

**NOAA/NESDIS**



**Commercial Weather Data Pilot (CWDP)**

**Round 2 Summary**

**June 2020**

## Background

Radio Occultation (RO) is an established method for remote sounding of the atmosphere. The technique uses an instrument in low-Earth orbit to track radio signals from Global Navigation Satellite System (GNSS) transmitters as they rise or set through the atmosphere. The occulting atmosphere refracts or bends the radio signals, and given the precise positions of both satellites, the bending angle can be deduced from the time delay of the signal. Collecting these measurements for a full occultation through the atmosphere provides a vertical profile of bending angles, from which profiles of physical quantities such as temperature, humidity, and ionospheric electron density can be retrieved. These data primarily feed numerical weather prediction (NWP) models that support weather forecasts, and also support space weather applications.

Deployable on small satellites, RO instruments complement microwave and infrared sensors, fill in the sparse geographical and temporal coverage of radiosondes, and provide vertical and temporal resolution complementing other satellite observations. Weather centers currently ingest thousands of RO profiles per day from various government satellite systems. Studies indicate that increasing the quantity of RO data, particularly in orbits and times not served by government systems, would further improve forecasts. Ionospheric observations from RO sensors also enhance space weather situational awareness, revealing variations in the ionosphere that impact GNSS performance and radio communications. Beyond these direct benefits, additional sources of RO data could provide risk mitigation for any unexpected reductions in other data streams.

NOAA began assessing the potential of commercial sources of RO data in 2008 as part of contracted studies to assess a variety of commercial capabilities. The availability of space-based commercial RO data has grown in recent years, with two companies providing RO data from space today.

## CWDP Program Overview

To assess the viability of currently available commercial RO data sources, NOAA solicited vendors with RO capabilities to participate in the Commercial Weather Data Pilot (CWDP) program. In Round 1 (2016–2018), NOAA awarded contracts to GeoOptics and Spire Global. However, GeoOptics did not have satellites in orbit in time to deliver any data and Spire only succeeded in delivering data to partially meet their contract deliverables. NOAA concluded, based on the results of Round 1, that the commercial sector was not able at that time to provide the quality and quantity of RO data that NOAA requires for use in operational weather forecasting. However, it showed potential and warranted further examination as capabilities progressed.

In Round 2 (2018–2019), NOAA awarded contracts to three vendors—GeoOptics, Spire Global, and PlanetiQ. In this second round the contracts identified additional performance features to determine the suitability of commercial sources to meet NOAA’s operational mission needs. GeoOptics and Spire delivered data to fulfill their contract requirements. PlanetiQ did not launch their first satellite in time to deliver any data. This document summarizes our evaluation of the GeoOptics and Spire datasets delivered in Round 2.

The CWDP program is managed and administered by the NOAA National Environmental Satellite, Data, and Information Service (NESDIS). For Round 2 technical evaluations, NESDIS leveraged expertise from the following groups:

- University Corporation for Atmospheric Research (UCAR): data processing and quality assessment
- NESDIS Center for Satellite Applications and Research: data quality assessment
- Joint Center for Satellite Data Assimilation: NWP impact assessment
- NOAA Space Weather Prediction Center: ionospheric product evaluation

Following data evaluation, all data were archived at the NOAA National Centers for Environmental Information.

NOAA shared the Round 2 Pilot data with partner government organizations. Those agencies may make independent value assessments of the data, matched against their specific agency mission objectives.

## Evaluation Results

### Data Volume, Coverage, and Vendor Processing Capabilities

The Round 2 Request for Proposal (RFP) set a minimum requirement of 500 profiles per day, and each vendor proposed to meet or exceed that minimum, with their respective contracts requiring a specific number of profiles per day over a specific data delivery period. NOAA contracted with GeoOptics to deliver data from November 2018 through July 2019. In order to meet the data quantity requirements of their contract, NOAA extended the data delivery period for GeoOptics through October 2019. Spire's data delivery period covered June and July 2019. Both datasets consistently exceeded the minimum requirement for 500 profiles per day and were of sufficient duration to assess their quality and viability for NWP and space weather applications.

Vendors provided Level 1 data (geolocated instrument signals) per the RFP requirements. Both vendors met all requirements for Level 1 data delivery.

