

**GPS measurements onboard Swarm  
satellites to study occurrence of the  
equatorial irregularities in the topside  
ionosphere**

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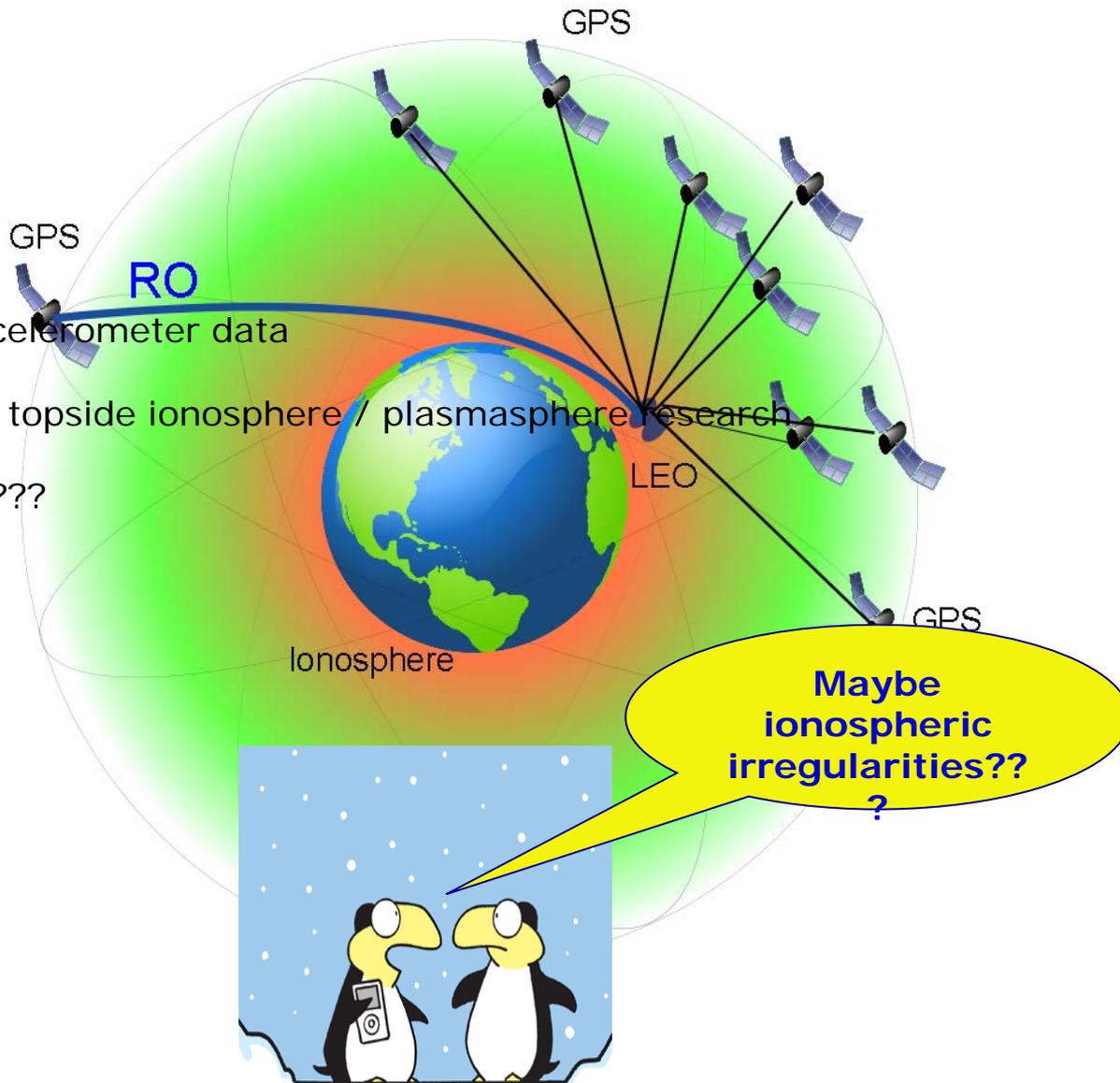
Can we squeeze every ounce of data?

# LEO GPS technique

**POD** – precise orbit determination

## Main objectives:

- ✓ Orbit solution
- ✓ Timing
- ✓ Calibration of accelerometer data
- ✓ Absolute TEC for topside ionosphere / plasmasphere research
- ✓ something else????

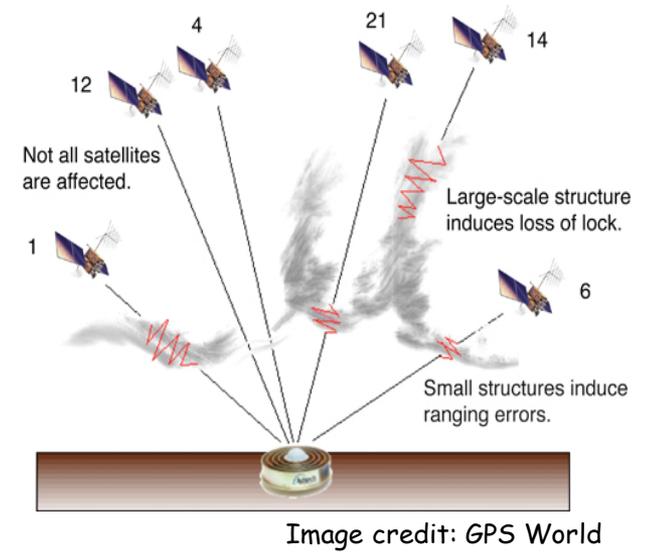


# Ionospheric irregularities seen in GPS data

Ionospheric irregularities can be characterized by measuring its impact on amplitude and phase of the received GPS signal.

*Pi et al.* [1997] introduced into the use two GPS-based indices for **ground** GPS data:

- ✓ **ROT** (rate of TEC change) as a measure of phase fluctuation activity
- ✓ Rate of TEC Index (**ROTI**) as a GPS-based index that characterizes the severity of the GPS phase fluctuations and detects the presence of ionospheric irregularities



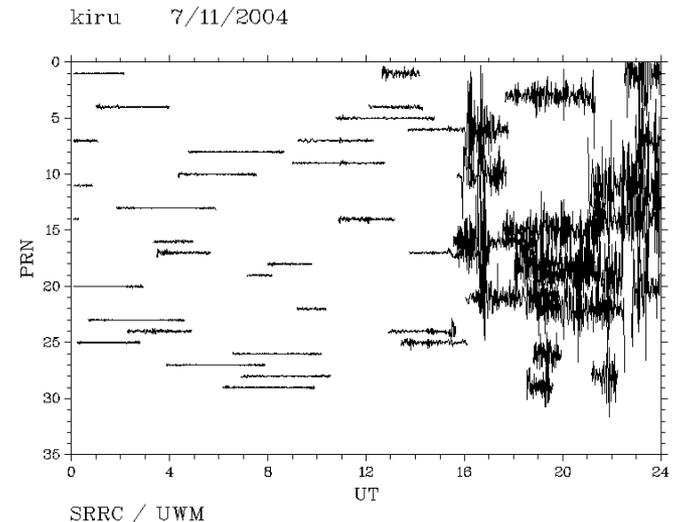
$$sTEC = \frac{f_1^2 \cdot f_2^2}{f_1^2 - f_2^2} \cdot \frac{L_1 - L_2}{K}$$

