



GNSS-RO data assimilation advancement and implementation at JCSDA and NCEP

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Special acknowledgement to UCAR/CDAAC and NESDIS/STAR

Outline

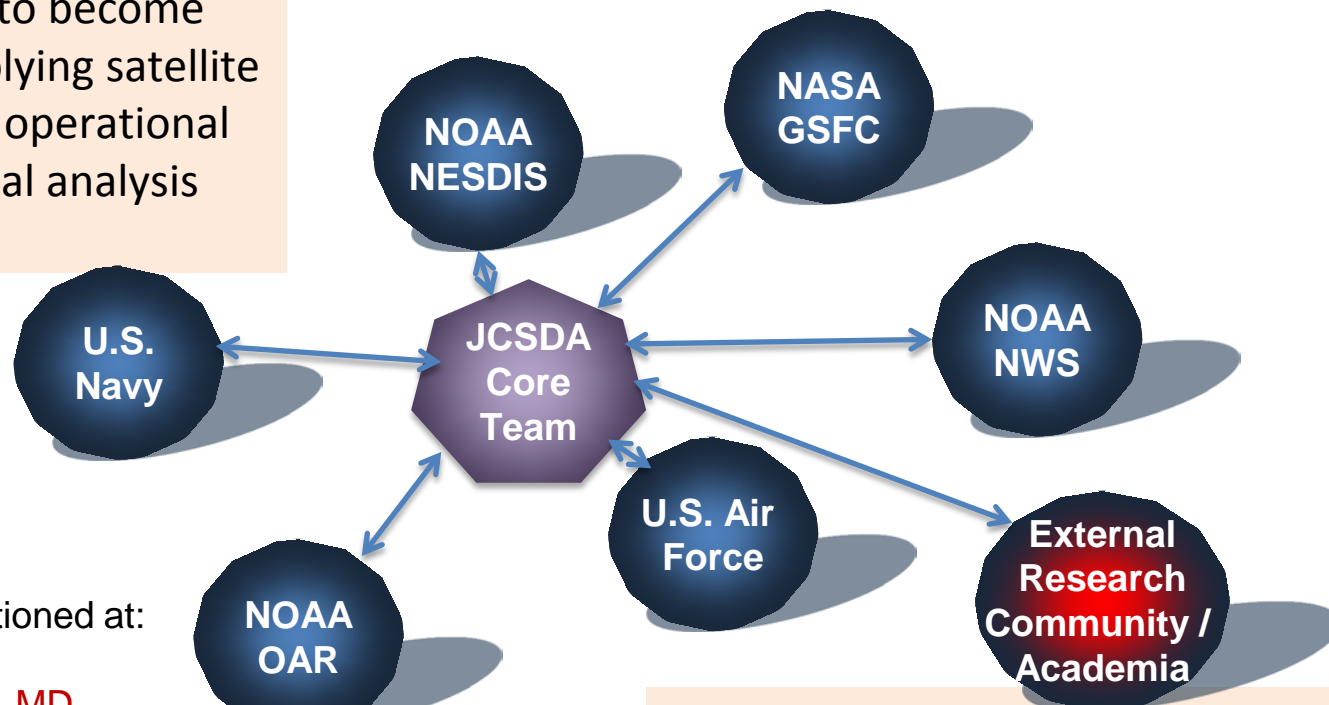


- Background
 - What is JCSDA? NCEP? And where to fit in?
- Current efforts for Global Navigation Satellite System Radio Occultation (GNSS-RO) applications
 - (Pre)Operational development and Status
 - Next generation data assimilation (DA)
- Summary

Joint Center for Satellite Data Assimilation



Vision: An **interagency partnership** working to become a world leader in applying satellite data and research to operational goals in environmental analysis and prediction.



JCSDA core team is stationed at:

- UCAR, Boulder, CO
- **NCEP, College Park, MD**
- NESDIS, College Park, MD
- NASA, Greenbelt, MD
- University of Wisconsin, Madison, WI
- NRL, Monterey, CA (to be hired)

Mission: To **accelerate** and **improve** the quantitative use of research and operational satellite data in weather, ocean, climate and environmental analysis and prediction systems.



NWS National Centers for Environmental Prediction

Specialized Services – Common Mission

- 490 FTE
- 237 Contractors
- 20 visitors
- 5 NOAA Corps Officers



Aviation Weather Center
Kansas City, MO



Space Weather Prediction Center
Boulder, CO



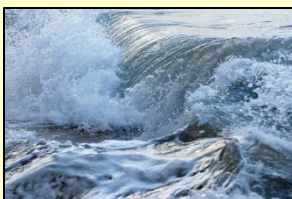
Storm Prediction Center
Norman, OK



National Hurricane Center
Miami, FL



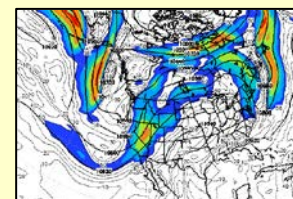
NCEP Central Operations
College Park, MD
(Supercomputers in Reston & Orlando)



Ocean Prediction Center
College Park, MD



Climate Prediction Center
College Park, MD



Environmental Modeling Center
College Park, MD



Weather Prediction Center
College Park, MD

Mission

NCEP delivers national and global operational weather, water and climate products and services essential to protecting life, property and economic well-being.

Vision

The trusted source for environmental predictions from the sun to the sea, when it matters most.



