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

JEDI is a Joint Effort

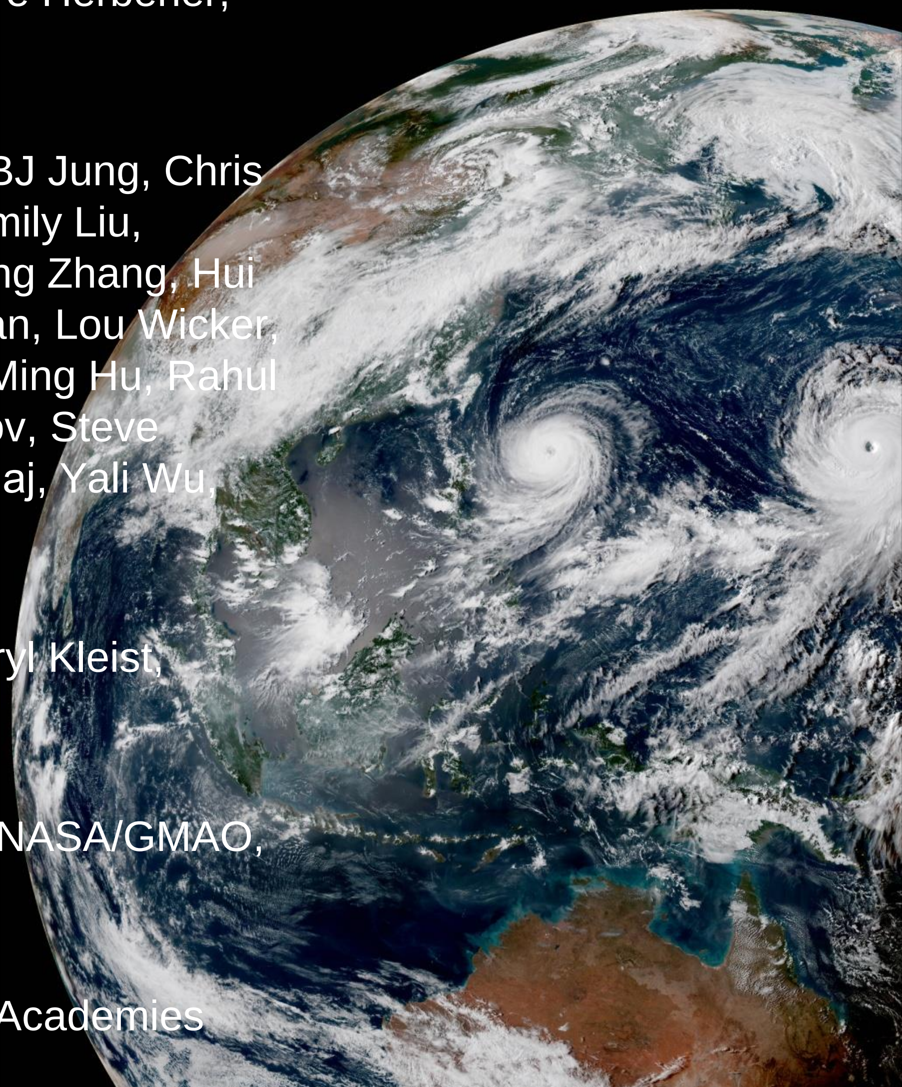
JEDI core-team: Yannick Trémolet, Anna Shlyaeva, Benjamin Ménétrier, Clémentine Gas, Dan Holdaway, Mark Miesch, Mark Olah, Maryam Abdi-Oskouei, Ryan Honeyager, Steve Herbener, Xin Zhang

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…

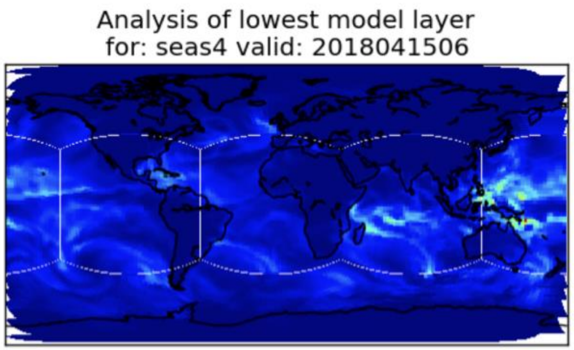
JEDI collaborators: Chris Snyder, Dale Barker, Daryl Kleist, Nancy Baker, Ron Gelaro

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

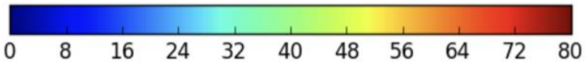
And about 120 padawans who attended three JEDI Academies



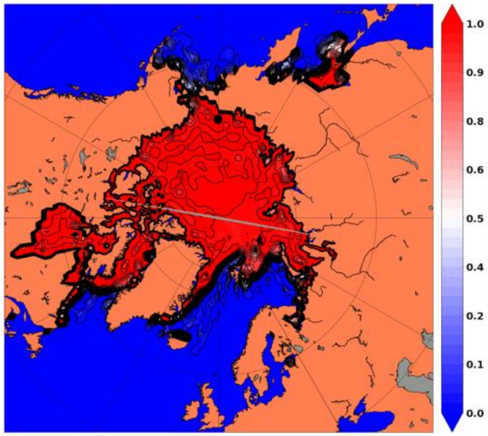
JEDI: One System with Multiple Configurations

