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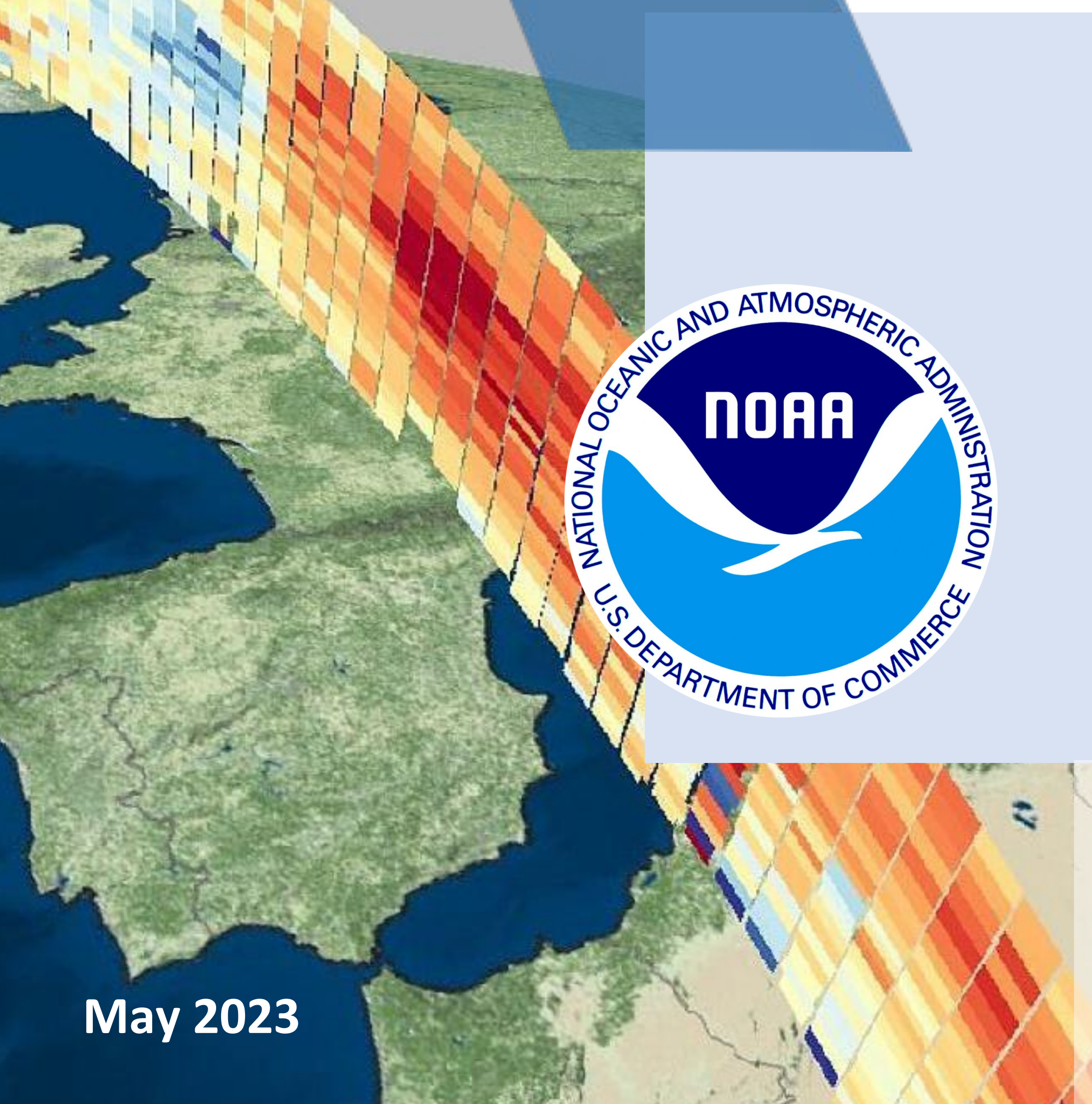

System for Analysis of Wind Collocations (SAWC):
A Novel Archive and Application for the Intercomparison of Winds from Multiple Observing Platforms Provides for Aeolus Evaluation

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Outline

- Motivation & Objectives
- SAWC Overview, Approach, & Available Data
- Example Output from Collocation Application Developed
- Summary

Background & Motivation

- The 2017-2027 decadal survey by the National Academies Press designated the observation requirement for highly accurate atmospheric wind observations as a top priority in the science community.

- Numerous wind comparison studies have been conducted over the years. Many involve AMVs, with each study using widely varying collocation criteria.
  - It is usually up to the researchers to acquire the data, reformat it, and develop analysis tools themselves. These steps can be time consuming and can hinder progress, particularly for projects assigned limited periods of performance

To address the requirement for accurate winds and to facilitate the intercomparison of winds from multiple platforms, a collaboration began between NOAA/NESDIS/STAR, UMD/ESSIC/CISESS, and UW-Madison/CIMSS …

Objective

To establish the System for Analysis of Wind Collocations (SAWC; pronounced "saucy")

SAWC presents–for the first time–a public archive of global 3D wind observations from multiple sources, collocated pairings between them, and a Python application specifically developed for their intercomparison, all in one central location.

Everything you need for wind observation research in one place

SAWC Overview

SAWC Components:

- Wind observation datasets (all in NetCDF)
- Index files containing array indices of matched winds (NetCDF)
- Application (Python) consisting of a collocation program and a plotting program
- SAWC User Manual

Application is designed to be flexible to handle additional datasets not yet available in the SAWC archive.

SAWC is currently hosted on S4 administered by UW-Madison’s Space Science and Engineering Center (SSEC), and is managed by NOAA/NESDIS/STAR.

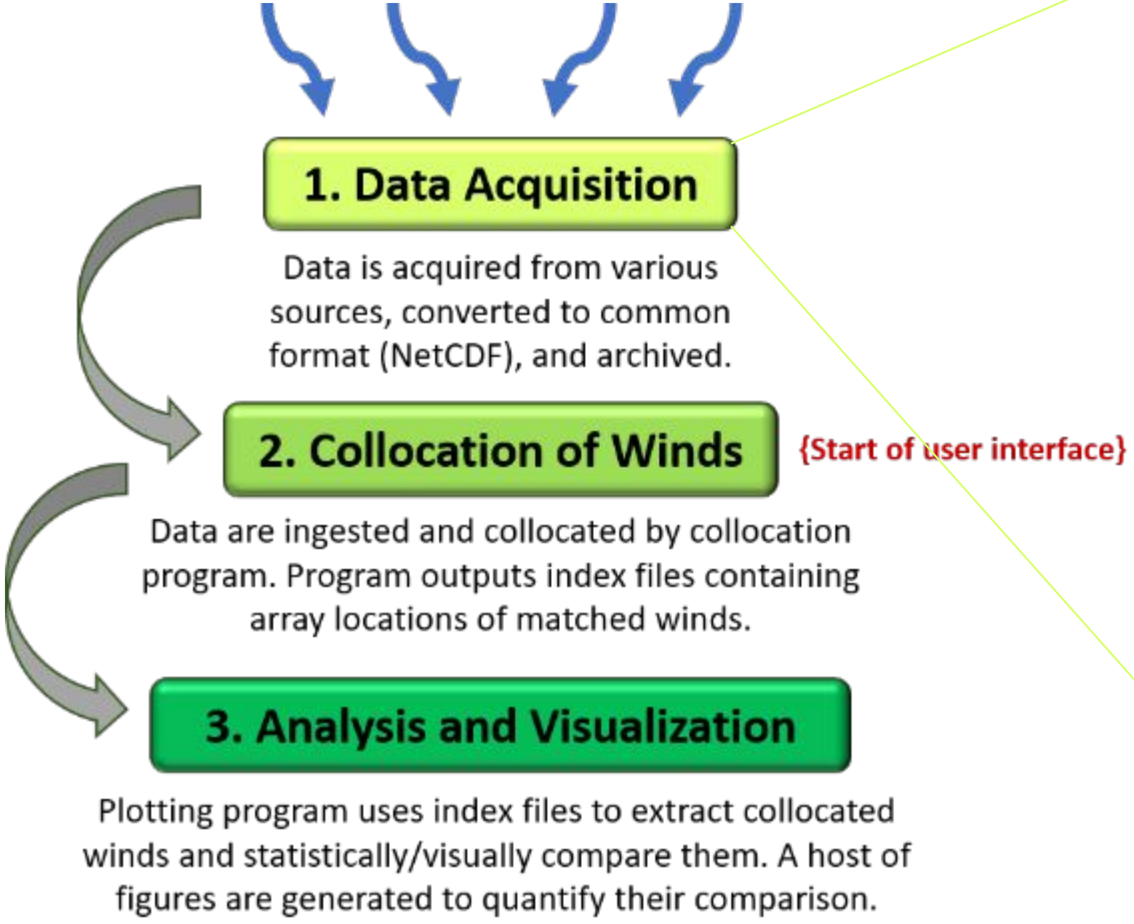
- **It is updated every 90 days** (Jan 15, Apr 15, Jul 15, Oct 15)
- **Note**: **SAWC will have a new home later this year!** An announcement about this is forthcoming

Current SAWC Access

- FTP: ftp.ssec.wisc.edu/wind-datasets
- URL: https://bin.ssec.wisc.edu/wind-datasets
- Application: https://bin.ssec.wisc.edu/wind-datasets/atmos-nc-dataset/collocation/application/
- User Manual: https://bin.ssec.wisc.edu/wind-datasets/atmos-nc-dataset/docs/User_Manual/

SAWC End-to-End Process

Approach:



