Development of Satellite-Based Global 3D Cloud Data and Aviation Applications

Yoo-Jeong Noh[1], John Haynes[1], Steven Miller[1]

with

Brandon Daub[1], Chris Camacho[2], Chuck White[1], Cindy Combs[1], Coda Phillips[3], Curtis Seaman[1], Evan Rose[1], Galina Chirokova[1], Hungjui Yu[1], Imme Ebert-Uphoff[1], Jason Apke[1], Jeremy Solbrig[1], Jesse Turner[1], John Forsythe[1], Katherine Haynes[1], Kyle Hilburn[1], Lander Ver Hoef[1], Leigh Cheatwood[1], Matt King[1], Mike Foster[3], Mindy Surratt[2], Natalie Tourville[1], Randy Chase[1], Renate Brummer[1], Robert Demaria[1], Ryan Lagerquist[1], Steve Wanzong[3], Yoonjin Lee[1]

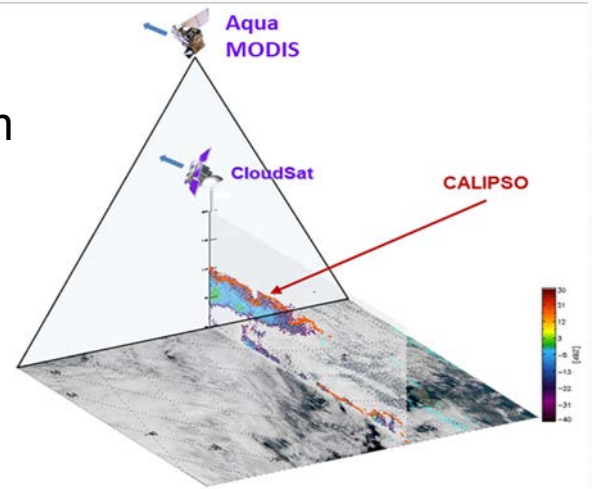
1 - Cooperative Institute for Research in the Atmosphere (CIRA)
2 - Naval Research Lab (NRL)
3 - University of Wisconsin-Madison (UW)

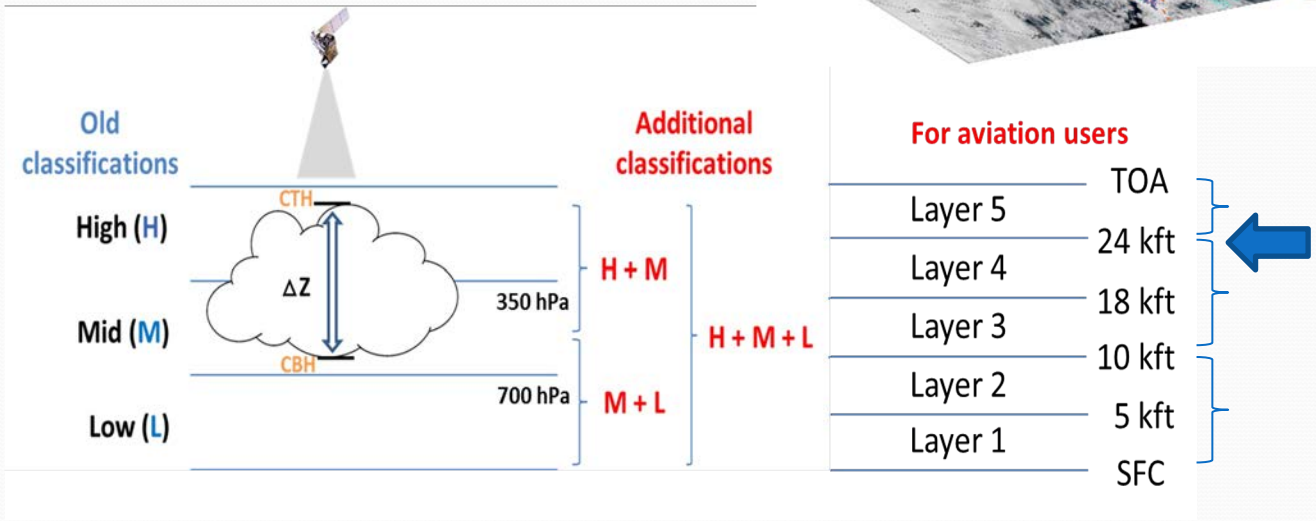
yjnoh@colostate.edu

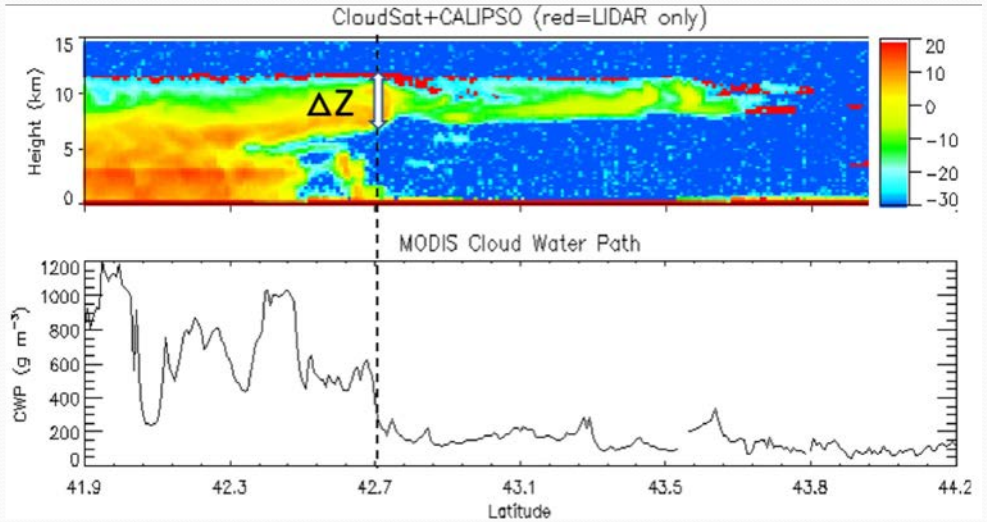
Satellite-Based Cloud Base/Layer Algorithms

- 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

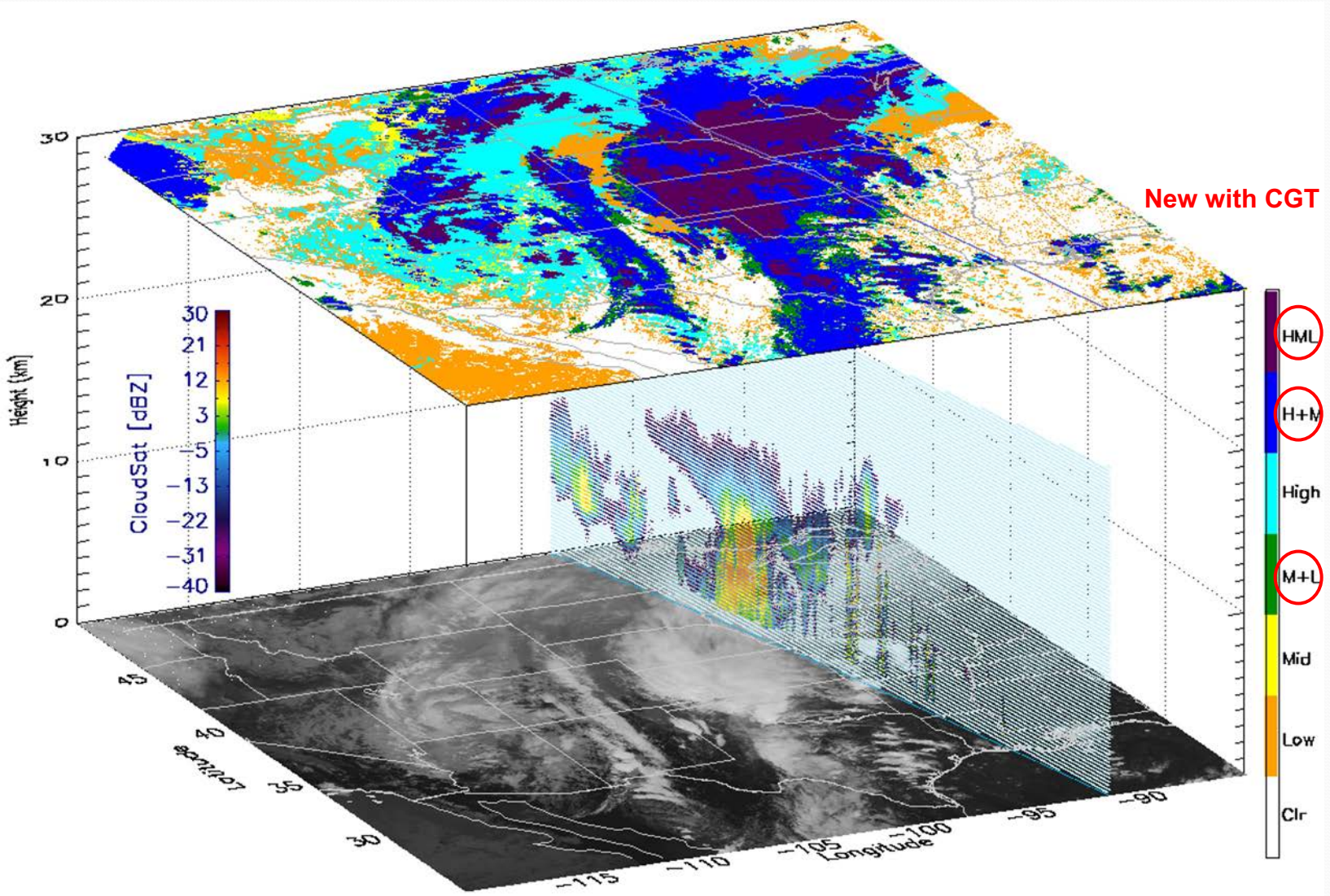
+ supercooled liquid & convective cloud layer flags

