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

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Tom George (Aircraft Owners & Pilots Association)**, Adam White** (Alaska Airmen Assoc.)
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Becca Mazur (Arctic Testbed), **Carl Dierking, Jay Cable, Jen Delamere** (CICOES/GINA)
Nadia Smith, Rebekah Esmaili (STCNET), **Jenny Colavito** (FAA), **Paul Suffern** (NTSB)

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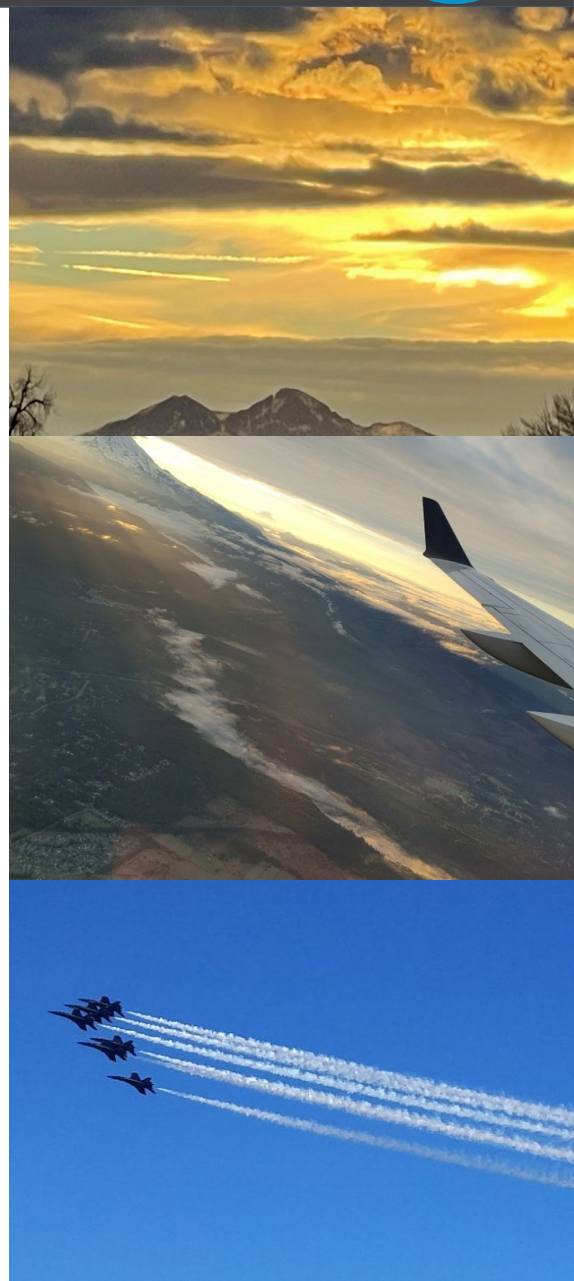
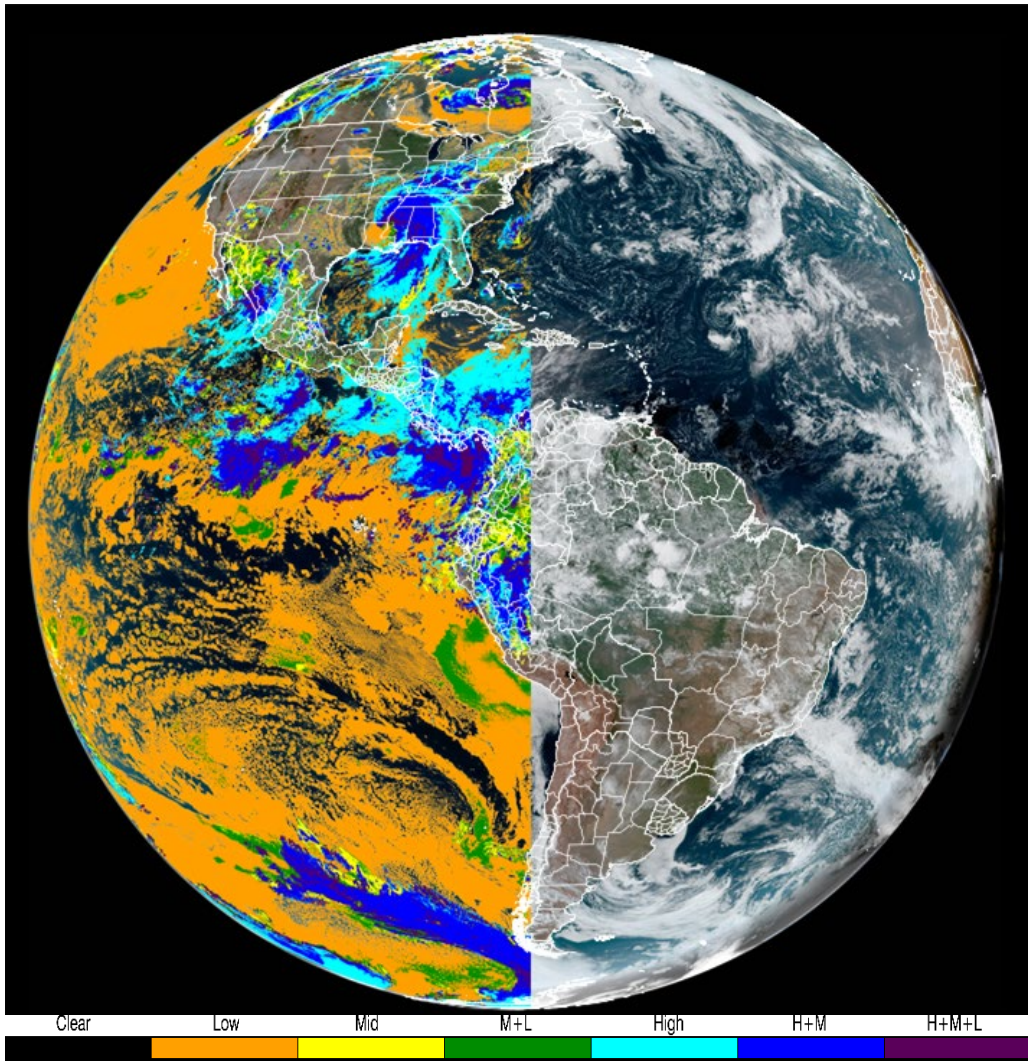


Satellite Imagery and Cloud Data



- 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.

