SPACE-BASED POSITIONING NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING ADVISORY BOARD

Twenty-Sixth Meeting

May 4-5, 2022

Crowne Plaza Annapolis

Annapolis, MD

ADM (USCG, ret.) Thad Allen, *Chair*

Mr. James J. Miller, *Executive Director*

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Agenda

(https://www.gps.gov/governance/advisory/meetings/2022-05/)

WEDNESDAY, MAY 4, 2022		
Livestream Recording: https://youtu.be/MMc63149Xr0		
9:30-9:35	**BOARD CONVENES** *Call to Order, Logistics, & Announcements*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:35-9:50	**26th PNTAB Welcome & Introduction** – Goals and objectives – Establishment of six new subcommittees *VIEW PDF*	ADM Thad Allen, *Chair, PNTAB*
9:50-10:05	**Opening Remarks** – Civil Sector National Priorities	Dr. Robert Hampshire, *Deputy Assistant Secretary for Research & Technology, Department of Transportation*
10:05-11:35	**Subcommittee Introductions** (15 min each) – Communications & External Relations (CER) *VIEW PDF* – Education & Science Innovation (ESI) *VIEW PDF* – Emerging Capabilities, Applications, & Sectors (ECAS) *VIEW PDF* – International Engagement (IE) *VIEW PDF* – Protect, Toughen, & Augment (PTA) *VIEW PDF* – Strategy, Policy, & Governance (SPG)	Subcommittee Chairs – Mr. Dana Goward – Dr. Jade Morton – Dr. Frank van Diggelen – Mr. Matt Higgins – Dr. John Betz – Mr. Jeff Shane
11:35 - 11:50	**BREAK**	
11:50 - 12:15	**Update on GPS Modernization & Emerging Capabilities** *VIEW PDF*	Mr. Cordell DeLaPena, *Executive Officer, MilComm & PNT, Space Systems Command (SSC), USSF*
12:15 - 12:30	**Communicating Technology Issues to Policymakers & Press** *VIEW PDF*	Ms. Melissa Harrison, *Sr. Director, Policy & Executive Communications, Consumer Technology Association*
12:30 - 1:30	**LUNCH**	
1:30 - 1:50	**The Geodesy Crisis** *VIEW PDF*	Mr. Everett Hinkley, *Geospatial Management Office, U.S. Dept. of Agriculture (USDA)*
1:50 - 2:20	**Protect, Toughen, & Augment: Status, Issues, & Observations** *VIEW PDF*	Dr. Brad Parkinson, *1st Vice Chair, PNTAB*
2:20 - 2:40	**Science & Technology (S&T) PNT Work under the Infrastructure Investment & Jobs Act** *VIEW PDF*	Ms. Brannan Villee, *S&T Directorate, Department of Homeland Security (DHS)*
2:40 - 3:00	**S&T's Resilient PNT Reference Architecture** *VIEW PDF*	Mr. Ernest Wong, *Technical Manager, S&T Directorate, DHS*
3:00 - 3:25	**Electric Grid Reliability / Center for Alternative Synchronization and Timing (CAST)** *VIEW PDF*	Dr. Carter Christopher, *Section Head, Human Dynamics R&D, Geospatial Science & Human Security, Oak Ridge National Laboratory*
3:25 - 3:40	**BREAK**	
3:40 - 4:00	**Space Weather Impact on Starlink Satellite Launches** *VIEW PDF*	Dr. Delores Knipp, *University of Colorado Boulder*
4:00 - 4:20	**Virtual GEO Satellite active-PNT (aPNT) System Concept** *VIEW PDF*	Dr. David Castiel & Dr. Cyrus Langroudi, *Virtual Geosatellite, LLC*
4:20 - 4:40	**Alternate Positioning & Navigation Using Magnetics**	Mr. Martin Neill, VP, Security & Defense, AstraNav
4:40 - 5:00	**GDGPS for Natural Hazards Early Warning: Tonga Volcano Tsunami** *VIEW PDF*	Dr. Attila Komjathy, *Supervisor, Near Earth Tracking Systems Group, JPL*
5:00 - 5:20	**GDGPS Contribution to a GPS High Accuracy Service (HAS): Potential Capabilities** *VIEW PDF*	Dr. Attila Komjathy, *Supervisor, Near Earth Tracking Systems Group, JPL*
5:20 - 5:30	**Closing Thoughts & Key Highlights** *Deliberation Preparation for May 5*	All members, led by ADM Thad Allen
5:30	**ADJOURNMENT**	

THURSDAY, MAY 5, 2022		
Livestream Recording: https://youtu.be/tKu-q93D1yg		
9:00 - 9:05	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:05 - 9:30	**PNTAB Leadership Observations from Day 1 and Member Feedback**	ADM Thad Allen, *Chair, PNTAB;* Dr. Bradford Parkinson, *1st Vice Chair, PNTAB;* Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
9:30-10:30	**Updates from International Members & Representatives** (10 min each) − Brazil − Croatia *VIEW PDF* − Australia *VIEW PDF* − United Kingdom − Resilient Navigation and Timing (RNT) Foundation *VIEW PDF* − Consumer Technology Association (CTA) *VIEW PDF*	Representatives (at member's discretion) − Dr. Sonia M. Alves-Costa − Dr. Renato Filjar − Mr. Matt Higgins − Prof. Terry Moore − Mr. Dana Goward − Mr. J. David Grossman
10:30 - 10:45	**BREAK**	
10:45 - 11:45	**Roundtable Discussion -- Recommendation Formulation** − Organization of Work for 2021-2023 (Subcommittees, Task Forces, etc.) − Developing Findings & Recommendations	All members, led by Chairs
11:45 - 12:00	**Wrap-Up** − Determine venue & date for next meeting − Redondo Beach, CA, Nov. 15-17, 2022 is proposed	ADM Thad Allen, *Chair, PNTAB;* Dr. Bradford Parkinson, *1st Vice Chair, PNTAB;* Gov. Jim Geringer, *2nd Vice Chair, PNTAB*
12:00 - 1:00	**LUNCH — *Working as needed***	
1:00	**ADJOURNMENT**	

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Executive Summary

The 26th Federal Advisory Committee Act (FACA) session of the National Space-Based Positioning, Navigation, and Timing Advisory Board (PNTAB) was held May 4-5, 2022, in Annapolis, Maryland. A fact-finding non-public prep meeting was held on May 3rd. The PNTAB has been sponsored by National Aeronautics and Space Administration (NASA) since its first session in 2007.

This document summarizes the key briefing points and deliberations during this meeting. Snapshots of some of the briefing slides are included in the minutes for clarity.

Links to the briefings and livestream recordings are embedded in the meeting agenda (pp 3-4). They can also be accessed through the official Global Positioning System (GPS) Portal (www.gps.gov), maintained by the National Coordination Office for Space-Based PNT (NCO).

Key actions and outcomes from this meeting are described below.

On March 24, 2022, six subcommittees were established by ADM Allen (Chair) to support the work as authorized by the PNTAB Charter, Section 13 (Subcommittees and Task Forces)[1]:

> *"13. Subcommittees and Task Forces: As authorized by the DFO, the PNT Advisory Board work may be organized and supported by subcommittees, and/or task forces, to ensure taskings are appropriately completed in a timely manner in consultation with the PNT Board Chair or Vice Chair. In addition, NASA may authorize consultants with special expertise to support such subordinate groups on an ad hoc basis. Such subcommittees, and/or task forces, will be comprised of appointed PNT Advisory Board members and will report their findings and recommendations to the PNT Advisory Board Chair or Vice-Chair. Information classified for national security reasons may be provided to appropriately cleared members of the PNT Advisory Board to support the mission of the PNT EXCOM."*

The subcommittee chairs and membership were organized based on expertise and interest of members. The subcommittees are:

1. Communications & External Relations (CER)
2. Education & Science Innovation (ESI)
3. Emerging Capabilities, Applications and Sectors (ECAS)
4. International Engagement (IE)
5. Protect, Toughen & Augment (PTA)
6. Strategy, Policy, & Governance (SPG)

A Designated Federal Officer (DFO) will be appointed to each subcommittee to implement the provisions of FACA sections 10(e) and (f). It is the responsibility of the subcommittee chairs to develop, in consultation with their DFOs, all briefing materials. The subcommittee chairs will report to the PNT Board Chair (ADM Allen) and co-chairs, collectively known as the PNT Leadership Committee, and abide by the following Federal Advisory Committee Act (FACA) and NASA regulations for advisory boards.[2,3,4]

Subcommittee recommendations will be considered as DRAFT until approved by the board the next FACA meeting.

To streamline the number of external briefings at the PNTAB-27 meeting in November and focus on addressing the specific areas of each subcommittee, the subcommittee chairs should start thinking about who they want to bring to the next meeting and how to steer the briefer towards addressing the specific recommendations they are working on. The proposed list of briefers will be down-selected at the PNT Leadership Committee to ideally, no more than one external briefer per subcommittee.

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[1] https://www.gps.gov/governance/advisory/charter/

[2] NASA Policy Directive 1150.11A, "Federal Advisory Committee Act (FACA) Committees." https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=1150&s=11

[3] Rausch, Diane. Presentation to National Space-Based Positioning, Navigation and Timing (PNT) Advisory Board. 29 March 2007. https://www.gps.gov/governance/advisory/meetings/2007-03/rausch.ppt

[4] U.S. General Services Administration, "Federal Advisory Committee Act (FACA) Management Overview." https://www.gsa.gov/policy-regulations/policy/federal-advisory-committee-act-faca-management-overview

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Session of Wednesday, May 4, 2022

Board Convenes
Call to Order, Logistics, & Announcements
Mr. James J. Miller, *Executive Director, National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board*

Mr. Miller called to order the 26th meeting of the PNT Advisory Board (PNTAB). PNT stands for the vital services that the Global Positioning System (GPS) and other similar Global Navigation Satellite Systems (GNSS) provide. He thanked those attending in person and online, noting that presentations will be recorded and available on www.gps.gov/advisory. GPS is a world utility. Board members work with the United States Government to ensure GPS services remain robust and reliable for all of society. The PNTAB initiated operations in 2007, and Mr. Miller recognized Mr. Badri Younes from the National Aeronautics and Space Administration (NASA) Space Communications and Navigation (SCaN) Program for sponsoring the board for so many years. The PNTAB is a mix of veteran members, like Dr. Brad Parkinson, and some who joined more recently. All members are internationally recognized experts. The PNTAB mandate is to ensure the user voice is truly heard. The board is chaired by ADM Thad Allen, U.S. Coast Guard Commandant (ret.) and Dr. Brad Parkinson, chief architect of the GPS program. Mr. Miller noted a quorum to proceed.

Mr. Miller turned to recognize the current leaders and operators of the GPS constellation from the U.S. Space Force (USSF), highlighting a long tradition of partnership. Mr. Miller specifically thanked Mr. Cordell "Del" DeLaPena for joining and noted a specific program update from USSF later in the agenda. The PNTAB was established per presidential policy, now under the authority of Space Policy Directive 7 (SPD-7) for Space-Based PNT, with the intention of providing independent counsel to the PNT Executive Committee (EXCOM). PNTAB deliberations are governed by the Federal Advisory Committee Act (FACA) and open to the public. Minutes will be posted online within 90 days and briefings will be posted online within 24 hours of presentations. All board members were nominated by PNT EXCOM federal agencies and appointed by the NASA Administrator after undergoing a thorough vetting process. As Special Government Employees (SGE) or Representatives of the board deliberate, they must abide by established ethics laws and not engage in deliberations that may be a conflict of interest. If any member believes a potential conflict is emerging, they must ask to recuse themselves for the record. Mr. Miller thanked Mr. Jason Kim (Department of Commerce, DOC) for his support of the GPS.gov website. Mr. Miller thanked the group and turned to ADM Allen.

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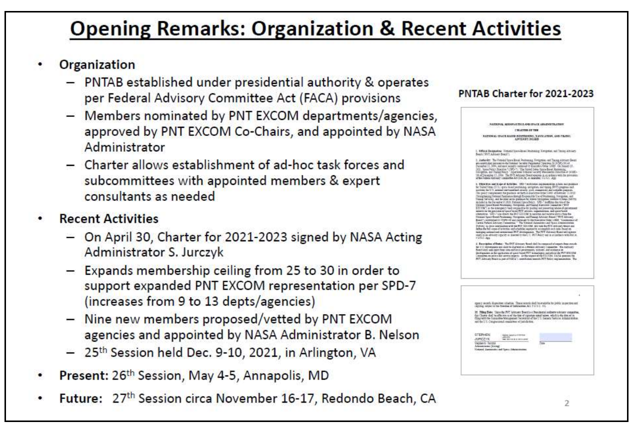
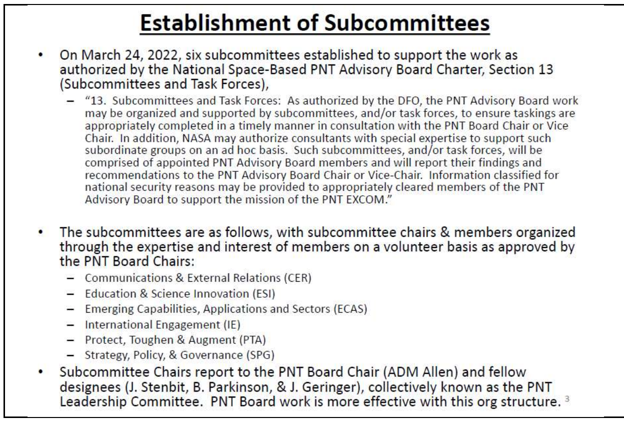
26th PNTAB Welcome & Introduction
Goals & Objectives, Establishment of Six New Subcommittees
ADM Thad Allen, *Chair*

ADM Allen thanked Mr. Miller and welcomed PNTAB members and colleagues to the meeting. He noted that the board was rechartered under the new administration and reconstituted with new membership. The membership has provided great diversity in terms of knowledge and understanding of GNSS nationally and internationally, adding immeasurably to the richness and depth of discussions moving forward (Slide 1).



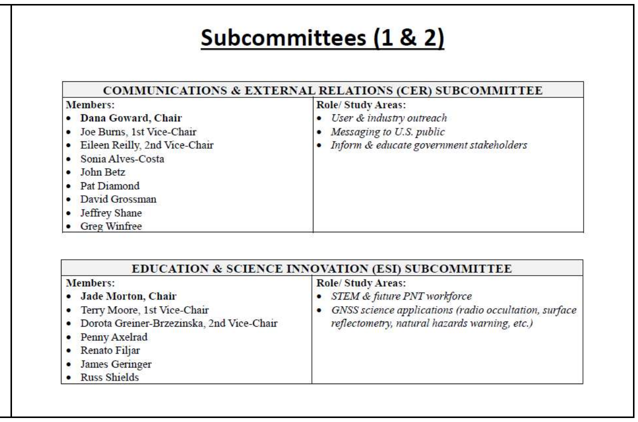
Slide 1

As a ubiquitous global utility, GPS and other GNSS impact every facet of critical infrastructure, making it challenging to identify a single point of focus for the advisory board. Over the previous six months, the PNTAB held a series of fact-finding meetings identifying a new subcommittee structure for the board where Subject Matter Experts (SMEs) may focus on various aspects of GPS/GNSS (Slides 2-5). With this approach, the PNTAB will have a more structured way to produce advice and content for the interagency and PNT EXCOM. These subcommittees will be subject to FACA rules and ethics laws. As one of the most complicated advisory board committees, the PNTAB does not report to a single entity of the U.S. Government. The PNT EXCOM is co-chaired by the Deputy Secretaries of the Department of Defense (DoD) and Department of Transportation (DOT), with almost every agency having an interest in what goes on there. The new subcommittee structure will support the PNTAB in how the work is structured and help to generate more advisory board content moving forward. ADM Allen thanked the board members for their contributions to this effort.



Establishment of Subcommittees

- On March 24, 2022, six subcommittees established to support the work as authorized by the National Space-Based PNT Advisory Board Charter, Section 13 (Subcommittees and Task Forces),
  - "13. Subcommittees and Task Forces: As authorized by the DFO, the PNT Advisory Board work may be organized and supported by subcommittees, and/or task forces, to ensure taskings are appropriately completed in a timely manner in consultation with the PNT Board Chair or Vice Chair. In addition, NASA may authorize consultants with special expertise to support such subordinate groups on an ad hoc basis. Such subcommittees, and/or task forces, will be comprised of appointed PNT Advisory Board members and will report their findings and recommendations to the PNT Advisory Board Chair or Vice-Chair. Information classified for national security reasons may be provided to appropriately cleared members of the PNT Advisory Board to support the mission of the PNT EXCOM."
- The subcommittees are as follows, with subcommittee chairs & members organized through the expertise and interest of members on a volunteer basis as approved by the PNT Board Chairs:
  - Communications & External Relations (CER)
  - Education & Science Innovation (ESI)
  - Emerging Capabilities, Applications and Sectors (ECAS)
  - International Engagement (IE)
  - Protect, Toughen & Augment (PTA)
  - Strategy, Policy, & Governance (SPG)
- Subcommittee Chairs report to the PNT Board Chair (ADM Allen) and fellow designees (J. Stenbit, B. Parkinson, & J. Geringer), collectively known as the PNT Leadership Committee. PNT Board work is more effective with this org structure. 3

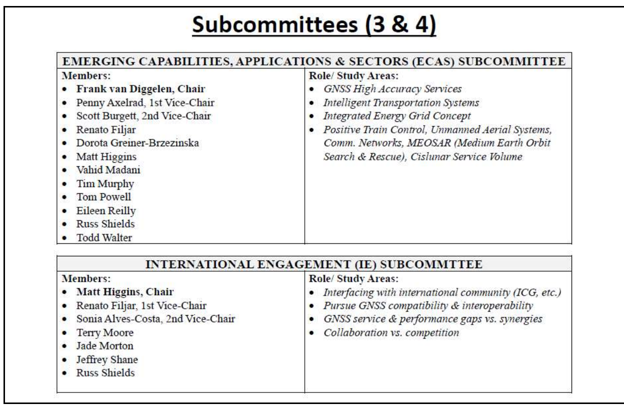


Subcommittees (1 & 2)

COMMUNICATIONS & EXTERNAL RELATIONS (CER) SUBCOMMITTEE	
Members:	**Role/ Study Areas:**
• **Dana Goward, Chair** • Joe Burns, 1st Vice-Chair • Eileen Reilly, 2nd Vice-Chair • Sonia Alves-Costa • John Betz • Pat Diamond • David Grossman • Jeffrey Shane • Greg Winfree	• *User & industry outreach* • *Messaging to U.S. public* • *Inform & educate government stakeholders*

EDUCATION & SCIENCE INNOVATION (ESI) SUBCOMMITTEE	
Members:	**Role/ Study Areas:**
• **Jade Morton, Chair** • Terry Moore, 1st Vice-Chair • Dorota Greiner-Brzezinska, 2nd Vice-Chair • Penny Axelrad • Renato Filjar • James Geringer • Russ Shields	• *STEM & future PNT workforce* • *GNSS science applications (radio occultation, surface reflectometry, natural hazards warning, etc.)*

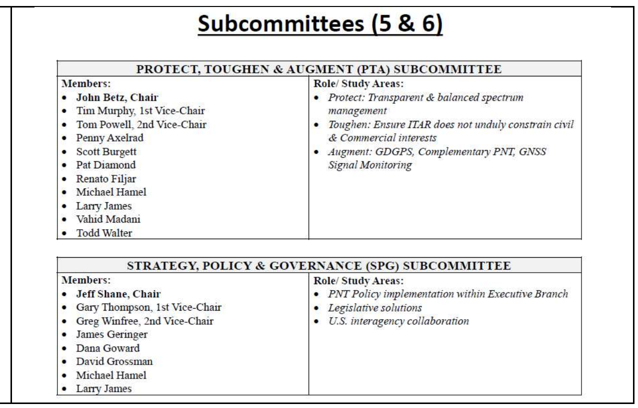
Slides 2-3



Subcommittees (3 & 4)

EMERGING CAPABILITIES, APPLICATIONS & SECTORS (ECAS) SUBCOMMITTEE	
Members:	**Role/ Study Areas:**
• **Frank van Diggelen, Chair** • Penny Axelrad, 1st Vice-Chair • Scott Burgett, 2nd Vice-Chair • Renato Filjar • Dorota Greiner-Brzezinska • Matt Higgins • Vahid Madani • Tim Murphy • Tom Powell • Eileen Reilly • Russ Shields • Todd Walter	• *GNSS High Accuracy Services* • *Intelligent Transportation Systems* • *Integrated Energy Grid Concept* • *Positive Train Control, Unmanned Aerial Systems, Comm. Networks, MEOSAR (Medium Earth Orbit Search & Rescue), Cislunar Service Volume*

INTERNATIONAL ENGAGEMENT (IE) SUBCOMMTTEE	
Members:	**Role/ Study Areas:**
• **Matt Higgins, Chair** • Renato Filjar, 1st Vice-Chair • Sonia Alves-Costa, 2nd Vice-Chair • Terry Moore • Jade Morton • Jeffrey Shane • Russ Shields	• *Interfacing with international community (ICG, etc.)* • *Pursue GNSS compatibility & interoperability* • *GNSS service & performance gaps vs. synergies* • *Collaboration vs. competition*



Subcommittees (5 & 6)

PROTECT, TOUGHEN & AUGMENT (PTA) SUBCOMMITTEE	
Members:	**Role/ Study Areas:**
• **John Betz, Chair** • Tim Murphy, 1st Vice-Chair • Tom Powell, 2nd Vice-Chair • Penny Axelrad • Scott Burgett • Pat Diamond • Renato Filjar • Michael Hamel • Larry James • Vahid Madani • Todd Walter	• *Protect: Transparent & balanced spectrum management* • *Toughen: Ensure ITAR does not unduly constrain civil & Commercial interests* • *Augment: GDGPS, Complementary PNT, GNSS Signal Monitoring*

STRATEGY, POLICY & GOVERNANCE (SPG) SUBCOMMITTEE	
Members:	**Role/ Study Areas:**
• **Jeff Shane, Chair** • Gary Thompson, 1st Vice-Chair • Greg Winfree, 2nd Vice-Chair • James Geringer • Dana Goward • David Grossman • Michael Hamel • Larry James	• *PNT Policy implementation within Executive Branch* • *Legislative solutions* • *U.S. interagency collaboration*

Slides 4-5

ADM Allen noted Dr. Hampshire from DOT was unable to join in the morning as scheduled and introduced Ms. Karen Van Dyke to make opening remarks on his behalf.

* * *

Opening Remarks
Civil Sector National Priorities
Dr. Robert Hampshire, *Deputy Assistant Secretary for Research & Technology, Department of Transportation*

Ms. Karen Van Dyke offered apologies on behalf of Dr. Hampshire and noted his plans to attend later in the afternoon and evening. She noted that PNT is extremely important to DOT, both in safety-of-life applications and broader civil use including surveying, timing, and high-precision applications for agriculture and mining. At DOT, safety is the top priority, and that is the lens through which they look at PNT. Ms. Van Dyke thanked PNTAB members Hon. Jeff Shane and Hon. Greg Winfree, applauding their concerted efforts during their tenure with DOT. There have been many resource challenges with both staffing and budget, but due to recent events, PNT is starting to get attention, as was reflected in the FY22 budget. It is still miniscule compared with DoD, but looking to the future, DOT embraces this momentum. Spectrum challenges are not going to get any easier moving forward. Ms. Van Dyke noted that SPD-7 requires the development of a nationwide interference detection monitoring capability. She noted that most civilian users have little awareness of who to contact or where to submit a report in the event of GPS interference so that it may be mitigated. In attending a PNT Situational Awareness workshop sponsored by MITRE on May 3, 2022, Ms. Van Dyke noted the discussion of a whole-of-government approach. This discussion falls under the "Protect" part of PTA. Regarding "Toughen," Ms. Van Dyke was glad to see the advisory board address ITAR restrictions and how civil equipment can take advantage of military technologies. Looking to "Augment," she appreciated the emphasis on "augment and adopt," as it is not sufficient to merely identify augmentations without incorporating them into current systems. Ms. Van Dyke highlighted the need to balance technological advancements with cost. DOT looks forward to future collaboration with USSF and takes its civil GPS leadership role seriously. Ms. Van Dyke thanked the group for their attention and mentioned that Dr. Hampshire wished to say a few words when he arrived later in the day. ADM Allen thanked Ms. Van Dyke for the remarks.

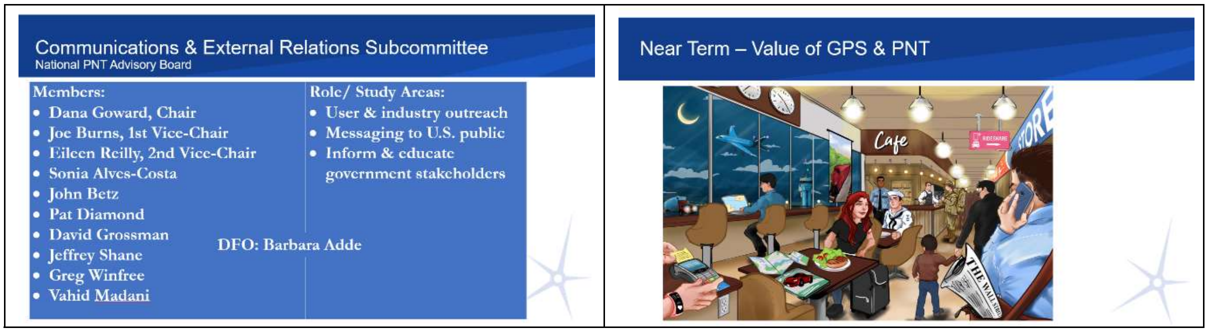
* * *

Subcommittee Introductions

ADM Allen asked subcommittee chairs to provide an update and review their progress.

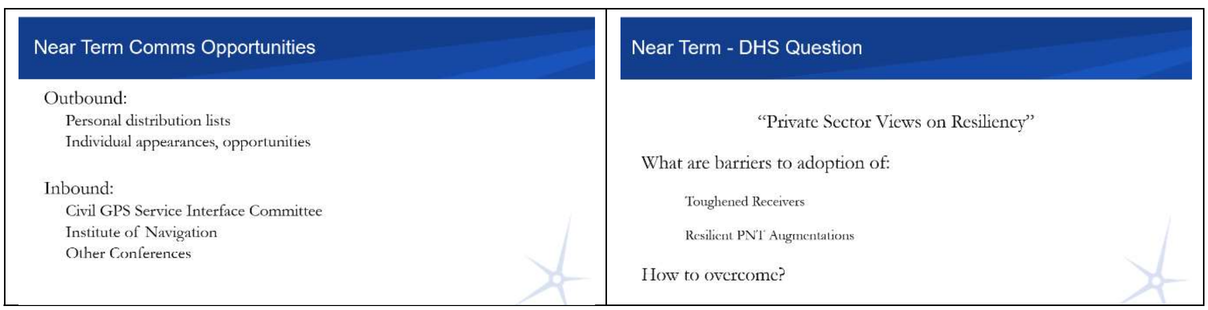
1) Communications & External Relations (CER) Subcommittee

Mr. Dana Goward (Resilient Navigation & Timing Foundation) chairs this subcommittee. The subcommittee is meeting every other week (Slide 1). One of its responsibilities is to help communicate the inestimable value of GPS and PNT to every facet of daily life. To that end, the subcommittee has obtained agreement from the RNT Foundation to allow their *GPS Café* application to be used on the GPS.gov site and other areas the board would like (Slide 2). As a user hovers over the graphic, explanations of how GPS supports an item, along with hyperlinks to more information, pop up.



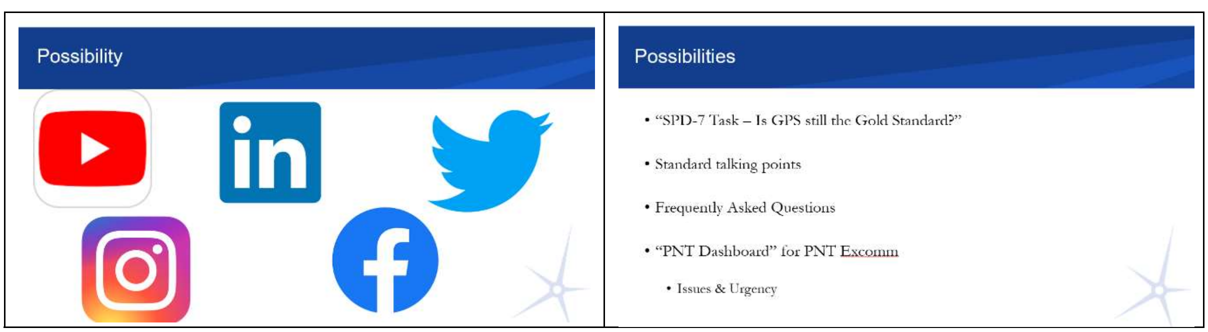
Slides 1-2

The subcommittee is also interested in helping the board communicate more effectively with leaders in government. To that effect, Mr. David Grossman arranged for Ms. Melissa Harrison from the Consumer Technology Association (CTA) to provide a talk about communicating technical issues to policymakers and the press, which is a core competency all board members should develop. The CER Subcommittee is not only responsible for information going out from the board, but also for intaking concerns from the GPS and PNT user communities (Slide 3). It has also met with Department of Homeland Security (DHS) representatives twice to discuss their questions about private sector views on resiliency. The subcommittee expects to formulate a document for full PNTAB review as a response (Slide 4).



Slides 3-4

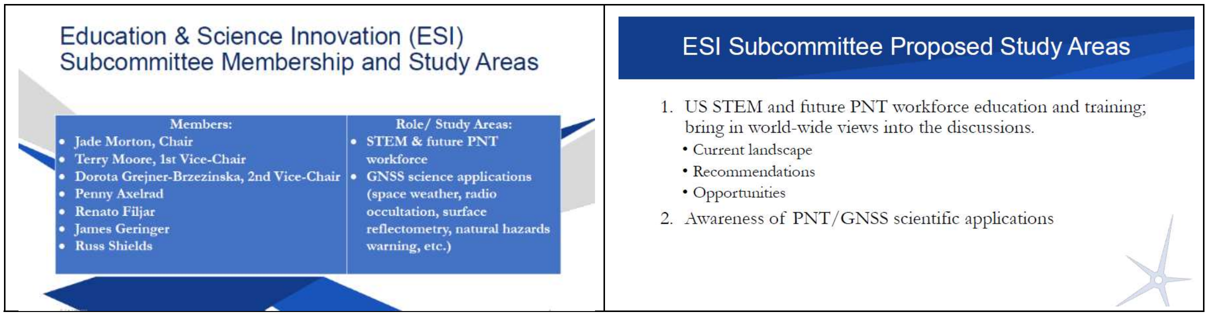
Another possibility for the subcommittee also involves the establishment of a social media presence for the advisory board, which would require resources to stand up and maintain on a regular basis (Slide 5). The CER Subcommittee has been in conversation with the National Coordination Office for Space-Based PNT (NCO) to discuss possible resources from their perspective. Other ideas the subcommittee has explored or that have been suggested to it are found below (Slide 6).



Slides 5-6

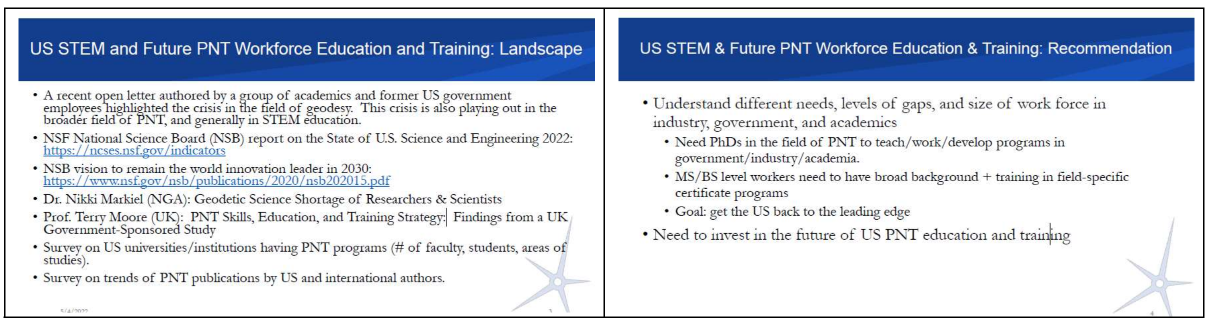
2) Education & Science Innovation (ESI) Subcommittee

Dr. Jade Morton opened the presentation for the ESI Subcommittee by reviewing the subcommittee membership (Slide 1). The primary study areas for the subcommittee are STEM & Future PNT Workforce and GNSS science applications (Slide 2). In these two areas, the subcommittee has looked into several aspects of Science, Technology, Engineering, and Math (STEM) & Future PNT workforce education and training, bringing worldwide views and perspectives of membership into the discussion. In terms of workflow, the group aims to build an understanding of the current landscape, then formulate recommendations based on opportunities available in the area of PNT.



Slides 1-2

There has been a clear and specific emphasis on the crisis in the field of geodesy, which is playing out in the broader field of PNT and generally in STEM education (Slide 3). Dr. Morton referred to the report from the National Science Foundation (NSF) National Science Board (NSB) on the state of U.S. STEM Education[5], as well as recent research by Dr. Nikki Markiel from the National Geospatial-Intelligence Agency (NGA) on the geodetic science shortage and Prof. Terry Moore's UK government-sponsored study. Some conclusions drawn from these works are that there is a need for a sufficient number of PhDs in the field of PNT to teach, work, and develop programs in government, industry, and academia (Slide 4).

