

5th European Space Weather Week

EFFECTS OF IONOSPHERIC EVENTS ON SATELLITE NAVIGATION SYSTEMS AS USED FOR AVIATION

**A. Lipp, R. Farnworth, F. Salabert
EUROCONTROL**

**Key source: ICAO NSP Paper
“Ionospheric Effects on GNSS Aviation Operations”**



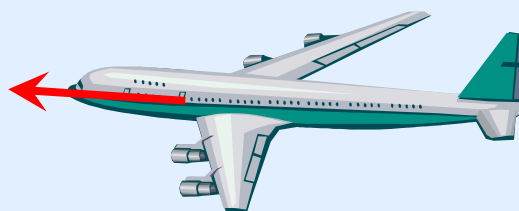
Aviation Use of Satellite Navigation Systems

Use for:



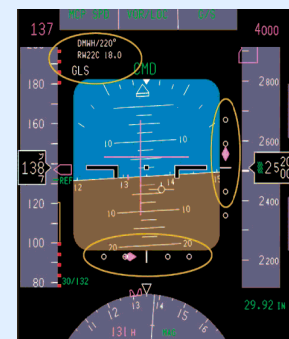
Time

Position



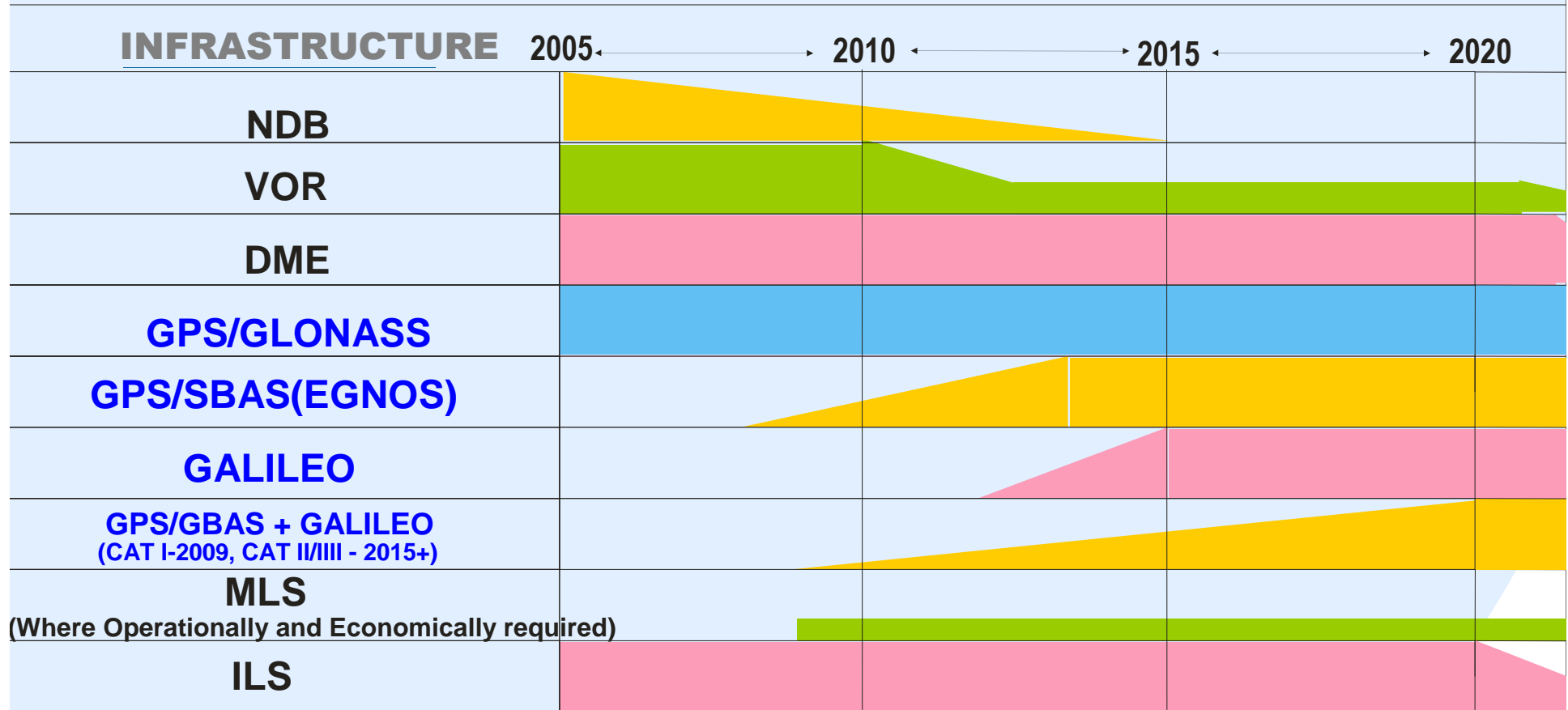
Velocity

Approach guidance
(with path data)

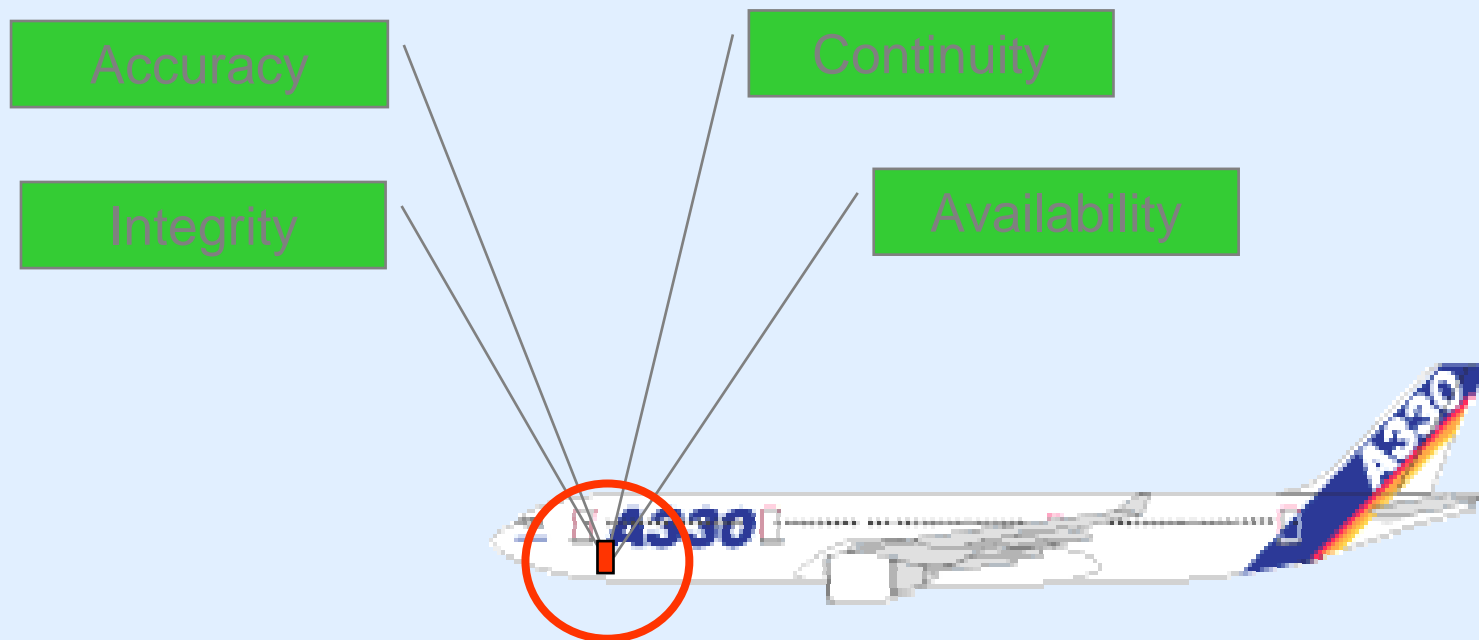


- GPS and GLONASS in standards, GALILEO in future
- Gradual increase in use of GNSS for all phases of flight

