Radio occultation electron density retrieval aided by:

1, Ground based GNSS observations +
2, Global ionospheric data assimilation model

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Content

- **Abel inversion and Error evaluation**

- **RO inversion aided by ground GNSS and data assimilation model:**

  1, Ground & LEO GNSS process

  2, Data assimilation model

  3, Simulation results

Abel inversion

✓ **Assumptions used in Abel inversion (error source):**

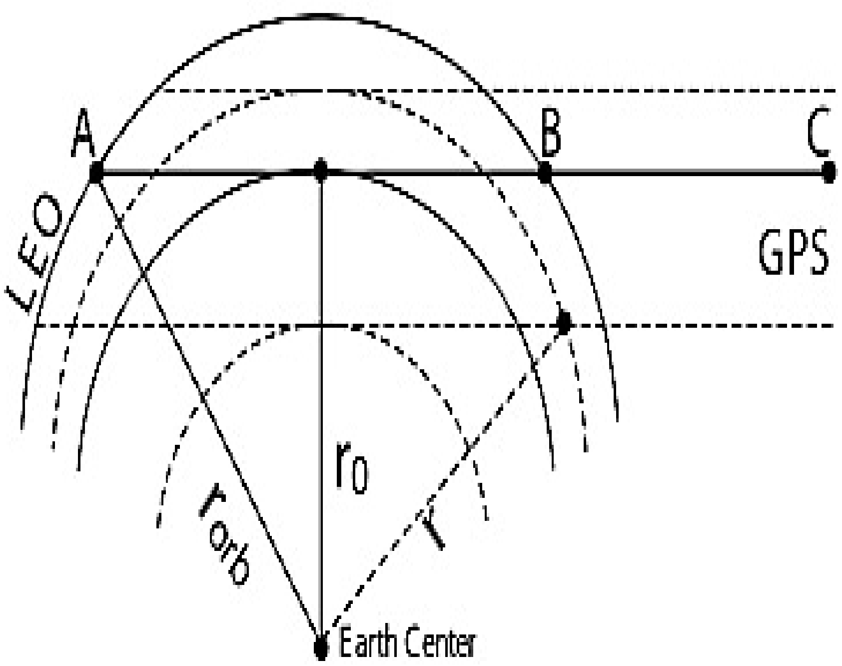
1. Straight-line signal propagation

2. Circular satellite orbit

3. occultation happens in the same plane

4. First-order estimation of electron density at the orbit altitude

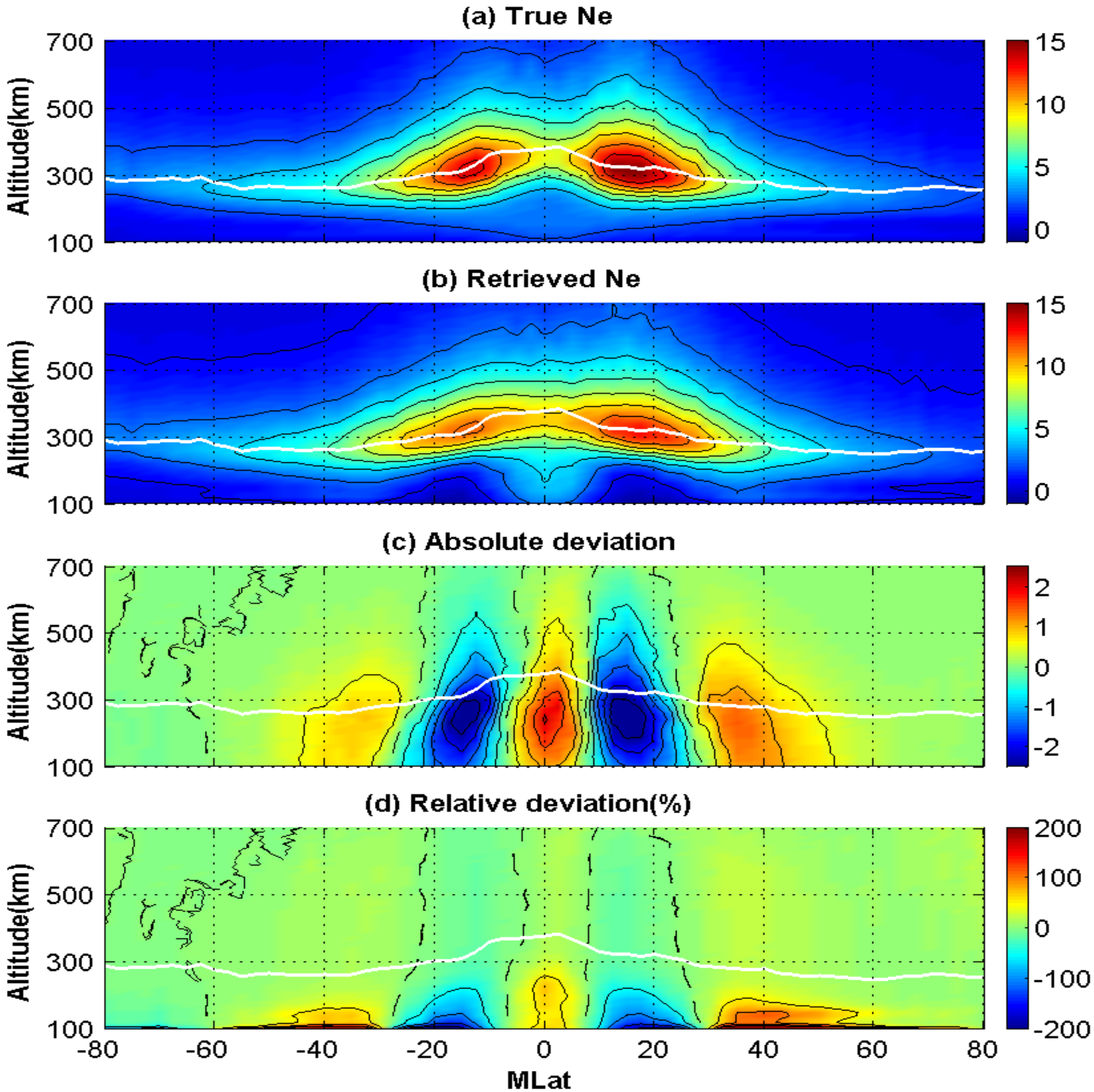
5. Spherical symmetry of electron density. [because of insufficient horizontal information].



