REPORT TO CONGRESS

COMMERCIAL WEATHER DATA PILOT PROGRAM

Developed pursuant to: Public Law 115-25, Title III, Section 302(c)(2)(B)

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TITLE III OF P.L. 115-25 INCLUDED THE FOLLOWING LANGUAGE

Title III—Weather Satellite and Data Innovation.

Section 302(c)(2)

(2)aPILOT CONTRACTS.—

(A)aCONTRACTS.—Not later than 90 days after the datea of enactment of this Act, the Under Secretary shall, through an open competition, enter into at least one pilot contract with one or more private sector entities capable of providing data that meet the standards and specifications set by the Under Secretary for providing commercial weather data in a manner that allows the Under Secretary to calibrate and evaluate the data for its use in National Oceanic and Atmospheric Administration meteorological models.

(B)aASSESSMENT OF DATA VIABILITY.—Not later thana the date that is 3 years after the date on which the Under Secretary enters into a contract under subparagraph (A), the Under Secretary shall assess and submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives the results of a determination of the extent to which data provided under the contract entered into under subparagraph (A) meet the criteria published under paragraph (1) and the extent to which the pilot program has demonstrated—

(i)athe viability of assimilating the commerciallya provided data into National Oceanic and Atmospheric Administration meteorological models;

(ii)awhether, and by how much, the data adda valuea to weather forecasts; and

(iii)athe accuracy, quality, timeliness, validity, reliability,a usability, information technology security, and cost-effectiveness of obtaining commercial weather data from private sector providers.

THIS REPORT RESPONDS TO THE CONGRESSIONAL DIRECTION.

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1. Overview

This document reports the results of the Commercial Weather Data Pilot (CWDP) Round No. 1 project conducted by the National Oceanic and Atmospheric Administration (NOAA) in 2016 and 2017. The report describes the project initiation and execution, summarizes the technical results and lessons learned by NOAA, then presents an assessment of the current readiness of the commercial radio occultation (RO) industry to provide viable operational weather data to meet NOAA's needs.

2. Executive Summary

NOAA executed the CWDP Round No. 1 project using funding appropriated in the Consolidatede Appropriations Act, 2016 (Public Law (P.L.) 114-113). On September 15, 2016, NOAA awardede contracts to two commercial vendors of RO data who were expected to be able to provide on-orbite data comparable to that provided by current government missions:e

- GeoOptics, Inc. of Pasadena, California, valued at $620,000; ande
- Spire Global, Inc. of San Francisco, California, valued at $370,000.e

NOAA entered into an agreement with the National Center for Atmospheric Research (NCAR) via the National Science Foundation to process that data using previously validated algorithms developed for existing RO missions, specifically the COSMIC-1 RO constellation. The value of this agreement was $948,454, of which $663,636 was carried over to Round 2 due to receiving less data than anticipated. NOAA used the University Corporation for Atmospheric Research (UCAR), within NCAR, as NOAA does not have an internal capability to process RO data, having contracted with UCAR for this service in the past. UCAR used processing procedures established by UCAR under NOAA mission contracts such as COSMIC-1.

The multi-agency Joint Center for Satellite Data Assimilation (JCSDA) was funded at $600,000 through the CWDP to assess the impact of the profiles in NOAA's NWP models, and carried over $375,000 of this funding to Round 2 due to receiving less data than anticipated. JCSDA is a partnership between NOAA, NASA, the U.S. Air Force, and the U.S. Navy.

The National Environmental Satellite, Data, and Information Service (NESDIS) is the entity responsible for executing the CWDP. This report partially fulfills the reporting requirement in section 302(c)(2) of P.L. 115-25.

