Heliophysics Takes the Stage at ION GNSS+ 2019

This year’s plenary session at ION GNSS+ will offer more light than heat — figuratively, at least — as two prominent international solar physicists lead off the 2019 technical program September 17 in Miami.

Although our Sun lies 93 million miles away, its behavior can wreak large and even catastrophic effects on Earth-based and near-Earth positioning, navigation, and timing (PNT) systems. And it is, after all, a star — the closest by far and much more accessible for scientific research than those twinkling lights in the night sky.

Those qualities, in fact, are the subject of the plenary speakers: Dr. Pål Brekke,

ION GNSS+ 2019 continued on page 6

Parker Solar Probe has successfully completed its second close approach to the Sun, called perihelion, and is now entering the outbound phase of its second solar orbit. At 6:40 p.m. EDT on April 4, 2019, the spacecraft passed within 15 million miles of our star, tying its distance record as the closest spacecraft ever to the Sun; Parker Solar Probe was traveling at 213,200 miles per hour during this perihelion.

NASA/Naval Research Laboratory/Parker Solar Probe

A new survey of companies offering location-based products has revealed that nearly one-quarter of them have solutions covering both indoor and outdoor location services. The capability is being applied for tracking assets through supply chains as well as personal navigation using mobile devices.

ABI Research, a technology-oriented market-foresight consultancy, conducted a study of 205 companies for the firm’s latest Location Technologies Supply Chain and Ecosystem Tracker. Of the surveyed companies, 24 percent are currently offering combined solutions that enable both indoor and outdoor position. Henrique Rocha, a research analyst at ABI Research, suggests that a growing demand for seamless indoor and outdoor integration will force more companies at the lower layers of the technology supply chain to create more flexible technology offerings.

The study validates the increasing attention that indoor and integrated indoor/outdoor positioning techniques are receiving at ION technical meetings. At the ION GNSS+ 2019 conference in Miami this September, for instance, Dr. Dorota Grejner-Brzezinska will present a short course on “Sensor Integration for Personal Indoor/Outdoor continued on page 9

T...
I was delighted to chair the ION’s Pacific PNT conference this past April, and read many of the papers written for the conference. This year was the first year that ION offered the opportunity to have papers peer reviewed prior to publication, and I would like to thank the program committee, and all of the session chairs, who diligently performed peer reviews and provided feedback. Additionally, the program committee selected a best paper in each track.

I enjoyed being able to read the very best papers the conference had to offer (see pages 4-5 for more information). We started the conference this year with Monday afternoon’s plenary session on policy and status updates. I appreciated the opportunity to hear firsthand from the researchers and developers directly responsible for the latest technical advances in BeiDou/BDS (China), QZSS (Japan), and COSMIC/FORMOSAT (U.S.-Taiwan) in the relaxed and personal environment of the Pacific PNT meeting.

ION Collaborates with the Chinese Satellite Navigation Conference (CSNC)

This past May, I had the opportunity to attend the CSNC’s 10th anniversary meeting in Beijing and co-chair a CSNC-ION joint panel with Dr. Jun Shen (Beijing UniStrong Science and Technology Co.) and Dr. Mingquan Lu (Tsinghua University). The jointly organized session opened with a keynote on “The Future of PNT Services” delivered by Prof. Yuanxi Yang, deputy chief architect of BeiDou and an ION Fellow.

ION members who presented as part of the U.S. delegation to Beijing included Dr. Dorota Grejner-Brzezinska, The Ohio State University; Dr. Sherman Lo, Stanford University; Jeff Auerbach, U.S. State Department; and Lisa Beaty, The Institute of Navigation. Additional speakers from the Beijing Satellite Navigation Center, Wuhan University, and UniStrong rounded out our session. Additionally, Dr. Grejner-Brzezinska and Dr. Lo delivered keynote addresses in other conference sessions.

A highlight of the conference was the opportunity for our U.S. delegation to tour the exhibit hall with Prof. Mingquan Lu. We visited the Chinese sister booths of many of the companies I see at ION GNSS+, but we also viewed some remarkable and exciting new technologies.

A highlight of my trip to China this year was the opportunity that Lisa Beaty and I had to tour China’s National Time Service Center (NTSC) Museum (part of the Chinese Academy of Sciences) in Xi’an. Dr. Xiaochun Lu, director of NTSC, was a wonderful host, and we found the historical Chinese navigational devices to be both exquisite in their artisanship and remarkable in their technology.

Award Nomination Reminder

I encourage you to acknowledge the contributions of your professional associates and nominate one or more of them for an ION award that recognizes individuals making significant contributions or demonstrating outstanding performance relating to the art and science of positioning, navigation, and timing. Nominations for ION’s Fellows and Annual Awards can be made at <www.ion.org/awards> until October 15.

Dr. Y. Jade Morton, ION president, and Dr. Xiaochun Lu, director of the Chinese National Time Service Center, Chinese Academy of Sciences, in the Timing Center’s Museum, located in Xi’an, China

Dr. Y. Jade Morton, ION president, and Dr. Xiaochun Lu, director of the Chinese National Time Service Center, Chinese Academy of Sciences, in the Timing Center’s Museum, located in Xi’an, China
The Purpose of the ION®

Founded in 1945, The Institute of Navigation is the world's premier non-profit professional society advancing the art and science of positioning, navigation and timing.

--- 2019 Executive Committee ---

**President:**  
Dr. Y. Jade Morton  
**Executive Vice President:**  
Dr. Frank van Diggelen  
**Treasurer:**  
Dr. Frank van Graas

**Eastern Region Vice President:**  
Mr. Elliott Kaplan  
**Western Region Vice President:**  
Mr. Steve Rounds

**Satellite Division Chair:**  
Dr. Chris Hegarty  
**Military Division Chair:**  
Mr. John Langer  
**Immediate Past President:**  
Dr. John Raquet

--- How to Reach the ION® ---

Telephone: 703-366-2723  
Facsimile: 703-366-2724  
Web site: ion.org  
E-mail: membership@ion.org

--- The ION® National Office Staff ---

**Executive Director:**  
Lisa Beaty  
**Director of Information Technology:**  
Rick Buongiovanni  
**Director of Membership & Marketing:**  
Kenneth P. Esthus  
**Program/Author Liaison/Executive Assistant:**  
Miriam Lewis  
**Meeting Planner:**  
Megan Andrews  
**Graphic Designer:**  
Gwen Rhoads  
**Newsletter Editor:**  
Glen Gibbons

Opinions expressed in ION Newsletter articles and columns do not necessarily reflect an official policy of the ION or the views of any other individual ION member(s).

--- NATIONAL TIME SERVICE CENTER ---

**Historical Chinese Clocks**

**Li Lan Steelyard Clepsydra**  
Invented around 450 A.D. by Li Lan, a Taoist of the Northern Wei Dynasty, the steelyard clepsydra — a water clock with a metal scale-stick — used the Chinese steelyard to scale the water flowing into the kettle to timing. The difference between the steelyard clepsydra and the traditional water clock is that the latter used the principle of equal leakage volume per unit of time to measure time, while the former used equal leakage weight per unit of time.

**Dragon Boat Incense Timing**  
The incense clock emerged in the Northern Song Dynasty (960-1127) and used burning incense to keep time. Lighted incense sticks were placed on the dragon boat container while several threads with metal beads on both ends were placed across the incense sticks. At regular intervals, a thread on the incense would burn out, causing the metal bead to fall into a copper tray below, making a sound and reporting the time.