**Simple and straightforward technique**

$$ROT = \frac{sTEC_k^i - sTEC_{k-1}^i}{(t_k - t_{k-1})}$$

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

## Example of ROT variations:



# Swarm



Three satellites A, B and C

Tandem (A&C) altitude ~460 km

Upper sat B altitude ~510 km

POD

8 channel GPS receiver

Time sampling 1 s

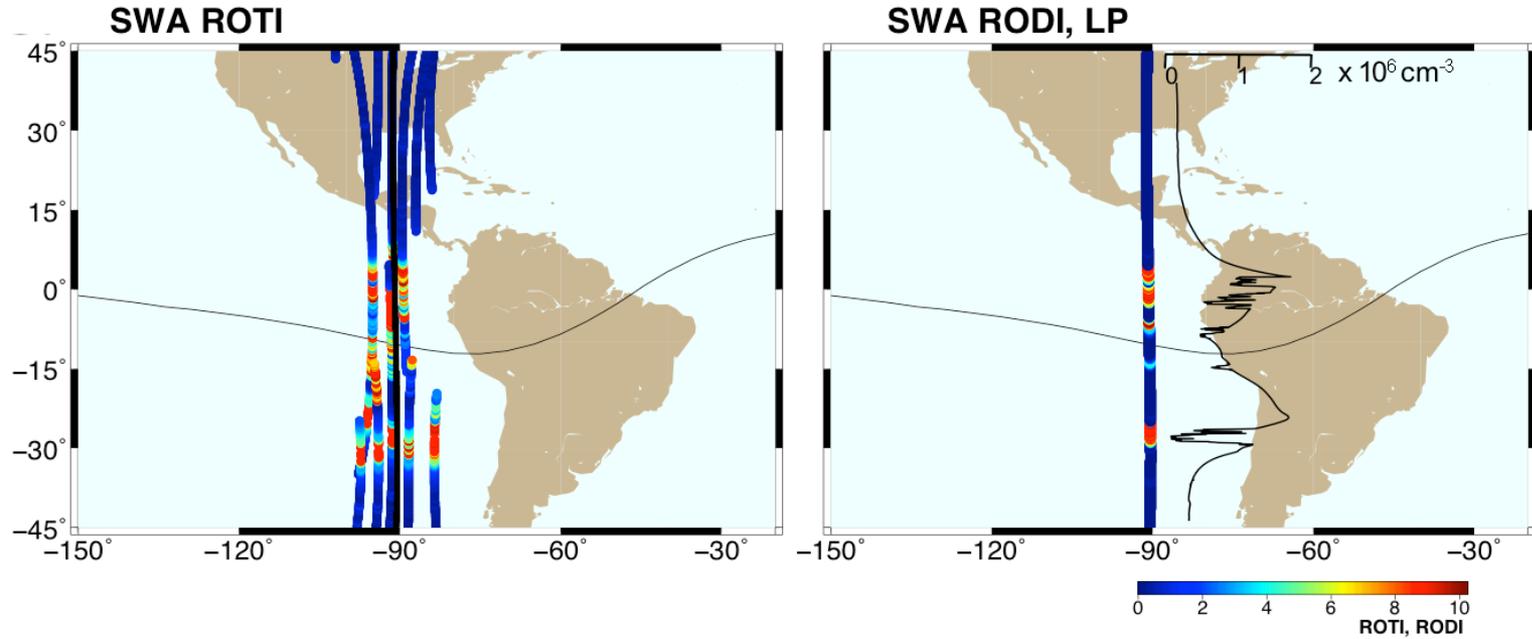
Langmuir Probe (LP)