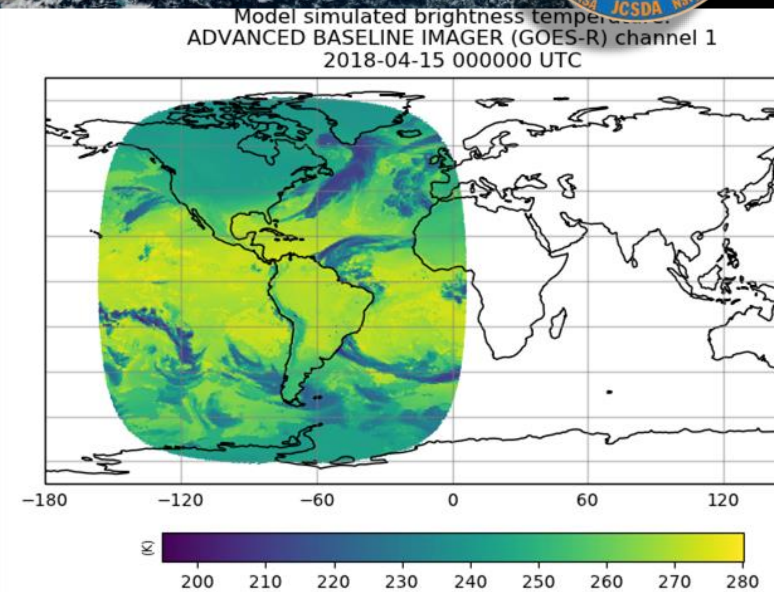


Analyzed aerosols

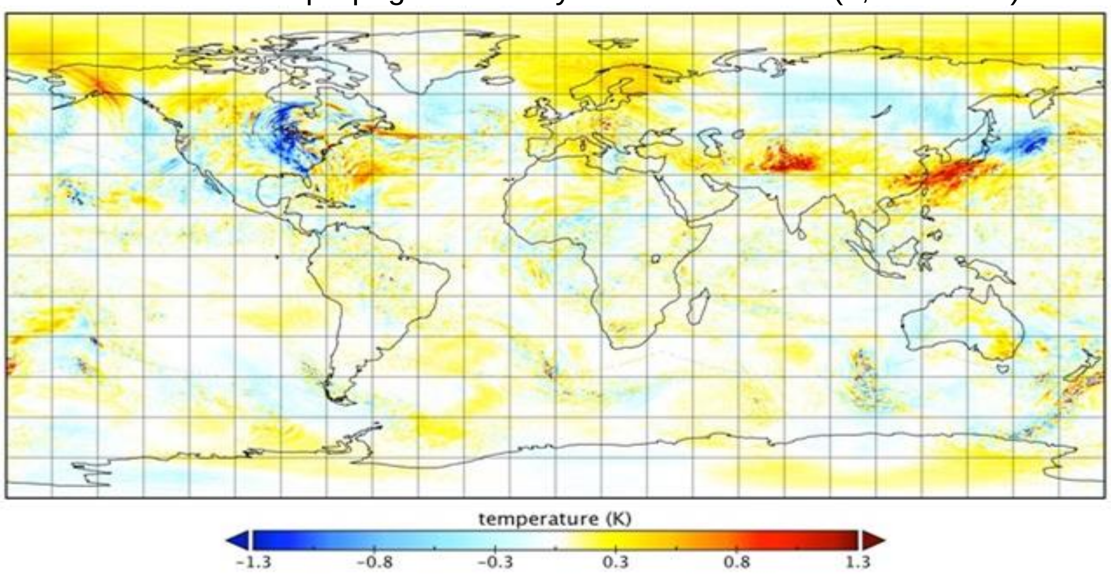


Analyzed ice fraction aggregate

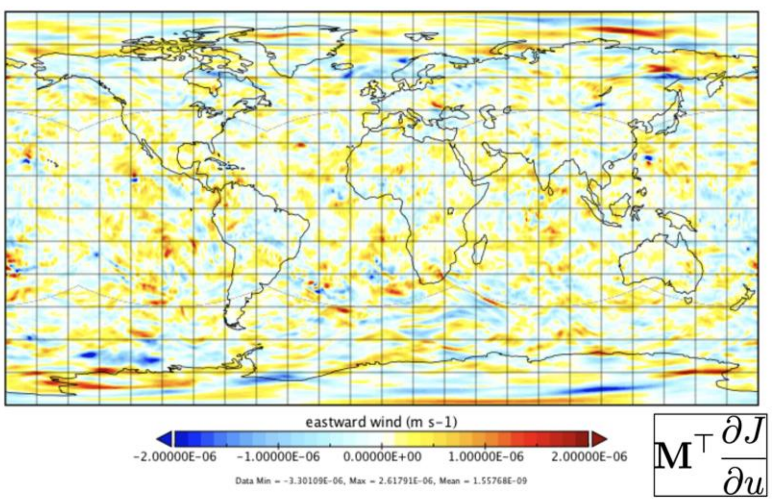




200 hPa T increment propagated 24h by GFSv15 on AWS (1,728 cores) in 7min20s

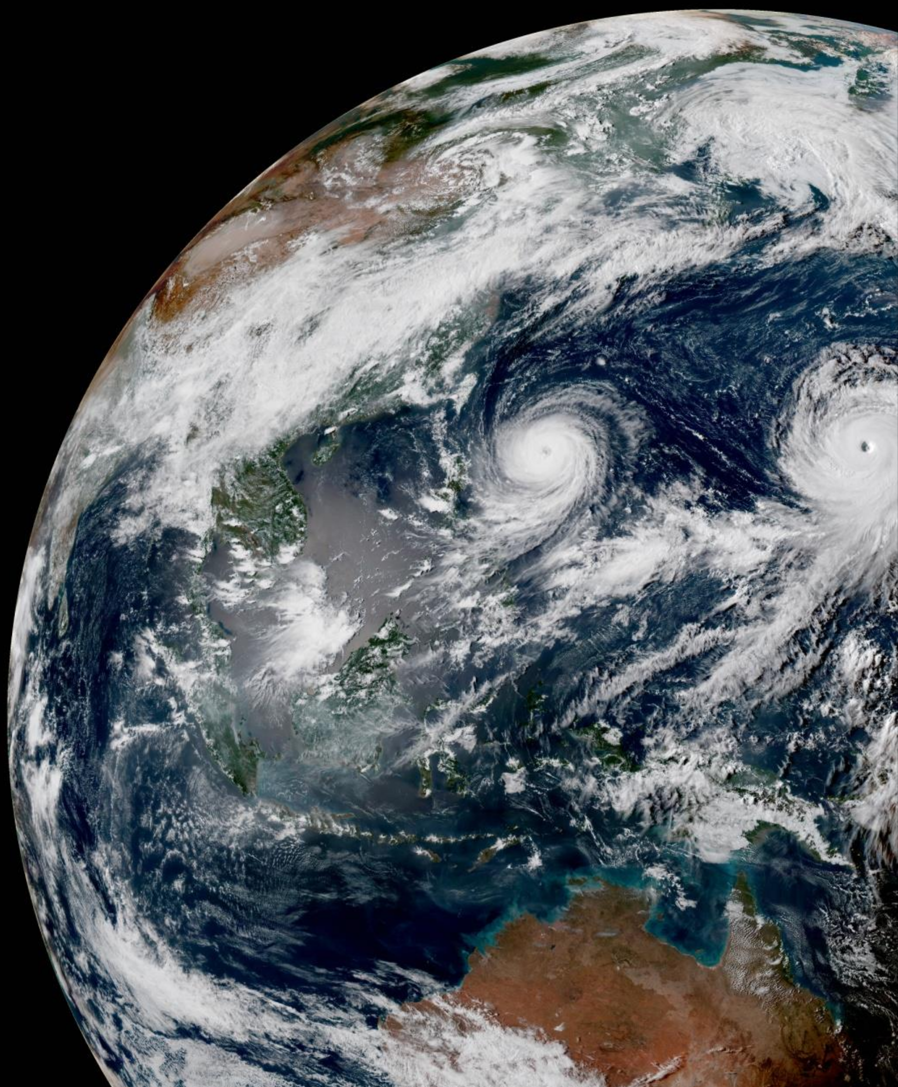


Adjoint Sensitivity to initial conditions @500 hPa

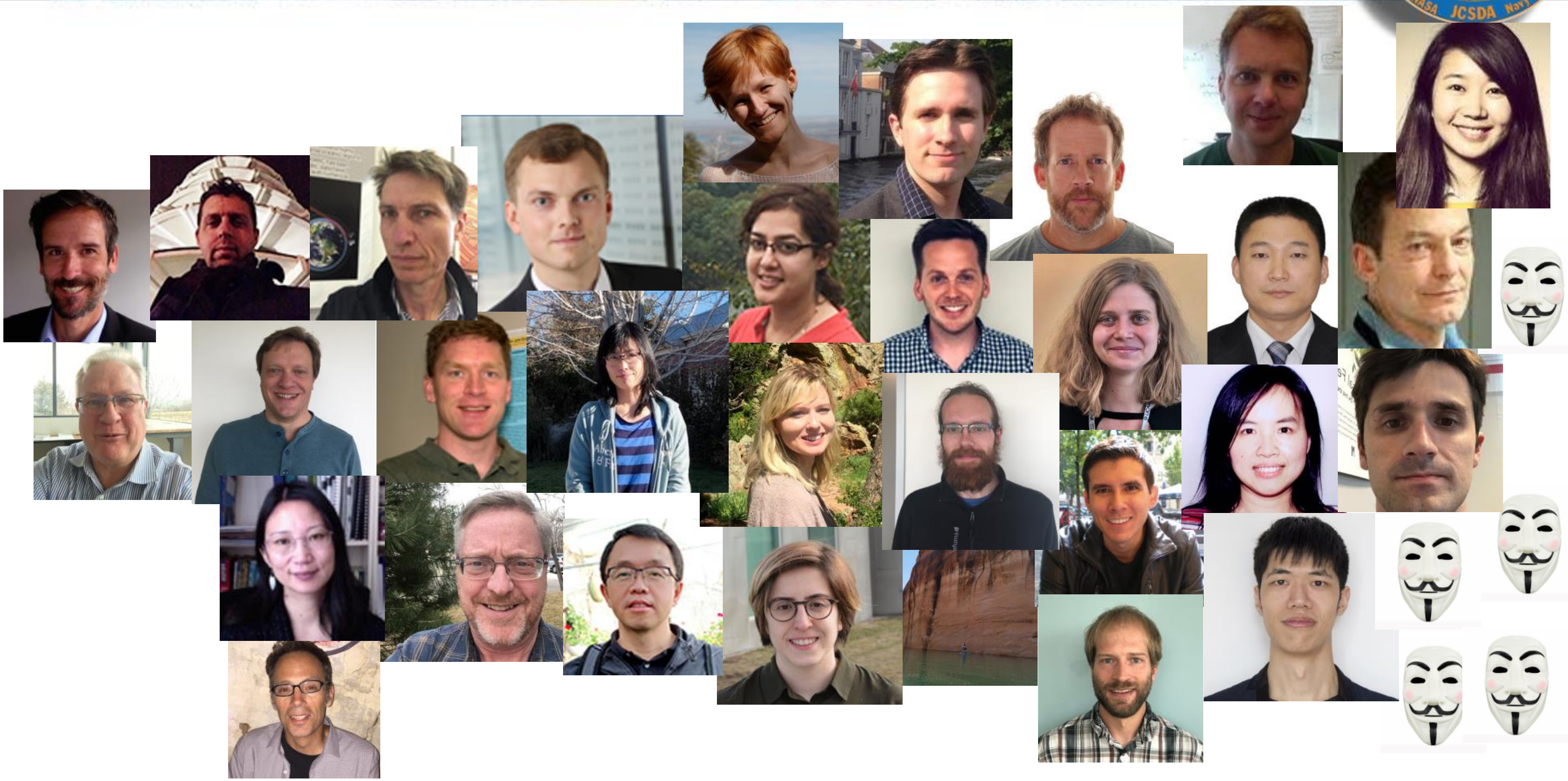


$$\mathbf{M}^\top \frac{\partial J}{\partial u}$$

What we accomplished
How we got here

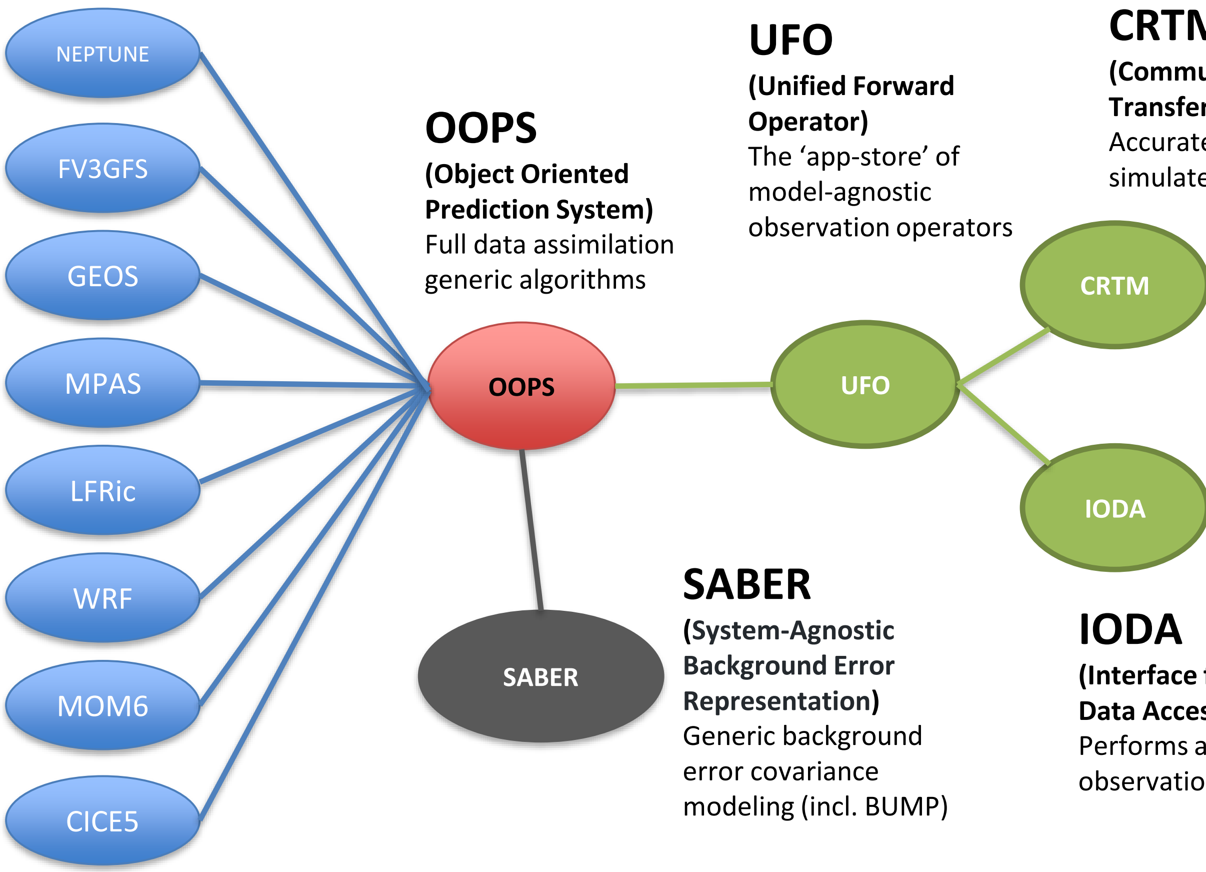


Assembling a Center of Excellence



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

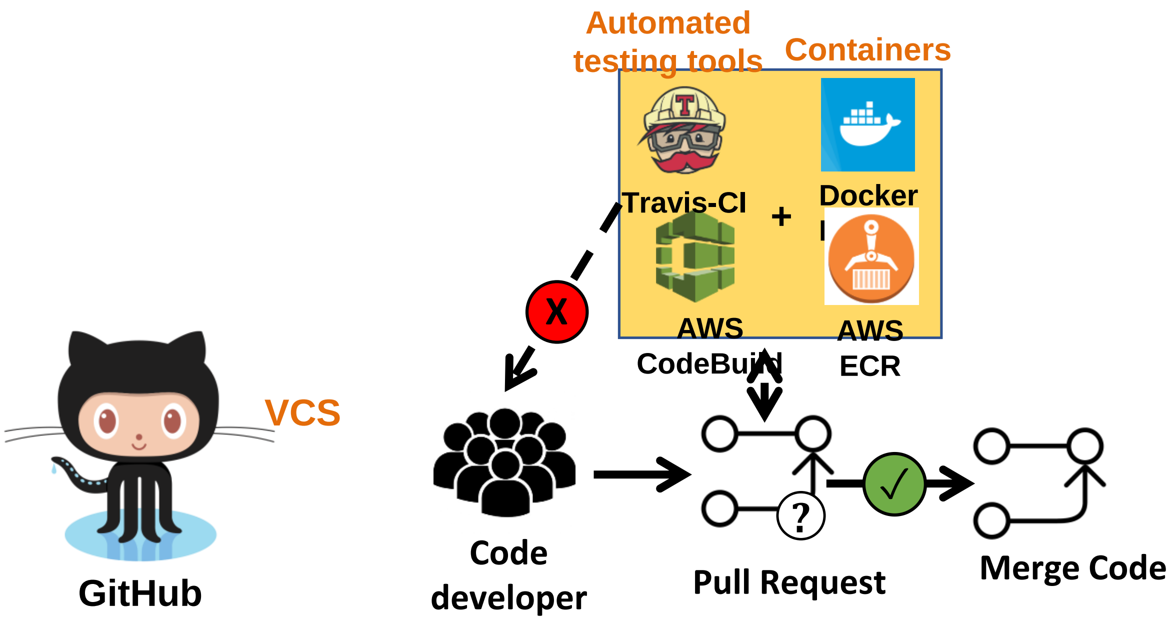
3rd JEDI Academy

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

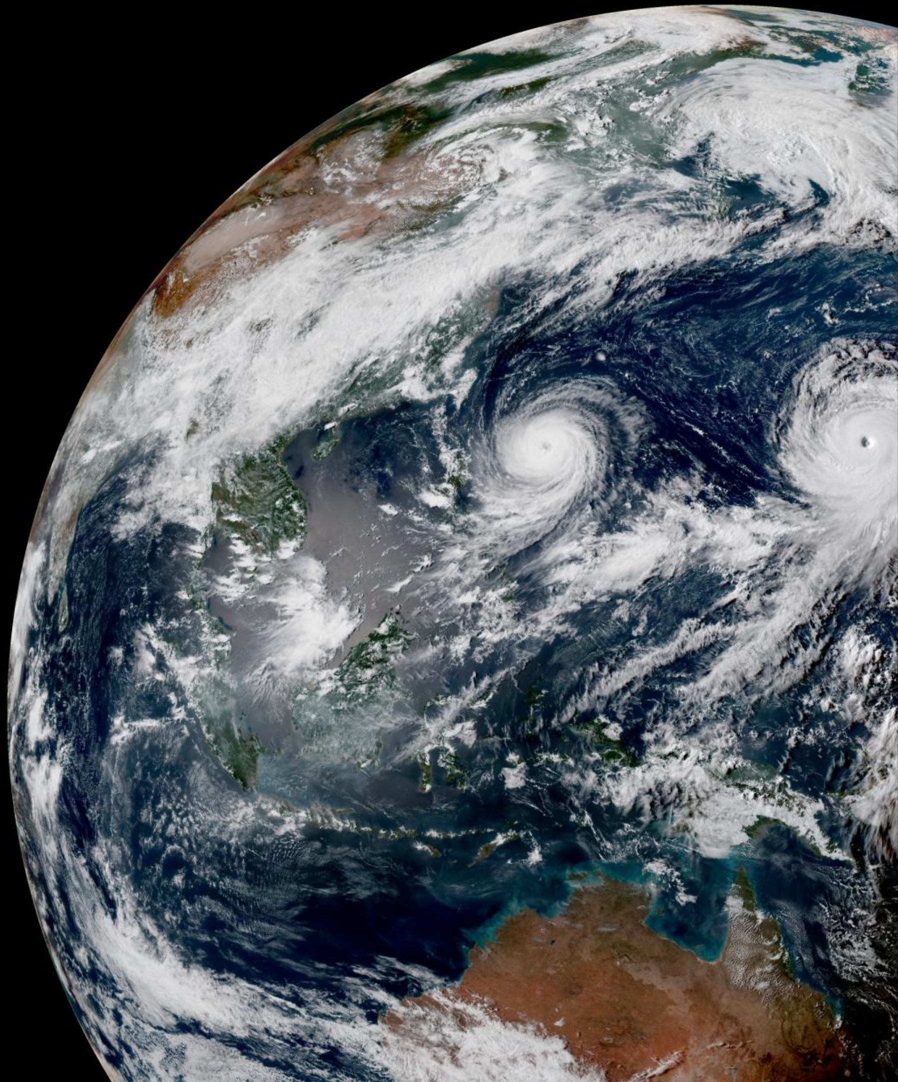
Oct. 2019 Marine DA transferred to EMC

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



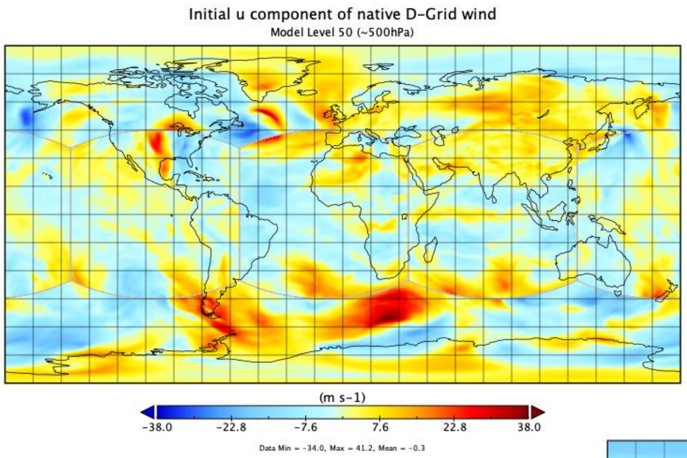
