Flight Trials to collect GPS data under Equatorial Ionospheric Plasma Bubbles

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Contents

- Bubble Impact on GBAS
- GPS Signal characteristics on Aircraft
  - Maneuver and Vibration Effects
  - Scintillation Effect
- Flight Test Configurations
- Measurement Results
- Summary

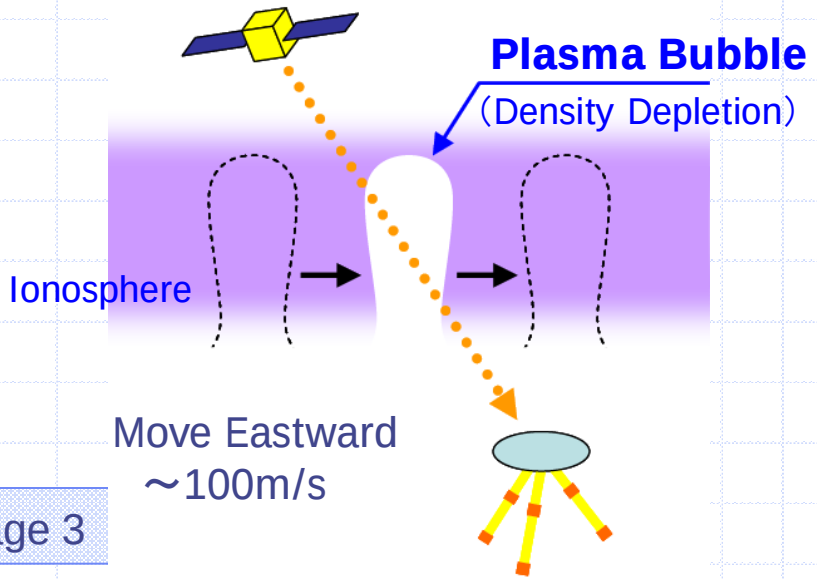
Ionospheric Anomaly

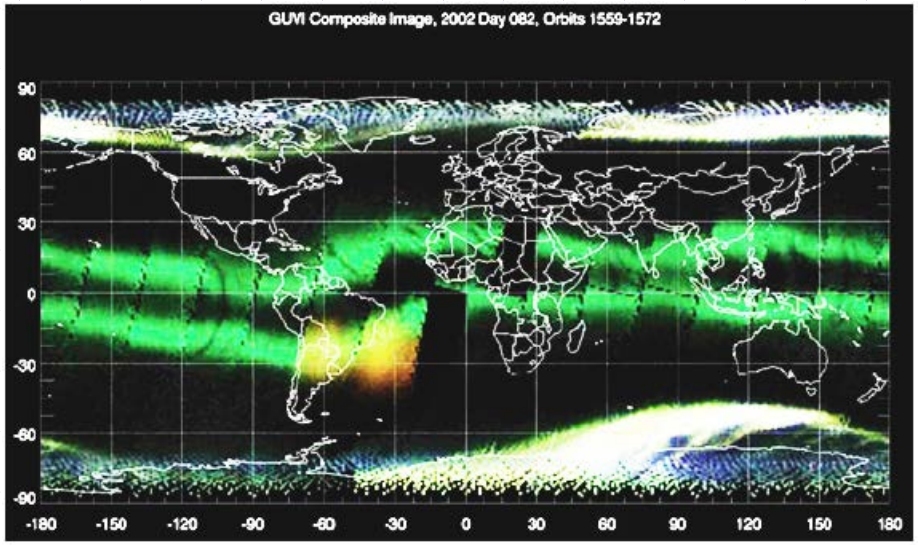
- Storm Enhanced Density (SED)
  - Mid~High Latitude Region
  - Spatial Gradient： ＞400mm/km

Rare

- Equatorial Plasma Bubble (EPB)
  - Low~Mid Latitude Region
  - Scintillation

Frequent



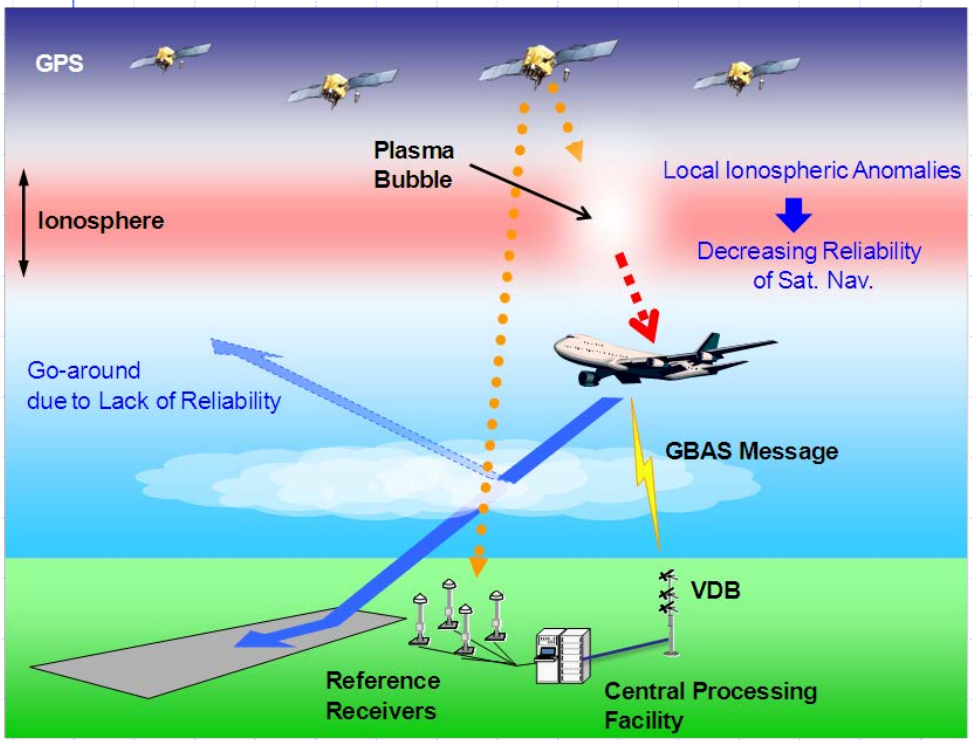


EPB observed by GUVI/TIMED satellite
（Christensen et al., 2003）

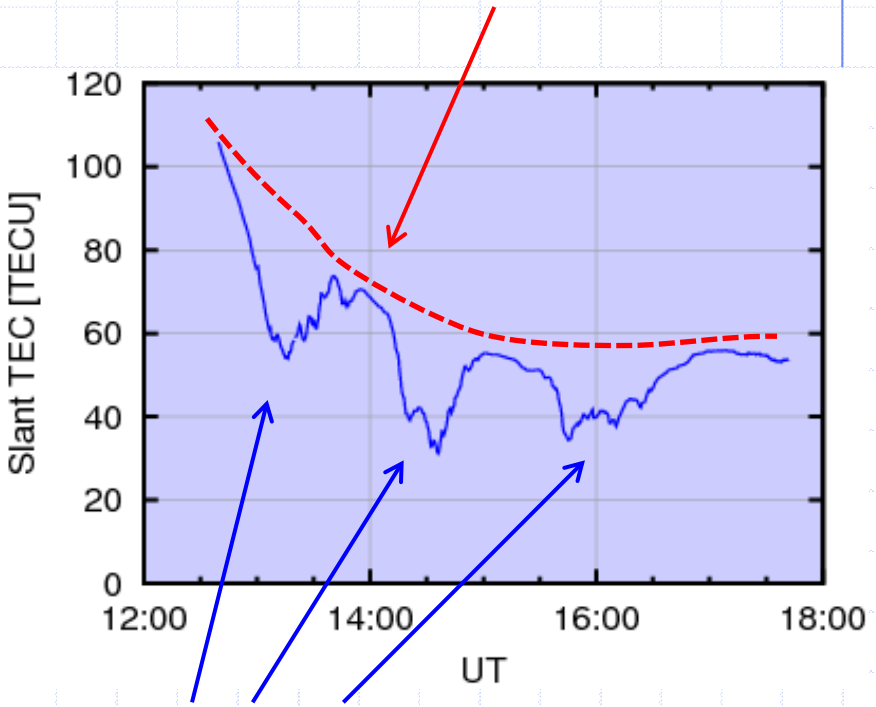
Green belt : Equatorial Ionospheric Anomaly
Black line : Equatorial Plasma Bubble

