Frontiers of Numerical Weather Prediction

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(CESAS)
March 29, 2017

Outline

- Background: Components for NWP Skill
- Status of NOAA's NWP Modeling Suite
- Evolution of NWP Model Suite
- Role of Satellite Observations
- Discussion
- Summary Remarks

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Today: Everything you read, see or hear about weather, climate and ocean forecasts begins with numerical prediction models

Key components of a successful forecast

- Global Observing System
- Computers (supercomputers, work stations)
- Data Assimilation & Modeling/Science
- Trained workforce

Global Observing System

- ~2 Billion / day
- 99.9 % remotely sensed, mostly from satellites
- ~ 45 different satellites/sensors now used

Satellite contribution dominated by LEO (Polar)

Key Components of a Successful Warning

Satellite contribution dominated by GEO

Services/products

- Situational awareness
- Rapid data access
- Increasingly remotely sensed observations
- Decision support services /training

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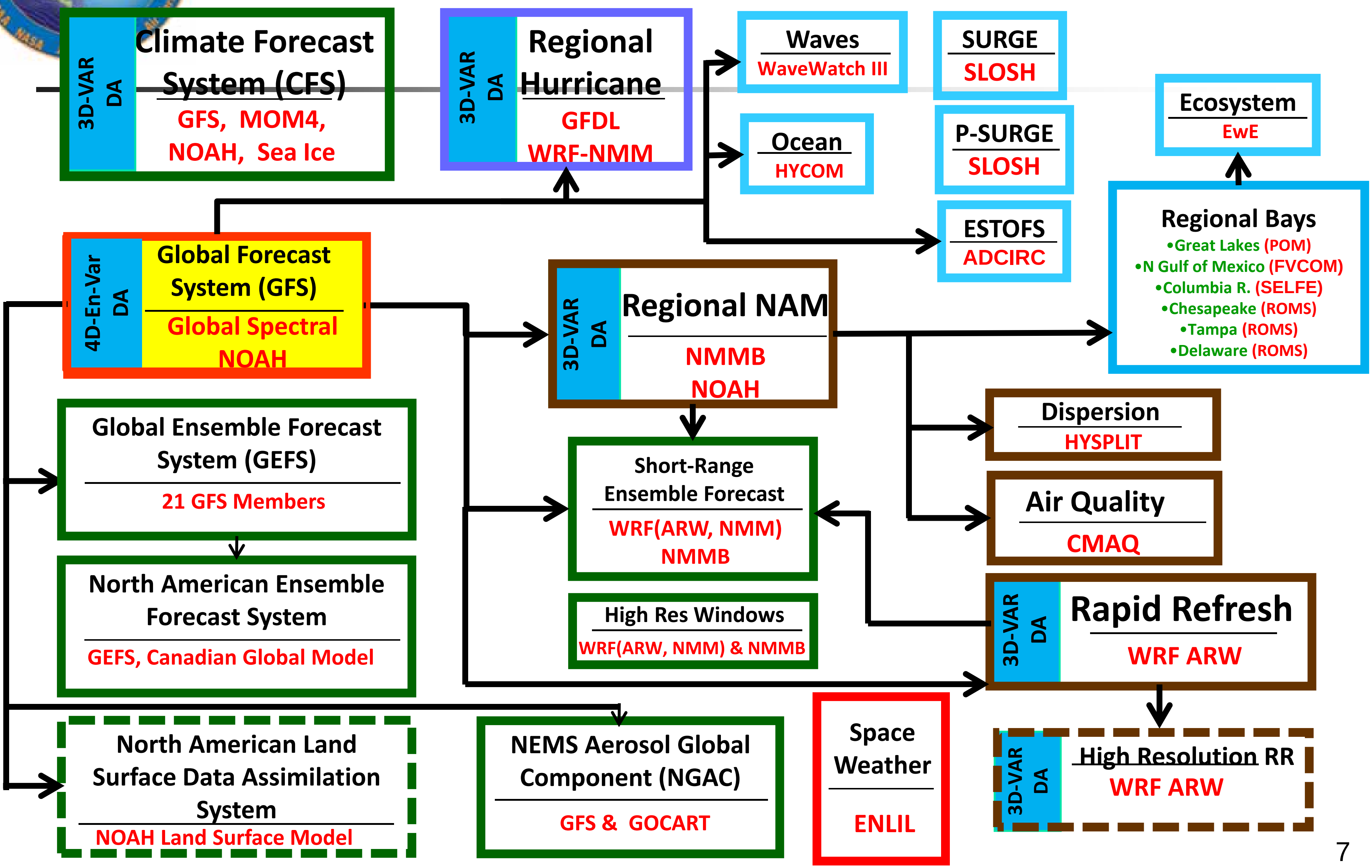
NOAA's Operational NWP Suite



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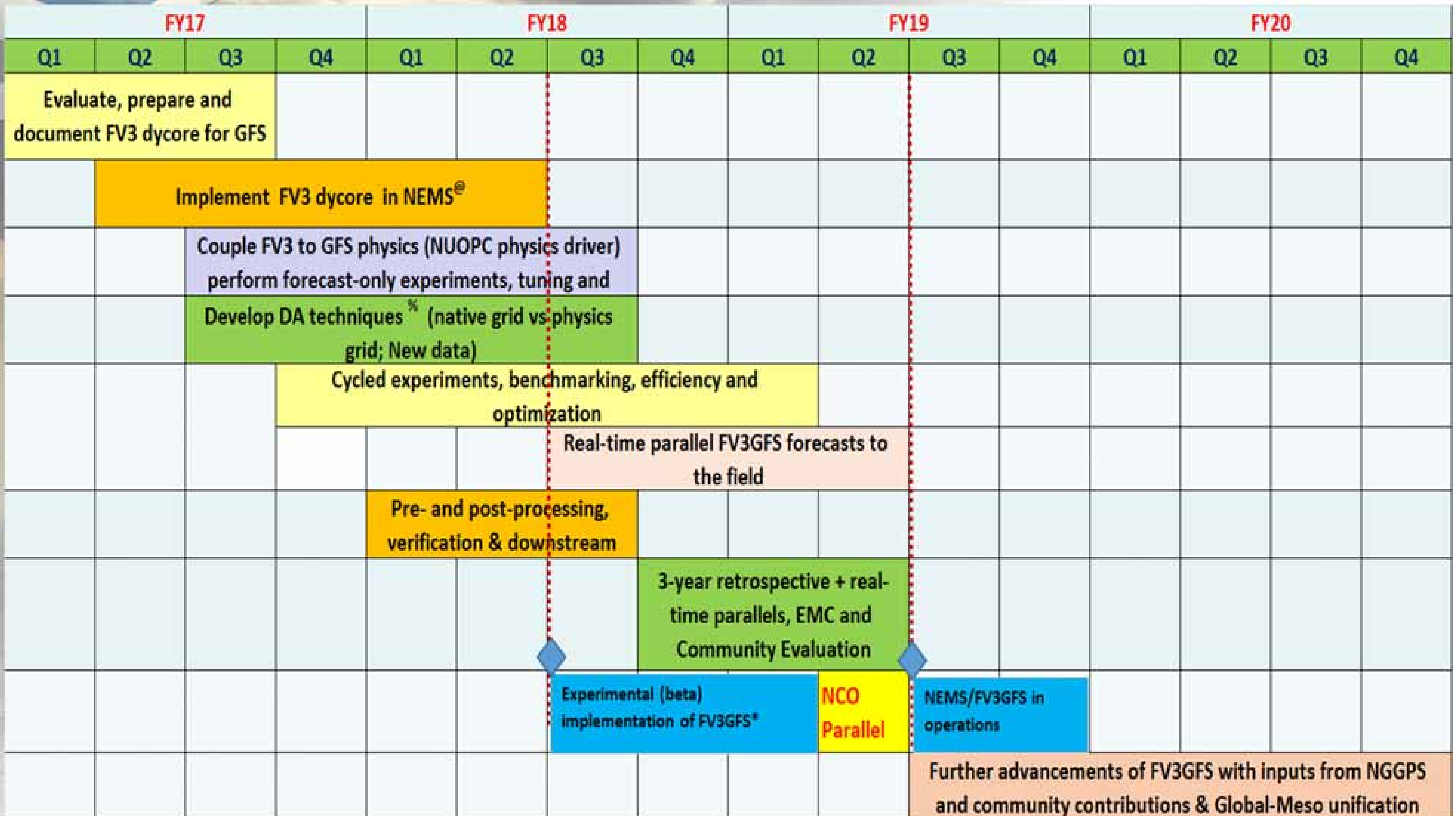
Model Evolution Drivers