Satellite Cloud Products

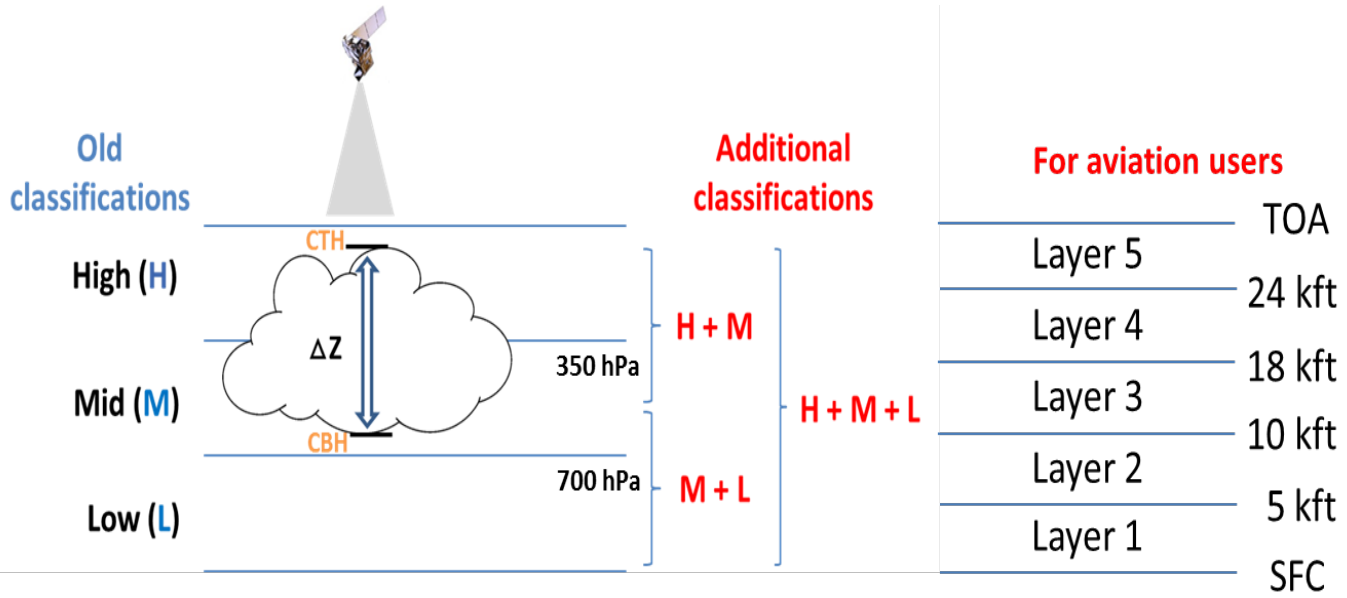
Product and Data Access

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

https://www.star.nesdis.noaa.gov/jpss/clouds.php

Satellite-Based Cloud Layer Data

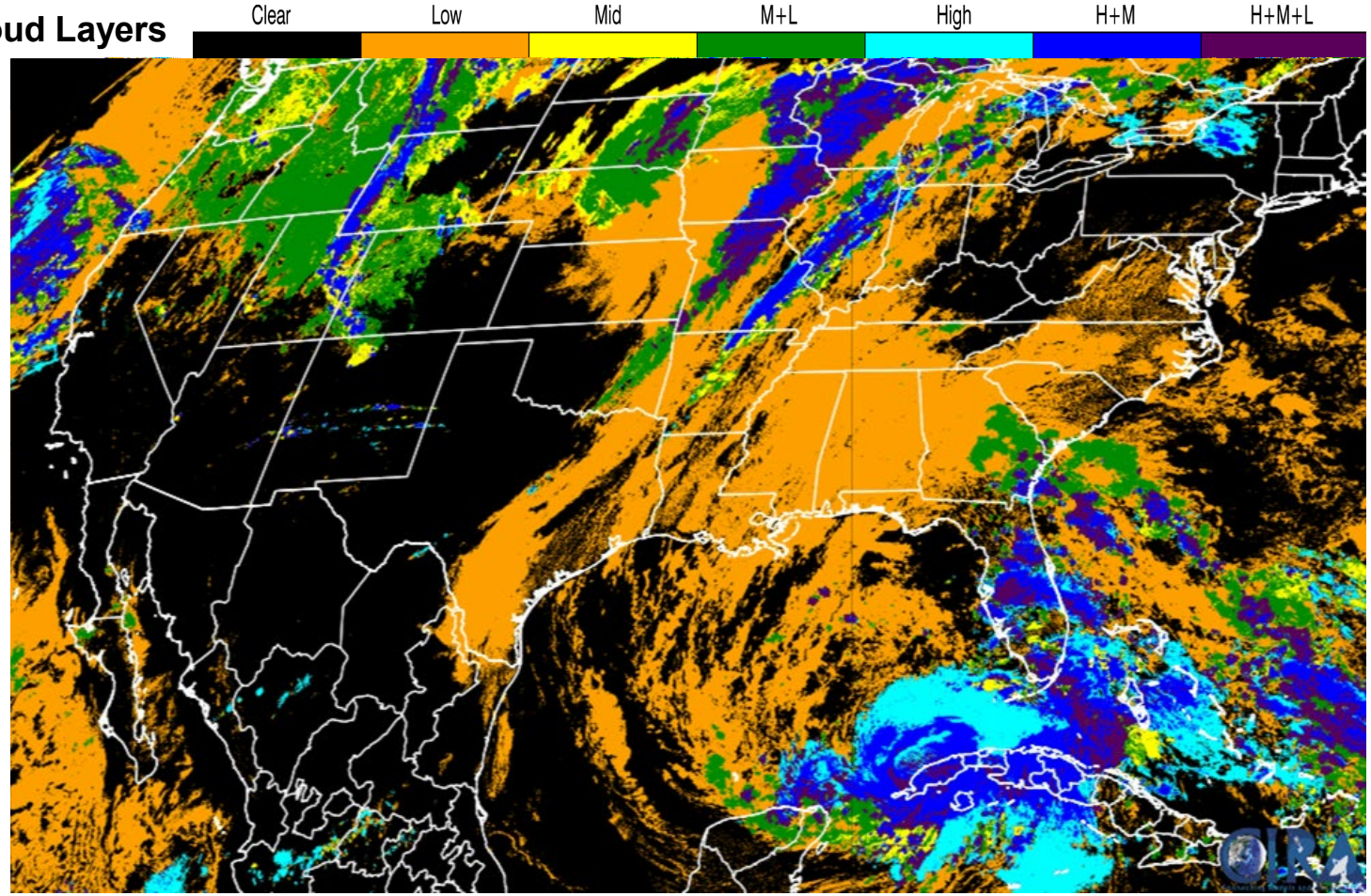


- The CIRA team developed a statistical algorithm for Cloud Base Height (CBH) and Cloud Cover-Layers, which is a key component to build the 3D cloud field
- *(Noh et al. 2017 JTECH)*

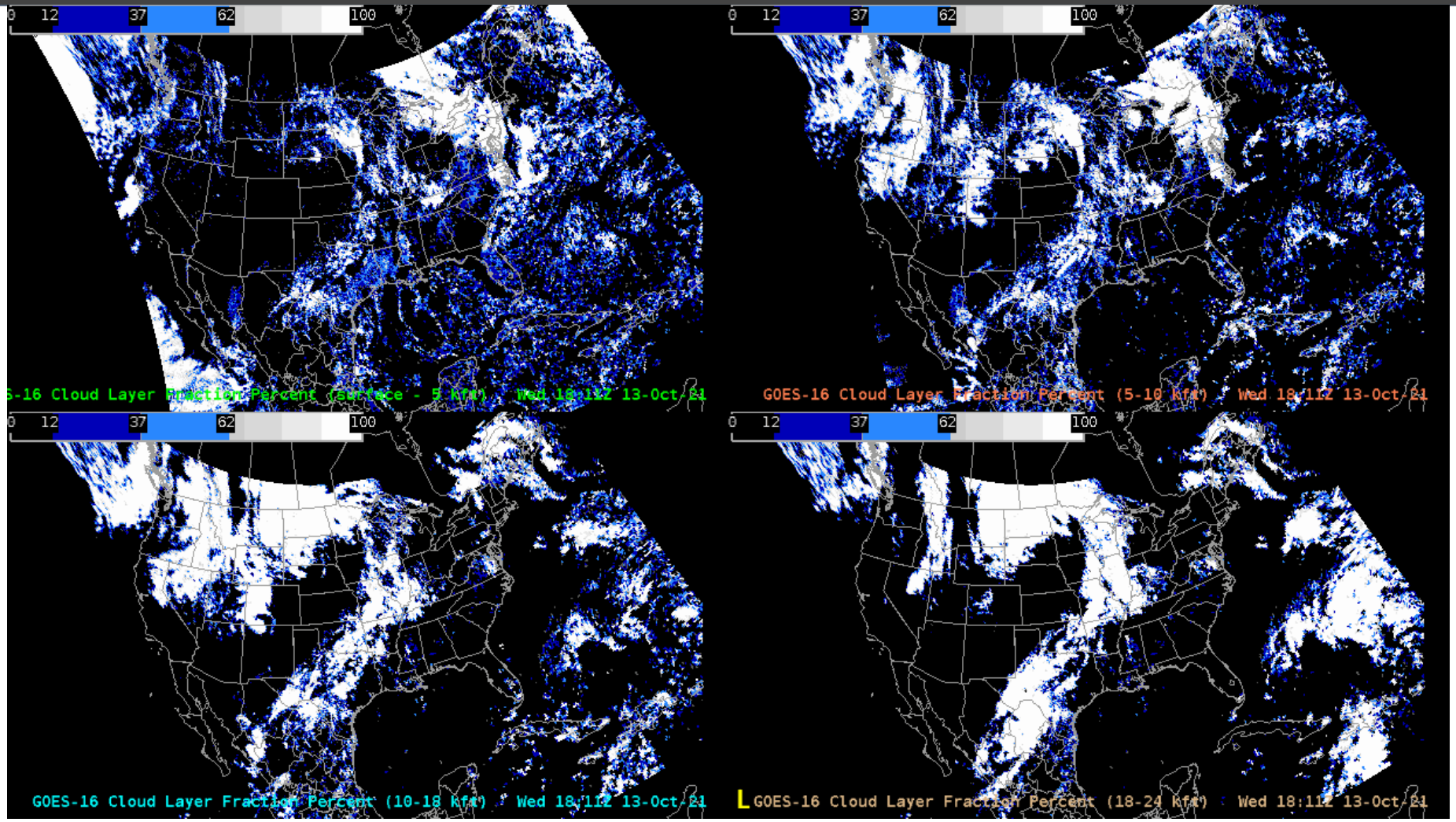
- Operational for JPSS VIIRS and GOES-R ABI as part of the NOAA Enterprise Cloud Algorithms

Cloud Cover Layers with Cloud Base information

- **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)