Bubble Impact on GBAS (1)

Steep Change of Iono. Delay



TEC without Bubble



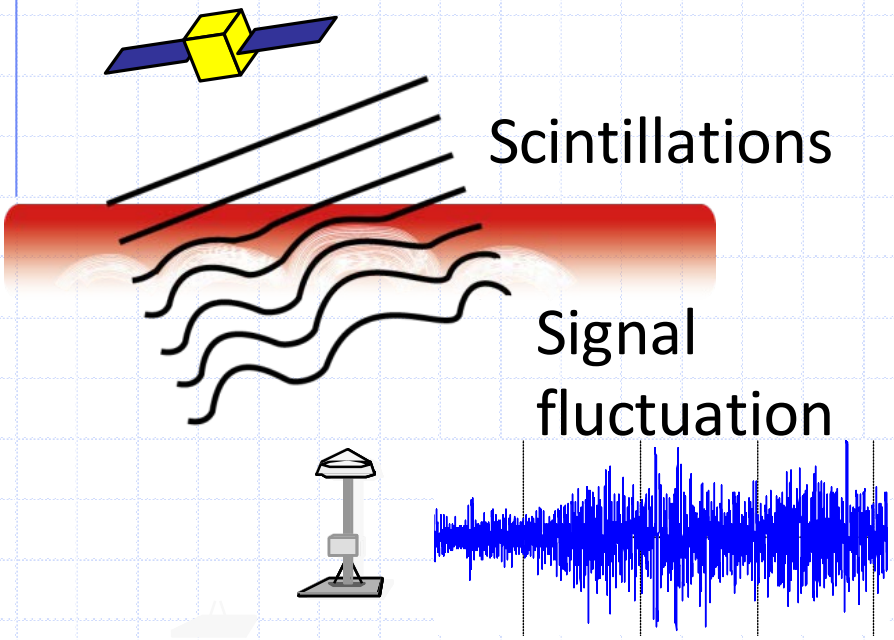
Three successive bubbles

Spatial gradient of TEC would result in wrong correction data

➢ Degrade DGPS Accuracy

Bubble Impact on GBAS (2)

Scintillation



Scintillation would cause temporal loss of satellite lock

→ re-initialization of PR smoothing

→ go around due to multiple satellites losses

Reduced Number of Satellite

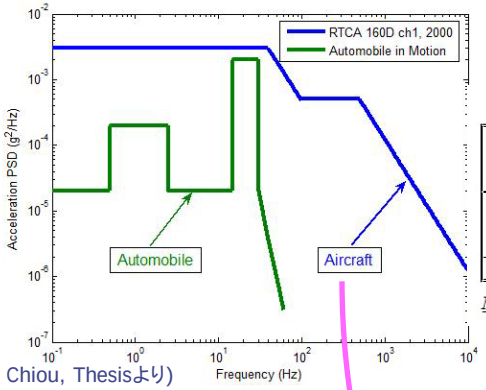
➡ Decrease GBAS Availability

GPS Signal characteristics on Aircraft

Carrier Tracking Error
at **GROUND** Receiver

Mainly affected by
Clock Jitter & **Thermal Noise**

Aircraft Vibration Effect
(RTCA DO-160F)



(T-Y Chiou, Thesisより)

Aircraft Masneuvour
(RTCA DO-253C)

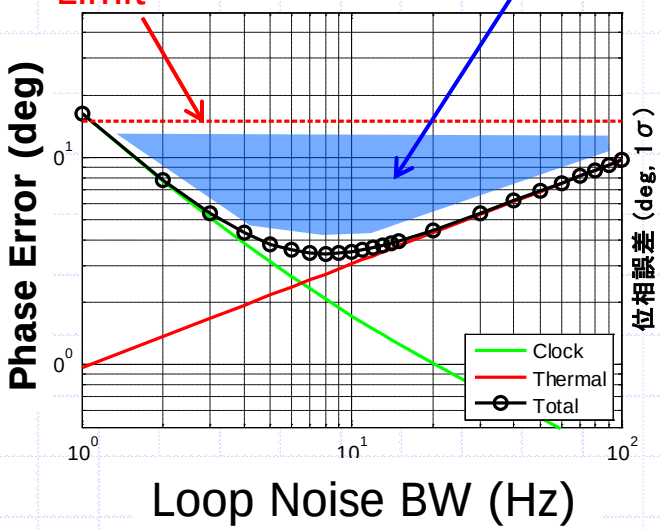
Table 2-5 Normal Maneuvers Maximum Values

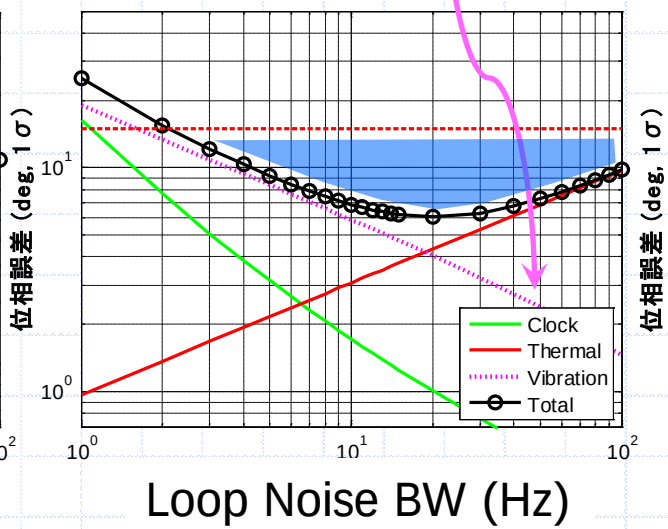
LAAS Equipment Outputs	Ground Speed	Horizontal Acceleration	Vertical Acceleration	Total Jerk
Precision Approach Guidance	250 kts	0.58 g	0.50 g	0.25 g/s
PVT	800 kts	0.58 g	0.50 g	0.25 g/s

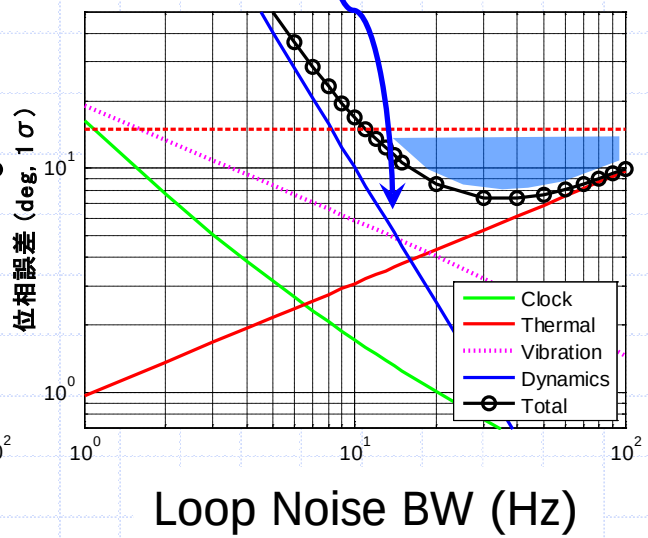
Note: *g = acceleration of gravity, i.e., 9.8 m/s².*

