International Civil Aviation Organization

THE FIFTH MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/5)

Okinawa, Japan, 16 – 18 February, 2015

Agenda Item 4: Review of progress of Task and related Action Items

e) Task 5 – Iono Models

IONOSPHERE THREAT MODEL FOR GBAS

(Presented by ENRI, Japan)
(Prepared by Takayuki Yoshihara and Susumu Saito)

SUMMARY

This paper presents a brief introduction of ionosphere threat model for GBAS (Ground-based Augmentation System).

1. Introduction

1.1 There are two kinds of ionospheric effects on GBAS. The first is ionospheric delay spatial gradient, which sometimes produces significant ranging errors. As the second, scintillation effect reduces available ranging source through loss of lock in signal tracking. It could reduce GBAS availability. GBAS messages are designed to mitigate effects of ionospheric spatial gradient under nominal condition. However, it is required to detect and exclude anomalous ranging sources with unacceptable error under anomaly ionospheric conditions.

2. Discussion

2.1 Threat model describes characteristics of the ionosphere from a view point of risks and defines the range of parameters that should be taken into account in designing a GBAS. Because ionospheric characteristics are different over the world, it is needed to develop ionosphere threat model through observation and simulation considering dominant ionospheric phenomena in each region.

3. Action required by the Meeting

3.1 The meeting is invited to do the following:

a) Develop ionosphere threat model considering characteristics in each region; and

b) Develop ionosphere threat model through observation and simulation analysis with appropriate methods.

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Ionosphere threat model for GBAS

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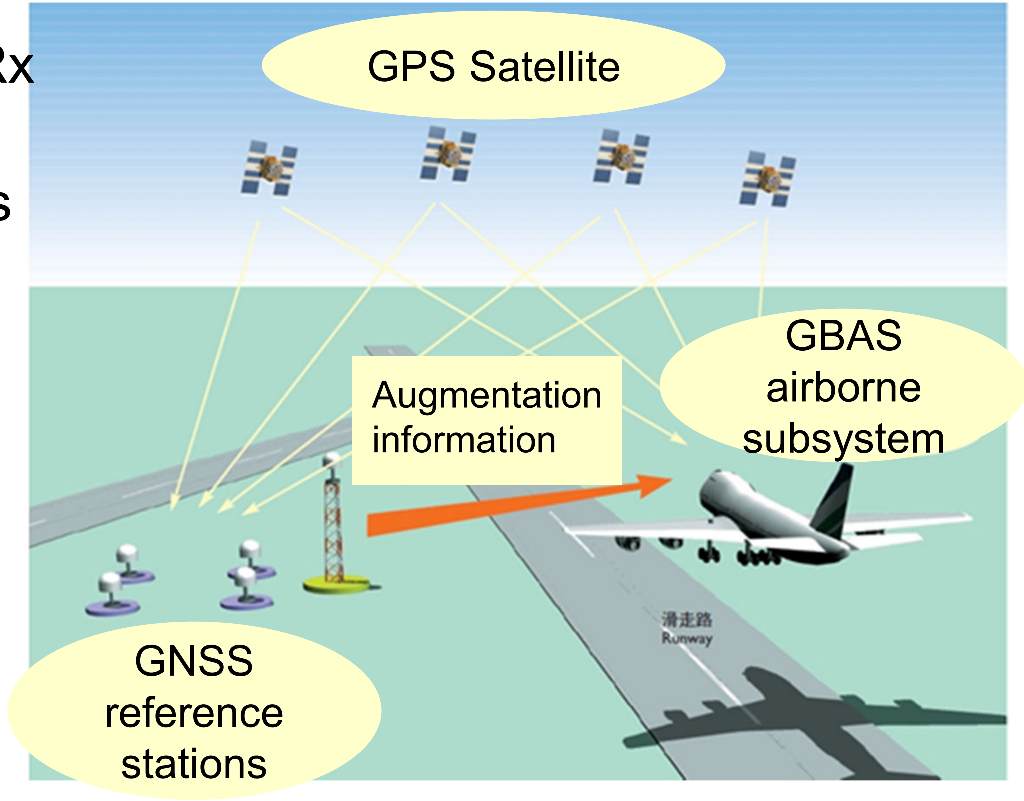
GBAS (Ground-based Augmentation System) Outline

- GNSS reference stations
  - Four sets of GNSS ANT & Rx
- Data processing system
  - Calculates range corrections and integrity information
  - Detects and excludes anomalous ranging sources including ground subsystem faults
- Transmitter of GBAS messages
  - VHF Data Broadcast (VDB)
  - Coverage: 20 NM (37 km)