**Astronomical Clock Tower.**  
The text below the tower indicates that this is a replica at 1/5 of the original device scale. Su Song and Han Gonglian began designing the astronomical clock tower in the first year of the Yuanyou period (1086 A.D.) in the Song Dynasty. The astronomical clock is powered by water. The top floor is equipped with an armillary sphere, and the rooftop has a shutter that can be opened and closed. The middle portion is the celestial sphere. The lower floor is the time broadcasting system.

The three parts are connected by a set of transmission devices and a set of wheels. The flushing water from the water clock drives the pivot wheel that, in turn, drives the armillary sphere, the celestial sphere, and the time broadcasting device, which rotate in unison. The isochronous rotation of the pivot wheel in a certain direction can be adjusted by controlling the uniform flow of water so that the rotation of the armillary sphere and the celestial sphere can keep pace with movement of the celestial bodies.

More than 160 small wooden people, and four musical instruments, are used in the time broadcasting device. It not only shows the hour and the minute but also reports dusk, dawn, and midnight.
In a four-day run, April 8–11, The ION hosted its biennial Pacific PNT conference in Waikiki Beach, Honolulu, Hawaii. The 2019 Pacific PNT symposium focused on PNT developments and issues facing the Pacific Rim nations, from which 40 percent of the 180 participants hailed.

The three-and-a-half-day technical program was full of in-depth and dynamic presentations. Front and center were the satellite missions currently being undertaken to provide improved navigation or a better understanding of navigation issues. From China, we had an update on Beidou/BDS performance, as well as a new testbed for a navigation small satellite launched by Wuhan University. Several presentations discussed the new long-term findings on the ionosphere made by the COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate)/FORMOSAT satellite missions. Other ionosphere talks focused on the effect of natural hazards such as earthquakes on the ionosphere.

Presentations on Japan’s Quasi Zenith Satellite System (QZSS) brought the attendees up to date on system improvements and services such as the new high-precision Centimeter Level Augmentation Service (CLAS). Speaking of high precision, many papers focused on precise point positioning (PPP) developments and methods for improving PPP, such as techniques to instantaneously resolve integer ambiguity using multi-frequency combinations.

Urban navigation is an important issue in East Asia with its many high-density cities. Several presenters discussed alternative navigation and aided-GNSS approaches operating in such environments.

Aviation navigation was another core topic with two sessions focusing on Advanced Receiver Autonomous Integrity Monitoring (ARAIM), and Ground-Based Augmentation Systems (GBAS) and Satellite-Based Augmentation Systems (SBAS). Several presentations examined the ionosphere gradient of lower latitudes and the effect of these phenomena on GBAS.

Navigation security is another growing concern for the PNT community, and we had interesting presentations on interfe-
Hawaiian surfer slang refers to “sharks” as “men in grey suits.” Does this make ION past presidents in their ION apparel “PNT sharks”?

Overall, the conference was well rounded with papers covering the span of GNSS and focusing on the important research that is taking place today as well as global cooperative development on positioning, navigation, and timing technology.

The ION has already planned to return to Waikiki on April 19-22, 2021, during which Dr. Sherman Lo of Stanford University will serve as the general chair.

Pacific PNT Best Paper Award Winners:

**TRACK A**, from the Emerging PNT Consumer Applications session: *Lifelog using Mobility Context Information in Urban City Area*: Yanlei Gu, Dailin Li, Yoshihiko Kamiya, Shunsuke Kamijo, The University of Tokyo, Japan

**TRACK B**, from the Aviation Applications of GNSS session: *Design and Analysis of a Public Key Infrastructure for SBAS Data Authentication*: Andrew Neish, Todd Walter, J. David Powell, Stanford University, USA

**TRACK C**, from the High Precision GNSS Correction and Monitoring Networks session: *Instantaneous Decimeter-level Positioning using Triple-frequency GPS/BeiDou/Galileo/QZSS Data Over Wide Areas*: Jianghui Geng, Jiang Guo, Hua Chang, Ran Zeng, GNSS Research Center, Wuhan University, China

**PACIFIC PNT 2019 RECAP**

Thank You, Pacific PNT Program Organizers!

Dr. Mikel Miller, Dr. Sherman Lo, Dr. Y. Jade Morton, Dr. Frank van Graas and Dr. John Raquet

Dr. Eugene Parker (seated in the foreground), a pioneer in heliophysics and professor emeritus for the Department of Astronomy and Astrophysics at the University of Chicago, watches the launch of NASA's Parker Solar Probe. This is the first agency mission named for a living person. Standing behind Parker is Nicky Fox, Parker Solar Probe project scientist at Johns Hopkins Applied Physics Laboratory.

A solar physicist and senior advisor at the Norwegian Space Agency, and Dr. Nicola Fox, the Heliophysics Division director in the Science Mission Directorate at NASA Headquarters in Washington, D.C.

Dr. Brekke, who worked for six years at NASA Goddard Space Flight Center as the deputy project scientist for the Solar and Heliospheric Observatory (SOHO) project, will pose the scenario, “A Day without Satellites.”

The important role that satellite-based services play are essentially invisible to most users, hidden inside the operations and location-dependent applications of mobile devices and nations’ critical infrastructures.

But what if a superstorm from the Sun disrupts all satellites? What would be the impact on our technology-based society? Space weather can change the orbits of satellites, shorten their lifetimes, or interfere with onboard electronics. Dr. Brekke’s presentation will explore how it would be to wake up one morning to a world without Satellites.

The Parker Solar Probe has traveled through the Sun’s atmosphere, closer to the solar surface than any spacecraft before it. The spacecraft is enduring brutal heat and radiation conditions — and will ultimately provide humanity with the closest-ever observations of a star. The Solar Probe has successfully completed its second close approach — within 15 million miles of the solar surface — on April 4, 2019, and is now entering the outbound phase of its second solar orbit.

Eventually, the spacecraft will fly as close as 3.8 million miles to our star’s surface, well within the orbit of Mercury and more than seven times closer than any spacecraft has come before. There it will, among other mission tasks, observe the behavior of the solar wind, a flow of ionized gases from the Sun that streams past Earth at speeds of more than 500 kilometers per second (a million miles per hour).

It is the solar wind that creates many of the effects that Dr. Brekke will describe in his speech. Disturbances in the solar wind shake Earth’s magnetic field and pump energy into the radiation belts, part of a set of changes in near-Earth space creating space weather.

**Meanwhile, Back on Earth**

The Tuesday evening ION GNSS+ 2019 plenary session will be followed by three days of technical presentations at Hyatt Regency Miami hotel, with 15 commercial and policy sessions, 17 research sessions, and 6 panel discussions.

This year’s Cognizant Autonomous Systems for Safety Critical Applications (CASSCA) Conference will be held September 16–17, 2019, on the two days preceding the ION GNSS+ 2019 conference.

The CASSCA 2019 Conference will explore the current state of the art in autonomous vehicles development with a focus on trust, policy, and ethics issues associated with the development and deployment of these autonomous. The ION rescheduled the event from January due to a partial U.S. government shutdown.

