# Joint Effort for Data Assimilation Integration

Status Update

Tom Auligné, Director, Joint Center for Satellite Data Assimilation
with inputs from Y. Trémolet and JEDI team

NGGPS Bi-weekly meeting:: January 29, 2020

# JEDI is a Joint Effort

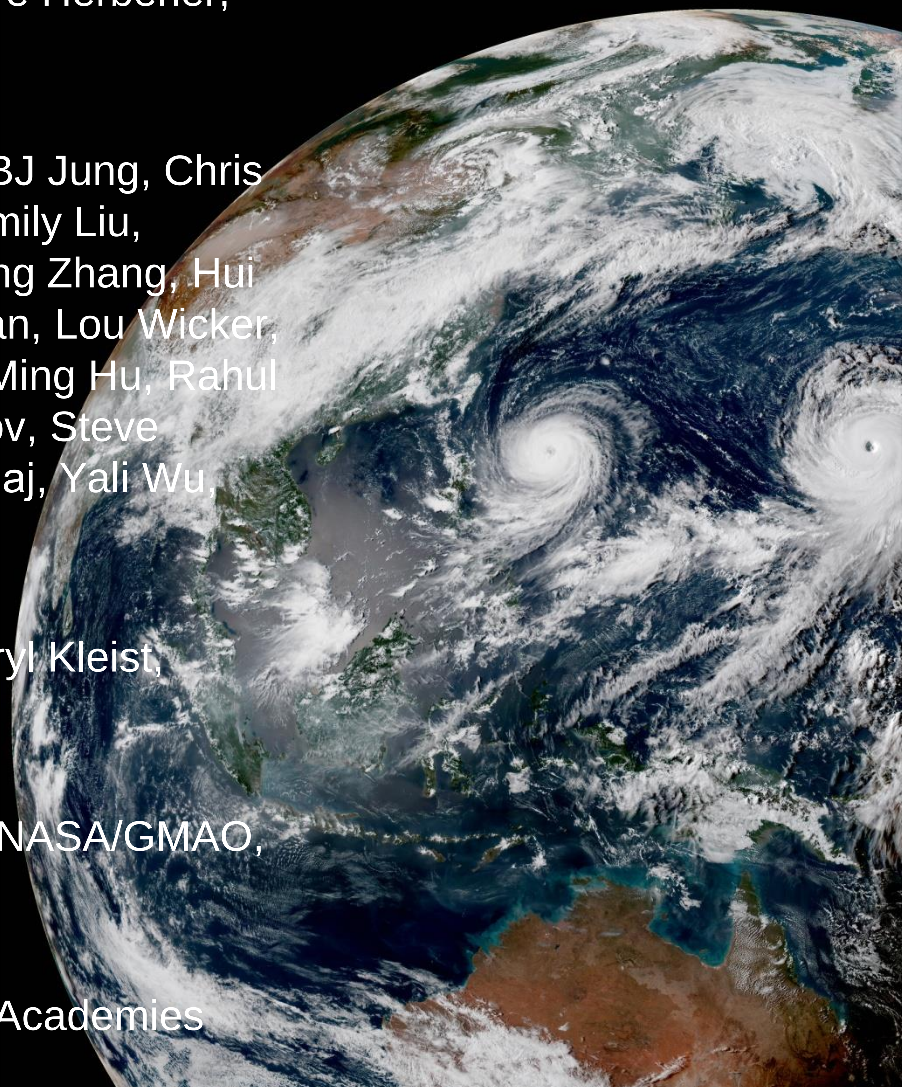
***JEDI core-team***: Yannick Trémolet, Anna Shlyaeva, Benjamin Ménétrier, Clémentine Gas, Dan Holdaway, Mark Miesch, Mark Olah, Maryam Abdi-Oskouei, Ryan Honeyager, Steve Herbener, Xin Zhang

***JEDI contributors***: Andrew Collard, Ben Johnson, BJ Jung, Chris Harrop, Clara Draper, Cory Martin, David Davies, Emily Liu, François Vandenberghe, Guillaume Vernières, Hailing Zhang, Hui Shao, Jeff Whitaker, Jonathan Guerrette, Junmei Ban, Lou Wicker, Marek Wlasak, Mariusz Pagowski, Michael Cooke, Ming Hu, Rahul Mahajan, Ricardo Todling, Sarah King, Sergey Frolov, Steve Sandbach, Steve Vahl, Travis Sluka, Wojciech Śmigaj, Yali Wu, Yanqiu Zhu, Yunheng Wang…

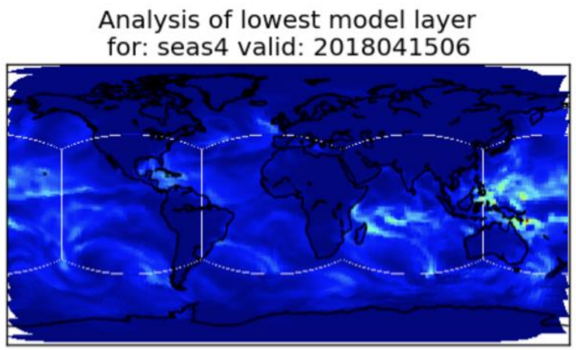
***JEDI collaborators***: Chris Snyder, Dale Barker, Daryl Kleist, Nancy Baker, Ron Gelaro

***Representing***: JCSDA, NOAA/EMC, NOAA/ESRL, NASA/GMAO, NRL, USAF, NCAR, UKMO

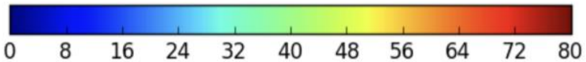
And about 120 padawans who attended three JEDI Academies



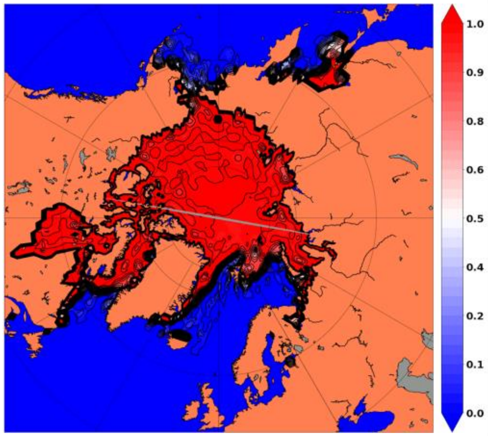
# JEDI: One System with Multiple Configurations