Improvement of Cloud Cover Layers with Cloud Base

Connecting Models and Observations

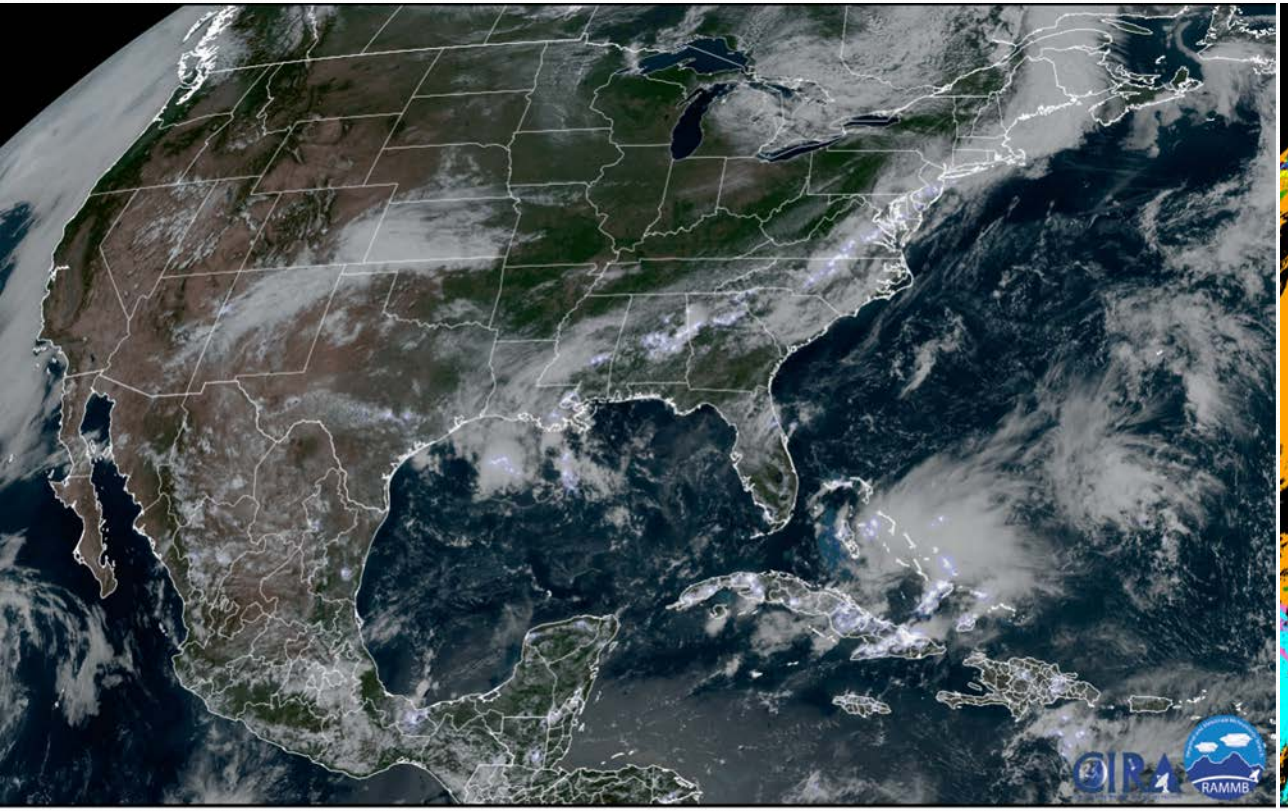
Applicable to both GEO and LEO

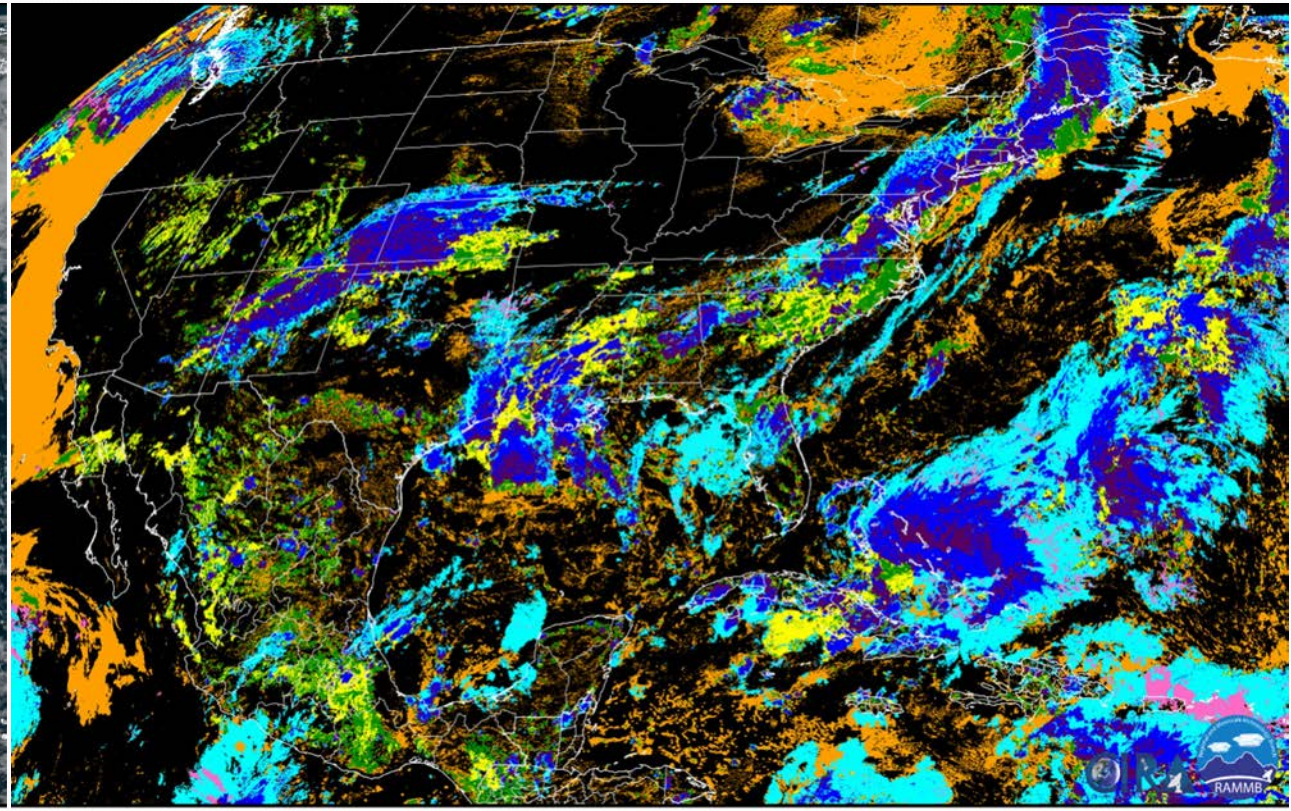
GOES-16 ABI



Improved Multilayer Cloud Detection 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



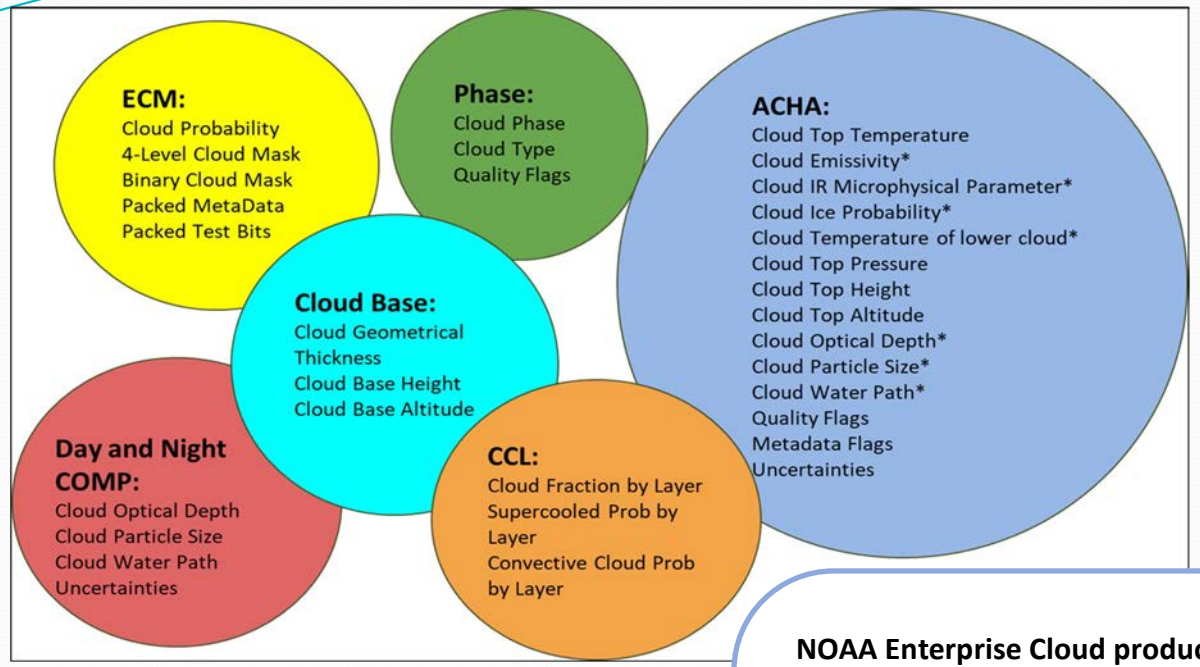


GOES-16 ABI GeoColor with GLM overlay (L2 group energy)
1851 – 1951 UTC (every 10 min) 27 June 2022

