THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

AAE6102 – Satellite Communication and Navigation

Ground Based Augmentation System

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ICAO Performance Requirement

<table>
<tr><th>Phase of Flight</th><th>Accuracy (95%)</th><th>Integrity Risk</th><th>Continuity Risk</th><th>Availability</th></tr>
<tr><td>En Route</td><td>H: 3.7 Km</td><td rowspan="3">$1x10^{-7}$/h</td><td rowspan="3">$1x10^{-4}$/h to $1x10^{-8}$/h</td><td rowspan="7">0.99 to 0.99999</td></tr>
<tr><td>Terminal</td><td>H: 0.74 Km</td></tr>
<tr><td>NPA</td><td>H: 220 m</td></tr>
<tr><td>APV I</td><td>H: 16 m
V: 20 m</td><td rowspan="3">$2x10^{-7}$/App</td><td rowspan="3">$8x10^{-6}$/ 15s</td></tr>
<tr><td>APV II</td><td>H: 16 m
V: 8m</td></tr>
<tr><td>Cat I</td><td>H: 16 m
V: 6 to 4 m</td></tr>
<tr><td>Cat II/III Surface Ops</td><td colspan="3">Under Development</td></tr>
</table>

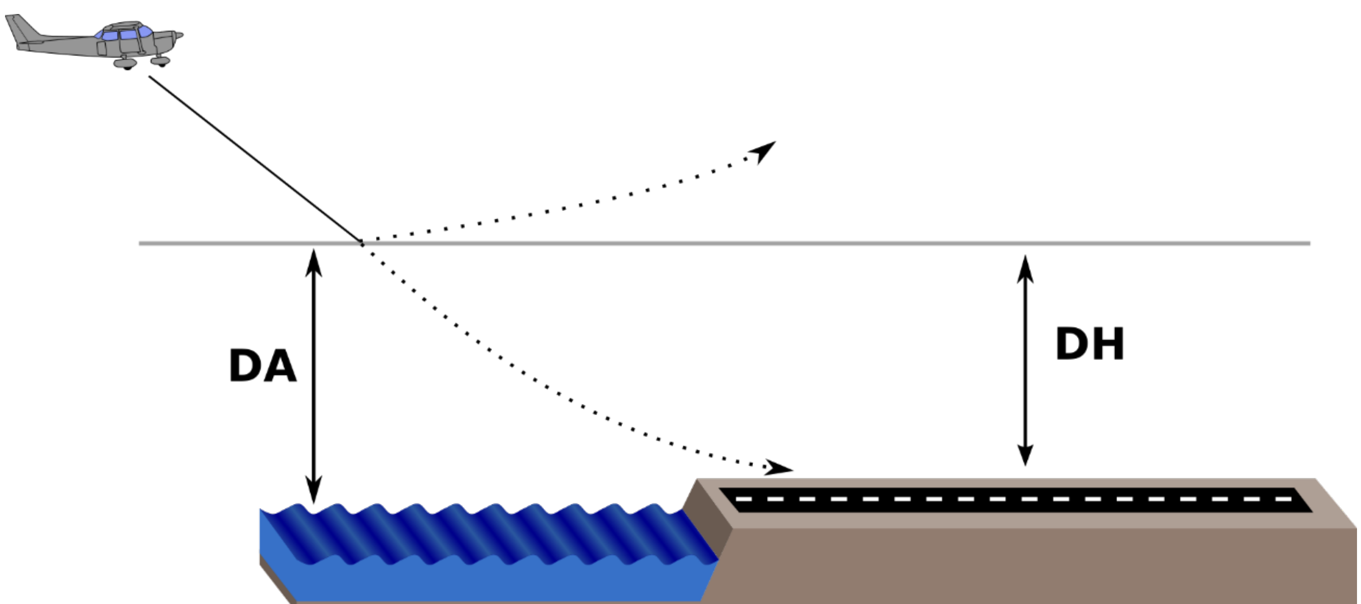
ILS Categories

- RVR Runway Visual Range

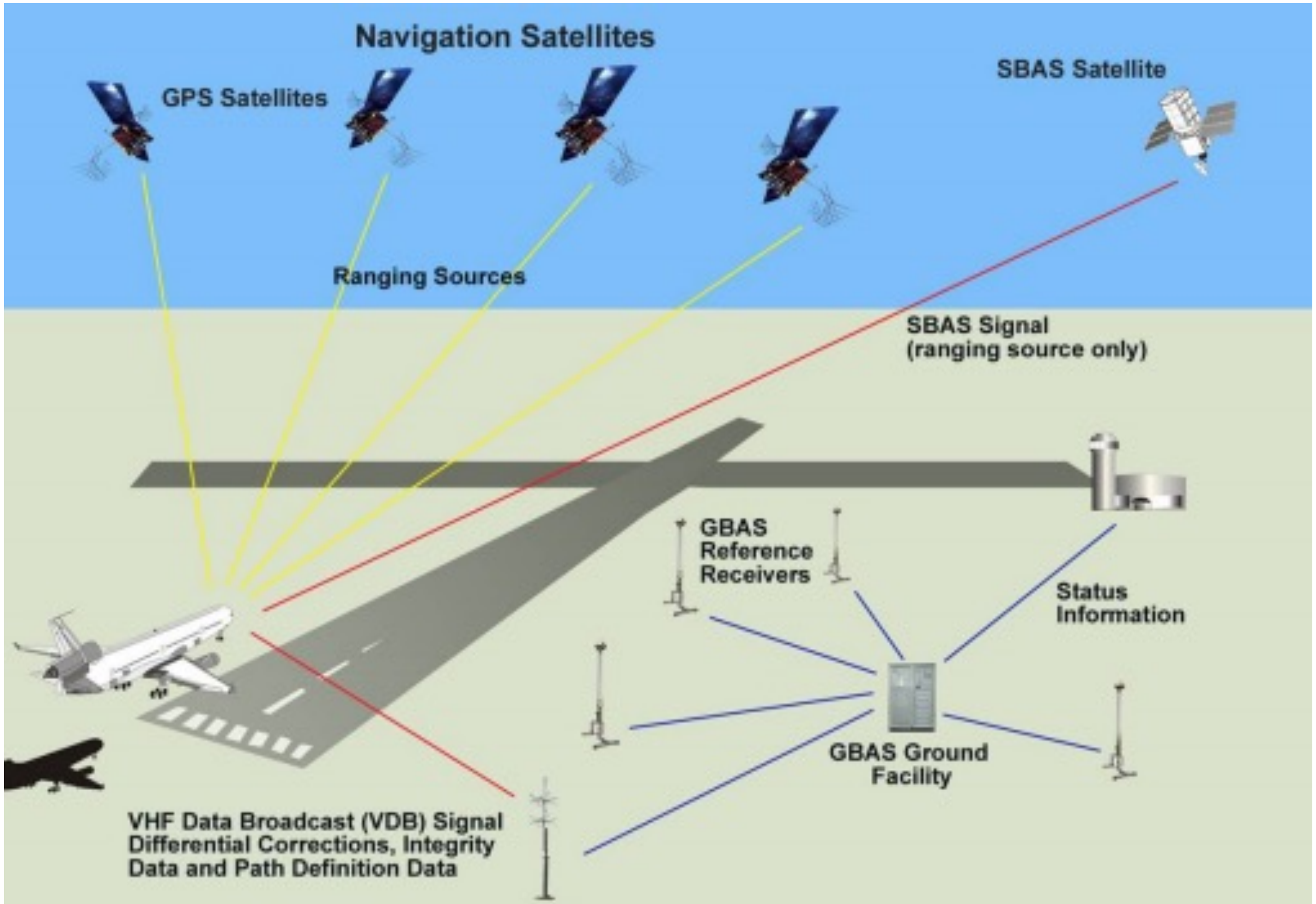
Category	Minimum DH	Minimum RVR	Remarks
I	200 feet	2400 feet	
I	200 feet	1800 feet	With touchdown zone and runway centerline lighting .
II	100 feet	1200 feet	Half the minimums of a standard Cat I approach
IIIa	100 feet	700 feet	
IIIb	50 feet	150 to 700 feet	
IIIc	No DH	No RVR limitation	Pray that your electronics and autopilot are accurate and reliable.

