Space weather effects on air navigation and utilization of space weather information

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✤ *ENRI (Electronic Navigation Research Institute) is a public research institute for aeronautical CNS (Communications, Navigation and Surveillance) and ATM (Air Traffic Management).*

AOSWA-3, Fukuoka, 2-5 March 2015

Outline

* Aeronautical navigation and GNSS
  - Requirements for air navigation
  - GNSS-based air navigation
* Ionospheric effects on GNSS and mitigation
  - Ionospheric disturbances and mitigation
  - Ionospheric threat model development in the Asia-Pacific region for air navigation
* Potential use of space weather information for air navigation
  - Five-year research program of ENRI

Requirements of air navigation

* Different levels of requirements for different flight operations

Phase	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	Integrity	Time-to-alert	Continuity	Availability
En route	2.0NM	-	$1-1\times10^{-7}$/hr	5min	$1-1\times10^{-4}$ to $1-1\times10^{-8}$ /hr	0.99-0.99999
En route, Terminal	0.4NM	-	$1-1\times10^{-7}$/hr	15sec	$1-1\times10^{-4}$ to $1-1\times10^{-8}$ /hr	0.99-0.99999
Initial, intermediate, NPA*(1)	720ft	-	$1-1\times10^{-7}$/hr	10sec	$1-1\times10^{-4}$ to $1-1\times10^{-8}$ /hr	0.99-0.99999
APV*(2)-I	52ft	66ft	$1-2\times10^{-7}$ in any approach	10sec	$1-6\times10^{-6}$ per 15sec	0.99-0.99999
APV*(2)-II	52ft	26ft	$1-2\times10^{-7}$ in any approach	6sec	$1-6\times10^{-6}$ per 15sec	0.99-0.99999
Precision Approach (Category-I)	52ft	26-13ft	$1-2\times10^{-7}$ in any approach	6sec	$1-6\times10^{-6}$ per 15sec	0.99-0.99999

[Annex 10 to the International Civil Aviation Convention]

***1 NPA: Non precision approach**
***2 APV: Approach operations with vertical guidance**

GNSS-based air navigation

* ICAO*(1) promotes migration to GNSS*(2)-based navigation from conventional (ground-based)
* Requirements defined by ICAO
  - Very high safety (integrity) requirements
  - All the requirements (accuracy, integrity, continuity, and availability) must be fulfilled together for operational systems
* Augmentation systems are required to meet the requirements
  - SBAS (Satellite-based Augmentation System): Wide area
  - GBAS (Ground-based Augmentation System): Local area
  - ABAS (Aircraft-based Augmentation System): Aircraft stand-alone
* Currently only L1 frequency signal can be used for air navigation
  - GPS L2 signal is not in a frequency band protected for aviation
  - L5 signal will be available for air navigation in the future

***1 ICAO: International Civil Aviation Organization**
***2 GNSS: Global navigation satellite system**

Errors in GNSS measurements

Clock offset
(receiver, satellite)

Pseudo-range $\rho = r + c\left[\delta t_u - \delta t^s\right] + I_\rho + T_\rho + \epsilon_\rho$

Measured values

geometric range

Ionospheric delay

Tropospheric delay

Multipath, thermal noise, etc.

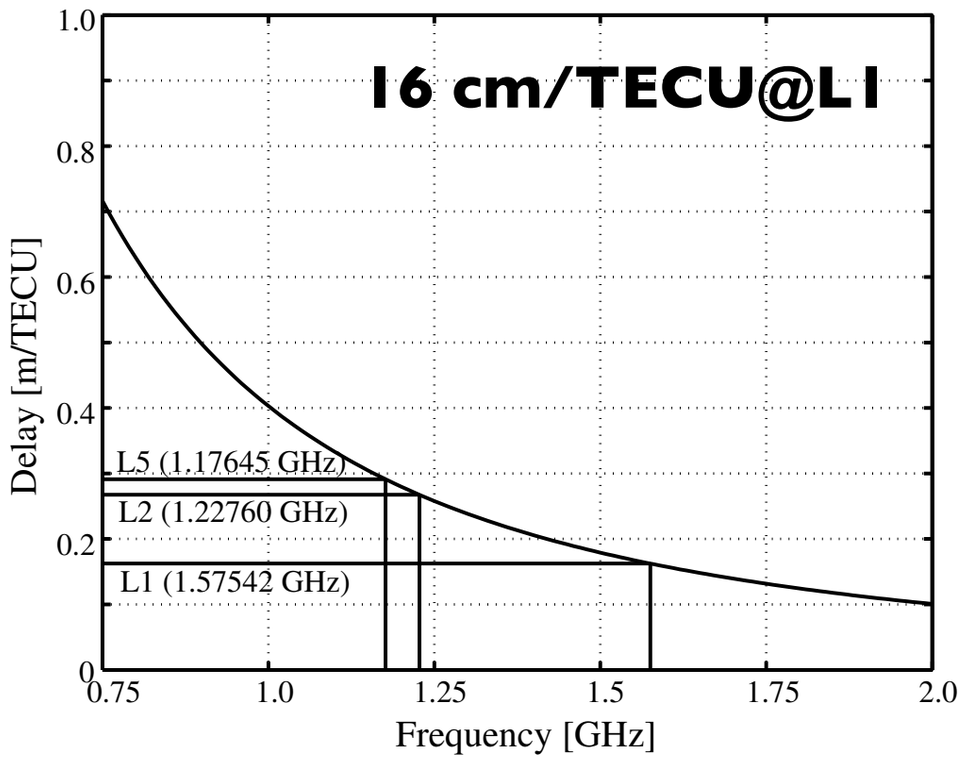
Carrier-phase $\phi = \lambda^{-1}\left[r + I_\phi + T_\phi\right] + \frac{c}{\lambda}\left[\delta t_u - \delta t^s\right] + N + \epsilon_\phi$