2 Probes

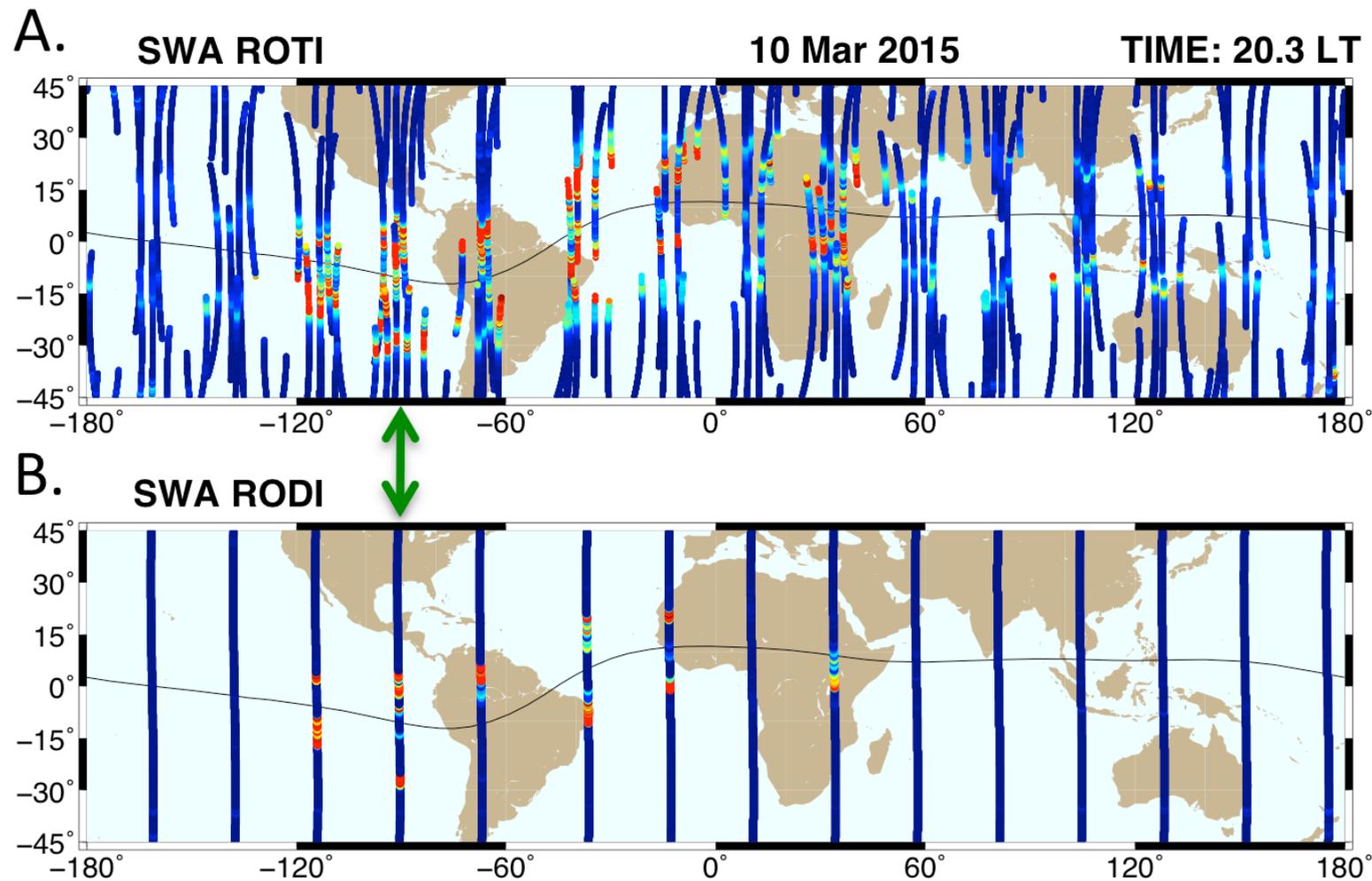
Time sampling 1 s

# GPS vs LP

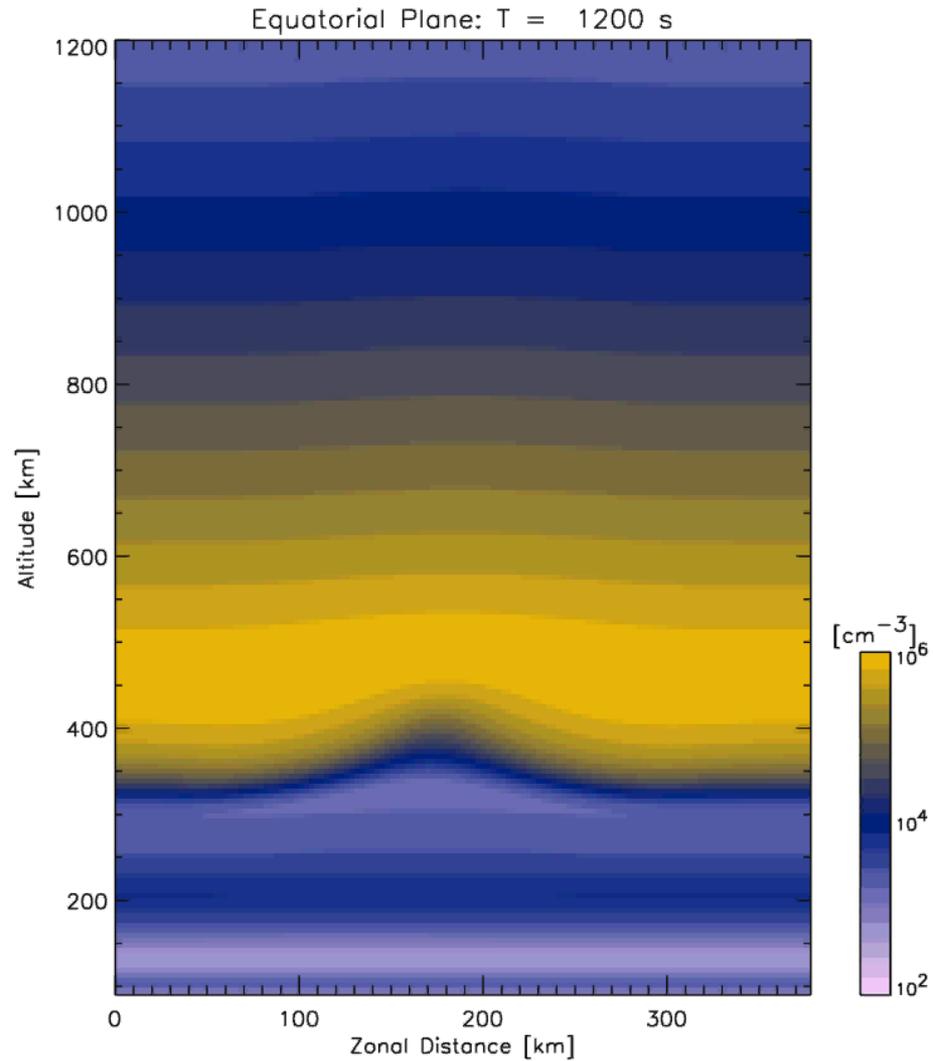
## ROTI vs RODI



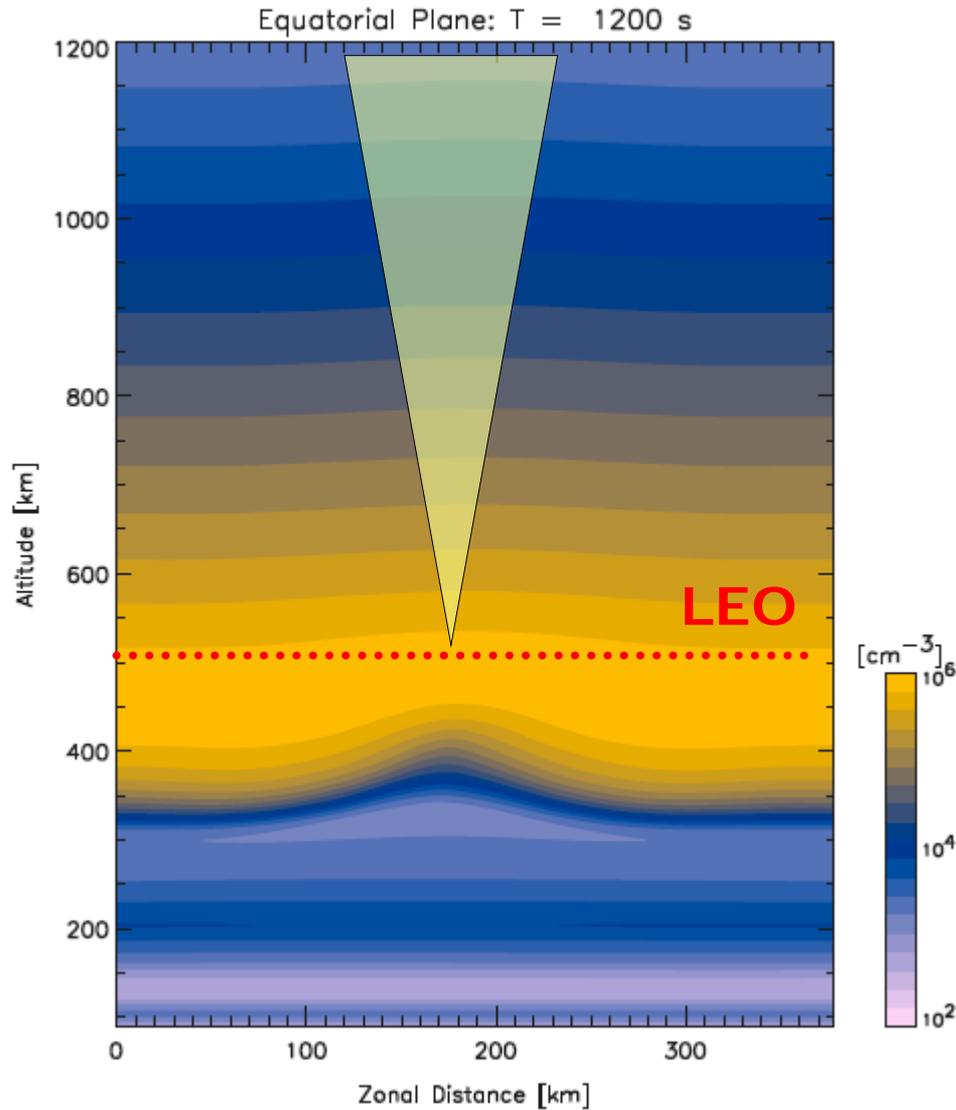
# ROTI vs RODI



# Model simulation of EPB



# LEO GPS vs. in situ

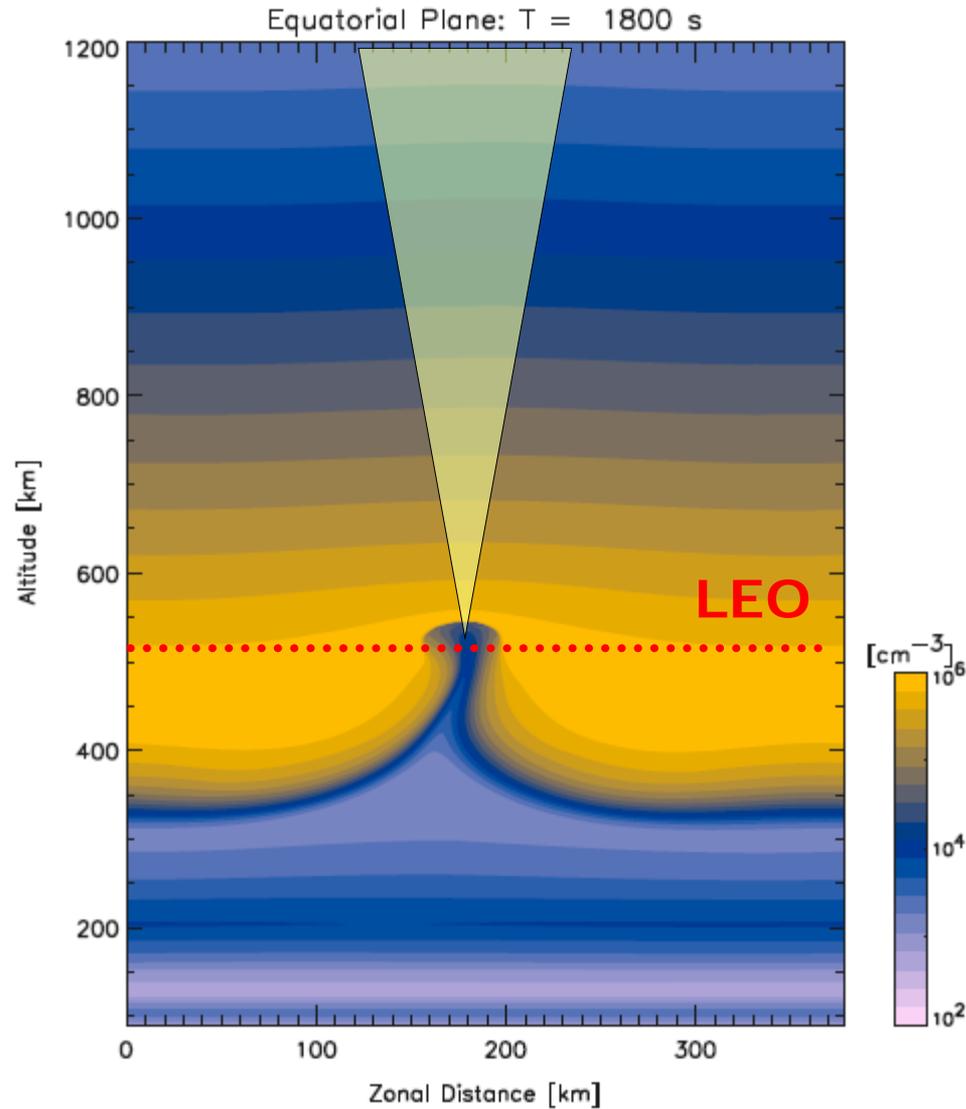


1

GPS ✘

LP ✘

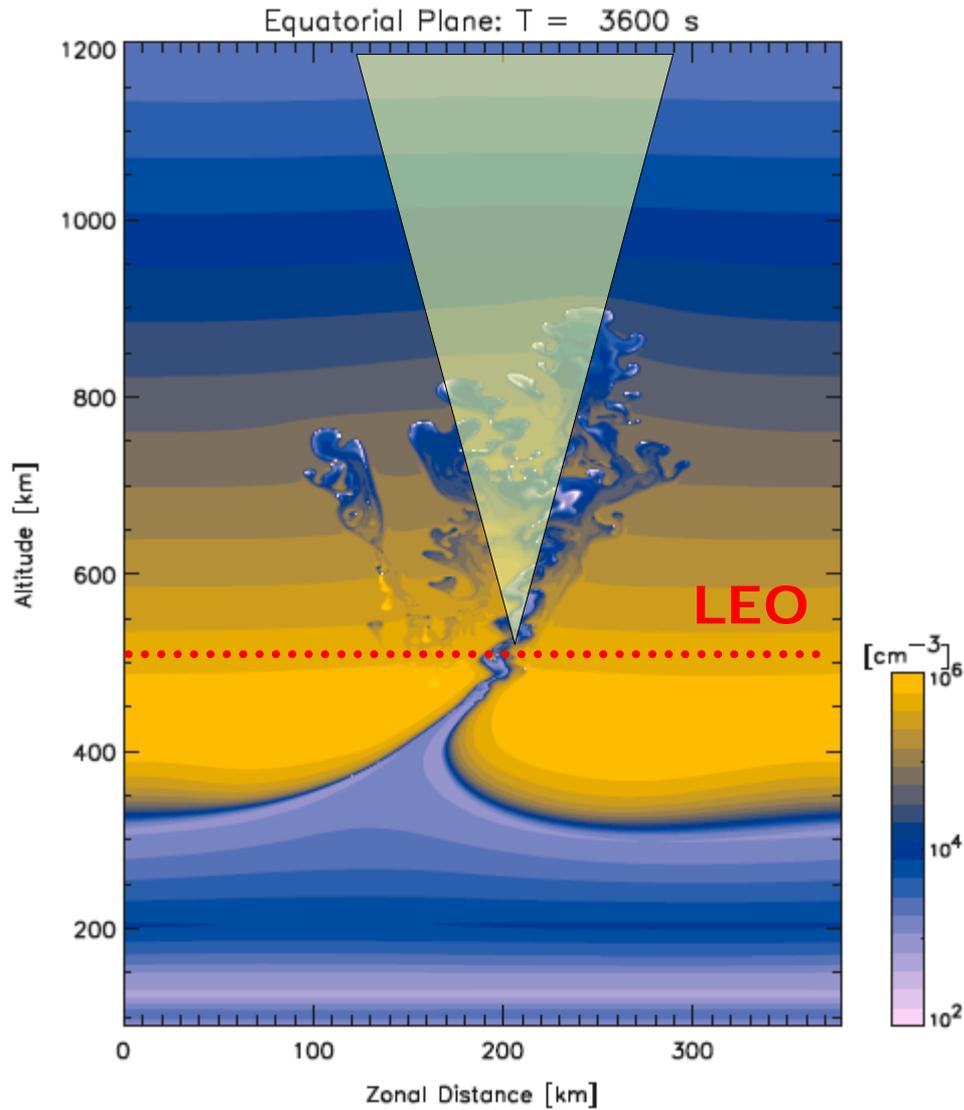
