National Aeronautics and
Space Administration

Novel hourly-resolved global cloud properties derived from operational satellites

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Global Cloud Properties from Satellite Imager Data for Weather and Climate

Satellite Cloud Observations and Radiative Property retrieval System (SatCORPS)

https://satcorps.larc.nasa.gov

Cloud Climate Data Records (supports NASA CERES/RBSP)

- Global cloud analyses from MODIS, VIIRS and GEOsats since 2000 needed to determine Earth's radiation budget and cloud feedbacks
- Algorithms designed for consistent application to 25+ satellites in the CERES record.

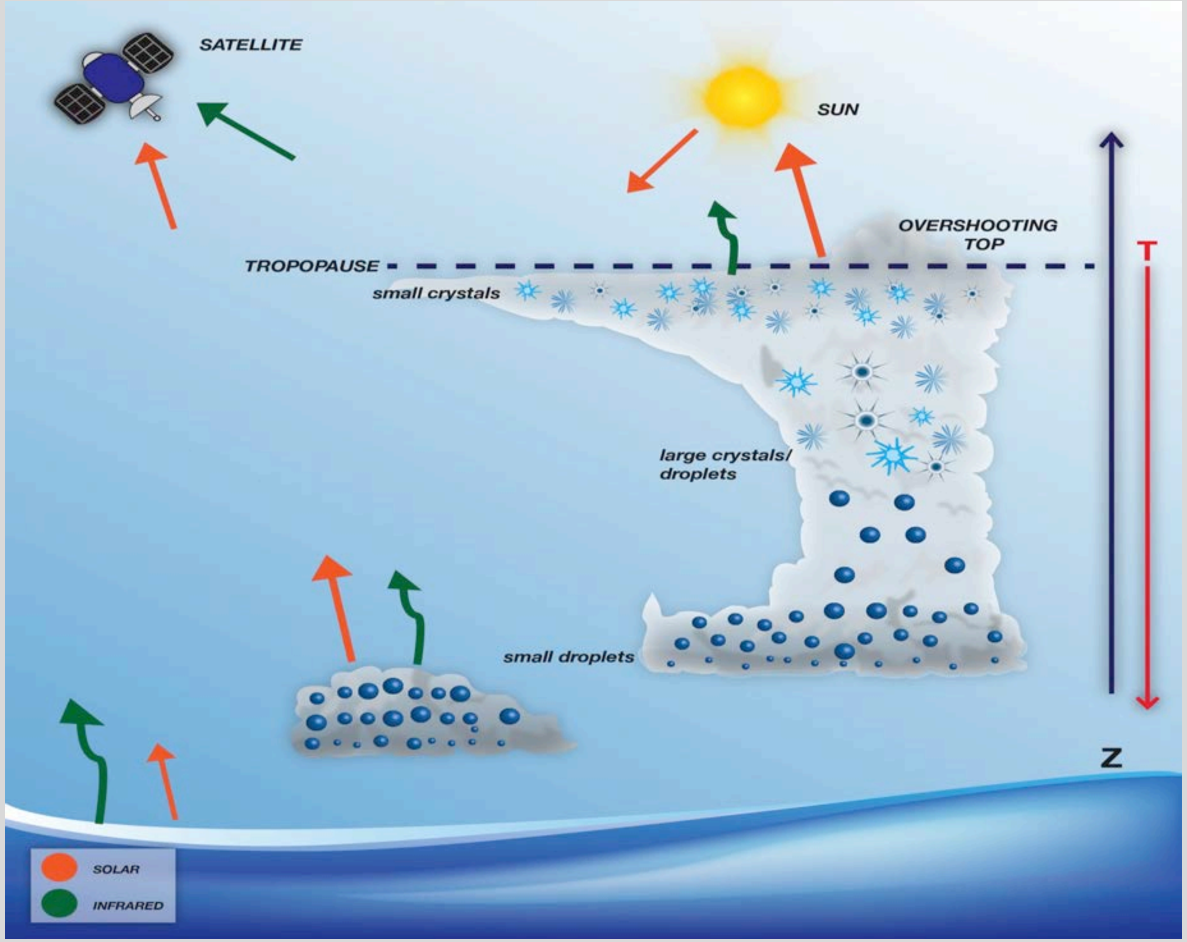
Operational applications and other research needs

- Near-realtime and historical cloud analyses (mostly focused on global GEO's)
- Data used to support field campaigns, weather forecasting, cloud process research, model development (cloud parameterizations), etc.

What Cloud Information do Satellite Imager Retrievals Provide?

Utilize spectral radiances from meteorological satellite imagers (e.g. MODIS, VIIRS, AVHRR, GEOsats)

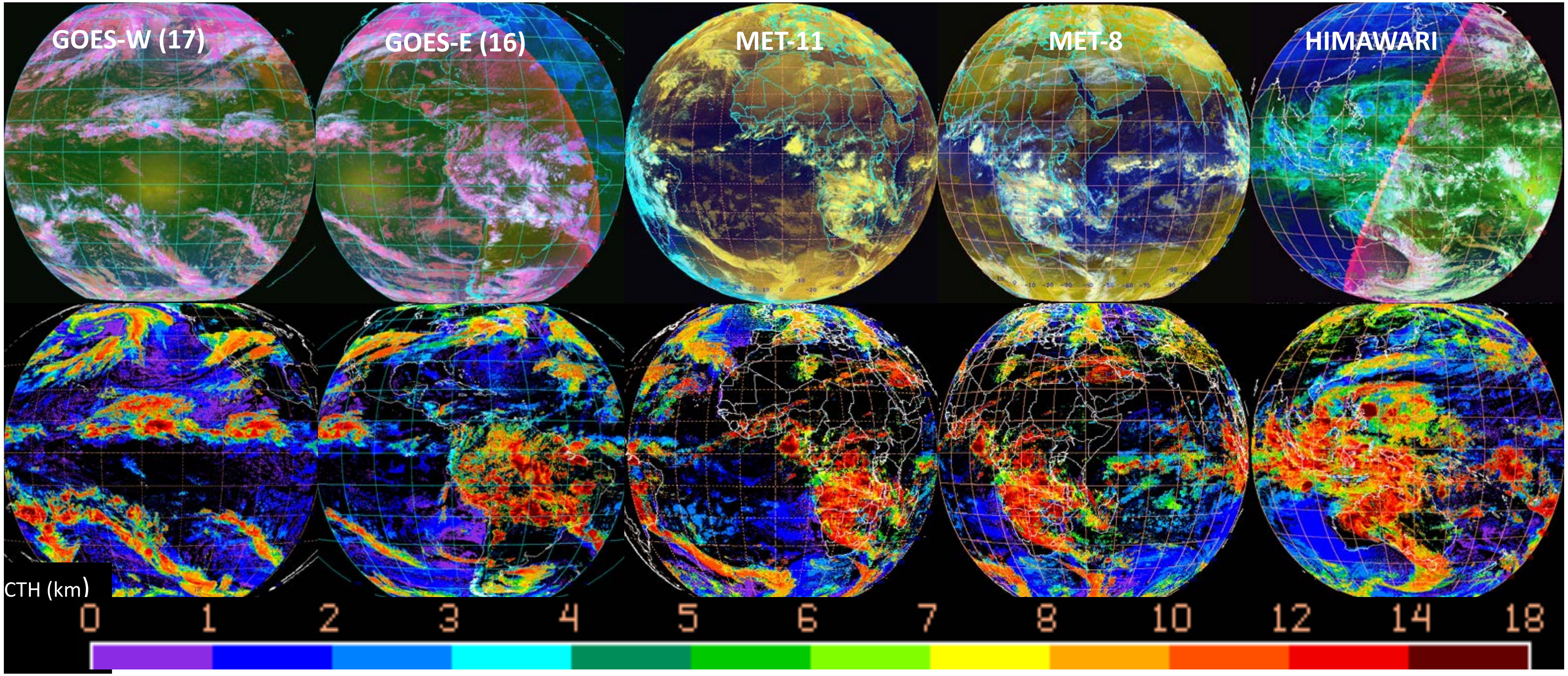
- Cloud parameters can be derived from just a few channels **(0.65, 3.7, 10.8 µm)** common to most satellites
- Additional channels on more modern satellites can provide more information, help better detect thin clouds, and better distinguish clouds from aerosols