Tracking Limit

Tracking Margin

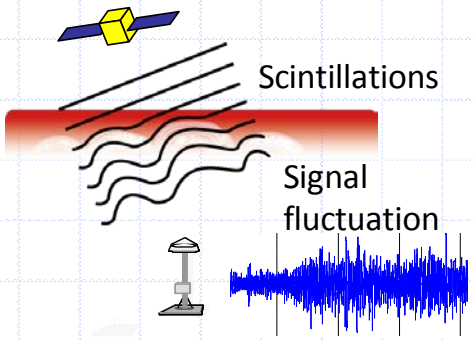




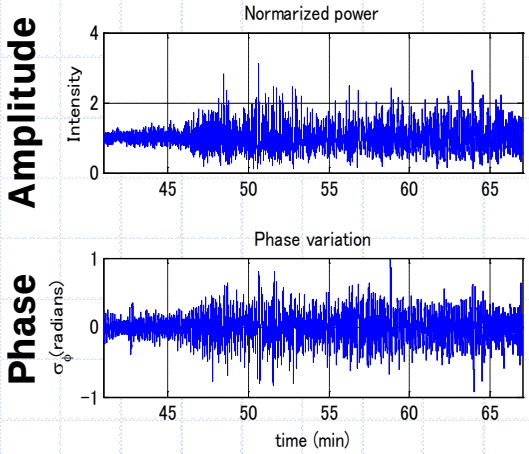


RTCA: Radio Technical Commission for Aeronautics

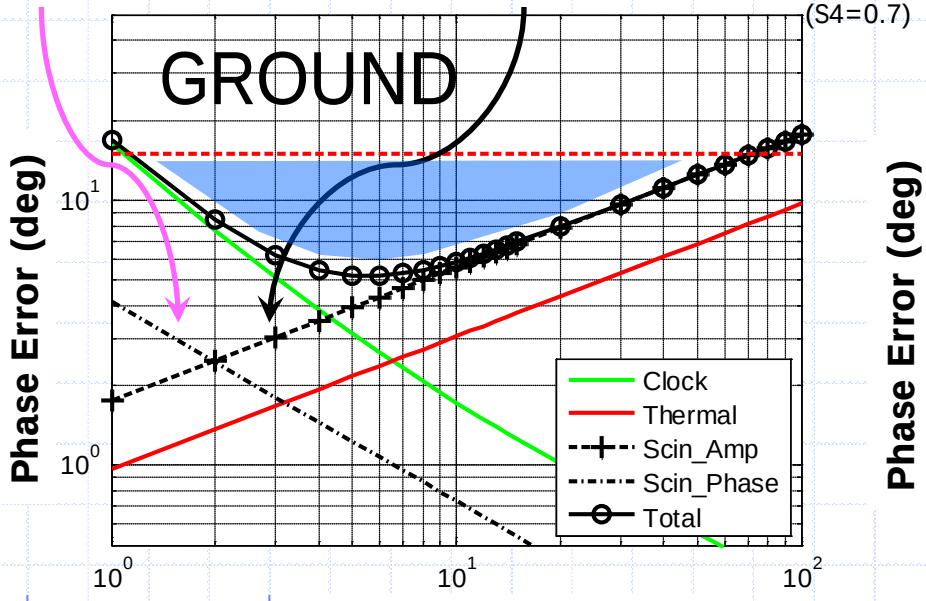
Scintillation Effect

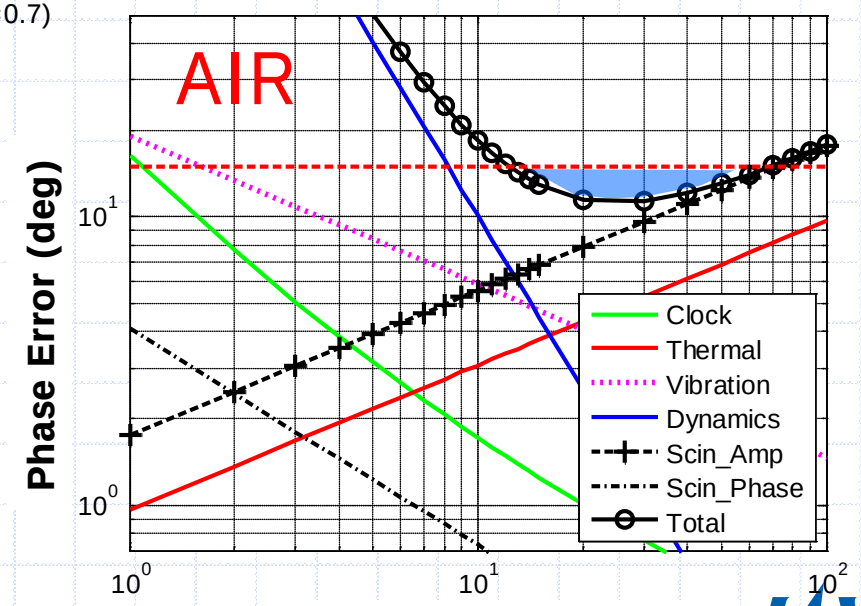


Amplitude and Phase variation due to scintillation



Phase Scintillation Amplitude Scintillation (S4=0.7)



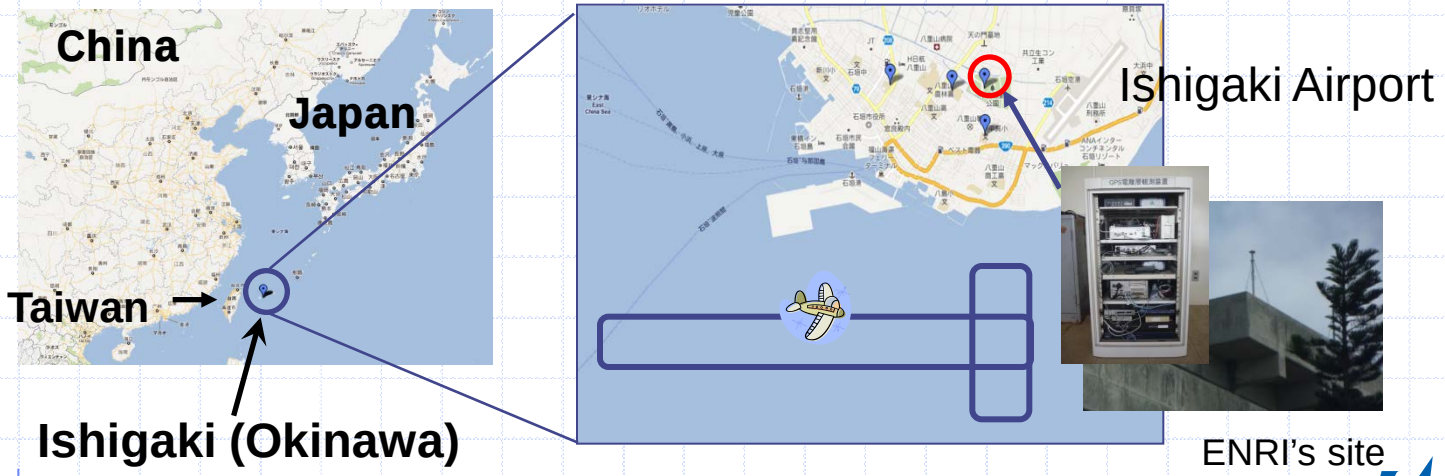


Flight Trial Campaign

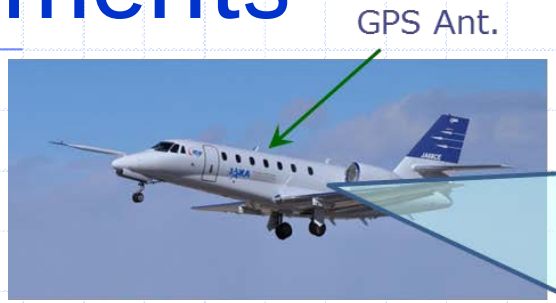
September 4 ～ 13th, 2012

Date	4	5	6	7	8	9	10	11	12	13
Bubble Occurrence	–	–	–	–	–	–	○	○	○	○
Flight test	–	–	–	○	–	–	○	○	○	○

