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Impact Assessment of Loon Stratospheric Balloon Observations Assimilated in NOAA's FV3GFS

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Outline

- Motivation & Objectives
- Loon Balloon System
- Wind Data Evaluation and Preprocessing
- NWP Impact Assessment Results
- Concluding Remarks

Motivation & Objectives

- There is a gap in the global Earth observing architecture where *in situ* stratospheric observational data are largely unavailable. This challenges product validation and numerical weather prediction (NWP) data assimilation (DA).
- Near-space Loon balloons have the potential to help fill this gap and improve analyses and forecasts through DA.
- Several balloon campaigns have been conducted to help fill this gap and contribute to the validation of (re)analysis, evaluation of lower stratospheric gravity wave spectra, and forecast skill improvements via NWP impact assessments.

The overall objective is to provide a comprehensive evaluation of the value, capability, and potential benefit of long-duration stratospheric balloon data to NOAA missions.

Project-specific objective:

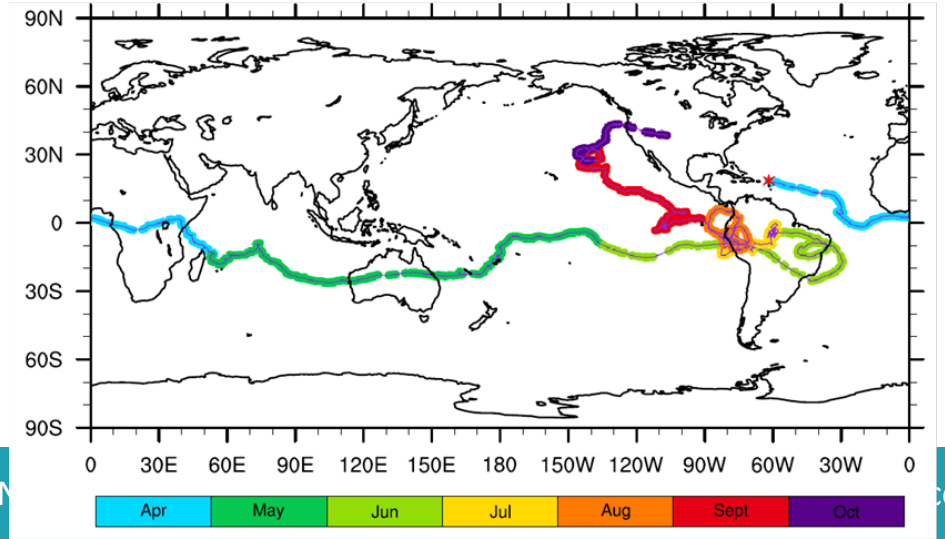
- Assess the impact of assimilating *in situ* stratospheric Loon wind observations on NWP forecast skill and the potential improvement to the assimilation of other observation types, using NOAA's Finite Volume Cubed-Sphere dynamical core based Global Forecast System (FV3GFS).

Loon Balloon System

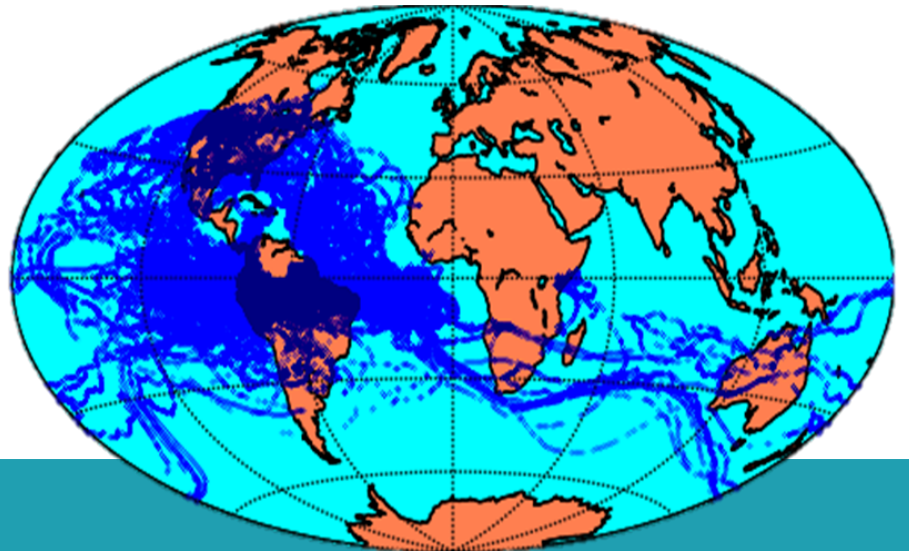
- **Loon™ balloon system** is a network of balloons designed to provide internet connectivity to regions with limited internet access.
- An instrument payload is tethered to a tennis court sized balloon designed to withstand harsh stratospheric conditions for months at a time.
  - Payload includes GPS (for wind derivation), a wire temperature sensor, solar panels, and onboard battery for power.
  - **Temporal frequency of Loon observations is ~1 min. Obs are recorded at a single upper-atmospheric level (18-20 km).**
- Horizontal spatial coverage is regional and dependent on Loon missions.

