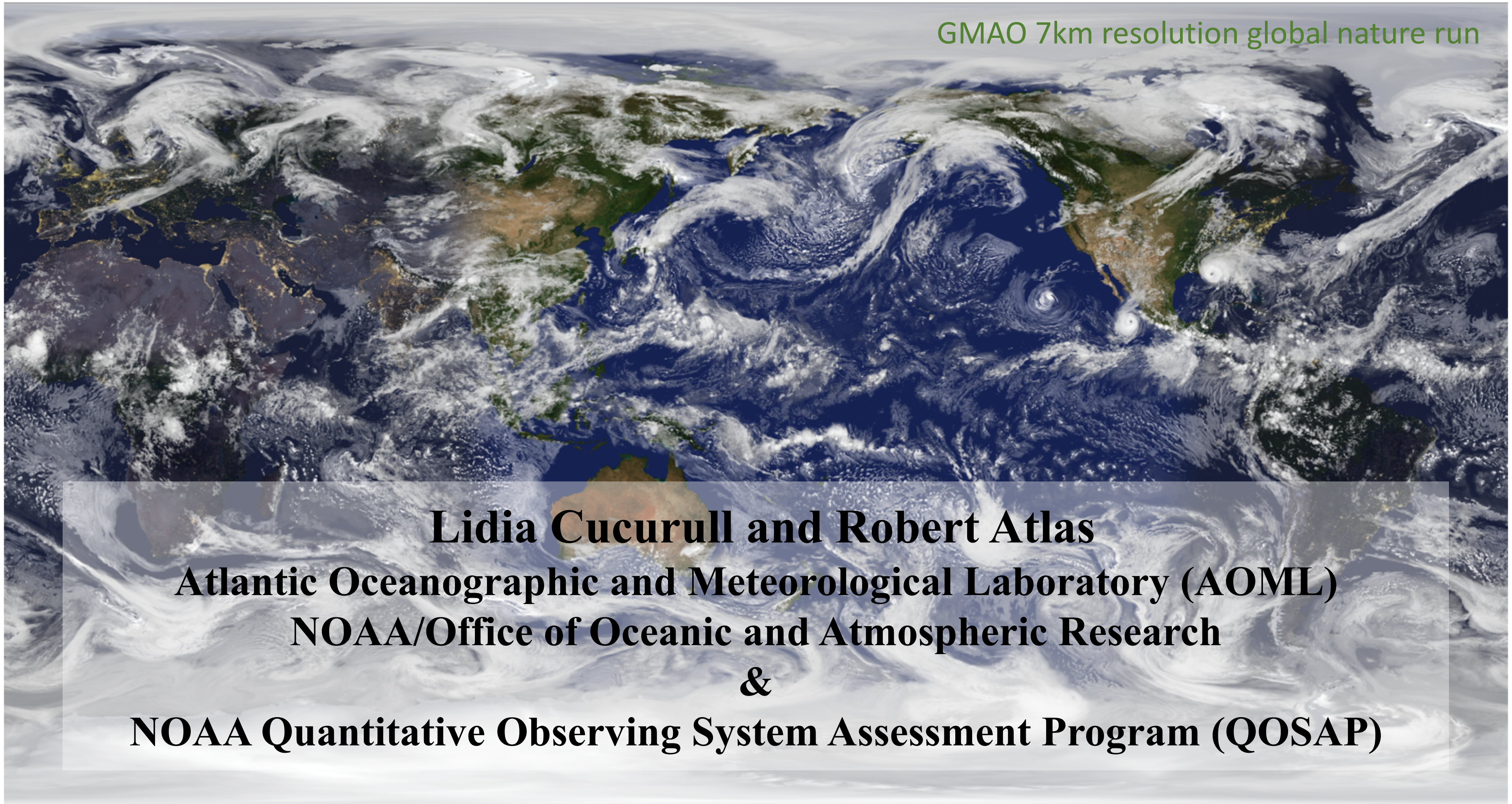
Quantitative assessment of impact of current and new observing technologies



Lidia Cucurull and Robert Atlas

Atlantic Oceanographic and Meteorological Laboratory (AOML)

NOAA/Office of Oceanic and Atmospheric Research

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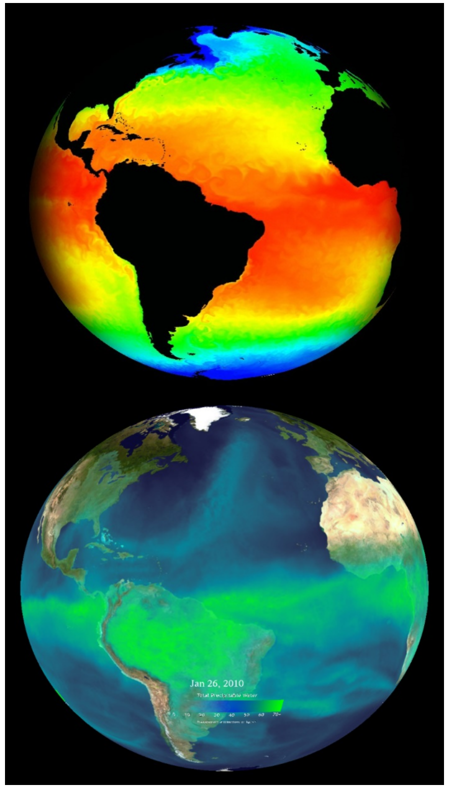
NOAA Quantitative Observing System Assessment Program (QOSAP)

Primary Objectives

QOSAP's primary objective is to improve quantitative and objective assessment capabilities to evaluate operational and future observation system impacts and trade-offs to assess and to prioritize NOAA's observing system architecture.

- Increase NOAA's capacity to conduct quantitative observing system assessments.
- Develop and use appropriate quantitative assessment methodologies.
- Inform major decisions on the design and implementation of optimal composite observing systems.