DH Decision Height

- DH is a specified lowest altitude in the approach descent at which, if the required visual reference to continue the approach is not visible to the pilot, the pilot must initiate a missed approach.
- Why DH is lower for more precise approaches?



Ground Based Augmentation Systems (GBAS)



youtube.com/watch?v=oVVaXpLB8CY&ab_channel=Sukhoi

Advantages of GBAS

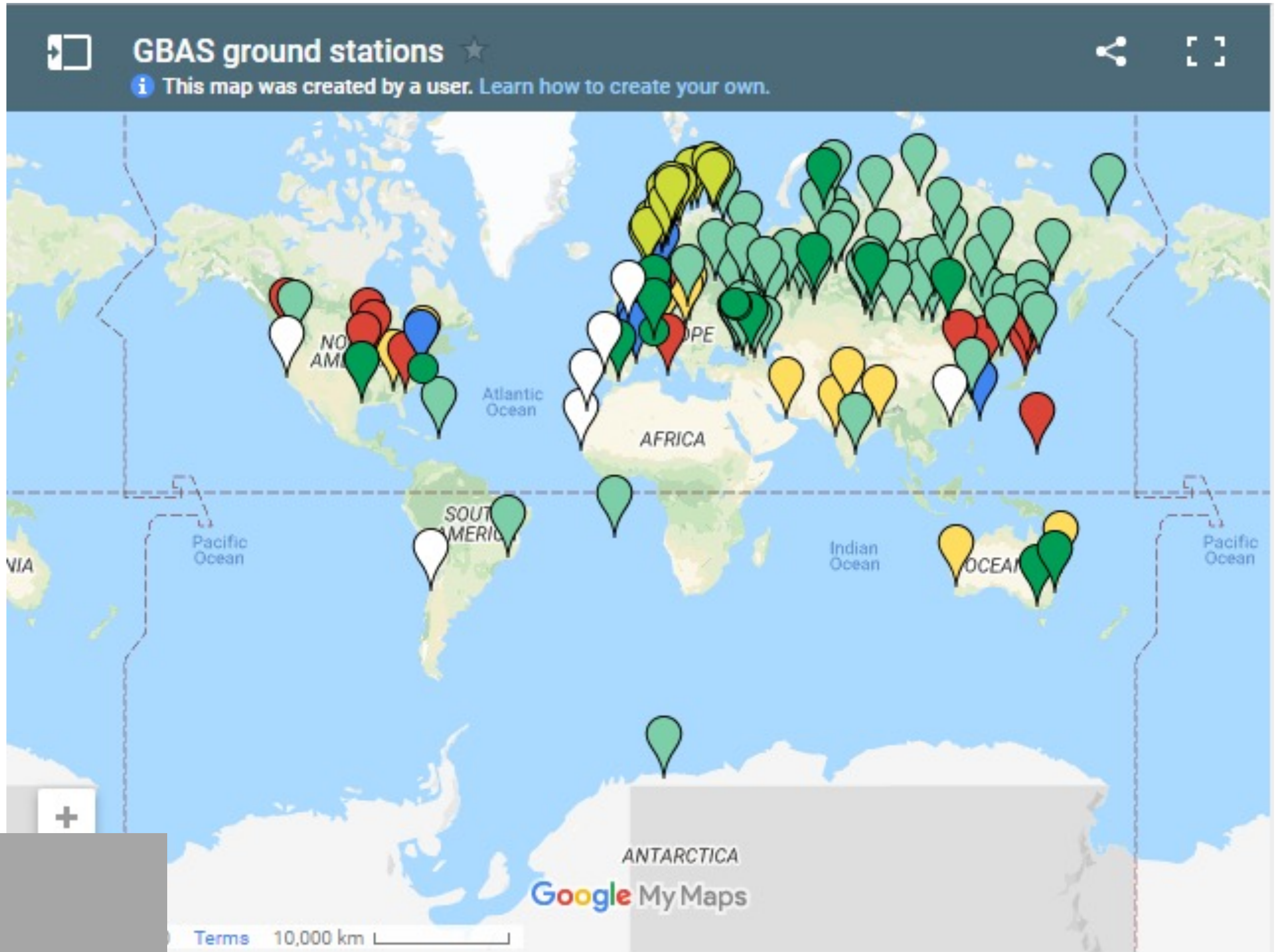
GBAS has several advantages compared with the traditional *ground based* ILS for aircraft approaches:

- One GBAS station can support multiple runways ends and reduce the total number of systems at an airport.
- ILS requires one frequency per system, GBAS only requires one VHF assignment for up to 48 individual approach procedures.
- ILS needs flight check every half a year, GBAS only needs one during its lifetime
- GBAS has more flexible siting criteria, allowing GBAS to serve runways which ILS is unable to support.
- Others: Less flight inspection, more stable guidance

GBAS facilities in the world

http://www.flygls.net/

https://www.google.com/maps/d/viewer?mid=14gN6IowjgVLlkjwgKKIUyjz6OXQ&ll=1.8038370519870024%2C0&z=2



Green: GBAS in operation
Blue: GBAS research / test
Yellow: S-CAT1* in operation
White: Planned location / Proposed site

Example: GBAS in Toulouse-Blagnac airport (1/2)

GBAS ground facility and omnidirectional VHF data broadcast

Example: GBAS in Toulouse-Blagnac airport (2/2)

End **T**o **E**nd **M**onitor**S**

GPS reference receivers

GBAS Typical Architecture

- GBAS is defined by ICAO as an augmentation system in which the user receives augmentation information directly from a ground-based transmitter.
- GBAS positioning is based on the Local-Area DGPS (LADGPS) principle.
- A control station, located at an airport for example, precisely measures errors and transmits them to a user so that he can eliminate them from his own measurement
- In civil aviation, this technique uses a data link in the VHF frequency band of ILS - VOR systems (108 - 118 MHz). The elements transmitted through this VHF link are:
  - integrity data of various satellites in view
  - pseudorange correction
  - database for the final approach segment

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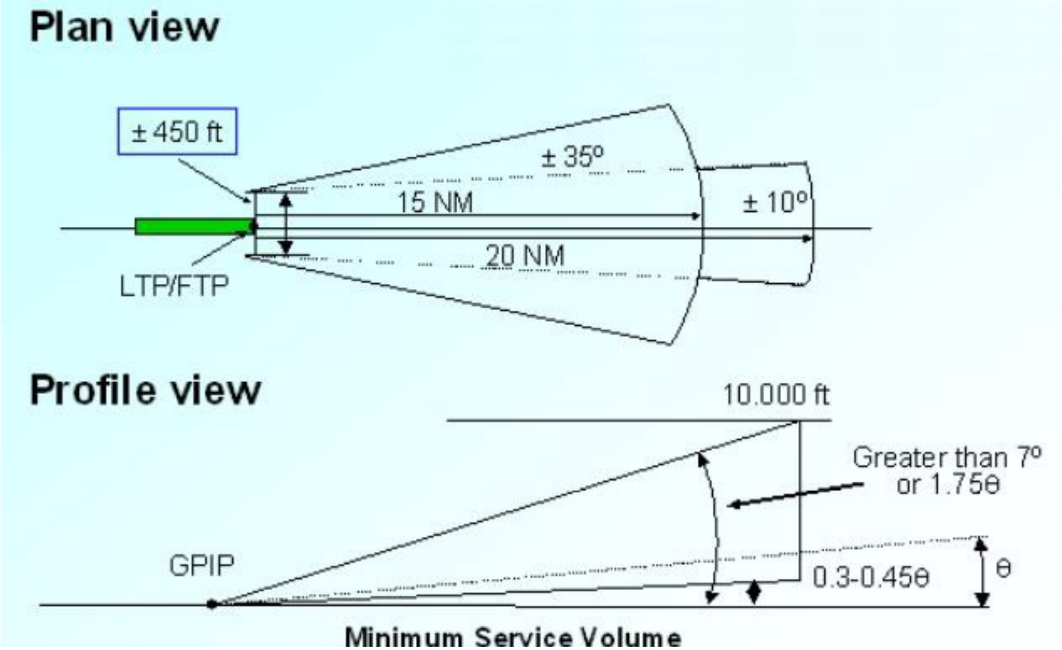
GBAS Coverage

