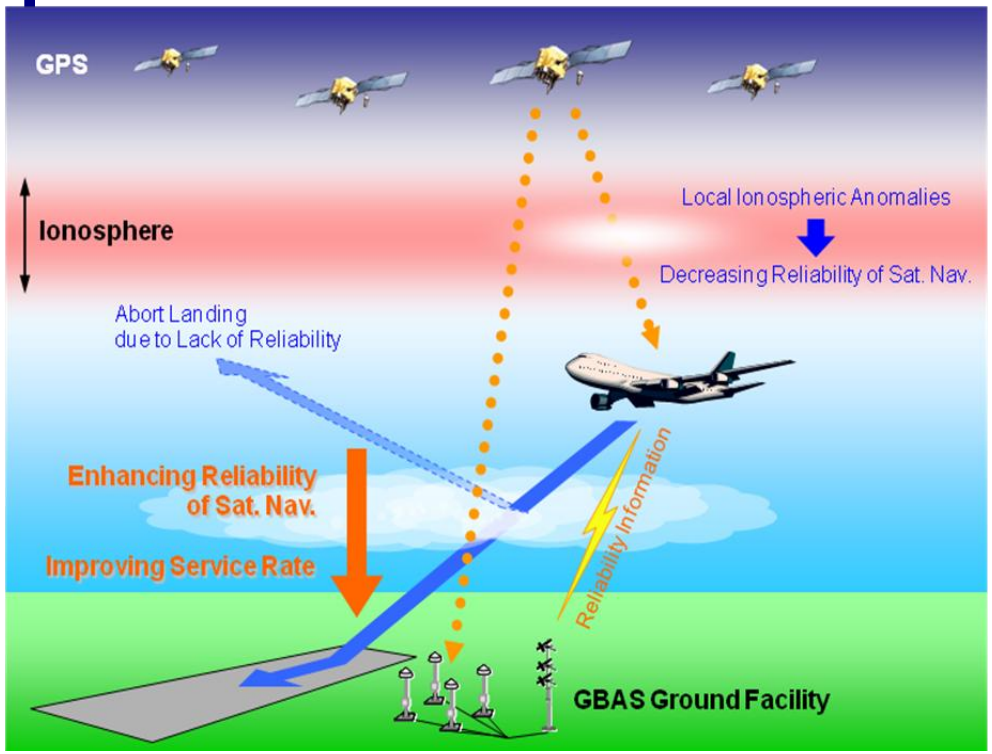
Study of INS-Aided GPS Tracking Performance under Simulated Ionospheric Scintillation Associated with Plasma Bubbles

Toshiaki Tsujii, Takeshi Fujiwara, Yoshimitsu Suganuma
Japan Aerospace Exploration Agency (JAXA)

and

Keisuke Matsunaga
Electronic Navigation Research Institute (ENRI)

Background (1/2)



Ionospheric effects would degrade availability of aircraft precision approach

GBAS

①Spacial gradient of TEC would result in wrong correction data

②Scintillation would cause temporal loss of satellite lock
→ re-initialization of PR smoothing
→ go around due to multiple satellites losses

Purpose of this paper

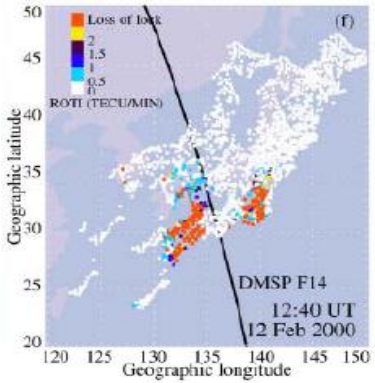
Evaluation of INS-aiding under scintillation

← Robust Tracking by INS-Aiding

Background (2/2)

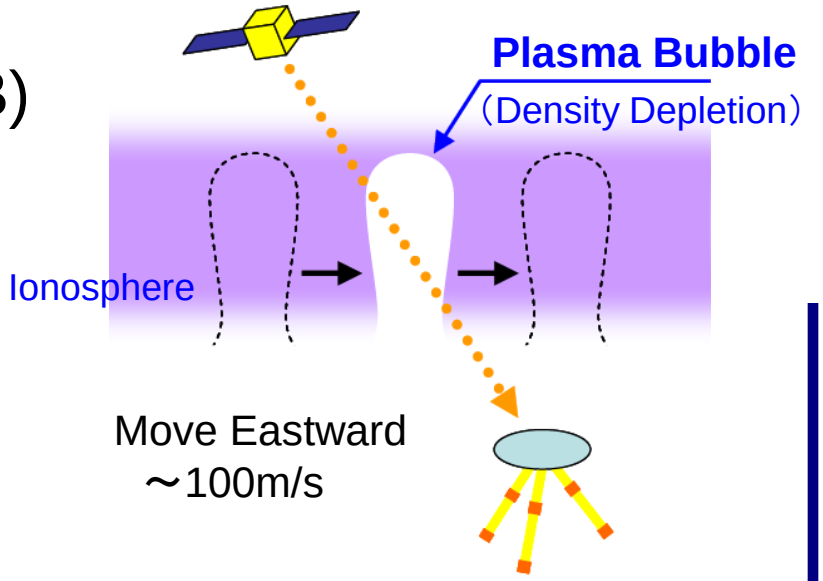
Ionospheric Anomaly

- Storm Enhanced Density (SED) — Rare
  - Mid~High Latitude Region
  - Spatial Gradient： ＞400mm/km
- Equatorial Plasma Bubble (EPB)
  - Low~Mid Latitude Region
  - Scintillation — Frequent