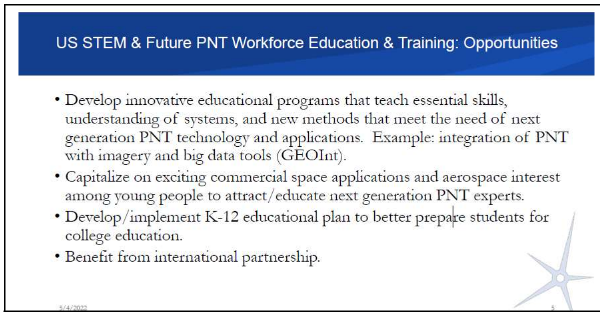


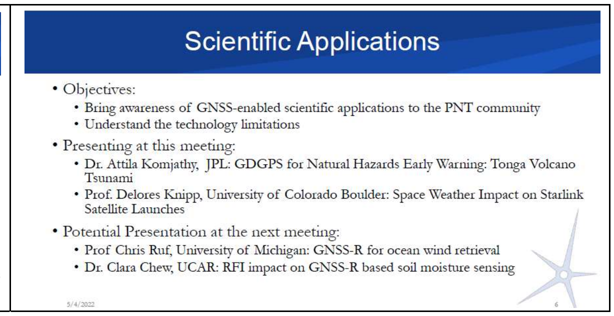
Slides 3-4

There's also a need to invest in future U.S. PNT education and training (Slide 5). The subcommittee has identified opportunities among these challenges to push for innovative educational programs that teach essential skills, understandings of systems, and new methods that will inform the next generation of PNT technology and applications. For example, Mr. Shields has highlighted the need to integrate PNT technology with imagery and big data tools. Another opportunity in the field is to capitalize on the commercial space industry to attract and educate the next generation of PNT experts. The subcommittee recommends promoting the development of K-12 educational plans to better prepare students for careers in PNT from an early age. Dr. Morton also highlighted the value of international partnerships and collaboration in this area.

Turning to scientific applications, the ESI Subcommittee aims to bring awareness of GNSS scientific applications to the broader PNT community and promote research which elucidates the technical limitations of GNSS (Slide 6). Two briefers will present later today on this topic, including Dr. Delores Knipp (University of Colorado Boulder), to talk about the Space Weather Impact on Starlink Satellite Launches, and Dr. Attila Komjathy (Jet Propulsion Laboratory) to talk about the use of the NASA Global Differential GPS (GDGPS) System for early warning of the Tonga volcano tsunami. The ESI Subcommittee proposes two potential presentations for the next PNTAB meeting, including Professor Chris Ruf from the University of Michigan regarding GNSS-R (GNSS Reflectometry) for ocean wind retrieval, as well as Dr. Clara Chew from the University Corporation for Atmospheric Research (UCAR) on the RFI impact on GNSS-R based soil moisture sensing. The goal of these presentations is to provide a perspective on GNSS-enabled specific scientific applications and the limits of technology.

[5] NSF National Science Board (NSB) report on the State of U.S. Science and Engineering 2022: https://ncses.nsf.gov/indicators





Slides 5-6

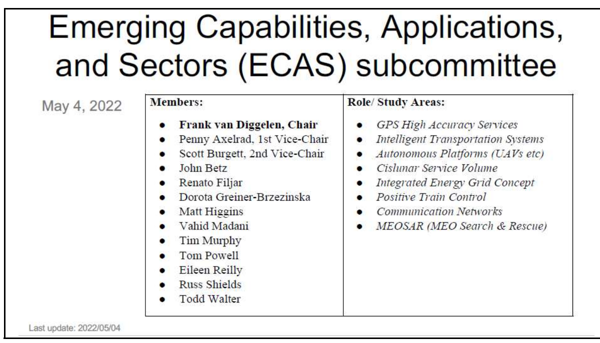
Q&A / Discussion:

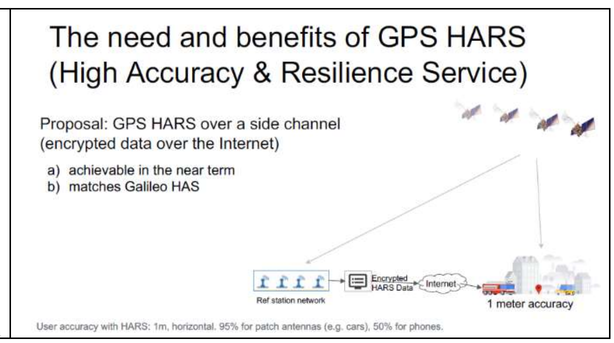
ADM Allen emphasized the need for the PNTAB to highlight the work of the subcommittees.

3) Emerging Capabilities, Applications, & Sectors (ECAS) Subcommittee

Dr. Frank van Diggelen introduced the subcommittee, noting it has the largest membership of PNTAB subcommittees (Slide 1). There are eight topic areas tasked to the subcommittee, including implementation of a GPS high accuracy service, intelligent transportation systems, autonomous platforms, the Cislunar Service Volume, integrated energy grid concept, positive train control, communications networks, and MEOSAR (Medium Earth Orbit Search & Rescue).

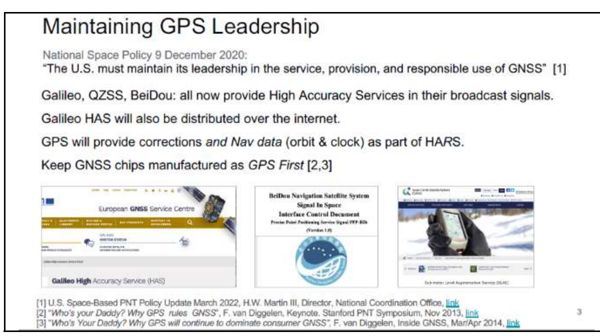
Over the previous months, the ECAS Subcommittee focused primarily on GPS High Accuracy & Resilience Service (GPS HARS), which follows naturally from the GDGPS study done by the PNTAB (Slide 2). The GPS HARS would provide corrections to orbit and clock errors over a side channel, encrypted over the internet. This would surpass what Galileo does in terms of resilience, adding a layer of protection similar to that of credit card transactions, which is resilience far beyond what is available right now. The basic architecture of the GPS system is of weak signals and slow data rates. This proposed system would distribute corrections direct to consumers with one meter accuracy.

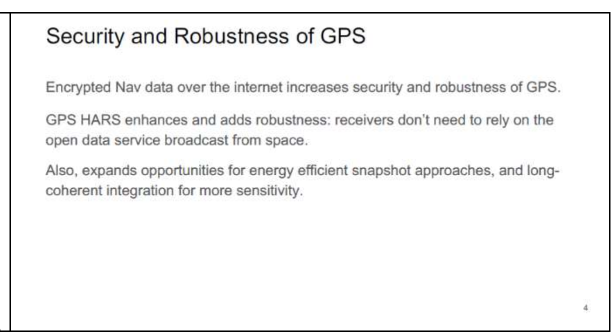




Slides 1-2

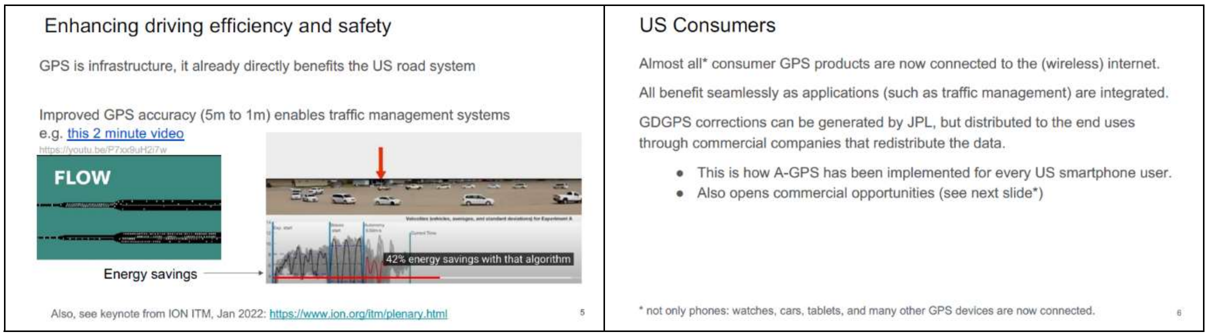
Many aspects to the GPS HARS system would allow the U.S. to maintain leadership in GNSS (Slide 3). Galileo is already implementing a similar system (Galileo High Accuracy Service, GPS HAS) to what is being proposed here with corrections provided over the internet. Coming from the mobile phone industry, Dr. van Diggelen noted that GNSS chips are built to acquire GPS first and then use that information to acquire other GNSS. As the processing power of these chips gets better, there is a risk that the advantage GPS has could fade away when other services provide corrections direct to consumers. Turning to a discussion of security and robustness, Dr. van Diggelen noted that encrypted navigation data would provide an additional level of security where receivers would not need to rely on open data service broadcast from space (Slide 4).





Slides 3-4

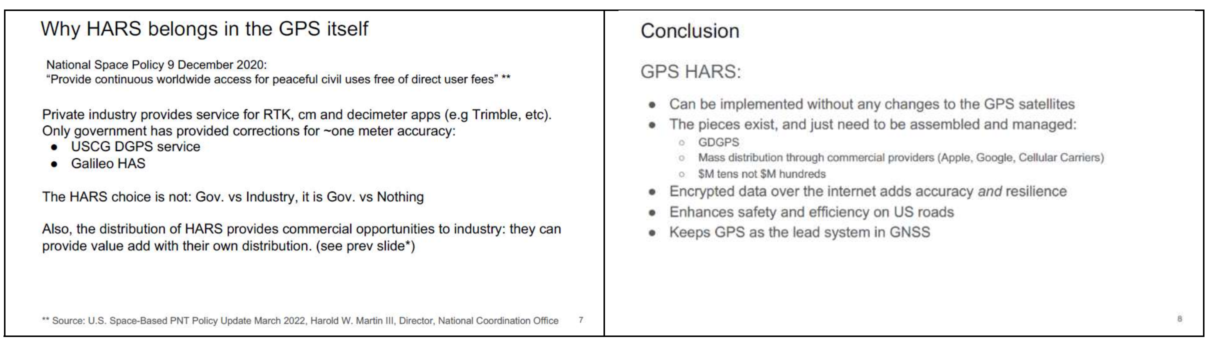
Corrections provided directly to the receiver would expand signal processing abilities on the chip itself. GPS accuracy would improve from 3-5 meters down to one meter with this proposed system. U.S. consumers already directly benefit from GPS, as the system improves efficiency of cars by approximately 15% by getting to their destinations faster (Slide 5). Dr. van Diggelen then played a short video from Dr. Alexandre Bayen from University of California Berkeley about how self-driving cars can reduce traffic jams. This kind of capability depends on knowing which lane the car is in, which could be enabled by something like GPS HARS. This system could be implemented in the next few years and benefit everyone, particularly with the rise in gas prices. The required elements of GPS HARS are already in place (Slide 6). Almost all consumer products are now connected to the wireless internet. Applications like traffic management would benefit even if particular individuals are not a user. GDGPS corrections can be generated by JPL and potentially distributed to end users through commercial companies, such as how Assisted GPS (A-GPS) has been implemented for every U.S. smartphone user.



Slides 5-6

Such a system belongs as part of GPS itself (Slide 7). Private industry provides Real-Time Kinematic (RTK) services at the centimeter and decimeter levels for a fee that is unreasonable for individual consumers. GPS HARS is not a matter of government versus industry – it is government or nothing. The distribution of HARS provides commercial opportunities to industry.

GPS HARS can be implemented without any changes to GPS satellites (Slide 8). The pieces exist, they simply need to be assembled and managed and distributed through commercial providers. This kind of initiative would cost in the tens of millions, not hundreds. It would create safety and efficiency on U.S. roads. It is also necessary to keep GPS as the leading GNSS system.



Slides 7-8

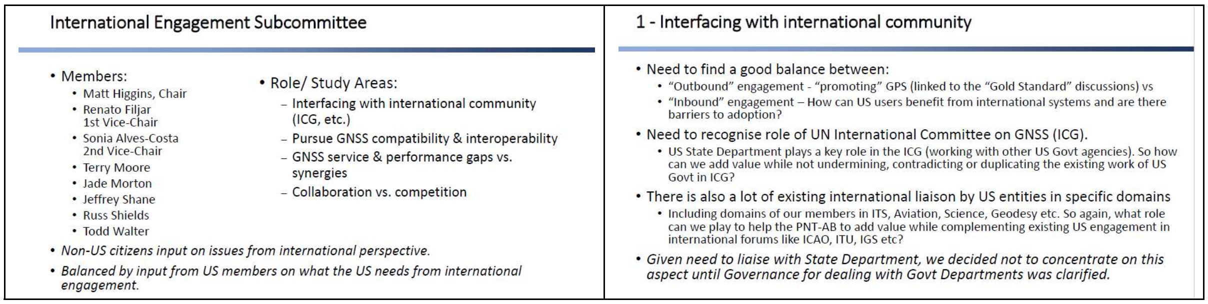
Q&A / Discussion:

ADM Allen thanked Dr. van Diggelen and noted that this discussion is relevant to the GPS Gold Standard topic.

4) International Engagement (IE) Subcommittee

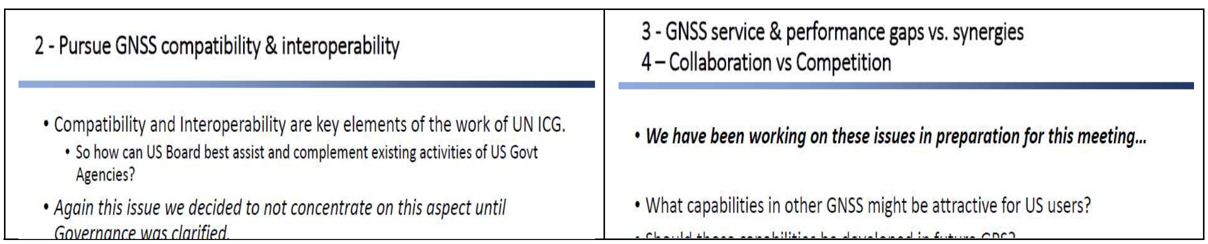
Mr. Matt Higgins provided an overview of the work of the International Engagement (IE) Subcommittee (Slide 1). Half of the subcommittee is U.S.-based, and the other half is international, providing a broad perspective on the value and opportunities of GPS around the world.

A key study area for the subcommittee is how the PNTAB can interface with the international community (Slide 2). Early on in deliberations, there was discussion around the ideal of outbound engagement, promoting GPS in relation to the "gold standard" discussions, as opposed to inbound engagement, looking at how U.S. users can benefit from international systems. The IE Subcommittee recognizes the role of the United Nations (UN) International Committee on GNSS (ICG), which plays a significant role in terms of representation from the U.S. government. The group is conscientious of what work can be done on behalf of the board that would add value without duplicating existing work. Mr. Higgins recognized Mr. Jeff Auerbach from the Department of State (DOS) as the U.S. lead for the ICG. Given that the IE Subcommittee would need to liaise with the State Department on this work, the subcommittee decided to hold on this topic until a Designated Federal Officer (DFO) is appointed.



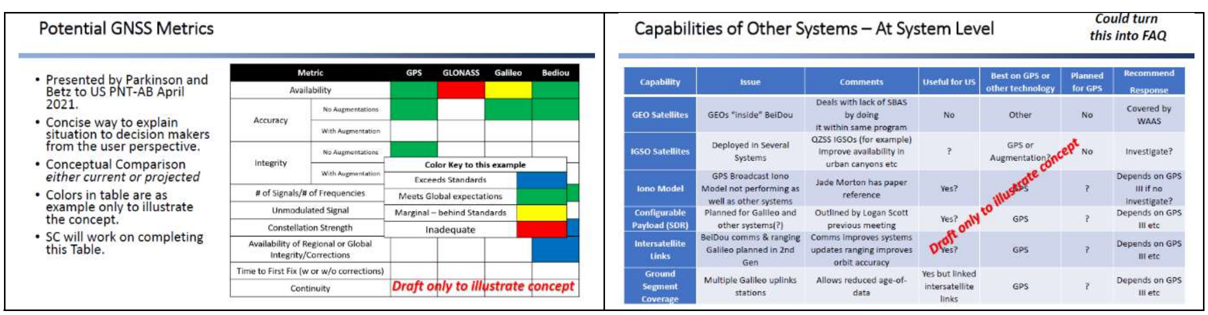
Slides 1-2

In preparation for PNTAB 26, the IE Subcommittee began work examining what capabilities in other GNSS might be attractive for U.S. users (Slides 3-4). This project goes to the heart of the GPS Gold Standard discussion.



Slides 3-4

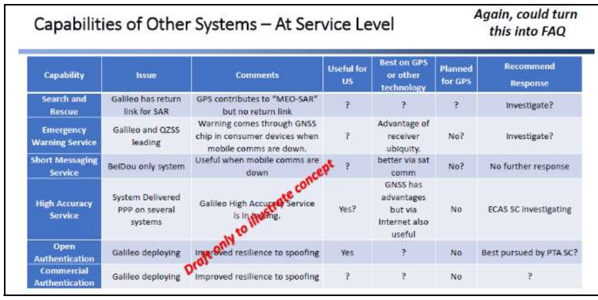
Dr. Parkinson and Dr. Betz put together the initial concept for this work in April 2021, building a table with metrics from a user perspective to see what different systems offer (Slide 5). This would also clearly communicate to decision makers how GPS compares to other systems. The IE Subcommittee also proposes putting together a comparative chart as an illustrative concept reviewing various capabilities of GNSS at a system level (Slide 6). This chart could include questions such as whether these capabilities are useful for the U.S. (including whether necessary or just beneficial), whether they are best accomplished on GPS or another technology, whether they are already planned for the future of GPS, and what further action should be taken.



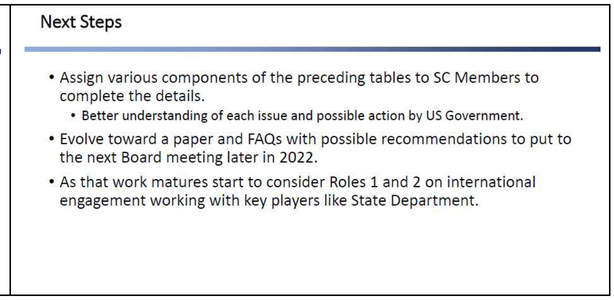
Slides 5-6

Similarly, there would also be a chart reviewing the various capabilities of GNSS at a service level (Slide 7). This analysis would lead to a recommended response from the subcommittee on a way forward (Slide 8). This working-level document could then be turned into a one-pager or FAQ document for high-level decision makers. In terms of next steps, the

IE Subcommittee is assigning members various components of the tables to complete and gain a better understanding of these issues. Once resolved, these will be shared with the PNTAB at large for review.



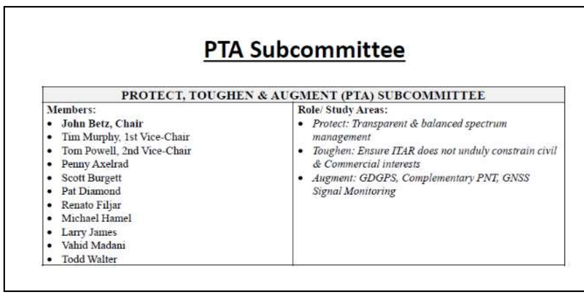
Capability	Issue	Comments	Useful for US	Best on GPS or other technology	Planned for GPS	Recommend Response
Search and Rescue	Galileo has return link for SAR	GPS contributes to "MEO-SAR" but no return link	?	?	?	Investigate?
Emergency Warning Service	Galileo and QZSS leading	Warning comes through GNSS chip in consumer devices when mobile comms are down.	?	Advantage of receiver ubiquity.	No?	Investigate?
Short Messaging Service	BeiDou only system	Useful when mobile comms are down	?	better via sat comm	No?	No further response
High Accuracy Service	System Delivered PPP on several systems	Galileo High Accuracy Service is in [illegible].	Yes?	GNSS has advantages but via Internet also useful	No	ECAS SC investigating
Open Authentication	Galileo deploying	[illegible] resilience to spoofing	Yes	?	No	Best pursued by PTA SC?
Commercial Authentication	Galileo deploying	Improved resilience to spoofing	?	?	No	?

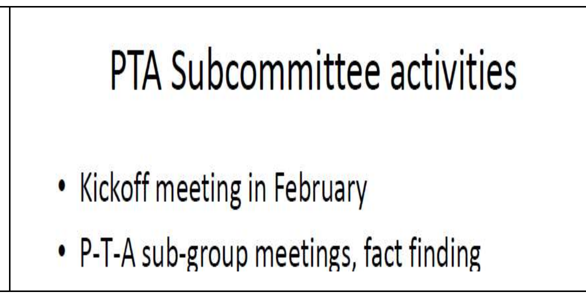


Slides 7-8

5) Protect, Toughen, & Augment (PTA) Subcommittee

Dr. Tom Powell provided an overview of the PTA Subcommittee on behalf of subcommittee Chair Dr. John Betz, who was unable to attend the meeting (Slide 1). PTA is a broad concept that applies to much of the work done by the PNTAB, creating a challenge for the subcommittee to boil the work down to actionable topics (Slide 2). "Protect" refers to spectrum, the regulatory environment, and detecting interference. "Toughen" refers to making PNT devices more resilient, for example with anti-jam antennas which were historically only available to the military. Mr. Murphy has put together a study in that area. The SPG Subcommittee conversation on regulatory issues overlaps closely with the Protect area of the PTA Subcommittee. Regarding "Augment", Dr. Betz proposes a particular study around augmenting critical timing systems. Each area of PTA has chosen a topic to study.





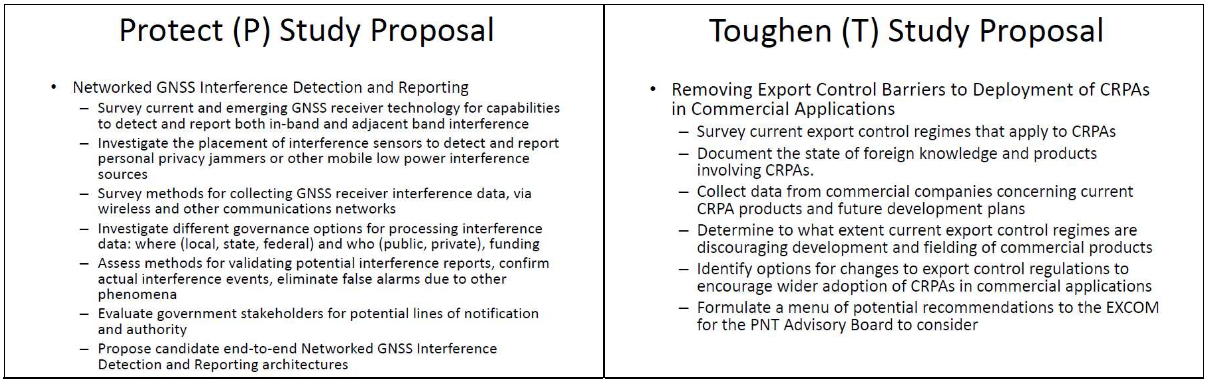
Slides 1-2

The subcommittee proposes the Protect study proposal on network interference (Slide 3). Nearly all devices are networked in some way, which presents a great opportunity to report what they see in the environment around them. Some devices are more sophisticated than others in terms of being able to measure that interference. For example, a cell phone can tell you if it has GPS signal or not, but a high precision receiver could do a detailed survey of the environment that could be valuable in certain circumstances. This is a great opportunity to crowdsource interference detection. Some major questions for the study to consider are who would be responsible for organizing it, who would fund it, and who would manage technical questions if and when they arise. There are also technical aspects to consider regarding processing the data and notifying or disseminating that data to whoever needs to respond to the interference.

The subcommittee also proposes a Toughen study which looks specifically at controlled radiation pattern antennas to help with anti-jamming (Slide 4). The controlled radiation pattern antennas form beams in the direction of satellites. This is an effective technology for mitigating interference, but is traditionally only available to DoD as it is subject to military technology International Traffic in Arms Regulations (ITAR) restrictions. From Boeing's perspective, if government regulations could be altered, there is considerable interest in providing these technology applications to those outside the military. The basic science behind this technology is now well known. Perhaps 10-20 years ago this technology was less understood, but perhaps now the time is right to adjust. There is some evidence that some foreign companies are starting to develop this technology. It is worth reexamining current regulatory barriers to see how U.S. industry could benefit from this technology.

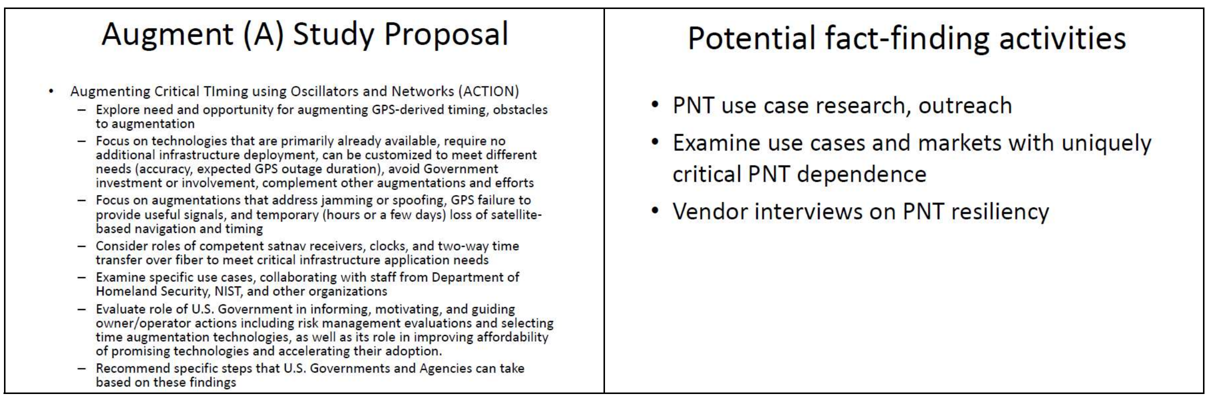
ADM Allen asked which agency or department would be appropriate to talk to about this issue.

Mr. Murphy responded that both DOS and DOC manage ITAR and Export Administration Regulations (EAR). If restrictions were to be changed, both DOS and DOC Commerce would need to be engaged.



Slides 3-4

The subcommittee also proposes an Augment study regarding GPS-derived timing services (Slide 5). As has been mentioned by the PNTAB, timing applications of GPS are often overlooked but are no less critical than positioning, and in many ways are more critical as the force behind financial markets and timing networks. It is critical that these timing applications be protected and have augmentations. This study proposal would focus on technologies already available and identify threats from jamming or spoofing that could affect timing networks. Not all timing use cases are the same. The goal of the study would be to develop proposed architectures to back up critical timing applications. As with the other proposed studies, there will be clearly identified parties in the U.S. Government who could take action on the proposal. Slide 6 describes the potential fact-finding activities for these studies.



Slides 5-6

Q&A / Discussion:

Mr. Younes asked whether the PTA committee had considered the use of cognitive technology wherein GPS receivers could make sense of whatever they observe before making decisions using Machine Learning (ML) or Artificial Intelligence (AI).

Dr. Powell responded that there would be no shortage of applications of that kind of technology, and that the subcommittee would consider it during their fact-finding endeavors.

Mr. Younes added that he would be happy to engage in that work on behalf of NASA. He also added that the ITAR issue should be elevated as an EXCOM topic as DOS, DOC, and DoD are involved on that level.

Mr. Goward remarked on the timing architecture study, saying that it seemed to be set up well within the subcommittee structure. He emphasized that in addition to considering the technology aspects, the subcommittee should consider whether the government has the responsibility and should proceed in ensuring a national timing architecture is instituted.

6) Strategy, Policy, & Governance (SPG) Subcommittee

Hon. Jeff Shane introduced the SPG Subcommittee, noting an impressive range of expertise within the membership. The SPG Subcommittee takes a higher-level perspective on PNT issues. The main function of the PNTAB is to give the government a view from the user perspective, looking in from the outside. When working within government, people work very hard and are passionate about the subject matter. The SPG Subcommittee has the opportunity to ask – we know you're working very hard, but is it working? Is the structure itself working? The SPG Subcommittee aims to support the PNTAB in framing PNT as the vital, enabling, foundational capability that supports all elements of critical infrastructure, so that it is addressed that way within government and international fora. The PNTAB knows, because it has been briefed as such, that the U.S. Government regards GPS as a single point of failure. The PNTAB has raised that issue for 20 years, but it has still not been addressed effectively. The conclusion that can be made here is that despite all the work and passion, PNT has not taken its rightful place in the national policy agenda, and the PNTAB has a solemn obligation to change that.

The goal of the SPG Subcommittee is to break the issue down into its component parts. First, it is looking at PNT governance itself and asking how effective the EXCOM structure really is in a whole-of-government policy approach. It proposes to look at how important PNT ranks on the individual agendas of the leadership of EXCOM. This isn't meant as a criticism, but rather as a realistic question regarding the balance of competing priorities. The SPG Subcommittee may also examine the impact on the budget process by engaging with Congressional committees. If PNT policy isn't taking its rightful place, the SPG Subcommittee may look at PNT governance and suggest change where change is warranted.

Turning to the Gold Standard discussion, is GPS is still truly the gold standard? Other systems have capabilities that GPS doesn't have. Most chips prioritize GPS first, but that doesn't necessarily make it the gold standard, more that it was the first technology to get there. It's not insignificant that it was the first, especially since it was provided to the entire world free of charge, which is one of the greatest gifts to humanity that any government has ever done. However, it is owned and operated by the U.S. military, so we can forgive other countries for thinking they ought not to rely on systems operated by a foreign military power. Other systems are now more advanced than GPS, so the question is raised whether competition with other systems is something to be worried about. If looking for the highest level of PNT accuracy and reliability, interoperability may be the best way to achieve that. If that is the objective of the U.S. Government, the PNTAB does not know. It is important to consider what "gold standard" means in today's interconnected world. GPS doesn't have to be the best system, and perhaps it is not a relevant question anymore.

Turning to spectrum management, the current system is designed so that decisions are made by an independent regulatory agency that is not part of the administration. Given its statutory authority to assign spectrum, it has done a good job as demand has increased and the spectrum has become increasingly crowded as a result. However, the governance of spectrum management within the U.S. makes executive branch agencies nothing more than "interested parties" without the ability to impact the final decision. This can be seen in the example of the conflict in 5G rollout with the commercial aviation industry. The Federal Aviation Administration (FAA) had communicated for two years prior to the decision that there would be a problem, and the Federal Communications Commission (FCC) thought they handled it by creating a buffer zone. The problem is that the FCC has neither the authority nor the accountability to make final decisions regarding aviation safety, and the FAA wasn't satisfied. Everyone is doing what they're supposed to do, but somehow the process isn't working. Turning to Ligado, despite the vehement objections of the DoD and a recent letter to the administration from 100 separate stakeholders objecting to the FCC decision, Ligado is still moving forward. Everyone is doing what they are supposed to do within the system, but something is wrong. What is most important to all is the reliability and integrity of PNT. The flip side of the spectrum management problem is receivers. The FCC has raised questions of whether the FCC can or should regulate receivers and create standards for receivers. With a more crowded spectrum and better technology, does that mean the FCC should step into this regulatory role? This is something the PNTAB could investigate. From a broader perspective, the SPG Subcommittee is also focused on getting specific feedback from government on recommendations made by the PNTAB.

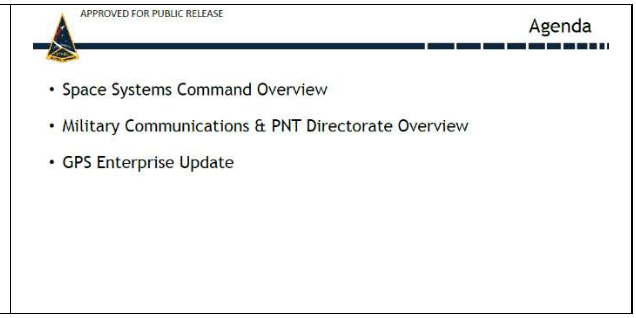
Q&A / Discussion:

ADM Allen responded that this is a priority for the PNTAB and expressed an interest in sharing a statement of the board for the record at the conclusion of the meeting.

* * *

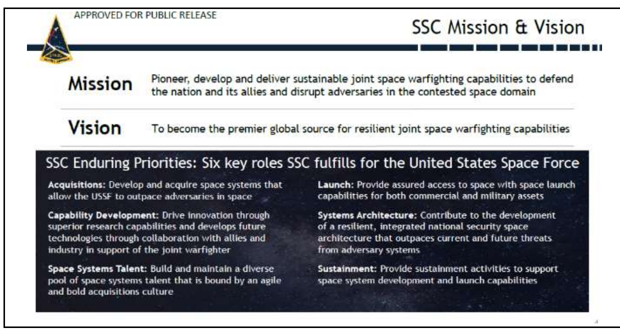
Update on GPS Modernization & Emerging Capabilities
Mr. Cordell DeLaPena, *Executive Officer, MilComm & PNT, Space Systems Command (SSC), USSF*

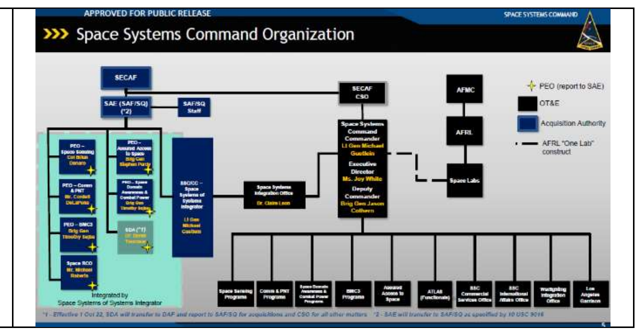
Mr. DeLaPena thanked ADM Allen for the opportunity to present an update on Military Communications & PNT Overview, including a GPS update (Slides 1-2).