- Need for Improved Accuracy
  - High-impact weather and related IDSS
  - Field requirements vetted in our strategic planning (i.e., Weather Ready Nation, OWA, vetted Phasing Diagram, etc.)
  - Political (e.g., HDRA 2013; 2016 Weather Bill)
- UCACN Modeling Advisory Committee
  - Simplify NCEP production suite
  - Unified modeling under single dycore + meso-unification (3-km ensemble)
  - Pursue required HPC upgrades
  - Strategic plan for modeling with community fully engaged

Implementation Plan for FV3-GFS (FY2017-2019)



* Q3FY18 FV3GFS will be very similar to operational GFS being implemented in May 2017

'@ Q3FY19 FV3GFS target resolution is ~10km grid with 127 layers, extends up to 80 km.

'& Advanced physics: Scale-aware convection, SHOC PBL, Double-moment microphysics, Unified convective and orographic gravity wave drag etc

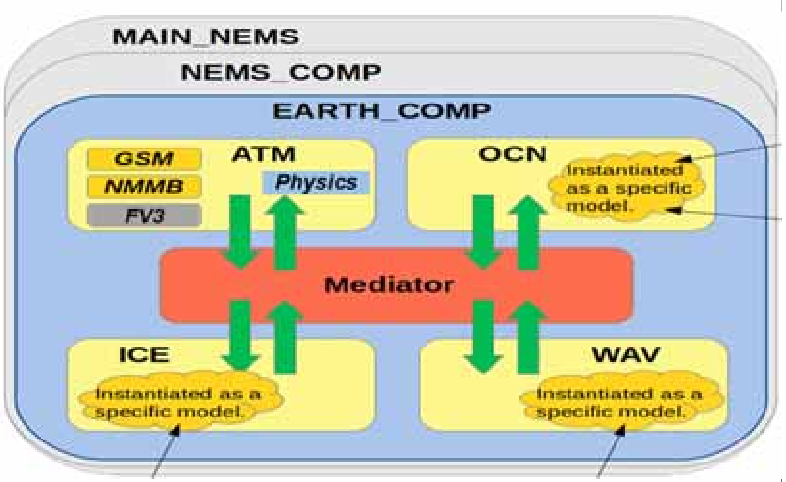
'% DA system will be @35 km 127 levels using 4d-Hybrid EnVAR

Advancement of Global Modeling at NCEP

Current and Future Plans

	2017	2018	2019	2020+
Model	NEMS GSM	NEMS GSM	NEMS FV3 (NGGPS)	NEMS FV3
Resolution	T_L1534L64 ~13 km	T_L1534L64 ~13 km	10 km L128	---
Physics	Scale-aware SAS, TKE-Moist EDMF PBL	Scale-aware SAS, TKE-Moist EDMF PBL	Advanced Physics supported by CCPP	Aerosol aware physics
DA	4D-Hybrid	4D-Hybrid + GOES-16 + JPSS + COSMIC2	4D-Hybrid + IAU	Coupled DA

- Community Model Development
- Unified Global Coupled System for all temporal scales
- High-Resolution Global Ensembles to follow deterministic model upgrades
- Eventual Global-Meso unification – global model with high-resolution nests coupled to earth system components



FV3 GFS Data Assimilation Plan

<table>
<tr><th colspan="4">FY17</th><th colspan="4">FY18</th><th colspan="4">FY19</th><th colspan="4">FY20</th></tr>
<tr><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th></tr>
<tr><td></td><td></td><td colspan="4">Adopt GDAS (4D Hybrid En-VAR) DA for FV3GFS</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Testing, Evaluation and Operational Implementation of new satellite datasets (GOES-16, JPSS, COSMIC-2 etc.)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="7">Increase vertical resolution to 127 levels and increase GDAS resolution to 35 km</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="9">Incorporate JEDI Unified Forward Operator and Modular GSI infrastructure</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">Develop and implement DA on native cubed sphere grid</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="6">Further advancements of FV3GDAS Global-Meso-Marine unification (Unified DA Development)</td></tr>
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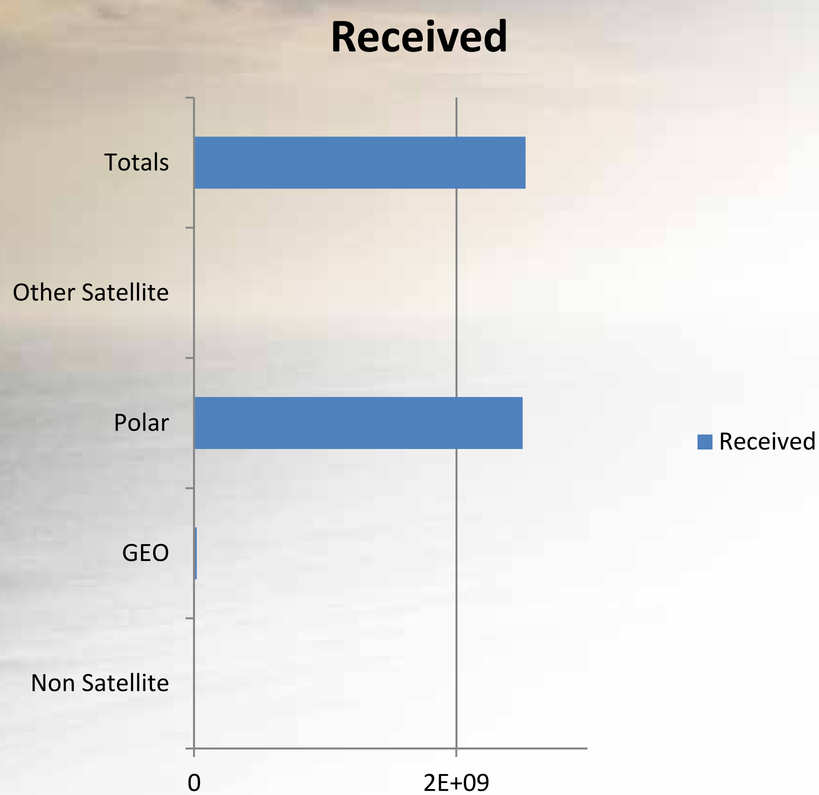
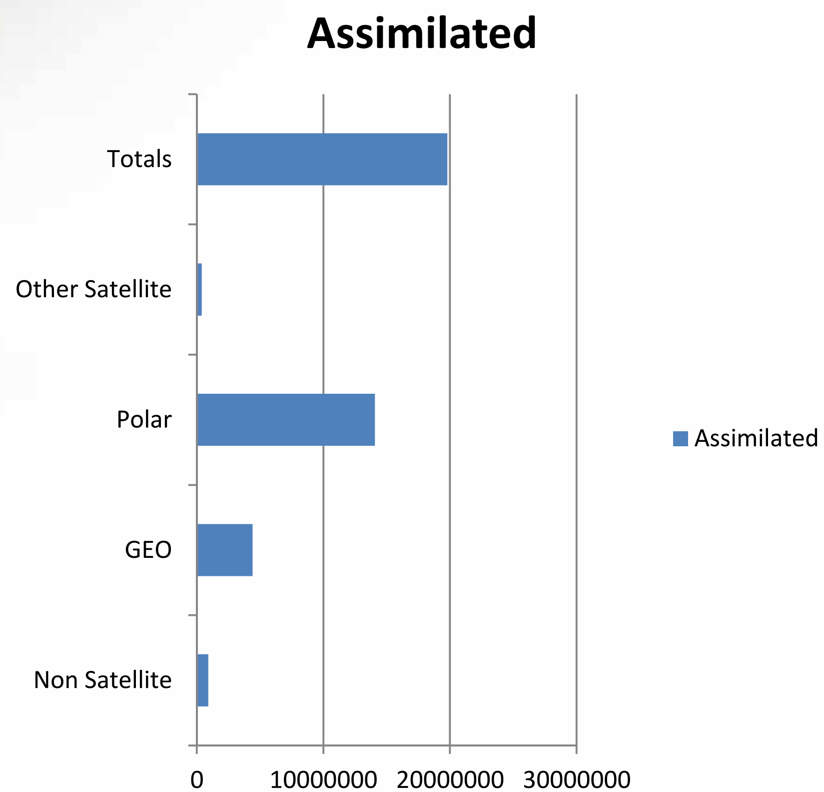
Observations in the GFS

