REPORT TO CONGRESS

Radio Occultation Data Gap Mitigation Plan

Developed pursuant to: Direction provided in Senate Report 115-275 incorporated by reference by Public Law 116-6; and Title III, Public Law 115-25

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THE SENATE COMMITTEE REPORT (S. REPT. 115-275) ACCOMPANYING THE CONSOLIDATED APPROPRIATION ACT, 2019 (PUBLIC LAW 116-6) INCLUDED THE FOLLOWING LANGUAGE:

Radio Occultation Data.--The Committee is concerned about NOAA's continued access to high quality radio occultation [RO] data for operational forecasts, and continued research to improve modeling capacity. Under Public Law 115-25, NOAA was directed to conduct a commercial pilot project to acquire RO data, and to proceed with the COSMIC program of record. While the Committee is optimistic about the role for commercial RO data, continued operational data is critical for weather forecasting. With NOAA's cancellation of COSMIC 2B and the original COSMIC program nearing the end of its life, the Committee directs NOAA to develop and submit a plan within 180 days of passage to manage the risk of an RO data gap and preserve the quality of NOAA forecasts. The plan should include a report on the implementation of the RO provisions of Public Law 115-25.

PUBLIC LAW 115-25, TITLE III – WEATHER SATELLITE AND DATA INNOVATION, SEC 301(a):

(a) SHORT-TERM MANAGEMENT OF ENVIRONMENTAL OBSERVATIONS. -

(1) MICROSATELLITE CONSTELLATIONS.—

(A) IN GENERAL.—The Under Secretary shall complete and operationalize the Constellation Observing System for Meteorology, Ionosphere, and Climate–1 and Climate–2 (COSMIC) in effect on the day before the date of the enactment of this Act—

(i) by deploying constellations of microsatellites in both the equatorial and polar orbits;

(ii) by integrating the resulting data and research into all national operational and research weather forecast models; and

(iii) by ensuring that the resulting data of National Oceanic and Atmospheric Administration's COSMIC– 1 and COSMIC–2 programs are free and open to all communities.

(B) ANNUAL REPORTS.—Not less frequently than once each year until the Under Secretary has completed and operationalized the program described in subparagraph (A) pursuant to such subparagraph, the Under Secretary shall submit to Congress a report on the status of the efforts of the Under Secretary to carry out such subparagraph.

THIS REPORT RESPONDS TO THE COMMITTEES' REQUESTS.

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I. Executive Summary

The COSMIC-1 mission was launched in 2006 as a proof-of-concept for a new, inexpensive radio occultation (RO) atmospheric sounding technique as a partnership between Taiwan and the United States, and led by the National Science Foundation with participation of the National Aeronautics and Space Administration (NASA), U.S. Air Force, and the National Oceanic and Atmospheric Administration (NOAA). Since early 2007, high fidelity RO atmospheric profile data from COSMIC-1 have led to important, measurable improvements in weather forecasts, and space weather monitoring and research. NOAA determined that continued access to RO measurements aligned with its mission to improve weather forecasts.

In 2012, NOAA and Taiwan developed the COSMIC-2 program to launch 12 RO satellites, six each in the equatorial (2A) and polar-orbit (2B). In 2017, through mutual agreement, NOAA and Taiwan decided to continue the COSMIC-2A equatorial mission and not pursue plans for the COSMIC-2B polar mission. COSMIC-2A (referred to as COSMIC-2 in this report), launched on June 25, 2019, will provide up to three times the data that COSMIC-1 was able to capture (though confined within ~+/- 40 degrees in latitude, as opposed to COSMIC-1 which also made observations in the mid- and high-latitudes), and with significantly improved performance over the COSMIC-1 instruments. Key atmospheric parameters such as temperature, pressure, density, and moisture will be derived from processing COSMIC-2 observations and used to improve forecasts.

In 2016, NOAA initiated Round 1 of the Commercial Weather Data Pilot (CWDP) to determine if the commercial sector could contribute to meeting NOAA’s RO data needs. NOAA determined that with additional time and with expected performance improvements the commercial sector could play an important role. In 2018, NOAA initiated Round 2 of the CWDP to assess the latest commercial capabilities for providing RO data, adding NOAA operational requirements for data latency and global distribution of observations.