QOSAP functions

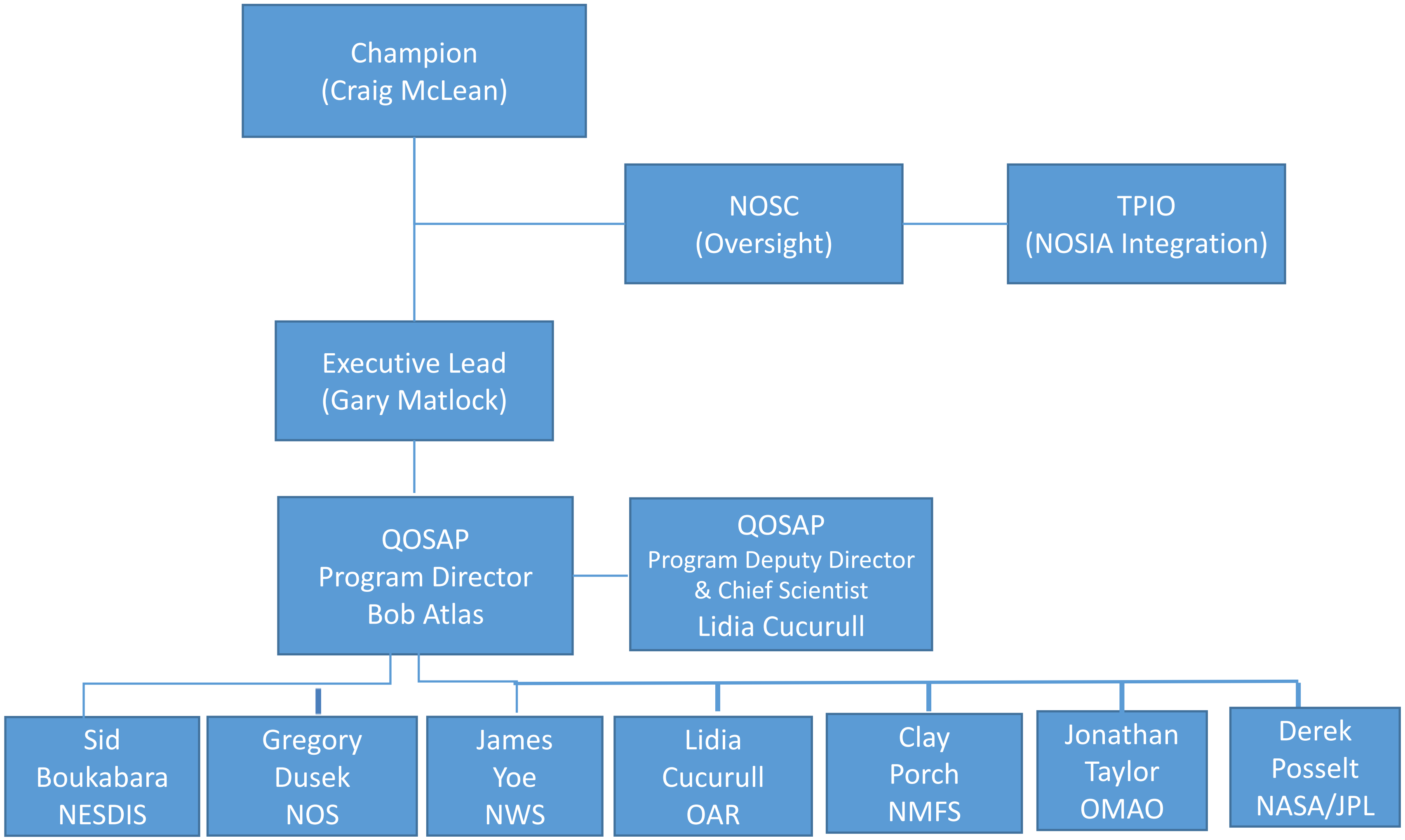
- QOSAP coordinates the assessment of the impact of current and new observations across the different NOAA Line Offices.

- QOSAP uses observing system experiments (OSEs), observing system simulation experiments (OSSEs) and ensemble/forecast sensitivity observations impact (EFSOI/FSOI) as effective techniques to evaluate the impact of the different observation types.

- These studies can help NOAA management prioritize mission designs in a cost-effective way by analyzing tradeoffs in the design of proposed observing systems.

- **Maintain OSSE and OSE inventory up to date in NOAA google drive (hyperlink above).**

QOSAP Organization Chart



Prioritization Schema

For each proposed assessment topic/question we answer:

Question 1: Is there a pressing need for the assessment to be executed in FY? [Yes/No]

Question 2: Does NOAA currently have the capabilities in place to execute the assessment in FY? [Yes/No]

Question 3: Are there existing resources available in FY for the assessment? [Yes/No] Estimate the amount needed/or additional above existing $ [$k]

Question 4: Can the assessment be completed in FY? [Yes/No]

Question 5: Potential value to NOAA and partners? [High, Medium, Low]

Coordination with the NOSC on additional guidance for performing, documenting and reporting quantitative assessments

Motivation for performing OSSEs

- Costs of developing, maintaining & using new space-based observing systems typically exceed $100-500 M/instrument
- Significant time lags between instrument deployment and eventual operational NWP use
- OSSEs can provide quantitative information on observing system impacts
  - New instruments
  - Alternative mix of current instruments
  - Data assimilation system diagnosis and improvement
- Information from OSSEs can lead to better planning and decisions

Objectives of an OSSE

1. To provide a QUANTITATIVE assessment of the potential impact of proposed observing systems on earth system science, data assimilation, and numerical prediction.

2. To evaluate and/or develop new methodology for the processing and assimilation of new types of data. (This enables improved and more rapid operational use of new observing systems).

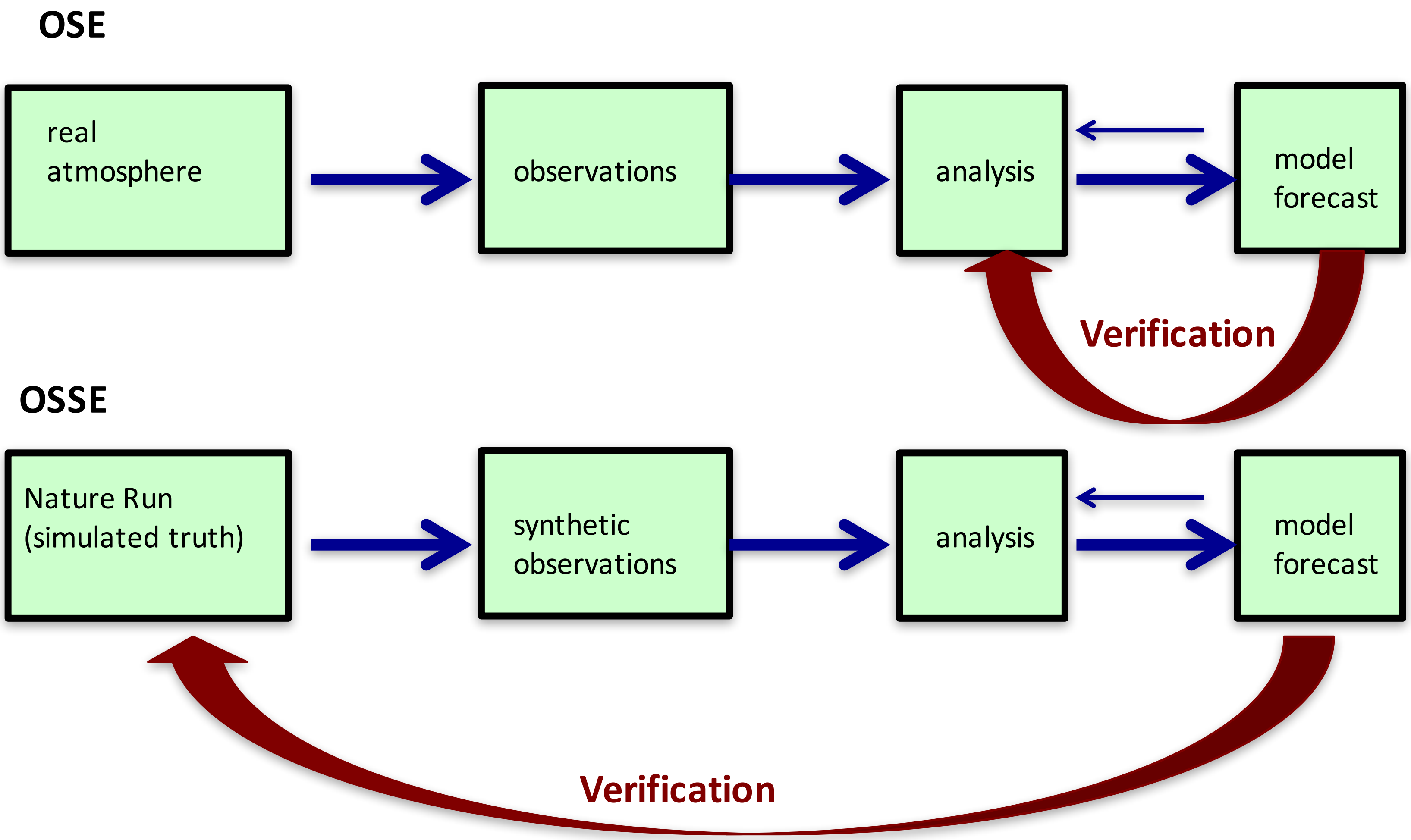
3. To evaluate tradeoffs in the design and configuration of proposed observing systems (e.g. coverage, resolution, accuracy and data redundancy).