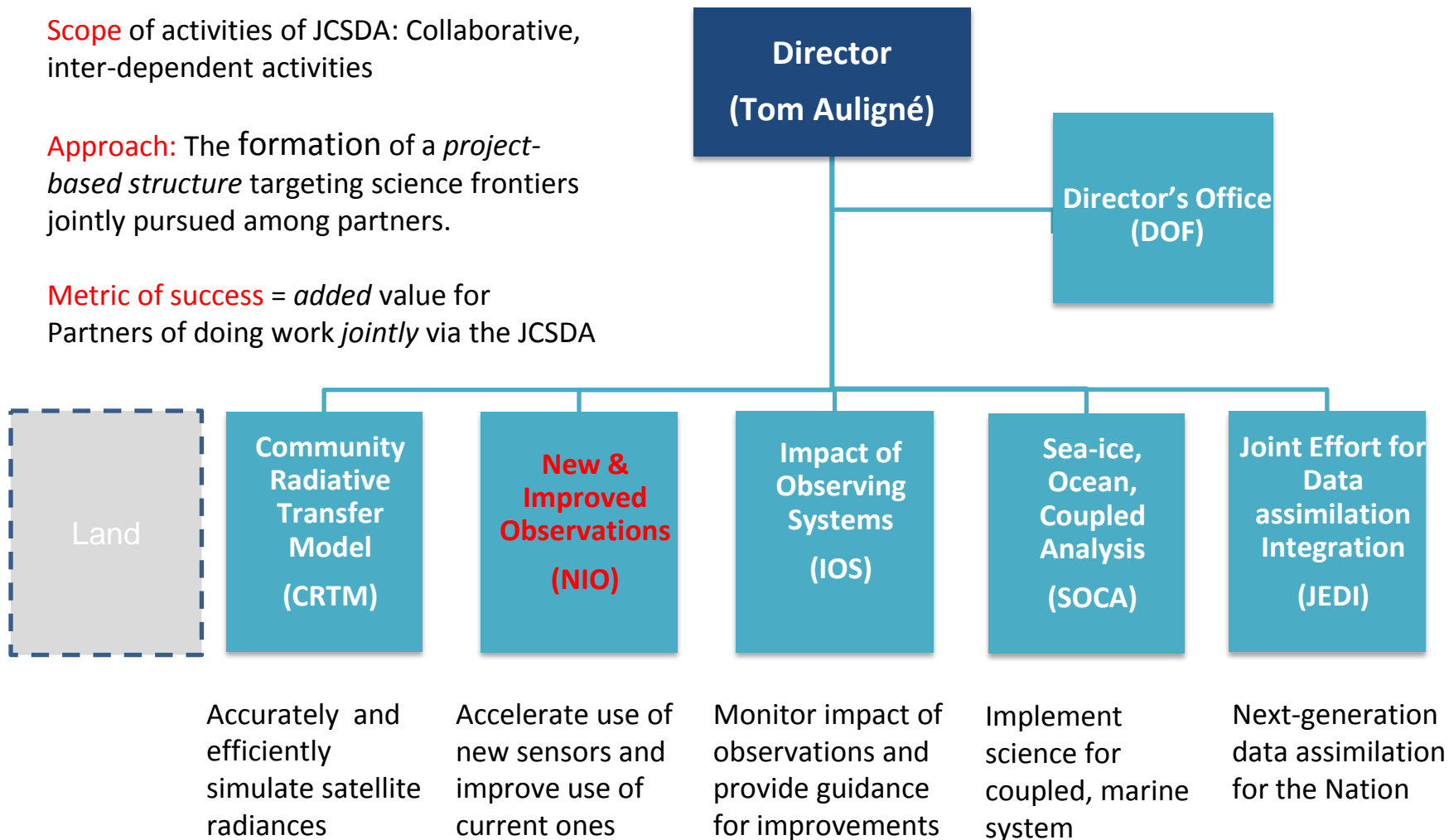
JCSDA Project Structure



Scope of activities of JCSDA: Collaborative, inter-dependent activities

Approach: The formation of a *project-based structure* targeting science frontiers jointly pursued among partners.

Metric of success = *added* value for Partners of doing work *jointly* via the JCSDA



GNSS-RO efforts at JCSDA



- JCSDA has joint sponsorship on GNSS-RO through the JCSDA Annual Operation Plan (AOP), including NOAA funds for COSMIC2 and commercial data evaluation
- Evaluate GNSS-RO data quality and its impacts in context of NWP in a research as well as quasi-operational environment (Francois Vandenberghe's talk)
 - KOMPSAT-5, Megha-Tropiques, PAZ, , METOP-C, COSMIC-2
 - Commercial data: CWDP (the Commercial Weather Data Pilot)
- **GNSS-RO data assimilation advancement**
 - Operational systems (e.g., NCEP GSI)
 - Next generation DA system - JEDI
- **Transition to operations – working with NCEP on implementations**

Operational readiness

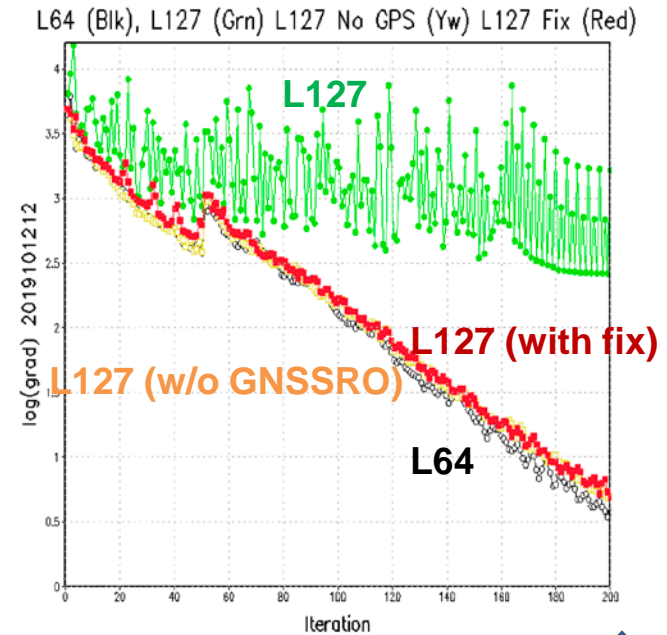


| Missions | NRT availability | Operation Status | Daily counts |
|-------------------------|----------------------------|--|--------------|
| COSMIC (US/Taiwan) | GTS | In operations | -> 0 |
| METOP-A/B (EUMETSAT) | GTS | In operations (only above 8km) | ~1200 |
| TerraSar-X (Germany) | GTS | In operations | ~200 |
| TANDEM-X (Germany) | GTS | In operations | ~100 |
| KOMPSAT-5 (Korea) | PDA | Retrospective test completed; In operational code; | ~200 |
| PAZ (SPAIN) | PDA | Retrospective test completed; in Q1/2020 code | ~150 |
| Megha-Tropiques (INDIA) | GTS (missing since March?) | Retrospective test completed; in Q1/2020 code | ~170->0 |
| METOP-C (EUMETSAT) | GFS | Retrospective test completed; in Q1/2020 code | ~600 |
| COSMIC2 (US/Taiwan) | PDA in November (TBD) | Testing; in Q1/2020 code | 0-3500 |
| CWDP (commercial) | | Testing (under NDA) | |

