INTERNATIONAL CIVIL AVIATION ORGANIZATION

A United Nations Specialized Agency

ICAO PBN Workshop

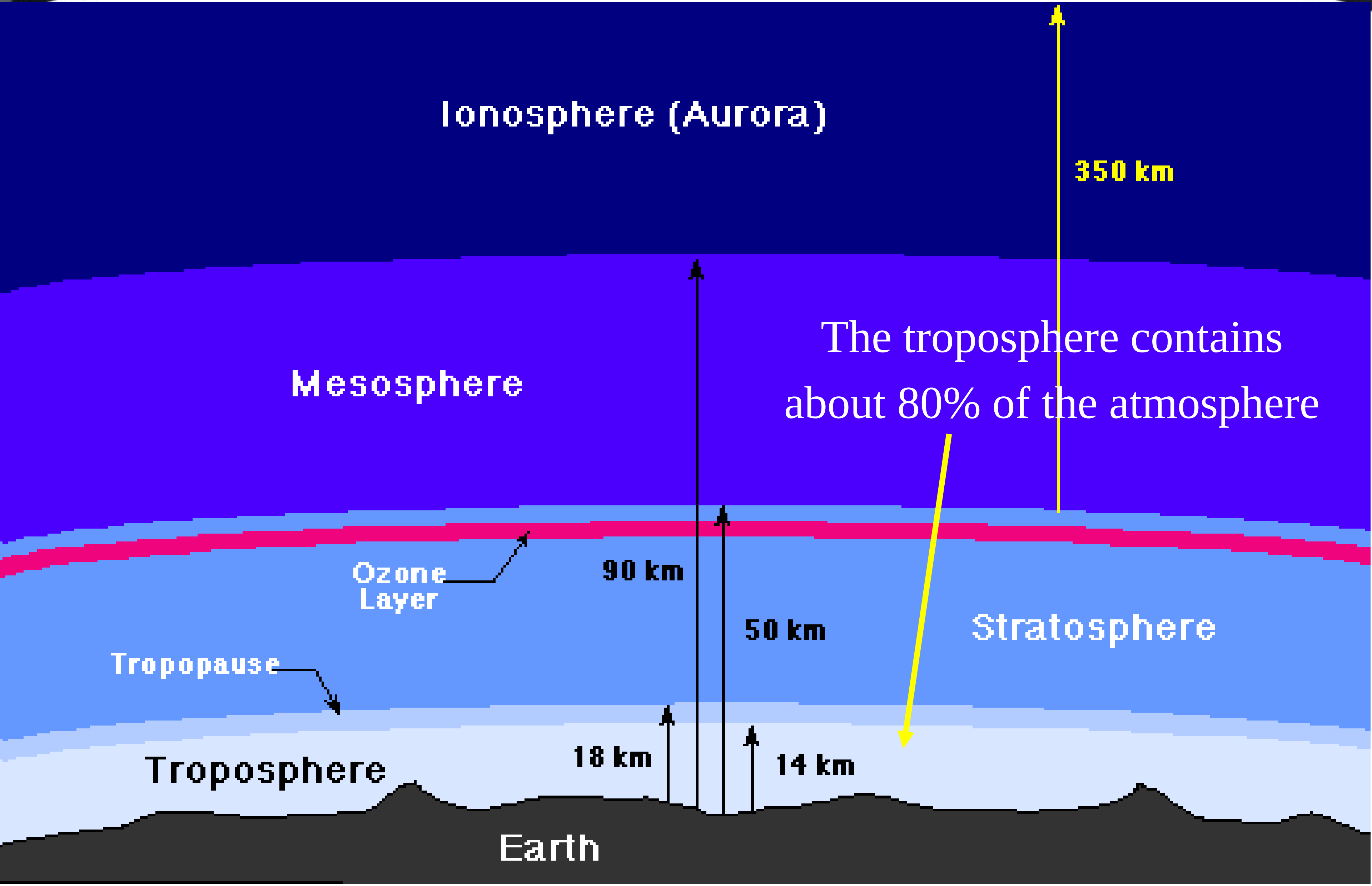
Ionospheric and Tropospheric Effects on GNSS

15-17 Aug 2016

Purpose

- Provide information of ionospheric and tropospheric effects on GNSS
- Provide overview of GBAS safety case project

