Novel Hourly-Resolved Global Cloud Property Composite from Operational Satellite Imagers

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INTRODUCTION

The NASA Satellite ClOud and Radiation Property retrieval System (SatCORPS) applies a suite of algorithms to meteorological satellite data to provide cloud properties, radiative fluxes and other parameters on a global scale.

SatCORPS framework provides two separate data stream :

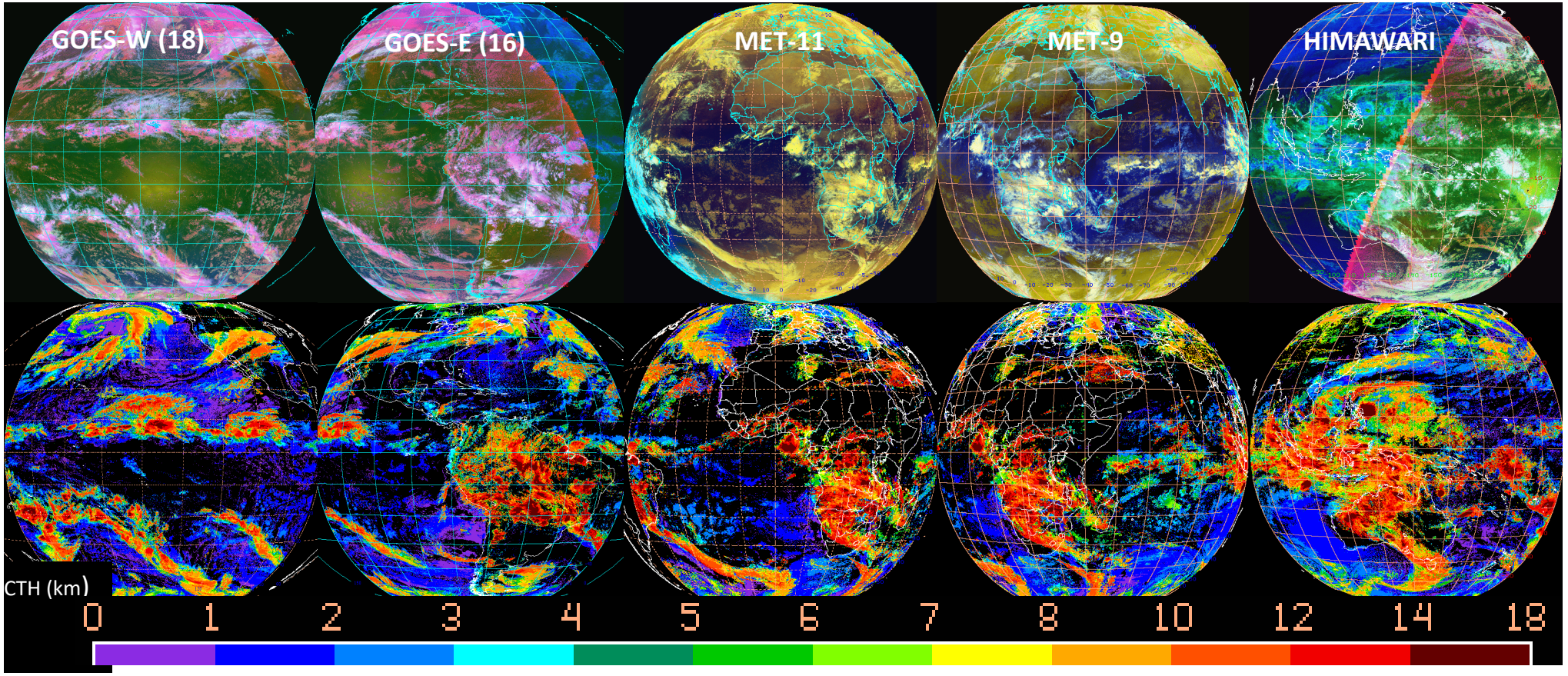
Cloud Climate Data Records (supports NASA CERES/RBSP)

- 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.

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

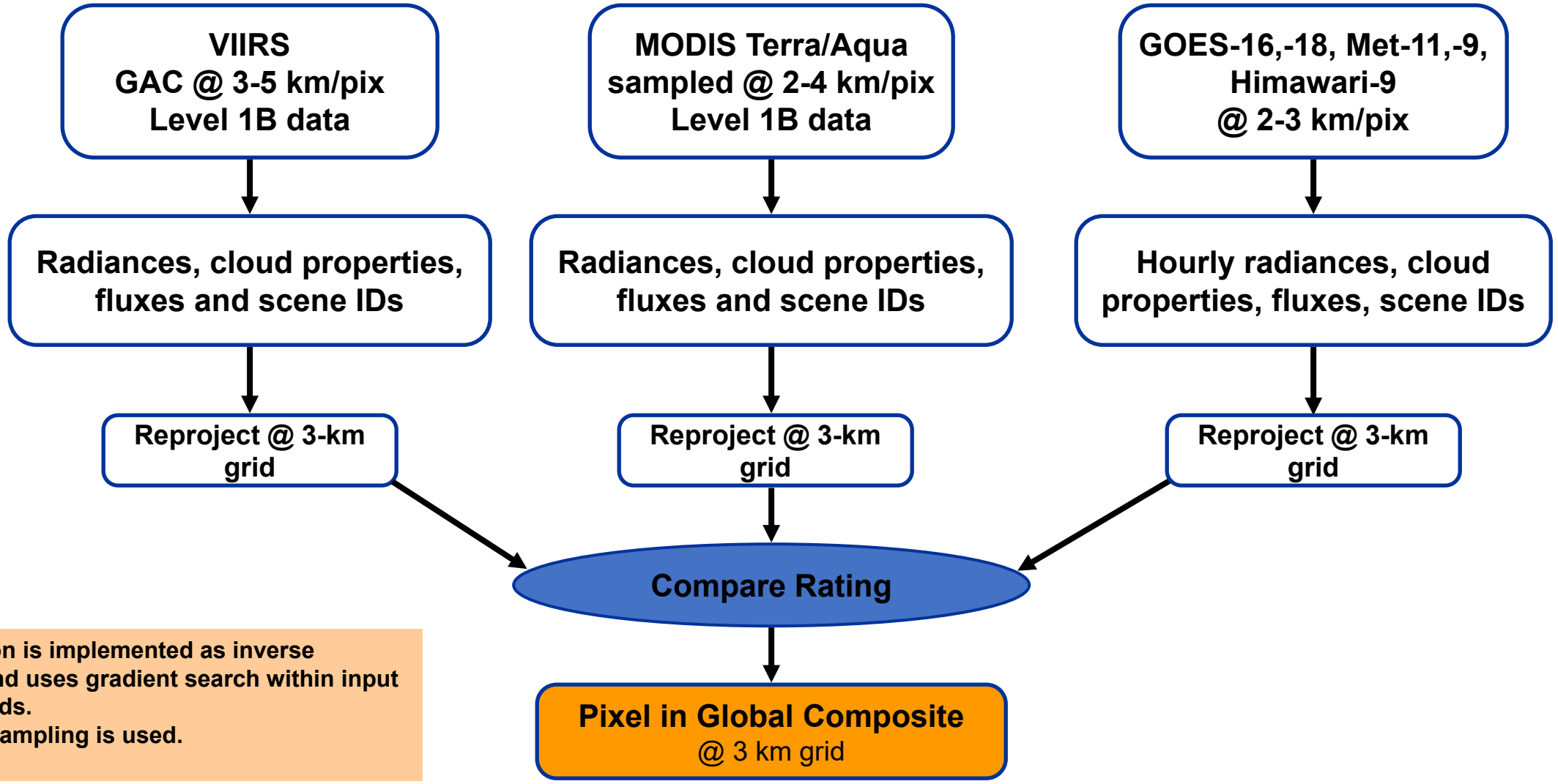
New Global Cloud Composites (GCC) from Satellites

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

New GCC system is streamlined enabling one overarching global data production system to support SatCORPS stakeholders