Clock offset (receiver, satellite)

Initial phase ambiguity

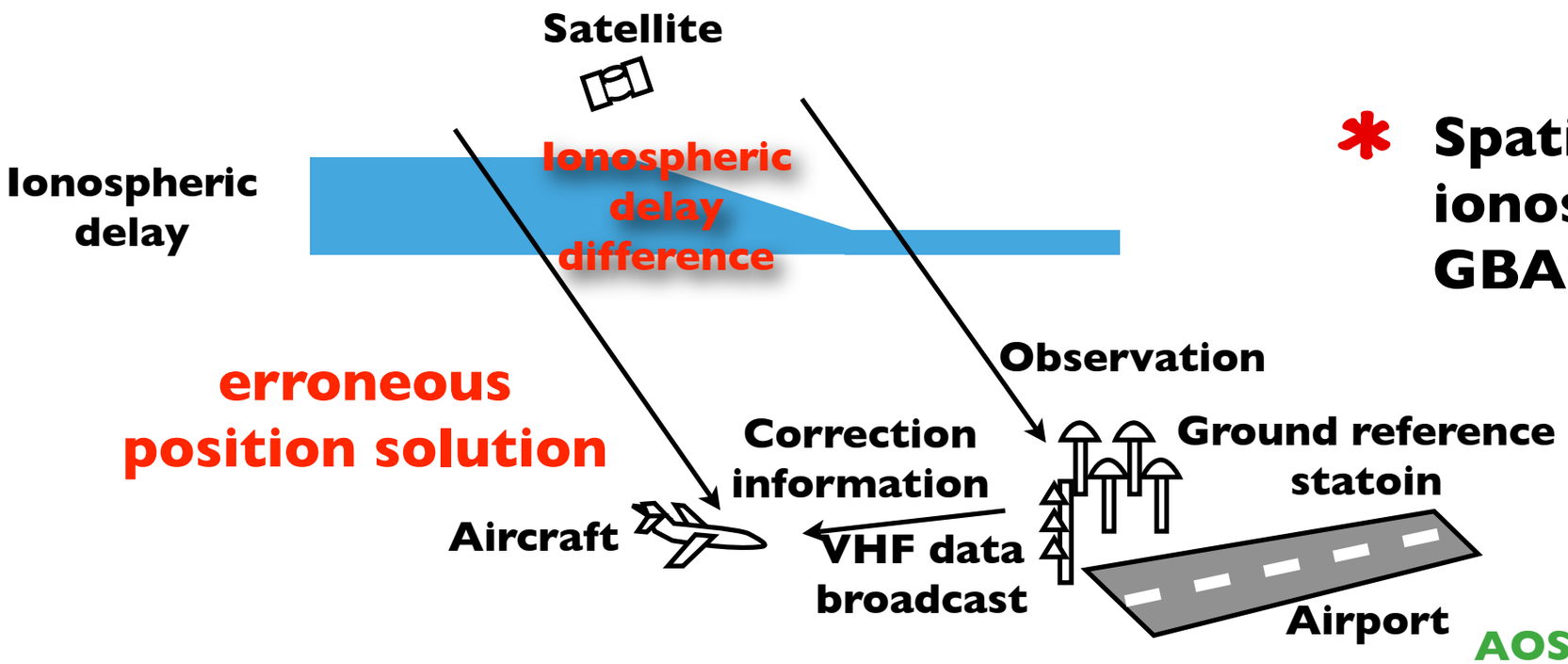
* Ionospheric delay is the largest one and the most difficult to correct for single-frequency users

$$I_\rho = \frac{e^2}{8\pi^2 m_e \epsilon_0 f^2}\int_S^R n_e(l)dl = \frac{40.3}{f^2}\underbrace{\int_S^R n_e(l)dl}_{\text{total electron content (TEC)}}$$



