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 Tasks and related Action Items

e) Task 5 – Iono Models

IONOSPHERE THREAT MODEL FOR SBAS

(Presented by ENRI, Japan)
(Prepared by Takeyasu Sakai)

SUMMARY

This paper presents a brief explanation of the ionosphere threat model developed for WAAS/MSAS to enhance development of threat models for Equatorial Regions.

1. Introduction

1.1 Augmentation systems need certified ionosphere threat model to meet integrity requirements. Here the author presents a brief explanation of the ionosphere threat model developed for WAAS/MSAS as an example to encourage development of threat models for Equatorial Regions.

2. Discussion

2.1 For SBAS, ionosphere progagation delay must always be overbounded by GIVE information broadcast along with vertical delay. Each SBAS provider needs to develop ionosphere threat model applicable within its service volume based on observation data in past and/or some ionosphere disturbance models. To enlarge SBAS service towards Equatorial Regions, we need to develop the ionosphere threat model acceptable for the intended regions.

3. Action required by the Meeting

3.1 The meeting is invited to do the following:

a) Develop ionosphere models including spatial and temporal threat representations acceptable for participating States/Regions;

b) Encourage refinement of the existing threat models to improve availability of systems; and

c) Develop other estimation algorithms which can be standardized for equatorial regions.

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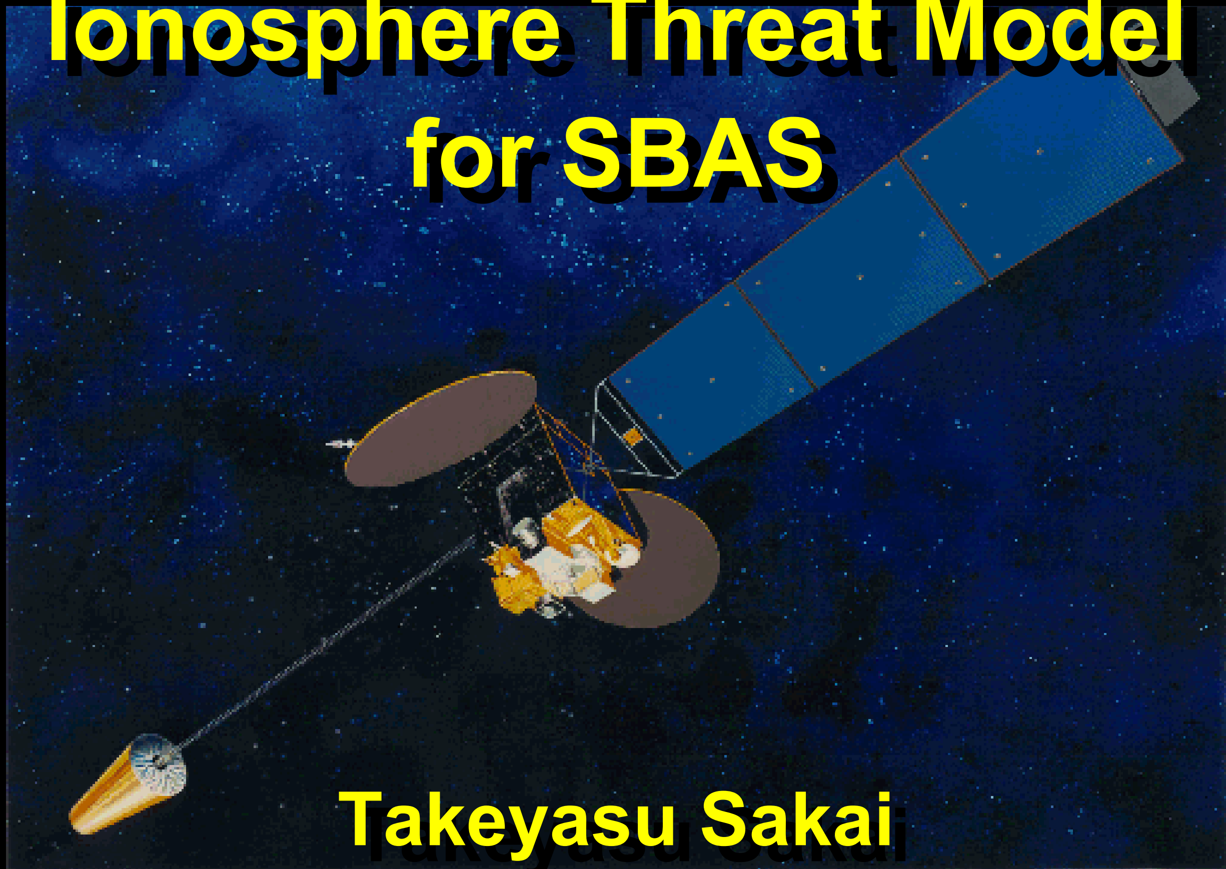
ICAO ISTF/5
Ishigaki Island, Japan
Feb. 16-18, 2015

Ionosphere Threat Model for SBAS



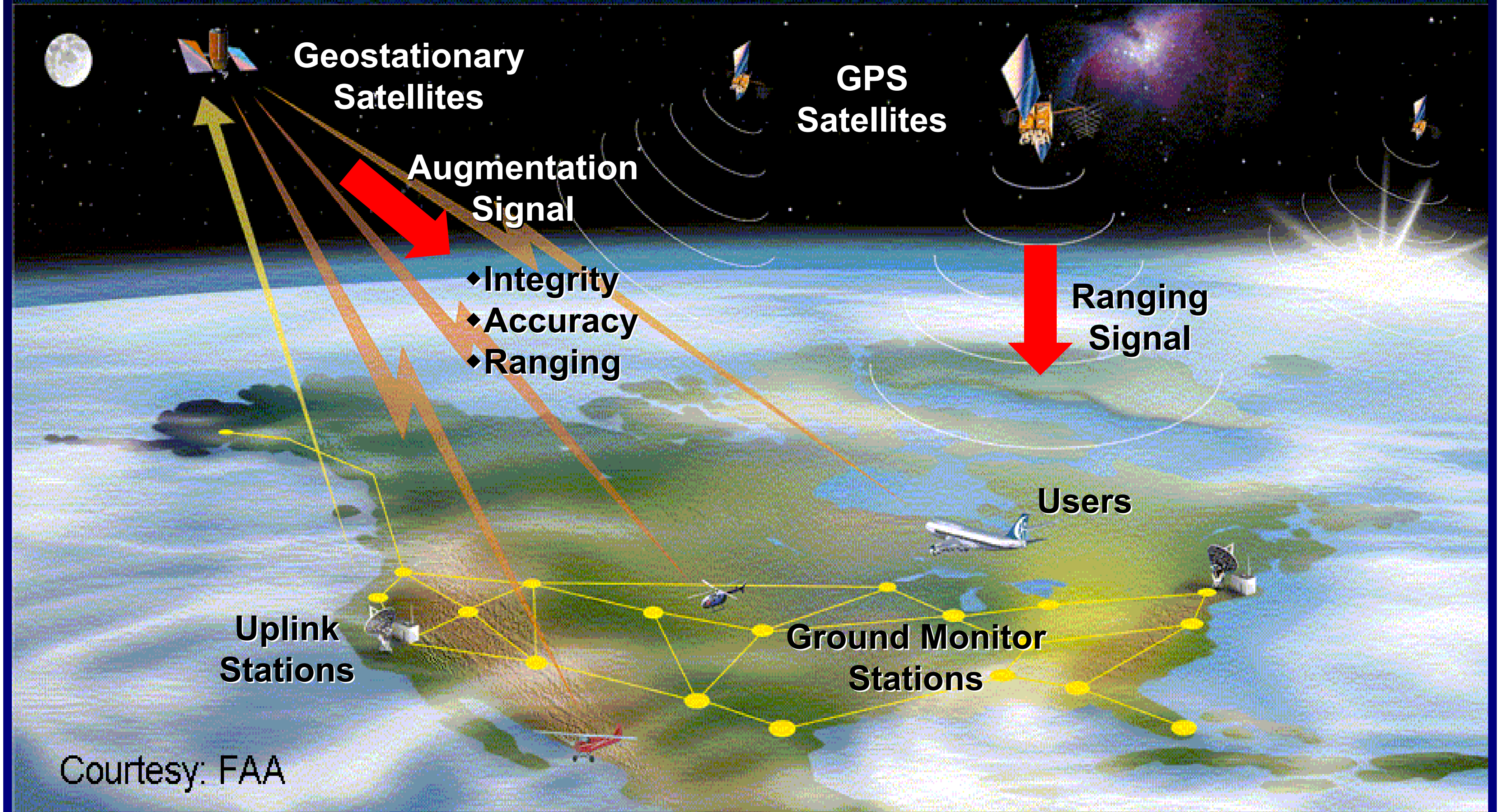
Takeyasu Sakai
Electronic Navigation Research Institute

