



Satellite-based 3D Cloud Structure and Interactions with Aviation Users

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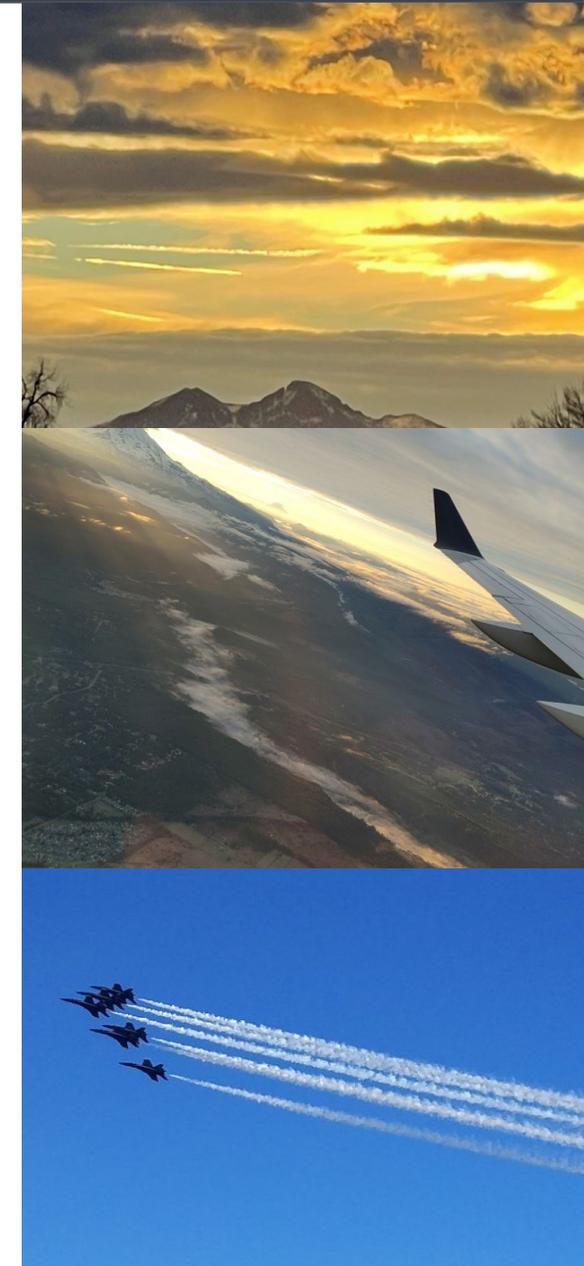
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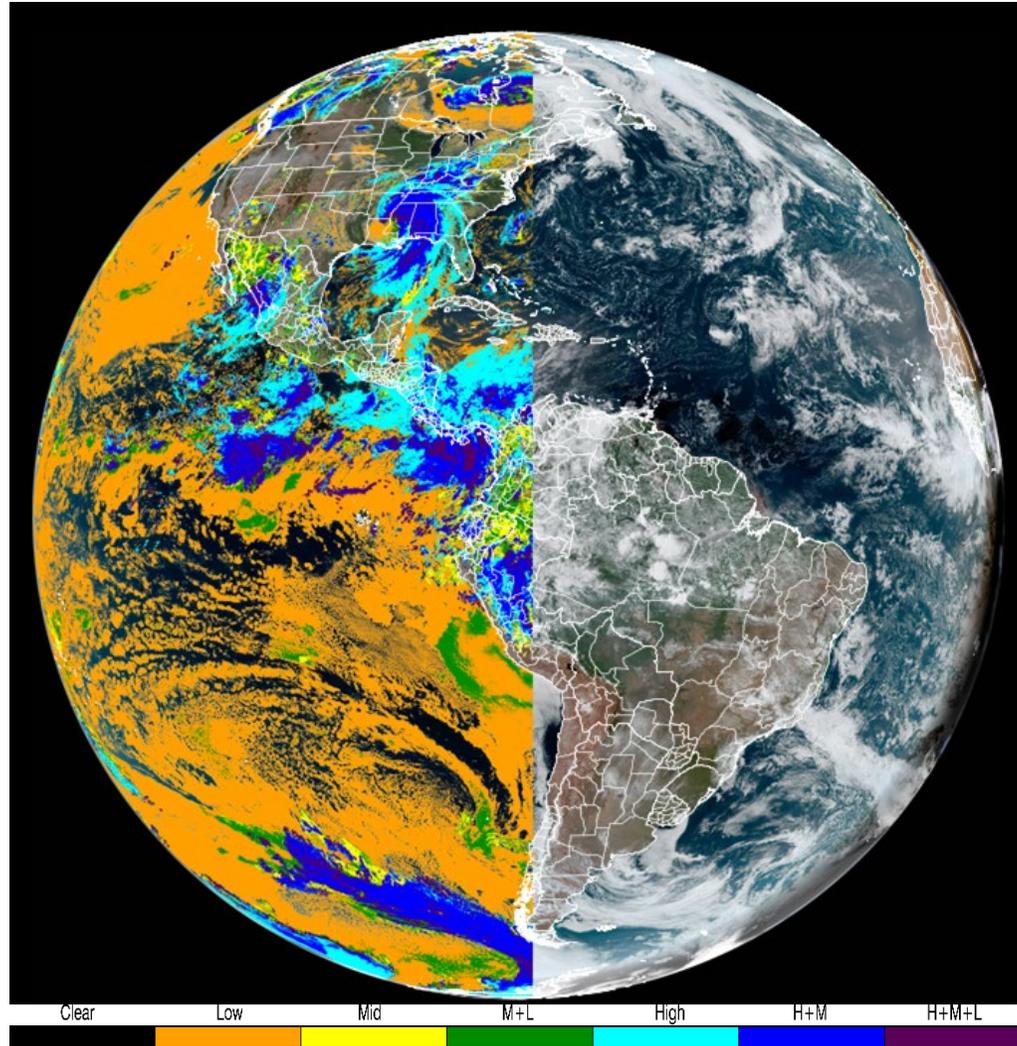
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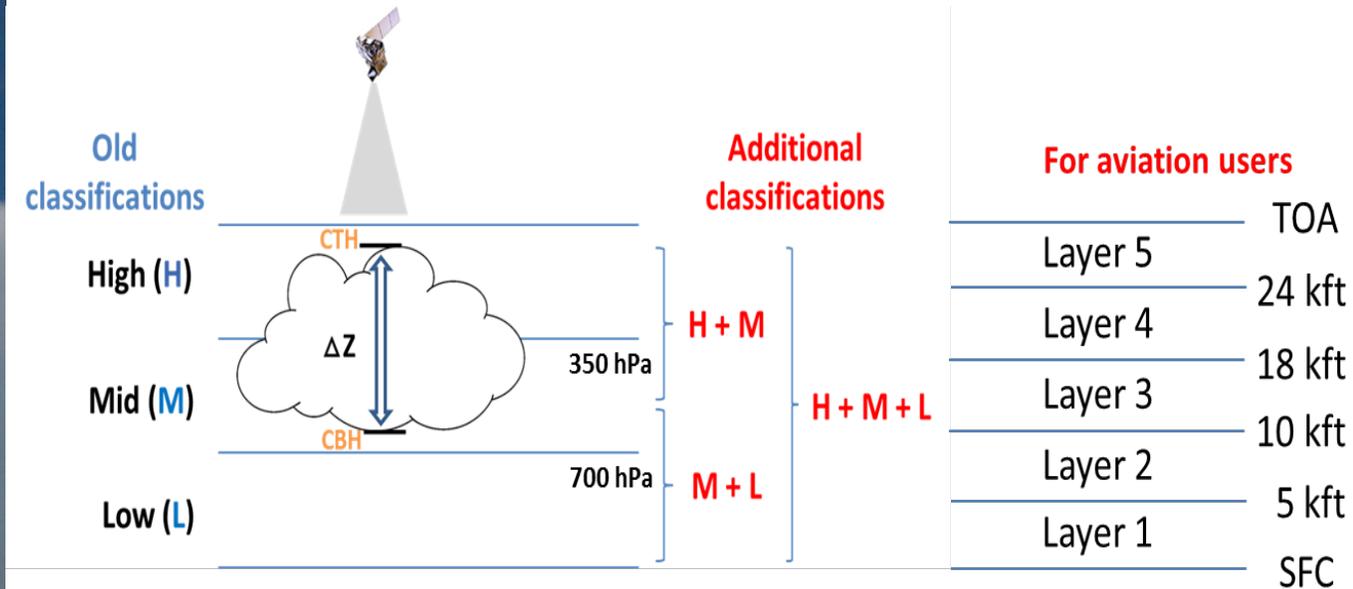
- Satellites have provided valuable cloud observations.
- But the information from conventional sensors (passive radiometers such as ABI and VIIRS) is often limited to 2D cloud top views.