# LEO GPS vs. in situ



GPS ✖

LP ✔

# LEO GPS vs. in situ



3

GPS ✓

LP ✓

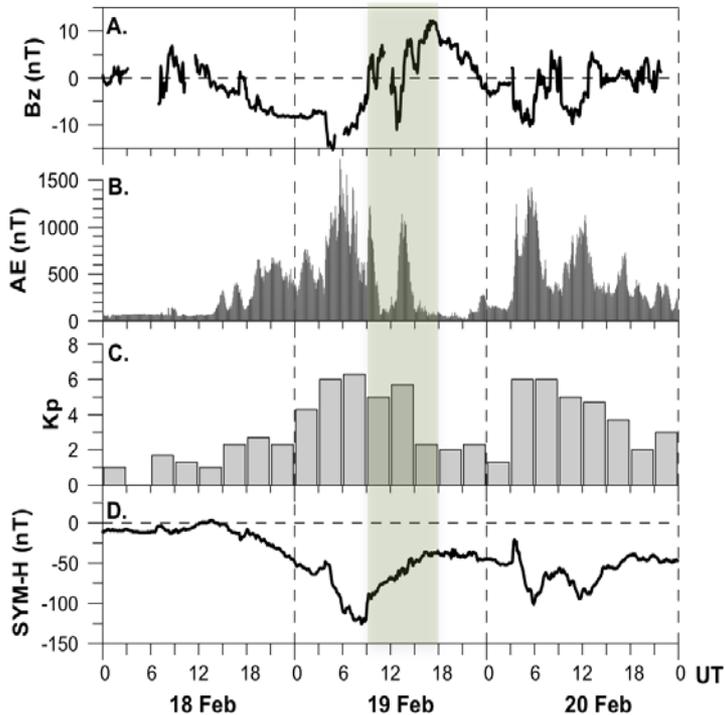
4

GPS ✓

LP ✗

# Case study: 19 Feb 2014

Recovery  
phase



## Very specific configuration of Swarm:

- 1) Three satellites had orbit alt  $\sim 500$  km
- 2) Tandem B&C followed A by  $\sim 30$  min
- 3) LT sector  $\sim 07$  LT (19 LT)