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

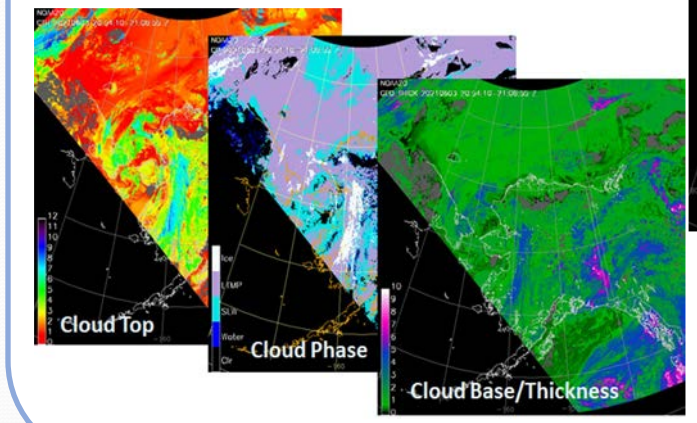
(Haynes et al. (2022 JTECH)

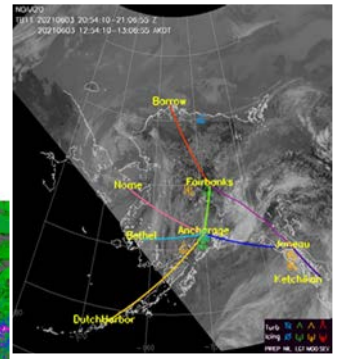
Gridded 3D Cloud Data for Aviation



- 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 aviation users -> ***Custom Cloud Cross-sections***

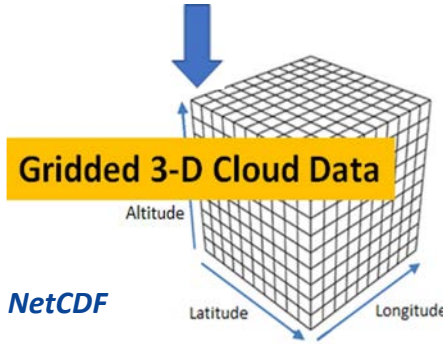
NOAA Enterprise Cloud products
(2D pixel data for the individual granules)





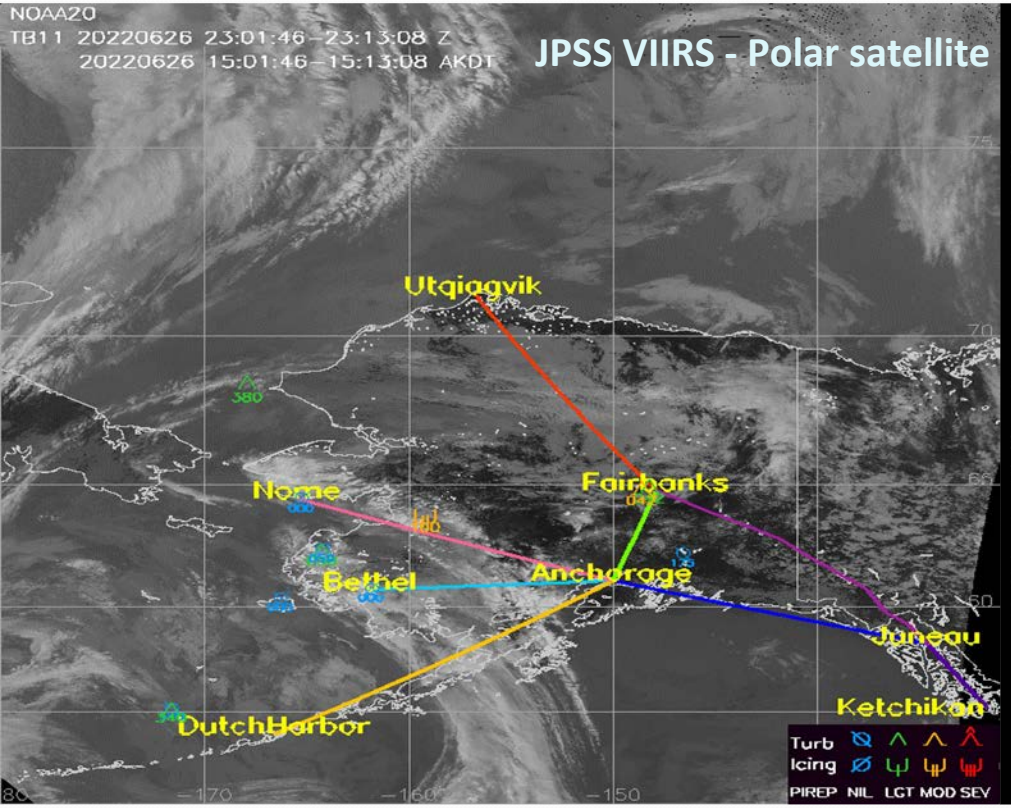
Additional information
- Temperatures (NUCAPS/NWP)
- PIREPs (Icing/Turb)
- Terrain