The objectives for CWDP Round No. 1 were to: 1) assess existing commercial RO capabilities; and 2)edevelop and exercise systems and processes for ingesting commercial weather data for futuree operational use.e

One of the commercial vendors under contract was unable to launch its satellites in time to provide data during the prescribed period, while the other vendor deployed several "CubeSats" (very small satellites built from 10 centimeter cubed base structures) equipped with RO instruments into Low

Earth Orbit, and provided their on-orbit data to NOAA for processing and analysis. While Congressional direction regarding the CWDP was to "*...assess the potential viability of commercial weather data in [NOAA's] weather modeling and forecasting*", the data provided were not of sufficient quantity to perform a statistically significant assessment of the data's impact on NOAA's numerical weather prediction models.

The majority of commercial satellite data provided to NOAA failed to consistently meet quality thresholds for viable RO measurements included in the contract. Analysis of the data revealed performance issues meeting specifications in the contract such as the quantity and quality of navigation (GPS) satellite data used for Precise Orbit Determination, and signal noise and interference issues with the RO measurements.

UCAR processed the data that did meet quality thresholds to derive "atmospheric profiles", which is the format the data must be in to be ingested into Numerical Weather Prediction (NWP) models. UCAR's operational processing system ensured unbiased processing and evaluation of commercial data from all vendors, and subjected the commercial data to the same quality control standards that have been developed and vetted to ensure government RO data is suitable for operational use in weather forecasting. The atmospheric properties derived from those profiles showed close agreement with outputs from weather models. This demonstrated that these CubeSats had the technical capability to provide acceptable RO data when other quality conditions were met.

NOAA has concluded, based on the results of the CWDP Round No. 1 pilot project, that the commercial sector was not able to provide the quality and quantity of RO data that NOAA requires for use in operational weather forecasting at the time of this initial round. However, commercial RO systems show potential and, if progress continues, could serve in the future as complementary sources to existing and future government systems. NOAA believes this warrants further pilot project purchases of a greater set of commercial RO data in order to conduct a more thorough evaluation.

3. CWDP Background

The CWDP Project was initiated by Congress via the Consolidated Appropriations Act, 2016 (P.L. 114-113). The Explanatory Statement accompanying this Act included the following language:

"Commercial Weather Data Pilot. – NOAA shall, through an open competitive process, seek to enter into at least one pilot contract to assess the potential viability of commercial weather data in its weather modeling and forecasting. This funding shall be used to purchase, evaluate, and calibrate available data, which meets the standards and specifications set by NOAA in its Commercial Data Policy."

In its "Commercial Weather Data Pilot Program" Report to Congress on March 17, 2016[1], NOAA

[1] http://www.space.commerce.gov/wp-content/uploads/CWDP-FY16-Congressional-Report.pdf

committed to documenting the results of each round of CWDP data evaluation. This report meets that commitment for CWDP Round No. 1. The Weather Research and Forecasting Innovation Act of 2017 Section 302(c)(2)(B) (codified at 15 U.S.C. § 8532(c)(2)(B)) calls for an assessment of data viability as part of the CWDP Program required in Section 302(c). This report also partially fulfills the Section 302(c)(2)(B) requirement.

Based on input from the commercial sector via recent market research using Federal Acquisition Regulation (FAR) processes, NOAA focused on RO as the most suitable data type for CWDP Round No. 1, to be evaluated by NESDIS.

The National Weather Service (NWS) uses supercomputers to run NWP models to predict the future state of the atmosphere, which provide the foundation of weather forecasts. Those NWP models require accurate data on the current state of the atmosphere to initiate the model run. The majority of the data comes from satellites, traditionally operated by government agencies. RO is one of many data types that provide current atmospheric conditions to initiate NWP models. The RO data delivered to the ground from satellites must be processed into profiles prior to being ingested into NWP models.

The objectives stated by NESDIS for CWDP Round No. 1 were to: 1) assess existing commercial RO capabilities; and 2) develop and exercise systems and processes for ingesting commercial weather data for future operational use. Evaluation of the CWDP Round No. 1 demonstration data took place through FY 2017, and NESDIS issued its interim report in March 2017.

