ECONOMIC STUDIES OF GPS AND THE NGS GRAVITY PROGRAM

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OUTLINE

- GPS benefit studies and recommendations
- Economic and engineering studies of GOES geostationary weather satellite benefits and loss from signal interference
- Research on economic benefits of the NGS Gravity Program
  - The Gravity Program
  - Analysis of economic benefits of the Gravity Program
- Appendices
  - A: GPS benefit studies
  - B Vulnerability of GOES broadcast signals to interference
  - C: The NGS Gravity Program

GPS BENEFIT STUDIES AND RECOMMENDATIONS

THE 2015 GOES ECONOMIC REPORT

- EXCOM Action Item: "DOC to lead interagency team in consultation with the National Space-Based PNT Advisory Board to develop a way forward for an updated, authoritative GPS economic benefit assessment."
- Conducted for the PNT Board under the auspices of the PNT Coordination Office
- Objectives of the study*
  - Describe the major uses of GPS and its position in the U.S. civilian value chain
  - Provide updated, more complete and methodologically sound estimates of economic scope and benefits of GPS to the U.S.
  - Provide an Interim Report that can serve as a core for development of follow-on analysis and final reports on GPS benefits in Part 2

*Irving Leveson, *GPS Civilian Economic Value to the U.S., Interim Report*, prepared for the National Executive Committee for Space-Based Positioning, Navigation and Timing, August 31, 2015 http://www.performance.noaa.gov/wp-content/uploads/2015-08-31-Phase-1-Report-on-GPS-Economic-Value.pdf and Irving Leveson, "The Economic Value of GPS," *GPS World* (September 2015), pp.36-42 http://gpsworld.com/the-economic-benefits-of-gps/

5 BENEFITS IN THE 2015 GOES STUDY

- Benefits were measured relative to what would have been expected if there were no GPS
  - Considered availability of alternative technologies and ways markets could have evolved without GPS
- Economic benefits were measured primarily by productivity improvements, cost savings and cost avoidance
- Indirect and induced economic benefits were calculated based on a multiplier analyses
- Safety-of-life and environmental benefits were not included
- Less tangible values of GPS to the U.S. and other nations were discussed

- Benefits were estimated as $34.9-$62.4 billion in 2013, with a midpoint of $51.0 billion
- If benefits were updated from 2013 to 2019 for growth in nominal GDP, which includes both real growth and general inflation, they would be higher by 28%
- This would place the values in 2019 at $44.7-$79.9 billion with a midpoint of $62.3 billion

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TREATMENT OF TIMING

- The 2015 study measured the benefits of GPS timing as the avoided cost of an alternative system based on Loran or one using precise atomic clocks on geostationary satellites
- Avoided costs of alternatives are much lower than the potential cost of loss of availability of GPS timing, especially since it has become more widely relied on since 2013
- Scenarios for the loss of timing would have to consider whether there was a loss of timing information from other GNSSs as well

7 TREATMENT OF MULTI-GNSS

- The 2015 study estimates for 2013 did not have to take into account Galileo and BeiDou because they were not yet operational, and it did not account for GLONASS which was used in limited applications and not as fully evolved. That is no longer possible
- A new analysis of GPS benefits would have to decide among three approaches:
  1. Assume benefits of other GNSSs are incremental to those of GPS
     - If appropriate to the purpose, that could include benefits from use of GPS technologies in other GNSSs and benefits of GPS signals to other nations, if measurable
  2. Assume benefits are shared among GNSSs to the extents signals from multiple constellations are comparable and used in particular applications
  3. Provide as estimate of combined benefits of all GNSSs

RESEARCH RECOMMENDED BY THE 2015 STUDY (1 OF 2)

1. Develop benefit estimates for **additional sectors** where possible, including sectors for which estimates could not be made in Part 1
2. Refine economic benefit estimates and update based on additional data and reports and more extensive interviews
3. Examine technologies in greater detail and seek expert opinion to better assess the shares of benefits attributable to GPS in each sector
4. Refine economic multipliers and assess impacts of GPS on **tax revenues and jobs**
5. Estimate selected values of current **benefits in safety and reduced loss of life** in critical applications and explore possible magnitudes of environmental benefits