Global Observation Datasets Available

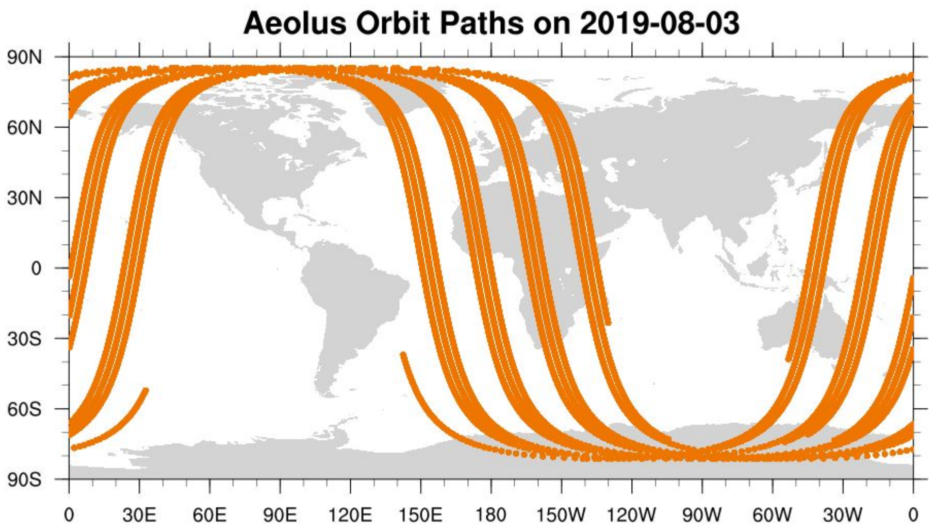
- Aeolus Rayleigh-clear, Mie-cloudy, and some Rayleigh-cloudy winds [ESA]
- Atmospheric Motion Vectors (AMVs) [NCEP]
- Aircraft winds [NCEP]
- Rawinsonde (RAOBS) winds [NCEP]
- Loon stratospheric balloon winds [Loon]

Temporal Ranges

- *Aeolus*: Sep 2018 – Apr 2023
- *AMVs, Aircraft, RAOBS*: Sep 2018 - Present
- *Loon*: 2011-2021

Datasets: Aeolus Winds

- Level-2B (L2B) data observed by Doppler wind lidar on dawn/dusk orbit.
  - Complete orbit every ~92 min.
  - Global coverage every 7 days.
- Winds are observed in profile along laser's horizontal line-of-sight (HLOS) **[red arrow in diagram]**
- Two main wind regimes:
  - **Rayleigh-clear** (molecular backscattering) representing winds in clear scenes
  - **Mie-cloudy** (aerosol backscattering) representing winds in cloudy scenes



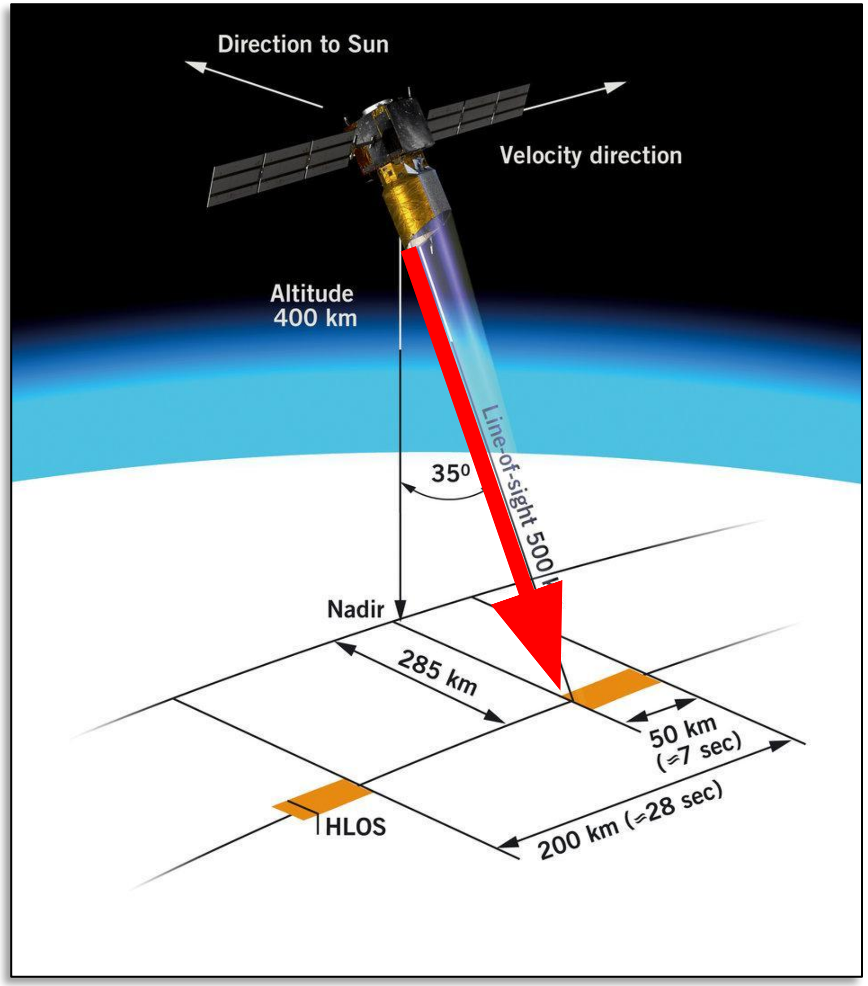


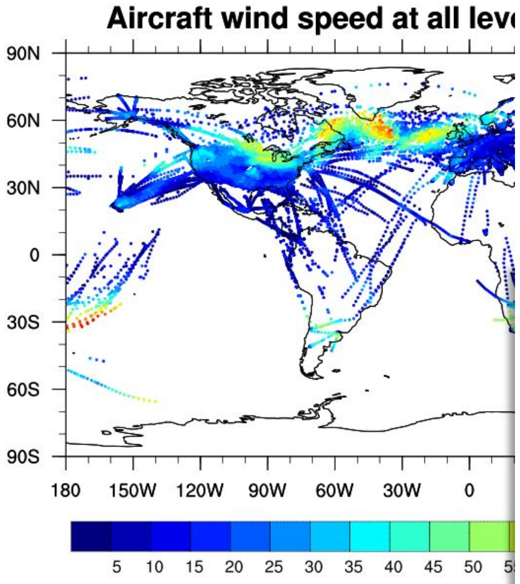
Diagram of Aeolus Measurement Geometry

Credit: ESA - Baseline Aeolus measurement geometry
https://www.esa.int/Enabling_Support/Operations/Aeolus_operations

Datasets: Conventional Winds

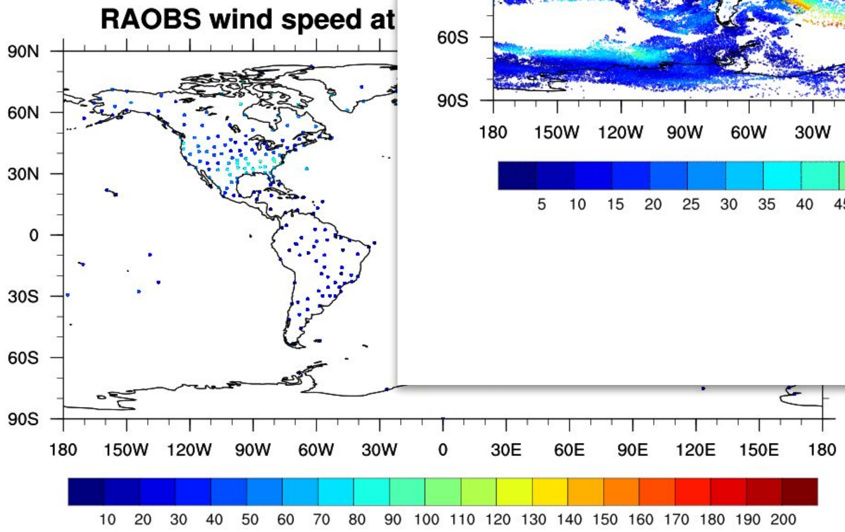
Aircraft

- Winds observed at flight level in the upper troposphere/lower stratosphere and in ascending and descending legs of each flight.
- Regional coverage, mostly in the NH.



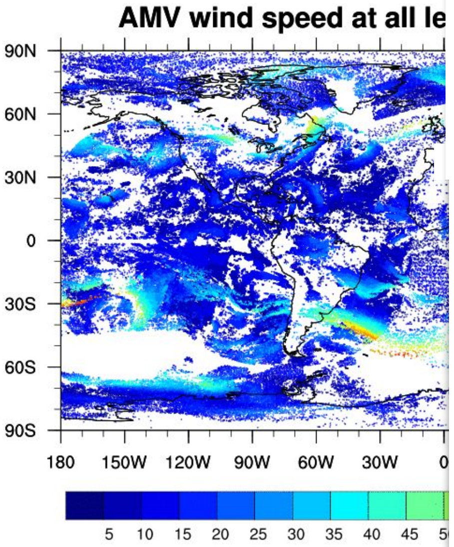
RAOBS

- Direct *in situ* wind ob
ranging from the surf
troposphere/lower st
- Sparse coverage, mos



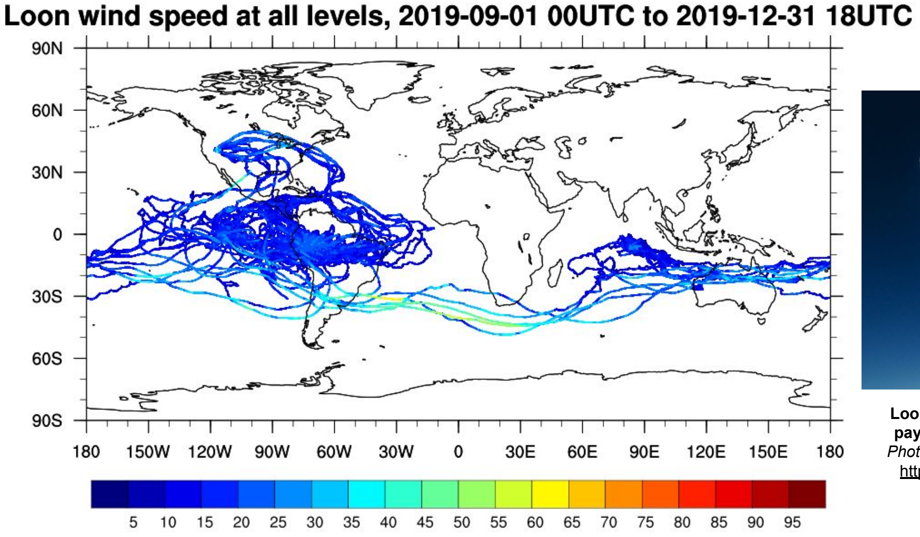
Atmospheric Motion Vectors (AMVs)

- Wind observations derived from tracking clouds and water vapor features in satellite images through time.
- Near-global coverage at