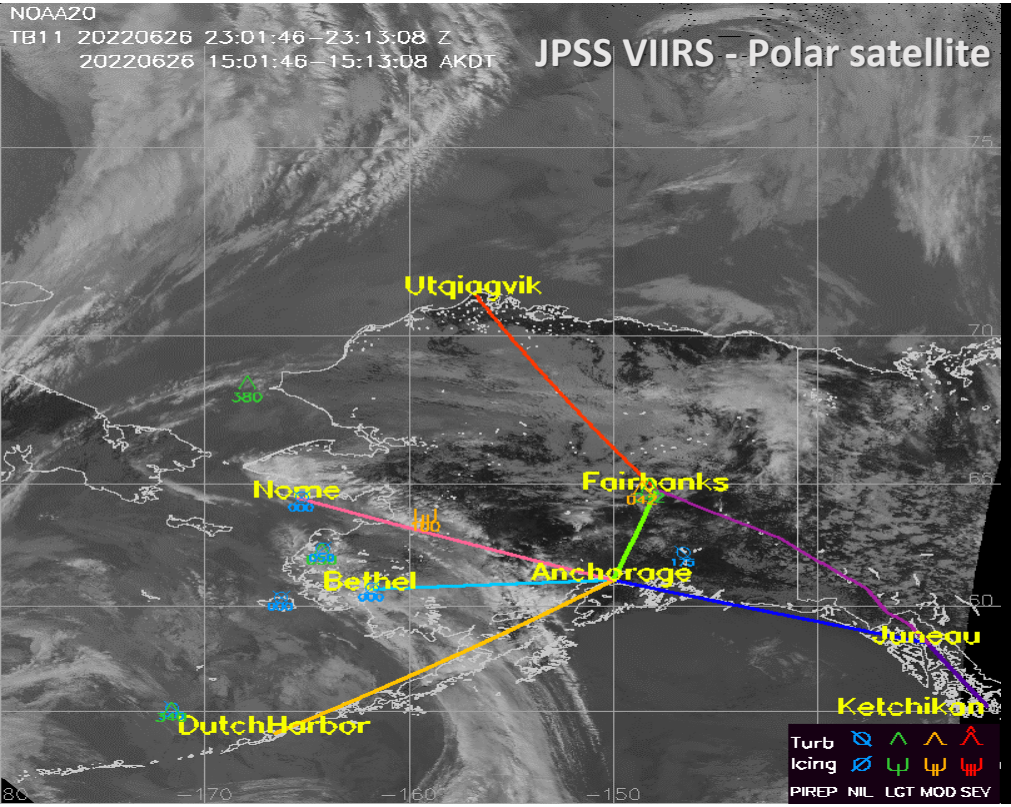
Cloud Layer Fractions in AWIPS-2 for Forecasters

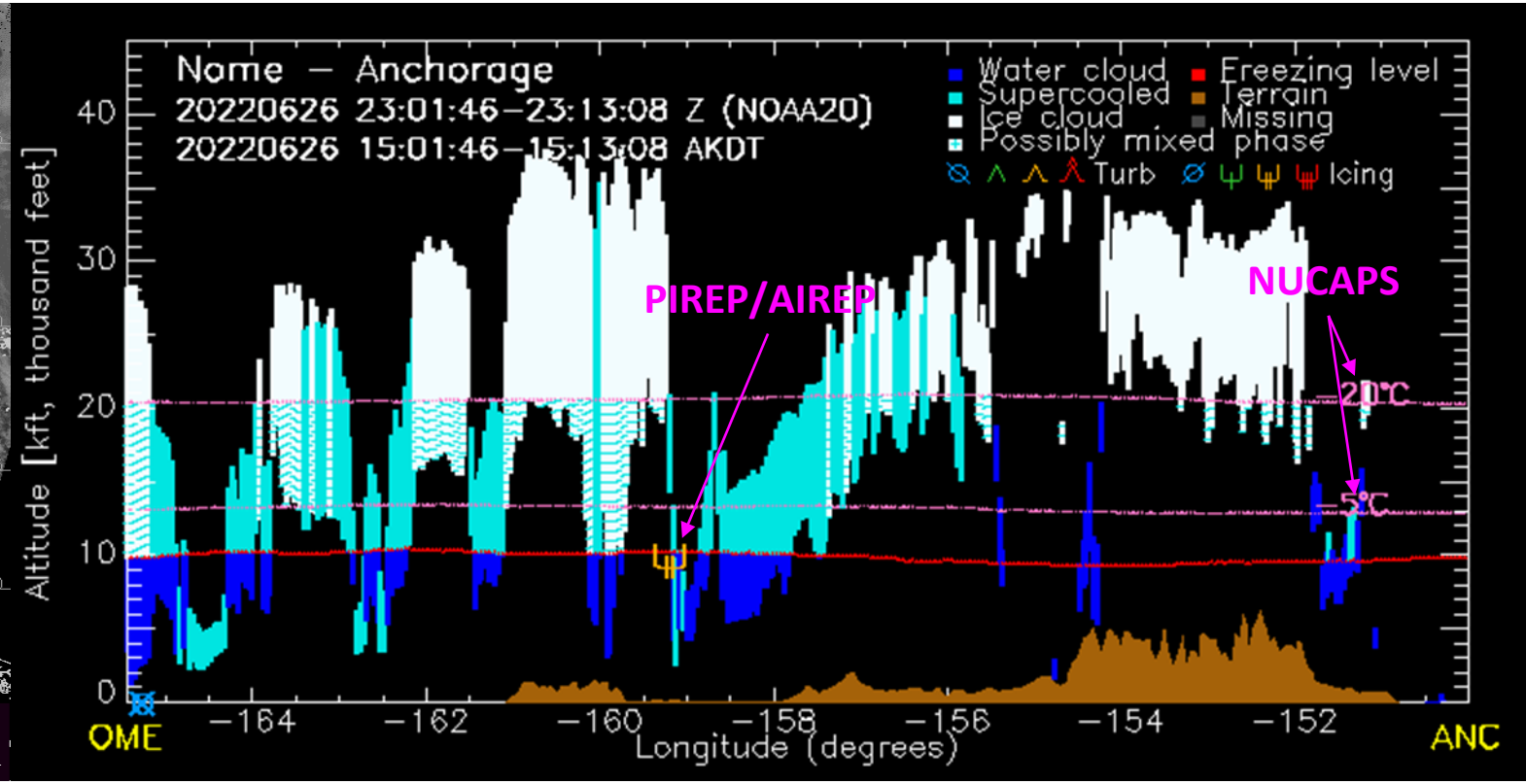


- Layer cloud fractions improved with Cloud Base in AWIPS-2 at the Aviation Weather Center
- Layer1 <5 kft, Layer2 <10 kft, Layer3 <18 kft, Layer4 <24 kft (and Layer5 > 24 kft)
- The operational ABI Cloud Layer products will be released later this year

Cloud Vertical Cross-sections along flight paths

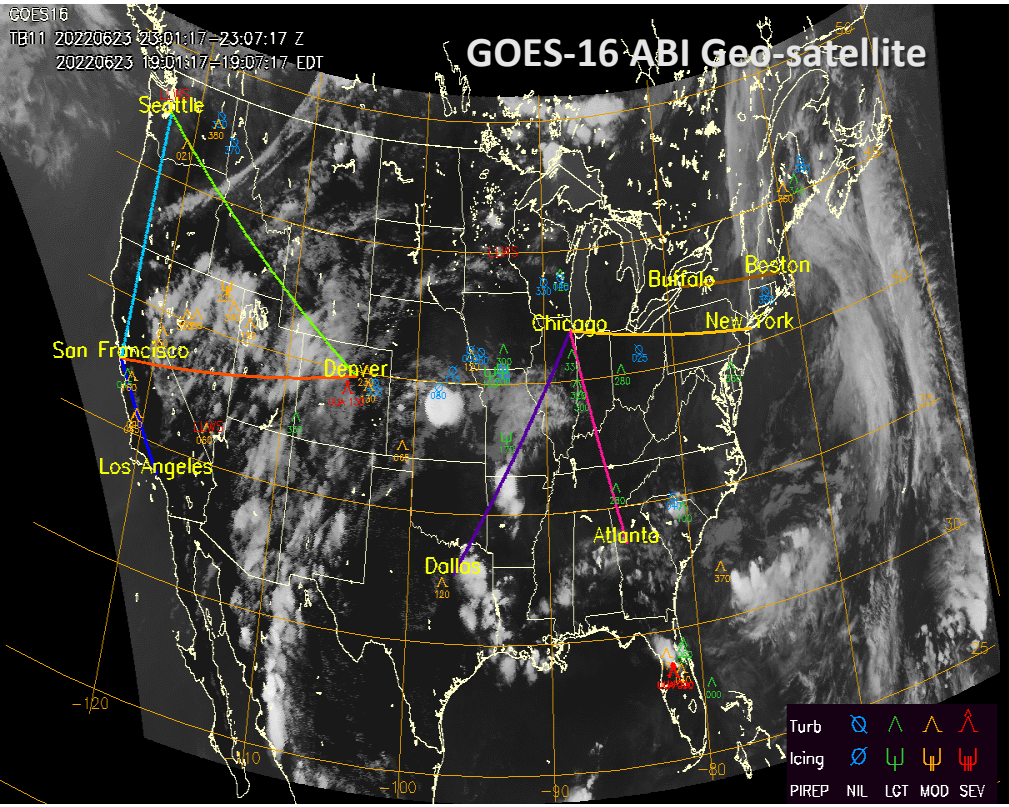
- Experimental satellite cloud products for aviation users
  - Cloud Vertical Cross-sections along selected flight routes from NOAA Enterprise Cloud Products, temperature (NWP/NUCAPS), terrain, PIREPs (icing/turbulence)
  - Ongoing improvements based on user feedback
  - NOAA JPSS Aviation Initiative/Alaska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