RESEARCH RECOMMENDED BY THE 2015 STUDY (2 OF 2)

6. Estimate the nature and orders of magnitude of benefits of GPS to **other regions and the world**
7. Assess potential future applications and markets and make projections of **future** market penetration and values of economic and safety **benefits** of GPS to the U.S. **under alternative scenarios**
8. **Estimate orders of magnitude of current economic costs of partial and complete long-term loss of GPS availability in selected applications** under alternative scenarios, including rough estimates of economy-wide impacts
9. Conduct **further analyses of the costs of loss of GPS in the context of rapidly evolving future use**
10. **Integrate analyses and findings into 1) a "showcase report" designed to appeal to a general audience, and 2) a full technical report and briefings covering all stages of the analysis**

OTHER GPS BENEFIT STUDIES

- RTI is conducting a study for NIST which will be released shortly on the NIST Web site
  - The description in the March 7, 2016 announcement of Federal Funding Opportunity, which since may have been modified, called for the study to conduct a retrospective analysis to: "…identify key technologies developed by and transferred from federal laboratories that support GPS, estimate the qualitative and quantitative economic impact of these investments,…"
  - The scope included "analysis of the impacts and use of GPS and precise time measurements across an array of applications, industries and throughout supply chains…"
- DHS is finalizing the results of its FY2017 NDAA requirements. DHS is approaching this from a risk management perspective, which includes a cost-benefit analysis
- The 2013 NDP Analytics and 2011 NDP Consulting studies are noted in a supplementary slide and reviewed in the Leveson 2015 study

VALUING LOSS FROM SIGNAL INTERFERENCE

- Economic, safety-of-life and environmental benefit estimates reflect largely long run adjustment of activities and how they are conducted to present conditions
- If signal interference is small and temporary and/or rescheduling of activities is possible without great cost, counting a portion of long run benefits as the value of the loss may be appropriate
- However, if interference is not small and is frequent or persistent and/or rescheduling is costly or not possible, the direct effects can be large
- Under the latter conditions there may be large effects on other activities of varying severity and duration which have to be included in the costs of disruption
- Many interference scenarios are possible. Which threats are most likely to occur and which may be more successfully countered with the aid of analysis can be uncertain. Resources have been limited to adequately address enough use cases and far-reaching consequences

ECONOMIC AND ENGINEERING STUDIES OF GOES GEOSTATIONARY WEATHER SATELLITE BENEFITS AND LOSS FROM SIGNAL INTERFERENCE

13 IMPACTS OF INTERFERENCE ON GOES AND GOES-R

- At present the 1670-1680 MHz frequency band can experience 30% spillover from lower frequencies. 100% signal overlap with the 1670-1680 MHz band will have 5 times the power of the 30% overlap that has been examined in initial tests by Alion Science and Technology
- Sensor Data at 1673.4-1678.6 MHz would be completely engulfed by high-powered broadband transmissions at 1670-1680 MHz, preventing use of all GOES Imager and Sounder data during interference
- Other users of direct broadcasts from GOES may have strict timeliness or data availability requirements to generate forecasts and warnings of severe weather
- GOES Variable (GVAR), which is used to transmit Imager and Sounder meteorological data in full resolution without reduction of data resolution or content, has its front end open down to 1673.2 MHz and it would see some of the proposed terrestrial signal as interference within its passband
    - The GVAR signal has no digital correction scheme and is likely to be extremely susceptible to interference, with serious impacts on weather forecasting and other applications
- GOES-R DCPR (DCS) occupies the narrow band at 1679.7-1680.4 MHz. Powerful in-band effects and spillovers to adjacent frequencies would make DCPR data unusable during interference
- Adjacent band interference from the bands at 1695 MHz and above could have an impact on LRIT, EMWIN and HRIT and GOES DCPR