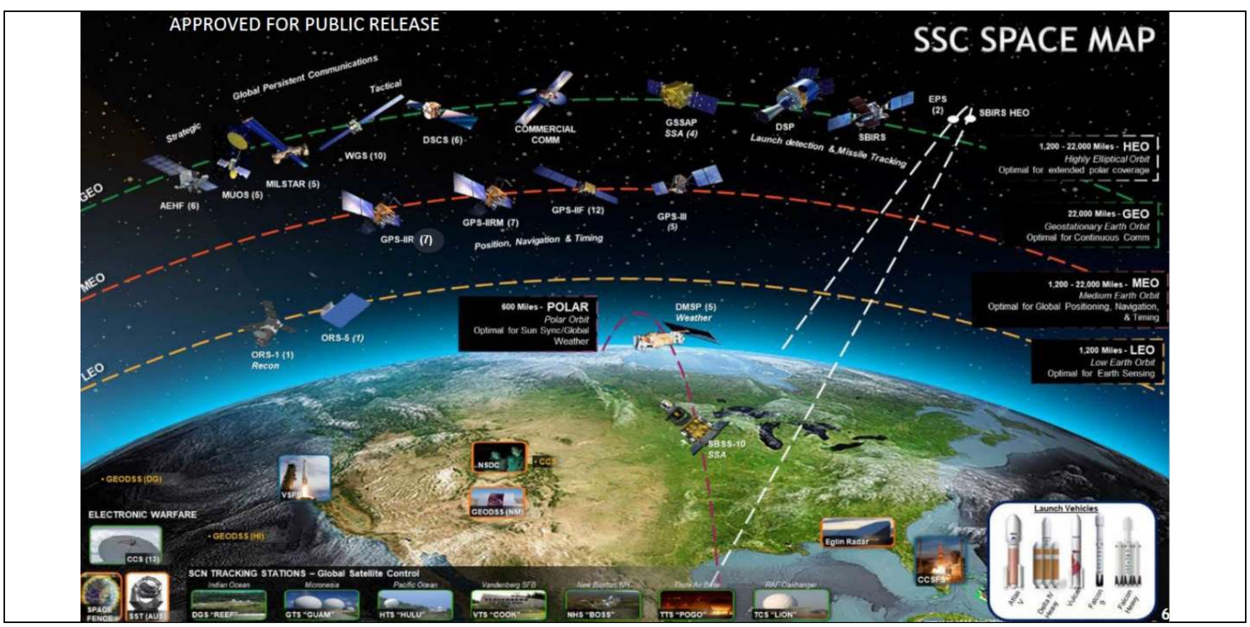
Slides 1-2

SSC Overview (Slides 3-5): The USSF was stood up in December 2019. The primary reason the Nation decided to break out a separate service was the threat to on-orbit peacetime conversations by the Russian ASAT test and China's launch of a hypersonic weapon. In the conversation around the gold standard for GPS, the gap is reducing between GPS and other GNSS. Mr. DeLaPena noted that many topics identified earlier in the day by the subcommittees will be valuable in developing new capabilities to address emerging threats. He also said he loved the idea of sponsoring PhDs in PNT. Mr. DeLaPena reviewed the organizational chart for USSF and described Program Executive Officers (PEOs) for the different offices. SSC is responsible for all DoD space capabilities, both on the ground and in space.



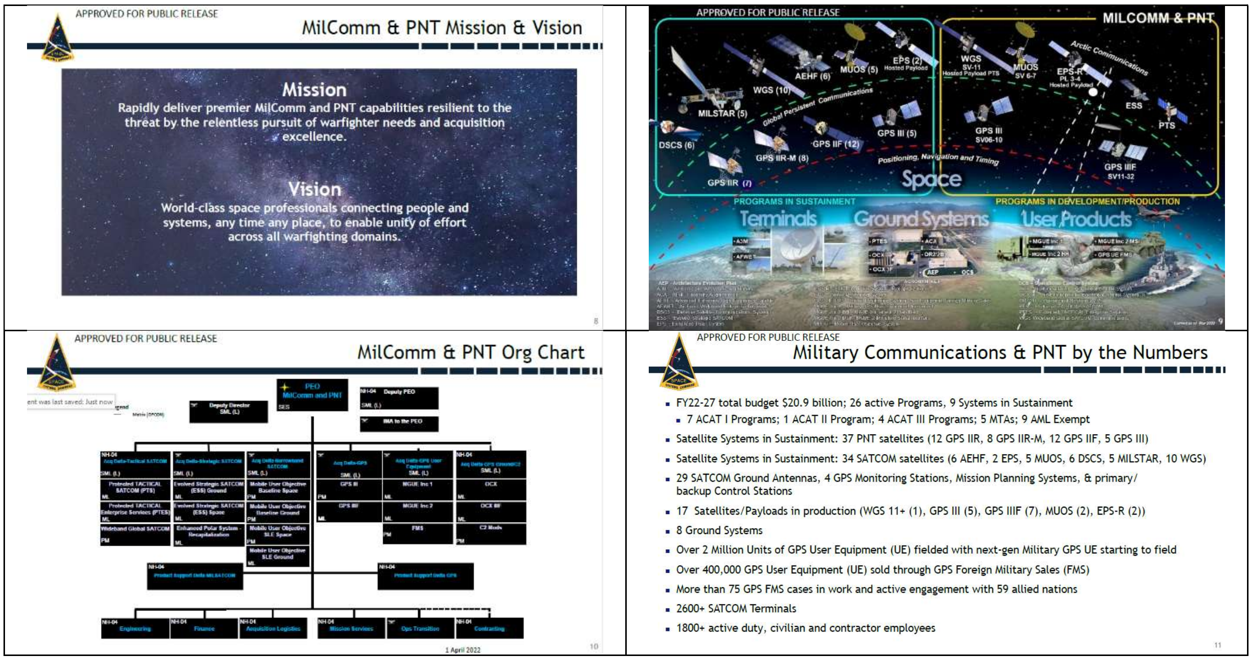


Slides 3-4



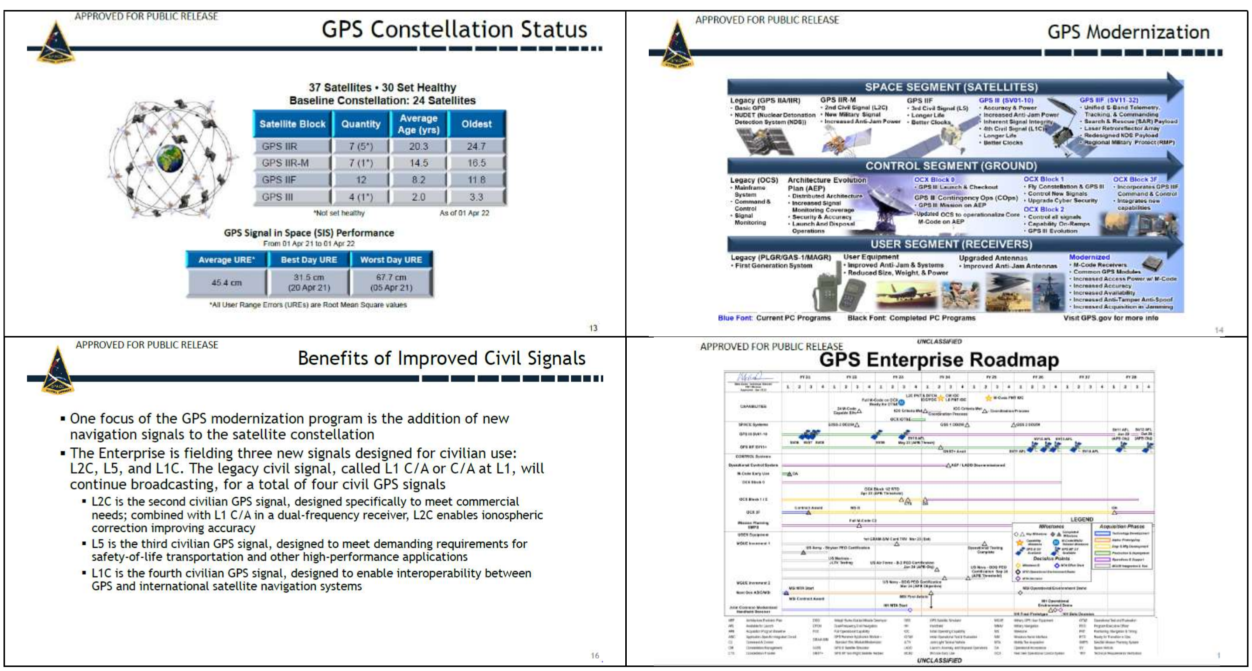
Slide 5

MilComm & PNT Directorate Overview (Slides 6-9): Mr. DeLaPena's particular portfolio is communication assets and PNT. The SSC budget reflects the challenges from China in all space domains and supports the fielding of capabilities to ensure the U.S. maintains its advantage. SSC is fully funded in FY22 and FY23.



Slides 6-9

GPS Enterprise Updates (Slides 10-13): Mr. DeLaPena reviewed the GPS Constellation status and GPS Modernization charts provided at the PNTAB 25th meeting. GPS III Space Vehicle (SV) 11 will be launched in 2026, and the DoD has reached an agreement that NASA will name SV11. This is an important marker for both organizations, as it represents the value of international, civil, and commercial partnerships. It is a new paradigm in the history of partnerships on all PNT satellites.



Slides 10-13

Q&A / Discussion:

Mr. Miller thanked Mr. DeLaPena for providing valuable information on the latest GPS plans and showing great interest in continuing the relationship and collaboration with the PNTAB.

Hon. Jeff Shane asked if the slides will be available on GPS.gov and Mr. Miller confirmed they will be.

Lt Gen Hamel reflected on PNT and GPS in a broader strategic context. He asked how the USSF and DoD go about defining what the gold standard means for GPS and PNT.

Mr. DeLaPena responded that from an execution perspective, what is currently funded in the baseline is to maintain the constellation, which includes continuing to field the on-orbit capability. The U.S. sustains over 30 transmitting satellites as a nation and continues to invest in the production and fielding capabilities, and producing and launching two satellites a year. The main orbital battle from the DoD perspective is defeating jammers. In the DoD budget, PNT is fully funded. From a space gold standard, if there is a war that extends to include space, the DoD wants to be prepared. There is a clear perspective on priorities that what gets funded is what gets done. Mr. DeLaPena said he appreciates the initiatives undertaken by the board. Particularly in thinking about PTA initiatives, there needs to be thought on a funding strategy. If it is a PNT capability, there needs to be a civil funding strategy for how to do that.

Dr. Parkinson thanked Mr. DeLaPena for coming. He commented that as long as navigation is maintained as a top priority, that will be okay in his eyes. He reiterated that he would like to see an emphasis on toughening at the receiver level. He does not see enough motion within the Armed Forces or the commercial side to make receivers as tough as it is possible to make them. He urged the Armed Forces to do so.

Mr. DeLaPena referred to the Air Force Research Laboratory (AFRL) Navigation Technology Satellite 3 (NTS-3) experiment with reprogrammable software as an example of some of on-going efforts to improve GPS capabilities.

Dr. Parkinson commented that he does not see as many active programs on the civil side due to ITAR constraints and suggested a closer look at that topic.

* * *

Communicating Technology Issues to Policymakers & Press
Ms. Melissa Harrison, *Sr. Director, Policy & Executive Communications, Consumer Technology Association (CTA)*

Mr. Grossman introduced Ms. Melissa Harrison from CTA. As context for the presentation, Mr. Grossman shared that it came out of discussions in the CER Subcommittee about how to message the GPS story more effectively. GPS is a powerful story and a brand that everybody knows, so this presentation will help the PNTAB to better tell that story.

Ms. Harrison began by outlining the key points in her presentation, including why effective communication matters to the PNTAB, a review of the policymaker landscape, a review of the media landscape, and principles of effective communication (Slides 1-2).

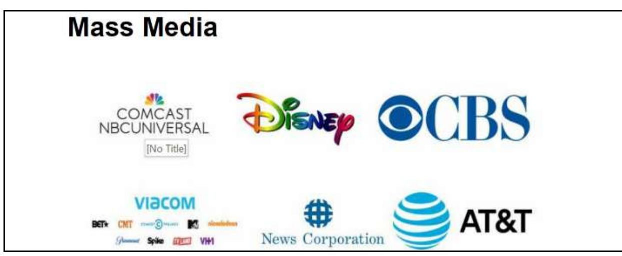
Slides 1-2

PNTAB members are the best people to communicate about this issue because they are experts in this field (Slide 3). Expertise matters, and PNTAB members are already setting a high bar for any conversations because of the work done throughout their careers. Subject matter expertise can be used to build relationships to make progress on key issues. As experts, PNTAB members have special knowledge that can be brought to conversations between decision makers in the moment.

For situational awareness, it's important to understand what the priorities are of the members that are in the policymaker landscape (Slide 4). The U.S. currently has Democratic leadership, and this is likely to change in the upcoming midterm elections. It is important to note that midterms are often a time that coincide with personnel changes, so the staff with whom you may have built relationships may no longer be there.

Slides 3-4

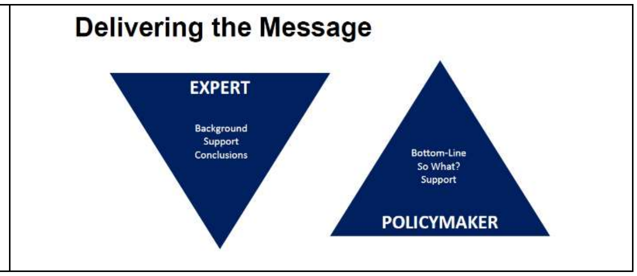
Turning to the media landscape, Ms. Harrison highlighted that most of the mass media is controlled by six entities in the U.S. (Slide 5). Looking a bit deeper, particular people focus on particular news outlets (Slide 6). For instance, members of Congress are going to read things like Politico, Punchbowl News, or Axios. It is important to consider what type of media is reaching the audience you want to speak with. She noted that the media and news writers themselves are not the audience you want to speak to, merely the vehicle to get to the wider audience.



Slides 5-6

Ms. Harrison turned to how to become effective communicators to policymakers and the press (Slide 7). Policymakers are inundated with 100+ issues a day, so it is vital to be clear and articulate with the key takeaways for whoever you are speaking to. As a SME, you walk in with a certain level of credibility. However, you must be persuasive. The messages have to include something that persuades them into action. If you're talking just to talk, it is not moving the issue along to become an actionable item on that member's agenda.

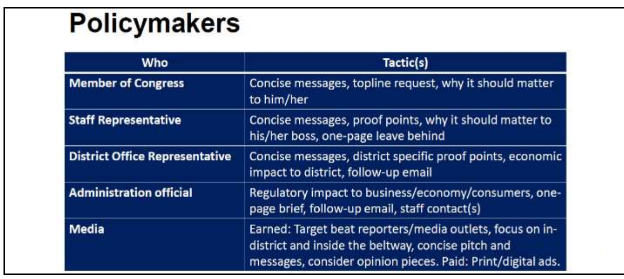
Oftentimes, when experts deliver messages, they focus on the background, build support, then draw conclusions (Slide 8). For policymakers, it's best to start with the bottom-line up front, then follow with the "so what?" or why it matters, then provide support.



Slides 7-8

There are many different ways to enter into a conversation with a policymaker (Slide 9). When talking to a member of Congress, plan to deliver concise messages with a topline request, knowing that you have a short window of time. Remember to focus on why it should matter to that lawmaker in his or her district. If the member of Congress isn't available to speak with you, you may talk to their staff representatives. It's important to treat staff representatives like the member of Congress, and to provide them proof points so that they can build the argument back to their member. Ms. Harrison recommended creating a half-page or one-page document to leave behind so they can remember what they talked to you about and why it matters to their boss. Another potential party is the District Office Representative. In this case, be sure to have a specific message for the district itself, perhaps highlighting the economic impact of that issue in their area. Since District Office Representatives are often on the move, Ms. Harrison recommends sharing a digital version of the one-pager with them via email.

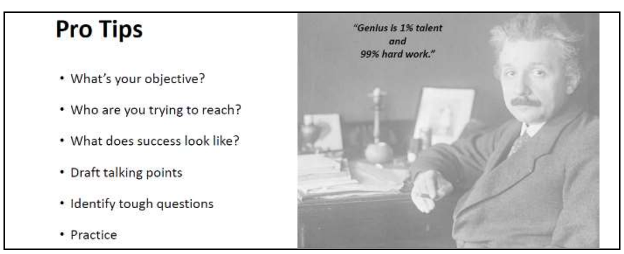
When talking to the media, Ms. Harrison recommends getting specific to the issues you care about (Slide 10). There are many niche outlets out there covering specific issues, which are great vehicles for communicating to audiences. See who key reporters are on these specific issues, then have conversations with these folks. She recommends concise emails and pitches that are succinct and to the point. Opinion pieces are harder to place, but may be more effective when targeting the local media within a specific member's district. In general, when talking to media, the more you talk, the more editing that is going to happen. Be colorful with details and shine a light on how the work you're doing impacts real people. Most importantly, Ms. Harrison emphasized the value of timely responses with the media as they are under a lot of pressure to meet deadlines, and you may miss your window if you don't respond in a timely manner.


Policymakers

Who	Tactic(s)
Member of Congress	Concise messages, topline request, why it should matter to him/her
Staff Representative	Concise messages, proof points, why it should matter to his/her boss, one-page leave behind
District Office Representative	Concise messages, district specific proof points, economic impact to district, follow-up email
Administration official	Regulatory impact to business/economy/consumers, one-page brief, follow-up email, staff contact(s)
Media	Earned: Target beat reporters/media outlets, focus on in-district and inside the beltway, concise pitch and messages, consider opinion pieces. Paid: Print/digital ads.

Slides 9-10

Finally, Ms. Harrison emphasized the value of practice (Slide 11). Identifying your target audience and the desired outcome will set you up for success. Drafting talking points ahead of time will be especially valuable, and those can be brought with you into the conversation. Ms. Harrison also recommended preparing answers to potential tough questions ahead of time. She reiterated the value of practice and thanked the PNTAB for their time.



Slide 11

Q&A / Discussion:

ADM Allen emphasized the need for the PNTAB to produce collateral content in order to facilitate these kinds of conversations.

* * *

The Geodesy Crisis

Mr. Everett Hinkley, *Geospatial Management Office, U.S. Department of Agriculture (USDA)*

Mr. Hinkley introduced the topic by thanking Dr. Morton for mentioning the importance of the geodesy crisis in her briefing on behalf of the ESI Subcommittee earlier in the day (Slides 1-2).

Slides 1-2

What the crisis is (Slides 3-4): Many are familiar with the whitepaper that was put out in early January (Slides 3-4), which rang a lot of alarm bells and ruffled feathers at U.S. Geological Survey (USGS) and NGA (Slides 3-4). In preparation for this presentation, Mr. Hinkley talked to many folks that work specifically in the field of geodesy, including Dr. Drew Smith, Dan Roland, Larry Hothem, and Dr. Sandwell. Referring to the whitepaper, Mr. Hinkley summarized that there are not enough trained geodesists in the U.S., and that the U.S. may be permanently eclipsed in geodesy and downstream geospatial technologies. The authors of the whitepaper purport that this threatens national security, particularly in the comparison between the U.S. and China.

Slides 3-4

Why we should care (Slides 5-12): Nearly all disciplines in PNT are built on a geodetic foundation. From the terrestrial reference frame to the time scale, geodesy is vital in documenting and characterizing sea-level rise and change and improving decadal forecasts. Geodesy facilitates the operation of long term stable GNSS sites with .5 mm per year vertical accuracy. When comparing the forecasted rate of U.S.-trained geodesists to those trained in China, then comparing the technological capacity and user base of BeiDou (China's GNSS) to GPS, the situation looks grim. If the situation is not reversed very quickly, the U.S. will no longer have the capacity to take corrective action.

Don’t we have GPS for Navigation & Positioning?
Things to Consider

Positioning vs. Navigation.

GPS signals received can be processed in a couple of ways: The predicted ephemeris in the broadcast message is a where we *think* the satellite will be. The predicted ephemeris good enough for navigating **but nowhere suitable for accurate positioning**. If one takes received signals from ground control receivers (e.g., CORS), then they can be post processed to produce very accurate positions.

The **broadcast signals** are WGS84. The **post-processing** gets positions to the current ITRF coordinates.

WGS84 is a space based reference system. **Unless** one operating in space (and, in the middle of the ocean or in the air counts as "space"), then you probably shouldn't use **WGS84**. **For precise and accurate navigation near or on land, you will want a reference system tied to the earth's crust like ITRF2014 or NAD 83.**

Using a broadcast signal means you are working with a single GNSS signal. There is no redundancy, extra observations, or different radio spectra to give a different solution. That's both good and bad, and perhaps ugly.

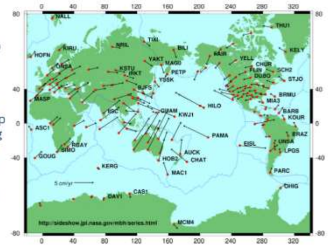
The DoD controls GPS. What about Galileo or GLONASS? How much trust do we have in those signals? More data is usually good, but only if it is trustworthy.

Plate Tectonic Motions

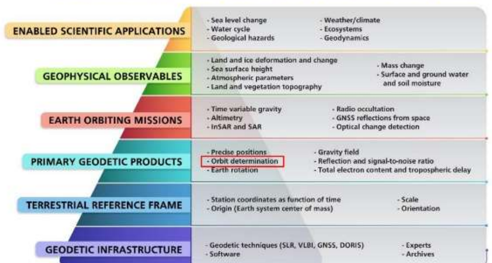
Everything is moving relative to everything else!

These velocity vectors must be understood to keep datums (Lat/Long and elevations) accurate/precise

Locations of any point are time-dependent!



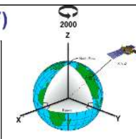
Science Enabled by the Geodetic Infrastructure



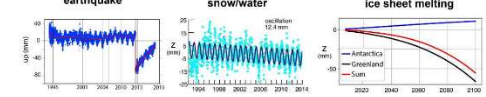
NAS 2020

Terrestrial Reference Frame (TRF)

- Origin, orientation, and scale defined by the Geodetic Infrastructure (7-parameters)
- Allows diverse geodetic measurements to be linked over space and time
- Changes over a wide range of time scales as mass is redistributed over Earth's surface



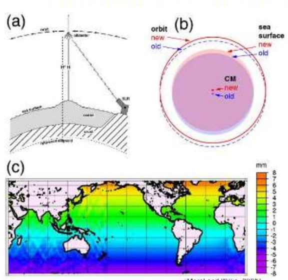
increasing time scale



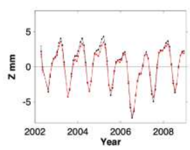
[Altamimi et al., 2016; Argus personal communication; Adhikari et al., 2015]

NAS 2020

Connection between TRF error and sea level



[Morel and Willis, 2005]



Motion of the CM of the Earth due to seasonal variations in water loading [Wu et al., AGU 2019]

NAS 2020

Sea-Level Change

Decadal Survey science questions:

C-1. How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage?

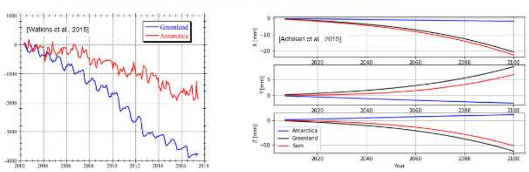
S-3. How will local sea level change along coastlines around the world in the next decade to century?

C-6. Can we significantly improve seasonal to decadal forecasts of societally relevant climate variables?

H-1. How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods?

NAS 2020

Ice Sheet and Glacier Mass Changes

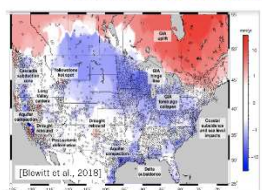


Ice sheet mass changes require multiple measurements:
- monthly gravity change (e.g., GRACE), GIA correction, ice sheet elevation (e.g., ICESAT-2, CRYOSAT-2), ice stream velocity (i.e., NISAR), visco-elastic rebound (e.g., GNSS)

Mass loss of Greenland and Antarctic ice sheets over the next 100 years will cause large CM motions, so need to maintain absolute accuracy of TRF.

NAS 2020

Relative Sea Level and Vertical Land Motion



Relative sea level at coastlines = sea level rise + land subsidence/uplift

Causes of vertical land motion:
- extraction of groundwater or hydrocarbons
- sediment compaction
- glacial rebound
- tectonics

Need long-term stable GNSS sites with 0.5 mm/yr vertical accuracy

NAS 2020

US Workforce - The contrast with China

The Chinese military and defense industries now have access to hundreds of Ph.D. geodesists. In contrast, the number of Ph.D. geodesists in the entire DOD, including the NGA, is now approaching zero. The same is true of the U.S. defense industry.

A competitive advantage in science soon translates into a competitive advantage in technology. For example:

- China's BeiDou system is at least as good as GPS, and arguably it is significantly better. BeiDou now has more world-wide users than GPS.
- The geodetic sub-systems that enable China's satellites and space program seem to have reached parity with our own.
- The near disappearance of American geodesists has led to large numbers of young geospatial engineers who are inadequately trained in the scientific underpinnings of their own discipline*.

See the white paper for additional examples.

* In 2019, Trevor Greening, CTO of Towill, Inc., a geospatial engineering company, stated: "we have noted that the rapid development of many new technologies has placed a premium on geodetic science knowledge" but "we see graduates insufficiently skilled to comprehend the basis of the new technology including hardware, software, and procedures"

Bevis et al., 2022

US Workforce - The contrast with China

Academic geodesy programs in the USA are now few, mostly shrinking, and scientifically balkanized*.

The lack of funding for basic research in geodesy has not only lowered the rate of innovation in America's geodetic technologies, it has led to very little graduate training of Americans in geodesy for two decades**. America's training capacity in geodesy is now absurdly small compared to that of Germany and China, and it continues its slow collapse.

If this situation is not reversed very quickly, the US will no longer have the capacity to take corrective action.

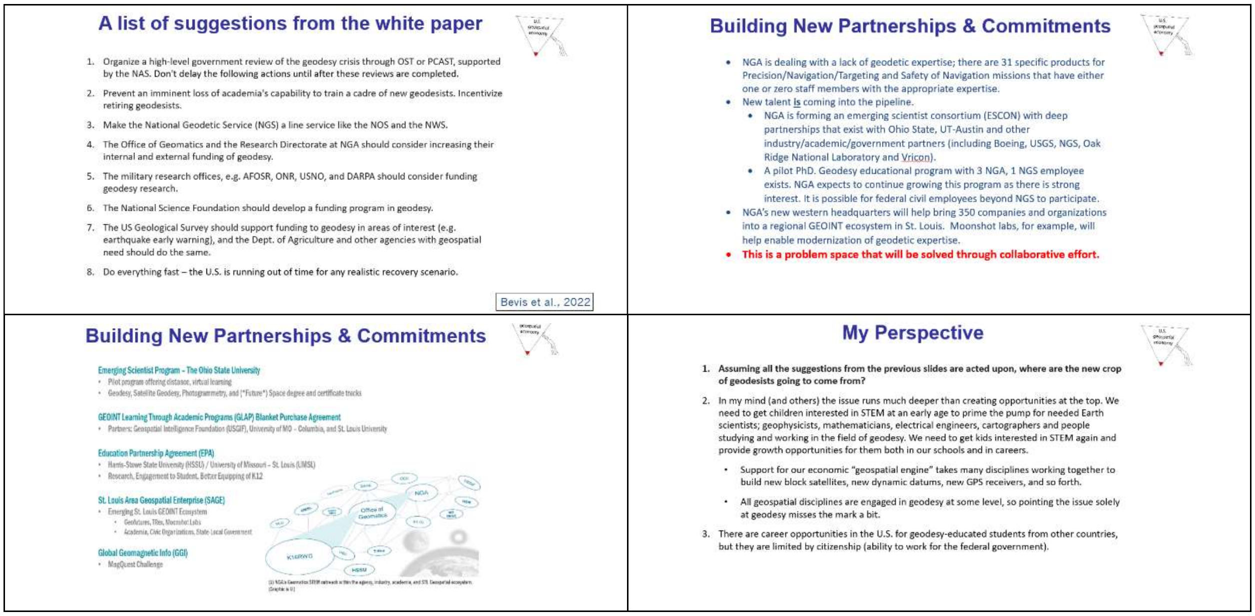
* In some universities there will be a GNSS geodesy group, in another an InSAR or radar altimetry group, etc. Most isolated groups won't teach geodesy *per se*, but rather their tools applications to other sciences or engineering. OSU seems to be only remaining US geodesy program that researches and teaches courses in every major branch of geodesy.

** Juliana Blackwell, the Director of NGS, wrote in 2018 "the reduction in the population of graduate students training in this field is clearly tied to declines in government funding of geodetic research in academia".

Bevis et al., 2022

Slides 5-14

What we can do (Slides 15-19): Mr. Hinkley asked what can be done to change the course of geodesy in the U.S.. He suggested that government agencies can incentivize research and development at academic institutions to produce more geodesists. When looking at where this new crop of geodesists will come from, Mr. Hinkley emphasized the importance of getting kids interested in STEM and creating pipelines for getting students into the universities. If the U.S. does not focus on STEM in schools to the level that they could be, they are not going to get people into higher education that could be drawn into geodesy.



Slides 15-18

Q&A / Discussion:

Dr. Parkinson commented that often, the activity follows the money. If geodesy is as important as we say it is, the U.S. government should fund university research. For young PhDs who have gotten education in geodesy, the government should ensure they have jobs. The STEM problem is larger than the PNTAB alone can handle. There is also the challenge of competing for bright undergraduate students.

Mr. Hinkley agreed on the importance of looking at the full ecosystem and thanked Dr. Parkinson for his comment.

Mr. Younes emphasized the value of promoting STEM and reaching out to young folks to pursue the kinds of studies that support these activities. He specifically highlighted the NASA SCaN summer internship program led by Ms. Barbara Adde, which has 100+ students on a yearly basis. Students in the internship program do hands on work of scientific value and often go on to gain full time employment with NASA.

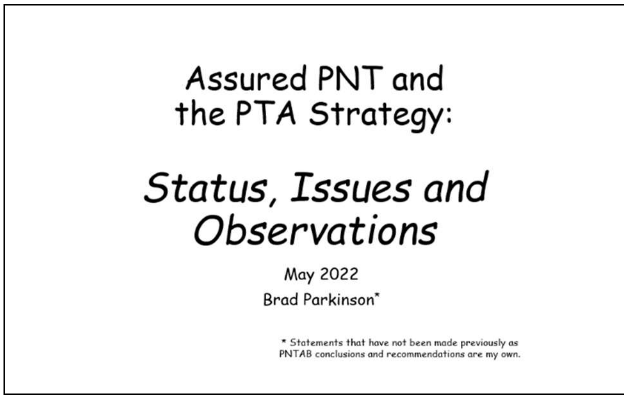
Dr. Filjar noted that geodesy has become an example of a multidisciplinary issue. He emphasized the importance of engaging students in Computer Science, mathematics, and other disciplines in participating in geodetic work, as geodesy itself is fading in attraction.

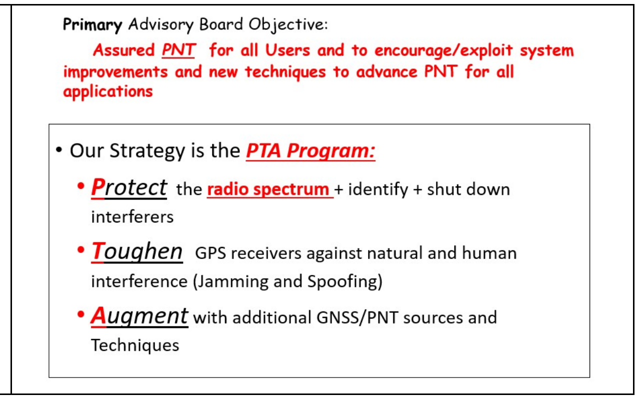
* * *

Protect, Toughen, & Augment: Status, Issues, & Observations
Dr. Brad Parkinson, *1st Vice Chair, PNTAB*

My objective is to address what is the balance among the elements of PTA (Slide 1). As usual, these are my opinions and not those of the board, except to the extent some have already been put forward by the board.

The primary objective of the board is assured PNT for all users and to encourage/exploit system improvements and new techniques to advance PNT (Slide 2). Over the past years we have employed a strategy we called PTA. First, *protect* the radio spectrum + identify + shut down interferers. Second, *toughen* GPS receivers, in particular against jamming and spoofing. While there are other things one might do in space, in terms of near term the thing that can be done most quickly is to toughen the receivers themselves. Third, *augment* GPS with additional GNSS/PNT sources and techniques.

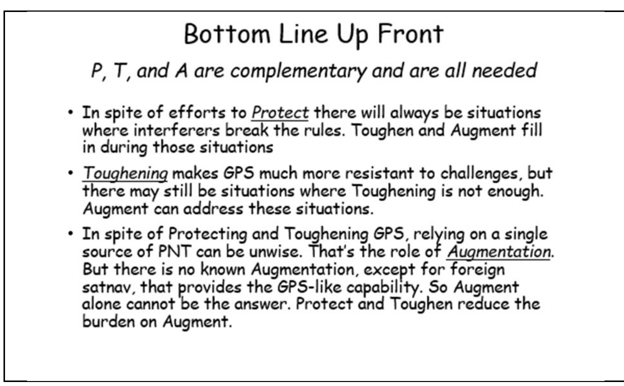


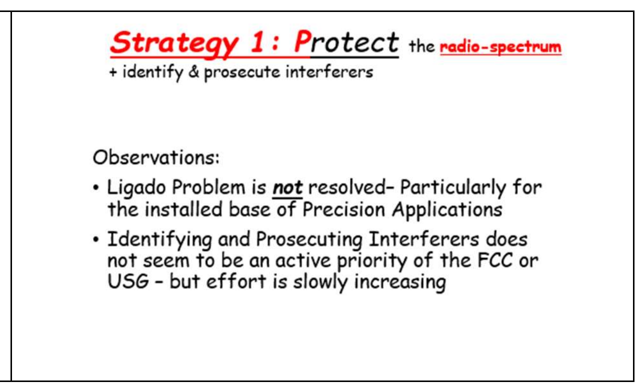


Slides 1-2

The bottom line upfront is that P, T, and A are complementary and are all needed (Slide 3). Despite efforts to *protect*, there will always be situations where interferers break the rules, and the *toughen* and *augment* strategies can help us with that situation. *Toughening* makes GPS much more resistant to challenges, but there may still be situations where *toughening* is not enough and *augment* can help. So, in spite of *protecting* and *toughening* GPS, the role of augmentation is to try to do something else. There has been a lot of focus on this recently, but *augment* alone cannot be the answer.

