JCSDA Atmospheric Composition Activities Overview: Aerosols

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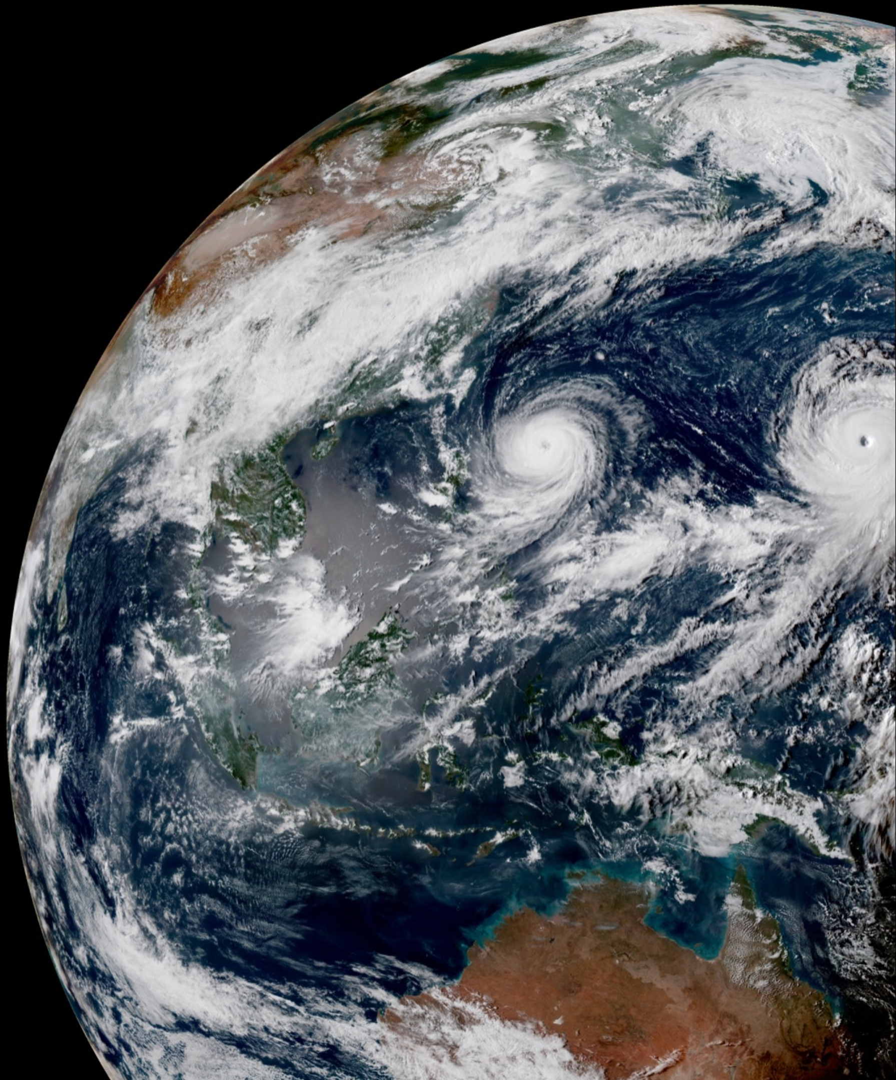
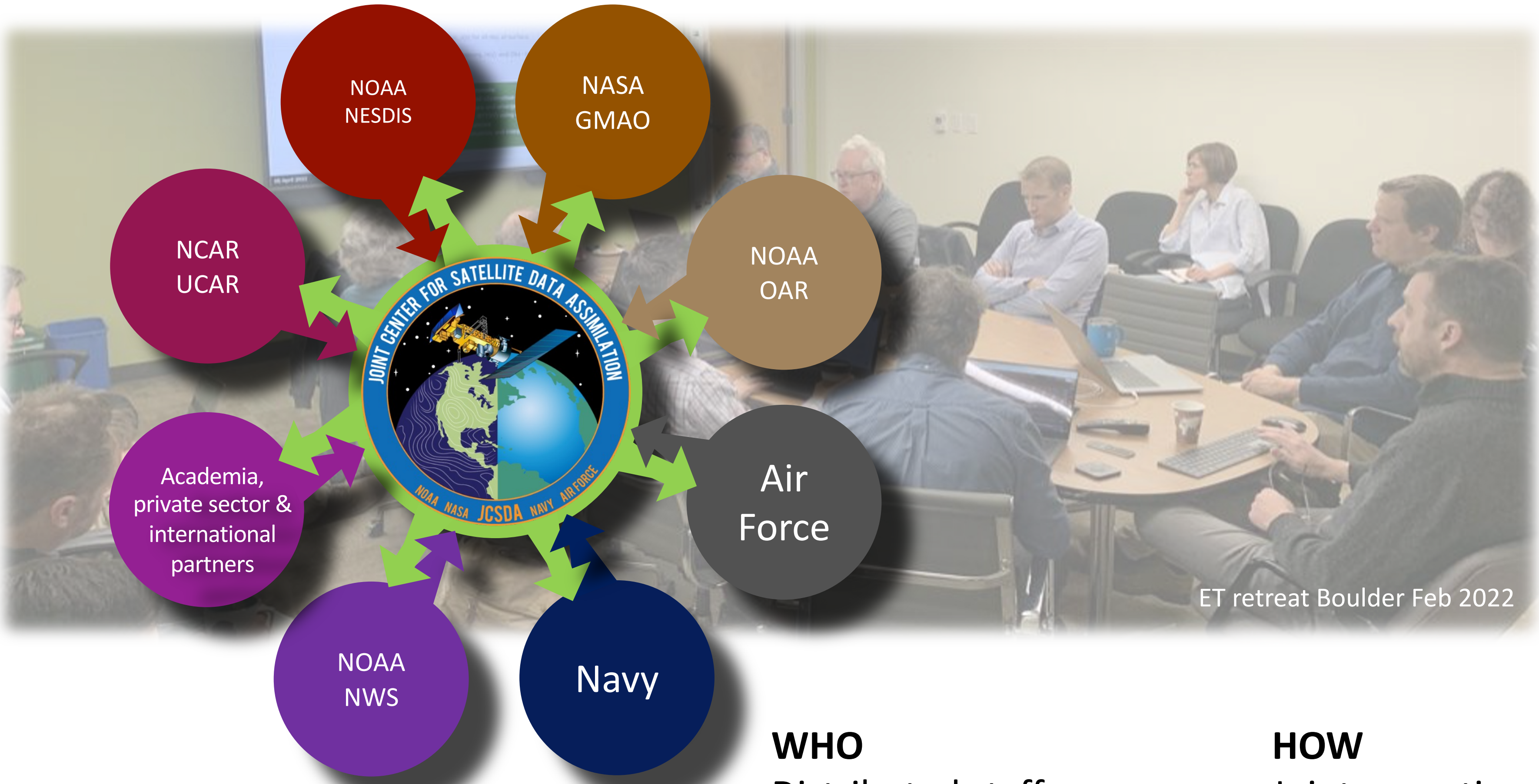