NOAA’s long-term plan is to maintain an RO constellation that includes a government backbone of RO observations, augmented with data from commercial data buys and with data from interagency and international partners. The successful launch of COSMIC-2 in June 2019 in equatorial orbit is the beginning of implementation of this long-term strategy. NOAA continues to examine its next generation architecture, but potential plans will phase in future government RO capabilities by flying RO payloads on satellites in low earth orbit and augment these observations with commercial purchases and data sharing arrangements with international partners.

II. NOAA’s RO Requirements

RO data can be quantified by the number of occultation profiles or “soundings” that are obtained in a given day and/or geographical region. Several studies over the last decade have sought to quantify the relationship between number of occultations and the impact on operational weather forecasting. In 2015, the International Radio Occultation Working Group (IROWG) recommended “targeting at least 20,000 occultations/day to be made available to the operational and research communities of Numerical Weather Prediction (NWP), Climate, and Space Weather.” In 2016, the NOAA Observing Systems Council (NOSC) also endorsed the objective of 20,000 occultations per day.

The most critical satellite observations that enable NOAA’s NWP are global temperature, pressure, and humidity measurements of the atmosphere. These are produced by two independent approaches: observations of the passive microwave and infrared emissions from the atmosphere, observed globally and near simultaneously, and observations of the distortion of the Global Navigation Satellite System (GNSS) signals as they transit the atmosphere. The passive sounding observations, collected through NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) high performance satellites, provide comprehensive coverage of the globe.

In addition to its observation utility for Numerical Weather Prediction, RO observations collect narrow atmospheric transect soundings in a totally independent method that lets them serve as critical unbiased, calibration measurements to complement the passive observations. In particular, RO observations provide a definitive altitude registration that serve to calibrate the vertical position of the passive observations. The performance of the overall observing system is significantly improved by the mixture of the three measurement types: microwave, infrared, and radio occultation soundings.

In 2018, the NOAA Satellite Observing System Architecture (NSOSA) study assessed the most cost-effective means of satisfying NOAA’s space-based requirements following the Geostationary Operational Environmental Satellite-R (GOES-R) Series, Joint Polar Satellite System (JPSS), COSMIC, and space weather programs. In support of NOAA’s space architecture analysis, the architecture team worked with NOAA Line Offices, under the auspices of the NOSC, to establish the reliability requirements on all space-based observations, including RO measurements. This process determined the optimal observing system includes a combination of all three sounding types. Regarding RO observations, the study established a threshold of 5,000 globally distributed occultations per day must be provided at the highest quality and availability. The remaining 15,000 observations per day, which provide important atmospheric sounding information, may have more flexibility in performance level, availability, and geographical distribution. The remainder of this document will refer to 5,000 occultations as the threshold requirement and 20,000 occultations as the NOSC-recommended level objective. Some research has indicated that added value to NWP may continue to accrue for as many as 50,000 occultations per day; therefore, collecting more than 20,000 occultations per day is not precluded in NOAA’s plans. Working with the science community, NOAA will continue to monitor and adjust quantity and geographic distribution thresholds as additional information about their expected impact to NWP models becomes available from the scientific community (see Figure 2 and Appendix D).

III. Current Status of Meeting NOAA's RO Requirements

RO technology supports the National Weather Service's (NWS) mission to provide weather, water, and climate forecasts for the protection of life, property, and enhancement of the national economy. The consistent inclusion of globally, geographically distributed RO sounding profiles improves the quality of these forecasts and can help mitigate the impact of a gap in other types of data such as radiosondes and space-based infrared and microwave sounding.

However, only a relatively small number of RO sounding profiles are available to support weather forecasts today (see Appendix C, Figure 2; and Appendix D):

- The satellites that have provided the majority of the RO sounding profiles until recently; the COSMIC-1 satellites, were launched in April 2006 into polar orbits. Now well past their 5-year design life, only one of the original six COSMIC-1 satellites remains operational, at a reduced duty cycle.

- NOAA's international partners currently produce RO data from several satellites that NOAA assimilates for operational use.

- Neutral atmosphere profiles from the recently launched COSMIC-2 mission will be available in fiscal year (FY 2020 for incorporation into NOAA's NWP systems.

- Congress has provided funding in the *Consolidated Appropriations Act, 2020,* for the operational purchase of commercial RO data.