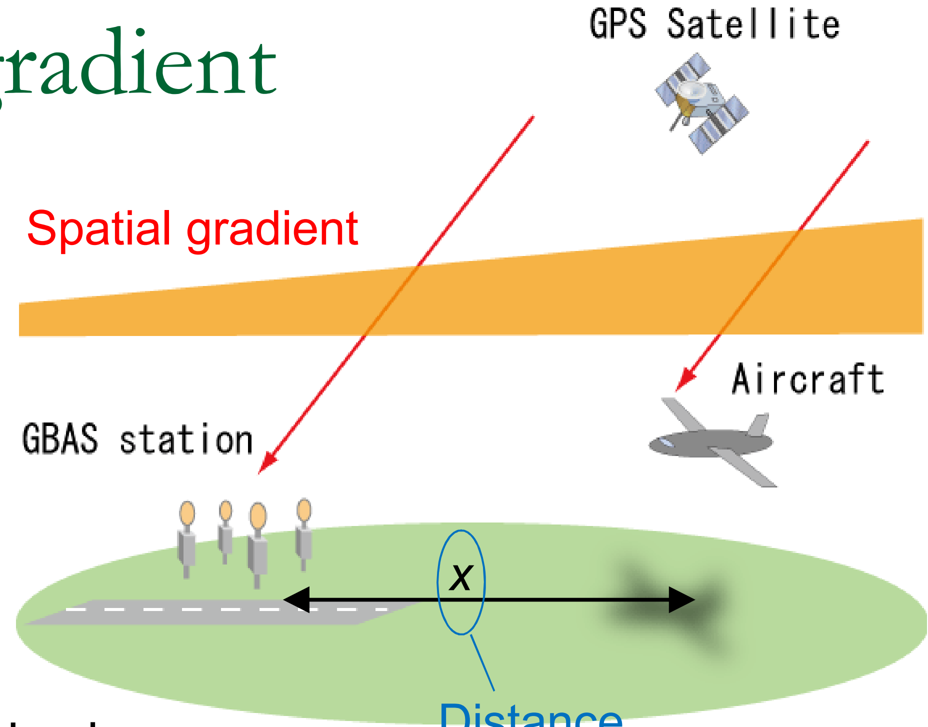


GBAS
Ionospheric delay correction

- GBAS: Based on differential positioning
  - Common error component
    - Between reference stations and a user near airport (~40km away) for each ranging source
    - Using known positions for reference stations
    - Satellite position and crock error
    - Ionospheric and tropospheric delays
  - Receivers' clock errors: averaged by four reference stations
- User's ionospheric delay
  - Almost removed under nominal conditions

GBAS
Ionospheric spatial gradient

- User's range error due to ionospheric delay (δI)
  - Spatial decorrelation
  - Carrier smoothing
- Carrier smoothing (CS)
  - Code range is smoothed based on carrier changes
  - Reduce receiver noise and multipath effect
- CS increases range error due to ionospheric effects
  - Code: delay
  - Carrier: advance
  - Depends on time constant and aircraft velocity



User's range error

Distance

Effect of CS

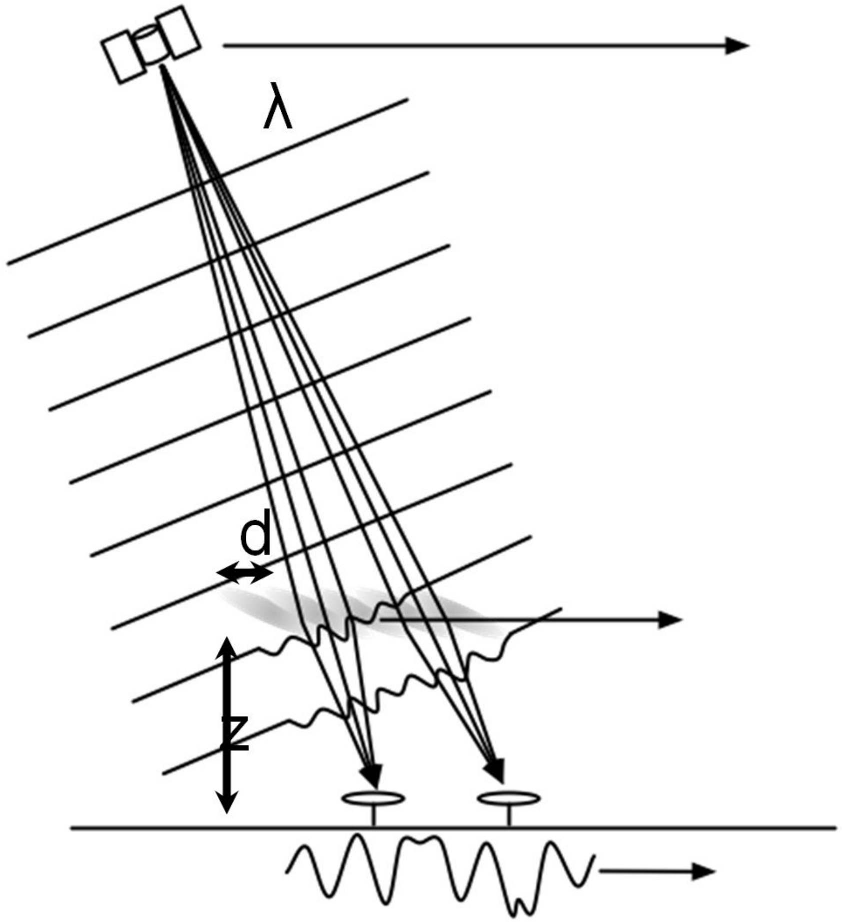
$$\delta I \cong F \frac{dI_v}{dx}(x + 2\tau v)$$