Product and Data Access

Enterprise Cloud Products (Operational: S-NPP: July 5, 2017; NOAA-20: March 7, 2019):

- Enterprise Cloud Mask
- Enterprise Cloud Type and Cloud Phase
- Enterprise Cloud Height
 - Cloud Top Height
 - Cloud Top Pressure
 - Cloud Top Temperature
 - Cloud Cover Layers ←
- Enterprise Cloud Base Height ↩
- Daytime/Nighttime Cloud Optical and Microphysical Properties (DCOMP/NCOMP)
 - Cloud Optical depth
 - Cloud Effective Radius
 - Liquid Water Path
 - Ice Water Path

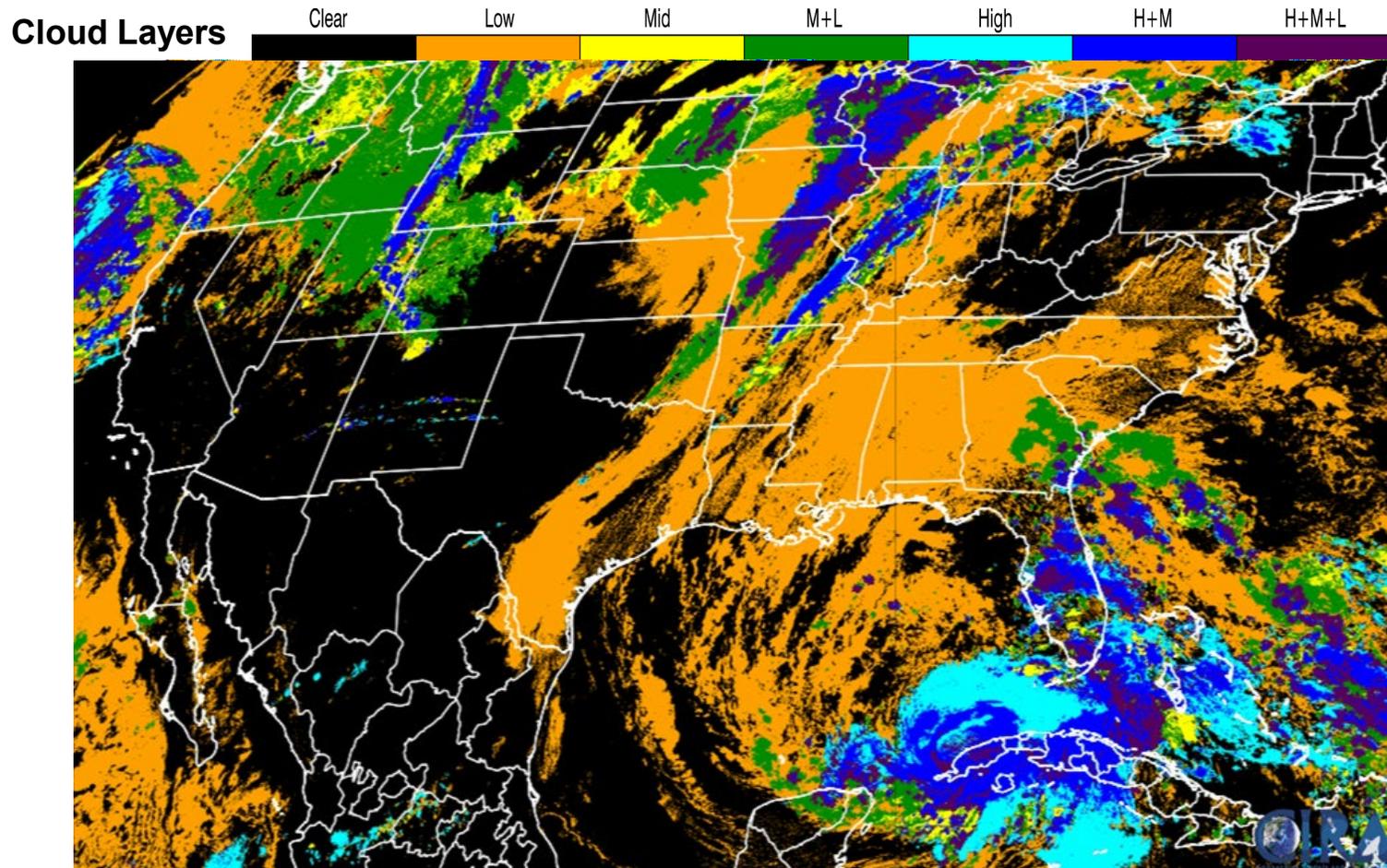




- The CIRA team developed a statistical algorithm for Cloud Base Height (CBH) and Cloud Cover-Layers, which is a key component to build the 3D cloud field
- *(Noh et al. 2017 JTECH)*

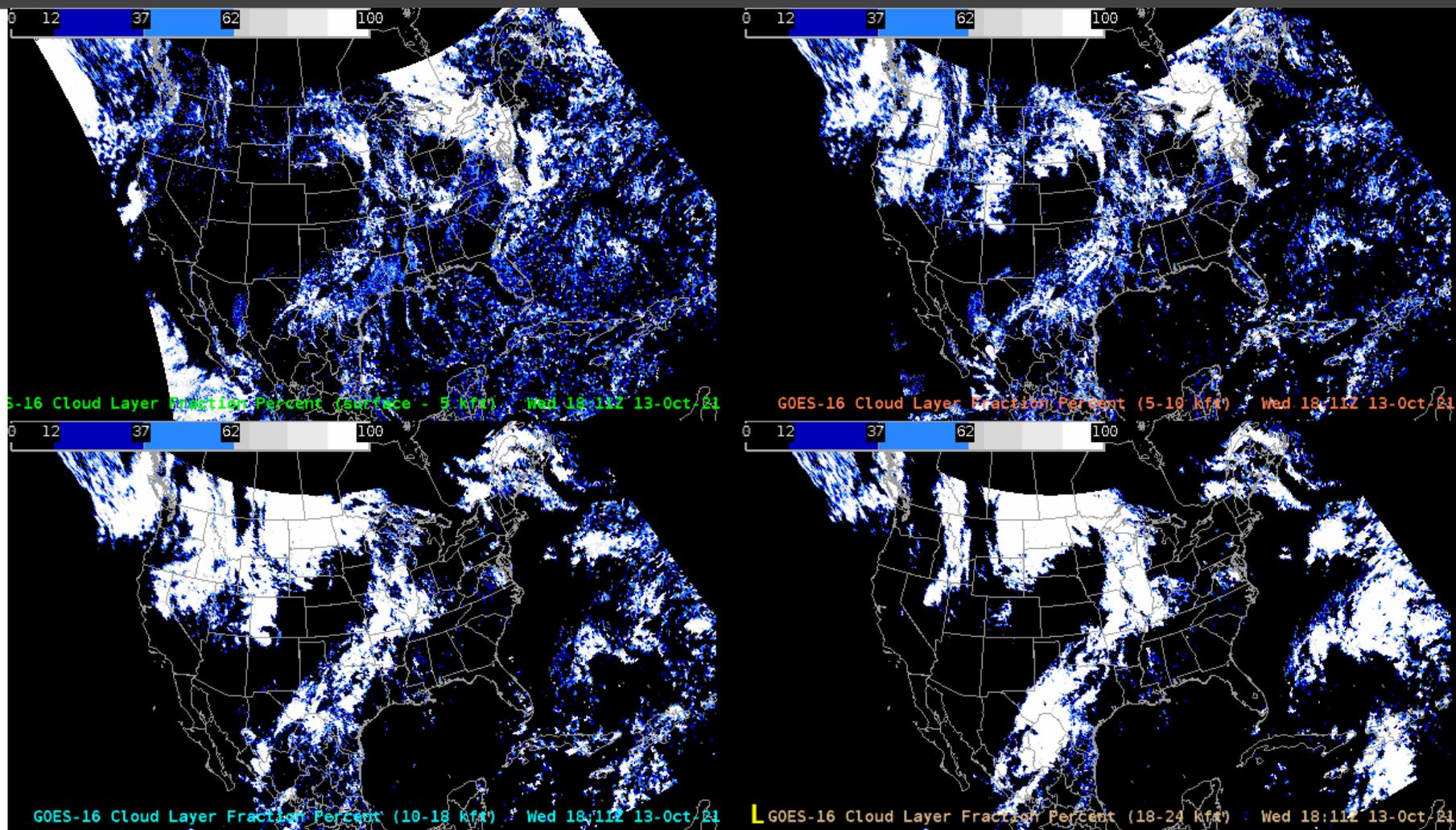
- Operational for JPSS VIIRS and GOES-R ABI as part of the NOAA Enterprise Cloud Algorithms