The six COSMIC-2 satellites in equatorial orbits will provide high quality RO sounding profiles of the tropics and subtropics. The COSMIC-2 instruments benefit from advanced instrumentation that provide a greater number of sounding profiles per instrument, with improved accuracy and deeper atmospheric penetration than COSMIC-1. The higher accuracy and deeper extension into the lower troposphere of COSMIC-2 data is expected to have a significantly increased impact on NWP beyond that achieved through the increased density and spatial coverage of the observations. While the COSMIC-2 constellation is still undergoing early activation and validation at the time of this report, NOAA expects the constellation will provide over 5,000 soundings per day in the topics and prove highly beneficial to NWS in FY 2020, particularly for monitoring the evolution of tropical storms.

The RO data from international partners listed in the table in Appendix D are less accurate than COSMIC-2 because they are all derived from the previous generation of RO sensors. Metop-C is flying the GNSS Receiver for Atmospheric Sounding (GRAS) which provides better RO quality information from the mid-latitudes pole-ward than the aging COSMIC-1 constellation. However, because the Metop series are in a sun-synchronous orbital plane, they do not provide the global temporal resolution that was available from COSMIC-1. It is too early to know how GRAS RO will perform compared with COSMIC-2.

IV. Mitigation Plan

The NSOSA study demonstrates that NOAA can cost-effectively satisfy the critical 5,000 observations in the future by including RO payloads on future Joint Polar System (NOAA and EUMETSAT) low earth orbiting (LEO) satellites. A disaggregated, distributed set of LEO sounder satellites could provide the geographical coverage desired for RO measurements without dedicated RO satellite programs. The Joint Polar System, a 2015 bilateral Joint Polar System agreement between NOAA and EUMETSAT, contemplates such arrangements. NOAA plans to work with partners and vendors to secure; the remaining 15,000 observations per day. NOAA has data access partnerships in place with national agencies, including NASA, EUMETSAT, German Aerospace Center, Japanese Aerospace Exploration Agency, and others (see Appendix D), and will continue to pursue others as they are available. NOAA will also work with vendors for additional observations, depending on the value per occultation at the offered performance level and price as commercial capabilities become available, consistent with NOAA's Commercial Space Policy (January 2016). Through its CWDP Round 2, NOAA is evaluating purchased commercial data, with a commercial data purchase expected as early as CY 2020. All RO data used in NOAA's operational products are subject to quality verification, regardless of the source. NOAA will execute this strategy in a phased approach, as described in the following sections.

<u>Near Term (now through mid-2020s)</u>

COSMIC-2 will provide 5,000 occultations per day when fully operational. However, because of COSMIC-2's low-latitude, the occultations are not sufficiently evenly distributed around the globe. EUMETSAT's Metop-A, -B, and -C add another 1,800 occultations per day, but are concentrated into narrow orbits, and thus do not provide a uniform distribution across middle and high latitudes.

Including occultation data from partners still results in an insufficient number of mid- and high-latitude distributed occultations to meet NOAA's threshold requirement. Current occultations of COSMIC-2 and its partners are displayed in Figure 1. Thus, a gap in global mid- and high-latitude RO coverage still exists.

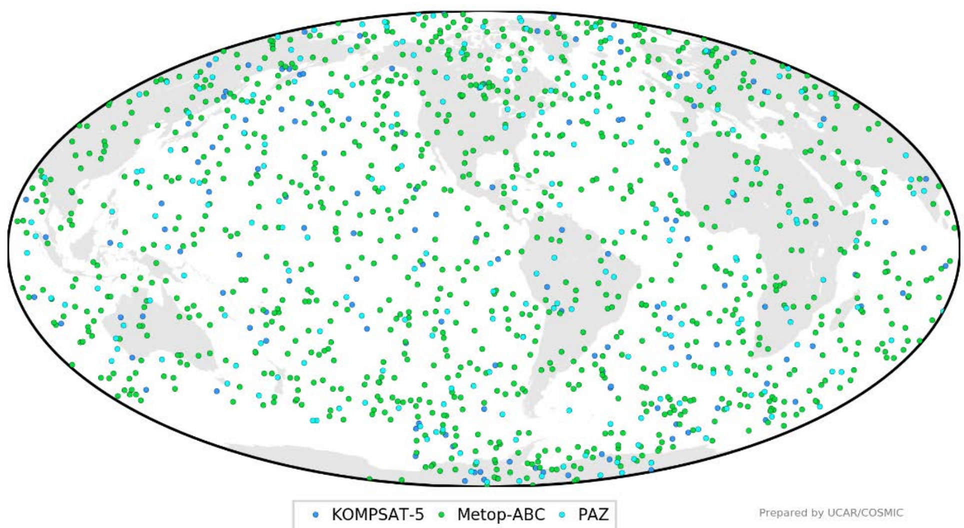
In the near-term, through the mid-2020s, NOAA will mitigate this gap through the following actions:

1. NOAA will leverage the approximately 450 RO soundings per day (Appendix D) from international partnerships with South Korea's KOMPSAT-5; and the Spanish PAZ satellite. The Metop series of spacecraft, KOMPSAT-5, and PAZ are all on the same orbital plane, spanning approximately the same local times in coverage and will help mitigate the gap in polar regions. The National Weather Service plans to assimilate Metop C RO soundings in its Numerical Weather Prediction system during the second quarter of 2021.

2. To ensure global coverage, NOAA will continue to leverage "missions of opportunity" to fill out additional orbit planes. This includes promoting RO as a basic capability on all relevant platforms of partner space agencies.

3. NOAA is concluding the assessment of commercial RO data in FY 2020 and will seek to augment the mid- and high-latitude RO coverage and to fill in the remaining need for occultations with commercial data buys, as quality data are available. NOAA will evaluate the cost of government and commercial sources and their impact.

4. NOAA will continue the COSMIC-2 mission (six satellites operating in the low latitudes) and evaluate the impact of the higher accuracy RO data and the deeper level of penetration in the lower tropical troposphere to inform requirements in accuracy and coverage for future government, partner, and commercial RO missions.



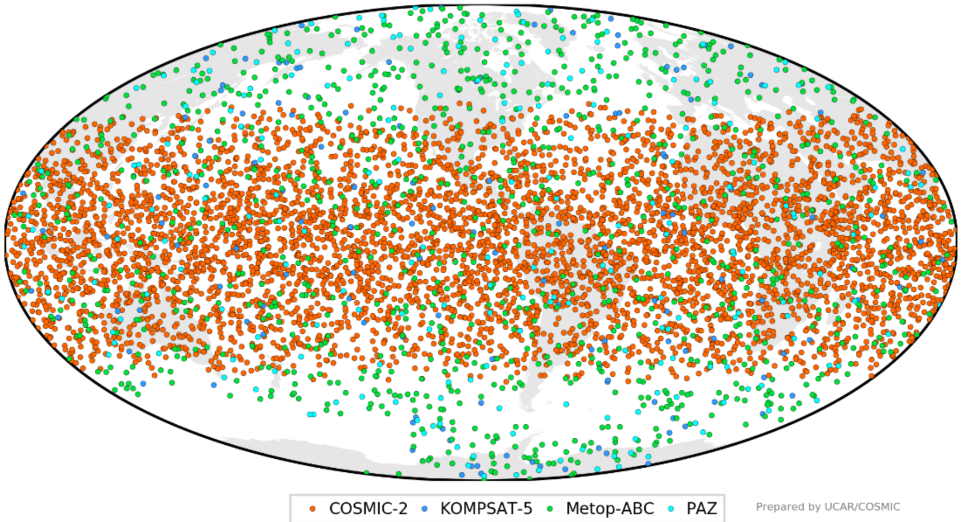


Figure 1: Current Radio Occultations without (above) and with (below) COSMIC-2 Over a 24-hour Period

<u>Transitional (2020s to 2030s)</u>

Based on the performance of COSMIC-1 satellites, the COSMIC-2 constellation may provide measurements beyond its 5-year design life, albeit with likely degradation of capabilities over time.

NOAA conducted the NSOSA effort to analyze options for the next generation of weather satellites. Based on NSOSA findings, NOAA is considering meeting the 5,000 occultations as part of a broader disaggregated next generation LEO constellation by including RO payloads on future NOAA LEO small and medium size satellites. EUMETSAT, NOAA's partner in the Joint Polar System, is planning to do the same.