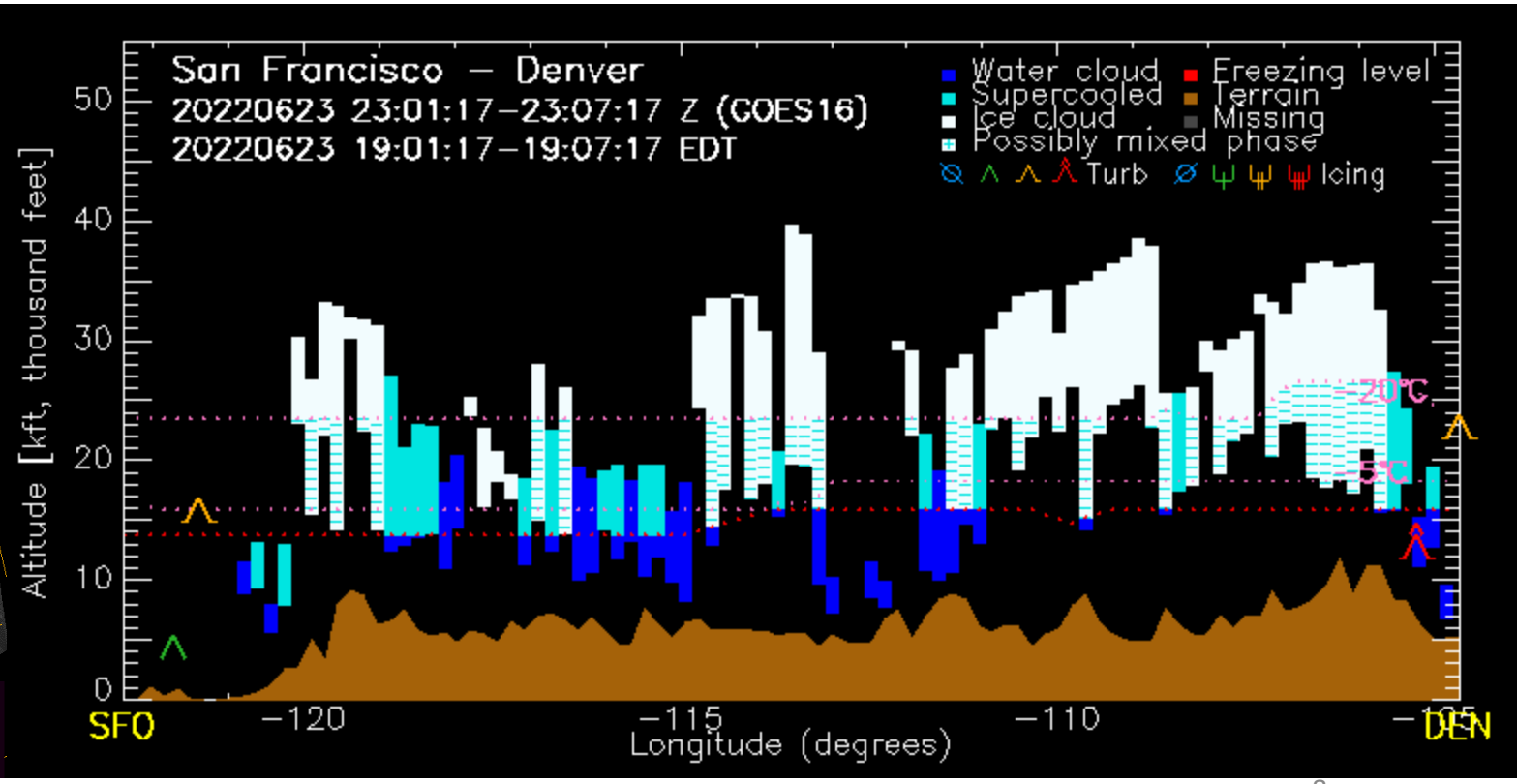




Cloud Vertical Cross-sections along flight paths

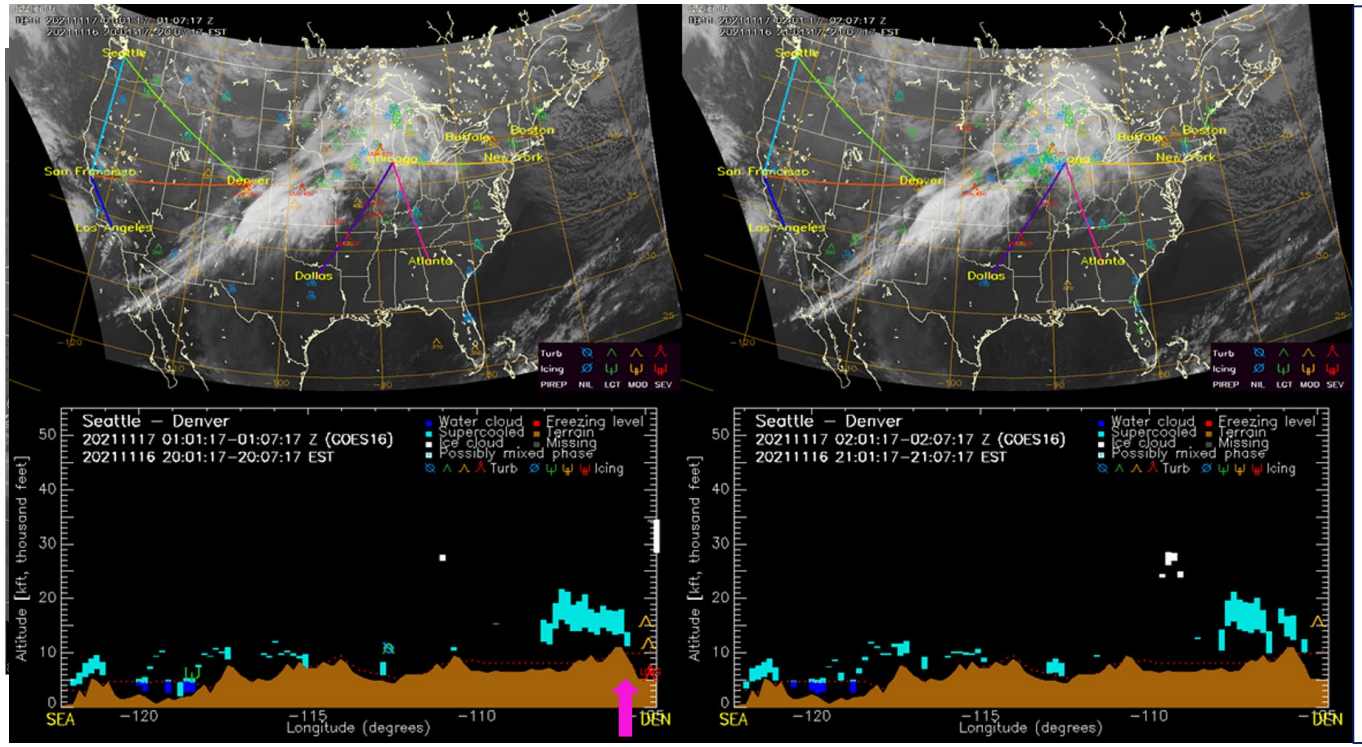
- Experimental satellite cloud products for aviation users (**CONUS**)
  - Extending the test domain to CONUS using both **JPSS-VIIRS and GOES-R ABI data**
  - Provide an evaluation tool for VIIRS/ABI cloud product inter-comparisons