- The VDB broadcasts the GBAS signal throughout the GBAS coverage area to avionics in GBAS-equipped aircraft. GBAS provides its service to a local area (approximately a 30 kilometer radius). The signal coverage is designed to support the aircraft's transition from en route airspace into and throughout the terminal area airspace.

The GBAS equipment in the aircraft uses the corrections provided on position, velocity, and time to guide the aircraft safely to the runway. This signal provides ILS-look-alike guidance as low as 200 feet (60 m) above touchdown. GBAS will eventually support landings all the way to the runway surface.



LTP/FTP: Landing/Fictitious Threshold Point
GPIP: Glide Path Intersection Point

GBAS Ground Station

- GPS/GLONASS antennas
- Receiving Unit (up to 4 Reference Receivers) provides:
  - Carrier measurements
  - Code measurements
  - Ephemeris data
  - Time
- Data Processing Unit provides:
  - Code carrier smoothing and Differential Corrections Calculation
  - Integrity Monitoring Functions
  - GBAS Messages Elaboration
- Data Broadcast Unit
- Differential Message Broadcast Antenna

GBAS Airborne equipment

- Precision approach: GBAS avionics standards:
  - Mimic the ILS in terms of aircraft system integration (ILS-look-alike scaling and deviation output)
  - Minimize impact of installing GBAS on existing avionics
- Multi-Mode Receiver (MMR):
  - Due to the ICAO precision approach transition strategy:
    - A mix of systems is possible (ILS / MLS / GLS : XLS)
    - MMR offers a great flexibility to users
    - No hardware update is foreseen (software only)
  - When not applying differential corrections from a GBAS station:
    - The receiver functions in GPS or SBAS mode (if available and suitable)

GBAS Corrections

Message type	Message name
1	Code pseudorange correction
2	GBAS related data
3	Acquisition of pseudolite data (GBRS)
4	Final Approach Segment (FAS) data
5	Predicted ranging source availability
6	Reserved (Cat II/III)
7	Reserved (national applications)
8	Reserved (test)

- E.g. GBAS message MT1
  - Message information: Global data
    - Modified Zcount (reference time)
    - Message flag
    - Number of measurements (N)
    - Measurement type (C/A L1, …)
  - Satellite measurements block: specific data for each satellite
    - Ranging source ID
    - IODE (Issue Of Data Ephemeris)
    - PRC (Pseudorange Corrections)
    - RRC (Range Rate Corrections)
    - Integrity related data (eg., GS receivers noise uncertainty)
    - …

GBAS information from ANSP

- EUROCONTROL:

https://www.eurocontrol.int/concept/ground-based-augmentation-systems

- FAA:

https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/laas/

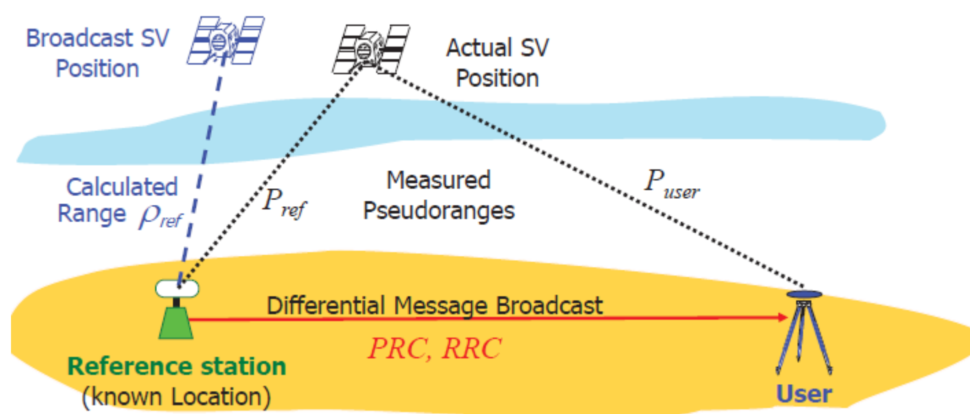
- CAD News on GBAS:

https://www.cad.gov.hk/reports/an2017-2018/en/ch6_07.html

https://www.indracompany.com/en/noticia/indra-successfully-completes-gbas-flight-trials-hong-kong-cad

Differential GPS (DGPS)

- The reference station(s) provides information to the end user via a data link that may include:
  - Corrections to the raw end user's pseudorange measurements, corrections to GPS satellite-provided clock and ephemeris data, or data to replace the broadcast clock and ephemeris information;
  - Raw reference station measurements (e.g., pseudorange and carrier phase);
  - Integrity data (e.g., "use" or "don't use" indications for each visible satellite, or statistical indicators of the accuracy of provided corrections);
  - Auxiliary data including the location, health, and meteorological data of the reference station(s).



Carrier-Smoothed Code Pseudoranges

- The noisy (but unambiguous) code pseudorange measurements can be smoothed with the precise (but ambiguous) carrier phase measurements.
- Carrier-smoothed-code (CSC) algorithm is an effective pseudorange multipath mitigation technique, which can alleviate the computational burden and reduce the communication bandwidth needed for the transmission of GPS observations.
- Why CSC does not contain carrier ambiguity?
- $\bar{\rho}_g = \overline{\rho - \varphi} + \varphi$
- $\bar{\rho}_a = \overline{\rho - \varphi} + \varphi$

$$\bar{\rho}_{\mathrm{g}}(t) = \alpha\rho(t) + (1-\alpha)[\hat{\rho}(t-T) + \varphi(t) - \varphi(t-T)]$$

Derivation of the corrections

- Using the broadcast ephemeris and clock data, the reference receiver estimates, thanks to its known location, the ref. pseudorange PR_{ref} from the sat to its antenna
- This reference pseudorange is affected by the sum of iono, tropo, residual ephemeris and clock error, multipath, noise and interference errors at the reference receiver site
- Comparing this value with the actual pseudorange measurement made by the reference receiver, the receiver deduces a pseudorange correction for each tracked satellite
- These pseudorange corrections are transmitted to the airborne receivers, using proper links and data formats, so that they can correct their measurements PR:
  - $PRC=PR_{ref}-PR_{act}$
  - $PR_{corrected}=PR+PRC$

GBAS Accuracy

- Only the errors common to the reference and user receiver can be eliminated: this includes all errors (iono, tropo, clock and ephemeris) except the local ones (eg. multipath, interference, receiver noise).
- It can be shown that the final corrected pseudorange error is of the order of 1 m when:
  - The airborne user receivers are close to the reference receiver (<100km)
  - Delay between corrections elaboration at reference site and application in user receiver is short (<5s)

GNSS Threats in Civil Aviation

- differences between Accuracy and Integrity
- Integrity is most critical for safety of life applications, e.g. civil aviation
- GNSS threats are the sources of harm for integrity in civil aviation
- Characterized threat types: satellite clock and ephemeris threat, ionosphere threat, signal deformation threat, code carrier divergence threat

Satellite Clock and Ephemeris Error

- Between 1999 and 2007, the broadcast ephemeris errors greater than 50 meters occurred on 24 different occasions. An outlier occurred on April 10, 2007, when the broadcast ephemeris for Space Vehicle (SV) 54 contained an error of at least 350 meters.
- Large clock runoffs were experienced on SV22 on July 28, 2001; SV27 on May 26, 2003; SV35 on June 11, 2003, and SV23 on January 1, 2004. These events generated range measurement errors of 1000 meters or more. The pseudorange error on SV22 on July 28, 2001, was reported to be 200,000m by some users and 300,000m by others.

