



# Space Weather and GPS-Reliant Industries

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**Abstract** Since the last solar maximum, our society has become extremely dependent on the Global Positioning System (GPS) often referred to as the "4th utility" behind electricity, water, and natural gas. Precision GPS is now required by numerous applications--railway control, highway traffic management, precision agriculture, emergency response, commercial aviation, and marine navigation. With such widespread and critical usage, GPS-reliant industries are now concerned about space weather impacts on the once thought "all weather proof" GPS system. Space weather can have a tremendous effect on GPS operations by causing signal delays, increasing errors in timing, position, and navigation, as well as total loss of signal ultimately resulting in total navigational failure. In this presentation we investigate the types of industries that are interested in space weather products and services for navigation uses. In doing so, we can now begin to understand the wide-ranging uses for GPS and the potential impacts of GPS signal errors. We examined over 600 customers who currently subscribe to the NOAA Space Weather Prediction Center (SWPC) navigation products, carefully analyzing each customer according to their sector and industry. We concluded with a wide ranging list of companies, as well as a discussion of why and how they use space weather information. This analysis highlights the need for understanding the impacts of space weather phenomena on GPS systems and the need for robust and efficient mitigation strategies to prevent the ripple effect GPS degradation can create.

## Introduction

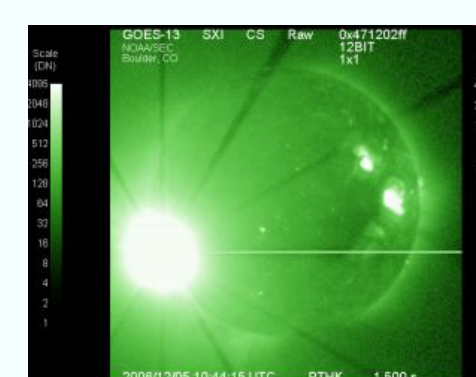
As we approach Solar Maximum in 2013, society is more at risk from space weather storms than during the last solar cycle, partially due to our dependence on GPS-based technologies which will be fully tested for the first time

The NOAA Space Weather Prediction Center (SWPC) navigation customer list was analyzed to investigate the types of companies reliant on GPS

There are 3 primary effects of space weather on GPS: 1) propagation delay of signals caused by the presence of the ionosphere resulting in increased errors in position and navigation, 2) loss of signal due to scintillation effects caused by small-scale irregularities in the ionosphere resulting in increased errors due to decreased number of useable satellites and possibly inability to navigate, and 3) solar radio burst (SRB) impacts on receivers

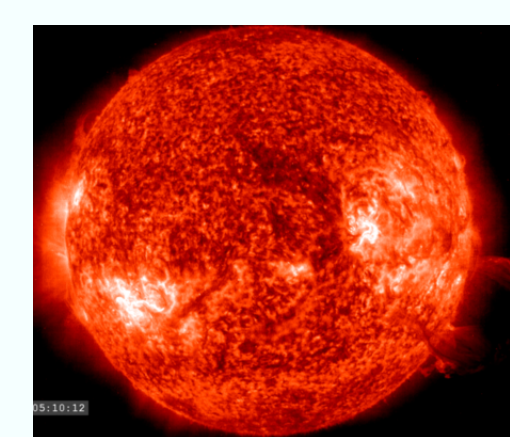
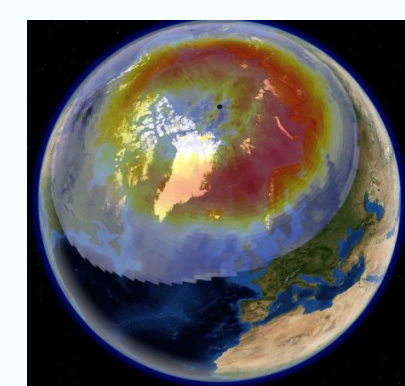


## Examples of space weather induced errors on GPS



December 6, 2006: an extremely large solar radio burst affected GPS receivers over the entire sunlit side of the Earth. Many GPS receivers experienced total loss of lock. This event prevented Global Differential GPS from generating corrections for users and marked the first time a SRB event was detected on the Wide Area Augmentation System (WAAS)