Standard data products

- Cloud mask
- Cloud optical depth
- Cloud top thermodynamic phase, and droplet effective radius
- Cloud temperature => top height, pressure
- Cloud thickness and base height
- Liquid and Ice Water Path
- Icing, HIWC, Convection/OT’s

The Satellite ClOud and Radiative Property retrieval System (SatCORPS)



SatCORPS team operates and utilizes a LEO and GEO imager data production and visualization system with real-time and historical capabilities

Satellite Remote Sensing of Clouds from Passive Sensors

Steps:

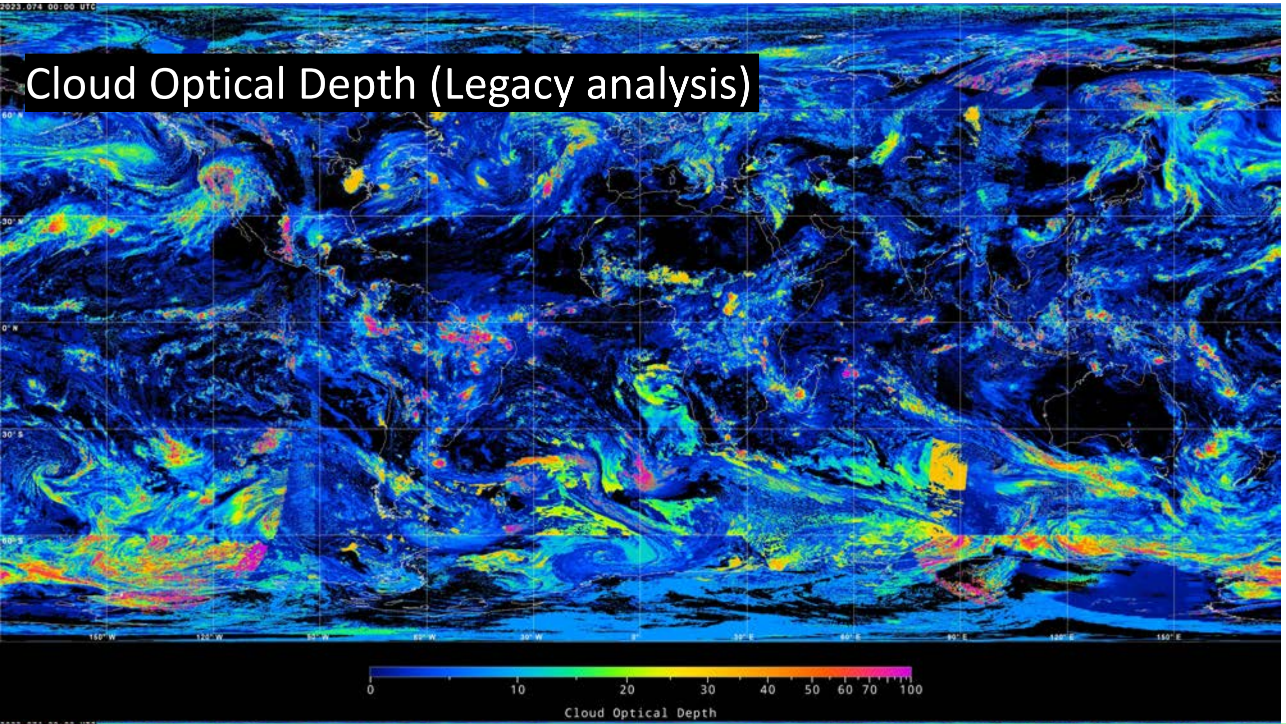
1) <u>Imager Intercalibration</u>: Tie calibration of various imagers together so they are on same radiometric scale
2) <u>Apply Cloud Mask</u>: Apply series of threshold tests involving various imager channel combinations to determine if an imager pixel is clear or clouds
3) <u>Derive Cloud Properties</u>: Inversion procedure compares calculated radiances from a 1D radiative transfer model for a wide range of cloud conditions with the measured radiances and selects the cloud properties that provide the closest match between computed and measured radiances (applies atmospheric corrections and accounts theoretically for variations in Earth-sun-satellite geometry)

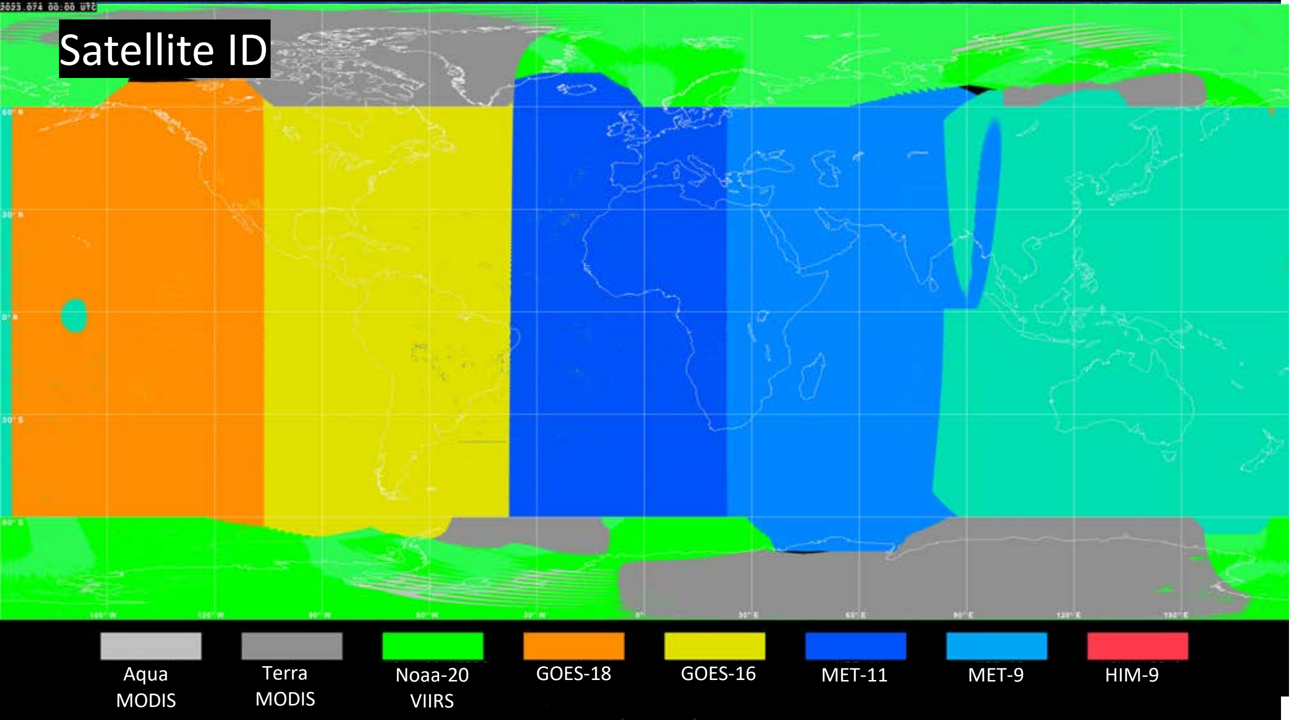
Validation:

- Compare cloud properties with those from active sensors (e.g. CloudSat and CALIPSO), from ground stations (e.g. ARM microwave radiometers, lidars, etc) and from aircraft (e.g. ICICLE and other airborne science campaigns)

Improvements: improve cloud retrievals and applications as state-of-the-art advances

Global Cloud Composites (GCC) from Satellites



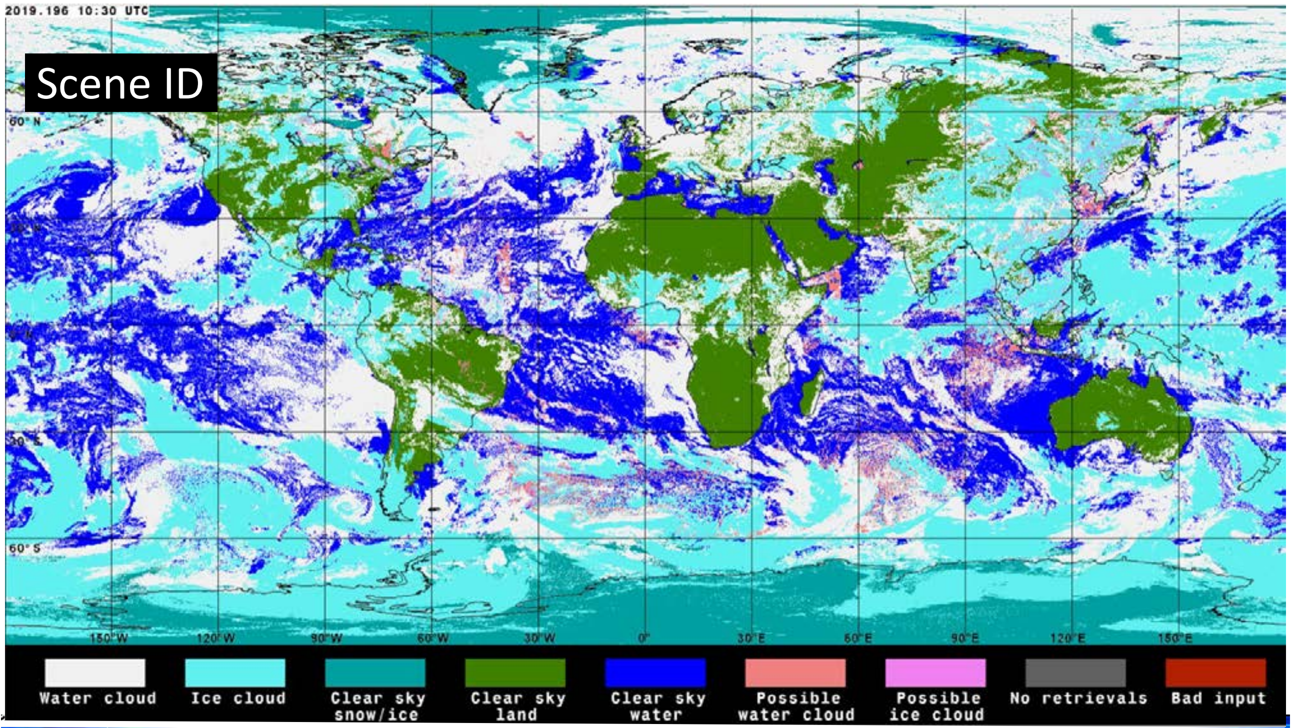


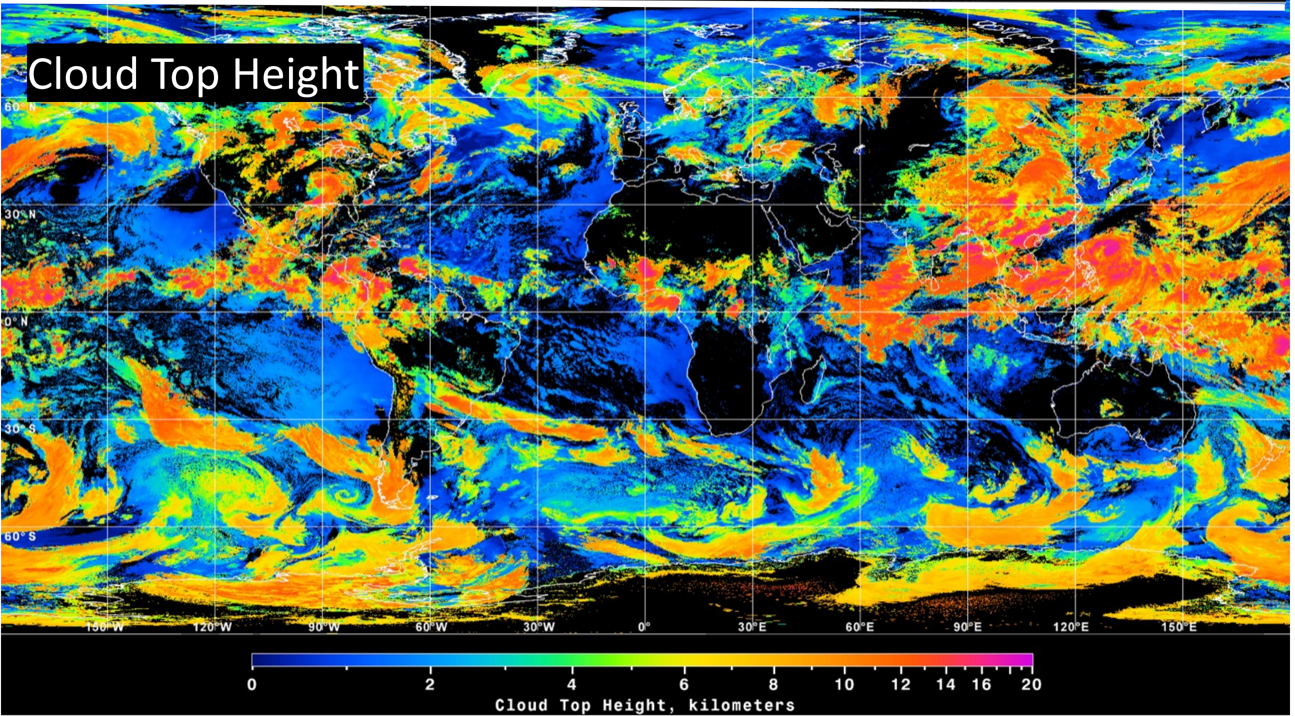
Objective: Optimally combines GEO and LEO radiances and derived products (cloud properties and radiative fluxes) as seamlessly as possible into a unified global data product

Legacy system is complex with many independent processes to support the various applications.