EPB and signal loss-of lock observed over Japan

12 Feb. 2000. Red color shows the signal loss-of lock. [Ma and Maruyama, GRL, 2006]



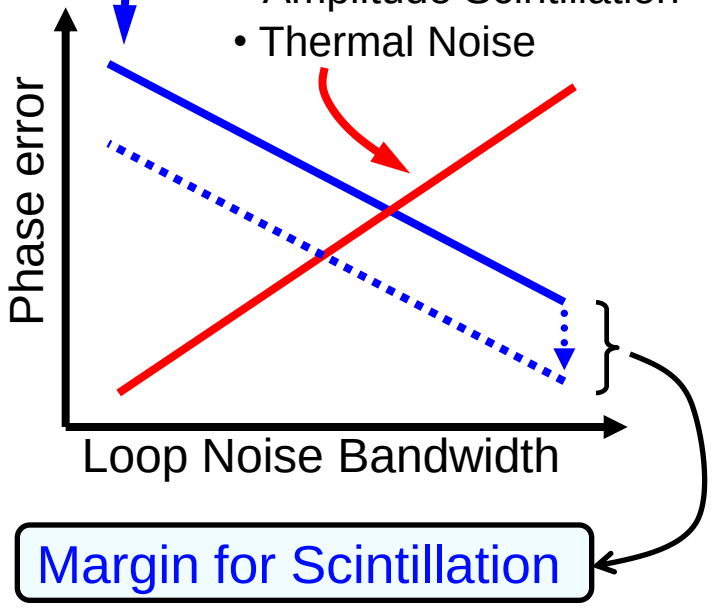
Doppler aiding by INS

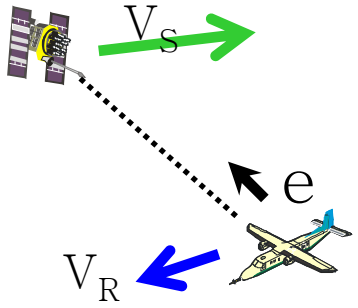
Phase Error Sources

- Clock Dynamics
- Phase Scintillation
- Aircraft Dynamics

Removed by Doppler-Aiding

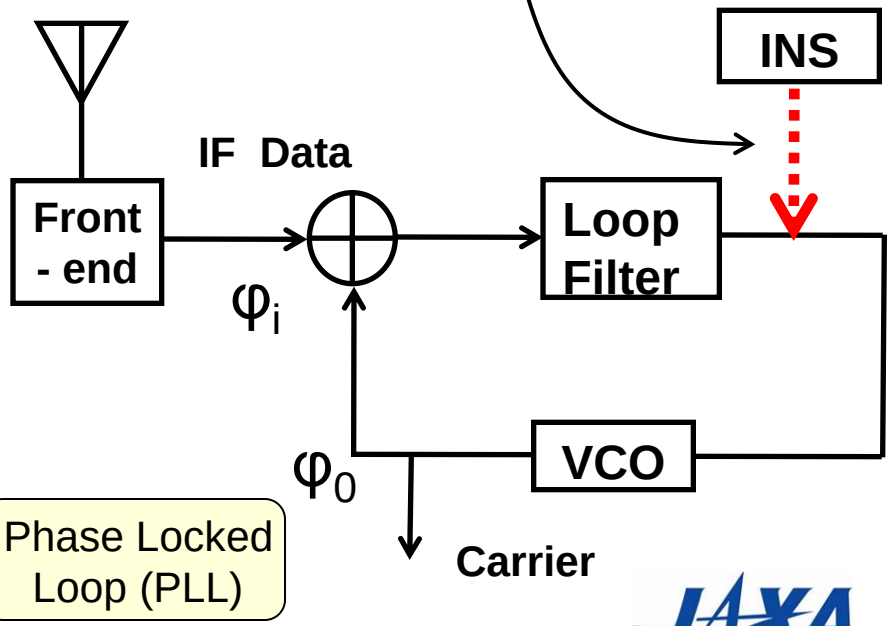
- Amplitude Scintillation
- Thermal Noise





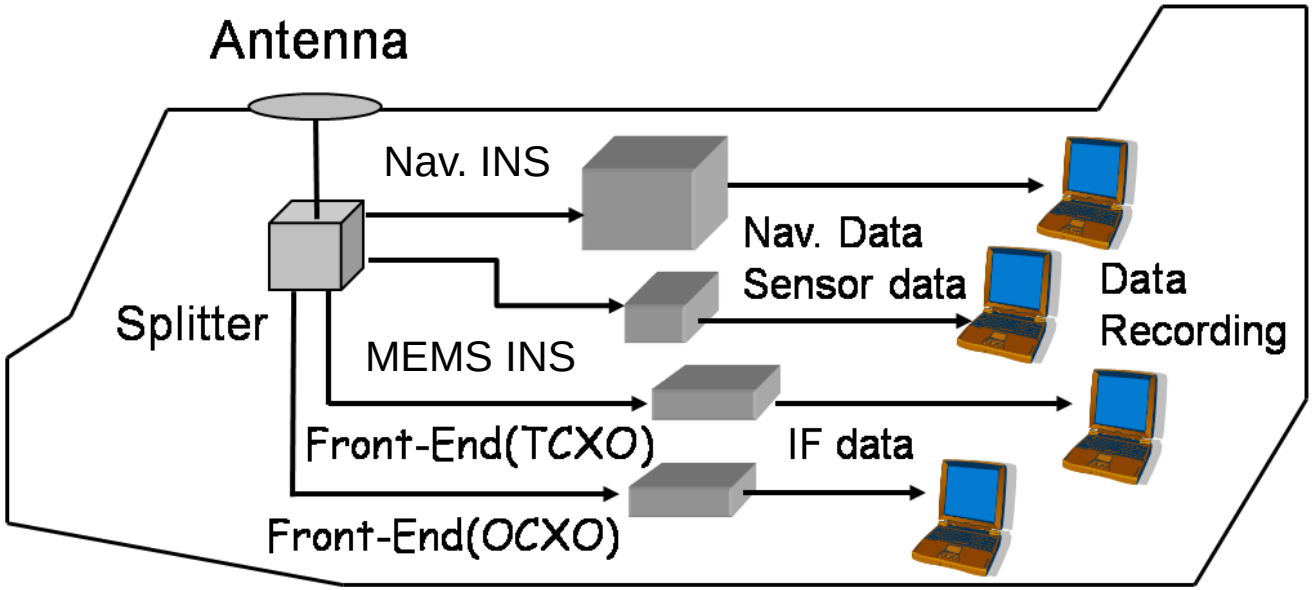
$$f_D = \frac{\mathbf{e}\cdot(\mathbf{v}_S - \mathbf{v}_R)}{\lambda}$$