NCEP provisional implementation



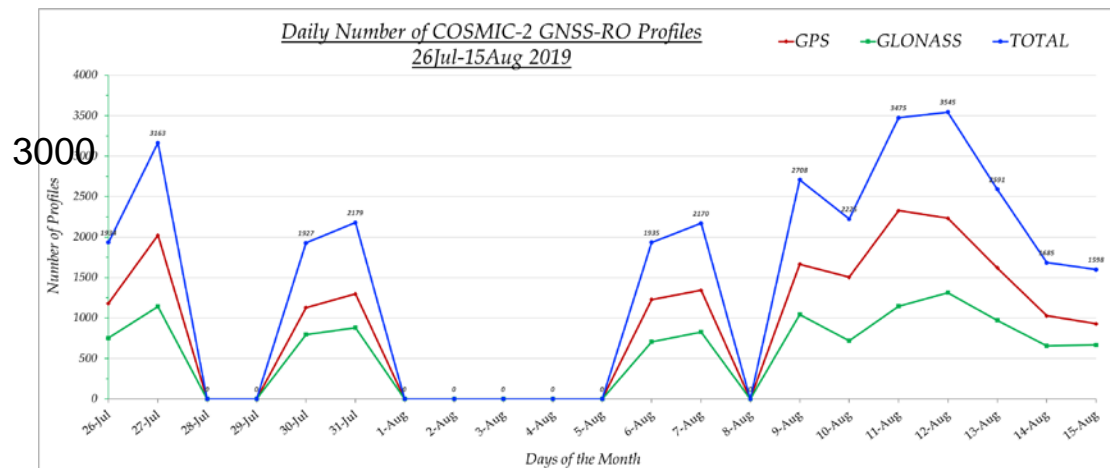
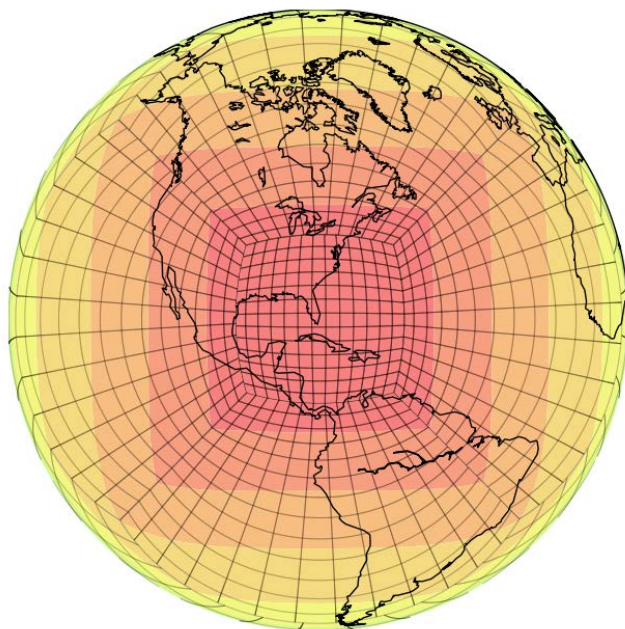
- NCEP Global Forecast System (GFS) v15.2 : early 2020
 - COSMIC-2, PAZ, METOP-c code changes were committed, August, 2019
- GFS V16: 2021, with increased model top (50km->80km) and vertical resolution (L64->L127)
 - Bug fix to current GNSSRO operator (due to configuration change): completed
 - Initial code changes for new GNSSRO missions will be committed by end of September
 - **Generating and tuning observation errors and QC**



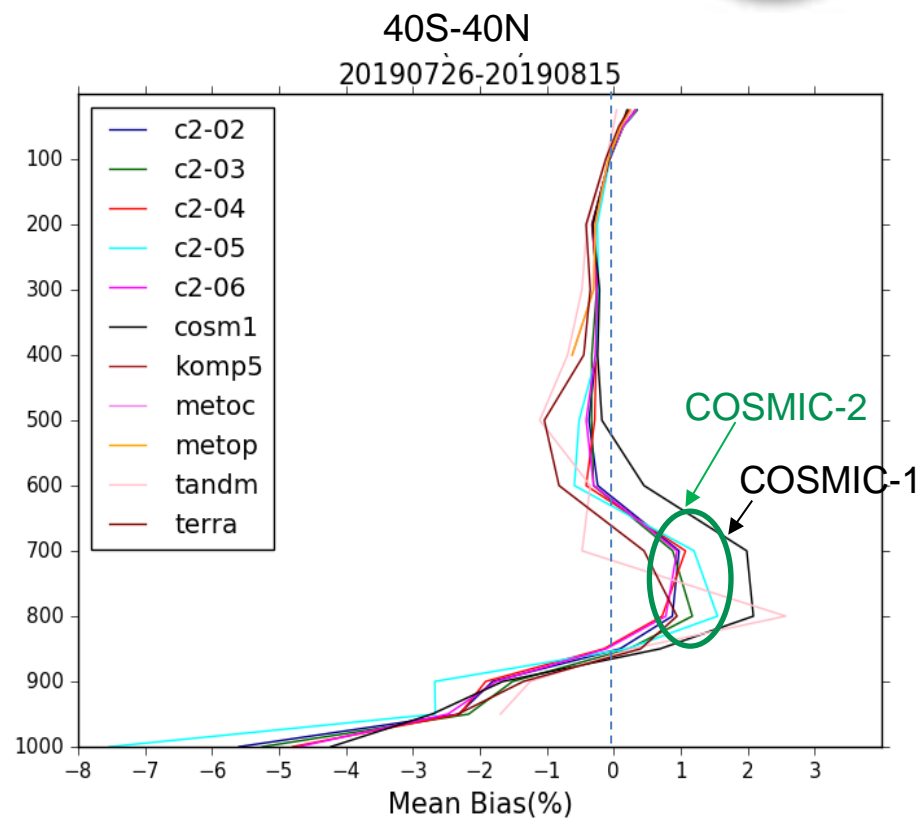
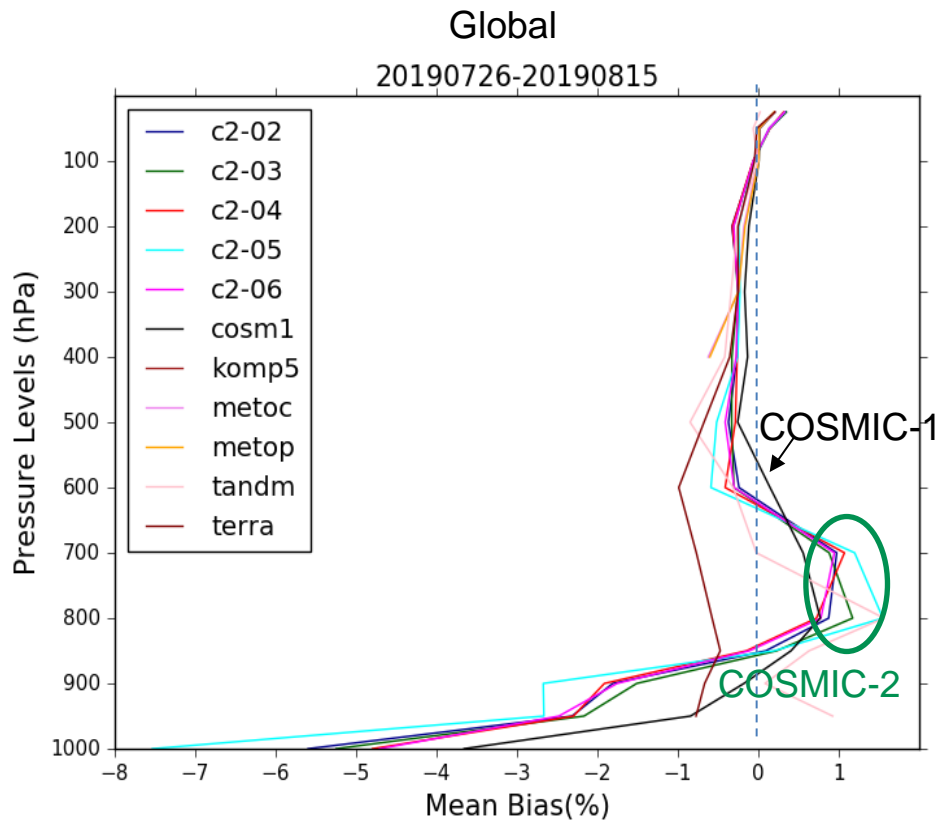
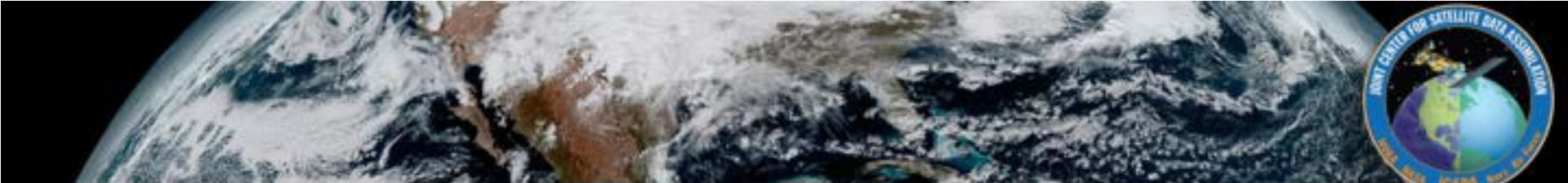
Initial assessment of COSMIC-2 using GSI