EUROCONTROL Navigation Strategy



Key Performance Requirements



Use only with **augmentations**

- ABAS (RAIM, Baro-RAIM, AAIM)
- SBAS (WAAS, EGNOS, MSAS, ...)
- GBAS (LAAS, ...)

Relevant Space Weather Effects

- Relevant effects on the satnav signals
 - Functioning of the **satellites** in MEO/GEO orbits
 - ⇒ Design issue (not covered here)
 - **Ionospheric** transmission variations
 - Key influence – **largest single error source for GNSS systems**
 - **Tropospheric** transmission variations
 - Indirect effects, minor in respect to iono (not covered here)
- Key task of augmentation is assurance of **Integrity** (Safety)
- Degradation of **Accuracy** ⇒ loss of **Availability**
- Loss of **Availability** during operation ⇒ loss of **Continuity**

Availability is mainly an economic factor

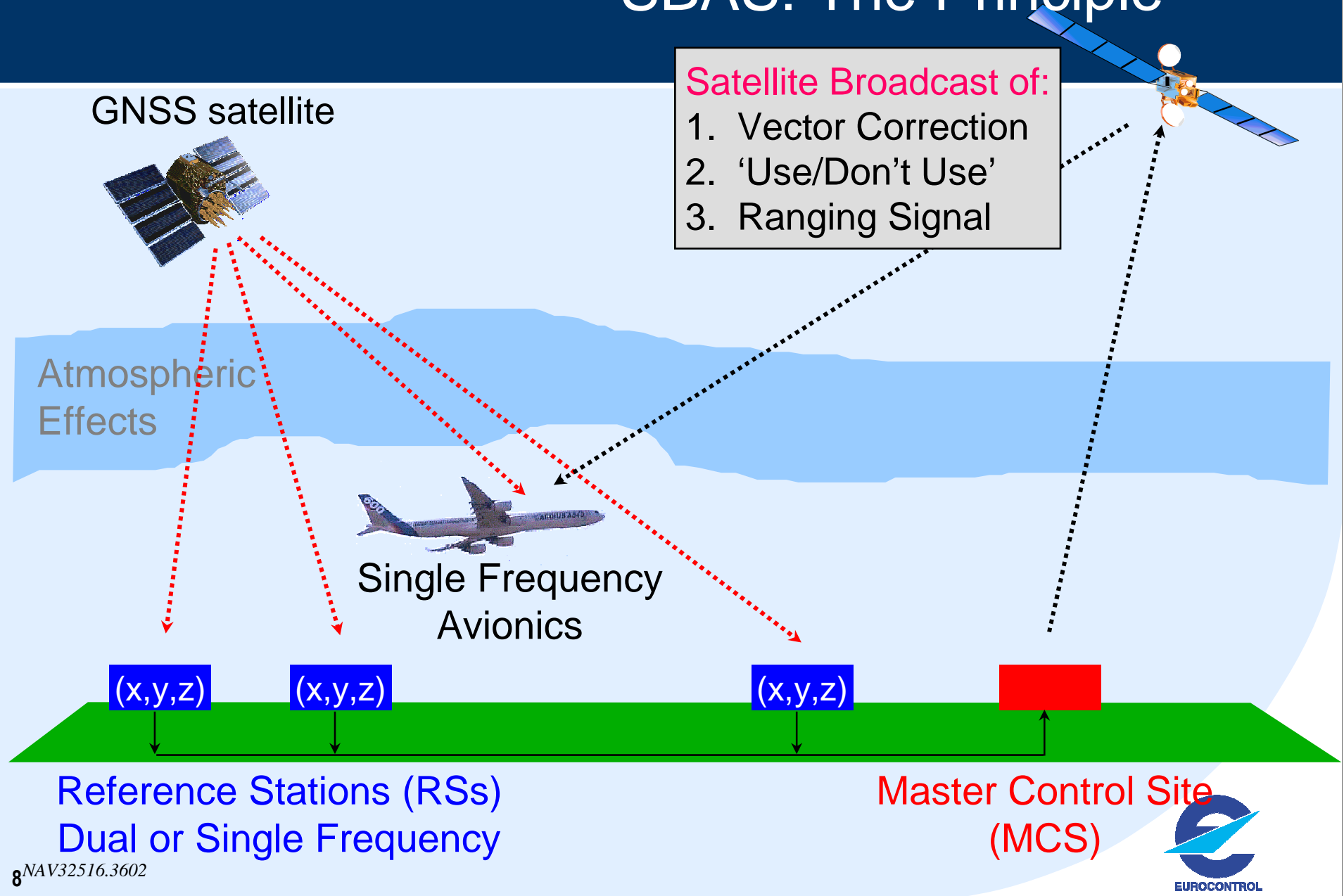
Ionospheric Effects in Detail

- Group delay \Rightarrow **Integrity, Accuracy, Availability, Continuity**
 - Frequency dependent
 - Direct pseudorange measurement influence
- Scintillation (amplitude/phase) \Rightarrow **Availability, Continuity**
 - Frequency dependent
 - Influences Signal/Noise Ratio
 - May lead to loss-of-lock
- Faraday rotation (polarization)
 - GNSS signals are circular polarized \Rightarrow **no major influence**

Effects on ABAS Systems

- Single GNSS receiver
 - Integrity algorithm depends on satellite redundancy
 - Klobuchar model (GPS) accounting for 50-80% of group delay error – designed for average conditions
 - Performance reserves (En-route, non-precision approach)
- Current issues:
 - Loss of redundancy due to fading
(Mitigation: Tracking loop design)
 - Risk of storm effects with horizontal position error > 100m?
- In future:
 - Issues linked to use of dual-frequency receivers (L1/L5) ?