Introduction

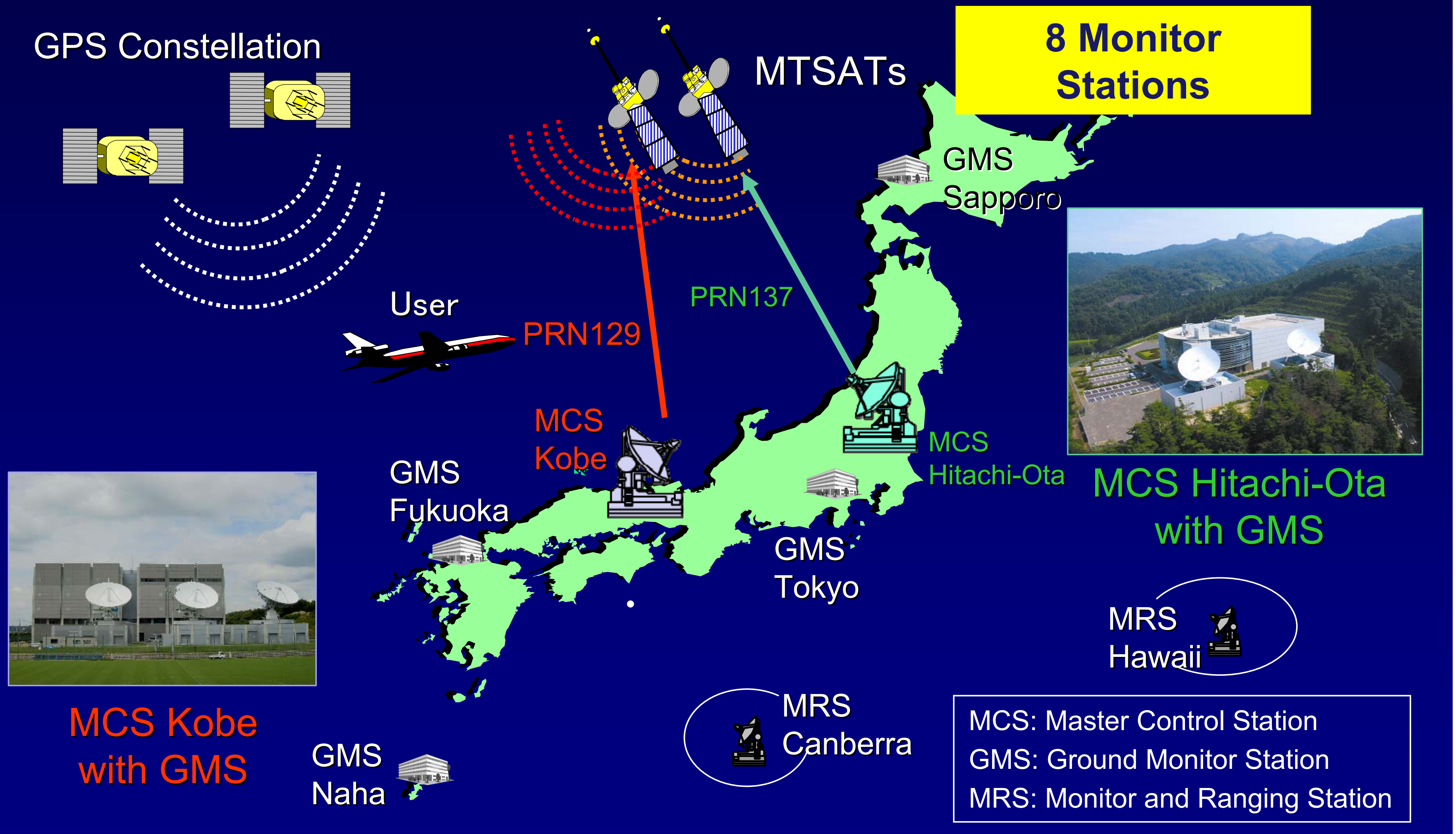
- ISTF Task 5: Ionosphere Models
  - Various ionosphere models, both theoretical and empirical, have been developed to provide information on ionospheric activities and ranging delays.
  - Augmentation systems need to generate ionospheric corrections:
    - Fitting into the message structure defined by SARPS;
    - Accurate enough to improve position accuracy; and
    - Meeting integrity requirements.
  - For integrity, we need ionosphere 'threat' model.
- Ionosphere Threat Model for SBAS
  - Each existing SBAS has its own ionosphere threat model for generation of ionospheric correction information to meet integrity requirements.
  - Here is an explanation of the threat model used for WAAS and MSAS.

  - *For detailed discussion, see 'Modeling Ionospheric Spatial Threat Based on Dense Observation Datasets for MSAS' presented at the ION GNSS 2008 and other references.*