NOAA is in the early planning stages for the first of these satellites, which will include the three primary types of sounding instruments (infrared, microwave, and RO) together on smaller, more cost-effective satellites that can be launched more frequently to maintain the required high availability levels.

NOAA is investigating approaches to shorten development timelines by partnering with other government agencies and industry through the proposed Joint Venture funding line and use of mechanisms like Other Transaction Authority. During this transitional time as NOAA determines and implements the future observation architecture, NOAA will:

1. Build a "foundational" backbone of government satellites to provide a set of high-quality post COSMIC-2 RO data, the number of small satellites and coverage required will be based on the assessment of COSMIC-2 impact. The current expectation is that this government backbone will consist of RO instruments on the

next generation LEO sounder satellites in addition to RO sensors hosted on NOAA (and possibly other U.S. government) LEO satellites, Jason Continuity of Service mission on the Sentinel-6 spacecraft (Jason-CS/Sentinel-6), and Joint Polar System EUMETSAT observations.

2. Augment RO coverage through commercial data buys as it becomes operationally available and at an effective price point, quality, and capability maturation.

3. Continue to leverage "missions of opportunity" and other partnering opportunities.

V. Long Term Plans (2030s and beyond)

In the long-term, NOAA's plans, informed by NSOSA, will adaptively provision the RO requirement mix of RO on U.S. civil and military missions, and through commercial data purchases, and international partnerships. The ultimate performance objective for satellite sounding observations is to provide essential data to support accurate and timely weather forecasts. The optimal mix of observation types changes over time, as the instrument capabilities change and as the models evolve and assimilate more and better data. NOAA will routinely re-evaluate the needs and return, given its current understanding of the need, for this period will:

1. Continue the operation of a base of small NOAA LEO satellites dedicated to producing soundings, including high-quality RO data. RO payloads on other NOAA LEO satellites, and our ongoing partnership with EUMETSAT (Metop-Second Generation) will provide a backbone set of global measurements to satisfy threshold requirements.

2. Augment this base with high quality RO data from additional international partner missions that will be coming online in the 2020s (e.g., follow-on missions to Jason-CS/Sentinel-6).

3. Supplement the foundational and partner coverage using commercial RO data as it becomes operationally available and at an effective price point, quality and capability maturation.

Appendix A: Acronym List

COSMIC:	Constellation Observing System for Meteorology, Ionosphere and Climate
CWDP:	Commercial Weather Data Pilot
EUMETSAT:	The European Organisation for the Exploitation of Meteorological Satellites
FY:	Fiscal Year
GFS:	Global Forecast System
GNSS:	Global Navigation Satellite System
GOES:	Geostationary Operational Environmental Satellite
GLONASS:	Global Navigation Satellite System
GRACE:	Gravity Recovery and Climate Experiment
GRAS:	GNSS Receiver for Atmospheric Sounding
IROWG:	International Radio Occultation Working Group
JPSS:	Joint Polar Satellite System
KARI:	Korean Aerospace Research Institute
KOMPSAT:	Korea Multipurpose Satellite-5
LEO:	Low Earth Orbiting
Metop:	Meteorological Operational
NASA:	National Aeronautics and Space Administration
NESDIS:	National Environmental Satellite, Data, and Information Service
NOAA:	National Oceanic and Atmospheric Administration
NOSC:	NOAA Observing Systems Council
NSOSA:	NOAA Satellite Observing System Architecture
NWP:	Numerical Weather Prediction
NWS:	National Weather Service
RFP:	Request for Proposal
RO:	Radio Occultation
Tri-G:	Tri-Global Navigation Satellite System

Appendix B: References

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- May 4, 2015. Outcome and Recommendations from the IROWG-4. http://irowg.org/wpcms/wp-content/uploads/2014/05/Outcome_and_Recommendations_from_the_IROWG-4.pdf

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Appendix C: Background

COSMIC-2 Activity to Date

COSMIC is a partnership mission between the United States and Taiwan counterparts. The original COSMIC mission, COSMIC-1, was launched in 2006 as a proof-of-concept for a new inexpensive atmospheric sounding technique. Since 2008, NOAA has used COSMIC-1 RO sounding profiles in operational NWP models. Today, the single operational COSMIC-1 satellite, which is operating 8 years past its design life, provides up to approximately 200 sounding profiles daily.