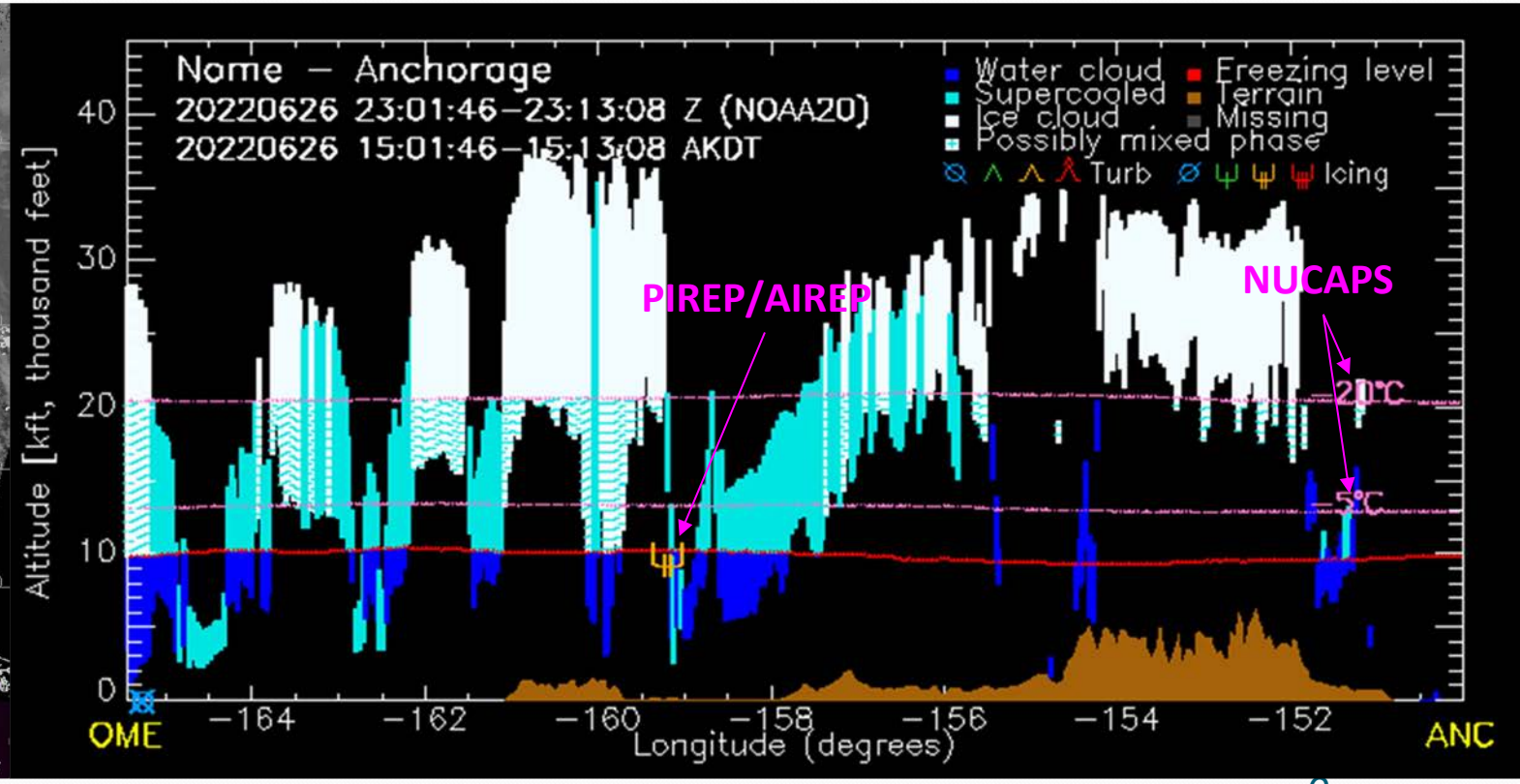
Compact integers into NetCDF



Cloud Vertical Cross-sections

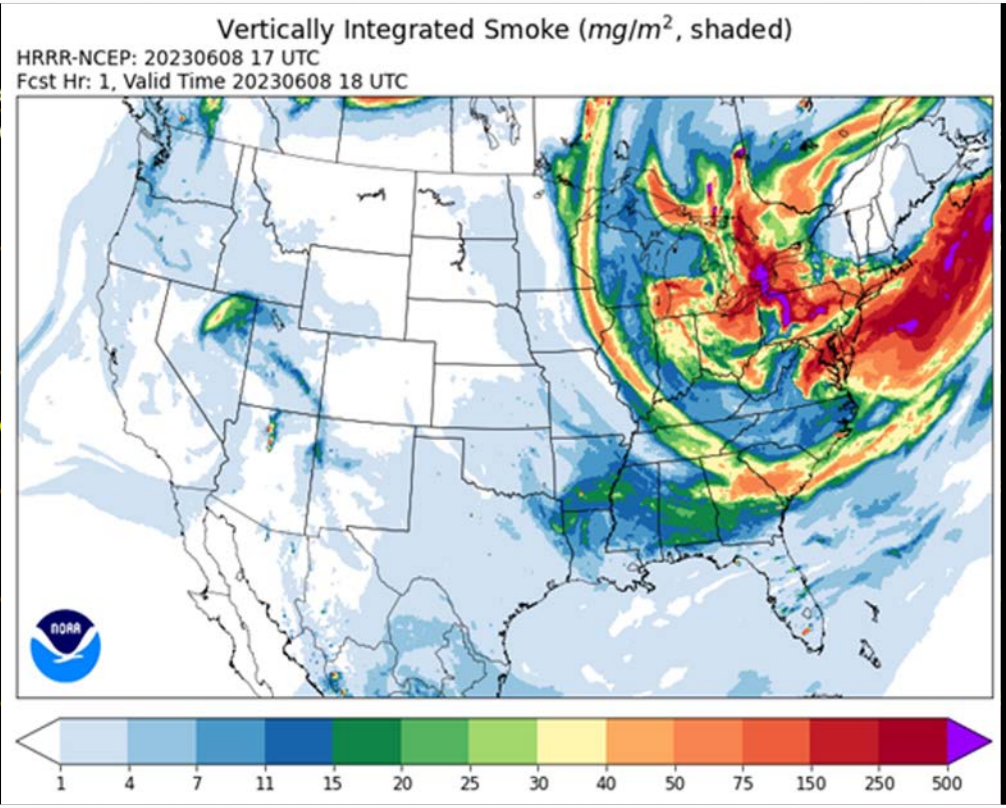
- **Experimental satellite cloud products for aviation users**
  - A comprehensive package to extend the benefit of satellite data into the vertical dimension
  - Cloud Vertical Cross-sections along selected flight routes from NOAA Enterprise Cloud Products, temperature (NWP/NUCAPS), terrain, PIREPs (icing/turbulence)
  - Ongoing improvements based on user feedback through NOAA JPSS Aviation Initiative

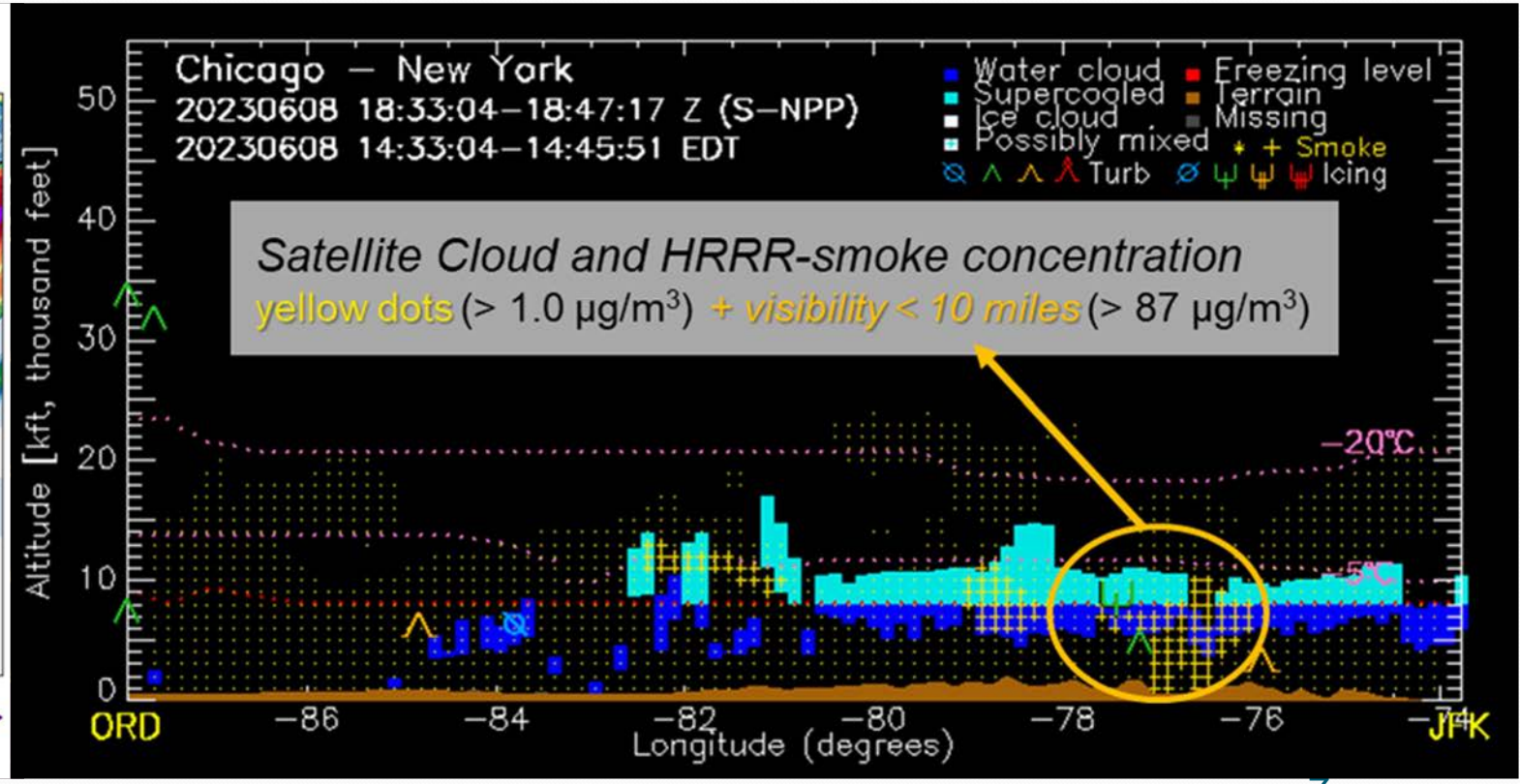




Cloud Vertical Cross-sections

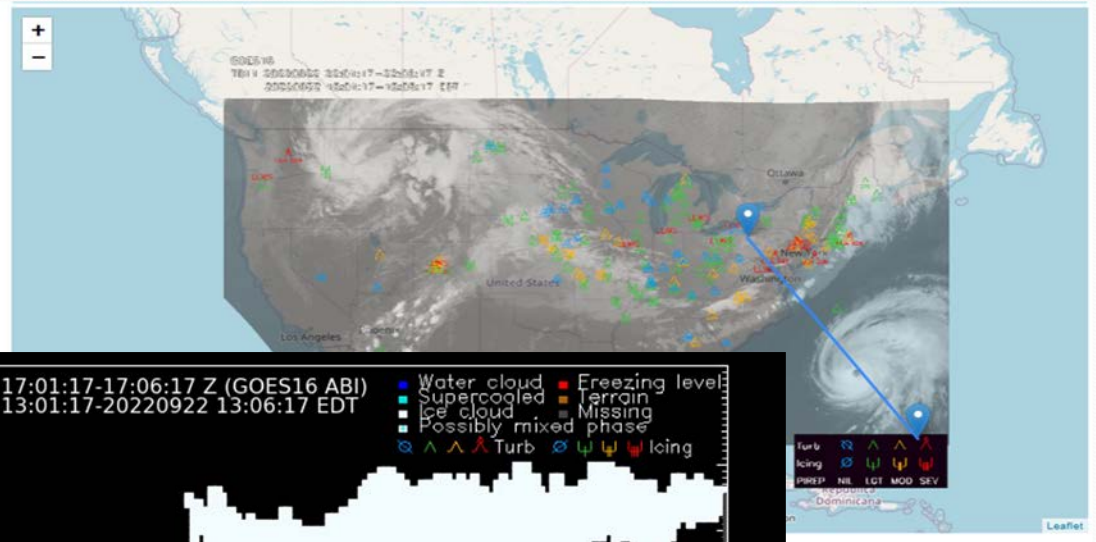
- **Experimental satellite cloud products for aviation users**
  - A comprehensive package to extend the benefit of satellite data into the vertical dimension
  - Cloud Vertical Cross-sections along selected flight routes from NOAA Enterprise Cloud Products, temperature (NWP/NUCAPS), terrain, PIREPs (icing/turbulence)
  - Add HRRR-smoke data for better visibility information