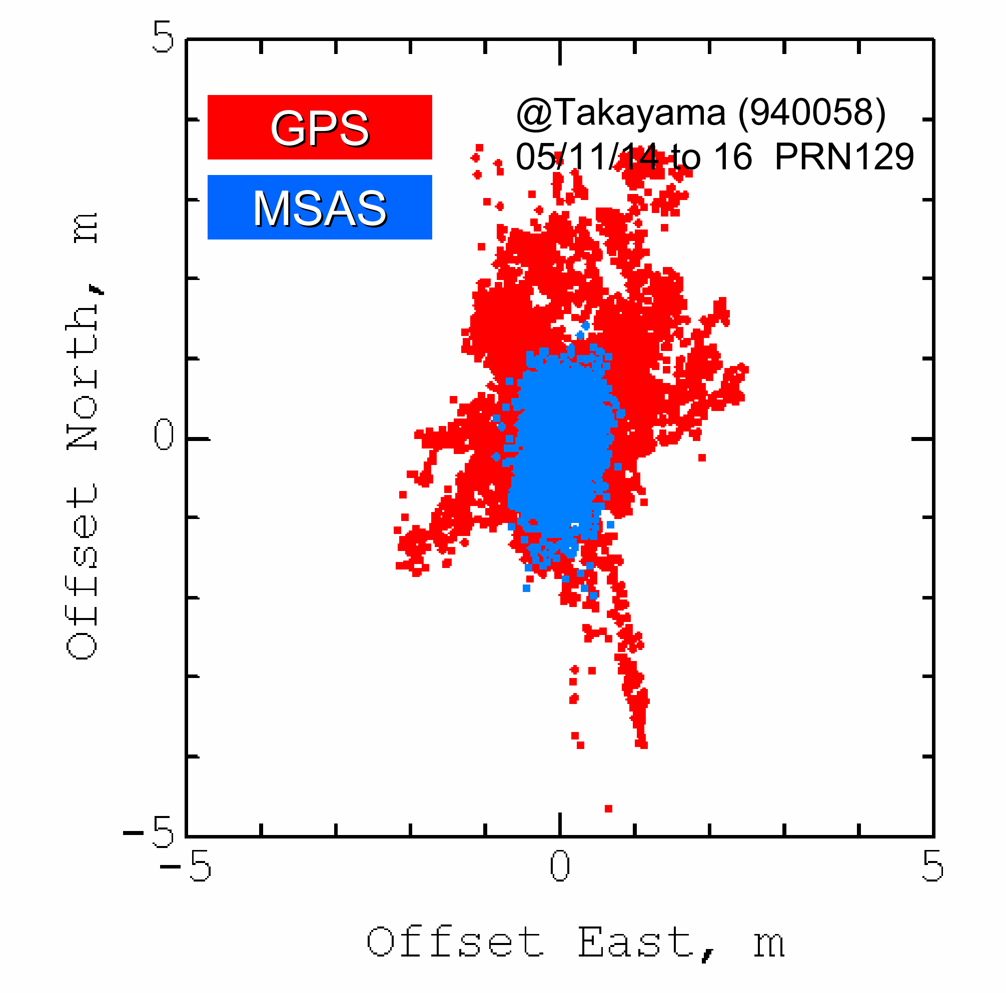
Concept of SBAS



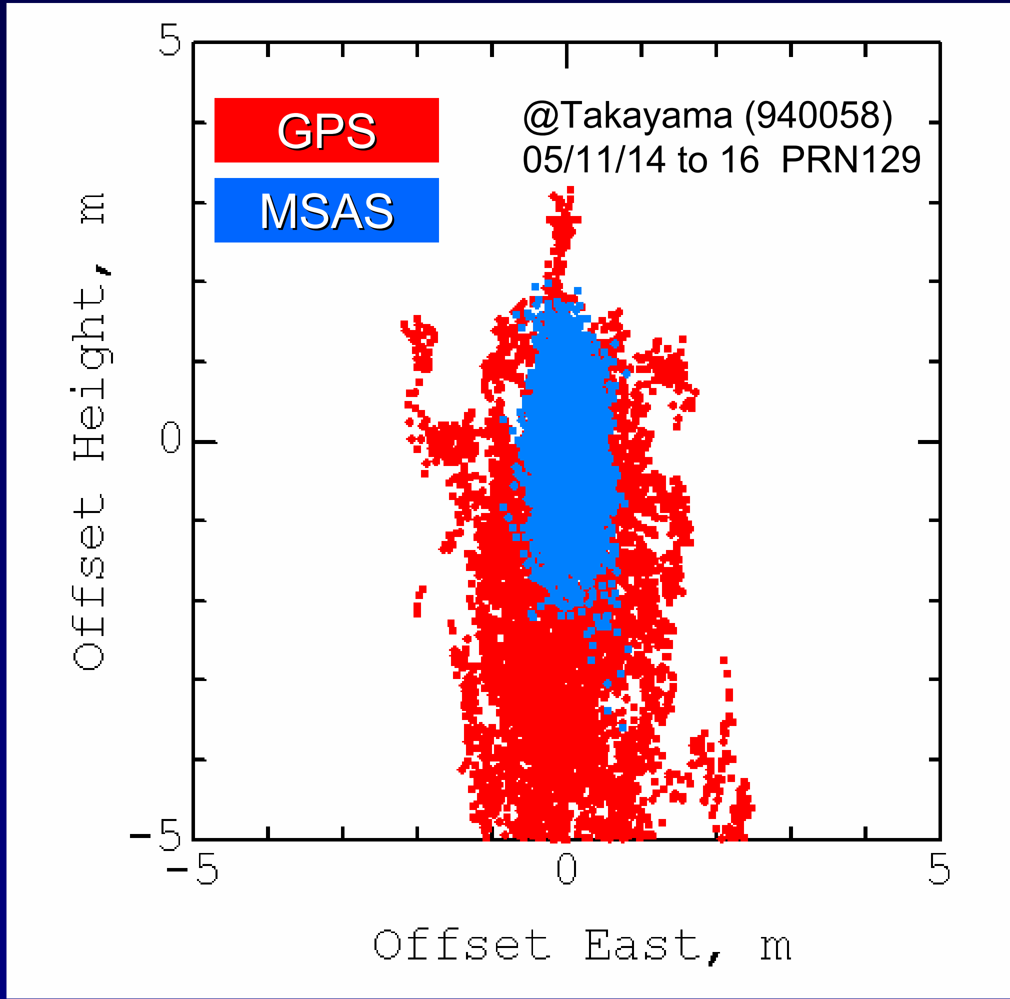
MSAS Configuration



Position Accuracy with MSAS



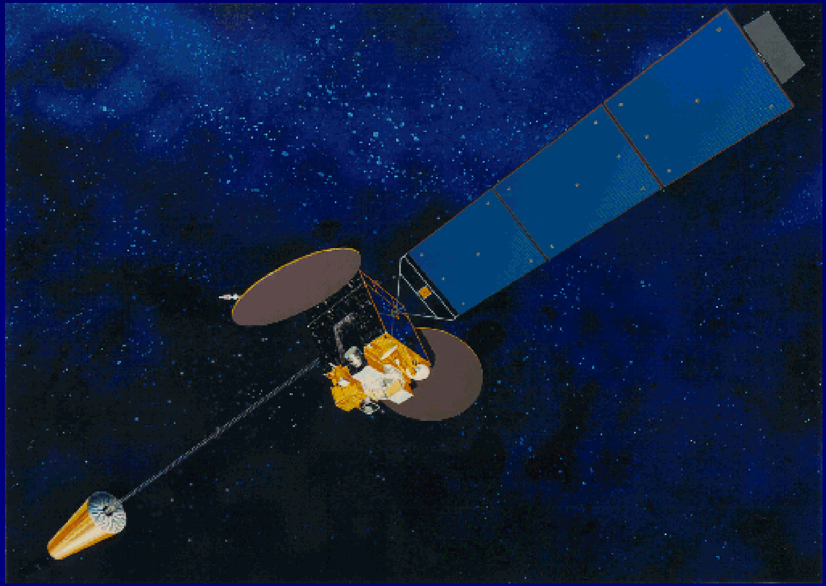
Horizontal
RMS 0.50m MAX 4.87m



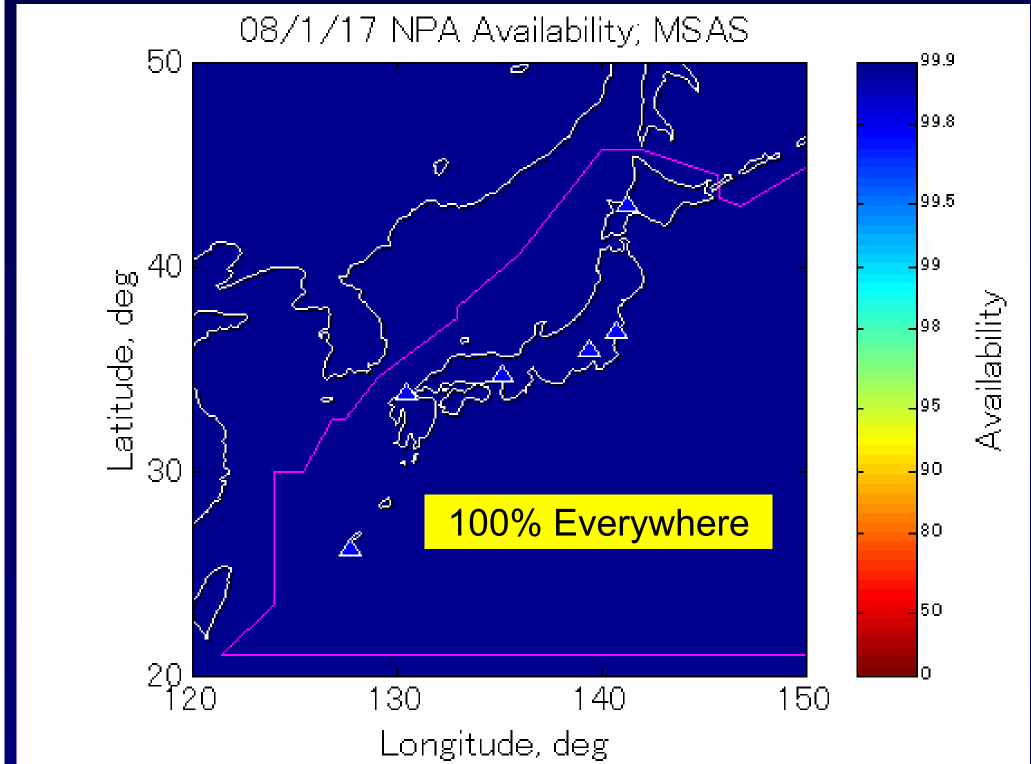
Vertical
RMS 0.73m MAX 3.70m

Concerns for MSAS

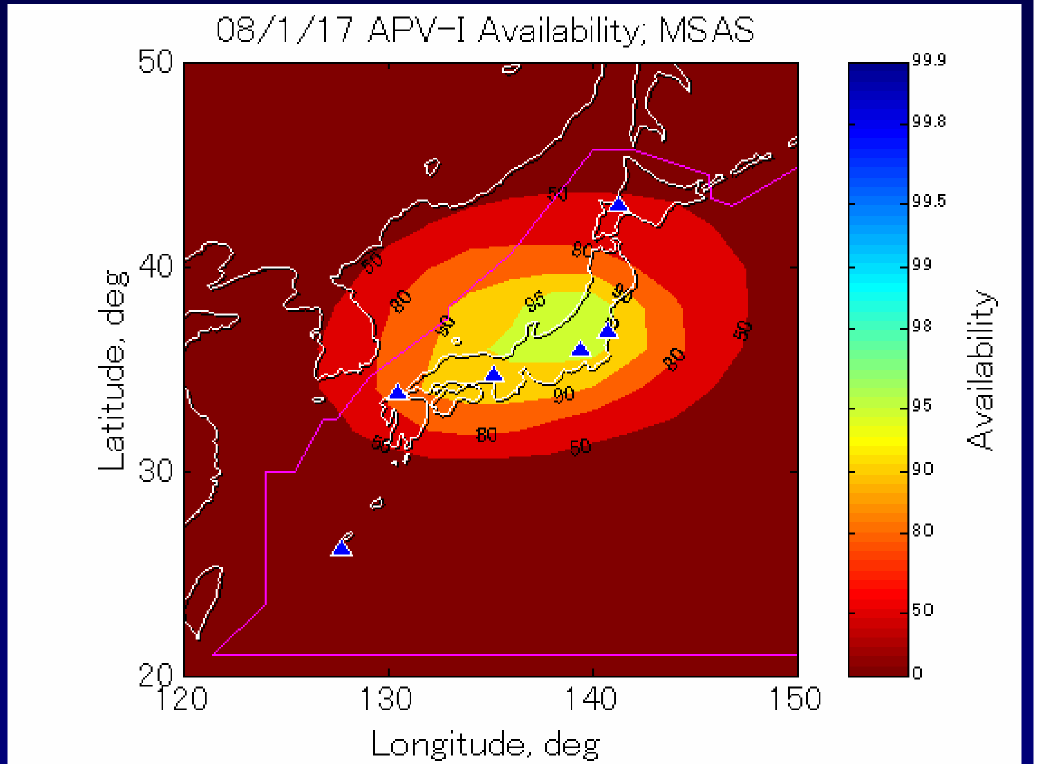
- The current MSAS is built on the IOC WAAS:
  - As the first satellite navigation system developed by Japan, the design tends to be conservative;
  - The primary purpose is providing horizontal navigation means to aviation users; Ionopsheric corrections may not be used;
  - Achieves 100% availability of Enroute to NPA flight modes.
- The major concern for vertical guidance is ionosphere:
  - The ionospheric term is dominant factor of protection levels due to large uncertainty;
  - Necessary to reduce ionospheric term to provide vertical guidance with reasonable availability.