Loon

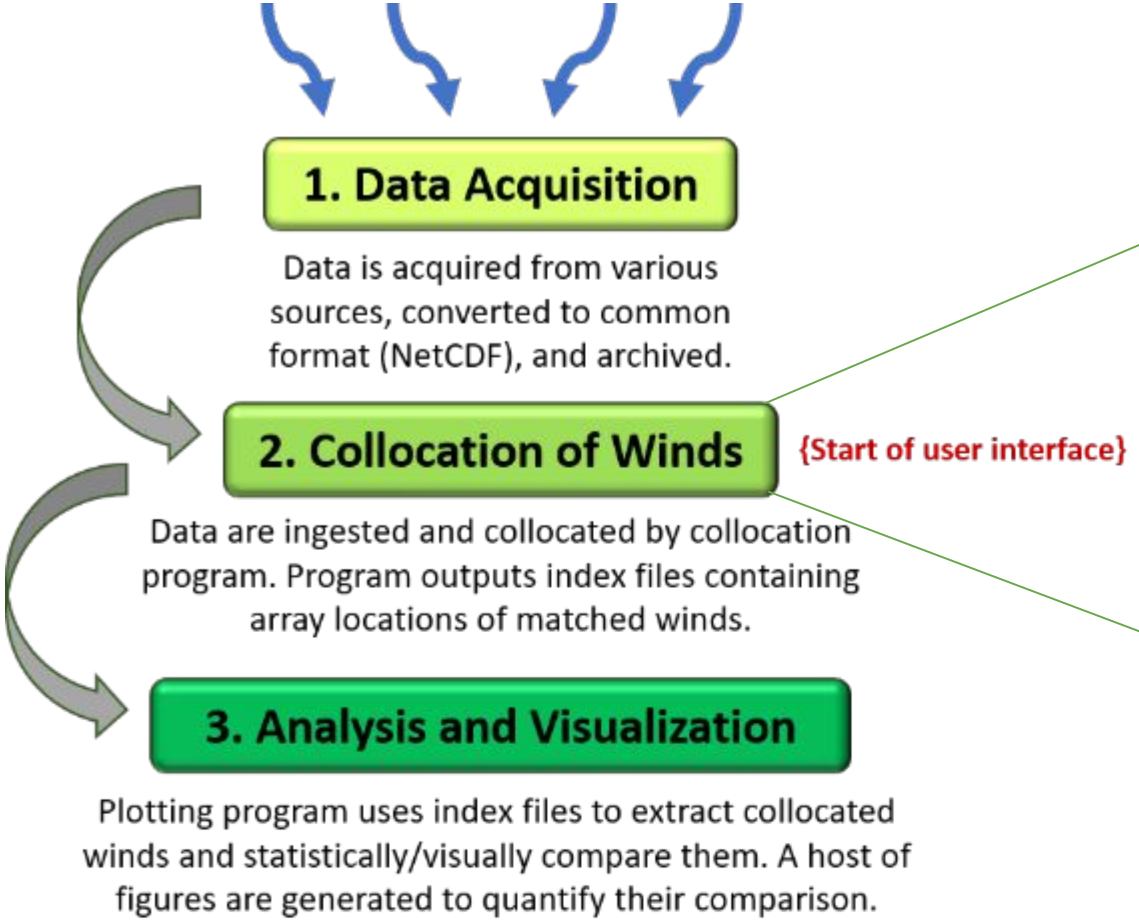
- Large stratospheric superpressure balloons designed to fly at 50-100 hPa for months at a time.
- Regional coverage.



Loon balloon with payload platform
Photo Credit: Loon - https://loon.com/

SAWC End-to-End Process

Approach:



- ***4D collocation*** between one "Driver" dataset and multiple "Dependent" datasets.
- ***User*** can select multiple parameters prior to collocation, including the experiment period, datasets to compare, collocation criteria, and whether QC is applied
- ***Index files (output)***: Note that by saving array locations and not a copy of the collocated data, we save disk space.

SAWC End-to-End Process

Approach:

1. Data Acquisition

Data is acquired from various sources, converted to common format (NetCDF), and archived.

2. Collocation of Winds {Start of user interface}

Data are ingested and collocated by collocation program. Program outputs index files containing array locations of matched winds.

3. Analysis and Visualization

Plotting program uses index files to extract collocated winds and statistically/visually compare them. A host of figures are generated to quantify their comparison.

Example: Collocation check

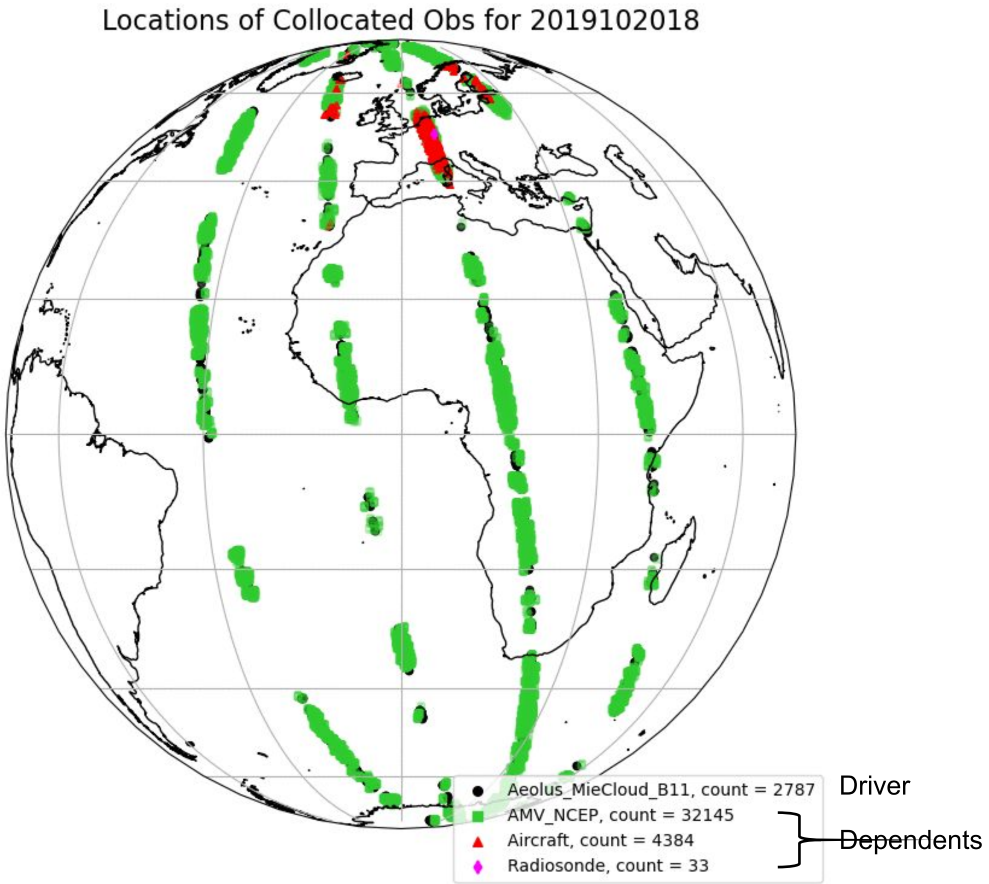
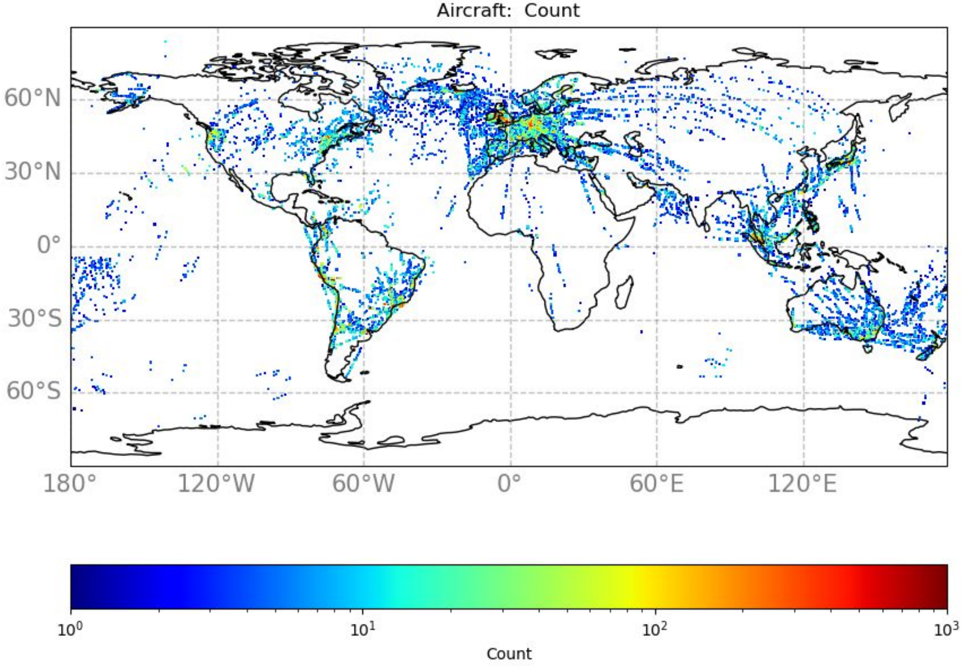
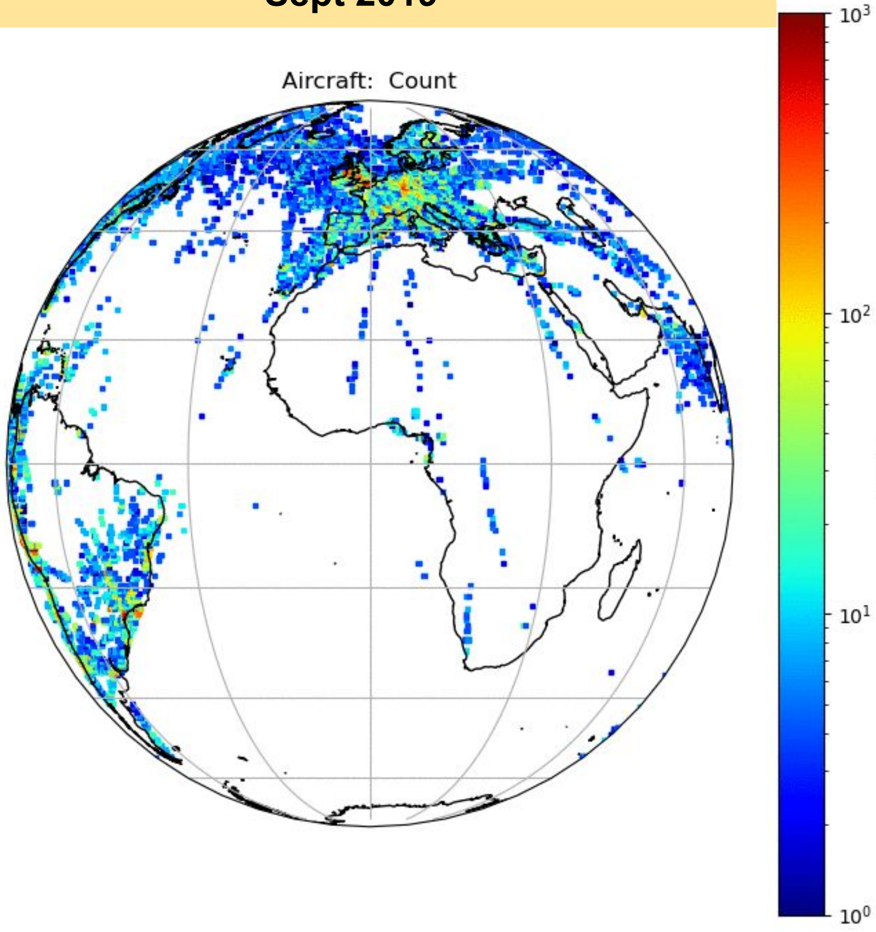