Obliquity factor for slant path

Spatial gradient

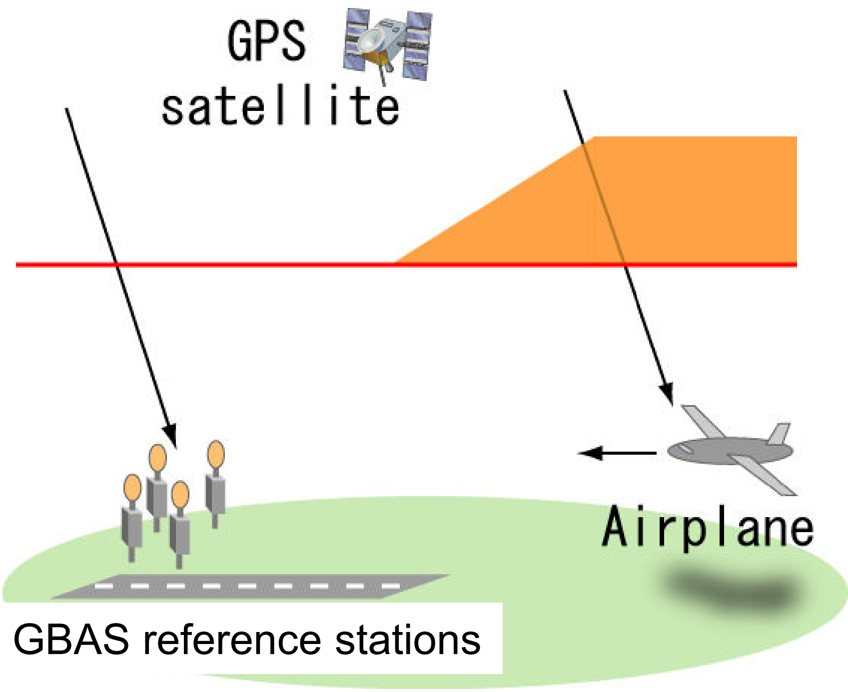
GBAS
Scintillation

- Iono irregularities
  - Sometimes occurred with ionospheric disturbances
  - Produces rapid changes in received signal intensity and carrier phase measurement
- Loss of Lock
  - Reduces available ranging source
  - Degrade satellite geometry and enhance positioning errors



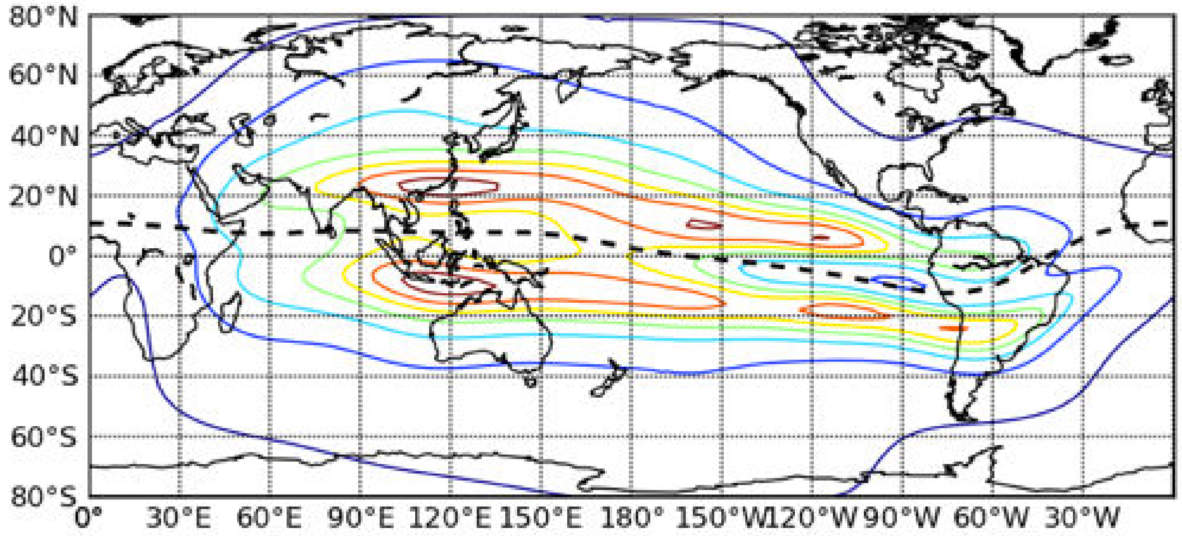
Mitigation of ionopheric effects Nominal and anomalous conditions

- Protects users under “nominal” ionosphere condition
  - Differential correction
  - Evaluation parameter for ionospheric error (σ_{iono})
- “Anomalous” ionosphere condition
  - Unbounded by σ_{iono}
- Mitigate “Anomalous” ionospheric effects
  - Detect and exclude affected ranging sources at GBAS ground stations
  - Existence of undetectable cases by the stations