New GCC system is streamlined enabling one overarching global data production system for most needs

- 3-km gridded cloud properties every 30-60 minutes
- Many new cloud algorithm enhancements are being implemented that improve accuracies, cross-platform consistency, and reduce artifacts
  - New atmospheric corrections (satellite dependent)
  - Improved clear sky radiances
  - More realistic ice cloud scattering model





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Satellite Cloud Remote Sensing Challenges Being Addressed with **AI/ML**

Problem Areas	AI/ML Approach
Image quality – bad scan lines in radiance imagery	Apply human visual or **CNN** QC for most cases and satellites; apply radiance reconstruction using **KNN** for severely corrupted images
Day/Night Consistency (cloud optical properties)	**ANN** to help overcome theoretical limits due to IR blackbody limit; **KNN** to extrapolate optical properties from daytime
Data products in the solar terminator and sun-glint	**KNN** to extrapolate information from surrounding space/time domain
Assumption that clouds are single-layer and have vertically homogeneous phase and PSD's	New IWP/LWP parameterizations that better account for cloud vertical structure; **ANN** for multi-layer cloud retrieval methods
Poor knowledge of land surface emission temperature (affects cloud mask and retrievals)	**DNN** to correct model reanalysis skin temperature based on correlations with satellite-derived values in clear conditions
Nighttime cloud detection in polar regions	**ANN** trained with CALIPSO data for application to MODIS/VIIRS
Cloud thickness and ceiling	Parameterizations based on CloudSat/CALIPSO groundtruth**; KNN** for satellite/ceilometer data fusion over U.S.

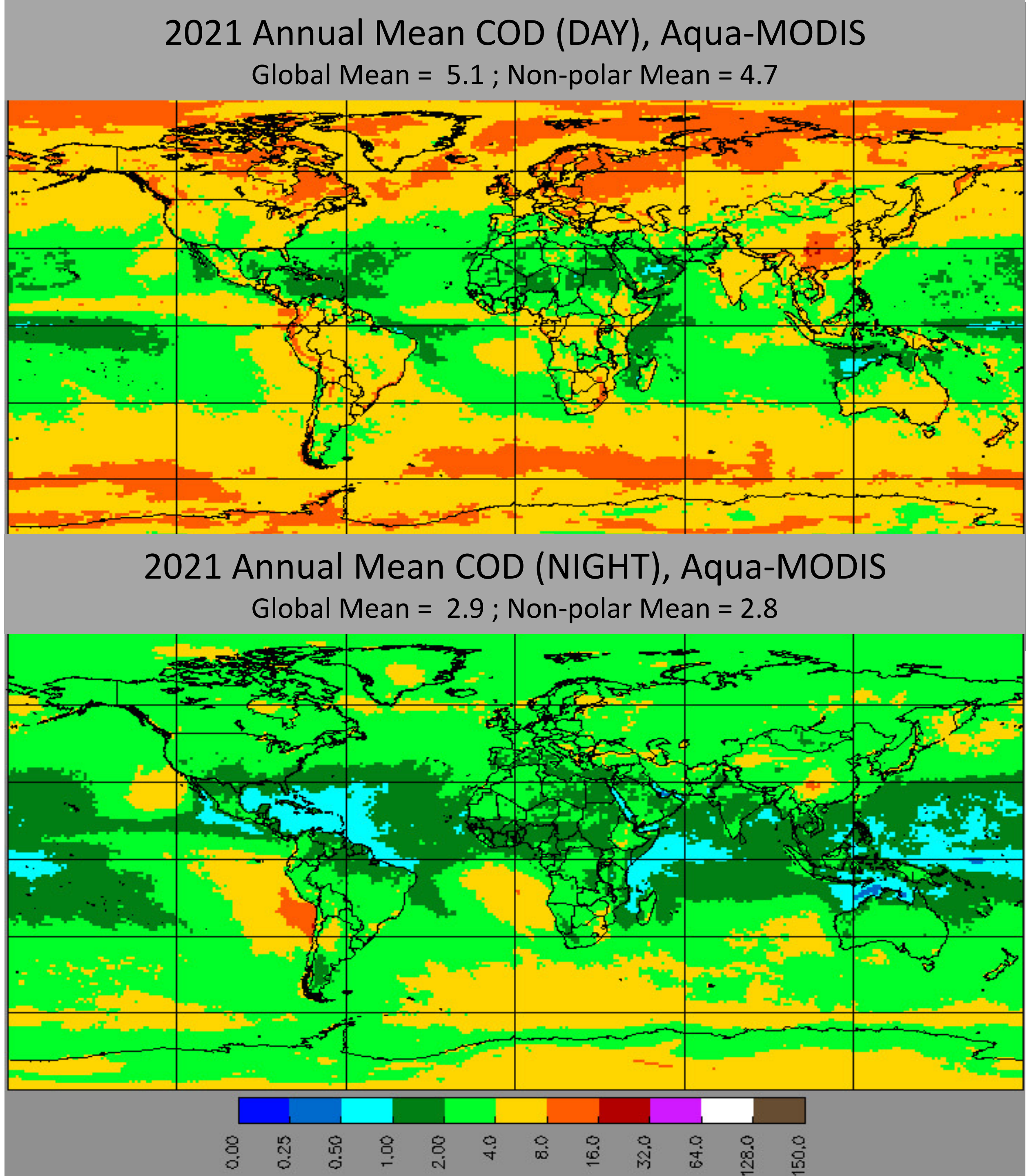
Active research areas to reduce uncertainties and improve the utility of data products

Nighttime Cloud Optical Depth (COD)

Poor consistency between daytime and nighttime

Problem:

- COD can be estimated theoretically from solar channels over a wide range during daytime
- At night, only thin cloud retrievals are theoretically possible (COD < ~6) due to IR blackbody limit
- Optically thick COD's set to pre-assigned fill values (not consistent with daytime retrievals)
- Other parameters derived from COD at night also very inconsistent and less accurate than daytime
  - Cloud ice and liquid water path
  - Cloud geometric thickness and ceilings
  - Radiative fluxes, especially SFC LW↓
  - Aviation weather hazards, e.g. icing conditions