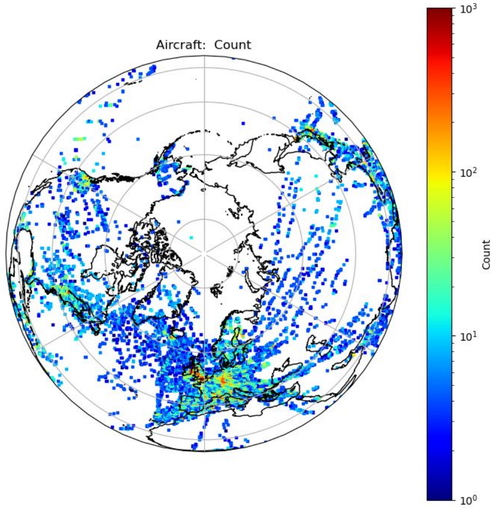
Figure produced from collocation application developed for this project. AMVs, aircraft winds, and rawinsonde winds are collocated with Aeolus Mie-cloudy winds from 2nd reprocessed campaign.

Example Figures: Map Projections

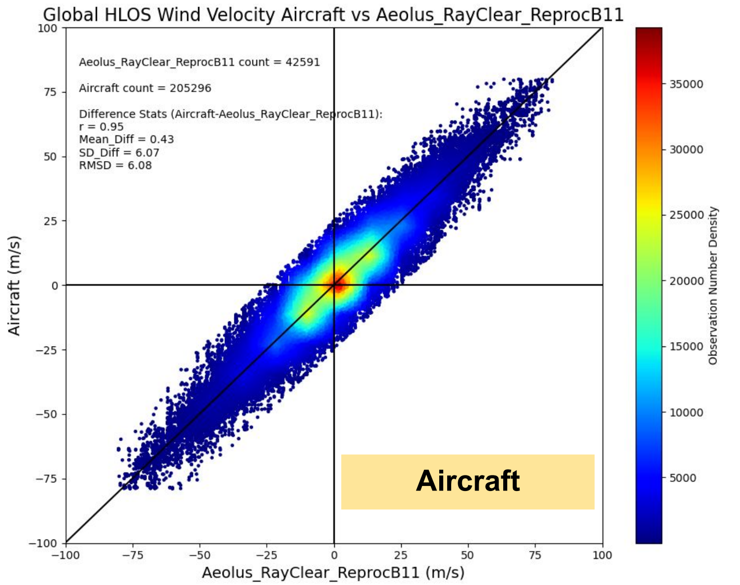


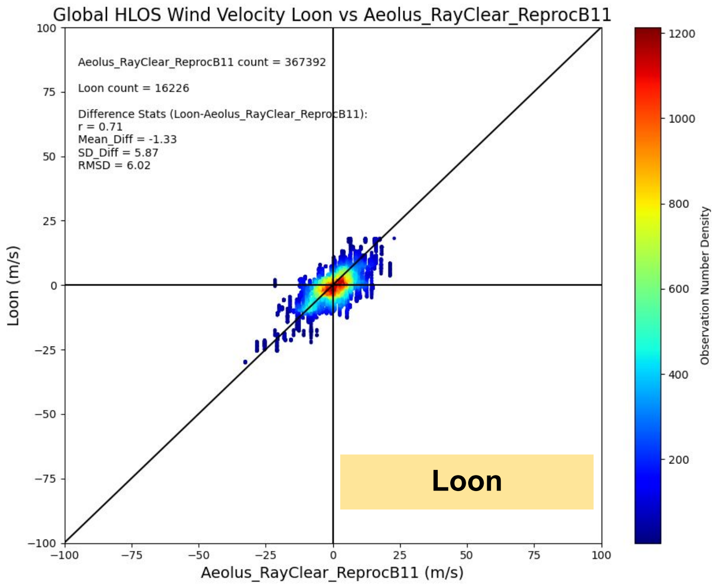
Aircraft Observation Density (i.e., Counts)
collocated with Aeolus Rayleigh-clear
Sept 2019