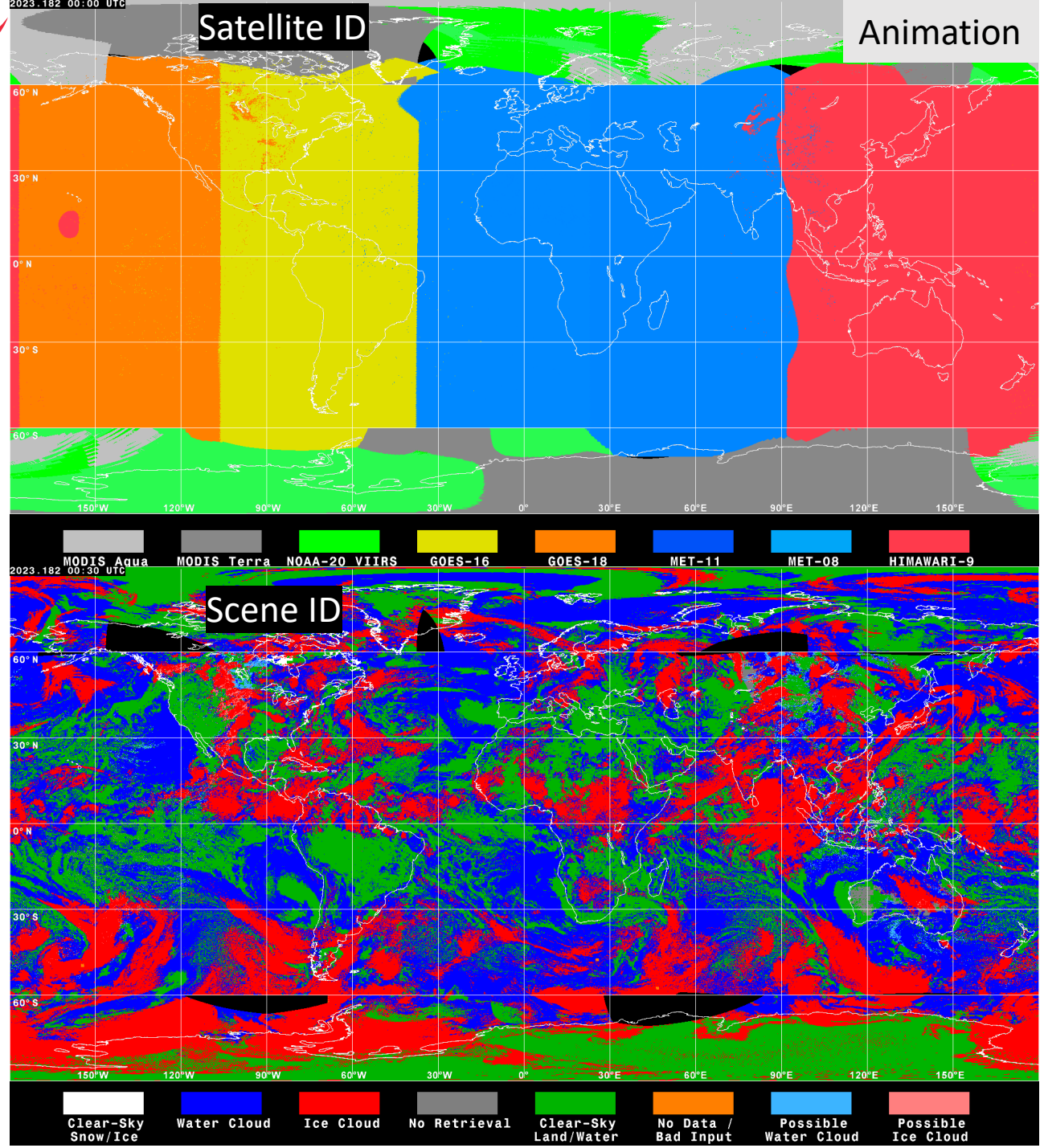
- 3-km gridded cloud properties every 30-60 minutes
- Many new cloud algorithm enhancements are being implemented that improve accuracies, cross-platform consistency, and reduce artifacts
  - New atmospheric corrections (satellite dependent)
  - Improved clear sky radiances
  - More realistic ice cloud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

Global GEO/LEO composites



Reprojection is implemented as inverse mapping and uses gradient search within input Lat/Lon fields.
Bicubic resampling is used.

Global Cloud Composites (GCC) Parameters



- granule_MJD_list
- granule_name_list
- map_data
  - BT_10.8um
  - BT_6.75um
  - cloud_bottom_height
  - cloud_bottom_pressure
  - cloud_bottom_temperature
  - cloud_eff_height
  - cloud_eff_particle_size
  - cloud_eff_pressure
  - cloud_eff_temperature
  - cloud_emittance
  - cloud_lwp_iwp
  - cloud_optical_depth
  - cloud_phase
  - cloud_top_height
  - cloud_top_pressure
  - cloud_top_temperature
  - lat
  - lon
  - LW_broadband_flux
  - ref_0.63um
  - relative_azimuth
  - relative_time
  - satellite_ID
  - slw_icing_index
  - solar_zenith
  - SW_broadband_albedo
  - vi_iwp
  - vi_lwp
  - view_zenith
- time

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)

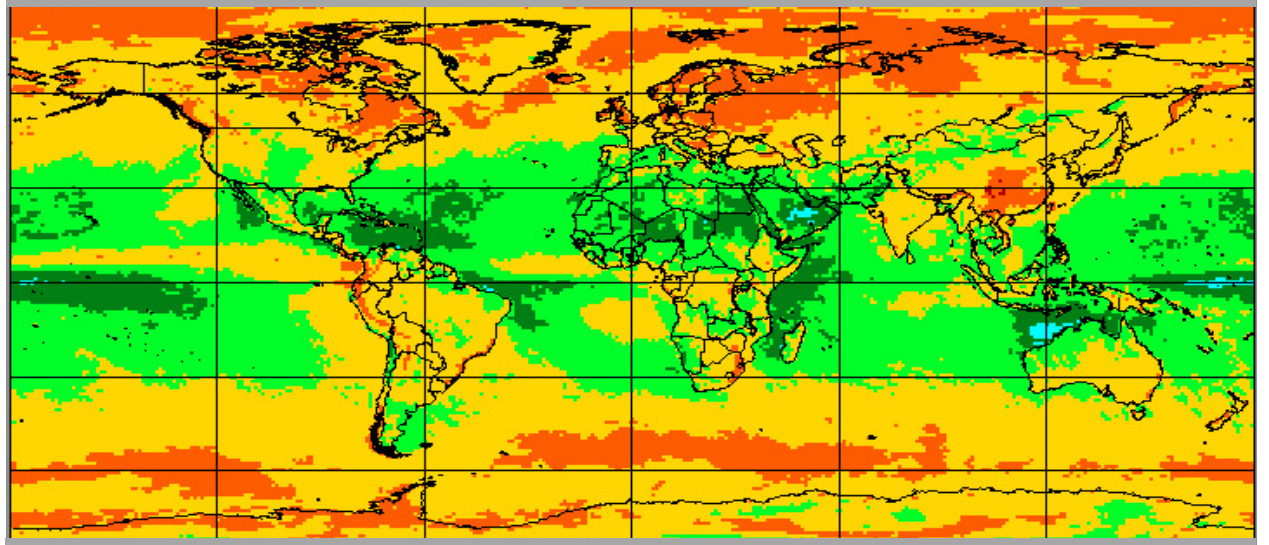
Poor consistency between daytime and nighttime