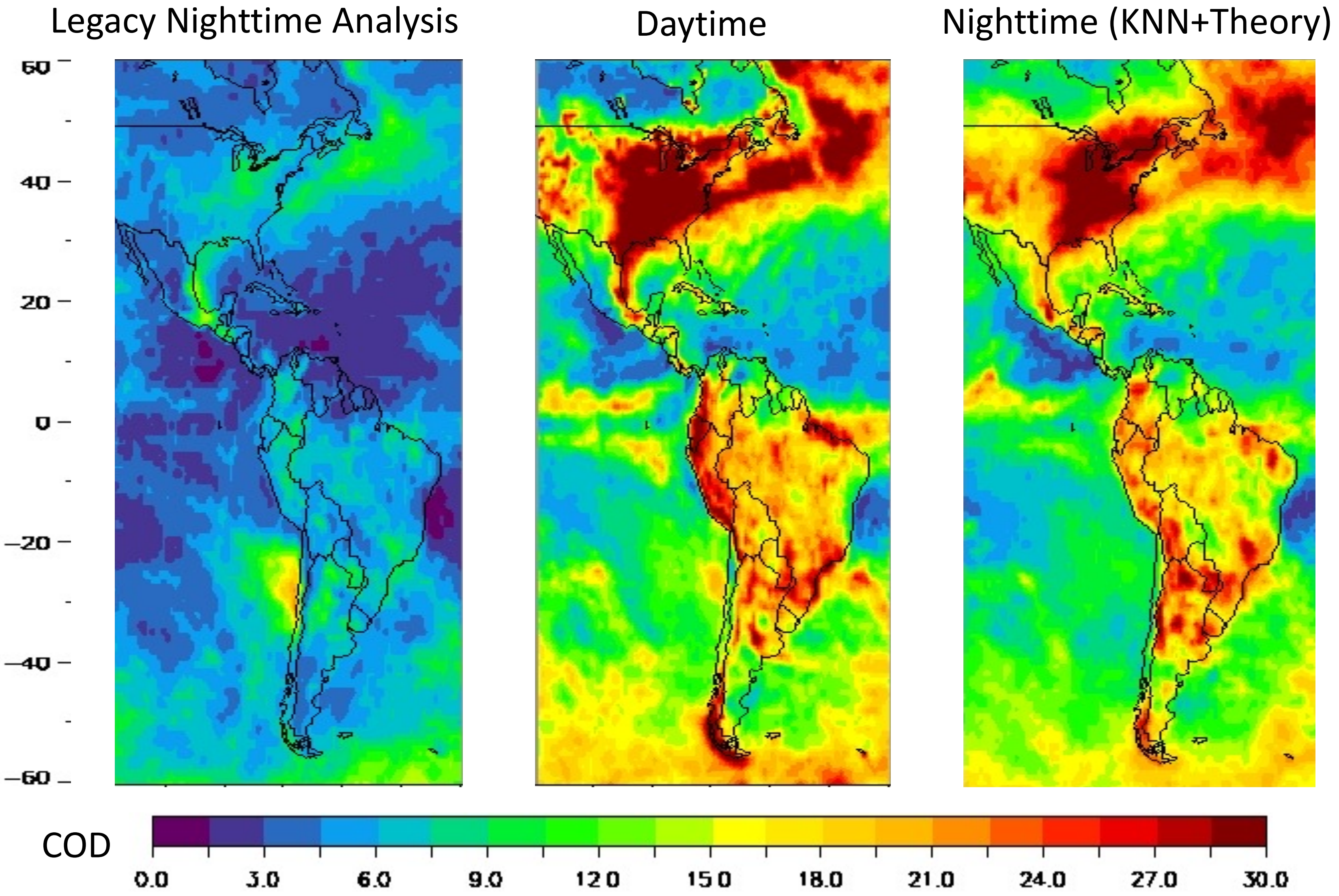
KNN Improves Nighttime Cloud Analyses

Solution:

- Apply **KNN** to extrapolate daytime COD into nighttime using 6.7 and 11 µm bands and local relationships with daytime COD

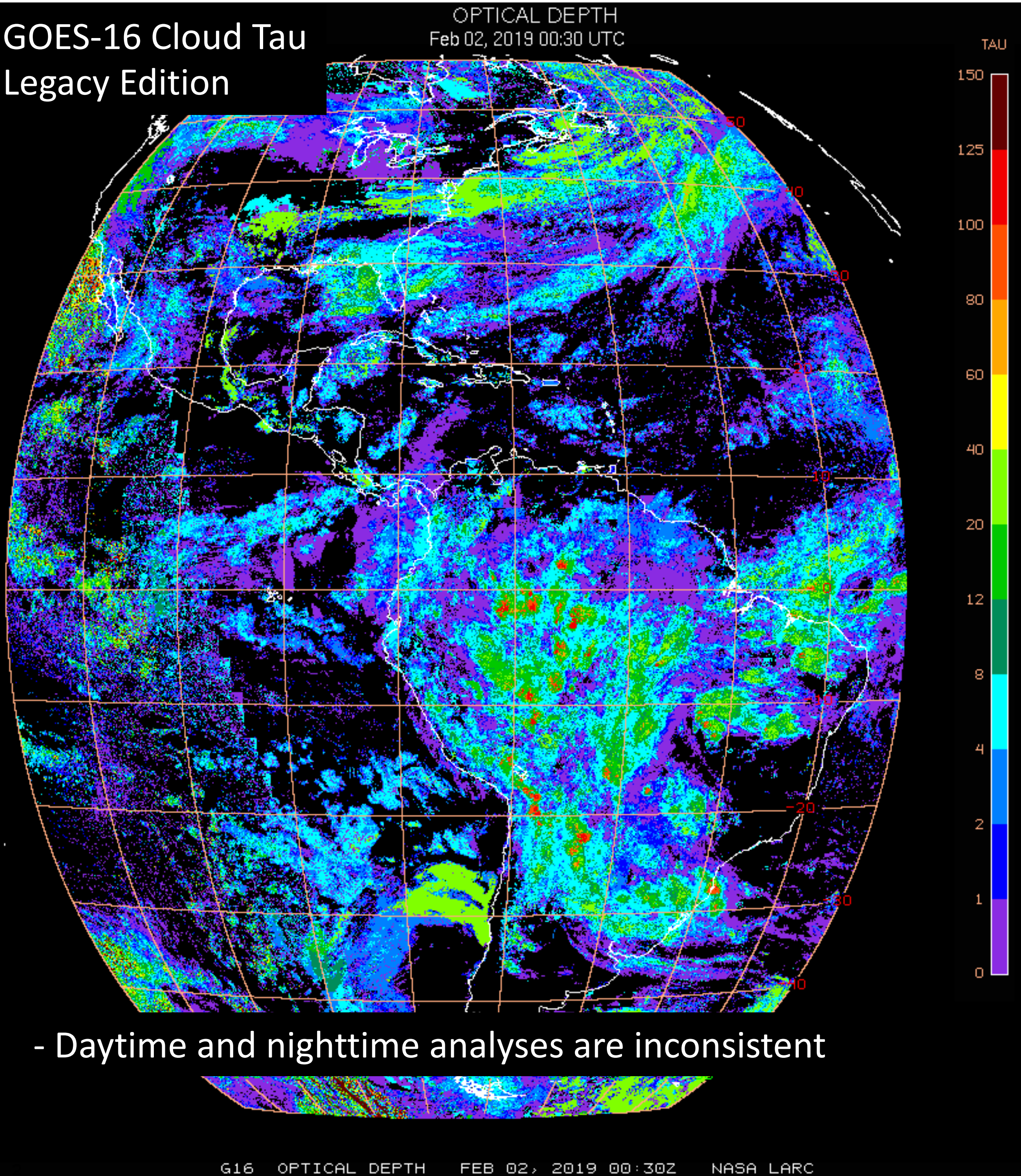
Outcome:

- Much more realistic filling method for nighttime optically thick COD
- More accurate downstream derived parameters