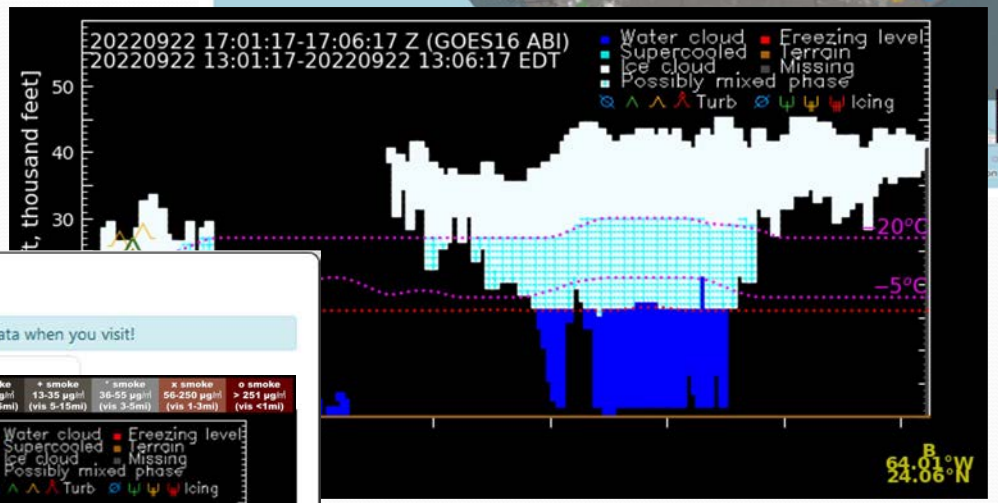


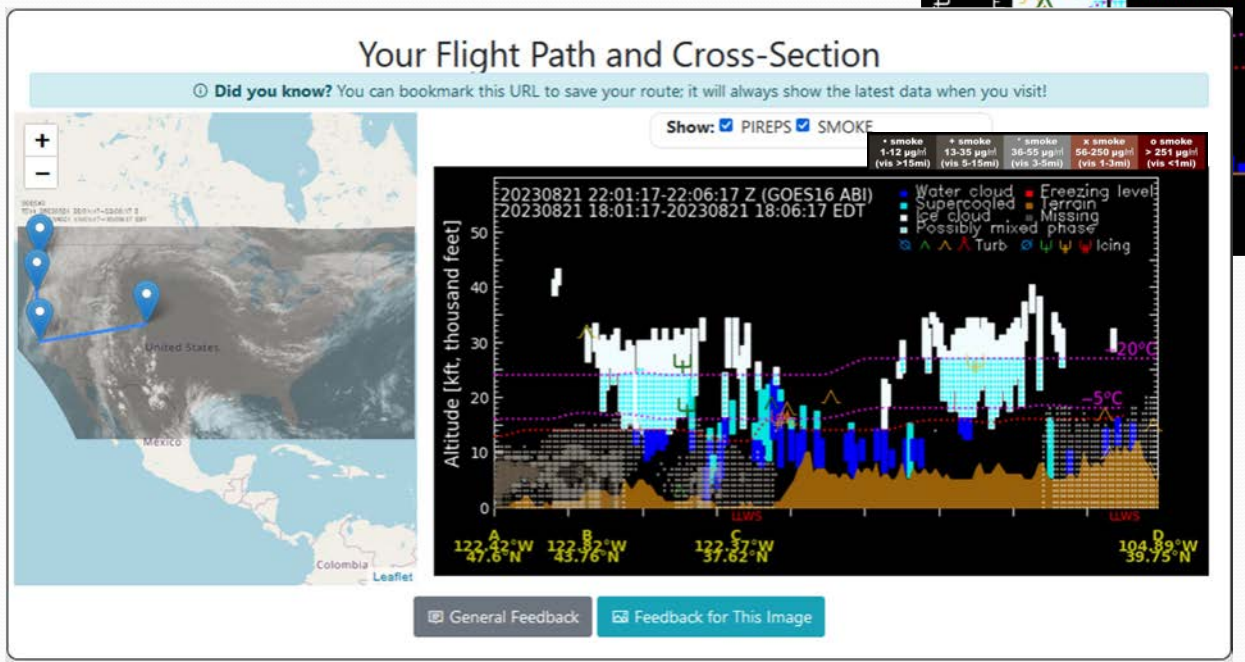


Gridded 3D Cloud Data for Aviation

- *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
- HRRR-smoke data – *new addition*







User Engagement

- Regular interactions with pilots and operational users for feedback (NOAA Aviation Initiative)
- Partner with **AWC** forecasters for product eval
- Featured in Aircraft Owners & Pilots Association ePilot newsletter and weekly program, as well as the annual survey, receiving favorable marks
- **Data support for NTSB accident case investigation**

NOAA-20 VIIRS IR image and cloud vertical cross-sections provided to NTSB for an aircraft accident case investigation. A small air taxi (Cessna 208B Grand Caravan) declared an emergency due to flight control issues (2251 UTC 16 Aug 2021 near Fairbanks, AK) →

remote sensing

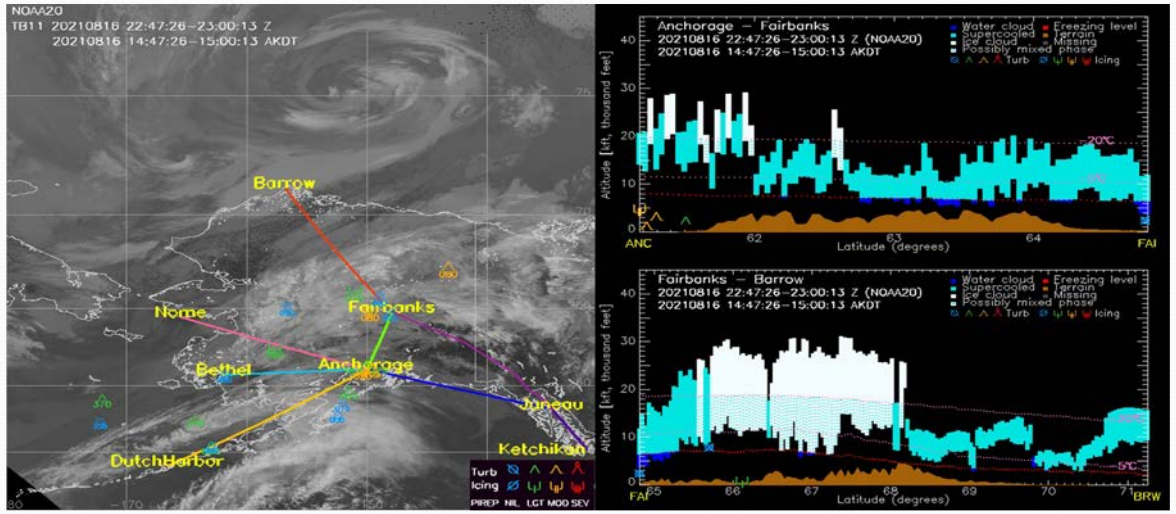
Noh et al. 2022, Remote Sens. 14, 5524. Special Issue "VIIRS 2011–2021: Ten Years of Success in Earth Observations",
https://doi.org/10.3390/rs14215524

Article

A Framework for Satellite-Based 3D Cloud Data: An Overview of the VIIRS Cloud Base Height Retrieval and User Engagement for Aviation Applications

Yoo-Jeong Noh [1,*], John M. Haynes [1], Steven D. Miller [1], Curtis J. Seaman [1], Andrew K. Heidinger [2], Jeffrey Weinrich [3], Mark S. Kulie [2], Mattie Niznik [1] and Brandon J. Daub [1]

Acknowledgments: The authors would like to thank collaborators and Alaska aviation users: William Straka, Yue Li, Steve Wanzong (all from Cooperative Institute for Meteorological Satellite Studies; CIMSS), Tom George (Aircraft Owners and Pilots Association), Adam White (Alaska Airmen's Association), Becca Mazur (NOAA Arctic Testbed), Carl Dierking, Jay Cable, Jen Delamere (all from Cooperative Institute for Climate, Ocean, and Ecosystem Studies; CICOES, formerly University of Alaska Fairbanks/Geographic Information Network of Alaska; GINA), Amanda Terborg, Ty Higginbotham (both from NOAA Aviation Weather Center/Aviation Weather Testbed), Nadia Smith, Rebekah Esmaili, Amy Leibrand (all from Science and Technology Corporation /NOAA), Jenny Colavito (Federal Aviation Administration), Paul Suffern (National Transportation Safety Board; NTSB), and Jeremy Goldstein (Global Science and Technology, Inc.).