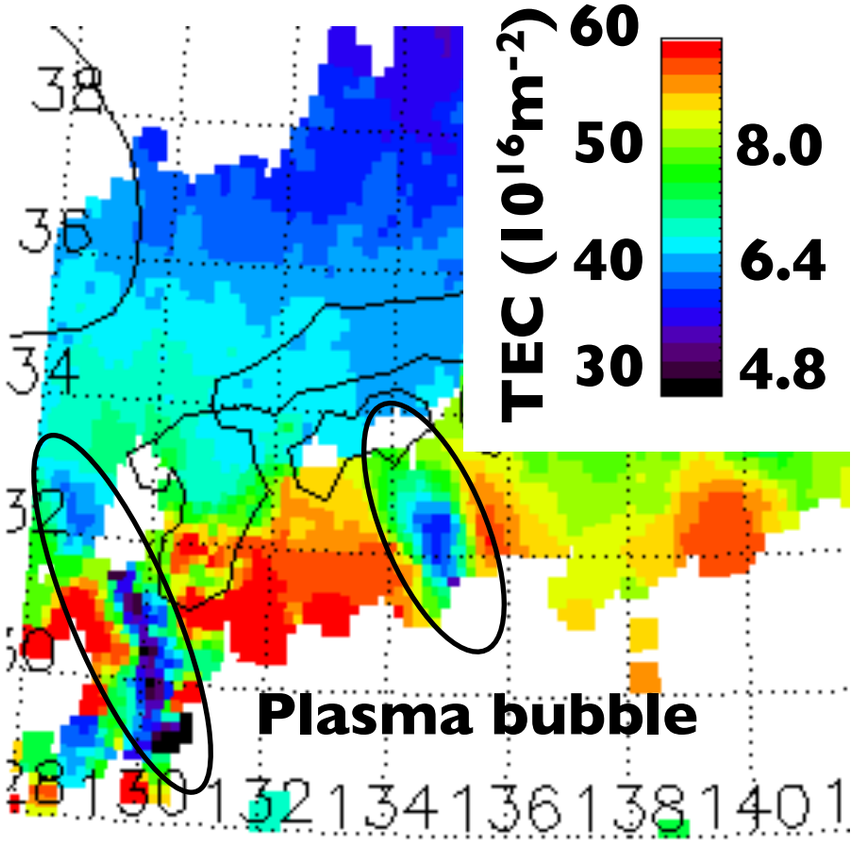
Ionospheric impacts on GNSS-based air navigation