Earth’s Atmosphere



The troposphere contains about 80% of the atmosphere

Tropospheric Effects

- The effect of the troposphere on the GNSS signals appears as an extra delay in the measurement of the signal traveling from the satellite to receiver.
- Delay depends on the temperature, pressure, humidity as well as the transmitter and receiver antennas location.
- Two Primary Delays:
  - Hydrostatic component delay:
    - Caused by the dry gases present at the troposphere.
    - Effects vary with local temperature and atmospheric pressure in a very predictable manner,
    - Variation is less that the 1% in a few hours.
  - Wet component delay:
    - Caused by the water vapor and condensed water (clouds)
    - Delay is small - tens of centimeters but random and difficult to model.

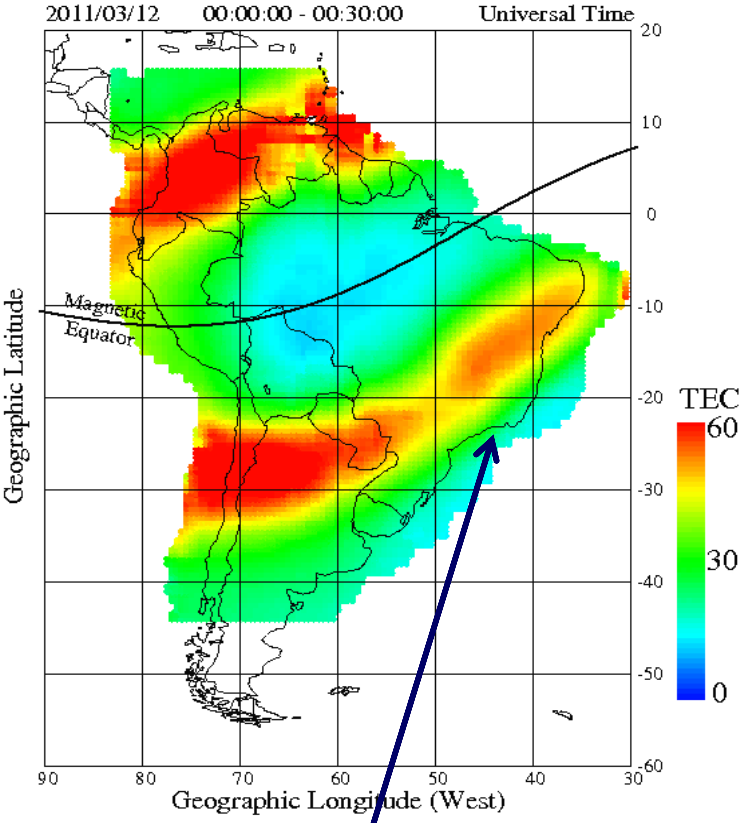
Ionospheric Effects

- The ionosphere is a highly variable and complex physical system.
  - Region between 250 and 400 km
- Depletions – spatial and temporal gradient inducing ranging errors
  - Can be mitigated by dual frequency
- Scintillation- patches of irregularities that can induce ranging errors and loss of lock
  - Cannot necessarily be mitigated by dual frequency
- Other spatial gradients
  - Tight spatial gradients in the anomaly regions
  - Post-midnight enhancements
  - Geomagnetic storms
- All threats are highly variable
  - Local time, day-to-day, season, geographic location, geomagnetic activity, SOLAR ACTIVITY!

The Equatorial Ionosphere

- Region of the world with the most dynamic geophysical environment that includes the highest values of range error, the strongest spatial gradients over latitude, and the most frequent and intense occurrence of plasma bubbles and scintillation in the worldwide ionosphere.