+ TerraSAR-X satellite flew nearby (06 LT) with orbit alt  $\sim 510$  km

## Scheme of multi-sat analysis:

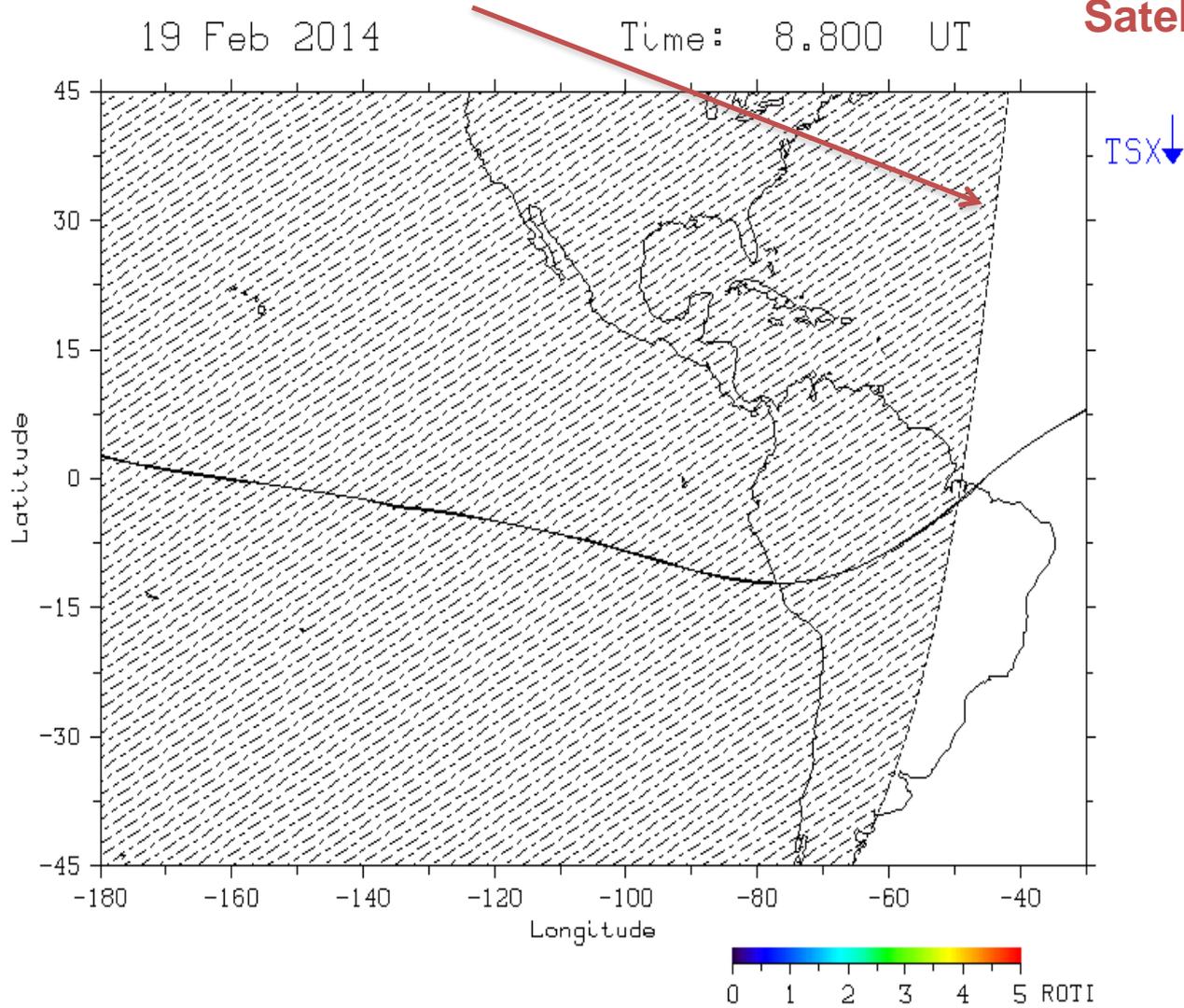


# LEO GPS - ROTI

Terminator  
@100km

Time

Satellite



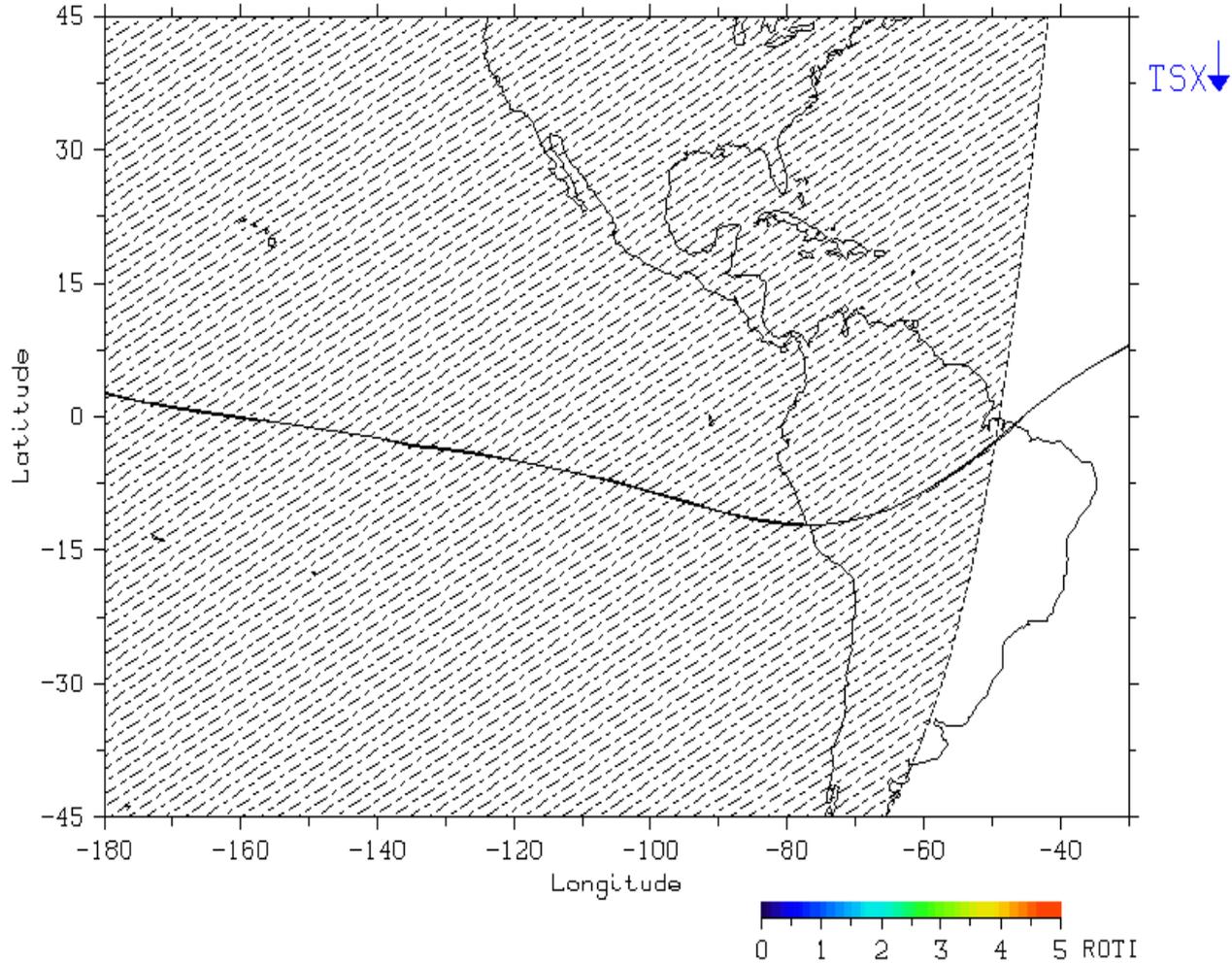
# LEO GPS - ROTI

Time

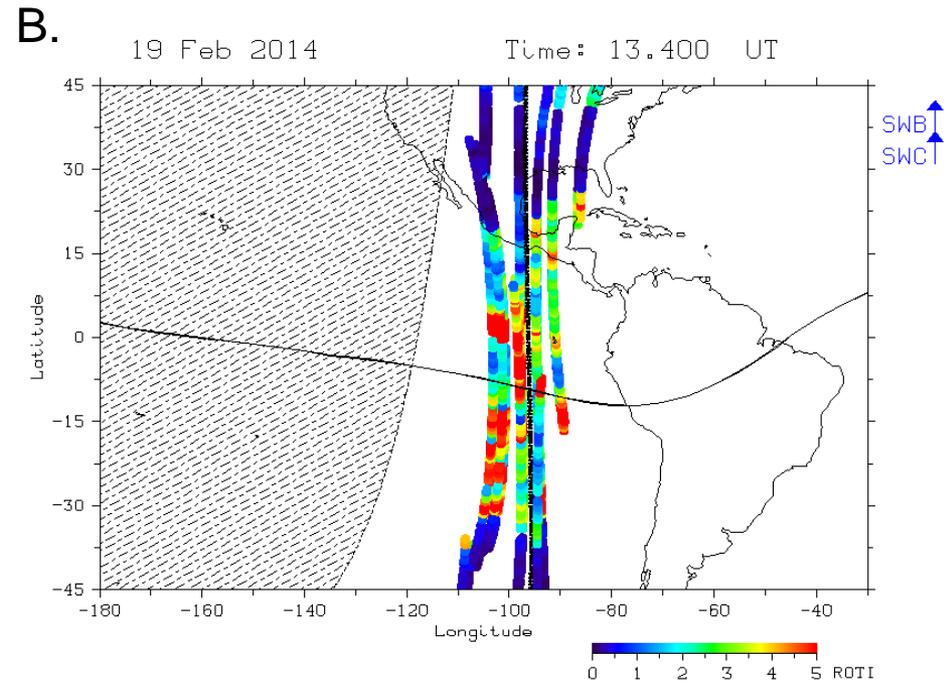
