Evaluation of Spire GNSS-R Ocean Surface Wind through Comparison with ERA5 Reanalysis and Jason-3 Altimeter Wind Data

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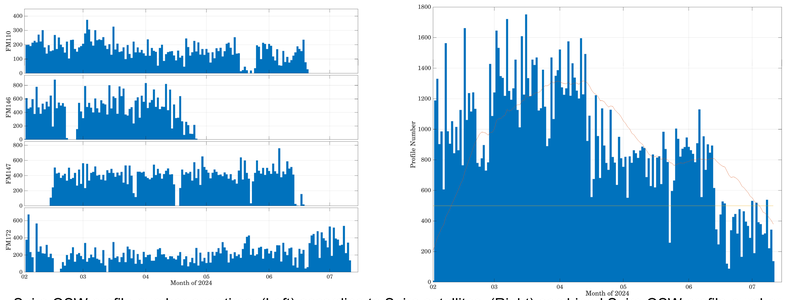
Abstract

- GNSS-R uses surface-reflected GNSS signals to gather information about the Earth's surface. GNSS-R measurements can be used to retrieve the ocean surface wind (OSW) and soil moisture.
- Spire Global Inc. launched its first GNSS-R satellites in 2019. As part of the NOAA Commercial Data Program (CDP), a Pilot study was conducted to assess the quality and impact of Spire GNSS-R observations for measuring OSW and other characteristics.
- This study evaluates the Spire GNSS-R ocean surface winds by comparing them with collocated ECMWF Reanalysis v5 (ERA5) wind data and Jason-3 Altimeter wind data.
- The dependence of Spire versus ERA5 and Jason-3 altimeter OSW difference is characterized with respect to Spire satellites (i.e., FM110, FM146, FM147, and FM172) and GNSS transmitters (i.e., GPS, Galileo, and BeiDou),. The difference in Spire OSW biases among GNSS transmitters are reported.
- The functional relation of Spire retrieval to the Normalized Bistatic Radar Cross-Section (NBRCS) is examined by comparing NBRCS with collocated ERA5 and Jason-3 altimeter wind data and understanding their dependences.
- The dependences of the Spire OSW data on antenna beamforming and incidence angle are also discussed

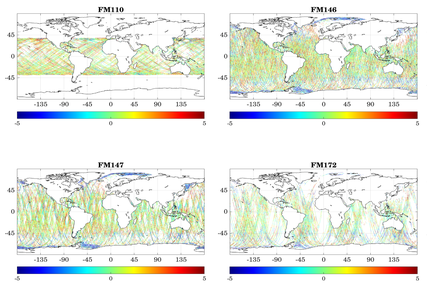
Spire Ocean Surface Wind Profile Number Variation



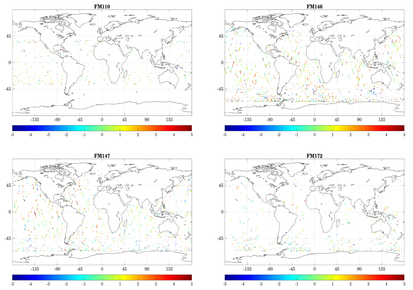
- Spire OSW profile number over time. (Left) according to Spire satellites. (Right) combined Spire OSW profile number from 4 satellites. Red line is 30-day moving average. After middle June, only one Spire sensor (FM172) remained to deliver data.