4. CWDP Round No. 1 Data Processing and Evaluation

NOAA entered into an interagency agreement with the National Center for Atmospheric Research (NCAR) – through its sponsor organization the National Science Foundation – to fund on-orbit data quality assessment and processing by UCAR. Under this arrangement, UCAR: 1) ensured data received from vendors met quality thresholds specified by NOAA in the contract; 2) processed data received into profiles; and 3) compared the characteristics of the resultant profiles to characteristics of profiles from government RO satellites and outputs of weather models.

With the exception of specific software changes to account for small format differences in the commercial data, UCAR used identical data quality checks against contract requirements, processing routines, and analysis methods for the commercial RO data as for existing U.S. and international partner RO missions (i.e., COSMIC-1; NASA Gravity Recovery and Climate Experiment; EUMETSAT GNSS Receiver for Atmospheric Sounding on Metop-A and -B). These procedures were established by UCAR under NOAA mission contracts such as COSMIC-1. UCAR's operational processing system ensured unbiased processing and evaluation of commercial data from all vendors, and subjected the commercial data to the same quality control standards that have been developed and vetted to ensure government RO data is suitable for operational use in weather forecasting.

5. CWDP Round No. 1 Data Contracts

At the time of formulation of the CWDP Project in early 2016, market research revealed that no commercial vendors had yet established a system of on-orbit RO receivers, but concrete plans for first launches were in place by several companies, leading NESDIS to expect multiple compliant bids to a formal Request for Quotation (RFQ).

In accordance with the NOAA Commercial Space Policy and the NESDIS Commercial Space Activities Assessment Process, NESDIS released a Request for Information (RFI)[2] as the first step in purchasing RO data from commercial companies for analysis. The RFI, released on May 24, 2016, solicited information about status and plans for deploying RO systems, and requested pre-launch samples of ground-based test RO data on a no-cost basis. The RFI was tailored in this manner to allow a range of potential vendors to participate, from those with satellites already on orbit, to those with systems not yet deployed but in the advanced stages of instrument, satellite, and mission development.

The response period for the RFI closed on June 13, 2016, and the responses received from industry provided valuable inputs as NESDIS considered what criteria to include in a RFQ, the next step in executing the CWDP project.

On June 21, 2016, NESDIS released a draft RFQ[3] for on-orbit RO data from commercial sources, seeking public comment by July 15, 2016. NESDIS held the third in its series of community engagements with the commercial satellite industry[4] on July 7, 2016, in conjunction with the public comment period. This event focused on addressing questions about the draft RFQ, and these questions and answers were subsequently posted online alongside the draft RFQ.

On July 28, 2016, based on the community engagement and public comments received, NESDIS prepared and released the final RFQ for CWDP Round No. 1. Responses to the solicitation were due on August 12, 2016. The RFQ was designed to allow for broad industry participation in the CWDP, consistent with the preceding RFI. The RFQ requested vendors to provide three to six months of on-orbit RO data collected daily and delivered monthly to NOAA using industry-standard data formats. While the RFQ did state the number of occultations needed per day for NOAA to conduct an assessment of the data's impact on NOAA's numerical weather prediction models, the RFQ did not set minimum requirements for number of occultations per day, spatial distribution of RO measurements around the globe, data latency, or secure real-time data delivery, again to allow broad

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[2] https://www.fbo.gov/index?s=opportunity&mode=form&id=09512e960853e562024b6bd2f631ee6b&tab=core&_cview=0

[3] The full docket containing the CWDP Round 1 draft RFQ, Industry Day notes, and final RFQ is at: https://www.fbo.gov/index?s=opportunity&mode=form&id=4cc131a9206cac6e4b88bfe8c34a8807&tab=core&_cview=0.

[4] This series of Community Engagement events was initiated in 2015, with the first two events held on April 28, 2015 and December 7, 2015.

participation in the CWDP.