Loon balloon with payload platform
Source: https://loon.com/

Flight path of single balloon in 2017
Red star denotes launch site



Loon Balloon Trajectories in 2018
142 balloons launched

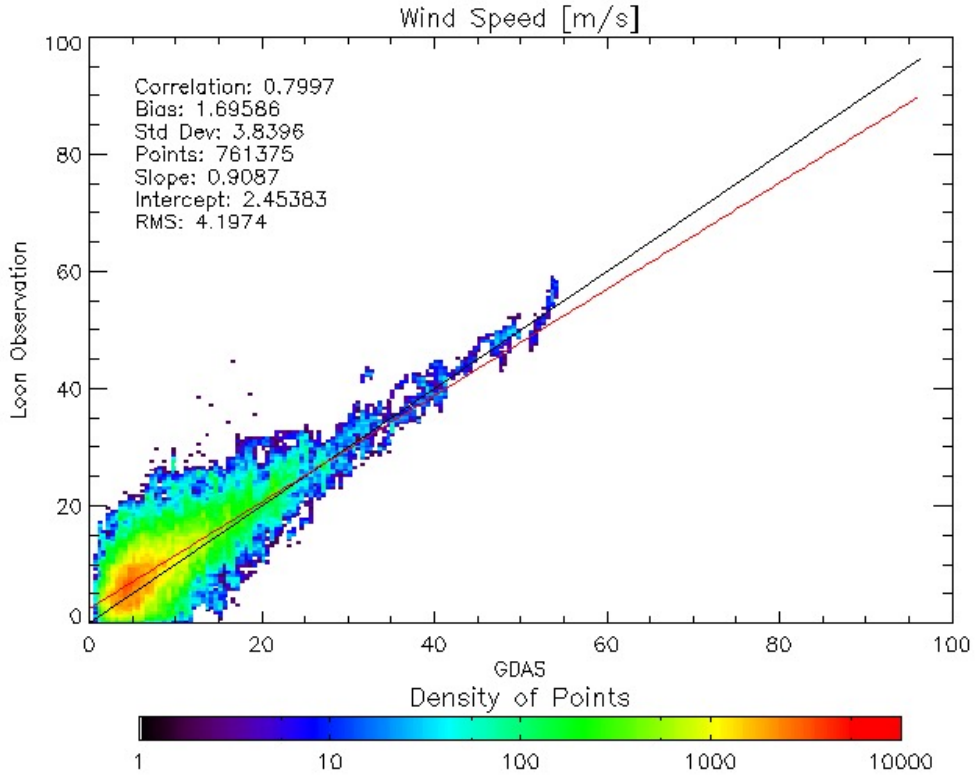


Loon is a registered trademark of Loon, LLC.

Loon Wind Observations

Loon winds at 50-100 hPa are found to be in good agreement with collocated NOAA Global Data Assimilation System (GDAS) analysis.

- Biases are small and tend to be < 2 m/s, with RMS error range of 3-4 m/s which is similar to that for radiosonde winds.
- Biases are likely from the model background, not the observation.



Example density scatter plot comparing Loon WSPD observations on y-axis with (a) GDAS analysis on x-axis for all flights in October 2017. Colors indicate the number of observations. Red line indicates the best linear fit. Black line is the one-to-one line. A list of statistics are provided in the top left corner of each plot. Units are m/s.

Loon Preprocessing & OSE Setup

Experiment Setup

- NOAA's GSI-based FV3GFS v15 (latest version as of January 2020)
  - 80 ensemble members
  - 64 vertical levels
  - Horizontal resolution:
    - C384 (25 km deterministic)
    - C192 (~50 km ensemble)
- *Initial conditions*: 2018-11-30 18 UTC
- *Spin-up period:* 2018-12-01 00 UTC – 2018-12-07 18 UTC
- *Experiment period*: 2018-12-08 00 UTC – 2019-01-31 18 UTC
- *Experiments*
  - **LoonMON** (Control): Loon winds monitored, not assimilated
  - **LoonASM**: Loon winds assimilated
  - Use of larger observation error for Loon winds: $\sqrt{R}$ = 10 m/s

Loon Preprocessing

- Removal of duplicate observations (adjacent observations with copied geolocation along same balloon trajectory)
- Removal of "maneuver periods" (intentional adjustments in altitude) represented as large jumps in pressure, height, and time for adjacent observations.
- No bias correction.
- No thinning applied.
- **All preprocessed Loon winds in experiment period are converted to BUFR and assimilated.**
  - **Loon balloons are treated as aircraft.**

Verification

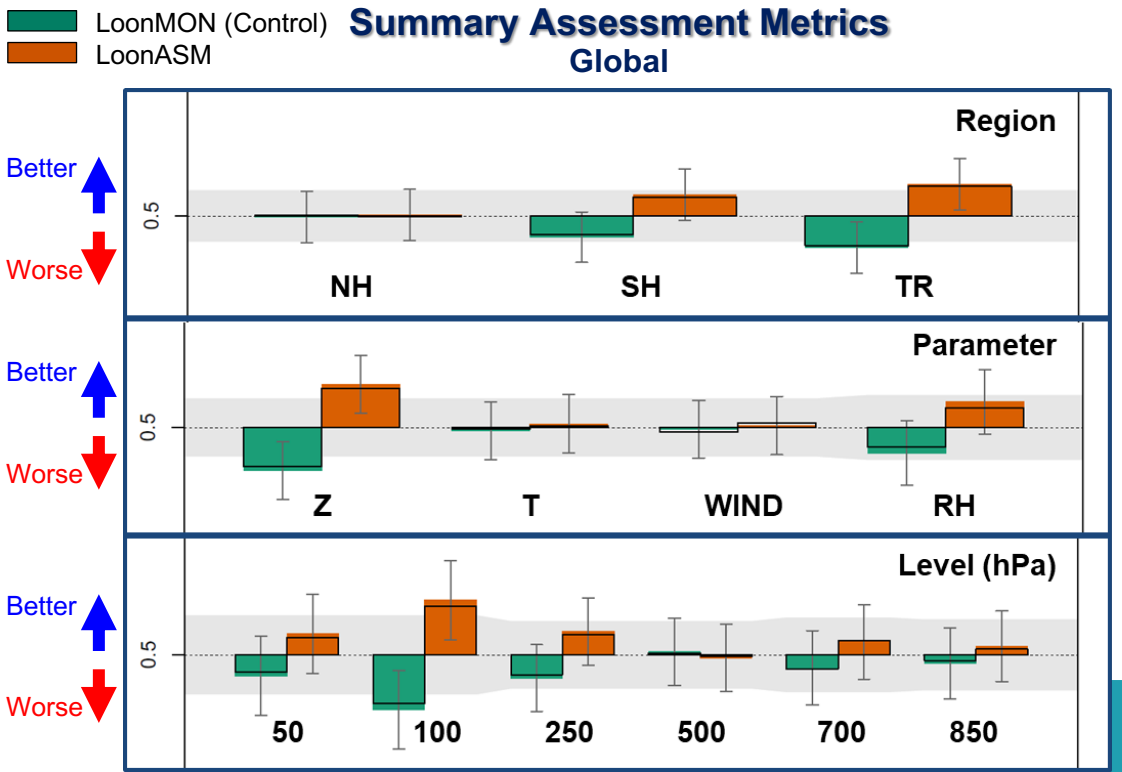
- Compare LoonASM to LoonMON (Control)
- Verify against GFS operational analysis (GFS_OPER) at 1-degree horizontal resolution, considered to be "truth"
  - GFS_OPER is downscaled from original GFS analysis run at highest operational resolution (~13 km)