- Testing period: July 26-August 15, 2019
 - COSMIC-2 vs GFS (v14, operational prior to Jun 12, 2019) (Francois Vandenberghe's talk)
 - COSMIC-2 vs FV3GFS (v15, operational, L64)

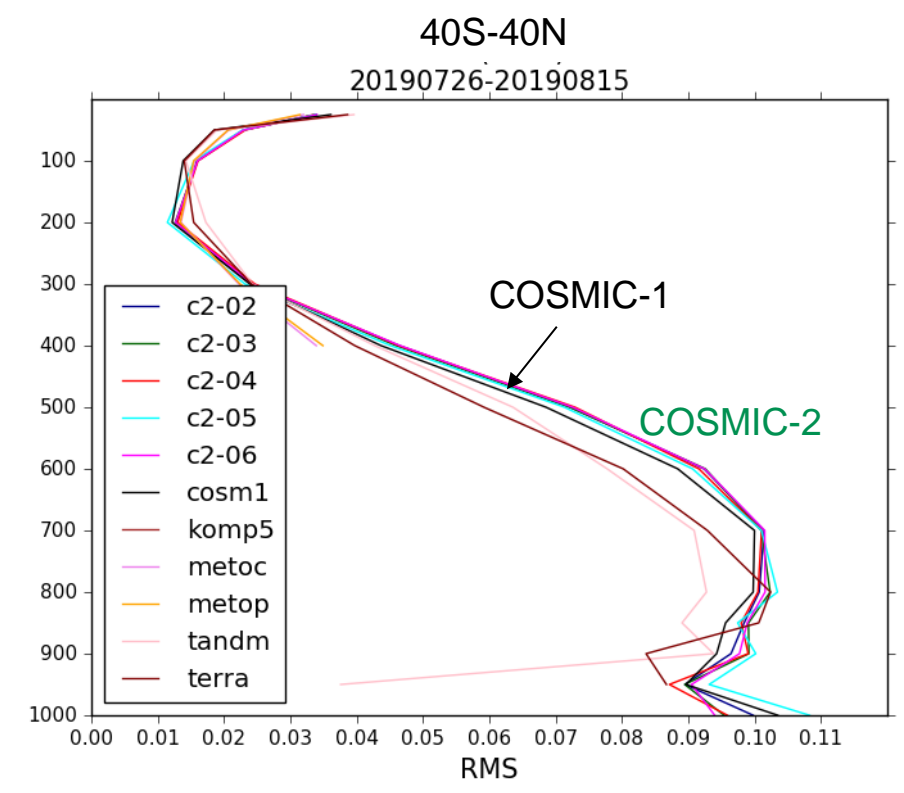
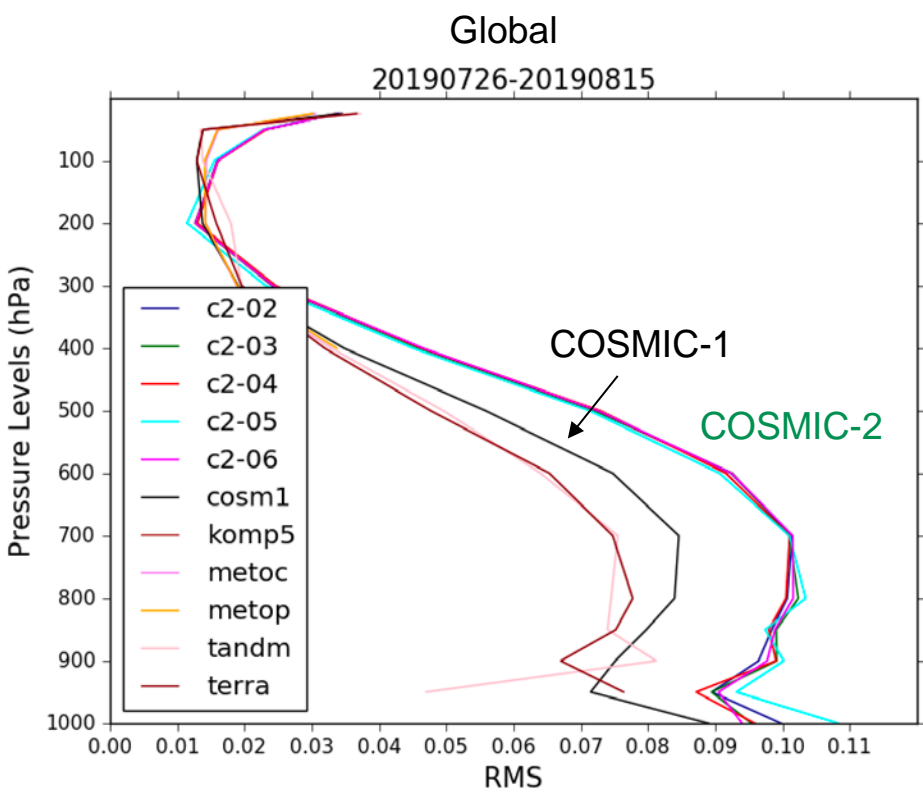