Availability of MSAS



MSAS NPA Availability

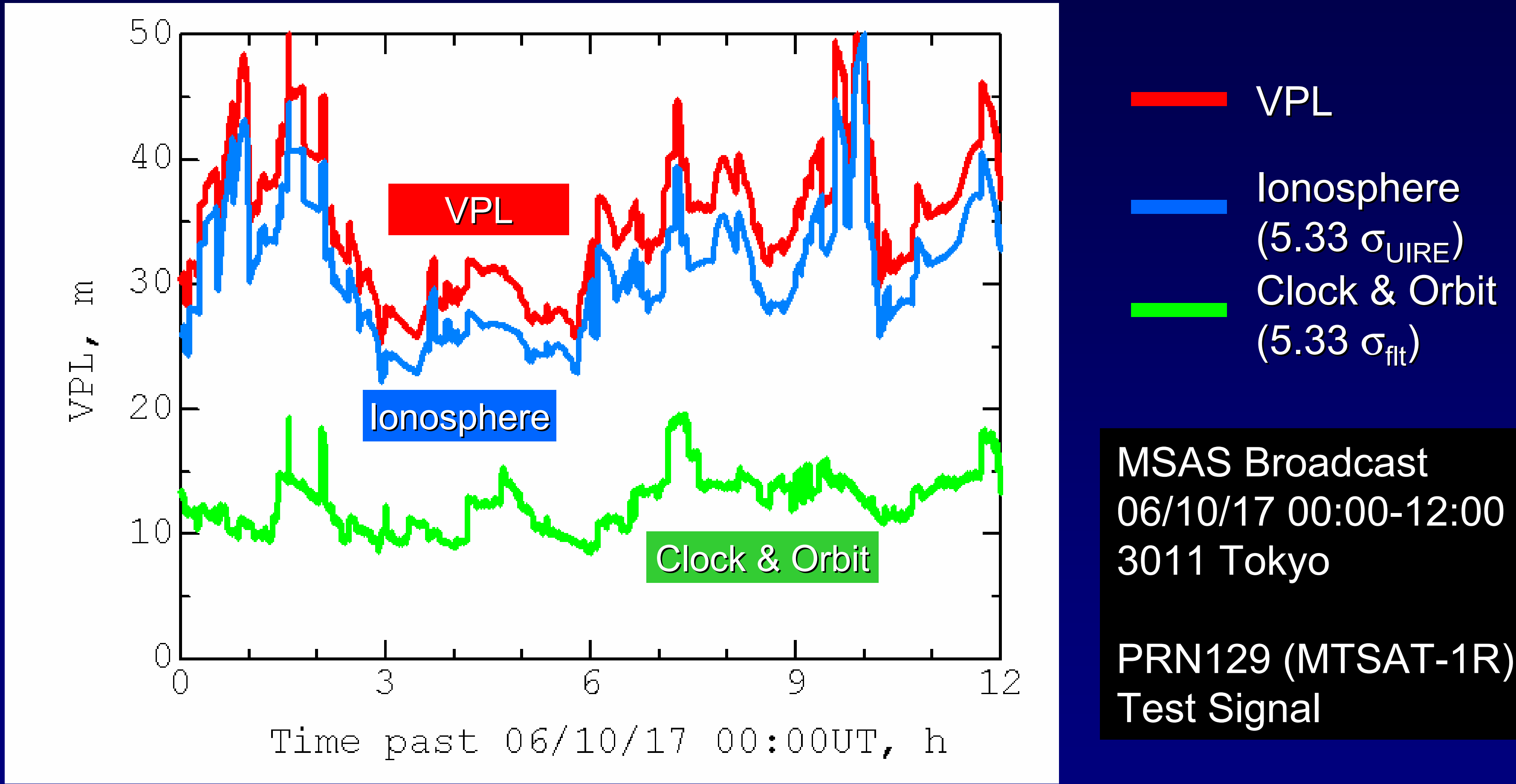


MSAS APV-I Availability

- Enroute thru NPA modes available at the whole Fukuoka FIR.
- APV-I is not available always; 95% at the center of Japan and less than 50% at Okinawa islands (Including Ishigaki Island here) because of large protection levels due to large uncertainty of ionospheric errors.

ENRI

Components of Protection Level



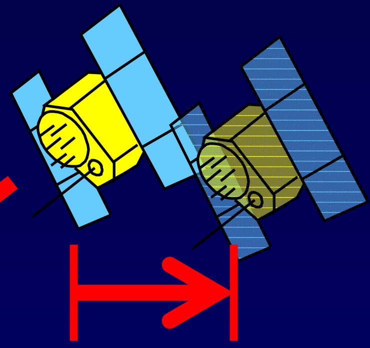
MSAS Broadcast
06/10/17 00:00-12:00
3011 Tokyo

PRN129 (MTSAT-1R)
Test Signal

- The ionospheric term (GIVE) is dominant component of Vertical Protection Level.
- The availability of vertical guidance of MSAS is lowered by the ionospheric term.

ENRI

SBAS Corrections



Ionospheric Correction

- Function of user location;
- Up to 100 meters;
- Vertical structure is described as a thin shell.

Clock Correction

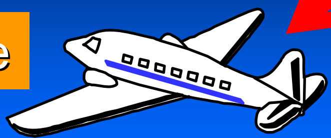
- Same contribution to any user location;
- Not a function of location;
- Needs fast correction.

Orbit Correction

- Different contribution to different user location;
- Not a function of user location; but a function of line-of-sight direction;
- Long-term correction.

Ionosphere

Troposphere



Tropospheric Correction

- Function of user location, especially height of user;
- Up to 20 meters;
- Corrected by a fixed model.

SBAS Message

Preamble	Message Type	Data Field	CRC parity
8 bits	6 bits	212 bits	24 bits

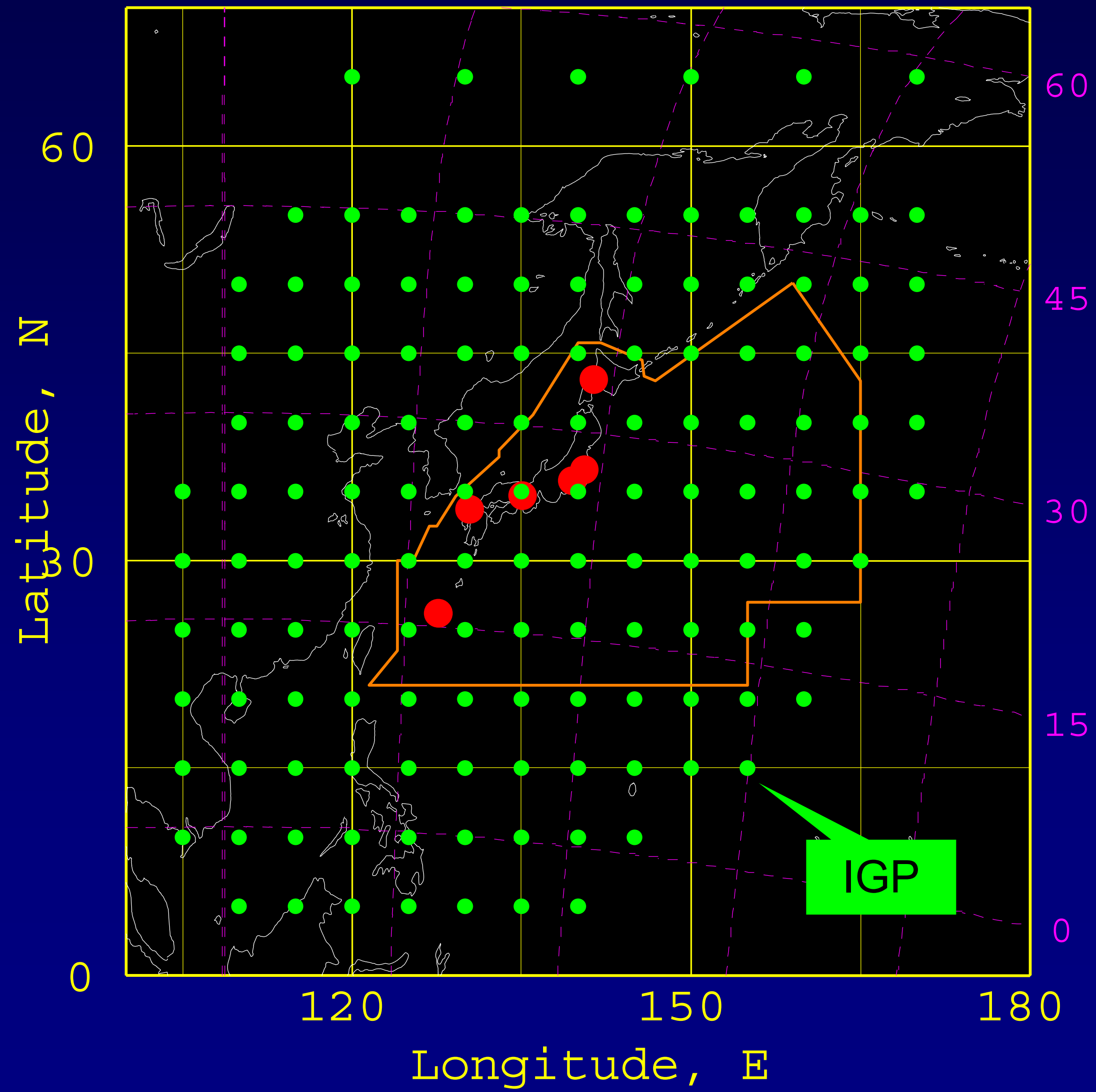
Transmitted First

1 message = 250 bits per second

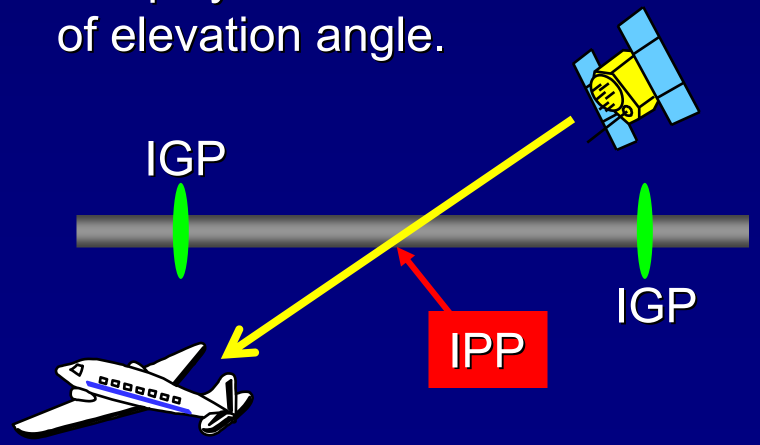
MT	Contents	Interval [s]
0	Test mode	6
1	PRN mask	120
2～5	Fast correction & UDRE	60
6	UDRE	6
7	Degradation factor for FC	120
9	GEO ephemeris	120
10	Degradation parameter	120
12	SBAS time information	300