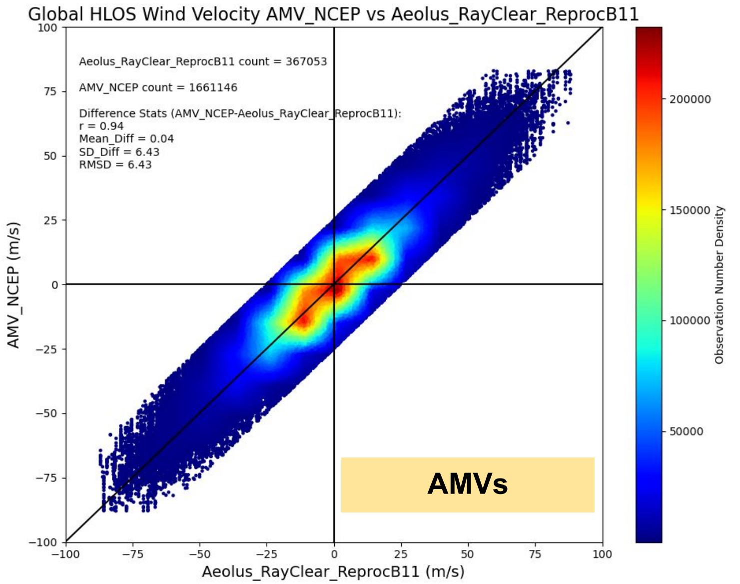


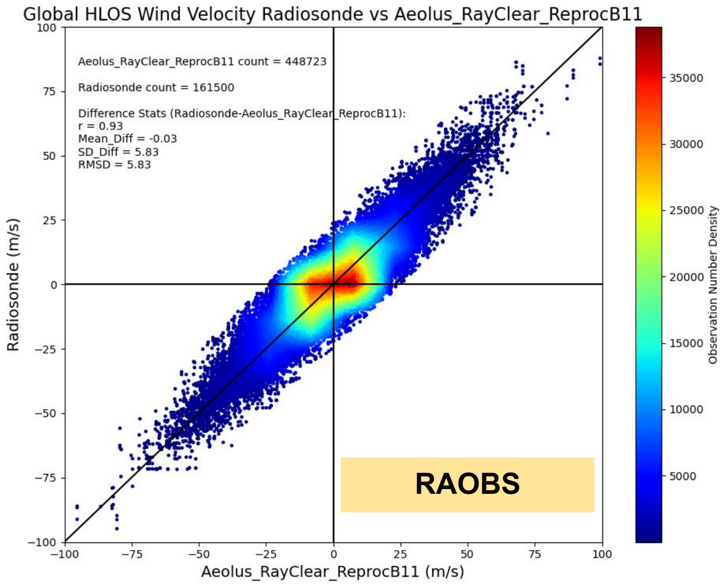


Example Figures: Scatterplots



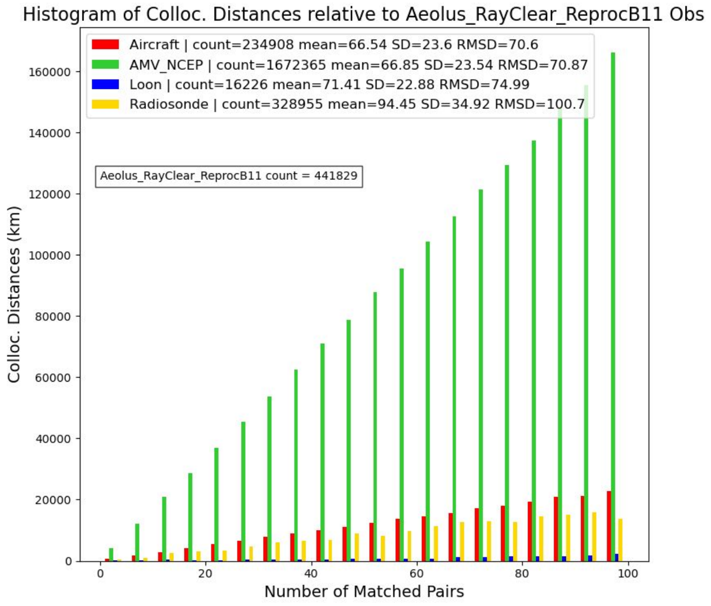


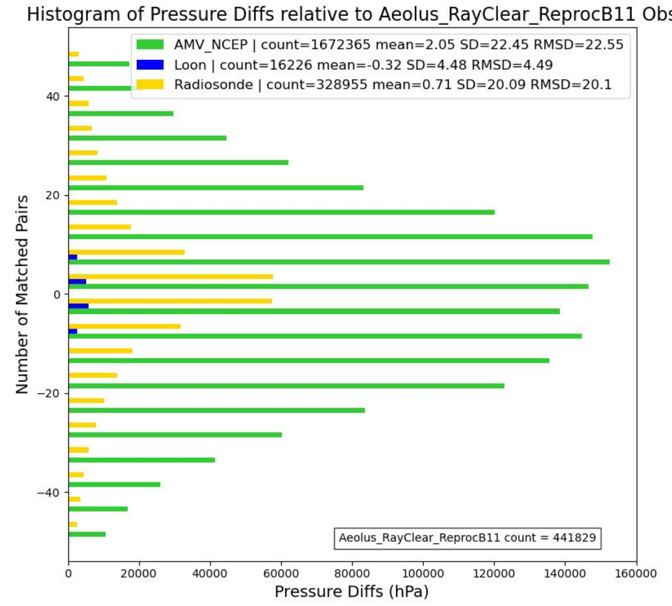


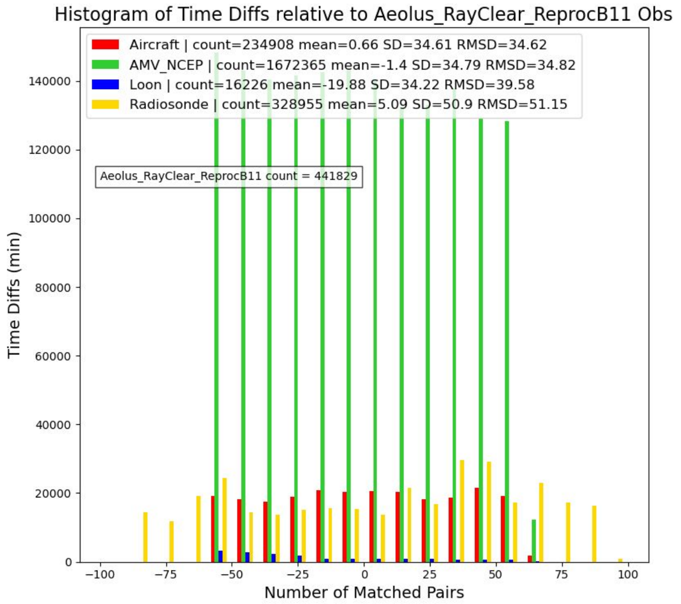


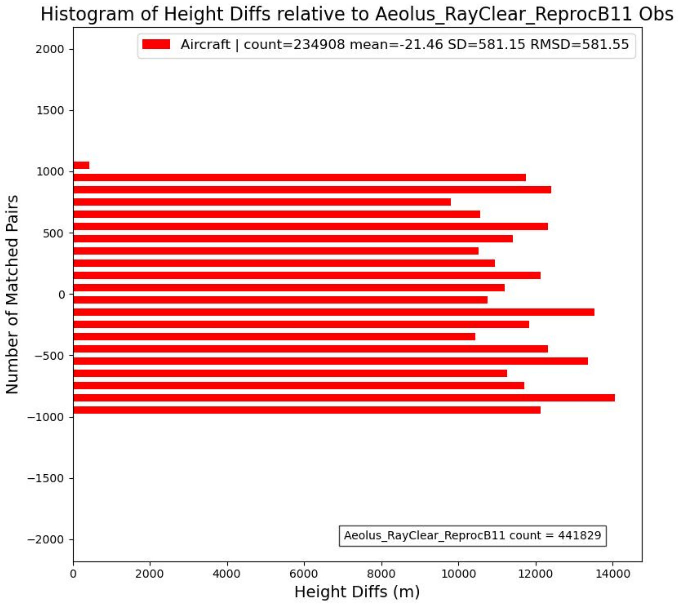
Example Figures: Histograms of Colloc. Criteria

Sept 2019









Example Figures: Daily Mean Time Series

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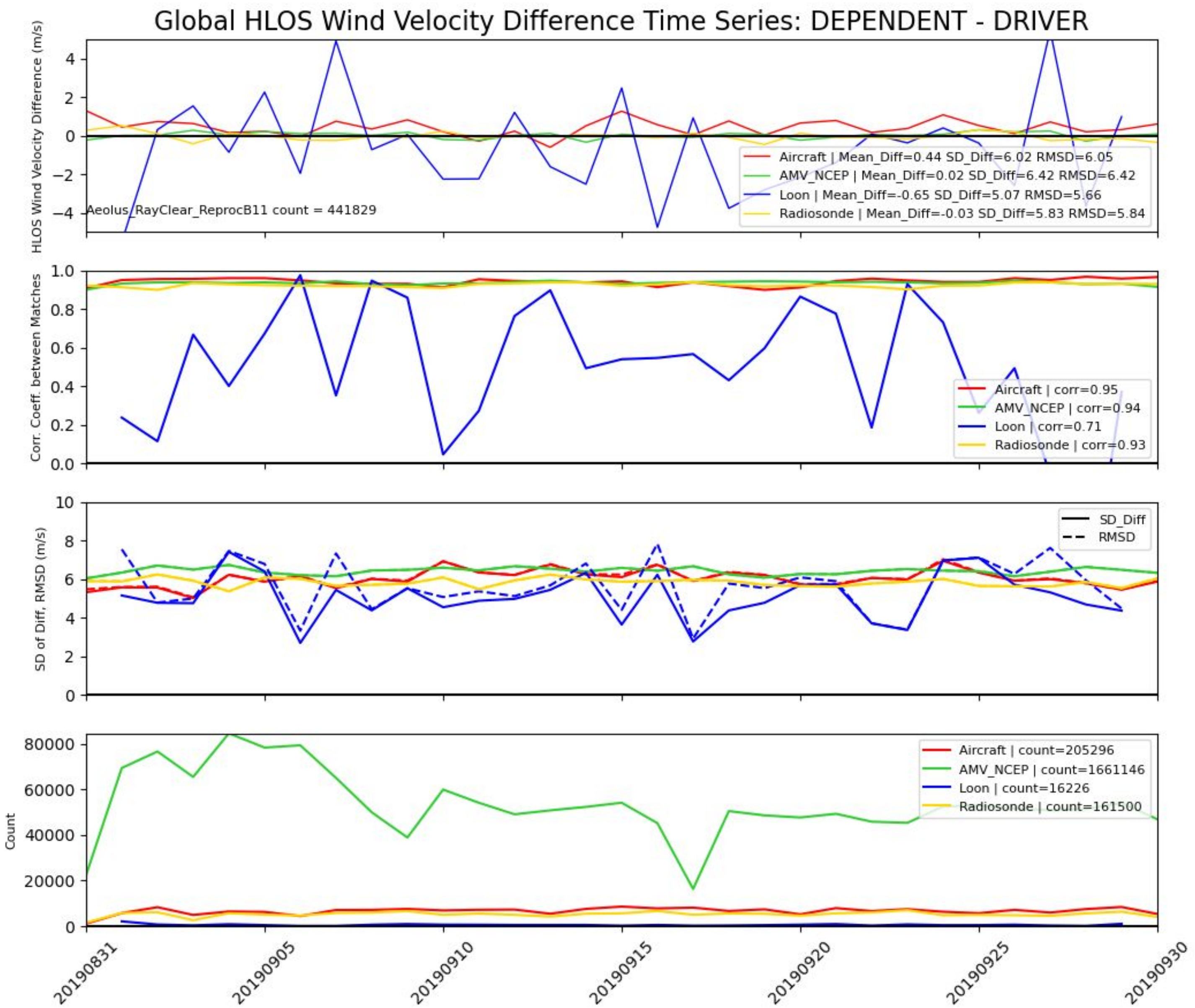

Example Figures: Winds at Specific Levels

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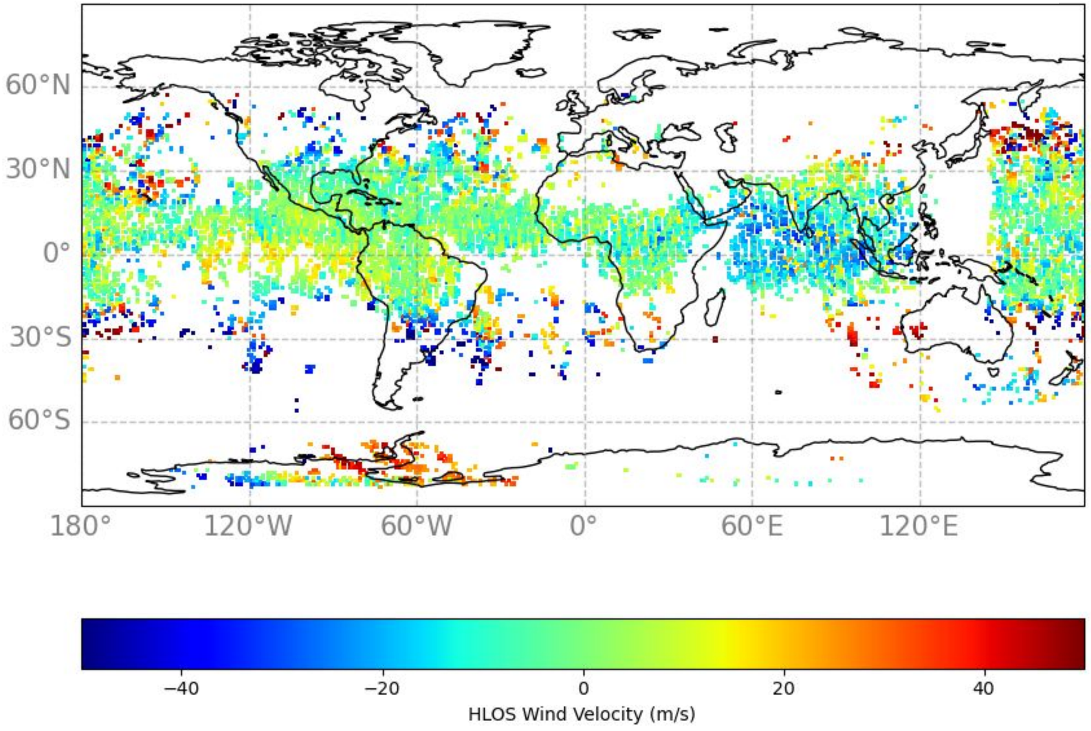
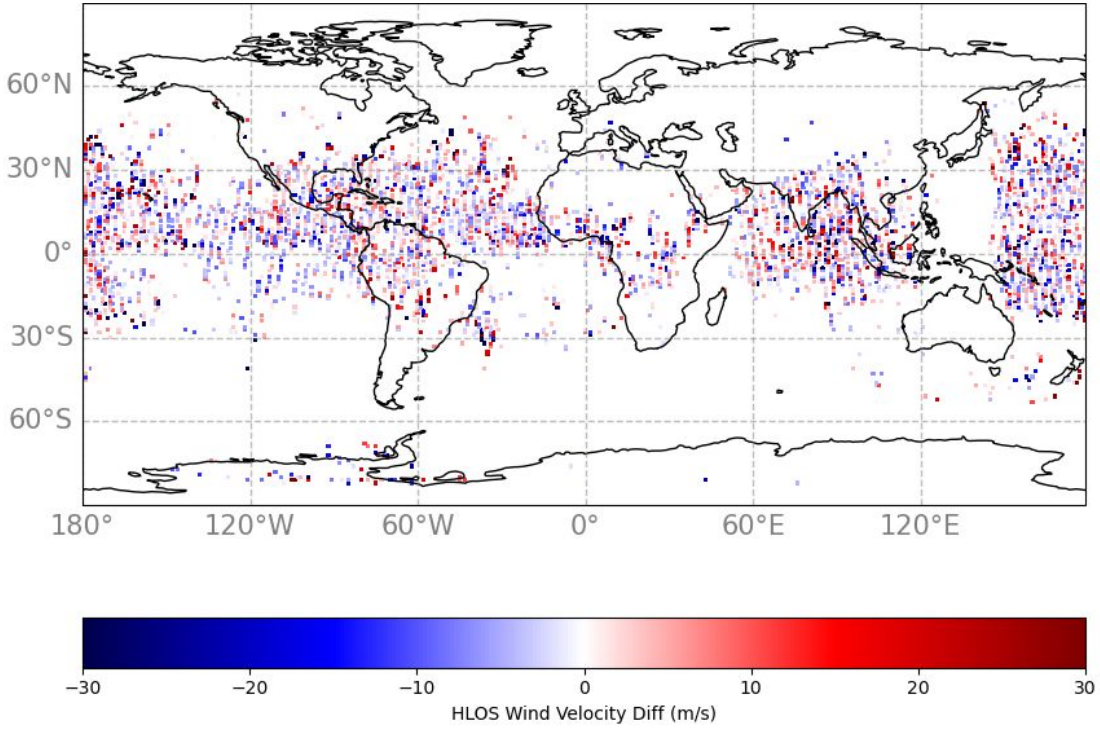
Mean AMV HLOS within layer centered on 200 hPa