- Applicable to both polar and geostationary satellite sensors (JPSS VIIRS and GOES ABI)
- Real-time display for the products available in CIRA's SLIDER (<http://rammb-slider.cira.colostate.edu>)





Cloud Layer Fractions in AWIPS-2 for Forecasters

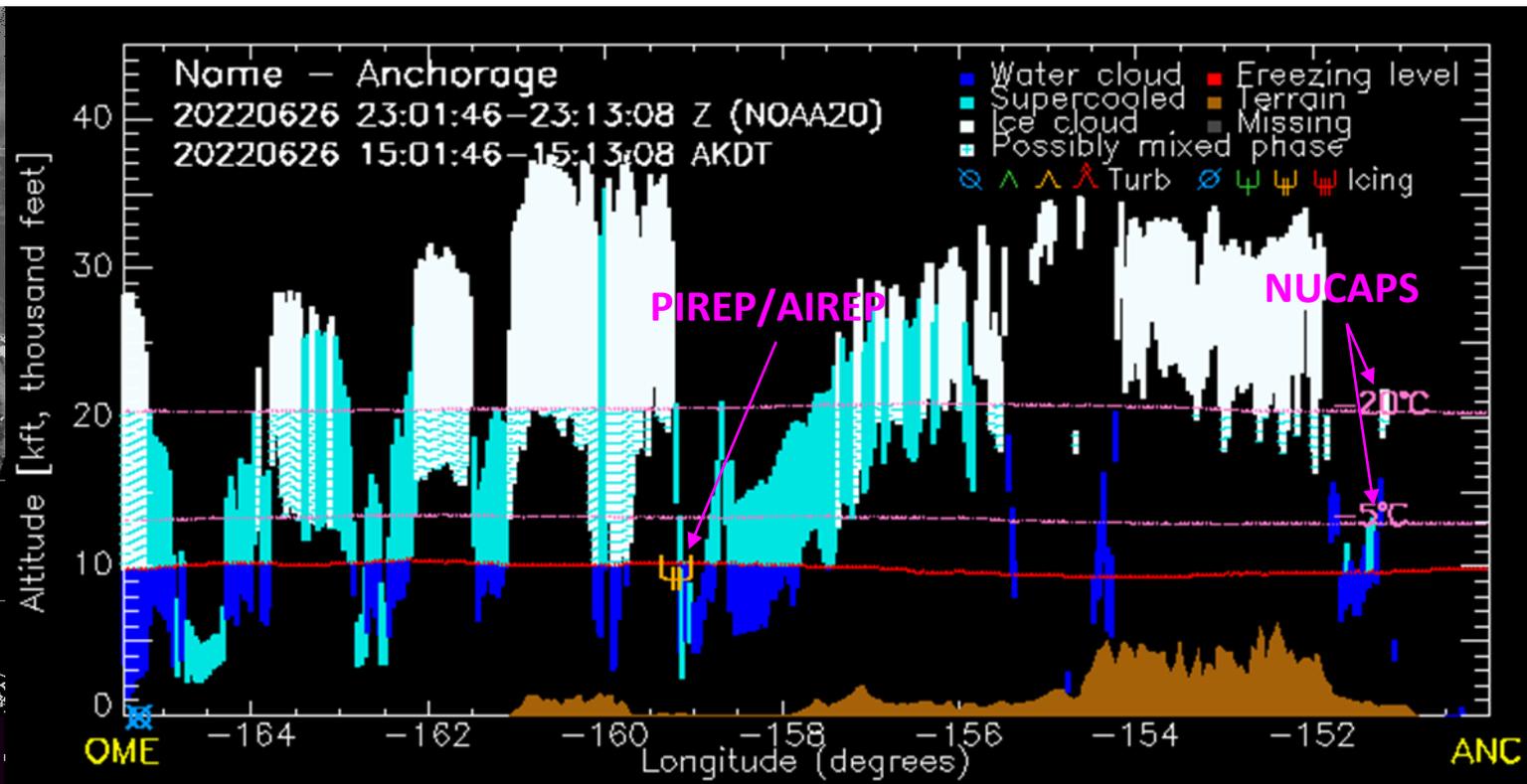
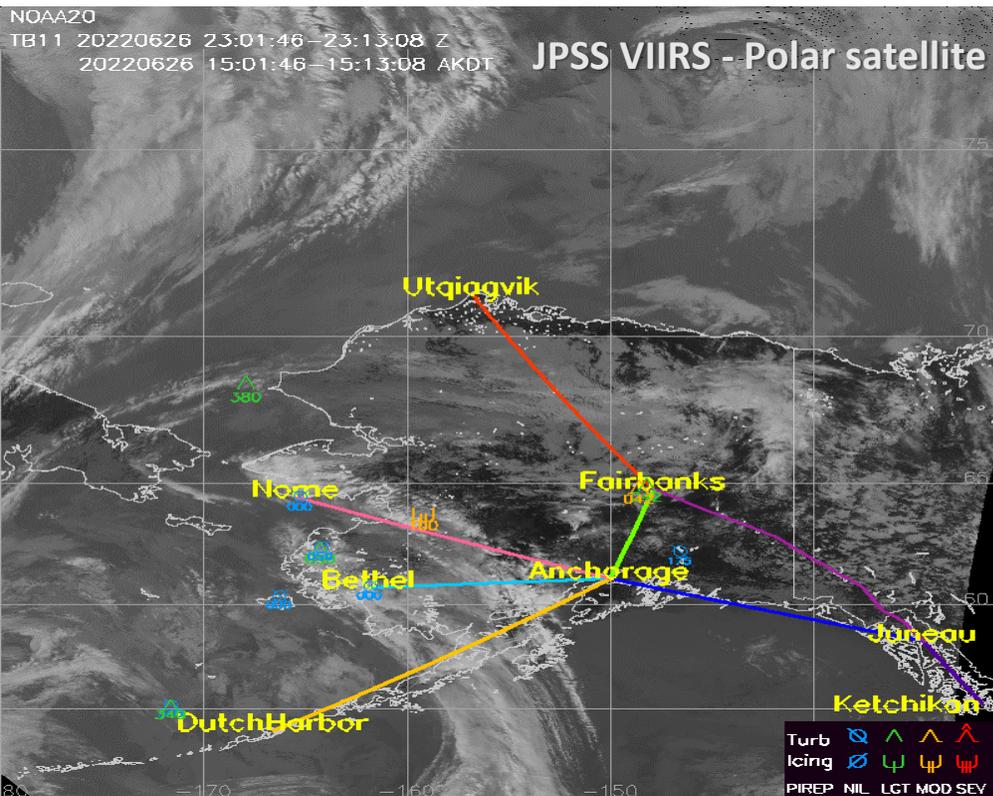


- Layer cloud fractions improved with Cloud Base in AWIPS-2 at the Aviation Weather Center
- Layer1 <5 kft, Layer2 <10 kft, Layer3 <18 kft, Layer4 <24 kft (and Layer5 > 24 kft)
- The operational ABI Cloud Layer products will be released later this year