User engagement

- 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**

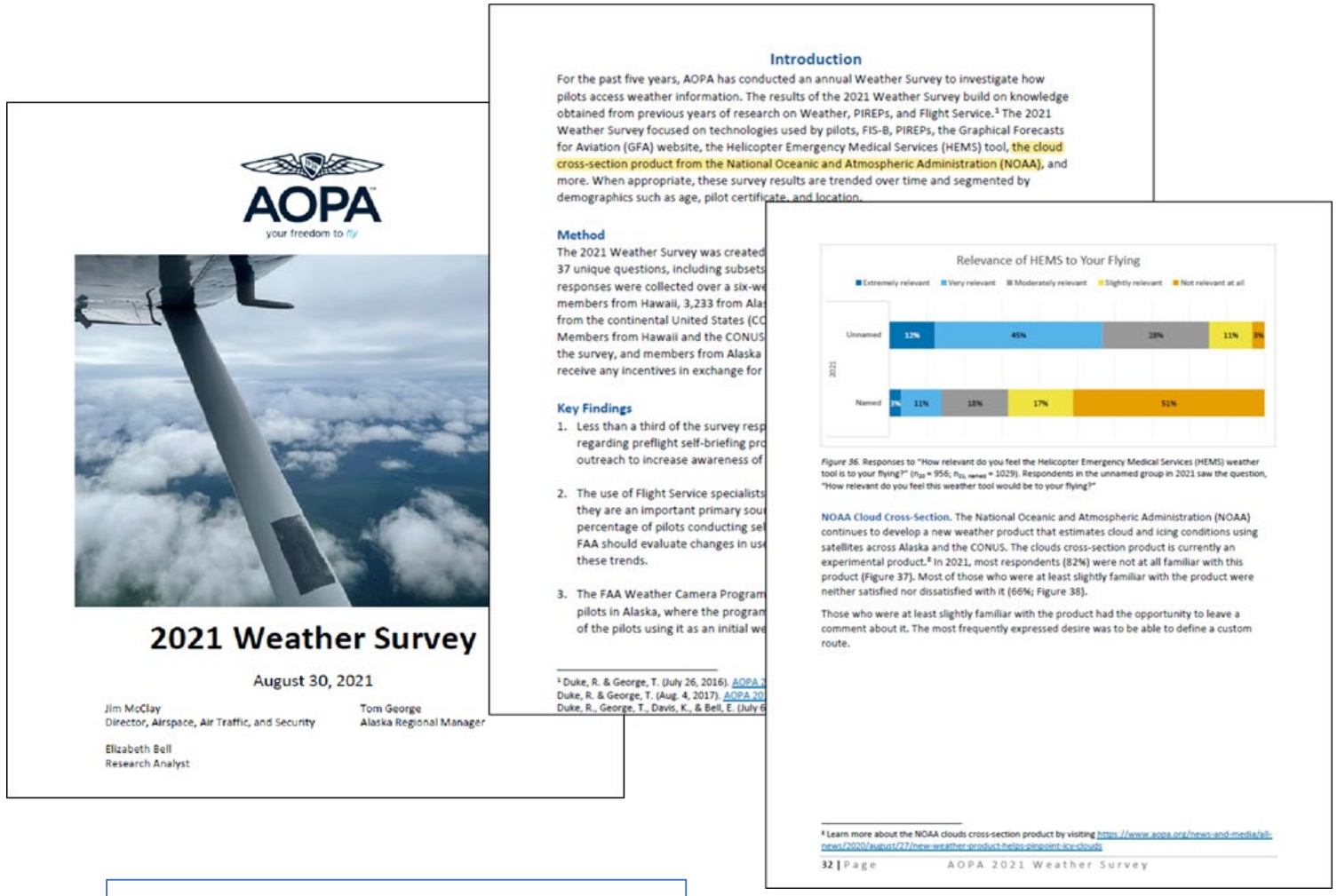


The CIRA team provided NTSB with imagery and cloud vertical cross-section products for the fatal Kruger Rock fire fighting air tractor crash case (an Air Tractor AT-802A) which occurred around1844 MST (0144 UTC Nov. 17) on 16 November 2021 near Estes Park, Colorado. The cross-sections are from GOES-16 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.

User Feedback

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*

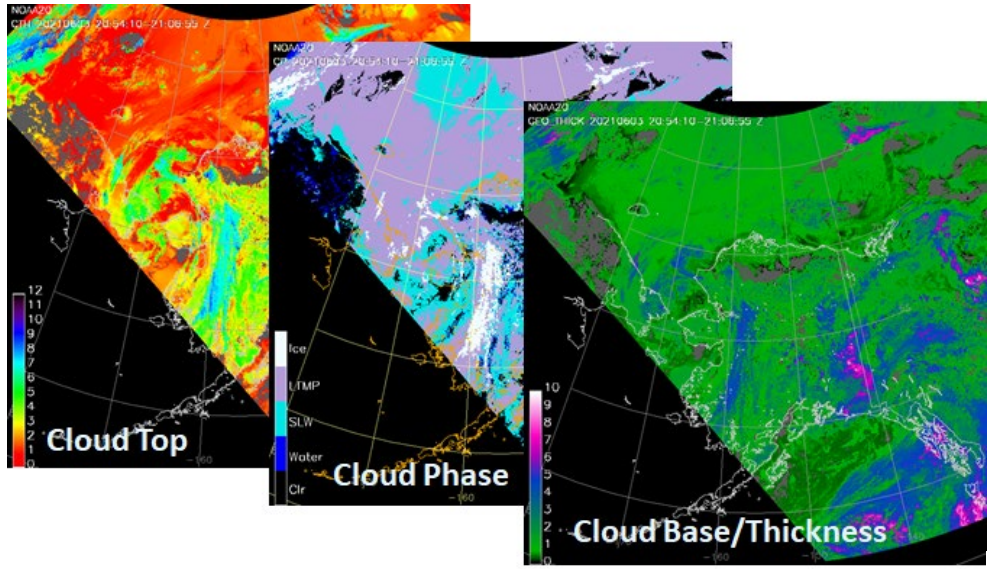


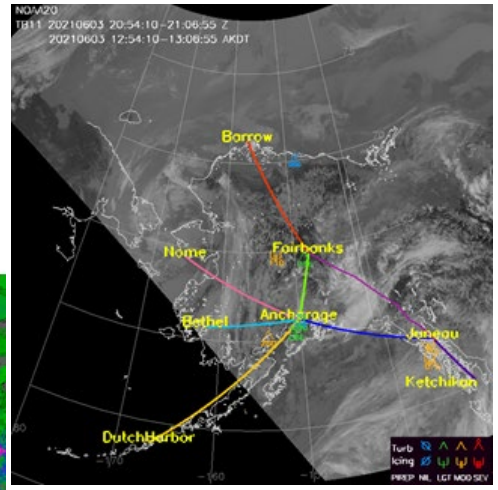
Thanks to Tom George (AOPA) and Adam White (AK Airmen Assoc.)

Gridded 3D Cloud Data

- 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)

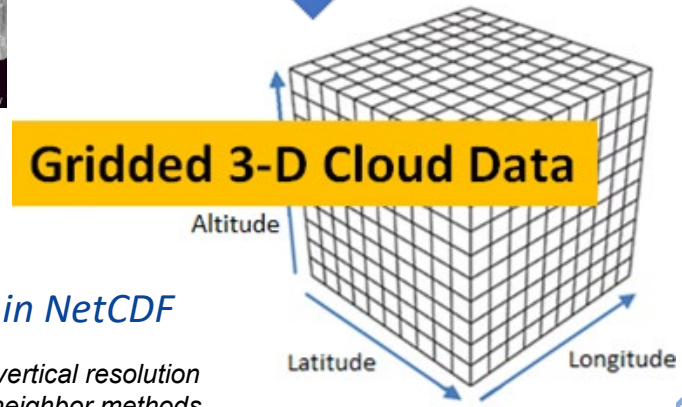




Temperatures (NUCAPS/NWP)
Terrain
PIREPs (Icing/Turb)

Compact 16-bit integers in NetCDF

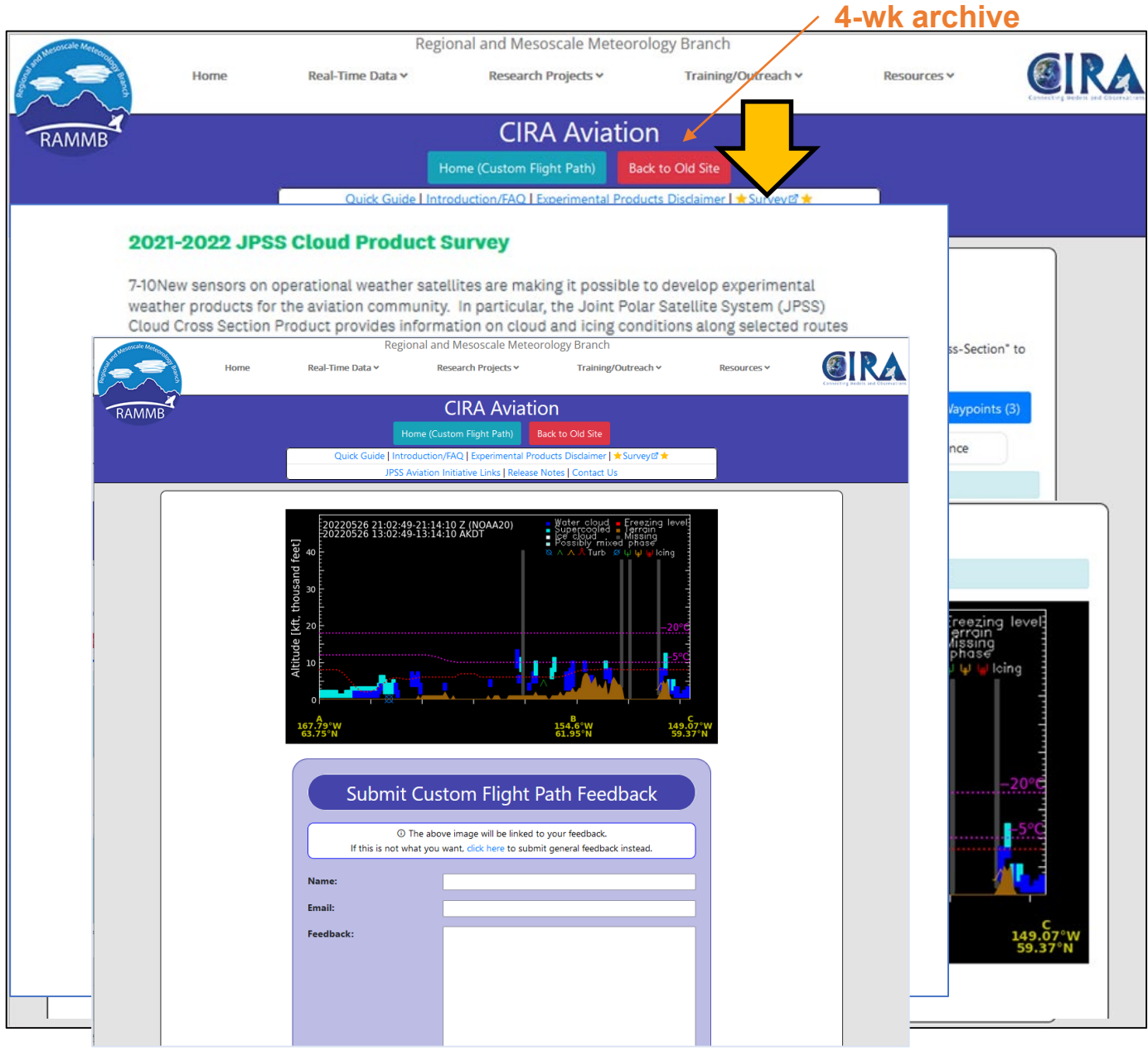
0.02 ° X 0.02° with 51 levels at 1000 ft vertical resolution over AK with inverse distance/nearest neighbor methods