4. To optimize the global observing system for weather and climate, as well as other applications.

Basic Concepts

- In OSSEs
  - **"Nature Run" is proxy for Real Nature**
    - Free run of a forecast model
      - Realistic phenomenology and variability vs. Nature
    - As independent as possible from Data Assimilation system used in the assessment experiments
      - Correlated biases introduce optimism
      - Construction of observations from Nature Run should also be independent
  - **Truth is known**
    - Verification vs truth can reveal characteristics of the data assimilation system
  - **Simulated observations should be as realistic as possible**
    - Exhibit same system impact as real observations
    - Contain same kinds of errors as real observations (e.g. representativeness)
  - **New observations can be simulated**

- For application to advanced observing systems
  - Data Assimilation system should be leading edge but well tested
  - OSSEs should be run periodically leading up to deployment of new instruments


OSE
real
atmosphere
observations
analysis
model
forecast
Verification
OSSE
Nature Run
(simulated truth)
synthetic
observations
analysis
model
forecast
Verification

Key Aspects of a credible OSSE

1. Will the study be completed in time to be useful?

2. Is the Nature Run (NR) and the difference between the NR and forecast models realistic?

3. Are the coverages and error characteristics of simulated observations realistic?

4. Are the forecast accuracy and impacts of existing observing systems in the OSSE comparable to the real world?

5. Have the limitations of the OSSE system been determined? (*Conclusions should not be drawn that go beyond these limitations*.)

Current Status of OSSEs in NOAA

- Numerous OSSEs have been performed using the global OSSE system based on an ECMWF T511 nature run and the regional Hurricane OSSE system developed at AOML. *(These have evaluated Geo HSS, GNSS RO, CYGNSS, TROPICS, DWL, UAS, Recon Aircraft, and others.)*

- A state of the art global OSSE system based on the NASA Cubed Sphere at 7 km resolution NR has been developed and is currently being used in multiple OSSEs to evaluate issues relating to satellite, sub-orbital, and in situ observing systems. *(These are focused right now on GNSS RO and GEO HSS.)*

- Ongoing work with a new nature run being generated by ECMWF (Cubic Octahedral Nature Run ECO1280, 9 km).

- New and expanding regional OSSE systems for high impact weather are being developed. *(This includes an advanced Hurricane OSSE System based on the basin scale version of HWRF.)*

- A state of the art ocean OSSE System has been developed and is expanding. *(OSSEs related to the role of ocean observations in hurricane prediction are being performed.)*

Recent OSSE/OSE conducted under QOSAP

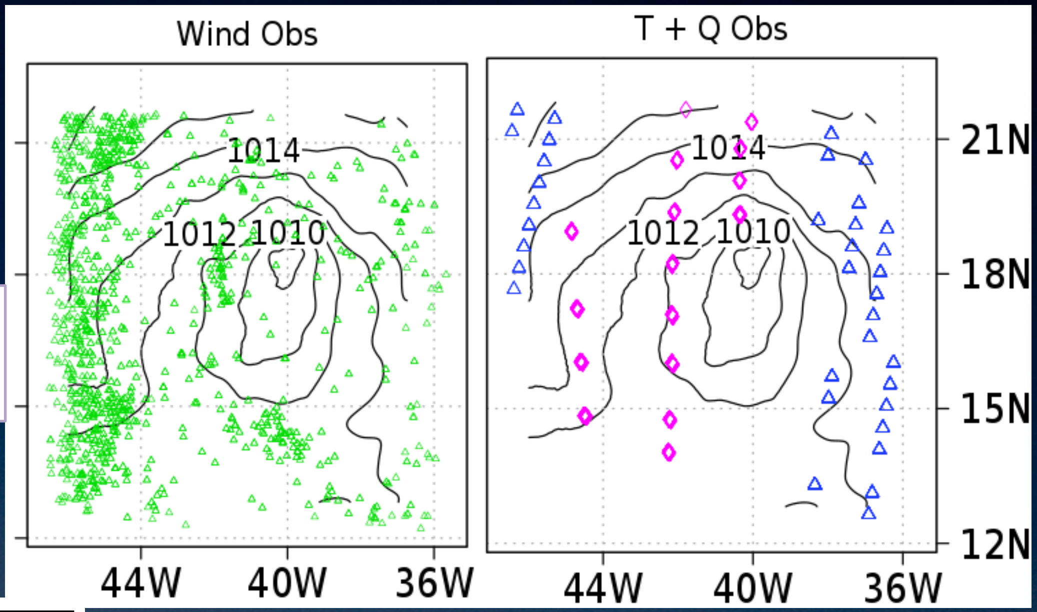
- Observing System Simulation Experiments (OSSEs) with:
  - Cyclone Global Navigation Satellite System (CYGNSS) mission.
  - Cubesats (microwave and infrared).
  - Unmanned aircraft systems (UAS) with Global Hawk and G-IV aircrafts.
  - Targeted dropsondes for Pacific mid latitude winter storms.
  - Geostationary Hyperspectral sounders (requested by U.S. Congress).
  - GNSS RO (requested by U.S. Congress).
  - GNSS RO with COSMIC-2 (requested and funded by NWS).

- Observing System Experiments (OSEs) with:
  - Wind lidar onboard the P3 aircraft.
  - Radio Occultation from COSMIC.
  - Data gap mitigation strategies.
  - Advanced assimilation algorithms for Radio Occultation observations.
  - Advanced assimilation algorithms for GOES-R lightning data.