NOAA GFS Daily Ave 2017





Observational Requirements Process

- Flow from Mission Service Requirements
- Observation requirements are maintained and validated at the NOAA level
  - NOAA Observing Systems Council
- Tools are utilized to determine mission impacts as well as impacts on numerical weather prediction
- NOAA Satellite Architecture Effort is Underway
  - Supporting by Space Platform Requirements Working Group

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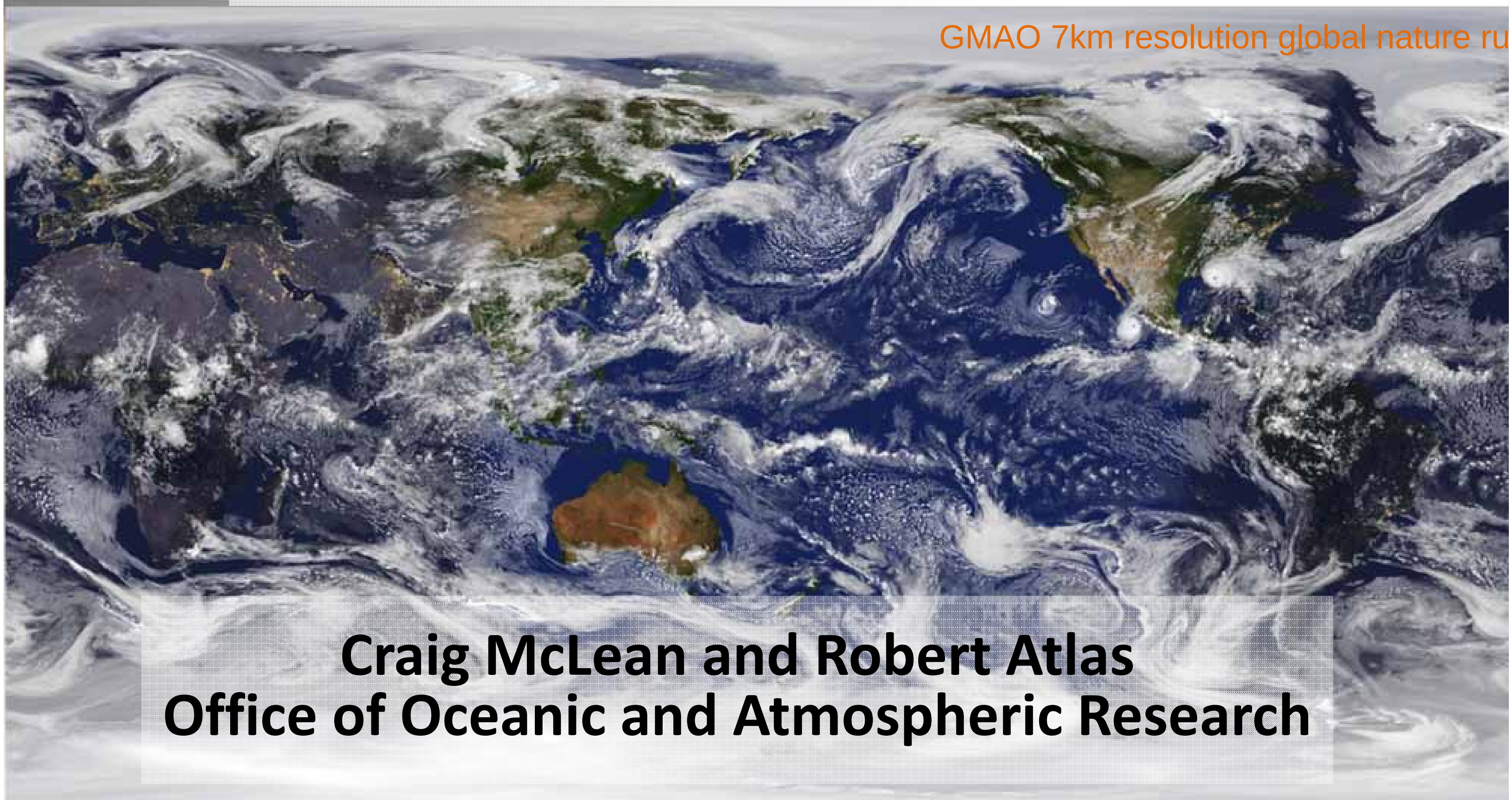
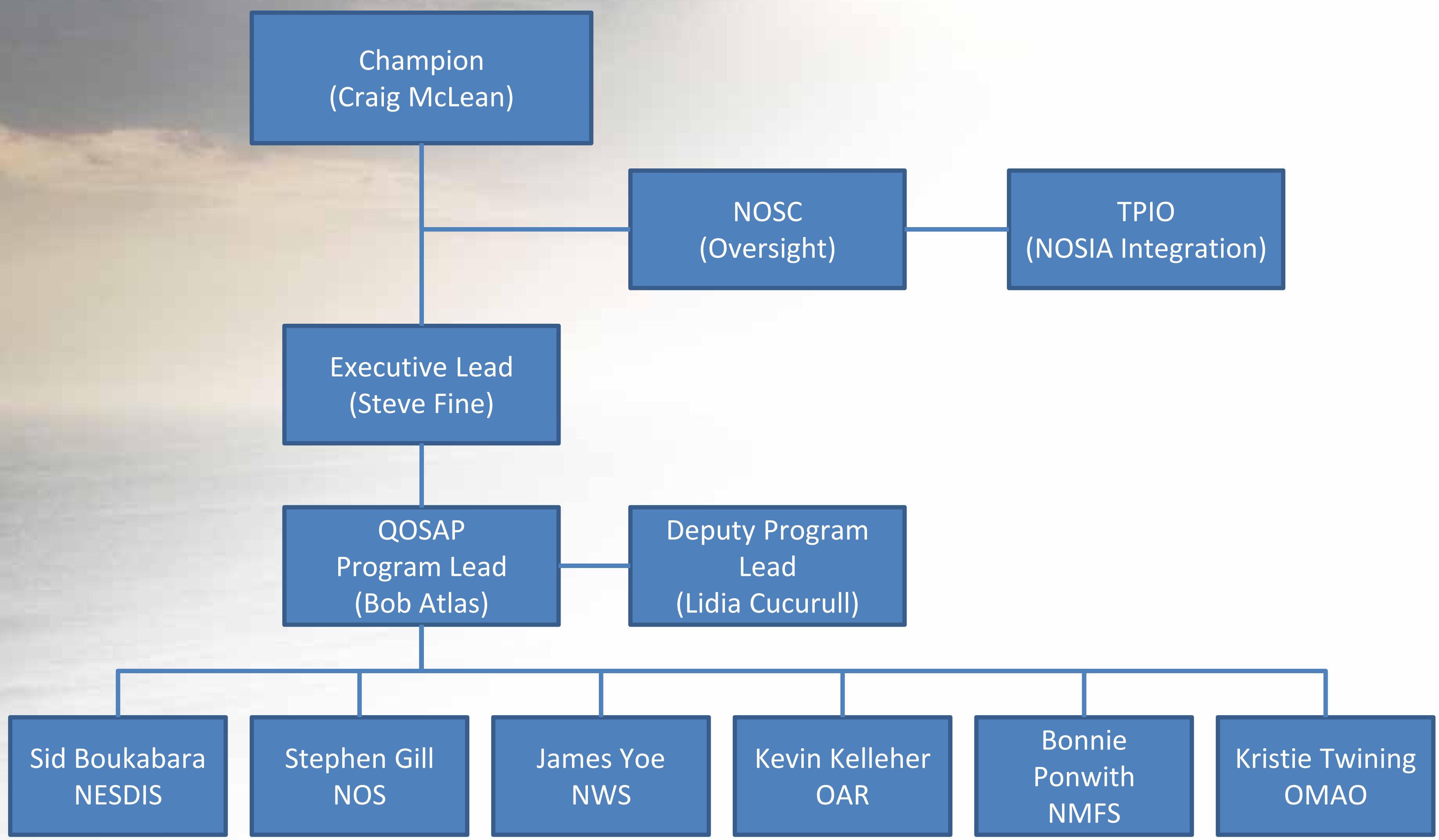
Quantitative Observing System Assessment Program (QOSAP)