COMPONENTS OF THE ECONOMIC ANALYSIS FOR NESDIS

- Estimation of sizes and benefits of the U.S. Weather and Water Enterprise and broad component sectors
- A footprint (trade space) analysis describing and quantifying the uses and users of data distributed by GOES-13-15, which includes far more data than collected by the GOES satellites
  - Consisting of applications in prescribed use cases relating to specific GOES downlinks
  - A companion report with David G. Lubar provides technical information on the satellites and detailed descriptions of existing applications
- Estimation of orders of magnitude of benefits of GOES-13-15, overall, for major sectors of the U.S. Weather and Water Enterprise, and for the specific use cases
- Illustrative assessment of possible losses of economic and some safety-of-life benefits from full or partial interference with GOES signals for broad sectors and specified use cases
- Advance preliminary estimates of some GOES-R GLM benefits and updates and adaptation of earlier estimates of GOES-R ABI benefits

Completed in 2018 for integration with the engineering analyses

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SOME FINDINGS OF THE ECONOMIC ANALYSIS

OVERALL ECONOMIC BENEFITS OF GOES 13-15

- Gross economic benefits of GOES-13-15 Broadcast were estimated at **$3.2-$5.2 billion in 2016** (midpoint $4.2 billion) based on 14%-17% of NOAA's weather and water-related benefits of $23.1-$30.9 billion.

- Net economic benefits of GOES were approximated assuming the contribution of GOES data is 50% of gross value. On that basis GOES net share of economic benefits of NOAA's weather and water-related services was on the order of magnitude of **$1.6-$2.6 billion in calendar year 2016** (midpoint $2.1 billion)

Summary of GOES Partial Losses of Gross Economic Benefits for Use Cases, 2016

Use Case	Benefits	Percent Applied
Surface weather and water management (DCS)		
Motor vehicle	$79.6-$119.4m	4%-6%
Storm surge and flood forecasts and warnings	$5.1-$13.6m	3%-4%
USACE & USBR water except hydropower	$43.7-$58.1m	3%-4%
USACE	$37.9-$50.6m	3%-4%
USBR	$5.6-$7.5m	3%-4%
TVA	not estimated	predominantly hydropower
Inland navigation	$22.8-34.3m	3%-4%
Heat watches and warnings		
Management of hydroelectric power by USACE, USBR and TVA	$5.1-$6.8m	3%-4%
USACE	$3.2-4.3m	3%-4%
USBR	$1.1-$1.5m	3%-4%
TVA	$0.8-$1.0m	3%-4%
Physical Oceanographic Real-time System (PORTS®) (DCS)	$9.6-$14.4m	4%-6%
National Hurricane Center (GVAR)	total $33.3-$79.6m: dependent on GVAR $25.0-$63.6m	3%-4%
Aviation Weather (GVAR)	$6.3-$28.5	4%-6%
Weather services for the Alaska and Pacific Regions ((GVAR)	$2.6-4.7m	3%-4%
Alaska	$0.08-$0.14m	3%-4%
Pacific Region	$2.6-$4.5m	3%-4%
Addendum: volcanic ash avoidance	$60,000-$220,000	3%-4%
Commercial sector meteorology (GVAR)	$384-$784m for GVAR loss	3%-4%
Sensor data (SD)	$87-$200m	3%-4%
Wildfire weather (DCS)	$9.5-$12.6m	3%-4%
Tsunami warnings (DCS)	$360,000-$480,000	3%-4%
Near-earth space weather services (MDL)	$18.4-$38.0m	3%-4%
EMWIN	$1.6-$2.2m for weather $48,000-$464,000 for fire	3%-4%

SPECTRUM PIPELINE REALLOCATION ENGINEERING STUDY

The Spectrum Pipeline Reallocation Engineering Study (SPRES) for NESDIS assesses the potential for sharing the 1675-1680 MHz frequency band and the adjacent frequency bands with commercial mobile wireless carriers, nationwide. It’s tasks are to:

- Establish a user/customer data flow and user needs baseline to facilitate quantifying impacts to end users resulting from a loss of access to data received via direct broadcast links
- Identify options to mitigate interference – occurrences and impacts
- Perform interference analysis to determine Interference Protection Criteria (IPC) for federal Earth stations and protection zones around these downlink sites
- Examine Radio Frequency Interference (RFI) monitoring and other mitigation techniques
- Examine alternative architectures for future implementation on space and ground based assets, i.e., GOES-Next
- Complete study March 2020