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

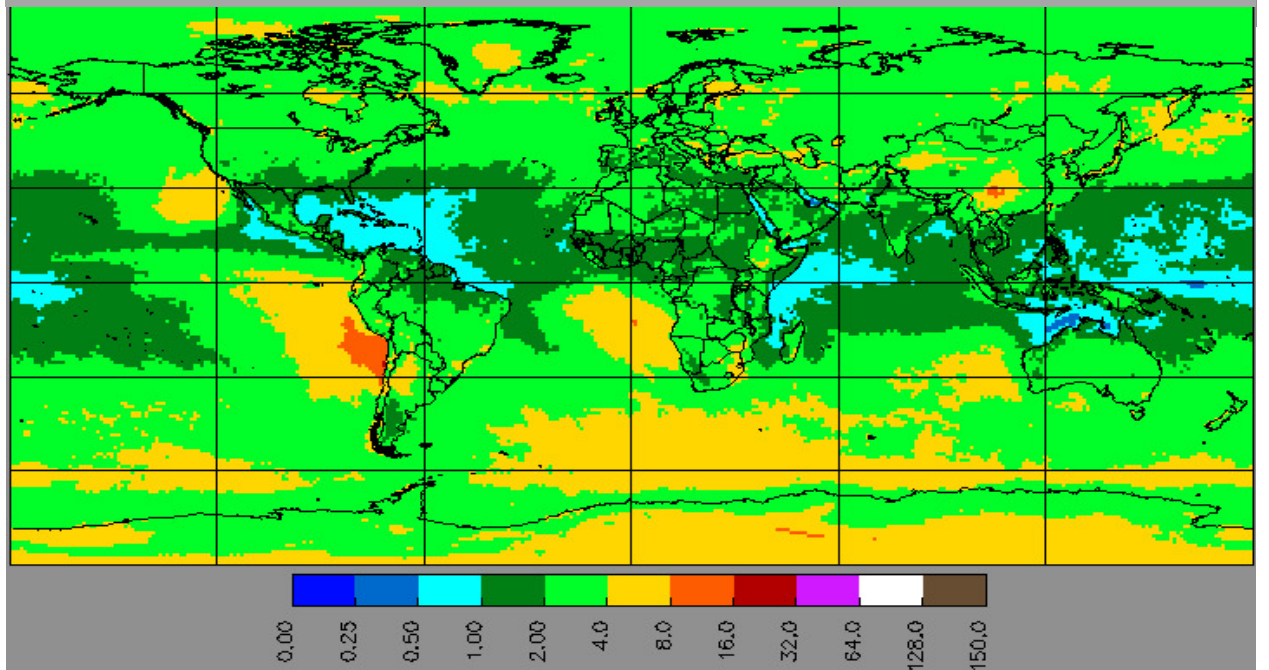
2021 Annual Mean COD (DAY), Aqua-MODIS

Global Mean = 5.1 ; Non-polar Mean = 4.7



2021 Annual Mean COD (NIGHT), Aqua-MODIS

Global Mean = 2.9 ; Non-polar Mean = 2.8



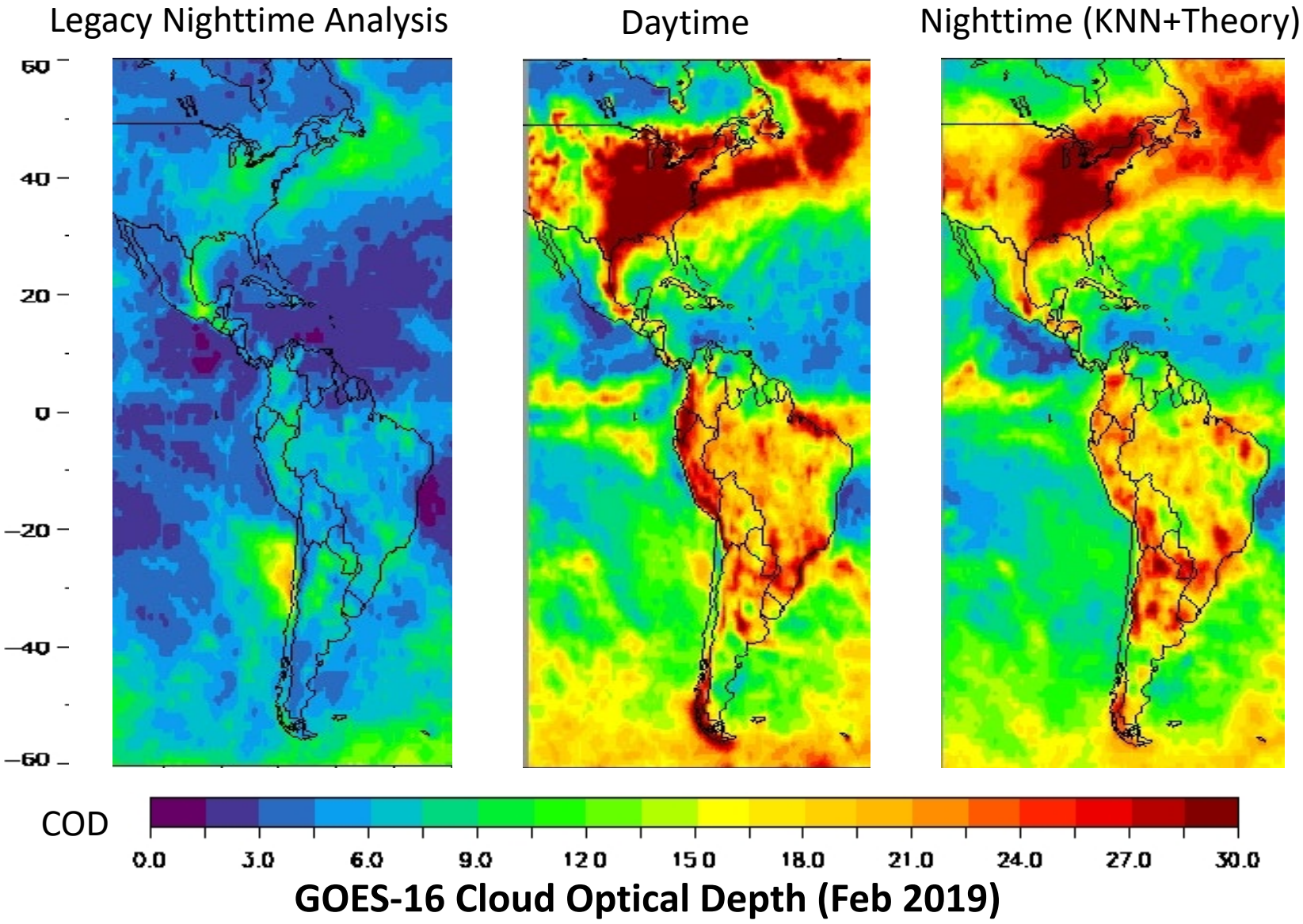
KNN Improves Nighttime Cloud Analyses

Solution:

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

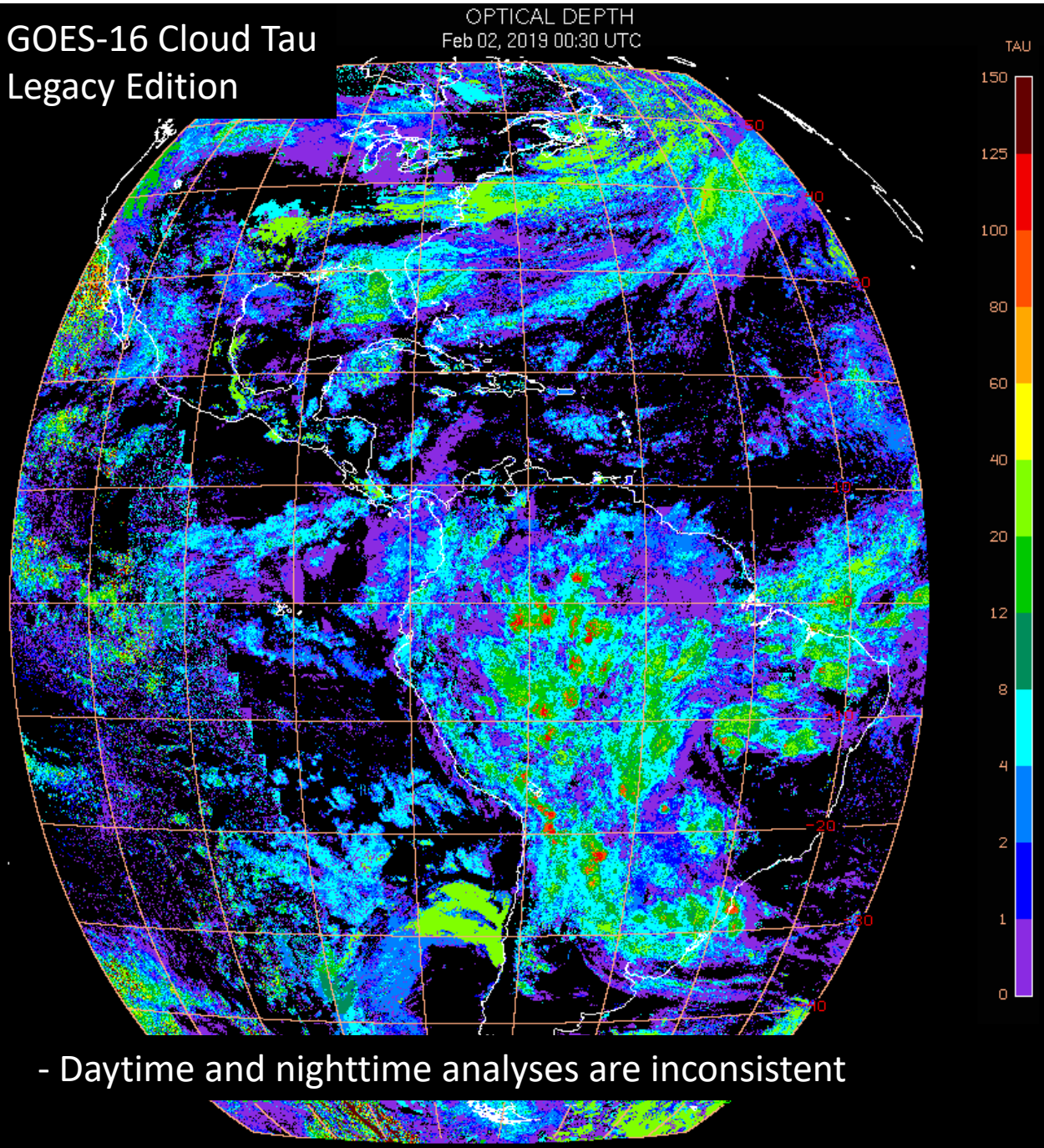
Outcome:

- Much more realistic filling method for nighttime optically thick COD
- More accurate downstream derived parameters (e.g. waterpath, ceilings, icing conditions, etc)



GOES-16 Cloud Optical Depth (Feb 2019)