Cloud Vertical Cross-sections along flight paths

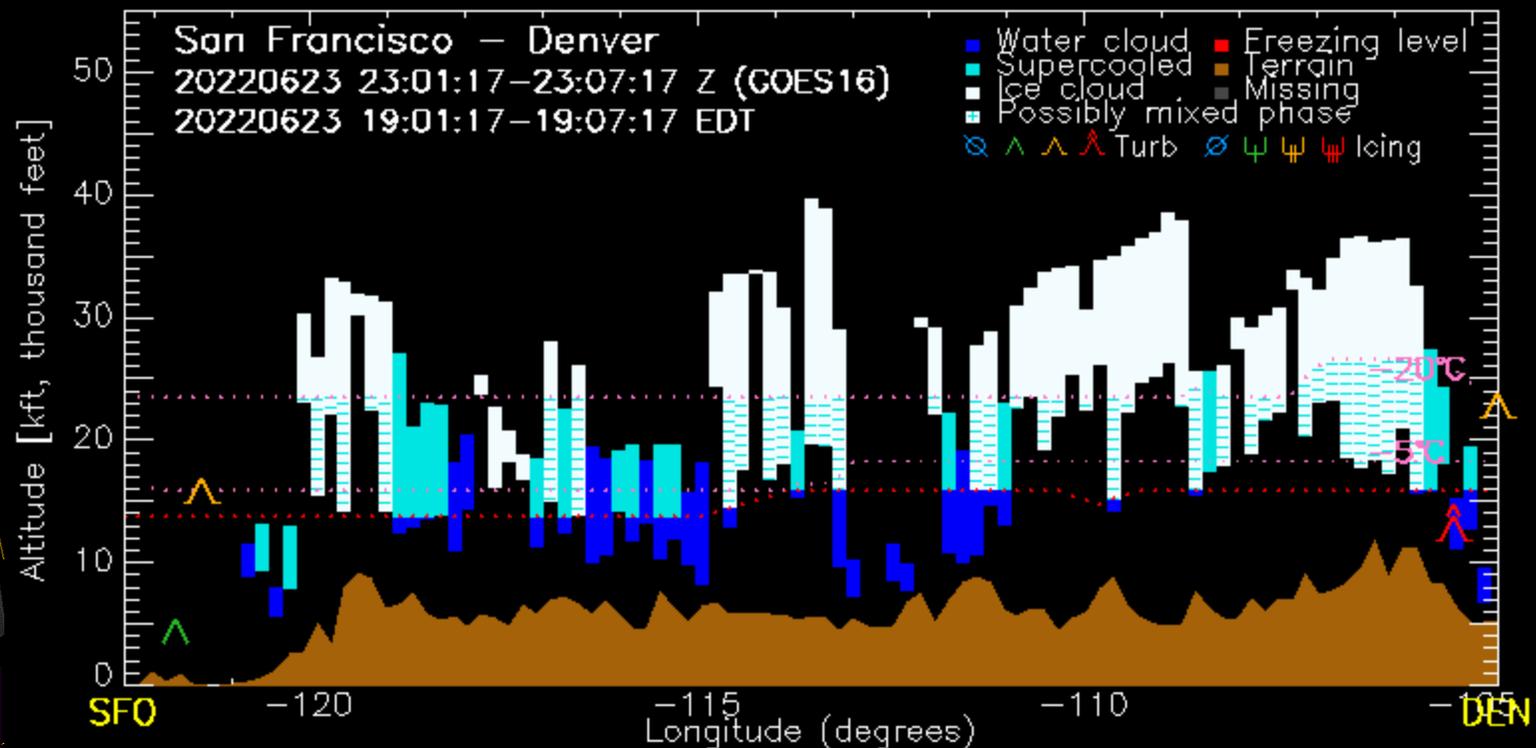
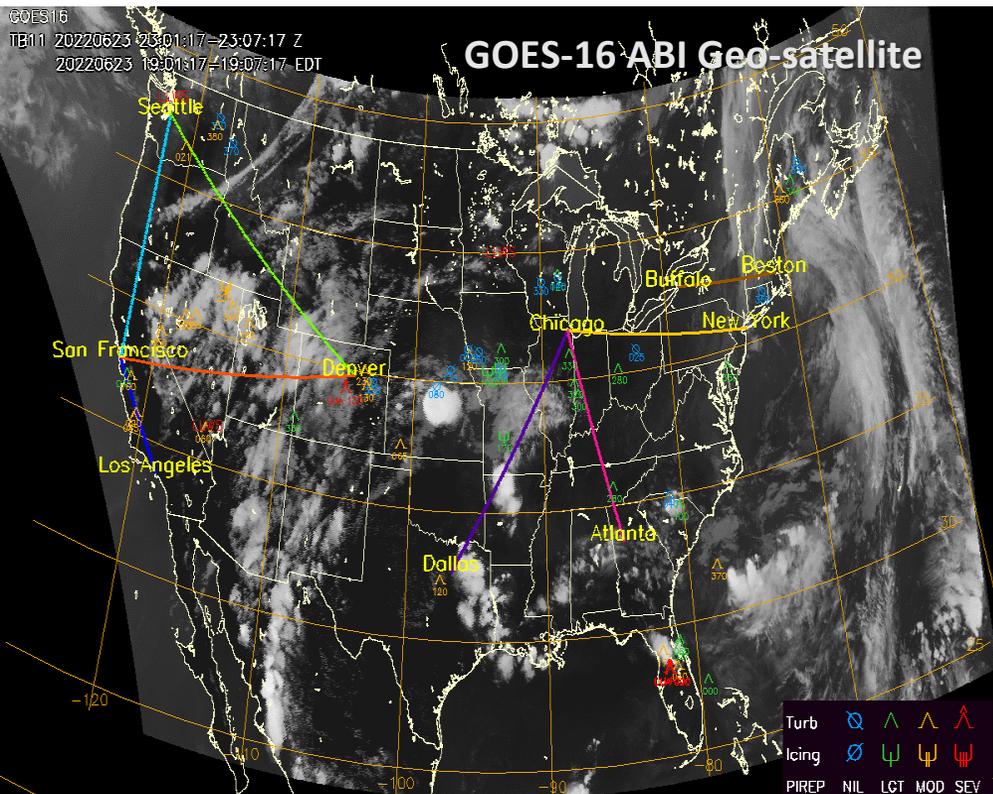
- Experimental satellite cloud products for aviation users
 - Cloud Vertical Cross-sections along selected flight routes from NOAA Enterprise Cloud Products, temperature (NWP/NUCAPS), terrain, PIREPs (icing/turbulence)
 - Ongoing improvements based on user feedback
 - NOAA JPSS Aviation Initiative/Alaska VIIRS Cloud Demonstration



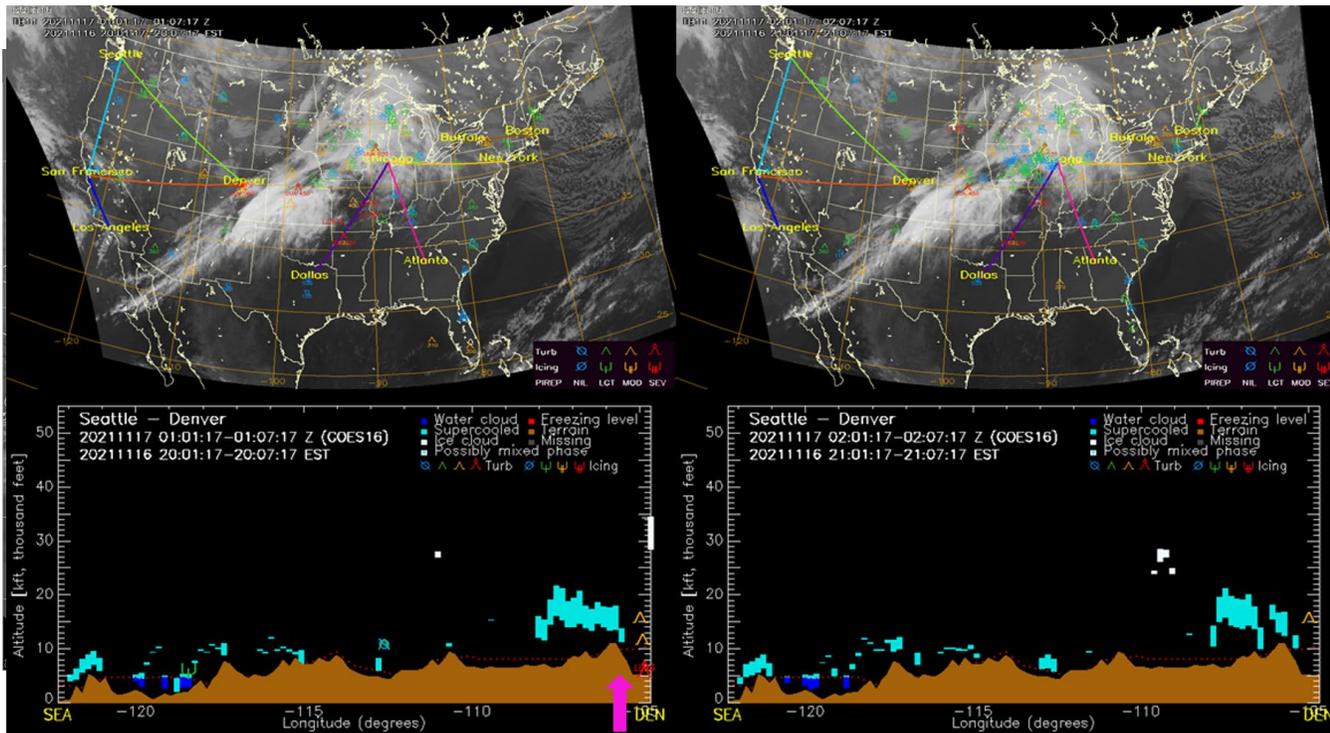


Cloud Vertical Cross-sections along flight paths

- Experimental satellite cloud products for aviation users (**CONUS**)
 - Extending the test domain to CONUS using both **JPSS-VIIRS** and **GOES-R ABI** data
 - Provide an evaluation tool for VIIRS/ABI cloud product inter-comparisons