CASSCA 2019 will explore how autonomous systems are transforming society and whether society will allow them to do so. Conference discussions will investigate the unique challenges and difficulties associated with addressing the...
The Cognizant Autonomous Systems for Safety Critical Applications Conference will discuss the opportunities and challenges (technical, commercial, ethical, and legal) associated with developing fully autonomous systems that are cognizant and trustworthy for safety critical applications.

Session Topics Include:
- Trust in Autonomous Vehicles
- Ethics and Policy
- Aerial Vehicle Autonomy
- Human-Machine Symbiosis
- Ground Vehicle Autonomy

Technical Program Organizers:
- General Chair: Prof. Zak Kassas, University of California, Irvine
- Program Chair: Dr. Robert Leishman, Air Force Institute of Technology

Access to CASSCA sessions is included for ION GNSS+ attendees.
needs of safety-critical applications in the deployment of autonomous vehicles.

Prof. Zak Kassas, University of California, Irvine, will return as the general chair of CASSCA. Dr. Robert Leishman, Air Force Institute of Technology, is serving as the Technical Program Chair.

Also on Monday, attendees will have their choice of six 90-minute, pre-conference short courses presented by ION Master Instructors and included with all paid conference registrations. Six half-day tutorials will be available on Tuesday, with additional registration fees required.

As has become a long-standing tradition, on Monday and Tuesday the Civil GPS Service Interface Committee (CGSIC) will meet in the Hyatt Regency Miami. Diana Furchtgott-Roth, deputy assistant secretary, Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation, will present the keynote address at the CGSIC plenary session.

A commercial exhibition will be open in the exhibit hall on Wednesday and Thursday.

ION GNSS+ 2019 is formally the 32nd International Technical Meeting of the Satellite Division of The Institute of Navigation. Program organizers include: general chair, Dr. Chris Hegarty, The MITRE Corporation; program co-chairs, Tim Murphy, Boeing Commercial Airplanes, and Dr. Heidi Kuusniemi, University of Vaasa and Finnish Geospatial Research Institute; tutorials chair, Dr. John Raquet, IS4S; and plenary chair, Patricia Doherty, Boston College.
Indoor/Outdoor continued from page 1

Navigation” that touches on this subject. On Friday, September 20, the conference offers a technical session, “Development of Indoor Positioning.” Other sessions including a two-part “Aided GNSS and Sensor Fusion in Challenging Environments” and “Technologies for GNSS-Denied Environments” include presentations on related challenges of achieving ubiquitous positioning and navigation.

Computing the position of a person or asset outdoors is usually done by means of GNSS technology, although in some cases auxiliary technologies such as cellular networks. To a lesser extent, low-power wide area network (LPWAN) approaches that provide less-accurate tracking are also used in products and services.

However, GNSS signals do not penetrate buildings and other structures well and suffer from interference issues. For such environments, infrastructure based on short-range wireless anchor points provide a source for tracking mobile devices in the vicinity. These anchor points use various location technologies, including Bluetooth low energy (BLE), ultra-wideband (UWB), RFID, or Wi-Fi.

**Overcoming the Indoor/Outdoor Divide**

“As things stand, there is a hard line between the indoor and the outdoor technologies and services used for location use cases,” says Rocha. “Offering seamless tracking between these two environments raises the possibility of having unprecedented visibility into the supply chain, as any item can be tracked end-to-end between factories, warehouses, and retailers up to the point-of-sale.”

Some of the benefits from acquiring visibility into the supply chain include more efficient planning and less asset shrinkage, which quickly revert to business owners in the form of return on investment.

While several companies offer both indoor and outdoor location solutions separately, only a few have managed to offer a single end-to-end solution providing seamless indoor/outdoor tracking capabilities. Some 63 percent of location companies featured in ABI Research’s survey are involved with indoor solutions only. Positioning people and assets indoors remains more demanding than outdoor tracking in the industrial and logistics spaces as it often requires high accuracy and real-time tracking capabilities of diverse assets, as well as on-site dedicated infrastructure.

With a consolidating location ecosystem, however, ABI expects that more companies will turn to offering full supply chain visibility solutions, which require seamless indoor/outdoor tracking. The survey identified companies that have developed sensors that can be attached to individual assets, pallets, or vehicles. One of the most common combinations for seamless asset tracking involves BLE communication for indoor tracking and GNSS for outdoor tracking, with an LPWAN-like long term evolution for machines (LTE-M) approach employed to relay location data. ☛
This column features one of ION’s Technical Representatives each quarter to highlight the depth and breadth of their work, research, and interests. During their two-year terms the ION’s Technical Representatives guide and advise The Institute of Navigation and the positioning, navigation, and timing (PNT) community. — Interview and write-up by Dr. Kyle Wesson

Dr. André Hauschild is a member of the scientific staff of the GPS Technology and Navigation Group at the DLR (German Space Agency). In talking with André, it seems clear that he is at one with his work and his field. While he hopes to see himself taking on more teaching and instructional roles in the future, he enjoys the practical challenges he is undertaking at DLR now.

As for his time away from DLR duties, keeping work/play activities in balance André dances the Lindy Hop every week and plays trumpet in his church’s brass band. He also said that he wouldn’t want to sacrifice a hobby or replace his current professional responsibilities with anything that he does for fun outside the office.

André wants to give a shout out to the ION professional staff, whom he notes are doing a great job organizing all of our conferences. He even admitted that he stopped going to other conferences because ION meetings fulfill everything he needs. To that end, you will find André at the next ION GNSS+ and International Technical Meeting.

1. How did you first get involved with ION?
My first ION conference was the GNSS meeting in September 2007, where I presented the results of my Masters thesis. From then on, I have returned almost every year. I have since been an ION GNSS+ session chair and track chair, and I was the Program Chair for ION’s International Technical Meeting in 2017.

2. What is your favorite aspect of being a member of ION?
In my opinion, ION provides a perfect platform for networking with experts from academia and industry. The membership of many other organizations is typically much more limited to a certain specialized area of expertise or role. The ION community on the other hand includes people from all different areas of GNSS and many related fields. Every event is a great opportunity to get in touch with people one would not have met otherwise and receive an overview of the latest developments in all the fields.

3. What type of GNSS work do you do currently or have you done in the past?
I am a researcher in the GNSS Technology and Navigation Group at DLR’s German Space Operations Center at Oberpfaffenhofen near Munich, where we mostly focus on space-borne applications of GNSS. I have been involved in projects for space-borne GNSS applications, like precise orbit and attitude determination of satellites, radio occultation, and launcher trajectory determination.

Since the beginning of my career at DLR, I have had a strong focus on generating real-time GNSS corrections for precise positioning for both terrestrial and space users. In supporting these efforts, I developed DLR’s Real-Time Clock Estimation (RETICLE) engine.

4. What do you consider some of the most important current research, education, policy, or technical topics in GNSS for the next year?
I believe we will continue to see an increased dependency on Internet connectivity and location-based services. This trend is already apparent across industries where more and more machinery is autonomously controlled as well as in our daily lives.
Most of us would have to change our lives significantly if we had to get along without our smartphone, the Internet, or a global navigation system guiding us everywhere — even if it were only for a day or two. Not so long ago, we got along fine without any of these tools, and only recent history should make us appreciate how rapidly these technological developments have taken place. Outages of these services certainly make us aware of how dependent on them we have become.

I fear the introduction over the next years (and maybe even decades) of even more of these Internet-based and location-dependent services in our personal lives. I hope to see an increased awareness of our vulnerability and dependency coupled with more research and development focused on making these services robust against any potential service outages.