November 8, 2004: a fast moving auroral arc caused ionospheric irregularities affecting GPS signals. Even though this event lasted only 10 seconds, due to the intensity, it caused a receiver to lose lock. The event was observed by receiver sites in Norway and Finland



October 29-31, 2003 (Halloween Storms): a coronal mass ejection (CME) required precise GPS users to delay operations. For a 15 hour period on October 29 and an 11 hour period on October 30 the WAAS system was severely impacted. An international oilfield service company reported 6 cases of survey instrument interference from sites around the world

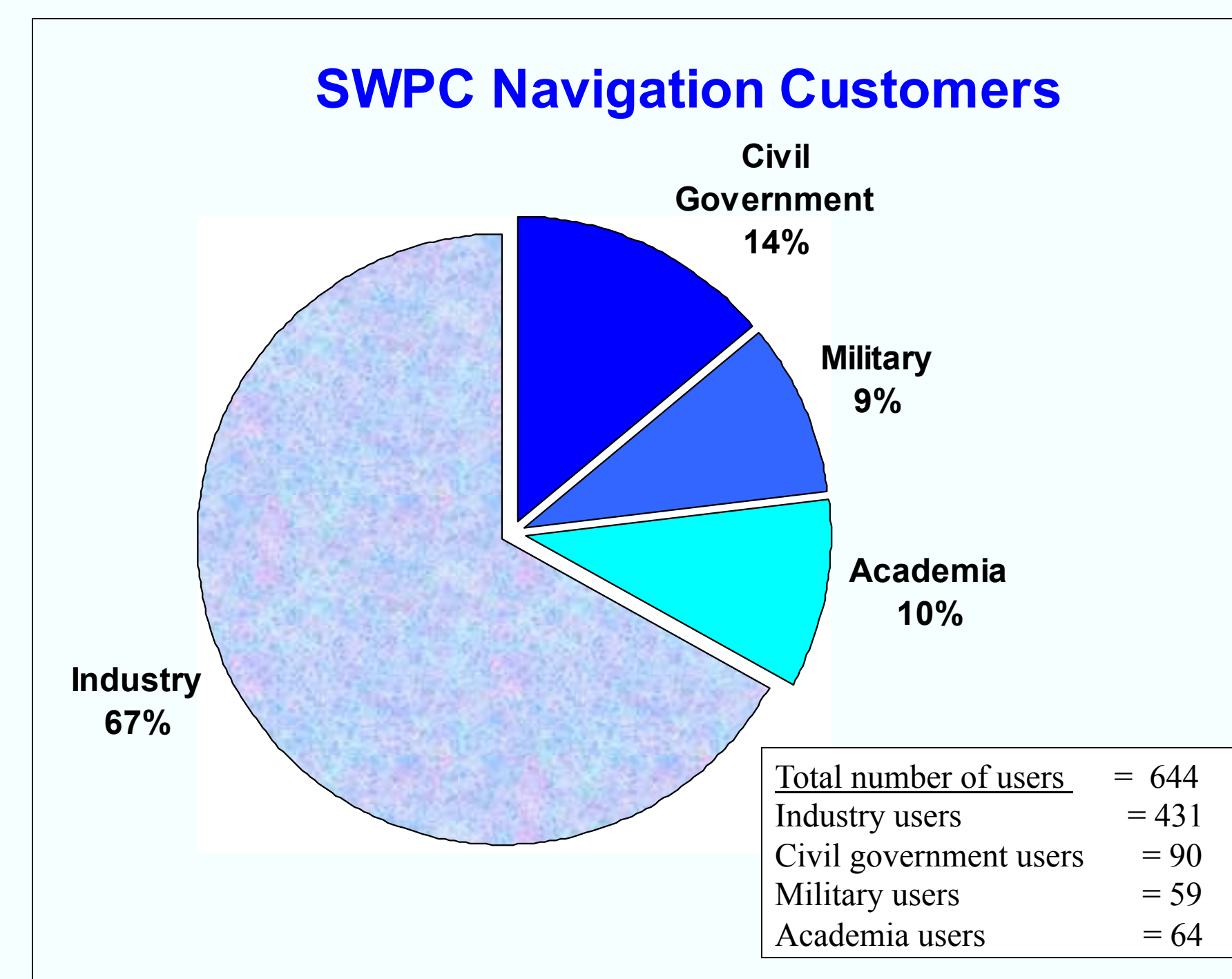
July 14-17, 2000 (Bastille Day Storm): a coronal mass ejection caused an extremely intense geomagnetic storm that lasted for over 9 hours. There were reports of aurora sightings as far south as El Paso, Texas. The solar particles from this event damaged satellites and degraded the accuracy of GPS for several hours