NOAA retrieved Level 2 products from the vendors' Level 1 data using the UCAR-hosted COSMIC Data Analysis and Archive Center (CDAAC) systems. NOAA uses the CDAAC to process RO data from COSMIC-1/2, Kompsat, and PAZ. All results described below are based on the CDAAC-processed Level 1 data that passed CDAAC quality control.

Both vendors also provided Level 2 products (retrieved physical parameters from the Level 1 data) per an option to do so provided in the RFP. The GeoOptics Level 2 products exhibited a number of intrinsic issues and underwent multiple version changes throughout the data delivery period. Spire's Level 2 products were mature and stable, with only one minor revision to the delivered data.

GeoOptics provided data from two satellites in high-inclination sun-synchronous orbits, with well-distributed global sampling but limited local time coverage. Data from a third, non-sun-synchronous GeoOptics satellite enhanced the local time coverage, but the satellite failed early in the delivery period. Spire operated many satellites, from which a subset of twelve provided data

for Round 2. The majority of the Spire satellites were also in sun-synchronous orbits. Latitude and local time distributions of the measurements for both vendors for the June–July 2019 period are shown in Figure 1. The geographic coverage of the data from both companies is similar, extending from pole to pole with a concentration in the midlatitudes. Such sampling would complement the six operational COSMIC-2 satellites, which are in low-inclination orbits and measure between  $\pm 40$  degrees latitude. More evenly distributed local time coverage would be beneficial, particularly for climate applications, however, such distribution was not a requirement of the Round 2 Pilot.

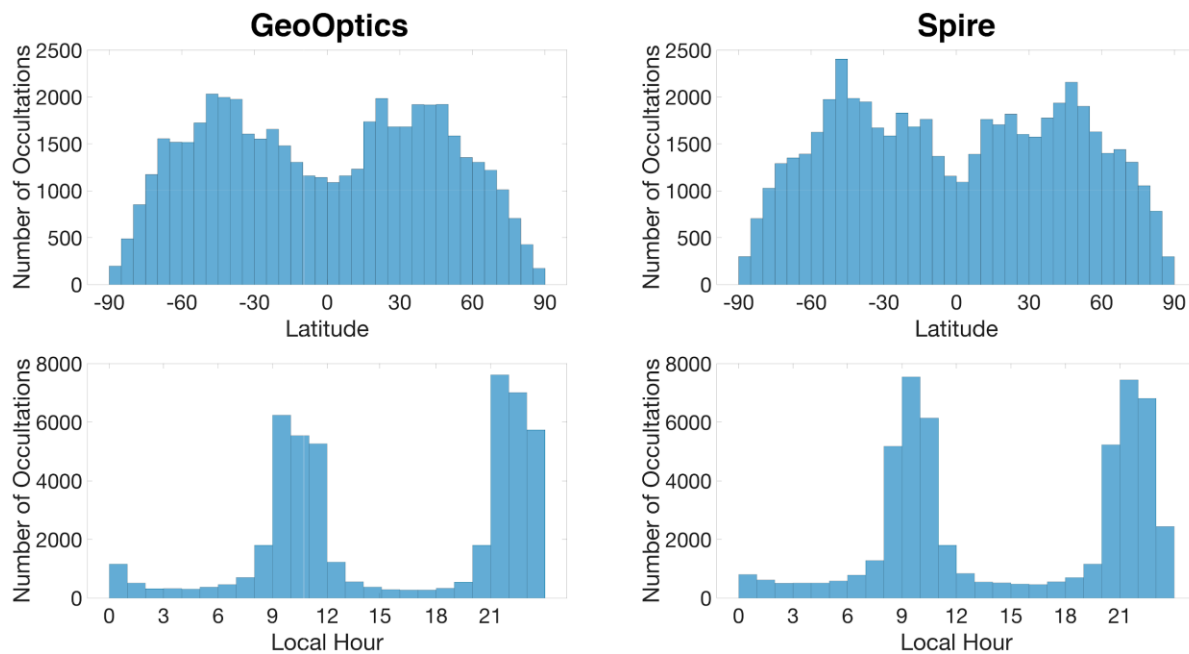


Figure 1: Latitudinal distribution (top row) and local time sampling (bottom row) for June and July, 2019. Results for GeoOptics are on the left and results for Spire are on the right.

NOAA included an option to provide near-real-time data in the Round 2 RFP, but neither vendor pursued this option. As such, NOAA was not able to assess the providers' ability to meet NWP or space weather latency requirements.