NWP Impact Assessment

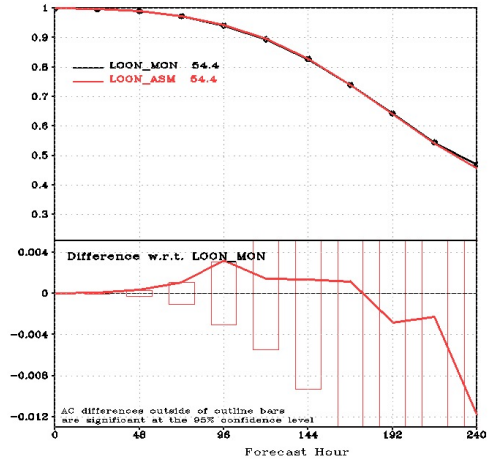
Summary of Results

Assimilation of Loon winds has positive impact on forecast skill:

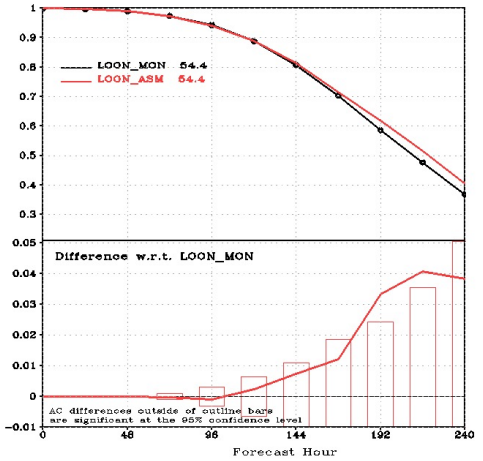
- In Tropics and SH
- In upper troposphere, lower stratosphere
- For winds (in Tropics)
- For height and relative humidity (in SH)