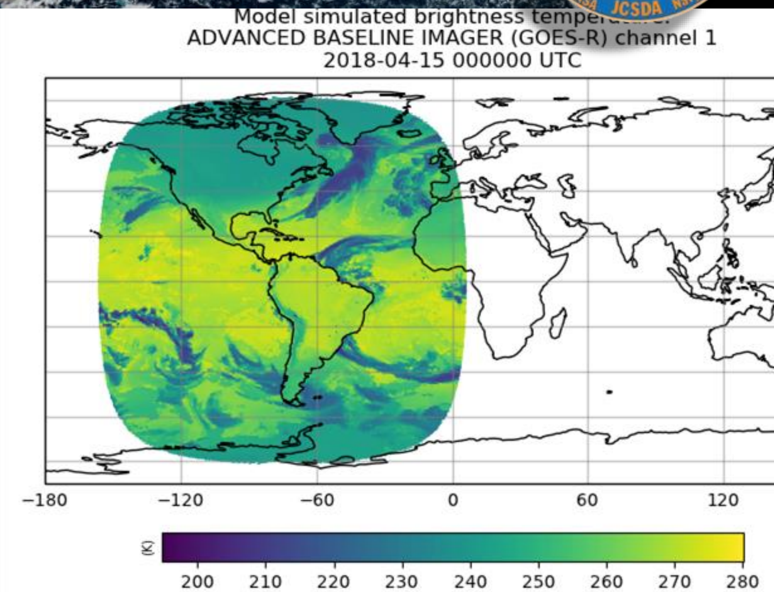



Analyzed aerosols

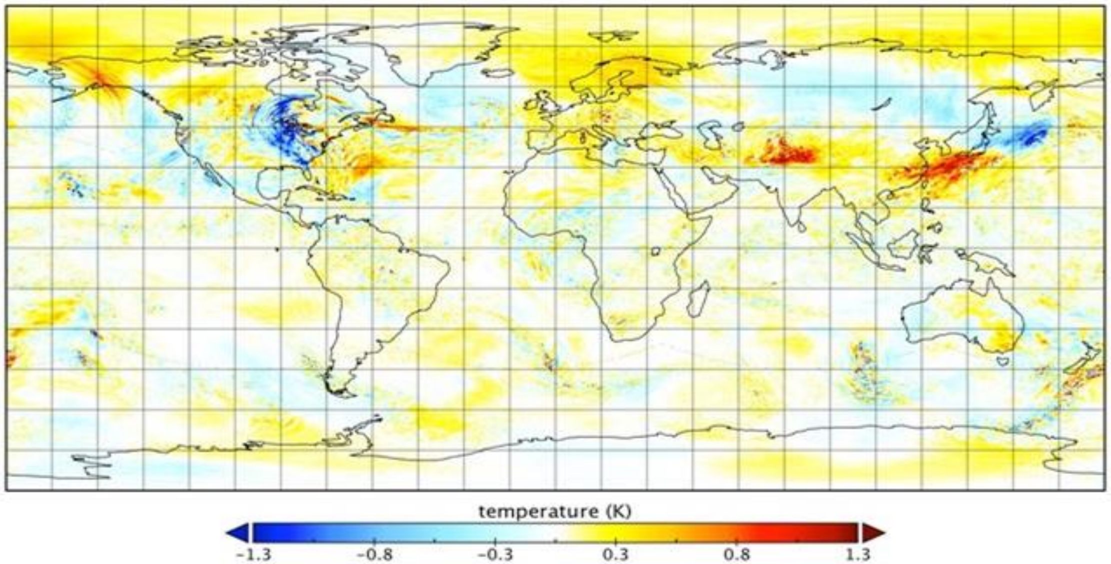



Analyzed ice fraction aggregate

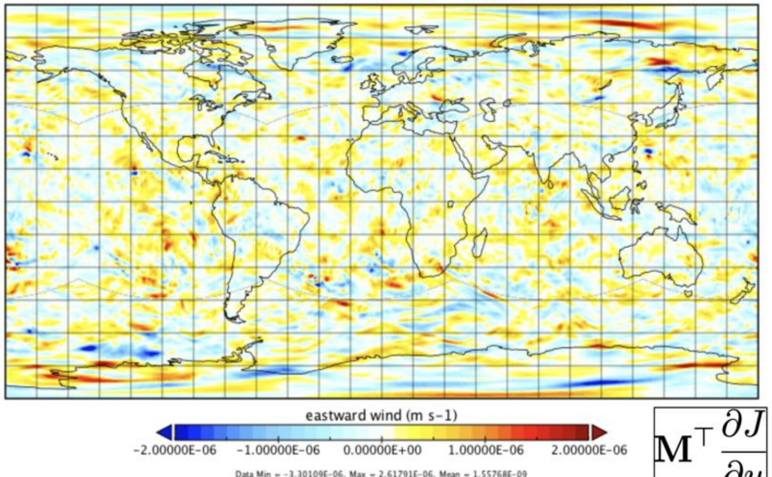



200 hPa T increment propagated 24h by GFSv15 on AWS (1,728 cores) in 7min20s

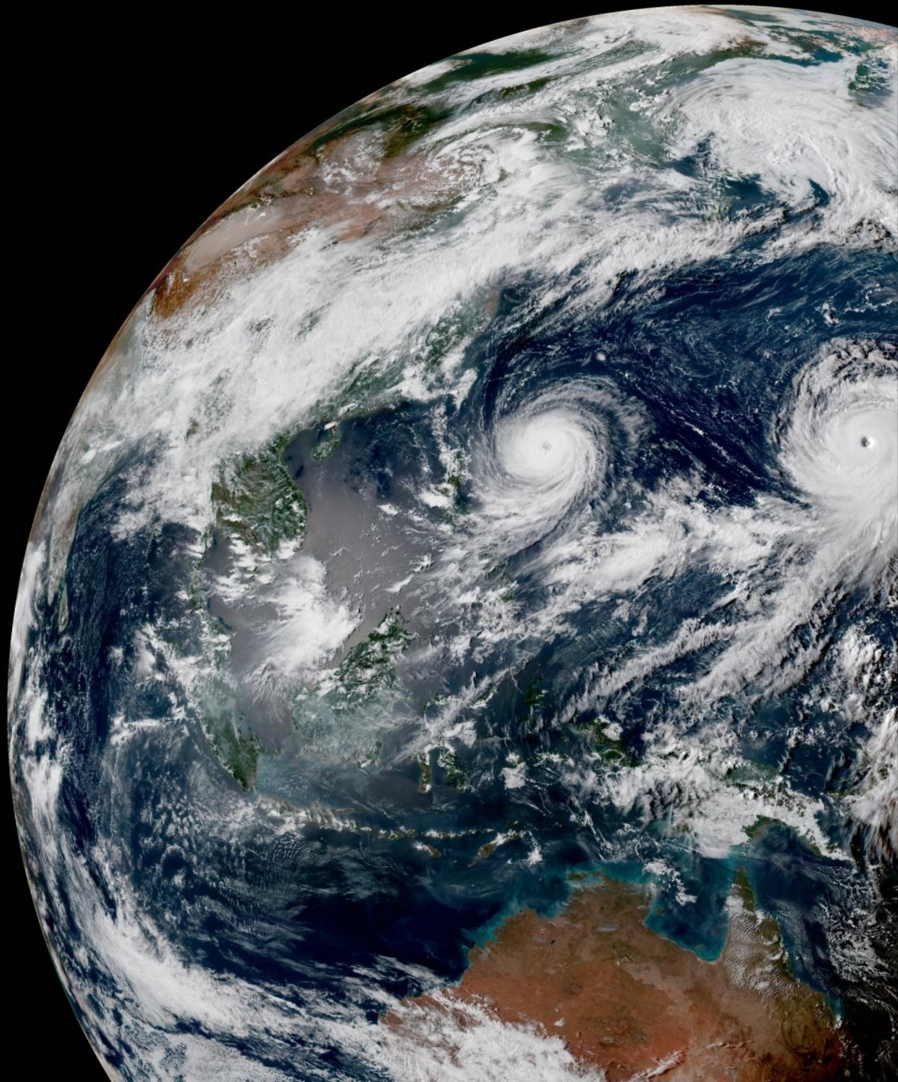



Adjoint Sensitivity to initial conditions @500 hPa

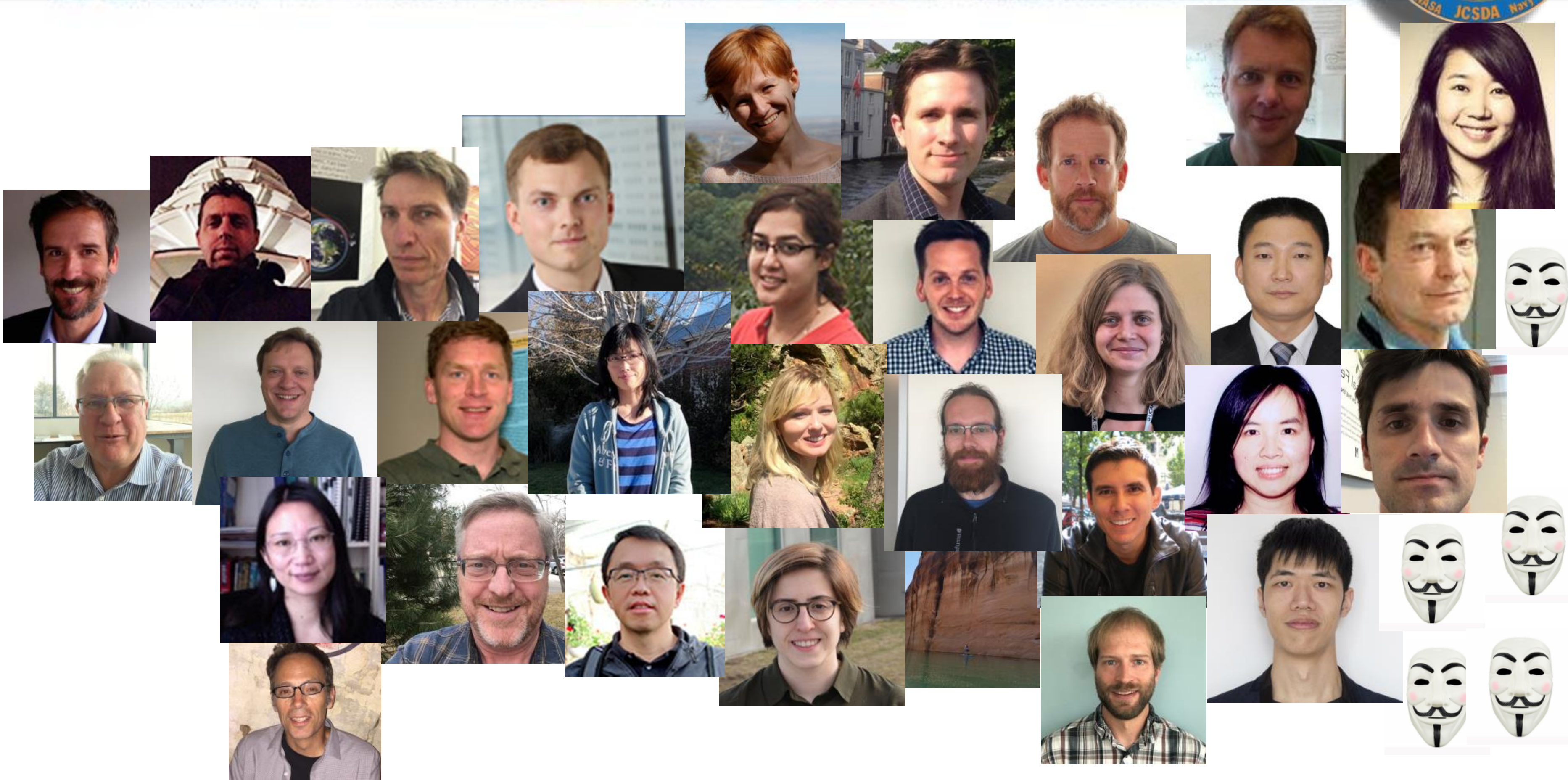



$$\mathbf{M}^{\top}\frac{\partial J}{\partial u}$$

What we accomplished
How we got here

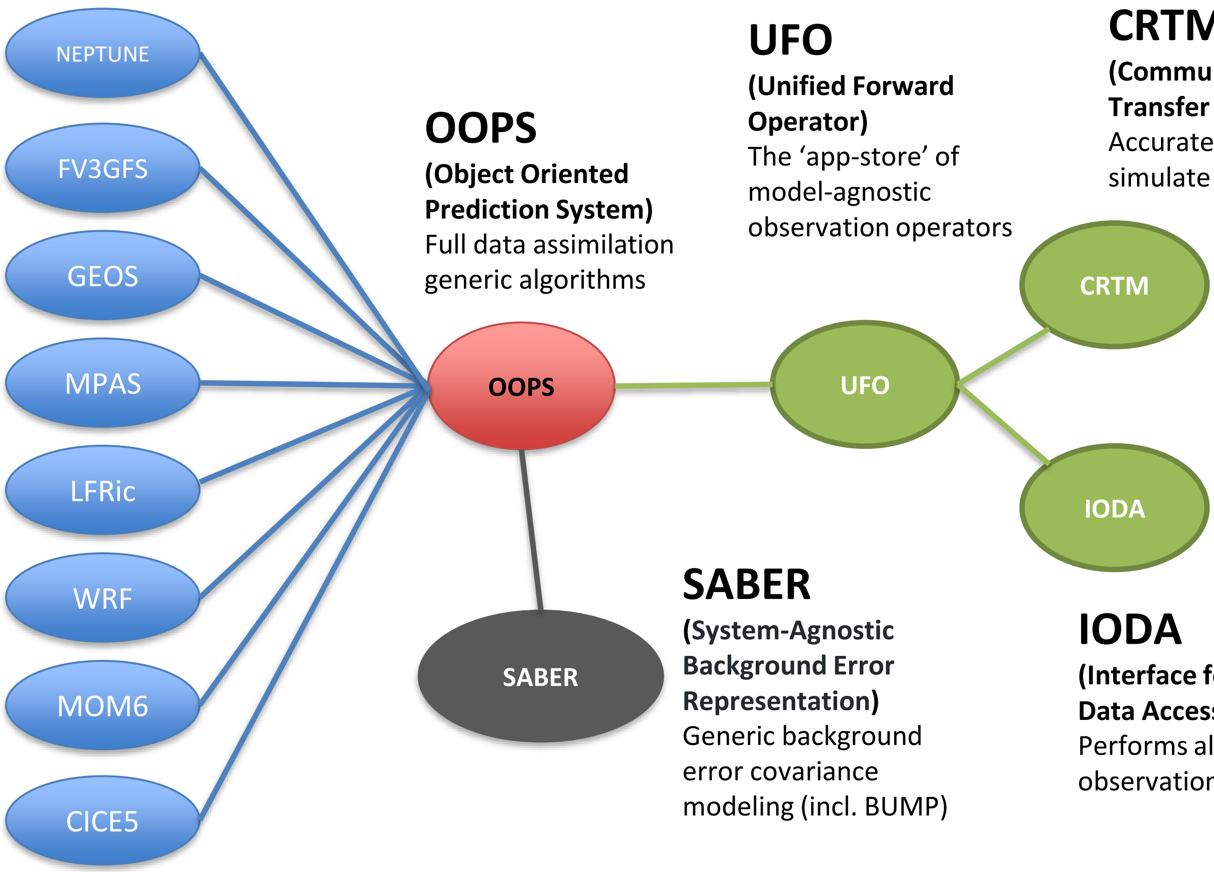


# Assembling a Center of Excellence



2017 → 2018 → 2019

# Separation of Concerns, Code and Repositories




**OOPS**
**(Object Oriented Prediction System)**
Full data assimilation generic algorithms

**UFO**
**(Unified Forward Operator)**
The 'app-store' of model-agnostic observation operators

**CRTM**
**(Community Radiative Transfer Model)**
Accurately and efficiently simulate satellite radiances

**SABER**
**(System-Agnostic Background Error Representation)**
Generic background error covariance modeling (incl. BUMP)

**IODA**
**(Interface for Observation Data Access)**
Performs all the I/O of the observations

Abstract interfaces are the most important aspect of the design
The end of the monolithic gigantic jumble of code