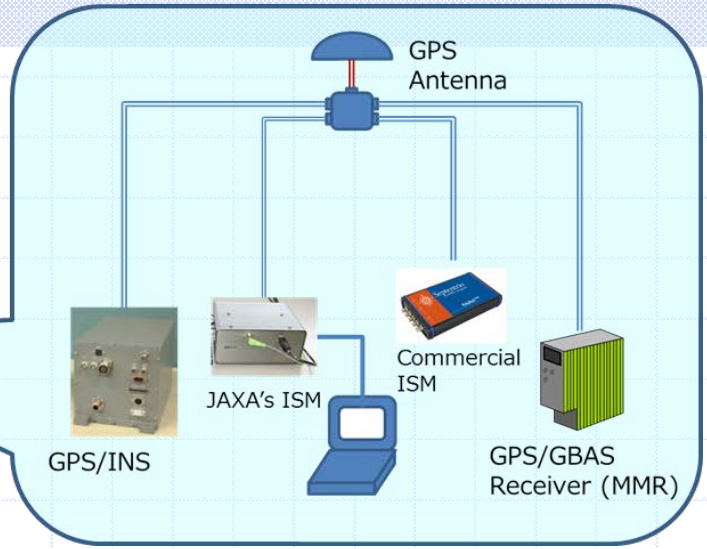
Ishigaki-Island, Okinawa, Japan.
(N24.3452668, E124.183674)



Equipments



JAXA's Flying Test-bed



Research aircraft(Cessna Citation Sovereign) and onboard equipments

Main Airborne Equipments:

- ✓ MMR, Rockwell Collins GNLU-930-redlabel
- ✓ Ionospheric Scintillation Monitor (ISM), Septentrio PolaRxS Pro
- ✓ Software-based ISM, JAXA
- ✓ Javad Delta GNSS receiver (50Hz)

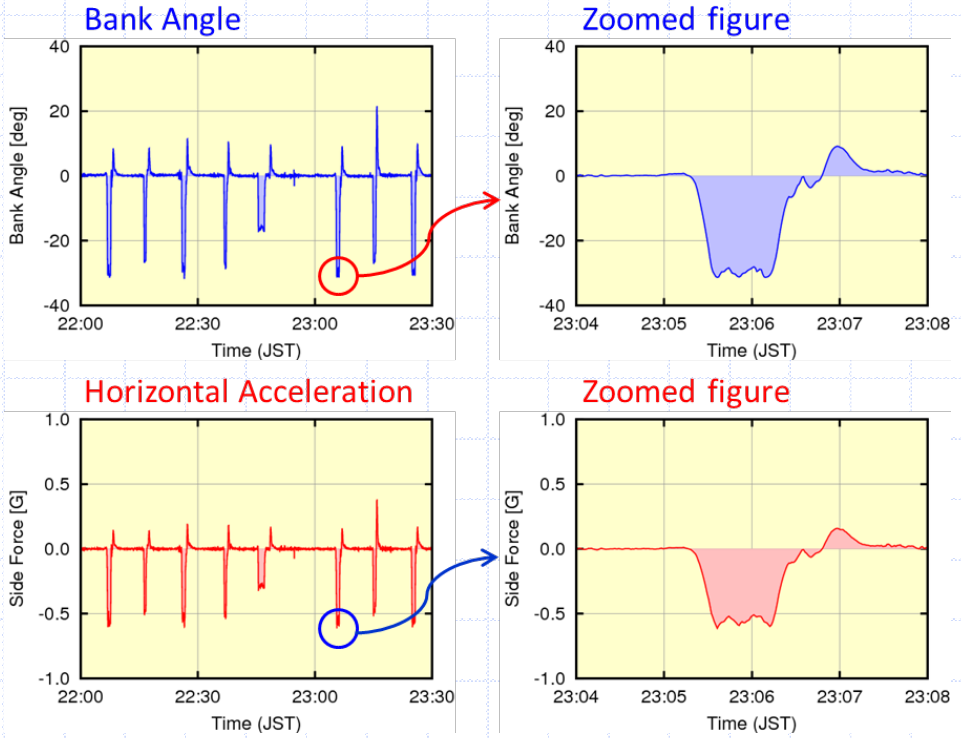
Main Ground Equipments:

- ✓ Ionospheric Scintillation Monitor (ISM), Septentrio PolaRxS Pro
- ✓ Software-based ISM, JAXA
- ✓ Javad Delta GNSS receiver (50Hz)

Flight Pattern

- Straight Level flight (20 NM Legs)
- Horizontal Acceleration (0.58g, MOPS) induced by banking (～30 deg)

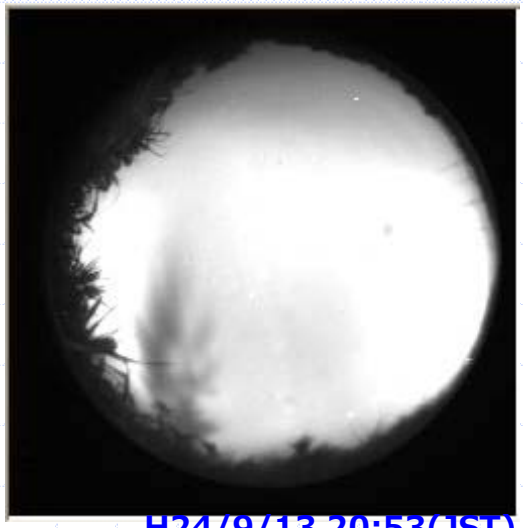
Flight Profile (Sept.10)