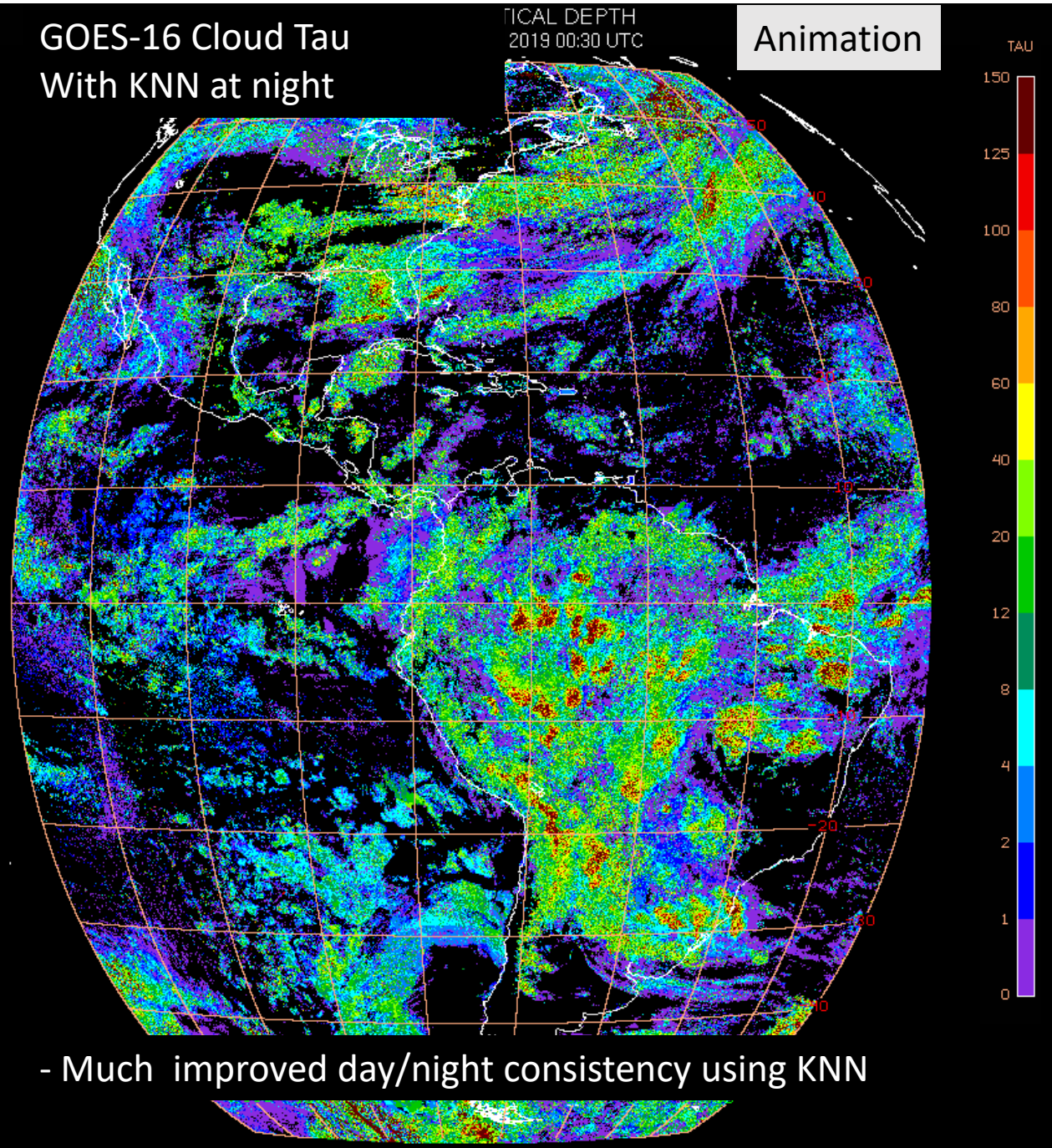
GOES-16 Cloud Tau
Legacy Edition



- Daytime and nighttime analyses are inconsistent

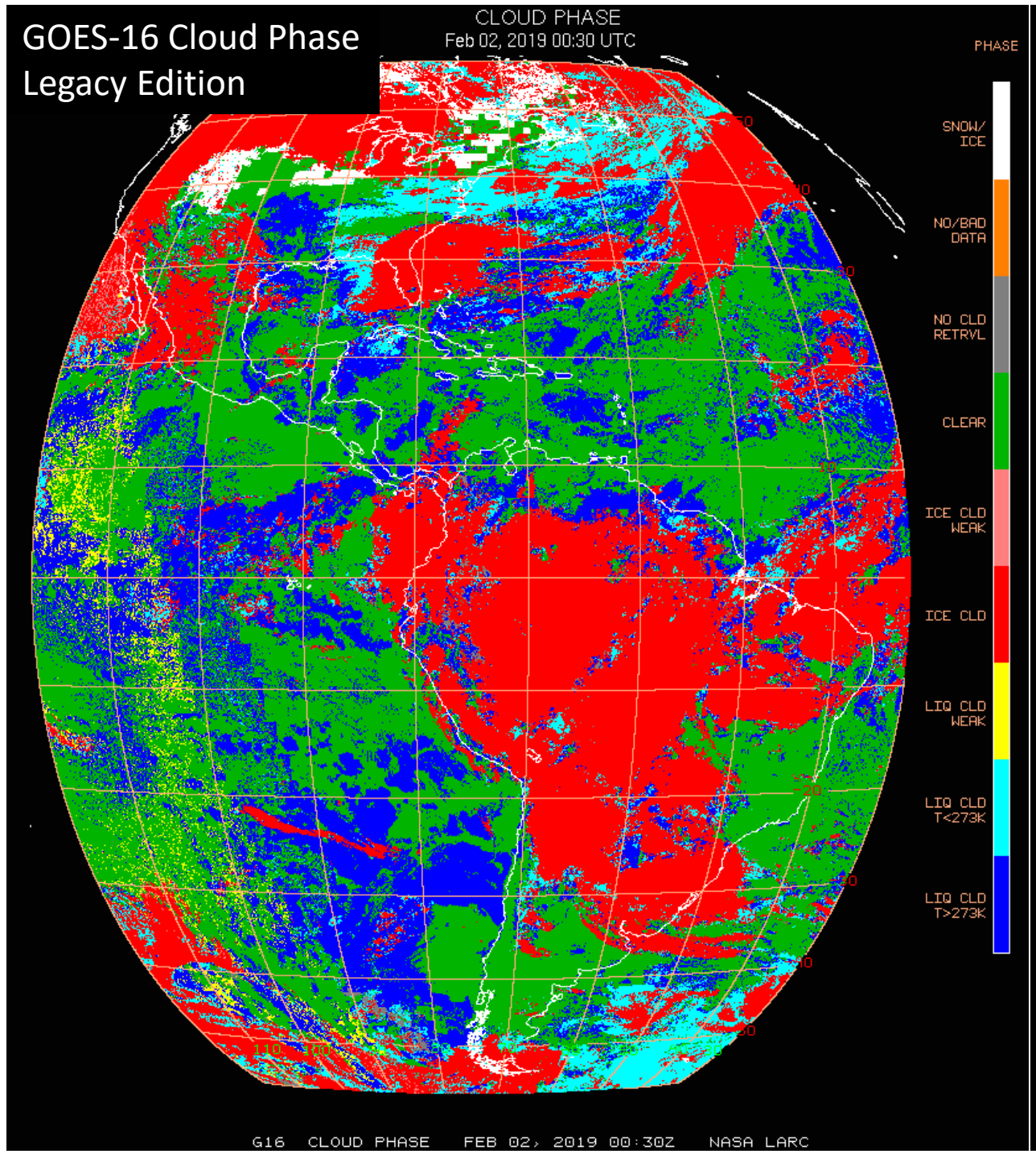
GOES-16 Cloud Tau
With KNN at night

Animation



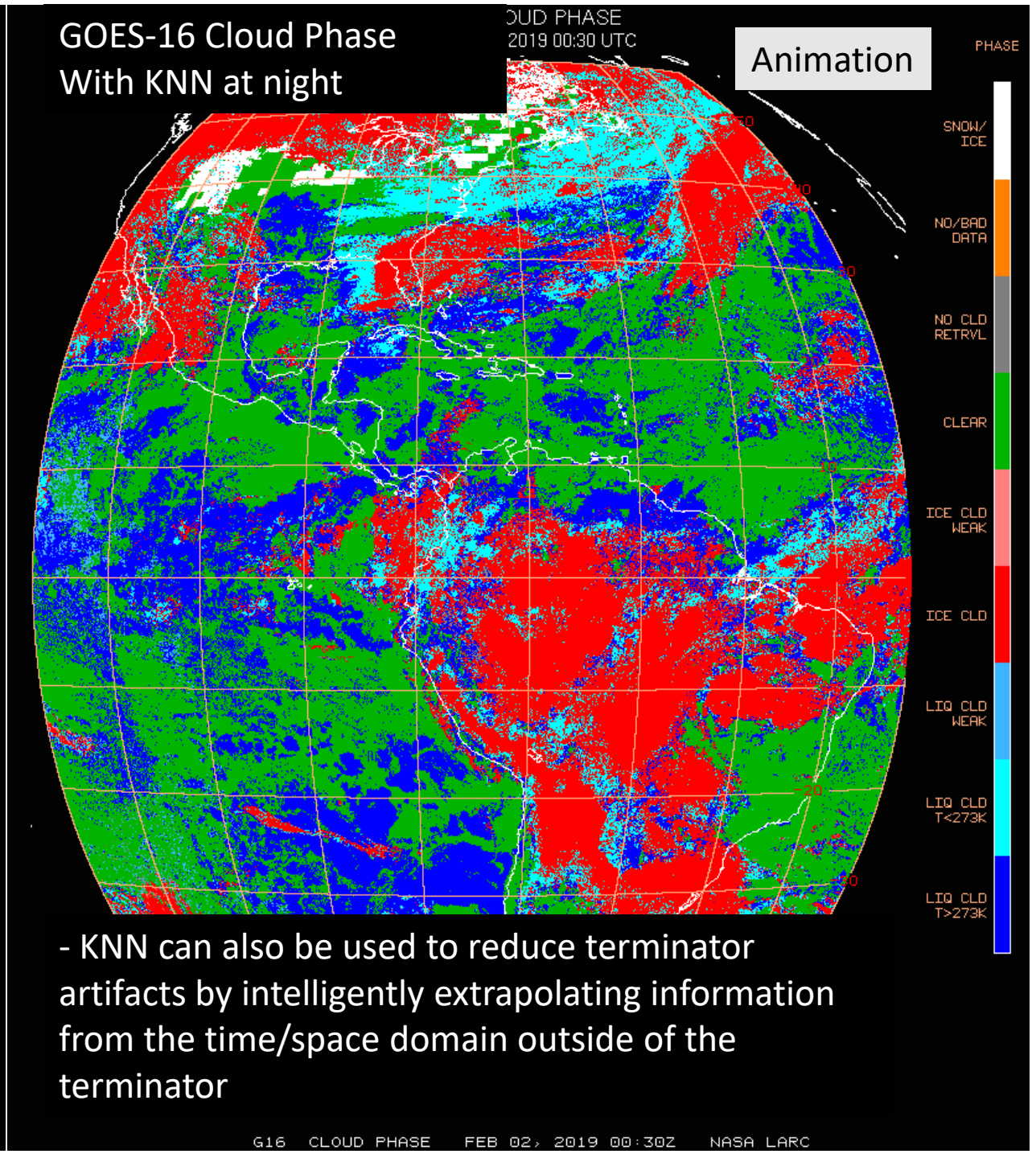
- Much improved day/night consistency using KNN