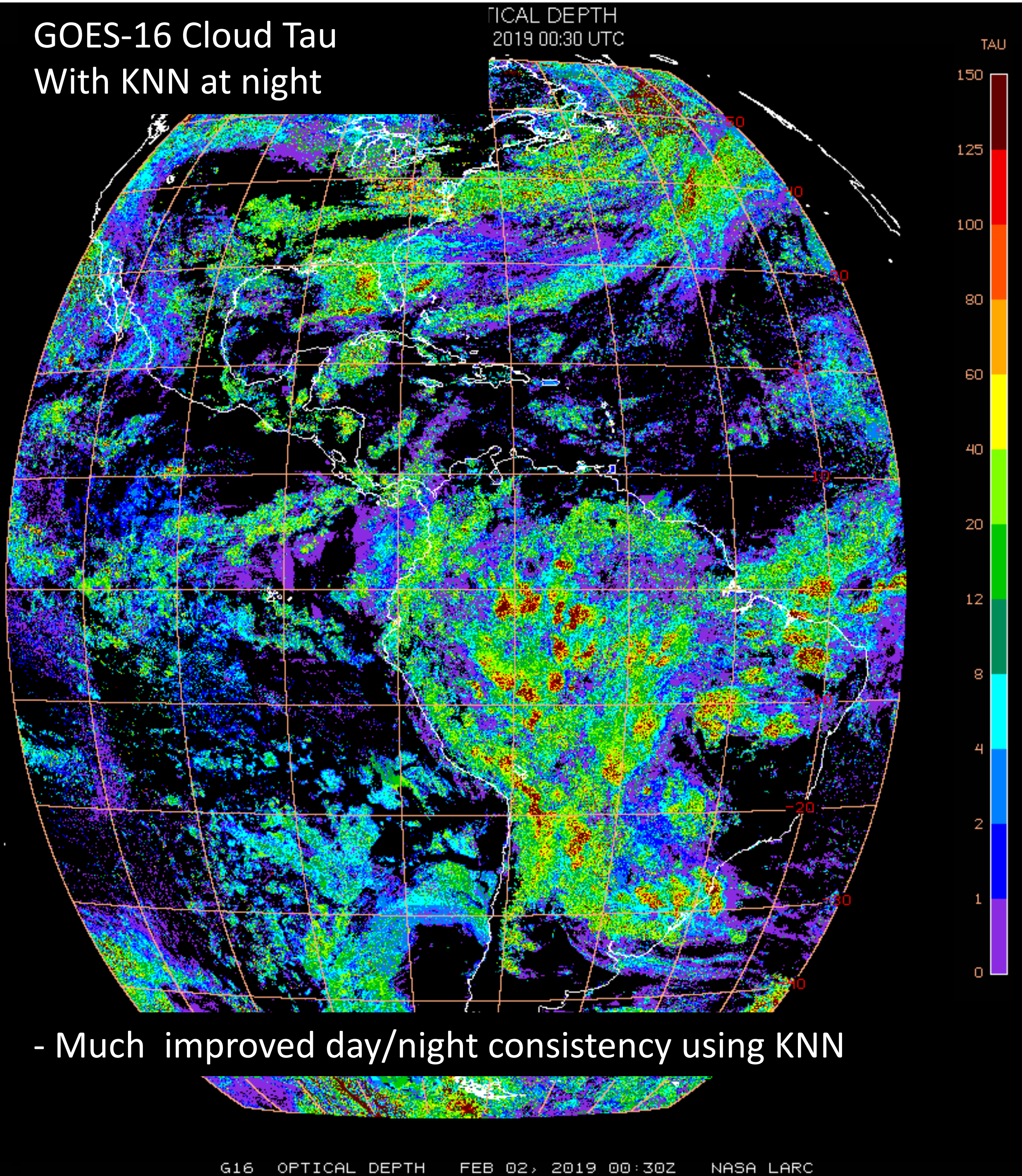
GOES-16 Cloud Optical Depth (Feb 2019)

GOES-16 Cloud Tau
Legacy Edition



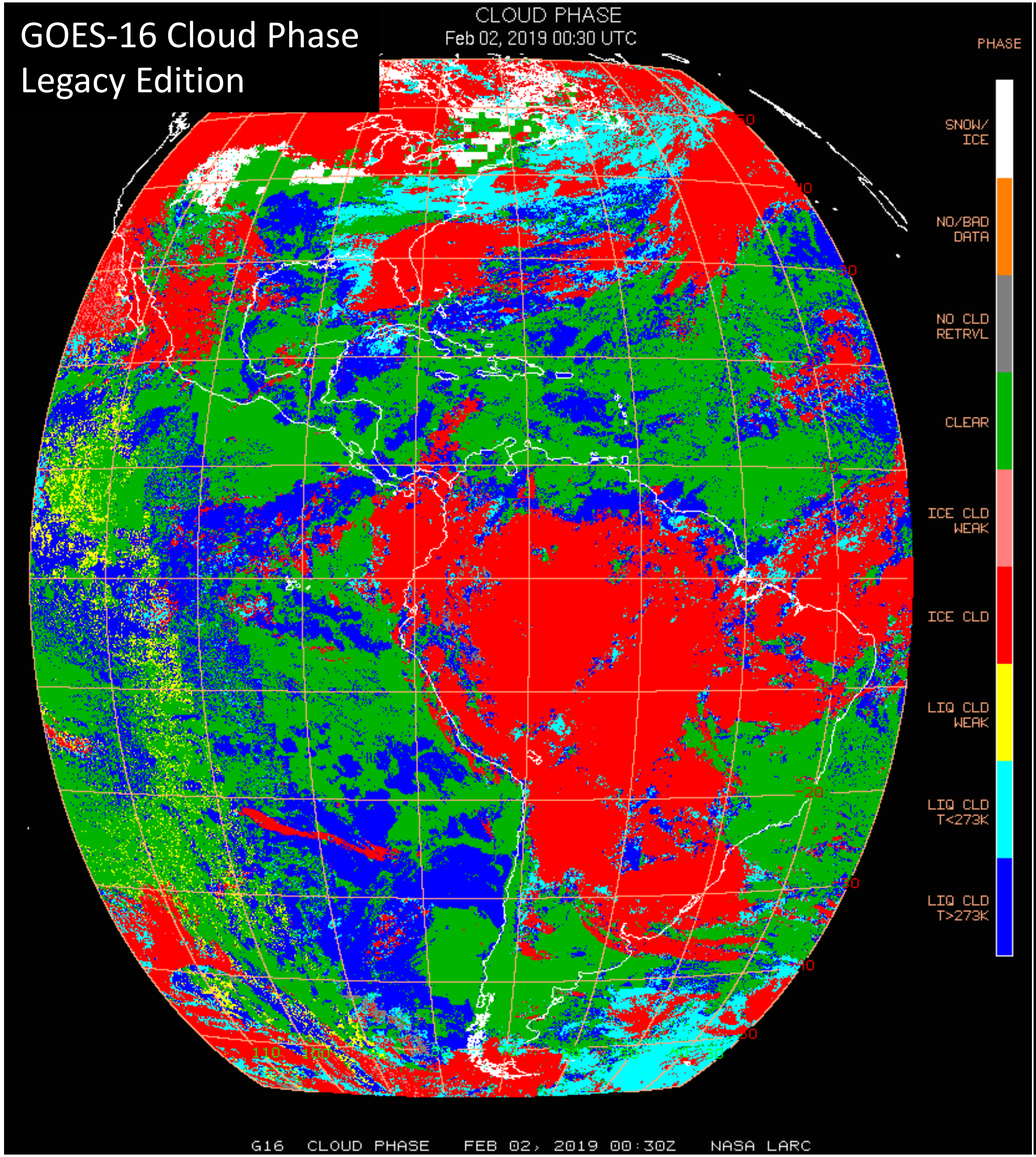
- Daytime and nighttime analyses are inconsistent