Craig McLean and Robert Atlas
Office of Oceanic and Atmospheric Research

QOSAP's Multi - LO Governance



Toward Effective Impact Assessment

Development and use of methodologies for quantitative assessment of the actual value of observing systems.

Observing System Experiments (OSE), ***Observing System Simulation Experiments (OSSE)***, and ***Forecast Sensitivity to Observations Impacts (FSOI)*** provide quantitative and objective assessment, analysis and evaluation of observation system impacts and trade-offs as well as improve the overall impact of individual observing systems. (adapted from McLean & Atlas)

OSE and OSSE (adapted from McLean and Atlas)

- **Observing system experiment (OSEs):** An OSE focuses on identifying the impact of a ***current*** observing system on data assimilation and numerical weather prediction while testing ways to improve the quality and usefulness of data products.
- **Observing system simulation experiment (OSSEs):** An OSSE is a type of observing system experiment that assesses the potential impact of ***proposed/future*** observing systems on numerical weather, ocean, and climate prediction of assimilating observations from proposed/future observing systems.
  - Trade-offs in instrument or orbital configurations and methods of assimilating a new type of observing system can be determined by an OSSE and ultimately result in both time and cost savings.
  - Data impact experiments can identify an optimal configuration for a future observing network and help recognize weaknesses in the processing or assimilation of the observations.

The same data assimilation systems, models, and diagnostic tools used for performing OSEs are also used for OSSEs.

One OSE Design:What Satellite Data?

(Boukabara, Garrett, Kumar, 2015)

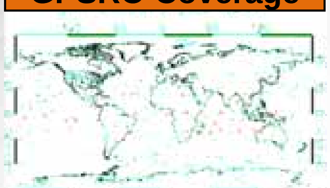
3PGPS

Remove quasi-redundant satellite data.

Remove GPSRO data with no future mission or uncertain.

Polar Coverage

GPSRO Coverage

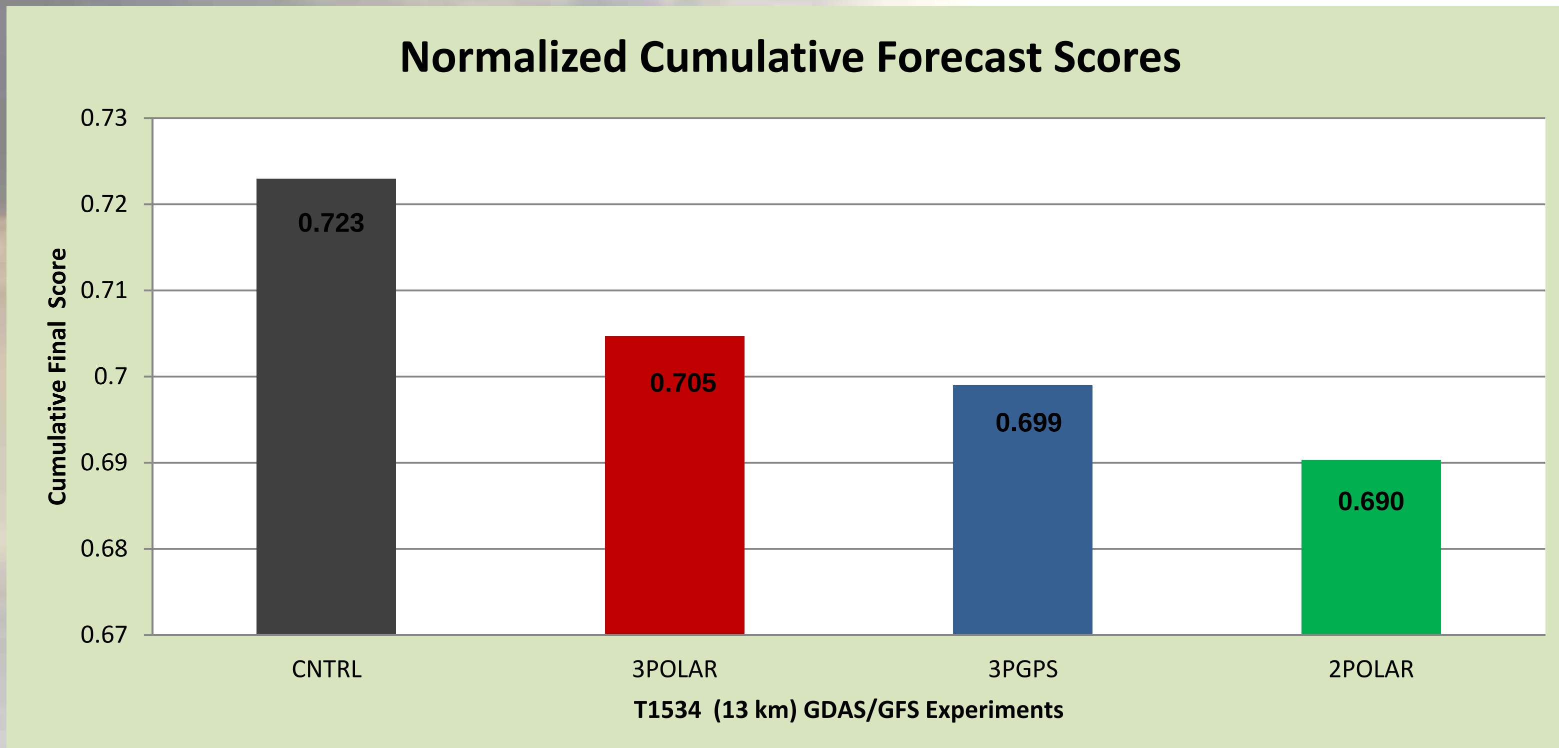


Current Operational	Type	Orbit	3polar	2polar (PM Gap)	3pgps (Expected RO)
F16 (SSMI/S)	MW	Early-AM			
F17 (SSMI/S)	MW	Early-AM			
F18 (SSMI/S)	MW	Early-AM			
N15 (AMSU)	MW	Late PM			
N18 (AMSU/MHS)	MW	PM			
N19 (AMSU/MHS)	MW	PM			
SNPP (ATMS/CrIS)	MW/IR	PM			
Metop-A (AMSU/MHS/IASI/HIRS)	MW/IR	Mid-AM			
Metop-B (AMSU/MHS/IASI)	MW/IR	Mid-AM			
Aqua MODIS IR Winds	IR	PM			
Aqua AIRS	IR	PM			
Aqua MODIS WV Winds	IR	PM			
Terra MODIS IR/WV Winds	IR	AM			
WindSat		Early-AM			
GOES Sounder, AMVs	IR	GEO			
JMA AMVs	IR	GEO			
METEOSAT AMVs	IR	GEO			
COSMIC	RO	n/a			
Metop-A (GRAS)	RO	n/a			
Metop-B (GRAS)	RO	n/a			
TerraSAR-X	RO	n/a			
GRACE	RO	n/a			
C/NOFS	RO	n/a			
SAC-D	RO	n/a			