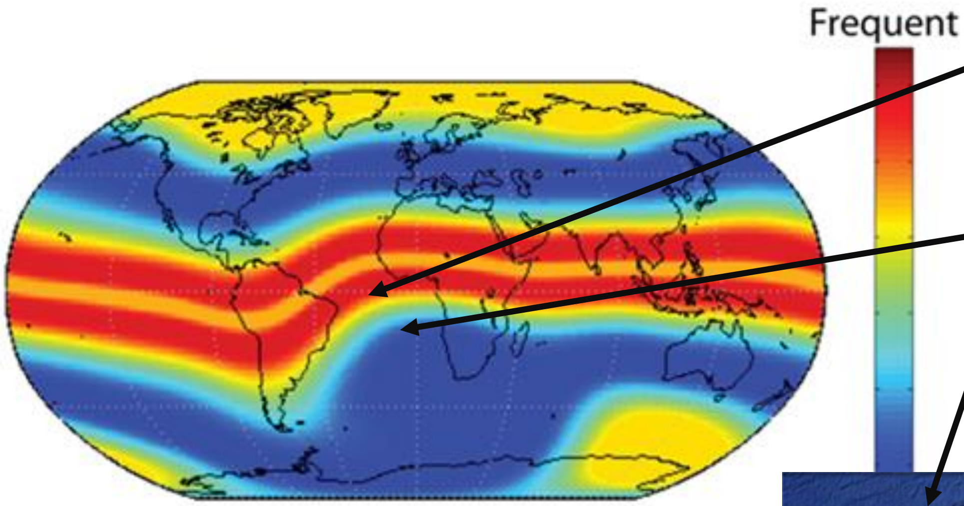
- Space weather affects GPS and hence GBAS which uses GPS; GBAS provides an extremely high level of safety by design so it is intentionally sensitive to the disturbances.



Solve Rio, solve space weather for GBAS at similar latitudes around the globe.

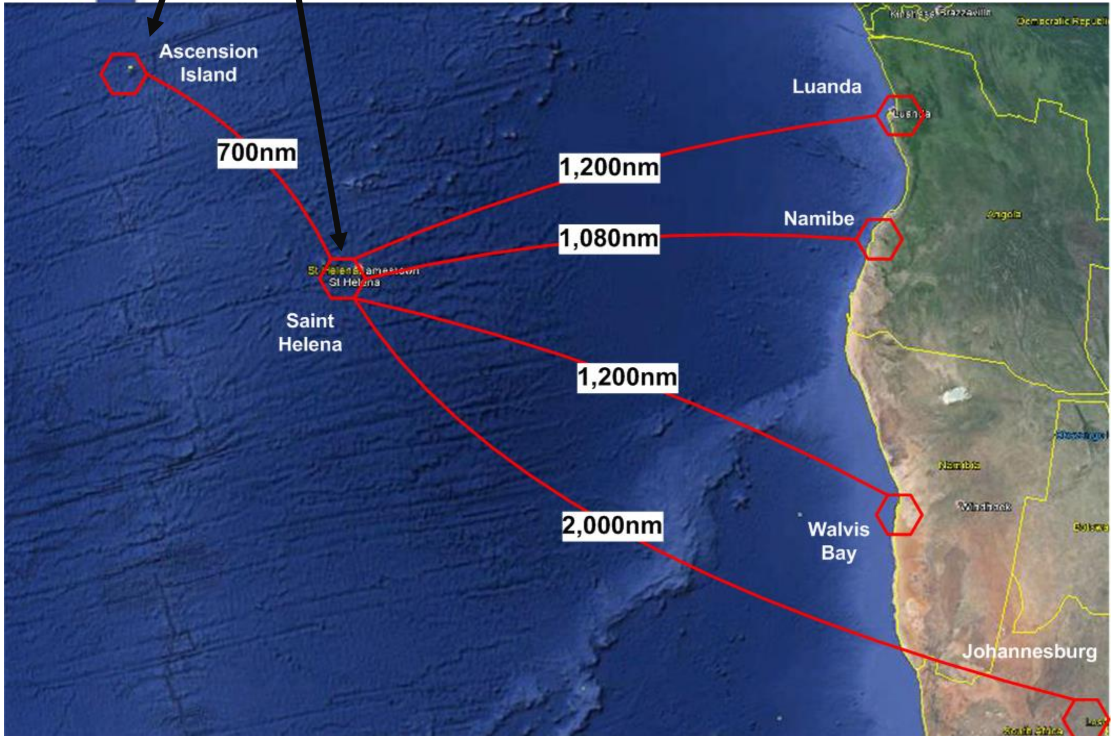
Courtesy of Institute for Scientific Research, Boston College