Mitigation of ionopheric effects Nominal condition

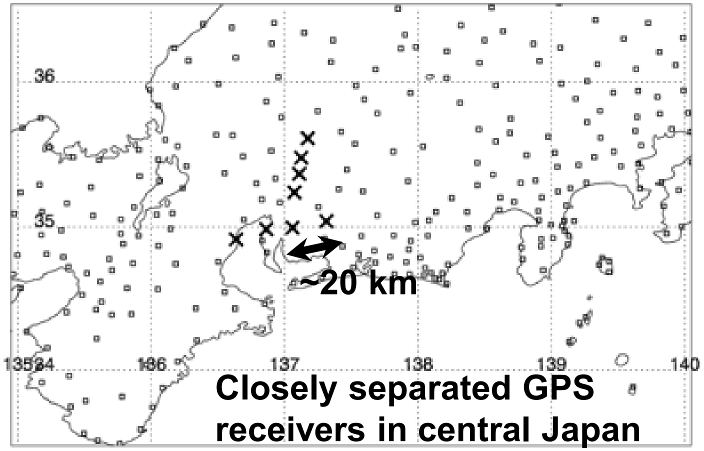
- Equatorial anomalies
  - Dominant factor to determine background ionospheric condition
  - Variation: daytime / night time
  - Spring and Autumn
  - Solar activity with a cycle of about 11 years
- Such kind of effects should be covered by evaluation parameter of σ_{iono}
  - But, it depends of system safety design

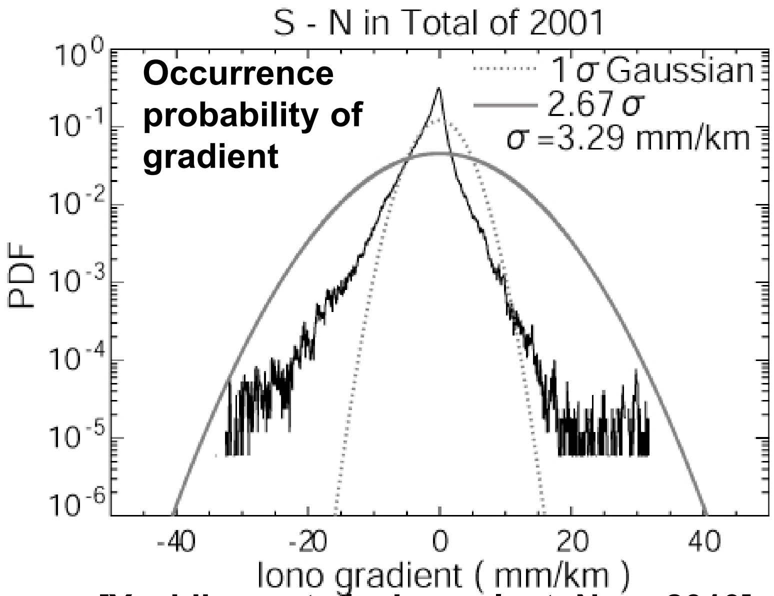


Mitigation of ionopheric effects

Evaluation example

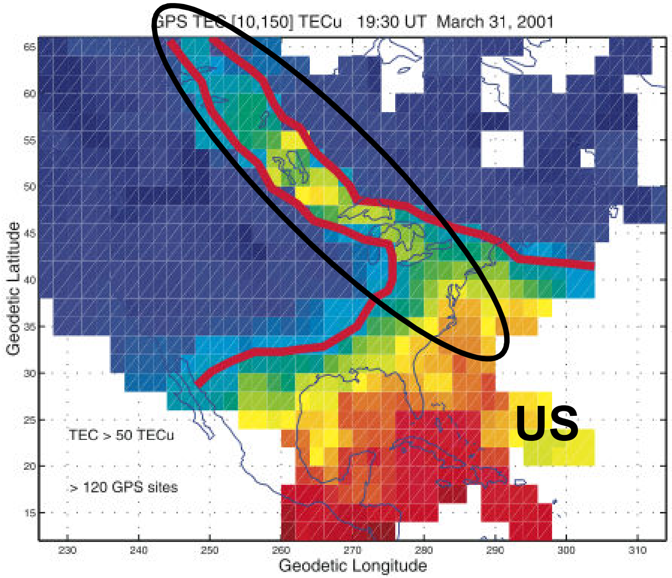
- σ_{iono} should be determined to bound an observed occurrence distribution
- Large number of observations with closely separated observing stations are necessary
- Data analysis only using data in a low solar activity period could lead underestimation for high activity period



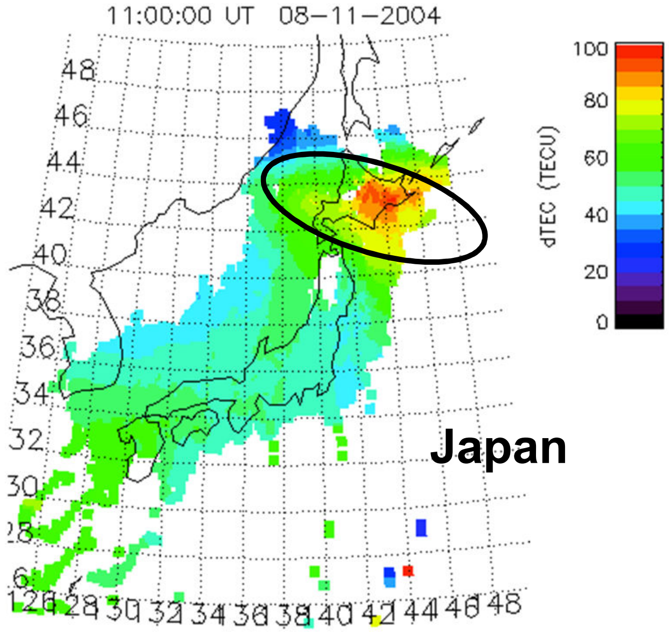


[Yoshihara et al., Japan Inst. Nav., 2010]