## Researching the customers

- Obtained SWPC Navigation Customer list containing only the names of the organizations
- Researched each organization online and grouped them into corresponding categories
- Categories based on GPS application uses
- After extensive researching, 644 out of 733 customers were identified and categorized

## Who's using navigation products?

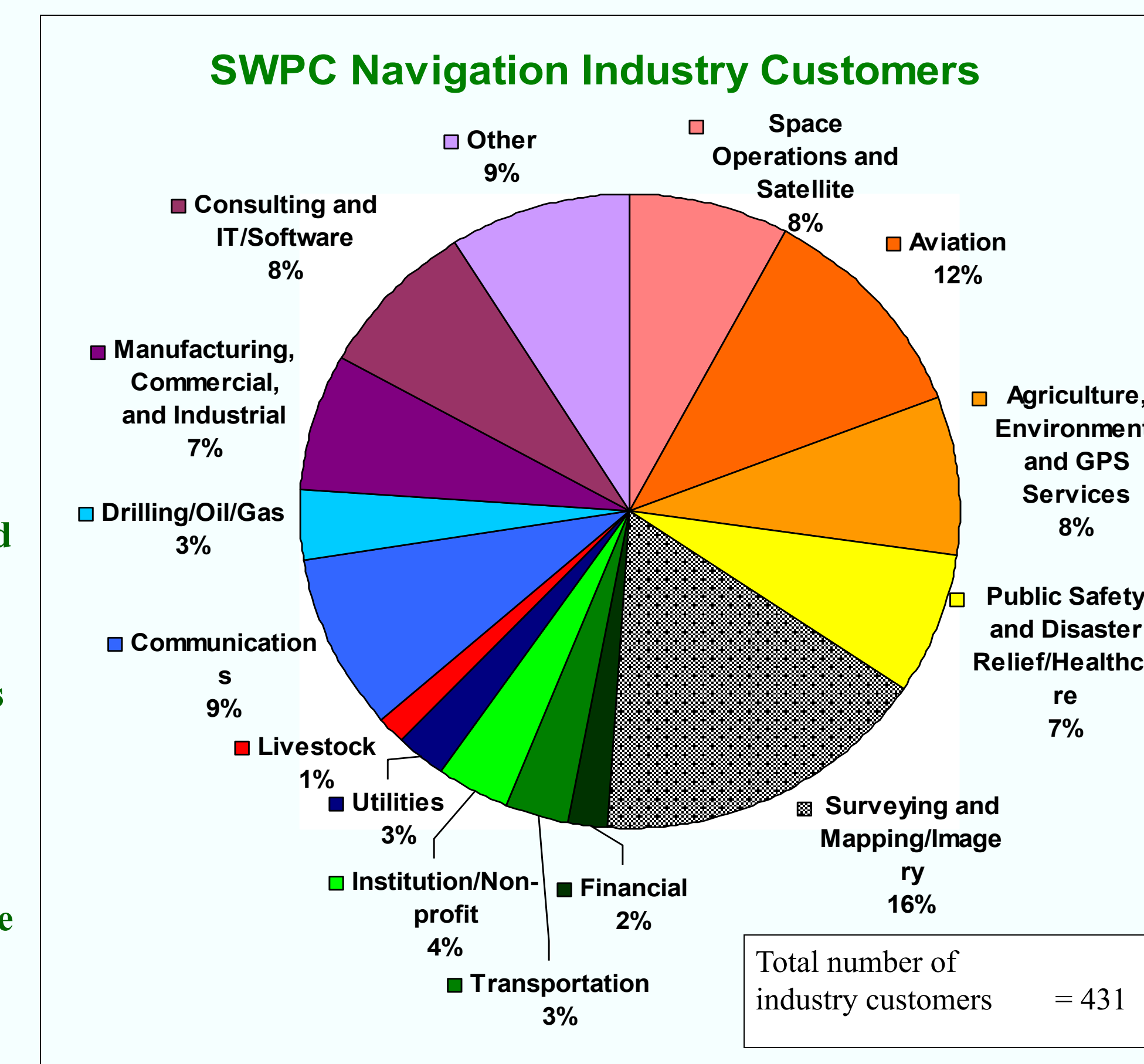


SWPC Navigation Customers chart shows all organizations as a percentage of sector.