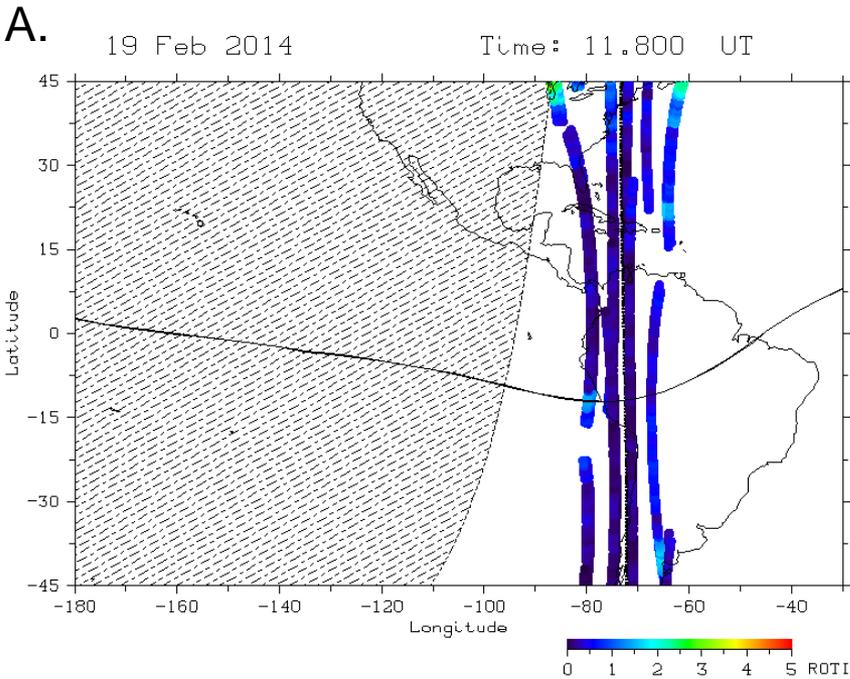
19 Feb 2014

Time: 8.800 UT

Satellite



# LEO GPS - ROTI



From **LEO ROTI** data we can get info about EPB:

- location
- intensity

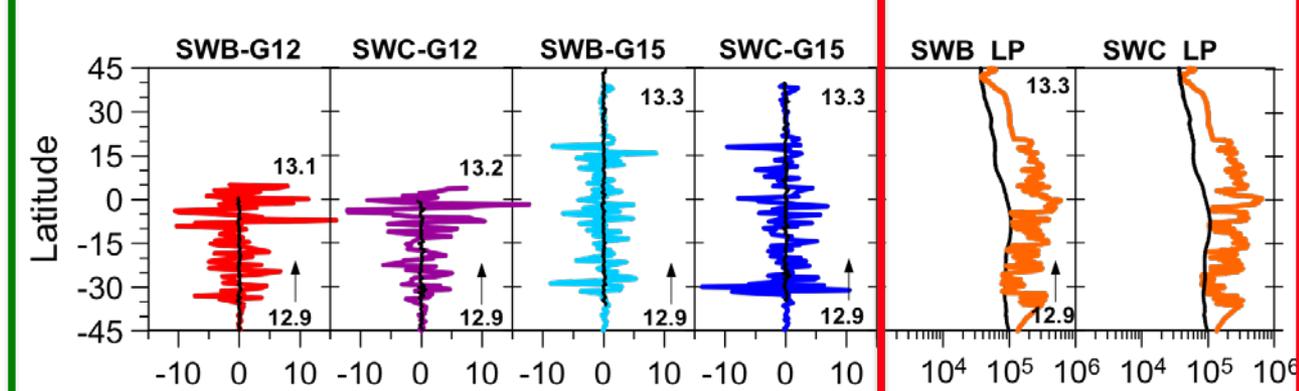
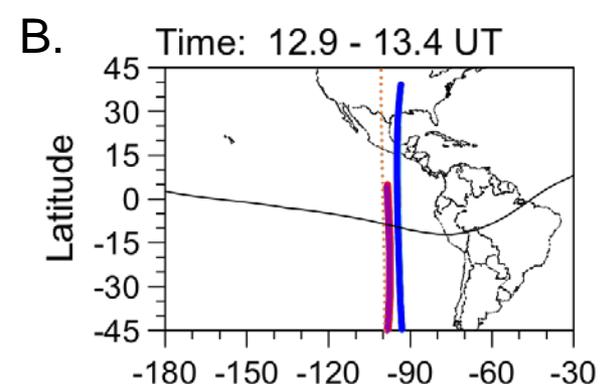
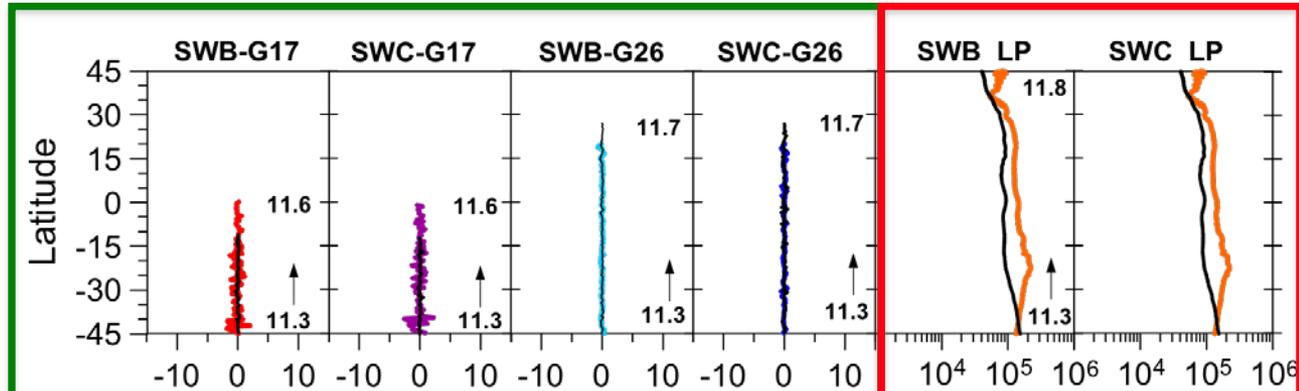
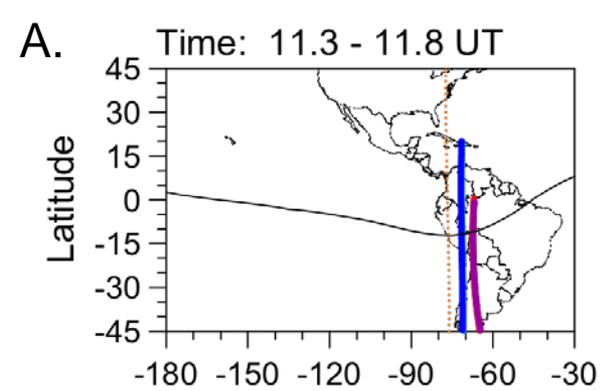