- JPSS Alaska Cloud Product Demonstration/JPSS Aviation Initiative
- CIRA Polar SLIDER and VIIRS Cloud Vertical Cross-sections for the cloud product demonstration
 - @NOAASatellites twitter to promote NOAA's Proving Ground Website, Alaska users' blogs
 - NOAA/NASA online articles, Aircraft Owners & Pilots Association (AOPA) *ePilot* newsletter and weekly video program "AOPA Live" for Alaska pilots
 - Direct feedback from local pilots, data support for **NTSB accident case investigation**



The CIRA team provided NTSB with imagery and cloud vertical cross-section products for the fatal Kruger Rock fire fighting air tractor crash case (an Air Tractor AT-802A) which occurred around 1844 MST (0144 UTC Nov. 17) on 16 November 2021 near Estes Park, Colorado. The cross-sections are from GOES-16 ABI between Seattle and Denver airports to match the accident location and time. The accident location is close to the Denver airport, which shows lots of turbulence reports from pilots and aircrafts.

The cross-section product question for Alaska pilots in the Aircraft Owners and Pilots Association “2021 Weather Survey” report

- The top request by pilots was to create their own cross-sections → *Our current effort to develop the new aviation website with a user-interactive interface for custom cross-sections*

2021 Weather Survey
August 30, 2021

Jim McClay
Director, Airspace, Air Traffic, and Security

Elizabeth Bell
Research Analyst

Tom George
Alaska Regional Manager

Introduction

For the past five years, AOPA has conducted an annual Weather Survey to investigate how pilots access weather information. The results of the 2021 Weather Survey build on knowledge obtained from previous years of research on Weather, PIREPs, and Flight Service.¹ The 2021 Weather Survey focused on technologies used by pilots, FIS-B, PIREPs, the Graphical Forecasts for Aviation (GFA) website, the Helicopter Emergency Medical Services (HEMS) tool, the cloud cross-section product from the National Oceanic and Atmospheric Administration (NOAA), and more. When appropriate, these survey results are trended over time and segmented by demographics such as age, pilot certificate, and location.

Method

The 2021 Weather Survey was created 37 unique questions, including subsets. Responses were collected over a six-week period from 3,233 from the continental United States (CONUS) Members from Hawaii and the CONUS Members from Alaska and the CONUS Members from Alaska receive any incentives in exchange for their participation.

Key Findings

1. Less than a third of the survey respondents requested preflight self-briefing product outreach to increase awareness of the product.
2. The use of Flight Service specialists was an important primary source of weather information for 30% of pilots conducting self-briefing. The FAA should evaluate changes in use of these trends.
3. The FAA Weather Camera Program was used by 18% of pilots in Alaska, where the program was used by 17% of the pilots using it as an initial weather source.

¹ Duke, R. & George, T. (July 26, 2016), [AOPA 2016 Weather Survey](#)
² Duke, R. & George, T. (Aug. 4, 2017), [AOPA 2017 Weather Survey](#)
³ Duke, R., George, T., Davis, K., & Bell, E. (July 6, 2021), [AOPA 2021 Weather Survey](#)

Thanks to Tom George (AOPA) and Adam White (AK Airmen Assoc.)

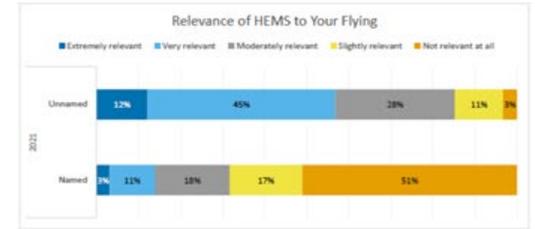


Figure 36. Responses to “How relevant do you feel the Helicopter Emergency Medical Services (HEMS) weather tool is to your flying?” (N_{UNNAMED} = 956; N_{NAMED} = 1029). Respondents in the unnamed group in 2021 saw the question, “How relevant do you feel this weather tool would be to your flying?”

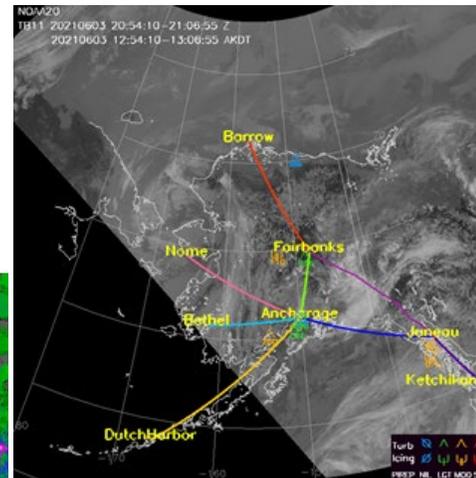
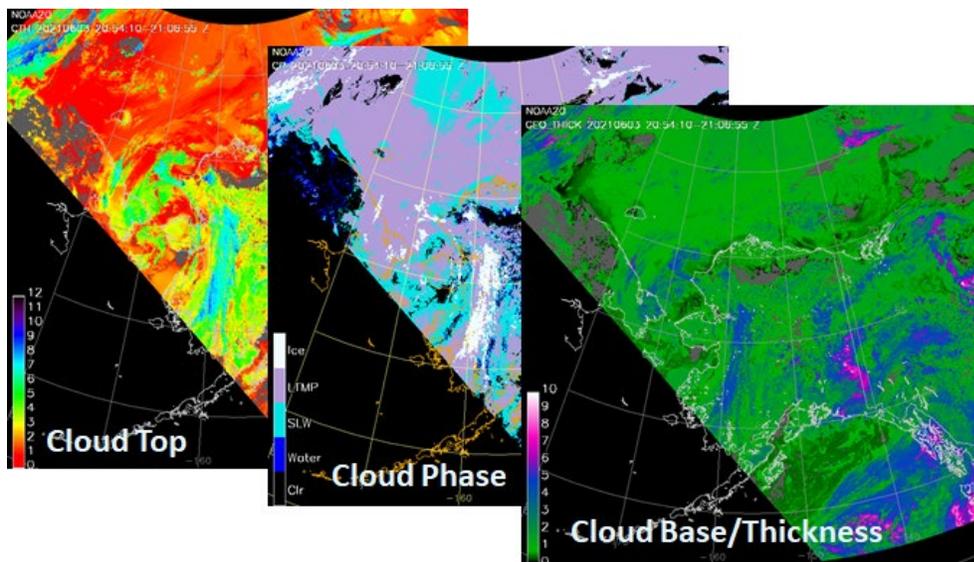
NOAA Cloud Cross-Section. The National Oceanic and Atmospheric Administration (NOAA) continues to develop a new weather product that estimates cloud and icing conditions using satellites across Alaska and the CONUS. The clouds cross-section product is currently an experimental product.⁴ In 2021, most respondents (82%) were not at all familiar with this product (Figure 37). Most of those who were at least slightly familiar with the product were neither satisfied nor dissatisfied with it (66%; Figure 38).

Those who were at least slightly familiar with the product had the opportunity to leave a comment about it. The most frequently expressed desire was to be able to define a custom route.