Doppler Frequency due to Satellite and Aircraft Dynamics



Flight test to verify fundamental function of INS-Aiding

equipments



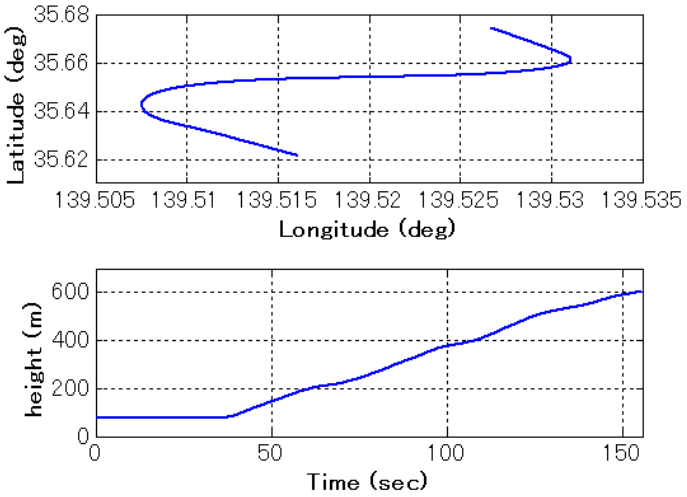
Nav-grade GPS/INS

MEMS GPS/INS

GPS Front-End (Left: TCXO, Right: OCXO)

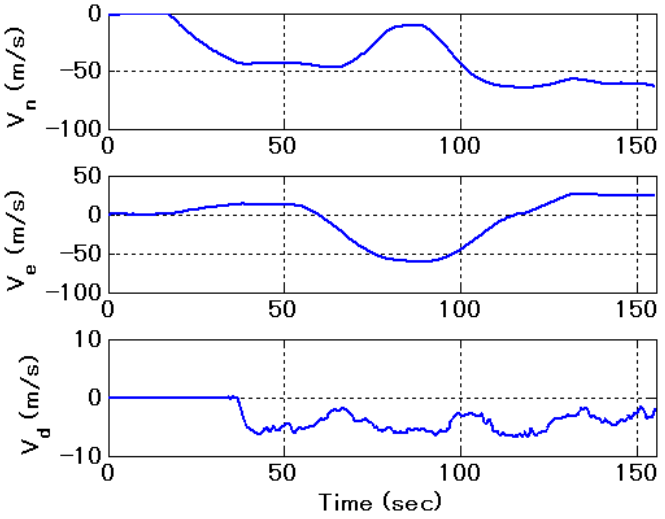
Inter mediate Freq. data recorded
IF frequency : 4,130,400 Hz
sampling rate : 16,367,600 Hz

Flight Profile – Take/Off -

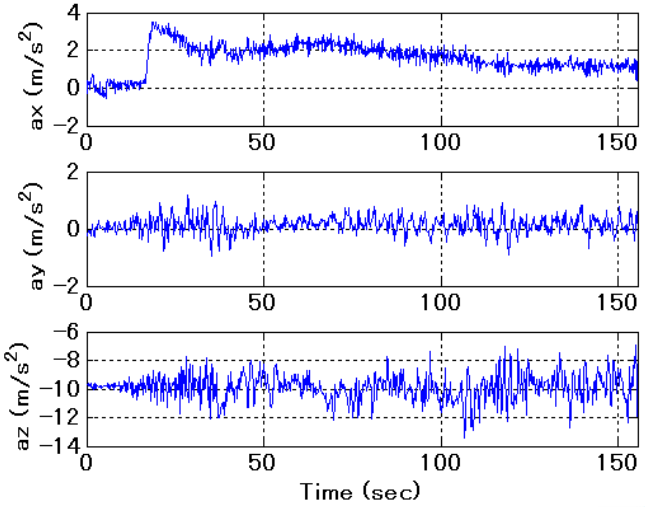


Trajectory

Velocity (NED)



Acceleration (body)



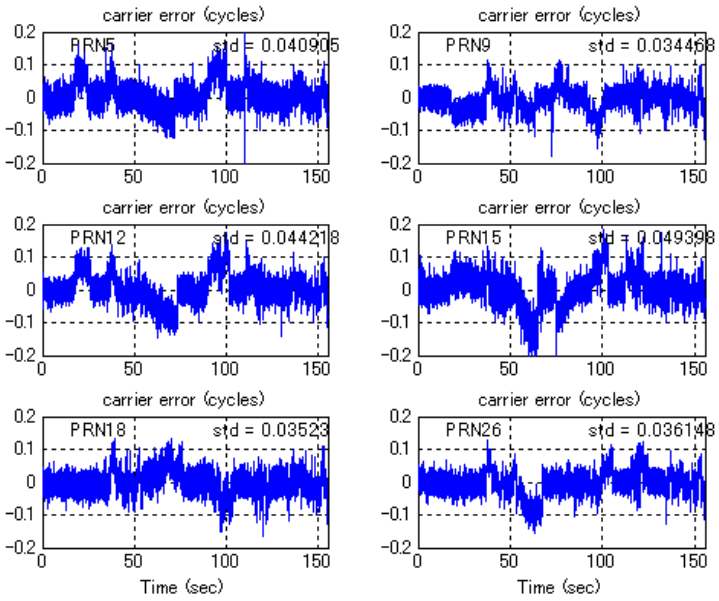
Beechcraft Model 65 QueenAir

Effect of Doppler Aiding

Carrier phase error for each satellite

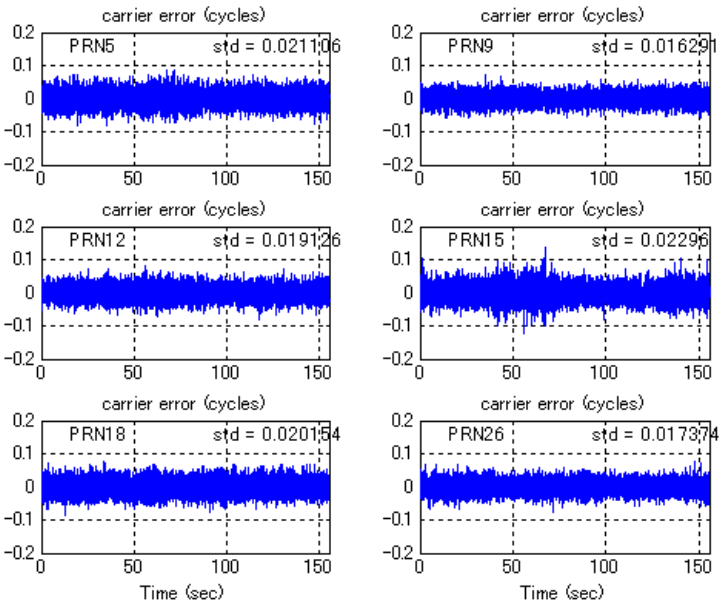
(B_L=3Hz, TCXO, MEMS-INS)