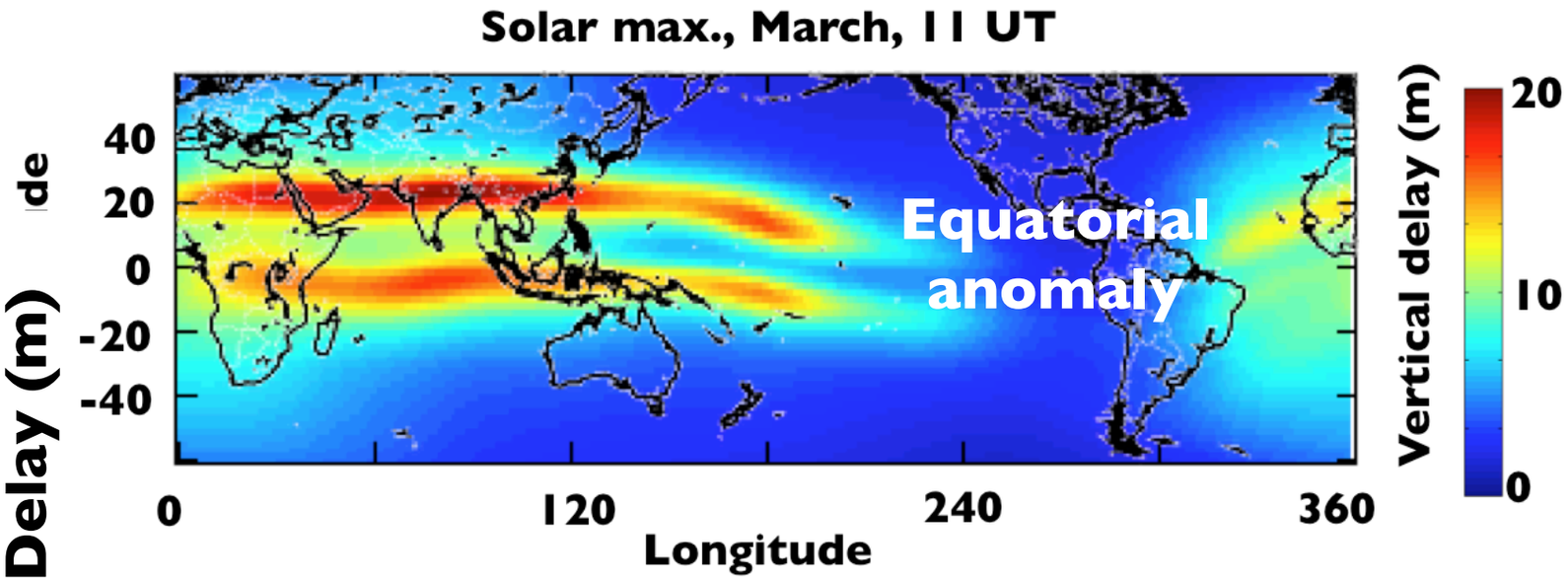
* SBAS and GBAS are based on differential GNSS technique
  - Spatial decorrelation of ionospheric delay is the major error source
* Number of available satellites is an important factor
  - More satellites, better satellite geometry and
  - Better position accuracy with smaller error bound