Models being Interfaced to JEDI

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

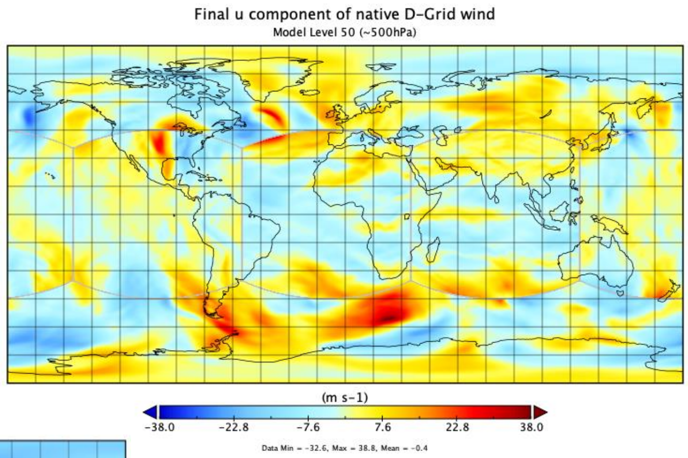
<table>
<tr><th>Milestone</th><th>GFS</th><th>GEOS</th><th>FV3 Solo</th></tr>
<tr><td>3DEnVar</td><td colspan="3">✓</td></tr>
<tr><td>4DEnsVar</td><td>✓</td><td>✓</td><td>NA</td></tr>
<tr><td>4DVar</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>4DVar with linear physics</td><td>✗</td><td>✓</td><td>NA</td></tr>
<tr><td>Ensemble H(X)</td><td colspan="3">✓</td></tr>
<tr><td>4D H(x) in-core</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Multiple outer loops (IO)</td><td colspan="3">✓</td></tr>
<tr><td>Multiple outer loops in-core</td><td>✓</td><td>✗</td><td>✓</td></tr>
<tr><td>Multiple resolutions</td><td colspan="3">✓</td></tr>
<tr><td>EDA</td><td colspan="3">✓</td></tr>
<tr><td>Multiple resolution outer loops</td><td>✗</td><td>✗</td><td>✓ (simple B)</td></tr>
</table>