GOES-16 Cloud Phase
Legacy Edition

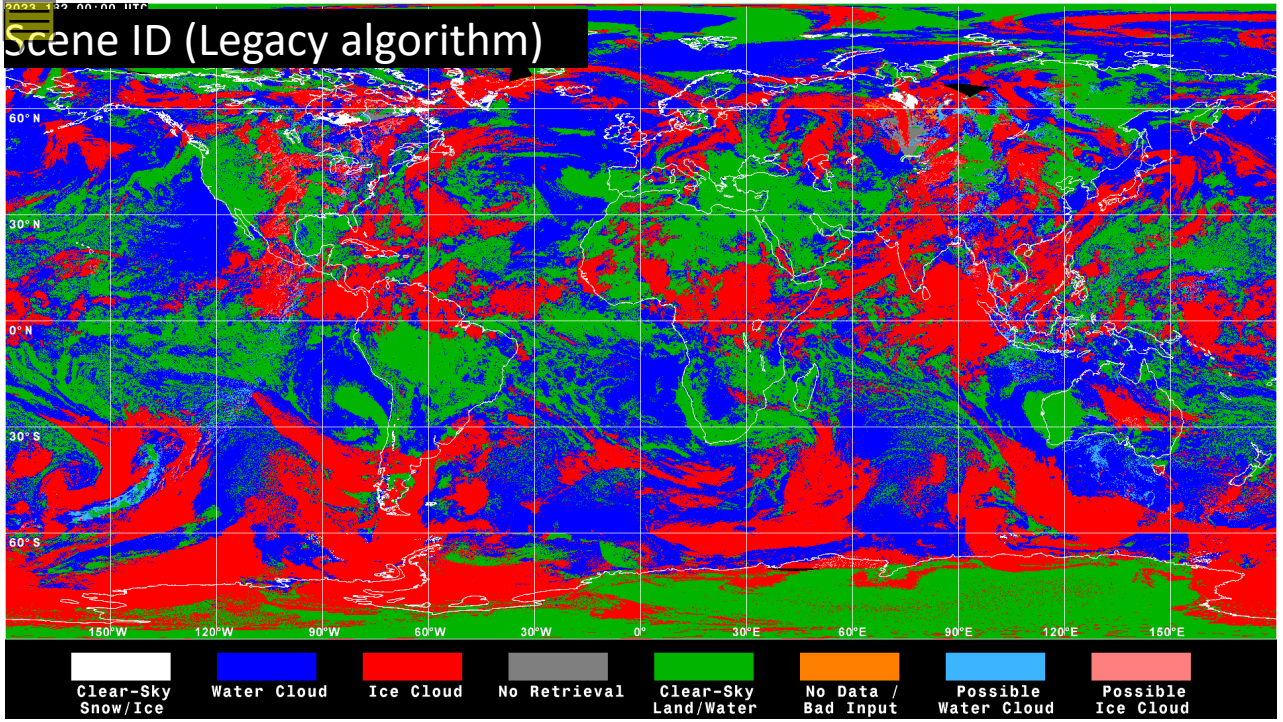


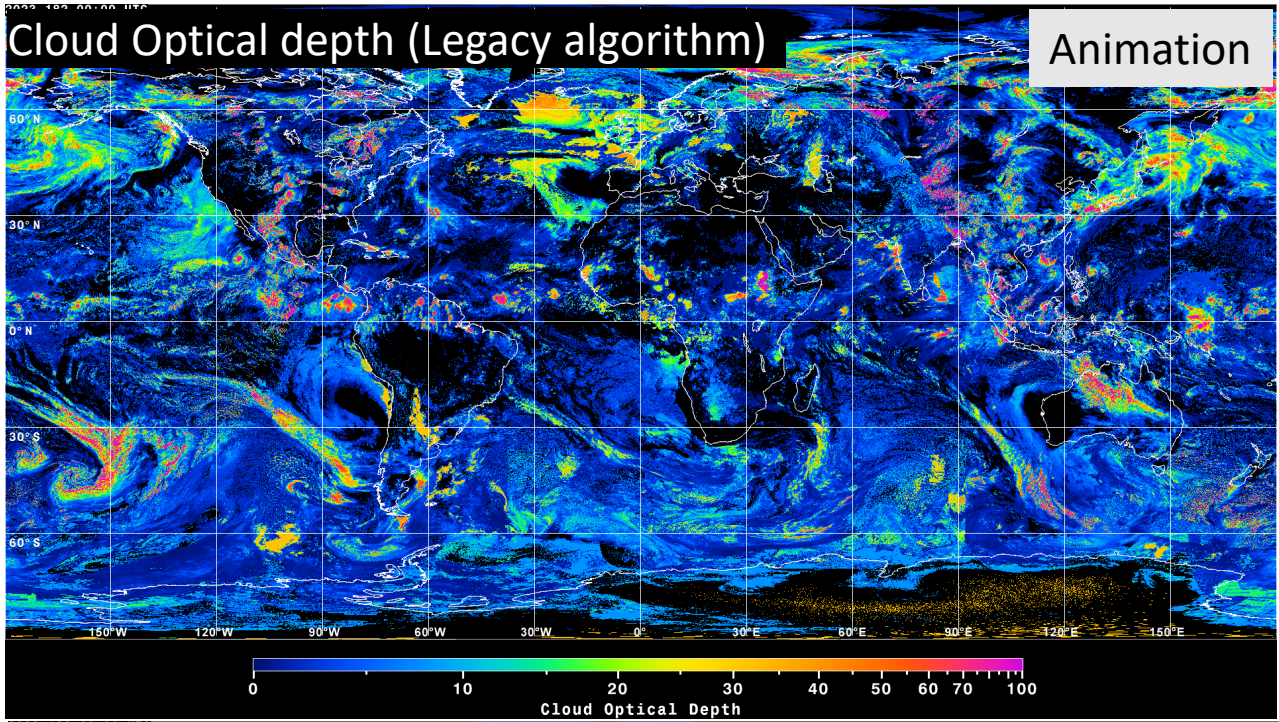
GOES-16 Cloud Phase
With KNN at night

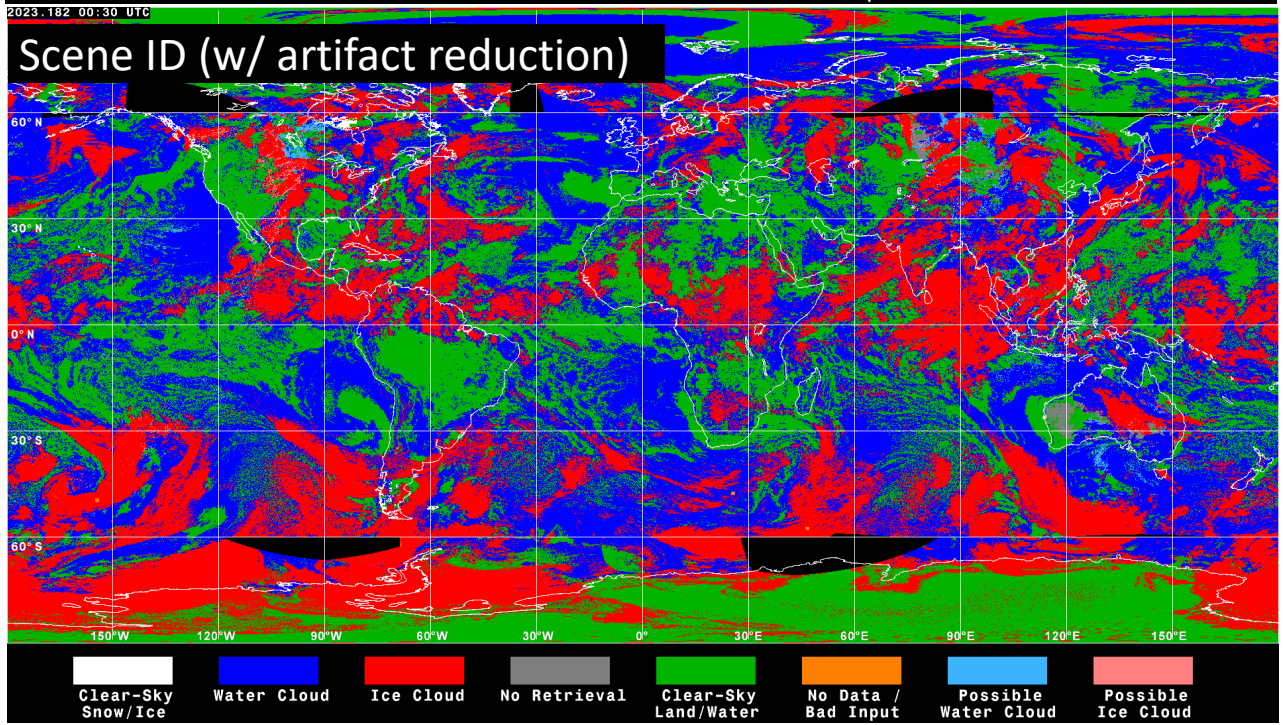
Animation