Joint Center for Satellite Data Assimilation (JCSDA)

Interagency partnership dedicated to improving and accelerating use of research and operational satellite data in weather, ocean, **climate and environmental analysis** and prediction systems



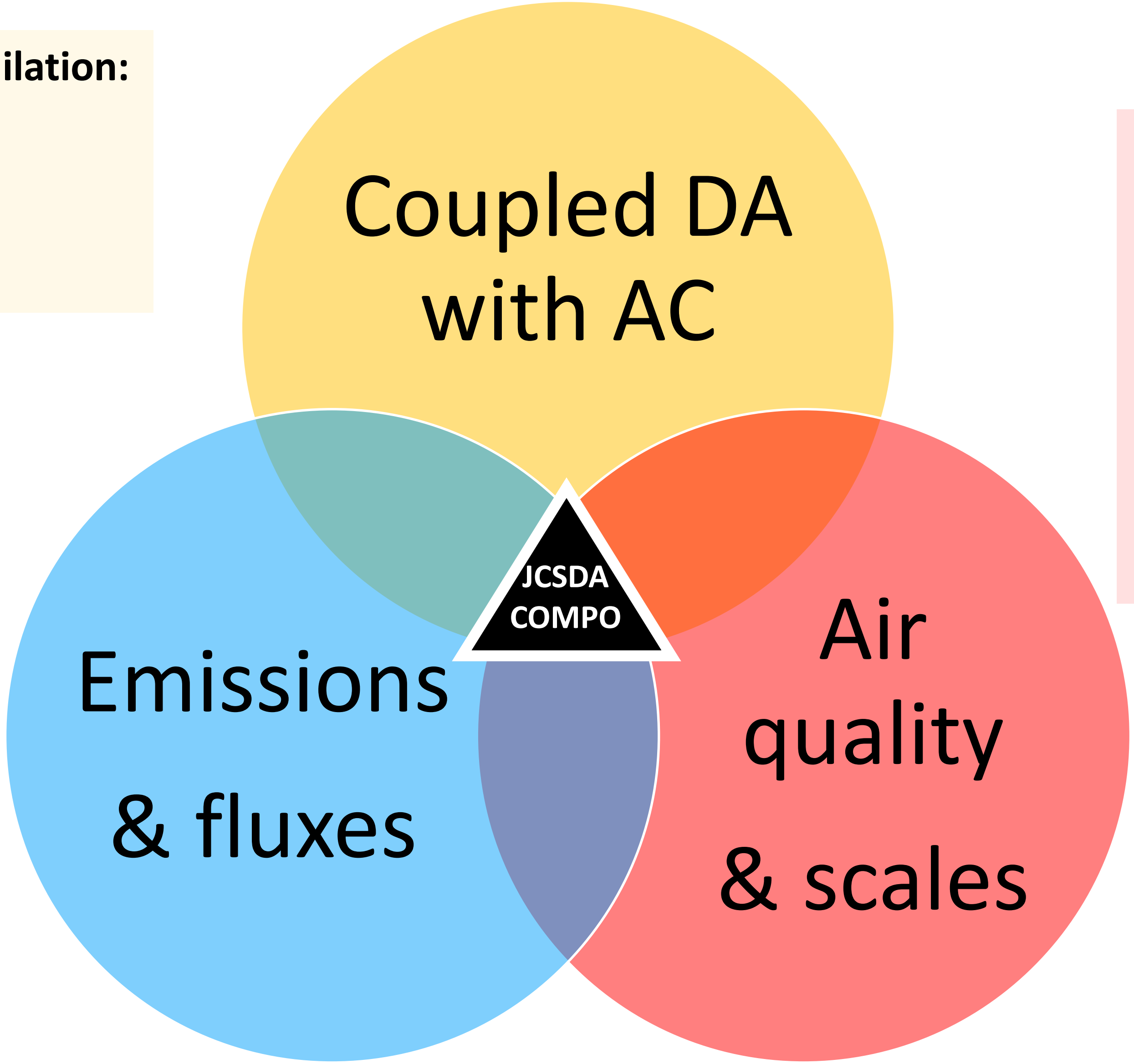
WHO
Distributed staff

HOW
Joint operating plan

WHAT
Critical path to oper.

The JCSDA Atmospheric COMPOsition – “palette”

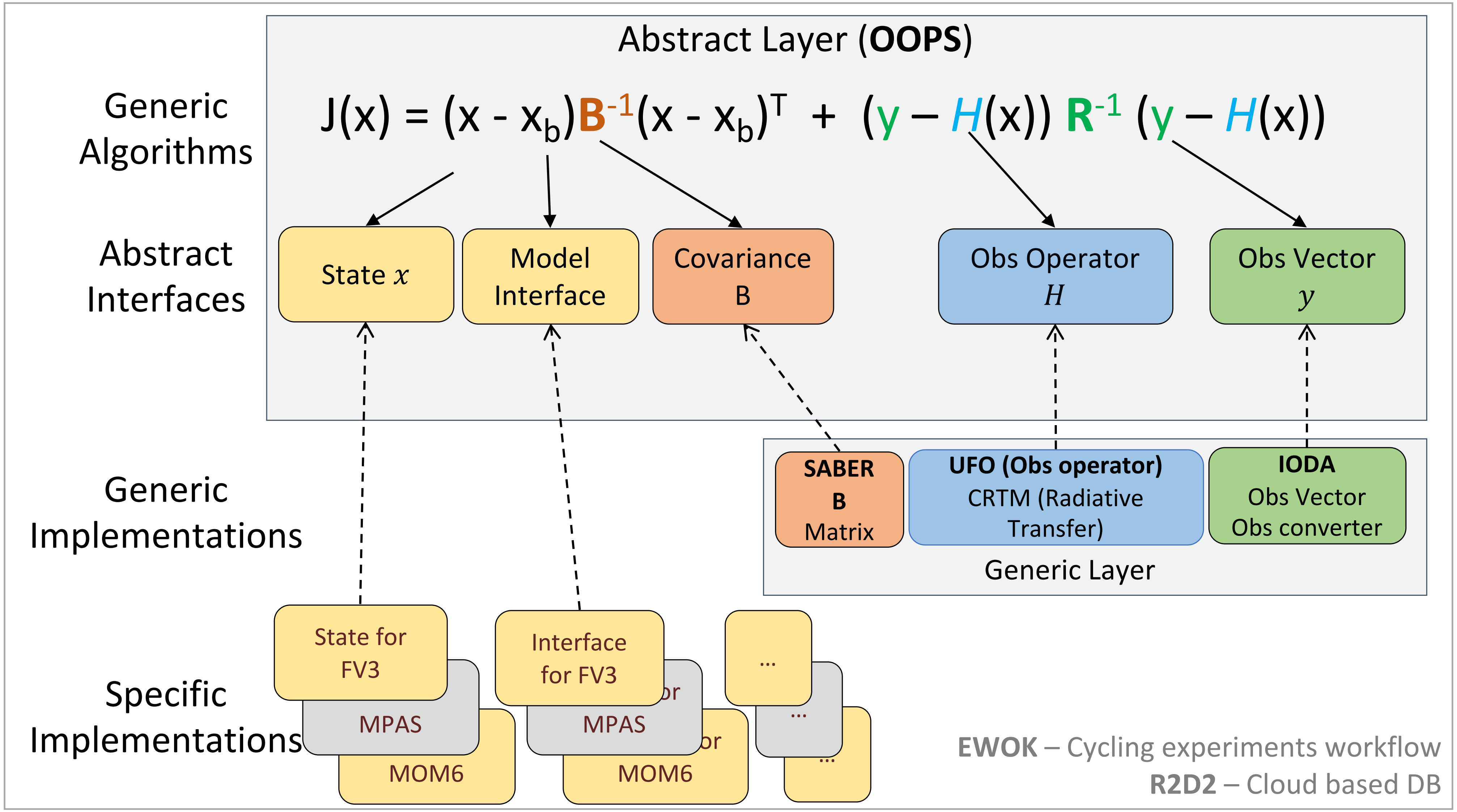
Enhance Coupled Data assimilation:
- Aerosols
- Stratospheric Ozone
- Other sensitive trace gas
- <u>L1 DA</u>