Static B and Cube-Sphere Poisson Solver

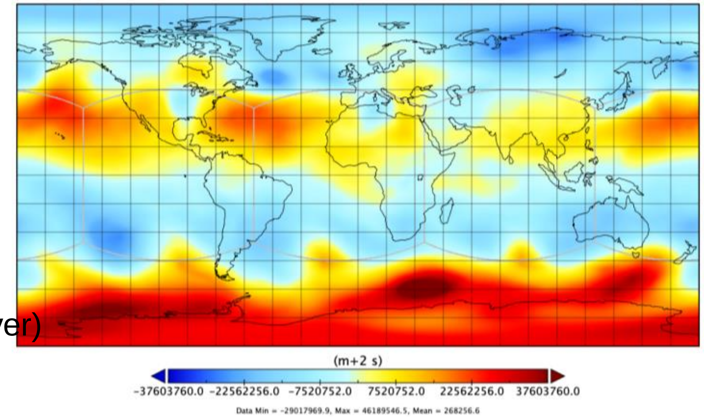


Initial D-Grid winds
(correlation length scales ~200km)

Final D-Grid winds



Poisson



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

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

Stream function
(and velocity potential)

Correlation length scales ~4000km

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

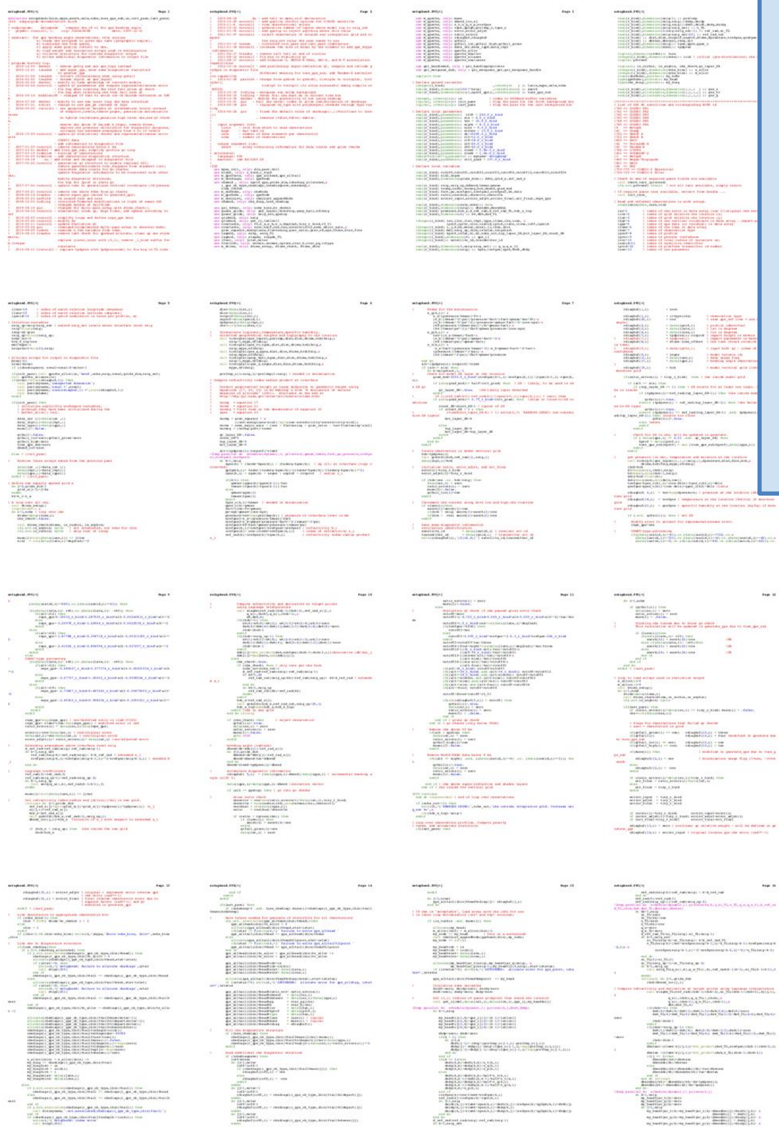
Interface for Observation Data Access (IODA) and Unified Forward Operator (UFO)

Observation Type (Instrument)	IODA obs file	H(x)	Notes
Aircraft	✔	✔	
Radiosonde	✔	✔	
Satwinds	✔	✔	
Additional conventional	✔	✔ (orange)	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)	✔ (orange)	✔ (orange)	