So, let's turn to that first strategy: *protect* (Slide 4). My first observation is that the Ligado problem is not resolved, particularly for the installed base of precision applications. The second thing is that identifying and prosecuting interferers does not seem to be a very active priority. There are examples where we have found interference and done something about it, but usually this doesn't happen until after a protracted delay, and the various pieces of hardware and authority do not seem to reside where they should.

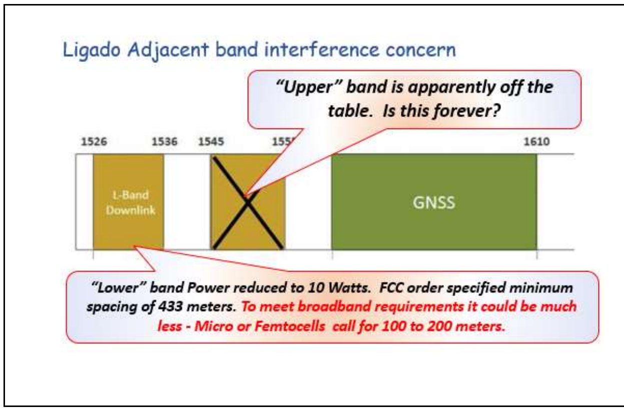


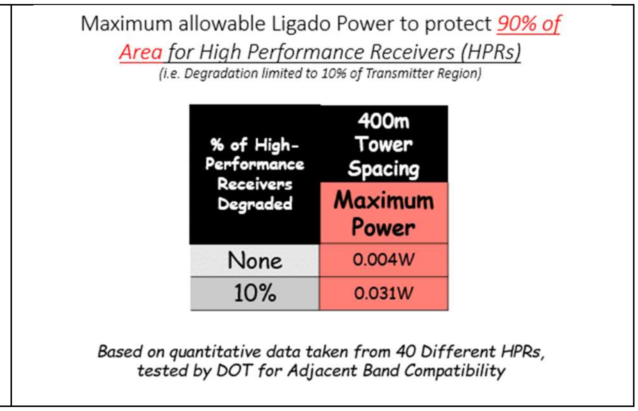


Slides 3-4

Just to review, the Ligado situation is that the two brown squares in the diagram on Slide 5 were authorization a previous company had (LightSquared), and virtually all the primary signals of GNSS constellations reside in the green square (Slide 5). The upper band (1545-1555 MHz) originally authorized is apparently now off the table, but it's that lower band (1526-1536 MHz) that gives us problems. The FCC authorization specified that the maximum transmitter power should be 10 W and that they shouldn't be any closer than 433 m. For my analysis, I'll use a round number of 400 m. Also, I'll point out that in broadband when they go to smaller cells the spacing is much smaller.

This is a summary of some analysis that was done (Slide 6). If you were to consider protecting only 90% of an area, and looked at high performance receivers (HPRs), the transmission power would have to minuscule (only 0.004 W). And, if you were to throw out the most sensitive receivers, say 10% of them, we're still at an extremely low power (0.031 W). This is the installed base that was actually tested by the DOT.

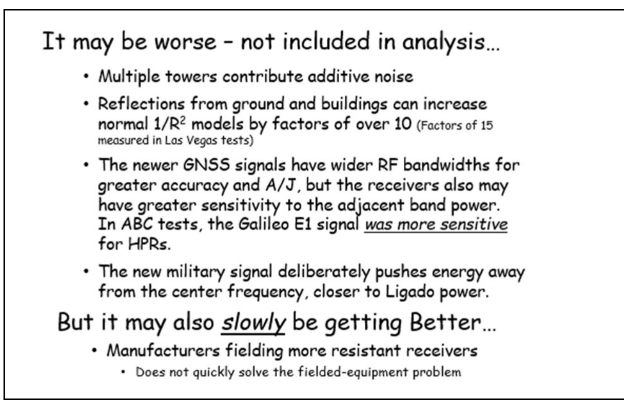


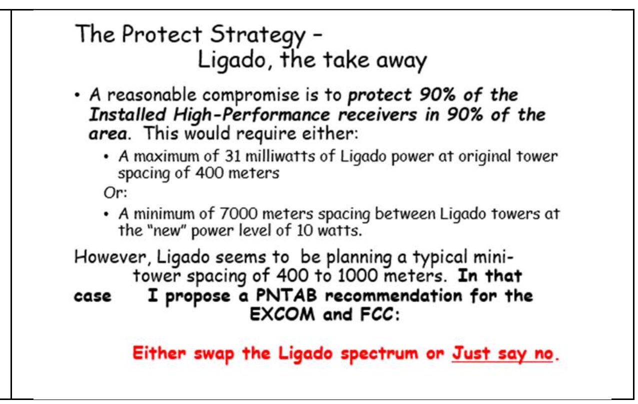


Slides 5-6

Moreover, I must add that the situation might be even worse (Slide 7) because not included in that analysis are the problems associated with multiple transmission towers, and then during tests some time ago we saw reflections. Communications people tend to use a $1/R^2$ model for these reflections, which is the correct model in free space but unfortunately in the real world the power levels we found were more than a factor of 10, and in fact got up to a factor of 15 in a test, greater than the $1/R^2$ model would predict. This model is not necessarily "truth" when talking about interference, and data backs this statement. Moreover, newer GNSS signals have even wider RF bandwidths, and initial testing showed even greater sensitivity for greater accuracy and anti-jamming (A/J), but the receivers also may have greater sensitivity as they get closer to the transmitter as one might expect. And, of course, the new military signal (M-Code) deliberately takes what used to be P(Y) in the middle and pushes it out to the edge. All this is the bad news. There is some good news, but it's coming about slowly. We've been screaming about this problem for over a decade and manufacturers have started fielding equipment that is more resistant to the Ligado problem

My takeaway is that a reasonable compromise in terms of the existing High-Performance Receiver (HPR) base is to 90% installed receivers across 90% of an area (Slide 8). But when doing this we find that the maximum required power for Ligado would be 0.031 W for 400 m spacing between transmitters. Or, if you stick to 10 W, you find that the minimum spacing between towers would have to be 7,000 m (7 km). I'm not certain where Ligado will end up (we don't have the detailed plans), but if they indeed deploy then I propose a recommendation for the PNT EXCOM and the FCC to either swap that Ligado spectrum out where it will do no harm or just say no. So, that's my summary on the *protect* strategy.

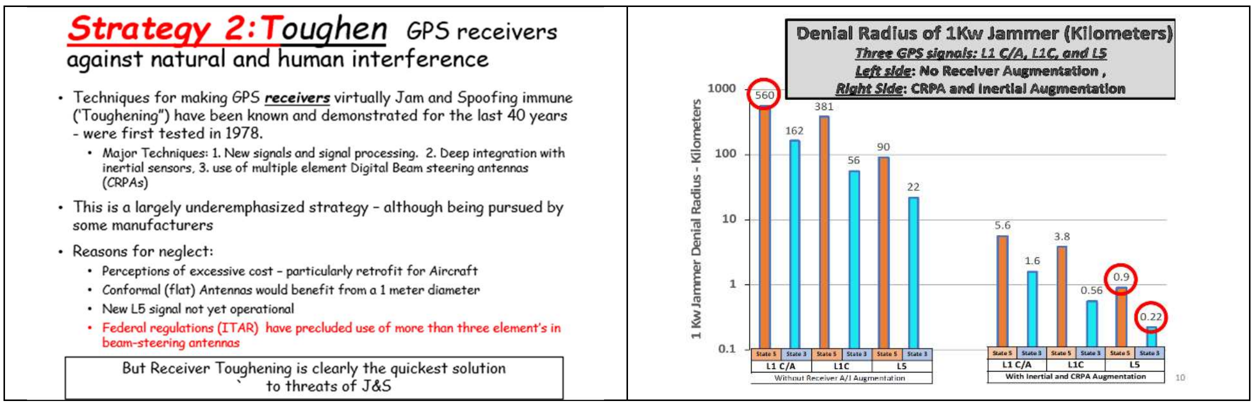




Slides 7-8

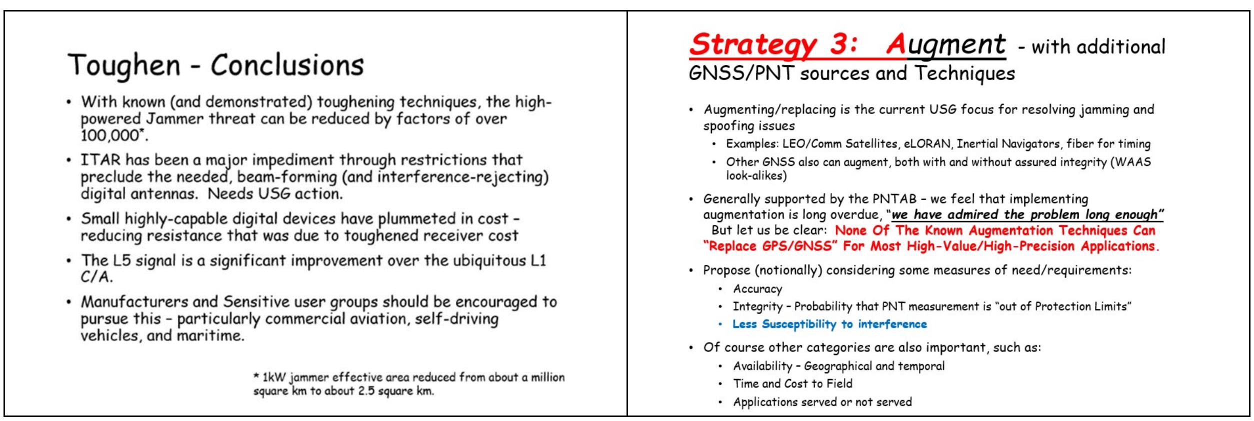
Let's turn to the second strategy, *toughen* GPS receivers against natural and human interference (Slide 9). Techniques to do this have been well known. They were demonstrated way back when I was running the GPS Joint Program Office (JPO) in 1978, and those receivers were really tough; you could fly over a large jammer and not have any effect at all. But it was the extra stuff we put on that receiver that made that possible. The major techniques to do this now are: new signals and signal processing, deep integration with inertial sensors, and multiple element antennas which allow you to do beam steering and point directly at the satellite while rejecting the noise. I believe that's an underemphasized strategy, although it is being pursued by some manufacturers. There are some reasons for that neglect that are understandable. First is the perception that it costs too much, which is aggravated by the low production numbers of such equipment. Second, there is the issue of size. It will not go into a cellphone, but for airplanes it is possible. Third, there is a new GPS signals (L5) which has been coming for the last 15 years. The last point is that we're shooting ourselves in the foot with the ITAR, which don't let civilians and commercial users with safety-of-life applications to have more than three elements in beam-steering antennas. As a result, the race is a handicap race, and it does not recognize the current state of the art in terms of technology. Toughening is clearly the quickest way to get real defense against threats of jamming and spoofing.

This chart (Slide 10) shows the effective radius of a 1 kW jammer. The red lines show the denial radius in meters for a receiver to obtain full accuracy (also referred to as State 5), and the blue lines shows the jamming radius when we're able to resist jamming at the price of a little accuracy (also referred to as State 3). The chart is logarithmic and shows the denial radius for L1 C/A, L1C, and L5 under two conditions: a receiver with no toughening and a receiver with all those extra toughening tricks I was talking about. Note the improvement when using L1C and L5, and the amazing improvement when also using the toughening techniques. As we can see, trying to take out a toughened L5 receiver with a 1 kW jammer is clearly a fool's errand. To me this chart summarizes the powerful argument on why this strategy really deserves a lot of credit. As a reminder, we've gone from a jamming radius of 560 km down to just under 1 km.



Slides 9-10

So, my conclusion in terms of *toughening* is that with known toughening techniques the high-powered jammer threat can be reduced by a factor of 100,000 in terms of affected area (Slide 11). But ITAR is a major impediment, and this restriction has become a major self-inflected wound on the U.S. At the time it was implemented it had a good reason, but in my opinion that's no longer the case. These techniques are now well-known internationally, and costs are plummeting, so this restriction no longer precludes any adversary to do the same thing. Therefore, in my opinion equipment manufacturers and sensitive user groups should be encouraged to pursue this.



Slides 11-12

Now let's turn to the third strategy of augment, typically done with additional sources of navigation (Slide 12, see previous page). I see that as the current U.S. Government focus for resolving jamming and spoofing issues. The examples we have seen include Low Earth Orbit (LEO) communication satellites, enhanced LORAN (which I recommended 21 years ago but, alas, the network has been dismantled since), inertial navigators (they drift hopelessly fast, but still have a place during short outages), use of fiber optics for time dissemination (to users fixed on the ground), and use of other GNSS. Use of other GNSS can be done with or without integrity. I'm encouraging the FAA to also provide Galileo, a system owned by friendly countries, a correction on their Wide Area Augmentation System (WAAS). This whole area is generally supported by the board. But let us be clear: none of the known augmentation techniques can replace GPS/GNSS for most high-value / high-precision applications. Let's do a comparison of some of the proposed alternatives to GPS. Slides 13-14 shows some of the applications of GPS, both high-precision and non-precision. By and large, augmentations tend to address non-precision GPS applications, which is fine as it can become a back-up capability for those that are doing precise navigation for some other reason.

High Precision – need accuracies of a few meters or better

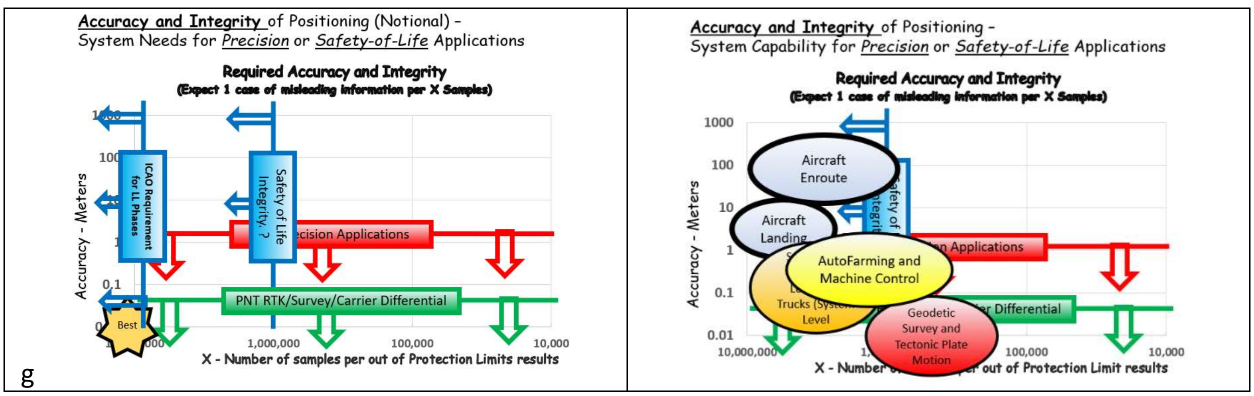
Categories	Example applications
Aviation	Precision and non-Precision Landing To Cat III, Nextgen
Agriculture	Auto farming: Precision Cultivating, Yield Assessment
Automotive	Driverless Cars And Trucks
Emergency and Rescue Services	IFR Rescue Helicopters
Intelligent Transportation	Train Control And Management, Precision UAVs, Intelligent Highways
Military	Precision Weapon Delivery
Recreation	
Robotics and Machine Control	Bull Dozers, Earth Graders, Mining Trucks, Oil Drilling
Scientific	Earth Movement And Shape, Atmosphere, Ionosphere, Space Weather
Survey and GIS	Mapping, Tectonic Motion Monitoring,
Timing	Require High Availability but do not press accuracy
Tracking	

Non-Precision GPS Applications

Categories	Example applications
Aviation	Area navigation
Agriculture	crop spraying
Automotive	Turn-by-turn guidance, OnStar
Emergency and Rescue Services	911, ambulance, fire, police, emergency beacons, airplane and ship locaters, OnStar
Intelligent Transportation	
Military	Rescue, unit and individual location
Recreation	GeoCaching, control of models, hiking, outdoor activities
Robotics and Machine Control	
Scientific	weather forecasting, climate modeling, tsunami warning, soil moisture, ocean roughness, wind velocity, snow, ice, and foliage coverage, ……
Survey and GIS	tagging disease outbreaks
Timing	Cell phone towers, banking, power grid
Tracking	Fleets, assets, equipment, shipments, children, Alzheimer's patients, wildlife, animals, law enforcement, criminals, parolees,

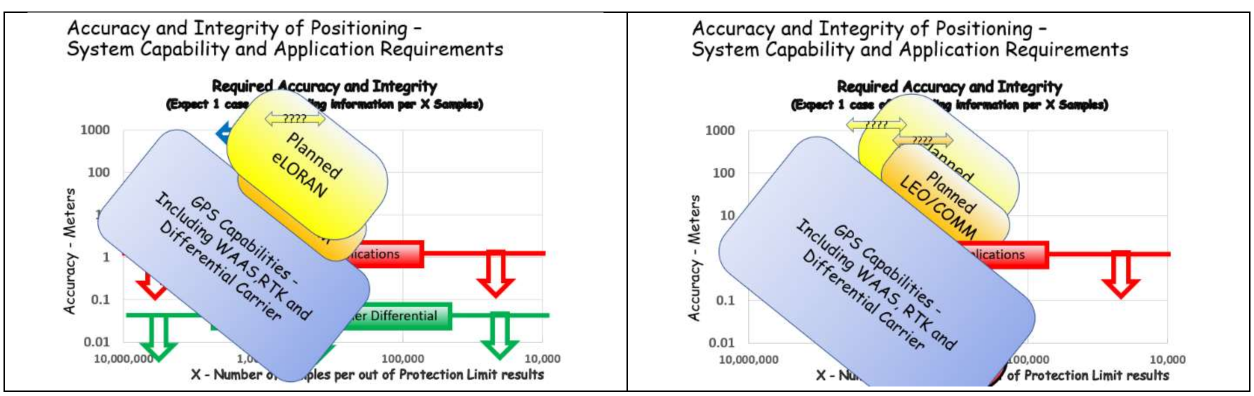
Slides 13-14

We're going to do a quick run through the required accuracy and integrity for various applications (Slides 15-18). This analysis is notional. The charts depict logarithmic scales of accuracy on a logarithmic scale vs. the number of samples out of protection limits. Integrity is usually expressed as a part in a million or ten million events when the system is not operating within specifications. I'm going to invert that and instead express it as the number of samples out of the protected limits during the time you are operating. So, on the bottom left of the x-axis we have once in 10 million samples, and on the bottom right we have once in 10,000 samples. On slide 15, the red line shows where precision applications (~ 2 m) fall, and the green line shows where really high precision applications (~ 4 cm) fall. Then we can ask ourselves how much integrity we really need. Many of the users have never stated that. Notionally, a typical number for safety-of-life applications might be something like better than one in a million (10^{-6}), but aviation folks typically want better than one in ten million (10^{-7}). The best of the accuracy and integrity attributes falls in the lower left corner of this chart. Slide 16 shows where the applications discussed earlier fit on this table. Note that applications such as self-driving cars (orange circle) will need both high integrity and high precision.



Slides 15-16

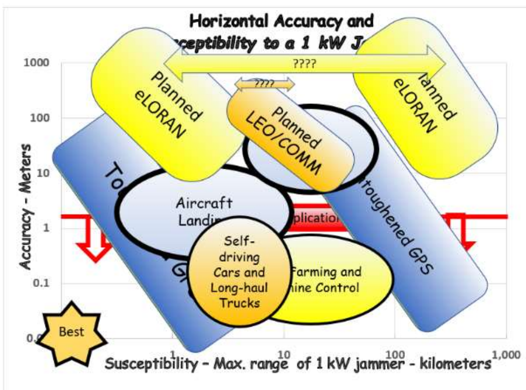
So, against that, what do we have? GPS capabilities pretty much cover all those applications I've shown (Slides 17-18). I don't know what the LEO communications satellites can provide as they haven't yet been subject to deep scrutiny, but my guess is in terms of integrity and accuracy they're not as good on their own (Slide 17). I'm not certain exactly where eLORAN would stand on the integrity, but I believe there are a set of applications that would not be able to depend on it (Slide 18).

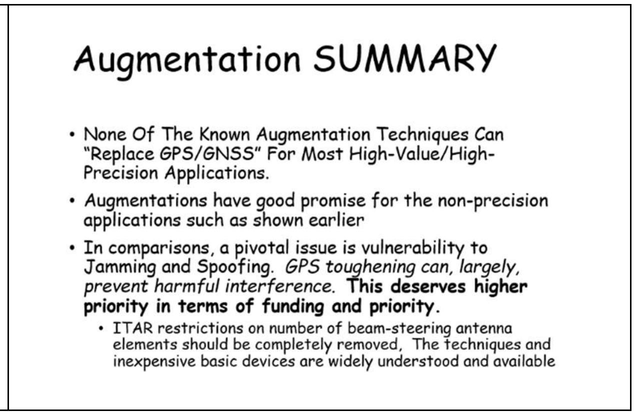


Slides 17-18

Now let’s plot the susceptibility to jamming (Slide 19). First, we show where toughened and untoughened receivers fall, and then we can add where the various applications fall. I’m not sure exactly where eLORAN would fall, but a 1 kW jammer for eLORAN is extremely improbable because you’d need to have the same type of antenna (it’s a very low frequency system, and therefore needs a huge antenna), so I don’t think eLORAN would have a jamming problem. On the other hand, the LEO comm satellites are probably going to be better than untoughened GPS, but not better than toughened GPS.

So, the summary on *augmentation* to me is that none of the known augmentation techniques can replace GPS/GNSS for most high-value / high-precision applications (Slide 20). Augmentations do have good promise for the non-precision applications, particularly if they don’t involve safety-of-life. In comparison, the pivotal issue to me is the susceptibility to jammers. GPS toughening can, largely, prevent harmful interference. But current ITAR restrictions impede achieving this.

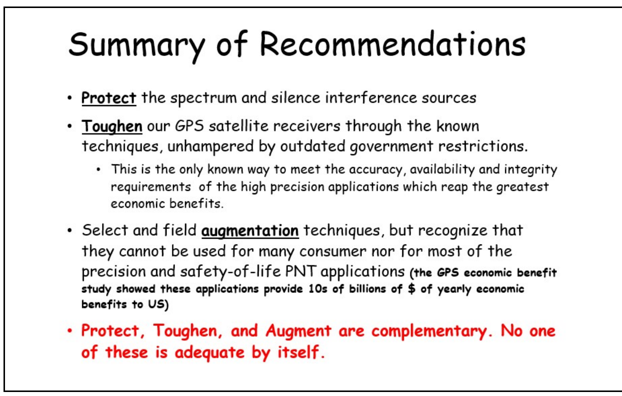


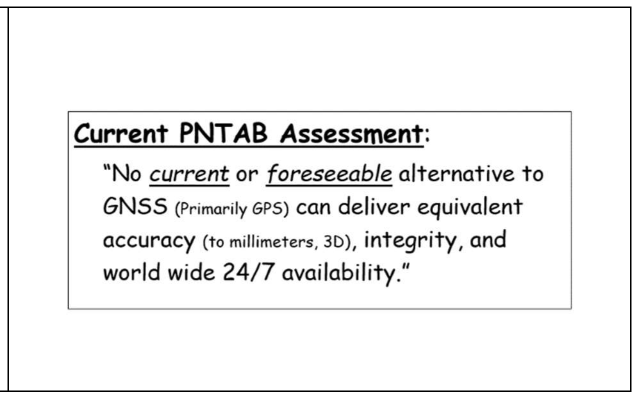


des 19-20

My summary of recommendations (Slide 21) is to: (1) *Protect* the spectrum and silence interference sources; (2) *Toughen* our GPS satellite receivers through known techniques, unhampered by outdated government restrictions, and that’s the only way I know to still satisfy the requirements of those high precision applications; and (3) Select and field *augmentation* techniques, but recognize that they cannot be used for many applications for which many people may want to use PNT, particularly safety-of-life. Protect, Toughen, and Augment are complementary. We don’t want to cut any of these three out. No one of these is adequate by itself.

I’ll wrap it up (Slide 22) by saying that the current PNT Advisory Board assessment is that no current or foreseeable alternative to GNSS can deliver equivalent accuracy down to millimeters and in three dimensions, integrity with supplements down to a part in 10 million, and provide worldwide 24/7 availability.





Slides 21-22

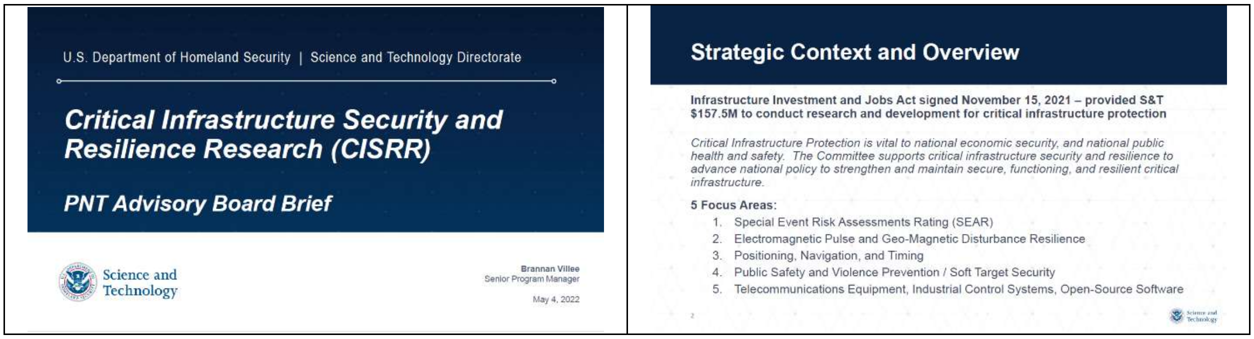
Q&A / Discussion:

ADM Allen commented that, as discussed earlier, the PTA subcommittee needs to put all this together to deliver an institutional position.

* * *

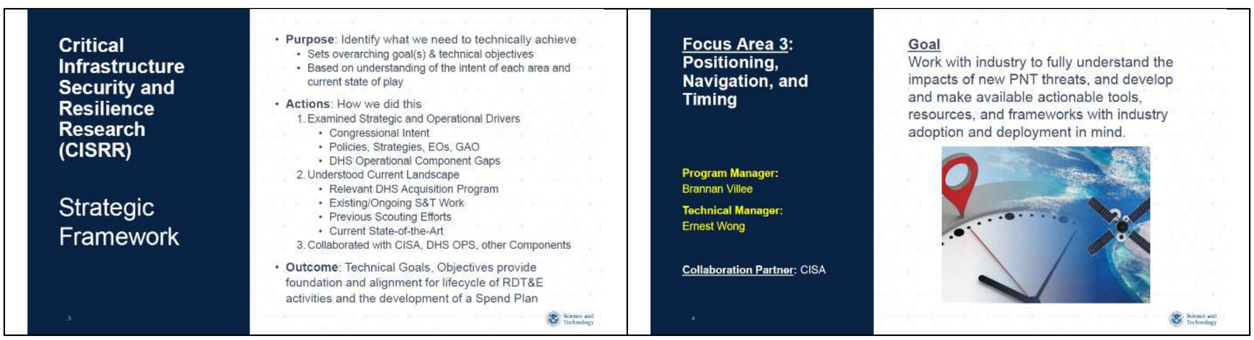
Science & Technology (S&T) PNT Work under the Infrastructure Investment & Jobs Act
Ms. Brannan Villee, *S&T Directorate, Department of Homeland Security (DHS)*

Ms. Villee provided an overview of the DHS Resilient PNT Performance Framework (Slide 1). She noted that, as Mr. DeLaPena had mentioned, what gets funded is what gets done. S&T had been planning on sunsetting the PNT program until the Critical Infrastructure Bill was passed last year (Slide 2). This provided $157.5M to conduct research and development for critical infrastructure protection. Ms. Villee became the manager for Critical Infrastructure Security and Resilient Research (CISRR), which has five focus areas and eight separate topic areas.



Slides 1-2

Ms. Villee then reviewed the CISRR Strategic Framework (Slide 3). This framework aims to develop technical goals and objectives, to provide foundation and alignment for lifecycle activities, and to develop a spending plan. CISRR has a goal to work with industry to fully understand the impacts of new PNT threats and to respond by developing and making available actionable tools, resources, and frameworks with industry adoption and deployment in mind. The Federal government doesn't control the adoption of technology (Slide 4). Rather, CISRR is making sure that the tools and frameworks are developed that can be adopted to make a difference.



Slides 3-4

Q&A / Discussion:

ADM Allen asked how CISRR's work may align with WH priorities.

Ms. Villee responded that a lot of the programs are still being stood up. A lot more information will be available in the coming six months.

ADM Allen asked about coordination among existing interagency working groups like the PNT EXCOM, DHS PNT WG, and the DHS PNT Executive Steering Committee. Is there a DHS listing of appropriations that the PNTAB could look into to get more information?

Ms. Villee noted that the Critical Infrastructure Bill designated money to different parts of DHS, and that the money for PNT came directly to S&T.

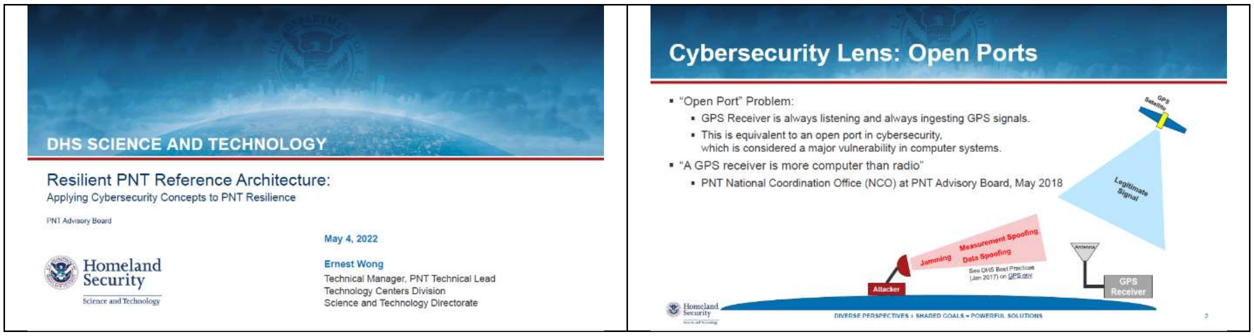
Hon. Shane mentioned ongoing concerns around drones and drone operators. Is that research part of the CISRR program?

Ms. Villee noted that S&T is doing a lot of research, including some on UAS, although that is not currently funded under the Critical Infrastructure Act. A lot of activities are still being defined in the coming year.

* * *

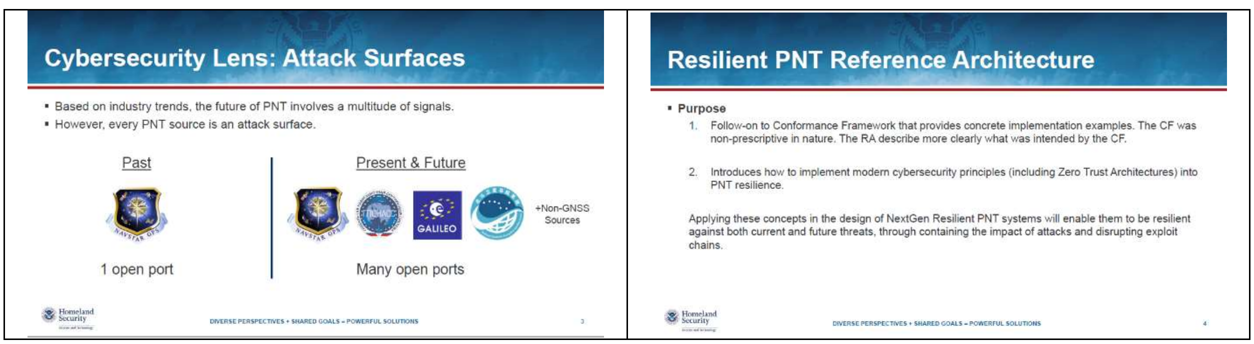
S&T's Resilient PNT Reference Architecture
Mr. Ernest Wong, *Technical Director, S&T Directorate, DHS*

This briefing is going to focus on the part of Resilient PNT Reference Architecture regarding the implementation of cybersecurity concepts (Slide 1). I encourage you to look at the full document once it is published and posted on www.gps.gov. To begin we need to reframe the problem of PNT disruption through the lens of cybersecurity, and the first reframing is the problem of Open Ports (Slide 2). GPS/GNSS receivers are always on and listening/processing GPS signals. From a perspective of computer systems, this is the equivalent of an open port, and in cybersecurity that's a major issue. We need to consider this as we look at the design of future PNT systems.