The RFQ requirements did specify satellite data quality factors such as tracking of dual-frequency navigation satellites to enable Precise Orbit Determination (POD) of the satellites during RO measurements.[5] For those vendors ultimately placed under contract, the capabilities stated by the vendors in their proposals were incorporated into the requirements of the final contracts.

The CWDP Round No. 1 project exercised NESDIS processes for commercial contract structure and technical evaluation methods. Round No. 1 did not exercise NESDIS processes for secure ingest of data with operational latency or commercial data distribution rights negotiation.

Prior to the CWDP, NOAA had conducted market research to estimate industry price points to be in the range of $12-$18 per operational RO observation based on significant economies of scale gained for operational quantities of data. The CWDP Round No. 1 pricing offered by vendors for demonstration data was three to eight times higher than this, which reduced the number of observations NESDIS was able to purchase.

Based on evaluation of the three RFQ responses received, NESDIS awarded contracts totaling $990,000 for delivery of on-orbit radio occultation and related satellite data to: GeoOptics, Inc. of Pasadena, California, valued at $620,000; and Spire Global, Inc. of San Francisco, CA valued at $370,000.

Per the RFQ, the on-orbit data delivery period opened October 1, 2016, and the vendors had until April 30, 2017, to provide data. Due to launch delays, GeoOptics did not deliver on-orbit data to NESDIS before the deadline; the contract was cancelled by bilateral agreement, without prejudice, and the funds were de-obligated.

NESDIS did receive on-orbit data from Spire; Spire's final contract award amount was eventually reduced to $87,300 to reflect the volume of usable data that was delivered by April 30, 2017. The remaining $282,700 was de-obligated.

Of the total funding obligated to Round No. 1 contracts, only $87,300 was paid to Spire Global, one of the two contractors. NESDIS will carry over the $902,700 of deobligated funds and will direct these funds towards future CWDP Round No. 2 activities in FY 2018.

6. Commercial Data Quality Assessment

6.1 Analysis of the Quality of GeoOptics Data

As noted above, GeoOptics did not deliver any data for analysis.

[5] The full set of technical requirements may be viewed in Attachment 1 to the RFQ, available at https://www.fbo.gov/index?s=opportunity&mode=form&id=b98b3972cc76d98391dd84ba98b3c4ae&tab=core&_cview=1.

6.2 Analysis of the Quality of Spire Data

Spire had eight CubeSats with closed-loop RO instruments on orbit in time to support the contracted on-orbit data provision period. Spire provided NOAA with RO data from four of those eight satellites. Spire delivered the data to UCAR for processing during the data delivery window of October 1, 2016, to April 20, 2017. Analysis of the data occurred between when the first data arrived and September 30, 2017.

Initial quality checks of the on-orbit data during the delivery period to ensure compliance with contract requirements showed quality issues with the majority of the data making it unusable for processing, as confirmed during discussions between NOAA and the vendor. The main issues found were:

- GPS signals picked up by the RO instrument and its dedicated antenna were harder to distinguish from background "noise" caused by GPS signals scattered or reflected by the Earth, noise internally generated by the antenna, and electromagnetic interference (EMI) from the satellite itself;
- Some RO data were acquired without the high-accuracy navigation data required by the contract[6], leading to uncertainty in precise RO satellite position at the time of the occultation, which is a key aspect of deriving quality RO profiles; and
- Measurement timestamps in the RO data and the navigation data did not correspond; these clock offsets made it difficult to align the two data sets.

NOAA gained insight into the sensitivity of the overall processing chain to these variations in data collection while processing the Spire data. NOAA informed Spire of these issues, and in response Spire made adjustments to improve the quantity and quality of the data collected over the final week of the delivery period, though this data still did not meet all contract requirements. The following analysis is based solely on this improved data from the final week of the delivery period, which will be referred to in the rest of the report as Spire's "second-delivery" data.