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
```

Using ROPP error estimates

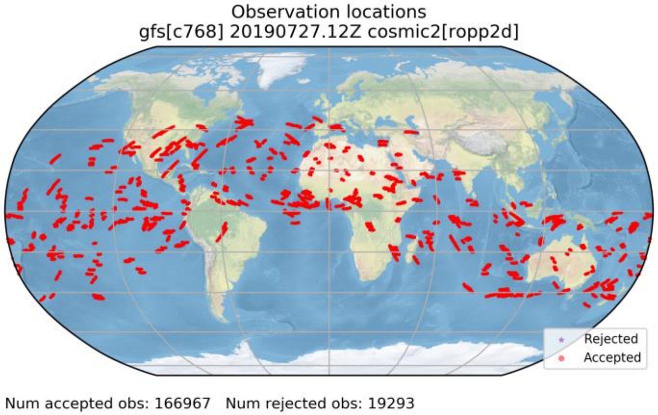
```yaml
ObsFilters:
- Filter: Domain Check
  variable: ascending_flag
  is_not_in: 1
  where:
  - variable: occulting_sat_id
    is_in: 825
```

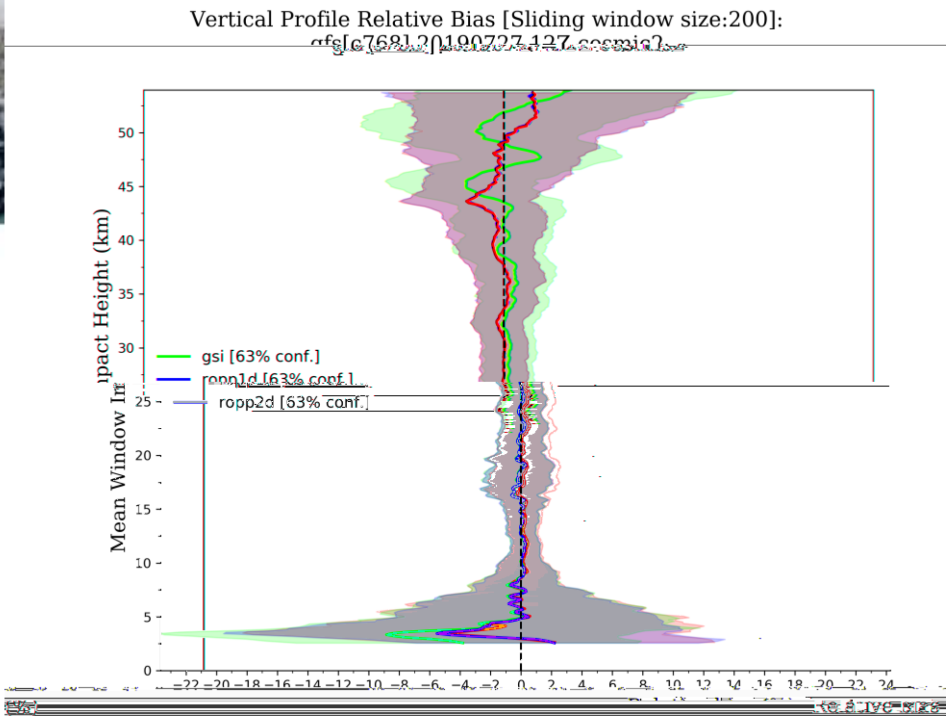
Rejecting KOMPSAT5 rising profiles

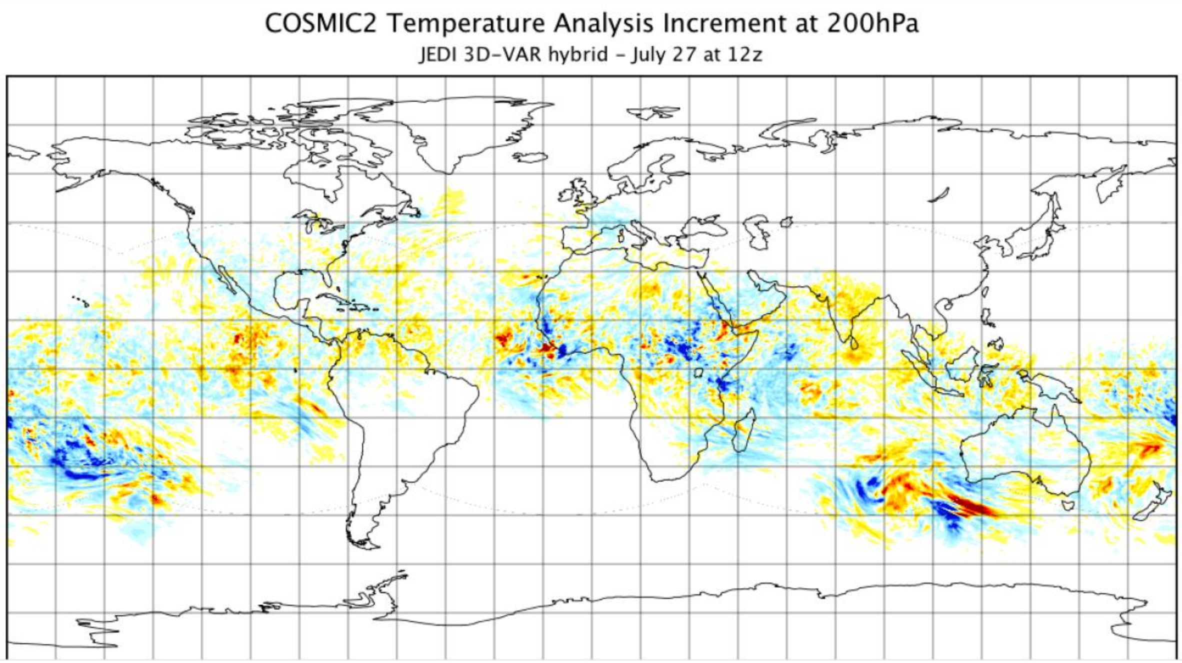
About 18 pages (fairly small font!) of GNSSRO QC code replaced by generic filters and yaml configuration files

No factory reconfiguration (i.e. no recompilation)

Future-proof: can accommodate unplanned configurations

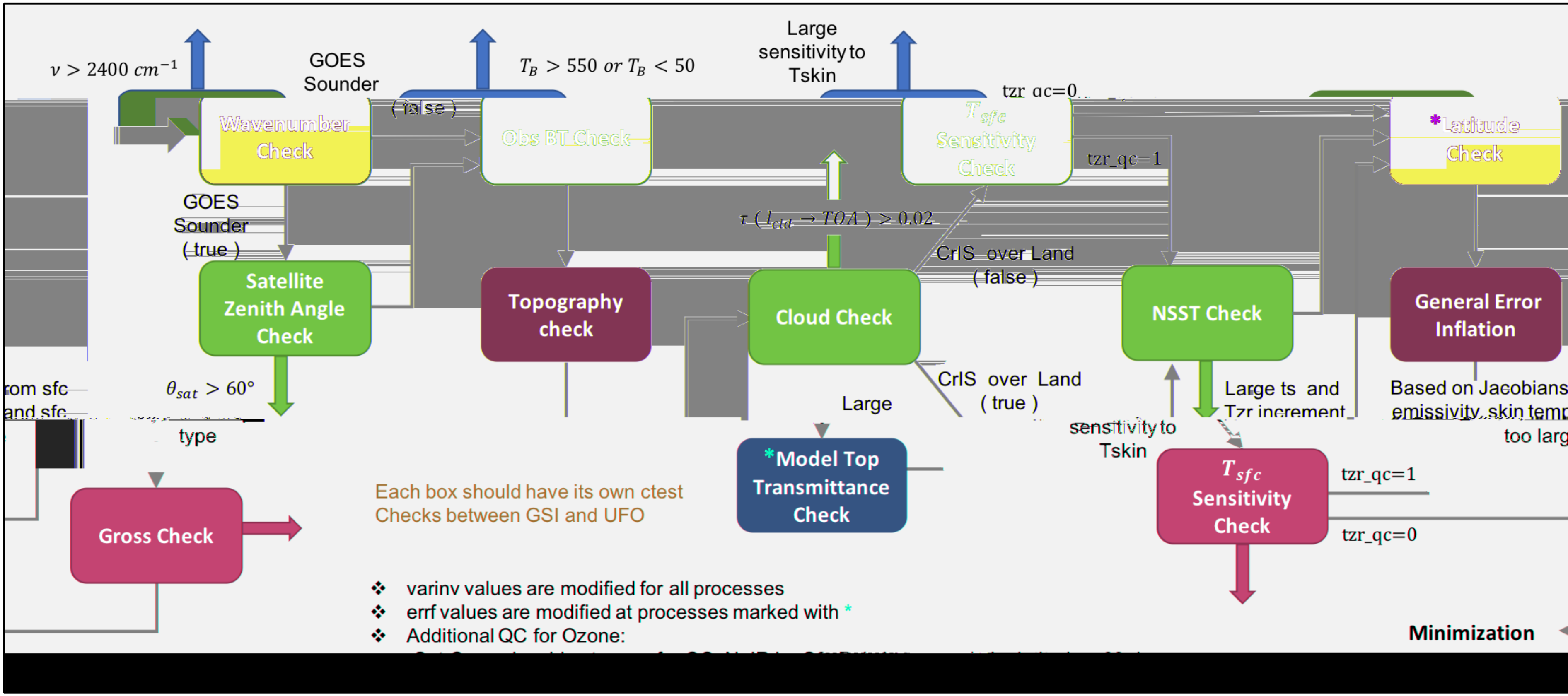

Observation locations
gfs[c768] 20190727.12Z cosmic2[ropp2d]
Rejected
Accepted
Num accepted obs: 166967   Num rejected obs: 19293


Vertical Profile Relative Bias [Sliding window size:200]:
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



(Emily Liu)

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

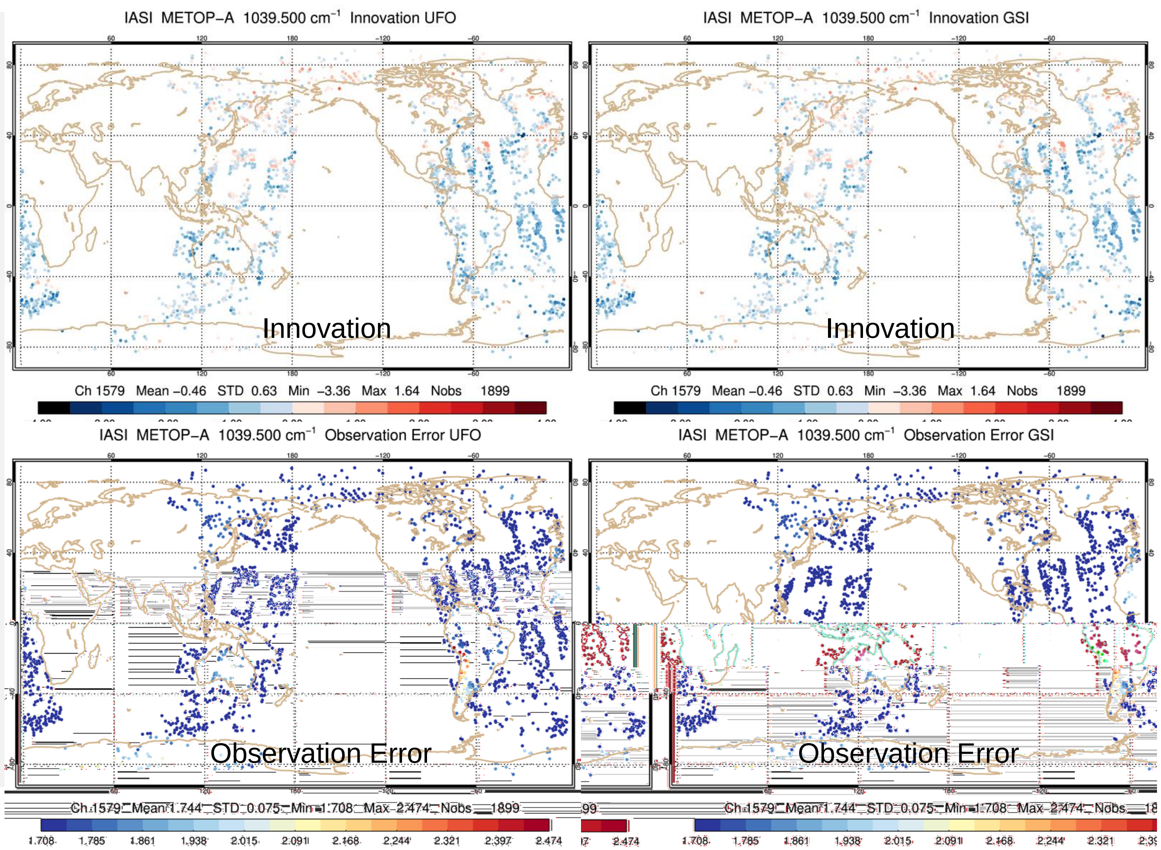
IASI QC Comparison

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

Section of YAML for Cloud Detection QC

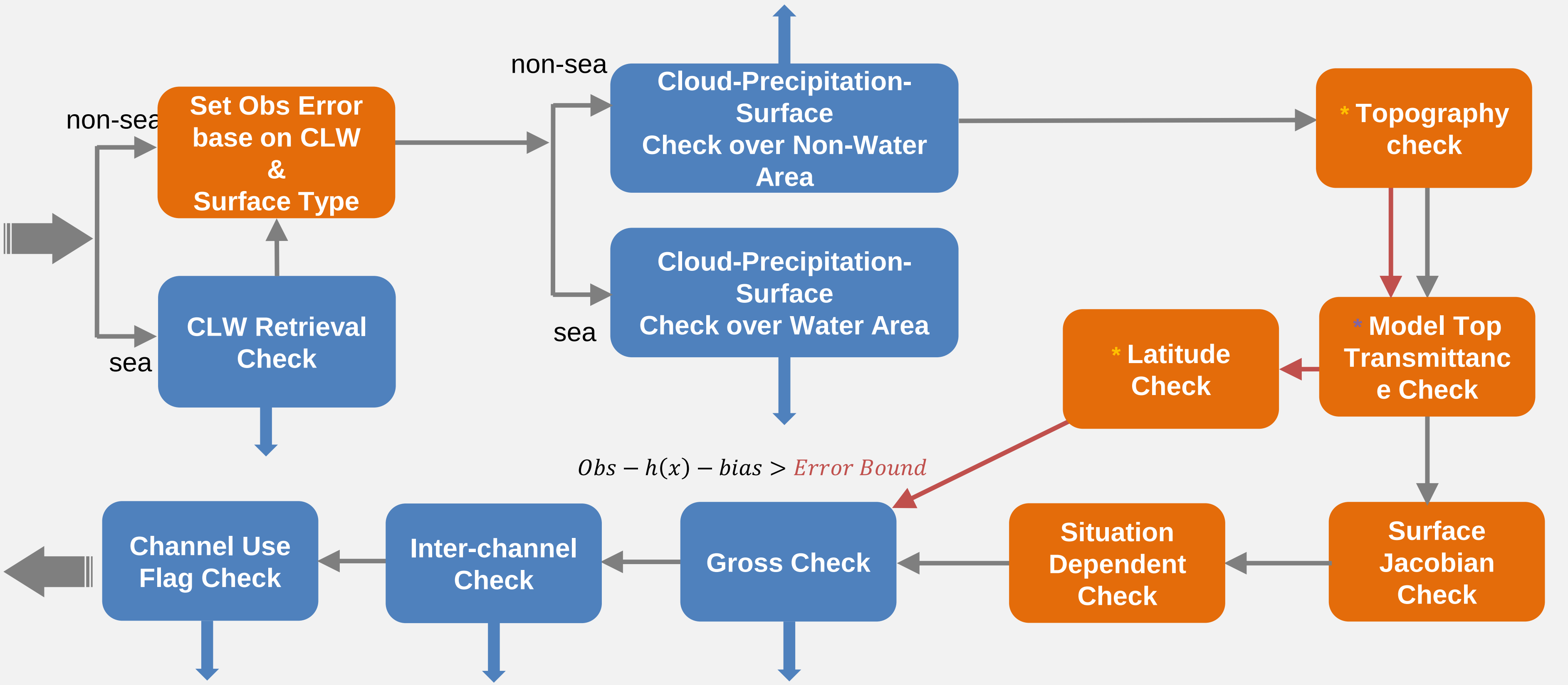
```
#  Cloud Detection Check
 - Filter: Bounds Check
   filter variables:
   - name: brightness_temperature
     channels: *all_channels
   test variables:
   - name: CloudDetect@ObsFunction
     options:
       channels: *all_channels
       use_flag: [ 1,  -1,  -1,  -1,    1,  -1,  -1,  -1,   1,  -1,   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