– Without Aiding –



$\sigma_\phi = 7.2\ mm$

– With Aiding –



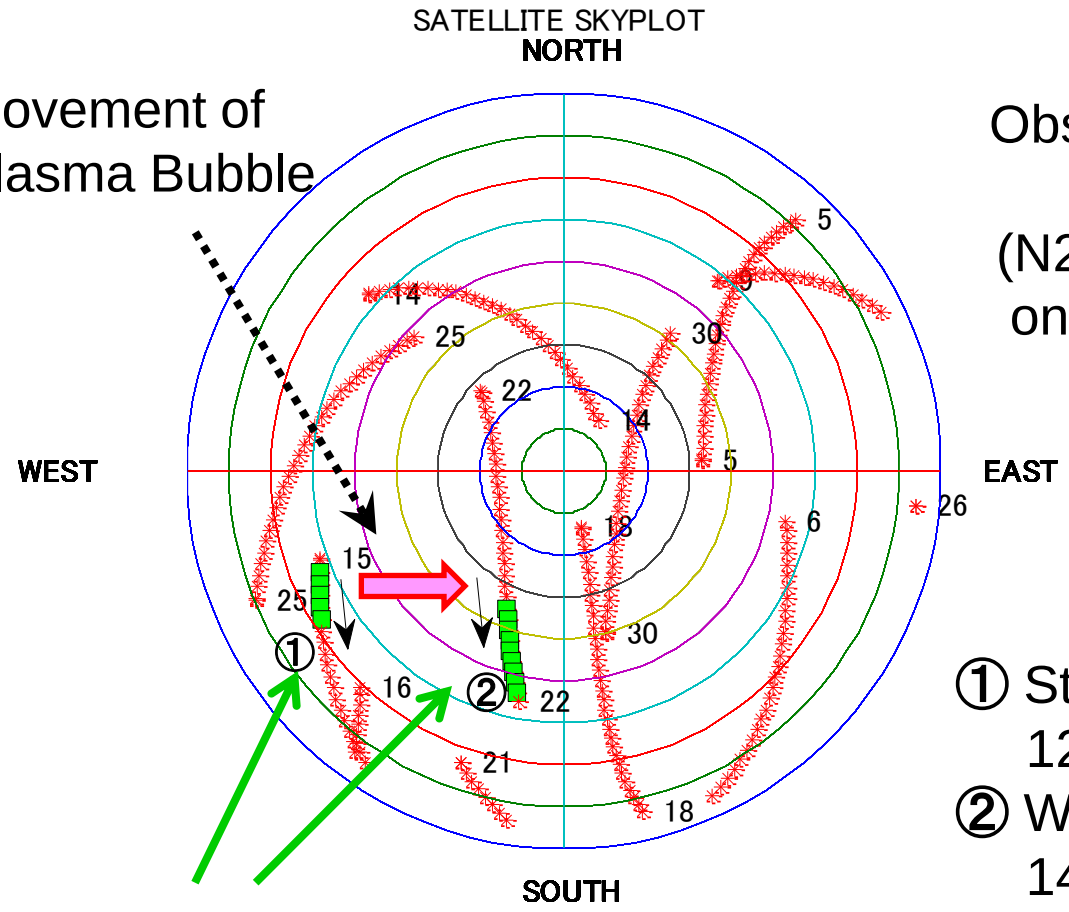
$\sigma_\phi = 3.8\ mm$

Effect of Aiding is demonstrated by using real data

(Without Scintillation)

Analyses of Scintillation Associated with Plasma Bubble

Movement of Plasma Bubble



Observation data of GSV4004 @Naha, Japan (N26° 13' 43, E127° 40' 44), on April 14, 2004 (by ENRI)

Local Time: 9:40pm~0:05am

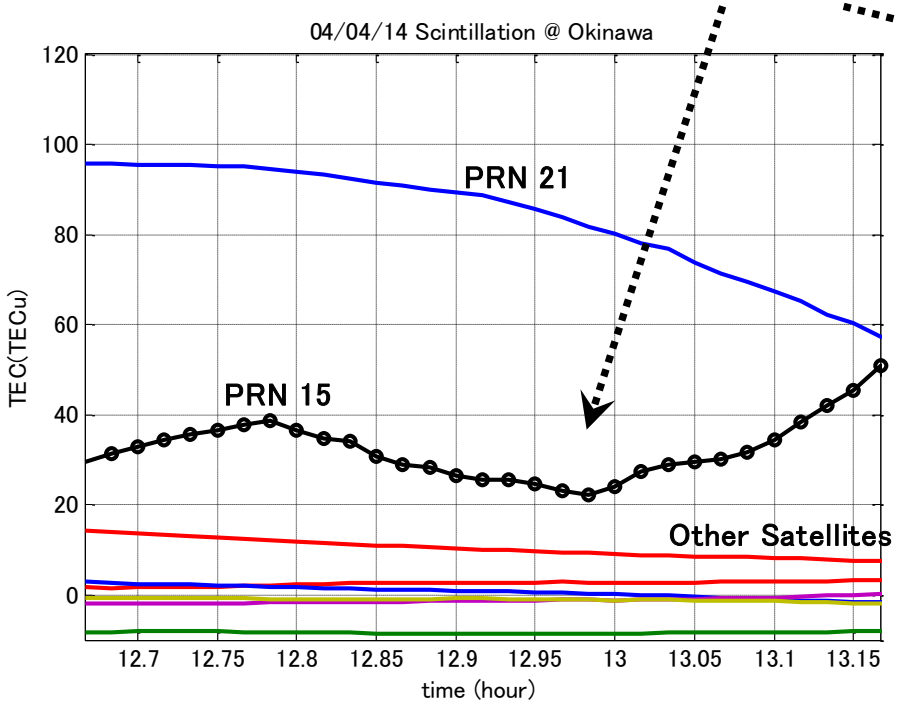
① Strong Scintillation（PRN15）
12:40-13:10
② Weak Scintillation（PRN22）
14:20-15:05 (GPS Time)

(Local Time = UT + 9 hours)