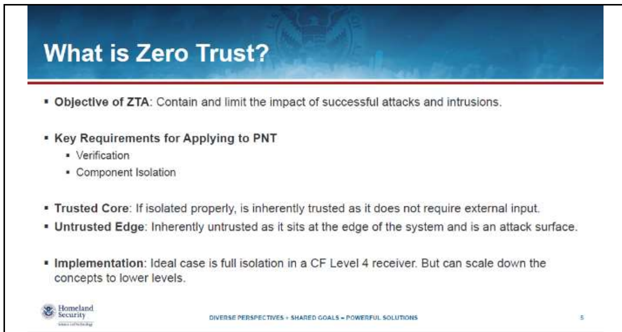
Slides 1-2

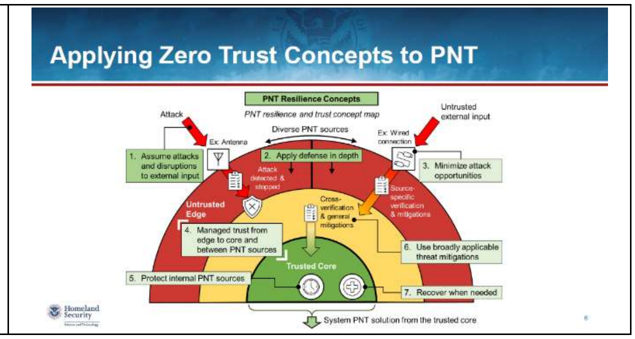
The second reframing is to recognize the attack surfaces on PNT systems (Slide 3), where each PNT source is a potential attack surface. With multi-GNSS systems we are dealing with many open ports, each one of them also being an attack surface. This is something we need to consider and account for when developing the next generation of PNT systems. Before getting into the reference architecture, we need to take a step back and provide context on where all this fits in (Slide 4). We tend to focus on the technology solutions, but when solving any kind of security problem, we have to develop the rules, policy, and procedures. In cybersecurity these include rules on how to use computers, training, how to configure network traffic, etc. When we look at PNT, it's similar. We begin with the Executive Order 13905 (Responsible Use of PNT) and the National Institute of Standards and Technology (NIST) PNT profiles in critical infrastructure. The PNT profiles establish how PNT is used, where they get PNT, their actual PNT requirements, whether there really is a need to use GPS, etc. Following this process, then you do some risk mitigation for those critical applications that have dependency on PNT. The Reference Architecture introduces how to implement cybersecurity concepts into PNT systems, including things such as Zero Trust Architectures, defense in depth, etc. These concepts will enable PNT systems to be resilient against future threats by making it very difficult for an attacker to go through the exploit chain and also help contain the effects of such attack.



Slides 3-4

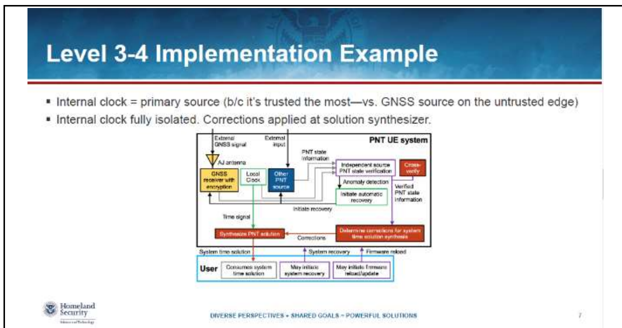
Zero Trust is a key part of the Reference Architecture (Slide 5). We call this 'managed trust' in the Reference Architecture, but the principle is the same. A Zero Trust Architecture (ZTA) is based on two key concepts. First is the assumption that your system will not only be attacked, but that the attack will penetrate your defenses and compromise your system. Second, you have to figure out how to continue operating under such circumstances. The key requirements when applying this to PNT are verification and component isolation. Two other things we talk about in the reference architecture is establishing a Trusted Core and an Untrusted Edge (Slide 6). We start in box 1 in the diagram, where we assume attacks are going to penetrate our defenses. These happen through the attack surfaces, such as our GPS, Galileo, etc., sources or other alternative PNT sources. That's why these sources are in the Untrusted Edge. On the other side we have our trusted core. These are the things that are critical to our systems, such as recovery functions and our protected internal PNT source. For example, in a timing system this protected internal source would be our clock. Anything in the trusted core must be highly isolated to protect it from external influences. As information comes in from external sources, we want to be able to conduct lots of layers of verification (defense in depth) as well as cross-verifying our source, and we can also have application-based constraints (for example, not allowing a vehicle to go above a certain speed). We also want to have lateral protection between the PNT sources so, for example, should something happen to our GPS source we want to make sure this does not also affect our Galileo source.

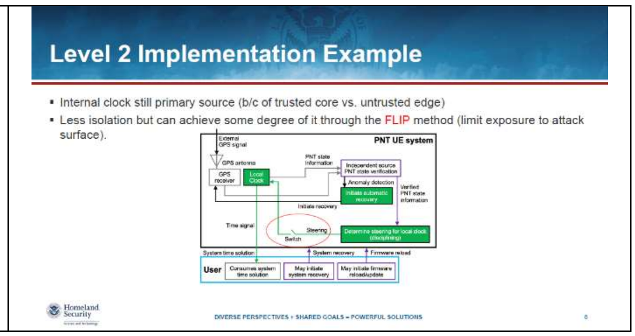




Slides 5-6

So, how do we isolate our internally protected trusted core (Slide 7)? This is an example implementation of a Level 4 receiver. First, our local clock is treated as primary timing source. Second, note there are no arrows going into the clock. Instead, we use a secondary component (solution synthesizer) to apply the timing corrections provided by GPS and other GNSS sources. If one cannot afford a Level 4 receiver, we have a Level 2 implementation example (Slide 8). The internal clock is still our primary source, but there is less isolation at this point. This can be achieved through the FLIP method (see red circle on graph), which is a switch. For many applications we don't really need to listen to GPS 24/7, so instead we have a switch that can be turned on and off to steer our clock.





Slides 7-8

As far as schedule goes, the PNT Reference Architecture is currently going through the public release process and should hopefully be released within the next 1-2 months (Slide 9) and available on the S&T website and www.gps.gov. Additional resources are available at the Resilience Repository in www.gps.gov as well the DHS website (Slide 10).

Slides 9-10

Q&A / Discussion:

ADM Allen to Scott Burgett (Garmin): what do we do with this?

Scott Burgett: A lot of these concepts have already been implemented. Certainly not the Level 4 (and we don't make timing receivers), but we do a lot of the cross checks to ensure the sources don't pollute each other. Of course, we can still do better and try to be more resilient. In the past, when we've had a GLONASS outage, we've sailed through that because of our ability to cross check between systems.

ADM Allen to Tim Murphy (Boeing): same question.

Tim Murphy: If this became an industry-wide standard we would reference it in the specifications we give our suppliers, and they would have to show that they met it at the receiver level. We would do some exercises at the airplane level to make sure our integration is cybersecure, but I'm not really allowed to talk about that.

ADM Allen: Per the phrase, "If you build it they will come," I'm trying to figure out if they will come.

Ernest Wong: As Garmin and Boeing alluded to, the industry has already moved far ahead in receiver design. I've seen some variations in how industry implements. Some may only apply certain types of verification methods, or only protect against certain types of threats. Others are more rigorous and have layers of protection methods. Once we publish the PNT Reference Architecture we also intend to build an implementation prototype to demonstrate this is all feasible.

ADM Allen: This applies to federally-provided systems, correct?

Ernest Wong: EO 13905 has contracting language for the acquisition of PNT systems. We're trying to avoid being overly prescriptive in the PNT Reference Architecture.

ADM Allen: Would this not apply in the private sector that does not involve the Government?

Ernest Wong: Correct. This only applies to federal acquisitions, but it can help accelerate the development of these products and their use.

Dr. Parkinson: Frank van Diggelen (Google), what are your comments about this?

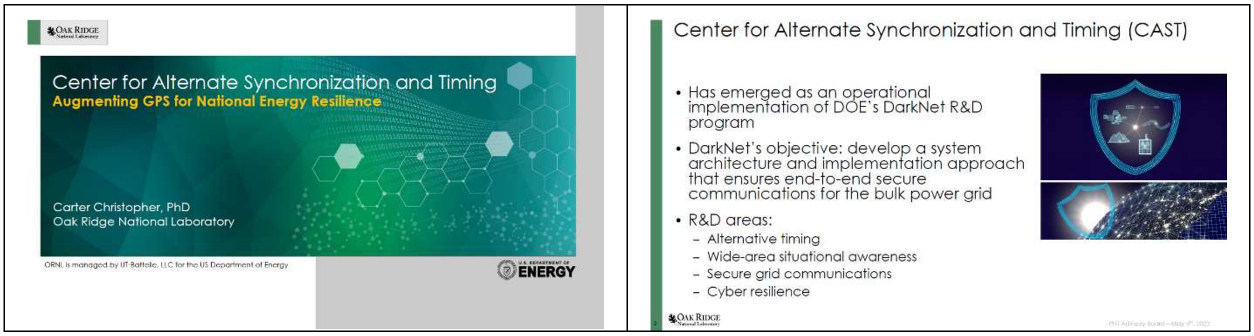
Frank van Diggelen: We don't make GPS chips at Google. As Scott mentioned, many manufacturers are already implementing many of these concepts.

ADM Allen: I'd like to set up a process so that the board can take the information being briefed and provide feedback. I think this presentation fits within the 'T' (Toughen) in PTA. I'd like everyone to think about how we could set up such process.

* * *

Electric Grid Reliability / Center for Alternative Synchronization and Timing (CAST)
Dr. Carter Christopher, *Section Head, Human Dynamics R&D, Geospatial Science & Human Security, Oak Ridge National Laboratory*

Dr. Christopher introduced the Center for Alternative Synchronization and Timing (CAST) at the Oak Ridge National Lab (ORNL), which aims to build a terrestrial network for alternative timing to augment GPS and ensure resilience in the event of GPS vulnerability. CAST is the byproduct of a Department of Energy (DOE) program called DarkNet with the central goal of hardening the electric grid by using commercial off the shelf technologies to improve security (Slides 1-2). A critical piece of this architecture is the timing component. There has been lots of testing and evaluation of off the shelf solutions to develop a matured architecture that CAST believes is ready to use for the commercial power sector. CAST is now in the process of operationalizing the research and development components into something that can be maintained and support operational requirements for power delivery.



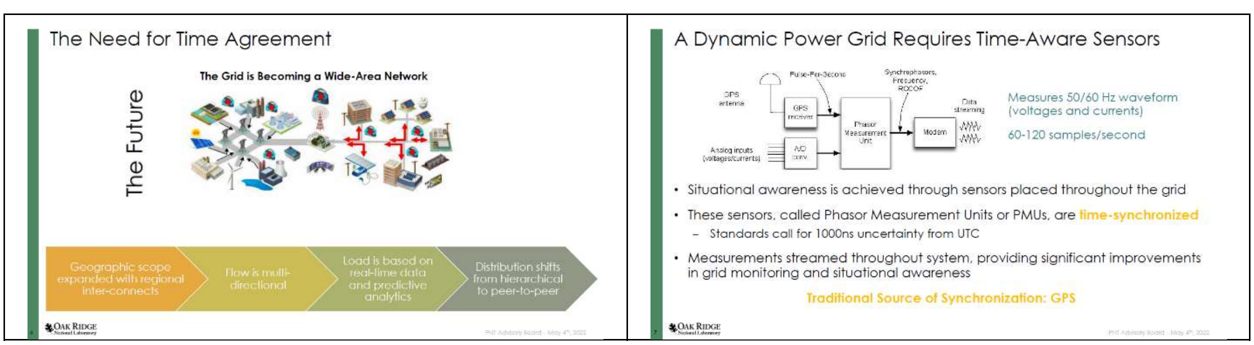
Slides 1-2

As many on the PNTAB are aware, time is a critical component for electric grid operations and supports the regulatory flow of power. The load provisioning for the electric grid of the past was built on past usage (Slide 3). However, the modern electrical grid is looking a lot more like the internet these days, with interconnections across geographies and multidirectional flow (Slide 4).

Slides 3-4

Looking towards the future, load balancing will be based much more on real time data and predictive analytics than assumptions based on past behaviors. The ability and need to regulate the distribution of power in new ways is critical (Slide 5).

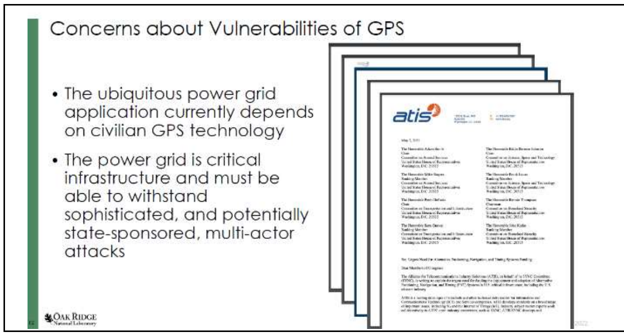
One of the ways that power companies and DOE seeks to understand and regulate the flow of power through the network is through sensors (Slide 6). Phasor Measurement Units (PMUs) are critical for understanding the flow of data from source to sink. Time synchronization is an important component in this system that essentially feeds into the data collection stream. The traditional source of time synchronizations for PMUs is GPS.

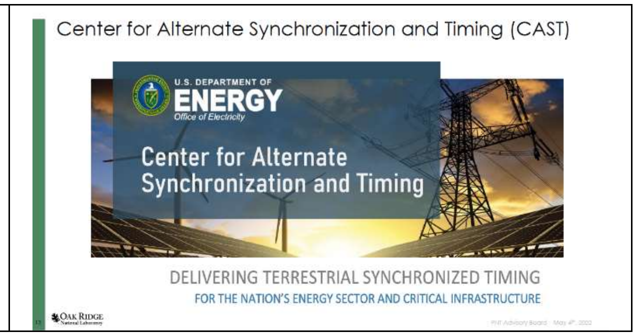


Slides 5-6

The use of timing on the electric grid is no different than the vulnerabilities around GPS discussed today. Fundamentally, the system is built on open ports, where weak signals are prone to disruption. These vulnerabilities ultimately led to a conversation around alternative sources of timing for the power grid to help augment the use of GPS and improve grid resilience (Slide 7).

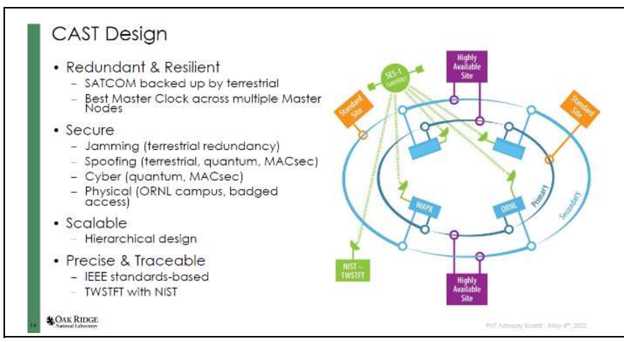
CAST is an early-stage program at DOE with the goal of delivering alternative synchronization service for the power grid community (Slide 8). The program envisions that the power grid community, largely run by commercial entities, can integrate into a federally operated network in the event that GPS becomes compromised.

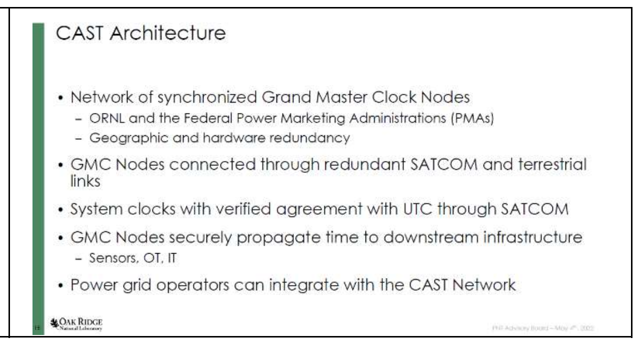




Slides 7-8

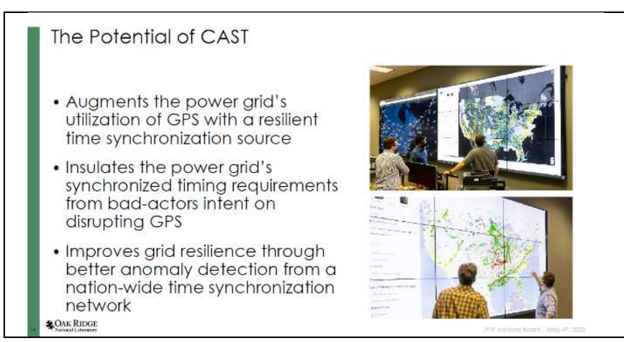
Key components of CAST are redundancy and resiliency (Slide 9). Satellite communications (SATCOM) is backed up by terrestrial networks, and if one of the clocks fail, the network persists because of the master clock architecture (Slide 10). CAST is designed to be resilient in the face of jamming, spoofing, cyber, and physical concerns. The master nodes of the master clock architecture are safeguarded by physical badged access at sites that live in multiple geographic zones. At least one Grand Master Clock Node will be located in each time zone with SATCOM redundancy. Time is propagated downstream to federal and commercial customers using a blueprint of scalable hierarchical designs.

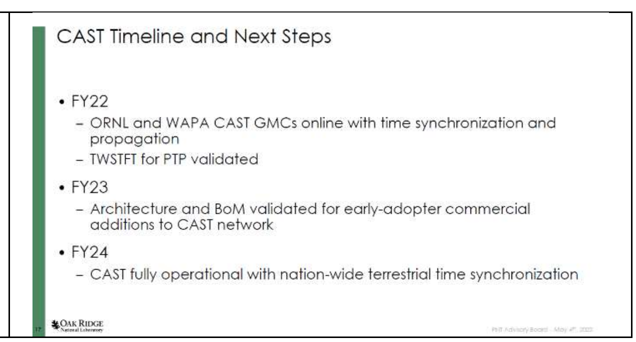




Slides 9-10

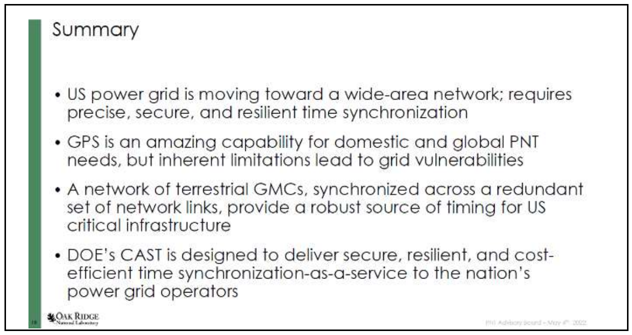
CAST has the potential to augment utilization of GPS with resilient time synchronization sources, insulate the grid from bad actors intent on disrupting GPS, and improve grid resilience through anomaly detection (Slide 11). CAST aims to be operational in FY24 (Slide 12).





Slides 9-10

Summarizing, the U.S. power grid is moving toward a wide-area network which requires precise, secure, and resilient time synchronization (Slide 11). GPS is valuable, but inherent limitations lead to grid vulnerabilities. This network of terrestrial Grand Master Clocks synchronized across a redundant set of network links will be a robust source of timing for the U.S.



Slide 11

Q&A / Discussion:

ADM Allen thanked Dr. Christopher for the presentation and asked about the business element of the program. Will there be fees associated with this architecture since it would be run by the Federal government?

Dr. Christopher responded that they are still building out the model of subscriber fees and costs. The program will be operated through the national labs, but the system will be maintained as part of the DOE.

ADM Allen asked for clarification on the level of precision on timing synchronization.

Dr. Christopher noted that they had reached a level of 100 nanoseconds of accuracy for the grand master clocks. In the field at distributed sites, it is down to one microsecond. As long as that can be maintained, that is more than enough precision.

Mr. Goward commented that there are federal sections of the power grid that will get this service for free as Federal facilities. He asked how other grid operators will be incorporated into the system.

Dr. Christopher responded that one of the key components of the DarkNet project is working through how to ensure cost-efficient adoption for commercial providers. If it isn't a strong value proposition for them, they will not adopt it. If there is a low cost, the return on investment will be high.

Mr. Goward asked for clarification of whether Oak Ridge would run this program.

Dr. Christopher stated that he wasn't in a position to answer that in the long term, but that is the current model they are executing under. Once the system is fully established, it could be operated by a third party.

Hon. Winfree asked if anyone from Texas is participating in this project, as there is a strong history of challenges with the Texas electrical grid.

Dr. Christopher responded that they are not currently collaborating with the Electric Reliability Council of Texas (ERCOT), but they would be happy to set up a conversation and get into partnership with them.

Mr. Burgett from Garmin thanked Dr. Christopher for the presentation. He asked how long the system plans to operate independently in the event of a longer-term GPS outage.

Dr. Christopher noted that they have proven out a 50-nanosecond holdover for up to 14 days at this point.

Dr. Madani asked specifically about synchrophasers, as the traveling wave system requirements are near 400 nanoseconds. To his knowledge, this would require a level of precision around 400-500 nanoseconds, so if a utility is using the traveling wave system, it may need to rely on both GPS and the CAST system.

Mr. Goward asked if CAST hooked into NIST, why could the system not just be GPS independent?

Dr. Christopher responded that NIST only delivers frequency, not phase.

Mr. Goward noted that Dr. Pat Diamond is working on this topic and would be a good connection. He thanked Dr. Christopher for the great presentation and noted the wide interest from the board.

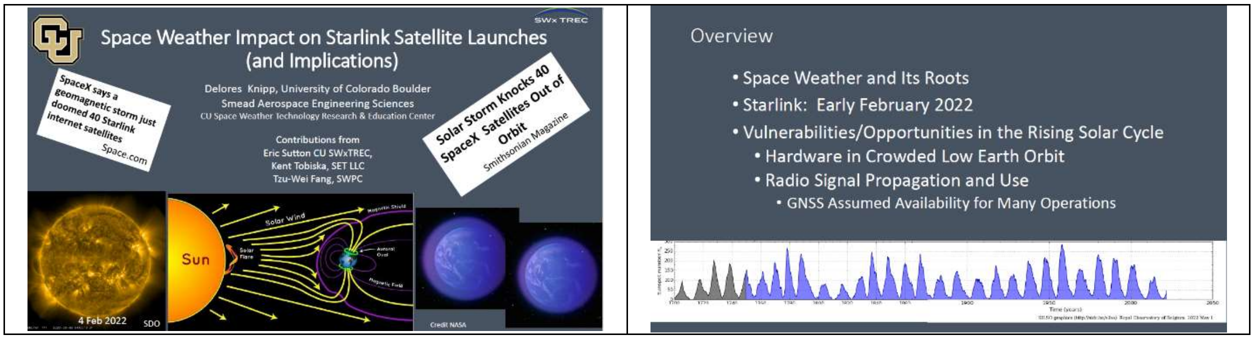
Dr. Parkinson noted that what CAST is doing seems to be analogous to the JPL system.

ADM Allen clarified that it may be similar to the Federally Funded Research and Development Centers (FFRDC) model for GDGPS.

* * *

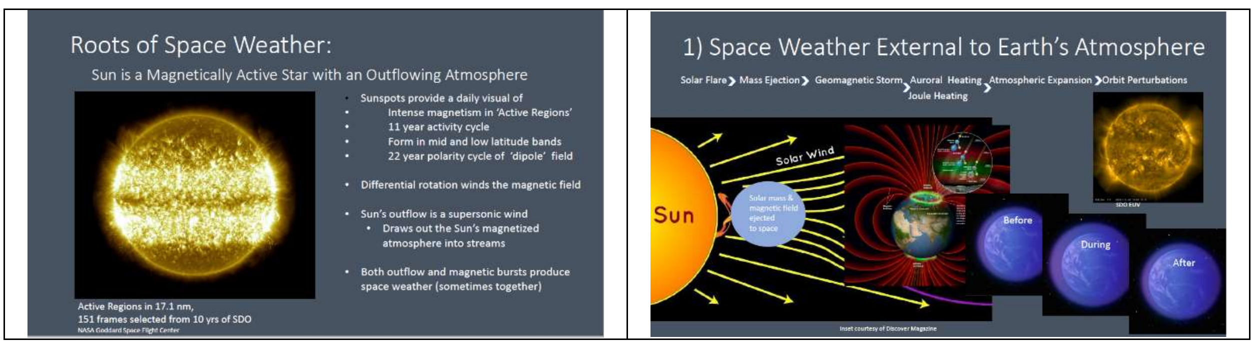
Space Weather Impact on Starlink Satellite Launches
Dr. Delores Knipp, *University of Colorado Boulder*

Dr. Knipp thanked the PNTAB for the opportunity to present as a SME on space weather (Slide 1). Dr. Knipp's research is focused on assessing vulnerabilities on Starlink operations (Slide 2). All opinions expressed in the presentation are her own. On February 8th, 2022, major newspapers released headlines that the SpaceX Starlink constellation had failed to reach their intended orbit. This event may reveal other vulnerabilities in other constellations where assumptions have been made about benign behavior in space weather. Dr. Knipp reviewed the cycles of space weather since the 1700s (see bottom of slide 2). There is a pattern of cyclical behavior every 11 years where the sun has many sunspots in active regions.



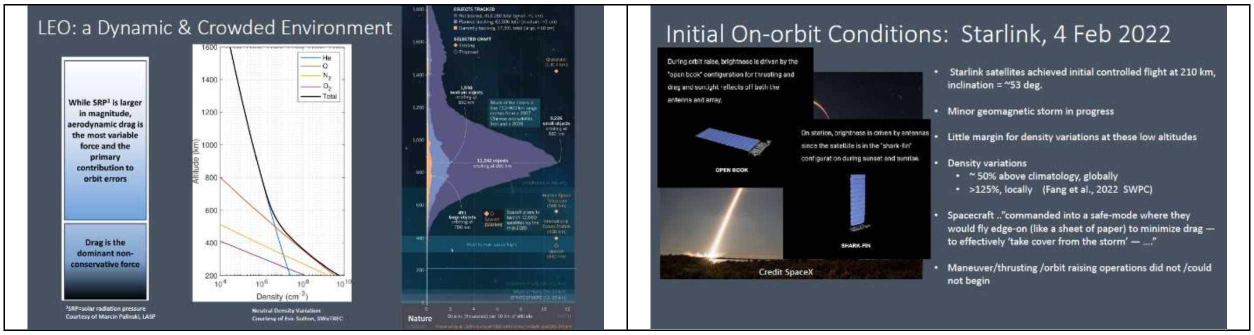
Slides 1-2

Sunspots come from the differential rotation of the sun that twists the sun's magnetic field (Slide 3). In peak moments, there are extreme ultraviolet emissions, which likely played a large role in the Starlink situation. Bursts of activity come out and leave the sun at supersonic speeds, causing geomagnetic storms (Slide 4). Space weather involves the expulsion of mass and magnetic material from the sun. 2-3% of the solar wind energy enters into Earth's magnetic domain, concentrated in regions called the Auroral zone. From there, solar wind energy is brought further outward and dispersed into the atmosphere, creating zones of energy deposition that end up dispersing and creating upheaval in the Earth's atmosphere.



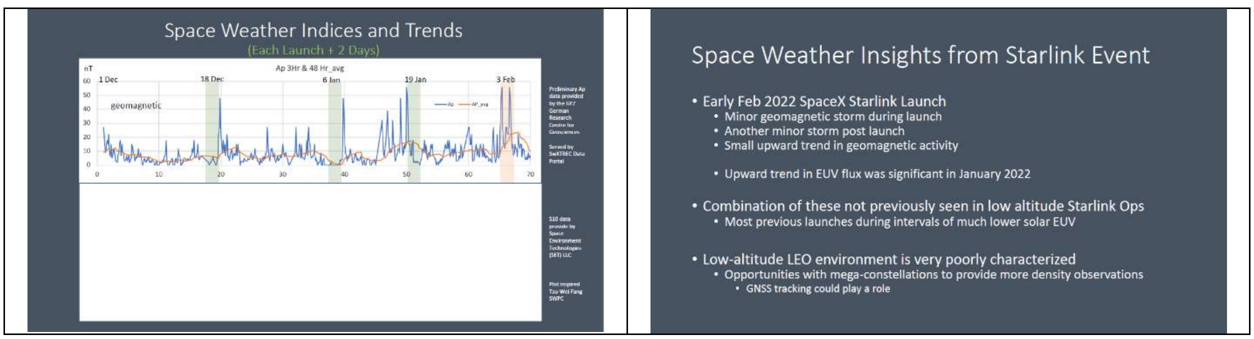
Slides 3-4

Dr. Knipp then described the Earth's atmosphere in terms of density (Slide 7). For altitudes up to 1600 km, scientists recognize that over the course of a solar cycle, Earth's density and regions of LEO will vary by at least one order of magnitude. This is important information for mega-constellations like Starlink, which plans to have ~12,000 spacecraft. Starlink initially planned to orbit at a higher altitude, but recently made a shift to lower orbits because of the argument of better coverage if the satellites are lower. As a result, there will be a much larger number of satellites in lower regions of the atmosphere where there are significant shifts in density over the solar cycle. On February 3rd, SpaceX launched 50 satellites to 210km with the intent of elevating up to 550 km (Slide 8). The launch that occurred did so during a minor geomagnetic storm, which typically occurs once a week. Density variations that they launched into saw a 50% rise above background climatology and 120% locally, which are not large values. When SpaceX realized their satellites were not behaving as expected, they turned on safety mode to minimize drag and take cover from the storm. Unfortunately, many of the satellites were unable to pull themselves out of safety mode, so maneuvering and thrusting did not turn on. The Starlink satellites are about the size of a 6ft table and fly in "shark fin" mode when on orbit.



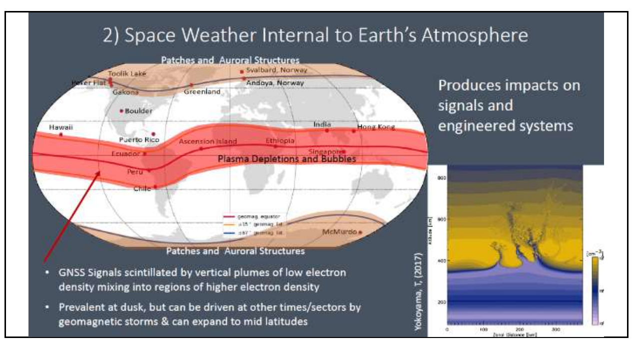
Slides 5-6

Turning to the space weather activity during that period, there was a record of geomagnetic activity from 1 December 2021 through 3 February 2022 (Slide 7). Every 27 days, the sun's rotation causes a rise in activity. This record was substantially above the typical behavior they had encountered with the sun since starting preliminary launches in 2017. SpaceX should have been ready for this kind of solar activity, but the margin of operations to go to LEO were thin on the February 3rd launch, so when they experienced more satellite drag than they were expecting, 39 satellites did not make it out. Dr. Knipp hypothesized that SpaceX will increase their launch target from 220 to 310 km from here on out. Dr. Knipp summarized that these were the major conclusions from the space weather analysis of the Starlink event (Slide 8). There was a combination of factors that they had not previously seen on low altitude operations. The LEO environment is very poorly characterized in terms of space weather, and she expects that in the future SpaceX will provide additional info about what is going on with their satellites so the science community may learn more about the space environment.



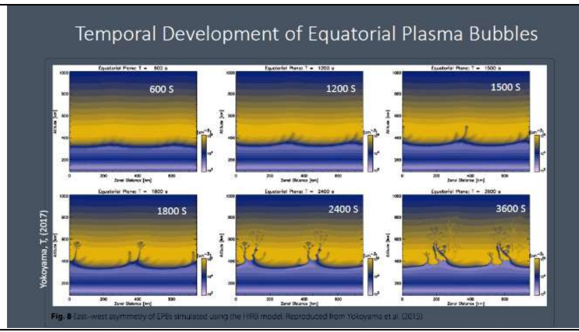
Slides 7-8

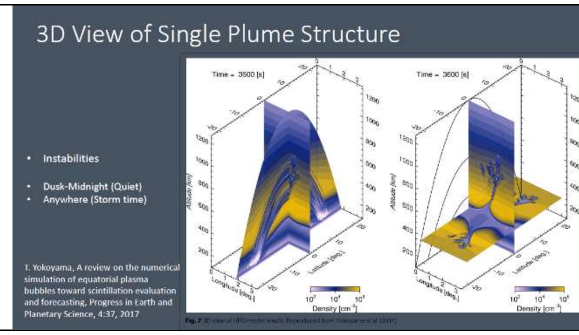
Looking to the future, space weather internal to Earth's atmosphere does in fact produce impacts on spacecraft (Slide 9).



Slide 9

Bubbles of plasma among the geomagnetic equator scintillate signals and change the ability to precisely locate in these regions (Slides 10-11).





Slides 9-10

The implications of that are that GNSS signals are going to be used in a crowded LEO environment, which indicates a vulnerability that hasn't been explored much yet (Slide 11). GNSS may learn a lot about the nature of the signal environment and what is happening as a result of variations in the ionosphere (Slide 12). Spacecraft may be operating in regions where there are plasma bubbles on top of them, causing potential disruptions particularly to radio occultation operations

Slides 11-12

Q&A / Discussion:

Mr. DeLaPena remarked that he would talk to USSF GPS operators to get GPS signal data on February 3rd to see if there were any effects on the GPS constellation.

Dr. Knipp added that not much is known about minor space weather events and their impacts on constellations.

Mr. DeLaPena asked if Dr. Knipp had any other concerns with signals downlinking in this environment.

Dr. Knipp recommended Mr. DeLaPena get in touch with Dr. Morton as the local GNSS expert. In terms of downlink signals, she noted that operations in the arctic can and will be affected by the space weather environment.

Mr. Burgett asked if Dr. Knipp had heard directly from SpaceX about their reasoning for why Starlink could not go into their orbit raising maneuver.

Dr. Knipp responded that she has not personally talked to SpaceX, nor have they ever been specific about why they could not operate as intended. It is understood that they needed to deploy the array horizontally, and the last thing they wanted to do was create more area to mass ratio in the middle of a solar storm. It seemed to be an autonomous issue from the spacecraft rather than operator error.

Mr. Burgett commented that it was an expensive mistake.

Dr. Knipp agreed, but also added that it was rather impressive that 2.5 weeks later, SpaceX completed a successful launch and seemed to learn from their mistakes.