# Community Engagement and Support

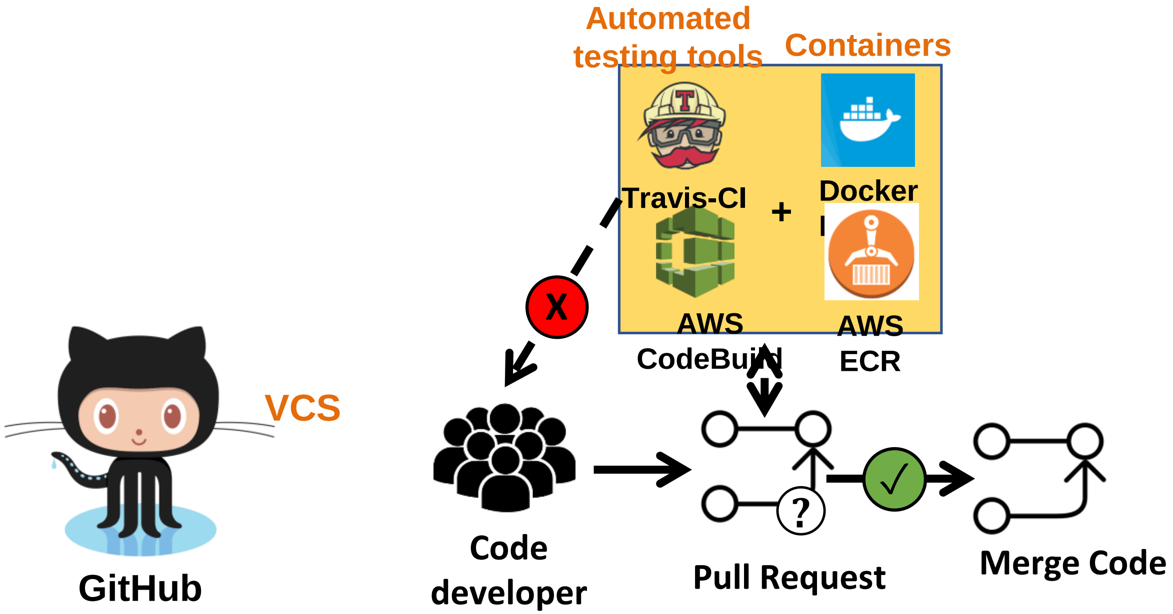
3rd JEDI Academy

17th JCSDA Science Workshop

Marine IODA/UFO Code Sprint

# Graduate Student Test

| | |
|---|---|
| Access ***latest*** code and build | **10 min** |
| Run test experiment (on laptop, Cloud, HPC) | **10 min** |
| Submit issue ticket and new development | **5 min** |
| Automatic testing | **10 min** |
| Peer-review | **Same day** |
| Merge code back to community code | **5 seconds** |



# Community Engagement and Support

- 2nd JEDI Academy. November 13-16, 2018. College Park, MD
- 7th JCSDA Symposium @Annual AMS Meeting. January 6-10, 2019. Phoenix, AZ
- 2019 JCSDA Executive Retreat. February 5-7, 2019. Estes Park, CO
- 2019 JCSDA IODA Workshop. February 11-13, 2019. Monterey, CA
- Marine IODA/UFO Code Sprint. March 25 - April 5, 2019. Boulder, CO
- Joint CMA/ECMWF/JCSDA Workshop on Radiative Transfer Models for Data Assimilation. April 29-May 3, 2019. Beijing, China.
- 17th JCSDA Technical Review Meeting and Science Workshop. May 29-31, 2019. NASA Headquarters. Washington, DC
- 3rd JEDI Academy. June 10-14, 2019. Boulder, CO
- JEDI UFO Code Sprint. August 19-30, 2019. Boulder, CO
- 8th JCSDA Symposium @Annual AMS Meeting. January 12-16, 2020. Boston, MA
- Joint ECMWF/JCSDA Workshop. February 3-5, 2020. Reading, UK
- 2020 JCSDA Executive Retreat. February 11-13, 2019. Estes Park, CO
- 4th JEDI Academy. February 24-27, 2020. Monterey, CA
- CRTM Users/Developers Workshop. February 28, 2020. Monterey, CA

Quarterly Newsletter, Seminars, Visiting Scientist Program, www.jcsda.org

# JEDI Timeline

Aug. 2017 First line of code, univariate B matrix, decision on OOPS

Nov. 2017 Introduction of Unified Forward Operator (UFO)

May 2018 Marine UFO

May 2018 4D-Var with FV3 (dry)

Aug. 2018 Multivariate B matrix

Dec. 2018 One month cycling 3D-Var (MPAS)

Aug. 2019 Introduction of generic QC filters

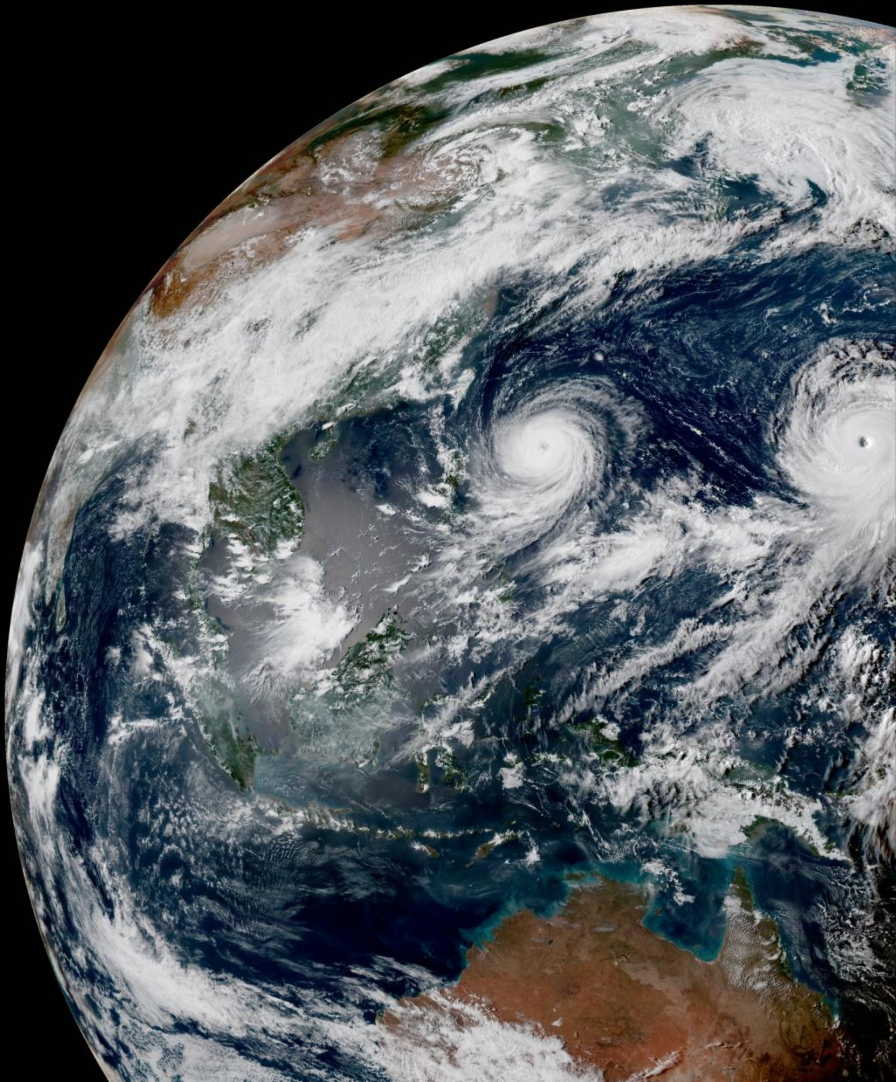
Oct. 2019 Marine DA transferred to EMC

Nov. 2019. 4D-Var with outer loops (Sept. for GEOS)

Dec. 2019 Generic QC filters for IR radiances

Jan. 2020 Cycling 4D-Var (FV3-GEOS)

# Where we are today



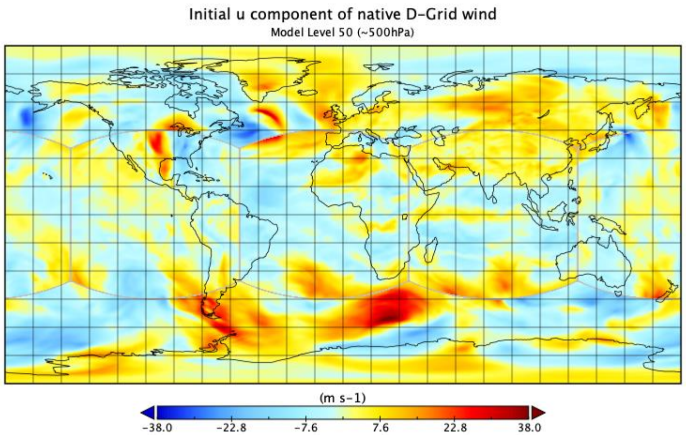
# Models being Interfaced to JEDI

| MODEL | TYPE | INTERFACE | CENTER |
|---|---|---|---|
| FV3GFS | Atmosphere | fv3-jedi | NOAA-EMC |
| GEOS | Atmosphere | fv3-jedi | NASA-GMAO |
| FV3GFS GSDChem | Atmospheric chemistry | fv3-jedi | NOAA-ESRL |
| GEOS-AERO | Atmospheric aerosols | fv3-jedi | NASA-GMAO |
| MPAS | Atmosphere | mpas | NCAR |
| WRF | Atmosphere | wrf-jedi | NCAR |
| LFRic | Atmosphere | lfric | Met Office (UK) |
| MOM6 | Ocean | soca | NOAA-EMC |
| SIS2 | Sea ice | soca | NOAA-EMC |
| CICE6 | Sea ice | soca-cice6 | NOAA-EMC |
| NEPTUNE | Atmosphere | neptune | NRL |
| QG | Toy model | oops | ECMWF |
| Lorenz 95 | Toy model | oops | ECMWF |
| ShallowWater | Toy model | shallow-water | NOAA-ESRL |

# FV3 Model Interfacing Status

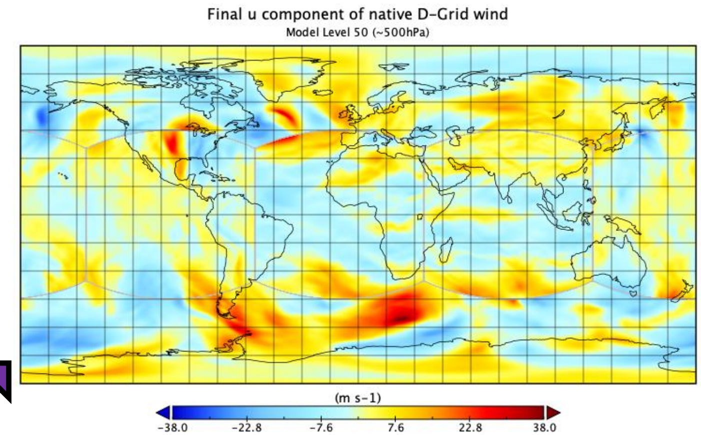
| Milestone | GFS | GEOS | FV3 Solo |
|---|---|---|---|
| 3DEnVar | | √ | |
| 4DEnsVar | √ | √ | NA |
| 4DVar | √ | √ | √ |
| 4DVar with linear physics | ✗ | √ | NA |
| Ensemble H(X) | | √ | |
| 4D H(x) in-core | √ | √ | √ |
| Multiple outer loops (IO) | | √ | |
| Multiple outer loops in-core | √ | ✗ | √ |
| Multiple resolutions | | √ | |
| EDA | | √ | |
| Multiple resolution outer loops | ✗ | ✗ | √ (simple B) |