5. What areas of ION have you been involved in, and what areas do you hope to see grow in the future?

I hope to see that ION maintains (or even grows) its potential as a networking platform, especially for young professionals. This is how I became involved in ION, and I believe it is vitally important for young engineers and researchers early in their careers to meet other professionals in the field. I have met most of the people I work with professionally today through ION.

6. If you were not in your current field, what would you want to do for a living?

I have honestly never really thought about this. I believe I found a profession that suits me best. In addition, I believe more in gradual change. If there really was a serious alternative to my current activities, I believe I would already be doing it. Eventually, I would like to be more involved in teaching and educating, if that opportunity arises.
During the 20th century, the automotive industry was the engine that propelled the American economy, but it wasn’t until the 21st century that car navigation really caught on — until then people drove cars, they didn’t navigate them.

It certainly wasn’t that drivers of early land vehicles did not wish to know where they were and how to get to where they are going, but the enabling technologies they needed to do that were still many decades in the future. For the most part, 20th century drivers were stuck with maps, road signs, and the occasional well-informed gas station attendant.

Although GPS has become a shorthand term for modern driving aids, satellite navigation is not the only technology that has enabled true navigation of land vehicles. Key advances in microelectronics, memory storage, wireless communications, geographical information systems, and micromechanical inertial sensors have all been crucial to the proliferation of car navigation systems.

However, prior to the ubiquity and precision of multiple global navigation satellite systems, most approaches had to rely primarily on dead-reckoning techniques, which largely consisted of wheel speed sensors for along track movement augmented by magnetic compasses and/or differential odometers.

Bounding the inevitable accumulation of position errors using dead reckoning techniques required either radionavigation position-fixing or continuous “snapping,” i.e., correlating dead reckoning calculations with maps featuring accurately plotted roads.

Neither of the latter resources were available for many decades after the advent of automobiles.

Arguably the first land vehicle navigation system appeared in China. During the Song dynasty (960-1279 A.D.), Chinese inventors combined the South-pointing chariot with the mechanical odometer. This crude navigation device had to be initialized both in position and by aligning it to South, in addition to imposing constraints on maneuvering.

However, the limitations of 10th century manufacturing and the geometrical approximations underlying the technique generated large errors and produced a very coarse form of long-distance overland navigation.

See the USA
Fast-forward six centuries: Although the automobile was to have its greatest social and economic impact in the United States, it was initially achieved in Germany and France toward the end of the 19th century by such men as Gottlieb Daimler, Karl Benz, Nicolaus Otto, and Emile Levasseur. Bicycle mechanics Charles and J. Frank Duryea of Springfield, Massachusetts, designed the first successful American gasoline automobile in 1893. They won the first American car race in 1895 and went on to make the first sale of an American-made gasoline car the following year.

Thirty American manufacturers produced 2,500 motor vehicles in 1899, and some 485 companies entered the business over the next decade. In 1908 Henry Ford introduced the Model T, and William Durant founded General Motors. The new companies operated in an unprecedented seller’s market for an expensive consumer goods item. With its vast land area and a hinterland of far-flung and isolated settlements, the United States had a far greater need for automotive transportation than the nations of Europe and, thus, offered a large and growing market for car manufacturers. Great demand was ensured, too, by a significantly higher per capita income and more equitable income distribution than European countries at the time.

Given the emerging American manufacturing sector, it was perhaps inevitable that cars would be produced in larger volume at lower prices than in Eu-
rope. The absence of tariff barriers among the states encouraged sales over a wide geographic area. Inexpensive raw materials and a chronic shortage of skilled labor encouraged the mechanization of industrial processes in the United States. By 1913, the United States produced 485,000 of the total world output of 606,124 motor vehicles.

The Ford Motor Company greatly outpaced its competitors in reconciling state-of-the-art design with moderate price. The company’s Model N (1906–1907), for example, cost $600 ($16,349 in 2019 dollars). Cycle and Automobile Trade Journal called the four-cylinder, 15-horsepower Model N “the very first instance of a low-cost motorcar driven by a gas engine having cylinders enough to give the shaft a turning impulse in each shaft turn which is well built and offered in large numbers.”

Deluged with orders, Ford installed improved production equipment, and after 1906 was able to make deliveries of 100 cars a day.

Despite the popularity of the automobile, nothing had yet appeared that could be called a car navigation system. The first item that might be called a commercially available navigation device was the Baldwin Auto Guide introduced by the Baldwin Manufacturing Company of Boston, Massachusetts, in late 1909.

As extolled in the vivid and immodest marketing language of the day, the company’s ads showed a scrolled map that is attached to the steering wheel column. Similar to how film is wound inside a canister, the Baldwin Auto Guide contained custom map directions, which a driver would scroll through by hand. The device even came with a battery-operated light for map reading at night.

No information could be found about the number of Baldwin Auto Guides that were actually deployed, how the paper route map reels were made, or how many distracted drivers survived.

The Italian Job
An Italian company took the Baldwin Auto Guide a step further in the early 1930s. Developed by Touring Club Italiano, the Iter-Auto was similar in concept to the Baldwin Auto Guide including a similar braggadocio in its advertising.

The Iter-Auto added a level of automation by linking the scrolling map to the car’s speedometer. Iter-Auto users would insert map scrolls for their chosen routes, which also identified any gas stations as well as road features such as bridges. This appears to be the first device that attempted to show a car’s position in real-time.

An advertisement (in Italian) of the Iter-Auto device, aided by Google Translate, read as follows:

The Trade Fair in Milan this year has seen the triumph of a manifestation of Italian genius and intelligence! Technicians, amateurs, Sportmans [sic] all have fairly recognized and boasted the practicality and usefulness of “Iter-Auto,” an elegant and practical guidepost that every motorist will feel the need to apply with quick and easy operation to the dashboard of your car! Motorists, the Iter-Auto is your patron saint on Earth that will guide you by the hand, showing you in your travels with impeccable accuracy, by means of a map-route carried on in perfect synchronization with the driving of your car, the way to go as well any data or practical information of those continuing needs such as: Crossroads – Bridges – bumps – Level crossings – dangerous Turns – Supplies – Relief – Garages – Hotels etc., advising in a timely manner (about 3 km. before) the driver must slow down in the face of danger.

No more stops to peer at often illegible maps or check cards [that are] inconvenient and often indecipherable to the layman.

No more breakdowns for lack of fuel.

A major operational constraint not addressed in the Iter-Auto’s advertising was that the map could only scroll vertically; so, if the drivers decided to turn onto another road, they would need to remove the current reel and load another map scroll.

The post-World War II recovery saw the automobile become the driving force of the American economy and a primary influence in its evolving culture. The automobile ended rural isolation, fueled the modern city with its industrial and residential suburbs, and liberated women from the confines of the home. Until the rise of the Internet and mobile smart phones, probably no other historical force had so revolutionized the way Americans (and to a somewhat lesser extent, Japanese and Europeans) work, live, and play.

But, as we will recount in subsequent articles, it wouldn’t be until the mid-1960s, well after the commercialization of car radios, that significant further progress in car navigation was made.

Marvin B. May is the Chief Scientist of the Pennsylvania State University’s Applied Research Laboratory Navigation Research and Development Center in Warminster, Pa. He also teaches navigation courses; his emails are <mbm16@ari.psu.edu or mayven4@comcast.net>.