COSMIC-2 is a follow-on mission that will provide improvement in sounding penetration over the current COSMIC-1 GNSS-RO data:

- COSMIC-2 was launched as part of the U.S. Air Force STP-2 mission on June 25, 2019.
  - The launched COSMIC-2 mission consists of six satellites in a 24-degree inclination, a near equatorial orbit.
  - COSMIC-2 will provide ~5,000 sounding profiles per day in the tropical Equatorial region.

- Prior to FY 2018, the COSMIC-2 program had been designed as a 12 satellite constellation, launching six satellites into two different orbits. COSMIC-2B would have provided an additional six satellites at 72-degrees inclination, a high latitude polar orbit that would have yielded 4,000-5,000 sounding profiles per day.
  - In October 2017, the joint, international COSMIC-2 Executive Steering Committee made a decision not to exercise the 2B option, citing difficulties in securing funding necessary to sustain the partnership.

The cancellation of COSMIC-2B has resulted in a reduction in the projected number of RO observations in the mid- and high latitudes in the early 2020s (when COSMIC-2 might have been flying), and a projected gap in NOAA's capability. To mitigate this gap of mid- and high-latitude RO measurements, NOAA has analyzed the options including pursuing COSMIC-2B-like or a similar mission, additional exploitation of current and upcoming international missions with RO capability, as well as the purchase of commercial weather data.

COSMIC-2, as currently configured as six satellites flying in low latitude, has the potential for even greater positive impact on predicting and forecasting heavy rainfall and tropical cyclone events. COSMIC-2 carries a JPL Tri-GNSS (TriG) RO receiver and will collect more soundings per receiver by adding tracking of Russia's Global Navigation Satellite System (GLONASS) and potentially Europe's Galileo, which will produce a significantly higher spatial and temporal density of profiles in the tropics. With the advanced TriG receiver and improved antenna system, COSMIC-2 is expected to produce many more soundings in the tropics with higher accuracy and a greater number of soundings penetrating deeper into the tropical planetary boundary layer. These observations have the potential to increase the impact of RO observations on tropical cyclone forecasts and an opportunity to study in greater detail the impact of dynamic error specification of RO data and more accurate RO data assimilation algorithms in global and regional weather forecasting.

NOAA's Current Use of Partner Radio Occultation Data Sources

NOAA currently assimilates RO data into its NWP models from a number of different data sources (Figure 2) including the GRAS RO instruments on EUMETSAT's Metop-A, launched in 2006, and Metop-B, launched in 2012. Metop-C, which was launched in the first quarter of FY 2019, also carries a GRAS. In addition, NOAA receives RO data from TerraSAR-X and TanDEM-X, German Earth observation satellites launched in 2007 and 2010 (see Appendix D).

NOAA is also receiving RO data from KOMPSAT-5, launched in 2013 and flown by the Korean Aerospace Research Institute (KARI) under a data sharing agreement with KARI and the Korea Astronomy and Space Science Institute, which is responsible for data application in the Republic of Korea. NOAA assimilation of KOMPSAT-5 data is enabled by the new operational data assimilation component of the Global Forecast System (GFS) based on the Finite-Volume on a Cubed-Sphere dynamic core developed by NOAA's Geophysical Fluid Dynamics Laboratory. KOMPSAT-5 will be assimilated using GFSv15.2 planned for operation in November, 2019. NOAA has also signed an agreement regarding the Spanish PAZ satellite, launched on February 22, 2018. NOAA began providing RO data from the PAZ mission for NWP assimilation in August 2019 for use in GFS.

NOAA is currently investigating the availability of Oceansat 2, Oceansat 3, and Gravity Recovery and Climate Experiment – Follow On (GRACE-FO) RO data and assessing the effort and resources available to be added to the NOAA portfolio.

NOAA's Commercial Engagement to Date

NOAA has engaged commercial RO providers for over 10 years, including a study contract in 2008 and a Request For Information in 2014. In the last 2 years, NOAA has taken additional proactive steps to (1) develop policy documents to guide and standardize NOAA's use of commercial capabilities, and (2) execute a pilot program to demonstrate the quality of on-orbit commercial data and its impact to NOAA's NWP models.