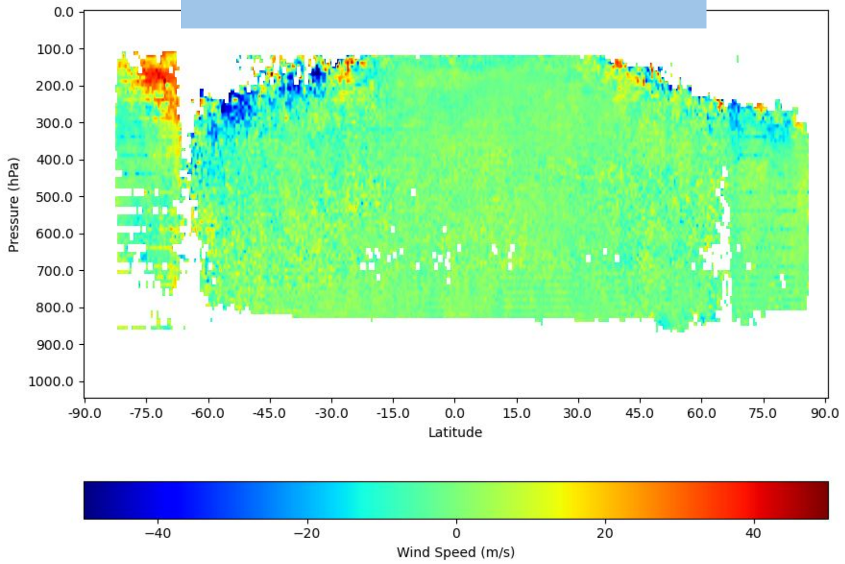


Mean AMV - Aeolus within layer centered on 200 hPa

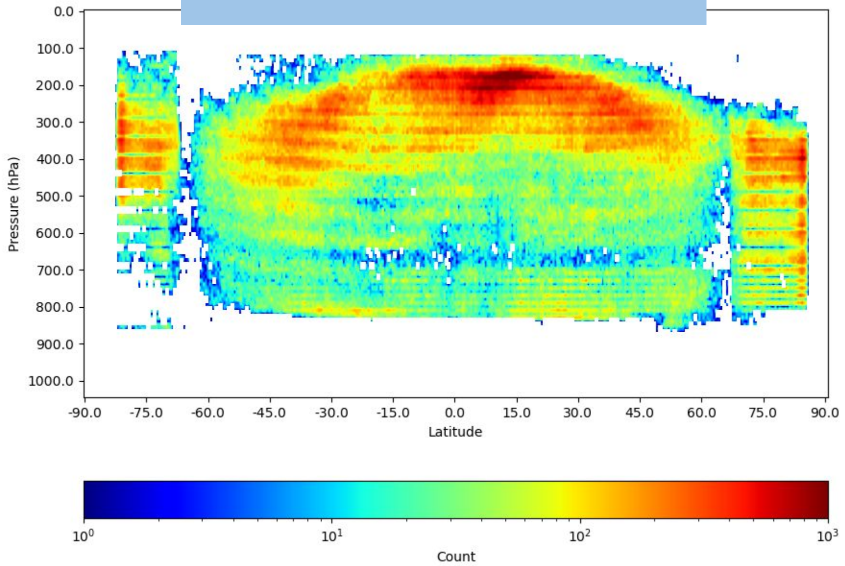


Example Figures: Zonal Means & 3D Plots

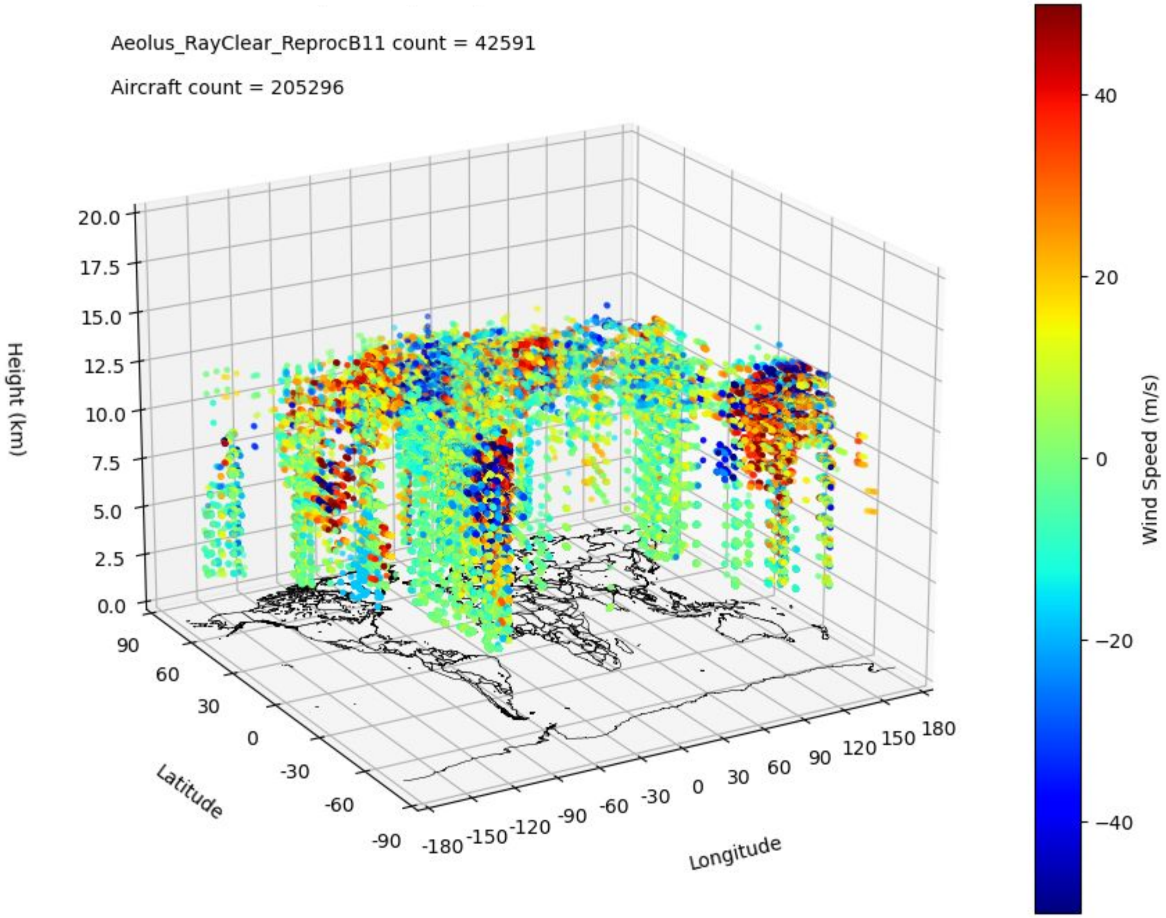
AMV Zonal Mean Zonal Wind



AMV Obs Count



Aircraft HLOS Wind collocated with Aeolus Rayleigh-clear winds

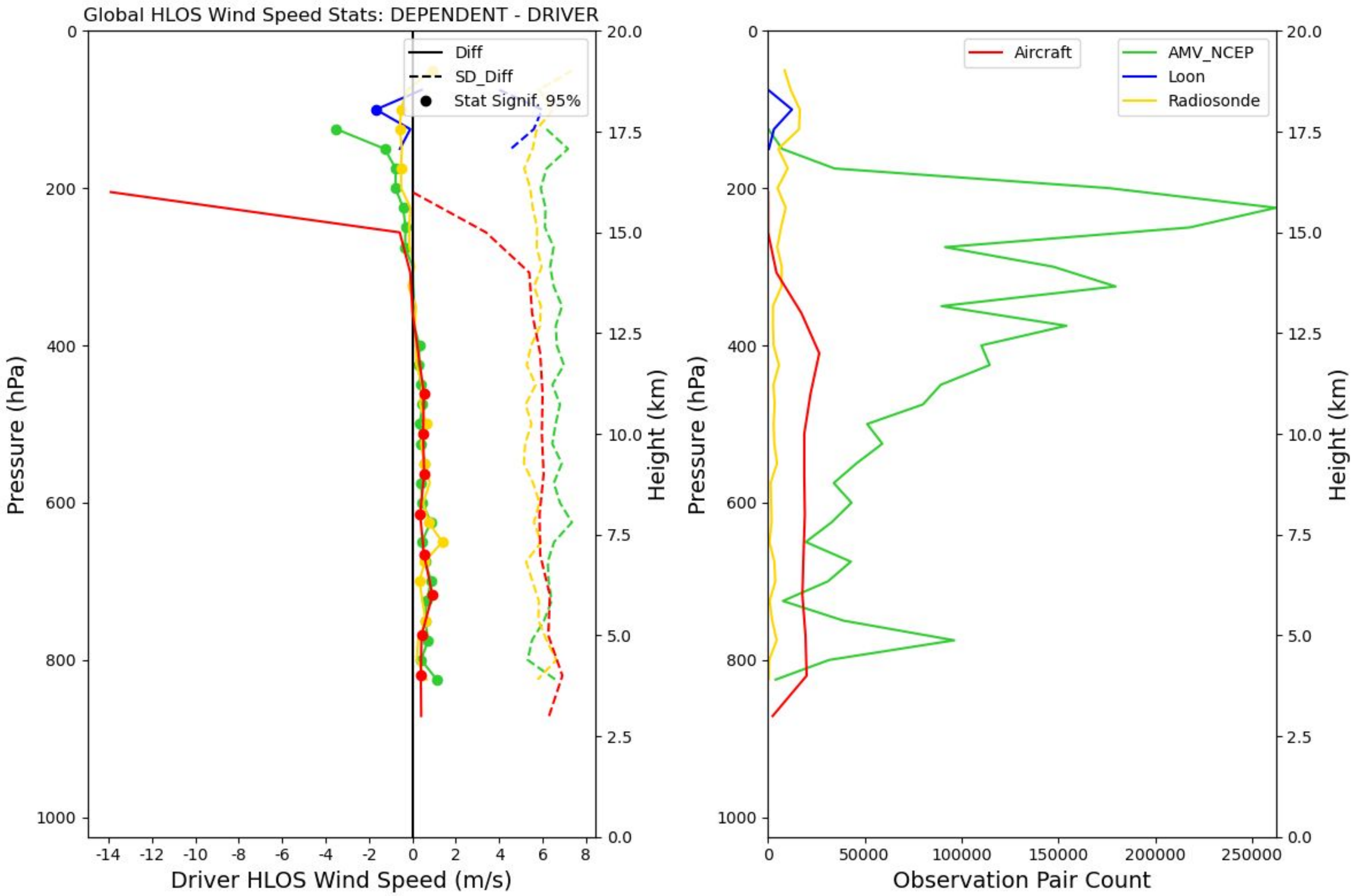


Sept 2019

Example Figures: Vertical Distributions

Sept 2019

HLOS Wind Differences **per Dataset**



Diff = HLOS wind difference
SD_Diff = Standard deviation of Diff

Example Figures: Diff, Error vs Driver Wind Speed