# Static B and Cube-Sphere Poisson Solver

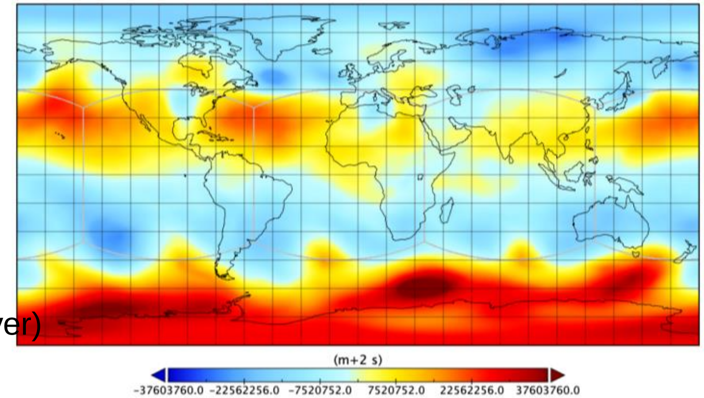



Initial D-Grid winds
(correlation length scales ~200km)

Final D-Grid winds




Poisson




Stream function
(and velocity potential)

Correlation length scales ~4000km

$$B = K_h K_v D C D^\top K_v^\top K_h^\top$$

- $D$ : Standard deviation
- $C$ : Correlation (BUMP)
- $K_h$ : Horizontal Balance (Poisson solver)
- $K_v$ : Vertical balance (BUMP)

Work done with John Thuburn (University of Exeter, UK) and Benjamin Menetrier (JCSDA)

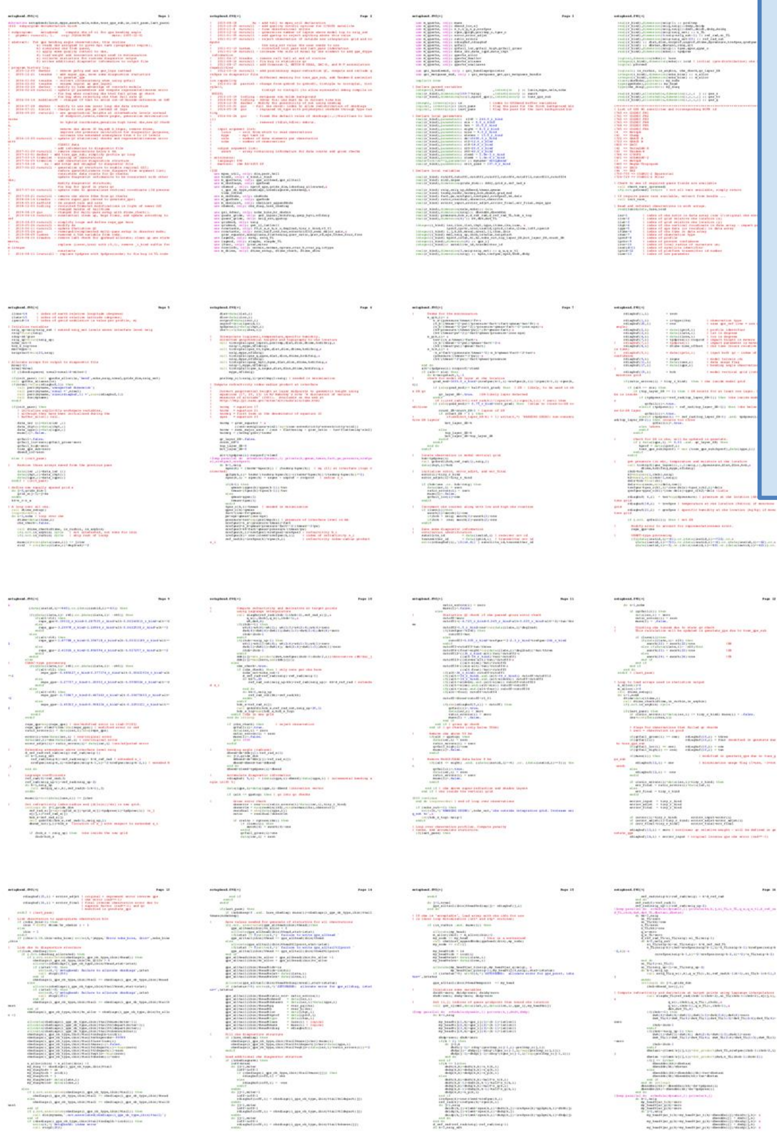
# Interface for Observation Data Access (IODA) and Unified Forward Operator (UFO)

| Observation Type (Instrument) | IODA obs file | H(x) | Notes |
|---|---|---|---|
| Aircraft | ✔ | ✔ | |
| Radiosonde | ✔ | ✔ | |
| Satwinds | ✔ | ✔ | |
| Additional conventional | ✔ | ✔ | Sfc obs, ship obs, wind profiler, etc. |
| AMSU-A | ✔ | ✔ | n15, n18, n19, metop-a, metop-b, aqua |
| AIRS | ✔ | ✔ | aqua |
| CRIS | ✔ | ✔ | npp |
| HIRS-4 | ✔ | ✔ | metop-a, metop-b |
| IASI | ✔ | ✔ | metop-a, metop-b |
| MHS | ✔ | ✔ | n18, n19, metop-a, metop-b |
| VIIRS AOD | ✔ | ✔ | |
| GNSSRO | ✔ | ✔ | |
| Marine (retrievals) | ✔ | ✔ | SST, SSS, SSH, Insitu Temp, Seaice (frac, thick) |
| Marine (radiances) | ✔ | ✔ | |

# UFO Status

- Specific observation operators being implemented
- Generic QC Filters
  - Entirely controlled from yaml configuration files (no coding, no compilation)
  - Filters are written once and used with many observation types
  - More filters will be developed as needed
- Generic observation bias correction
  - Use same generic concepts as QC (ObsDiag, ObsFunction)
  - Generic collection of predictors (controlled from yaml files)
- Current Status and Validation (vs. GSI):
  - Generic filters: 26 differences in QC flags out of 6M IASI obs (rounding errors)
  - VarBC predictors identical (machine precision) to GSI (IASI and AMSU-A)
- The system is getting mature

# Generic QC Filters



```yaml
ObsTypes:
- ObsOperator:
    name: GnssroBndGSI
  ObsFilters:
  - Filter: Domain Check
    where:
    - variable:  impact_height
      minvalue: 0
      maxvalue: 50000
  - Filter: Background Check
    variables: [bending_angle]
    threshold: 3.0
  - Filter: ROobserror
    variable: bending_angle
    errmodel: ROPP
```

```yaml
ObsFilters:
- Filter: Domain Check
  variable: ascending_flag
  is_not_in: 1
  where:
  - variable: occulting_sat_id
    is_in: 825
```

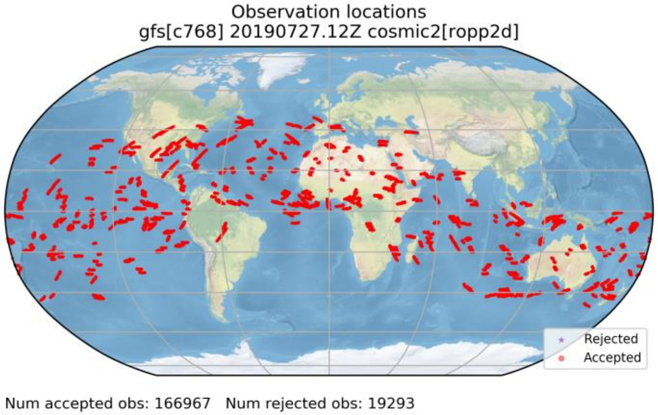
Rejecting KOMPSAT5 rising profiles

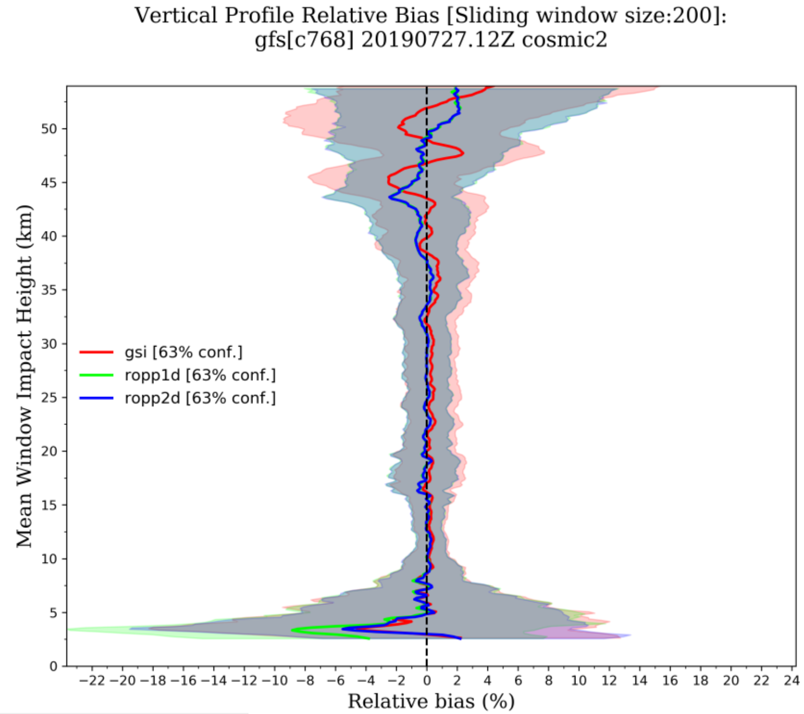
Using ROPP error estimates

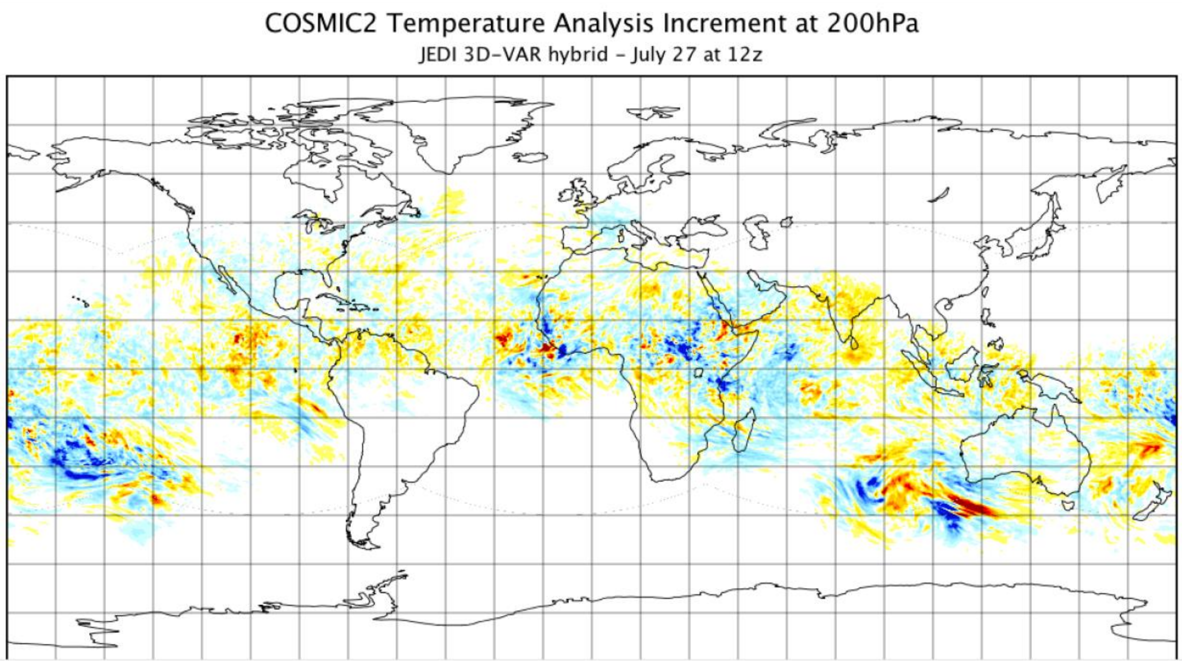
About 18 pages (fairly small font!) of GNSSRO QC code replaced by generic filters and yaml configuration files