⁴ Learn more about the NOAA clouds cross-section product by visiting <https://www.aopa.org/news-and-media/all-news/2021/august/27/new-weather-product-helicopters-look-to-clouds>

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

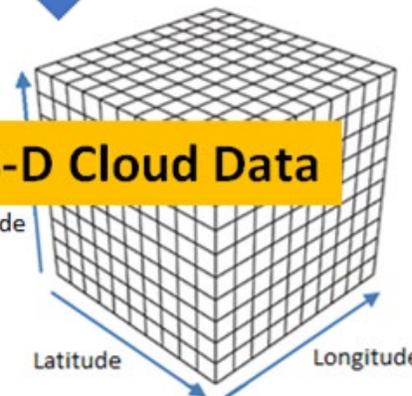
NOAA Enterprise Cloud products
(2D pixel data for the individual granules)



Temperatures (NUCAPS/NWP)
Terrain
PIREPs (Icing/Turb)



Gridded 3-D Cloud Data



Compact 16-bit integers in NetCDF

0.02° X 0.02° with 51 levels at 1000 ft vertical resolution
over AK with inverse distance/nearest neighbor methods



New Aviation Website for custom cross-sections

- <https://aviation.cira.colostate.edu>
- Airport selection: Click random waypoints on to the IR image, Manual Entry, or Dropdown list
- A layer feature for icing/turb (PIREPs)
- User quick guide and documents
- **User online survey**
 - For forecasters and pilots
- Product evaluation/User feedback during the NOAA JPSS Alaska Cloud Demonstration

Ongoing collaborative efforts for product improvements!

The screenshot displays the CIRA Aviation website interface. At the top, a navigation bar includes 'Home', 'Real-Time Data', 'Research Projects', 'Training/Outreach', and 'Resources'. A '4-wk archive' label with an arrow points to a 'Back to Old Site' button. Below the navigation is a 'CIRA Aviation' header with 'Home (Custom Flight Path)' and 'Back to Old Site' buttons. A 'Quick Guide | Introduction/FAQ | Experimental Products Disclaimer | Survey?' link is also present.

The main content area features a '2021-2022 JPSS Cloud Product Survey' announcement, stating that new sensors on operational weather satellites are enabling experimental weather products for the aviation community. Below this is a 'Submit Custom Flight Path Feedback' form with fields for Name, Email, and Feedback. A note indicates that the submitted image will be linked to the feedback.

The central focus is a cross-section plot showing altitude (kft, thousand feet) on the y-axis (0 to 40) and waypoints (A, B, C) on the x-axis. The plot includes data for water cloud, supercooled liquid, ice cloud, and possibly mixed phase, along with freezing level, rain, and icing. Waypoint A is at 167.79°W, 63.75°N; B is at 154.6°W, 63.95°N; and C is at 149.07°W, 59.37°N. A zoomed-in view of the icing data at waypoint C is shown on the right side of the plot.



New Aviation Website for custom cross-sections

- <https://aviation.cira.colostate.edu>
- Airport selection: Click random waypoints on to the IR image, Manual Entry, or Dropdown list
- A layer feature for icing/turb (PIREPs)
- User quick guide and documents
- **User online survey**
 - For forecasters and pilots
- Product evaluation/User feedback during the NOAA JPSS Alaska Cloud Demonstration
- Adding a preliminary CONUS domain with ABI (to be launched soon!)

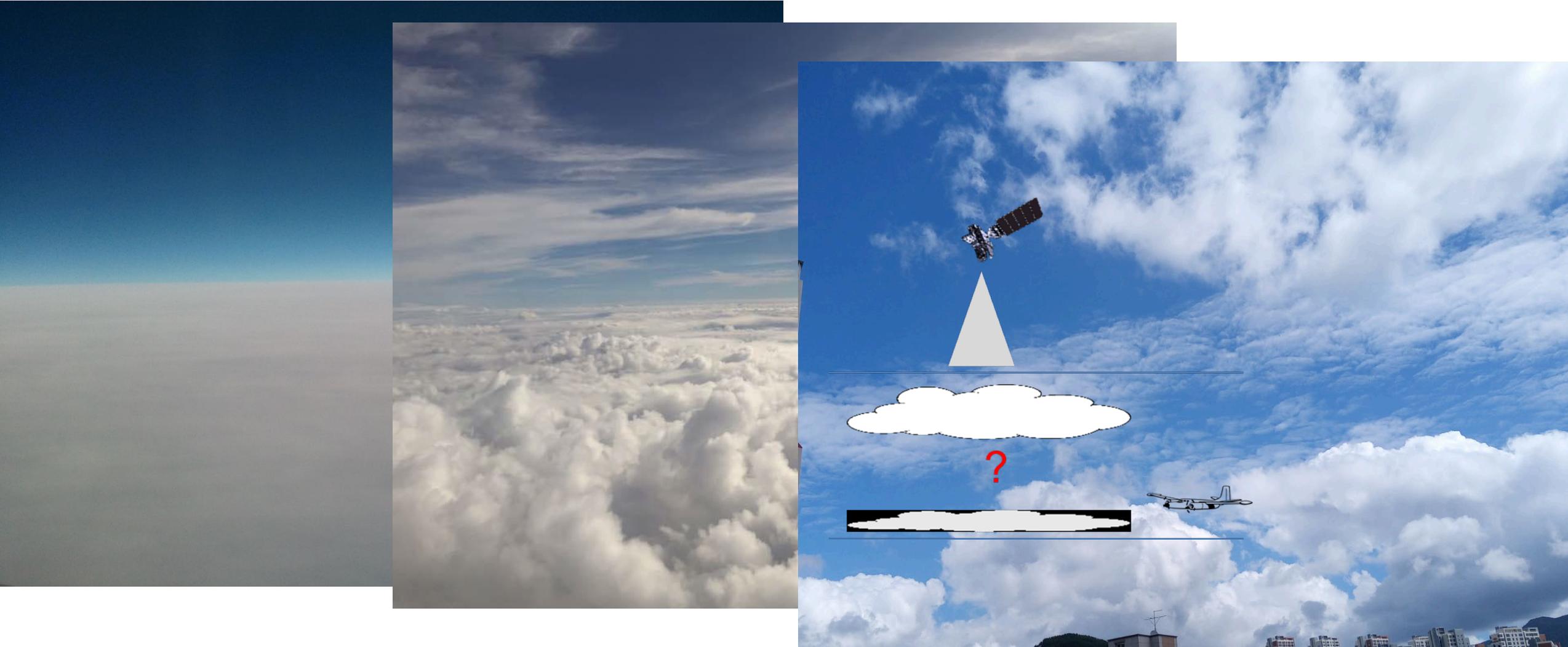
Ongoing collaborative efforts for product improvements!

The screenshot displays the CIRA Aviation website interface. At the top, there is a navigation bar with links for Home, Real-Time Data, Research Projects, Training/Outreach, and Resources. The main header includes the CIRA logo and the text "CIRA Aviation". Below this, there are buttons for "Home (Custom Flight Path)" and "Back to Old Site", along with a menu containing "Quick Guide", "Introduction/FAQ", "Experimental Products Disclaimer", and "Survey". A secondary menu lists "JPSS Aviation Initiative Links", "Release Notes", and "Contact Us".

The central section is titled "Custom Flight Path" and contains a "Please Note" message: "This is an experimental aviation cross-section product (see disclaimer link above)." Below this, instructions state: "Click on each point along your flight path, or select an airport from the drop-down list, then click 'Confirm Waypoints' and then 'Generate Cross-Section' to generate a cross-section for your flight path. If you need to start over, click 'Clear All'." The interface includes a "Clear All" button, a "Manual Entry" button, a dropdown menu for "Add an Airport", and a "Confirm Waypoints (0)" button. There is also an "Opacity" slider and a "Show:" section with checkboxes for "Icing" and "Turbulence". A "Did you know?" tip suggests clicking the map to add waypoints.