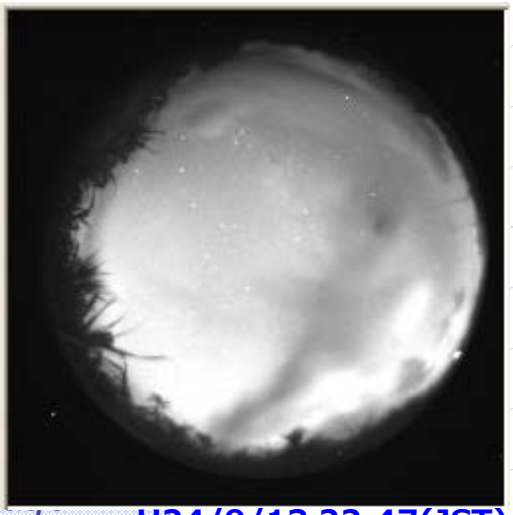
Bank angle and horizontal acceleration

Observation of Plasma Bubbles

Airglow image (630nm)@Yonaguni（by ENRI）

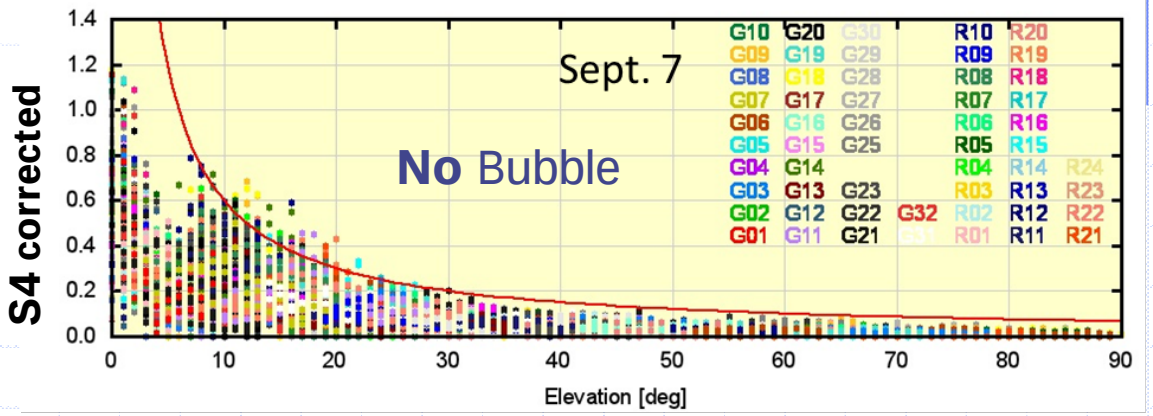


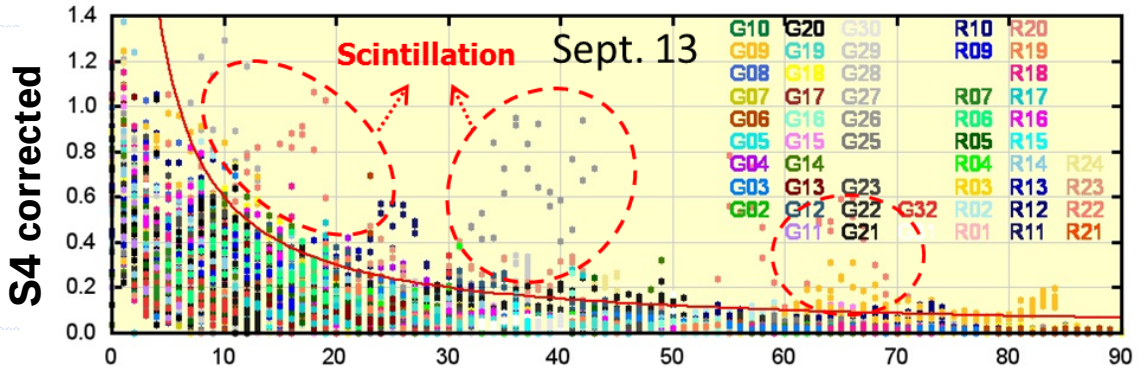
H24/9/13 20:53(JST)



H24/9/13 22:47(JST)

S4 vs. Elevation

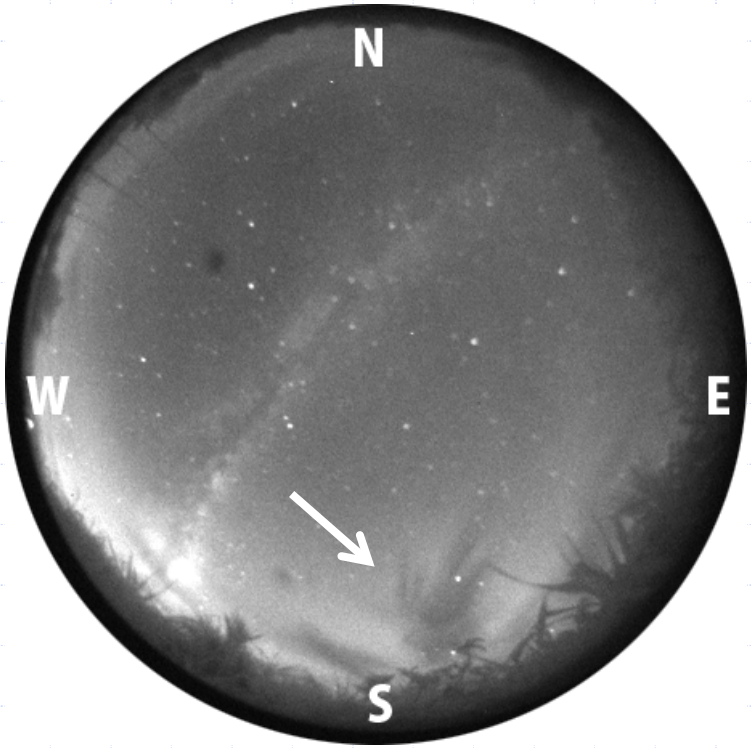




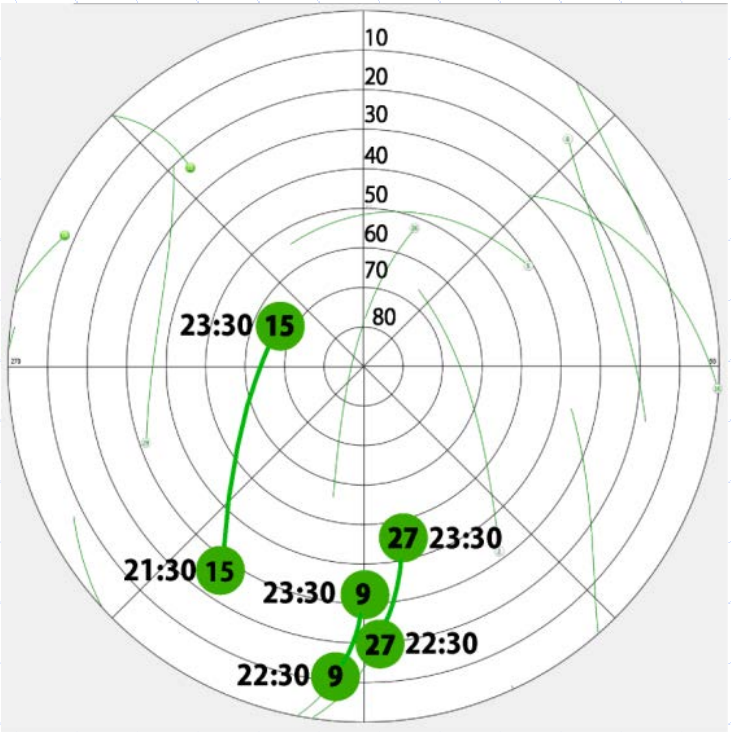
Elevation (Deg)

Sept. 13 Bubble occurred

Example of Analysis Results (Data of Sept. 12)

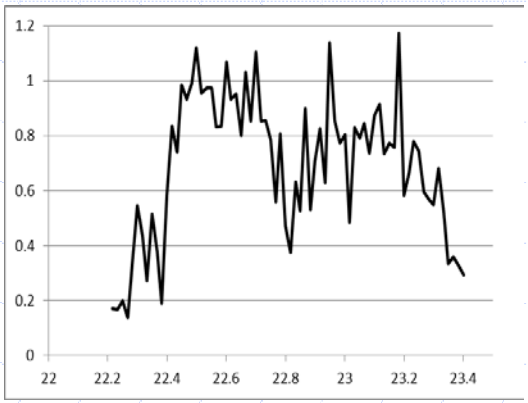


Airglow (777.4nm) image at 22:34 LT
(by ENRI)

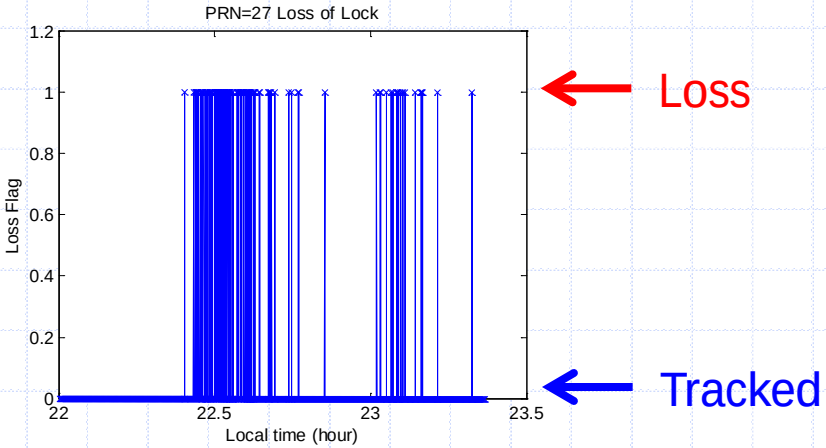


Satellite trajectories.
(PRN9, 15 and 27 are emphasized)