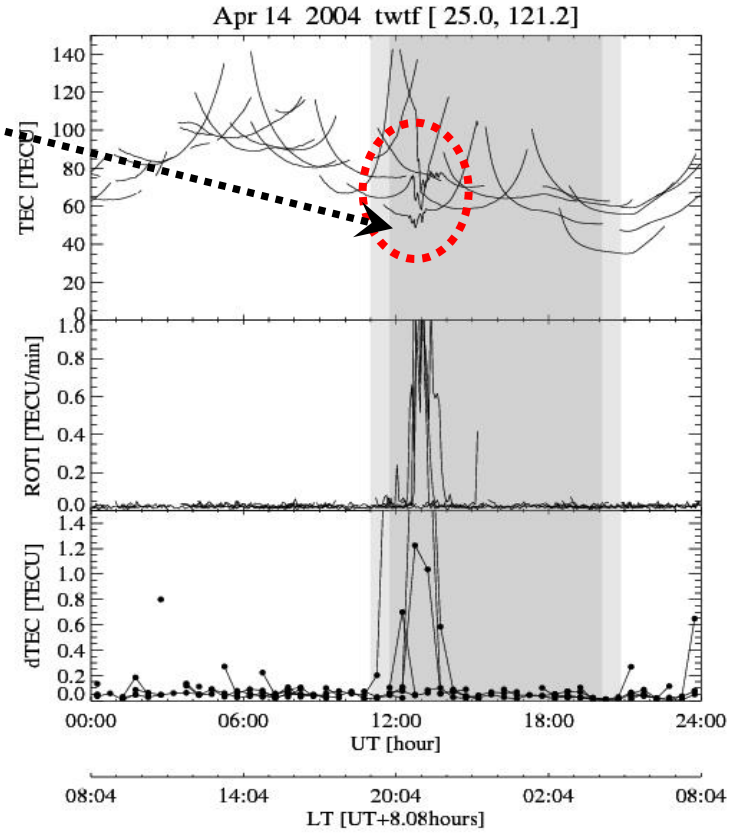
Scintillation associated with Plasma Bubble

TEC Variation during strong scintillation ①

TEC Depletion due to Plasma Bubble



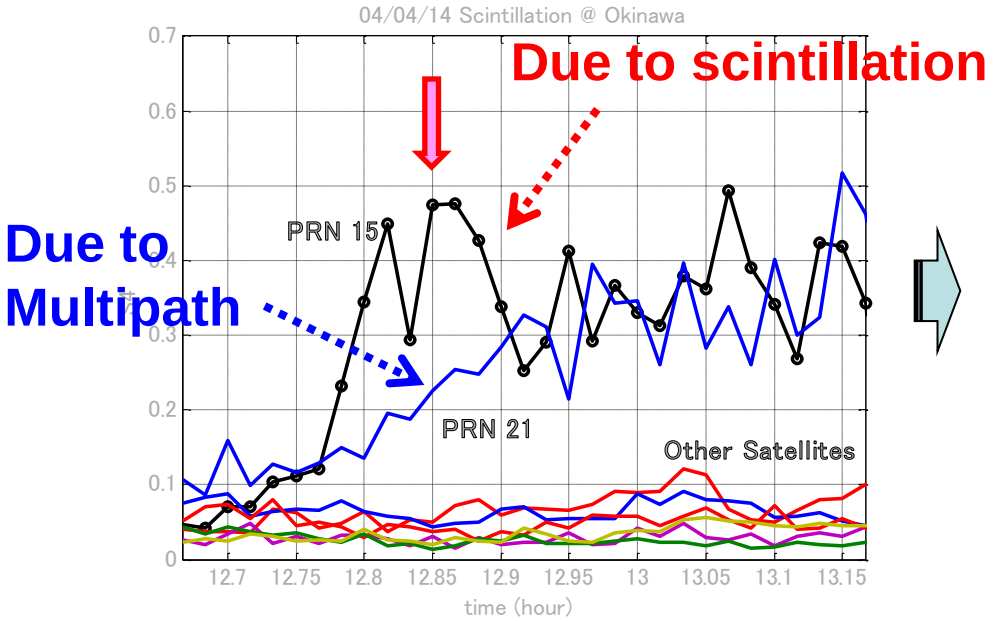
Variation of TEC @ Naha
(bias not calibrated)



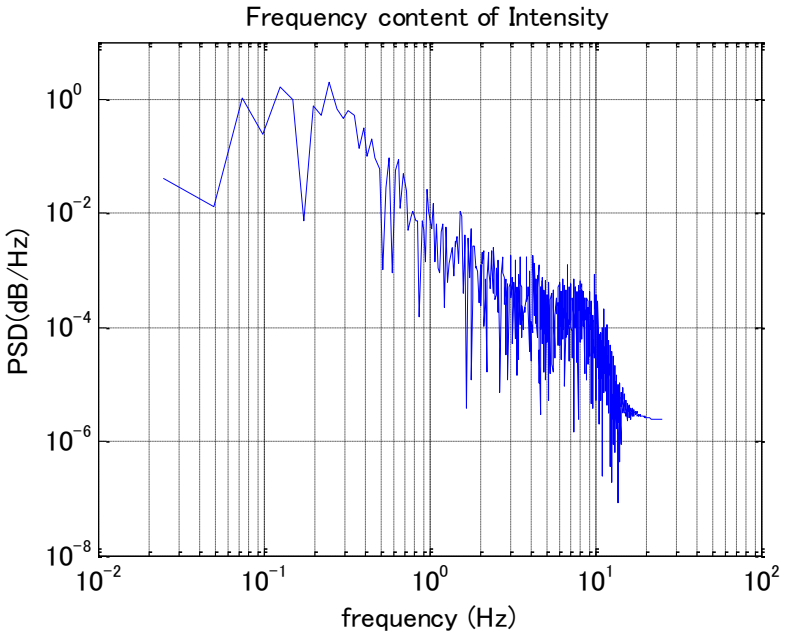
TEC variation @Taiwan
(http://wdc.nict.go.jp/IONO2/TEC-ROTI/)

Amplitude Scintillation Parameter and PSD of Intensity extracted from real data during Strong Scintillation ①

S4 Variation



Intensity spectral density (12:51)