SBAS: The Principle



EGNOS: Ground Segment



● Control Center

● Ranging and Integrity Monitor Station

● Uplink

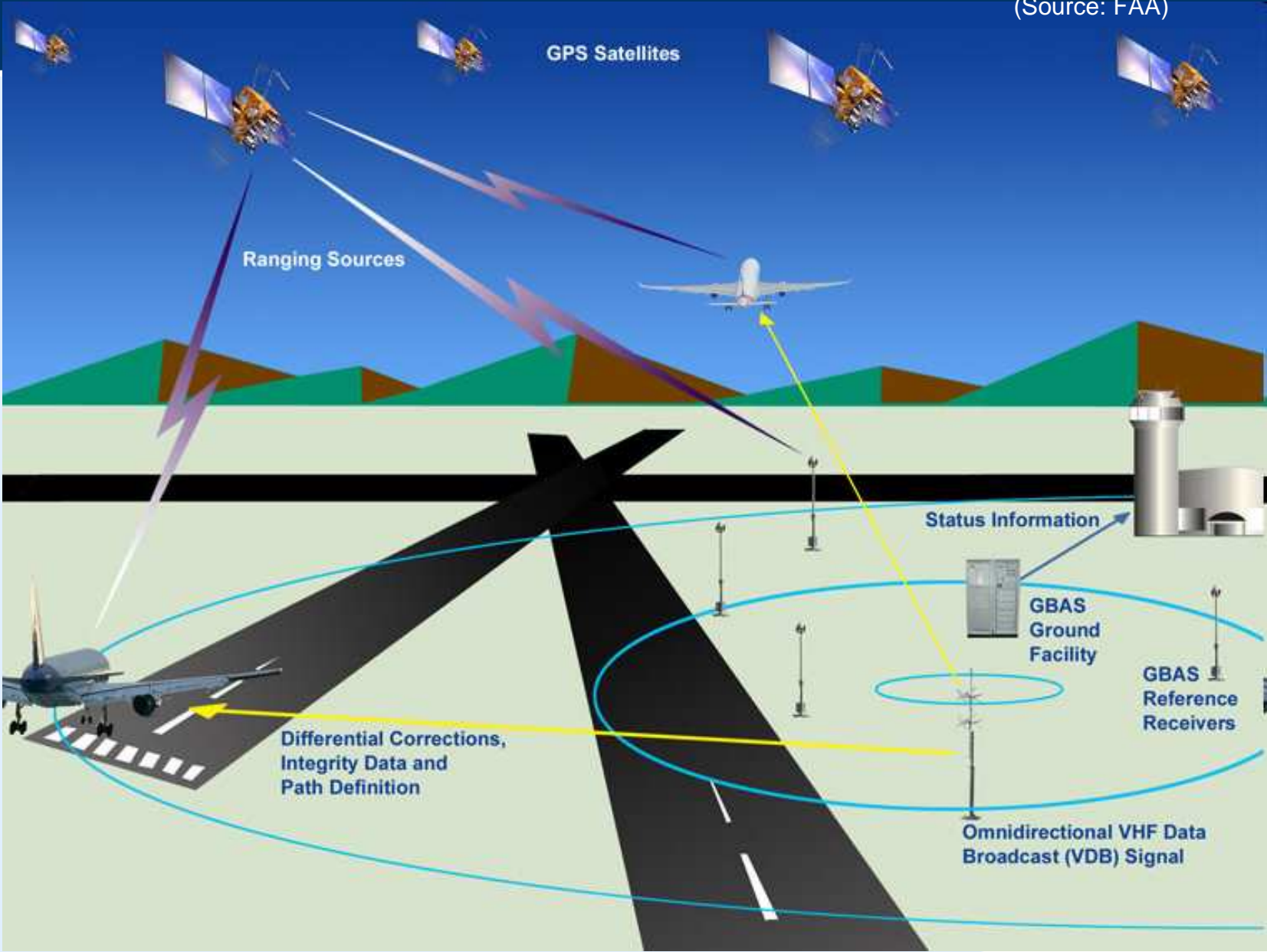


Effects on SBAS Systems

- Aircraft outside SBAS coverage \Rightarrow as for ABAS receiver
- Aircraft inside SBAS coverage area
 - No measurement redundancy required
 - Iono corrections on grid, fixed grid size poses limitation
 - GEO link (data message) is fade sensitive (Mitigation: Dual GEO)
 - Approach (APV,PA) requirements critical in equatorial regions
- Ground system reference receivers
 - L2 codeless receivers (iono delay estimation) – fade sensitive
 - By 2020 to be replaced by L1/L5 receivers
- SBAS Iono Working group meeting during ESSW

GBAS: The Principle

(Source: FAA)



Effects on GBAS Systems

- Use only within ground system coverage
 - Only relative effects (ground system – aircraft)
 - No iono influence on correction link
 - Effects decrease with decreasing distance
 - Fading for ground system less relevant due to spatial redundancy
- Performance requirements extremely high
- “History” of errors due to smoothing relevant
- Unobservable storm effects

Ionospheric Storm Integrity

- **Ionospheric storm activity **unobservable** to a GBAS station can not be mitigated by detection**
- **The GBAS airborne user can be impacted by a storm before the ground facility can see it, and integrity could be compromised**
 - These cases must be shown to be sufficiently rare, or mitigated
- **The ionospheric tiger team has determined a solution for the CAT I system**
 - The results are based on ionospheric storm threat model created from data collected within CONUS and assumptions about how a user will be threatened
 - **Other implementer must evaluate their ionospheric environment to ensure that the CONUS threat model contains potential threats in their regions of interest**