Facilitate high resolution data integration:
- New sensors i.e. TEMPO, S4, GEMS, (GeoXO)
- Novel geometries, stretched and refined grids
- Surface observations

Extend DA for fluxes and emission constraint:
- Anthropogenic emissions
- Fires
- Vegetation
- Chemical reactions

JEDI principles:
Build DA blocks once and update for all components of earth-system in one DA system



AQ and global AC model interfaces

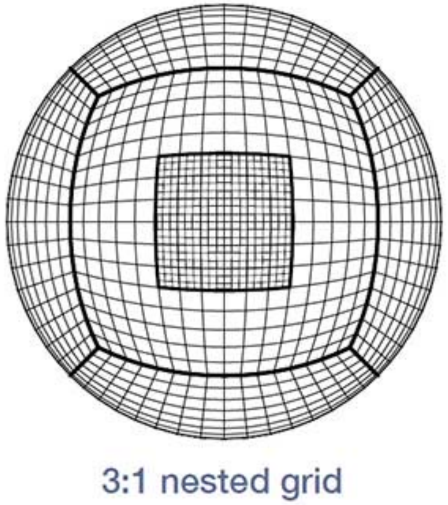
Modelling configurations

FV3 – nested domain

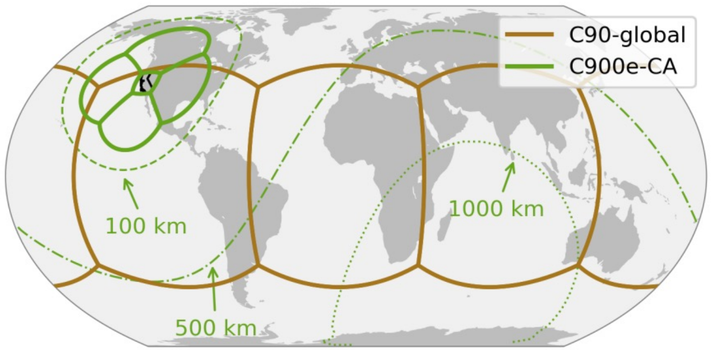
FV3 stretch grids

MPAS refined grid

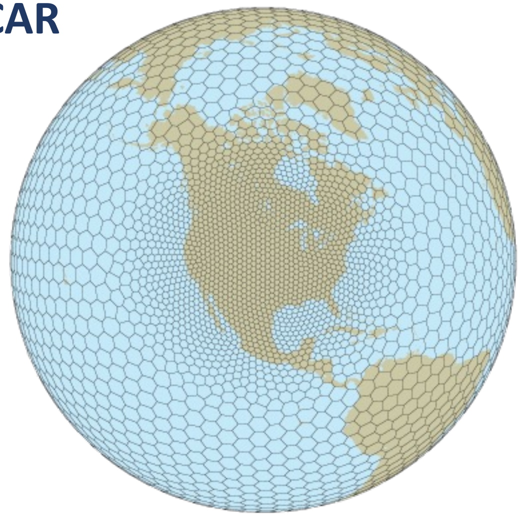
NOAA



NASA



NCAR



GOCART global, CMAQ regional
3DFGAT

GMAO GEOS-CF (w GOCART)
3DFGAT

Implementation of GOCART aerosols in development

IODA and UFO for aerosol

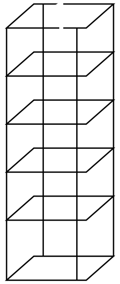
IODA-converters:
Obs native format to IODA format

IODA (observation traits)

lon, lat

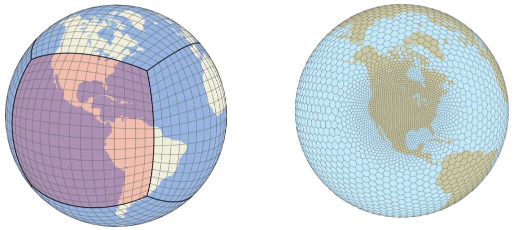
OOPS (abstract layers)

Model profile at
obs location



Model Interface

(e.g FV3, MPAS, etc)



IODA (observation traits)

pressure vertices, averaging
kernel, apriori

UFO

CRTM AOD

Any AOD retrieval with
variable LUTs.
Model independent

GEOS AOD

Extinction computed
in GEOS.

UKMO

Dust AOD.

Tested and/or Assimilated observation products in JEDI

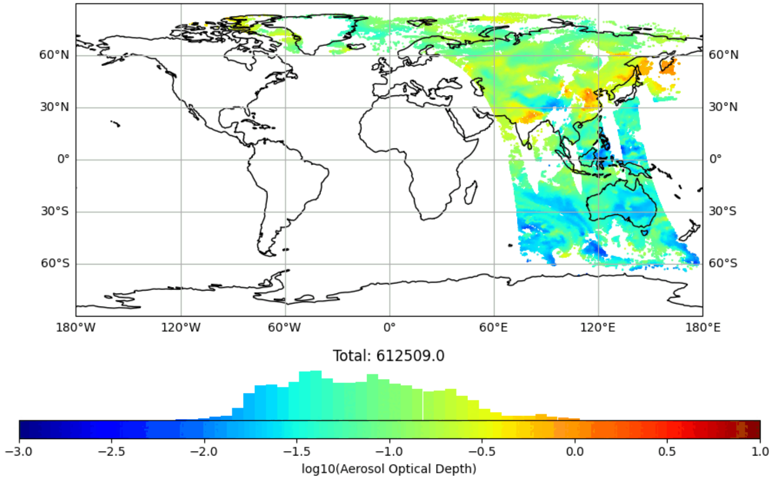
Aerosols:

- VIIRS NPP AOD
- VIIRS NOAA 20 AOD
- MODIS Aqua AOD
- MODIS Terra AOD
- PACE AOD planned

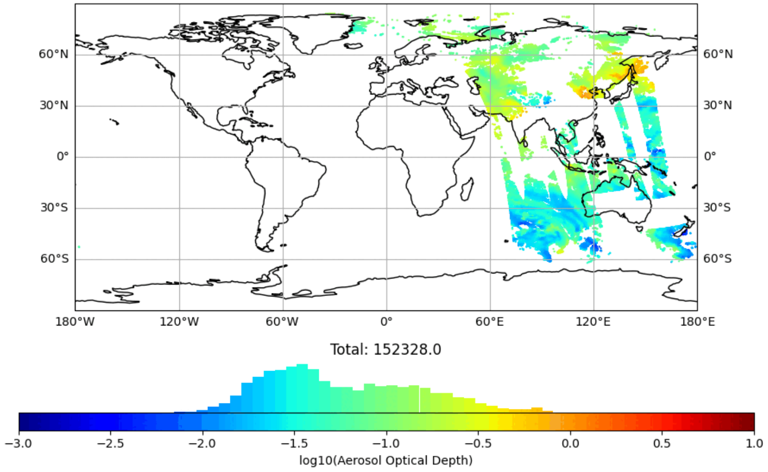
Trace gas

- TropOMI NO2 (tropospheric and total columns)
- TropOMI CO total column
- MOPITT CO total column
- **TEMPO Proxy NO2 and HCHO tropospheric columns**
- MLS O3 limb profile
- OMPS LP O3 limb profile
- OMPS TC O3 total column

VIIRS NPP AOD



MODIS AQUA



JEDI-SkyLab

- Turnkey solution for *real-world* experimental testbed for the community.

- Point of convergence for rapid prototyping & validation of developments.

- Continuous delivery of functional system for downstream operational applications.

- Quarterly release of the code associated demonstrations experiments. Current is JEDI-Skylab v7

What did Skylab demonstrated and integrated so far?

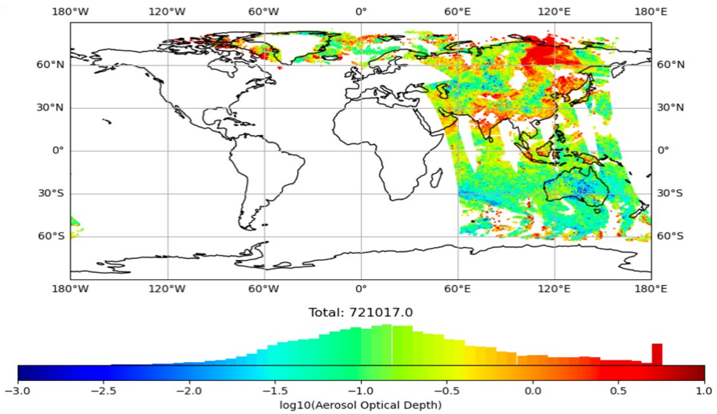
Ensemble of Data Assimilation:
- GFS a C96 (~1 degree)
- 21 members

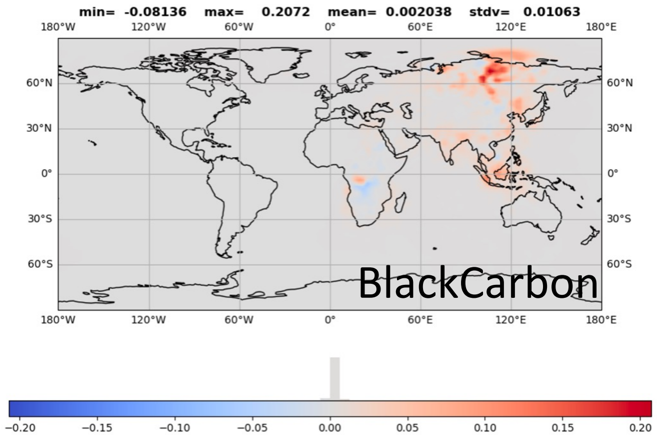
3FGAT with GEOS(CF):
- GEOS a C90 (~1 degree)
- Stretch grid C540r25 over conus
- Trace gas only

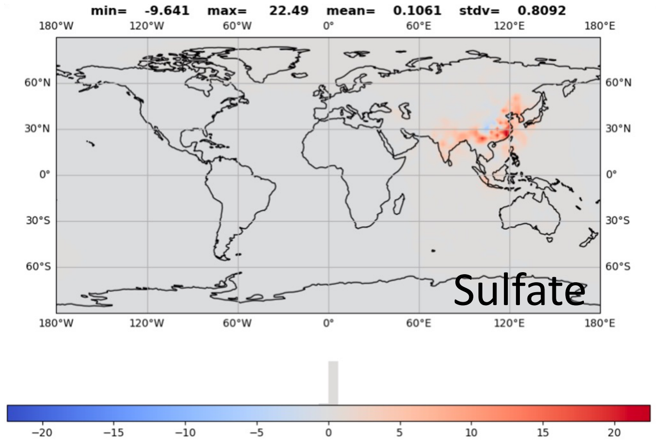
Currently working on aerosol DA configs:
- 32 members at C90
- Aerosol + meteorology DA
- 3DEnVar
- 4DEnVar
- 4DHTLMVar

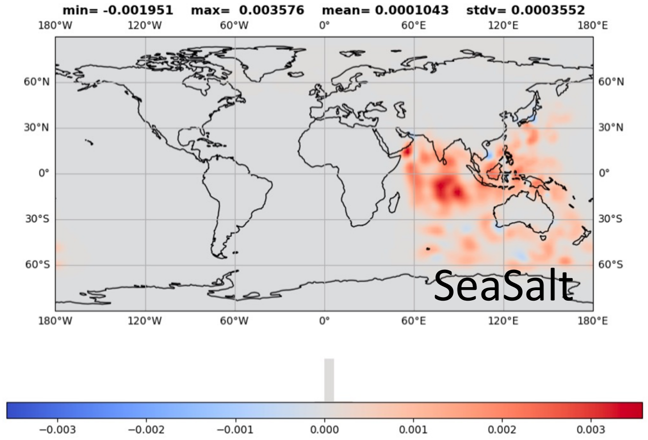
Leveraging from NWP efforts and collaborations w NOAA, NASA and UKMO

VIIRS_npp AOD (ObsValue)





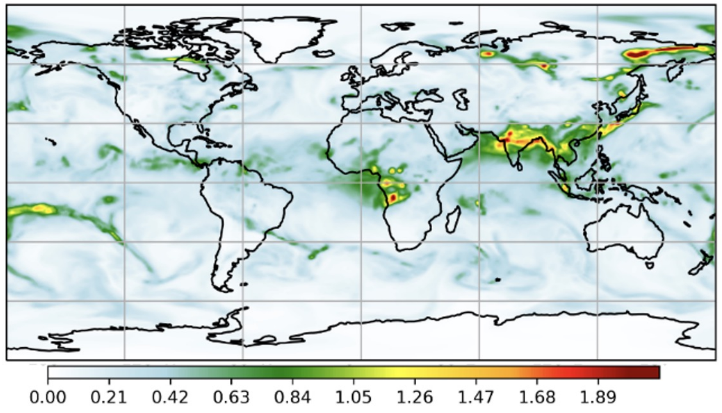




Examples of 3DVar increments

Summary of underway and planned composition DA capabilities at NOAA's National Weather Service using JEDI

Through NOAA/NWS's transition to the Unified Forecast System (UFS) comes the development of a unified coupled data assimilation system using JEDI.