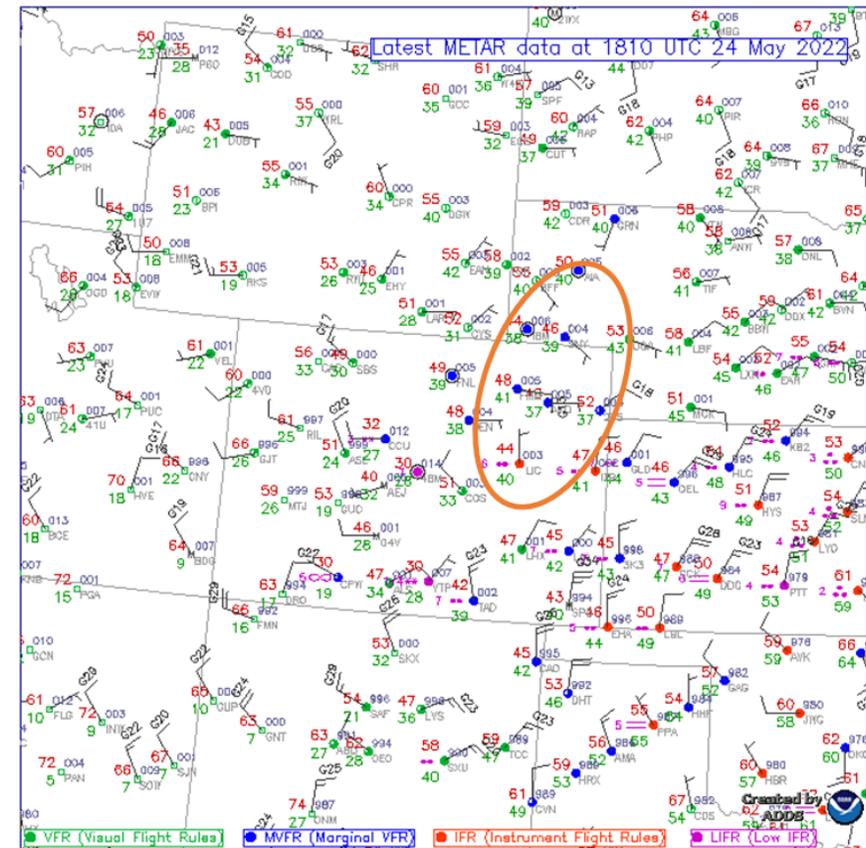
The bottom section, titled "Your Flight Path and Cross-Section", features a "Did you know?" tip: "You can bookmark this URL to save your route; it will always show the latest data when you visit!". On the left is a map of the CONUS region with a flight path indicated by a blue line and two blue pins. On the right is a cross-section plot showing "Altitude [kft, thousand feet]" on the y-axis (0 to 40) and time on the x-axis. The plot displays various atmospheric conditions: Water cloud (blue), Supercooled (cyan), Ice cloud (green), Possibly mixed phase (black), Freezing level (red), Terrain (orange), and Missing (grey). A legend on the right side of the plot identifies these elements. The plot also shows a temperature profile with a pink line and a dashed red line. The time range is from 20220601 19:56:17-20:01:17 Z (GOES16) to 20220601 15:56:17-16:01:17 EDT. The plot is titled "A" and "B" with coordinates: A (107.1°W, 41.06°N) and B (93.65°W, 37.04°N). At the bottom, there are buttons for "General Feedback" and "Feedback for This Image".

- Aviation is particularly concerned with the location of **low clouds** (IFR conditions, icing, etc.) but still challenging in **multilayer scenes**





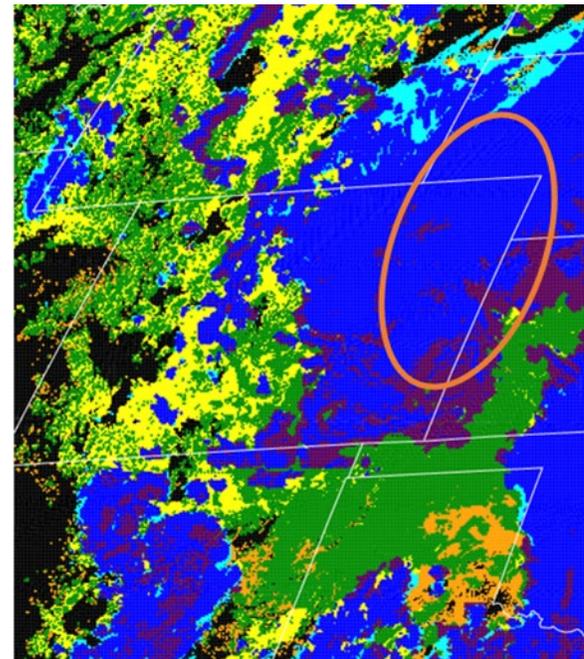
Use Machine Learning (ML) approaches



Example case study: upper-level low exits Rockies

Marginal VFR conditions with 1-3kft ceilings in northeast Colorado and Neb. Panhandle

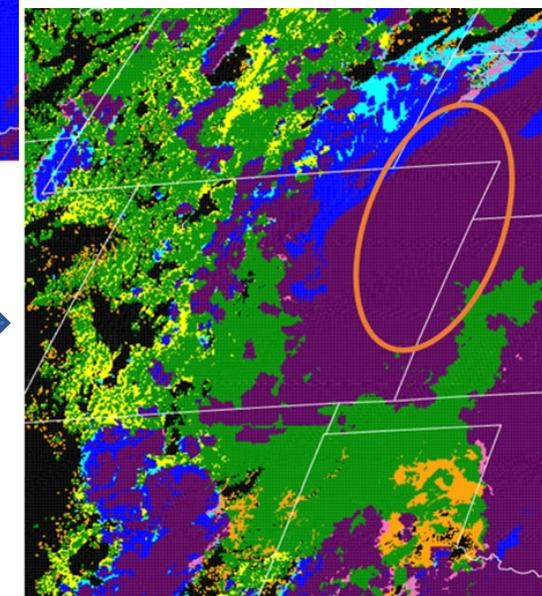
These ceilings are better represented with machine learning addition



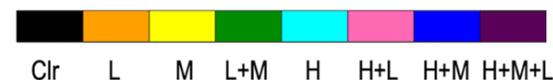
CCL supplemented by RF on global scale

Before machine learning

After machine learning



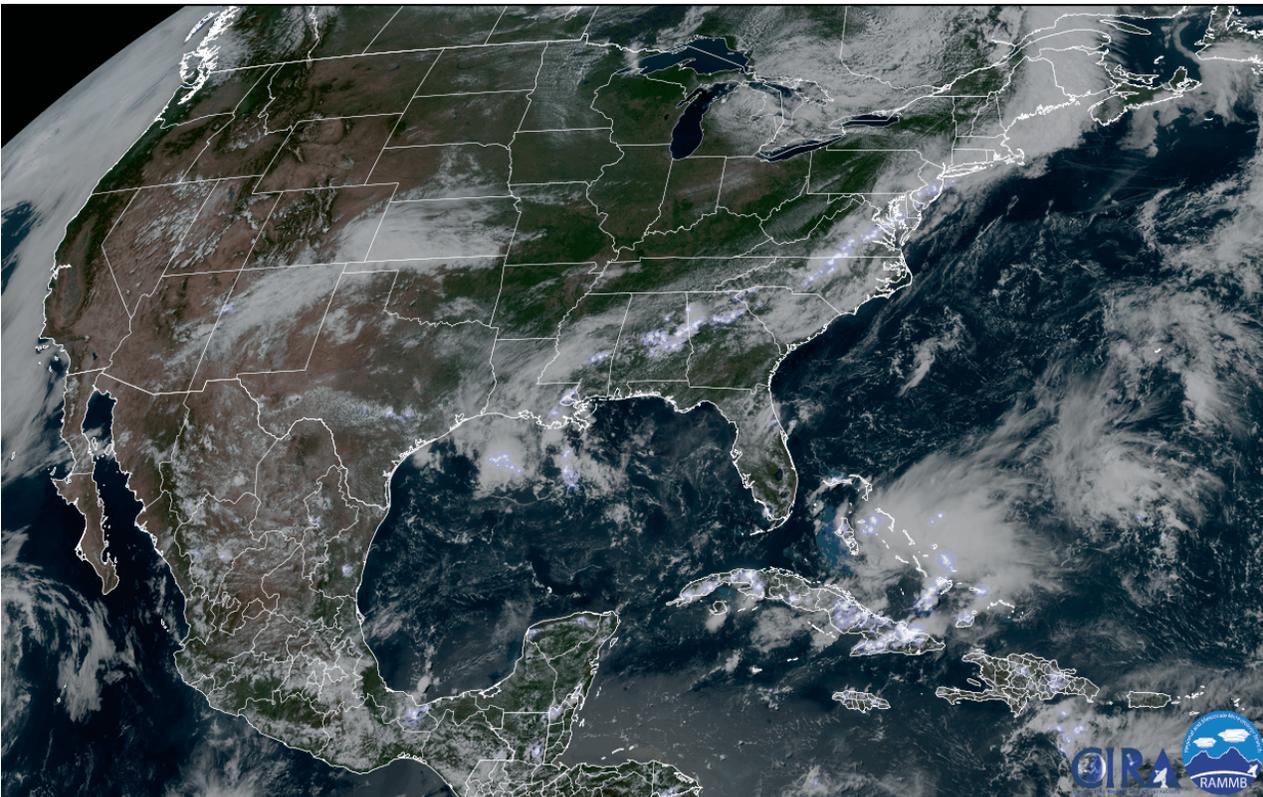
More deep clouds (purples)
NEW high-over-low (pinks)