* * *

Welcome Remarks
Civil Sector National Priorities
Dr. Robert Hampshire, *Deputy Assistant Secretary for Research & Technology, Department of Transportation*

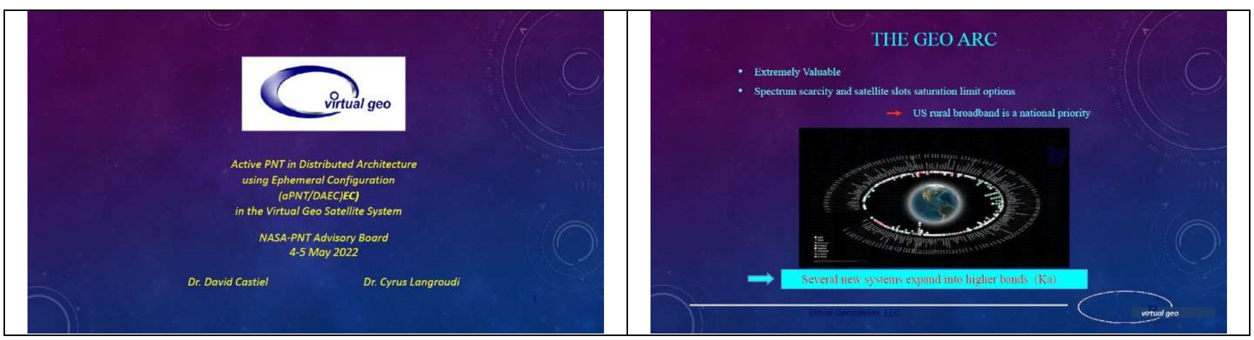
Dr. Hampshire apologized for his delayed arrival and thanked Ms. Van Dyke for providing opening remarks on his behalf earlier in the day. He introduced himself as the Deputy Secretary for Research & Technology at the Department of Transportation. DOT has been the civilian lead for PNT and GPS for some time and is eager to continue its leadership position within the ESG and EXCOM. Dr. Hampshire thanked his colleagues within the DOT and the NCO for their coordination and support of PNT. Dr. Hampshire noted the need for more, not less coordination in the interagency around critical issues to Protect, Toughen, and Augment PNT systems. DOT is committed to working with colleagues at DoD, DHS, and others to make sure every option is considered and that the interagency is being as proactive as possible to ensure national assets are protected, toughened, and augmented. This is a bipartisan issue throughout multiple administrations. GPS is a world-class leading set of capabilities, and this group has fought for many years to get additional resources for complimentary PNT systems. Dr. Hampshire praised the conversation on feedback around PNTAB recommendations to create an iterative loop. Dr. Hampshire's background in policy, engineering, and applied mathematics is deeply relevant to the world of spectrum and PNT. He noted his knowledge of a range of PNT challenges with interference. He thanked the White House for their dedication to this issue and noted that Secretary Pete Buttigieg is engaged in these issues as well. The DOT is committed to developing proactive solutions on a range of issues related to PNT.

* * *

Virtual GEO Satellite active-PNT (aPNT) System
Dr. David Castiel & Dr. Cyrus Langroudi, *Virtual Geosatellite, LLC*

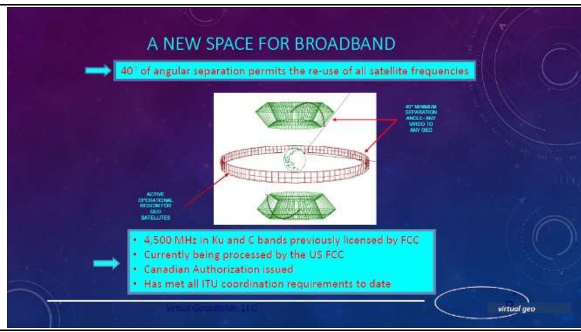
1) Dr. David Castiel

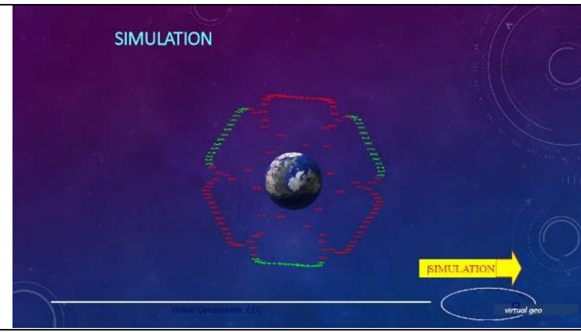
We're going to be presenting a PNT concept based on a distributed architecture using ephemeral configuration with a virtual Geostationary Orbit (GEO) satellite system (Slide 1). Some of the other space-based navigation systems you've heard about are in circular orbit, whether LEO, Medium Earth Orbit (MEO), or GEO. Instead, the virtual GEO system is based on an elliptical orbit, which has an apogee and perigee that creates an asymmetry in your system. We're going to use this asymmetry to create applications, one being PNT. All the slots in GEO are basically taken as well as the spectrum available at GEO for communication (Slide 2). As such, there has been a push to use satellites outside GEO (for example, in LEO) to improve communication capacity.



Slides 1-2

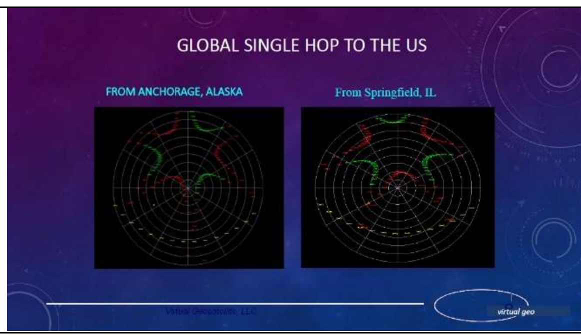
As shown in slide 3, the virtual GEO system has a region around apogee of the elliptical orbit, starting at ~17,000 km altitude, culminating at the apogee (~ 26,200 km), and then returning to 17,000 km altitude along the trajectory [Ed. note: these are represented by the green lines on chart]. As the satellite heads back towards the perigee, it shuts down below 17,000 km altitude and the cycle repeats. The orbital period is 8 hours, and the active arc (when the satellite is moving along the apogee region) is about 5 hours. This results in approximately 15 hours within the active arc every day per satellite. By offsetting several satellites along these orbits, at least one of the satellites will be operating within the apogee region at all times, thus giving the appearance of a more or less 'fixed' single GEO satellite over a specific landmass, hence the term 'Virtual GEO Satellite'. [Ed. note: satellites in elliptical orbit move fast at perigee and slow at apogee, thus giving the appearance that they are 'hovering']. There are approximately 40° of angular separation between equatorial orbit and the orbit of the virtual GEO satellite. When we approached the FCC, they were happy because such system could reuse all the frequencies (a total of 4,500 MHz in bandwidth available in Ku-band and C-band) that had already been authorized for the GEO satellites. So far I have focused on the northern hemisphere but, of course, you could have a mirror image should you want to instead provide coverage over the southern hemisphere. Slide 4 depicts the view above the North Pole looking down towards the equator. The graphic shows a total of 72 satellites, but we don't need all of those. We need three ground tracks per day to provide 24-hour coverage, which requires at least five satellites moving along the orbit (three of which will be 'active' within the apogee region). Each of the 'petals' represents one of those ground tracks, and the overall system consists of at least three petals. The satellite orbits have 63.6° inclination to avoid precession.

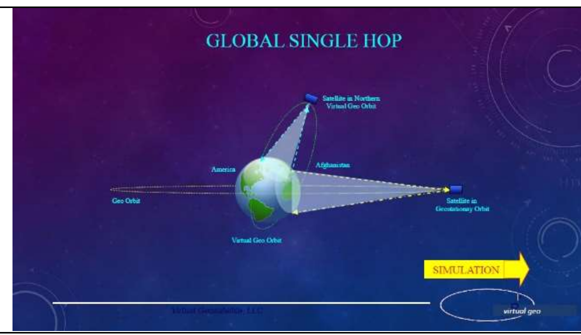




Slides 3-4

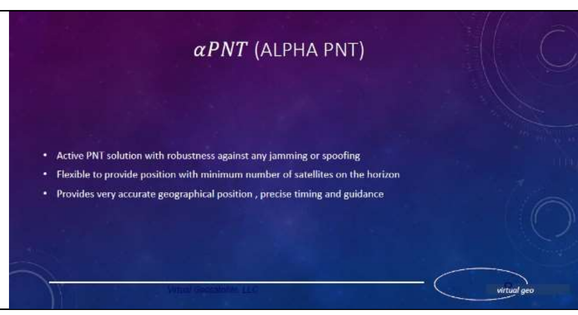
Slide 5 depicts the ground track as seen when looking up from the surface. Because of the geometry, a person in Anchorage, Alaska looking up would hypothetically see satellites operating over Asia and the Pacific with a least 5° elevation. As we move lower in latitude to, say, Springfield, Illinois, you still get coverage from those satellites. What this means is that one satellite at any point over the northern hemisphere can provide communications pretty much from one end to the other of the northern hemisphere (Slide 6). We refer to this as a 'single global hop'. This can be used for many applications. For example, being able to use a single satellite at a time, we have all the blockchain validators going up and going down at the same time. Another application is PNT, where each satellite can provide additional measurement for navigation. Our intent is not to replicate GPS, or other GNSS, but could supplement it through a two-way communication signal. Therefore, we could use this to provide timing signals. This would be very difficult to hack since a hacker would have to be right next to you, and moreover you can change frequencies/satellites at any time so the hacker would not be able to guess what you're doing. Because it's a two-way communication system, a hacker must communicate with the system, so it identifies itself automatically. However, this approach can be expensive since all the satellite resources are going into communicating back and forth with you, so it would be used to protect very high-value assets.





Slides 5-6

Dr. Cyrus Langroudi will describe how we achieve these algorithms in the active PNT ephemeral configuration solution (Slide 7).



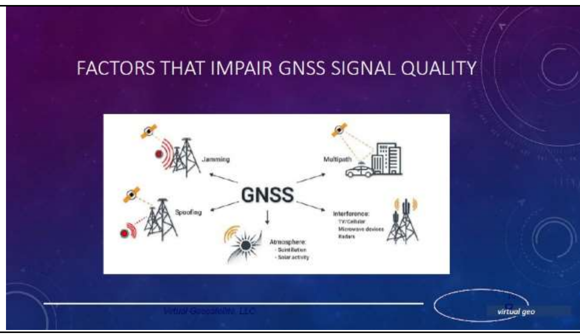
Slides 7

2) Dr. Cyrus Langroudi

The PNT systems discussed so far (Slides 8-9) have the same common problem: they're passive and expect to receive a signal from a satellite (GPS/GNSS) or ground station (eLoran, etc.). Our system is active. The first step is for the user to send a signal to a satellite (satellite A) and then a navigation analysis is going to take place inside the satellite. This satellite then communicates to second satellite (satellite B), which returns the signal from the navigation analysis back to the user. In the second step the user sends a signal to satellite B, and then he gets a return signal from satellite A. During this time, the navigation analysis is conducted at the satellites themselves.

Slides 8-9

Therefore, the user is not affected by the factors that typically impair GNSS signal quality (Slide 10) or GNSS vulnerabilities to spoofing (Slide 11). First, a spoofer would have to be at the exact position the user is in, which is not feasible. If the spoofer tried to send a signal to the satellite, the satellite would know that the spoofer is not in the same position as the user. Second, we are integrating our system with blockchain technology. This is a private network, so authorized users are inside this network when communicating with the satellite, and the satellite is also inside this network when the satellite is responding to the user's inquiry. If the spoofer is not inside this private network, the satellite will ignore his communications. Another application is search and rescue, since this system is in constant communication with the user, and the satellites know the position of the user.



Slides 9-10

[Ed. Note: there were additional slides in that were not briefed. See links in the meeting agenda for full presentation]

* * *

Alternate Positioning & Navigation using Magnetics
Mr. Martin Neill, *VP, Security & Defense, AstraNav*

Mr. Neill introduced AstraNav as a capability that complements GPS. There is a well-known need for augmentation to GPS. AstraNav is rolling out its technology across customers and clients. AstraNav is a software solution that takes magnetic signals and turns them into ultraprecise positioning in real time. AstraNav works where GPS doesn't. Navigating using magnetics is nothing new; migrating birds have been doing it for millennia. There are a good number of papers out there about this navigation technique. There can be a number of problems with the basic concept, including isolating beyond the magnetic field and the seeming impossibility of using a different magnetometer to do positioning and navigation.

AstraNav uses machine learning to identify changes in the magnetic field, updating magnetic maps on a regular basis to offer 3D positioning anywhere in any environment. Any device or platform can be turned into a PNT device using a magnetometer on a host platform. It doesn't matter whether it's a cell phone, weapons system, aircraft, robotic vehicle, mining equipment, or a submarine. AstraNav provides independent verification and validation. It is a software-based solution using magnetometers that already exist in millions and billions of devices, which use considerably less power than GPS does and doesn't take up much memory, even without commercial compression techniques. This technology can be applied in markets such as security & defense, submarines, weapons systems, logistics management, transportation, autonomy, and other areas where technology could be applicable. This is not theoretical, but practical.

Mr. Neill shared some case studies around complex outdoor navigation. A client asked for a demonstration of navigating through a GPS-compromised area, which was done in coordination with the U.S. Strategic Command (STRATCOMM) and the FAA. AstraNav provided the technology to a representative who walked a 13 km route where GPS was compromised by spoofing and jamming. They then asked the technology to repeat the route exactly, which was accomplished with +/- 1 m accuracy without any technicians onsite. For indoor navigation, the technology demonstrated .5 m accuracy without any infrastructure, only a pre-built magnetic map.

The capabilities and applications of this technology are seemingly vast. This alternative navigation technology can operate in GPS denied environments including underwater, in caves, underground, and inside buildings. It can also tell the difference from the first floor to the 75th floor in a skyscraper, increasing the capability of E911 services. This service offers precision navigation on a software basis using existing magnetometers, and the ones that already exist in cellphones work just fine. The magnetometer in most cellphones cost about $80, and the more expensive magnetometers are about $1.60. This technology is reliable, continuous, and secure, and most importantly, is a reality.

Q&A/ Discussion:

Dr. Grejner-Brzezinska asked if locations need to be mapped first, and if so, how often places need to be re-mapped and what changes in the environment would require re-mapping.

Mr. Neill responded that magnetic maps are very stable, especially indoors. In more open spaces like Manhattan, AstraNav can use data on a regular basis to update maps, so the sheer fact that someone is interacting with the environment updates the map. New buildings or significant construction would impact the map, but most don't go up overnight. There is also a distinction as to whether changes in the magnetic map are fixed or transitory.

Prof. Filjar asked about the anticipated means and potential mitigation of spoofing for this technology.

Mr. Neill responded that he is confident that the technology cannot be spoofed.

Mr. Goward asked about the quality of model and map accuracy.

Mr. Neill replied that a magnetic map is required in order to navigate, so going into a space for the first time, that map may not exist. Publicly available NOAA maps can be used at altitude but cannot be projected into urban environments.

Dr. van Diggelen referred to the real-life example where in using a sailboat, it's not advisable to use a magnetic compass in dock because it is affected by whatever is around. He asked how that can be reconciled with mapping indoors, for example when walking by speakers.

Mr. Neill offered to give a longer answer offline, but as a short answer, there are localized magnetic impacts that can be identified, and magnetometers can be calibrated accordingly.

An audience member asked a question about space weather impacts on magnetic data.

Mr. Neill responded that if significant space weather is occurring while gathering magnetic data, that may have an impact, but space weather is predictable so it would be possible to identify when that might occur in advance.

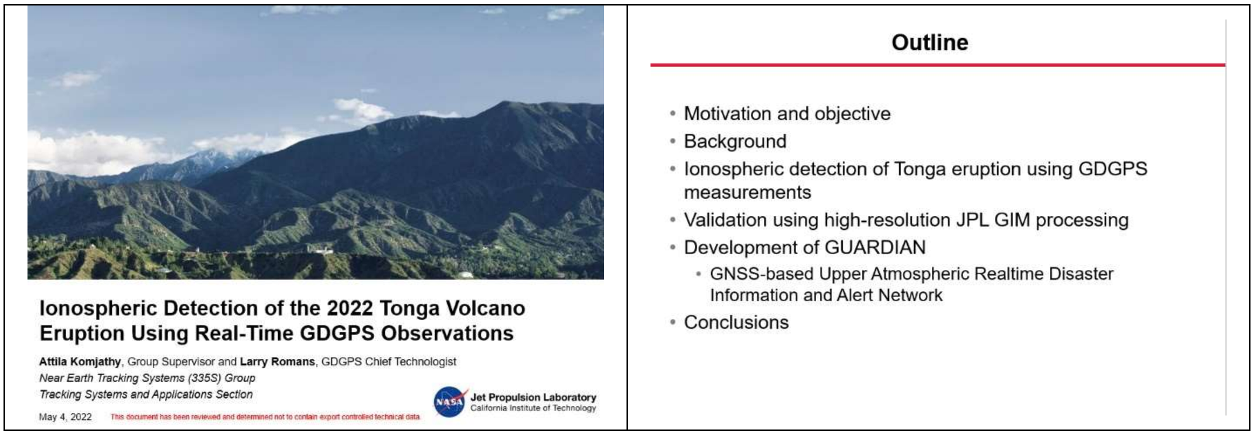
Mr. DeLaPena asked if there were any near-term experimentation involving UAVs.

Mr. Neill noted that AstraNav had completed successful experimentation with UAVs previously, but is now no longer in the experimentation phase as a proven technology that is now rolling out with clients.

* * *

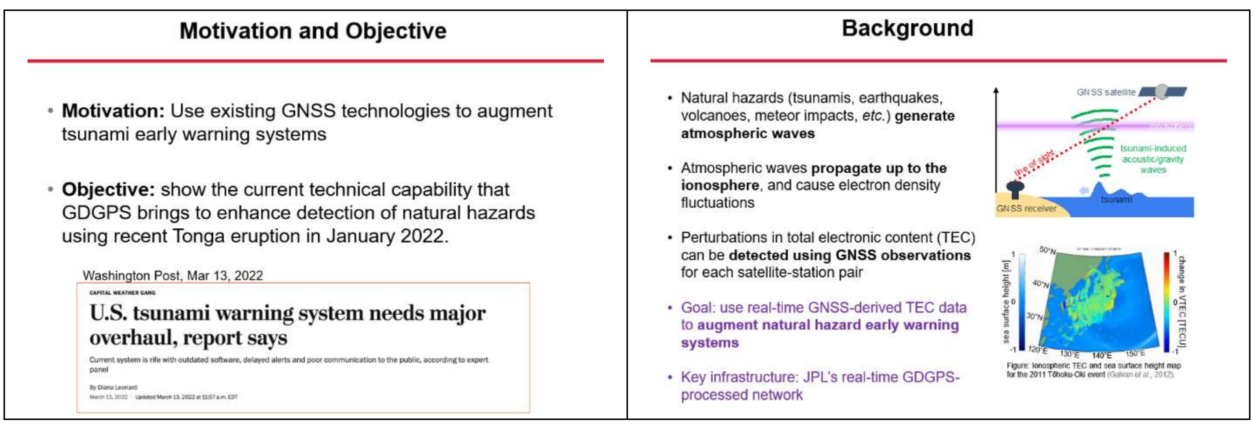
GDGPS for Natural Hazards Early Warning: Tonga Volcano Tsunami
Dr. Attila Komjathy, *Supervisor, Near Earth Tracking Systems Group, JPL*

Dr. Komjathy noted that his co-author, Mr. Larry Romans, was also in attendance. He also recognized the JPL Near Earth Tracking System Group and the Ionospheric and Atmospheric Remote Sensing Group for working very with him on this topic (Slide 1). This briefing includes a review of the data sets the GDGPS team has been working from, the results and validation of results, and development of the GUARDIAN system upper atmosphere real-time disaster information and alert network (Slide 2).



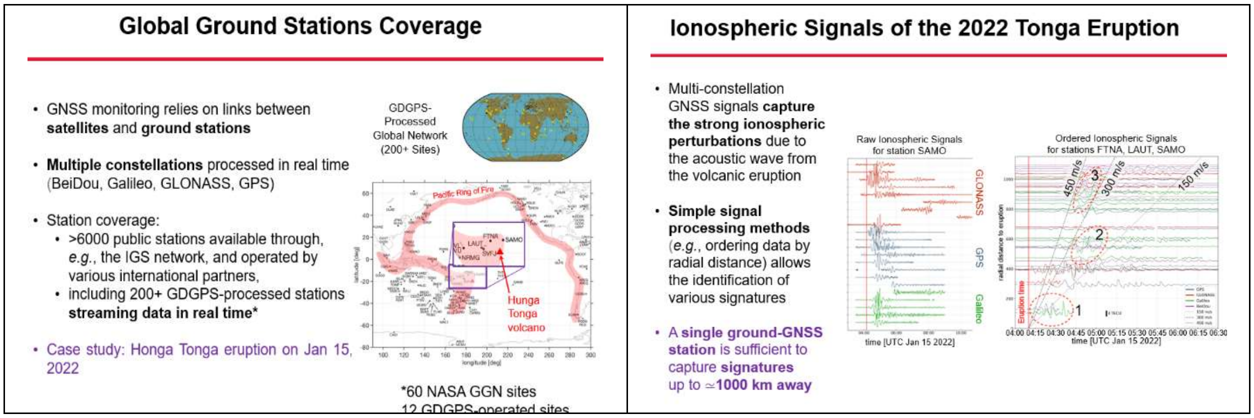
Slides 1-2

A recent government report urged the National Oceanic and Atmospheric Administration (NOAA) to look at the Nation's tsunami warning system and found a number of issues that delay warnings and the response time (Slide 3). This provides our motivation to use existing GNSS technologies to augment existing tsunami early-warning systems. Our objective is to study the capabilities GDGPS can provide to enhance detection of natural hazards using the recent Tonga event. There has been much research over the past 20 years to look at the ocean surface's interaction with the atmosphere, including the 2011 Tōhoku-Oki earthquake/tsunami and the resulting propagation of acoustic and gravity waves in the upper atmosphere (Slide 4). GPS itself is very sensitive to observe perturbations in the ionosphere, and our goal is to use the GDGPS network as part a system that can process this data in real-time.



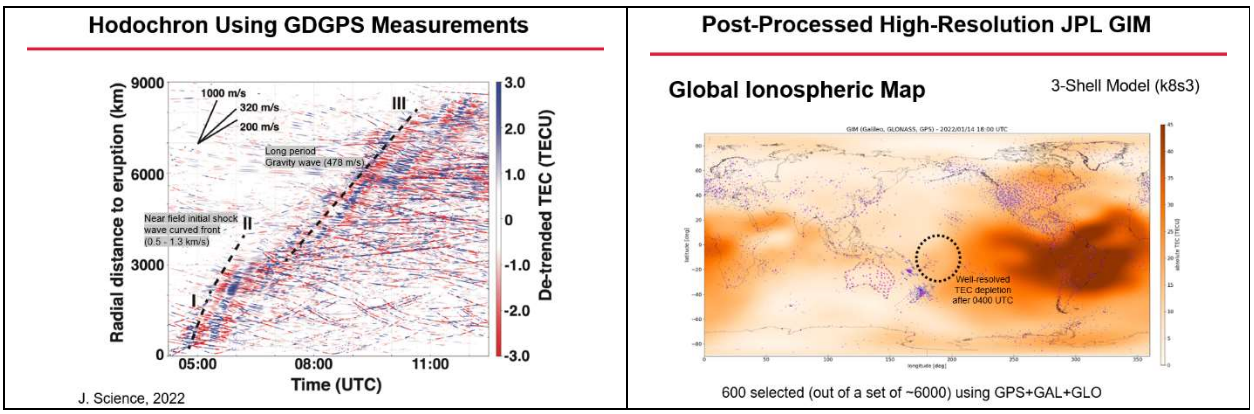
Slides 3-4

We use NASA's Global GNSS Network (GGN), which includes sixty sites, to provide data to our processing scheme (Slide 5). There are a few GDGPS-owned sites also providing data, and we also take advantage of over 100 International GNSS System (IGS) public sites that stream data in real-time. There are 75 real-time sites across the Pacific Ring of Fire that we have access to, and we'll be focusing on three particular sites that were close to the Jan. 15, 2022, Tonga event. The ripples on the graphs on the left in slide 6 depict the ionospheric perturbations during the event. The eruption happened at 4:00 UTC, and we were able to see effects on GLONASS, GPS, and Galileo signals four to ten minutes afterwards. The graph on the right in slide 6 depicts these signals in ordered fashion for the FTNA, LUIA, and SAMO real-time stations, and the slopes show the propagating waves following processing of the GNSS data. Note the three areas of interest (indicated as 1, 2, and 3), which show the propagation waves as measured at three locations, the first one being the closest, the second one about 500 km away, and the third one approximately 1000 km away.



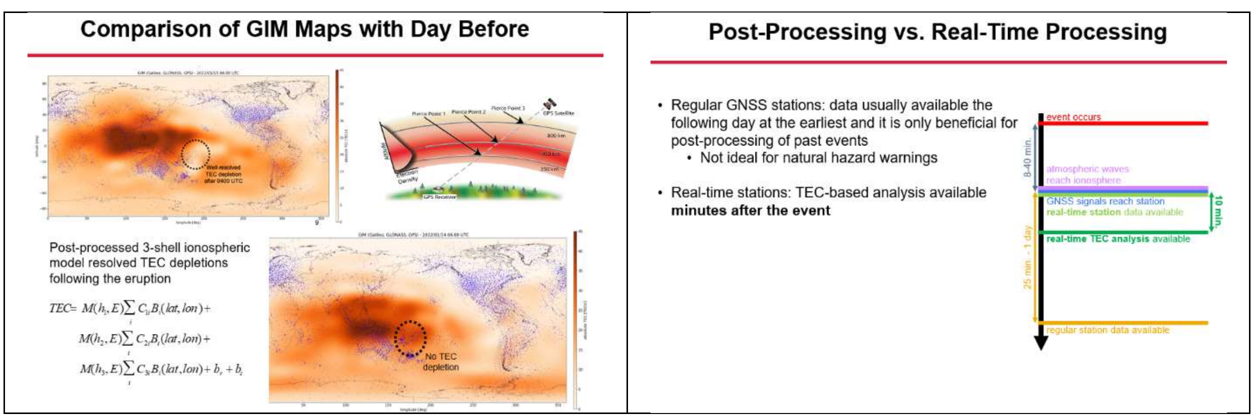
Slides 5-6

Slide 7 shows the variation in electron count at various radial distances vs. time. Note the measurement of the shock wave near the eruption and the long-period gravity wave measured farther out. The animation on Slide 8 shows the Total Electron Count (TEC) depletion following the eruption (see 7:46:17 in webcast recording). This depletion is generated by the mechanical displacement of electrons in the ionosphere.



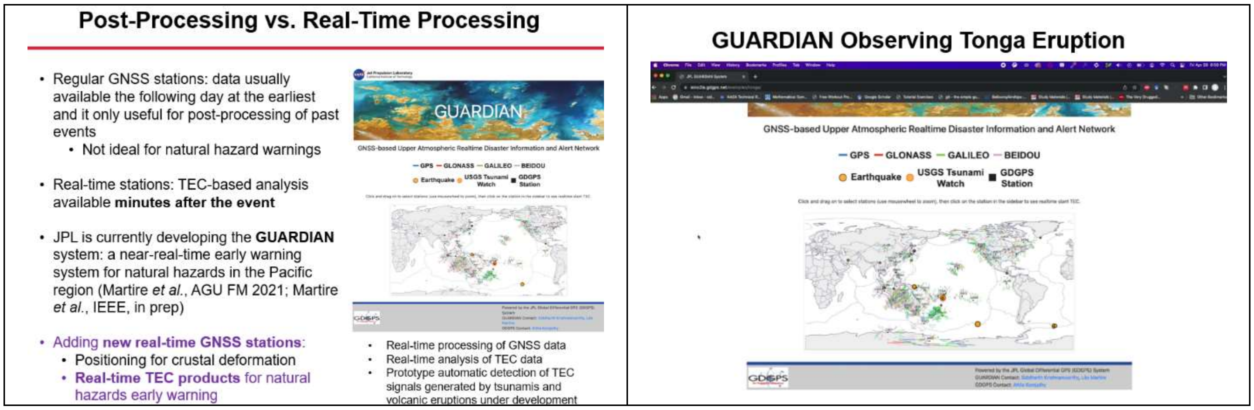
Slides 7-8

Slide 9 depicts a comparison of the Global Ionospheric Models the day of the event and the day before, as captured by over 600 GPS monitoring stations. The advantage in using real-time stations is that a TEC-based analysis is available within minutes after the event, where are post-processing stations usually will not have the data available until the next day (Slide 10).



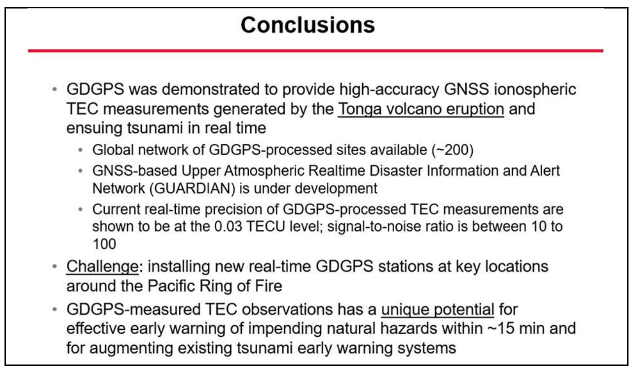
Slides 9-10

Now I'd like to introduce the GUARDIAN system, which is our next-generation tsunami-warning system (Slide 11). Slide 12 includes a movie showing GUARDIAN's observations following the Tonga eruption (Note: see 7:48:16 in webcast recording).



Slides 11-12

In summary, this technology is already available using a global network of approximately 200 real-time sites (Slide 13). Future improvements could include additional GDGPS stations across the Pacific Ring-of-Fire to address coverage gaps, particularly in along the Aleutian Islands, which are of great importance for early warning along the U.S. West Coast. GDGPS-measured TEC observations have a unique potential for an effective early warning system that could potentially be issued within 15 minutes of an event. This could also be a valuable augmentation to existing tsunami-warning systems.



Slides 13

Q&A / Discussion:

Frank van Diggelen: Would this system allow you to detect the progress of the tsunami on a smartphone?

Attila Komjathy: That’s where we’d like to take this system. The processing scheme already supports this. Plate Boundary Observatory (PBO) stations are being added across the West Coast that would further contribute to showing the progress of the tsunami. This would be very useful as it takes approximately 8-10 hours for a tsunami to reach the West Coast.

Frank van Diggelen: What kind of other atmospheric perturbation could mimic this effect and lead to a false alarm? What’s the amount of time you need to differentiate between a false alarm and an actual tsunami?

Attila Komjathy: Yes, there are other signals in the atmosphere that could mask this, such as a geomagnetic storm. There is a lot of science we still have to do to address that issue.

Greg Winfree: There was a map in the New York Times showing reflection of energy at the surface level as energy reverberated across the globe. Could we overlay such data with the one you obtained from ionospheric measurements?

Attila Komjathy: It would be possible. We’re also looking at the infrasound signal data as it reverberates multiple times across the globe.

Matt Higgins: Was the TEC disturbance due purely to the eruption? Are you inferring the tsunami, or actually seeing it?

Attila Komjathy: We see the tsunami, particularly as we move farther from the event since those waves are caused directly by the gravity waves generated by the tsunami. The signal is very characteristic.

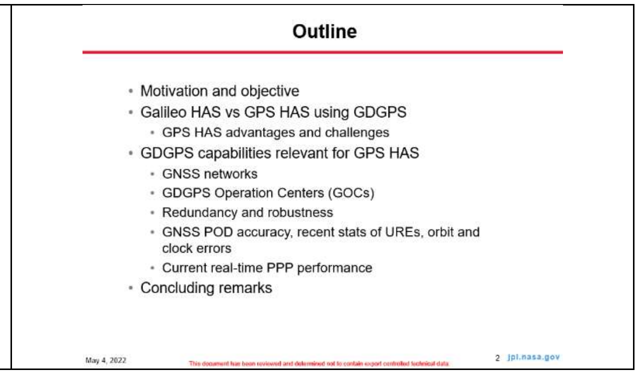
Matt Higgins: Did you also look at the troposphere?

Attila Komjathy: Not at this time, but we could look into it.

* * *

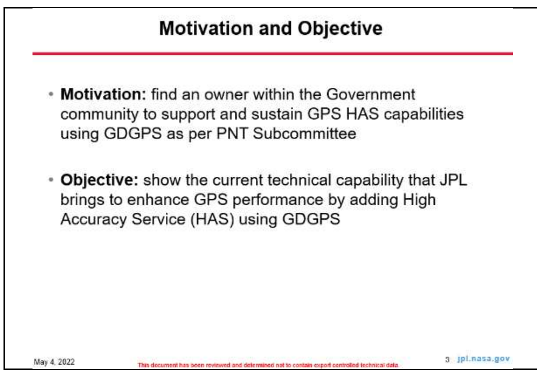
GDGPS Contribution to a GPS High Accuracy Service (HAS)
Dr. Attila Komjathy, *Supervisor, Near Earth Tracking Systems Group, JPL*

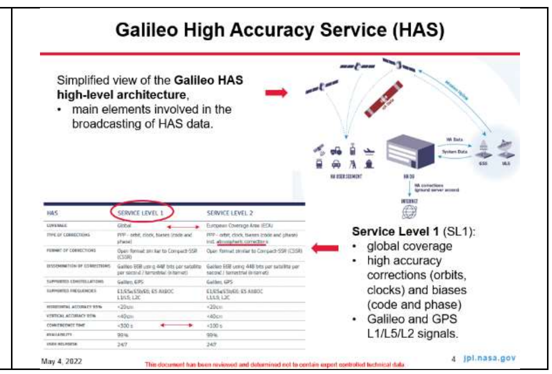
This briefing covers the potential contribution of GDGPS to a proposed GPS High Accuracy Service (GPS HAS), and will compare it with the existing Galileo HAS[6] (Slides 1-2).



Slides 1-2

This briefing describes the technical capabilities that GDGPS could contribute (Slide 3) to a GPS HAS. Galileo HAS features both a signal-in-space capability and distribution of corrections via the internet (Slide 4). See Slide 4B (expanded view of the table in slide 4) for details on the specific services.