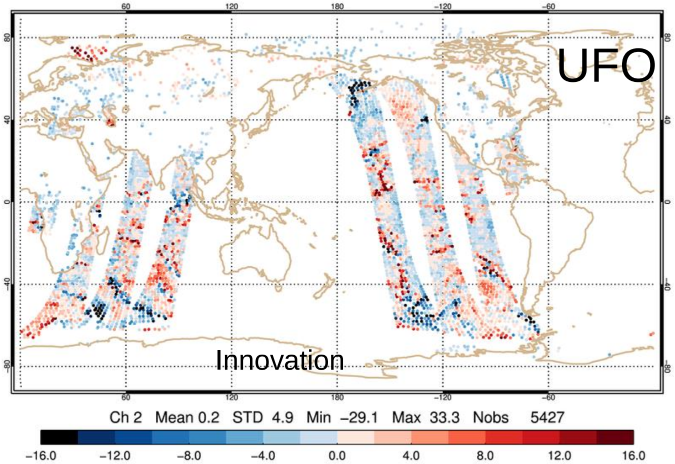
MW QC Applications

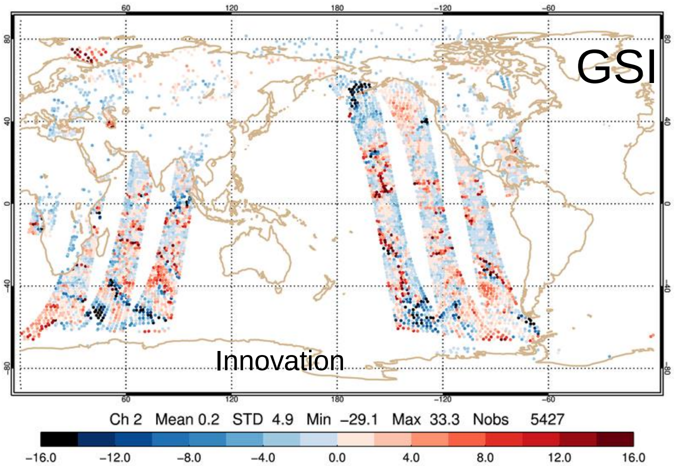
MW QC for Surface and Hydrometeor Sensitive Channel