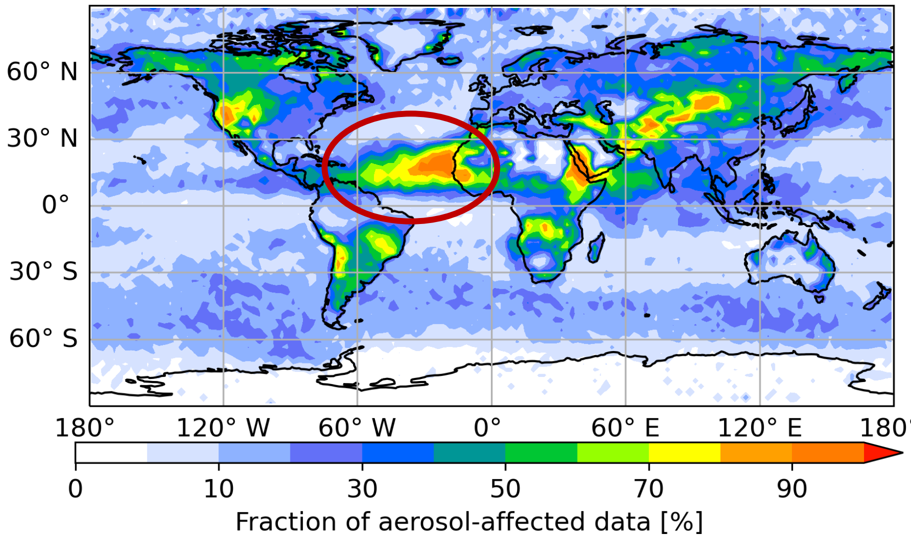
Right: Example of forecast AOD from a low resolution prototype for the next version of the Global Forecast System

Application / Modeling System	Short Term DA Plans	Longer Term DA Plans
Global Aerosol Prediction (GOCART) - GFS/GEFS	Assimilation of polar orbiting AOD retrievals in ~25km global system; 3DVar	hybrid 4DEnVar system; strongly coupled with meteorology; direct assimilation of radiances
Regional Smoke and Dust (simplified parameterization/transport) - RRFS-SD	Assimilation of PM surface obs + AOD retrievals in a 3km regional 3DVar system	hybrid 3DEnVar
Regional Air Quality (CMAQ) - NAQFC	Surface PM, space based AOD and trace gas retrievals in a ~13km regional 3DVar system	Simultaneous state and emissions adjustment

Hazy-sky IR DA (Shih-Wei Wei)

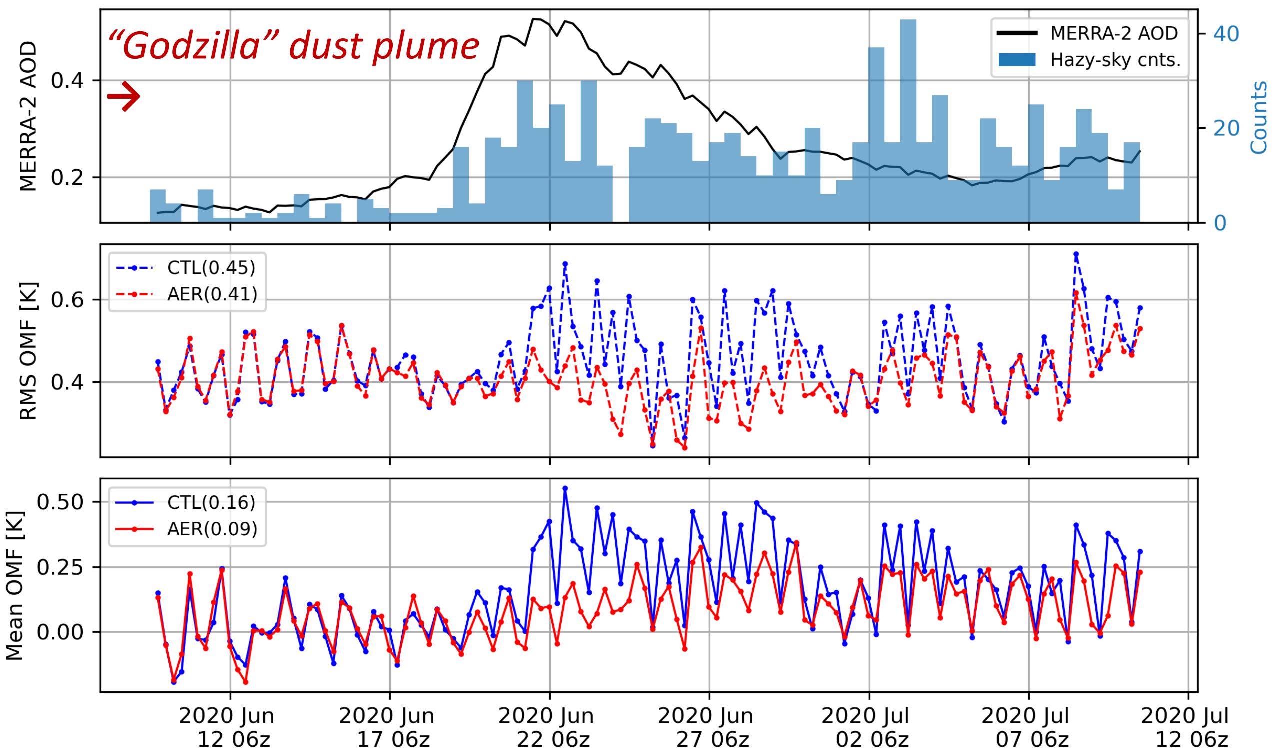
For an infrared (IR) sensor, aerosol-affected (i.e., hazy-sky) data can be over 60% or more under episodic dust event over transatlantic ocean.

Aerosol-aware IR data assimilation framework
- identifies the hazy-sky data,
- considers aerosol impacts on IR brightness temperature via the forward operator, and
- inflate the observation error.