## Measurement Quality

To assess the sensitivity of the instruments, the analysis conducted by NOAA examined several metrics, including:

- Standard deviation of the difference between the bending angles and a model climatology in the 60–80 km region, denoted STDV
- Signal-to-noise ratio (SNR) of the commercial systems for each GNSS frequency
- Mean and standard deviation of differences between the RO data and collocated radiosondes, satellite measurements, and modeled measurements from NWP forecasts

STDV is of particular interest because it is predominantly determined by receiver noise and other residual errors, and thus is a good indication of the system's inherent noise floor. Figure 2 shows the distribution of STDV values for June–July 2019. Statistics are broken out separately for the

different GNSS constellations<sup>1</sup>, as they vary in performance. Both vendors provided profiles from GPS and GLONASS, while Spire also provided measurements from Galileo and QZSS (QZSS results are not shown here).

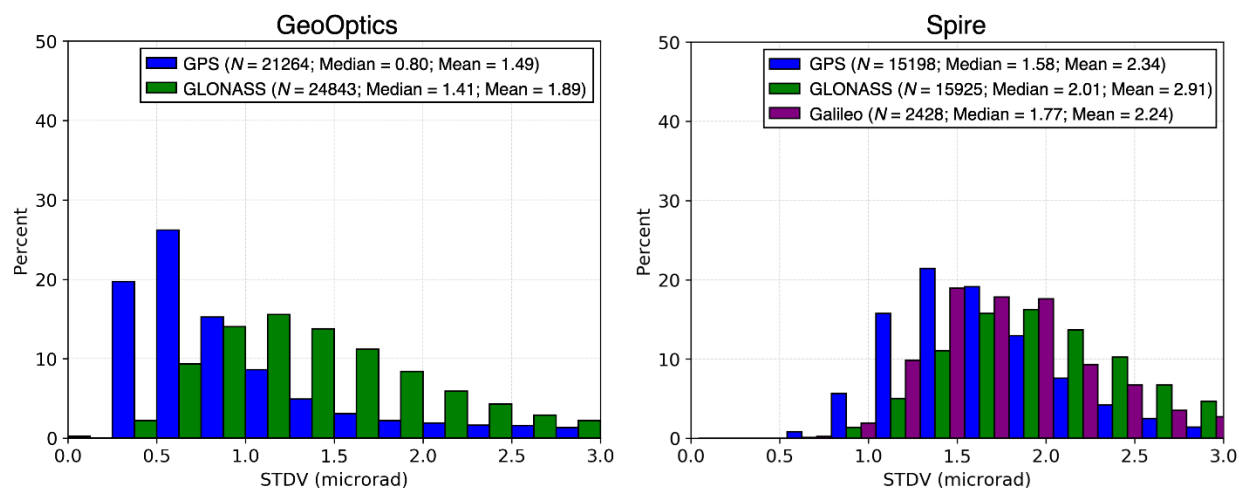


Figure 2: Distributions of high-altitude bending angle standard deviation (STDV) for Jun-Jul 2019 profiles passing CDAAC Quality Control. Note, some values exceed 3 microradians.

NOAA also computed the SNR to characterize the responsiveness of the systems to GNSS transmissions. SNR and STDV results are summarized in Table 1 with COSMIC-1/2 values listed for comparison. SNR values shown here are for the GPS L1 frequency, as all RO instruments measure this signal. Higher SNR and lower STDV are indicative of superior sensitivity and performance.

Table 1: Sensitivity of Commercial RO Systems as Compared to COSMIC-1/2

RO System	Mean GPS L1 SNR (Volts/Volt)	Mean High Altitude Bending Angle Noise, STDV (microradians)
GeoOptics	649	1.49
Spire	366	2.34
COSMIC-1	750	1.40
COSMIC-2	1513	1.05

Our analysis of the Pilot data also assessed the accuracy and precision of the bending angle profiles by comparing them with nearby radiosonde measurements, other established satellite measurements, and NWP models. One such comparison is shown in Figure 3. Here we computed the average bias with respect to the GFS model for operational data from COSMIC-1, KOMPSAT, TerraSAR, TanDEM, and Metop A-C sensors for July 2019. Figure 3 shows the difference between the bias of the vendor data and the operational RO data. Both GeoOptics and

<sup>1</sup> GPS (Global Positioning System, USA); GLONASS (GLObalnaya Navigatsionnaya Sputnikovaya Sistema, Russia); Galileo (Europe); QZSS (Quasi-Zenith Satellite System, Japan).