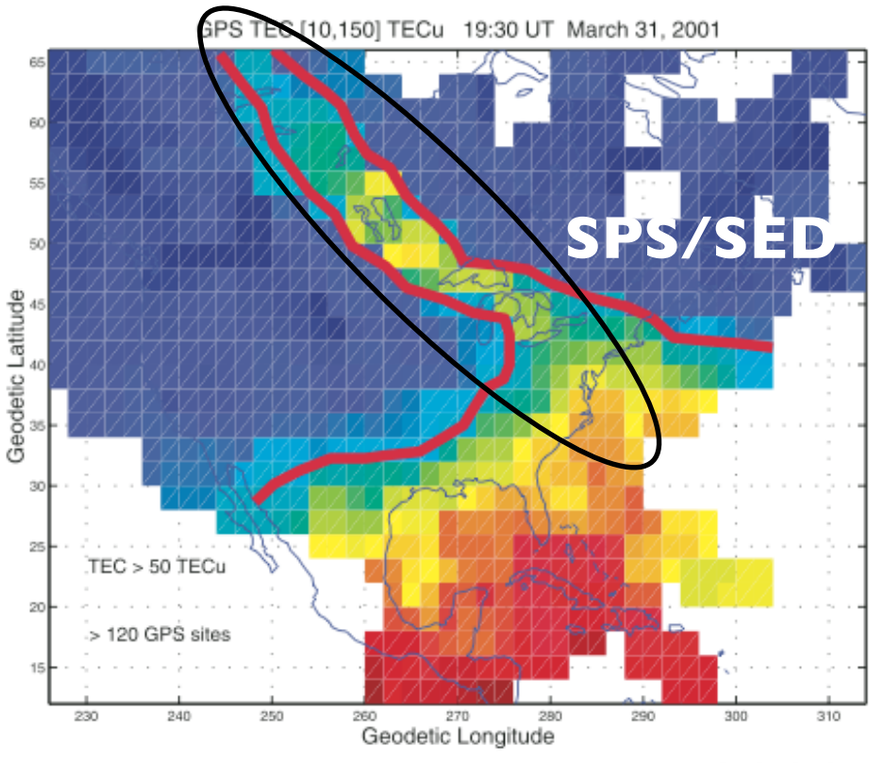


* **Spatial difference in ionospheric delay and GBAS**

Ionospheric disturbance with large spacial decorrelation





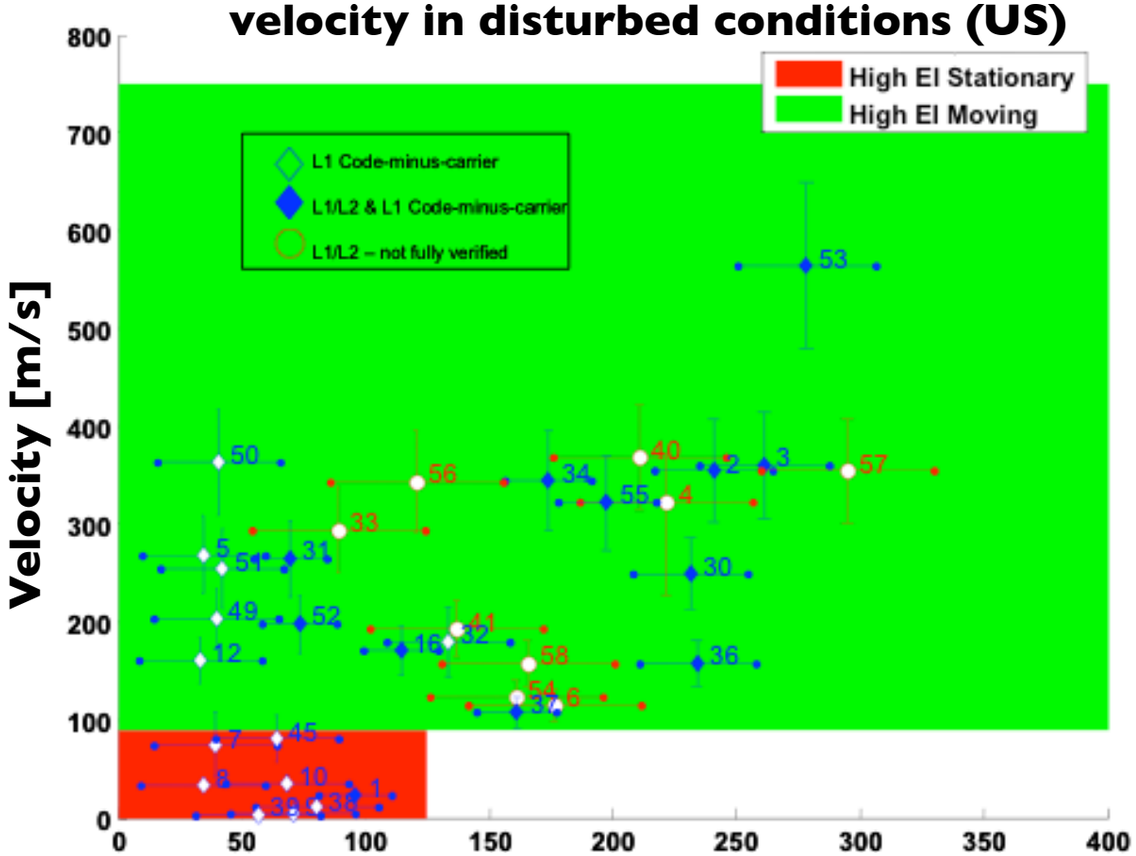


[Foster et al., 2002]

Ionospheric threat model

* Ionospheric threat model describes how the ionospheric parameters relevant for a specific GNSS-based systems

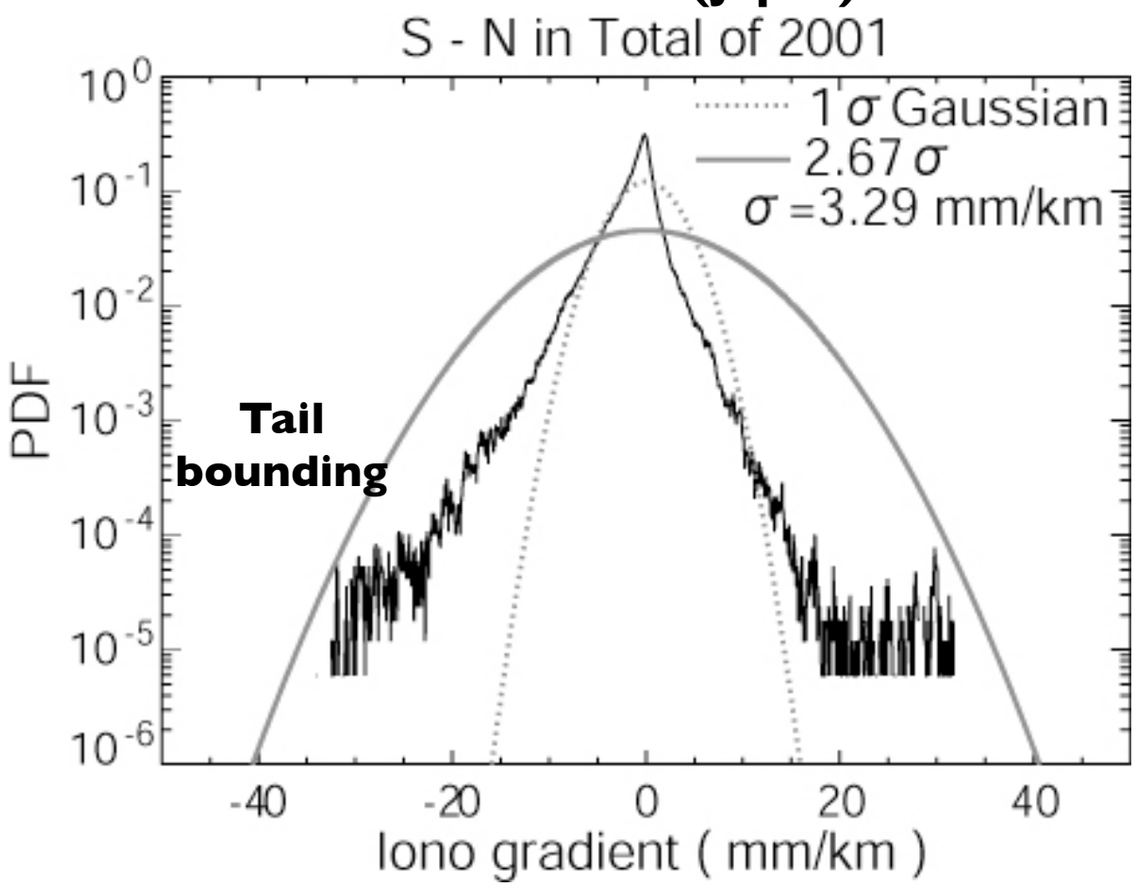
Ionospheric delay gradient and velocity in disturbed conditions (US)