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
```

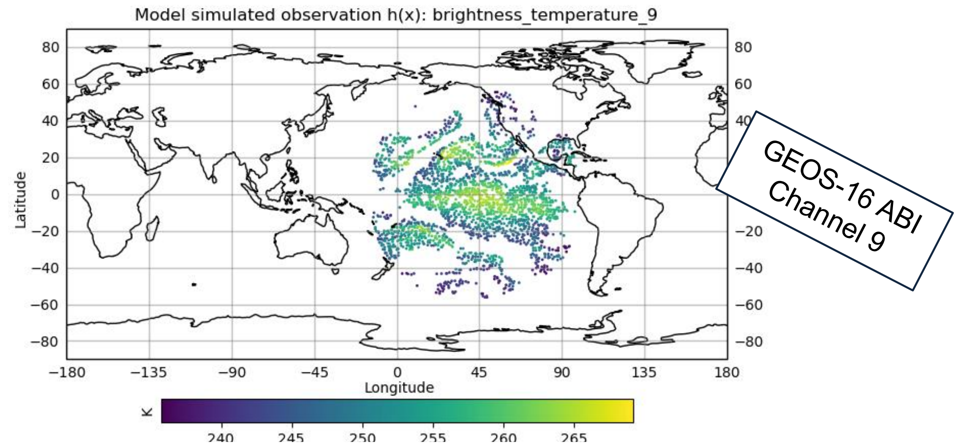
AMSUA N19 31.4 GHz Innovation UFO

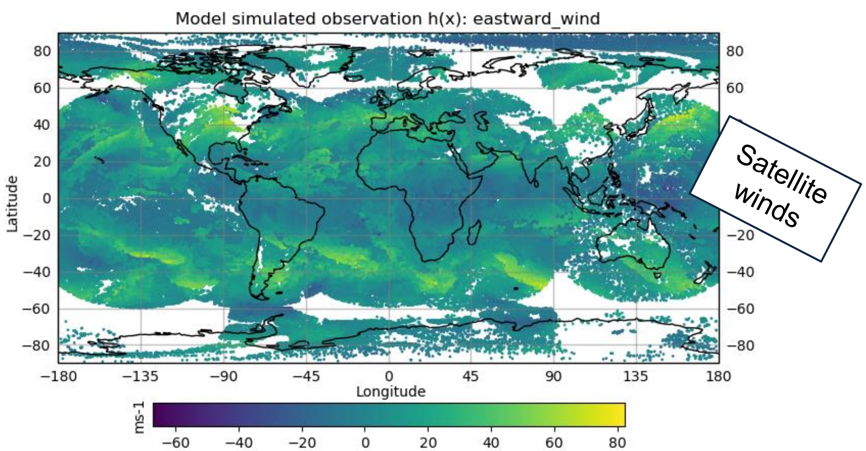


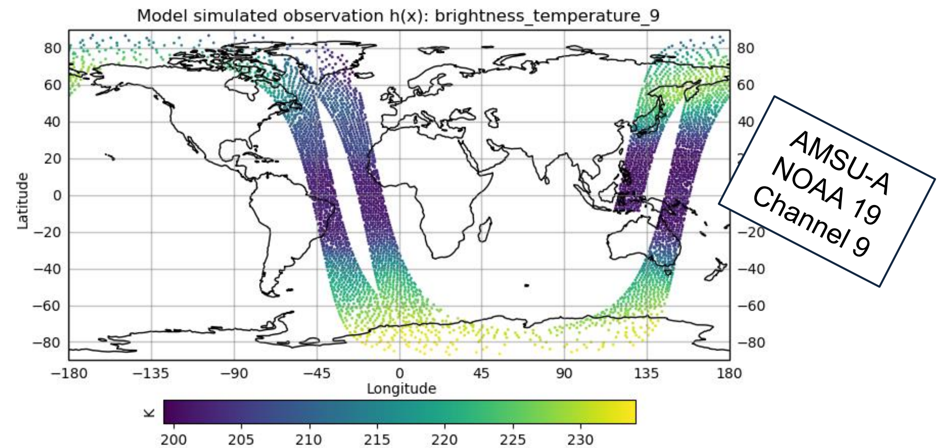


In-Core Data Assimilation – 4D H(x)

- 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.

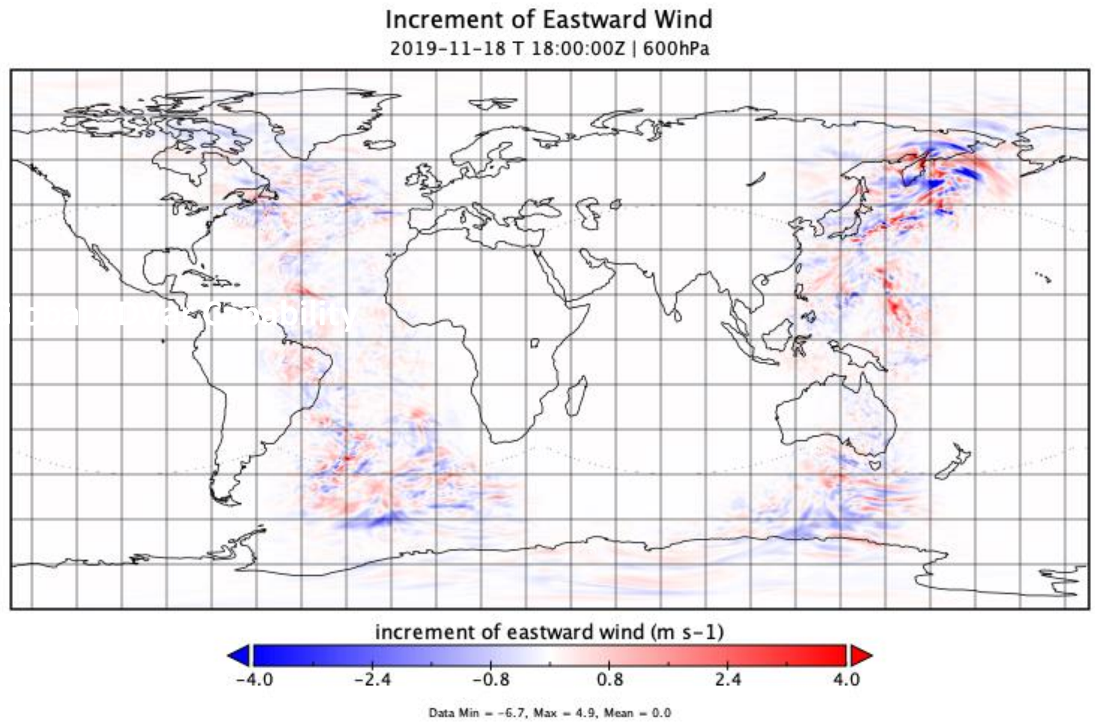


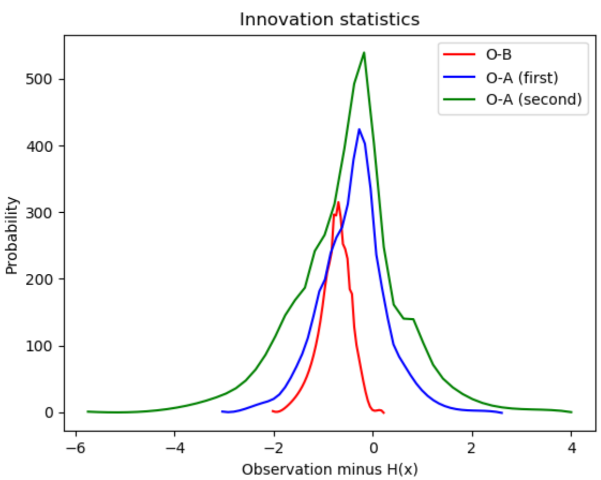




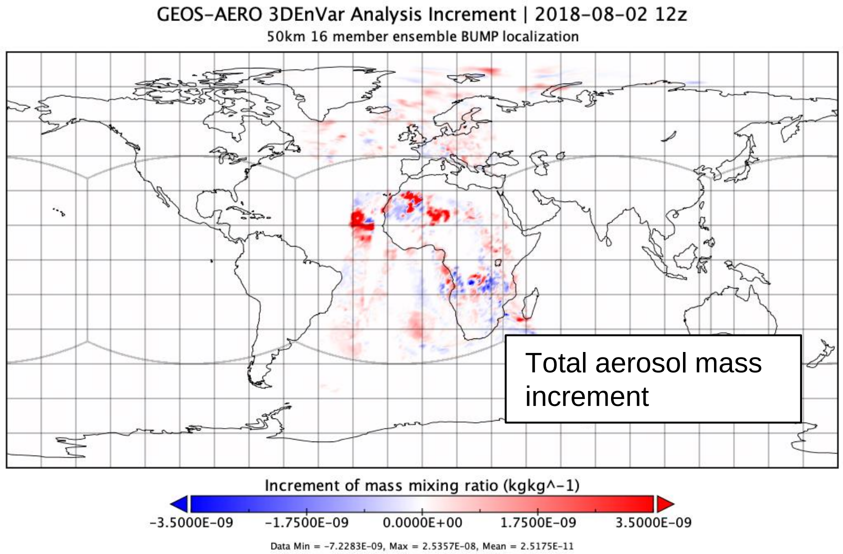
In-Core Data Assimilation – 4DVar

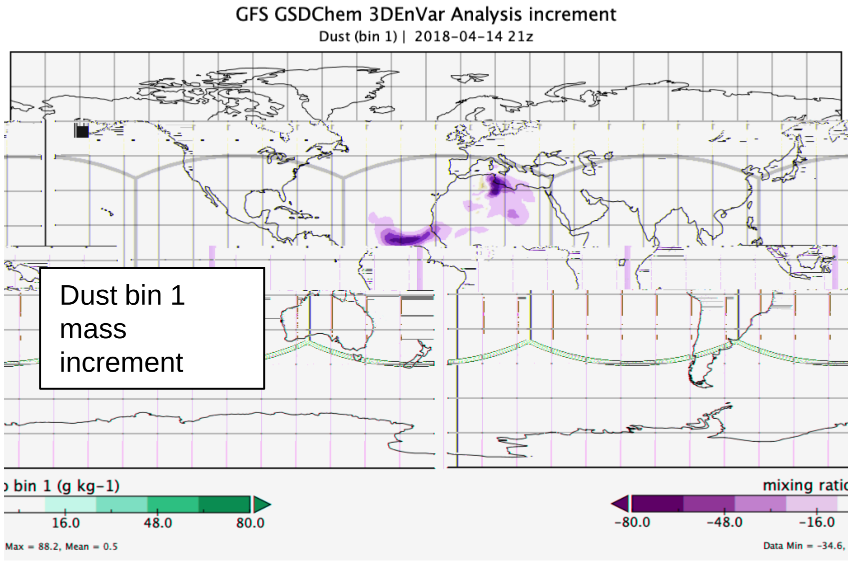
- C768 background (from ops) and forecast.
- Native grid and resolution observer.
- Pure ensemble B matrix from C384 (25km) 40 member ensemble (from ops).
- C192 (50km) increment.
- All AMSU-A NOAA 19 (~20,000 obs).
- 3 hour window
- 2 outer loops **in-core**.
- BUMP for localization, interpolation etc.





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
3°	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5
1°	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5
0.25°	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5	MOM6 MOM6-CICE5

Implemented
In progress
Not implemented

Target system

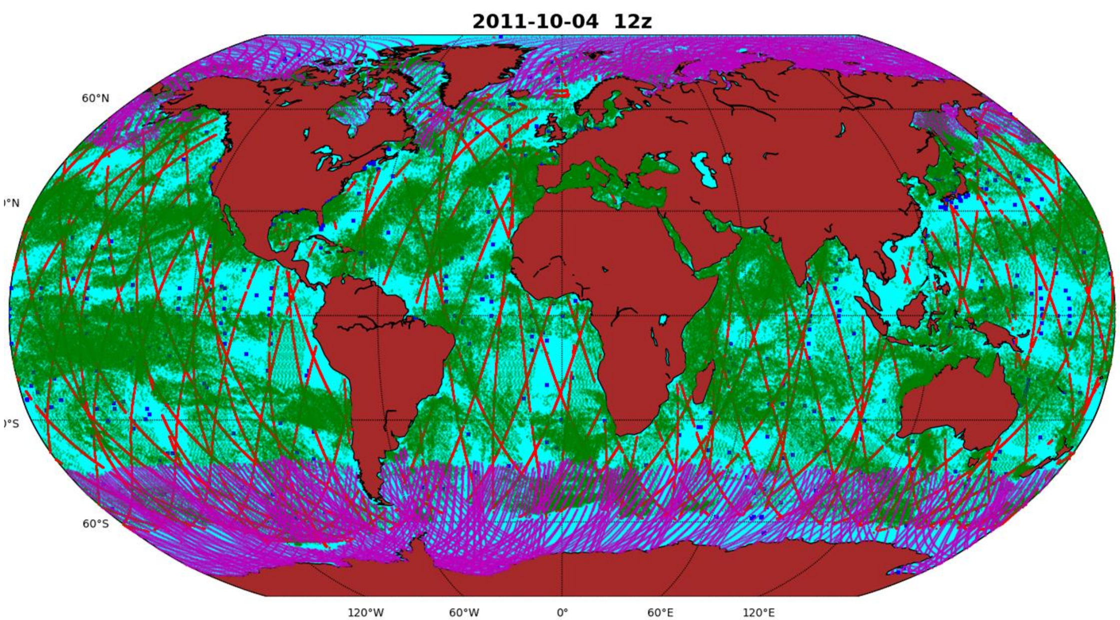
Cycling experiment

Marine Data Assimilation

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

Cycling Experiment

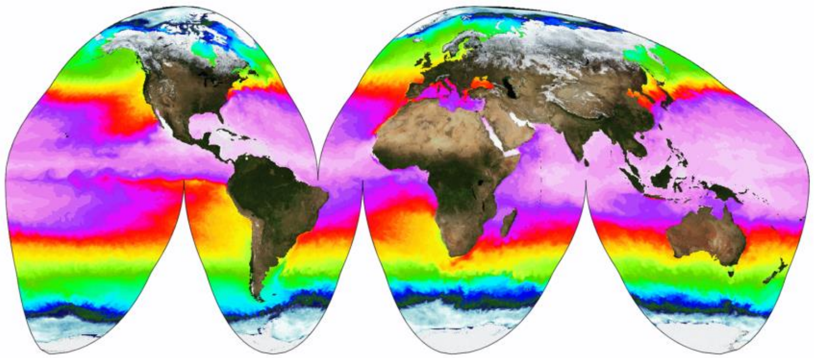
- October 1, 2011 to November 2, 2011
- Coupled forecast modelat ¼ degree resolution MOM6-CICE5-DataAtmosphere