Spire data exhibit good agreement with the operational data between about 8 and 40 km (note the scale is 1%). Below 8 km, the number of measurements declines and interference from water vapor and other sources becomes significant, so RO measurements are generally less reliable, and above 40 km, measurement error limits their accuracy.

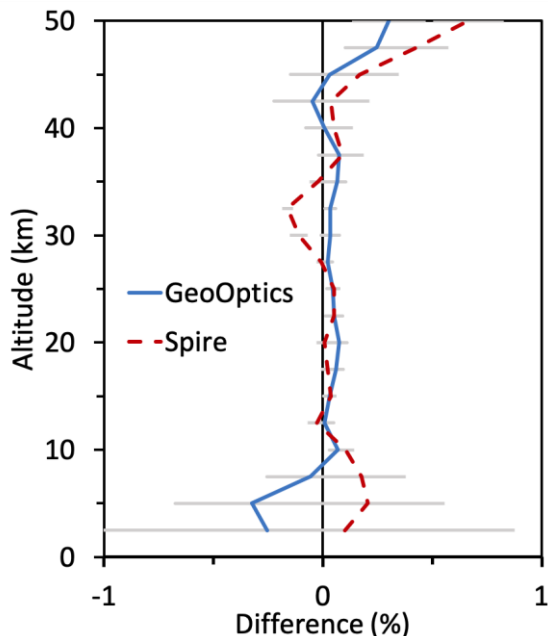


Figure 3: Comparison to operational RO measurements. The average bias in bending angle with respect to the GFS model background was computed for COSMIC-1, KOMPSAT-5, TanDEM-X, TerraSAR-X, and Metop A-C data from July 2019. The difference between the bias of the operational sensors and the average bias for GeoOptics (solid) and Spire (dashed) for the same period are shown. No collocation of measurements was performed, and measurements were effectively globally distributed. Error bars indicate the standard deviation of the bias in the operational sensors.

## Data Assimilation Studies and Impact on NWP

To assess the impact of the commercial RO data on NWP, NOAA conducted data assimilation experiments for each dataset. In these experiments, the GFS forecast model was run with and without the vendor's data incorporated, in addition to the existing operational data sources, and the accuracy of the two forecasts was compared. Forecasts were run for two 30-day periods for each vendor. For GeoOptics, January and July 2019 were used, as it is instructive and customary to evaluate data from separate seasons. For Spire, only June and July data were available, and these months were used in two separate trials. In each experiment, we measured the data's impact on the 1, 3, and 5 day forecasts for temperature, wind, and height, stratified by pressure level. Results were quantified in terms of the mean, variance, and anomaly correlation (a relative skill measure), and broken down by latitude band or region. Here we detail the results of the data assimilation experiments, which assessed the impact of each vendor's data against standard benchmarks. The vendors were not evaluated against each other.

*GeoOptics*: The strongest positive impact of the GeoOptics data was seen in the Day 1 forecast in southern latitudes. A positive impact also extended to some aspects of the Day 3 forecast in southern latitudes, and the Day 1 forecast in the north. Some positive impacts extended to the Day 5 temperature forecast in southern latitudes. The anomaly correlation impact was positive or neutral everywhere. The vendor data tended to reduce the temperature and wind forecast variability globally through Day 3. However, the data had a slightly negative impact on the mean bias, increasing it in several instances.

*Spire*: The data produced a marked positive impact on the Day 1 forecast; in the southern latitudes this was seen for all variables, and for height and temperature in the north. The positive effect was generally weaker near the surface, and the height forecast was slightly degraded at some pressure levels. Beyond Day 1, there was no beneficial impact on any variable in the north, and a slight improvement in Day 3 high altitude wind forecast in the south. Anomaly correlation was positive or neutral everywhere, with the exception of a small negative effect on heights in the northern latitudes. Variability was significantly reduced for all variables at almost every pressure, but the bias increased almost everywhere. In the tropics, reduced wind and temperature variability for some pressure levels persisted to Day 3.

In general, for both vendors, NOAA's data assimilation experiments showed slightly positive impact for the 1- to 3-day forecasts, and neutral results for the 5-day forecasts. These results are comparable to preliminary results seen in similar experiments run on data from operational systems (e.g., PAZ, Metop-C), and indicates that long-term ingestion of the vendors' data would be beneficial to NOAA's NWP systems. It is notable that the doubling of the number of profiles per day from Spire in July, as compared to June, produced a clear beneficial impact.