Ionospheric delay gradient at L1 rfrequency [mm/km]

[Lee et al., ION GNSS 2006]

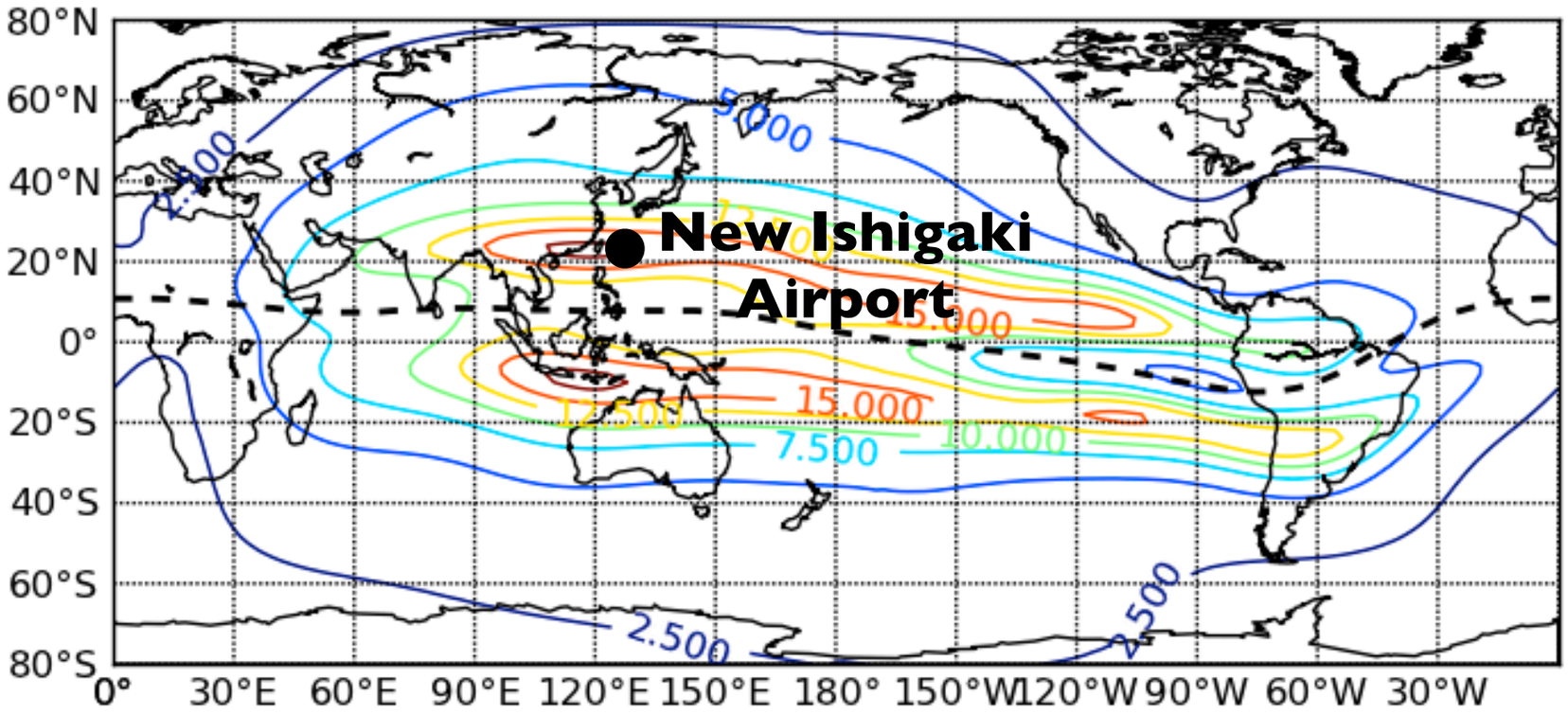
Ionospheric delay gradient in the nominal condition (Japan)