The following web sites were or will be used in the preparation of these articles on car navigation:

<https://www.wired.com/2013/04/history-in-car-navigation/?mbid=email_onsiteshare>  
<https://en.wikipedia.org/wiki/Automotive_navigation_system>  
<https://www.gislounge.comgps-navigation-1920s-1930s>  
<https://www.history.com/topics/inventions/automobiles>  
<https://www.historicvehicle.org/automotive-navigation-systems>  
During an Information Warfare Senior Leadership Symposium held in Washington, D.C., on June 3rd the Chief of Naval Operations, Admiral John Richardson, announced that — effective immediately — the Navy’s Space and Naval Warfare Systems Command, referred to as “SPAWAR,” was changing its name to the Naval Information Warfare Systems Command, or simply, “NAVWAR”.

The announcement indicated that the change was made to reaffirm “the command’s commitment to outpace adversaries in the information warfare domain to enable a competitive edge in all other warfare domains.” See <https://www.navy.mil/submit/display.asp?story_id=109773>.

Although the announcement seeks to focus the change as a step forward in confronting the challenges of dealing with information warfare, one can’t help but speculate that the change is also an attempt by the Navy to protect itself from becoming a source of resources for the new Space Force being established as an independent military branch.

Whatever the reason, the Navy’s action to drop “Space” from its Warfare Systems Command’s name and adopt the name “NAVWAR” will very likely prove to be confusing to those in the Department of Defense (DoD) that for decades have viewed the term NAVWAR as a foundational element of PNT Assurance.

How the Space Force will be dealt with in the FY2020 National Defense Authorization Act (NDAA) is not yet clear at the time of this writing. However, what is clear is that “NAVWAR” has been officially defined and used in the DoD for over twenty years in association with Navigation Warfare as it relates to the Global Positioning System and Positioning, Navigation, and Timing technology within contested environments.

A Brief NAVWAR History
From a historical perspective the term “Navwar” was first introduced in a March 18, 1996, DoD memorandum jointly signed by the then–Under Secretary of Defense for Acquisition & Technology, Dr. Paul Kaminski and the then–Vice Chairman of the Joint Chiefs of Staff, General Joseph Ralston. The subject line of that memo was “Department of Defense Navigation Warfare (Navwar) Initiative.” The focus of the memo was to “provide guidance for initiation of Navwar activities within the Department of Defense.”

In the sequence of events surrounding how Navwar became an important initiative within DoD, it is not coincidental that the aforementioned memo preceded by just 11 days the issuance of the Clinton Administration’s first Presidential Decision Directive on GPS (PDD NSTC-6), dated March 29, 1996.

Although the Clinton era 1996 NSTC-6 did not include the term “Navwar,” it did include as one of the DoD responsibilities that remains foundational today the requirement to: “Develop measures to prevent the hostile use of GPS and its augmentations to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses.”

Moving forward 22 years, the following is quoted from the “Strategy for the DoD PNT Enterprise,” signed and issued by the DoD chief information officer in November 2018:

“This strategy also enables execution of the full range of Navigation Warfare (NAVWAR) Operations by Combatant Commanders to maintain a U.S. military PNT advantage in support of both national security and strategic military objectives.

The PNT Enterprise encompasses governance, capabilities, applications, and effects. It includes...the effects generated by the use of PNT information in the execution of NAVWAR Operations.”

The term “NAVWAR” specifically relates to navigation warfare in the GPS/PNT community. It is defined in “Joint Publication 3-14 (Space Operations),” dated April 10, 2018, and in the Dictionary
of Military and Associated Terms, dated May 2019, as “deliberate
defensive and offensive action to assure and prevent PNT informa-
tion through coordinated employment of space, cyber space
and electronic warfare operations.”

This definition is also noted in the most recent “Chairman
of the Joint Chiefs of Staff Master Positioning, Navigation, and
Timing Plan (CJCS Instruction 6130.01G),” coincidentally
issued on June 3, 2019, the same day as the Navy’s SPAWAR to
NAVWAR name change was announced.

How Will It Play Out?
The transformation of Navwar, as it was first used in the 1996
Kaminski/Ralston Memo, to NAVWAR as it is now used in
various DoD documents is captured in the evolution of DoD
Instruction 4650.08, last updated as recently as December
2018 (see <https://standards.globalspec.com/std/13156644/ DODD%204650.08>).

This Instruction, a compliance document binding on all DoD
Components, states as DoD policy, “DoD will use NAVWAR to
ensure DoD use of and prevent adversary use of PNT informa-
tion through coordinated employment of space, cyberspace, and
electronic warfare operations.”

It also states, “Programs producing or using PNT information
must be NAVWAR-compliant in accordance with this issuance,
and will report NAVWAR compliance to the Milestone Decision
Authority (MDA) at each acquisition program milestone. . . .”

These requirements are applicable to all military services, and
so the designation of a Navy organization as “NAVWAR” will
undoubtedly further confuse already long-standing issues with
implementation of responsibilities for “NAVWAR compliance”
by all the Services. As an example, will some in OSD and the
other Services now look to the Navy to define NAVWAR com-
pliance per the policy, since the Navy now has an organization
designated as “NAVWAR?”

Finally, and circling back to the first point about the Navy
potentially seeking to protect resources before the Space Force
becomes a reality, the term “NAVWAR” in the context of GPS
and PNT still carries with it a direct association with space. This
fact alone will very likely provoke questions and debate when the
inevitable resource hunt begins in pursuit of funding to establish
the Space Force.

Although I suspect that it is unlikely that the Navy’s renaming
of SPAWAR to NAVWAR will be reconsidered, I do anticipate
that the execution of NAVWAR responsibilities in both arenas,
e.g., the DoD PNT Enterprise and Naval Information Warfare,
will ultimately lead to confusion that won’t be beneficial to either
activity.

Time will tell.

ION Institute of Navigation
IEEE/ION Position Location and Navigation Symposium (PLANS)
April 20–23, 2020
Hilton Portland Downtown
Portland, Oregon
ion.org/plans
PORTLAND
A key U.S. advisory body for GNSS affairs, the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board, inducted new members at its June 6 meeting. Inductees included its new chair, Admiral (Ret.) Thad W. Allen, a senior executive advisor at Booz Allen Hamilton, a management and technology consulting and engineering services firm based in McLean, Virginia.

The Advisory Board was established under a 2004 presidential policy directive and is chartered as a federal advisory committee operating under the rules of the Federal Advisory Committee Act.

NASA sponsors the Advisory Board on behalf of the National Executive Committee for Space-Based PNT. Advisory Board members are nominated by the agencies of the National Executive Committee and appointed by the NASA administrator. The board meets twice a year.

“I am very pleased to assume the chair of the Space-Based Positioning, navigation, and Timing Advisory Board to the National PNT Executive Committee,” said Admiral Allen. “This cohort represents an extraordinarily broad spectrum of expertise and user knowledge of PNT issues related not only to GPS but the broader Global Navigation Satellite Systems (GNSS). We live in an increasingly ‘all source’ PNT world where technology is advancing rapidly, sometimes outpacing international legal regimes and governing structures.