MT	Contents	Interval [s]
17	GEO almanac	300
18	IGP mask	300
24	FC & LTC	6
25	Long-term correction	120
26	Ionospheric delay & GIVE	300
27	SBAS service message	300
28	Clock-ephemeris covariance	120
63	Null message	—

SBAS Ionospheric Correction



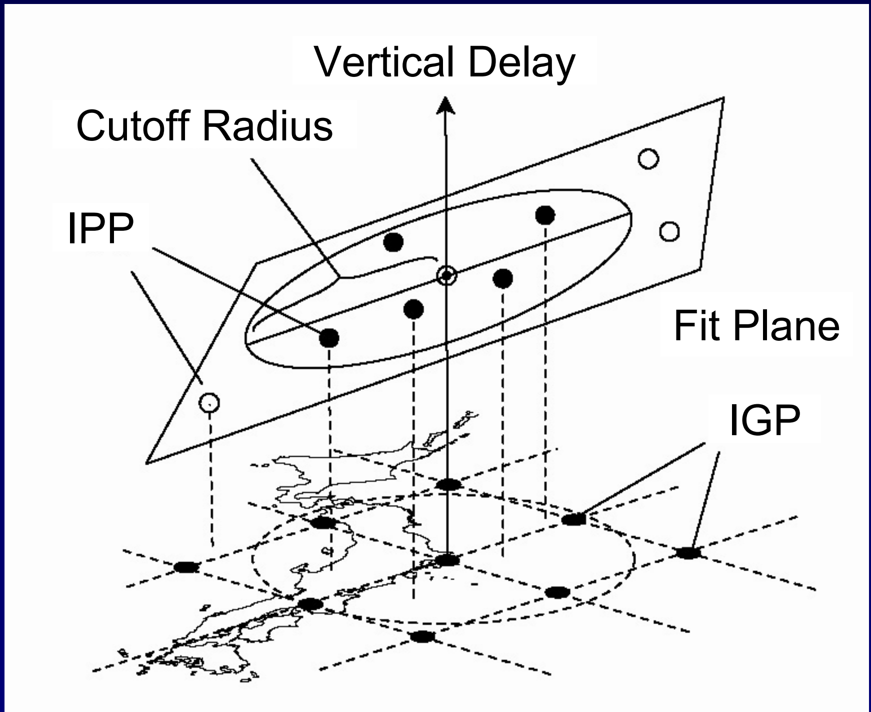
- Vertical ionospheric delay information at IGPs (ionospheric grid point) located with 5-degree interval will be broadcast to users.
- User receiver computes vertical ionospheric delays at IPPs with bilinear interpolation of delays at the surrounding IGPs.
- Vertical delay is converted to slant delay by multiplying so-called obliquity factor which is a function of elevation angle.



Ionosphere Term: GIVE

- Ionospheric component: GIVE (Grid Ionospheric Vertical Error)
  - Uncertainty of estimated vertical ionospheric delay used in computation of protection levels to overbound ionospheric errors.
  - Broadcast as 4-bit GIVEI index.
- Current algorithm: 'Planar Fit':
  - Vertical delay is estimated as parameters of planar ionosphere model.
  - GIVE is computed based on the formal variance of the estimation.
- The formal variance is inflated by:
  - Rirreg: Inflation factor based on chi-square statistics handling the worst case that the distribution of true residual errors is not well-sampled; a function of the number of IPPs; Rirreg = 2.38 for 30 IPPs.
  - Undersampled Threat Model: Safety margin for threat due to the significant structure of ionosphere not captured by IPP samples; A function of spatial distribution (weighted centroid) of IPPs available for estimation.

Planar Fit and GIVE



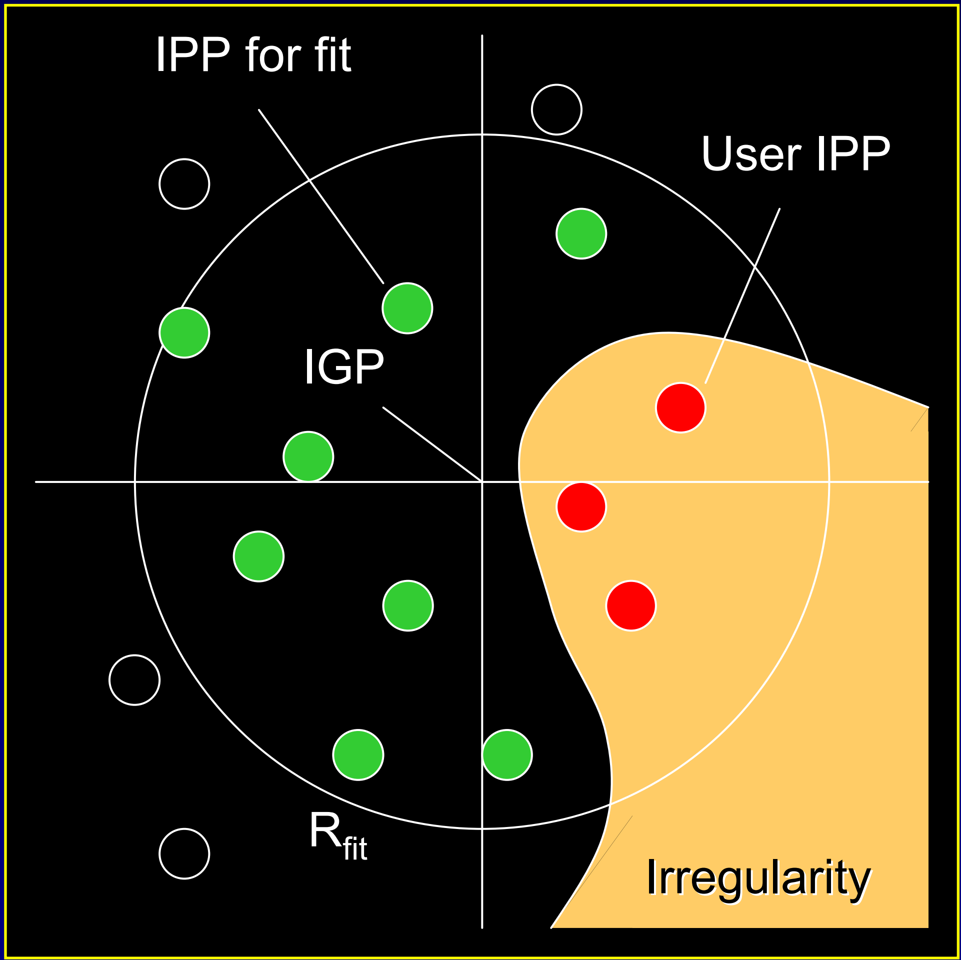
- Developed for WAAS; MSAS employs the same algorithm.
- Assume ionospheric vertical delay can be modeled as a plane.
- Model parameters are estimated by the least square fit.
- GIVE (grid ionosphere vertical error): Uncertainty of the estimation including spatial and temporal threats.