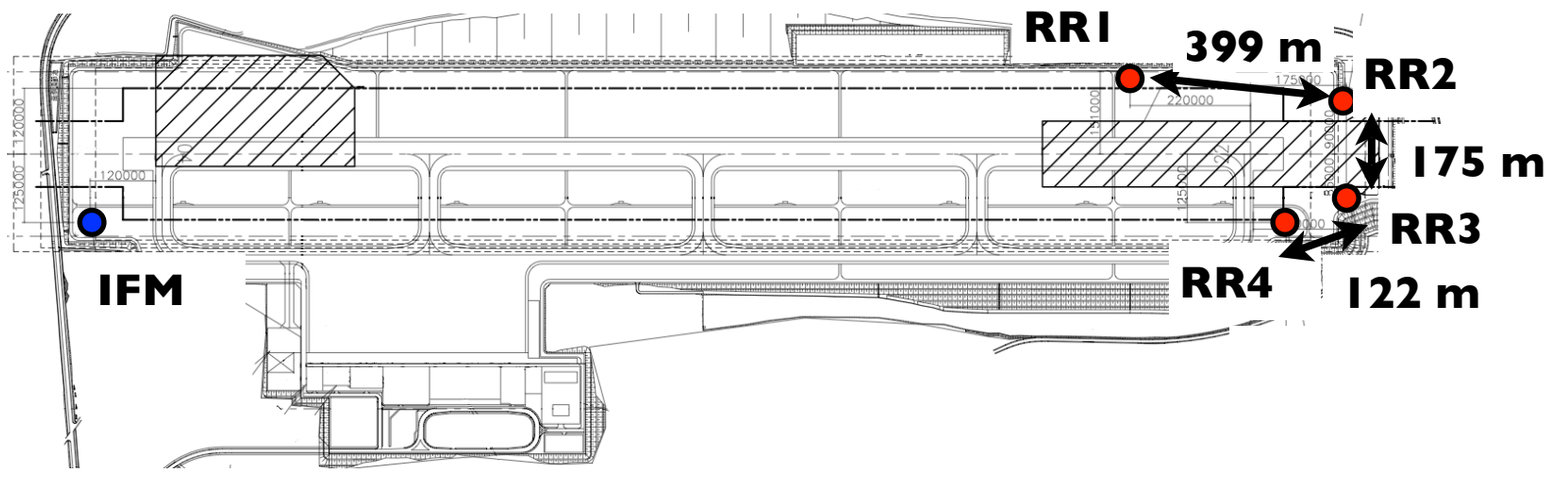
[Yoshihara et al., Japan Inst. Nav., 2010]