Slide courtesy of Al Wissman, CFO, NOAA satellite division (NESDIS)

RESEARCH ON ECONOMIC BENEFITS OF THE NATIONAL GEODETIC SURVEY GRAVITY PROGRAM

THE NEED FOR IMPROVED ORTHOMETRIC HEIGHTS

- Orthometric heights which take into account of the direction of gravity are essential for determining the direction water will flow
- Orthometric height information is used in a wide range of commercial, scientific, resource and environmental applications
  - Examples of critical applications include floodplain management and local sea level measurement in coastal zones
- Improvements in measurement are needed because traditional orthometric height measurement with surveying techniques is expensive and not accurate in hard to reach areas where bench marks are not available and where coverage of large geographic areas is needed

19 WHERE THE NEED FOR IMPROVEMENT IS GREATEST

- Terrain that is mountainous so ground-based techniques cannot cover many areas. Few have been previously measured from the air
- Low lying coastal areas which are subject to flooding from hurricanes and sea level rise
- Topography of the continental shelf, which is not well-measured and can influence the extent to which winds push water onshore
- Flood plains for which measures of height and therefore water flow have not been adequate for regulating construction, warnings and insurance
- Areas that need updating and monitoring because of earthquake activity, post-glacial rebound (uplift), subsidence of land due to withdrawal of water, and/or that have been affected by melting of glaciers
- Areas with insufficient numbers of bench marks or where bench marks have been damaged, removed or buried due to road and infrastructure construction or natural or other events

THE EARLIER TRANSITION TO GPS

The 1998 National Height Modernization Study* clearly described the transition from traditional leveling that depended on triangulation and leveling networks that require line of sight to the transformation that took place with the use of GPS for orthometric heights referenced to the current datum NAVD 88.

> "Until recently, NGS has relied on using conventional line-of-sight survey measurements… through a network of physical reference points accessible to users throughout the nation….
> Conventional leveling methods required crews of geodetic surveyors to have literally walked from border to border and coast to coast, carrying surveying equipment and taking geodetic surveying measurements every hundred yards or so, to establish and maintain a national coordinate system accessible to all users. In this fashion, a system of more than a million reference points was eventually built and serves today as the nation's geodetic reference framework.
>
> The advent of the Global Positioning System (GPS), however, has irreversibly transformed this landscape…. GPS…enables geodetic positioning to be accomplished without having to physically see between points. Using GPS, a survey that once took days to complete can now be done in a few hours at a much lower cost. GPS has also introduced the fourth dimension of time, enabling more accurate modeling of the earth's crustal motion. In addition, GPS techniques have enabled "realtime" positioning applications. As a result, GPS has not only revolutionized the traditional civilian navigation, surveying, and mapping professions, but has spawned numerous new applications…"

*Dewberry & Davis and Psomas & Associates, *National Height Modernization Study: Report to Congress*, Washington, DC: National Oceanic and Atmospheric Administration, National Geodetic Survey, June 1998, pp.xi-xii
https://www.ngs.noaa.gov/PUBS_LIB/1998heightmodstudy.pdf

THE GRAVITY PROGRAM

- The goal of the Gravity Program is to model and monitor Earth's geoid to serve as a zero reference surface for all heights in the nation
- The program seeks to support a geoid model with 2 cm or better of elevation accuracy in most areas up to horizontal distances of 200 or 300 km. This compares with the current NAVD 88 network accuracy of 5 cm
- In 2022 the Gravity Program will replace the current series of brass and concrete bench marks and rods that mark the position of individual reference points with heights based on a surface called a geoid. The geoid is defined so that the energy of gravity is the same at each point. Heights are measured through a program called GRAV-D
    - The new system is more accurate and stable because it is linked to four tectonic plates instead of three
    - It also will provide consistent updates over time for both horizontal and vertical information, which has not been possible in the past
    - The new reference frames will be accessed through the CORS network and a greatly enhanced NGS Online Positioning User Service (OPUS)