St. Helena (UK) Threat Model



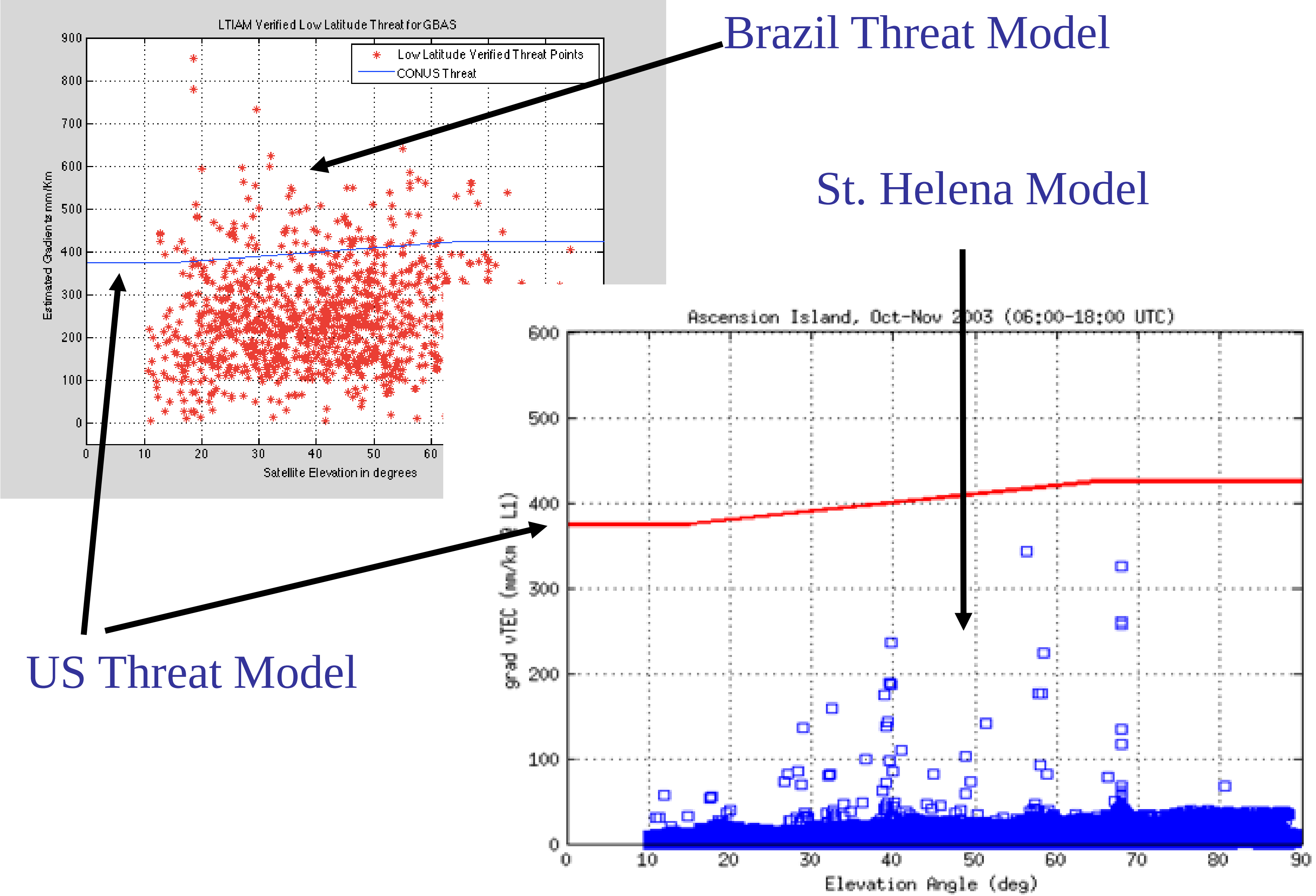
Ascension Island

St. Helena Island, UK



- Each installation should validate the threat model to ensure operational compliance as part of the System Design Approval Process
- St. Helena validation used Ascension Island data because it was worse case