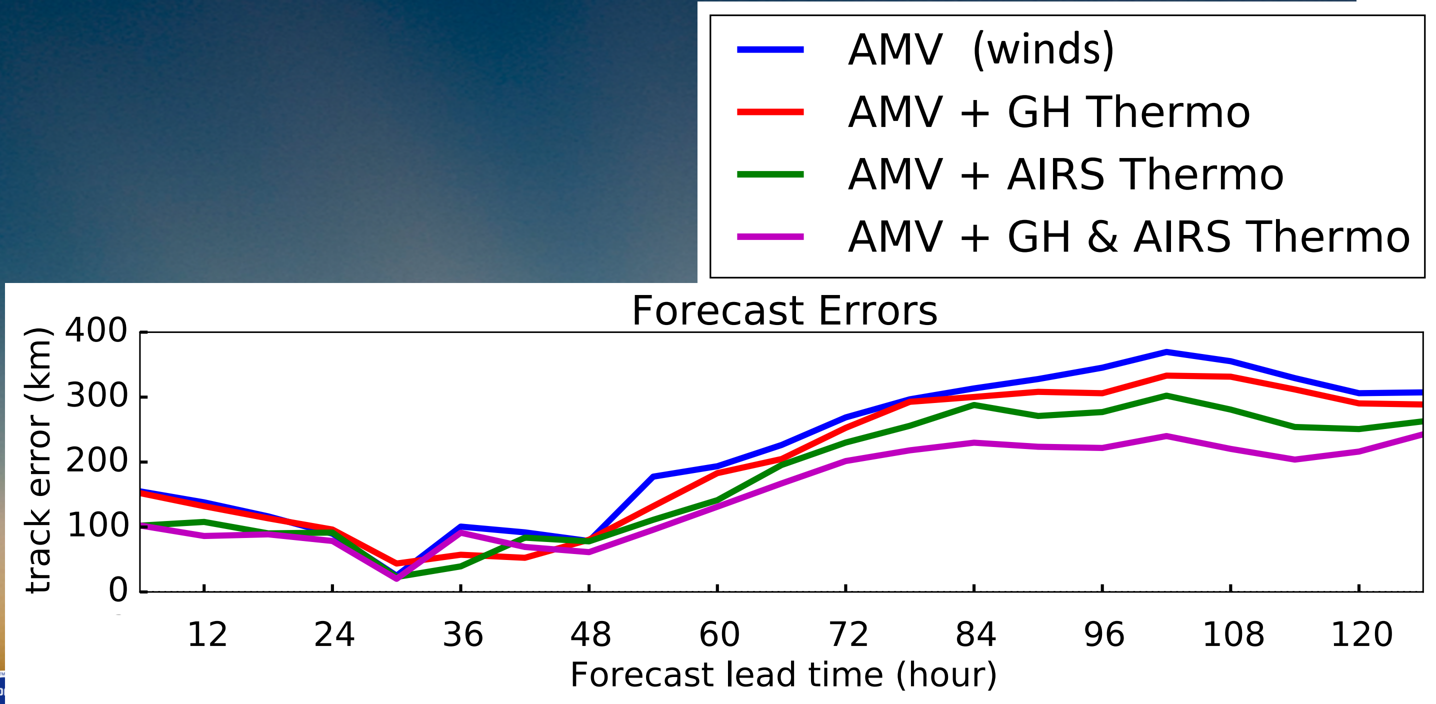
An OSE with Global Hawk

hurricanes

Hurricane Edouard (2014)



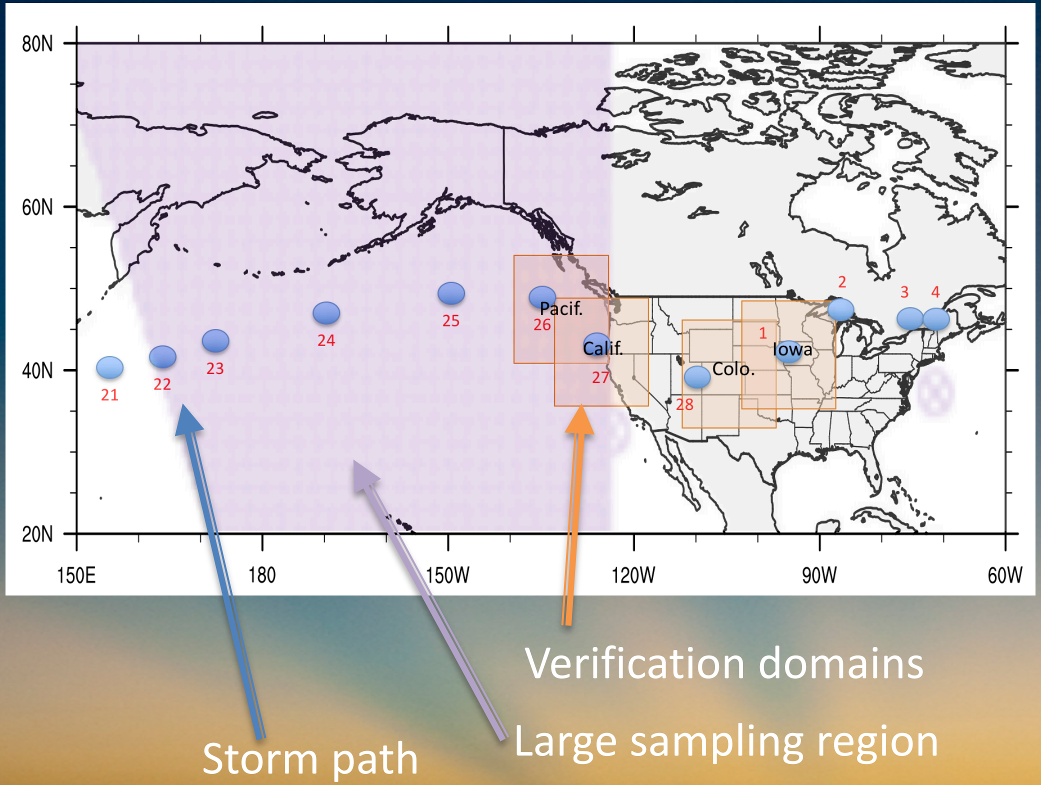
AMV wind observations
AIRS temperature & moisture observations
Global Hawk (GH) temperature & moisture observations