ANALYSIS OF ECONOMIC BENEFITS OF THE GRAVITY PROGRAM

- Estimates are very preliminary because the program is not yet operational
- Two estimates of direct economic benefits at full adoption are made by alternative methods
- An economic multiplier is applied
- Three quantitative scenarios for benefits are developed with alternative rates of adoption. The estimates cover the first 10 years of the program, from 2023 through 2032
- Present discounted values to 2019 are calculated
- Several aspects make the estimates conservative
- Uncertainty is reflected in ranges of estimates, alternative scenarios and alternative discount rates

A draft report has been briefed and is under review. The final report and leadership briefing are planned for August. The study is being done under an NGS contract to ARCBridge Consulting and Training, Inc.

THANK YOU

APPENDIX A. GPS BENEFIT STUDIES

Summary of 2013 US GPS Benefit Estimates in the 2015 Study

A. Confident

B. Indicative

C. Notional

	Application Category	Range of Benefits ($ billions)	Median Benefits ($ billions)
A	Precision Agriculture – grain*	10.0-17.7	13.7
A	Earthmoving with machine guidance in construction*	2.2-2.7	5.0
A	Air Transportation	.120 -.170	.145
C	Rail Transportation – Positive Train Control	.025-.250	.138
C	Maritime Transportation – nautical charts and related marine information	.106-.263	.185
A	Fleet Vehicle Connected Telematics*	7.6-16.3	11.9
A	Timing 1 – Loran	.025-.050	.038
A	Timing 2 – GEOs	.025-.075	.050
A	Surveying	9.8-13.4	11.6
B	Consumer Location-Based Services 1 – vehicle – willingness-to-pay*	4.7-6.3	5.5
A	Consumer Location-Based Services 2 – vehicle – value of time	5.3-17.0	11.2
	TOTAL (with alternative estimates for timing and consumer LBS averaged)	**34.9-62.5**	**51.0**

* Includes indirect benefits for this category.

GPS economic benefits as measured thus far were about 0.3% of GDP. This does not include sectors that were omitted, some indirect benefits, economic benefits induced in the rest of the economy, or benefits to health and safety and the environment.

AN EXAMPLE OF A TYPE OF STUDY THAT COULD PROVIDE MORE ACCURATE ESTIMATES OF GPS BENEFITS TO AGRICULTURE, ETC.

- Take an existing sample of farms that have introduced or enhanced GPS technology during the last few years
- Obtain information on:
  - A full set of GPS and non-GPS technologies used before and after the changes
  - Crop costs and yields before and after the changes
  - The mix of crops (or sample just one crop), farm size and shape, soil conditions, weather and other factors that may influence the outcomes
- Perform a multivariate before and after analysis of changes across farms to estimate the contribution of GPS
  - Allow for lagged effects on productivity and yield
  - Examine cases where mainly GPS changed
  - Test for interaction effects between GPS and other technologies among all farms with the same crop or with adjustment for crop mix

NDP Analytics, *The Economic Benefits of Global Navigation Satellite System and Its Commercial And Non-commercial Applications*, DEC. 2013

- Restated data on global GNSS markets from the NDP Consulting 2011
- Restated benefit data from the NDP Consulting 2011 report
  - The 2011 report assumed 100% adoption and that 100% of benefits with an application were attributable to GPS
- The 2013 study did not make any new estimates of benefits and was viewed by the PNT Board as only a literature review

APPENDIX B. VULNERABILITY OF GOES BROADCAST SIGNALS TO INTERFERENCE

29 GOES DISTRIBUTION SERVICES

Information collected by GOES-13-15 satellites and by instruments on other data collection platforms is relayed through GOES and distributed to users by means of several downlinks.