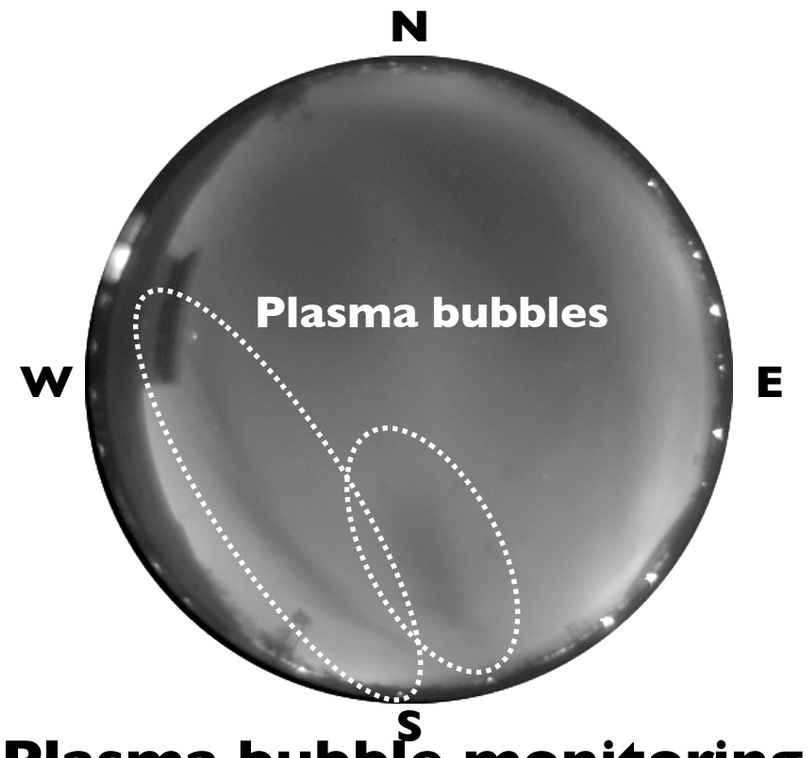
Prototyping and validation

GBAS airborne experimental subsystem and flight experiment



GBAS ground subsystem prototype





Plasma bubble monitoring by all-sky imager for GBAS experiments

AOSWA-3, Fukuoka, 2-5 March 2015

Mitigation efforts in Asia-Pacific region

* Ionospheric Studies Task Force (ISTF)
  - Established in the ICAO Asia-Pacific Region in 2012
  - Objectives
    - Facilitate ionospheric data collection and sharing
    - Study the need for **development of regional ionospheric threat models** for GBAS and SBAS,
    - Develop them if the need is identified.
* Observation data have been contributed by member States
* 5th meeting was recently held in Japan (16-18 February 2015)
  - 16 participants from 6 States
  - 7 observers from industries and air navigation service providers
  - Need of regional ionospheric threat model for GBAS was identified.
* ENRI is leading this activity.

Space weather information and air navigation

* **Ionospheric phenomena are important part of space weather.**

* ICAO 12th Air Navigation Conference recommended
  - to study optimum ways of utilizing space weather information to facilitate global use of GNSS
  - to work on the ionospheric issues in a coordinated manner

* Space Weather Concept of Operations (ConOps)
  - Under development
  - Define how space weather information should be utilized for mitigation of impacts on
    - Navigation
    - Communication
    - Radiation dose

Research program of ENRI for space weather information utilization

* Development of ionospheric threat mitigation algorithm for GNSS-based air navigation
  - Five-year program from April 2015 to March 2020
  - Utilize space weather information
    - ✦ Not limited to self-contained systems
    - ✦ Integrity consideration
  - Development of concept of space weather utilization suitable for the low latitude region
  - Development of ionospheric anomaly mitigation technique for GNSS with space weather information
  - Feed back to ICAO Space Weather ConOps
  - Ionospheric observations to understand characteristics of ionospheric and space phenomena that have impact on GNSS

Summary

* GNSS is expected to be a main enabler of next generation air navigation
* High safety (integrity) is required for air navigation at the same time as accuracy, continuity, and availability
* Mitigation of Ionospheric impacts (ionospheric delay gradient, scintillation) is the key point to facilitate GNSS implementation for air navigation
  - Ionospheric threat assessment and threat model development undertaken by ICAO Ionospheric Studies Task Force in the Asia-Pacific region
  - ENRI will launch a five-year program for development of ionospheric threat mitigation algorithm for GNSS-based air navigation

EIWAC 2015

THE 4TH ENRI INTERNATIONAL WORKSHOP ON ATM/CNS

～ Global Harmonization for Future Sky ～

Dates	Nov. 17 (Tue.) - 19 (Thr.), 2015
Venue	KFC Hall & Rooms Tokyo, JAPAN
Organiser	Electronic Navigation Research Institute
Admission	Free
Language	English • Simultaneous interpretation provided (Plenary session only)

Deadline for abstract submission March 31, 2015

Scope

EIWAC 2015 is a conference in the area of Air Traffic Management (ATM) and its enabling technologies in Communication, Navigation and Surveillance (CNS). EIWAC 2015 includes presentations for both tracks of academic discussions and interchanges such as introductions of R & D activities, project updates and perspectives.

Program

Nov. 17 (Tue.)	Nov. 18 (Wed.)	Nov. 19 (Thu.)
Opening	Special Talk	Special Talk
Plenary session - Keynote Addresses	Technical sessions	Technical sessions
Exhibition	Poster session	Poster session
Reception(evening) *meal charges ¥3,000	Exhibition	Exhibition

Topics

- ATM Modeling
- ATM Performance
- Trajectory Management
- Airport Management
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