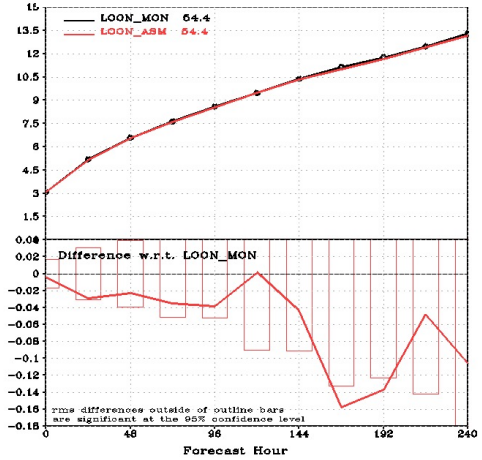
NH Height AC
500 hPa



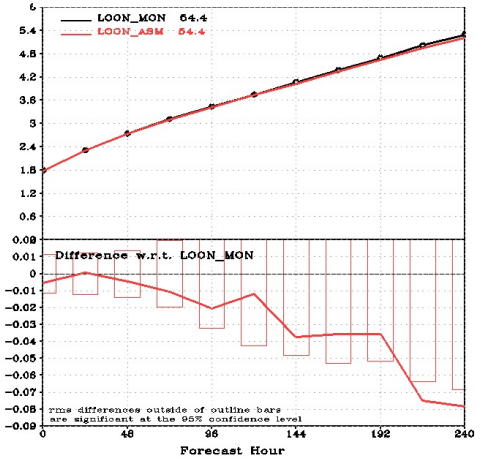
SH Height AC
500 hPa



Tropical Wind RMSE
250 hPa

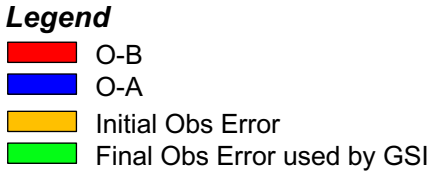


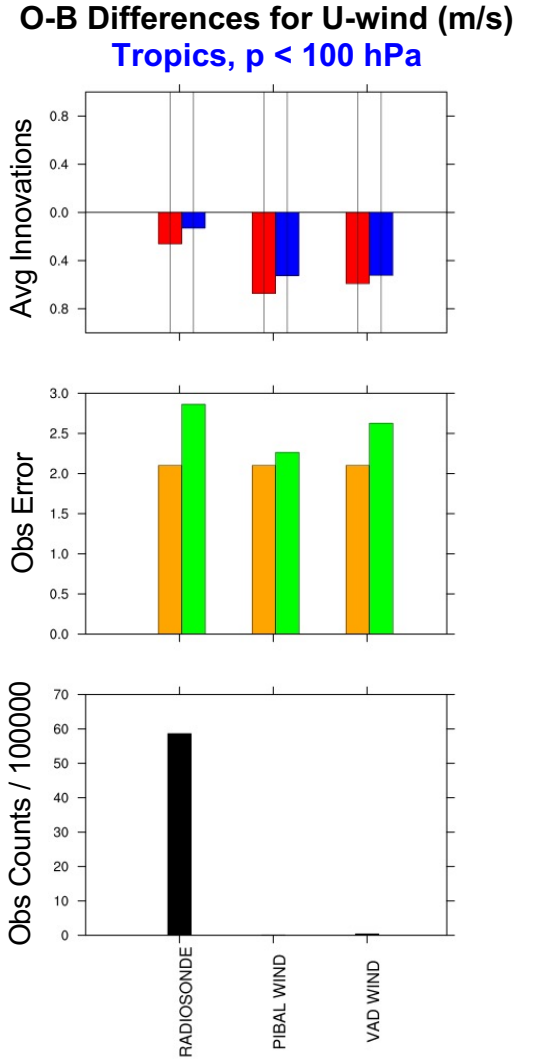
Tropical Wind RMSE
850 hPa

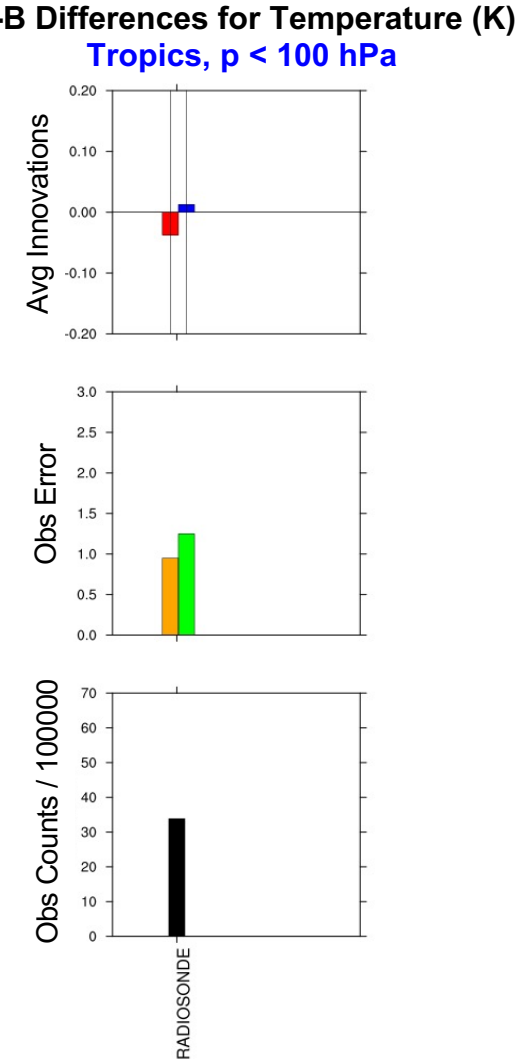


NWP Impact Assessment

Impact on Innovations in Tropics







Loon wind assimilation has local positive impact:

- O-B innovations are reduced for temperature and other wind observations in Loon region (Tropical lower stratosphere).
- Decreases in innovations are not statistically significant.

NWP Impact Assessment

Impact on RMSD

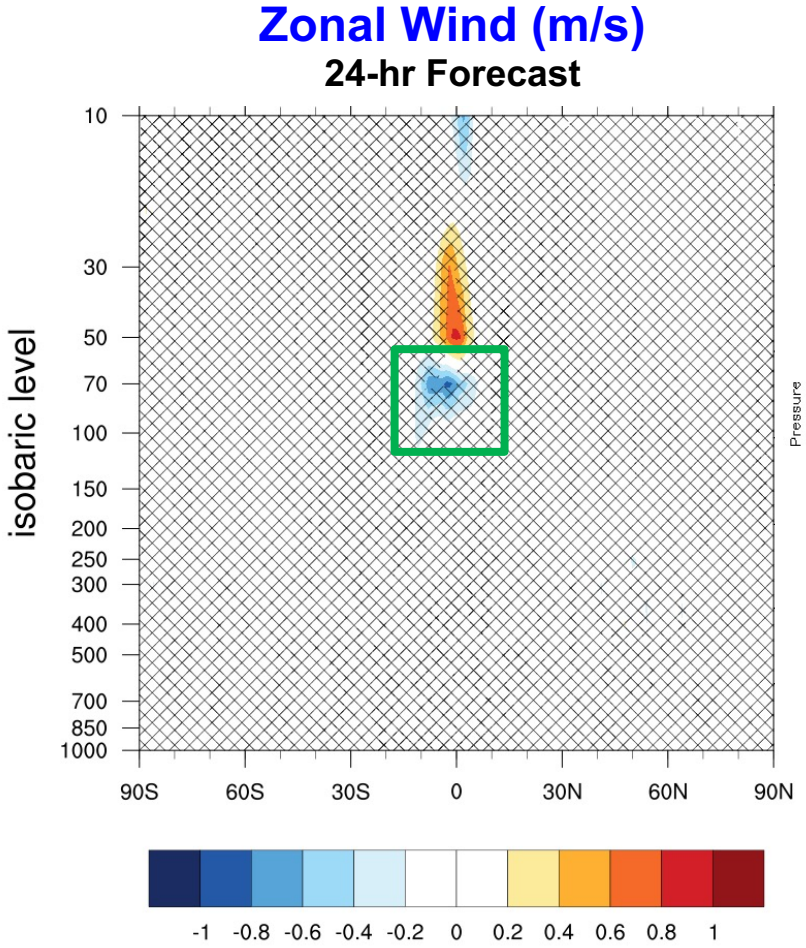
RMSD of zonal wind forecast is reduced in Loon region out to 4-5 days, with statistically significant differences on Day 1 (24-hr forecast).