GOES Sensor Data downlink (SD) which contains all the raw Imager and Sounder data from the satellites to NOAA data acquisition stations

The Multi-Use Data Link (MDL) which is an independent data link to the NOAA Spacecraft Operations Control Center

GOES Variable (GVAR) which contains the entire calibrated instrument and imagery set

Low Rate Information Transfer (LRIT) which lets users that are unable to get GVAR data receive a reduced data set (useful for ships at sea and users who do not require the entire data set)

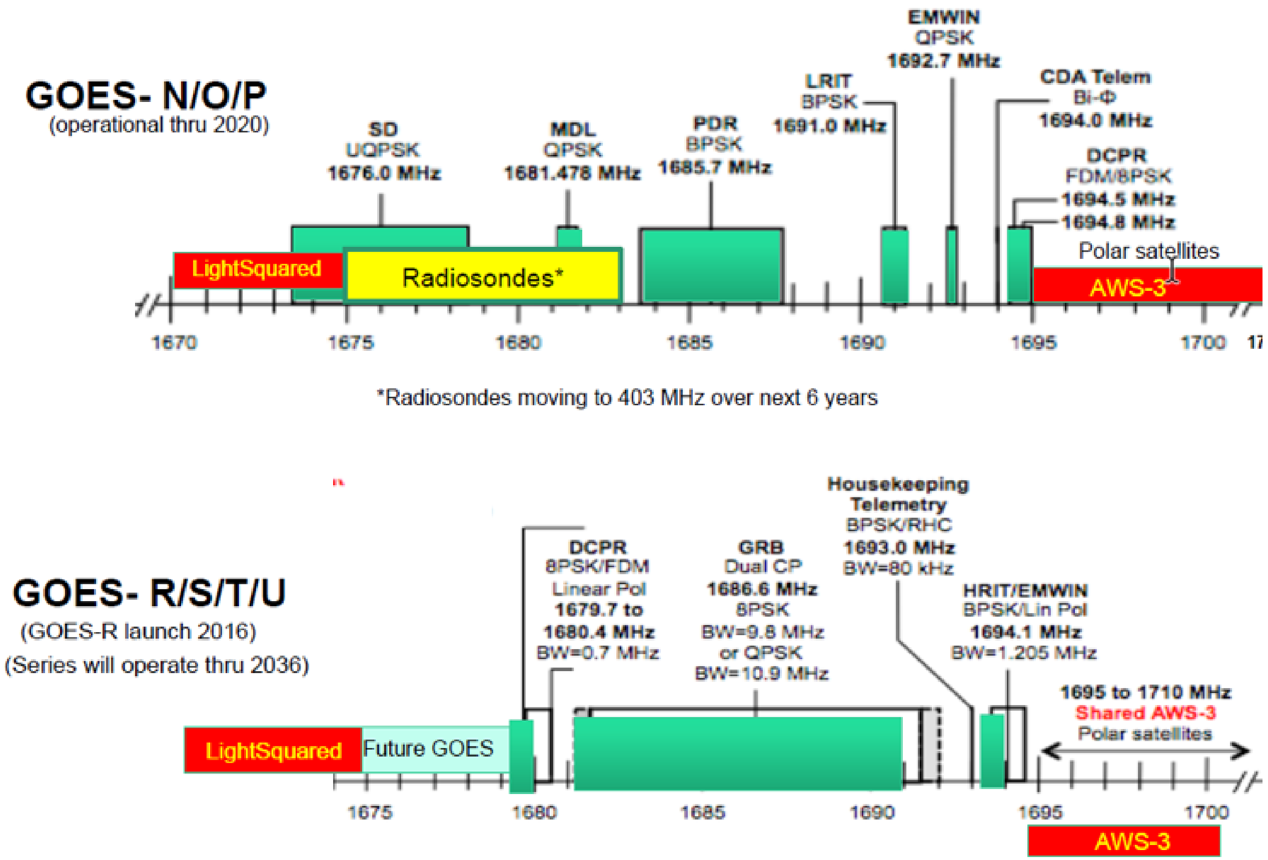
GOES Data Collection System (DCS) which relays near-real time information from terrestrial, sea and air sensors for critical applications. “DCPR” refers to the Data Collection Performance Report with DCS data

Emergency Management Weather Information Network (EMWIN) which provides broadcasts of low-resolution GOES satellite imagery data along with other data useful to emergency managers and first responders