Collocation-based Comparison between Spire and ERA5/Jason-3 OSW

Spire – ERA5 OSW Difference Distribution

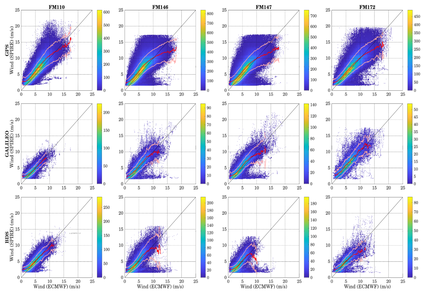


Spire – Jason-3 OSW Difference Distribution

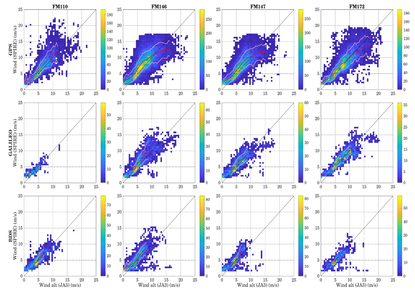


- Spire OSW data: v02.07 from Feb. 15 to Apr. 15
- ERA5 wind data at 6-hour interval and over 0.5-degree grids. Spatial and temporal interpolations of ERA5 wind data to enable collocated comparison with Spire OSW.
- Jason-3 wind speed from altimeter measurement: Calculated with the Ku-band backscatter coefficient and the significant wave height using the Gourrion approach [Gourrion et al, 2002] and Collard's model [Collard, 2005].
- The collocation between Spire and Jason-3 altimeter measurements is constrained to be within 1 hour and 50 km.

Spire OSW vs. ERA5 OSW



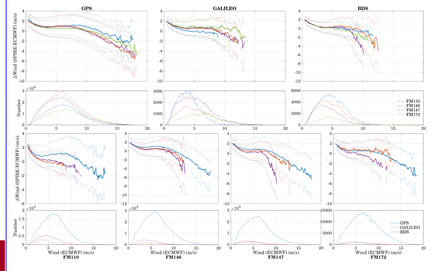
Spire OSW vs. Jason-3 OSW



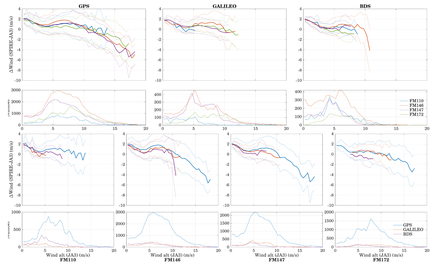
- Spire/GPS OSW has more data compared to those from Spire/Galileo and Spire/Beidou.
- The overall dependence on FM and GNSS are consistent between Spire vs. ERA5 and Spire vs. Jason-3
- The lower cutoffs of Spire OSW appear to be the same for all FM and GNSS; Spire OSW high cutoffs vary with Spire FM and GNSS. Spire/GPS FM146, 147 and 172 have clear OSW cutoffs < 20 m/s; FM147/Galileo OSW can be > 20 m/s
- Spire OSW from Galileo and Beidou have narrower wind speed range for FM110 than from GPS.
- Spire vs. Jason-3 comparison has less false low Spire OSW data when the reference OSW is high

Inter-comparison of Spire versus Jason-3 and ERA5 OSW Differences among Spire FM and GNSS

Spire vs. ERA5 OSW Differences



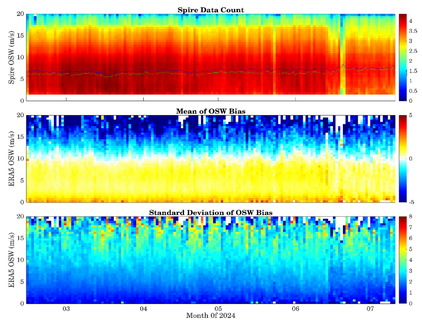
Spire vs. Jason-3 OSW Differences



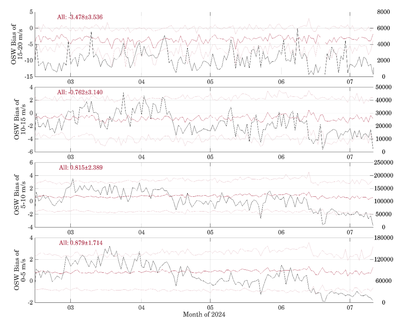
- In general, Spire vs. ERA5 and Jason-3 OSW differences are consistent for different FM and GNSS (GPS, Galileo and Beidou) combinations.
- The OSW range with the lowest OSW difference, i.e., the most consistent between Spire and ERA5/Jason-3, is in the 2-10 m/s region
- Spire/GPS vs. ERA5/Jason-3 differences are more consistent and with larger OSW range than Spire/Beidou.
- Spire FM147/Beidou has large negative biases for OSW above 8m/s from Spire vs. ERA5 comparison
- FM 146, FM 147 and FM 172: Spire/GPS vs. ERA5/Jason-3 OSW differences are in general consistent with Spire/Galileo