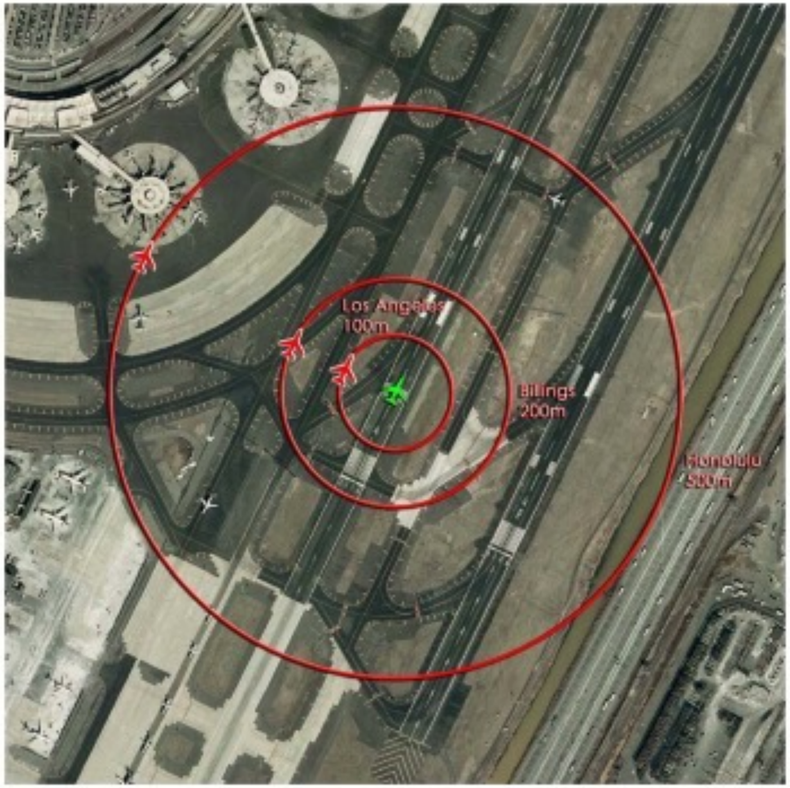
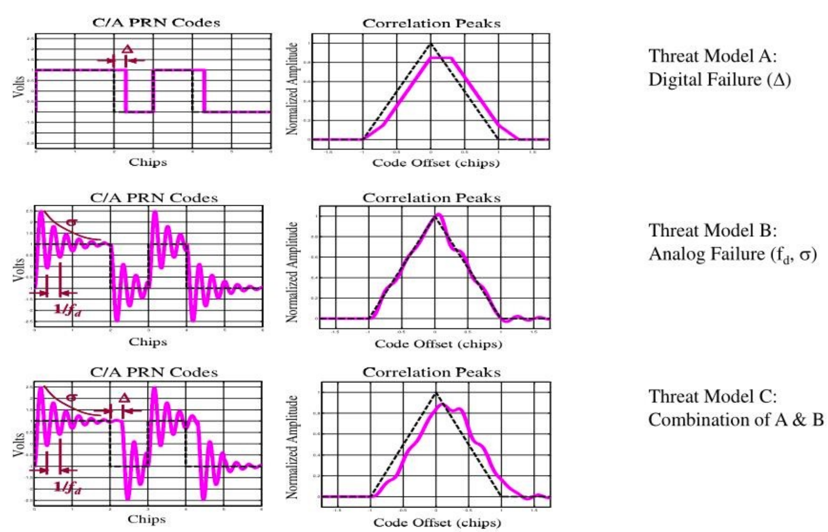


Fig. 1. ***An unflagged maneuver on April 2007 caused ephemeris errors in one GPS satellite. This ephemeris error caused location-dependent position errors of up to 500 m on receivers without detection capability. Clock runoffs cause similar errors about twice a year.***