No factory reconfiguration (i.e. no recompilation)

**Future-proof**: can accommodate unplanned configurations

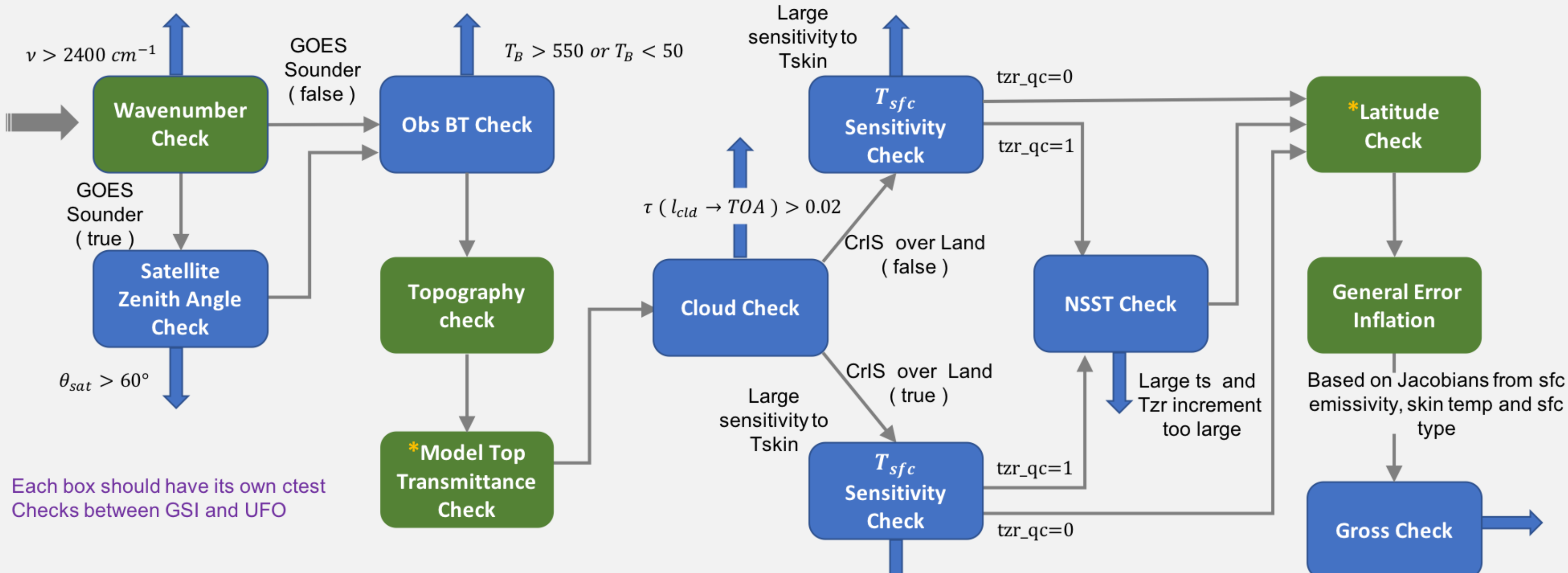

Observation locations
gfs[c768] 20190727.12Z cosmic2[ropp2d]
Rejected
Accepted
Num accepted obs: 166967   Num rejected obs: 19293


Vertical Profile Relative Bias [Sliding window size:200]:
gfs[c768] 20190727.12Z cosmic2
Mean Window Impact Height (km)
Relative bias (%)
gsi [63% conf.]
ropp1d [63% conf.]
ropp2d [63% conf.]


COSMIC2 Temperature Analysis Increment at 200hPa
JEDI 3D-VAR hybrid - July 27 at 12z

# Operational QC Procedures for IR

## Operational (GSI) QC Flowchart for Infrared Sounders




- varinv values are modified for all processes
- errf values are modified at processes marked with *
- Additional QC for Ozone:
  Set Ozone jacobian to zero for QC_NoIRJacO3_Pole is true and obs latitude > 60 degree

(Emily Liu)

A process of observation **Error Inflation** or called **Inverse of Error ( varinv ) Reduction** and ***Bound ( errf ) Tightening** from their original values

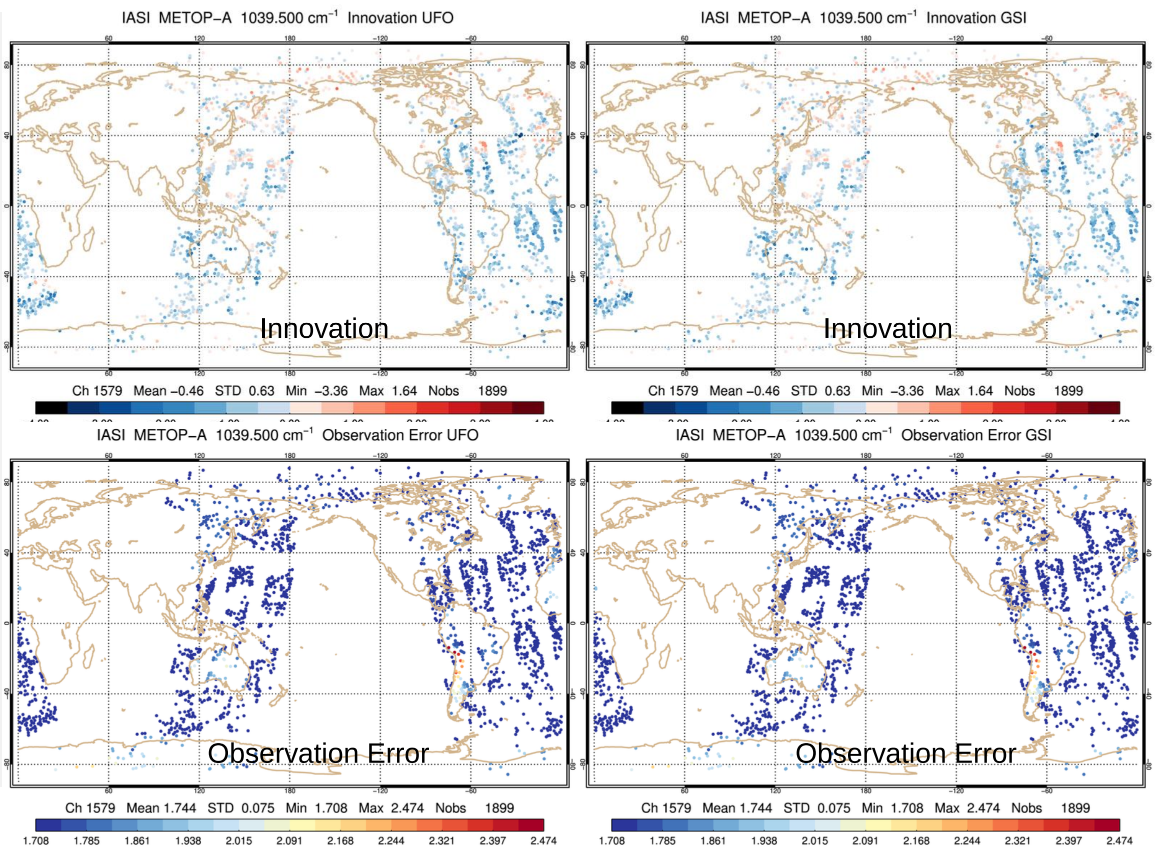
# IASI QC Comparison

**Innovation & Observation Error after QC** | **Surface and Clod Sensitive Channel**

Section of YAML for Cloud Detection QC

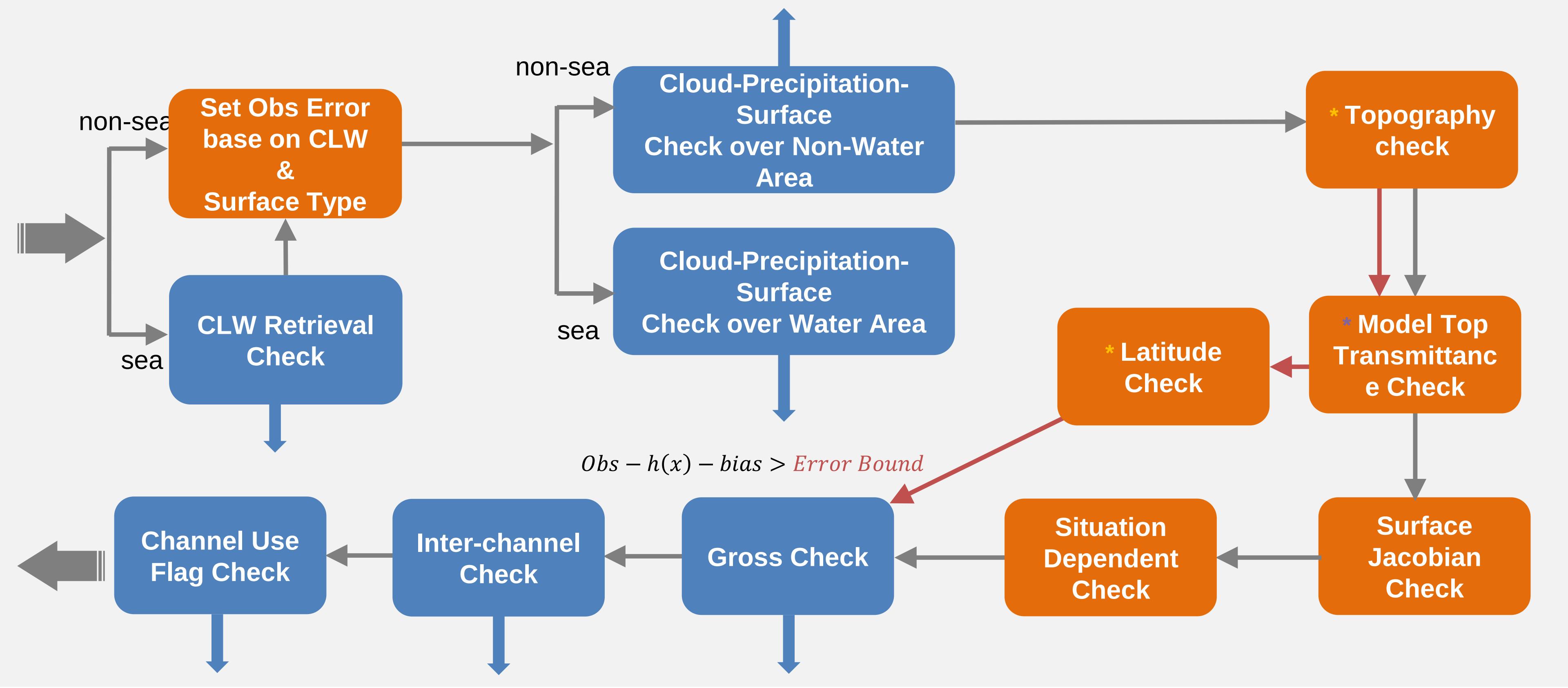
```
#  Cloud Detection Check
 - Filter: Bounds Check
   filter variables:
   - name: brightness_temperature
     channels: *all_channels
   test variables:
   - name: CloudDetect@ObsFunction
     options:
       channels: *all_channels
       use_flag: [ 1,  -1,  -1,  -1,   1,  -1,  -1,  -1,   1,  -1,   1,  -1,  1,
                   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1 ]
       use_flag_clddet: [ 1,  -1,  -1,  -1,   1,  -1,  -1,  -1,   1,  -1,   1,
                          - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                          -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1,  -1 ]
       obserr_demisf: [ 0.01, 0.02, 0.03, 0.02, 0.03 ]
       obserr_dtempf: [ 0.5, 2. 0,4 .0, 2.0, 4.0]
   maxvalue: 1.0e-12
   action:
     name: reject
```