More details can be extracted from **ROT** variation along separate links LEO-GPS

# LEO GPS - ROT

Swarm GPS  
ROT

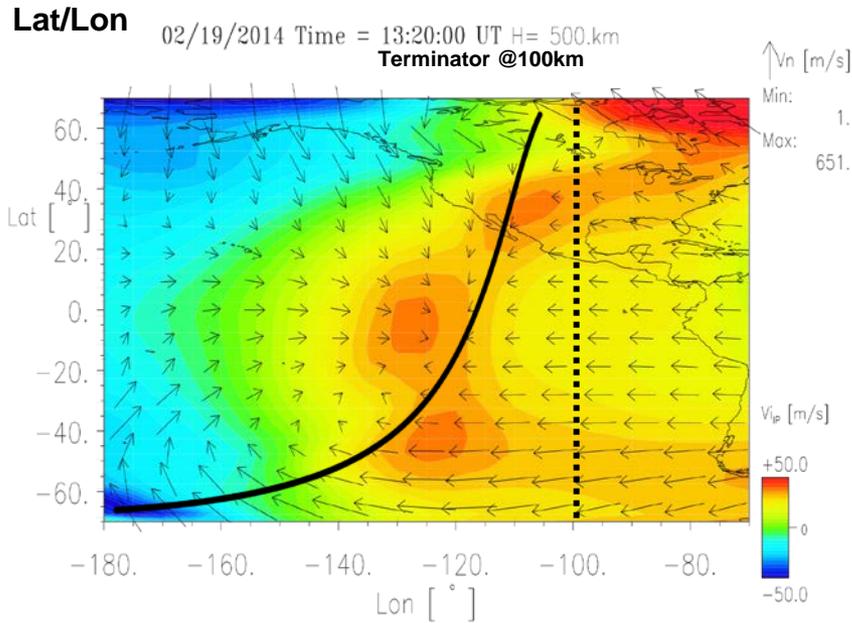
Swarm LP  
In situ Ne



Color lines – 19 Feb 2014

Black lines – quiet day of 18 Feb 2014

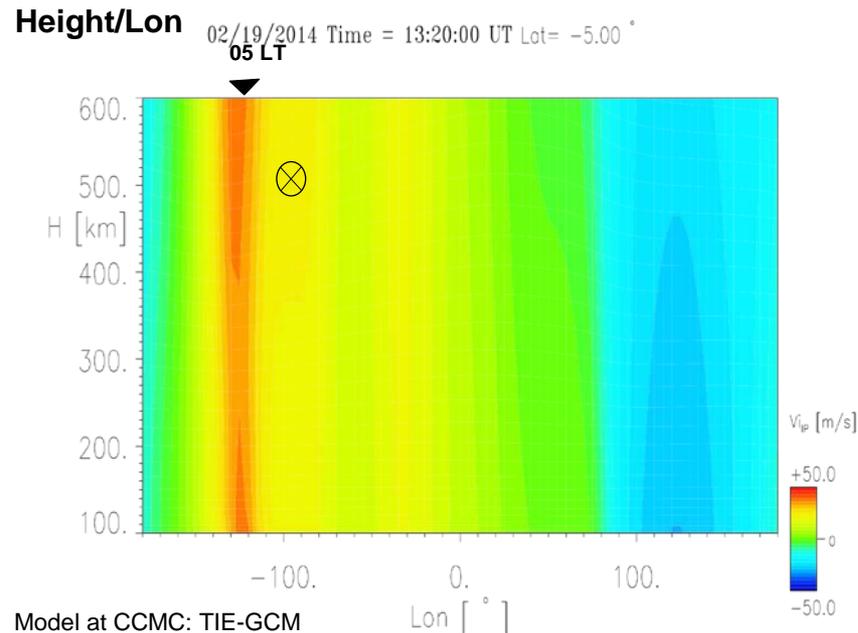
# TIE GCM simulations



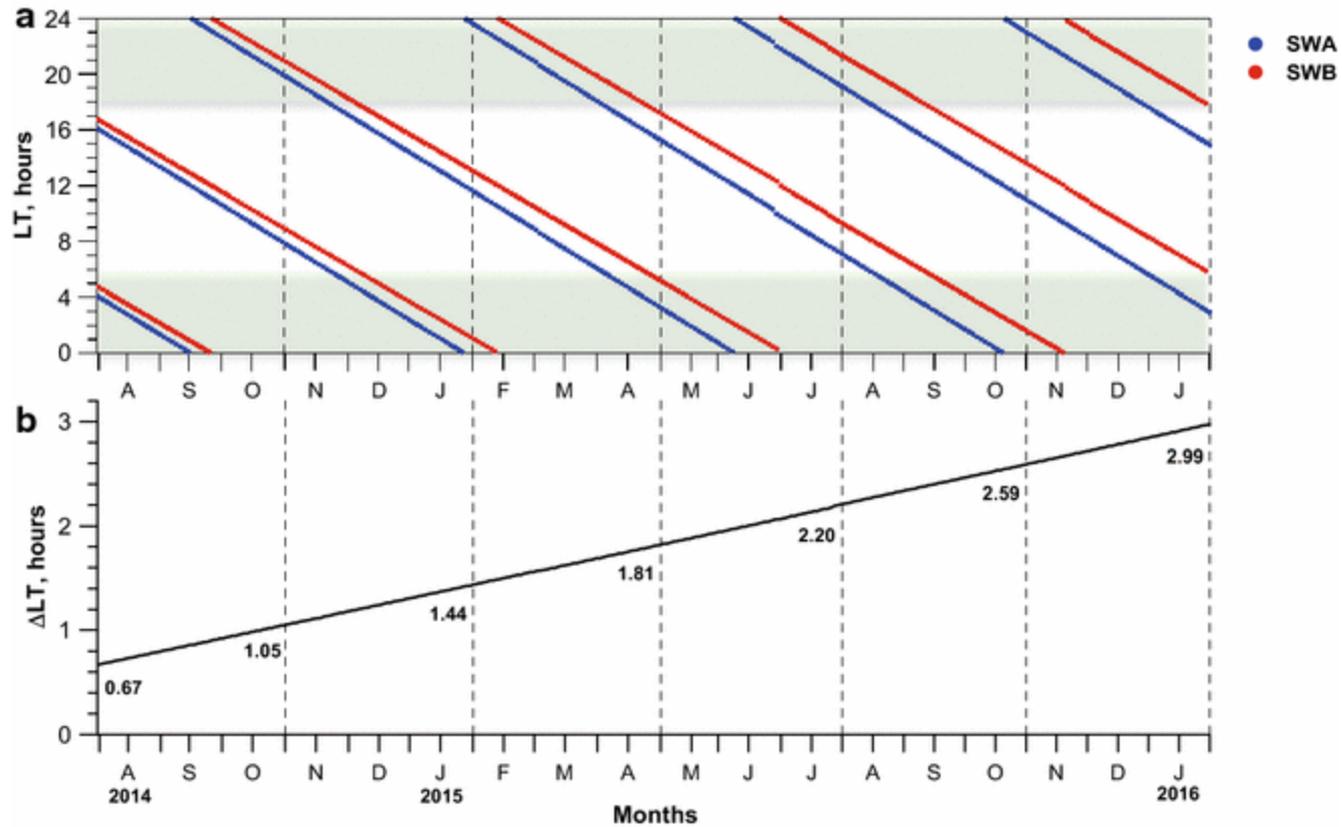
**Very fortunate position of Swarm**  
in right place and right time –  
just 1 h after terminator