**MODIS IR winds are a proxy for SNPP VIIRS*

Assimilated | Denied

Tier 1: Cumulative Forecast Score
Reference: CNTRL Analysis



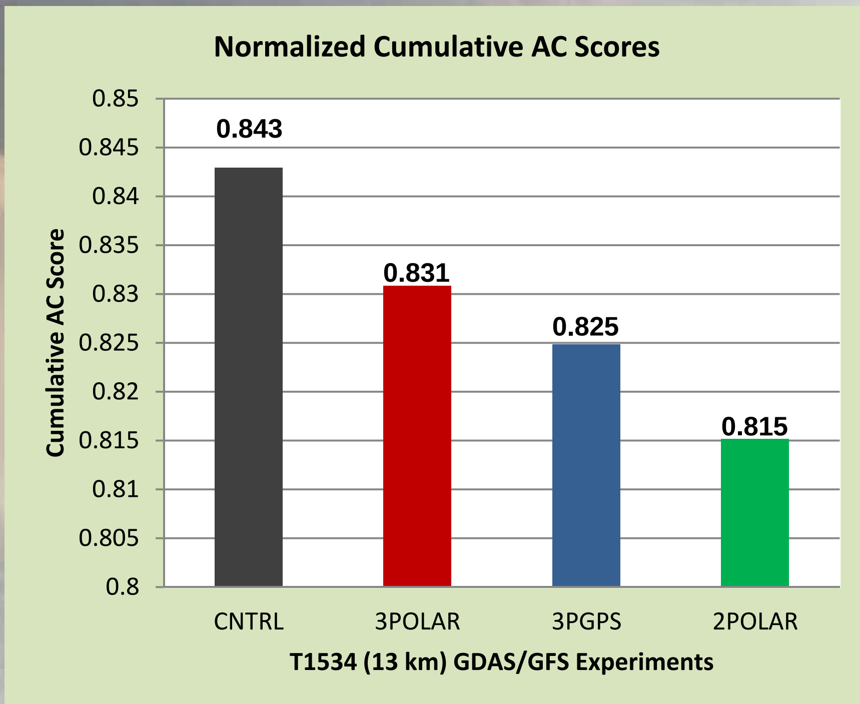
Cumulative Forecast Scores

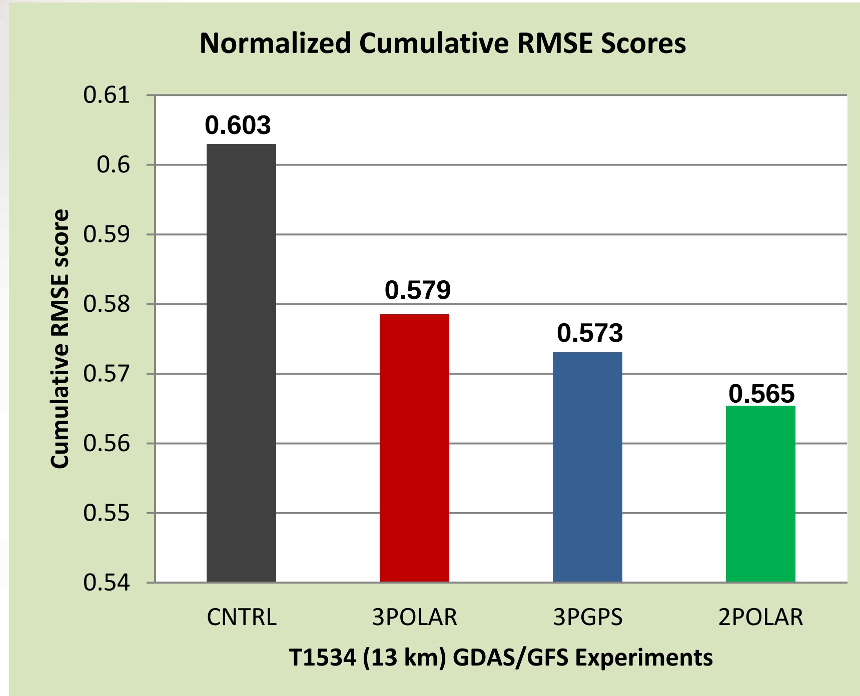
1). The loss of a quasi-redundant polar satellite constellation results in a significant degradation of overall forecast quality.

2). The further loss of the Primary PM polar orbit data further degrades forecast quality

3). The altered GPSRO coverage in 3POLAR configuration shows minor degradation

Tier 1: Cumulative Forecast Score
Reference: CNTRL Analysis





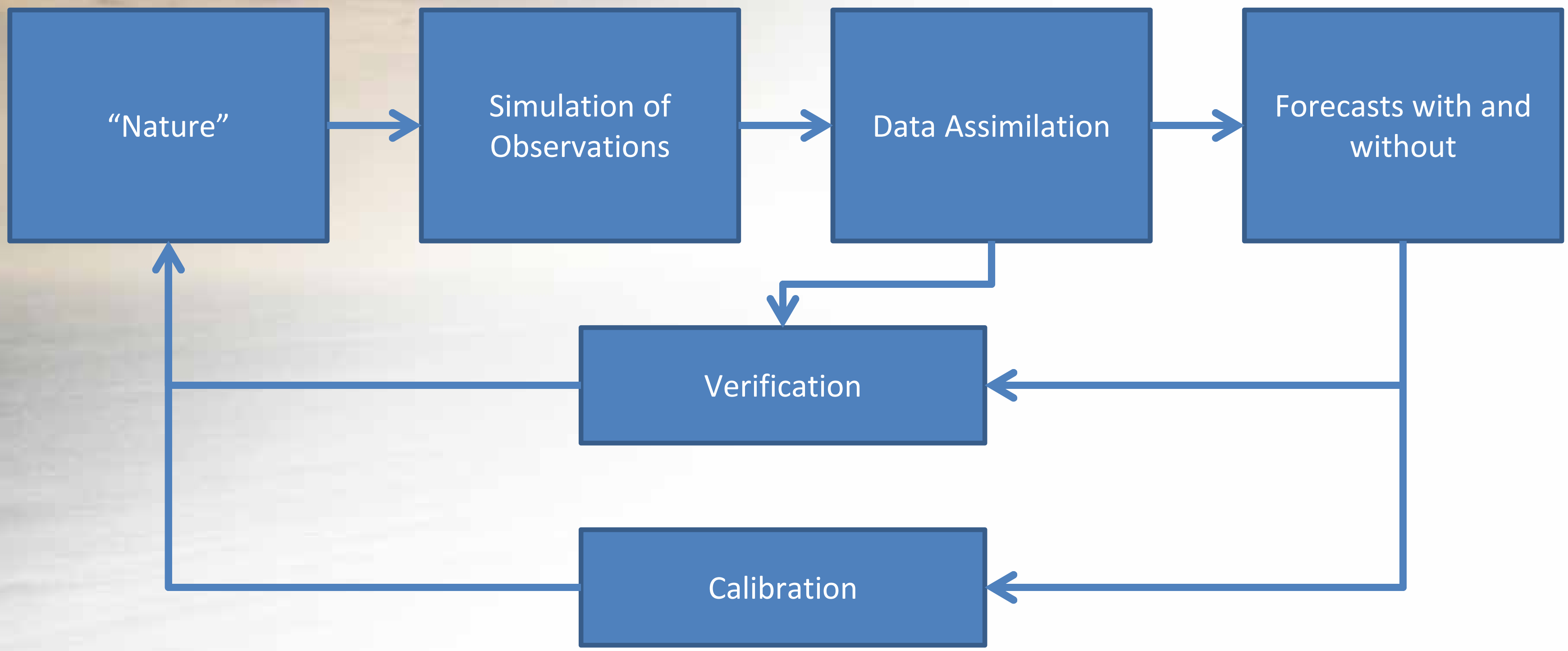
Cumulative Anomaly Correlation Scores

- **3POLAR – Removal of quasi-redundant polar data results in reduction of C_{AC}**
- **3PGPS – Removal of quasi-redundant polar data plus additional loss of polar GPSRO further degrades C_{AC}**
- **2POLAR - Removal of quasi-redundant polar data plus additional loss of PM polar data results in more significant degradation of C_{AC} than loss of GPSRO**