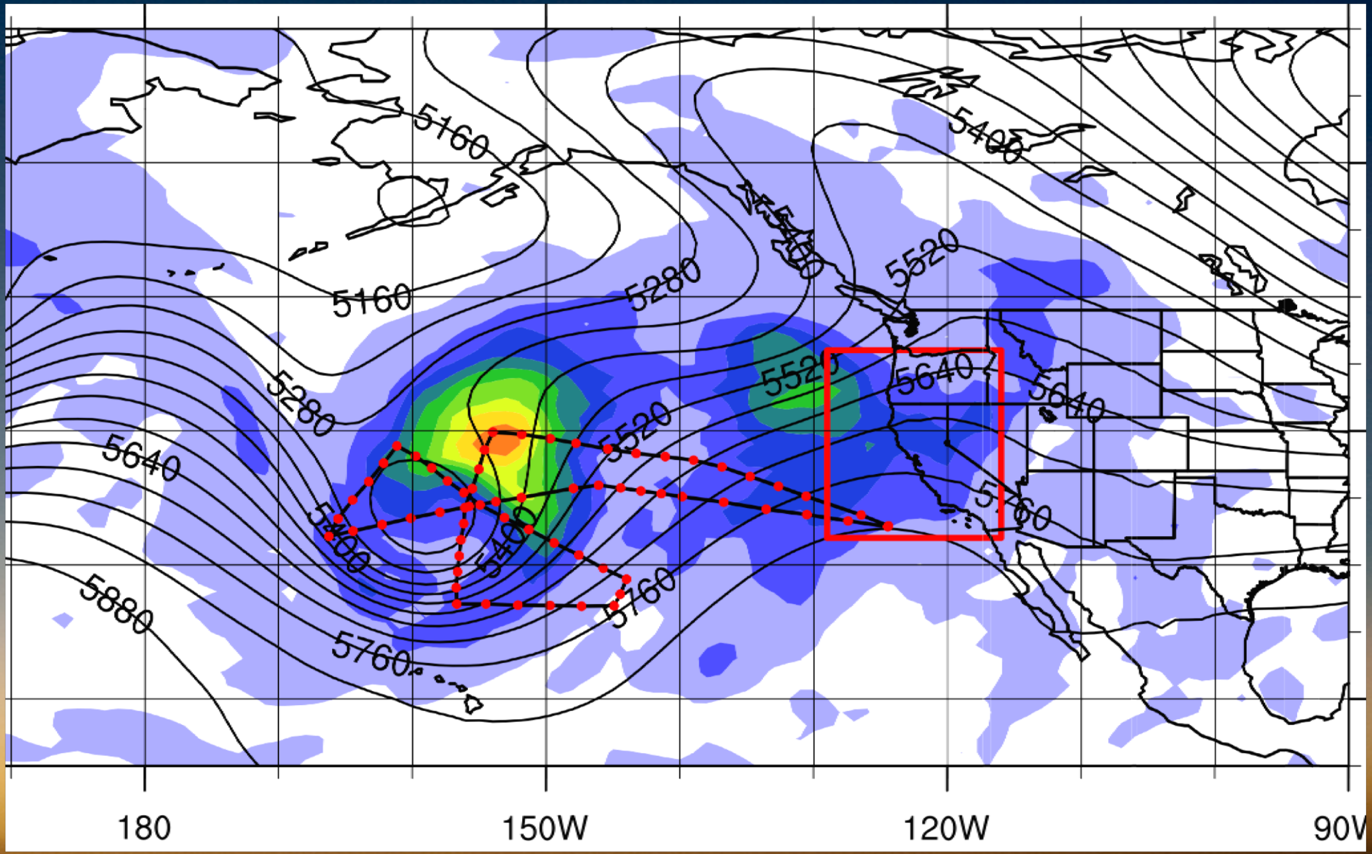


Significant reduction in hurricane track error when using Global Hawk observations in combination with satellite observations

OSSEs and OSEs with Global Hawk

high-impact weather events





Peevey et al. 2018; Kren et al. 2018

OSSE with GNSS-RO (COSMIC-2)

- QOSAP conducted comprehensive experiments with a previously existing global OSSE system to determine the potential value of RO constellations for current operational NWP. Results were extended to a newly developed OSSE system (Request from US Congress under Law HR353).
- RO (COSMIC-2) observations increased the length of the reliable forecast by 0.6 hours in the Northern Hemisphere extra-tropics (a 0.4% improvement), 5.9 hours in the Southern Hemisphere extra-tropics (a significant 4.0 % improvement) and 12.1 hours in the tropics (a very significant 28.4% improvement). [Note: improvement in the extra-tropics is reported as an increase in the forecast time to reach AC=0.8 for the 500 ha geopotential heights. Improvement in tropics is reported as an increase in the forecast time to reach RMSE= 6 m/s for the 200 hPa winds].
- **Experiment design:**
  - NASA GMAO G5NR Nature Run (non-hydrostatic, ~ 7 km, 72 vertical levels).
  - NCEP’s model configuration very similar to what was operational in 2015 (Q1FY15, Jan 2015 implementation) but at a lower resolution of T670/T254 (~ 27 km/50 km).
  - The RO observations were simulated with the geographic sampling expected from the Constellation Observing Satellites for Meteorology, Ionosphere, and Climate-2 (COSMIC-2) system, with 6 equatorial (total of ~6,000 soundings/day) and 6 polar (total of ~6,000 soundings/day) receiver satellites.
  - Quality control algorithms were modified in COSMIC-2 experiments to allow deeper penetration in the lower troposphere, according to expected performance.

OSSE with COSMIC-2

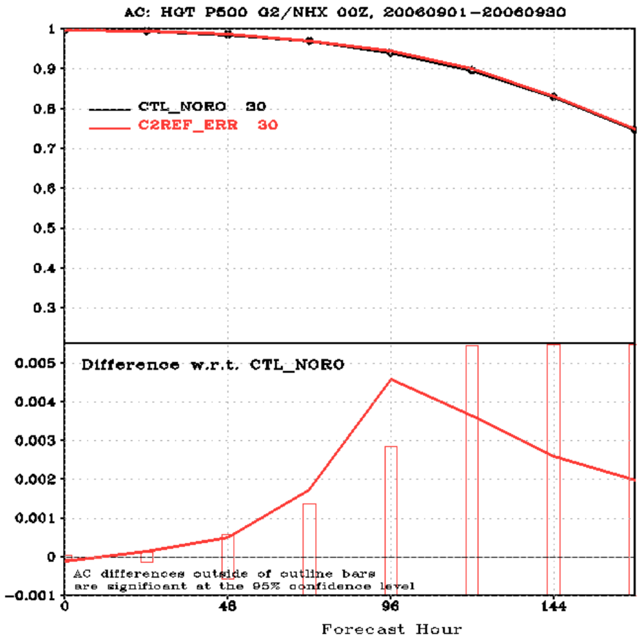
Positive impact with RO assimilation (larger in SH)

Anomaly Correlation: 500-hPa Heights

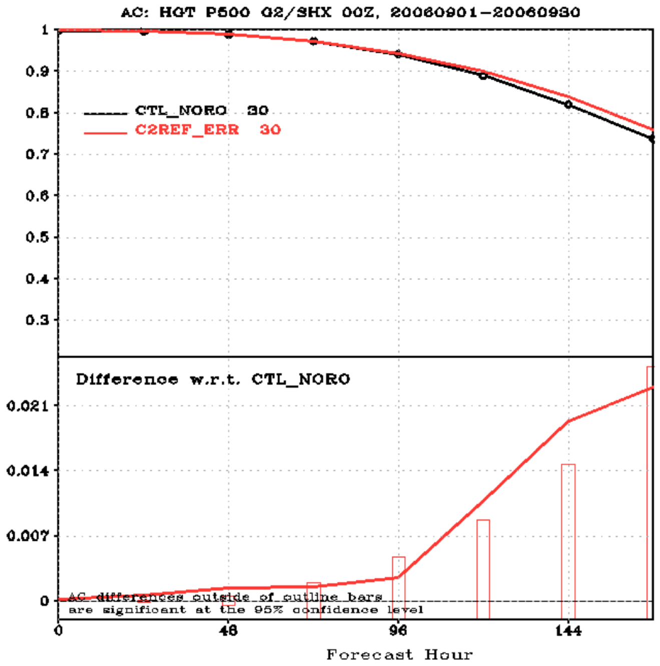
CTL_NORO: operational satellite radiances and conventional observations (no RO)

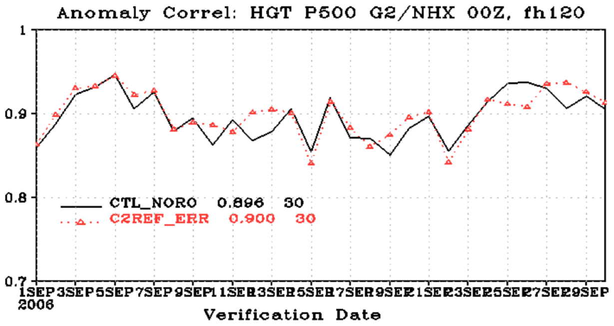
C2REF_ERR:
CTL_NORO + constellation of 12 RO satellites (COSMIC-2 orbit configuration)