Time Variation of Daily Spire vs. ERA5/Jason-3 OSW Difference and Standard Deviation

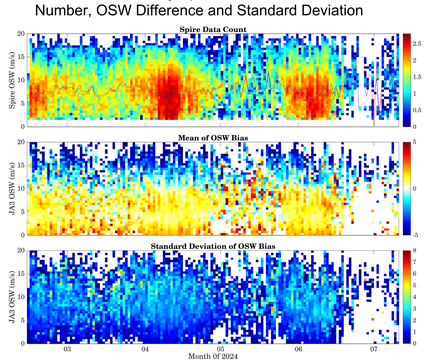
Time variation of Daily Spire vs. ERA5 OSW Data Number, OSW Difference and Standard Deviation



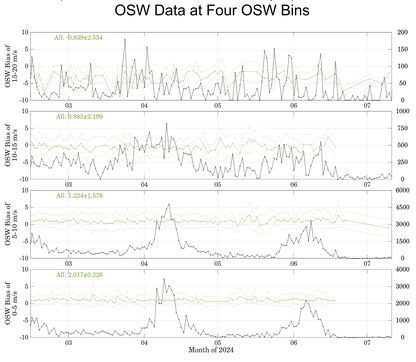
Comparison of Time variation of Daily Spire vs. ERA5 OSW Data at Four OSW Bins



Time variation of Daily Spire vs. Jason-3 OSW Data Number, OSW Difference and Standard Deviation



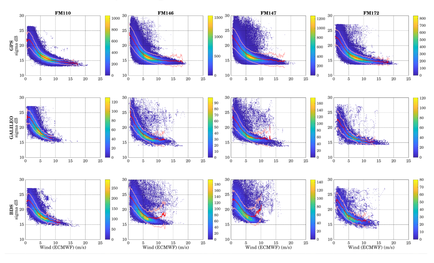
Comparison of Time variation of Daily Spire vs. Jason-3 OSW Data at Four OSW Bins



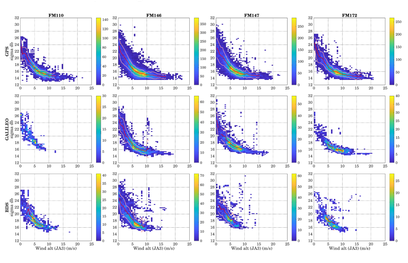
- Spire OSW has a lower cut off OSW speed at 2 m/s.
- Both the Spire vs. ERA5 and Jason-3 OSW biases show persistent positive OSW bias below ~10 m/s and negative bias above ~10 m/s over the entire data delivery period.
- The Spire vs. ERA5 OSW standard deviation shows larger variation for OSW > 10 m/s.
- The Spire vs. ERA5 OSW biases are in general stable for OSW < 10 m/s. But, when Spire FM172 became the only one to deliver OSW data after the middle of June, we can see the small decrease of Spire vs. ERA5 OSW biases (in 0-5 and 5-10 m/s bins) in comparison with the periods when more than one Spire FM satellites were delivering the data.
- For OSW > 10 m/s, the Spire vs. ERA5 OSW biases are negative with mean OSW bias of -0.76 and -3.48 m/s for OSW bins of 10-15 m/s and 15-20 m/s, respectively.
- The Spire vs. ERA5 OSW biases fluctuate more for OSW > 15 m/s, possibly due to less OSW reaching such magnitude of OSW.
- The concentrated collocations between Spire and Jason-3 in April and June can be due to their orbital characteristics.
- The Spire vs. Jason-3 OSW biased are in general quite stable for OSW < 10 m/s before middle of June. For periods after middle of June and OSW > 10 m/s, the collocated number is too few to make an assessment.