Abel Error distribution versus latitude and altitude: Modeling results, Spring Equinox

Noon time
LT=13

Unit:
$1\times10^{11}/m^3$



True' Ne

Retrieved Ne

Absolute Deviation

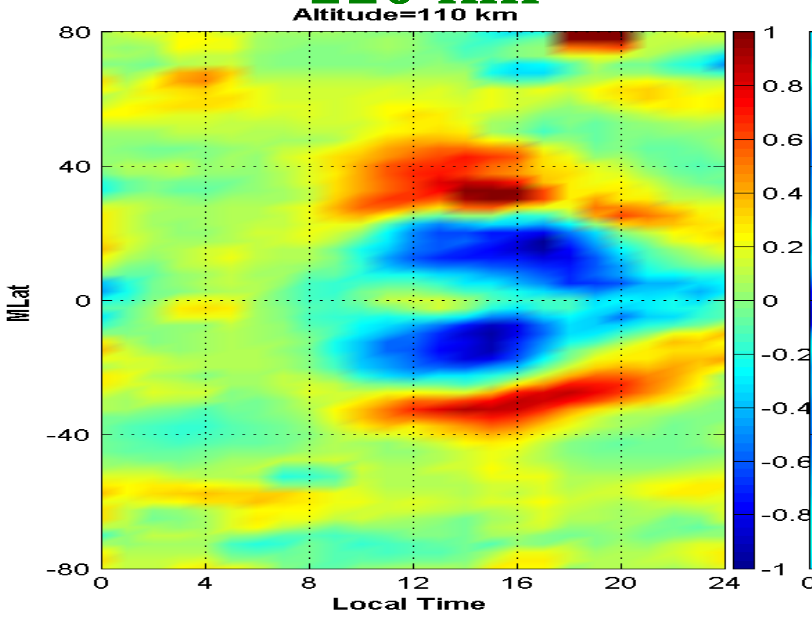
Relative Deviation

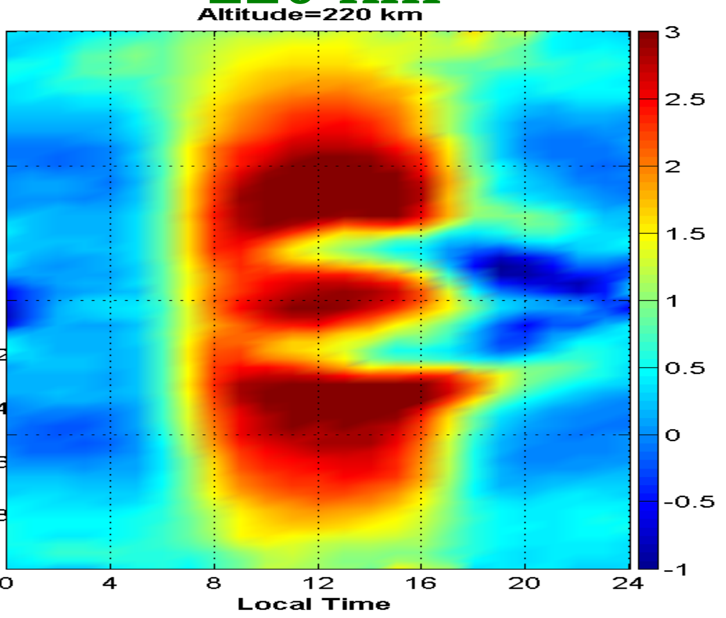
COSMIC observations (same time/duration as simulation):