Cumulative RMSE Scores

- **3POLAR – Removal of quasi-redundant polar data results in significant reduction of C_{RMSE}**
- **3PGPS – Removal of quasi-redundant polar data plus additional loss of polar GPSRO has small impact on C_{RMSE}**
- **2POLAR - Removal of quasi-redundant polar data plus additional loss of PM polar data results in more significant degradation of C_{RMSE} than loss of GPSRO**

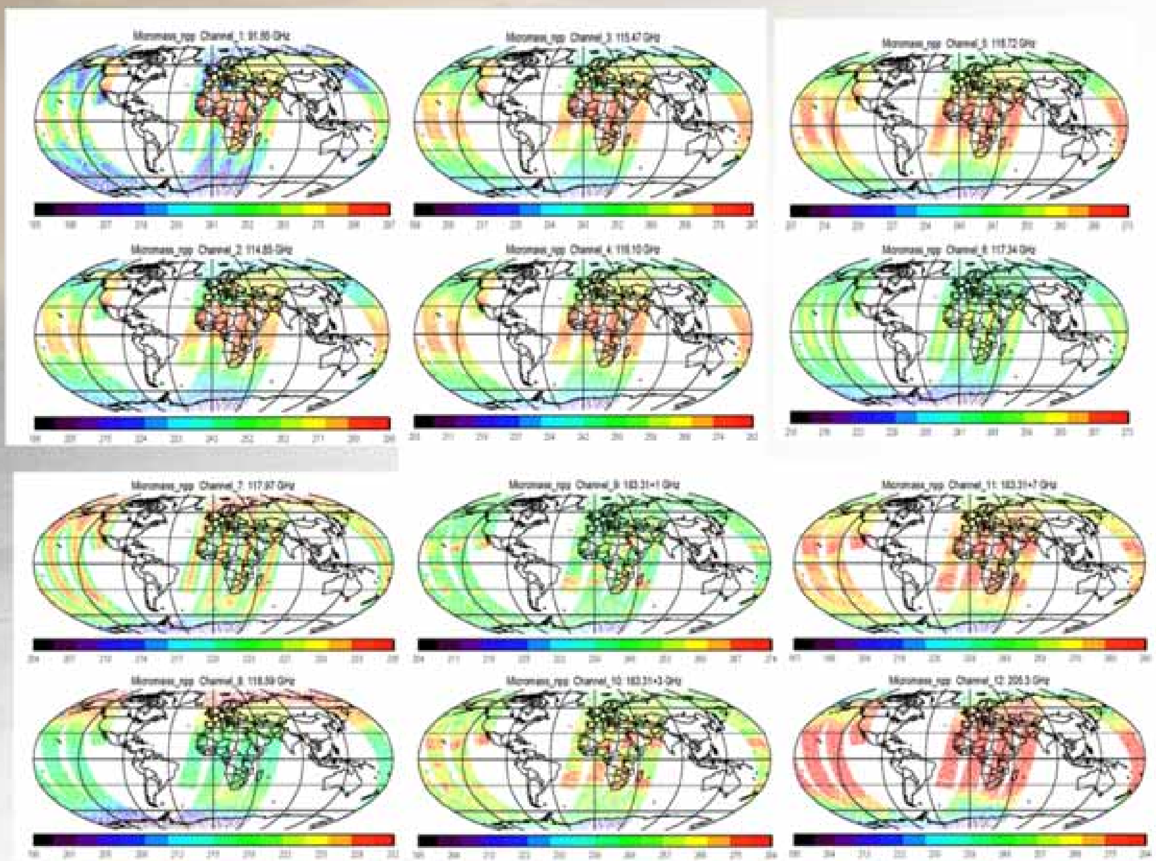
OSSE Schema (adapted from McLean and Atlas)



View Nature Run Simulation

Simulation of MicroMas Observations

- Mircomas-2 observations were simulated from NR using CRTM
- The orbit and angle is the same as the S-NPP orbit (just one orbit)
- The maps show the simulated observations for each channel of MicroMas for 1 cycle at the first day of the NR (Boukabara et al, 2016)

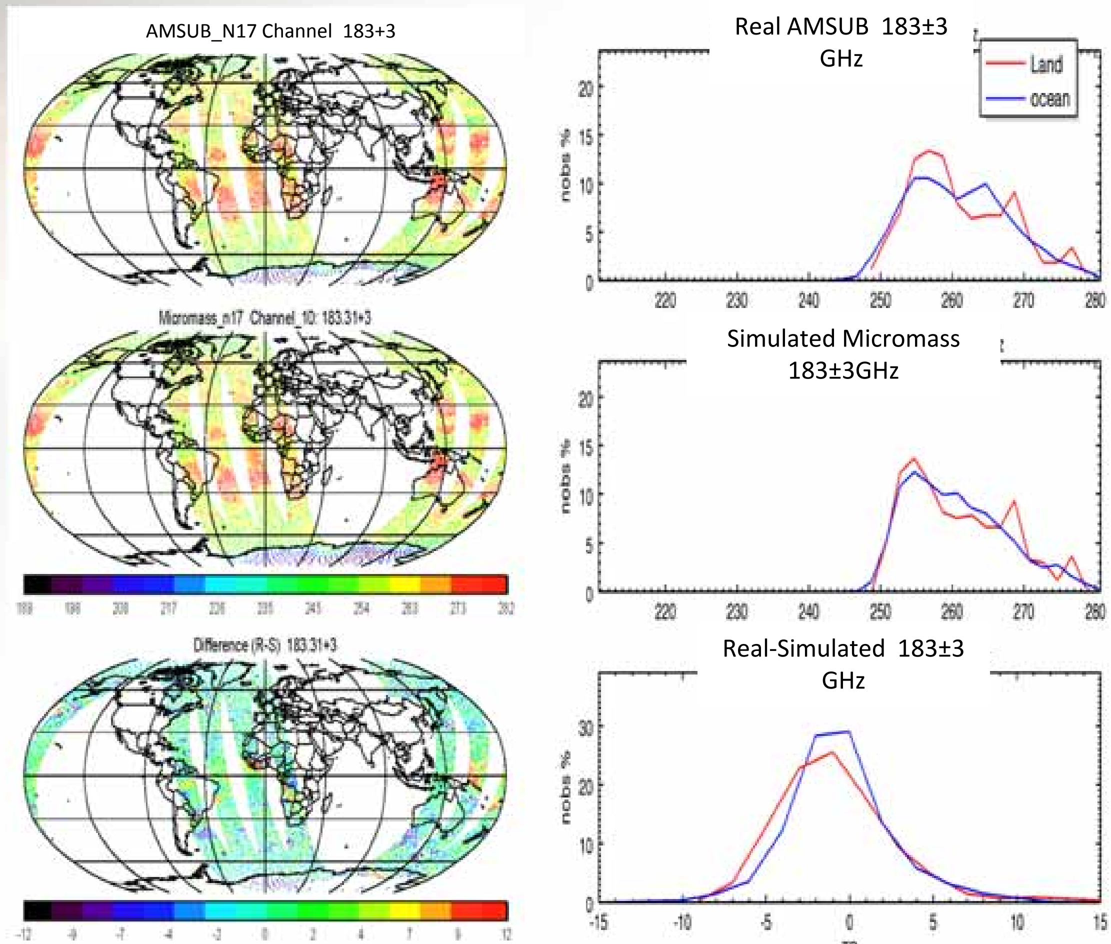


MicroMas Channels	Frequency (GHz)
1	91.65
2	114.85
3	115.47
4	116.10
5	116.72
6	117.34
7	117.97
8	118.59
9	183.31±1
10	183.31±3
11	183.31±7
12	205.3