Mitigation of ionopheric effects
Anomalous condition: SED

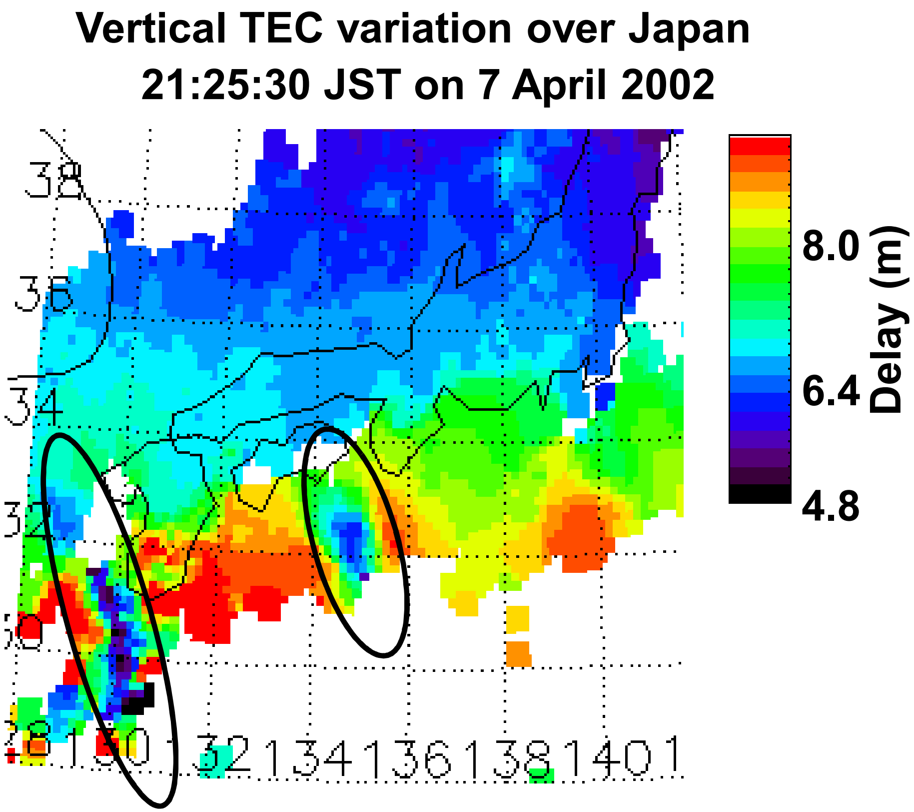


[Foster et al., 2002]



- Storm enhanced Density (SED): Extreme ionospheric density enhancement associated with severe magnetic storm
- Localities: Mid- to high latitude
- Occurrence rate: Relatively rare

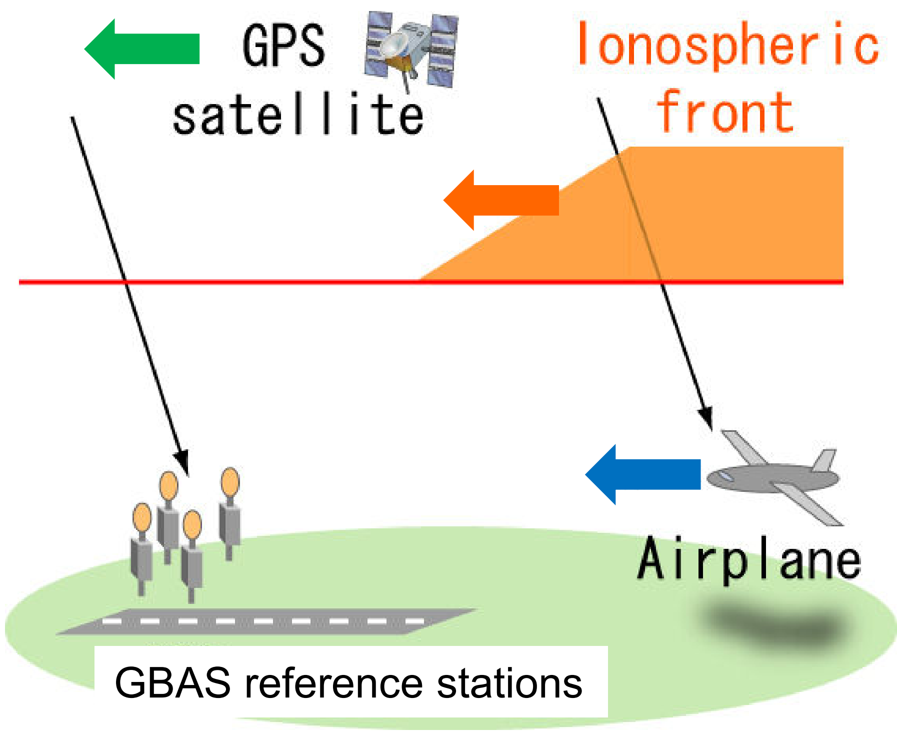
Mitigation of ionopheric effects
Anomalous condition: Plasma bubble