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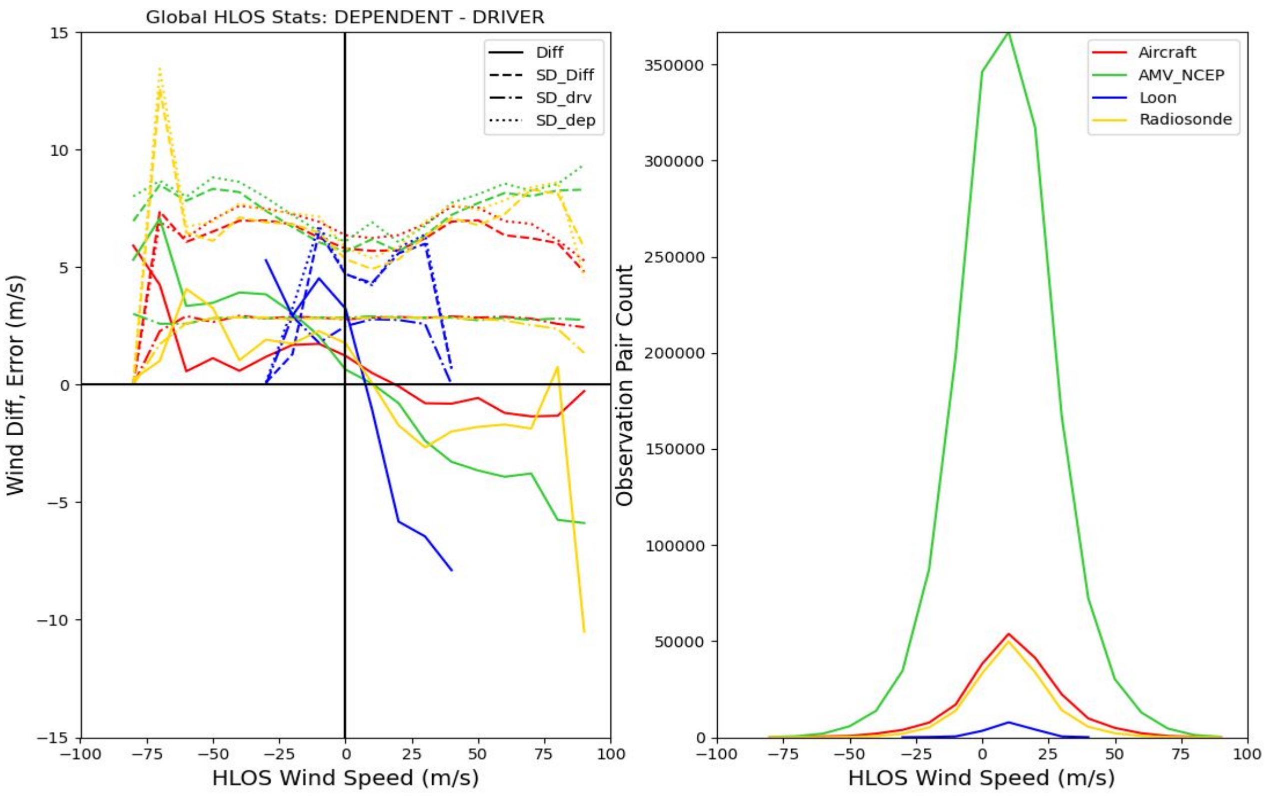
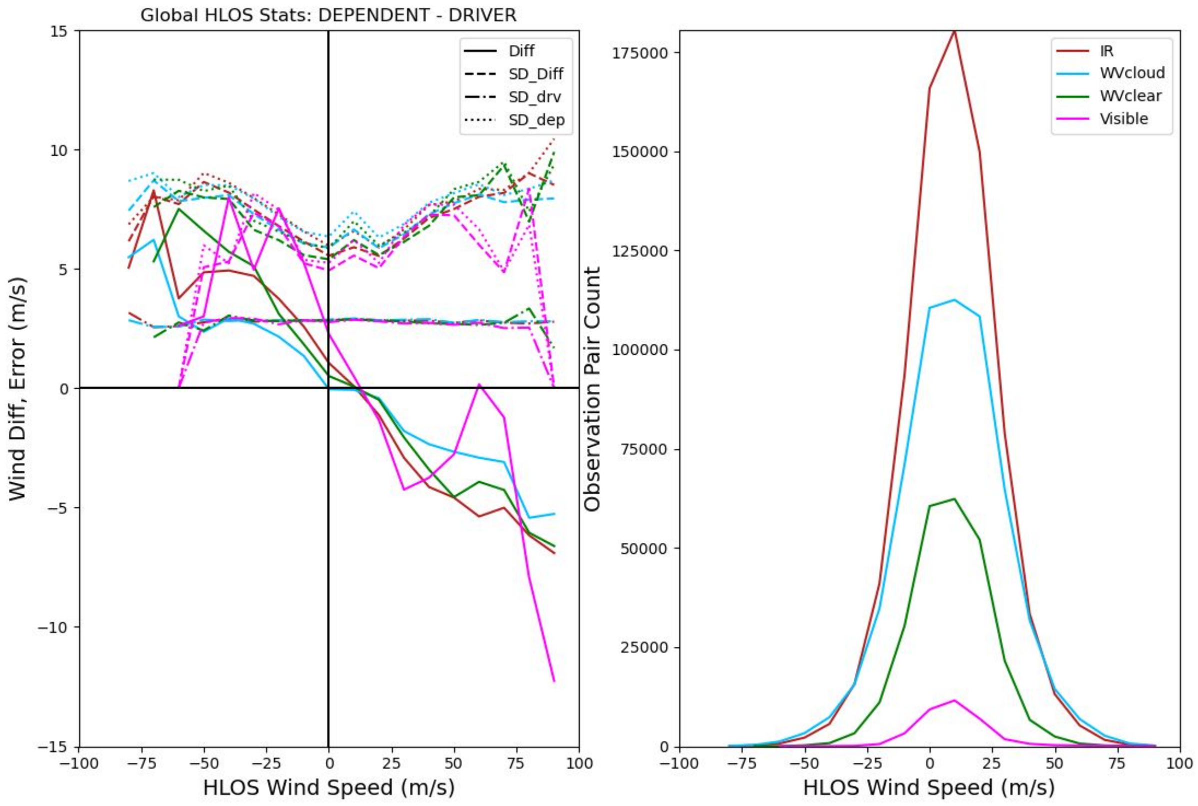
Wind Diff, SD of Diff **per Dataset**



Wind Diff, SD of Diff **per AMV type**



Diff = HLOS wind difference
SD_Diff = Standard deviation of Diff
SD_drv = SD of Driver wind
SD_dep = SD of Dependent wind

Summary

The **System for Analysis of Wind Collocations (SAWC) was jointly developed between STAR, CISESS, and CIMSS** to quantify the high priority for accurate wind observations and to facilitate wind intercomparisons from multiple sources.