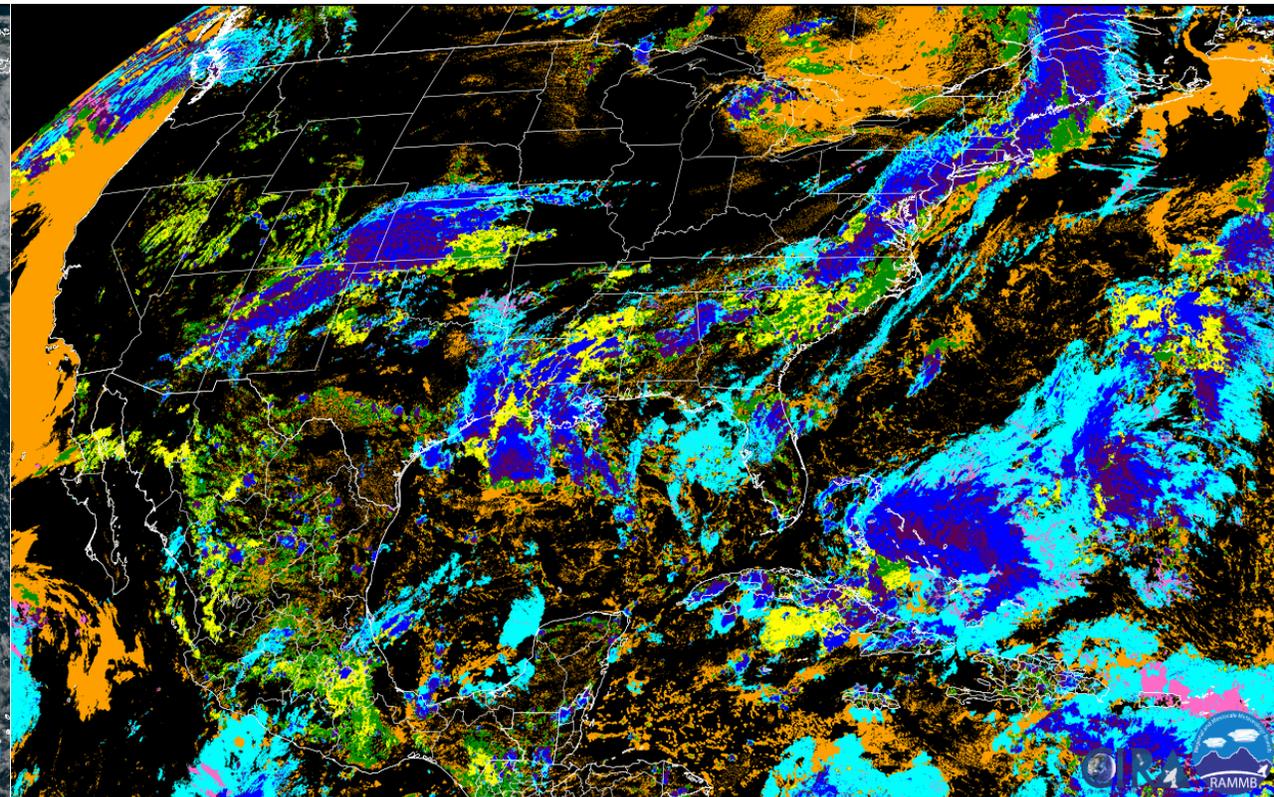
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KSTK 241735Z AUTO 04004KT 10SM OVC021 09/05 A3004 RMK AO2

Case: 2022/05/24 18:10 UTC

- Applicable to both polar and geostationary satellite sensors (JPSS VIIRS and GOES ABI)
- Real-time display for the *new* products available in CIRA's SLIDER (<http://rammb-slider.cira.colostate.edu>)



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



Clear Low Mid M+L High H+L H+M H+M+L

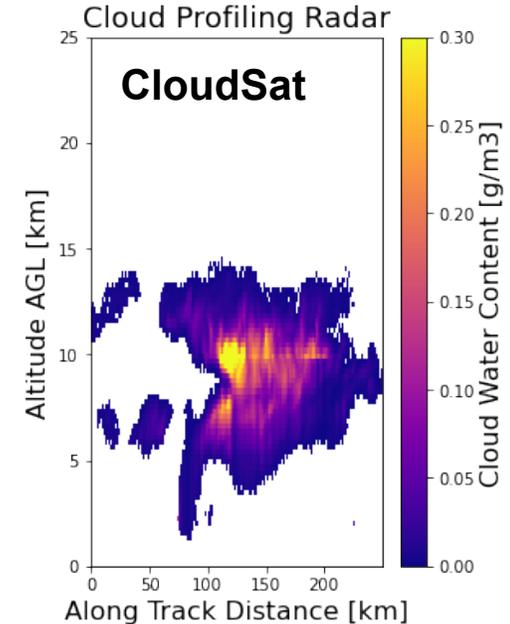
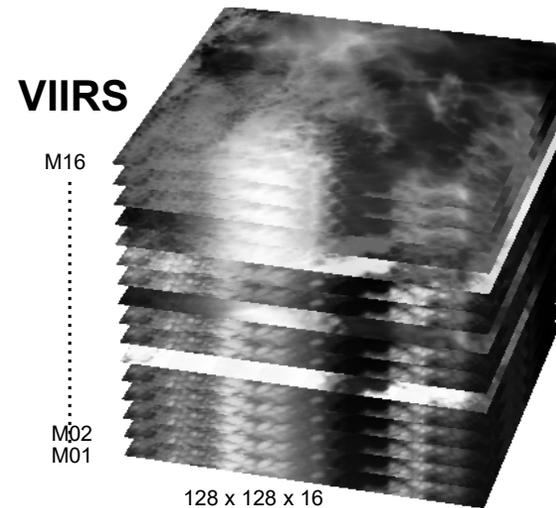
Cloud Layers



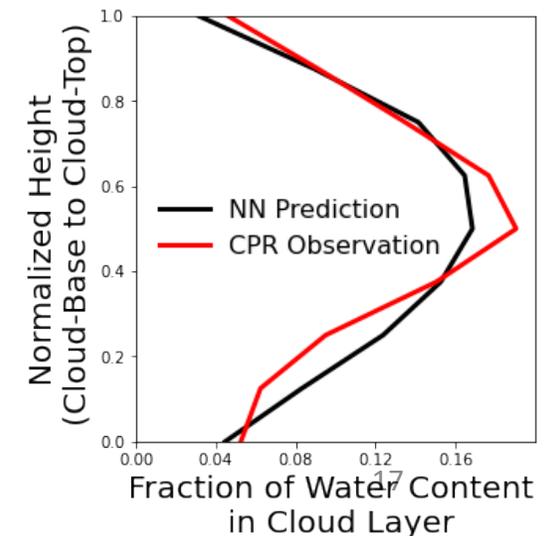
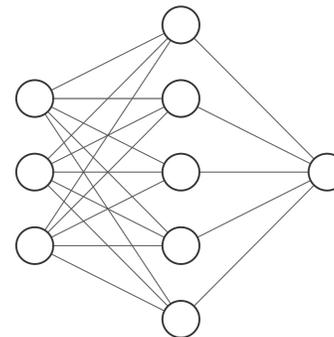
- CloudSat radar (CPR) offers detailed **vertical profiles of cloud water content**
- Building a neural network to estimate the shape of the cloud water profile based on VIIRS observations matched with CloudSat

- *Complete the 3D cloud structure information*
- *Potentially to help improve the vertical icing potential detection*

(Chuck White et al.)



Fully-Connected or Convolutional Neural Network





- Cloud Base/Layers and Cloud Vertical Cross-section products to provide **satellite-based 3D cloud information** for aviation weather applications
- **An experimental website** for new products & user feedback
 - User-Developer interaction-based product development/improvement
 - Construct fully gridded 3D Cloud data (currently for Alaska users)
 - *Work in progress*: CONUS and global 3D cloud data
 - Preparation of data processing for new satellite data (G18, JPSS-2)
- Improve science algorithms and validation
 - Multilayer clouds using AI/machine learning approaches
 - Collaboration with AWC leveraging each other's expertise for improved cloud layer products
 - Validation using surface measurements (ARM/METAR) and satellite data

<https://aviation.cira.colostate.edu>