OVERCAST:

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

Generate quantitative global, near real-time 3D satellite cloud analysis based on:

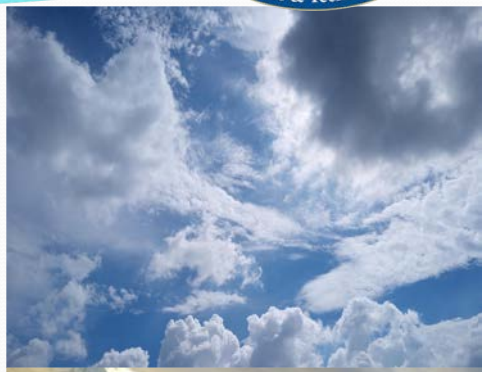
- Interfaces with NOAA Enterprise Cloud algorithms (CLAVR-x)
- ***Cloud Geometric Thickness*** (developed using NASA A-Train data, operational at NOAA)
- Combines physical retrievals and Machine Learning for advanced 3D-blended product Hidden layer estimation, Ice/Water profile estimation

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

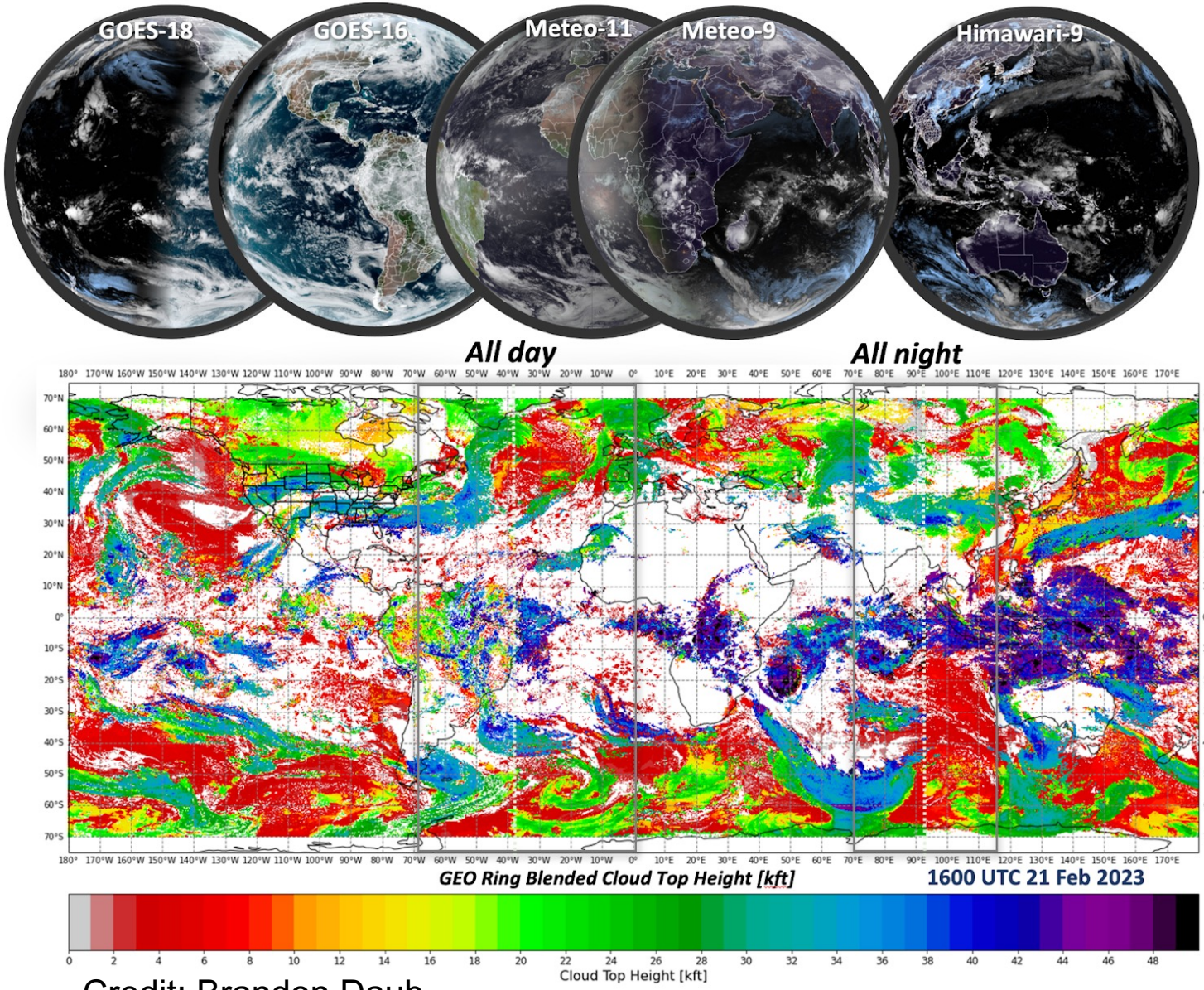
Be mindful of the past, present, and future of global cloud data development activities in parallel:

- WWMCA (World Wide Merged Cloud Analysis) by Air Force Weather
- ISCCP-NG (International Satellite Cloud Climatology Product—Next Generation)