Spire RO data could be processed into profiles when:

- Navigation and RO signals were stronger against background "noise", with limited or no EMI present;
- Four or more GNSS satellites were in the field of view, allowing more precise computation of CubeSat positions; and
- Spire software fixes were created to account for the clock offset.

With the assistance and advice of Spire, NOAA's data processing partner UCAR adapted the processing chain to ingest the second-delivery Spire data and filtered out remaining lower-

[6] These properties include dual-frequency navigation data and the number of navigation satellites in the field of view of the CubeSat.

quality inputs from the final week. The UCAR processing chain then derived more viable profiles for quality assessment, and provided the profiles as inputs to non-operational NWP models for impact assessment.

6.2.1 Analysis of the Suitability of Spire Data for NWP use

NOAA did not receive enough data to perform a statistically significant NWP impact analysis or quality evaluation, but some of the individual profiles derived from the Spire data showed a good fit to expectations. In evaluating the data NOAA examined both: 1) whether the data met specifications in the contract; and 2) how the data compared to other sources of RO data and to model data.

Figure 1 shows an example of one such atmospheric temperature profile. The **red line** represents a single "dry" temperature profile derived from Spire's RO measurements. The **green line** represents the model of predicted temperature from the European Centre for Medium-range Weather Forecasting (ECMWF). The vertical axis is altitude above the Earth's surface.

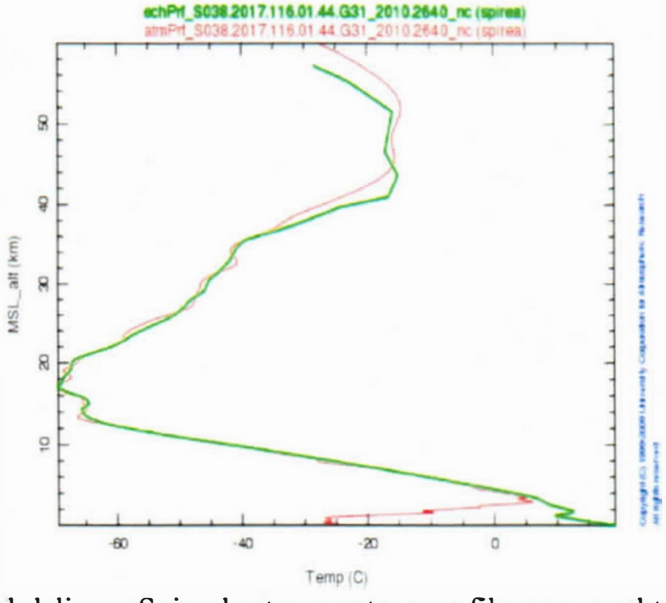

Figure 1. Second-delivery Spire dry temperature profile compared to ECMWF model

Figure 1 shows that a Spire profile from the second-delivery data set is in close agreement with the model. This agreement is similar to what would be expected from other spaceborne RO systems such as COSMIC-1, EUMETSAT's Metop-A and Metop-B, NASA's Gravity Recovery and Climate Experiment-B (GRACE-B) satellite, Germany's TerraSAR-X, and Korea's KOMPSAT-5.

A common method of monitoring radio occultation data quality is to compute statistics comparing them with global numerical weather model or analysis products. Figure 2 shows how data points from COSMIC-1 data and the second-delivery set of Spire data, collected over the same time period, deviate from an NCAR climatology model. The figures are based on 109 Spire data points and 967 COSMIC-1 data points available from the same time period, April 24-28, 2017, in the 60km – 80km altitudes (note several Spire data points fall out of the range of the graph). The Spire graph on the right shows a greater standard deviation (shown on the x-axis) of the Spire profiles from the NCAR model than the COSMIC-1 profiles. The greater standard deviation in the Spire data represents less consistency and less agreement with expected values than the COSMIC-1 data.