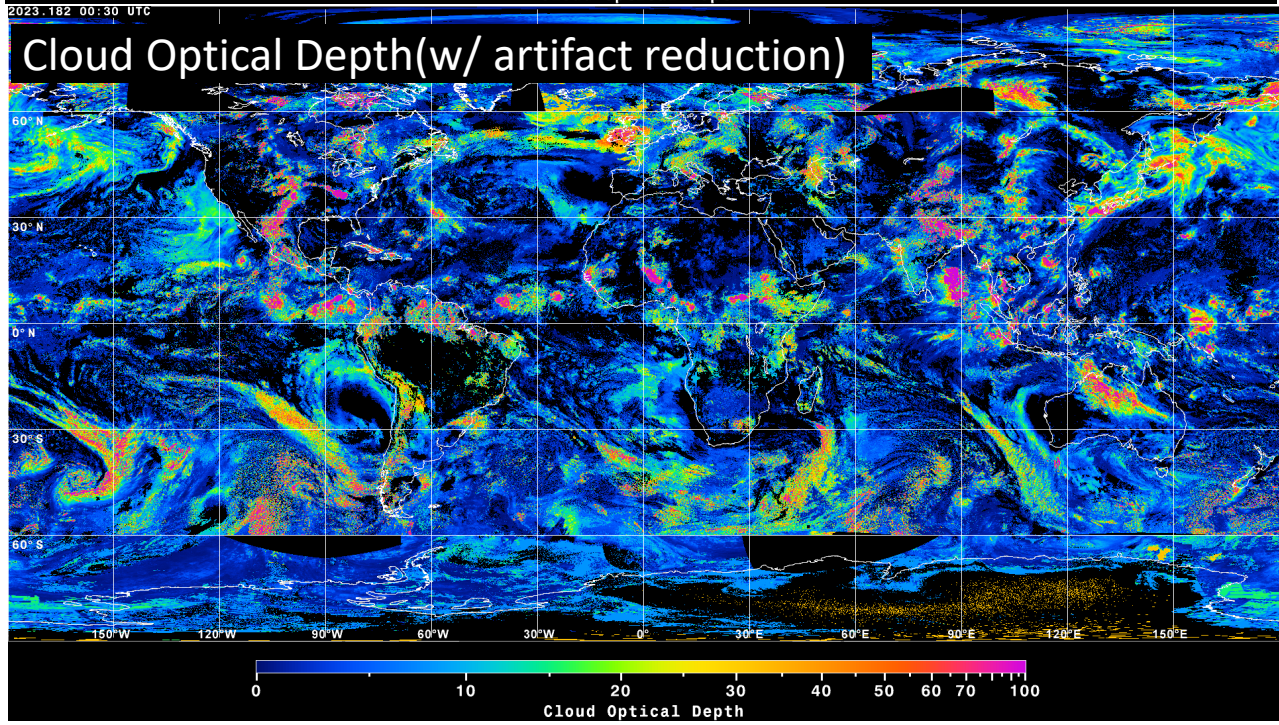


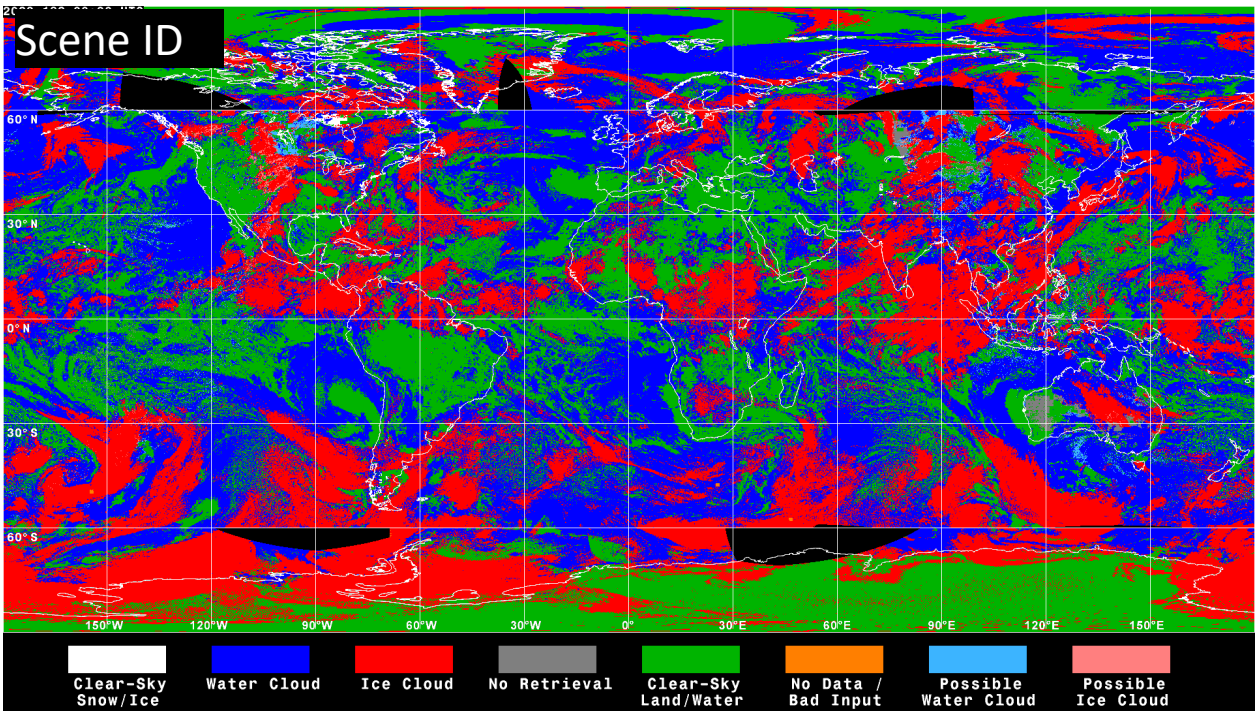
- KNN can also be used to reduce terminator artifacts by intelligently extrapolating information from the time/space domain outside of the terminator