“The PNT AB embraces those challenges and understands the increasing importance of PNT services to diverse, global civil users who are driving innovation. That innovation, from expanded use of PNT services for high orbit satellite navigation to new and more precise environmental sensing and mapping, will inform our work.”

Potentially relevant article:


Advocating the protection of signals from interference, toughening user equipment, and augmenting space-based signals with difficult to disrupt terrestrial systems, the RNT Foundation’s educational efforts influence individual users, corporations, and national policy makers, according to the Acquisition International award. The foundation has been instrumental in legislation in the United States and policy development in Europe. Its educational efforts have extended into Africa, the Middle East, and Asia.

RNTF President Dana A. Goward said of the honor, “We were surprised and pleased to be chosen for this cyber award, especially since we are not a technology-heavy organization. A big part of cybersecurity though, is achieved through procedures, policies and process, which are PNT areas in which we spend a lot of time.

“Safeguarding GNSS signals and users requires a holistic approach like our Protect, Toughen, and Augment recommendations. It is gratifying to have this kind of independent recognition.”
Searching for Dot Lemon: Who Was She?

A biography of an ION past president, Dot Lemon, has been authored by Dick Kinsman and published by Kinsman Publications. Searching for Dot Lemon: Mystery Woman - Who Was She? chronicles Lemon’s life as an aviator, gold-mining entrepreneur, and global nomad.

Lemon was an expert in navigation, meteorology, and astronomy and recognized as a practicing navigator. The book briefly chronicles Lemon’s term as the ION’s first female president (1961–62) during a time when the organization’s membership was almost certainly 99 percent male. Lemon was believed to have became involved in ION through her friendship with the ION’s founder, Capt. P.V.H. Weems and his wife Margaret.

Kinsman was a former CIA officer who first met Lemon in Venezuela while assigned to the U.S. Embassy in Caracas. Lemon died in 1986.

The book is available on Amazon.

ION President Visits Tsinghua University

Following the Chinese Navigation Conference, Prof. Mingquan Lu hosted Prof. Jade Morton, ION president, for a visit to Tsinghua University with Dr. Sherman Lo, Stanford University, and Lisa Beaty, The Institute of Navigation. The group had the opportunity to tour the engineering buildings and present to a group of Tsinghua graduate students.

Morton Awarded RIN Fellow

In July Dr. Y. Jade Morton, ION president, was awarded the grade of Fellow by the Royal Institute of Navigation (RIN) in recognition of significant contributions to the understanding of ionospheric effects on navigation satellite signals, development of several innovative signal processing algorithms and excellence in navigation education. Pictured: Dr. Y. Jade Morton (ION president and ION Fellow), Dr. Terry Moore (RIN president) and Princess Anne (The Princess Royal).

Calendar of Upcoming Events

SEPTEMBER 2019
16-17: Cognizant Autonomous Systems for Safety Critical Applications Conference (CASSCA), Hyatt Regency Miami, Miami, Florida
Contact: ION
Web: ion.org
16-20: ION GNSS+ 2019, Hyatt Regency Miami, Miami, Florida
Contact: ION
Web: ion.org

NOVEMBER 2019
18-21: International Navigation Conference (INC), Edinburgh International Convention Center, UK
Contact: The Royal Institute of Navigation (RIN)
Web: www.rin.org.uk

JANUARY 2020
Contact: ION
Web: ion.org

APRIL 2020
Contact: ION
Web: ion.org

MAY 2020
11-14: European Navigation Conference (ENC 2020), International Congress Center, Dresden, Germany
Contact: German Institute of Navigation
Web: www.enc2020.eu

JUNE 2020
1-4: ION Joint Navigation Conference (JNC) 2020, Northern Kentucky Convention Center, Cincinnati, Ohio/ Covington, Kentucky
Contact: ION
Web: ion.org

SEPTEMBER 2020
21-25: ION GNSS+ 2020, St. Louis Union Station Hotel, St. Louis, Missouri
Contact: ION
Web: ion.org
ION Announces Growth in NAVIGATION Journal Impact Factor

The Institute of Navigation (ION) is once again pleased to announce the continued growth of NAVIGATION, The Journal of The Institute of Navigation, reflected in the latest Journal Impact Factor (JIF) report.

The JIF of an academic journal is a measurement tool used to calculate the yearly average number of citations to recent articles published in a journal and is an indication of the relative importance of the journal within its field. It is generally recognized that journals with higher impact factors are deemed more important than those with lower ones due to its citation rate.

NAVIGATION’s Journal Impact Factor has now increased to 1.629, representing a 290 percent increase over the last four years. “Four years ago we strategically implemented a plan for strong and consistent growth of the Journal, and we are excited to see the measurable JIF results.” said Boris Pervan, NAVIGATION’s editor. “We have been consistent in our commitment to maintain the highest quality and content of papers published in NAVIGATION.

Dr. Pervan expressed his gratitude for the work of the NAVIGATION Editorial Board, which includes: Dr. Penina Axelrad, Dr. Liang Chen, Dr. Pau Closas, Dr. Paul Groves, Dr. Christopher Hegarty, Dr. Changdon Kee, Dr. Jiyun Lee, Dr. Gary McGraw, Dr. Michael Meurer, Dr. Thomas Pany, Dr. Jason Rife, Dr. Andrey Soloviev, Dr. Maarten Uijt de Haag, Dr. Todd Walter, Dr. Zheng Yao, Lisa Beaty (managing editor), and Fiona Walter and Miriam Lewis (administrative editors).

ION SECTION NEWS

Washington D.C. Section
The ION D.C. Section held its spring meeting on Wednesday, June 5, in downtown Washington, D.C.

Attendees heard from Coast Guard Rear Admiral Mike Ryan, who serves as the Assistant Commandant for Capability, RDML. Ryan spoke on the subject, “Requirements thru Time, Capability for the Ages,” which described how the Coast Guard is adapting and integrating PNT services throughout the global maritime commons. A lively discussion followed.

RDML Ryan is responsible for identifying and providing capabilities, competencies, and capacity along with developing standards for the staffing, training, equipping, sustaining, maintaining, and employing Coast Guard forces to meet mission requirements. The section would like to thank RDML Ryan and CDR Fred Bertsch for their time and support.

If section members have ideas for future speakers or venues, please email them to <dcsection@ion.org>.

New England Section
The New England section will host a presentation September 5 at the Draper Atrium by Dr. Chris Hegarty, ION and IEEE Technical Fellow and widely published Global Navigation Satellite System (GNSS) author, on the topic, “GNSS Avionics on Civilian Aircraft: Current and Future.” The section meeting will be held from 6 to 9 p.m.

Civilian aircraft are becoming increasingly reliant upon GNSS for positioning, navigation, and timing (PNT). Today, the certified GNSS avionics that are carried on most civilian aircraft are capable of tracking only GPS L1 C/A-code and satellite-based augmentation systems (SBAS) L1 C/A-code signals. These avionics achieve required levels of performance for en route through approach navigation operations using one or more augmentations standardized by the International Civil Aviation Organization (ICAO): aircraft-based augmentation systems (ABAS), SBAS, and ground-based augmentation systems (GBAS).

Dr. Hegarty’s presentation will provide an overview of current-generation GNSS avionics, including existing standards and augmentations. The talk will also describe the planned evolution to the next generation of certified avionics that will be more resilient and provide dual-frequency, multi-constellation (DFMC) capability.