- Ionospheric density depletion
  - North-south direction
  - Steep ionospheric gradient and scintillation
- Frequently occur after sunset in high solar activity periods
- In the Asia-Pacific region, higher during equinox seasons (March-April and September-October)

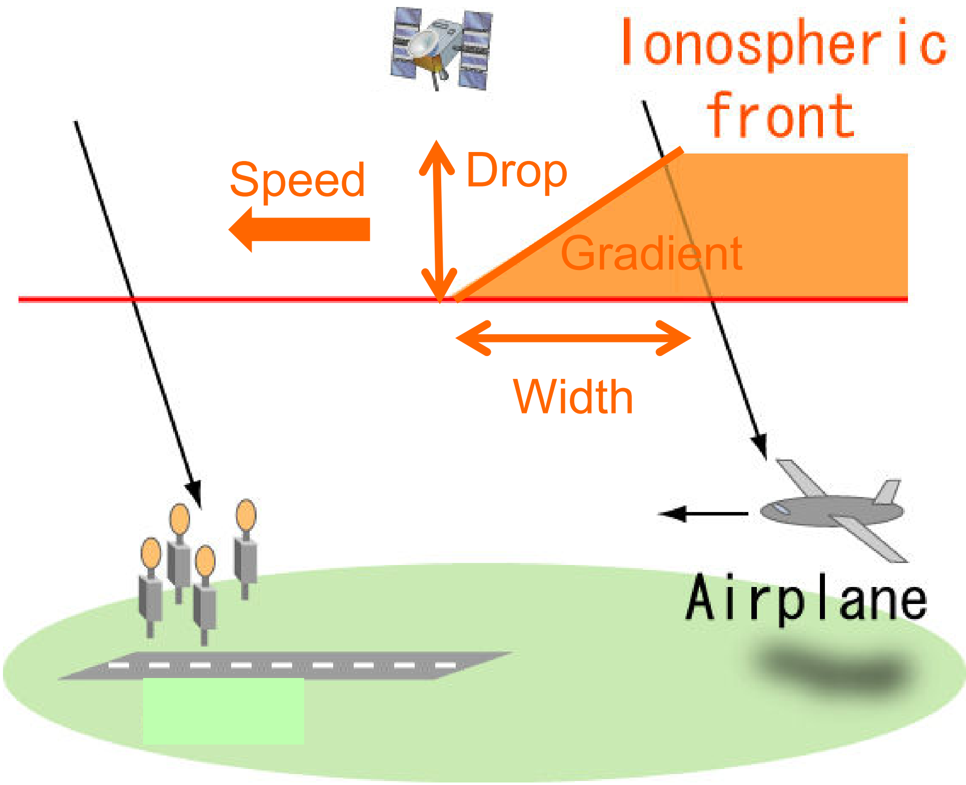
Threat model
Ionospheric front

- A model of ionosheric spatial gradient
- Range error
  - Relative geometrical relationship
  - Depends on ionospheric delay change at user side
- Moving velocities:
  - Ionospheric front
  - GPS satellite signal path on equivalent ionospheric layer
  - Aircraft



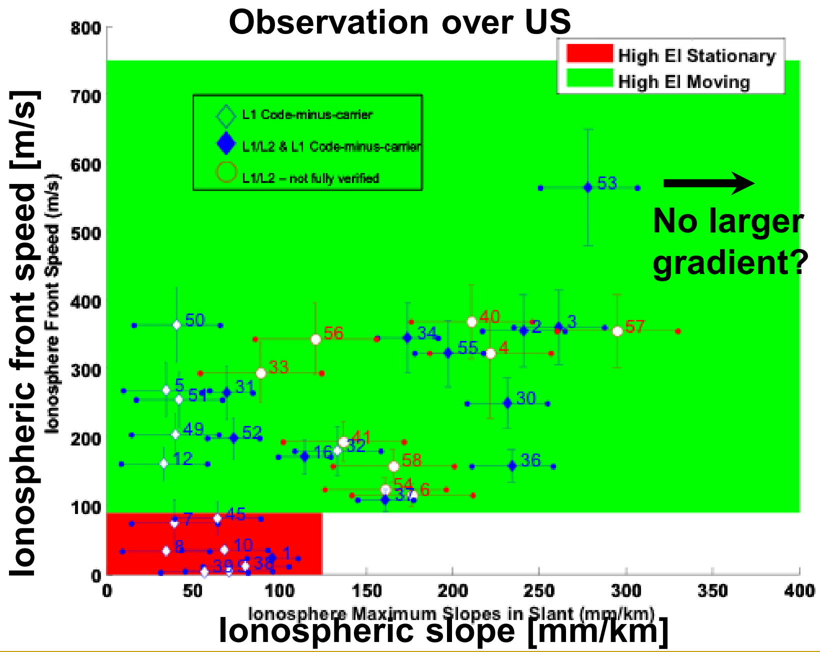
Threat model
Important parameters

- Ionospheric front
  - Gradient (mm/km)
  - Moving speed (m/s)
  - Width (km)
  - Drop: Total differential delay (m)
- Other characteristics
  - Occurrence mechanism
  - Localities
  - Occurrence rate
  - Dominant season / time
- Integrity requirement
  - “Any” approach