- GIVE Equation

Spatial Threat Model

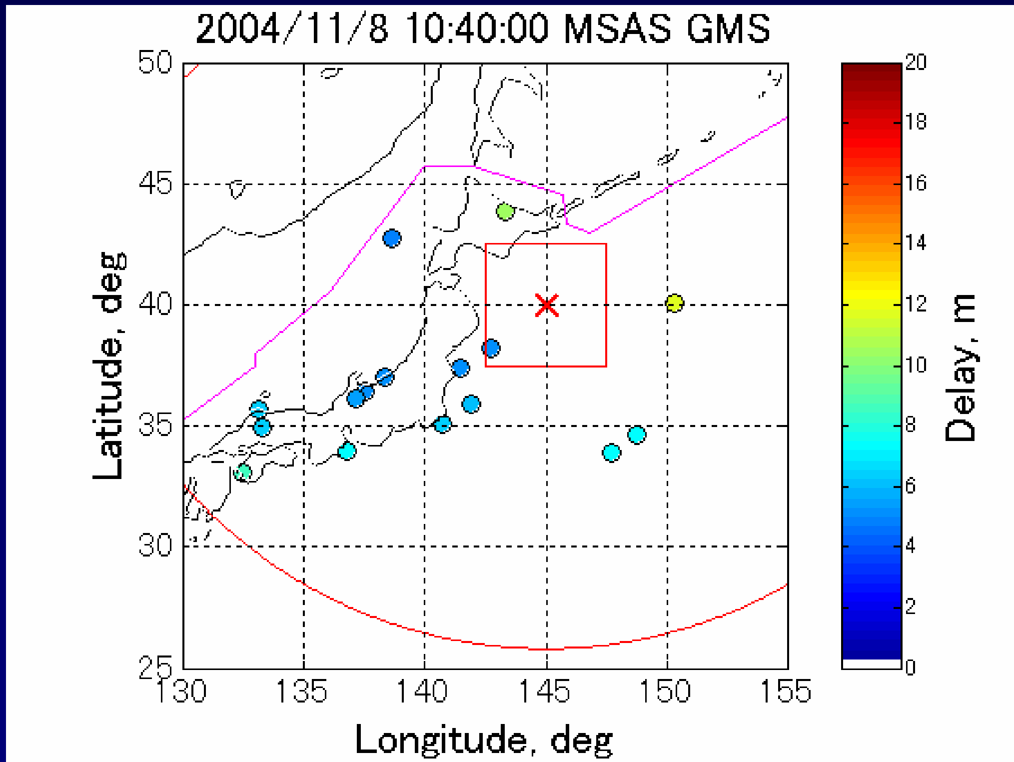
$$\sigma_{GIVE}^2 = \underbrace{R_{irreg}^2 \sigma_{IGP_k}^2}_{\text{Formal Sigma}} + \underbrace{\max\left(R_{irreg}^2 \sigma_{decorr}^2, \sigma_{undersampled}^2\right)}_{\text{Spatial Threat}} + \underbrace{\sigma_{rate-of-change}^2}_{\text{Temporal Threat}}$$

Ionosphere Spatial Threat



- Planar fit is performed with IPPs (ionospheric pierce points) measured by GMS stations.
- Local irregularities might not be sampled by any GMS stations.
- Users might use IPPs within the local irregularities; Potential threat of large position error.
- MSAS must protect users against such a condition; The spatial threat term is added to GIVE.
- Spatial threat model created based on the historical severe ionospheric storm data.

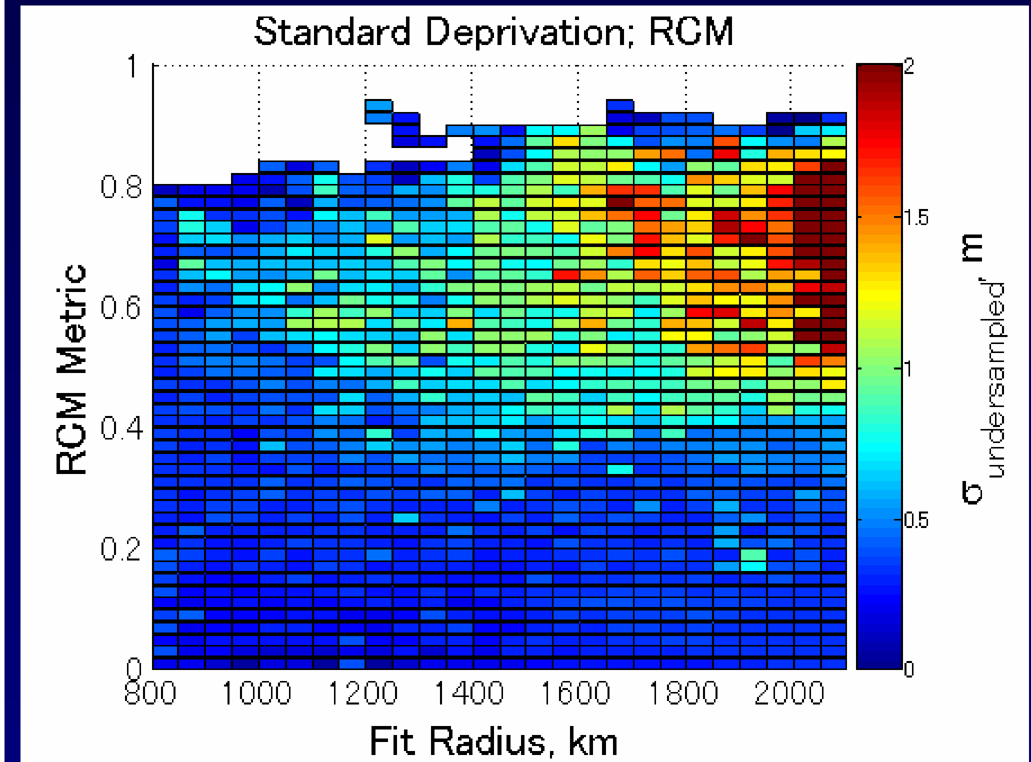
Ionosphere Spatial Threat



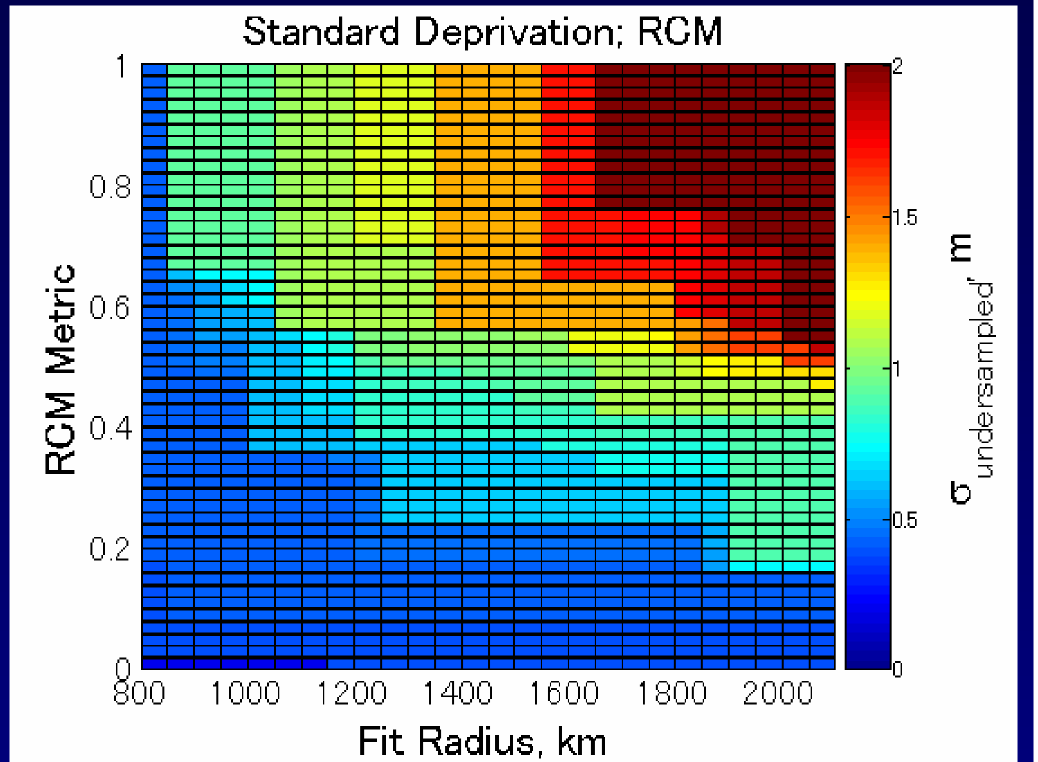
View from MSAS GMS (6-Station Set)