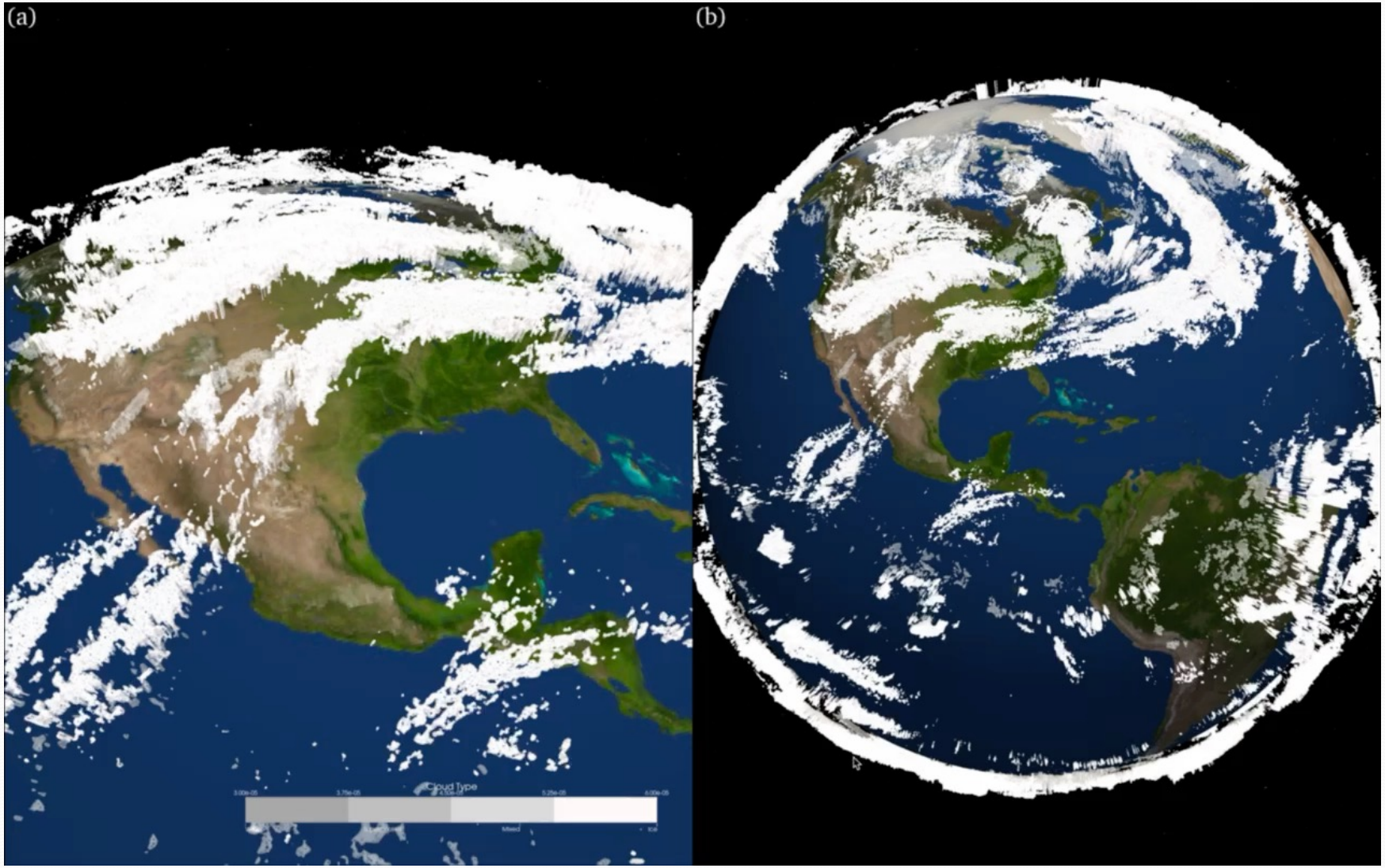
Gridded 3D Cloud Data

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



Credit: Brandon Daub

First look: 3D Cloud Product Visualization

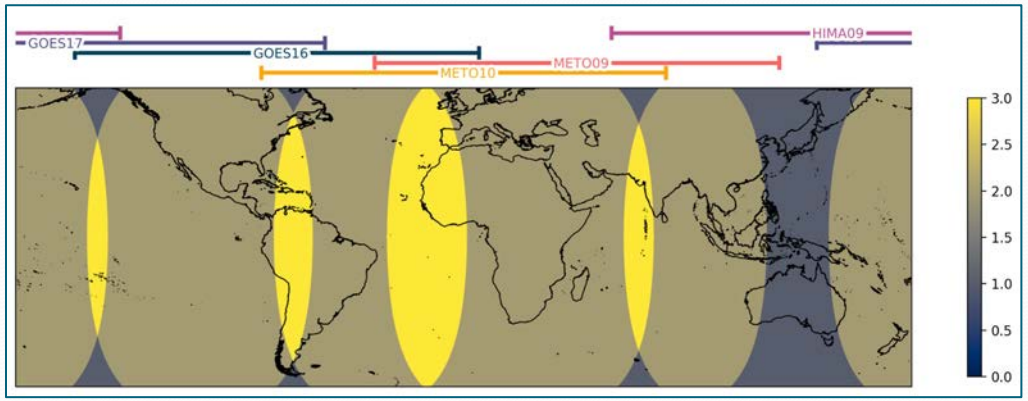


Credit: Evan Rose

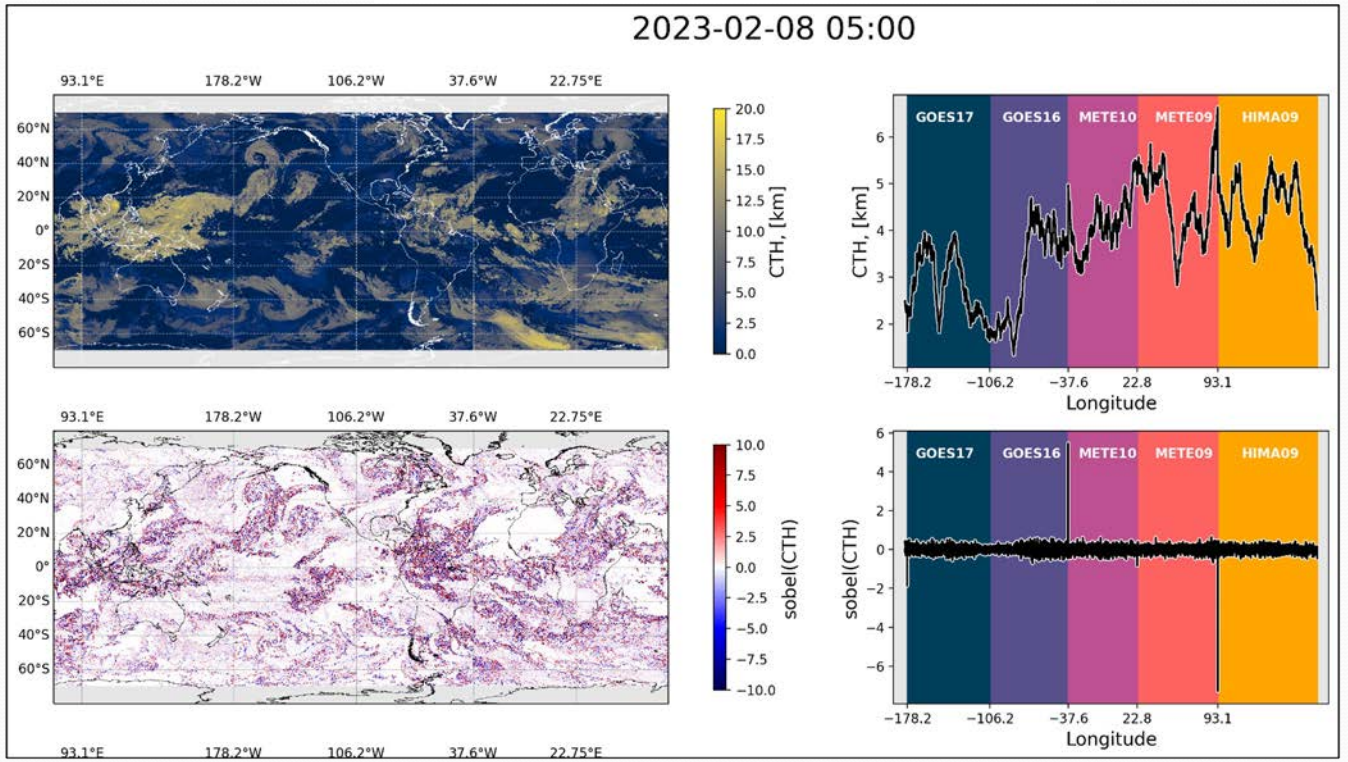
Seamless Blending: Towards a Solution

- Temporal blending
  - Addressed with Optical Flow (*led by Jason Apke*)
  - Allows us to largely remove time-driven discontinuities between two sensors

- Spatial blending
  - Current product uses the “level 0” approach – nearest neighbor
  - More sophisticated techniques are a current area of research



Evaluation Dashboard



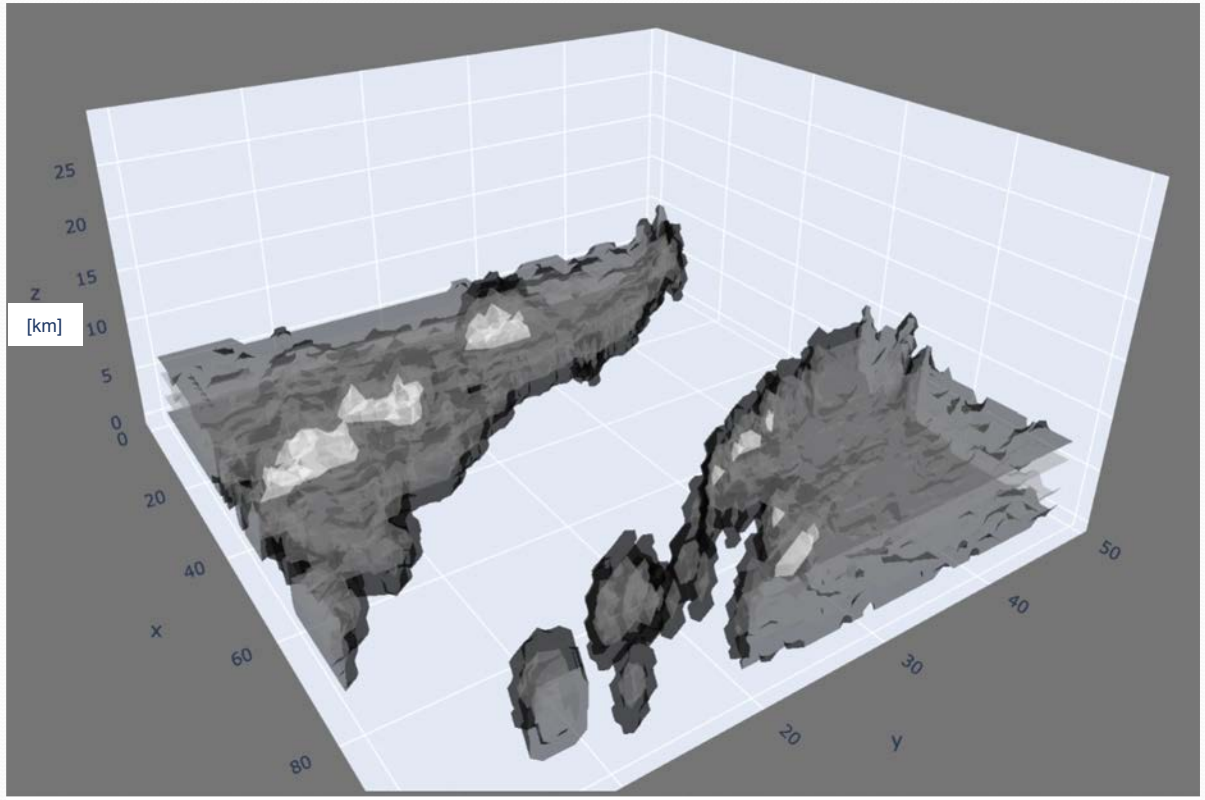
Credit: Randy Chase

AI-based Cloud Water Profile Estimation

- NASA CloudSat radar (CPR) 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***