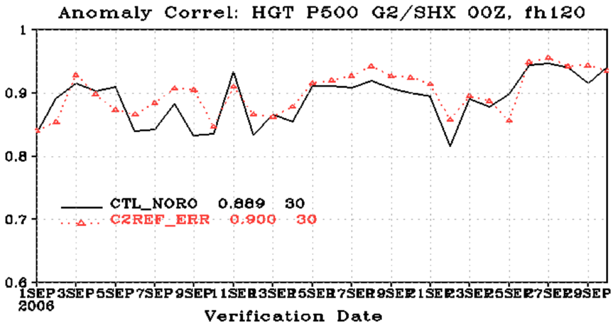
NHX (20N – 80N)



SHX (20S – 80S)





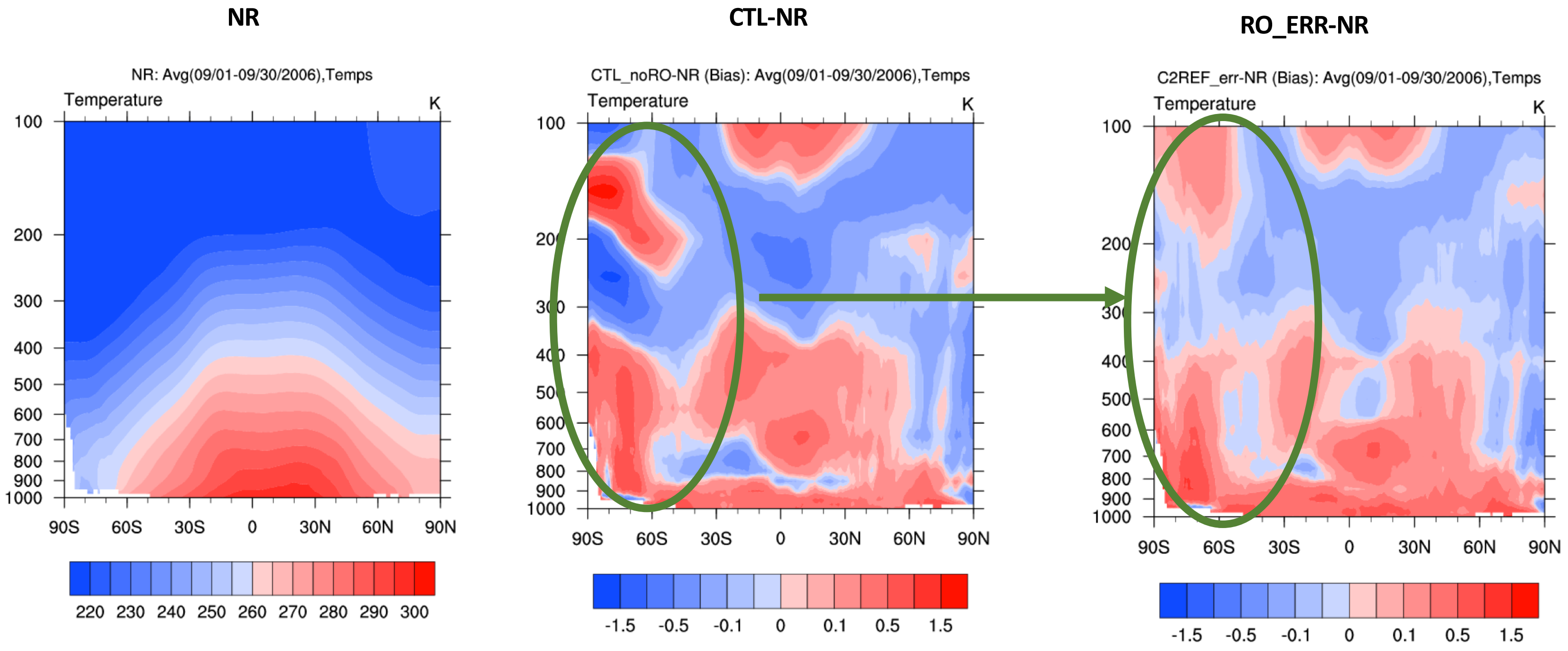


Cucurull et al. 2018, MWR (in review)

OSSE with COSMIC-2

Vertical Cross-Section: Temperature

Reduction of analysis bias with RO assimilation



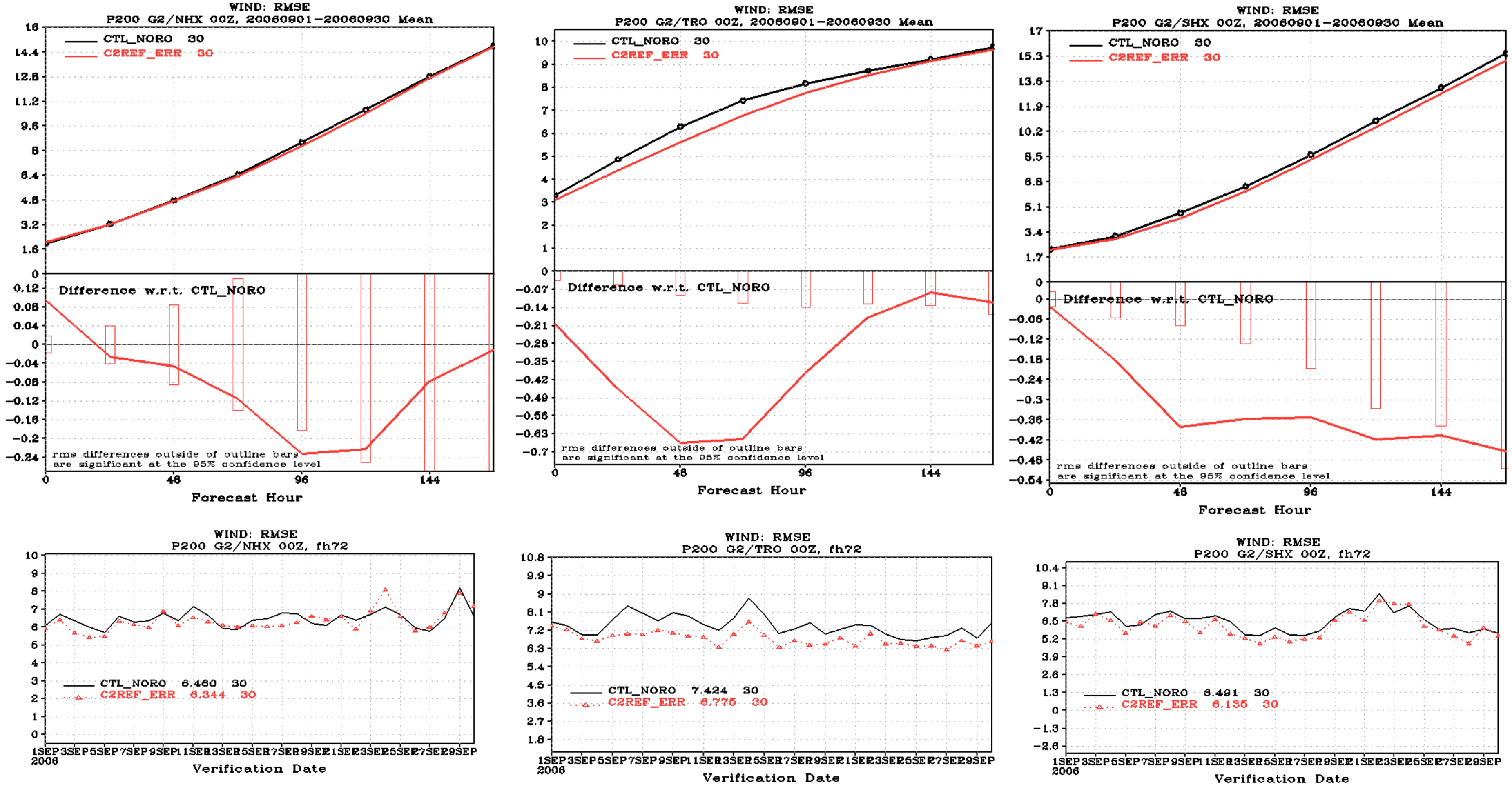
Cucurull et al. 2018, MWR (in review)