Signal Deformation

- In the Fall of 1993 signal deformation from SV19 was observed. The falling edge of the digital modulation was not synchronous with the master clock carried by the satellite and was actually occurring approximately 30 nanoseconds ‘late’. This lag caused a ranging error of approximately 3 meters. This situation was corrected by switching from the active modulation unit to a backup unit available on all GPS satellites



Ionosphere Threat

- Since the GPS signals occupy L-band the ionosphere nominally introduces a delay of a few meters during the day and approximately one meter at night. Nominally, the spatial and temporal variation in this delay is very smooth and readily correctable. However, every solar cycle contains a number of ionospheric storms where the propagation delay is much higher and spatial and temporal gradients exist as well. 40 significant events was recorded in the last solar peak period.

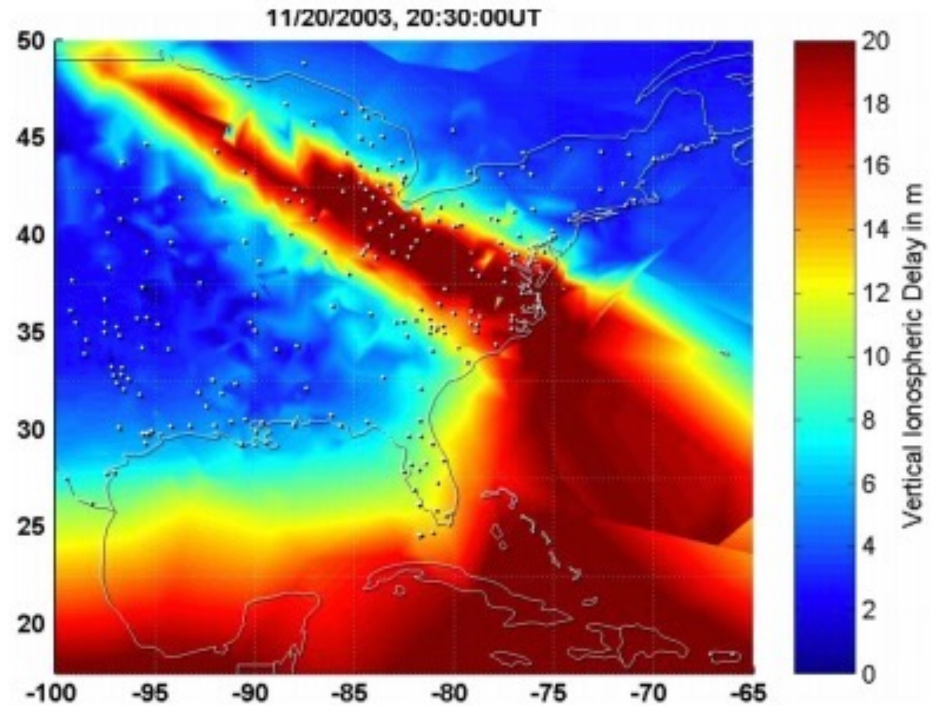


Fig. 2. *Ionospheric storms, such as the one that occurred in November 2003, cause large pseudorange delays. Single-frequency users rely on smooth ionospheric models which cannot capture these features spatially or temporally (figure courtesy of Seebany Datta-Barua). The map above shows the vertical delay: actual range delays can be up to three times as large.*

Integrity Monitoring with GBAS

- The GBAS SIS integrity is monitored by the ground GBAS sub-system and a real-time positive indication that SIS integrity is ensured is provided.
- The GBAS ground sub-system monitors the quality of all the system signals as well as the ground and space segments.
- The xPL computed by the airborne GBAS receiver assumes
  - a fault-free airborne receiver,
  - pseudoranges corrected by GBAS data affected by noise only - the other failures being detected by the ground sub-system,
  - plus the assumption that one of the reference receiver may be faulted.
- The constellation accounted is the common constellation used by both ground and airborne subsystems.

GBAS CAT I Integrity Risk Allocation