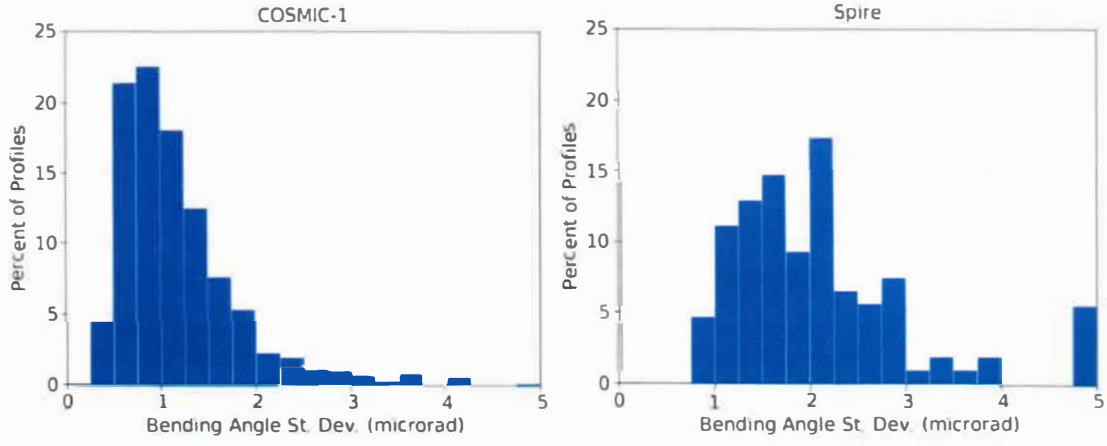

Figure 2. Histograms of COSMIC-1 and Spire bending angle standard deviations from NCAR Climatology Model, courtesy of UCAR COSMIC Data Analysis and Archive Center

In summary, information derived from the second-delivery set of Spire profiles showed some agreement with weather model outputs, as seen in Figures 1. However, this agreement was not consistent. Figure 2 additionally shows the lack of consistency seen in the set of Spire second-delivery profiles by illustrating a larger deviation within Spire profiles than within COSMIC-1 profiles. NOAA did not receive enough data to make statistically significant conclusions about the overall quality of the Spire data.

6.3 IT Security

Within the limited scope of Round 1, IT security was not an area explored. Vendors had no access to internal NOAA systems except through a secure FTP site to upload data on a monthly basis as required in the contract. In the future should NOAA use commercial data operationally, NESDIS will need to employ a method to securely ingest the data on operational timelines. This area will be further explored in CWDP Round No. 2.

7. Lessons Learned

NESDIS learned important lessons during the execution of the CWDP Round No. 1 project, based ono technical analysis and programmatic activities, as summarized in this section.o

a) **Having data in advance is critical to prepare for data processing**
A period of advance ground and/or on-orbit data for analysis and acceptance, before starting theo formal evaluation period, allows early screening for data quality and format issues.o

b) **NOAA must require that vendors state risks to their proposals**
NOAA needs to have all information necessary to decide whether and when to initiate a contracto based on all risk factors, including potential for delayed data provision periods due to reliance ono future launch dates.o

c) **NOAA must require verification and validation against contract requirements**
Satellite data must be quality-checked by the vendor soon after downlink, and NOAA must haveo insight into the quality check methods.o

d) **NOAA contracts must enable a post-award conversation with vendors**
NOAA and partners would benefit from continued vendor assistance in processing on-orbit datao during the project execution and data analysis phases. Post-award technical interchangeo meetings could be used as the basis for communication between parties throughout the contracto period. These meetings must be well-defined with limitations made clear.o

e) **NOAA must be able to state specific requirements without driving solutions**
NOAA needs to succinctly state pre-processed satellite data quality requirements for commercialo weather data sources, without unduly driving vendor system solutions and potentially system ando data costs. However, NOAA would require insight into vendor error analysis and quality controlo processes to confirm requirements are met.o

f) **Use demonstration projects as calibration/validation for future data streams**
CWDP Round No. 1 confirmed the need for calibration and validation, followed by ongoingo quality control during ingest, for data streams ingested for operational use by NOAA. Ino addition to evaluating the data's impact to inform an operational data purchase decision,o demonstration projects are a key first step in calibrating and validating a data stream prior to anyo operational ingest.o

g) **Ensure vendors understand contract requirements**
NOAA should hold a post-award kick-off meeting to clarify and confirm mutual understandingo of the technical and programmatic requirements.o

h) **Price may vary significantly between demonstration and operational offerings**