OSSE with COSMIC-2

RMSE: 200-hPa Wind

Positive impact with RO assimilation (larger in TR and SH)

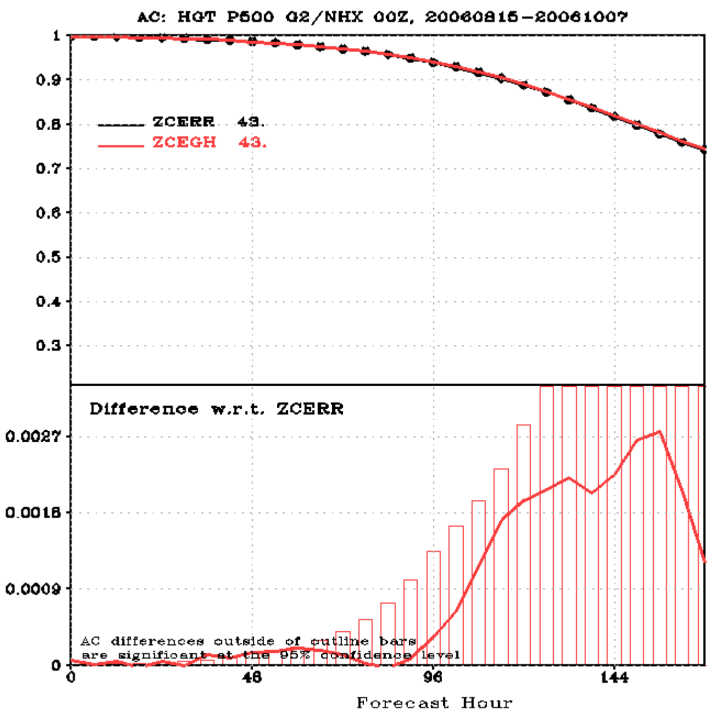
NHX (20N – 80N) | TRO (20N – 20S) | SHX (20S – 80S)



Cucurull et al. 2018, MWR (in review)

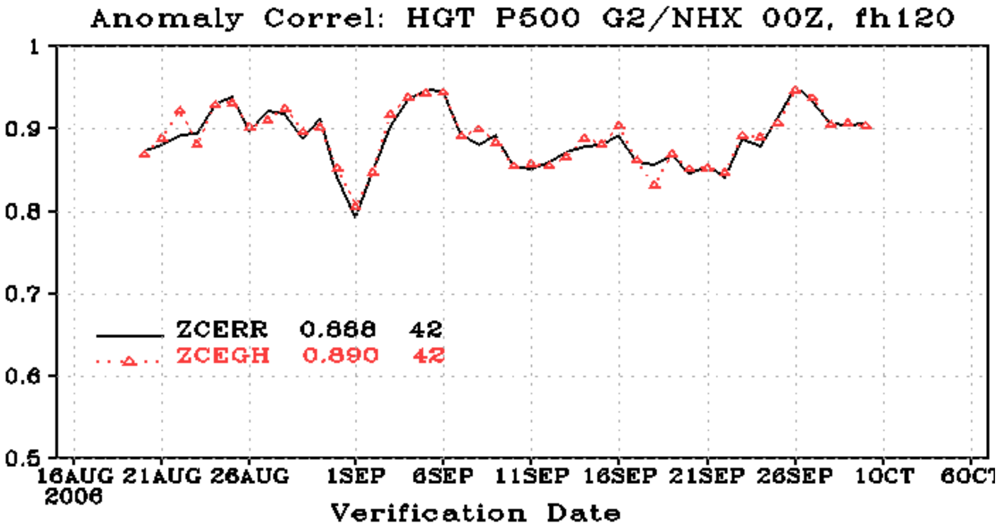
OSSE with GEO-HSS

Anomaly Correlation: 500-hPa Heights



Positive impact with Geo-HSS assimilation in Northern Hemisphere extratropics

Day-5 Forecast Skill



ZCERR: operational configuration

ZCEGH: ZCERR + five simulated IASI-like instruments in geostationary orbit spaced to give global coverage, removal of GOES, SEVIRI radiances

Casey et al. 2018, in preparation

OSEs with MW, IR, RO

- Experiment Design:
  - Q3FY17 NCEP's model configuration (4DEnvar, operational in July 2017).
  - T670 (GFS) / T254 (GSI and EnKF) horizontal resolution (highest resolution supported on Theia).
  - Two seasons: April-May 2016, August-September 2016.

- Results confirm that MW if the largest contributor in improving current operational NWP skill, followed by the assimilation of IR satellite radiances (see next slides.)
- The benefits of RO have decreased over the years, particularly in the SH, likely due to the reduction of the number of COSMIC soundings over time.

Example of # observations per assimilation cycle

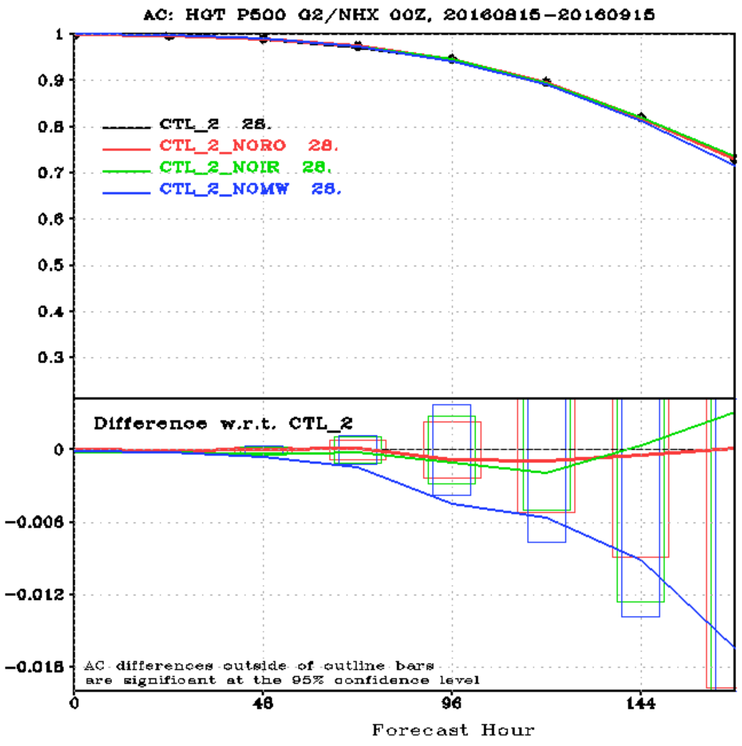
Satellite	# Read	# Assimilated
Infrared	~ 550 million	~ 3 million
Microwave	~ 35 million	~ 800,000
Radio Occultation	~ 150,000	~ 100,000

