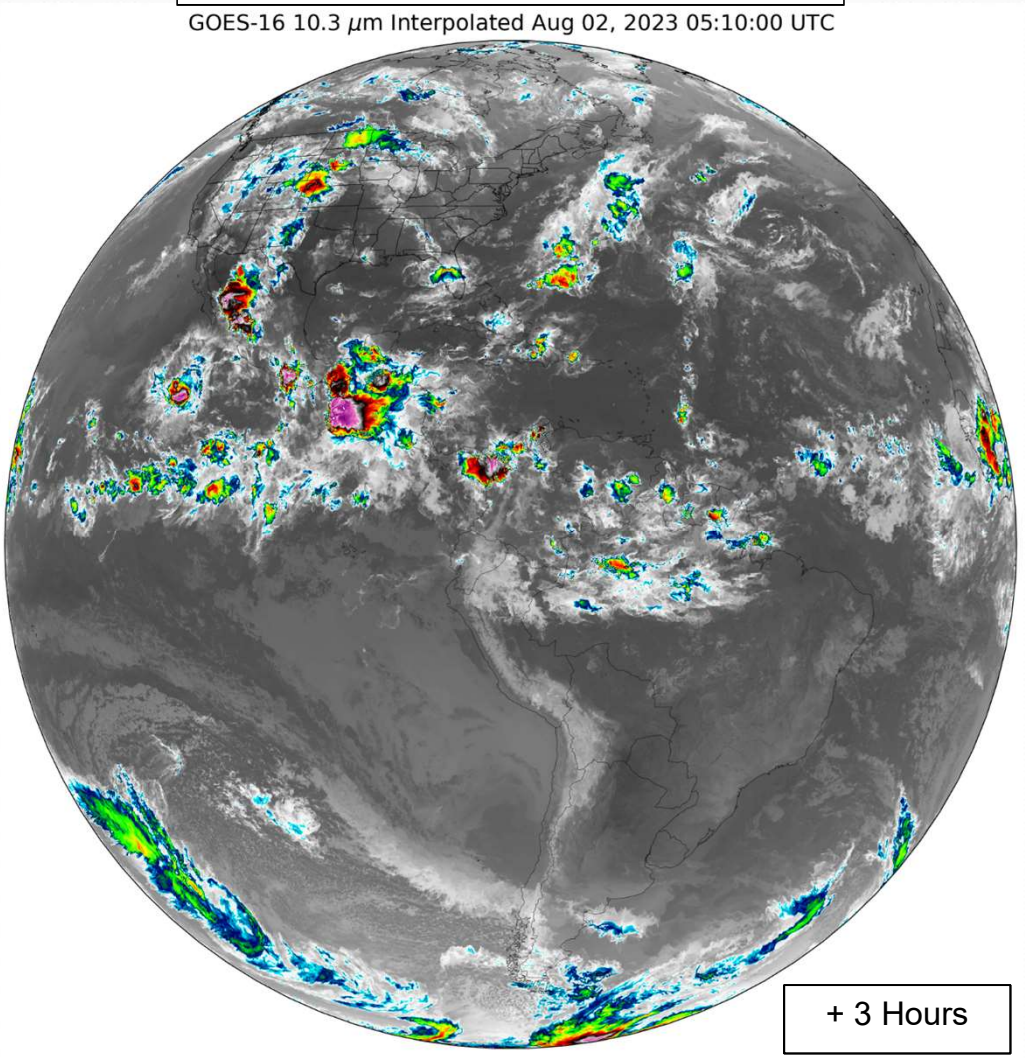
CFLOS describing *all regions* at an altitude (within an area) that can view a target on another level

Optical Flow – Nowcasting Example

Truth Imagery

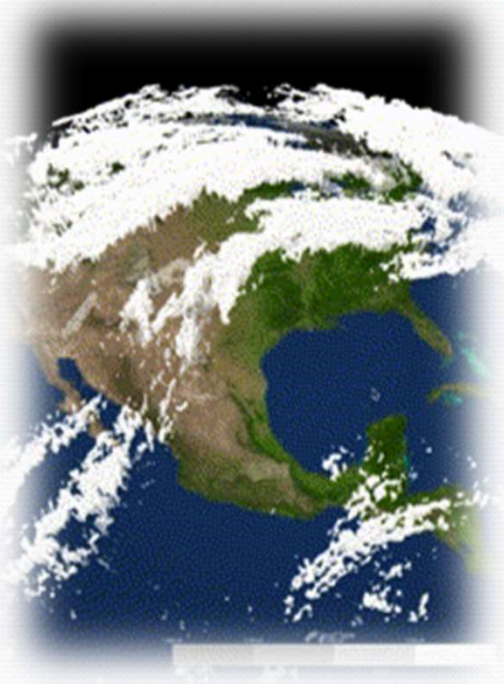


Optical Flow Nowcasted Imagery



+ 3 Hours

Summary



- Introduced Cloud Vertical Cross-section products to provide satellite-based 3D cloud information for aviation users, leveraging JPSS and GOES research
- CIRA's OVERCAST to provide a real-time, **global 3D cloud** analysis
  - A world-wide cloud analysis
  - Improve science algorithms and validation with applications related to visibility
  - A number of AI/ML-based advanced products, including refined multilayer clouds, vertical cloud water content profiles, global synthetic radar, proxy visible imagery, and synthetic passive microwave, and short-term advection to enable 4D applications

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