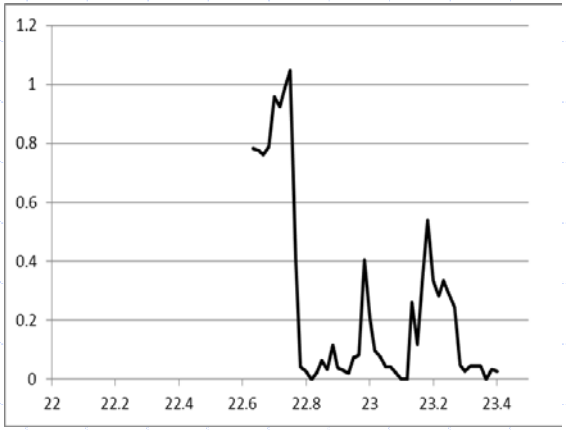
Loss of Lock



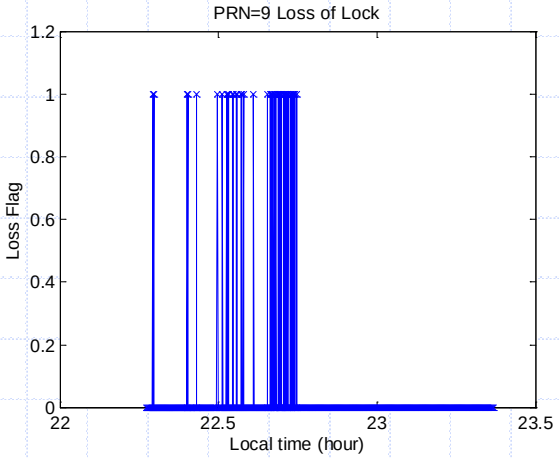
S4 from Airborne ISM, PRN 27



Lock Loss of PRN 27, MMR



S4 from Airborne ISM, PRN 9

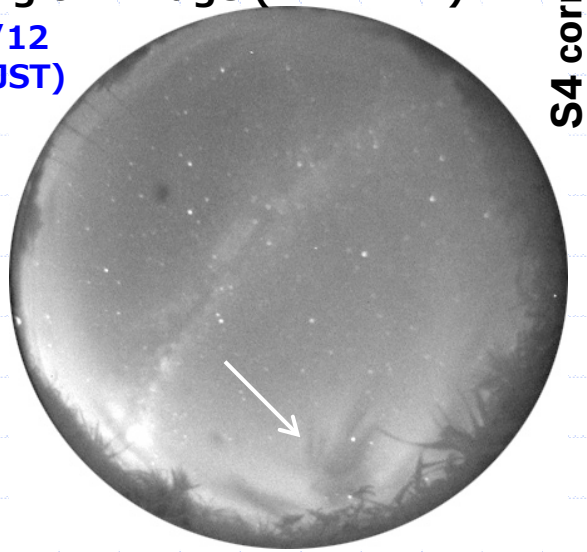


Lock Loss of PRN 9, MMR

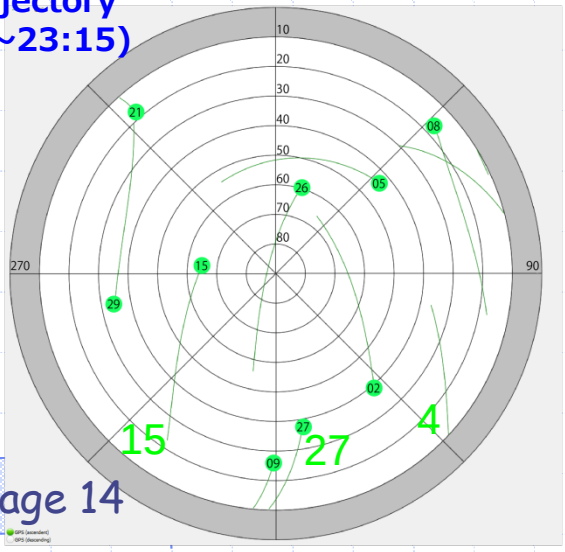
Amplitude Scintillation Index: S4

Airglow image (777.4nm)

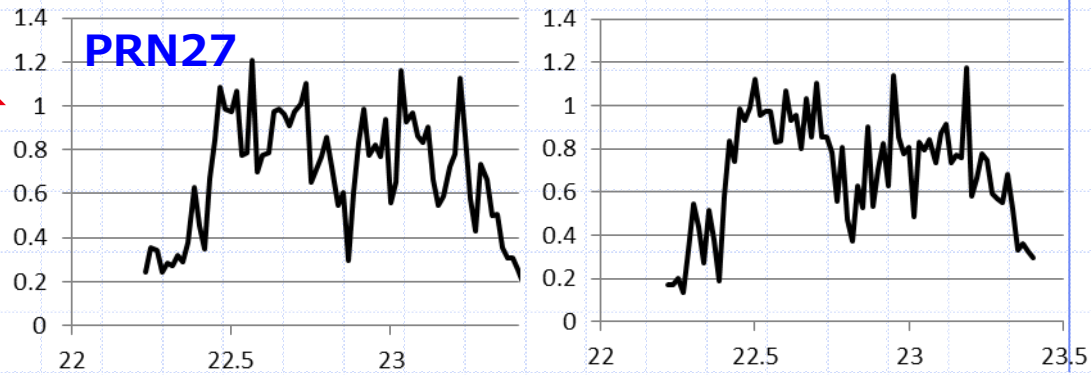
H24/9/12
22:34(JST)

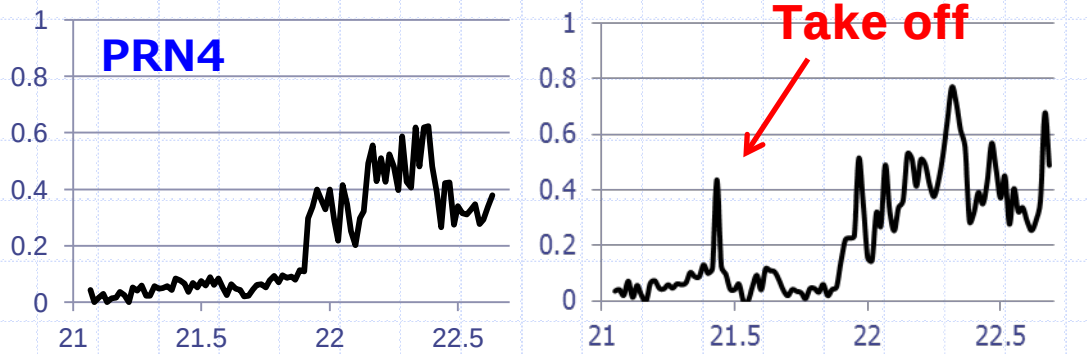


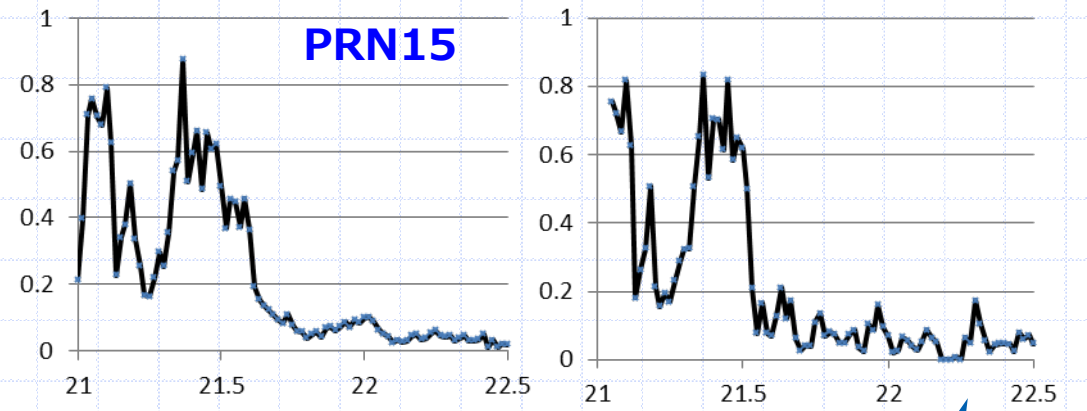
GPS Trajectory
(21:15～23:15)