NOAA received $3 million in the *Consolidated Appropriations Act of 2016* (P.L. 114-113) to initiate the CWDP, $5 million in the *Consolidated Appropriations Act of 2017* (P.L. 115-31), and $6 million in the *Consolidated Appropriations Act, 2018* (P.L. 116-5) to continue CWDP execution. NOAA is using the CWDP to learn not only about existing commercial capabilities, but also to develop and exercise internal processes for assessing the quality of commercial data and implementing their use in NOAA's future operational observation system.

CWDP Rounds 1 and 2, using FY 2016, FY 2017, and FY 2018 funds respectively, are focused on GNSS-RO data.

CWDP Round 1: In September 2016, NOAA entered into contracts with GeoOptics and Spire Global to purchase on-orbit GNSS-RO data. NOAA received and analyzed the data from Spire, for which the price paid was reduced from the original contract based on final data delivery volume. NOAA did not receive data from GeoOptics, and the contract was cancelled bilaterally. NOAA concluded, based on the results of the CWDP Round 1 pilot project that the commercial sector was not able to provide the quality and quantity of RO data that NOAA required for use in operational weather forecasting at the time of Round 1. However, NOAA found that commercial RO systems showed potential and, if progress continued, could serve in the future as complementary sources to existing and future government systems. NOAA found that Round 1 results warranted further pilot project purchases of a greater set of commercial RO data in order to conduct a more thorough evaluation, which is currently taking place via CWDP Round 2.

CWDP Round 2: On April 25, 2018, NOAA released the CWDP Round 2 RFP. In September 2018, NOAA entered into contracts with GeoOptics, Spire Global, and Space Sciences and Engineering (doing business as PlanetiQ) to purchase on-orbit GNSS-RO data. Round 2 data collections ended on September 30, 2019. As a follow up to the Round 1 pilot contracts, the Round 2 effort extends the work of the CWDP to incorporate additional operationally important requirements (e.g., data security, timeliness, availability) for a second round of RO data procurement and evaluation. Round 2 data analysis will conclude in FY 2020.

NOAA used CWDP Round 2 to:

- Conduct an evaluation of the purchased commercial data's impact on NOAA’s numerical weather prediction models with the goal of using results to support a decision to use commercially available RO data operationally; and

- Develop internal infrastructure needed to process, perform quality control, and securely assimilate commercial RO data operationally.

Systems Architecture and Engineering, Commercial Data Purchase: The Congress appropriated $5 million based on the President’s FY 2020 Budget request to take the next step in its activities with the commercial sector to initiate purchasing commercial GNSS radio occultation data for operational use. This request will also support continued development of the infrastructure and capability to securely import, transfer, process, and store external data from commercial partners for operational use.

Summary of NOAA Access to Radio Occultation Data Today

Currently, NOAA accesses less than 200 sounding profiles per day from the one remaining COSMIC-1 satellite and 1,475 sounding profiles per day from partner sources, for a total of 1,650 profiles per day, with fairly uniform global spatial distribution. As COSMIC-2 data undergo post-launch calibration and validation, NWS modelers will have access to these data for testing and evaluation. NOAA anticipates that NWS will start to use the data operationally in 2020.

During the period 2019-2023, this number will increase to approximately 5,000 per day, with a spatial distribution favoring observation of the tropics.

This falls well below the 20,000 daily profiles identified as the NOAA objective by the NOSC (see Figure 2 below), but substantially satisfies the threshold requirement of 5,000 (although the geographic distribution emphasizes the tropics versus a uniform global distribution). Thus, NOAA is planning to increase access to RO profiles in the future through NOAA, partner, and commercial sources.