Validation of MicroMas observations

- ➢Simulated MicroMas observations were validated against the real observations of the same frequency.
- ➢Comparing simulated MicroMas at 183±3 GHz with real AMSUB at 183±3 maps and histograms (clear sky)
- ➢For channel 1,9,10, and 11 this method was used. Channel 10 is shown as an example

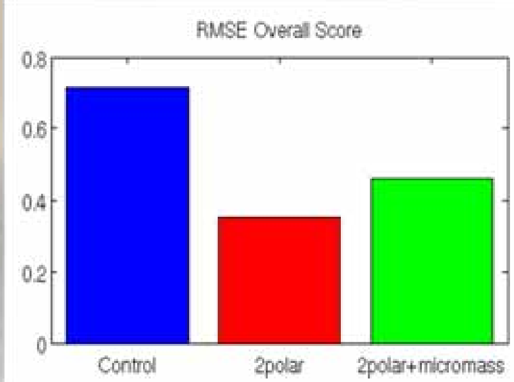
Boukabara et al, 2016 – NESDIS/SSTAR and CICS

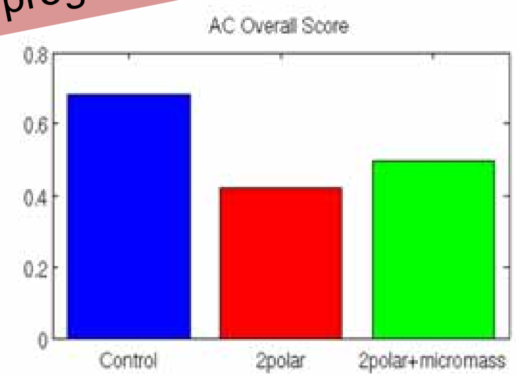


Analysis Impact of MicroMas Observations

MicroMass			
	RMSE	**AC**	**Overall**
Control	*0.716*	*0.682*	*0.699*
2Polar	*0.352*	*0.419*	*0.385*
2Polar+MicroMas	*0.461*	*0.496*	*0.479*
Control+ MicroMas			

In progress





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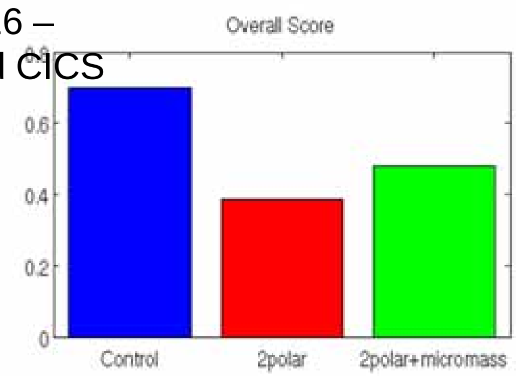
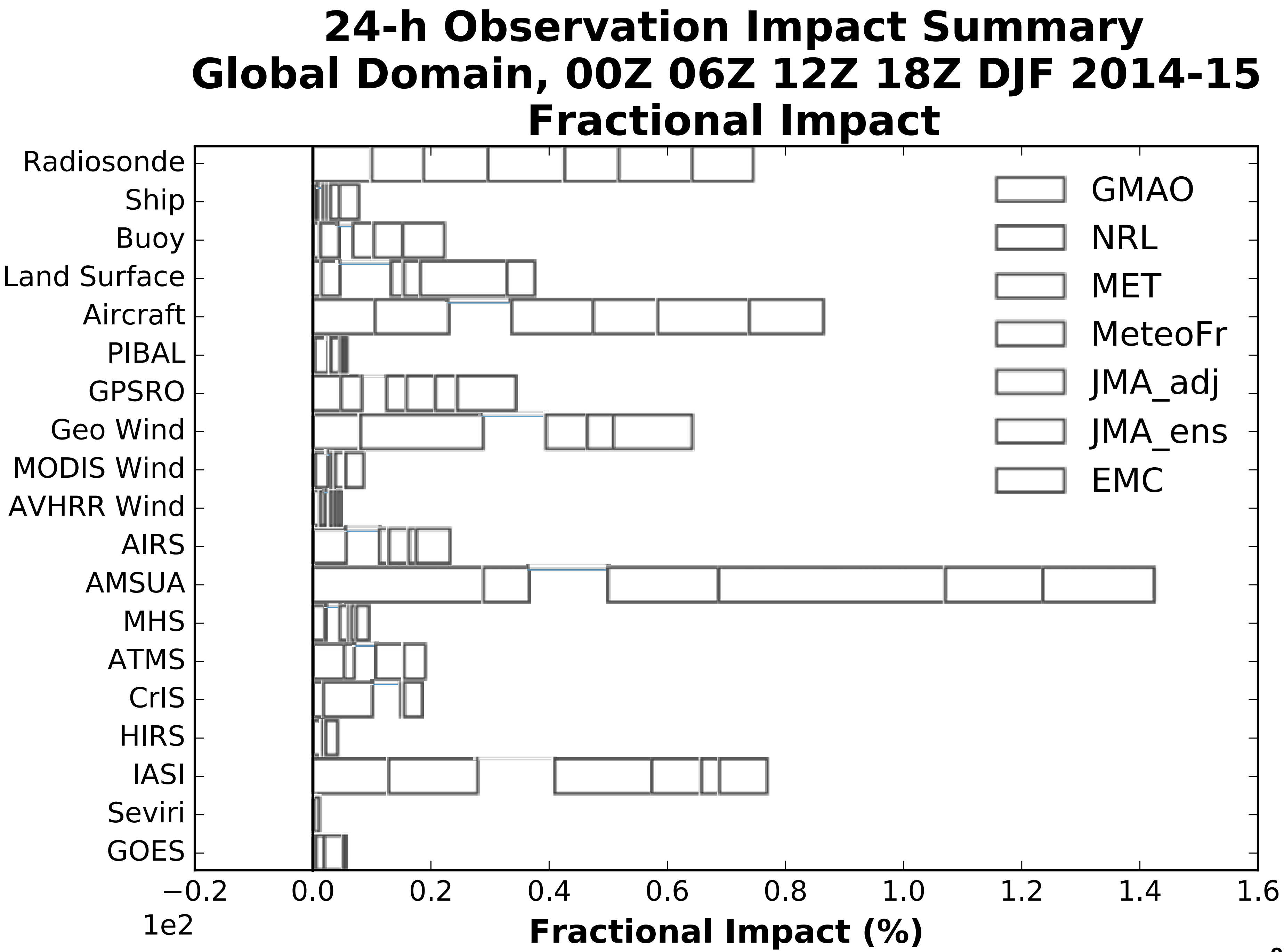


1) Cntrl: all operationally assimilated satellites and conventional observations ,
2) 2Polar assimilates only the early- and mid-AM satellites and the PM coverage are removed)
3) MicroMAS run, which adds the MicroMAS observations on the 2Polar run.

➢Overall analysis score (OAS): The normalized global overall RMSE, AC, and analysis scores.

➢They are calculated by geopotential height, temperature, vector wind, and relative humidity over different pressure levels, for the period of Aug 8th- Aug 28th, 2006.