GOES-16 Cloud Tau
With KNN at night

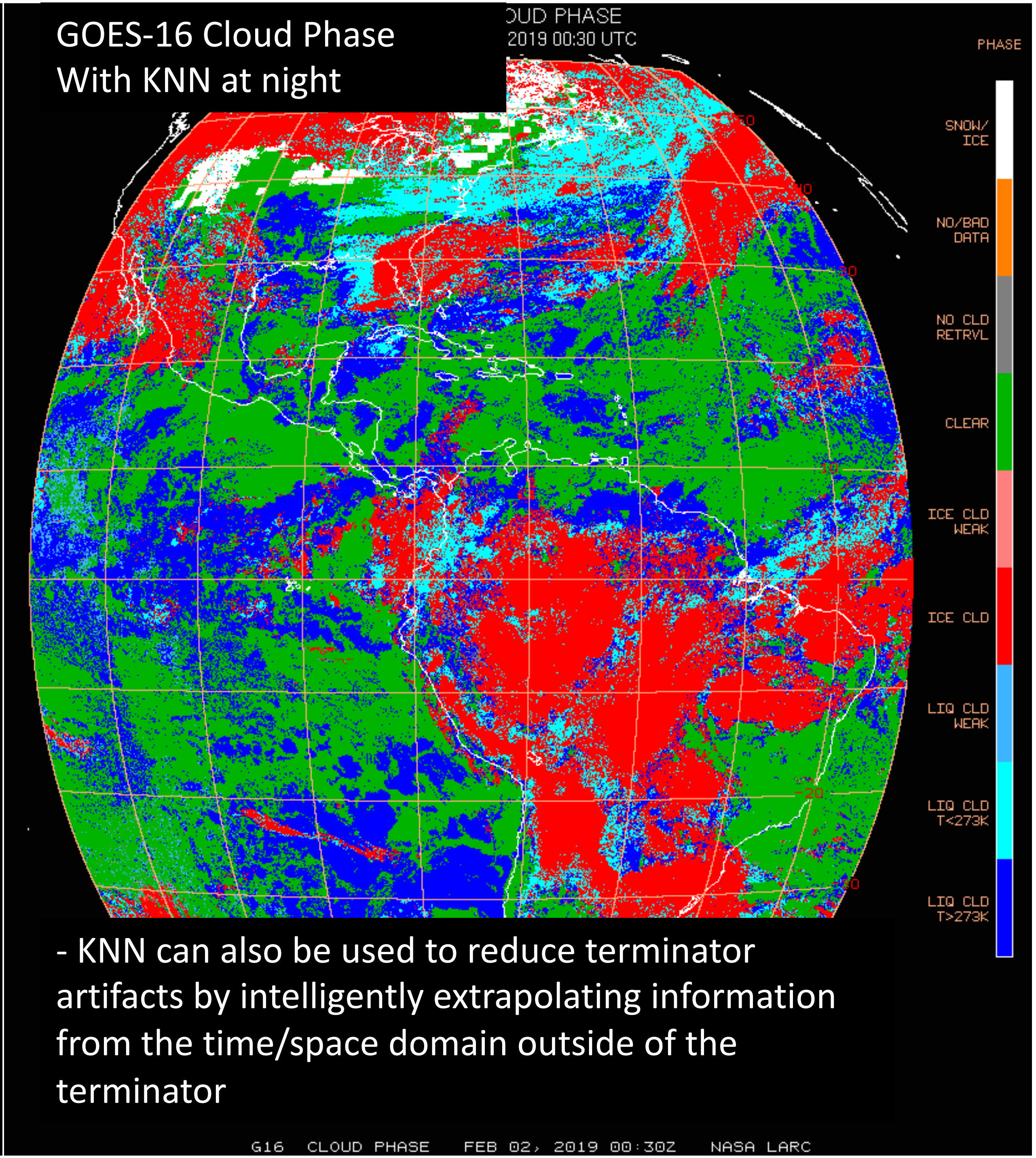


- Much improved day/night consistency using KNN

GOES-16 Cloud Phase
Legacy Edition



GOES-16 Cloud Phase
With KNN at night

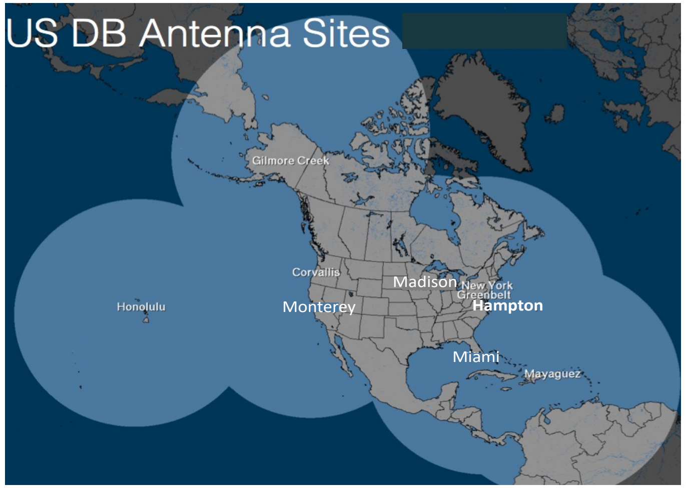


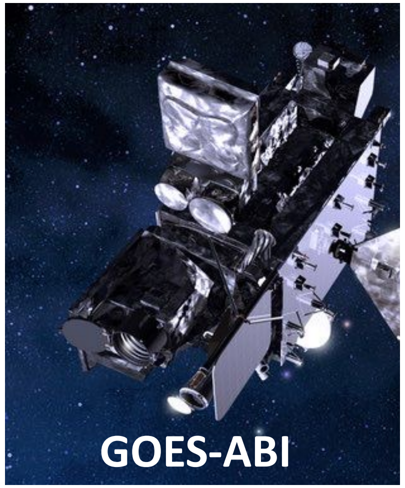
- KNN can also be used to reduce terminator artifacts by intelligently extrapolating information from the time/space domain outside of the terminator

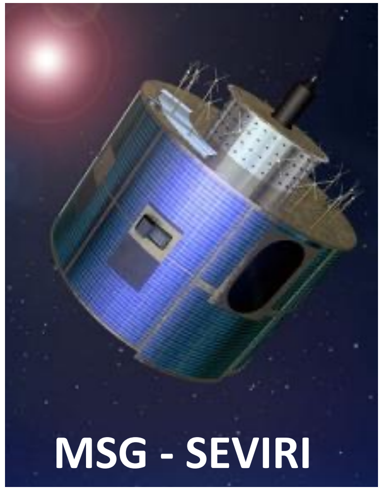
New tools for helping improve simulation of clouds

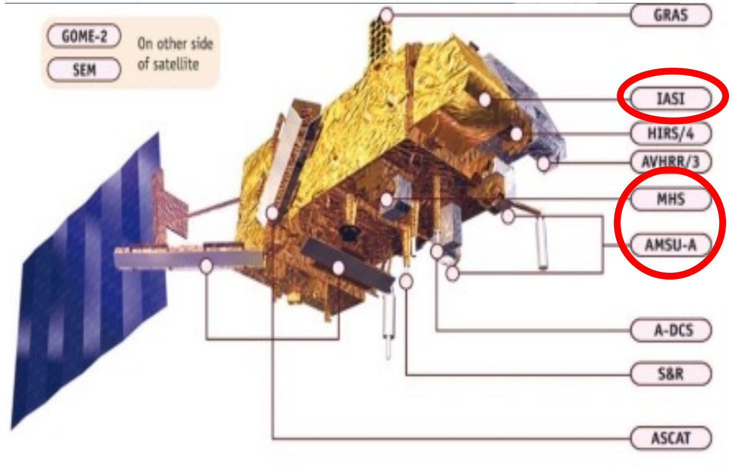
Enhancing the SatCORPS with Satellite Sounding Capabilities