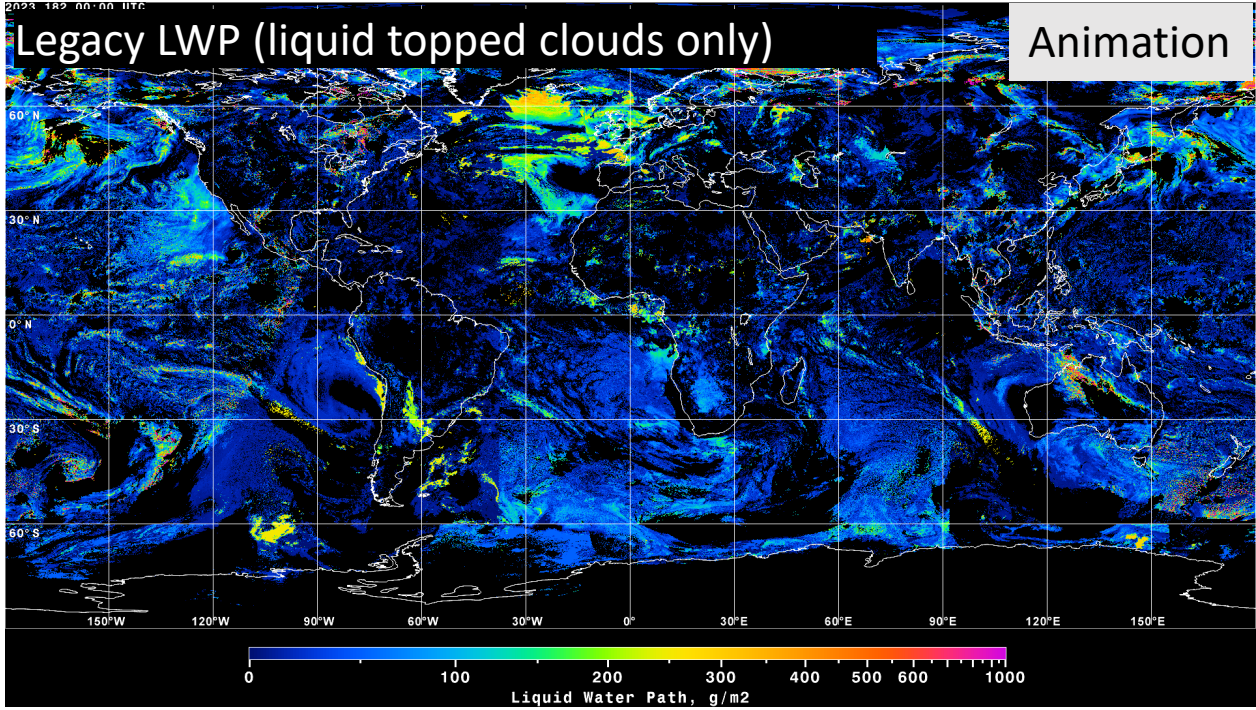

Scene ID (Legacy algorithm)
60° N
30° N
0° N
30° S
60° S
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
Clear-Sky Snow/Ice
Water Cloud
Ice Cloud
No Retrieval
Clear-Sky Land/Water
No Data / Bad Input
Possible Water Cloud
Possible Ice Cloud

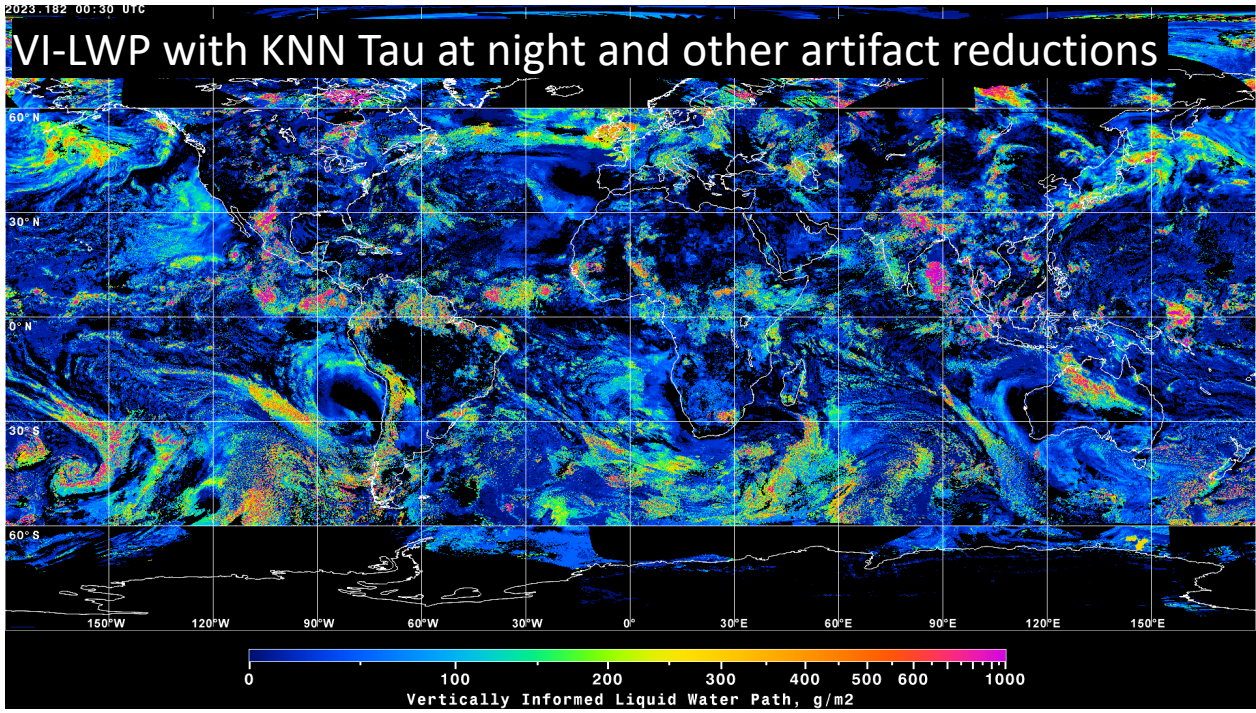

Cloud Optical depth (Legacy algorithm)
Animation
60° N
30° N
0° N
30° S
60° S
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
0 10 20 30 40 50 60 70 100
Cloud Optical Depth


2023.182 00:30 UTC
Scene ID (w/ artifact reduction)
60° N
30° N
0° N
30° S
60° S
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
Clear-Sky Snow/Ice
Water Cloud
Ice Cloud
No Retrieval
Clear-Sky Land/Water
No Data / Bad Input
Possible Water Cloud
Possible Ice Cloud


2023.182 00:30 UTC
Cloud Optical Depth(w/ artifact reduction)
60° N
30° N
0° N
30° S
60° S
150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E
0 10 20 30 40 50 60 70 100
Cloud Optical Depth


Scene ID
60° N
30° N
0° N
30° S
60° S
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
Clear-Sky Snow/Ice
Water Cloud
Ice Cloud
No Retrieval
Clear-Sky Land/Water
No Data / Bad Input
Possible Water Cloud
Possible Ice Cloud


Legacy LWP (liquid topped clouds only)
Animation
60° N
30° N
0° N
30° S
60° S
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
0
100
200
300
400
500
600
1000
Liquid Water Path, g/m2


VI-LWP with KNN Tau at night and other artifact reductions
60° N
30° N
0° N
30° S
60° S
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
0
100
200
300
400
500
600
1000
Vertically Informed Liquid Water Path, g/m2

SatCORPS GIS | Transformation & Distribution

Analysis Ready Data (ARD)

- Rolling 2-week data parameters stored in cloud-optimized format and full archive access
- Built with transpose to provide more-efficient time series retrieval
- Global composite and regional mosaic availability

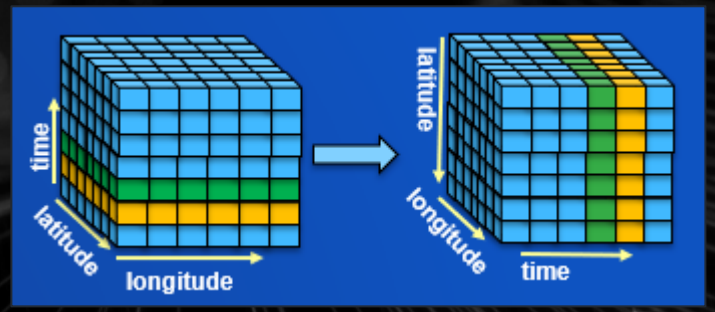
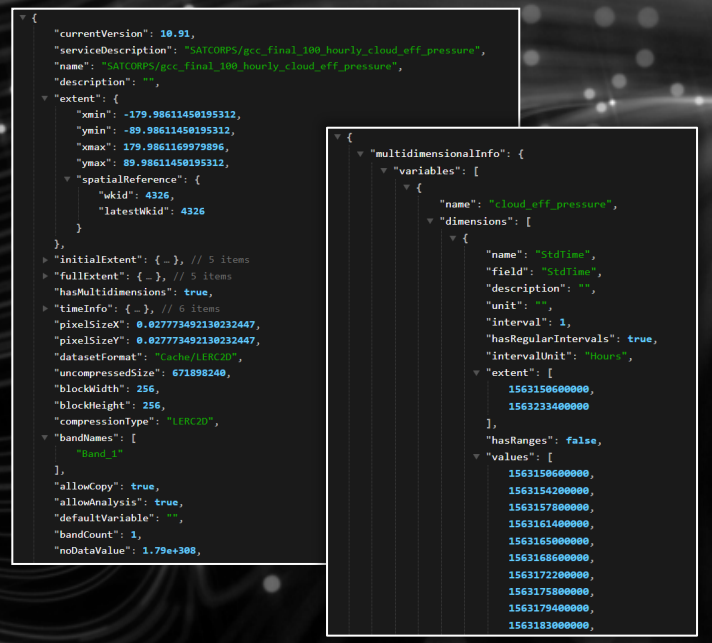