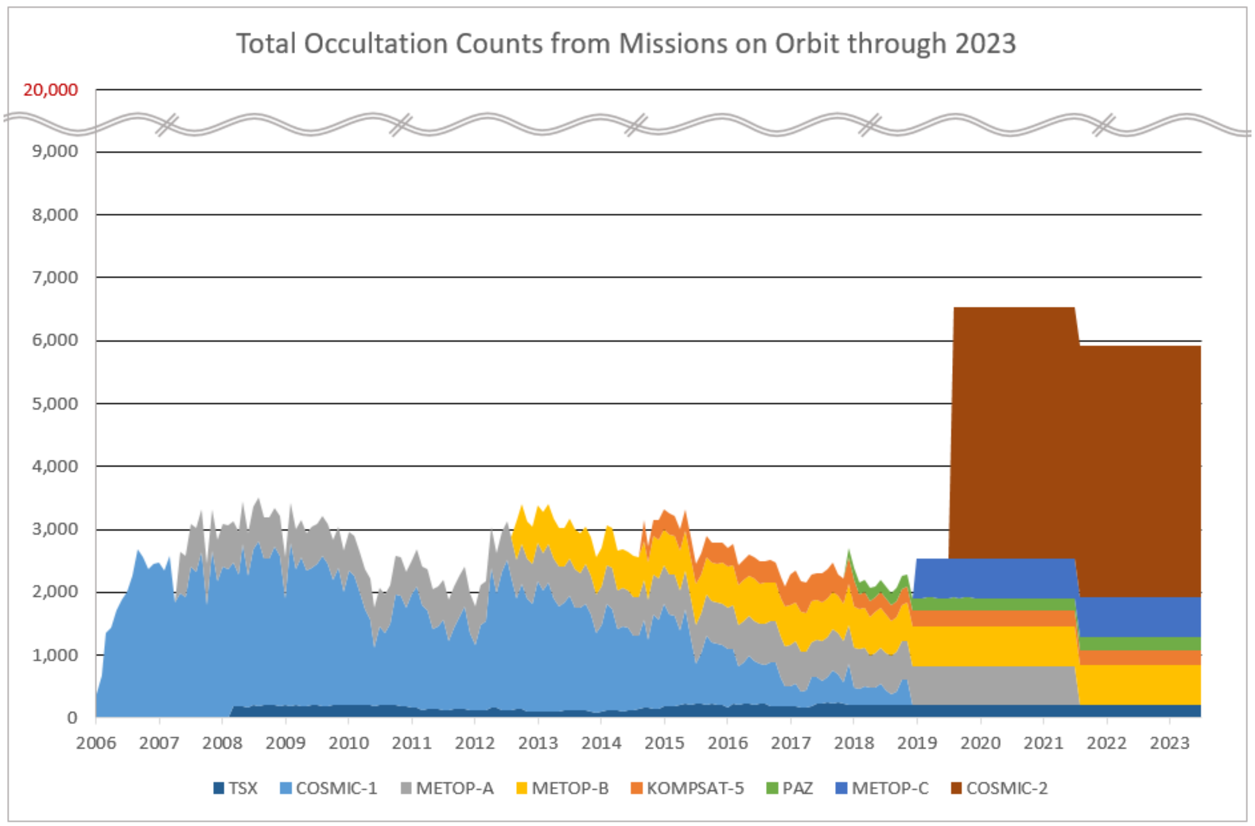

Figure 2: Total Occultation Counts from Missions on Orbit

Appendix D: Current Sources of RO Sounding Profiles

On-orbit satellites with RO payloads	Owner	Follow on planned?	Used by NOAA?	If used: Approximate profiles per day	Orbit Inclination
COSMIC-1	NOAA/National Space Organization (NSPO)	COSMIC-2A	Yes	200	Near-polar (72 deg)
GRACE-B	NASA/German Aerospace Center (DLR)	GRACE-FO	No		Near-polar (89 deg)
GRACE-FO	NASA/DLR	No	Anticipated	Not yet available	Near-polar (89 deg)
Metop-A	EUMETSAT	Metop-Second Generation	Yes	600	Polar (98 deg)
Metop-B	EUMETSAT		Yes	600	Polar (98 deg)
Metop-C	EUMETSAT		Anticipated 2021	600	Polar (98 deg)
Oceansat-2	Indian Space Research Organisation	Oceansat-3	No		Polar (98 deg)
TerraSAR-X	DLR	TanDEM-X	Yes	175	Polar (97 deg)
TanDEM-X	DLR		Yes	100	Polar (97 deg)
Kompsat-5	Korean Aerospace Research Institute (KARI)	Kompsat-6 is exploring adding RO capability	Yes	200 anticipated (Up to 500 if proposed flight software update is successful)	Polar (98 deg)
PAZ	HISDESAT/ICE	None	Anticipated, 2021	250 anticipated	Polar (98 deg)
COSMIC-2	NOAA/NSPO	COSMIC-2B canceled	Anticipated, Winter 2020	5000 across 6 satellites	Equatorial (24 deg)

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