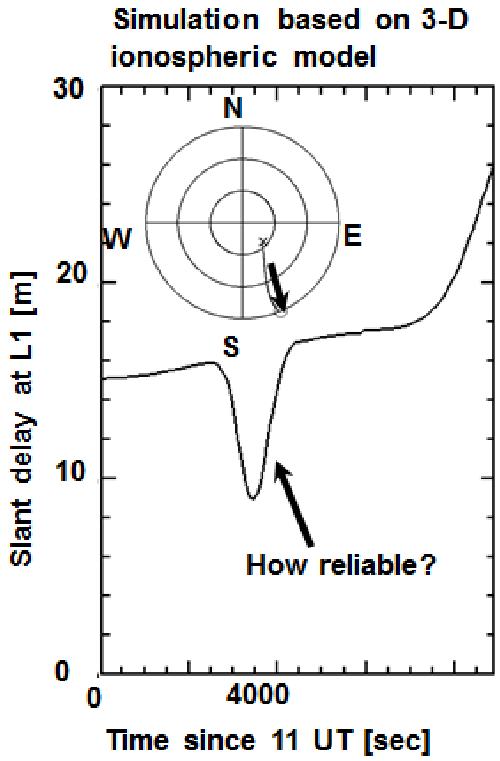


Threat model
Important parameters

- Observation-based approach
  - shows some aspects of reality, but a number of data is necessary.
- Simulation-based approach
  - Arbitrary situations can be tested
  - but validation is necessary based-on observations



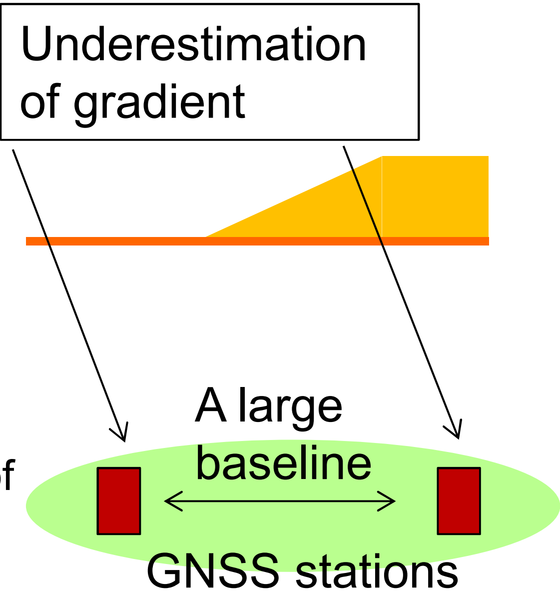
[Lee et al., ION GNSS 2006]

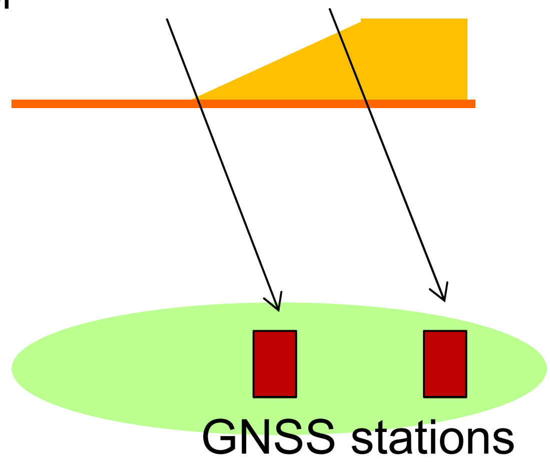


[Saito et al., ION ITM 2009]