**Great chance to detect morning  
EPB over Pacific Ocean!**

**Poster**

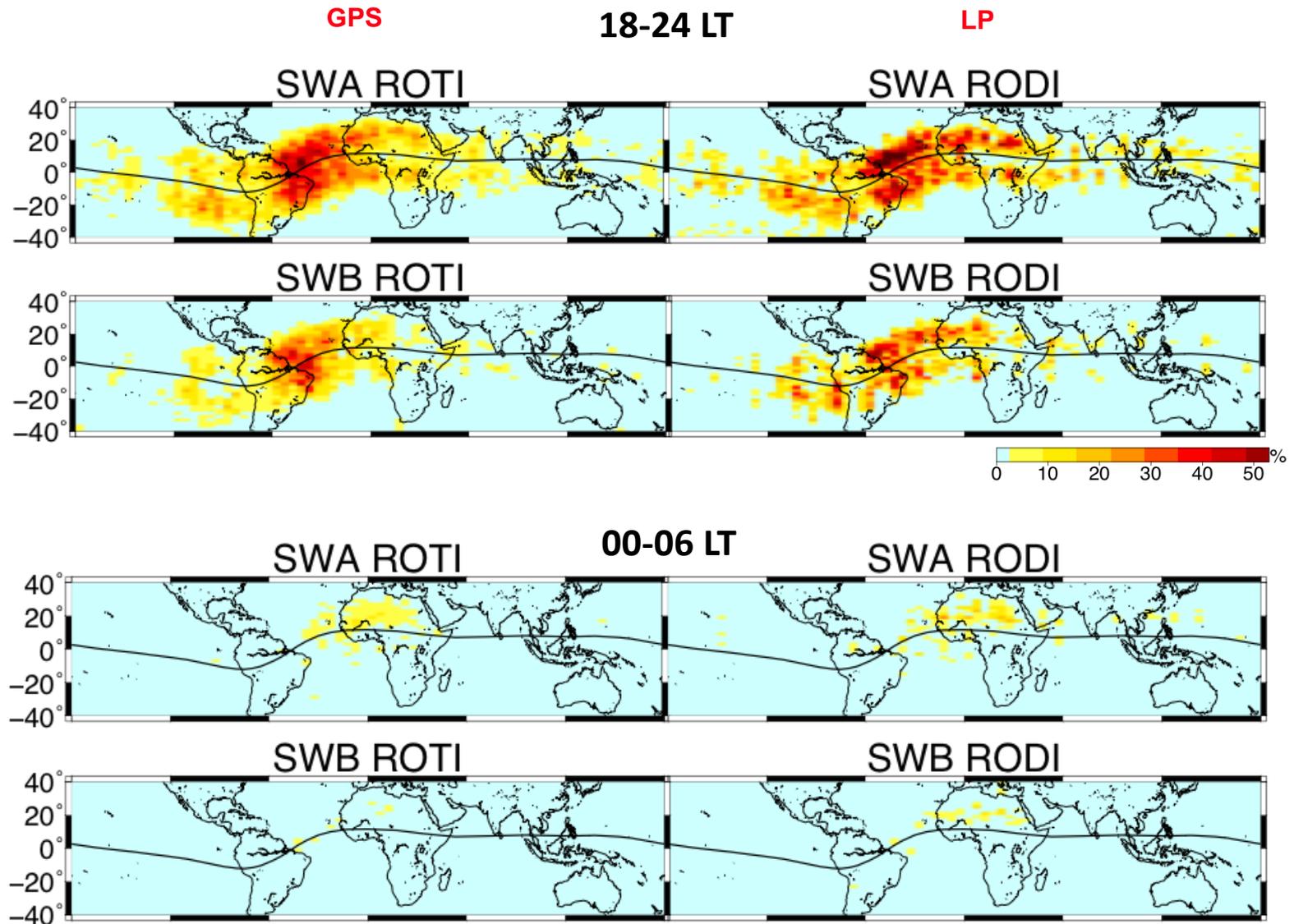


# Swarm LT coverage



# Swarm detection of EPB

SEP 2014



# GPS vs LP

## LP

- ✓ 1-D horizontal cut
- ✓ single track
- ✓ straight-forward
- ✓ known altitude of EPB

## GPS POD

- ✓ 2-D sampling
- ✓ tracking up to 8-12 sat
- ✓ ahead/behind/aside LEO and for much longer time
- ✓ unknown altitude of EPB

# What do these satellites have in common?

GRACE-A

JASON-1

CHAMP

SAC-C

MetOP-A

GRACE-B

JASON-2

MetOP-B

GOCE

Swarm A,B,C

CASSIOPE

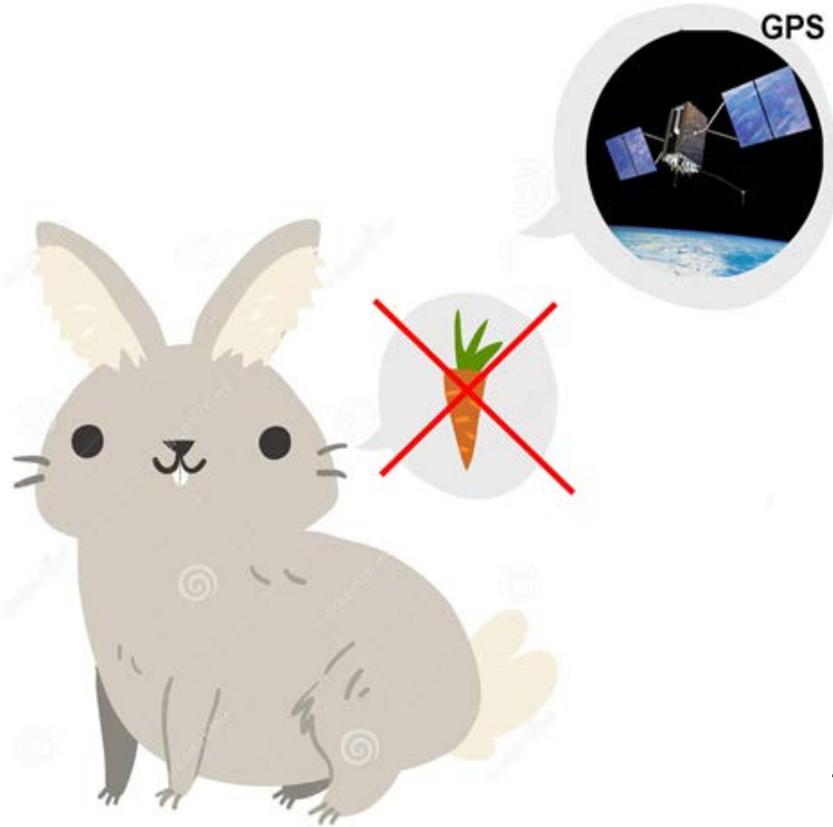
TerraSAR-X



**Onboard GPS receiver**

Non-ionospheric missions can supply us with ionospheric data along the road!





**Let's go  
beyond  
stereotypes!**

**Acknowledgements:**

- ESA for Swarm data
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