UFO | Channel 1579 1039.5 cm $^{-1}$ | GSI



# Operational QC Procedures for All-sky AMSU-A

A process of observation **Error Inflation** or called **Inverse of Error ( varinv ) Reduction** and ***Bound ( errf ) Tightening** from their original values

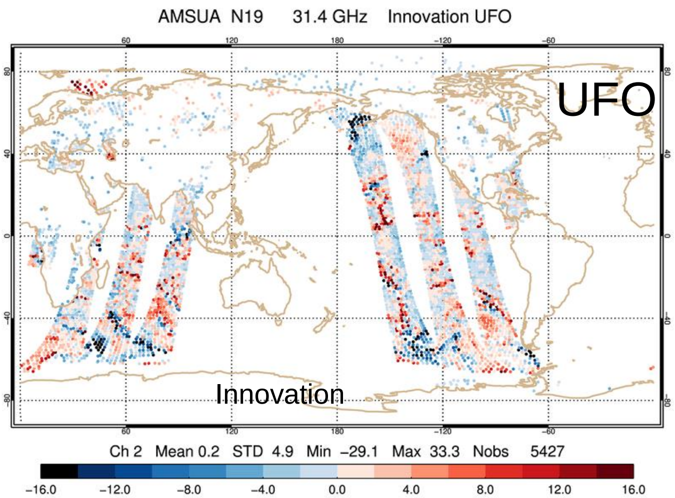


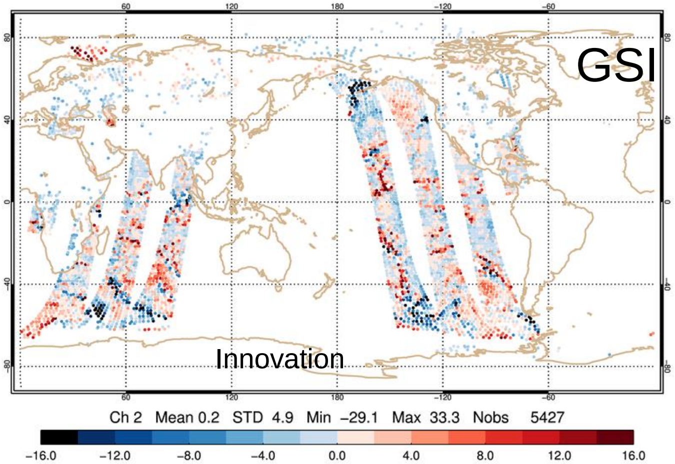
# MW QC Applications

## MW QC for Surface and Hydrometeor Sensitive Channel

Section of QC YAML for Cloud/Precipitation with Strong Scattering

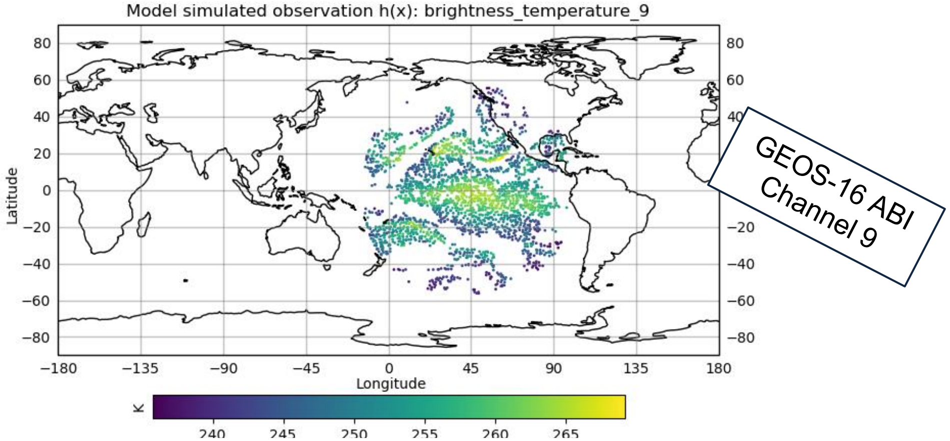
```
#   Hydrometeor Check
    - Filter: Bounds Check
      filter variables:
      - name: brightness_temperature
        channels: *all_channels
      test variables:
      - name: HydrometeorChk@ObsFunction
        options:
          channels: *all_channels
          clwret_type: [ObsValue, HofX]
          clw_clr: [0.050, 0.030, 0.030, 0.020, 0.000, 0.100,
                    0.000, 0.000, 0.000, 0.000,
                    0.000, 0.000, 0.000, 0.000, 0.030]
          clw_cld: [0.600, 0.450, 0.400, 0.450, 1.000,
                    1.500, 0.000, 0.000, 0.000, 0.000,
                    0.000, 0.000, 0.000, 0.000, 0.200]
          obserr_clr: [2.500, 2.200, 2.000, 0.550, 0.300,
                       0.230, 0.230, 0.250, 0.250, 0.350,
                       0.400, 0.550, 0.800, 3.000, 3.500]
          obserr_cld: [20.000, 18.000, 12.000, 3.000, 0.500,
                        0.300,  0.230,  0.250, 0.250, 0.350,
                        0.400,  0.550,  0.800, 3.000, 18.000]
      maxvalue: 1.0e-12
      action:
        name: reject
```

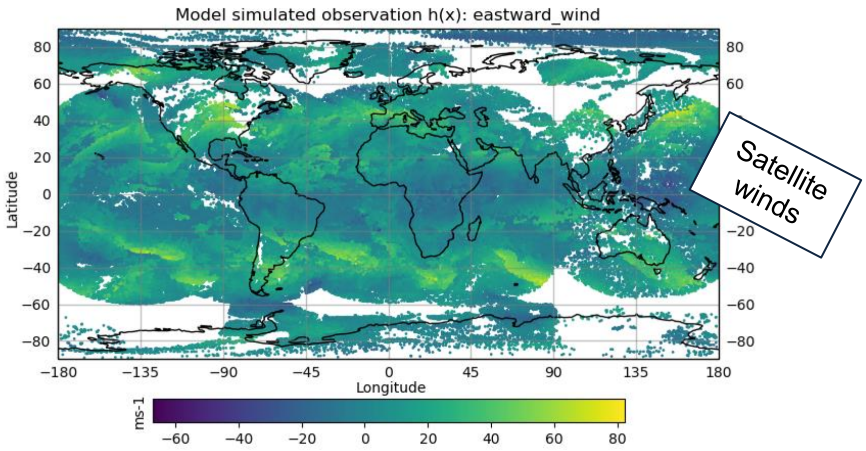


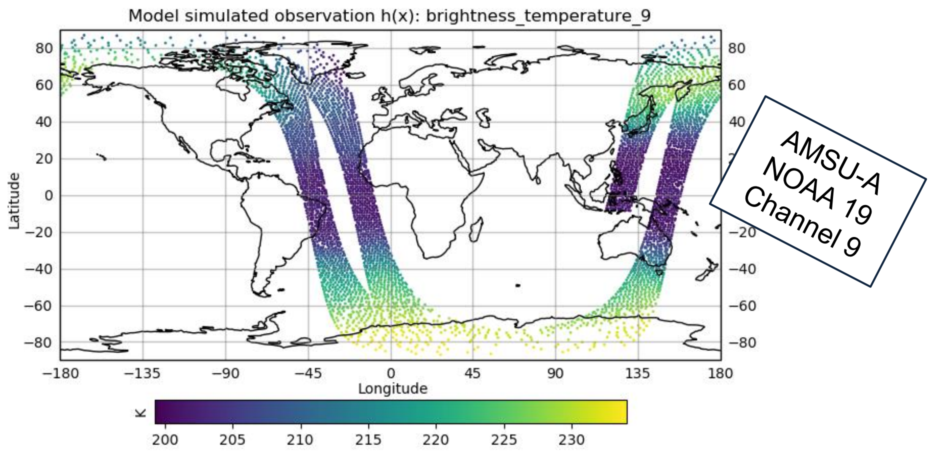



# In-Core Data Assimilation – 4D H(x)

- GFS C768 (~12km) forecast model called from FV3-JEDI for 6 hour window beginning 2019-11-18 18Z.
- GFS v16 model.
- Background from operations.
- H(x) calculated in core as a post processor of the model step, no storing of 4D State anywhere.
- Interpolation is from C768 cubed sphere grid to observation locations.