- 24hr assimilation window ~1M obs per cycle
- 3DVAR with background dependent parametric B



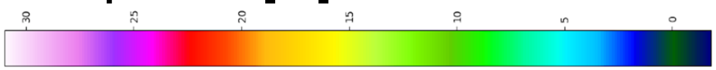
Variable	Satellite Sensor	In Situ
SST Infrared	NOAA-19, METOP-A AVHRR	
SST Microwave	WindSat	
Absolute Dynamic Topography	Jason-1 Jason-2 CryoSat-2	
Ice concentratio n	F-16/F-17 SSMI, SSMI/S	
Temperature		Argo, CTD, XBT, TAO, PIRATA, RAMA, ...

Marine Data Assimilation

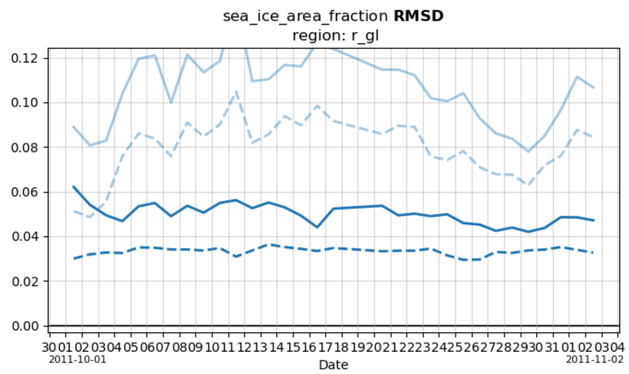
Forecast (sst, ice) 2011-10-01 to 2011-11-02



Temperature [°C]



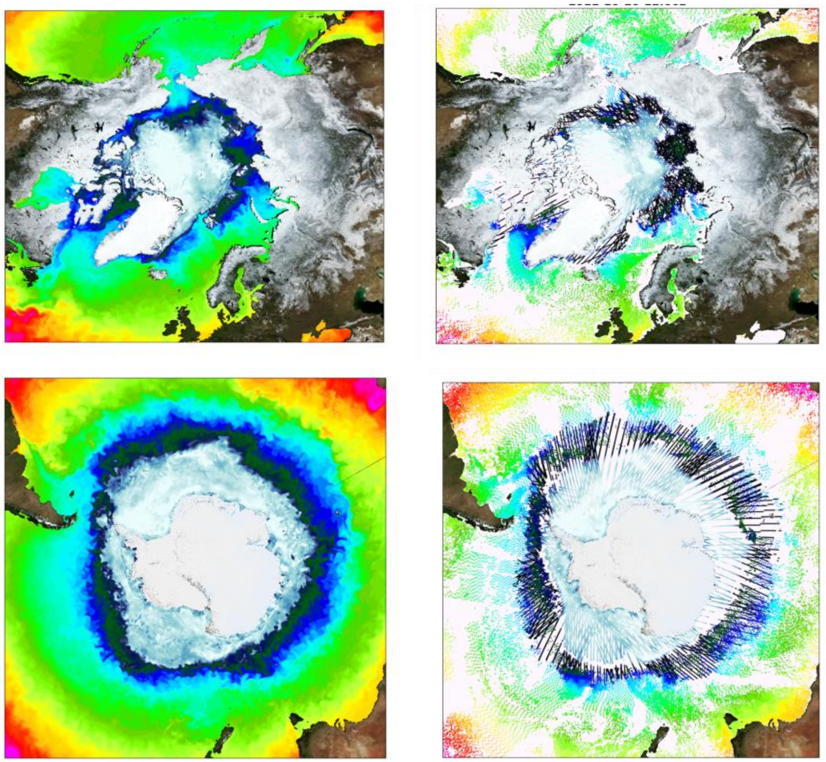
Sea ice concentration [°C]



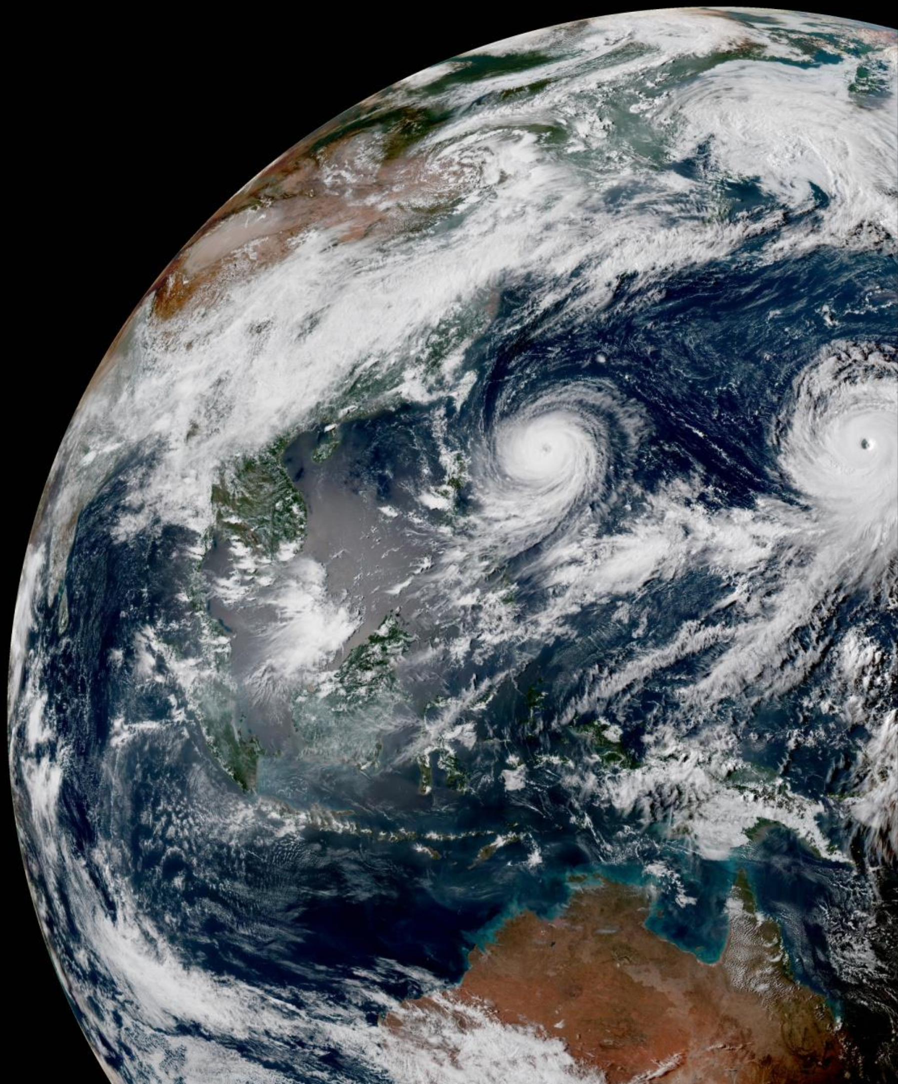
Preliminary Results

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)

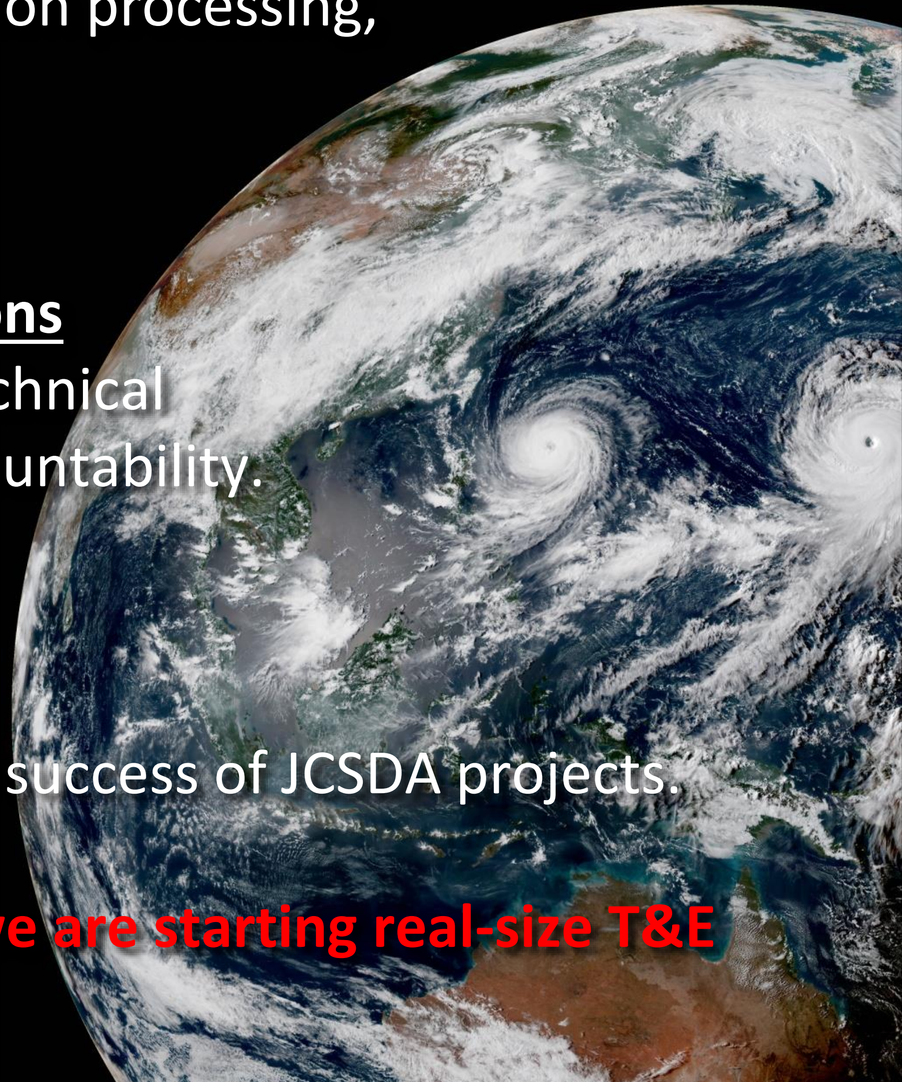
Final Remarks about the JCSDA

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

JOINT CENTER FOR SATELLITE DATA ASSIMILATION

NO. 66, Winter 2020

JCSDA Quarterly

NOAA | NASA | US NAVY | US AIR FORCE

https://doi.org/10.25923/rb19-0q26

IN THIS ISSUE

1 IN THIS ISSUE

1 NEWS IN THIS QUARTER

The Joint Effort for Data Assimilation Integration (JEDI)

Joint Effort for Data Assimilation Integration (JEDI) Design and Structure

Status of Model Interfacing in the Joint Effort for Data Assimilation Integration (JEDI)

Observations in the Joint Effort for Data Assimilation Integration (JEDI) -

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?