110 km

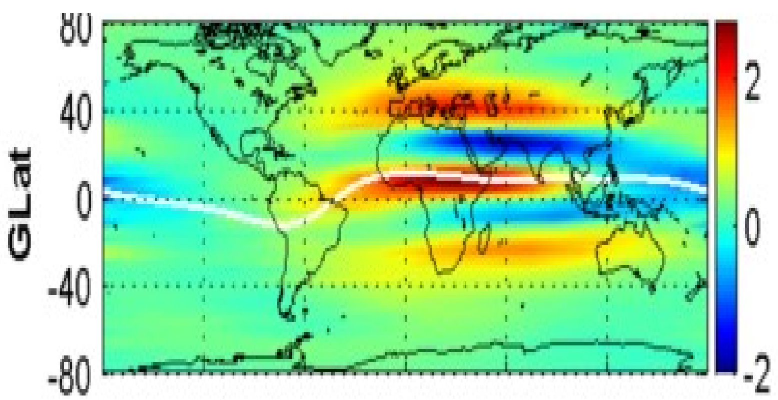
220 km

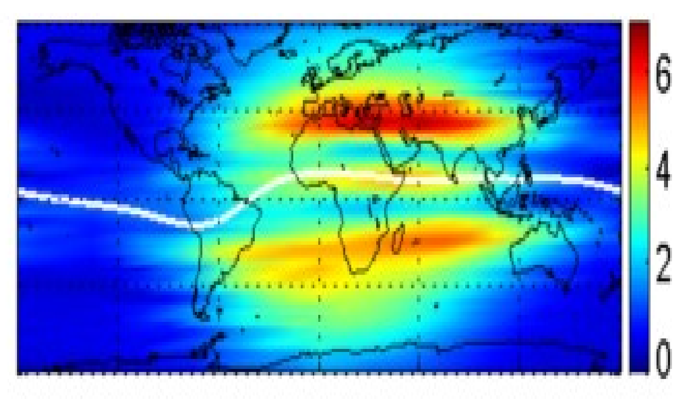
COSMIC





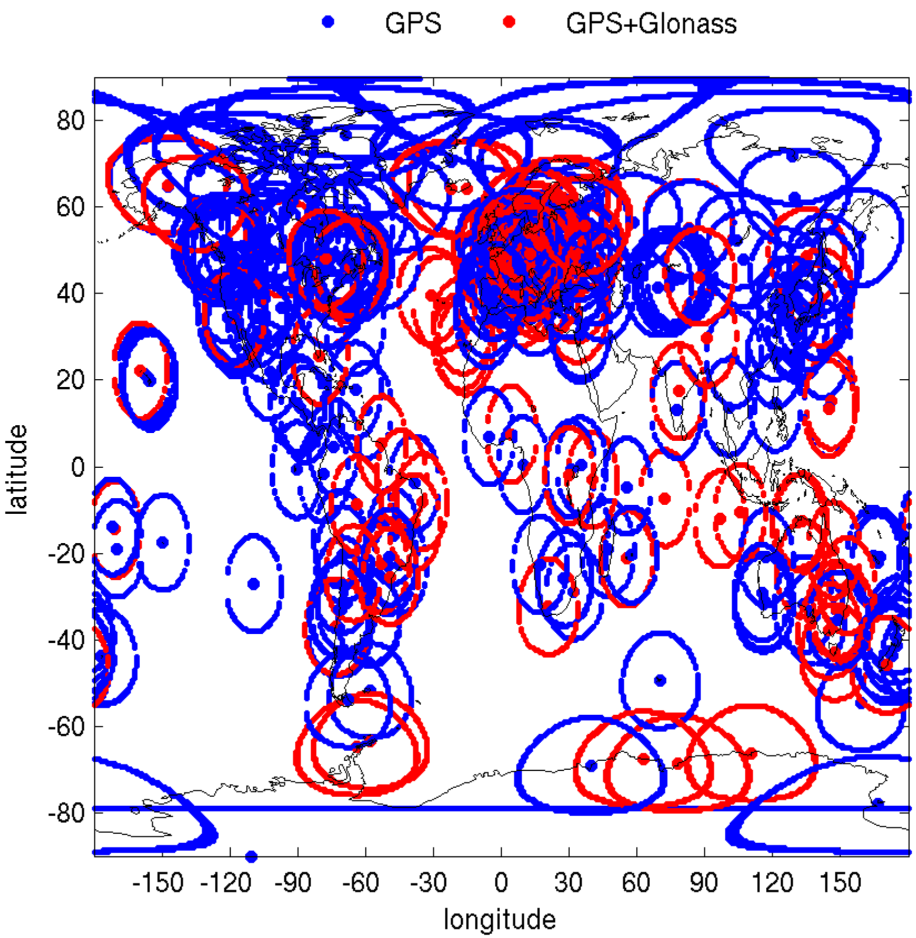
Abel retrieval from NeQuick model





Unit: $1 \times 10^{11}/m^3$