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!



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- **Adding a preliminary CONUS domain with ABI (to be launched soon!)**

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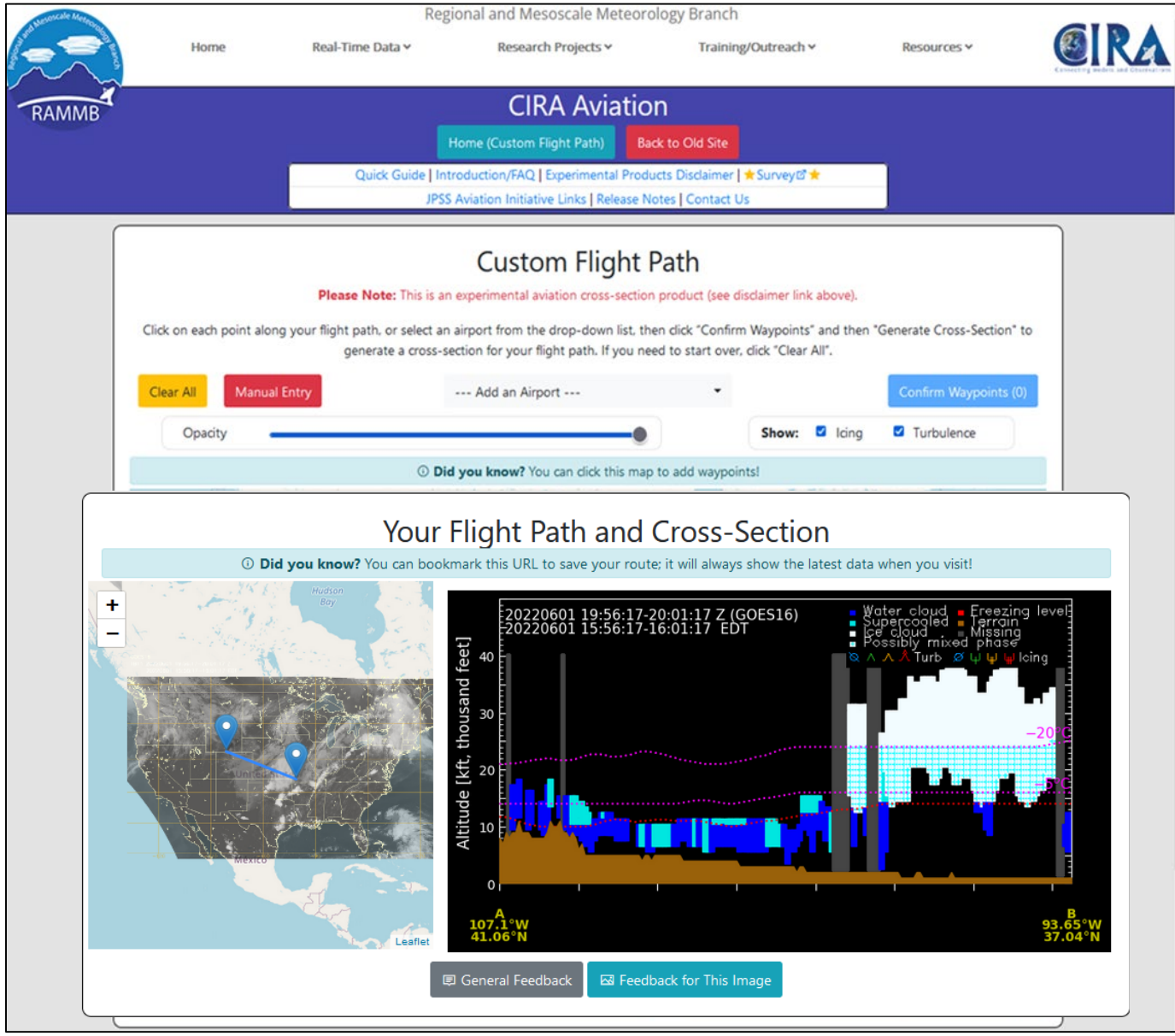
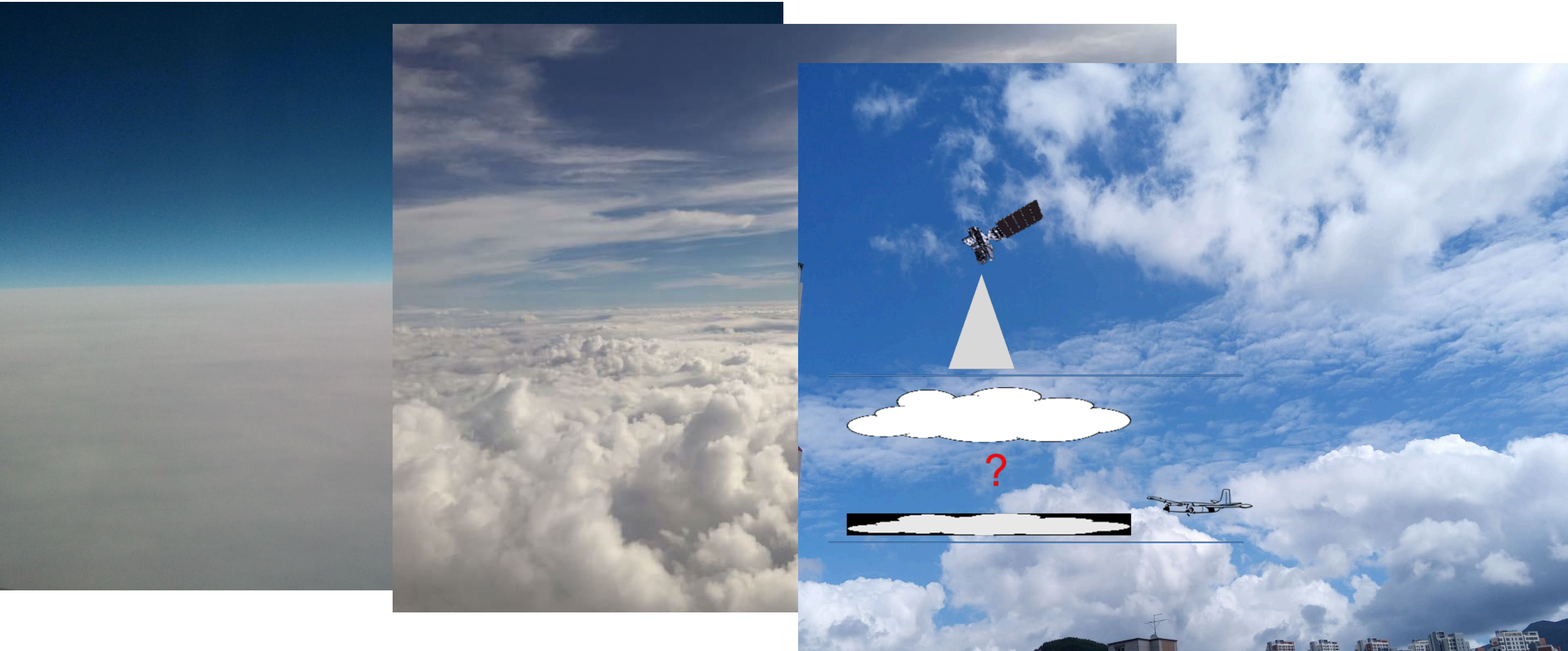
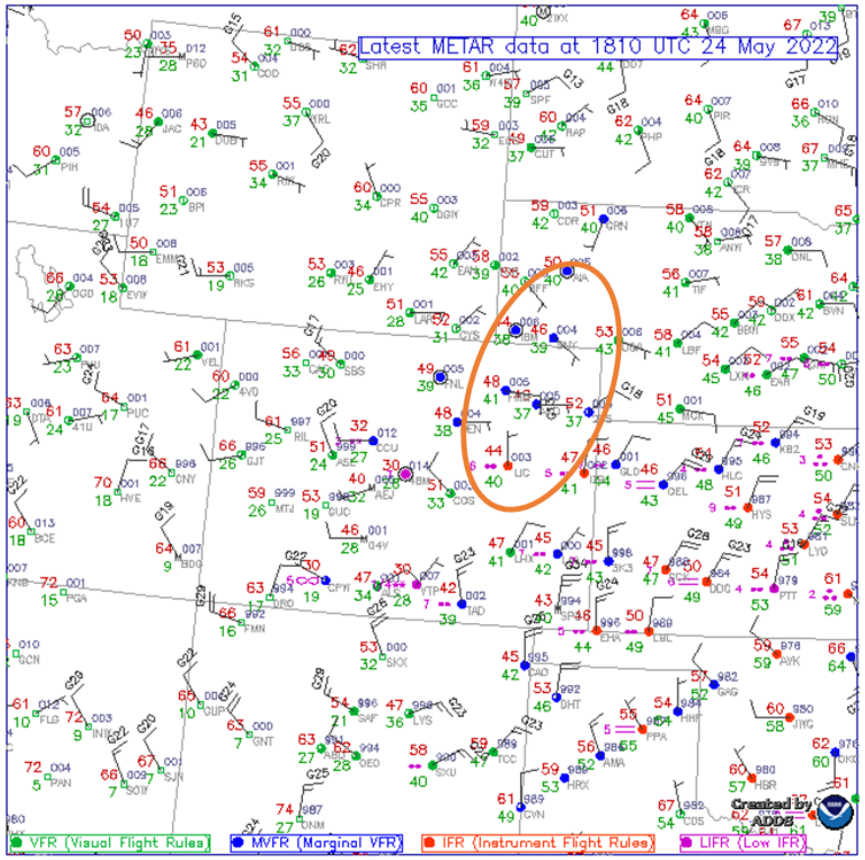