## Ionospheric Products for Space Weather

The NOAA Space Weather Prediction Center analyzed the quality and potential value of the Round 2 data for NOAA's space weather applications. Vendors provided total electron content (TEC: the number of electrons per unit area along the signal path) measurements, electron density profiles (EDPs: the number of electrons per unit volume as a function of altitude), and  $S_4$  and  $\sigma_\phi$  scintillation indices (measures of small-scale ionospheric variability). CDAAC independently produced TEC from the vendors' data. TEC and scintillation indices reveal any rapid variations in the ionosphere, which can impact the accuracy and availability of GNSS systems. EDPs are used to model and improve high frequency radio communications. Together, RO space weather products help end users plan and avoid operational delays in critical services.

*GeoOptics*: GeoOptics provided TEC measurements and  $S_4$  indices but did not provide  $\sigma_\phi$  indices or EDPs. GeoOptics' absolute TEC data matched the characteristics of the corresponding CDAAC-processed data. The TEC measurements improved results of NOAA's operational Global TEC (GloTEC) data-assimilation model. The GloTEC model provides situational awareness when ionospheric disturbances affect GNSS performance, radio communications, and satellite operations. GeoOptics' ionospheric products included measurements from GLONASS, which could improve data volume and coverage. Comparison against ground-based TEC measurements through GloTEC showed good agreement. The  $S_4$  indices were of mixed quality, with only one satellite providing data adequate for situational awareness.

*Spire*: Spire provided TEC measurements,  $S_4$  and  $\sigma_\phi$  scintillation indices, and EDPs. Quality varied across satellites and antennas, but some of the data showed usefulness in the GloTEC model, helping the model resolve small scale structures and rapid fluctuations in the ionosphere. Some TEC measurements contained excessive amounts of negative values, but others appeared adequate. Comparison with ground-based TEC measurements showed favorable agreement, with small but acceptable negative biases.  $S_4$  indices were low frequency (1 Hz) and inconsistent between different Spire satellites with many invalid values.  $\sigma_\phi$  measurements were noisy and difficult to evaluate. EDPs were well-calibrated, and

extracted measures related to peak electron density generally agreed with data from COSMIC-1 and co-located ionosonde measurements.

Overall, both vendors provided TEC measurements with the quality and coverage that would improve NOAA's space weather products. Scintillation measurements did not adequately cover lower elevation angles. Spire EDPs were of adequate quality. It should be noted that the evaluation period did not witness any significantly large space weather events, so the performance of the systems during such critical events was not evaluated.

## Summary and Conclusion

Table 2 provides a synopsis of the key findings of our Round 2 technical evaluation.

**Table 2: Key Findings of CWDP Round 2 Evaluation**

Evaluation	GeoOptics	Spire
<b>Neutral Atmosphere Products</b>	Noise and bias is comparable to C1 and K5. Error assessment is within range of other governmental RO platforms.	Noise and bias is slightly higher than C1 and K5, especially at high altitudes. Error assessment is within range of other governmental RO platforms.
<b>NWP Impact</b>	Comparable to government assets recently evaluated, such as C1.	Comparable to government assets recently evaluated, such as C1.
<b>Ionospheric Products</b>	Useful for space weather products. Scintillation data could improve situational awareness.	Noisy, but adequate for space weather products. Electron density profiles may also be useful.
<b>Geographical Coverage</b>	Polar orbits provide global coverage and complement C2, but local-time coverage is limited.	Polar orbits provide global coverage and complement C2, but local-time coverage is limited.
<b>Support for Problem Resolution</b>	Responsive to all requests and flexible on changing requirements.	Responsive to all requests and flexible on changing requirements.
<b>Delivery Latency</b>	Did not sign up for near-real-time deliveries in Round 2.	Did not sign up for near-real-time deliveries in Round 2.
<b>Maturity of Processed Products</b>	Initial data had significant issues. Over a dozen versions of data were provided.	Mature products, with only a minor update made during the delivery period.

Abbreviations: C1 = COSMIC-1; C2 = COSMIC-2; K5 = KOMPSAT-5

Based on the results of the technical evaluation of the data provided by two vendors in the CWDP Round 2 Pilot, NOAA has concluded that the commercial sector is capable of providing the quality of data needed to help support NOAA's operational weather forecasting needs. As a result, NOAA is proceeding with plans to acquire commercial RO data for operational use.