Image Source: Esri

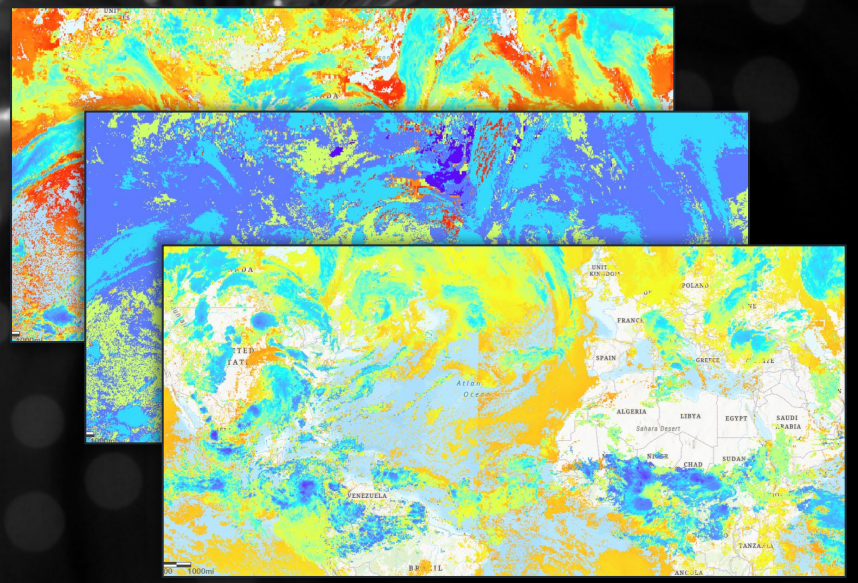
Cloud Raster Format with Transpose

Geospatial Services

- ~28 Multidimensional (time-enabled) parameter-level geospatial services as global and regional composites
- Exposed as RESTFul APIs, ArcGIS Image Services, Open Geospatial Consortium (OGC) Web Mapping Services/Web Coverage Services, & OpenDAP



RESTful API Endpoint



ArcGIS Image Services & OGC WMS/WCS

SatCORPS GIS | Visualization & Analysis

- Currently Under Development -

Data Layer Manipulation

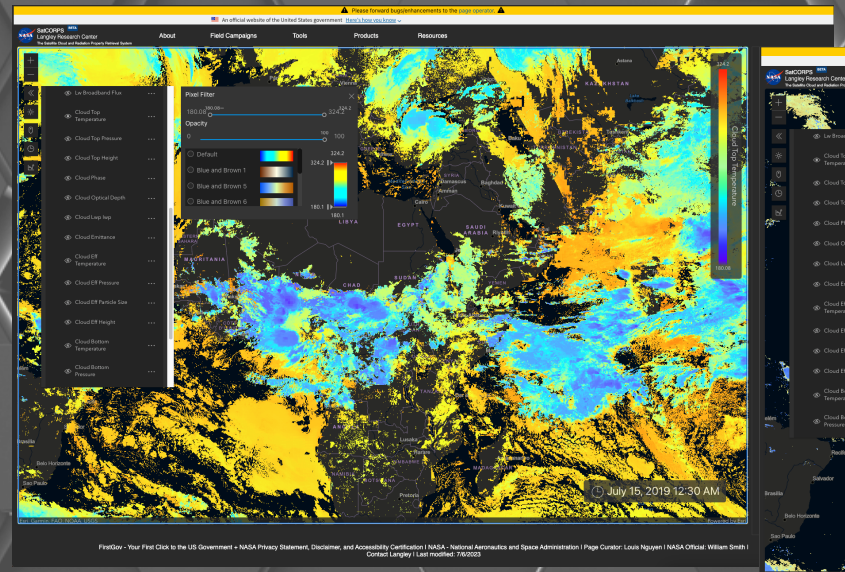
- Layer transparency settings and raw pixel value identification
- On-the-fly filtering of pixel values to identify areas of interest

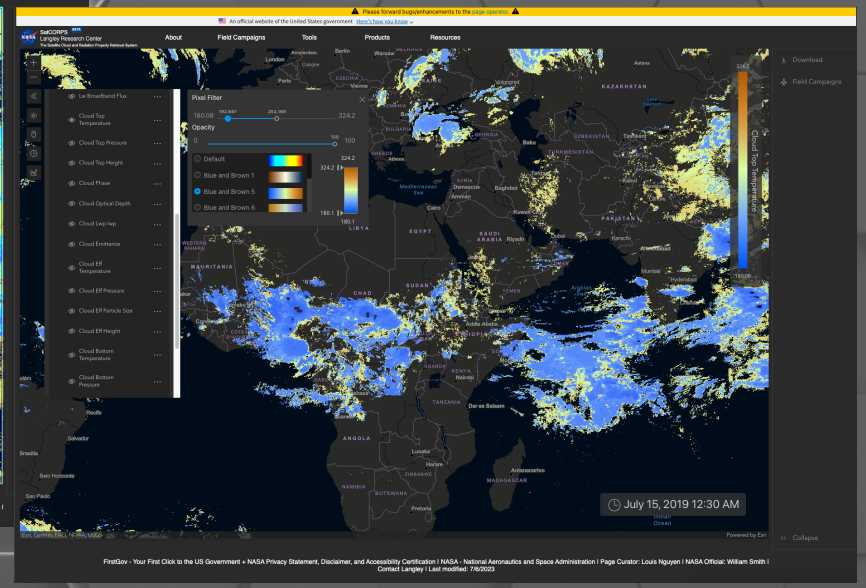
Multidimensional Analysis

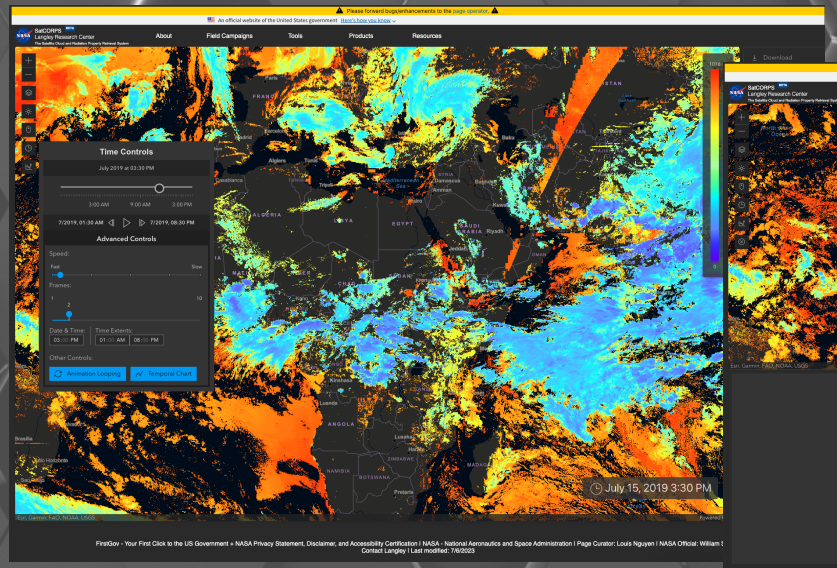
- Single point time series across 2 week rolling ARD service
- Time slider and user-defined animation functionality

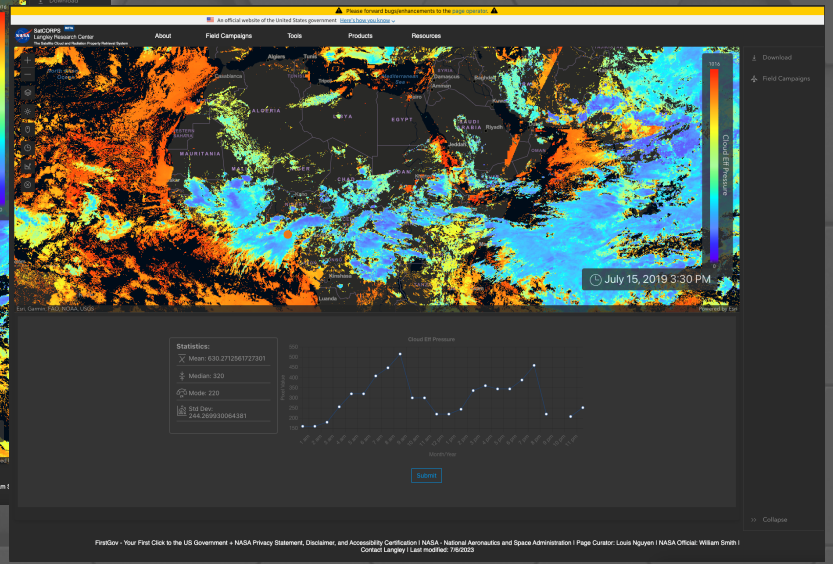
Parameter Subsetting

- Regional bounding-box subsettting delivering customized NetCDF/JSON









Global Cloud Composites (GCC) STATUS

- 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.
- **A one-month (July 2021) version 1 test dataset has been produced for SatCORPS Stakeholders: https://satcorps.larc.nasa.gov/GCC-SNWG**
- **Version 1 dataset** derived with legacy SatCORPS cloud algorithms and empirical narrowband to broadband TOA radiative flux formulas.
- **A version 2 system is nearly complete (release date January 2024)**
  - **Used to produce annual historical datasets for SNWG 'Clouds and Radiation' stakeholders**
  - **Operationalized to meet low latency operational needs within the weather community (e.g. NCEP), sustainable energy industry (e.g. NASA POWER), DOE ARM and elsewhere.**
- **Version 2** applies updated cloud algorithms that includes bug fixes, improved forward models, clear sky radiance maps, instrument calibrations, and atmospheric correction procedures.
- **Version 2** also applies AI/ML tools to correct level-0 satellite radiance artifacts (e.g. GOES-17 striping) and to derive more accurate and consistent level-2 cloud and radiation data products at all times of day
- A computed TOA and SFC radiative flux component is in development that ingests GCC products into a radiative transfer modeling system (25-km hourly global grids). Release date: Spring 2024
- 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.