*Fraction of hazy-sky data of IASI MetOp-A during 2020 June.

Assimilating small amount hazy-sky observations (blue bars) in IR window channel can improve the agreement with sea surface temperature during the Godzilla dust plume transported crossing Atlantic Ocean.



*Averaged over transatlantic region.
*Counts of a window channel at 962.5 cm^{-1}.

Coupled DA and L1b assimilation

- JCSDA is building a **earth system DA** capability that includes, weather, atmospheric composition, land and ocean.

- We are working towards demonstrating **joint assimilation of weather and AC** (AOD and then trace gas).

- Using radiances and AOD but we will experiment with assimilating **L1b for aerosol**. Having direct **CRTM** support at JCSDA makes it possible.

- There is also flourishing ideas of looking at the DA coupling between aerosol and ocean color. The **PACE** mission is an opportunity for JCSDA.

Community Radiative Transfer Model (CRTM)

<u>CRTM Project Team</u>

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Quanhua (Mark) Liu, Yingtao Ma *(NOAA STAR)*

<u>Thank you for your support and contribution:</u>

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Nick Nalli (NOAA STAR, now NGA)

Peng Xian, Jeff Reid (NRL)

Virginie Buchard, Peter Colarco, Arlindo da Silva (NASA)

Peng Xian, Jeff Reid (NRL)

James Hocking (Met Office)

Shih-Wei Wei, Cheng-Hsuan (Sarah) Lu (JCSDA/UCAR, University at Albany, SUNY)

Igor Polonsky (AER)

Andrew Tangborn (EMC)

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CRTM Recent Developments

CRTM version 3.0 was released for internal testing in JEDI skylab

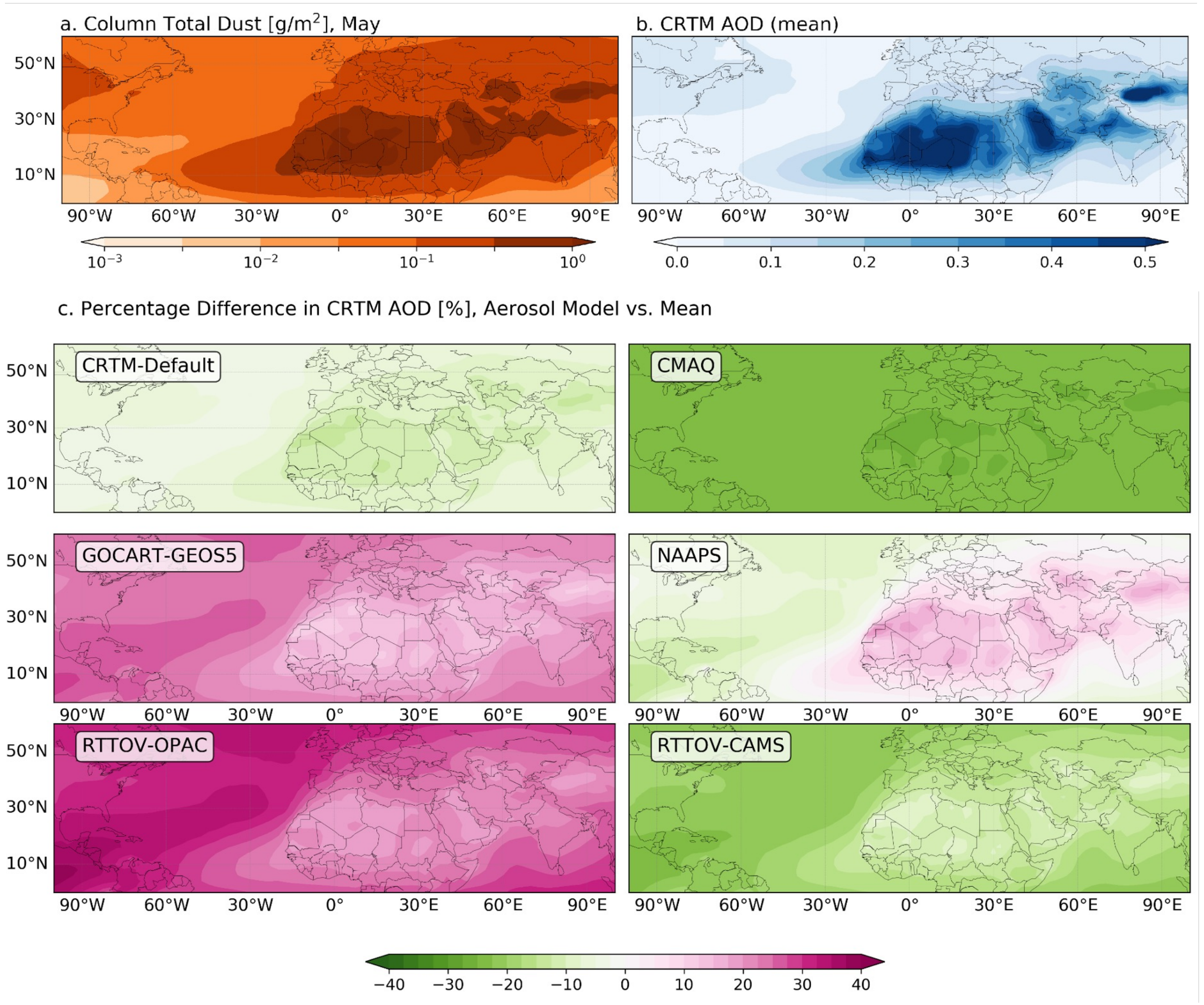
- **Full Polarization Solver Capability**
  - UV capable solver and polarization support is available and under evaluation.
- **Active Sensor Modules (Radar, Lidar)**
  - Active sensor simulator is available and under evaluation.
  - Improved Lidar backscattering and attenuation calculations.
- **Cloud / Precipitation**
  - Backscattering coefficients for CRTM active sensor capability.
  - Extended Ice Particle Scattering Properties
    - The CRTM MW ice particle scattering properties were updated and extended with the DDA database by Eriksson et al. (2018).
    - A microphysics-consistent snow optical parameterization was developed.
- **Surface**
  - Improved IR ocean and snow surface emissivity with temperature-dependent optical properties of water and ice.
  - Initial implementation of MW ocean surface BRDF model.
- **Visible Simulation**
  - Cloud, surface, and aerosol impacts on visible channels.
  - Adding TOA reflectance calculation for assimilating visible sensors.
- **Instrument Coefficients**
  - New visible and infrared imagers and sounders, including IASI-NG on MetOp-SG and VIIRS on NOAA-21.
  - New microwave imager and sounders, including MWI on EPS-SG and ATMS NOAA-21.