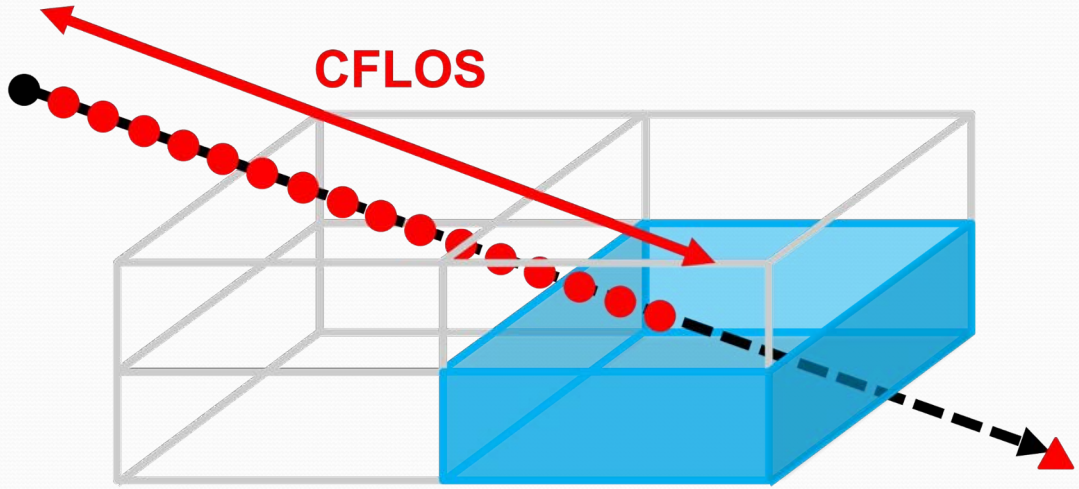
(Chuck White et al.)

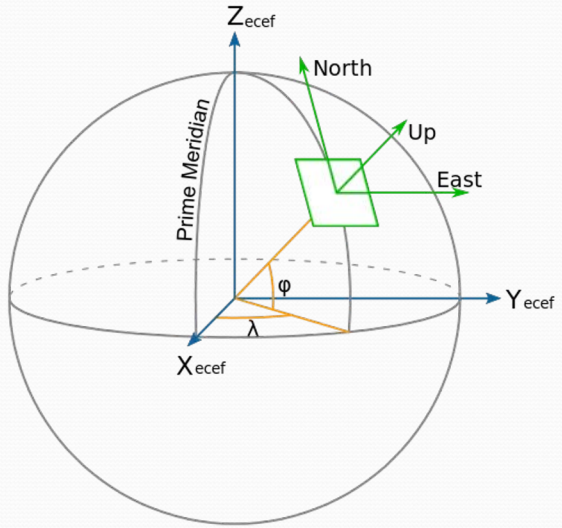


- Darker regions mean less cloud water content (g/m3) and whiter regions mean more cloud water content
- Test domain: 90 km x-axis and 45 km y-axis (z axis=altitude in km)
- Cloud top/base height from a neural network, cloud water from the CLDPROP cloud properties, and preliminary normalized profiles estimated by a neural network

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

- Cloud-Free-Line-of-Sight (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
- Develop CFLOS codes to the line-of-sight consisting of points with a specified interval



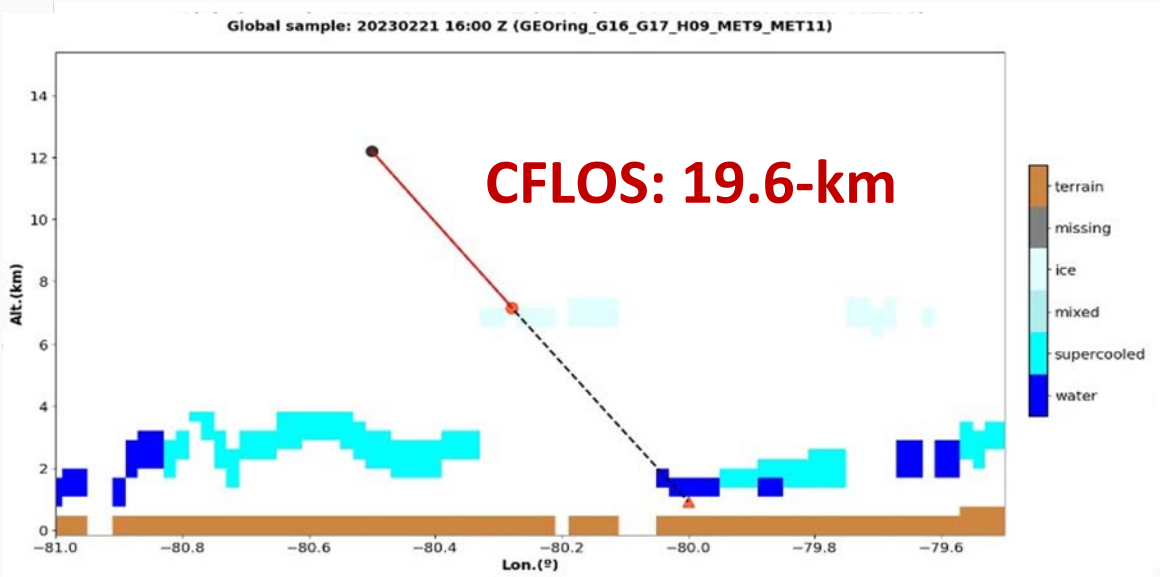


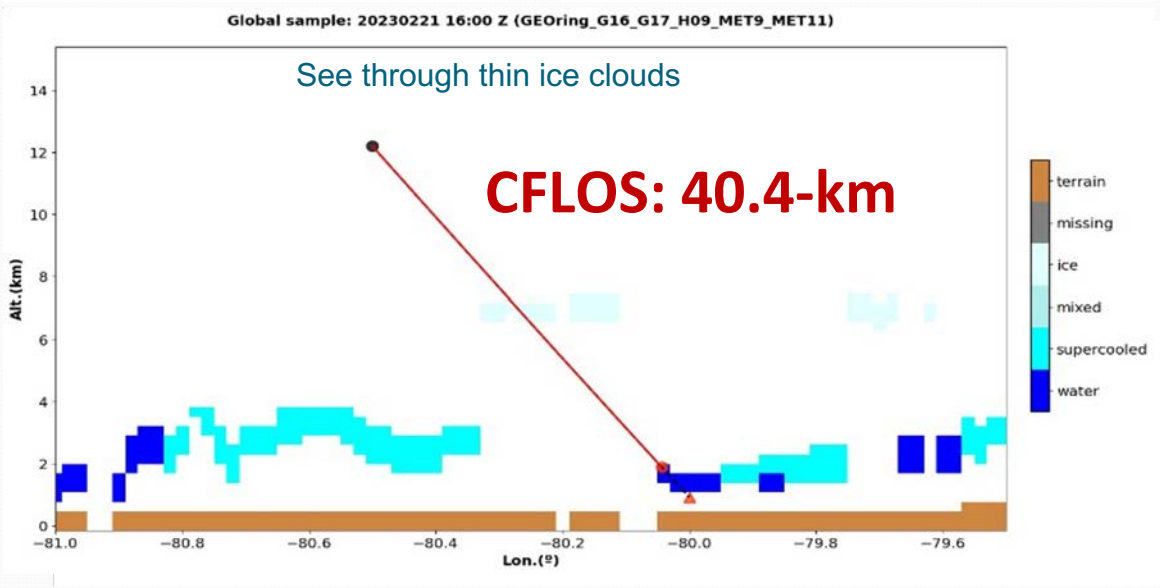
Mapping to Earth-centered, Earth-fixed (ECEF or geocentric) coordinate system

(Hungjui Yu et al.)

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

- Cloud-Free-Line-of-Sight (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
- Develop CFLOS codes to the line-of-sight consisting of points with a specified interval
  - Source: 80.5°W, 40°N, 40000-ft.
  - Target: 80°W, 40°N, 3000-ft.





More to Come

"OVERCAST" for advanced global 3D cloud structure estimation

Further improvement and application

Multilayer clouds

AI-based cloud water profile estimation

Deterministic Cloud-Free-Line-of-Sight

AI-based global hi-resolution microwave and synthetic radar data

Develop deep learning approaches to produce global hi-resolution microwave data (89-GHz from GEO) and synthetic radar reflectivity (GREMLIN)

Nighttime clouds

Adopt a data-fusion approach utilizing VIIRS Day/Night Band (DNB), NWP model, IR, and microwave

Develop synthetic DNB with ML/AI, leveraging CIRA's ProxyVIS research

Short-term advection

Explore potentials to introduce a nowcasting ability to the 3D cloud fields to enable 4D applications, leveraging CIRA's Dense Optical Flow research and using model data fusion.

Transition to Navy operations

Develop integration codes with the Navy Geolocated Information Processing System (GeoIPS)

Validation

Evaluate the products using independent satellite and ground-based data

Develop novel validation tools using statistical approaches and AI/ML methods

Interagency Synergy!

Summary

- Introduced Cloud Vertical Cross-section products to provide satellite-based 3D cloud information for aviation users, leveraging JPSS and GOES research
- Improve science algorithms and validation
- CIRA OVERCAST aims to provide a real-time, global 3D cloud analysis
  - A world-wide cloud analysis, including multilayer clouds, with applications related to visibility
  - Vertical cloud water content profiles, potential applications for aircraft icing
  - A number of add-on products, including global synthetic radar, proxy visible imagery, and synthetic passive microwave

yjnoh@colostate.edu