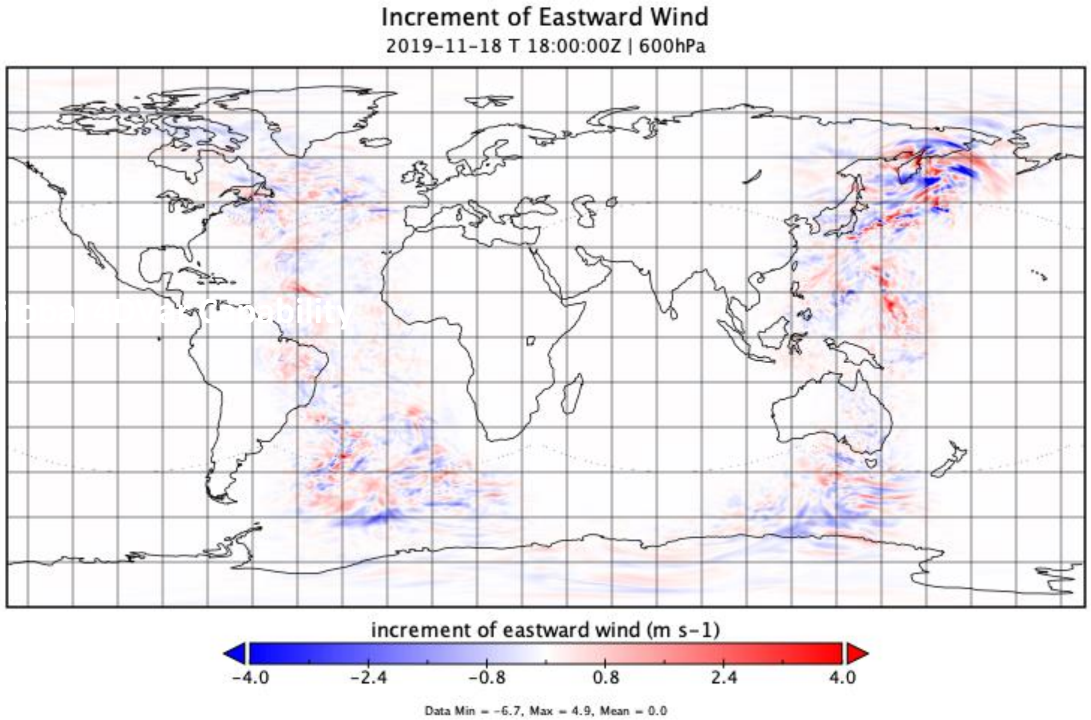


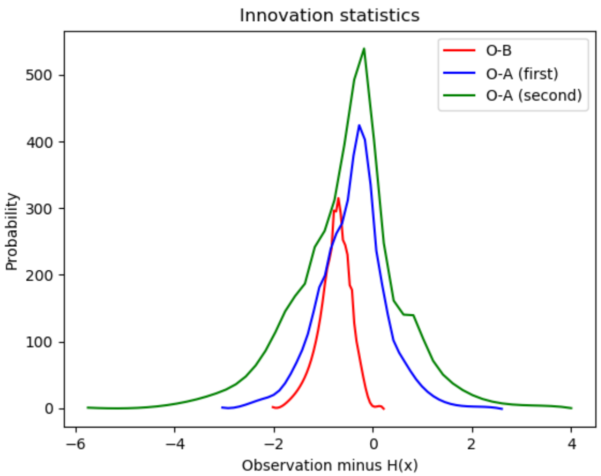



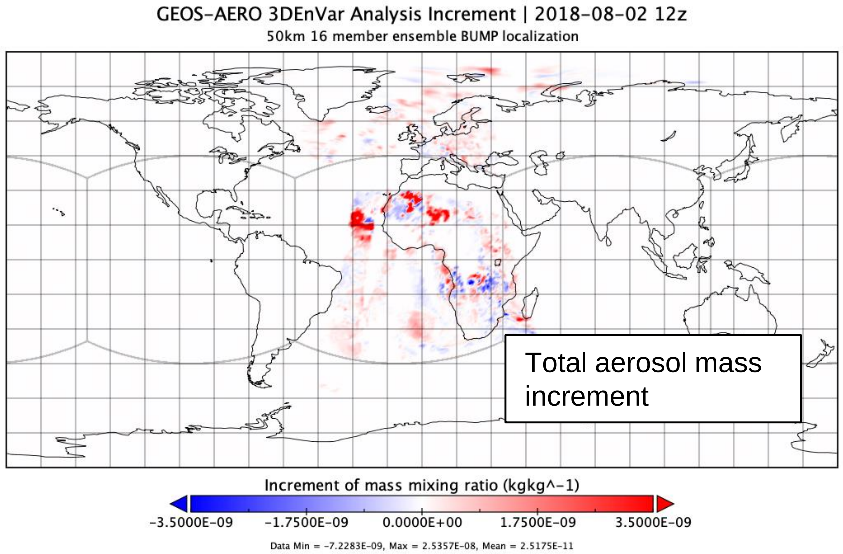
# In-Core Data Assimilation – 4DVar

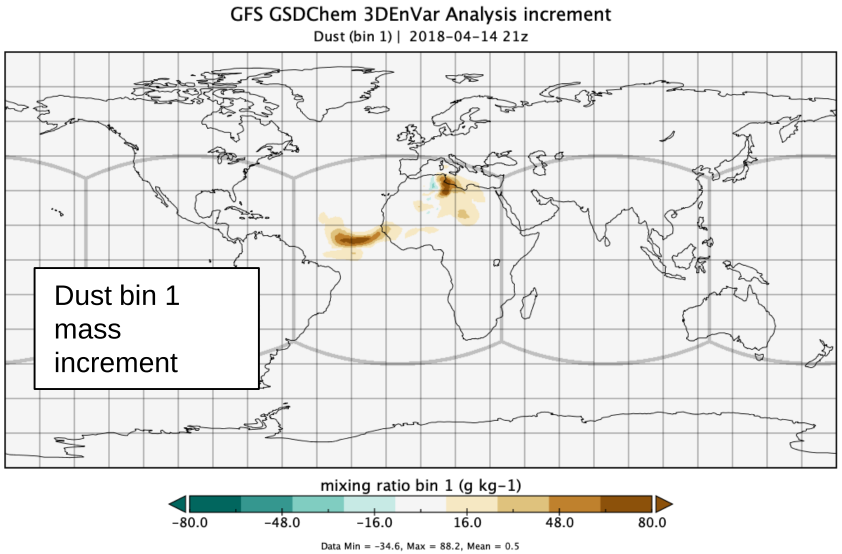
- C768 background (from ops) and forecast.
- Native grid and resolution observer.
- Pure ensemble B matrix from C384 (25km) 40 member ensemble (from ops).
- C192 (50km) increment.
- All AMSU-A NOAA 19 (~20,000 obs).
- 3 hour window
- 2 outer loops **in-core**.
- BUMP for localization, interpolation etc.



# Aerosol Data Assimilation




**GEOS GOCART**
C90 (~100km) 3DEnVar
20 members
550nm Neural Network Retrieval of AOD
~70,000 observations
Work done with Virginie Buhard (NASA GMAO)

**GFS GSD Chem**
C48 (~200km) 3DEnVar
10 members
CRTM simulated aerosol optical depth
VIIRS and SUOMI-NPP
Work done with Mariusz Pagowski (NOAA)

# Marine Data Assimilation

## Currently implemented in the EMC cycling workflow

| Resolution | Forecast | 3DVAR | UMD-LETKF | Hyb-EnVAR | Hyb-EnVAR + UMD-LETKF |
|---|---|---|---|---|---|
| 3º | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 |
| 1º | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 |
| 0.25º | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 | MOM6<br>MOM6-CICE5 |

Implemented
In progress
Not implemented

Target system

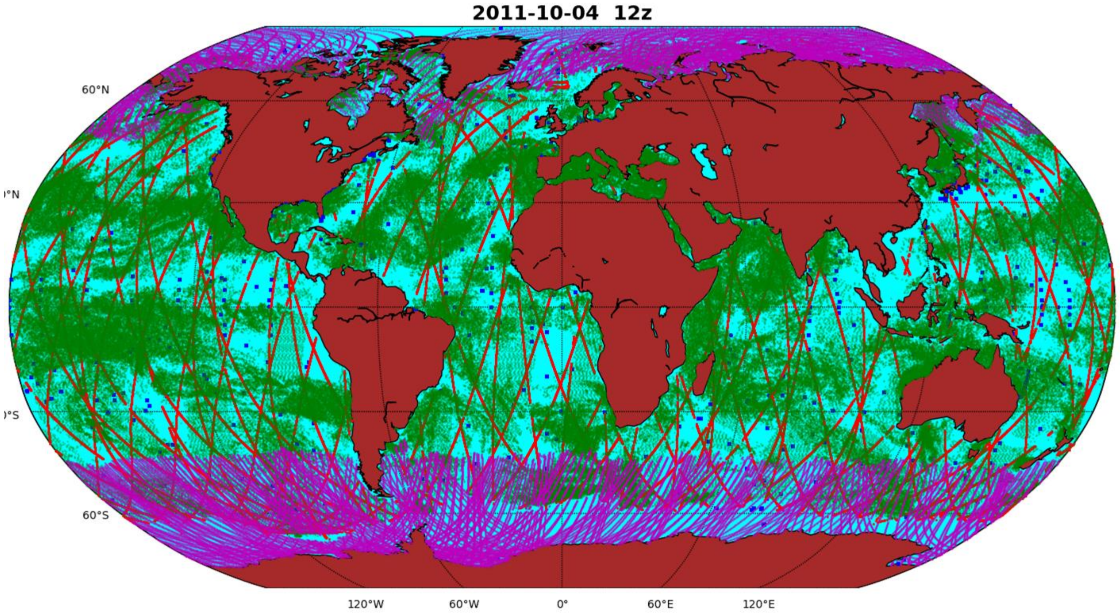
Cycling experiment

# Marine Data Assimilation

*JCSDA delivered to NOAA/NCEP the first version of JEDI-based next-generation community marine data assimilation*

## Cycling Experiment

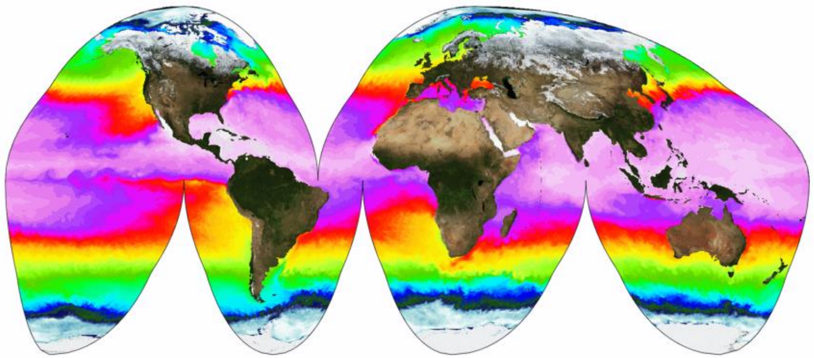
- October 1, 2011 to November 2, 2011
- Coupled forecast modelat ¼ degree resolution MOM6-CICE5-DataAtmosphere
- 24hr assimilation window ~1M obs per cycle
- 3DVAR with background dependent parametric B



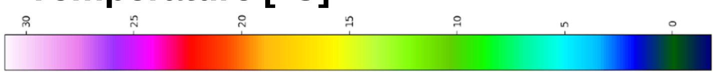

| Variable | Satellite Sensor | In Situ |
|---|---|---|
| **SST Infrared** | NOAA-19, METOP-A AVHRR | |
| **SST Microwave** | WindSat | |
| **Absolute Dynamic Topography** | Jason-1 Jason-2 CryoSat-2 | |
| **Ice concentration** | F-16/F-17 SSMI, SSMI/S | |
| **Temperature** | | Argo, CTD, XBT, TAO, PIRATA, RAMA, ... |

# Marine Data Assimilation

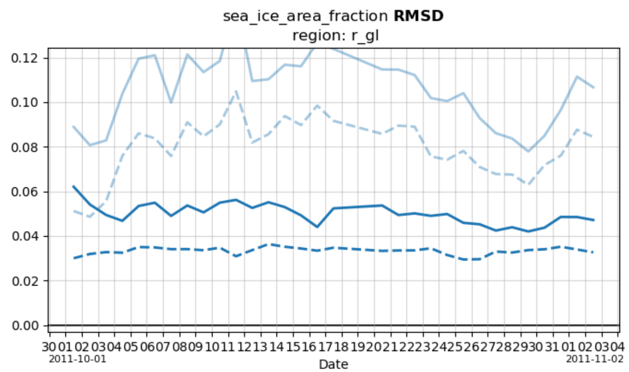
**Forecast (sst, ice) 2011-10-01 to 2011-11-02**