GFS V16 uses the Finite-Volume Cubed-Sphere (FV3) for its dynamical core



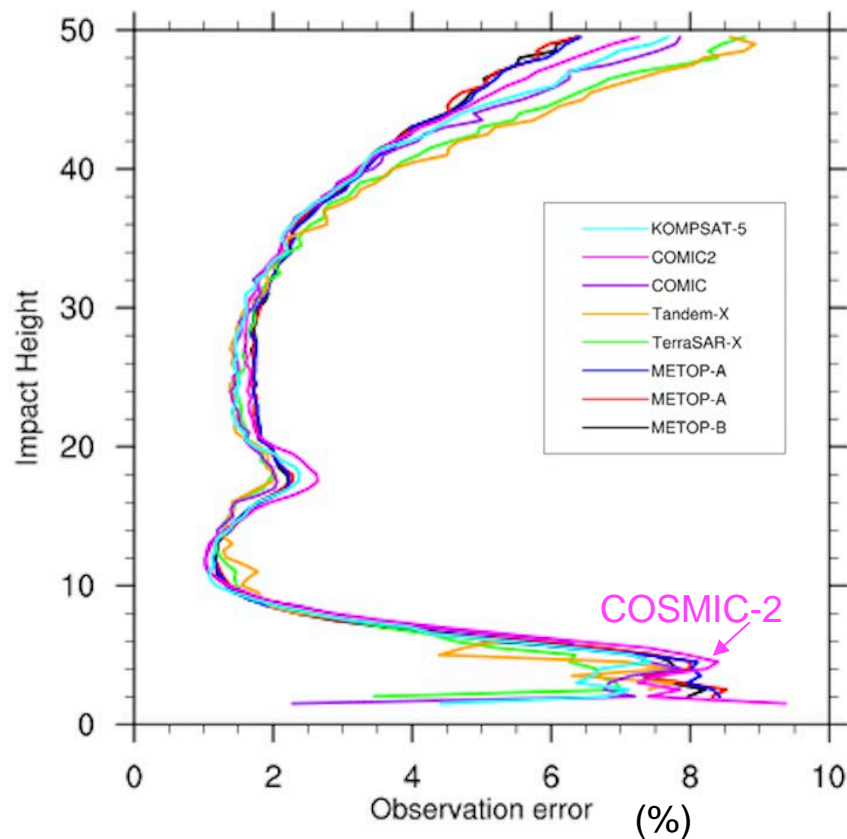
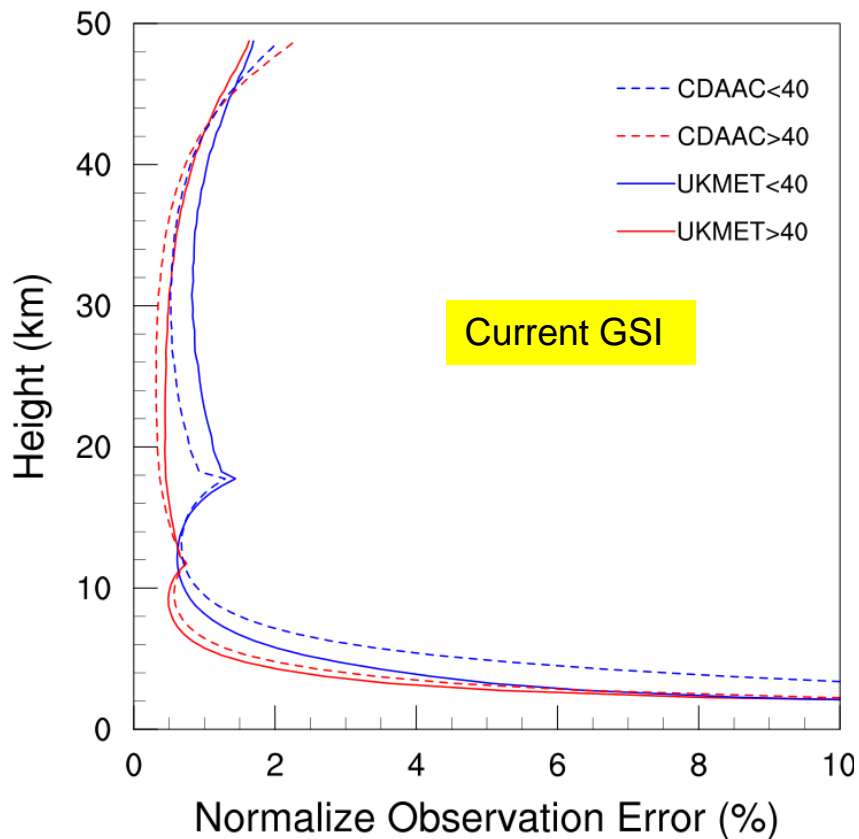
(O-B)/O

COSMIC-2 vs GFSv15



(O-B)/O

COSMIC-2 vs GFSv15

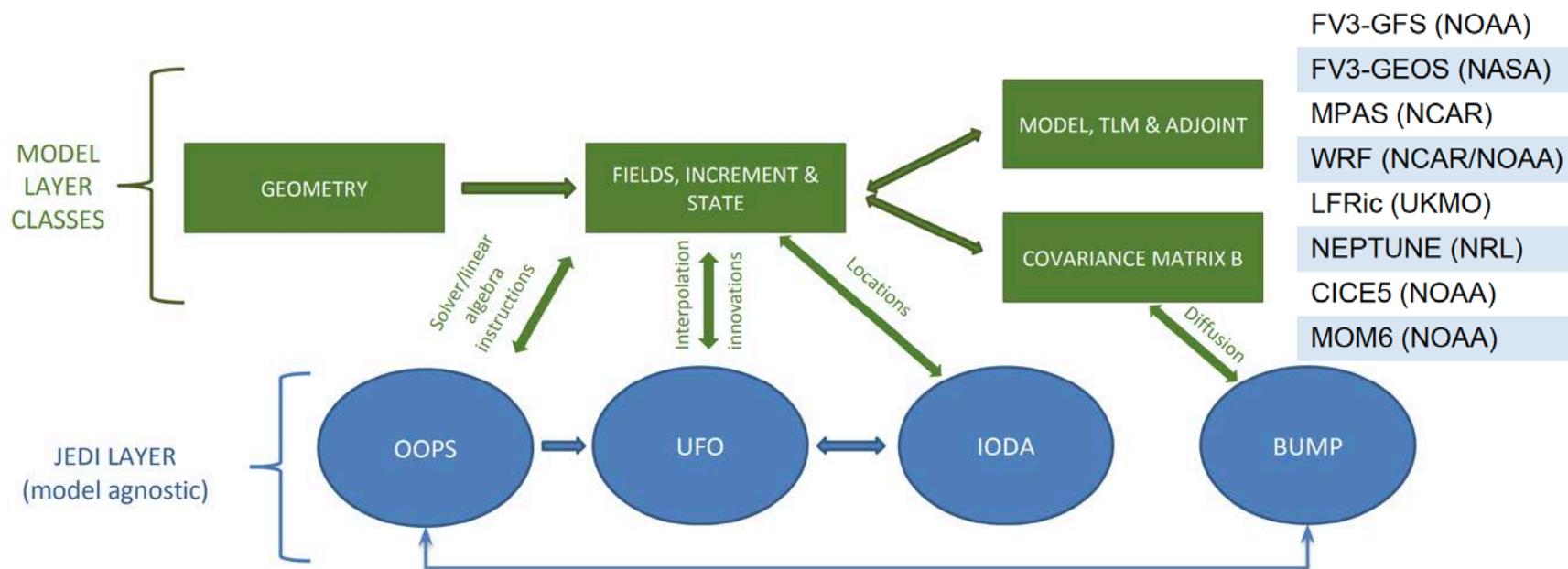


- Using the variance method described in Kuo, 2004, where model errors are estimated using the “NMC” method (lagged forecasts)
- Will adopt other methods for this estimation and perform tuning (3CH, Derozier, etc)