- Civil government includes a wide variety of non-military government agencies including international agencies
- Military includes all Department of Defense operations as well as international defense programs
- Academia includes colleges, universities, K-12 education programs and international universities
- Industry includes everything else that did not fit into the above sectors

SWPC Navigation Industry Customers chart shows industry organizations as a percentage of type of company.

- Wide-ranging company categories
- All categories include individuals and companies, domestic and international
- A majority of the industries provide GPS services and could experience tremendous economical impacts during signal errors or interruptions
- Some companies use GPS to improve safety and efficiency of systems, i.e. emergency response groups
- Some companies use GPS for the economic value, whether it be the money making business (consulting) or the money saving business (precision agriculture)



## A closer look...

### Public Safety and Disaster Relief/Healthcare

- Emergency Management
- Radio- Emergency Communications
- Air-rescue Operations
- Healthcare Services
- Healthcare Systems
- Healthcare other

### Financial

- Bank
- Insurance
- Law Firm

### Agriculture, Environment, and GPS Services

- Agriculture
- GPS Services
- Meteorology Services
- Space Weather Services
- Other Environment Services

### Communications

- Radio
- Telecommunications
- Internet Service
- Media
- Marketing
- Audio Entertainment
- Research

### Aviation

- Airline
- Aviation Services
- Air Traffic Control/Airport

### Surveying and Mapping/Imagery

- Surveying
- Mapping
- Engineering Services
- Imagery
- Airborne Geophysics

### Transportation

- Planes and Trains
- Shuttle Service
- Hazardous Materials Transportation
- Commercial Trucking
- Shipping
- Marine

### Livestock

- Pigeon Racing
- Dove Releases
- Equestrian

### Institution/Non-profit

- Astronomy
- Institution/Research
- Radio Observatory
- Applied Mathematics/Non-Profit

## GPS critical for many applications

### Precision Agriculture



- GPS used to estimate input needs such as fertilizers and predict crop yields
- Average input savings per acre are estimated at \$19/acre for corn, \$18.50/acre for beans, and \$39/acre for cotton

### Banks



- GPS satellites used to time-stamp financial transactions; GPS provides precise time signals for synchronization and fault detection
- During bank robberies, GPS tracking devices are thrown into bags of money for tracking and recovering

### Oil Drilling



- GPS used for very precise location requiring near pinpoint accuracy
- Space Weather impacts could result in a \$1 million loss in a single oil drilling operation in the Gulf

### Public Safety



- GPS is a huge component of E911 - the ability to locate cell phone transmissions during an emergency for immediate response
- Could save more lives

### Aviation



- GPS used for navigation; NextGen requires GPS for all navigational uses
- Could save up to \$10 billion in fuel cost by the year 2025

### National Security



- GPS used to enable DoD forces worldwide to maneuver into a militarily advantageous position and create effects ranging from tactical to strategic
- GPS provides critical services to deployed forces around the globe from the infantrymen walking the streets of Fallujah, to ships combating piracy off the coast of Somalia, to the aircraft patrolling our country's borders

### Pigeon Racing



- GPS used to measure the distance between bird's home loft and the race-point; winners are determined by special calculations of the bird's velocity
- (Geomagnetic storms can cause a "smash" and cost a handler tens of thousands of dollars, e.g., for price of birds, prize money, equipment, loft building, supplies)

## Concluding Remarks

- Our economy has become extremely reliant on GPS deeming it a necessary utility in our daily lives
- As our dependency on GPS increases, so will the corresponding vulnerabilities
- The average person does not realize how much of our infrastructure is based on GPS and how vulnerable it is
- Further education and research needs to be conducted on these vulnerabilities so the GPS users are aware of the impacts space weather can impose, and the space weather service providers can develop the right tools for mitigation

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