**Temperature [ºC]**



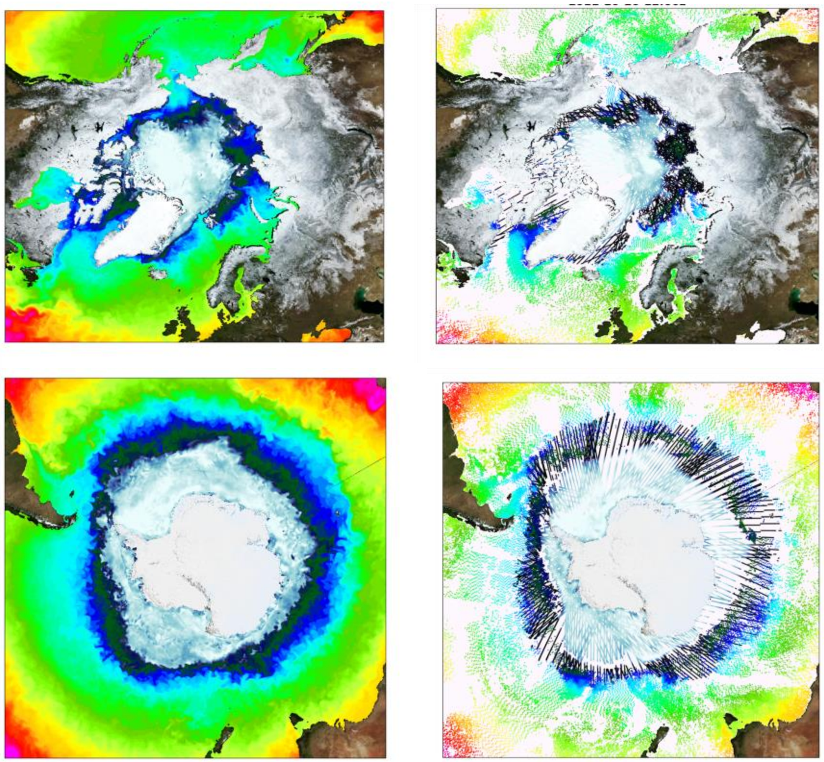

**Sea ice concentration [ºC]**

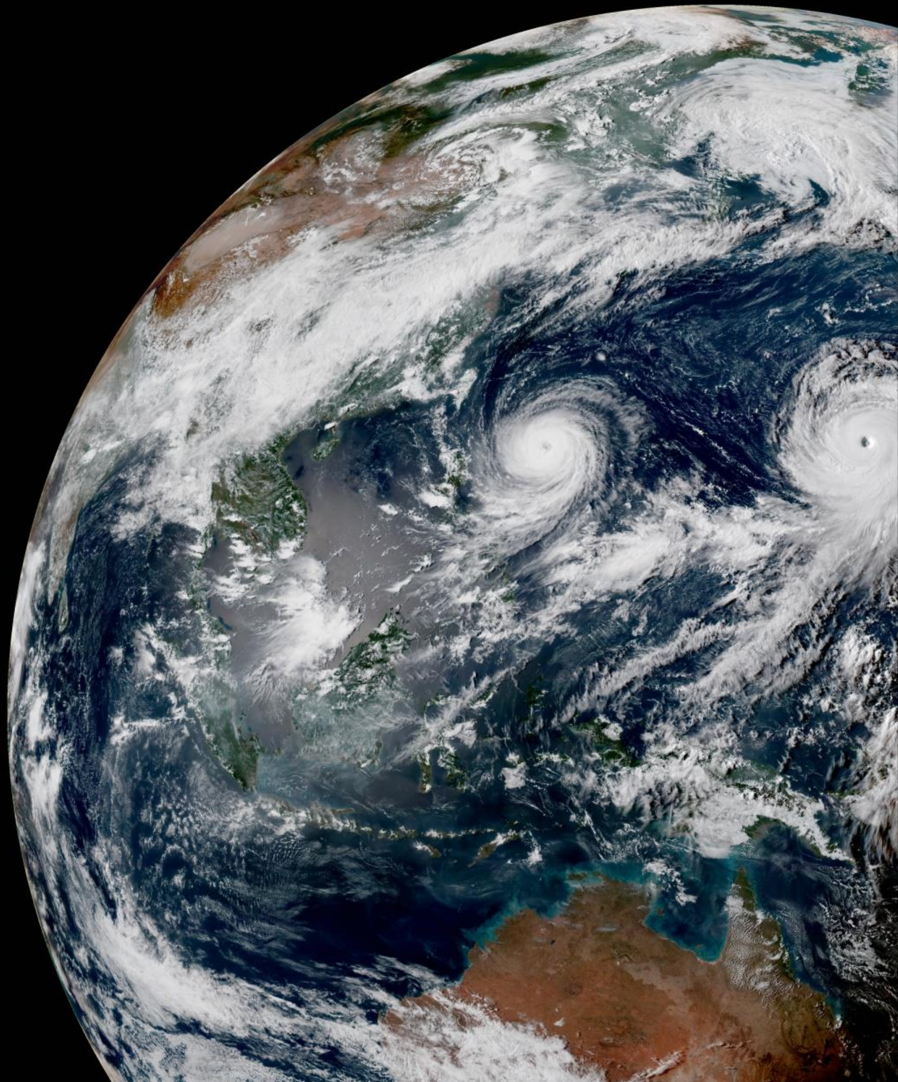

## Preliminary Results

*October 16, 2011*

**Forecast** | **Observations**



# Vision for future work



# JEDI Planned Timeline

**May 2020** Full set of generic QC filters

**Jun 2020** Variational bias correction

**July 2020** 30-year ocean/sea-ice reanalysis (GODAS)

**Aug 2020** Generic coupled UFO

**Dec 2020** Full resolution cycling 4D-Var with outer loops

**Q1 2021** Optimized ensemble (block) solvers

**Q2 2021** Machine learning for QC and bias correction

**Q3 2021** Continuous DA (depends on HPC resources)

**Q4 2021** Coupled DA solver

**2022** Coupled B matrix

**2023** JEDI-GFS (global), JEDI-SAR (regional), JEDI-HAFS (hurricane), JEDI-GODAS (marine) become operational (JEDI-SFS in 2025)

# Final Remarks about the JCSDA

**Conceptual leap:** More unified approach to algorithm development, observation processing, and maintenance of software.

**Streamlined processes and operations**
Unprecedented level of scientific/technical collaboration, coordination and accountability.

**Center of excellence for R2O/O2R**
Highly skilled staff committed to the success of JCSDA projects.

**JEDI system is getting mature and we are starting real-size T&E**

# Read All About It!

[jcsda.org/newsletters](jcsda.org/newsletters)

JOINT CENTER FOR SATELLITE DATA ASSIMILATION

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**IN THIS ISSUE**



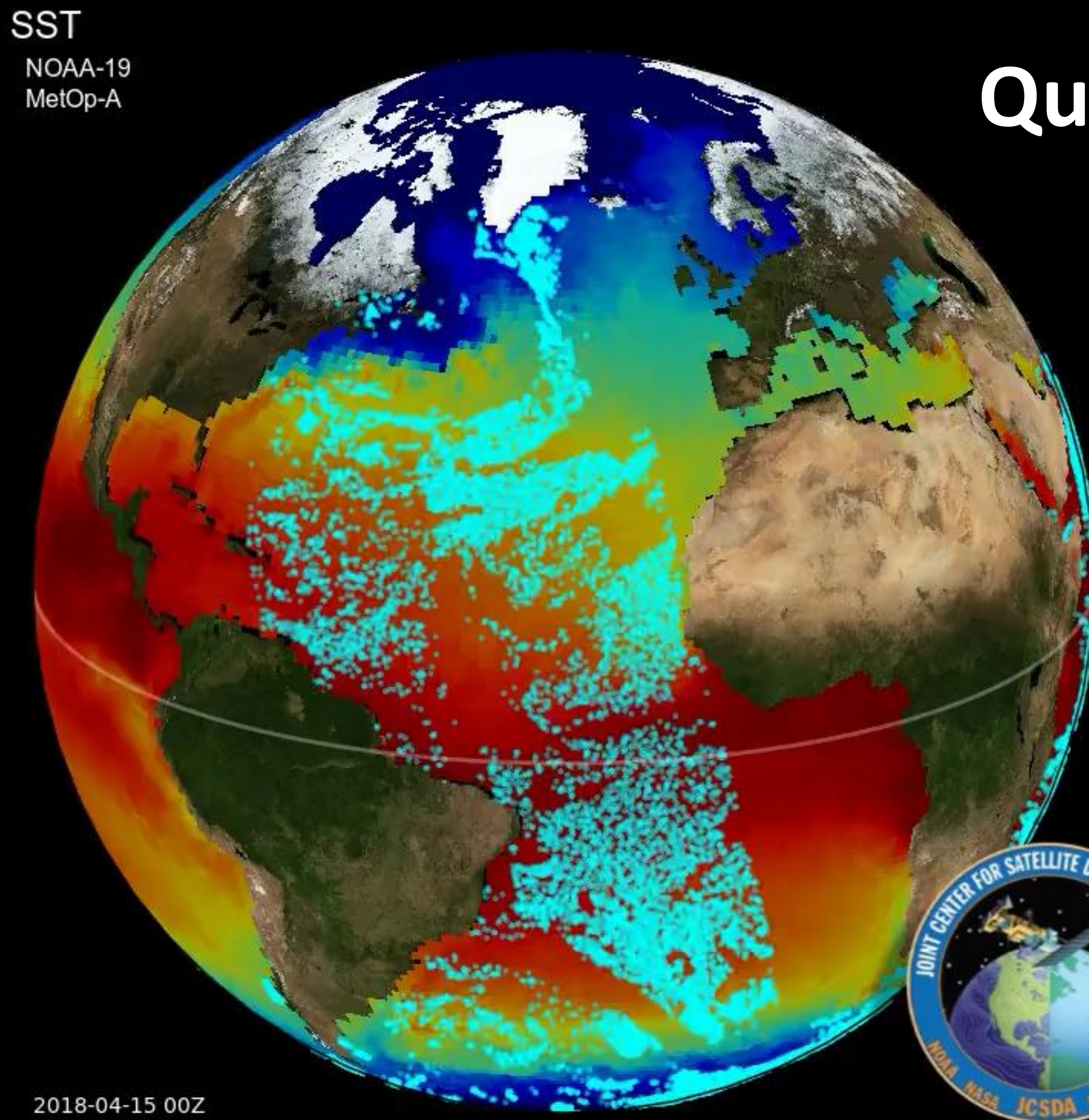
**NEWS IN THIS QUARTER**

## The Joint Effort for Data Assimilation Integration (JEDI)

### Data Assimilation Challenges

All partners of the Joint Center for Satellite Data Assimilation (JCSDA) run data assimilation algorithms applied to their own models and applications. In 2001, the JCSDA was created to accelerate and improve the use of new satellite observing systems into each member's data assimilation system. As Earth-observing systems constantly evolve and new systems are launched, continuous scientific developments for exploiting the full potential of the data are necessary. Given the cost and limited lifetime of new observing systems, it is important that this process happens quickly. This effort has been successful and continues to be; but, as the context evolves, new challenges emerge.

# Questions?

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NOAA NASA JCSDA Navy Air Force