Persons interested in attending must pre-register for the event. Registration
is open through August 28. Guests will be screened via metal detector/x-ray at the Atrium’s entrance, 555 Technology Square in Cambridge, Massachusetts. Free parking will be available from 5:30 - 9:30 p.m. in the Draper Garage across from the Atrium.

Draper requests that attendees do not take photos, videos or recordings during the briefing and that attendees should ensure in their conversations to keep content suitable for public audiences.

Contact information regarding the event: Rochelle Moore, New England section program chair and senior member technical staff, Systems Engineering, Draper; telephone, 617-258-4852; mobile, 617-253-1221; Email, <rmoore@draper.com>.

**Dayton Section**

The Dayton section’s meetings in April and May were hosted by Modern Technology Solutions, Inc. (MTSi) at their Beavercreek, Ohio, offices.

On April 11, two University of Cincinnati cooperative education students interning at MTSi — Adam Pendergrass and A. J. Stubbles — presented on their recent work. Pendergrass, a senior in electrical engineering, discussed development of an attitude determination system using data from a MEMS strapdown inertial measurement unit and magnetometers integrated with an extended Kalman filter. The algorithms will be implemented in a field-programmable gate array.

Stubbles, a fourth-year aerospace engineering student, then described his work building on a previously developed, loosely coupled Kalman filter that integrated a GPS system with an inertial navigation system by including two additional inputs from a barometer and a pitot system. He addressed the validation, in software, of the expanded filter.

On May 9 at the same venue, MAJ Juan Jurado, a Ph.D. student at the Air Force Institute of Technology, presented his dissertation research to improve multi-sensor resiliency. To date, only some sensor combinations, such as visual-inertial and GPS-inertial, have extensive resiliency research results, he said.

MAJ Jurado aims to achieve greater robustness through a framework applicable to a wider variety of sensor inputs by generalizing and interfacing functions such as fault detection, parameter estimation, and model selection. He compared the performance of his proposed framework to conventional filtering in two simulated scenarios that included multiple sequential sensor failures and incorrectly modeled sensors.

Also in May, the section announced Mr. Tristan Williams, a computer engineering student at Wright State University, as this year’s winner of the ION Dayton Section Scholarship, worth $2,500.

The section concluded its season on June 26 with dinner at a local pub. New section officers for the coming year were elected: Chair, Andrew Baster; Vice Chair, Jeremy Gray; Executive Secretary, Jason Pontious; and Treasurer, Boyd Holsapple.
A SHORT HISTORY

The World of WAAS: Part 3

Editor’s Note: This is the final installment of a three-part series describing the history of the Wide Area Augmentation System (WAAS) on the 25th anniversary of the first flight demonstrations of satellite-based augmentation to improve the performance of the Global Positioning System.

The articles were written by Dr. Bryant Elrod, former project manager at Stanford Telecom/STel for the WAAS National Satellite Testbed (NSTB); Frank Persello, a member of the Federal Aviation Administration (FAA) Technical Center’s NSTB engineering team; and Dr. Todd Walter, a past president of the ION and director of the wide-area differential GNSS laboratory at Stanford University where ground-breaking work on WAAS has long taken place.

The first demonstration in the world of using GPS plus space-based augmentation system (SBAS) technology took place in December 1993. (Note: In Part 1, an editorial error mistakenly listed December 1998 as the first GPS/SBAS flight demonstration.) The first parts of this article, published in the Winter and Spring 2019 issues of the ION Newsletter, took readers from the earliest interest in wide-area differential GPS (WADGPS) through declaration of WAAS as part of the National Air Space (NAS) in 2003. We conclude the story with a brief description of the evolution of WAAS over the past 15 years.

Since 2003, the FAA has continued building on the WAAS IOC capability. This includes several steps for improving performance and enhancing robustness to enable support of approaches down to a vertical goal of 200 feet above threshold (also known as LPV-200). The vertical guidance service provided by WAAS IOC covered much of the conterminous United States (CONUS), but it didn’t fully extend to all coasts nor did it cover Alaska. (See Figure 1a.)

The WIPP continued to refine the integrity algorithms while the FAA expanded the network of WAAS reference stations (WRSs) from the original set of 25. In 2006 four additional WRSs were added to Alaska, and in 2007 two were fielded in Canada and three in Mexico. Also in 2007, a significant upgrade was made to the ionospheric algorithms used to both estimate the amount of ionospheric delay affecting the GPS ranging measurements and the uncertainty remaining after applying those corrections.

Moreover, because the original ionospheric grid definition above 55° N was very sparse, having more WRSs in the far north allowed WAAS to better resolve the ionospheric behavior over Alaska and to provide a denser grid of corrections. This update significantly increased vertical guidance coverage to include nearly all of CONUS as well as the southern part of Alaska.

In 2008, two more WRSs were added to both Canada and Mexico bringing the total number of reference stations up to the current level of 38. The WIPP was also able to use the historical ionospheric observations (including severe storms observed in October and November of 2003) to more accurately model disturbed ionospheric error as well as to tune the uncertainty bounding equations and remove excessively conservative margins of error that had been incorporated into the earlier iterations of the model. This round of improvements now allowed vertical guidance to be available throughout virtually all of CONUS and Alaska.

At the same time, the two original GEOs located over the Atlantic and Pacific Oceans were replaced with two GEOs that were much more centrally positioned over CONUS. These new GEOs provided overlapping coverage at much higher elevation angles. In addition, they also provided ranging measurements that help to fill in gaps in GPS coverage.

Although nominal WAAS performance was quite good, occasions arose when the ionosphere was moderately disturbed and vertical guidance would briefly be unavailable. In late 2011 another improvement to the ionospheric algorithm, called kriging, was implemented to better handle these moderate disturbances, increasing the amount of time that vertical guidance would be available. Kriging also further improved coverage over Alaska.

Meanwhile, in 2007 the FAA began expanding use of LPV-200, which required tighter bounds on WAAS performance that were not supported on the West Coast. Once again, the ionospheric algorithms were modified to exploit the typically quiet behavior of the ionosphere and remove more conservatism. In 2016 a Moderate Storm Detector (MSD) was introduced that allowed for nearly full coverage of LPV-200 service throughout CONUS and most of Alaska.

Figure 1b illustrates the regional expansion of LPV-200 availability resulting from the various improvements since WAAS IOC. A more detailed exposition of WAAS improvements and important steps along the way can be found in the article “WAAS at 15” published in the Winter 2018 issue (volume 65, number 4) of the ION journal NAVIGATION.

More recent FAA activities involve preparing for dual-frequency operations as the new GPS L5 signal becomes available. This will allow for direct estimation and removal of ionospheric effects and better WAAS service over broader areas.

International SBAS Developments

Through its sharing of information gained from NSTB experience, numerous flight trials, and WAAS lessons-learned, the FAA has contributed significantly to the international expansion of satellite-based augmentation systems. These include SBASs currently certified for safety-of-life operations (Japan/MSAS in 2007, Europe/EGNOS in 2011, and India/GAGAN in 2015) or in development (Russia/System for Differential
Corrections and Monitoring, China/Beidou SBAS). (See Figure 2.)

SBASs in others regions are still under study or initial testing (e.g., Australia, South Korea). While the primary focus for such systems to date has been augmenting GPS for L1-C/A signal users to meet civil aviation requirements, the approaching phase for SBASs will involve SatNav augmentation in a multi-national constellation and multi-signal/frequency environment.