VULNERABILITY TO LOSS OF GOES BENEFITS FROM HIGH-POWERED COMMERCIAL WIRELESS SERVICES

- NOAA has been using the 1670-1695 band for 30 years so ground systems are designed to receive in those frequencies
- Satellite receiving systems may not function in the presence of terrestrial broadband
  - Terrestrial wireless base station power levels are vastly stronger than those from a GOES downlink signal
  - Impacts of current transmissions from terrestrial broadband wireless base stations are a small fraction of what they will be when they and others become fully operational
- Interruption or inability to use GOES signals can cause extensive economic harm for their many users and increased loss of life and injury
- Signal interference threatens to 1) reduce benefits currently being obtained, 2) impose heavy costs on users trying to maintain present capabilities, and 3) compromise the benefits from a new wave of innovation in weather, water and environmental information just as it is taking off

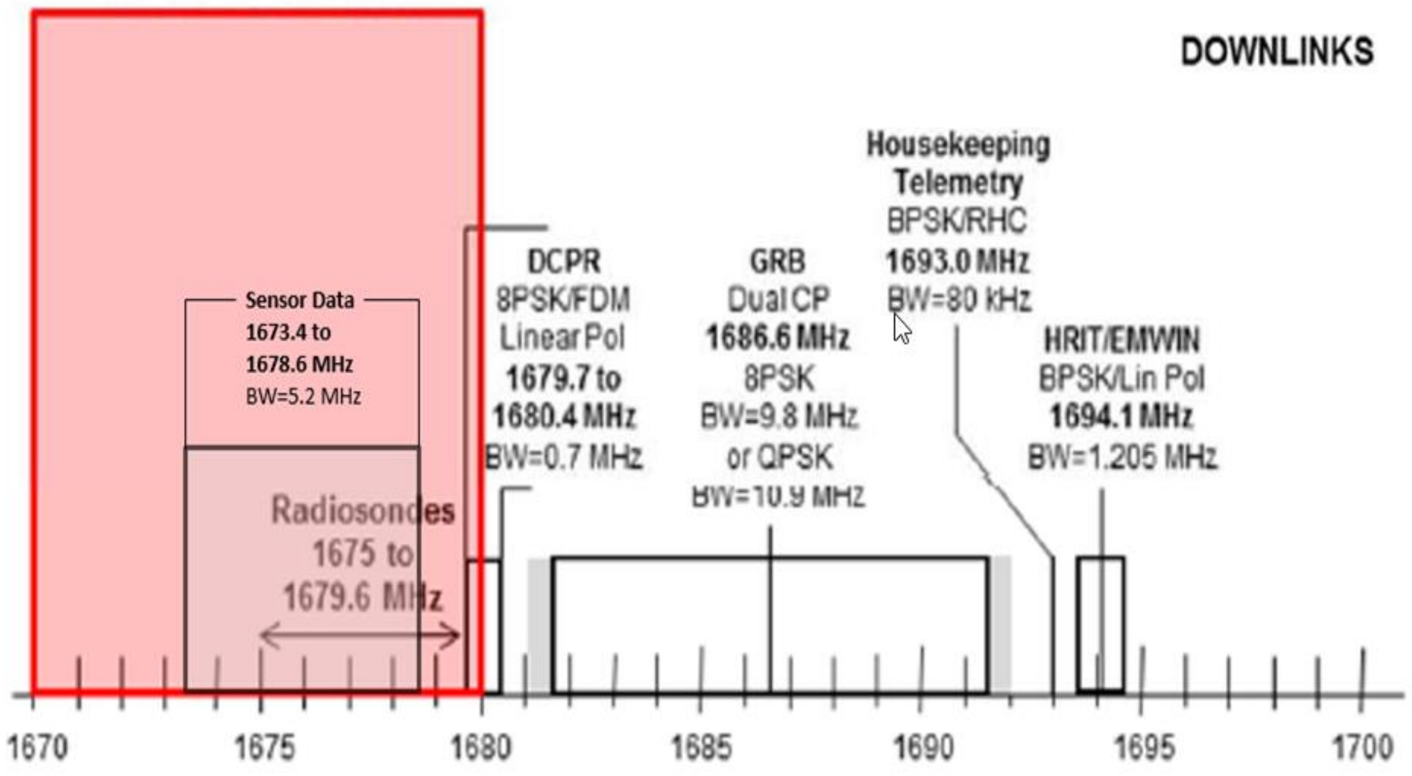
NOAA's Current and Planned Use of the 1675-1695 MHz Radiofrequency Band



Note: PDR is the Processed Data Relay transmission GVAR (GOES Variable Data Format) primarily used to transmit Imager and Sounder meteorological data.