➢The Overall Analysis Scores (OAS) of these three experiments were calculated, verified with the Nature Run. Greater OAS values refer to better agreement with the NR.


24-h Observation Impact Summary
Global Domain, 00Z 06Z 12Z 18Z DJF 2014-15
Fractional Impact
Radiosonde
Ship
Buoy
Land Surface
Aircraft
PIBAL
GPSRO
Geo Wind
MODIS Wind
AVHRR Wind
AIRS
AMSUA
MHS
ATMS
CrIS
HIRS
IASI
Seviri
GOES
GMAO
NRL
MET
MeteoFr
JMA_adj
JMA_ens
EMC
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1e2
Fractional Impact (%)

Observation Priorities (NWP)

- Imagery
- Vertical Sounding
  - Infer T, q; satellite sources include MW, IR, GNSSRO sounding
- 3-D Wind Profiles
- Ocean Surface Wind Vectors
- Sea-surface height and temperature
- Lightning
- Ozone profile/column
- Surface properties (ice, snow, soil moisture)
- Precipitation phase/rate, etc.
- Atmospheric composition
- Incoming/outgoing radiation

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A Point for Discussion

- Remember – Multiple Components to NWP Skill
  - Observations
  - Super-computing
  - Modeling and Data Assimilation Science/Technology
  - Trained Workforce

  - Have to advance all components harmoniously.

Model Drivers for Observations

- Quality – Accuracy, stability, etc.
- Scale of Coverage
  - Global has driven satellite-based solutions (and will)
- Resolution
  - Horizontal (observation size/FOV and observation spacing)
  - Vertical
  - Temporal
- Phenomenology
  - Processes – for example, convection

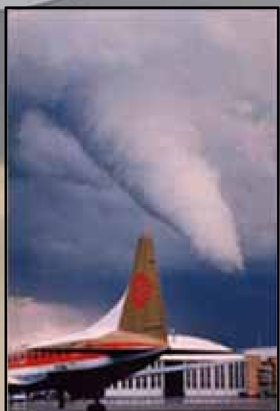
Other Drivers for Observations

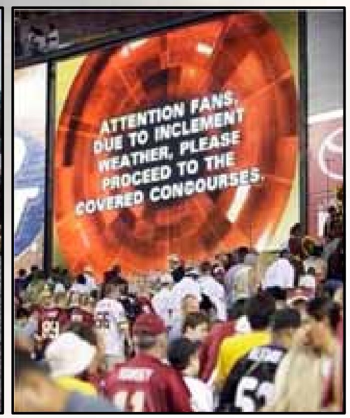
- Reliability
- Timeliness and Latency
- Characterization and Documentation
  - Established, known cal/val, algorithm and results

One Point: Drivers Are Agnostic

- Technology
  - Multiple T-, q- sensitive instrument approaches
- Source
  - USGA
  - Research versus Operational
  - International
  - Private/Commercial
    - Consider NOAA’s Commercial Weather Data Pilot Project

Another Point: The Job Doesn't End with Forecasts and Warnings





"First, it should be understood that forecasts possess no intrinsic value. They acquire value through their ability to influence the decisions made by users of the forecasts."

"What is a Good Forecast? An Essay on the Nature of Goodness in Weather Forecasting"

– by Allan H. Murphy; Weather and Forecasting (June 1993)

Increasing Societal Vulnerability to Environmental Hazards

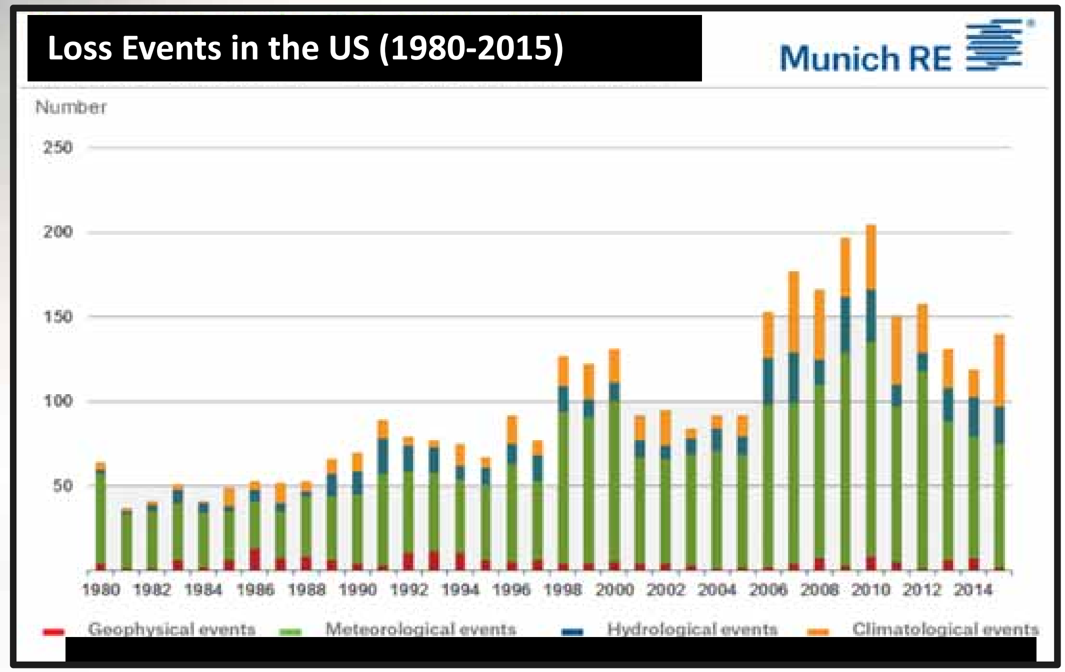
Average Year

26,000 Severe Storms

6 Atlantic Hurricanes

1,300 Tornadoes

5,000 Floods



4 out of 5 Americans live in counties that have been declared weather-related disaster areas in the past six years*

Factors contributing to increased risk

- ✓ **Increasing population**
- ✓ **Increasing vulnerability**
- ✓ **More infrastructure at risk**
- ✓ **Signs of climate change**

*Source: Environment America

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NWS Strategic Outcome:
A Weather- and Water-Ready Nation

"Ready, Responsive, Resilient"

Becoming a Weather-Ready Nation is about **building community resiliency in the face of increasing vulnerability** to extreme weather, water and climate events

Better forecasts and warnings

Consistent products and services

Actionable environmental intelligence

Connecting forecasts to decisions

Involves the entire US Weather, Water and Climate Enterprise WORKING TOGETHER

We have 3400 WRN Ambassadors

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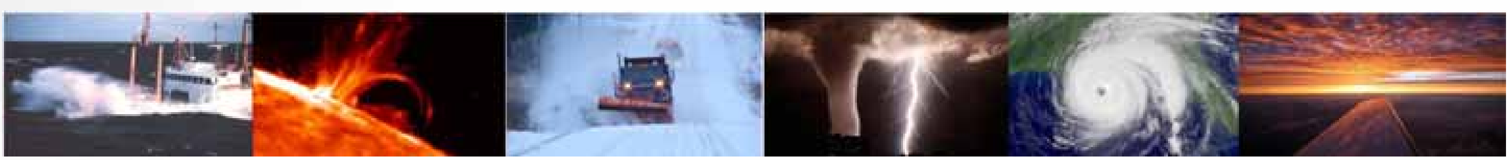
Summary Remarks

- We're building a Weather Ready Nation to mitigate our growing vulnerability to high-impact weather.
- Satellite data remains critically important to the forecast and warning mission of the NWS and to the global weather enterprise.
- Distinctions between LEO & GEO, Operational, Research, International, & Commercial sources are blurring, and leading to new challenges and opportunities for transitioning from research to operations.



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Additional Considerations

- Whole Atmosphere Modeling
- Space Weather Prediction – and observations