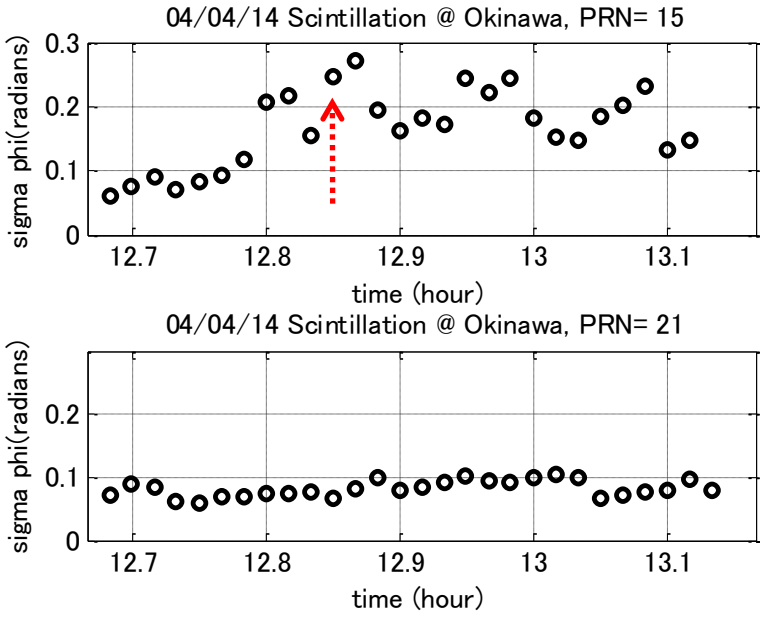


$$S4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

Scintillation Parameters and PSD are used to simulate scintillation data

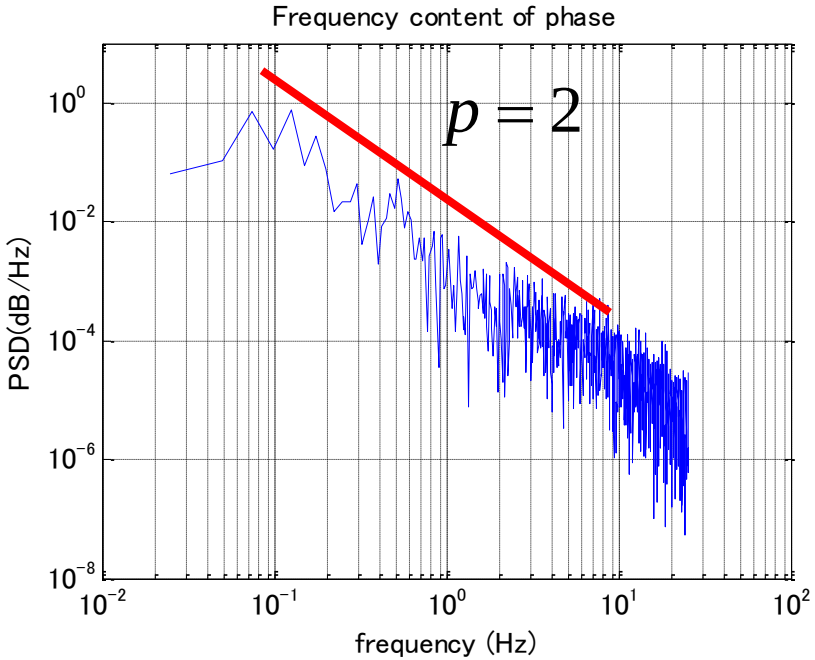
Phase Scintillation Parameter and PSD of Phase extracted from real data during Strong Scintillation ①

Sigma of Phase error



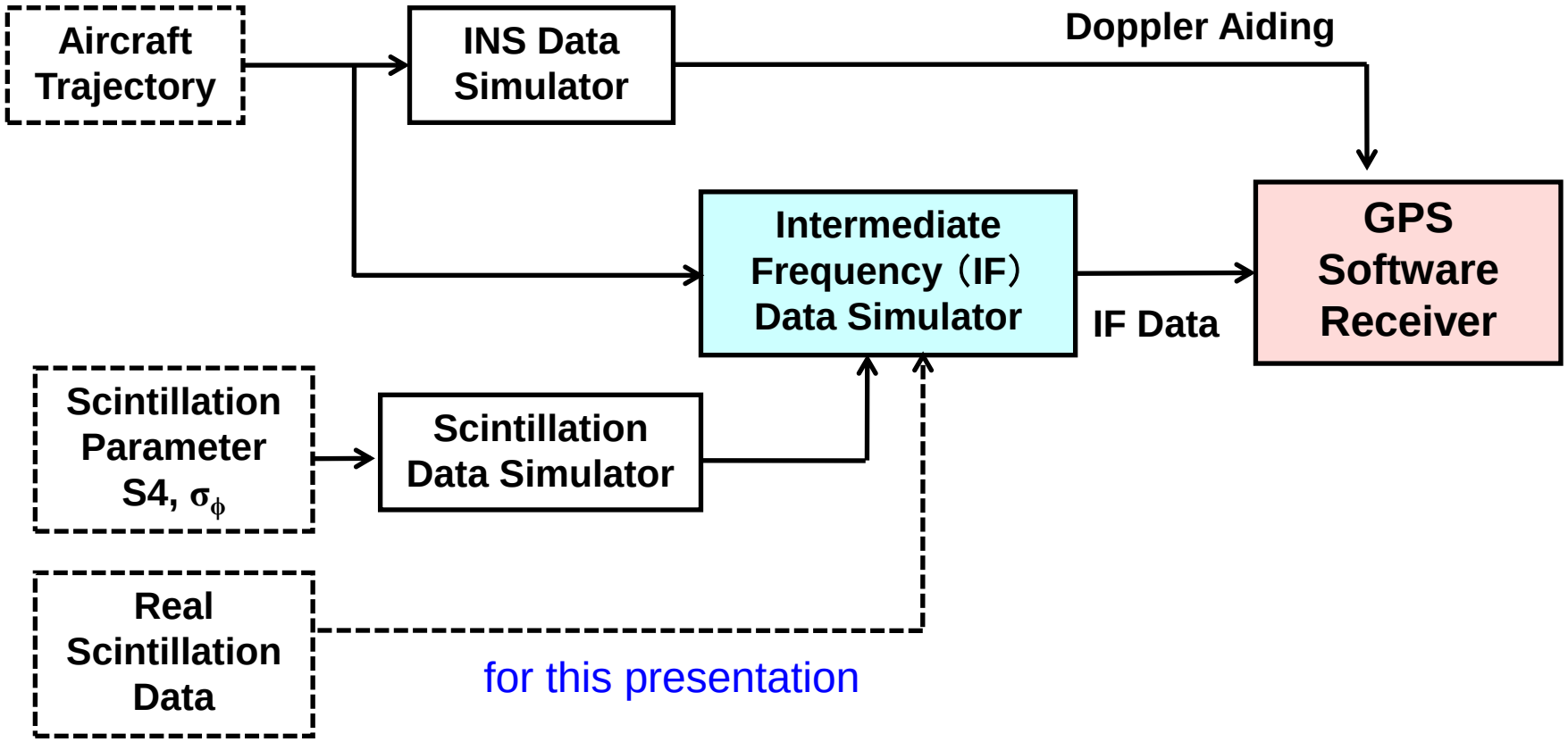
σ_ϕ for PRN15 (top) and PRN21 (bottom)