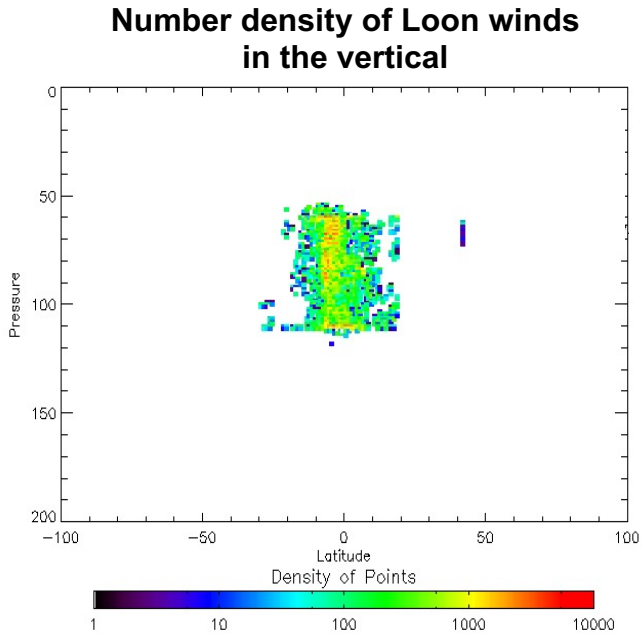
- Local impact is shown as difference in RMSD averaged over 180-60°W longitude:

$$\mathrm{RMSD}_{\mathrm{diff}} = RMSD_{1,V} - RMSD_{0,V}$$

where

0 = LoonMON (Control)
1 = LoonASM
V = GFS_OPER (Verification)





- Regions **without** hatching denote statistically significant differences at 95% using Student's t-test.

- Green box denotes Loon region.

Concluding Remarks

Objective: To evaluate impact of assimilating Loon stratospheric wind observations on NWP forecast skill using NOAA's GSI based FV3GFS.

- Loon winds correspond well with operational analysis and are assimilated in the FV3GFS.
- An NWP impact assessment is performed where the assimilation experiment is compared with the Control and verified against the GFS operational analysis.
- Loon wind assimilation has a positive impact on short-range forecast skill, particularly in the Tropical lower stratosphere where Loon balloons are found.
  - O-B innovations for other observation types are reduced.
  - RMSD of zonal wind forecast is reduced.
- **The findings support that near-space observing systems like Loon have the potential to provide critical *in situ* information in data-sparse regions that can positively impact operational forecasts.**

A manuscript is in preparation as we wrap up the NWP impact assessment.

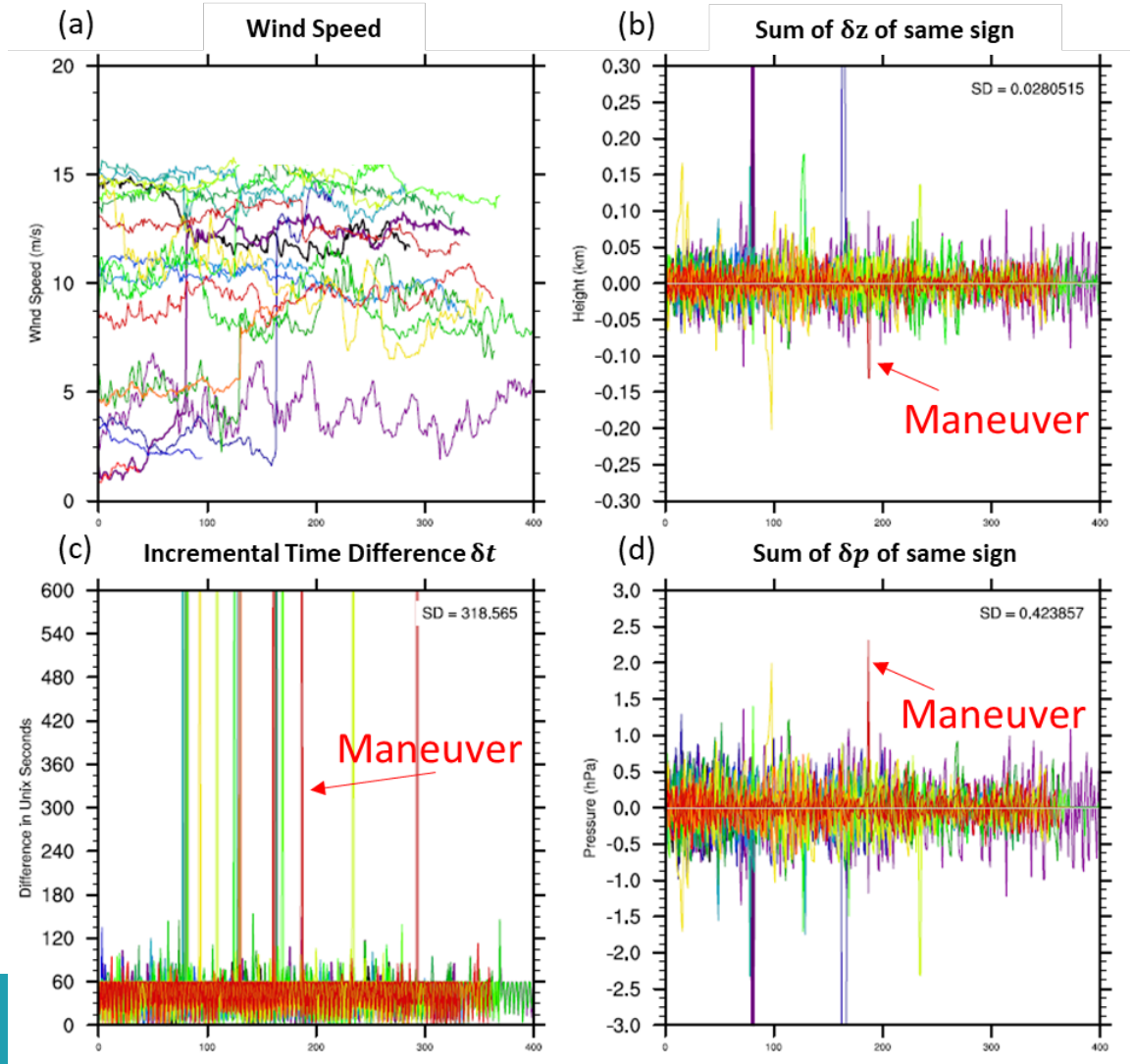
Thank you!