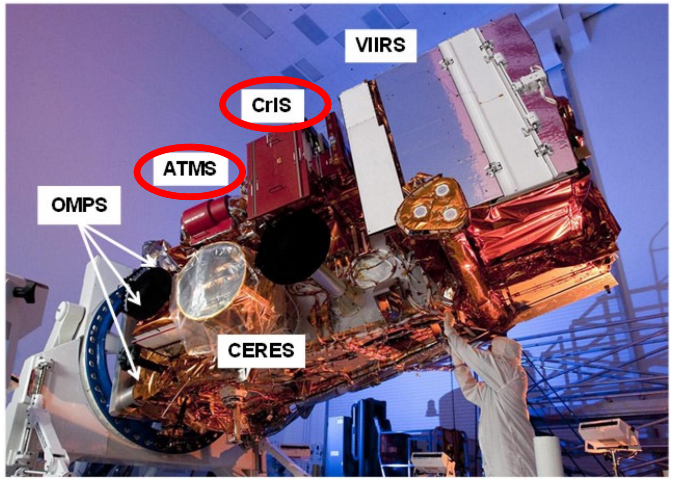
Creating next-gen high-res (2km /30min) GEO/LEO "hyperspectral" sounding proxy data via the fusion of current polar and geostationary satellite measurements









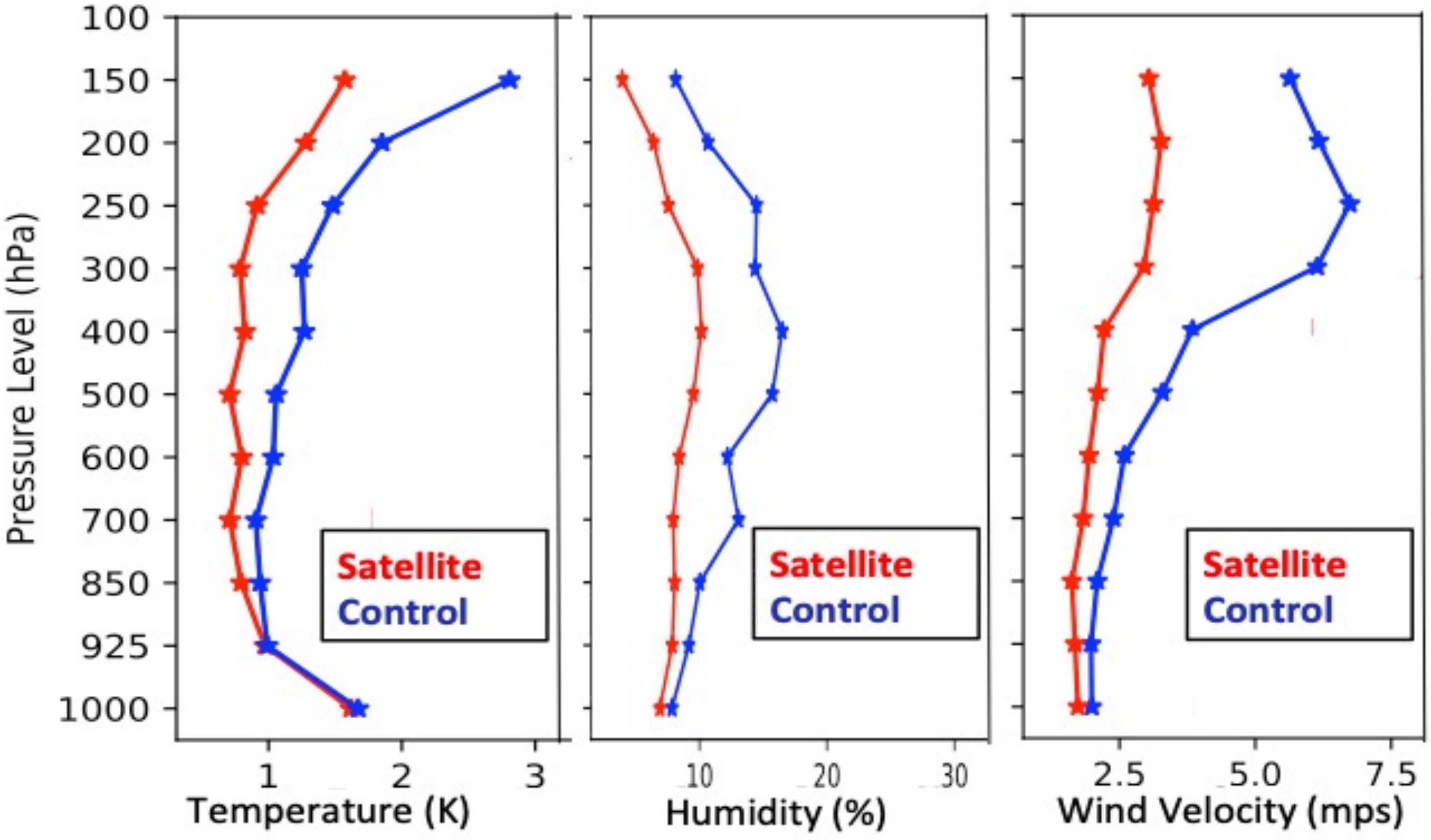


Data System Characteristics

- Full Spectral Resolution Used
- Full Spatial Resolution Used
- Polar Hyperspectral clear soundings above cloud & MW soundings below cloud are retrieved with 2-km spatial and 30-minute temporal resolution
- Soundings assimilated into 3-km Res. NWP (HRRR) Model
- Continuous Humidity data assimilation used to predict

  winds and dynamics
- 0-to-12-hour forecast cycle conducted every hour

Satellite soundings assimilation



<u>Standard Deviations Between Radiosondes and 6-hr Forecast Temperature, Humidity, and Wind Velocity Initialized With Vs Without (Fusion Satellite Vs Control) for Feb & Mar 2021.</u>

NWP Improved By Assimilating Fusion Satellite Sounding Data

- The benefits of assimilating satellite-derived profiles need to be further evaluated.

Summary

- A system is developed within the NASA SatCORPS to create hourly global composites of cloud properties from modern GEO and LEO imagers on a 3-km grid.
- Many recent cloud remote sensing advances are being incorporated including AI/ML tools used to correct level-0 satellite radiance artifacts and to derive more accurate level-2 cloud and radiation data products.
- First charter is to produce a multi-year, hourly dataset to serve modeling needs related to cloud parameterizations (sponsored by NASA SNWG). Initial dataset will be available by end of summer to garner feedback from the community.
- Radiative flux component is in development that ingests GCC products into a radiative transfer modeling system (25-km hourly global grids).
- The system is being operationalized to meet low latency operational needs within the weather community (e.g. NCEP operations), sustainable energy industry (e.g. NASA POWER) and elsewhere.
- Data products will be freely available and geospatially-service enabled as ArcGIS Image Services and Open Geospatial Consortium (OGC) Web Mapping/Coverage Services for visualization and analysis

(GCC Website: https://satcorps.larc.nasa.gov/gcc)

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