Multilayer Clouds

- 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



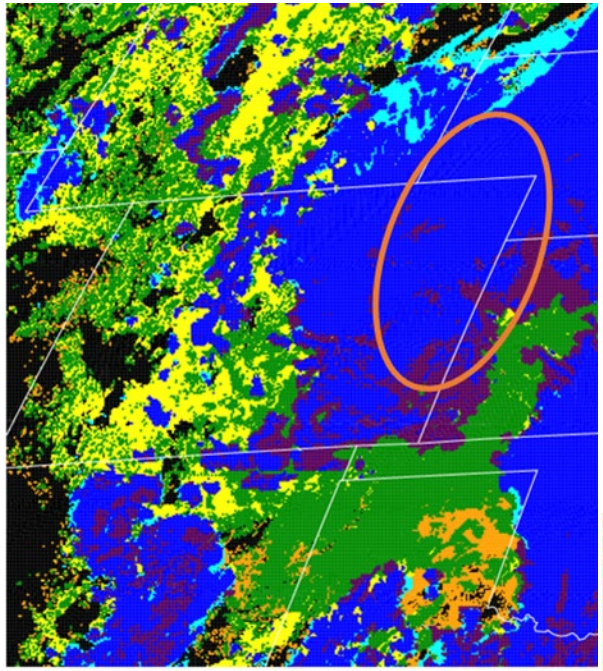
Example case study: upper-level low exits Rockies

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

These ceilings are better represented with machine learning addition

KOGA 241755Z AUTO 11003KT 10SM SCT027 SCT032 OVC038 12/06 A3006 RMK AO2 T01170061 10120 20070

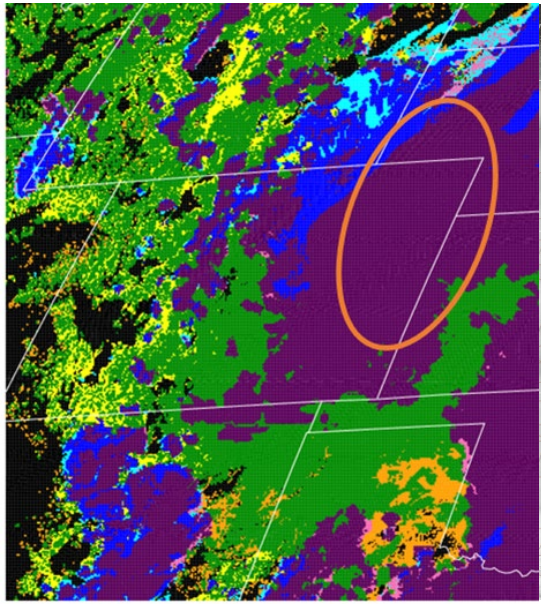
KSTK 241735Z AUTO 04004KT 10SM OVC021 09/05 A3004 RMK AO2



CCL supplemented by RF on global scale

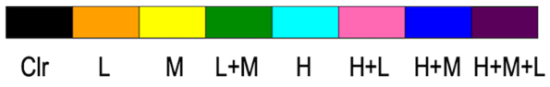
Before **machine learning**

After **machine learning**



More deep clouds (purples)

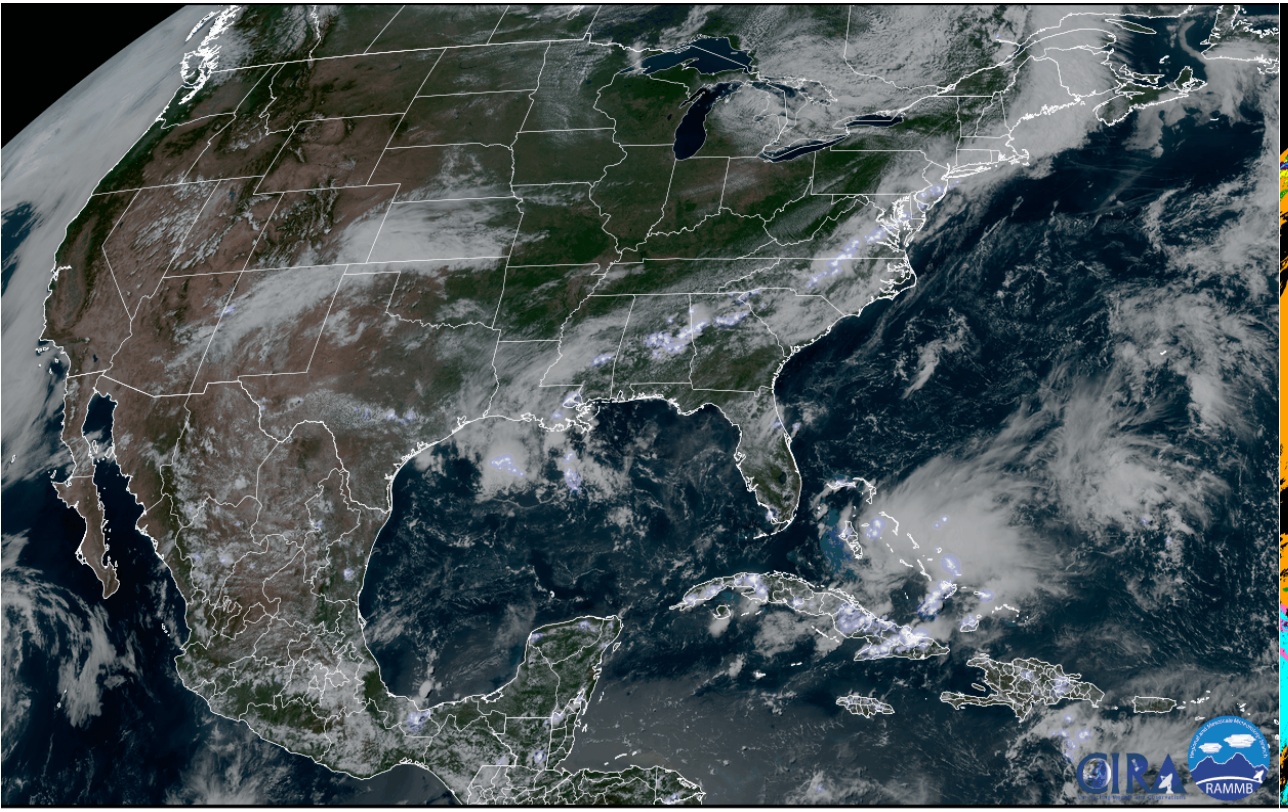
NEW high-over-low (pinks)