- *Acknowledgements*:
  -NOAA/NESDIS/OPPA Technology Maturation Program (TMP) for funding this work
  -Loon, LLC for providing the data
  -SSEC at UW-Wisconsin and NOAA for relevant HPC services

- *Contact*:
  Dr. Katherine Lukens katherine.lukens@noaa.gov

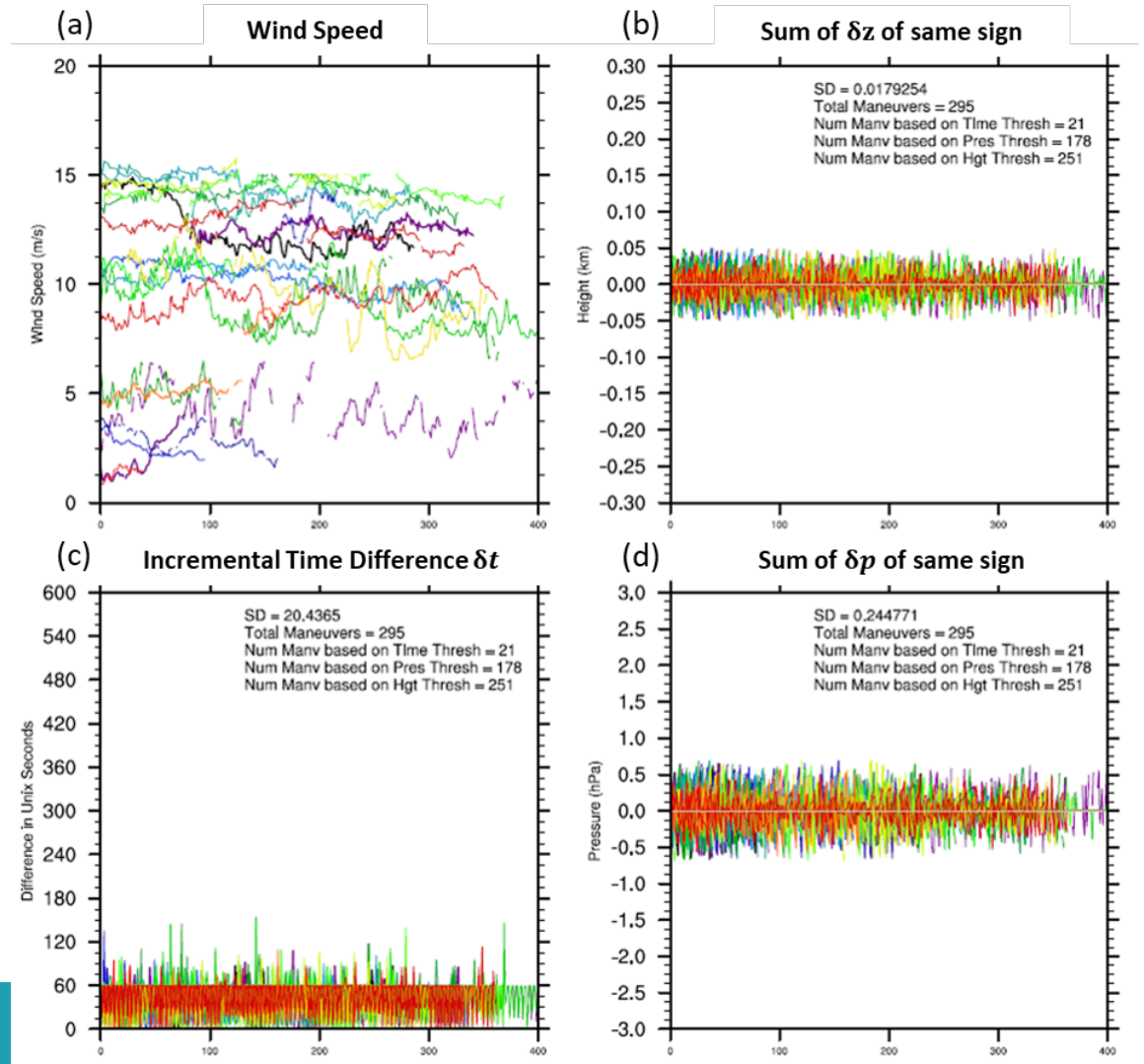
Supplemental:
Removal of Loon Maneuvers

- Maneuver periods are defined as large incremental differences ($\delta\mathbf{x}$) or 'jumps' in the data along each balloon trajectory.
  - These periods can lead to large oscillations in the balloon's movement which are reflected in the data and can impact data quality.
- Here, maneuver periods are removed if all of the following deltas (time (δt), pressure (δp), and height (δz)) exceed the corresponding thresholds:
  1. δt = 250 s
  2. δp = 0.7 hPa
  3. δz = 50 m



Supplemental:
Removal of Loon Maneuvers

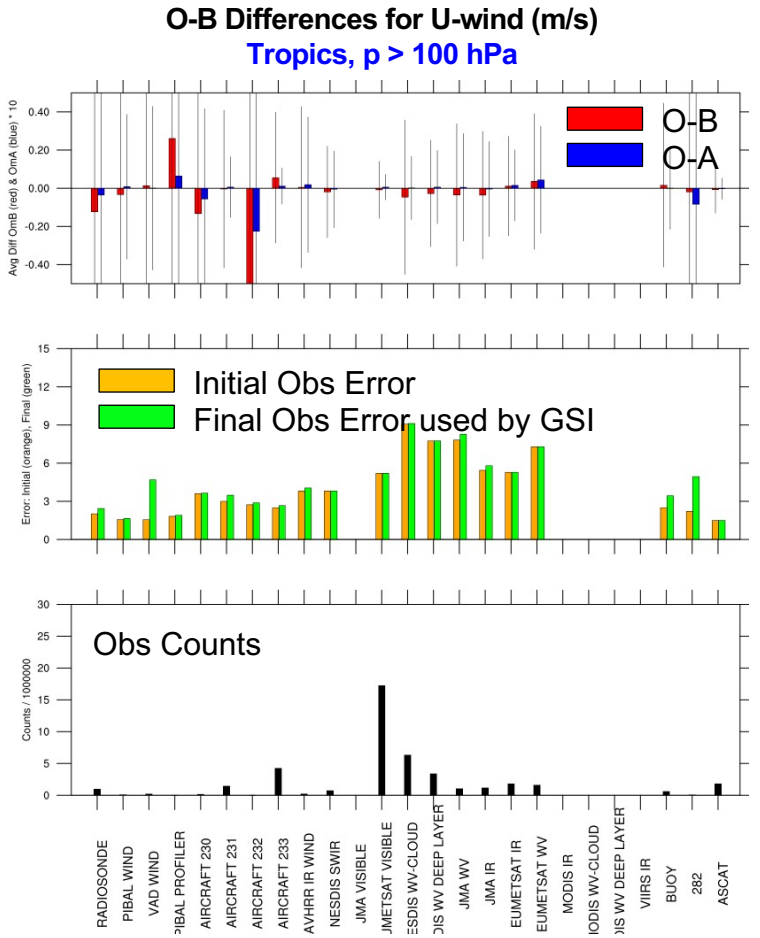
- Removal of maneuver periods ensures that only the most stable portions of each balloon flight are retained for use in DA.
  - *Example*:
    In one 6-hour cycle on 2018-12-01 at 00 UTC, 295 individual maneuvers were identified. After removal, standard deviations of increments were reduced and 95% of the data was retained.