As described above, the prices offered in CWDP Round No. 1 were three to eight times higher than prices for operational data given in previous NOAA market research. NOAA must be prepared to pay higher prices for demonstration data that will not exhibit the economies of scale of operational data purchases.

8. CWDP Round No. 1 Conclusion and Next Steps

CWDP Round No. 1 showed that the commercial sector was unable to meet NOAA RO requirements for use in operational weather forecasting during this time frame.

Some results from evaluating the commercial RO-derived profiles were promising, based on their comparison with numerical weather prediction models. Individual sounding comparisons of the second-delivery Spire profiles to those from NWP models indicate a close agreement, suggesting that Spire's on-orbit commercial satellite instruments can deliver viable atmospheric profiles when other satellite quality factors are met.

If commercial vendors are capable of consistently supplying accurate satellite data such as orbital position and attitude during the RO measurements with no onboard electronic interference, the data obtained from multiple satellites should yield valid profiles.

The limited number and geographic distribution of RO data supplied by just one commercial vendor during CWDP Round No. 1 does not enable NOAA to draw any conclusions regarding the general impact of commercial RO data on operational weather forecasting.

CWDP Round No. 1 has been successful in establishing and executing a process within NESDIS for evaluating commercial RO data in a manner consistent with how other data sources are evaluated. CWDP Round No. 1 also has helped NESDIS identify areas for improvement in future demonstration projects and potential operational data buys.

The results of CWDP Round No. 1 indicate that the commercial RO industry has the potential to be future suppliers of valuable atmospheric data to NOAA when their constellations are established and maintained over the long term, adding to the RO data sources available to NOAA from its core government and partner missions. Uncertainty remains regarding:

1.e The timeline for commercial RO data that meets NOAA operational requirements to be available;e
2.e The impact of commercial RO data on NOAA's weather forecasts and warnings;e
3.e The price of commercial RO data for operational use, as a market for this data has not beene established; ande
4.e The size of the market demand to sustain the number of vendors proposing to provide RO data ine the future.e

CWDP Round No. 1 has provided valuable early lessons in executing commercial weather data contracts, and based on these results, NESDIS has initiated CWDP Round No. 2 activities. CWDP

Round No. 2 is focusing again on RO data as commercial vendors progress with their plans. CWDP Round 2 seeks to: 1) extend the purchase of RO data from commercial vendors to larger quantity of data and more operational features requested such as global coverage, security, timeliness, and availability; 2) perform a more comprehensive assessment of the value of commercial RO data; and 3) advance NOAA systems readiness for future purchases of operational weather data from commercial sources.

Appendix A – List of Acronyms

COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CWDP	Commercial Weather Data Pilot
ECMWF	European Centre for Medium-Range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EMI	Electromagnetic Interference
FAR	Federal Acquisition Regulations
FTP	File Transfer Protocol
FY	Fiscal Year
GFS	Global Forecast System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE-B	Gravity Recovery and Climate Experiment-B
IT	Information Technology
JCSDA	Joint Center for Satellite Data Assimilation
KOMPSAT-5	Korea Multi-Purpose Satellite-5
Metop	Meteorological operational satellite
NCAR	National Center for Atmospheric Research
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWS	National Weather Service
POD	Precise Orbit Determination
RFI	Request for Information
RFQ	Request for Quotation
RO	Radio Occultation

UCAR University Corporation for Atmospheric Research

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