Phase spectral density (12:51)

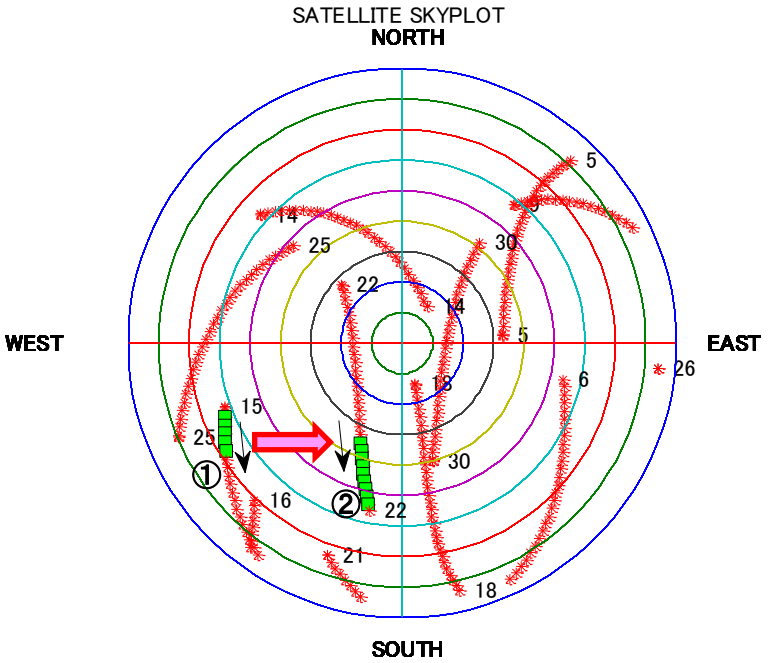


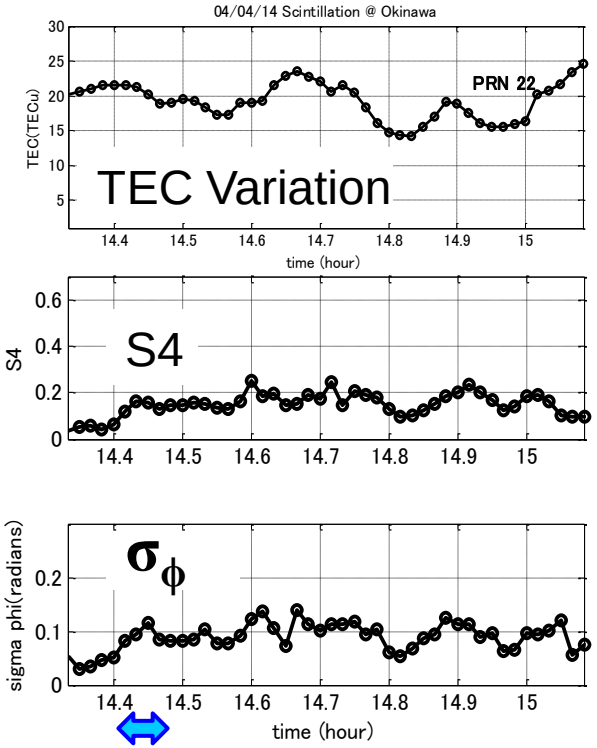
$$P_{\delta\phi}(f) = T \cdot f^{-p}$$

Simulation of GPS/INS Signal Under scintillation

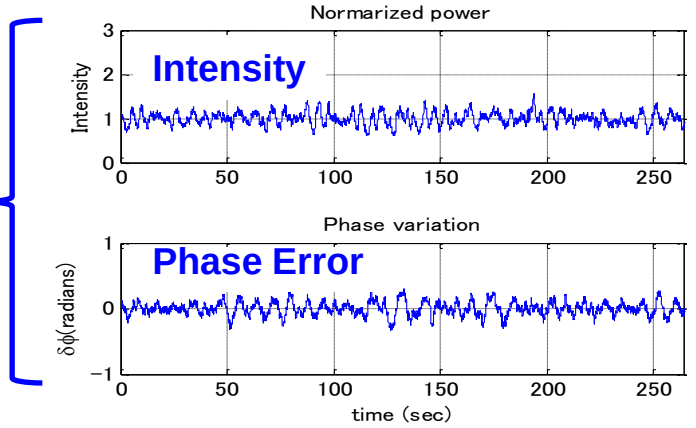


Data of Weak Scintillation ②





Real data (from 14h24m to 14h28m24s)