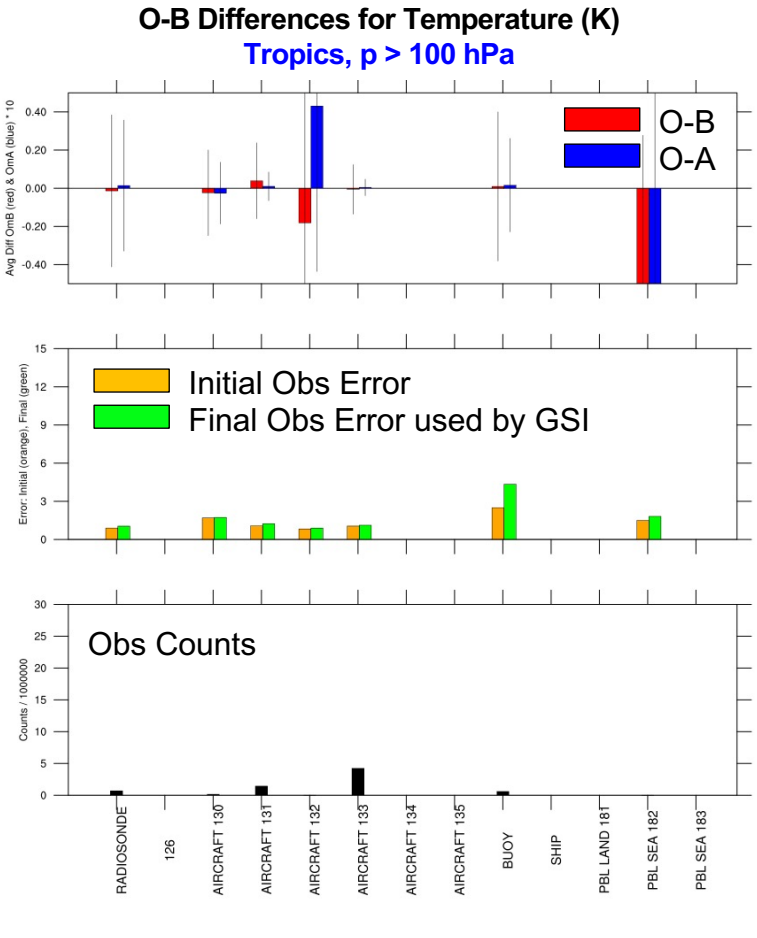


Supplemental:
NWP Impact Assessment

Impact of Loon wind assimilation on innovation statistics:

- O-B for radiosonde and some aircraft wind and temperature observations is reduced in Tropics at levels below where Loon is found.
- Reductions in O-B are not statistically significant.