- Problem: Is ionosphere sampled with enough density?
- In other words: Can MSAS guarantee there is no threat (large delay) at the box area?
- Threat model is created based on the largest delay observed in past.

Example Spatial Threat Model



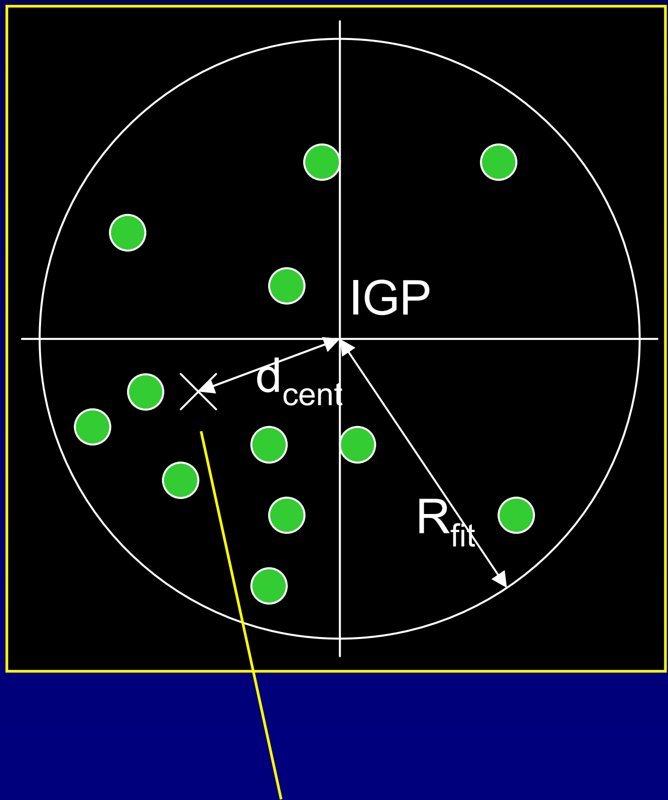
Max Residual



Threat Model

- Function of fit radius (cutoff radius) and RCM metric.
- Good and bad IPP geometries are distinguished by these two metrics.
- Resulted $\sigma_{undersampled}$ is roughly between 0 and 2.5.

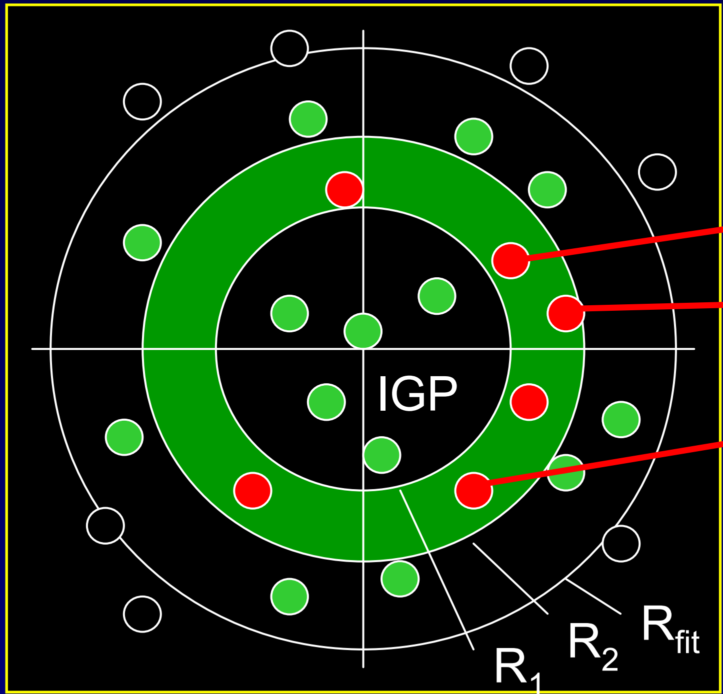
The Second Metric: RCM

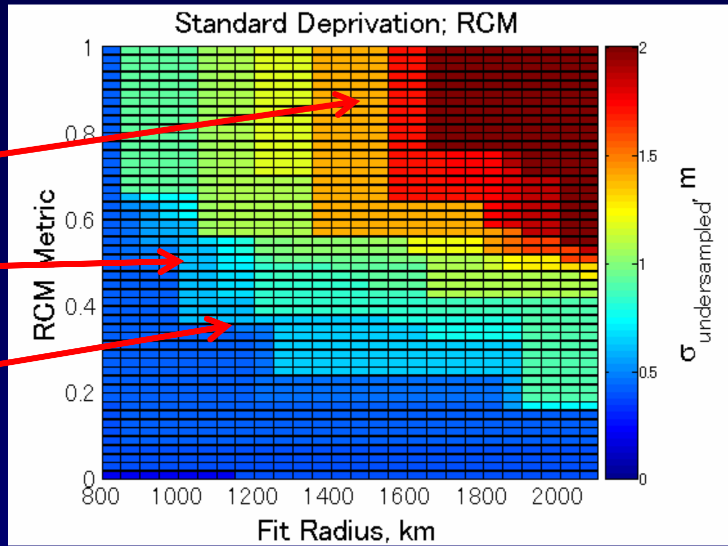


Weighted centroid of IPPs

- RCM (Relative Centroid Metric) is used as the second metric of the threat model; The first one is fit radius;
- RCM is the distance between the weighted centroid of IPPs and IGP divided by fit radius;
- Using Rfit and RCM, it is possible to distinguish good and bad geometries of IPP distribution, and thus reduce undersampled threat term;

Methodology: Data Deprivation





Threat Model

- Removes some IPPs (shown in red) for planar fit; They become virtual users;
- Residual: difference between estimated plane and removed IPPs (virtual users);
- Tabulates residuals within the threat region (5-deg square) with respect to fit radius and RCM; The largest residual in each cell contributes to the threat model because it means the possible maximum residual users may experience;
- MSAS employs annular (shown above) and three-quadrant deprivation.

Conclusion

- Ionosphere Threat Model for SBAS
  - For meeting integrity requirements, we need ionosphere threat model along with generation of ionospheric corrections.
  - An explanation of the threat model used for WAAS and MSAS is given.
- The ISTF meeting is invited to:
  - Develop ionosphere models including spatial and temporal threat representations acceptable for participating States/Regions.
  - Encourage refinement of the existing threat models to improve availability of systems.
  - Develop other algorithms which can be standardized for equatorial regions.

For further information, contact:

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