St. Helena Island, UK Threat Model



Brazil Threat Model

St. Helena Model

US Threat Model

Threat Model Findings

- Low Latitude Threat model project findings:
  - Low latitude ionospheric threat is significantly greater in frequency and magnitude from the US.
  - Use of the US threat model in the low-latitudes does not meet ICAO integrity requirements established for GBAS operations
  - To meet Annex 10 requirements a separate safety case must be accomplished in order to certify GBAS operations in low latitudes
- Why is the follow on project required
  - Space weather affects GPS and hence GBAS which uses GPS; GBAS provides an extremely high level of safety by design so it is intentionally sensitive to the disturbances.
  - Required for System Design Approval (SDA) in low latitudes
  - Allows DECEA/FAA team to address the issues together
  - Promote standardization - in revenue passenger service in other locations around the globe and installed on Boeing, Airbus, Embraer, Bombardier, etc.
  - Unlock global GBAS operations
  - Promote PBN and ASBU implementation

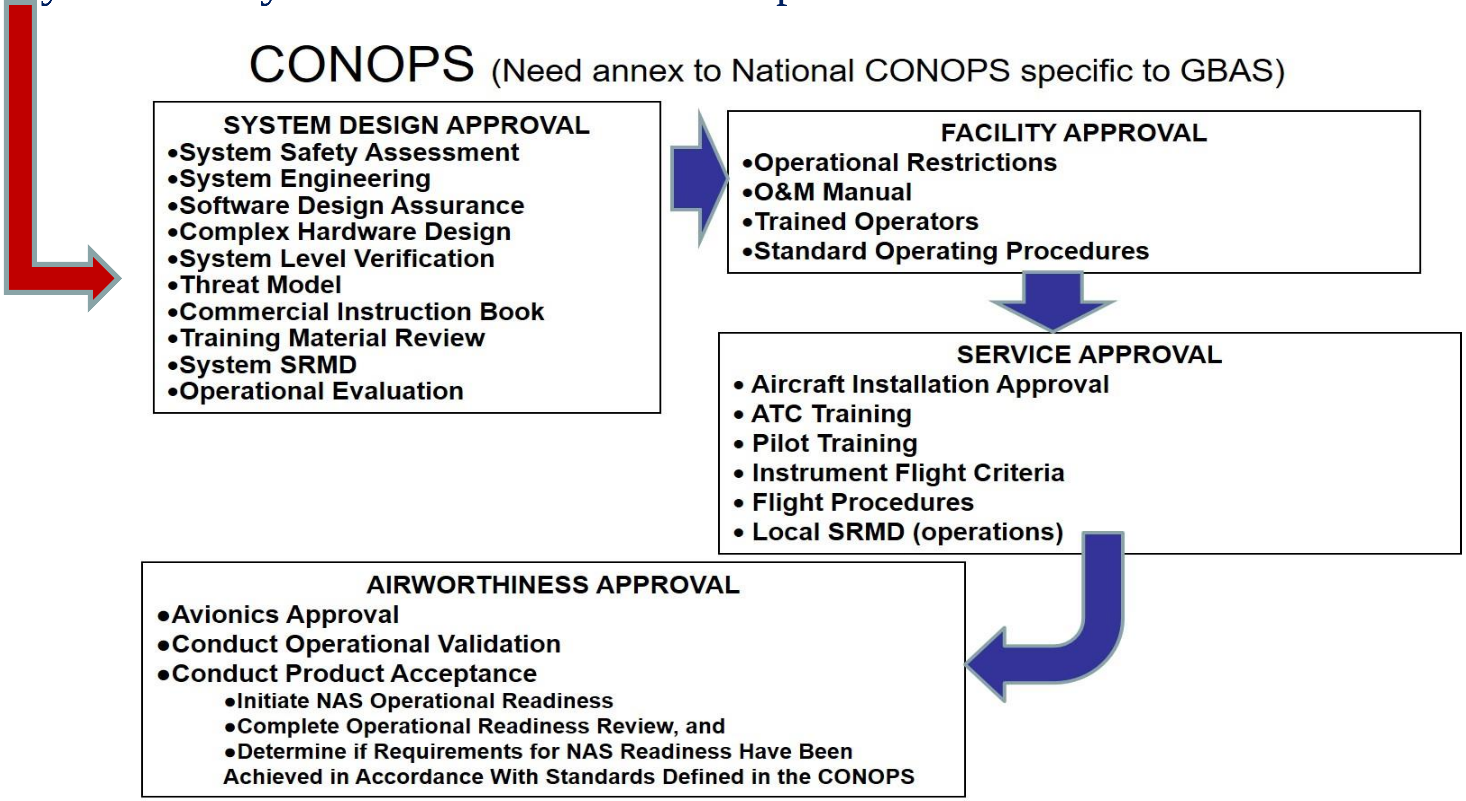
St. Helena Approval Strategy

- ***Interim Operational Approval***
  - Based on findings – grant interim operational approval to Comair for revenue service between the hours of 0800 and 1600 local time
    - GLS & RNAV/VNAV minima
  - UK, airline regulator and ICAO requirements for training (crews, ATC, etc.), documentation (SDA), and flight procedures apply
  - Conduct more formal approvals during Phase II