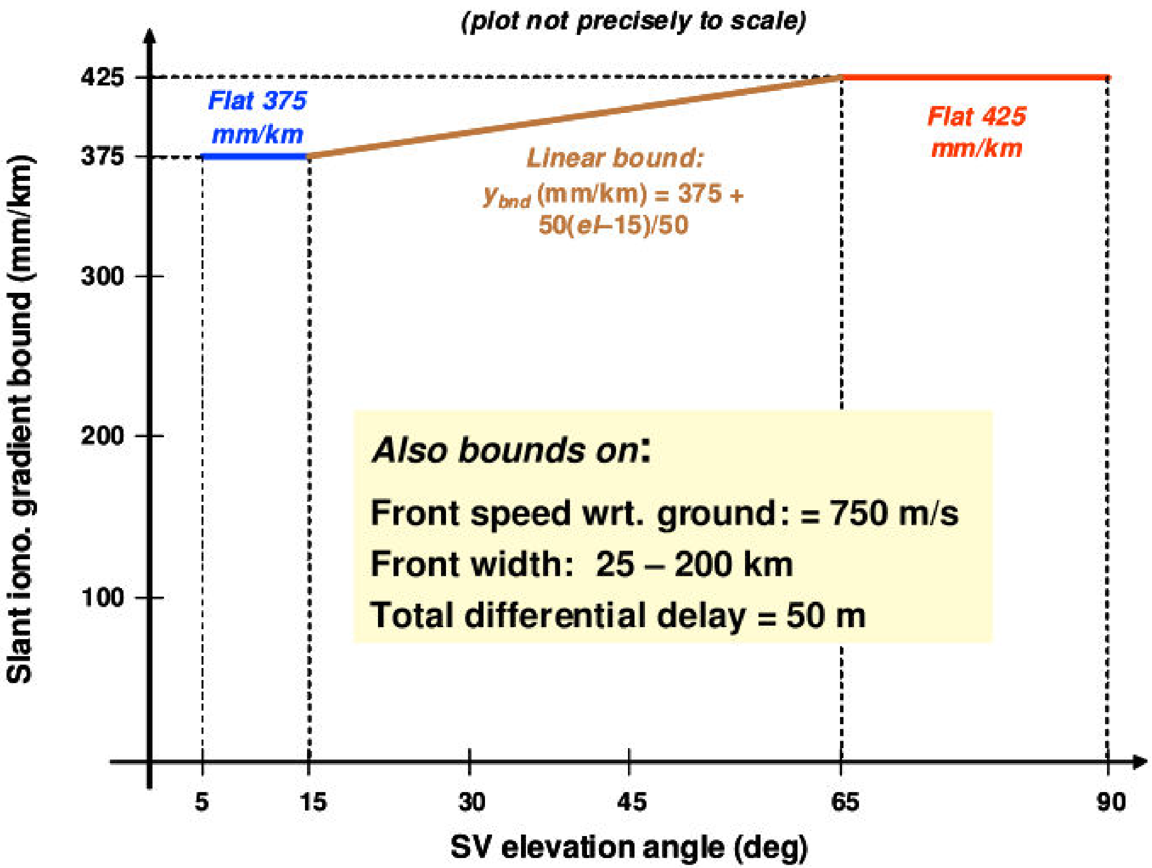
Threat model
Development and validation

- Observation-based approach
  - Two or more GNSS stations
  - Correction of inter frequency biases for dual frequency ionospheric delay measurement is needed
  - Consider measurement error especially in short baseline analysis because gradient is calculated from difference of ionospheric delay divided by baseline length
- Targeted phenomenon
  - Discuss and survey situations for impact on GBAS
  - SED: Parameters related to magnetic storm are useful for extraction of events
  - Plasma bubble: Parameters related to magnetic storms are not enough to extract events, but local time filtering are useful because it occurs in nighttime
  - Baseline length should be comparable or smaller to spatial scale of disturbances
  - Solar activity with a period of about 11 years





Threat model
US model



[Pullen et al., Radio Sci., 2008]

Threat model
CAT-III GBAS (GAST-D)

- GAST-D
  - GBAS Approach Service Type D
- A large difference between CAT-I (GAST-C) and GAST-D
  - GAST-C: Ground subsystem has all responsibility to protect users from ionospheric anomalies including potential impacts
  - GAST-D: Mitigation of ionospheric integrity risks by combination between monitors at the both ground and airborne subsystems
- A common threat model for the both
  - Ionosphere threat model in guidance material of Development Baseline SARPs of GAST-D (ATT D 7.5.6.2.7)

Threat model
CAT-III GBAS (GAST-D)

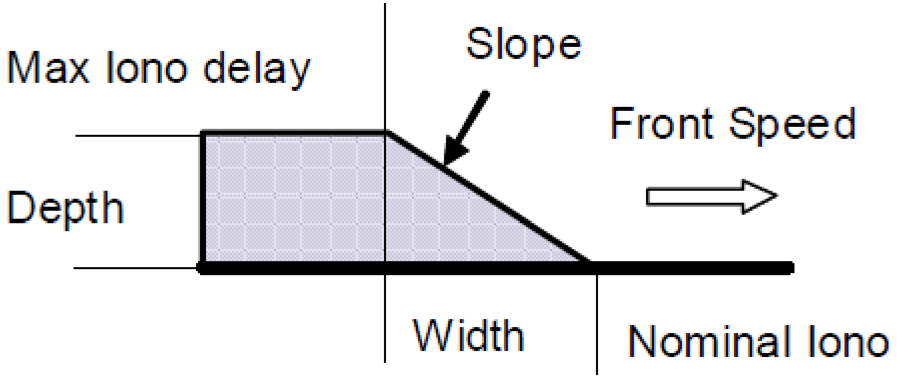


Figure A-1: Moving Wedge Ionospheric Anomaly Model

Table XX-1

Propagation Speed (v)	**Upper Bound on Gradient Slope (g)**
$v < 750$ m/s	500 mm/km
$750 \leq v < 1500$ m/s	100 mm/km

- Moving wedge model
  - W: 25-200km
  - D: 50m in max
  - Table: v and g

Summary

- GBAS is a navigation system based on differential positioning
  - Ionospheric delay is one of the most important error sources
- Ionospheric effects
  - Ionospheric spatial gradient: ranging error through carrier smoothing
  - Scintillation: reduction of available ranging source through loss of lock
- Mitigation of ionopheric effects
  - Nominal condition: GBAS broadcast parameter of evaluation for remained ionospheric error (σ_{iono})
  - Anomaly condition: Detect and exclude affected ranging sources
  - Ionospheric phenomena: SED and Plasma bubble
- Threat model
  - Two approaches: Observation and simulation
  - Ionospheric front
  - CAT-I and CAT-III GBAS