Slides 3-4

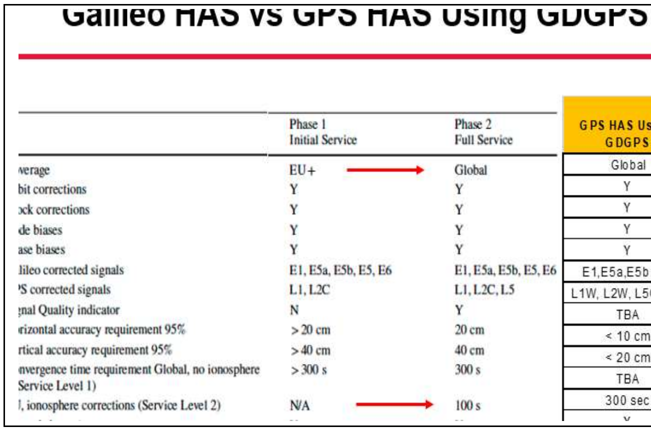
HAS	SERVICE LEVEL 1	SERVICE LEVEL 2
COVERAGE	Global	European Coverage Area (ECA)
TYPE OF CORRECTIONS	PPP - orbit, clock, biases (code and phase)	PPP - orbit, clock, biases (code and phase) incl. atmospheric corrections
FORMAT OF CORRECTIONS	Open format similar to Compact-SSR (CSSR)	Open format similar to Compact-SSR (CSSR)
DISSEMINATION OF CORRECTIONS	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)
SUPPORTED CONSTELLATIONS	Galileo, GPS	Galileo, GPS
SUPPORTED FREQUENCIES	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C
HORIZONTAL ACCURACY 95%	<20cm	<20cm
VERTICAL ACCURACY 95%	<40cm	<40cm
CONVERGENCE TIME	<300 s	<100 s
AVAILABILITY	99%	99%
USER HELPDESK	24/7	24/7

Slide 4B

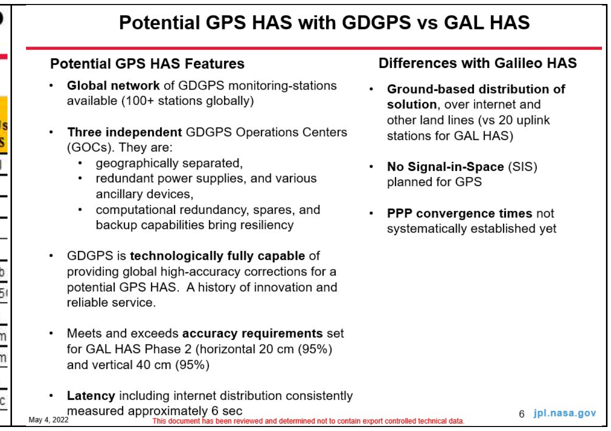
A recent paper by the GMV Group, a key contributor to Galileo HAS, defines Phase 1 (Initial Service) & Phase 2 (Full Service) (Slide 5). Phase 1 service relies on 14 reference stations to provide regional service. Phase 2 service will be global, and require additional stations. When comparing Galileo HAS to GDGPS, note that GDGPS relies on about 100 reference stations distributed globally and provides better horizontal and vertical accuracies. Slide 6 describes the key features of a potential GPS HAS with

[6] Galileo High Accuracy Service, briefing to 25th PNTAB. Dr. Ignacio Fernandez-Hernandez, Galileo Authentication & HAS Manager, European Commission. https://www.gps.gov/governance/advisory/meetings/2021-12/fernandez-hernandez.pdf

GDGPS and compares it to Galileo HAS. The key difference is that GPS HAS with GDGPS does not include a signal-in-space to distribute the data and instead relies on the internet and other land lines. In addition, the Precise Point Positioning (PPP) convergence times for GPS HAS with GDGPS has not yet been established systematically.

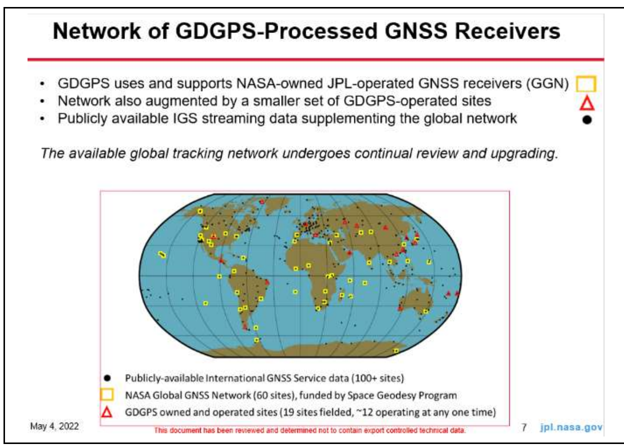


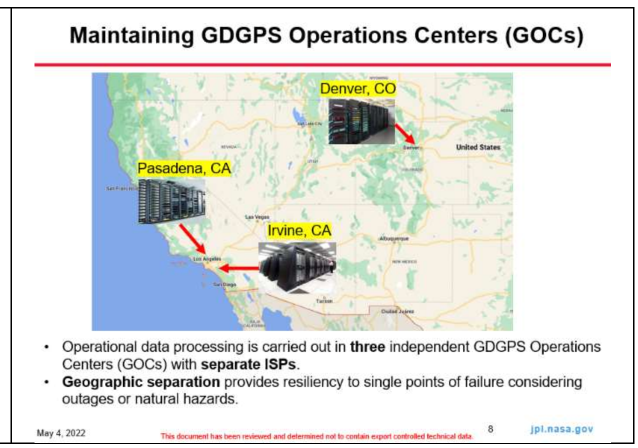
	Phase 1 Initial Service	Phase 2 Full Service	GPS HAS Us GDGPS
verage	EU+	Global	Global
bit corrections	Y	Y	Y
ock corrections	Y	Y	Y
de biases	Y	Y	Y
ase biases	Y	Y	Y
lileo corrected signals	E1, E5a, E5b, E5, E6	E1, E5a, E5b, E5, E6	E1,E5a,E5b
'S corrected signals	L1, L2C	L1, L2C, L5	L1W, L2W, L5
gnal Quality indicator	N	Y	TBA
rizontal accuracy requirement 95%	> 20 cm	20 cm	< 10 cm
rtical accuracy requirement 95%	> 40 cm	40 cm	< 20 cm
nvergence time requirement Global, no ionosphere Service Level 1)	> 300 s	300 s	TBA
l, ionosphere corrections (Service Level 2)	N/A	100 s	300 sec



Slides 5-6

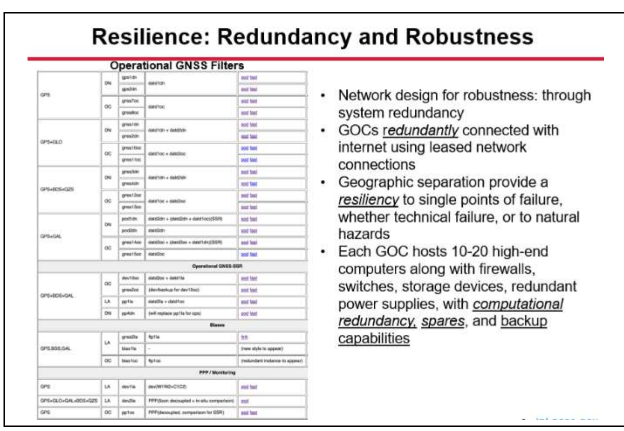
The network used by GDGPS consists of three parts: NASA's GGN (60 sites), a small number of GDGPS-owned sites, and publicly-available IGS streaming sites (100+ sites) (Slide 7). There are three independent GDGPS Operations Centers (GOCs), which provide resiliency to single points of failure whether outages or natural hazards (Slide 8).

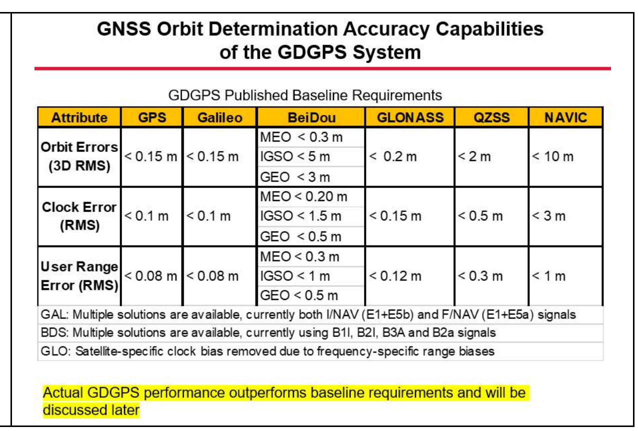




Slides 7-8

GDGPS uses combinations of about 50 GPS/GNSS filters (Slide 9). Each location has multiple filters, fed by redundant data servers. Each GOC has about 20 high-end computers. Slide 10 describes the baseline requirements. While GDGPS processes all GNSS constellations, for GPS HAS we've only focused on GPS and Galileo, with less than 10 cm Root Mean Square (RMS) User Range Error (URE).





Attribute	GPS	Galileo	BeiDou	GLONASS	QZSS	NAVIC
Orbit Errors (3D RMS)	< 0.15 m	< 0.15 m	MEO < 0.3 m IGSO < 5 m GEO < 3 m	< 0.2 m	< 2 m	< 10 m
Clock Error (RMS)	< 0.1 m	< 0.1 m	MEO < 0.20 m IGSO < 1.5 m GEO < 0.5 m	< 0.15 m	< 0.5 m	< 3 m
User Range Error (RMS)	< 0.08 m	< 0.08 m	MEO < 0.3 m IGSO < 1 m GEO < 0.5 m	< 0.12 m	< 0.3 m	< 1 m

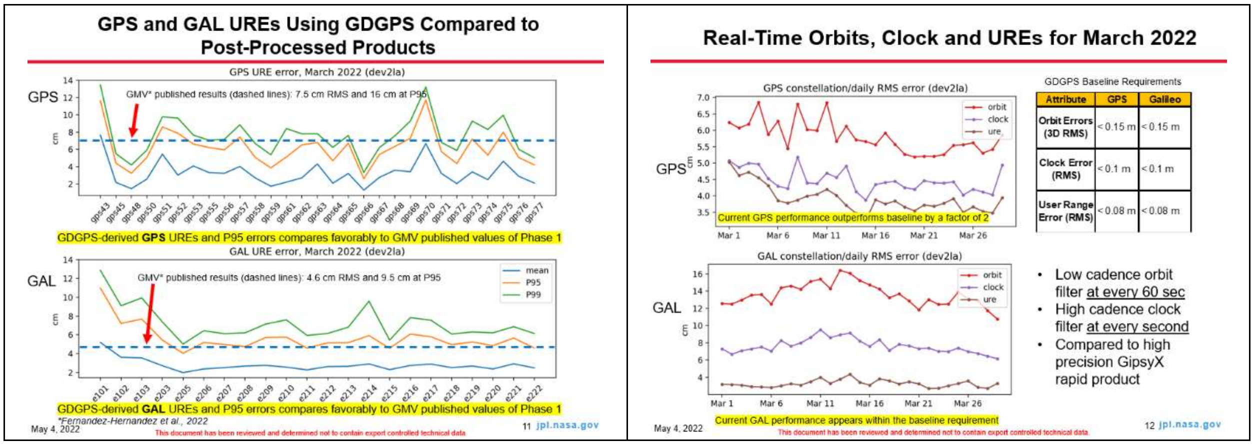
GAL: Multiple solutions are available, currently both I/NAV (E1+E5b) and F/NAV (E1+E5a) signals
BDS: Multiple solutions are available, currently using B1I, B2I, B3A and B2a signals
GLO: Satellite-specific clock bias removed due to frequency-specific range biases

Actual GDGPS performance outperforms baseline requirements and will be discussed later

Slides 9-10

Slide 11 compares GPS and Galileo UREs, when using GDGPS, measured in March 2022 and compares them to post-processed products. The blue line represents the mean RMS URE, which is 4 cm for GPS and 2.53 cm for Galileo. The orange and green lines depict the 95% and 99% errors. For context, the blue dashed line indicates the RMS URE for Galileo HAS, as published by GMV, which is 7.5 cm for GPS and 4.6 cm for Galileo. Therefore, at this time GDGPS-derived UREs compare favorably to the Galileo HAS results that have been published for their Phase 1.

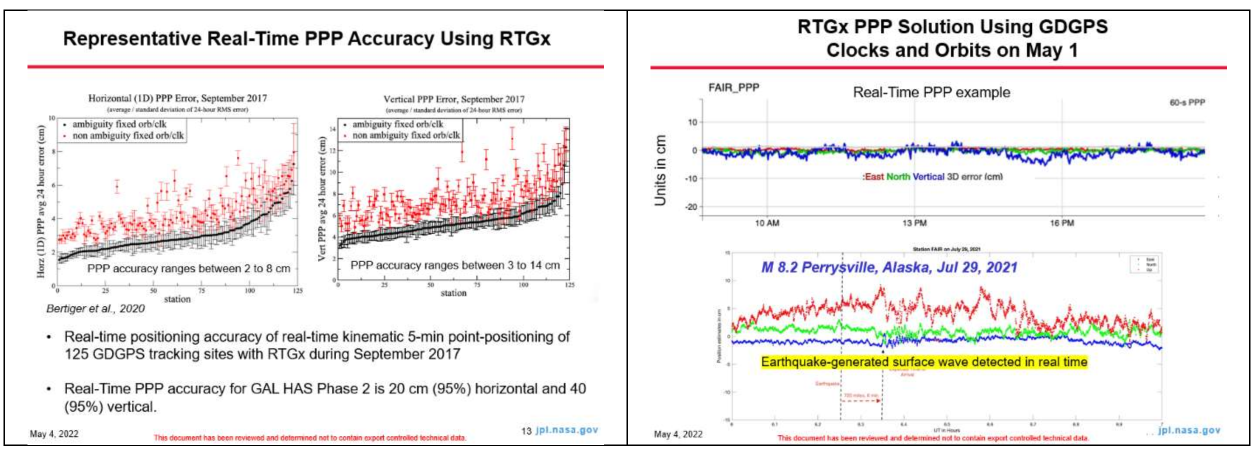
Slide 12 compares the real-time orbits, clock, and UREs vs baseline performance over the month of March 2022. GPS outperforms the baseline by a factor of 2, and the Galileo performance appears to be within the baseline requirement. GDGPS provides orbit states every 60 seconds and clock corrections every second. The truth is determined using the high precision GipsyX rapid product.



Slides 11-12

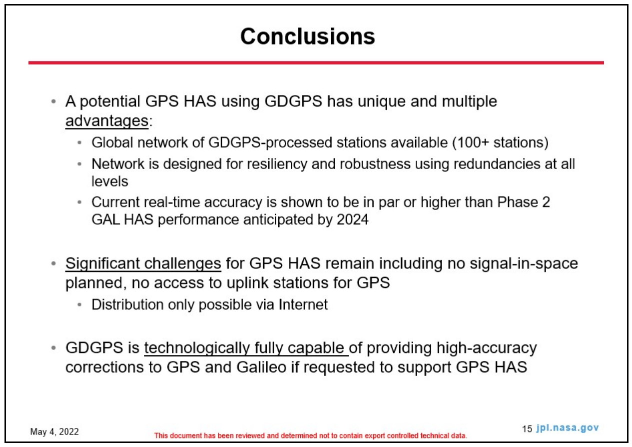
Slide 13 describes what the users would experience for real-time PPP. Data from 125 reference stations were processed using RTGx. The red points on the charts represent unresolved ambiguities, and the black dots show the non-ambiguity results. PPP accuracy is 2-8 cm horizontally, and 3-14 cm vertically for GDGPS, whereas the Phase 2 Galileo HAS requirement is 20 cm horizontal and 40 cm vertical.

Slide 14 depicts the real-time PPP solution at the IGS Fairbanks, Alaska station during the July 29, 2021, earthquake in Perrysville (700 miles away). You can see the oscillations very clearly. The noise level in this chart is about 1-2 cm.



Slides 13-14

In conclusion, a potential GPS HAS using GDGPS has unique advantages, including a resilient global reference network and real-time accuracy comparable to Galileo HAS (Slide 15). However, challenges include there being no signal-in-space planned nor access to uplink stations for GPS. In closing, GDGPS is technologically capable of providing high-accuracy corrections to GPS and Galileo via the internet.



Slide 15

Q&A / Discussion:

Renato Filjar: How do you anticipate the deployment of your service on smartphone-based GNSS receivers?

Attila Komjathy: JPL would not engage directly with the private sector, so we would need a government owner of this service. This government owner would provide these corrections to users through the internet. We are currently phasing out some customers and getting NASA funds to provide service in the interim.

Dorota A. Grejner-Brzezinska: What's the time for convergence of your PPP system?

Attila Komjathy: Larry (Romans), could you address that?

Larry Romans: It really depends on the client. It's about 5 min, but in some instances goes up to 10-20 minutes.

Matt Higgins: As I understand, Galileo is talking about having a higher network density in Europe. Would also having higher network density in the U.S. help with the ambiguity resolution?

Attila Komjathy: We don't really need that for ambiguity resolution, but we could do that to lower the convergence time. There is no physical limit on the number of stations we can process through GDGPS.

Frank van Diggelen: For consumer applications, PPP with 5 min convergence time would be a rarity. It might, for example, apply to a parked car. A typical use might be a car driving under the open sky for 30 seconds and then going under an overpass. Do you have some indication what the time accuracy the smartphone would provide following those 30 seconds?

Attila Komjathy: As opposed to Galileo HAS, that part of our system has not yet been established and needs further study. We'd like to work with the Galileo folks on this as it would help both systems.

ADM Thad Allen: One of the PNTAB subcommittees is working on this. The other subcommittee chairs should get in touch with them as we move along.

* * *.

Closing Thoughts & Key Highlights:
Deliberation Preparation for May 5
All members, led by ADM Thad Allen

Mr. Miller provided closing thoughts on Dr. Komjathy's presentation, thanking him for taking over the GDGPS program from Dr. Yoaz Bar-Sever. He noted potential applications for these technologies, particularly in NASA's collaboration with the European Space Agency (ESA). He thanked the board for their attention today and confirmed that there would be no presentations the next day, rather an opportunity for subcommittees to discuss and debrief.

ADM Allen thanked everyone for their participation. He acknowledged that many of the briefings had crossover into subcommittee work that would inform discussions the next day. He reminded the board that the meeting would begin the next day at 9:00am.

* * *

ADM Allen adjourned the Wednesday, May 4 session at 5:48pm.

* * *

Session of Thursday, May 5, 2022

Board Reconvenes
Call to Order
Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA*

ADM Allen opened the meeting and thanked the staff for their support. The PNTAB meeting operates in accordance with FACA guidelines. The PNTAB leadership aims to optimize the structure of the meeting in terms of content and the process by which speakers are identified. He noted several requests around raising standards for presentations and making the most out of the time available. He requested that in the future the board will be able to see briefs at least 96 hours in advance for review virtually.

Mr. Miller agreed with ADM Allen's commentary on room for improvement. He added that from an administrative perspective, he had done his best to ensure that each subcommittee had an opportunity to put forth experts. He emphasized the value of improving the process, keeping presentations streamlined and concise to keep everyone interested.

* * *

Updates from International Members & Representatives:

1) Brazil, Dr. Sonia M. Alves-Costa

Dr. Alves-Costa thanked the speakers for their interesting presentations about the future of GPS constellation improvement. She provided a few comments from her perspective at the institution for which she works, where she is responsible for statistics and geodesy. If it is possible to implement GDGPS corrections, it would be a big advancement in terms of positioning. She asked what is missing to start operations in GDGPS or real-time IGS so that everyone can use real-time corrections. As a high precision user of GNSS, she sees interoperability as important for the future of GPS. She noted that industry seems to be working hard on multi-constellation applications for high precision. Private companies seem to be investing a lot in that type of collaboration.

Q&A / Discussion:

ADM Allen thanked Dr. Alves-Costa for her comments and added that in the future the board might want to look at a thematic collection of topics to talk about at the meeting like High Accuracy Service or the Gold Standard. It may be useful to figure out a narrative to talk about these concepts.

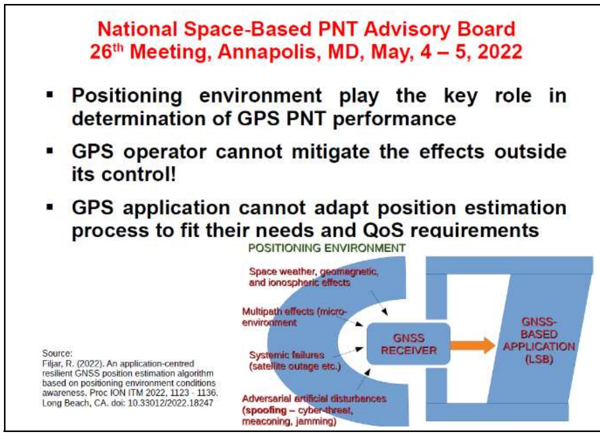
2) Croatia, Dr. Renato Filjar

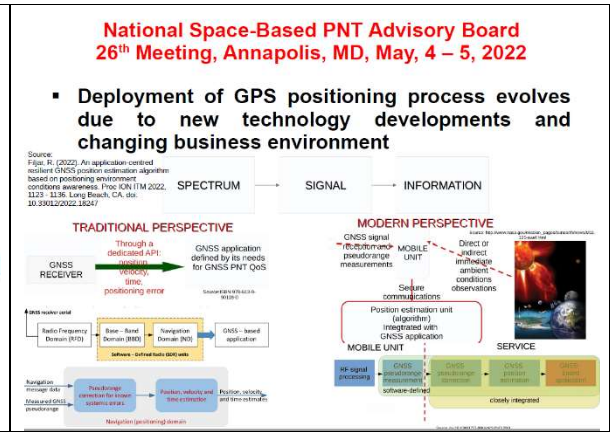
This briefing addresses the support and enhancement of the proposal for a GPS high accuracy and resilience service discussed yesterday (Slide 1). My group has identified some challenges to the use of GPS, including both natural sources of interference and overcoming adversarial interference (Slide 2). To mitigate these, I've highlighted the importance of identifying GPS and GNSS application needs and the specific parameters that are important to those applications. I've also stated the case of the European Union Agency for the Space Programme (EUSPA) establishment of a library/repository of individual requirements for each application using Galileo, and I propose a similar approach for GPS.

SPACE-BASED POSITIONING NAVIGATION & TIMING NATIONAL ADVISORY BOARD 26th Meeting May 4-5, 2022 Crowne Plaza Annapolis, Annapolis, MD Positioning environment conditions awareness, alignement to application needs and requirements, and interoperability benefit GPS adoption Renato FILJAR[1,2] [1]Faculty of Engineering, University of Rijeka, Rijeka, Croatia [2]Krapina University of Applied Sciences, Krapina, Croatia	National Space-Based PNT Advisory Board 26th Meeting, Annapolis, MD, May, 4 – 5, 2022 ▪ Matured to national infrastructure, GPS needs continued development to answer challenges: ▪ 1. Overcoming natural causes of vulnerabilities (space weather/ionospheric codnitions and distrubances, multipath etc.) ▪ 2. Overcoming growing artificial causes of vulnerabilities (spoofing, jamming, meaconing – cyber attacks on GPS) ▪ 3. Alignment with requirements, and facilitation and support of existing and emerging GPS-based applications ▪ 4. GNSS interoperability to facilitate the international GPS adoption

Slides 1-2

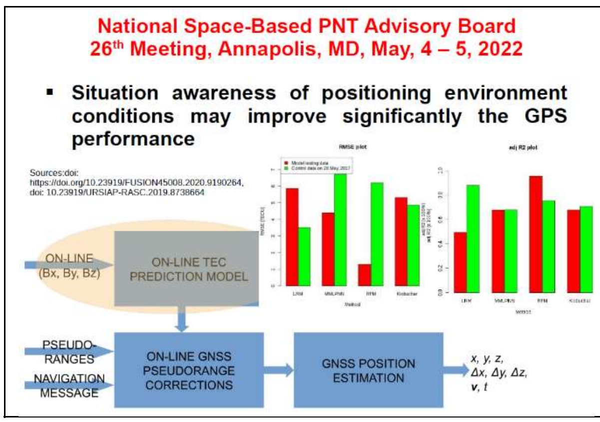
Those could be combined to focus on the mitigation of effects outside the control of GPS operators (Slide 3). User equipment needs to become more than a device tracking/processing GPS signals. There are techniques and technology advancements, especially in computers, communications, software-defined-radios, etc., we could incorporate into how we use GPS (Slide 4).

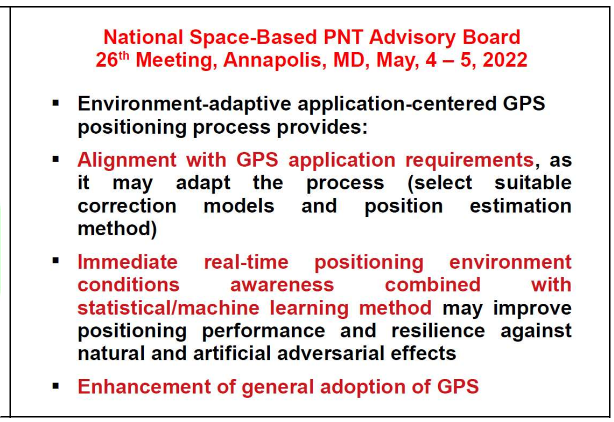




Slides 3-4

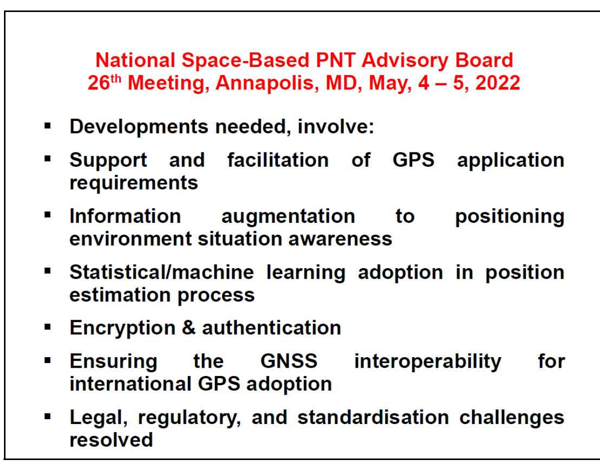
We have conducted research into overcoming ionospheric interference by allowing user equipment to monitor the immediate environment and do something to mitigate it (Slide 5). In this example we detect an upcoming geomagnetic storm and apply local correction models to address its effect. This can also be applied to other forms of interference, including intentional interference (Slide 6). This approach allows the alignment of user equipment with the specific GPS application requirement and apply the most suitable correction models and position estimations. It provides immediate real-time positioning awareness, combined with a statistical / machine-learning method to improve overall performance.





Slides 5-6

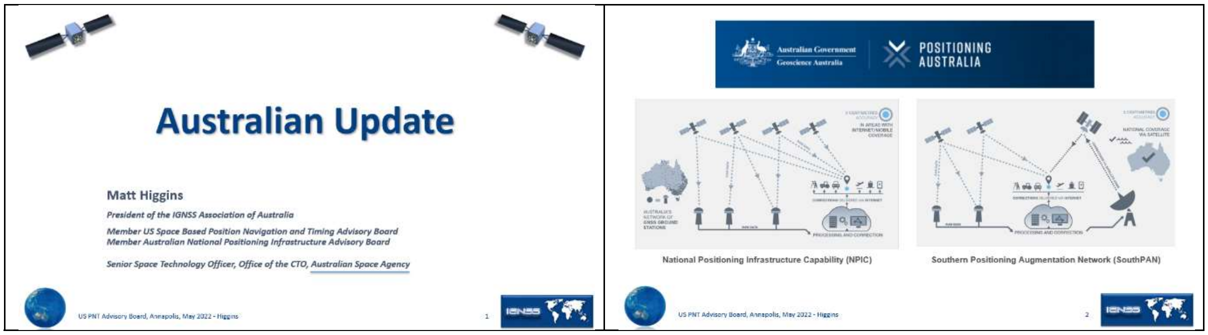
Implementation requires new developments such as methods and algorithms, machine learning, encryption and authentication, perhaps even the introduction of blockchain technology (Slide 7). This subject will be discussed at the Baska Spatial Information Fusion Meeting in early October 2022 (Slide 8). The objective of this meeting is to help develop the understanding of the spatial data, spatial analysis, and predictive modeling.



Slides 7-8

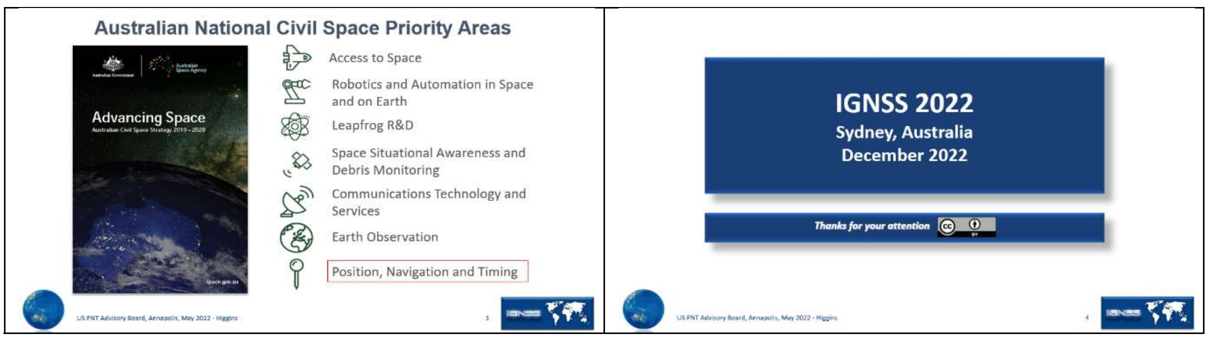
3) Australia, Mr. Matt Higgins

Mr. Higgins provided an update on activities in Australia National Positioning Infrastructure (Slide 1). Ongoing initiatives at Positioning Australia, his old employer, include the National Positioning Infrastructure Capability (NPIC) and the Southern Positioning Augmentation Network (SouthPAN), as depicted in Slide 2.



Slides 1-2

Mr. Higgins now works for the Australian Space Agency. The Australian Civil Space Strategy includes seven priority areas, each of which includes a technical roadmap identifying subtopics that Australia should concentrate on (Slide 3). The technical roadmaps on Communications, Earth Observation, and Robotics have been published. Work on the other topics is ongoing, including the PNT roadmap, which should have good progress to report on by the next meeting. Mr. Higgins also highlighted the IGNSS Conference in Sydney, Australia, scheduled for December 2022 (Slide 4)



Slides 3-4

Q&A / Discussion:

Mr. Higgins asked about the status of the list of recommended topics from the PNT EXCOM to the PNTAB.

ADM Allen noted that the PNTAB has responded to the NCO about which topics are feasible under the current resource constraints. These topics have been rolled up into three general areas: 1) views and advice on complimentary PNT; 2) GPS civil signal monitoring/ high accuracy service; 3) private sector views on how GPS compares to other systems.

Mr. Martin commented that the EXCOM has to produce an assessment on GPS civil capabilities every four years, so the work the PNTAB is doing on that will be useful.

ADM Allen referenced the table being developed by the IE Subcommittee, which can lay the groundwork for a report indicating the PNTAB's view on GPS as the gold standard.

4) United Kingdom, Prof. Terry Moore

Prof. Moore apologized for being unable to attend in person. He first commented on the geodesy crisis challenge presentation from the day before. He very much supports the discussion that took place after, noting the need for positive and firm action to make a change. The UK is also aware of some of the same problems. In response, a government research council established a research training center, which was sponsored to run a PhD program with a minimum of 5 cohorts of students over 9-10 years, funded for a minimum of 10-15 PhD students every year. This allows for nearly 100 new PhD graduates in geodesy and geospatial science. This is an example of positive action addressing the deficit that was recognized. Prof. Moore hopes that something similar could happen in the U.S. Although 100 PhD students in the UK is a small number, it is still a significant improvement.

Prof. Moore then discussed ongoing research in the UK on PNT dependency and resiliency. PNT is made up of a combination of experts and user groups with varying dependency on PNT. There are a broad range of use cases, but the depth of dependency and criticality on daily lives and services is often unknown. Over 2-3 years of work, a draft PNT strategy was submitted to the cabinet office in March 2021. A key point of this strategy which may be of interest to this group is the development of a national secure timing reference and a space-based PNT program. The space-based PNT program is being considered with a range of different constellation options, some that are innovative and others that are more traditional. Work is ongoing in this area as there is a particular need for space-based augmentation in the UK, particularly for maritime and autonomous vehicle services. Due to Brexit, the UK is no longer an active part of Galileo or the European Geostationary Navigation Overlay Service (EGNOS), so there is a need for alternative services in the UK.

Space-based PNT might be augmented by terrestrial PNT services, but the question comes to what mix of those is relevant and how the UK might build "plug and play" architecture to combine different positioning systems. Developments have begun in the user equipment application sector, and at the moment the cabinet office is pulling those together under one roof as a focal point for cross-government integration. All these avenues are working towards a system of systems. No single system is going to meet the needs for resilient PNT, so the UK will build a flexible architecture based on a system of systems approach. There are no formal announcements at the moment about how these things will move forward, but Prof. Moore expects something firmer will be shared in the next 12 months.

As part of the leadup, the UK PNT strategy group is working as subcommittees similar to those that the PNTAB has established. It was mentioned by Dr. Morton the previous day that Prof. Moore was involved with the Skills, Education, & Training group. He received full permission to share the findings of that study with the PNTAB ESI Subcommittee so they may get the maximum benefit from a study already completed. There are many generic suggestions and recommendations from this study that will help the PNTAB moving forward.

Due to the increased interest in PNT, the Royal Institute of Navigation (RIN) established a PNT advisory group to help government and industry provide an independent forum for discussion and information gathering and dissemination around PNT. Although the government is trying to move things forward, there is a need for communication with different user groups, so this forum is being set up at the RIN. On a general national level, there is the National Space Partnership, which is a collaboration between industry and government organizations to move the space agenda further forward in the UK. Part of their work at the moment is looking at preparations for the UK Space Agency (UKSA) ministerial meeting held at the end of 2022, which will release the funding scheme for ESA. UKSA is also an active partner in ESA.