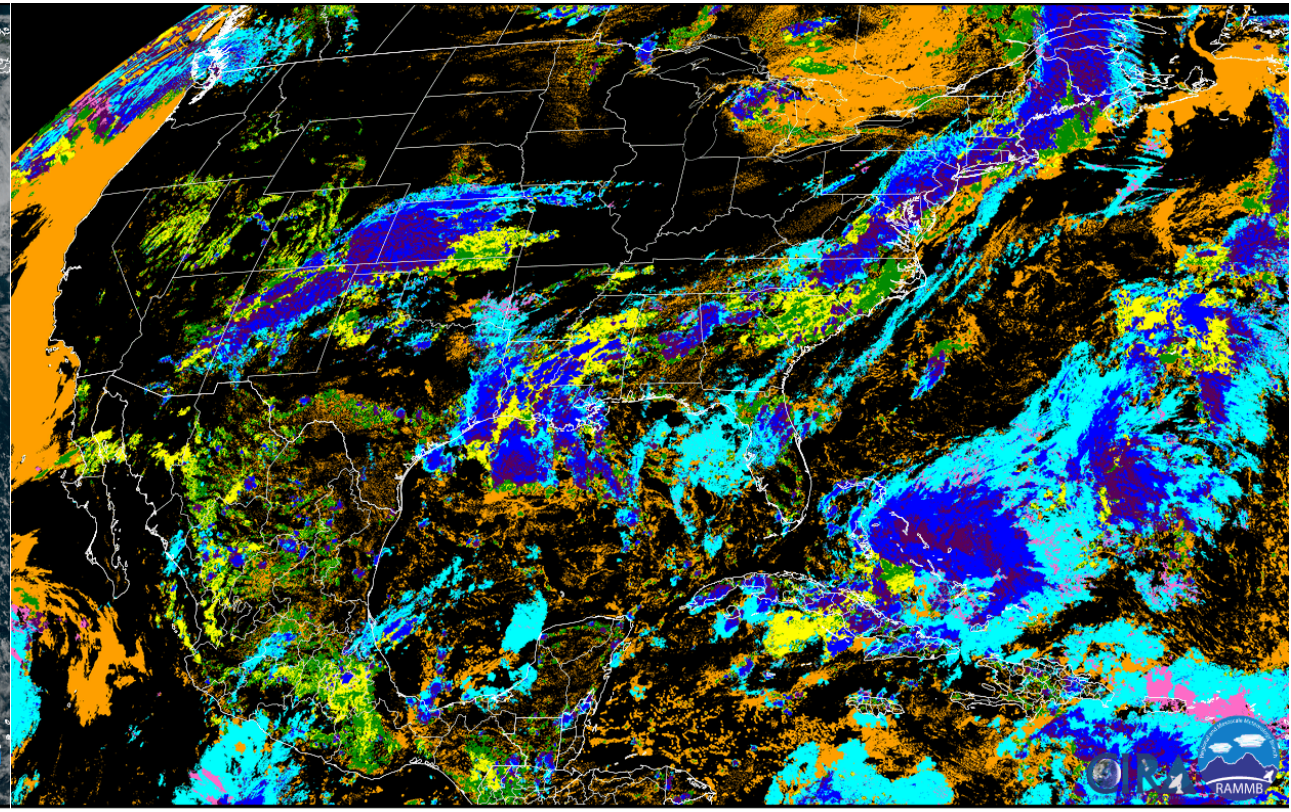


Case: 2022/05/24 18:10 UTC

Improved Cloud Cover Layers with ML

- **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)





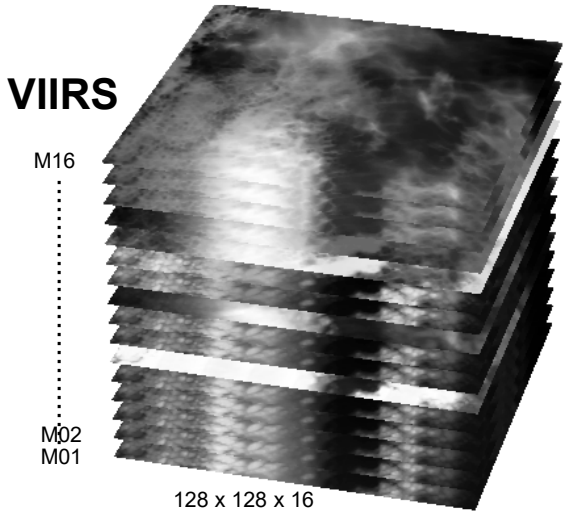
GOES-16 ABI GeoColor with GLM overlay (L2 group energy)
1851 – 1951 UTC (every 10 min) 27 June 2022

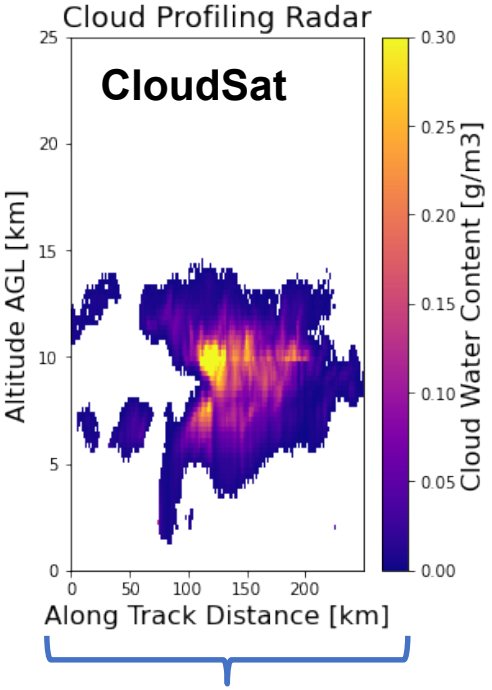
AI-based Cloud Water Profile Estimation

- 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

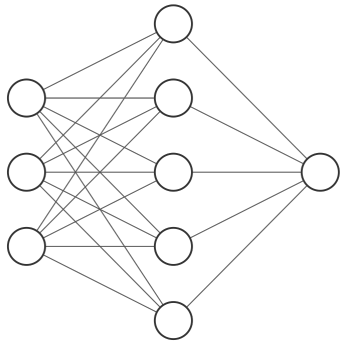
- ***Complete the 3D cloud structure information***
- ***Potentially to help improve the vertical icing potential detection***

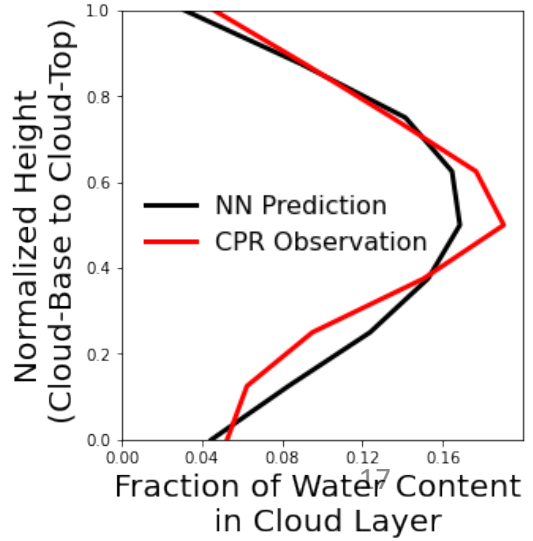
(Chuck White et al.)



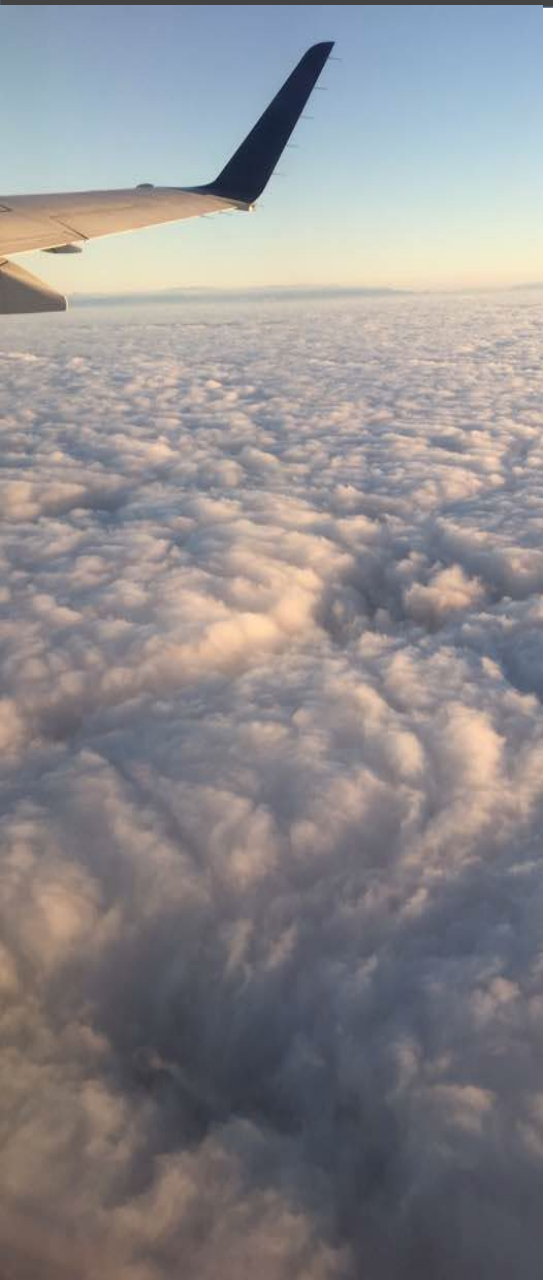


Fully-Connected or
Convolutional Neural Network





Summary



- 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