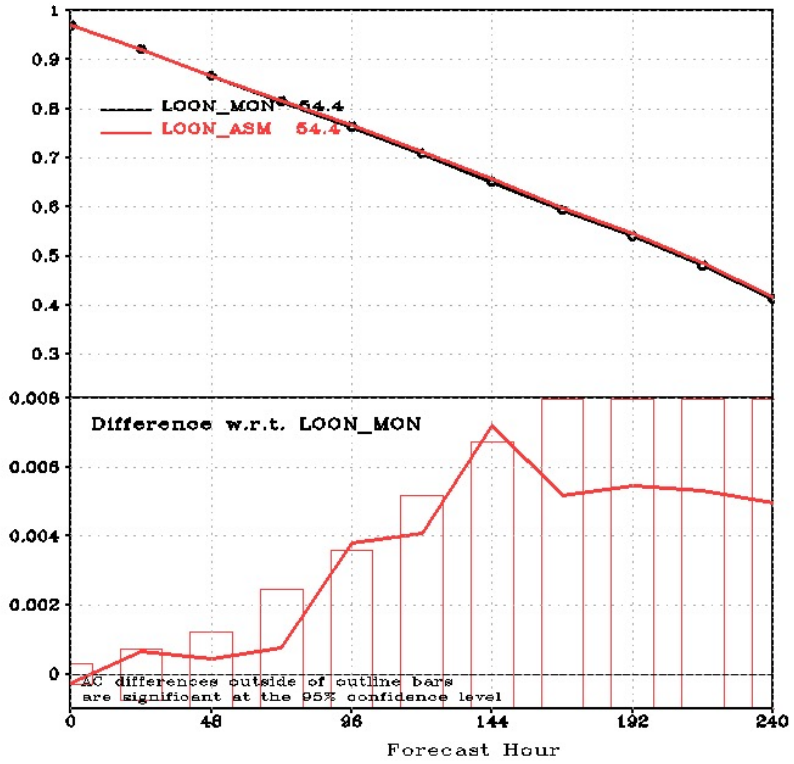


Supplemental:
NWP Impact Assessment

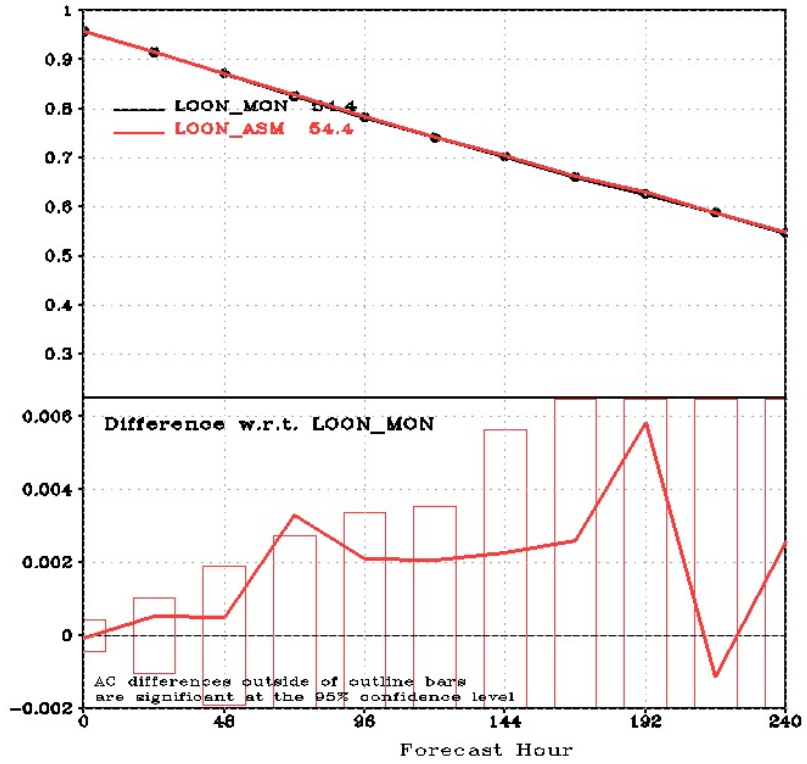
Impact of Loon wind assimilation on forecast skill:

- AC of wind increases with forecast time in Tropical upper troposphere (p=250 hPa).
  - AC > 0.8 out to Day 3.
- Impact of Loon winds on forecast skill in Extratropics and in lower troposphere is minimal and not significant.

Tropical Wind AC
p=250 hPa



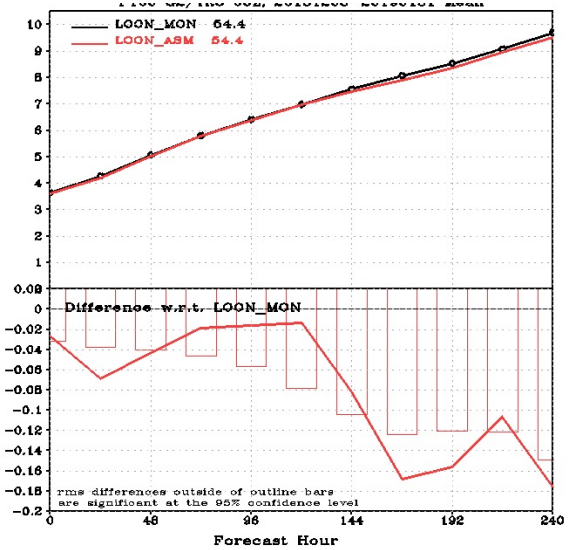
Tropical Temperature AC
p=250 hPa



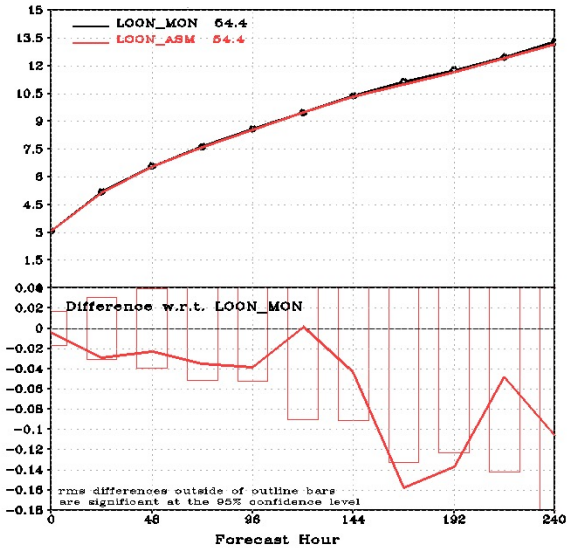
Supplemental:
NWP Impact Assessment

- Assimilation of Loon winds reduces RMSE of wind and temperature in Tropical lower stratosphere (p=100 hPa) and upper troposphere (p=200 hPa).
  - Decrease in wind RMSE at Loon levels (p=100 hPa) is significant out to Day 2.
  - Decrease in temperature RMSE at Loon levels (p=100 hPa) is significant out to Day 8.

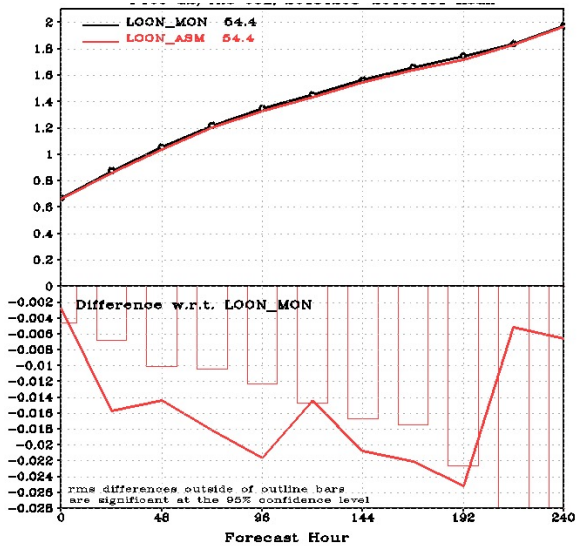
Tropical Wind RMSE
p=100 hPa



Tropical Wind RMSE
p=200 hPa



Tropical Temperature RMSE
p=100 hPa



Tropical Temperature RMSE
p=200 hPa