- SAWC contains an archive of available 3D wind observations, collocated pairings, and an application developed for their quantitative intercomparison, all in one central location.
- Application is designed to be flexible and handle additional datasets.
- **SAWC is available now:**
  - FTP: ftp.ssec.wisc.edu/wind-datasets
  - URL: https://bin.ssec.wisc.edu/wind-datasets
  - Application: https://bin.ssec.wisc.edu/wind-datasets/atmos-nc-dataset/collocation/application/
  - User Manual: https://bin.ssec.wisc.edu/wind-datasets/atmos-nc-dataset/docs/User_Manual/

Paper in preparation:

Lukens, K. E., K. Garrett, K. Ide, D. Santek, B. Hoover, R. N. Hoffman, and H. Liu, 2023: System for Analysis of Wind Collocations (SAWC): A Novel Archive and Application for the Intercomparison of Winds from Multiple Observing Platforms.

Ongoing study: Long-term evaluation of Aeolus winds relative to aircraft, AMV, Loon, and RAOBS using SAWC.

Summary of Contributions to Project

Component		Institution	Contributors
Project Management		NWS/OSTI	Kevin Garrett
		UMD	Kayo Ide
Data Acquisition & Processing	Acquisition of Wind Datasets • Aeolus winds from ESA (EE, BUFR) • Aircraft winds from NCEP (BUFR) • AMVs from NCEP (BUFR) • Rawinsonde winds from NCEP (BUFR) • Stratospheric balloon winds from Loon (NetCDF)	NWS/OSTI	Kevin Garrett
		NESDIS/STAR, UMD/CISESS	Katherine Lukens
	Data conversion to common format (NetCDF)	NESDIS/STAR, UMD/CISESS	Katherine Lukens
	Archival and public storage on S4 HPC system	NESDIS/STAR, UMD/CISESS	Katherine Lukens
		UW-Madison/SSEC	S4 Admins
Collocation Application	Original development of collocation procedures (Python)	UW-Madison/CIMSS	David Santek
		NCEP/EMC-Lynker	Brett Hoover
	Original development of plotting procedures (MATLAB)	UW-Madison/CIMSS	David Santek, Chia Moeller
		NCEP/EMC-Lynker	Brett Hoover
	Updated and stream-lined software to handle all available datasets. Upgraded tools to Python and expanded their capability.	NESDIS/STAR, UMD/CISESS	Katherine Lukens
		UW-Madison/CIMSS	David Santek
		NCEP/EMC-Lynker	Brett Hoover
	Archival and public storage of output collocation index files on S4	NESDIS/STAR, UMD/CISESS	Katherine Lukens
		UW-Madison/SSEC	S4 Admins

Thank You

Acknowledgments

- ESA, ECMWF, the NCEP/EMC Obsproc team, and Loon, LLC for providing the data
- Peter Marinescu for his contributions towards converting Aeolus BUFR data into 6-hour NCEP prepBUFR for the purpose of data assimilation in NOAA NWP
- Chia Moeller for her contribution towards the initial development of tools for analysis and visualization
- David Huber for his contribution towards optimizing the computational processing of SAWC
- Aeolus Cal/Val teams, Mike Hardesty, Erin Jones, Chris Barnet, and Sebastian Bley for their scientific and technical expertise
- Iliana Genkova, Jim Jung, Jaime Daniels, Cathy Thomas, and Emily Liu for their expertise on NCEP prepBUFR and winds in NOAA NWP
- SSEC at the University of Wisconsin (UW)-Madison for their support in creating and managing the SAWC archive. The UW-Madison S4 supercomputing system (Boukabara et al., 2016) was used in this work.
- Sid Boukabara for his leadership and support of this project.
- The authors acknowledge support from the NOAA/NESDIS Office of Projects, Planning, and Acquisition (OPPA) Technology Maturation Program (TMP) through CICS and the Cooperative Institute for Satellite Earth System Studies (CISESS) at the University of Maryland (UMD)/Earth System Science Interdisciplinary Center (ESSIC) (grant nos. NA14NES4320003 and NA19NES4320002) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at UW-Madison (grant no. NA20NES4320003).

Contact: Katherine Lukens katherine.lukens@noaa.gov

Supplemental: Aeolus HLOS Wind QC

Rayleigh Winds are rejected if obs:

- Are close to topography (pressure > 800 hPa),
- Have horizontal accumulation lengths < 60 km,
- Vertical accumulation lengths < 0.3 km,
- L2B uncertainty > 12 m s^{-1} at upper levels (pressure < 200 hPa),
- L2B uncertainty > 8.5 m s^{-1} at lower levels (pressure > 200 hPa).

Mie Winds are rejected if obs:

- Are close to topography (pressure > 800 hPa),
- L2B uncertainty > 5 m s^{-1} at any level.

Definitions

- ***L2B uncertainty***: Aeolus HLOS wind error estimate assigned to each wind measurement.
- ***Horizontal and vertical accumulation lengths***: Horizontal and vertical distances over which individual measurement signals are accumulated and averaged to improve the signal-to-noise ratio.
    - In this way, Aeolus observations represent wind volumes and not discrete points or levels.

*List is not all-inclusive

Global Wind Collocation Studies*: What's been done

Studies	Objectives	Challenges	Collocation Criteria
Borde et al. (2016)	**To highlight the performance of a new global AVHRR wind product** that extracts AMVs using pairs of images from MetOp-A and -B	Global AVHRR product performance exhibits large bias in tropics where AMV extraction is known to be problematic	**Horizontal distance < 0.25°** **Pres diff < 25 hPa** **Time diff < 45 min**
Bormann et al. (2003)	**To quantify spatial correlations of AMV obs errors** for use in DA	Seasonal variation of AMV obs errors	**Max distance = 150 km** **Pres diff < 25 hPa** **Time diff < 90 min**
Genkova et al. (2008)	**To compare AMVs** produced from international satellite wind producing centers	Varying QI applications and height assignment accuracy across centers	**Max distance: < 0.5 degrees lat/lon**
Lukens et al. (2022)	**To leverage Aeolus level-2B wind profiles as a potential comparison standard** to characterize AMV observation bias and uncertainty	• Sample size is relatively small. • AMV height assignment errors and co-location/representativeness errors in • the presence of high wind speeds and strong vertical wind shear, particularly for RAY comparisons	**Max time diff = 60 min** **Max pres diff = 0.04 log10(p) in hPa** **Max distance = 100 km great circle**
Martin et al. (2021)	**To validate Aeolus winds** using radiosonde data and NWP forecast equivalents	Rayleigh winds exhibit systematic differences that vary with latitude. Residual bias remains even with latitude bias correction.	**Max distance = 120 km** **Height diff < 500 m** **Time diff < 90 min**
Rani et al. (2022)	**To validate Aeolus winds** using radiosonde data, AMVs, and aircraft data	• AMV observation errors may contribute to slow and fast biases exhibited by Aeolus winds in lower and upper troposphere, respectively. • Limited temporal/spatial coverage of sondes and aircraft limit the validation of Aeolus.	**Max horiz. distance = 50 km** **Max vert. distance = 250 m** **Time difference < 30 min**
Santek et al. (2019)	To conduct a new **intercomparison study of AMVs** derived from updated algorithms from several satellite wind producing centers	Height assignment method has the biggest impact on the lack of agreement in AMVs between centers.	With RAOBS: **Max Distance = 150 km, Pres diff < 50 hPa, Time diff < 90 min** With AMVs: **Max Distance = 55-100 km, Pres diff < 50 hPa, Time diff < 60 min**
Velden and Holmlund (1998)	**To recommend standard colloc. criteria between RAOBS and AMVs**	Although these standards are still generally followed today, it is widely understood by most that the colloc. criteria can/should be lessened with AMVs generated from today's advanced imagers (correspondence with Jaime Daniels, STAR)	**Time diff < 90 min** **Distance < 150 km** **Height diff < 25 hPa**
Velden and Bedka (2009)	**To investigate the importance of height assignment accuracy** to AMV observation errors for DA	• Height assignments are a large source of AMV uncertainty. • Accurate height assignment in high-vertical-shear regions near and within upper-tropospheric jets. • Vertical spread of AMV information is not well understood in DA.	**Max distance = 50 km** **Time difference < 1-h**

Global Wind Collocation Studies*: Continued

*List is not all-inclusive

Studies	Objectives	Challenges	Collocation Criteria
Borde et al. (2019)	• To compare upcoming EUMETSAT AMV products with current operational products. • To compare the performance of SEVIRI and FCI algorithms to ECMWF forecast winds	None listed outright	**Max distance = 150 km** **Pres diff < 25 hPa** **Speed > 2.5 m/s**
Bormann et al. (2003)	To quantify spatial correlations of AMV obs errors for use in DA	Seasonal variation of AMV obs errors	**Max distance = 150 km** **Pres diff < 25 hPa** **Time diff < 90 min**
Genkova et al. (2010)	To compare AMVs produced from international satellite wind producing centers	Varying QI applications and height assignment accuracy across centers	**Max distance: < 0.5 degrees lat/lon**
Hoffman et al. (2021)	To proposed a method to apply an empirical feature track correction (FTC) in a new observation operator for atmospheric motion vectors (AMVs)	• Sample size is small. • Aeolus Rayleigh-clear winds exhibit larger RMSD values below cloud level that could misrepresent the true wind at AMV level.	**Max time diff = 60 min** **Max pres diff = 0.04 log10(p) in hPa** **Max distance = 100 km great circle**
Santek et al. (2014)	To update results of previous AMV intercomparison studies (e.g., Genkova et al. (2008)) by including new algorithms	• Not all centers define a • consistent AMV speed and direction from tracked feature displacements. • Distribution of AMV heights is highly variable due to the variability of how brightness T used for height assignment is defined.	Colloc. with RAOBS: **Max Distance = 150 km** Colloc. with AMVs: **Max Distance = 135 km**
Santek et al. (2021)	To evaluate Aeolus by comparing with AIRS 3D winds, radiosondes, and reanalysis data	Comparison is limited to polar regions and short time period	**Within 100 km (150 km for rawinsondes), +/- 90 minutes (+/- 60 min. for rawinsondes), +/- .04 difference in log10 pressures (approx. height) ... +/- 60 hPa at 700 hPa ... +/- 20 hPa at 200 hPa**