- ***Final Certification/Validation***
  - Collect aircraft & ground data during Phase II to support final system certification
  - Complete required documentation (CONOPS, Air Worthiness and Service approvals)
  - Validate 24 hour operations (if possible)

Why is this important?

- Current threat model (GBAS) was assembled based on all observed ionospheric storm data collected within continental United States
  - The FAA effort focused on mid latitude threats
- Most of South America’s NextGen/SESAR/ASBU architecture is based on GNSS/GBAS providing the navigation component
  - Safety case is key to GBAS low latitude implementation



CONOPS (Need annex to National CONOPS specific to GBAS)

SYSTEM DESIGN APPROVAL
- System Safety Assessment
- System Engineering
- Software Design Assurance
- Complex Hardware Design
- System Level Verification
- Threat Model
- Commercial Instruction Book
- Training Material Review
- System SRMD
- Operational Evaluation

FACILITY APPROVAL
- Operational Restrictions
- O&M Manual
- Trained Operators
- Standard Operating Procedures

SERVICE APPROVAL
- Aircraft Installation Approval
- ATC Training
- Pilot Training
- Instrument Flight Criteria
- Flight Procedures
- Local SRMD (operations)

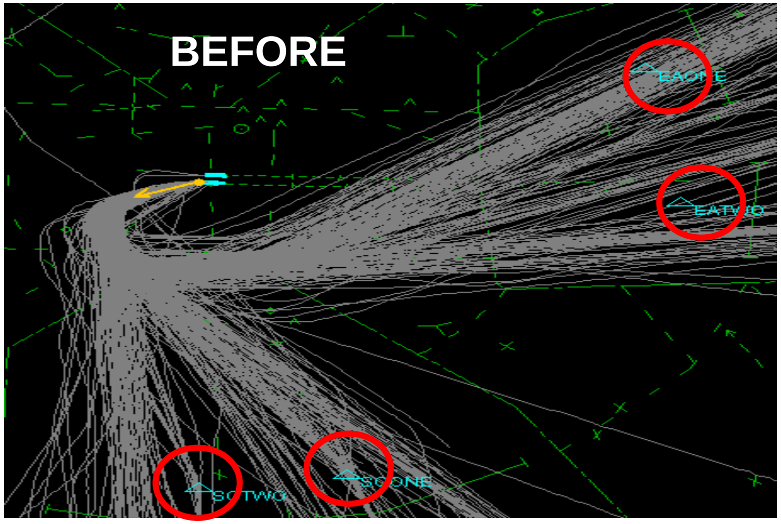
AIRWORTHINESS APPROVAL
- Avionics Approval
- Conduct Operational Validation
- Conduct Product Acceptance
  - Initiate NAS Operational Readiness
  - Complete Operational Readiness Review, and
  - Determine if Requirements for NAS Readiness Have Been Achieved in Accordance With Standards Defined in the CONOPS