Comparison of Spire Normalized Bistatic Radar Cross-Section (NBRCS) versus Collocated Jason-3 and ERA-5 OSW

Spire Sigma0-DB vs. ERA5 Wind

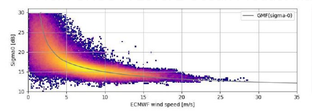


Spire Sigma0-DB vs. Jason-3 Wind



- Spire Sigma0-DB measured at the specular point vs. collocated ERA-5 and Jason-3 OSW relations for different FM and GNSS pair in general agree
- Spire Sigma0-DB vs. Jason-3 OSW shows more confined relation with less uncertainty than Spire Sigma0-DB vs. ERA5 OSW, which can be due to the more restrict collocation criteria used for Spire vs. Jason pairs.
- FM110 and FM172 have upper cut-off around 27 in Sigma0-dB; FM146 and FM147 can reach higher Sigma0-dB
- Galileo and Beidou do not seem to have good low Sigma0-dB coverage (< 15) corresponding to high wind speed

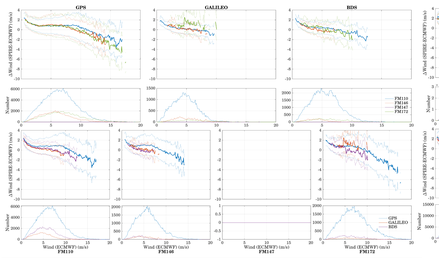
From GNSS-R Level 2 Ocean Product Manual



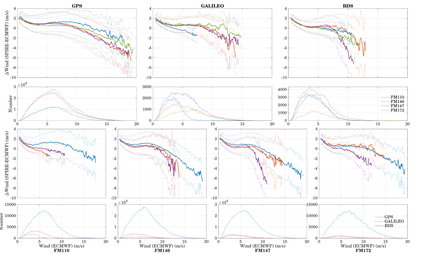
Density plot of 2D distribution of measured filtered Spire sigma0 and the ECMWF background wind. The grey line shows the empirical fucntion derived from the statistics.

Dependences of Spire OSW on Antenna Beamforming and Incidence Angle

With Beamforming



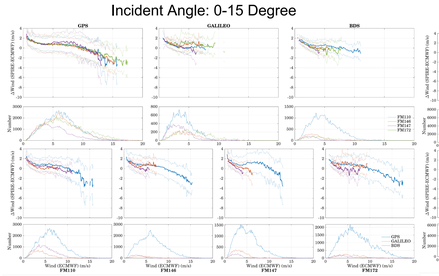
Without Beamforming



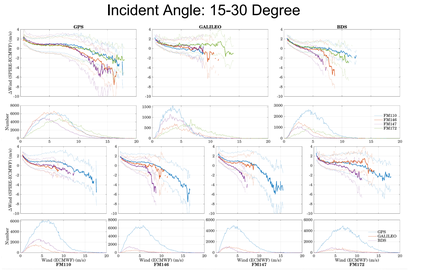
Dependence of Spire OSW vs. ERA5 wind speed difference on Antenna Beamforming

- Only middle beamforming is used for Spire FM110, 146, and 172; No-beamforming is the dominant usage; FM110 uses much more frequent beamforming than FM146 and FM172.
- Beamforming seems to help reduce the biases of FM110/Galileo
- Beamforming seems to improve the consistency between FM110/Galileo and FM110/Beidou, and among FMs for GPS.

Incident Angle: 0-15 Degree



Incident Angle: 15-30 Degree



- Dependence of Spire OSW vs. ERA5 wind speed difference on incident angle
- Four spire FM/GPS biases are quite consistent when incident angle is 0-15 degree; FM/146,147 start to deviate to lower bias with OSW > 10 m/s when incidence angle > 15 degree.
- Less occurrence with incident angle 0-15 degree than incident angle > 15 degree. Larger incident angle have more occurrence of high OSW

Summary

- Studied dependence of Spire vs. ERA5/Jason-3 OSW difference on Spire FM, GNSS transmitter, antenna beamforming and incidence angle; Trace Spire OSW to intermediate Sigma0 data.
- Spire/GPS OSW have significantly (5-20 times) more data than Spire/Galileo and Spire/Beidou; OSW dynamic ranges and cutoff are different among Spire and GNSS pairs.
- Spire vs. ERA5 and Jason-3 wind difference in general agrees and depends on Spire and GNSS pairs.
- Note: Spire/Galileo and Spire/Beidou OSW products are still experimental and needs further evaluations.
- This evaluation will help characterize and understand the Spire GNSS-R OSW data quality and prepare for Spire OSW observation error characterization for weather forecasting.

Acknowledgments

The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.