Note: the number of RO observations from COSMIC has been rapidly declining over the last past years

OSEs with MW, IR, RO

500 hPa HGT Anomaly Correlation

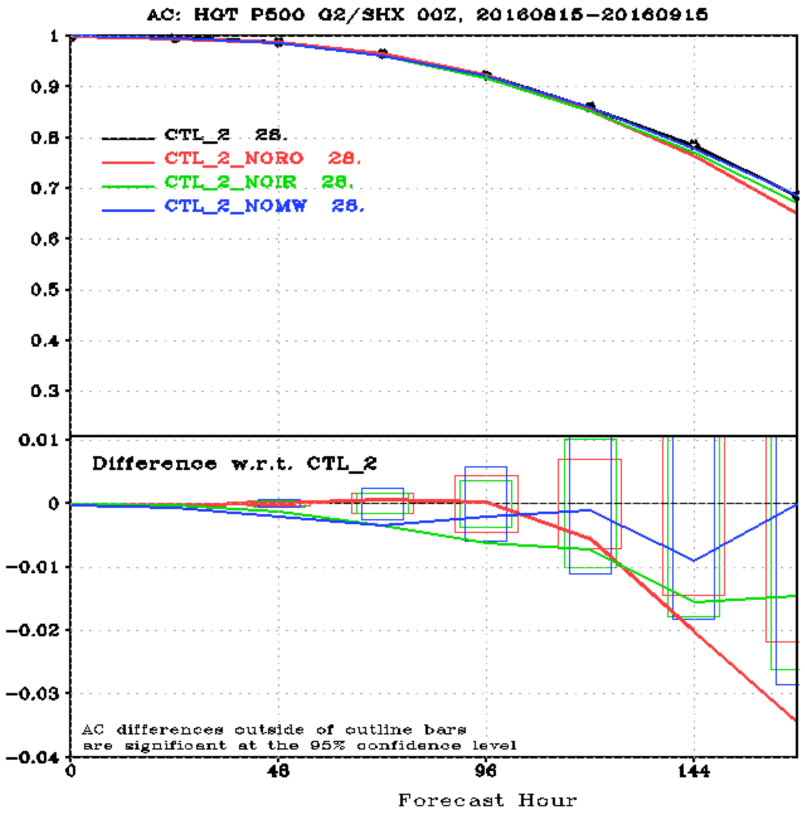
NH



CTL_2 : operational configuration
CTL_2_NORO: denial of RO
CTL_2_NOIR: denial of IR
CTL_2_NOMW: denial of MW

- **Largest positive impact is from MW in NH and from RO in SH for extended lead times**
- **Neutral (NH) to small positive (SH) impact from IR**
- **Neutral to positive impact from RO**

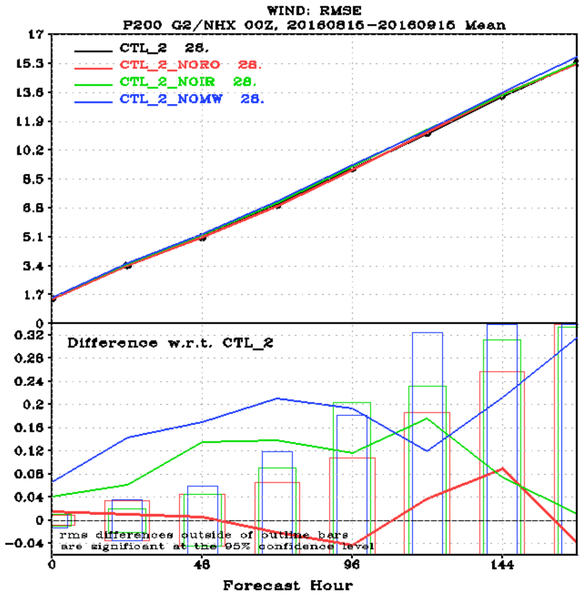
SH



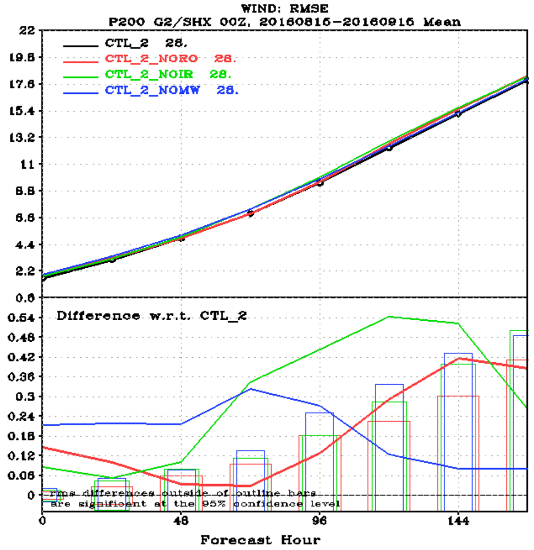
OSEs with MW, IR, RO

200 hPa WIND RMSE

NH

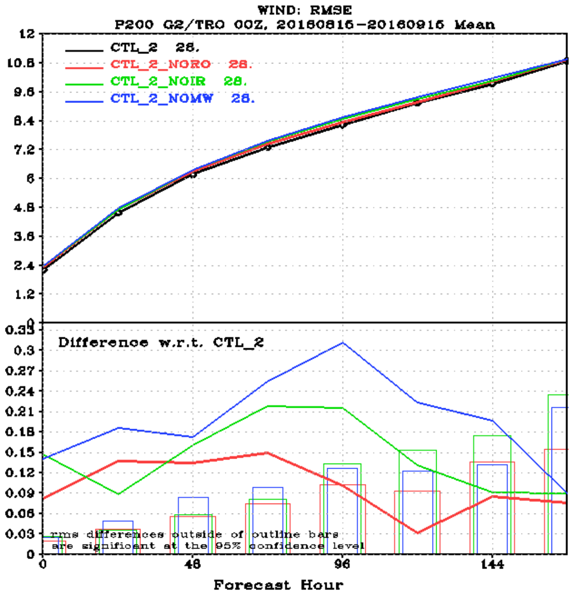


SH



CTL_2 : operational configuration
CTL_2_NORO: denial of RO
CTL_2_NOIR: denial of IR
CTL_2_NOMW: denial of MW

Tropics



- **Overall largest positive impact is from MW**
- **Smaller positive impact from IR**
- **Neutral (NH) to positive (TR and SH) impact from RO**

Summary

- NOAA’s Quantitative Observing System Assessment Program (QOSAP) coordinates OSE and OSSE across NOAA and strives to ensure that all OSSEs are performed in a credible manner.

- OSSEs provide an effective means to:
  - Evaluate the potential impact of proposed observing systems
  - Determine tradeoffs in their design
  - Evaluate new data assimilation methodology

- Great care must be taken to ensure the realism of the OSSEs and in the interpretation of OSSE results.

- OSSEs are currently being conducted to assess the potential impact of many new observing systems in current data assimilation systems.

- Rigorous OSSE methodology is being extended to air quality, severe storm, ocean, climate and biological applications.