Source: Zachary Goldstein, NOAA CIO, "NOAA Satellite Spectrum Sharing and Potential Impacts," December 10, 2017, slide 4.

RFI to Sensor Data and DCPR if Ligado Granted 1675-1680 MHz



APPENDIX C. THE NGS GRAVITY PROGRAM

COMPONENTS OF THE NGS GRAVITY PROGRAM

1) Collecting and processing gravity data (airborne and terrestrial)

2) Ingesting, performing quality control, processing and publishing gravity data

3) Monitoring gravity change

COVERAGE

- NGS relies on satellite data from GRACE and GOCE for distances of 250 km or more
- Airborne data is used for between 50 km and 250 km
- Surface measurements are used up to 50 km

36 ACCURACY AND COST SAVINGS

- Accuracy is greater with leveling than with the Gravity Program at short distances – it can be at the mm level for those who need it. Leveling will continue to be done locally because, for those who do not need mm accuracy, the Gravity Program can still provide cost savings over local leveling at distances below 20 km

- The accuracy of GPS combined with geoid models is about the same as leveling at the 20-200 km level. However, leveling at those distances can take several weeks in the field and would be far costlier. The greatest cost savings are expected to come in this middle tranche

37 GRAV-D

- Gravity for the Redefinition of the American Vertical Datum (GRAV-D) brings together a predominantly airborne high-resolution "snapshot" of gravity in the US, a low-resolution "movie" of gravity changes, and regional partnership surveys to achieve a 2 cm vertical datum level where possible for much of the nation

- In the new NAPGD2022, NAVD 88 will be replaced with a gravimetric geoid model (GEOID2022) based on GRAV-D

THE NEW PROCESS

- The gravitational geoid, which will be the standard, utilizes benchmarks through NGS Foundation CORS
- The Gravity Program will end bluebooking. The datums will be accessed through CORS network and a greatly enhanced NGS Online Positioning User Service (OPUS)

Replacing the NAD 83 Vertical Reference Frames	
Old	New
NAD 83(2011)	The North American Terrestrial Reference Frame of 2022 (NATRF2022) The Caribbean Terrestrial Reference Frame of 2022 (CATRF2022)
NAD 83(PA11)	The Pacific Terrestrial Reference Frame of 2022 (PATRF2022)
NAD 83(MA11)	The Mariana Terrestrial Reference Frame of 2022 (MATRF2022)

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Dr. Leveson has strong analytical skills in economics, business and public policy and extensive experience analyzing programs, markets and technologies. His background includes strategic and economic consulting and research in private industry, prominent research organizations, and government. Dr. Leveson has done extensive work on GNSS markets and issues over the last 16 years.

Dr. Leveson holds a Ph.D. in economics from Columbia University. Prior to establishing Leveson Consulting he served as Senior Vice President and Director of Research of Hudson Strategy Group, Director of Economic Studies of the Hudson Institute, Assistant Administrator for Health Systems Planning for the New York City Health Services Administration and as a research director for the New York City Planning Commission. He also served an economist for the RAND Corporation and an analyst with the National Bureau of Economic Research. Dr. Leveson is a member of the Institute of Navigation, the American Economic Association, the National Association for Business Economics and the American Meteorological Association.

His books include *Economic Security*, *American Challenges*, *Western Economies in Transition* (co-ed.), *The Future of the Financial Services Industry* (main author), *Analysis of Urban Health Problems* (co-ed.) and *Quantitative Explorations in Drug Abuse Policy* (ed.).