① Strong Scintillation（PRN15）

Cycle Slips for ground receiver

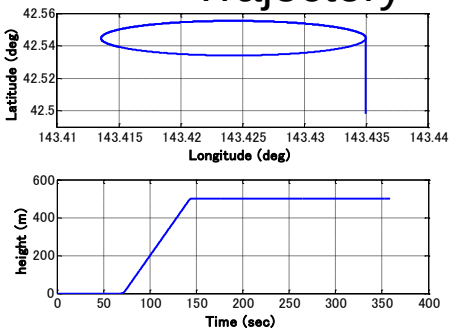
② Weak Scintillation（PRN22）

Used for Simulation in this presentation

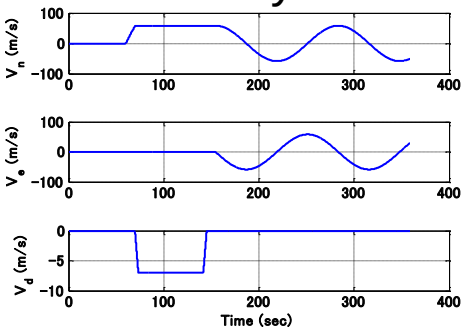
Embedded in Simulated IF data

Doppler Aiding Performance Under Scintillation

Trajectory



Velocity



Aircraft Trajectory

INS Data Simulator

Doppler Aiding

Intermediate Frequency (IF) Data Simulator

IF Data

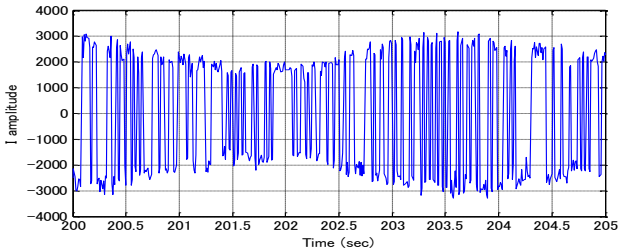
GPS Software Receiver

Phase Tracking Error

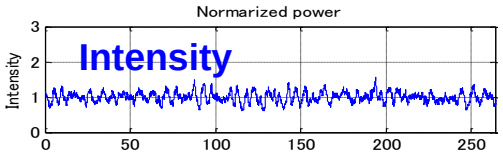
Scintillation Parameter S4, σ_ϕ

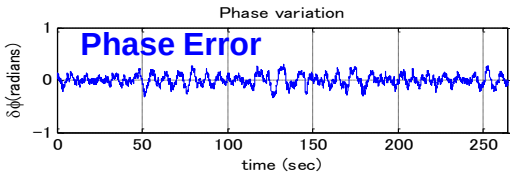
Scintillation Data Simulator

Real Scintillation Data



I-channel Amplitude Variation due to scintillation (time from 200 to 205 seconds)



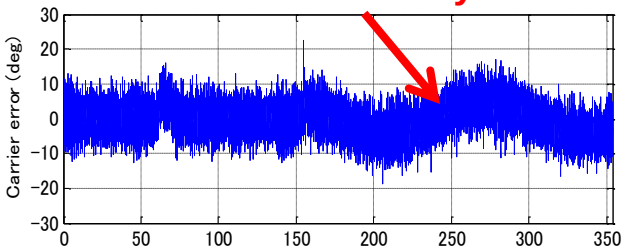


Effect of Doppler Aiding Under Scintillation

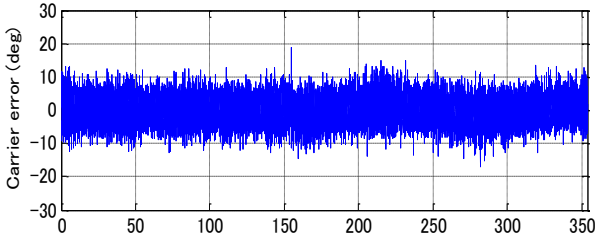
Without Aiding → **With Aiding**

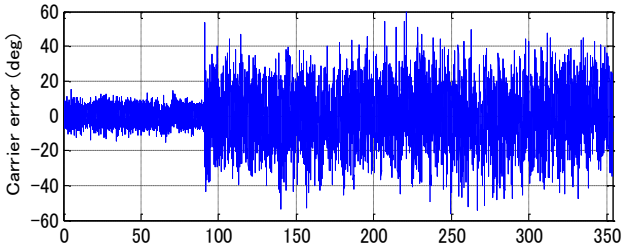
Carrier Tracking Error (deg)
For two satellites

Effect of Aircraft Dynamics

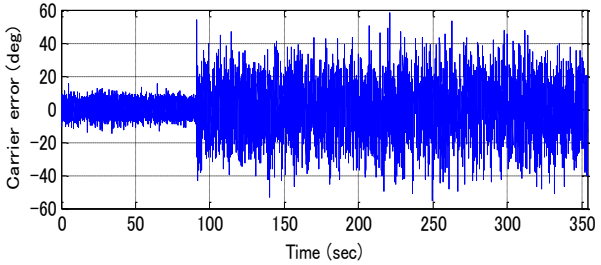


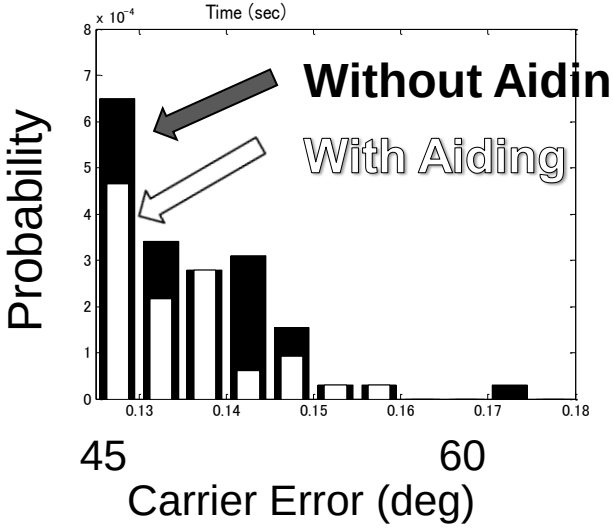
Without Scintillation





With Scintillation



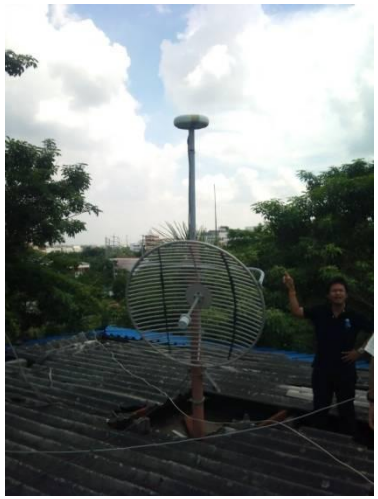


Rate of Cycle Slip
(Carrier Error > 45 degrees)

30 % Reduction

GPS-IF data Logging System

@ King Mongkut's Institute of Technology (KMITL), Bangkok



GPS Antenna
(NICT)

Internet

Logging Control,
Monitor

Measurement System
(NICT)

Splitter

IF Data Logging System

IF data

GPS Front-End

PC

HDD

IF Freq.: 4 MHz

Sampling Rate: 16 MHz

Summary

- Real data of scintillation associated with plasma bubble was analyzed and extracted intensity/phase variation were embedded in the simulated GPS IF data
- The improvement of carrier tracking by Doppler aiding was demonstrated and an example showed that the rate of cycle slip was reduced by 30 %

Future work

- Collect the real scintillation data (IF) and evaluate INS-Aiding performance under scintillation
- Verify the improvement of GBAS availability by INS-Aiding under scintillation associated with plasma bubble