S4 corrected







GROUND

AIR JAXA

Phase Scintillation Index: σ_ϕ

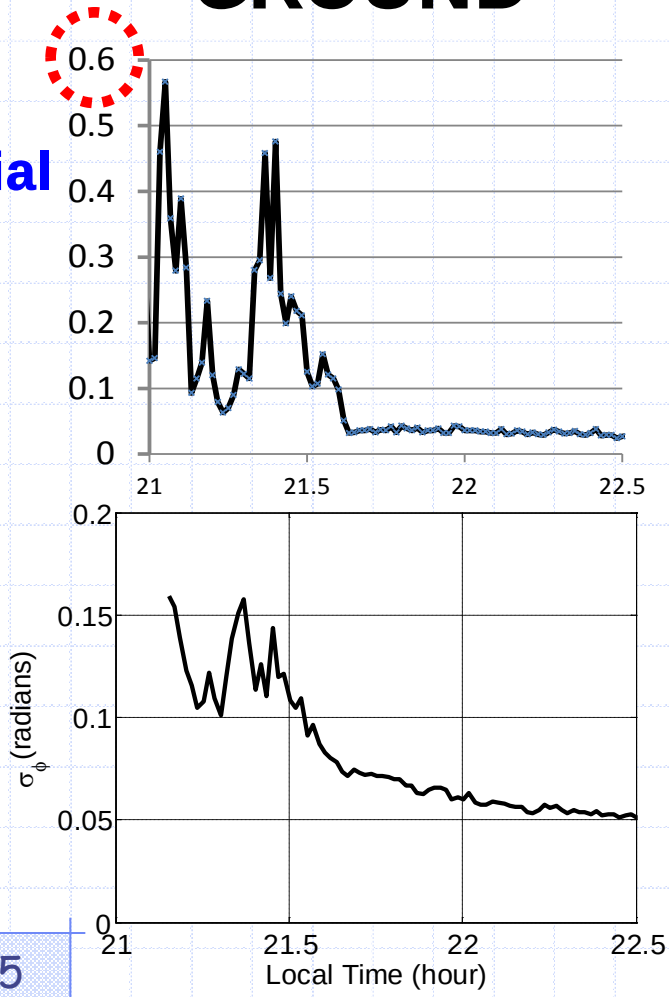
PRN15

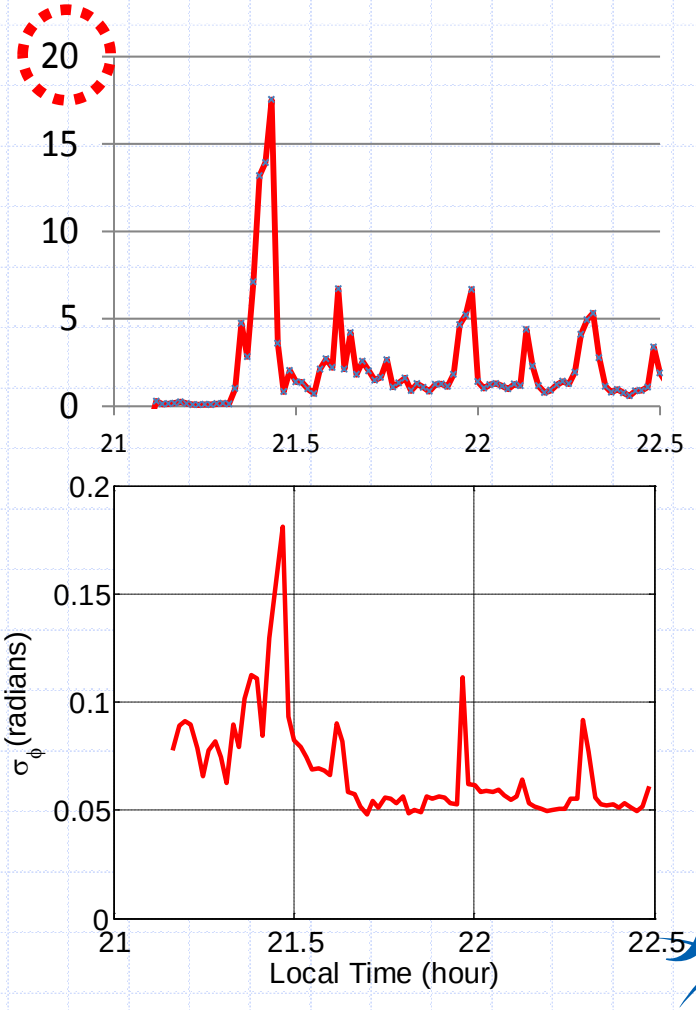
GROUND

AIRBORNE

Commercial ISM

JAXA ISM

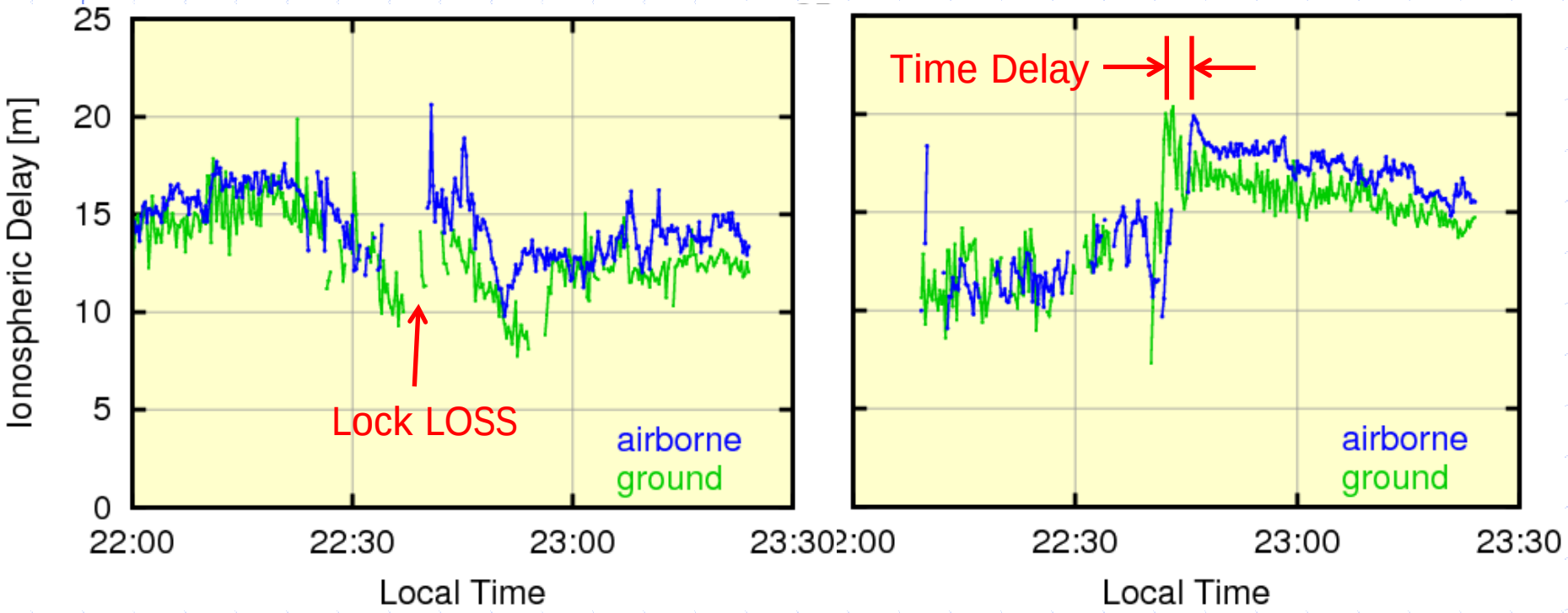




Ionospheric delay

Iono. Delay Measured by **GROUND** and **AIRBORNE** Rx

(output of PolaRxS Pro)