Joint Effort for Data assimilation Integration (JEDI)



JEDI is a collaborative effort to develop a next generation unified data assimilation system for the Earth system, using agile software development with advanced computing languages and techniques



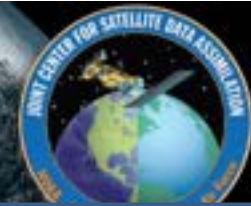
OOPS: Object-Oriented Prediction System

UFO: Unified Forward Operator

IODA: Interface for Observation Data Access

BUMP: B matrix on an Unstructured Mesh Package

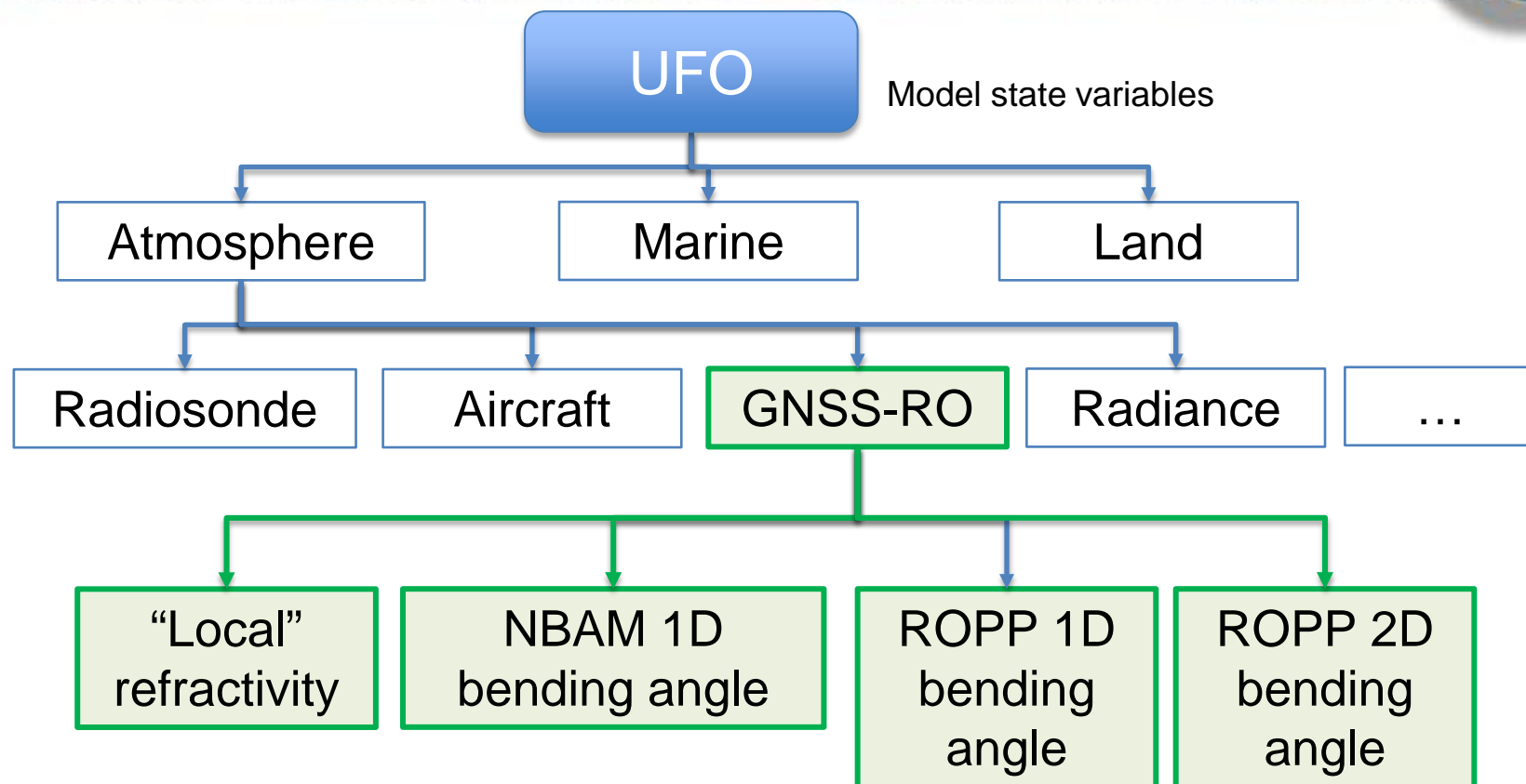
How we work together?



GNSSRO Code sprint, August, 2018



JEDI Unified Forward Operator



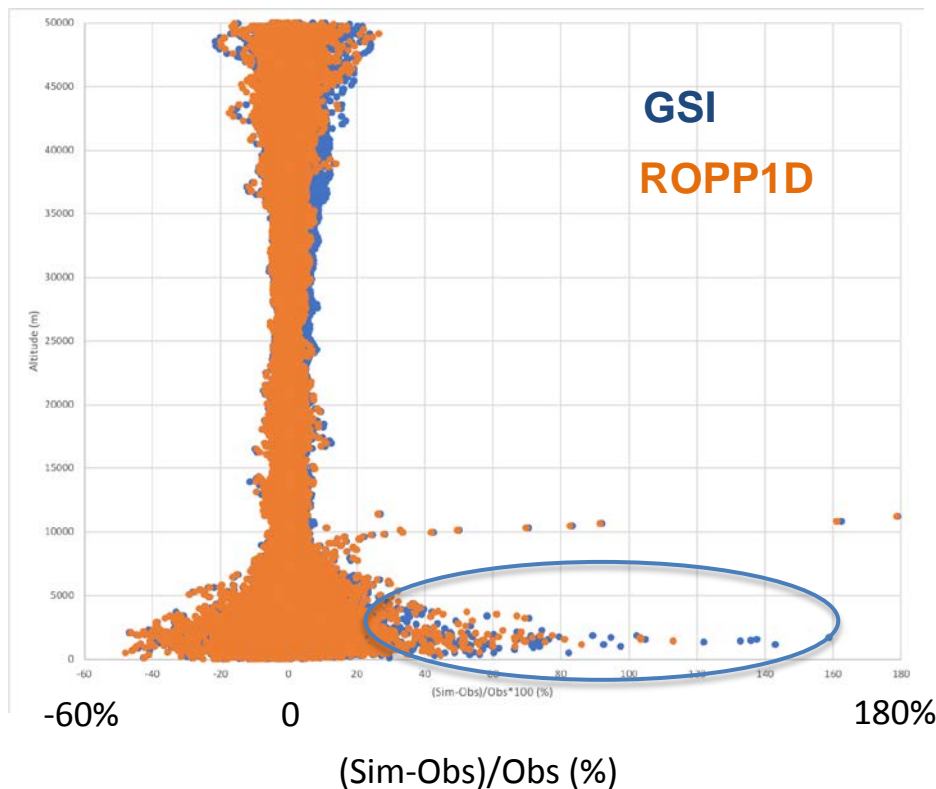
NBAM: based on NCEP bending angle forward operator