Prof. Moore is also personally involved with the GNSS Science Advisory Committee, which is very active in terms of looking at scientific applications of GNSS. The committee examines cislunar and lunar program activities like ESA's Moonlight, new proposed scientific missions, science developments, and applications of GNSS like the Genesis program, which combines geodetic sensors, Very Long Baseline Interferometry (VLBI) transmitters, and Laser Retro-Reflectors (LRR) into a single platform.

Q&A / Discussion:

ADM Allen thanked Prof. Moore for his comment on connectivity and noted that WebEx will likely continue to be part of the PNTAB moving forward.

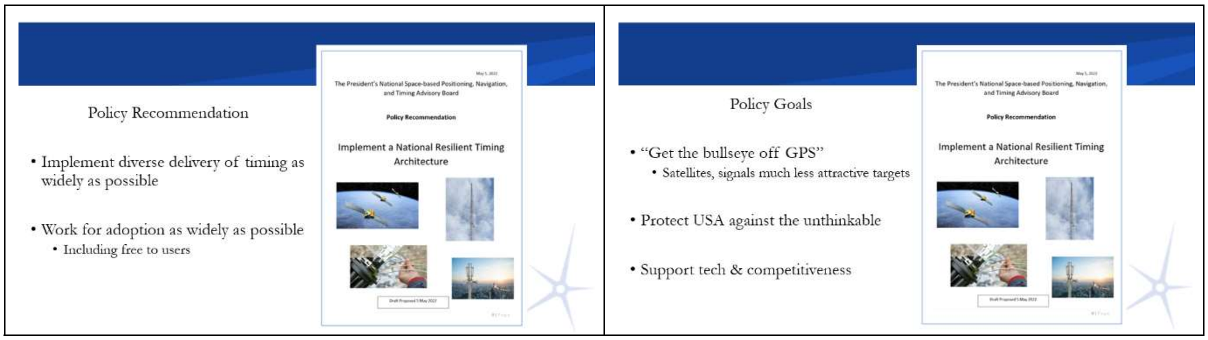
Mr. Higgins asked to learn more about the Genesis project.

Prof. Moore said he would be happy to share more about it after checking with ESA.

5) Resilient Navigation and Timing (RNT) Foundation, Mr. Dana Goward

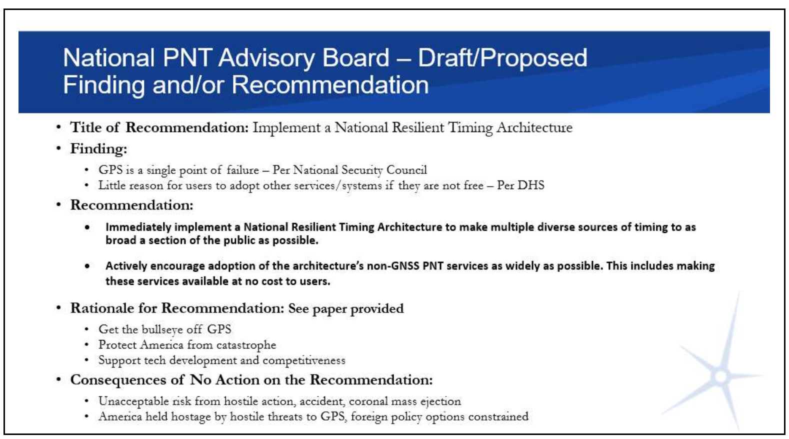
Mr. Goward shared that since the last PNTAB meeting, Russia invaded Ukraine in February 2022. GPS is still considered a single point of failure from the perspective of the White House. The U.S.'s biggest adversaries, Russia and China, are not as dependent on space or PNT because they have multiple terrestrial systems. In the midst of a great global conflict, GPS and PNT are a major factor for the U.S. to consider.

The PNTAB has recommended several times that the PNT architecture be filled in. This recommendation as scaled down in 2018 from "Complementary PNT" to "Complementary Timing". It aligns with what Congress passed in 2018 and what the National Security Telecommunications and Information Administration (NSTAC) recommended in 2021. Why focus on timing? Timing is everything. Mr. Goward asked why nothing has been accomplished. There are those within senior career positions in the administration that have developed a series of progressive justifications for why the government should but will not take action. Dr. Diamond and Mr. Goward developed a policy paper that discusses the appropriate and optimal ways to address this timing architecture (Slide 1). The goal is to get the bullseye off GPS, making it a less attractive target because it will no longer be a single point of failure (Slide 2).



Slides 1-2

A resilient national timing system would help prevent against vulnerabilities in the GPS system like solar weather, cyberattacks, or physical attacks on GPS satellites. The impact and risk to the nation is greater than we want to accept. A resilient national timing architecture would protect the U.S. against catastrophe and support technology and competitiveness. Mr. Goward suggested that the PNTAB develop a non-technical policy recommendation for the administration to move forward with a national timing architecture (Slide 3).



Slide 3

Q&A / Discussion:

Dr. Parkinson proposed further individual discussions within the PNTAB prior to any formal endorsement.

Mr. Goward noted that he is aware of some objections and concerns generally from specific individuals on the PNTAB. As mentioned the previous day after talking about the PTA Subcommittee's proposed efforts, he fully supports those initiatives and views them as complimentary. He recommends discussion on whether the U.S. should proceed in a national timing architecture, and if so, what that might look like. The DOT has done excellent work, and the board should have role to inform that going forward.

Dr. Diamond noted that this would be a phased strategic approach. All the technology that needs to be available to implement a resilient national timing architecture already exists, it is more a matter of who has the wherewithal and support to do it.

Hon. Shane said he was initially very attracted to the proposal, but was mindful of the concerns expressed by Dr. Betz and others.

Mr. Goward remarked that it seems the government isn't looking for a comprehensive approach, rather a segmented approach that may not be coordinated or integrated on a government wide basis.

Dr. Axelrad asked whether this recommendation is being proposed by Mr. Goward in his role as Representative of the RNT Foundation or whether it is being proposed by the CER Subcommittee.

Mr. Goward clarified that this effort is something that he and Dr. Diamond have worked on prior to the formation of the subcommittees, but that he would be happy to have it incorporated however the board would like.

ADM Allen said that now that the subcommittee framework is established, that is the proper way to move it forward. The PTA Subcommittee is probably the best place to move it forward. Dr. Betz is the Chair of that subcommittee, and it would be valuable to get his perspective on it before proceeding.

Gov. Geringer asked Mr. Goward if it would be possible to raise the context of the importance of timing architecture as a supplement to the other parts of PNT, positioning and navigation. He mentioned that a discussion of the Denver incident would be illustrative about the importance of all three elements of PNT. He asked if the PNTAB may bring forward the recommendation on PNT education as a policy approach emphasizing the need for more research and professional development. In the broader context, that issue can be highlighted as a top priority.

Mr. Goward thought that approach would work quite well. Another reason he had focused on timing was because that was the only topic they were able to get traction on within the administration. To do PNT with Timing as a first among equals may be more effective in the overall argument for PNT.

Dr. Parkinson reiterated that the recommendation should be brought up through the subcommittee structure in some way.

ADM Allen suggested that the various subcommittee may get together and discuss topics like this. Senior leaders need to be aware of the strategic context, both at a strategic, operational, and tactical level, with follow up items to be pursued at all levels.

Lt Gen Hamel added that an important aspect of this discussion is that timing is a central service associated with PNT that deserves an exquisite level of protection. He asked how there could be more coordination and collaboration across all areas of government. There are different ways to approach timing alternatives that are sector specific that connect to GNSS writ large, but may not solve the problem for all users.

ADM Allen remarked that the presentation by ORNL underscores that. The idea of developing transmitting stations that don't move, then taking the best of all the various systems and putting them together in an overall architecture seems effective.

Hon. Winfree noted that you can't know where you are until you know when you are. He suggested broadening the definition into the overall recommendation. The function of the advisory board is to provide top line advice without getting into the minutiae of developments as they move out over time. It is fine to make overall recommendations. The principal concern is to get the bullseye off GPS. From an analogous perspective in the climate change world, they aim to take the bullseye off petroleum. There is a multifactorial future where there's no one dependence on any particular energy source, and this analogy can be applied to timing and other architectures that get the bullseye off GPS.

ADM Allen agreed with Hon. Winfree. Because of this challenge, there is no one department or agency that owns it. The PNTAB may create a rebuttal presumption of what the architecture looks like, which can be part of the discussion moving forward.

Mr. Higgins pointed out that the "one ring that rules them all" analogy of solving all of PNT by creating resilient timing actually does not hold true. If you create a resilient timing system, all you have solved is resilient timing, not position or navigation.

Hon. Shane remarked that as noted yesterday in the SPG Subcommittee, they feel a big part of the problem is not knowing who the audience is for these recommendations. This is an institutional criticism. If the Board does not know to whom they are making their recommendations, they are not doing their job. He emphasized the importance of focusing on institutional dimensions, because without that, recommendations are a waste of time.

ADM Allen agreed that if recommendations are to be effective, they need to be taken directly to the deputies of DOT and DoD.

Hon. Shane noted that the system is failing the stalwarts who are working the issues today. It is not treated as a national priority at the level it deserves. If the PNTAB does not continue to hammer away at this fundamental issue, we will fail. In the opinion of the subcommittee, the subcommittee structure is important. It has changed the character of the advisory board and is important to rely on and use that structure effectively.

ADM Allen agreed and added that rural electrification and the enabling infrastructure of wi-fi both demonstrate the historical precedence of how government advocates for utilities.

Ms. Van Dyke shared some context for the board's consideration. In the 2008 timeframe, she was involved in the National PNT Architecture exercise with the DoD. Going back to look at those recommendations, many of them are still valid today. GPS is a cornerstone of that architecture. She recommended a presentation from the Office of Science and Technology Policy (OSTP) on their national research and development plan shared by OSTP in August 2021. There were 14 recommendations from that study on PNT resilience. Agencies were invited to self-select which recommendations they wanted to implement, and DOT selected 13 of the 14. She recommended OSTP as a presentation for a future board meeting.

ADM Allen asked for Mr. DeLaPena's perspective as to whether there is a single owner of PNT in government.

Mr. DeLaPena responded that DoD and the USSF have a responsibility to protect and defend assets and ensure operational capabilities. There is a classified budget for space resiliency that addresses many of these points. The responsibility of the DoD is what they bring to the day-to-day mission. - He appreciated the perspective on PTA particularly in providing more assurance of complimentary capabilities. As an observation for the board, he cautioned pursuing and studying overall space resiliency when there are many other parts to that architecture.

ADM Allen agreed, referring to his own experience in the military. He highlighted the complexity of this issue, particularly around the provision of signal utility and other decisions on where the government should spend their money as it relates to the issue. Where else but in this forum would this issue be discussed?

Mr. DeLaPena responded that there's a clear observation that GPS is the baseline gold standard for GNSS and that is what the DoD is investing in. There are other things for future consideration by this board, which DoD and DOT have already discussed.

Mr. Goward added that it comes down to money.

Lt Gen Hamel commented that the simplicity of PTA is a real asset. More than a strategy, it is a fundamental organizing principle for the board. He expressed his confusion around the discussion of "Protect," as it seems that 99% of the energy is around protecting spectrum. However, there are also the elements of cyber protection, jamming, and ASAT testing by adversaries. Protect is a sizable body of capabilities about delivering signals with high confidence, so the question is what the board is talking about protecting. He recommended that "Protect" should focus on assured delivery of fundamental enabling signals that support commercial, civil, and first responder applications.

Dr. Parkinson remarked that the question being raised seems to be around who the central authority in this area is. The only central authority he sees is the National Security Council, but he doesn't know how to influence them directly.

Mr. Shields noted that there is an article about a DoD program going on in LEO that lays out many of the issues the board is discussing. He recommended focusing on things that aren't yet being done, like the topic of education.

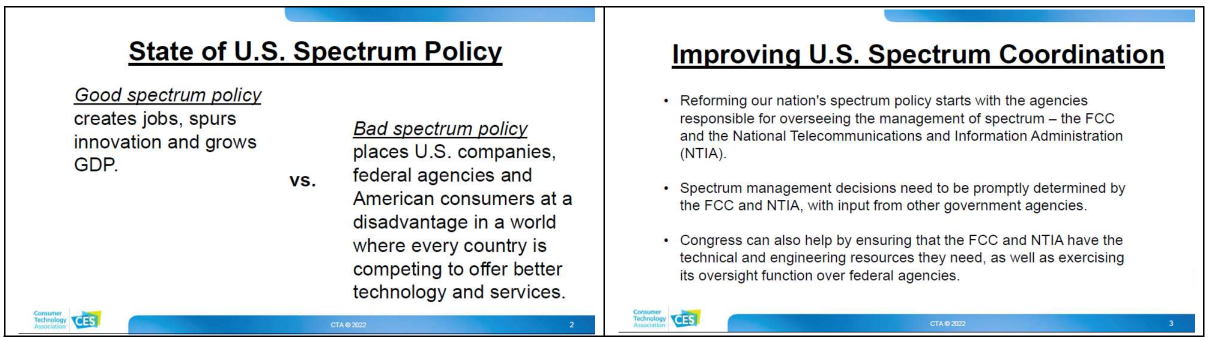
Mr. Goward returned to Dr. Parkinson's comment on the NSC, saying that the NSC is much larger than most understand. If there are issues with a routine concern, the NSC will collaborate with departments or agencies on how they can make the issues better, but there is not a whole lot of action otherwise. The OMB can step in and veto things, unless and until there is a champion at the political level who can advocate for change.

Mr. Martin clarified that SPD-7 dictates the advisory board advise the EXCOM, and the EXCOM will make recommendations to the President, National Security Council (NSC), and National Space Council (NSpC). There is a direct chain of communication, so if the advisory board says to make a recommendation to the President, there is a mechanism available to do that. It all comes together except those recommendations that are meant to go to Congress.

6) Consumer Technology Association (CTA), Mr. J. David Grossman

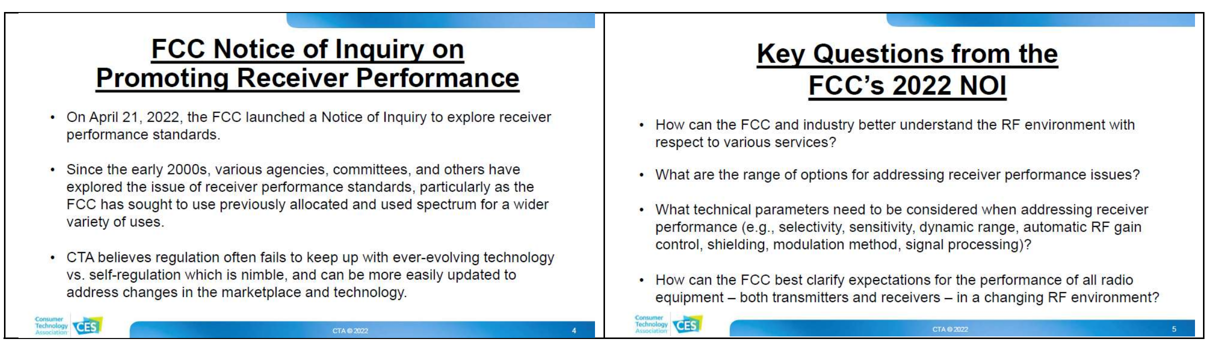
Mr. Grossman opened his presentation by highlighting two key topics, including the state of U.S. spectrum policy and activities at the FCC around receiver performance (Slide 1). Both topics are bigger than just the GPS community. For those in Congress and the FCC, discussions around L-band and GPS are driving conversations, so the PNTAB needs to have a seat at the table. For an overly simplistic description of good vs. bad spectrum policy, good policy works for all players in the market. CTA represents over 1500 member companies, including traditional wireless carriers, consumer electronics manufacturers, and Alternative PNT companies that like to see a diversity of options.

From the consumer standpoint, consumers believe that devices should work, the U.S. should have 5G services that are the envy of the world, GPS should be the gold standard, and these beliefs carry across to the automotive space. Mr. Grossman believes that this starts with reform in NTIA and FCC coordination (Slide 2). Starting in mid-February 2022, the National Telecommunications and Information Administration (NTIA) and FCC under new leadership announced an improved coordination process, which is a great start to outline a number of ways those two agencies can work together for the betterment of all stakeholders. The NTIA and FCC Memorandum of Understanding (MOU) is 20 years old at this point and in the process of being updated. CTA wants to ensure that NTIA has both the technical resources and expertise to address these issues. There is a common pattern here in spectrum issues where an expert agency who has jurisdiction over the issue hasn't been incorporated into the final position on spectrum. Mr. Grossman emphasized that he was not there to point blame. CTA represents wireless carriers who are investing billions to unlock the benefits of 5G for consumers, and with 900 million GPS receivers in the U.S., the goal is to ensure that every player in the game comes out as a winner.



Slides 1-2

On a related topic, Mr. Grossman reviewed the FCC Notice of Inquiry on Promoting Receiver Performance, which builds on many years of discussions in this space (Slide 3). FCC Commissioner Simonton recently talked about how receivers are a weak link in the conversation on spectrum efficiency. The NOI proposed a series of questions last month on how the FCC and industry better understand the RF environment and clarify expectations for radio equipment performance (Slide 4). No tentative conclusions have been reached at this point. One of the questions is around the FCC stepping in to regulate receivers. From the perspective of the consumer technology industry, getting the FCC in the business of regulating receivers would be very bad. There has been tremendous innovation in receivers across the board over the last two decades, including GPS receivers. The FCC doesn't have the expertise or resources to regulate high performance consumer devices. CTA hopes to provide additional perspective on evolved industry developments in this area and to work with the FCC about what industry can do to improve receiver performance while supporting the FCC's goal of improving spectrum efficiency.



Slides 3-4

The conversation in the FCC seems different now than it has on previous occasions, having been more of an academic exercise in the past. What has changed now is that the use of spectrum has increased dramatically in the last 20 years. Congress is taking notice of this, and one member is planning to introduce legislation to keep the federal government from buying technology with low receiver performance. Mr. Grossman recommended that there may be a way for the PNTAB to take a position on the receiver performance proceedings. If the board hopes to win in terms of GPS prevailing, they have to look at themselves as being a part of a broader ecosystem of spectrum users.

Q&A / Discussion:

Dr. Parkinson thanked Mr. Grossman for his presentation. He noted that the problem with the FCC is that it is misnamed for its emphasis on communications.

Hon. Shane agreed that it was a great presentation. He asked Mr. Grossman if the legislation he mentioned included any language to resolve the FCC's regulatory authority.

Mr. Grossman had not personally seen draft text of the legislation, but based on what he had heard, it would both address the question of FCC authority and provide some regulation around receivers purchased by the federal government rather than by the broader community at large. This may be viewed as low-hanging fruit in that federal users are often easiest to target first.

Hon. Shane responded that receiver efficiency is a critical part of the solution. With the FAA issue around radio altimeters, those were installed before the spectrum issue came into play. Any technology will have to operate over time. Hon. Shane reiterated his conviction that it requires an institutional solution, including a change in the burden of proof in FCC proceedings.

Prof. Filjar highlighted the importance of defining receivers. It should be noted that receivers themselves may function in a distributed process, and that interference can be found in all three domains of spectrum, signals, and data.

ADM Allen thanked Mr. Grossman for his presentation and recommended that he make a similar presentation at the beginning of every board meeting so that the board may understand where they are at in the regulatory environment.

* * *

Roundtable Discussion – Initial Findings & Recommendation Formulation as Appropriate
All members, led by Chairs

ADM Allen summarized the next steps for the board. He asked subcommittee chairs to review the presentations and provide a list of the top 2-3 topics they would like to address moving forward in preparation for other meetings. Future meetings should be more efficient and effective in terms of overall objectives for the board. ADM Allen proposed putting together a one-page description of PTA to indicate the position of the board, including the result of board deliberations.

Mr. Miller reviewed the PNTAB recommendation templates sent out in advance of the meeting. He specifically highlighted the General Services Administration (GSA) reporting requirements, which the PNTAB reports to the GSA every year on money spent, results generated, recommendations made, and government response to those recommendations. The PNTAB is now in a phase of taking a look at strategic issues. The GSA reports are due at the end of the fiscal year, so Mr. Miller proposed an interim fact-finding meeting be set up for early September to prepare for these reports. At this half-day meeting, subcommittee chairs may present proposed recommendations, which can then be adopted by the board, which will become input into the PNT EXCOM. ADM Allen will then submit those recommendations to the group, either verbally or with a memo. The co-chairs of the PNT EXCOM will then respond to that memo, allowing the PNTAB to see what they are interested in and willing to support. This is similar to the process undertaken by the NSpC UAG.

Hon. Shane asked for a point of clarification as the first product of the SPG Subcommittee was a recommendation on internal governance for the PNTAB. He asked whether that sort of recommendation should be filtered through this recommendation process.

ADM Allen responded that internal governance does not need to be managed through this process, but the internal governance recommendations would be taken into consideration and provided feedback moving forward.

Mr. DeLaPena commented that recommendations should be actionable in terms of planning and guidance. He noted that the PTA briefing from yesterday included good work, but that the recommendations are not at a level of maturity or specificity for the Deputy Secretaries to act upon.

ADM Allen agreed with the need for the SCs to work on actionable items.

Dr. Parkinson agreed and recommended a brief checklist of what qualifies recommendations as actionable before being formally submitted.

Mr. DeLaPena added that when DoD provides recommendations in the acquisition business, they provide guidance language and a recommended funding profile. Some intent must be made on the language of policy and funding.

ADM Allen noted that the PNTAB does not report to a four-star general, rather to the EXCOM, which operates differently than the DoD.

Mr. Miller thanked Mr. DeLaPena for his comments. He noted that on the topic of spectrum, there were many recommendations made, some more complex than others, but it is up to the government to respond. Unfortunately, there hasn't been a very consistent level of leadership at the EXCOM there to respond to these recommendations. The PNTAB has put out a number of recommendations, but it is unclear what is being acted upon.

ADM Allen noted that in his time as chair, the EXCOM has not been attended by the Deputy Secretaries.

Dr. Parkinson added that in the early days they had been involved.

Lt Gen Hamel noted that it is not the role of the PNTAB to be making budgetary decisions, but that is where it comes to a head.

Mr. Goward responded that we are in a different budgetary situation because of the Infrastructure Investment Act, and perhaps certain recommendations could be funded through that.

Mr. Higgins shared his concern about how actionable the recommendations needed to be. In the table prepared by the IE Subcommittee, the subcommittee can look at questions like whether GPS should have intersatellite links. There can be some investigation done by the subcommittee, but it does not have the resources to make a cost proposal to DoD. He asked for clarification on what level of detail is expected in the PNTAB recommendations.

ADM Allen shared that if it's possible to price it, prices should be indicated, but the point is more to create a framework by which to ask hard questions that drive the USG to a point of inquiry around what PNT architecture should be built around in the U.S. This is a way for us to frame the conversation.

Mr. Higgins commented that the PNTAB is an advisory board, not an action board.

Dr. Axelrad suggested that the HAS capability is relatively low hanging fruit as it is technically possible with the available system. It has a clear benefit and precedent with other international GNSS. In the PTA Subcommittee recommendations, the export control barrier is a similar topic to address that is both actionable and impactful. Using these issues, the PNTAB can establish a pathway for making more complex recommendations in the future.

Dr. Grejner-Brzezinka also suggested recommendations be made related to the work done in the ESI Subcommittee. From the perspective of the subcommittee, their job is to illuminate the problem. There have been reports made by other groups, and while some geospatial agencies understand the problem, they fail to bring it up to a decision maker level. One recommendation the subcommittee could make is that geospatial agencies come together, provide information on what is needed, then persuade government to create a budget for research and education. The only and fastest solution is government investment.

ADM Allen suggested that once that recommendation goes to the EXCOM, the PNTAB could also recommend they forward with their approval to OSTP.

Turning to logistics for the next meeting, Mr. Miller proposed the week prior to Thanksgiving, November 15-17, in Redondo Beach, CA. Mr. Shields has a conflict with this date.

ADM Allen proposed moving forward with those dates.

Mr. Miller noted that the SCs will continue meeting in fact-finding preparatory meetings prior to the next in-person meeting. He reminded the SCs that DFOs are required for all subcommittee meetings.

ADM Allen thanked the board for a productive meeting.

* * *

ADM Allen adjourned the 26th session of the PNT Advisory Board at 11:49 a.m.

* * *

Appendix A: National Space-Based PNT Advisory Board Membership as of the 26th Meeting

Special Government Employees

SGE's are experts from industry or academia who temporarily receive federal employee status during Advisory Board meetings.

- Thad Allen (Chairman), former Commandant, U.S. Coast Guard
- John Stenbit (Deputy Chairman), former Assistant Secretary of Defense
- Bradford Parkinson (1st Vice Chair), Stanford University
- James E. Geringer (2nd Vice Chair), Environmental Systems Research Institute (ESRI)
- Penina Axelrad, University of Colorado
- John Betz, MITRE
- Scott Burgett, Garmin International
- Joseph D. Burns, The Airo Group
- Patrick Diamond, Diamond Consulting
- Dorota A. Grejner-Brzezinska, The Ohio State University
- Michael Hamel, Former Commander, Space and Missile Systems Center
- Larry James, Jet Propulsion Laboratory
- Vahid Madani, GridTology
- Jade Morton, University of Colorado
- Timothy A. Murphy, The Boeing Company
- Tom Powell, Aerospace Corporation
- Eileen Reilly, Global Train Services
- T. Russell Shields, RoadDB
- Gary Thompson, North Carolina Geodetic Survey
- Frank van Diggelen, Google
- Todd Walter, Stanford University
- Gregory D. Winfree, Texas A&M Technology Institute

Representatives:

Representatives are individuals designated to speak on behalf of particular interest groups.

- Sonia Maria Alves Costa, Brazilian Institute of Geography and Statistics (Brazil)
- Renato Filjar, University of Rijeka (Croatia)
- Dana Goward, Resilient Navigation and Timing Foundation
- J. David Grossman, Consumer Technology Association
- Matt Higgins, International GNSS Society (Australia)
- Terry Moore, University of Nottingham (UK)
- Jeffrey N. Shane, International Air Transportation Association

Executive Director

The membership of the Advisory Board is administered by a designated federal officer appointed by the NASA Administrator:

- James J. Miller, Executive Director

Appendix B: Sign-In Sheets

Attendees: Wednesday, May 4, 2022

Advisory Board Members – In Person:
Scott Burgett, PNTAB
Pat Diamond, PNTAB
Renato Filjar, PNTAB
David Grossman, PNTAB
Mat Higgins, PNTAB
Larry James, PNTAB
Vahid Madani, PNTAB
Jade Morton, PNTAB
Tim Murphy, PNTAB
Eileen Reilly, PNTAB
Jeff Shane, PNTAB
Gary W. Thompson, PNTAB
Frank van Diggelen, PNTAB
Todd Walter, PNTAB
Greg Winfree, PNTAB

Advisory Board Members – Online:
Sonia Alves-Costa, PNTAB
Penny Axelrad, PNTAB
Jim Geringer, PNTAB
Terry Moore, PNTAB

Invited Speakers/ Guests:
David Castiel, Virtual GEO
Cordell DeLaPena, SSC
Robert Hampshire, DOT
Melissa Harrison, CTA
Everett Hinkley, USDA
Delores J. Knipp, Univ of Colorado
Attila Komjathy, NASA JPL
Cyrus Langroudi, Virtual GEO
Harold Martin, NCO
Martin Neill, AstraNav
Karen Van Dyke, DOT
Brannan Villee, DHS
Ernest Wong, DHS S&T

NASA Personnel:
Barbara Adde, NASA
RJ Balanga, NASA
Jimmy Durden, NASA
A.J. Oria, NASA
Lisa Valencia, NASA
Rebecca Zia, NASA

Other Attendees:
Jeff Auerbach, DOS
Jim Burton, NCO
Philip Castile, Virtual GEO
Ray Champion, Virtual GEO
David Choi, MITRE, USSF
Kevin Coggins, Booz Allen
Krzyonf Czaplewly, IAIN
Dale Dalesio, Continental Electronics
Wayne Deadwyler, Virtual GEO
DeeAnn Divis, Navigation Outlook
Jim Farrell, SERCO
Kevin Formby, Keysight Technologies
Jonathan Hardin, NIST
Jason Kim, NCO
Charlene King, SATELLES
Kerry Lawson, ADS
Stephen Mackey, Volpe
Stephen Malys, NGA
Larry Remans, JPL
John Rizzo, Sagrad
Joe Rolli, L3Harris
Mike Roskind, DHS/ NRMC
Emily Wallace, VIP Global Net
Hadi Wassaf, Volpe/ DOT

Attendees – Thursday, May 5, 2022

<u>Advisory Board Members</u>
Scott Burgett, PNTAB
Joe Burns, PNTAB
Dorota Brzezinska, PNTAB
Renato Filjar, PNTAB
Matt Higgins, PNTAB
Jade Morton, PNTAB
Tim Murphy, PNTAB

<u>NASA Personnel</u>
Chris Bonniksen, NASA
A.J. Oria, NASA
Angela Peura, NASA

<u>Other Attendees:</u>
Jim Burton, NCO
Kevin Coggins, Booz Allen
Rose Croshier, Center for Global Development
Krzysztof Czaplewly, IAIN
DeeAnn Divis, Navigation Outlook
Samari Ellison, VIP Global Net
Charlene King, SATELLES
Karen Van Dyke, DOT
Emily Wallace, VIP GlobalNet

Appendix C: Acronyms & Definitions

$	U.S. Dollar Currency
3D	Three Dimensions
5G	5^{th} Generation Mobile Communications Standard
911	Emergency telephone number in the U.S.
A/J	Anti-Jamming
A-GPS	Assisted GPS
ADM	Admiral
AFRL	Air Force Research Lab
ASAT	Anti-Satellite
BeiDou	China's GNSS
C/A	GPS Coarse Acquisition
C/N_0	Carrier to noise floor ratio
CAST	Center for Alternative Synchronization and Timing
CER	Communications & External Relations (PNTAB Subcommittee)
CISA	Cybersecurity & Infrastructure Security Agency
cm	Centimeter
CTA	Consumer Technology Association
DFO	Designated Federal Officer
DHS	Department of Homeland Security
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOS	Department of State
DOT	Department of Transportation
E911	Enhanced 911
EAR	Export Administration Regulations
EGNOS	European Geostationary Navigation Overlay Service
eLoran	Enhanced Loran
ESA	European Space Agency
ECAS	Emerging Capabilities, Applications, & Sectors (PNTAB Subcommittee)
ERCOT	Electric Reliability Council of Texas
ESI	Education & Science Innovation (PNTAB Subcommittee)
EUSPA	EU Agency for the Space Programme
EXCOM	National Space-Based PNT Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FAQ	Frequently Asked Questions
FCC	Federal Communications Commission
FFRDC	Federally Funded Research and Development Centers
FY	Fiscal Year (Oct.1 – Sep. 30)
Galileo	European GNSS
GDGPS	Global Differential GPS System
GEO	Geosynchronous Orbit or Geostationary Orbit
GGN	NASA's Global GNSS Network
GIM	Global Ionospheric Model

GLONASS	Russian GNSS
GNSS	Global Navigation Satellite System
GNSS-R	GNSS Reflectometry
GPS	Global Positioning System
GOC	GDGPS Operation Center
GSA	General Services Administration
HARS	High Accuracy & Resilience Service
HAS	High Accuracy Service
HPR	High Performance Receiver
Hz	Hertz
IE	International Engagement (PNTAB Subcommittee)
ICG	International Committee on GNSS
IGNSS	International Global Navigation Satellite Systems (IGNSS) Conference, Australia
IGS	International GNSS Service
ITAR	International Traffic in Arms Regulations
J/S	Jamming to Signal Ratio
JPL	Jet Propulsion Laboratory
JPO	GPS Joint Program Office
K-12	Kindergarten through 12th Grade
km	Kilometer
kW	Kilowatt
L1 C/A	1st GPS Civil Signal (C/A = coarse acquisition)
L1C	4th GPS Civil Signal (interoperable with Galileo)
L2C	2nd GPS Civil Signal (commercial)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
L-band	Operating frequency range of 1–2 GHz in the radio spectrum
LEO	Low Earth Orbit
LORAN	Long-Range Aid to Navigation
LRR	Laser Retro-Reflector
m	Meter
M-Code	GPS encrypted signal
MEO	Medium Earth Orbit
MEOSAR	Medium Earth Orbit Search and Rescue
MHz	Megahertz
ML	Machine Learning
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office for Space-Based PNT (hosted at Dept. of Commerce, Washington, D.C.)
NSB	National Science Board
NSC	National Security Council
NGA	National Geospatial-Intelligence Agency
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPIC	Australian National Positioning Infrastructure Capability
NSF	National Science Foundation
NSpC	National Space Council
NSTAC	National Security Telecommunications and Information Administration
NTIA	National Telecommunications and Information Administration

NTS-3	AFRL Navigation Technology Satellite 3
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
PEO	Program Executive Officer
PhD	Doctor of Philosophy
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-Based PNT Advisory Board
PPP	Precise Point Positioning
PTA	Protect, Toughen, and Augment (PNTAB Subcommittee)
Q&A	Questions and Answers
RIN	Royal Institute of Navigation (United Kingdom)
RFI	Radio Frequency Interference
RMS	Root Mean Squared
RNT	Resilient Navigation and Timing Foundation
RTK	Real-Time Kinematic
SCaN	Space Communications and Navigation Program (NASA)
SGE	Special Government Employee
SME	Subject Matter Expert
SouthPAN	Australian Southern Positioning Augmentation Network
SPD-7	Space Policy Directive 7 for U.S. Space-Based PNT
SPG	Strategy, Policy, & Governance (PNTAB Subcommittee)
SSC	USSF Space Systems Command
STEM	Science, Technology, Engineering, and Math
SV	Space Vehicle (formerly referred to as Satellite Vehicles)
TEC	Total Electron Count
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UN	United Nations
URE	User Range Error
U.S.	United States of America
UCAR	University Corporation for Atmospheric Research
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
USSF	U.S. Space Force
UTC	Coordinated Universal Time
VLBI	Very Long Baseline Interferometry
W	Watt
WAAS	Wide Area Augmentation System