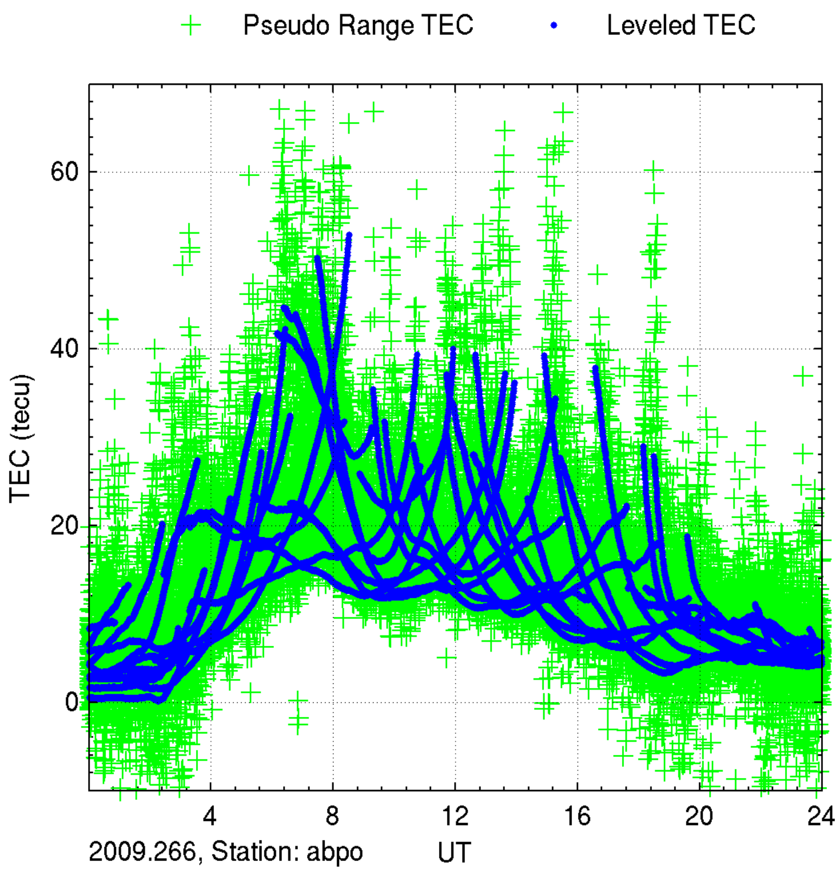
- ✓ **Ground based GNSS observation, higher horizontal resolution than RO, good coverage over land.**
- ✓ **~400 GNSS stations in IGS data center;>2000 + other data centers; 1/3 can observe both GPS and Glonass.**