ROPP: Radio Occultation Processing Package, part of the Radio Occultation Meteorology Satellite Application Facilities (ROM-SAF), managed by the European organization for the exploitation of METeorological SATellites (EUMETSAT)

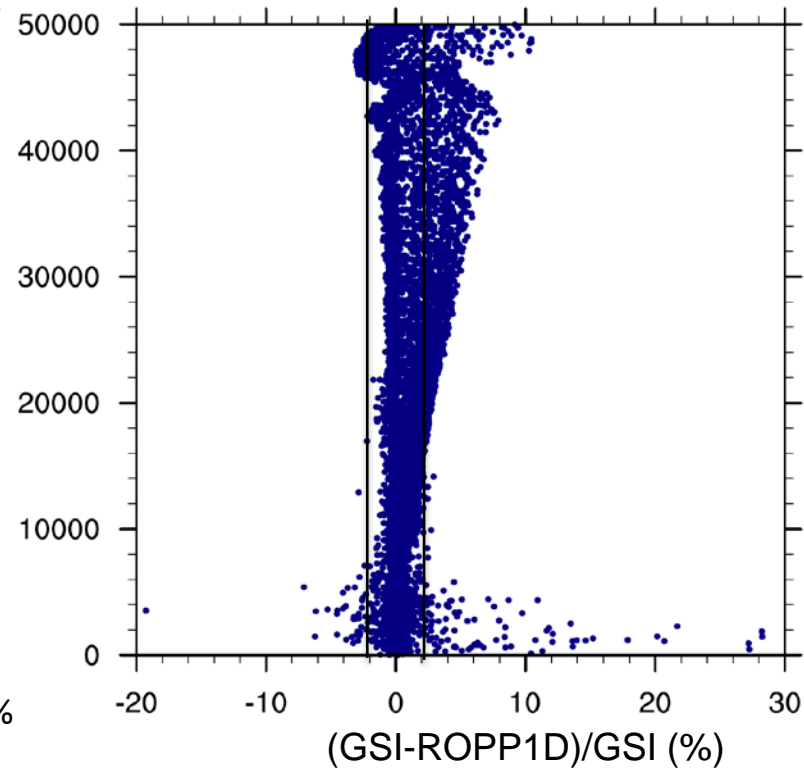
Comparing 1D bending angle operators



Differences between simulated and observed bending angles

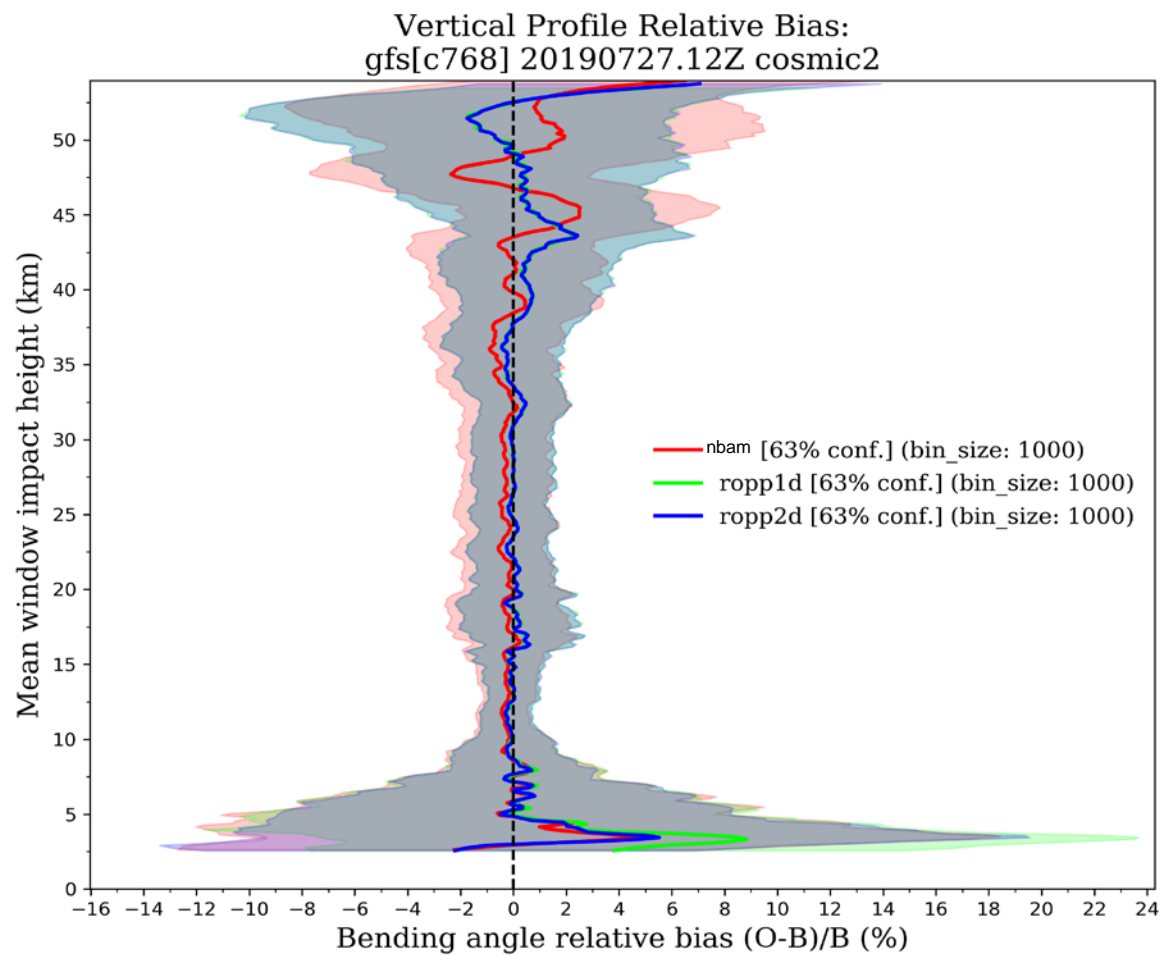


Differences between simulated bending angles using GSI and ROPP 1D algorithms



A total of 54943 data sets were used within a 6-hour window

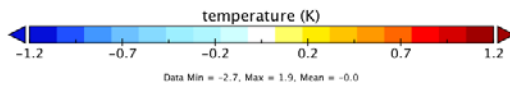
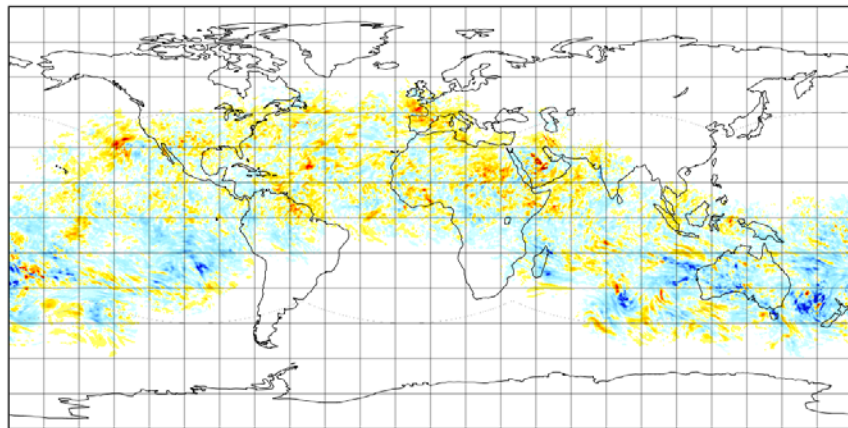
COSMIC-2/FV3 Innovations