CRTM Aerosol Schemes

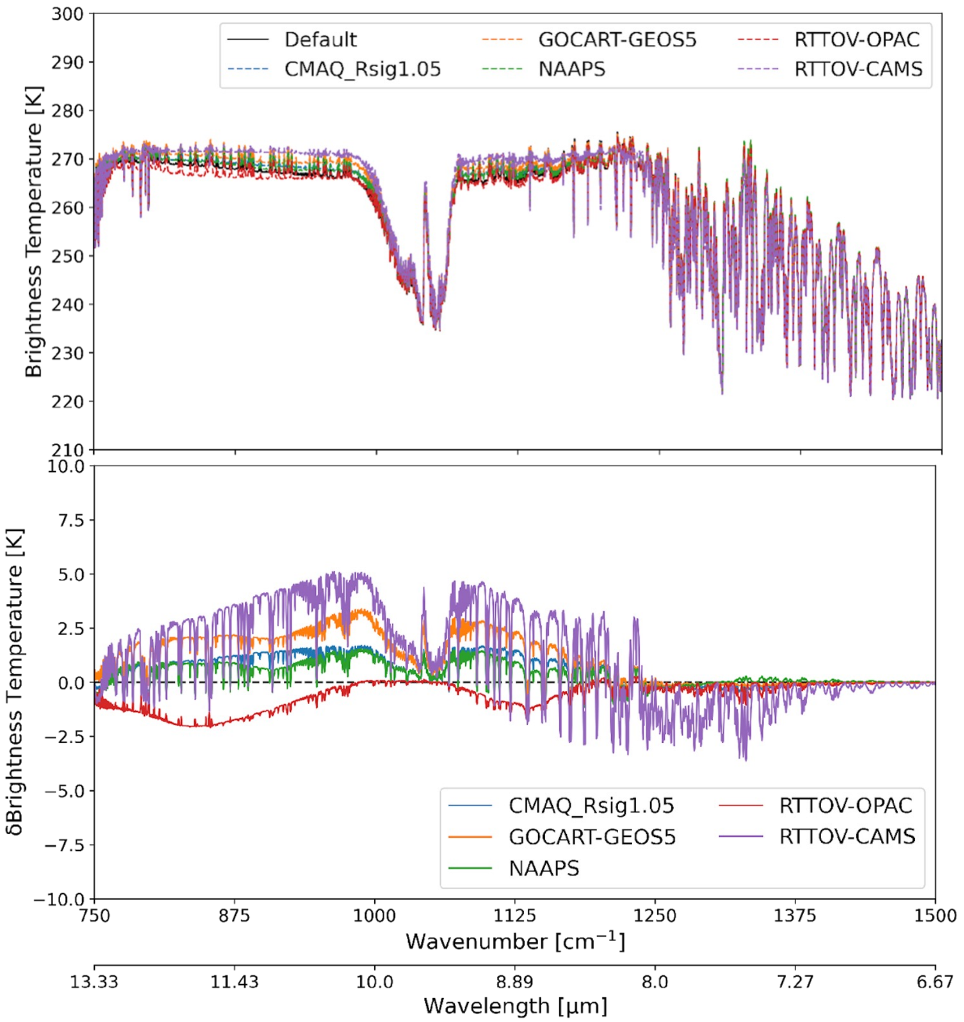
- CRTM version 3.0 continues support aerosol coefficients used in various chemical models and DA systems.
- The newly added LUTs are the two RTTOV tables based on OPAC and CAMS datasets.
- Users may use any of the following schemes for AOD and aerosol-impacted radiance simulation.
- The primary goal of CRTM team at the current stage is to evaluate the existing aerosol tables, in collaborating with JEDI COMPO and NCAR collogues.

CRTM Version	Model	Aerosol species	Aerosol properties	References
All versions	CRTM (Default)	dust, sea salt, organic carbon, black carbon, sulfate	**effective radius, hygroscopicity (implicit)**	Chin et al., 2002; Han, 2006
v2.4 – v3.0 NetCDF	CMAQ	dust, sea salt, water-soluble, soot, sulfate, water, insoluble, dust-like	effective radius, hygroscopicity (implicit), **radius standard deviation**	Binkowski and Roselle, 2003; Liu and Lu 2016
v2.4.1 – v3.0	GOCART -GEOS5	dust, sea salt, organic carbon, black carbon, sulfate, nitrate	effective radius, **hygroscopicity**	Colarco et al., 2010
v2.4.1 – v3.0	NAAPS	Bulk aerosol properties: dust, sea salt, smoke, anthropogenic and biogenic fine particles	hygroscopicity	Lynch et al., 2016
v2.4.1 – v3.0	RTTOV-OPAC RTTOV-CAMS	dust, sea salt, organic carbon, black carbon, sulfate, nitrate CAMS: aerosol climatology developed by Copernicus Atmosphere Monitoring Service	effective radius, hygroscopicity	RTTOV v13, https://nwp-saf.eumetsat.int/site/software/rttov/rttov-v13/

Example: AOD and brightness temperature simulated with six aerosol schemes in CRTM version 3.0



Figures: ***a.*** Column total aerosol concentration of May (MERRA-2 climatology) and ***b.*** the corresponding AOD (550nm) simulated using CRTM, averaged over six aerosol schemes. ***c.*** percentage differences in AOD computed using each aerosol scheme.



Figures: brightness temperature (top) simulated by CRTM with different aerosol schemes for IASI_metop-a between 750 to 1500 cm-1, for the same dust profiles. The bottom panel shows the difference in simulated brightness temperature.

CRTM Generic Interface

In CRTM version 3.1, we will release the newly developed CRTM generic interface. As discussed during ICAP 2022, this generic interface will enable optical profiles as input for CRTM AOD and radiance simulations.
This generic interface is independent of the existing CRTM framework and will be of no impact to the existing CRTM users.

The primary optical variables required from users are profiles of optical depth, single-scattering albedo, asymmetry factor, phase coefficients, and directional surface emissivity. For mixture of gaseous, aerosols, and cloud, the input values should be the weighted summary at each layer, for which CRTM will provide an offline Python code for demonstration.

As of October 2023, the forward generic modules are under testing. More development is under planning for the corresponding tangent liner and K-matrix modules.

Questions to ICAP community: is the forward calculation sufficient? Will you also request the TL and K-matrix modules?