Support for legacy GPS users will continue during what will probably be a lengthy transition period. Eventually, however, satellite-based augmentation will evolve to use higher power, dual-frequency signals (e.g., GPS L1C, L5 and/or Galileo E1/E5a) from more satellites. This will lessen interference vulnerabilities, enable self-canceling of ionosphere-induced ranging errors, and reduce the size and complexity of the ground system.

At the time of those first SBAS flight demos, 25 years ago, who would have thought of such possibilities?

Acknowledgment
We wish to applaud the many contributions made by members of government, industry, and academia who participated in the FAA’s successful program to develop SBAS technology that became WAAS. Special recognition goes to the succession of program leaders: J.J. Fee, who in 1990 convinced upper management of the need to establish an R&D program and began planning the NSTB; J. Dorfler, who in 1991–96 secured funding, established the NSTB team, and got the WAAS procurement underway; J.C. Johns, D. Peterson, D. Hanlon, L. Eldredge, D. Lawrence, D. Bunce, and D. Willkerson, who led the WAAS development through IOC and its subsequent evolution.
Recent developments in the world’s GNSS programs were highlighted by the longest system failure to date — a weeklong outage of Galileo’s “initial services.”

The July 11–18 anomaly involved substantial deterioration in the European GNSS systems signals in space, caused by “an equipment malfunction in the Galileo ground infrastructure, affecting the calculation of time and orbit predictions which are used to compute the navigation message,” according to the European GNSS Agency (GSA).

Elsewhere, the U.S. House and Senate lawmakers have agreed on authorizing nearly $1.75 billion in funding for the GPS program.

**GPS**
The U.S. Air Force plans to launch the second GPS III satellite no earlier than August 22. Originally scheduled for a July launch, the flight was delayed to allow time for technicians to replace and retest a faulty component.

Lockheed Martin is under contract to develop and build up to 32 GPS III/IIIF satellites for the Air Force. GPS III will be designed to deliver three times better accuracy and provide up to eight times improved anti-jamming capabilities. GPS III’s new L1C civil signal will make it the first GPS satellite to be interoperable with other international global navigation satellite systems, such as Galileo.

If approved, most of the proposed $1.75 billion GPS budget allocation would go towards the new Block III Follow-on (IIIIF) satellite program, a new ground control system, and development of military user equipment. The funding is part of a new, two-year budget deal reached in July by White House and congressional negotiators.

The House and Senate authorizing committees approved $445.30 million for the development of the Next Generation Operational Control System (OCX) and the associated GPS Enterprise Integrator and another $329.95 million for acquisition of military user equipment.

Meanwhile, President Trump nominated Gen. John Hyten, who has led Air Force Space Command and U.S. Strategic Command, to be the next vice-chairman of the Joint Chiefs of Staff. If approved, the nomination would advance an officer who is deeply familiar with military space issues — including those affecting GPS — to be the second-ranking member of the U.S. Armed Forces.

The National Space-Based Positioning, Navigation, and Timing Advisory Board held its June meeting with a new chairman, Admiral (Ret.) Thad W. Allen, now an executive vice president of Booz Allen Hamilton, and seven new members, including several current and past ION leaders: Dr. Frank van Diggelen, Google; Dr. Dorota Grejner-Brzezinska, The Ohio State University; Prof. Terry Moore, University of Nottingham (UK); and Dr. Todd Walter, Stanford University.

They join other notable ION members on the PNT Advisory Board, including Dr. John Betz, The MITRE Corporation; Dr. Penina Axelrad, University of Colorado; Tim Murphy, Boeing Commercial Airplanes; Dr. Brad Parkinson (the advisory board’s first vice chair), Scott Burgett, Garmin International; and Ron Hatch, private consultant. The immediate past board chairman John Stenbit, a
former assistant secretary of defense, will stay on the board as deputy chairman, and James Miller, NASA, will continue as the advisory panel’s executive director. (See photo on page 16.)

The PNT advisory board provides independent advice to the U.S. government on GPS-related policy, planning, program management, and funding profiles.

**GLONASS**

On June 22, Russia activated its most recently launched GLONASS-M satellite in plane 2, orbital slot 12. It replaced GLONASS satellite number 723, which had been operating since January 2008 and was moved to “spare” status. The new satellite, GLONASS 758, had been launched on May 27.

The GLONASS constellation continues to operate with a full set of 24 healthy spacecraft broadcasting signals, as well as two spares.

On July 23, the Russian State Duma (lower chamber of federal legislature) ratified an agreement between the Russian and the Chinese governments to cooperate in use of GLONASS and China’s BeiDou system, including mutual deployment of monitoring stations on their territories. Negotiators for the two nations signed the agreement in Beijing last November 7.

Russia plans to launch the first K2 satellite in late 2019 or early 2020, proposing to complete a 24-spacecraft, all-GLONASS-K2 constellation by 2030. Yury Urlichich, first deputy director general of Roscosmos, the Russian State Space Corporation, says the K2 user range error will be about 0.3 meter.

Meanwhile, Saudi Arabia may host GLONASS ground stations as part of a space cooperation agreement signed recently by the two countries.

**Galileo**

In an almost prescient coincidence, a plenary speaker at the Institute of Navigation’s GNSS+ conference in September will speak on the subject, “A Day Without Satellites.” But Galileo users could write a prequel, “Seven days Without Satellites,” following a prolonged outage in the European GNSS system in mid-July.

The European GNSS Service Center (GSC) website posted a Notice Advisory to Galileo Users (NAGU) at 14:45 UTC (coordinated universal time) on July 11. The NAGU indicated that an “event” — degraded satellite signal accuracy — had begun nearly 13 hours earlier.

Satellite signals apparently using outdated ephemerides — orbital positions of the spacecraft — or erroneous system time data were producing large errors in receiver calculations based on Galileo. The situation finally was resolved on July 18 when the GSC posted a NAGU announcing restoration of service at 08:20 UTC.

For GNSS users, the event had few, if any, practical consequences because most commercial receivers incorporate multiple GNSS systems and software that cross-checks the validity of the various signals. Galileo program managers emphasized that the European GNSS system is still in the phase of “initial services,” a provisional status that can be used until the system achieves full operational capability.

However, a proposed Galileo Commercial Service, recently reconceived as a free High-Accuracy Service (HAS) and a Commercial Authentication Service (CAS), has held out the prospect of signal authentication and service guarantees as well as improved positioning. Galileo operators had planned to roll out the HAS later this year. Although the “guarantee” aspect of such a service has been downgraded in more recent discussions, the latest incident undoubtedly will lead to yet another revisiting of the viability of these offerings.

**BeiDou**

China launched its 21st BeiDou-3 satellite on June 25 (local time), placing it as the second to in a planned three-spacecraft inclined geosynchronous orbit (IGSO). The first BeiDou-3 IGSO satellite was launched on April 20.

BeiDou’s operational constellations now has 18 BeiDou-3s and 15 BeiDou-2s broadcasting signals. The new generation of satellites features inter-satellite link capabilities and new versions of rubidium atomic clocks and passive hydrogen maser clocks.

China plans to complete the BeiDou Navigation Satellite System by next year with 27 satellites in medium Earth orbits and five in geostationary orbits, along with the three IGSOs. China has already established a continuous monitoring system with more than 20 ground stations around the world.