Snapshot: analysis increments

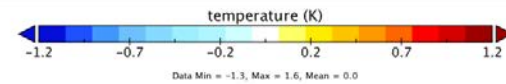
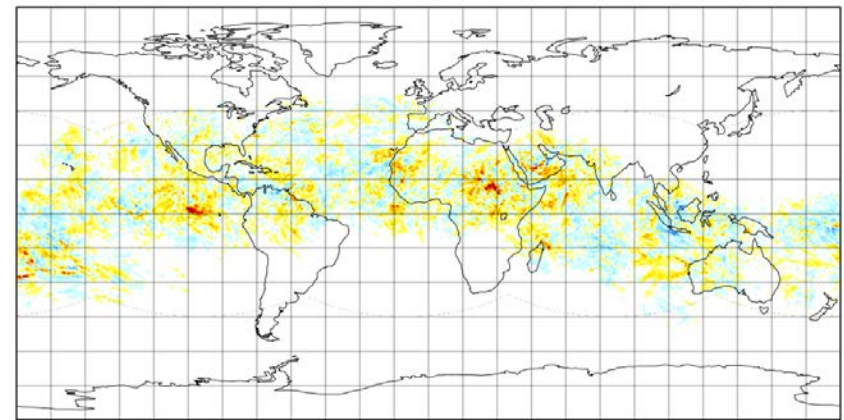


COSMIC2 Temperature Analysis Increment at 500hPa
JEDI 3D-EnVar - July 27, 2019 at 12Z



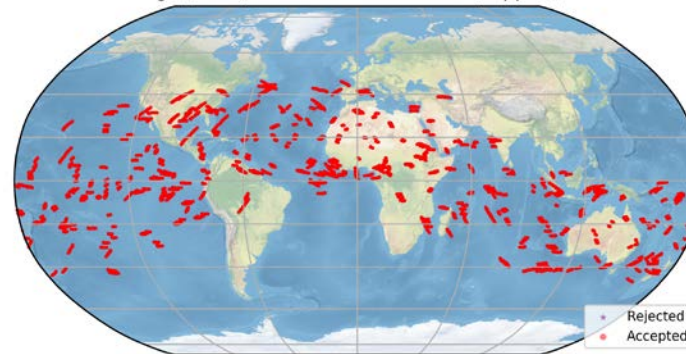
NBAM

COSMIC2 Temperature Analysis Increment at 500hPa
JEDI 3D-EnVar - July 27, 2019 at 12Z



ROPP2D

Observation locations
gfs[c768] 20190727.12Z cosmic2[ropp2d]



Num accepted obs: 166967 Num rejected obs: 19293

“Toy” model for new operator



Ongoing feasibility study for implementing 3D ray-tracing operators using advanced programming languages and mathematical libraries.

Demonstration code using C++ and its boost lib for solving a ray-tracing equation.

```
//[ coordinate_function
struct ray_coor
{
    ray_coor(){} }

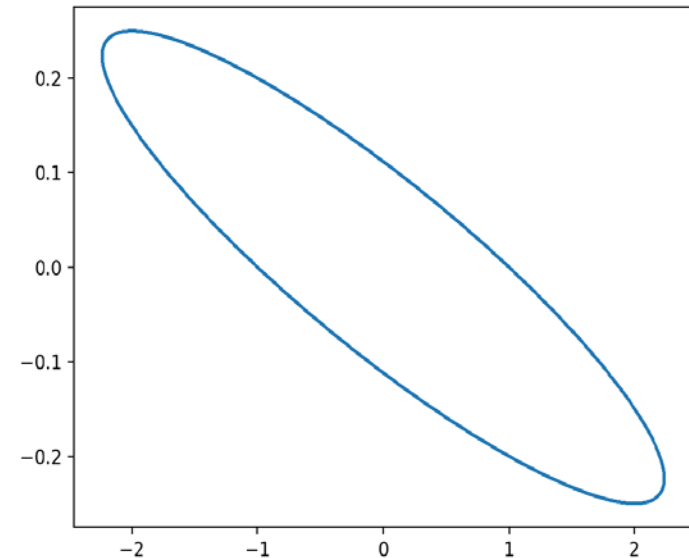
void operator()( const container_type &p , container_type &dqdt ) const
{
    for( size_t i=0 ; i<n ; ++i )
        dqdt[i] = p[i];
}
];

//[ momentum_function
struct ray_momentum
{
    ray_momentum(){} }

void operator()( const container_type &q , container_type &dpdt ) const
{
    const size_t n = q.size();
    for( size_t i=0 ; i<n ; ++i )
    {
        dpdt[i].m_val[0] = -1.0*q[i].m_val[0];
        dpdt[i].m_val[1] = -1.0*q[i].m_val[1];
    }
}
];
```

```
//[ integration_GPS_signal
typedef symplectic_rkn_sb3a_mclachlan< container_type > stepper_type;
const double dt = 0.1;

integrate_const(
    stepper_type() ,
    make_pair( ray_coor( ) , ray_momentum( ) ) ,
    make_pair( boost::ref( q ) , boost::ref( p ) ) ,
    0.0 , 50.0 , dt , streaming_observer( cout ) );
];
```



Ray trajectory for the Luneburg lens profile

P. Stegmann, B. Johnson, H. Shao, JCSDA Quarterly, No. 63, Spring 2019, <https://doi.org/10.25923/c23x-ac34>

Summary



- JCSDA and NCEP are working closely on adding **new missions/data**, e.g., COSMIC-2, into **operations**
- Initial assessment of **COSMIC-2** data are being performed (also refer to Francois Vanderberghen's presentation) and the initial code changes has been added to next operational code v15.2
- NCEP and JCSDA are also working together to prepare the GNSS-RO operator for FV3GFS v16, with increase of model top and vertical levels. – expected implementation in 2021
- Currently, JCSDA is working on **optimizing** the operational GSI system through the observation error (and QC) studies
- Meanwhile, GNSS-RO operators have been jointly developed inside the JEDI framework. Currently, operational capabilities are being duplicated. Additional (ground GPS, airborne) and **advanced** features are being developed
- JCSDA also starts looking at **new techniques** and develop ideas for data assimilation



Questions?



U.S. AIR FORCE