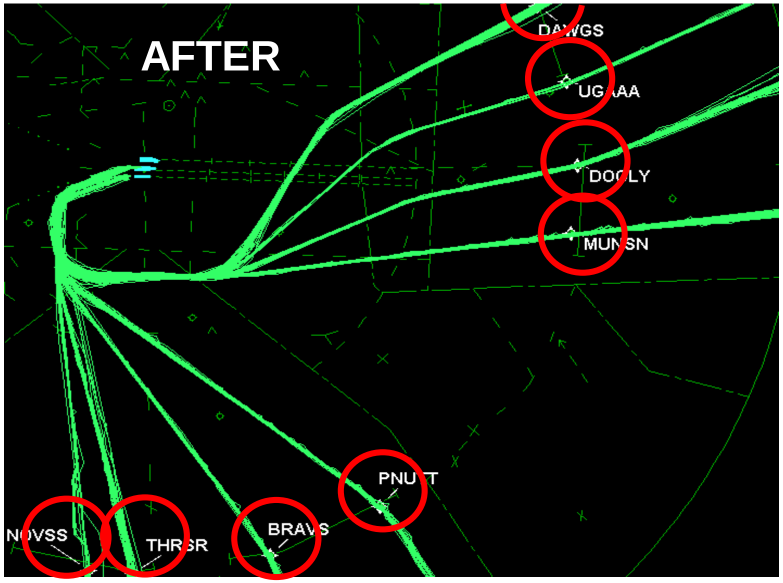
Foundational Capability for ASBU

Performance Improvement Areas	Block 0 (2013)	Block 1 (2018)	Block 2 (2023)	Block 3 (2028 & >)
Greener Airports	Optimisation of Approach Procedures Including Vertical Guidance (GBAS I)	Optimisation of Approach Procedures Including Vertical Guidance (GBAS II/III)		
	Wake Vortex Separation, Refined	Wake Vortex Separation (Time-based)	Advanced Wake Vortex Separation (Time-based)	
	Runway Sequencing	AMAN/DMAN Metroplex	Linked AMAN/DMAN	Integrated AMAN/DMAN/SMAN
	etc.	etc.	etc.	etc.

Tangible Benefits

- Predictable paths
  - Approach flexibility
  - Capacity gain of 9-12 departures per hour
  - Reduced communications
- Integrity of navigation position for Nextgen/ASBU ops
- Improved PBN/RNP operations
- Fuel savings per constant descent arrival (CDA) & departures
  - Average savings of 273 pounds of fuel per CDA at $0.273 per pound of fuel equals $75.87
- Automate routine ATC functions
  - Decreases workload, greater efficiencies
  - Procedural separation, transitions, clearances





GBAS Integrity Method

- Responsibility for Integrity resides in the GBAS Ground Facility
  - The user (aircraft) receives a set of integrity parameters in the broadcast and applies those in a set of standardized equations to determine protection levels
  - The user must check the calculated result against the requirement
    - A protection level bound, or Alert Limit, is transmitted from the GBAS with each procedure

- The Service Provider is responsible for ensuring that the uplink integrity parameters are accurate and that they provide the required function
  - When used in the specified equations, the protection level must always* bound the user error
    - *The probability of not bounding is the required integrity probability
      - CAT I is 2.0×10^{-7} per approach or one undetected event every 6.6 million approaches

Safety Case Approach

- Compliance must be demonstrated with the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) Annex 10
- The following areas will be the focus of the Safety Case:
  - Adjustment of the Vertical Alert Limit (VAL)
    - The current 10m VAL ICAO requirement can be changed based on a system-specific safety analysis per the notes for table 3.7.2.4-1
  - Addition of a far field monitor to the GBAS ground facility (GGF)
    - Use of monitor by ATC to determine GLS approach availability
    - Feed monitor data into SmartPath to automatically adjust sigma values
    - Not required at all airports
  - Investigation of various sensitivities of large gradients
    - Establish correlation between scintillation measurement and differential gradients observed between receiver pairs – specially for the SV track orthogonal to the receiver pair baseline

Safety Case Team

- Industry:
  - Mirus Technology - Prime contractor
  - Honeywell Aerospace - Subcontractor
- Government:
  - DECEA GBAS Team
    - Instituto de Controle do Espaço Aéreo (ICEA) – Certification Team Lead
    - Instituto Nacional de Pesquisas Espaciais (INPE)
    - SDTP
- FAATC
  - Stanford University/FAATC/KAIST/Boston College
- Team provides some of the world's leading experts on ionosphere, the Safety Management System (SMS) process, and certification.

Conclusions

- GBAS operations in low latitude cannot meet ICAO integrity requirements using mid latitude threat model
- Investigative Approach
  - Determine the following as individual items:
    - Acceptable maximum VAL for GBAS CAT I operations
    - Correlation between large gradients and SV IPP Tracks and S4 values
    - Viability of using a Far Field monitor to represent aircraft performance
  - Reach consensus on acceptable values for each and conduct research to determine aggregate value, if any
  - Collect data using modified ground station with airborne platform during high iono activity periods
- Develop viable safety case