If you are interested in discussing more about this interface or CRTM in general, please send me an email.
If you are going to AGU 2023 Fall Meeting, let's catch up in San Francisco! Cheng Dang, dangch@ucar.edu

Extra slides: TEMPO DA

JEDI-Skylab v7 release: stretch grid & 3D-FGAT

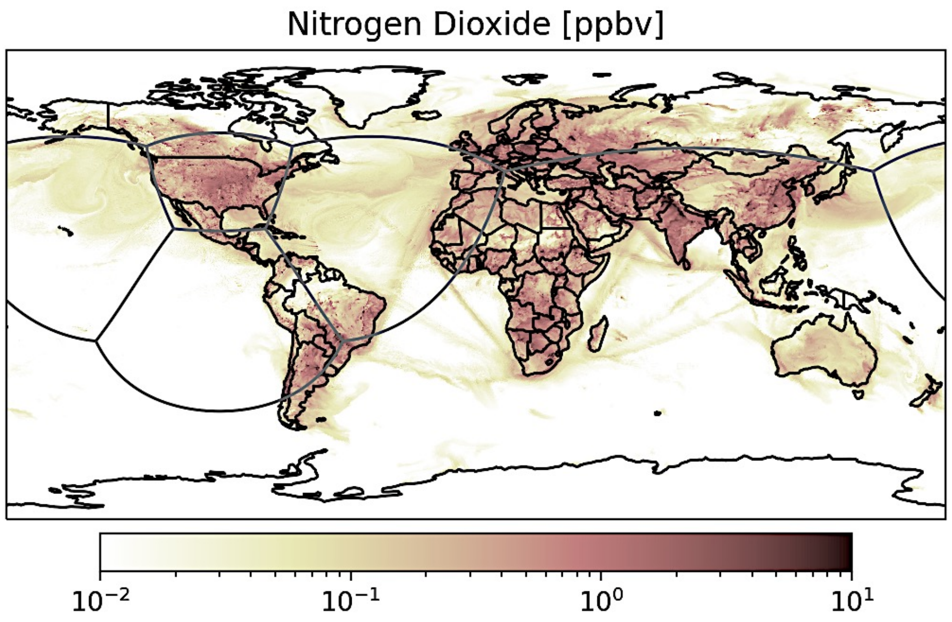
- FV3 Stretched Grid (SG)

Tested c540r25 high resolution backgrounds produced by C. Keller (GMAO) : ~7km over CONUS

Tested with TROPOMI NO2 3DVar and then 3DFGAT

Implemented FGAT with hourly model outputs as background.

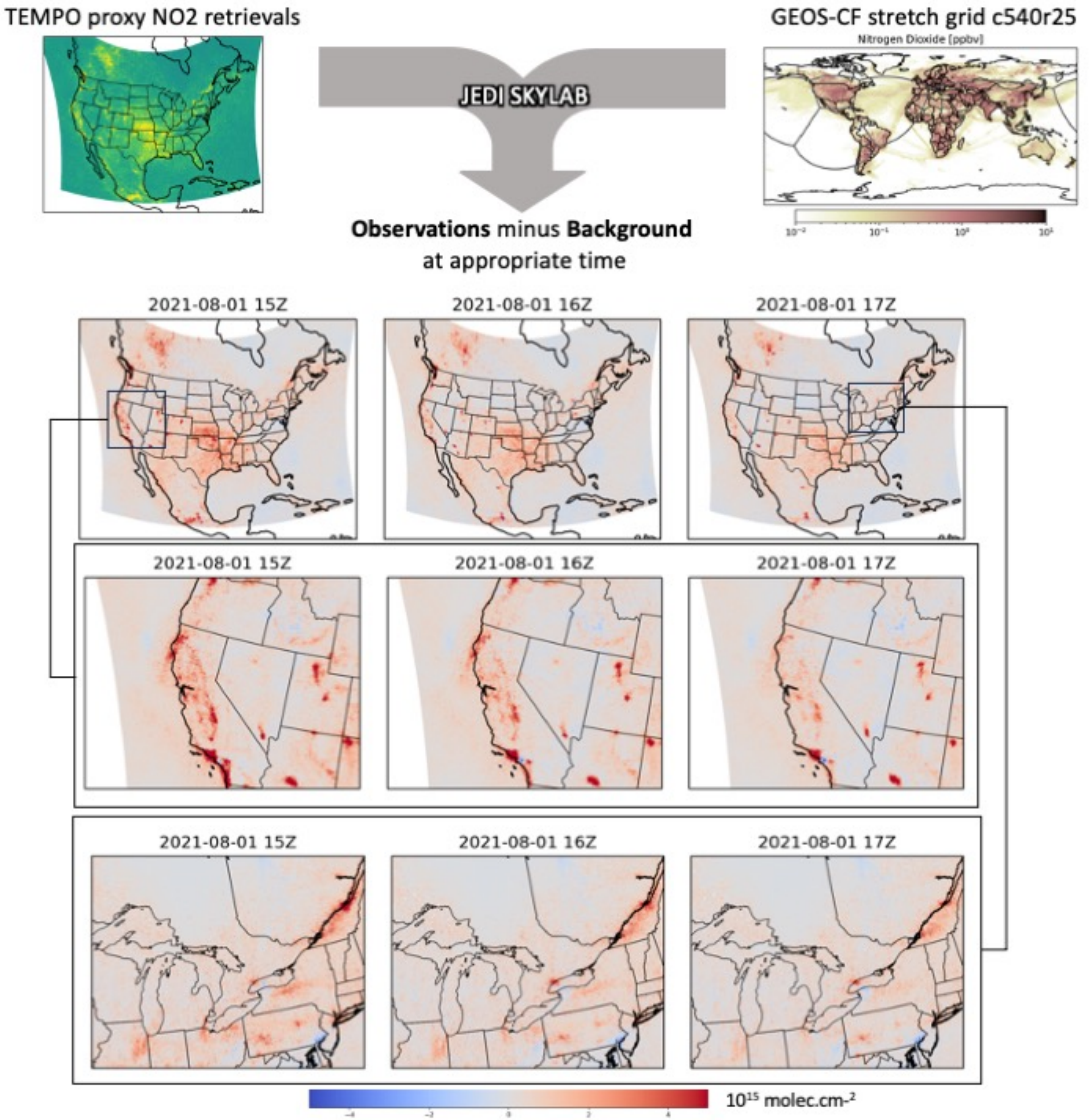
GEOS-CF stretch grid c540r25



TEMPO NO2 proxy data demo

Integrated TEMPO proxy NO2 retrievals:

- IODA converter for NO2 and HCHO retrievals
- Testing in UFO
- Integrated the TEMPO proxy retrievals in monitoring only with the stretch grid backgrounds
- Joint experiment with TROPOMI NO2
- Proxy data means no scientific relevance but means that the JEDI system is getting ready to assimilate TEMPO for the official product release in Apr 2024.
- **Next**: test with a real data sample to ensure readiness of the system for official release



Towards Emissions and fluxes capability

Towards a human emissions monitoring verification and support (MVS) capability in JEDI:
Assess what is the most suited DA flavor for source inversions and fit the needs of our partner agencies NASA and NOAA.

- We just finished setting up a TL/AD for any tracer tracers, i.e. we can do 4DVar now with JEDI for AC, bot no chemistry in.
- Add emissions in the CV
- Use 4D-HTLM-Var to add chemistry + physics tendency terms with ensemble info
- 4DEnVar will also be assessed: no need for a TL/AD

- Develop interface and workflow to handle emission post and pre processing in JEDI
  - Project emission perturbations from analysis to the next window
  - Increment/constraint on sectorial information

- **Ramp up with GHG capability**