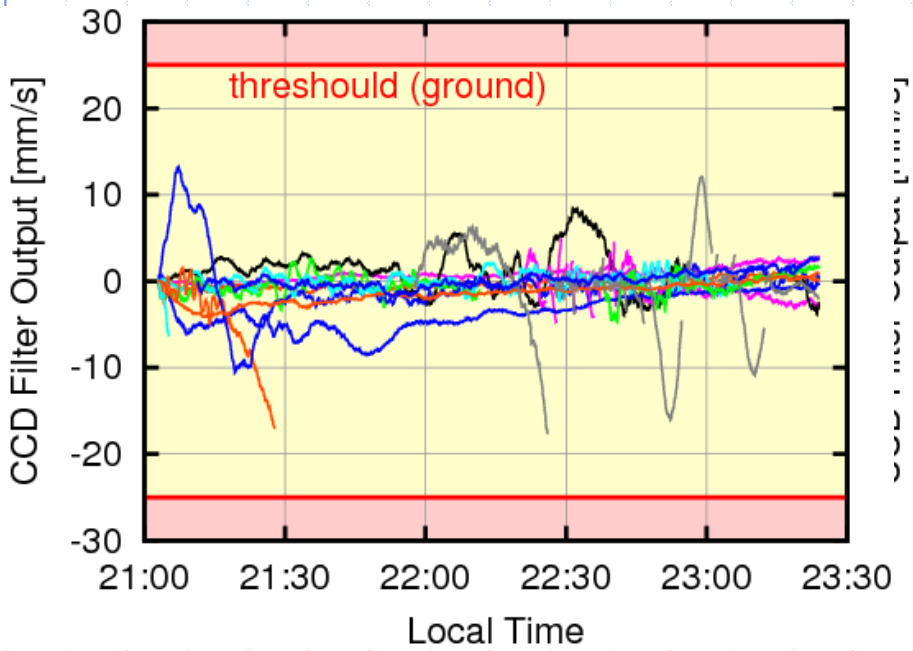


PRN 27

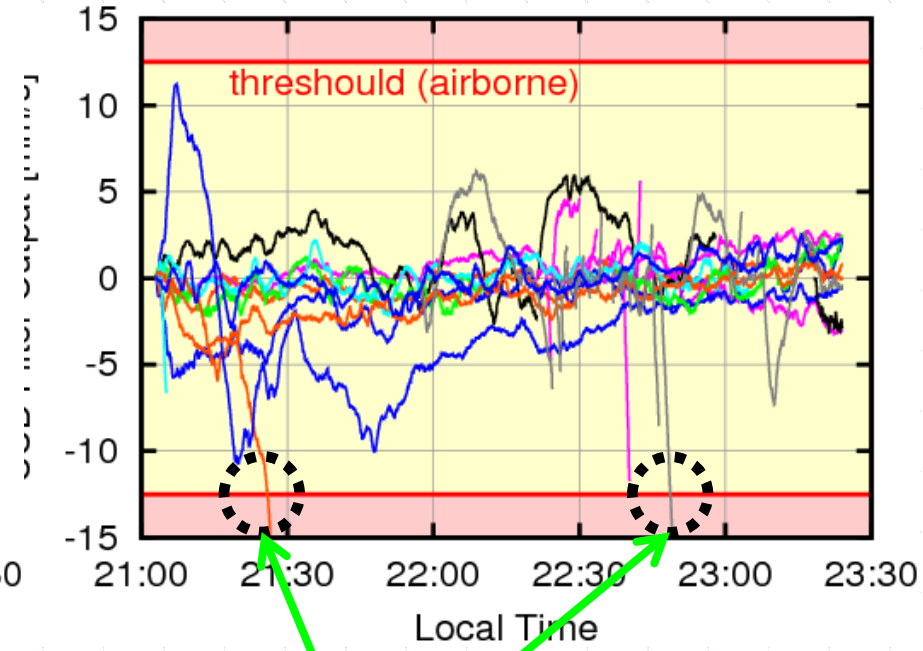
PRN 9

CCD Monitor

CCD filter output of **GROUND** receiver (Post-Processing)



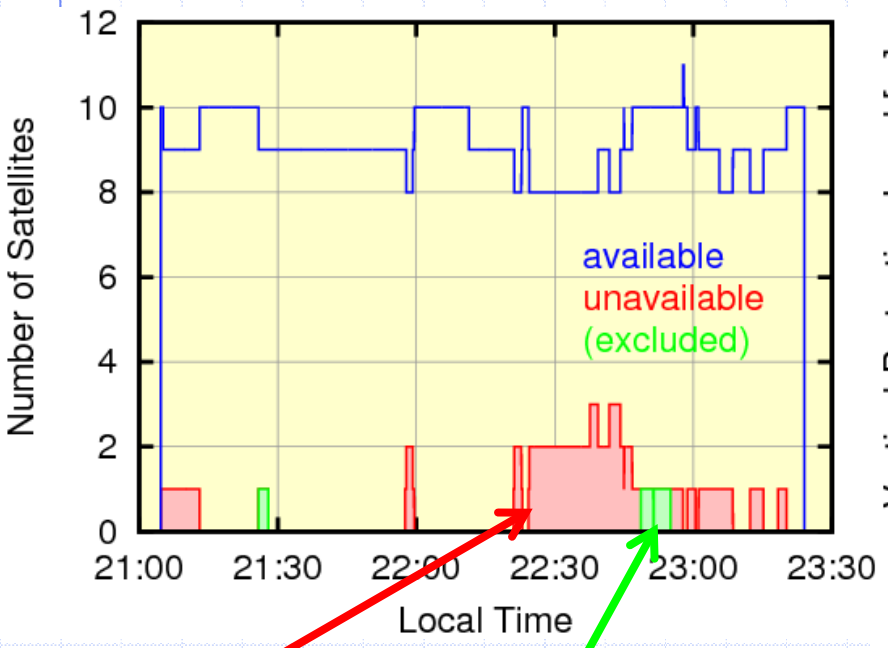
CCD filter output of **AIRBORNE** receiver (Post-Processing)



Excluded

No. of Sats and Protection Level

Number of used satellites (blue), lost satellites (red), excluded satellites (green) by CCD monitor

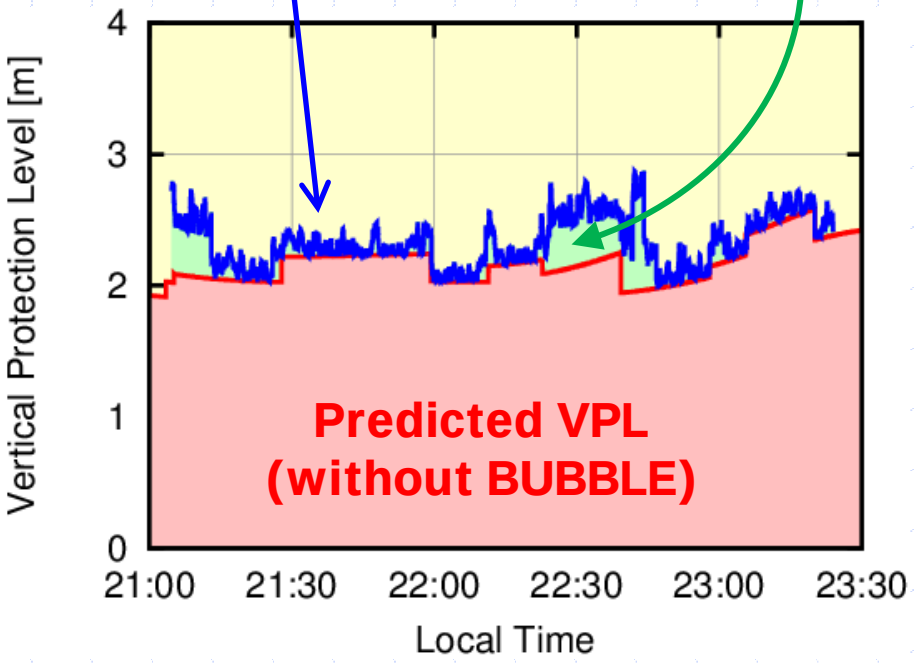


Lost

Excluded By CCD

VPL with BUBBLEs (real data)

VPL Increment Due to BUBBLEs



Summary

- Four flight tests were conducted under plasma bubbles
- A few satellites became unavailable due to loss of lock and CCD monitor (Maximum three satellites were unavailable on Sept. 12). VPL increased correspondingly.
- INS-aiding will be applied and airborne scintillation data will be investigated further.
- More flight tests are planned (March, Sept., 2013, March, 2014)
- Any Suggestions on flight pattern, data collection, etc. are welcome!