Mitigations for GBAS Systems

- Current
 - Inflation of integrity parameters to cover storm risk
 - Limitation of coverage range
 - Tracking loop design against fades
- Future
 - Single Frequency
 - Ionospheric storm responsibility not on ground system
 - Airborne differential smoothing and geometry monitors
 - Dual Frequency
 - Ionospheric-free and divergence free solutions
 - Airborne monitors

⇒ **research needed**

Ongoing/Future Work

- Complete modeling efforts (existing data)
- Measurements networks at adequate scale
- Validate current models during next solar Max.
- Monitor system performance continuously
- Improve threat models on global and notably regional scale

- Service providers and certification authorities are working on all these measures
- More research needed on fade robustness and benefit of multi-frequency systems

Questions?

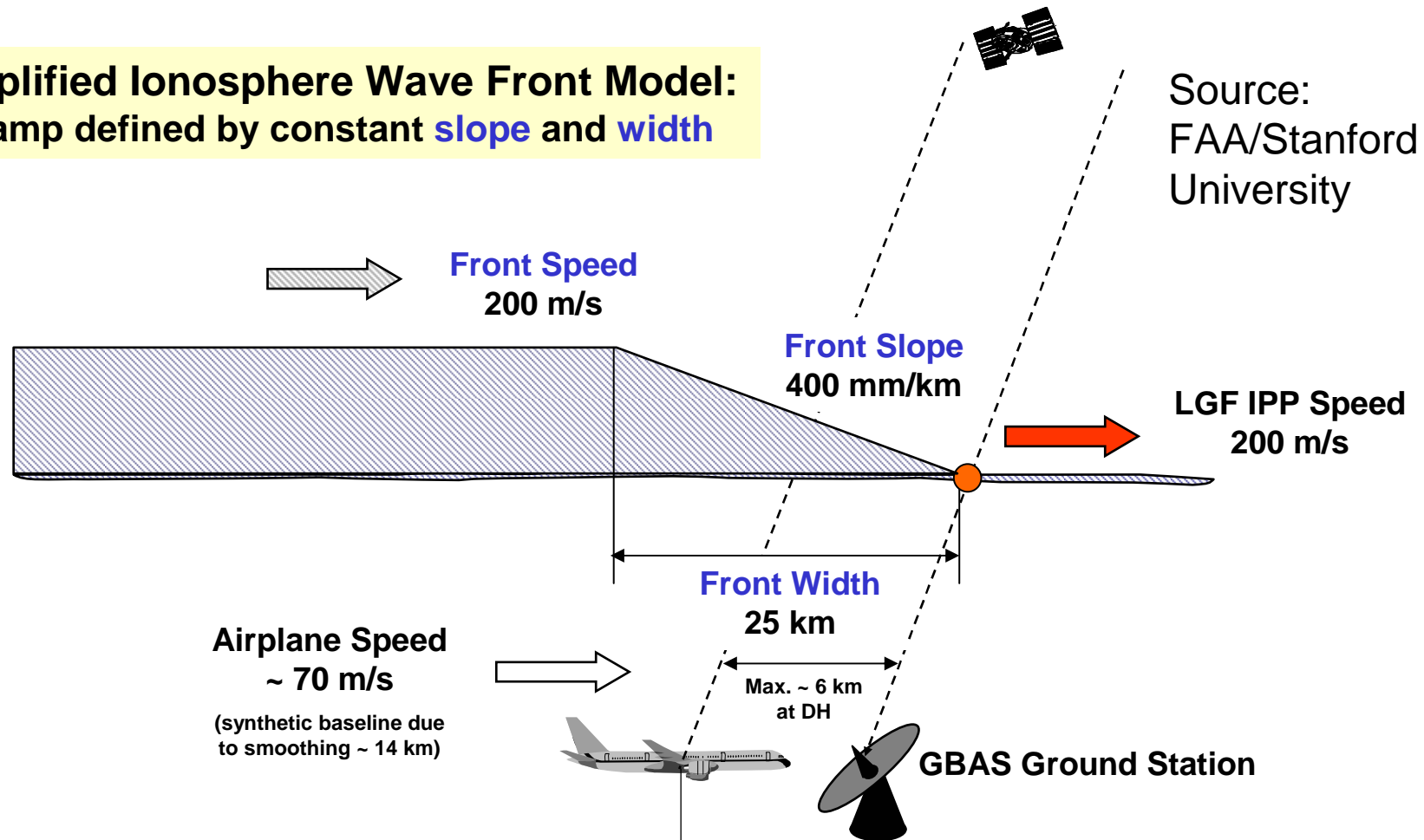
Key sources and further information:

- ICAO NSP Paper: GNSS Aviation Operations
([contact presenter](#))
- SBAS Iono Working Group
<http://propagation.esa.int/sbas-iono/>
- SBAS: EGNOS information
<http://www.egnos-pro.esa.int/index.html>
- International GBAS WG - OneSky online:
<http://extranet.eurocontrol.int>
- Flygls (GBAS Implementation)
<http://www.flygls.com>
- EUROCONTROL Navigation Strategy:
<http://www.ecacnav.com>
- FAA Satellite Navigation Website
<http://gps.faa.gov/>



Ionosphere Anomaly Wave Front Model: *Potential Impact on a GBAS User*

Simplified Ionosphere Wave Front Model:
a ramp defined by constant **slope** and **width**



Stationary Ionosphere Front Scenario:

Ionosphere front and IPP of ground station IPP move with same velocity.

Maximum Range Error at DH: $425 \text{ mm/km} \times 20 \text{ km} = 8.5 \text{ meters}$

Abstract

Aviation uses satellite navigation systems (GNSS – Global Navigation Satellite Systems) for a rapidly increasing number of applications. From initial applications in the en-route phase, to precision approach and landing and including surveillance applications such as ADS-B as well as the synchronisation of communication systems the aviation community is becoming more and more dependent on GNSS for both position and time information.

As an example, ionospheric effects on navigation applications using the different GNSS augmentations, notably space- and ground based, are discussed in this presentation. Three major aviation augmentation systems are currently defined:

ABAS – aircraft based augmentation systems,

SBAS – space based augmentation systems and

GBAS – ground-based augmentation systems

In all three augmentation systems, GNSS receivers are sensitive to loss-of-lock or the inability to capture the low intensity ranging signals under strongly disturbed ionospheric conditions. In addition space weather effects on the satellites themselves can reduce signal availability. Lower levels of disturbance may affect the systems as well, but in different ways:

- For ABAS systems a GNSS receiver in the aircraft calculates integrity information based on redundant GNSS measurements or information from other sensors onboard the aircraft, such as inertial or barometric systems. When using redundant satellite information (RAIM), correlated propagation effects, such as ionospheric effects may reduce the effectiveness of the algorithms used.
- SBAS systems provide an estimation of ionospheric effects through a network of ground-based reference stations. Central algorithms try to either detect or compensate for ionospheric disturbances, but may not be able to correct for all types of disturbances, affecting system availability.
- GBAS systems are based on a single ground system and, although designed to bound any potential error sources with sufficient integrity, may not be able to detect all relevant disturbances. The resulting conservative assumptions in the error estimations may affect system availability, notably at large distances from the ground system.

In general terms, the adequate monitoring and prediction of the space weather and the availability of technologically advanced receivers are the main mitigations against the effects of the solar activity on the GNSS signals. Significant measures are being taken by service providers, certification authorities and user representatives to limit the impact of space weather effects. These include detailed reviews of data collected in the past. However, reuse of data collected for other purposes may miss specificities of the aviation threat model, so further work is necessary and measurement campaigns for the next solar maximum are currently being planned.