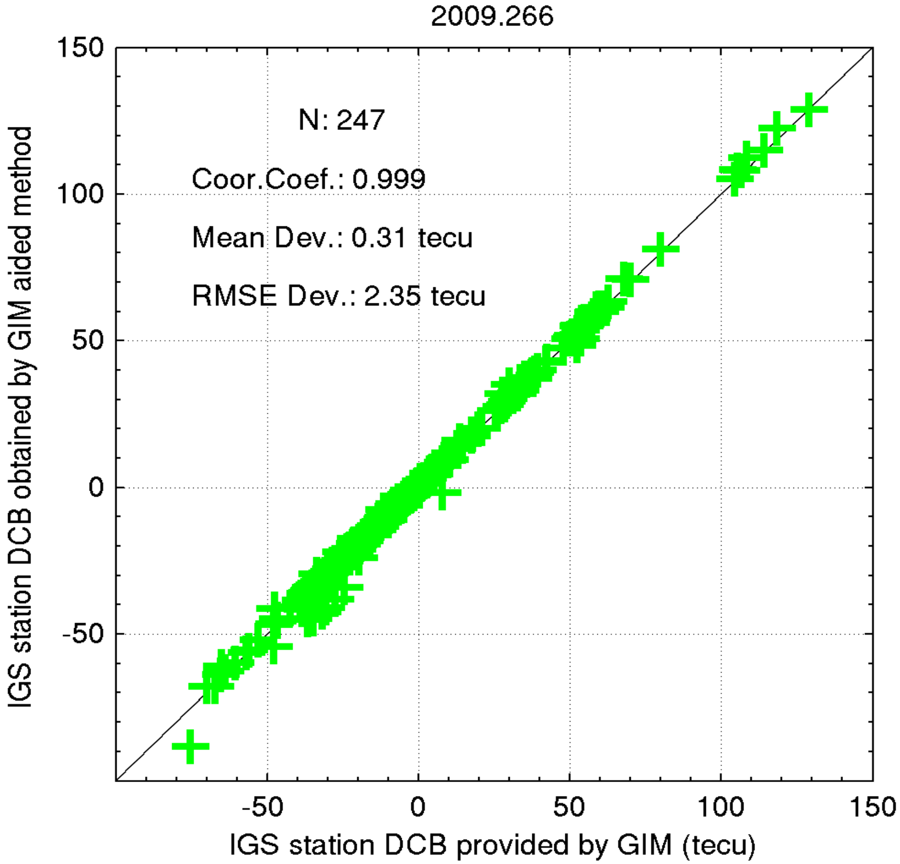


Left: IGS GNSS stations during 2009.266; >10 degree elevation coverage

✓ Ground based GNSS process mainly include:

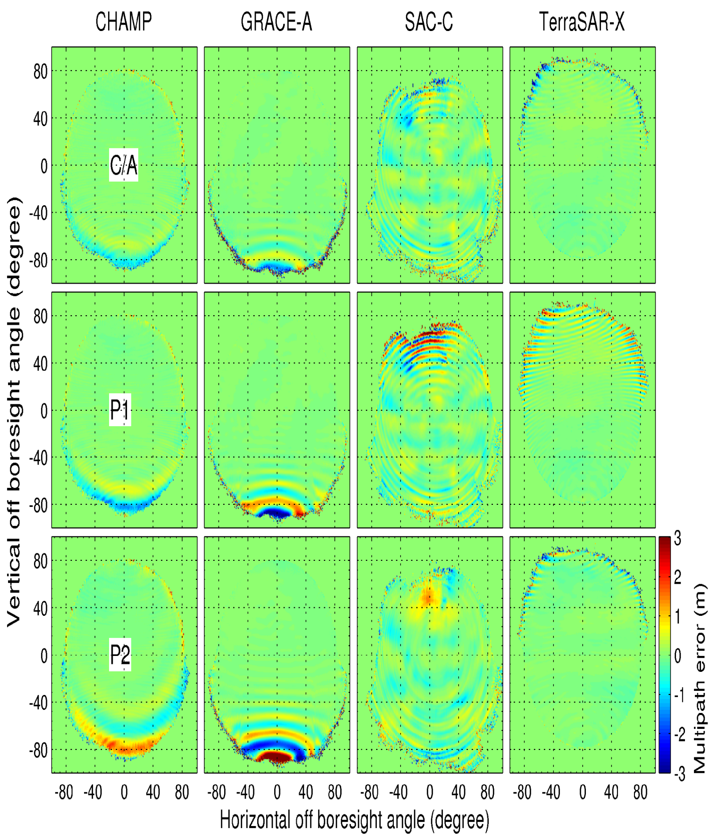
- **cycle slip detection;**
- **Leveling of phase TEC to pseudo-range TEC;**
- **Differential Code Bias (DCB) estimation: aided by IGS GIM**





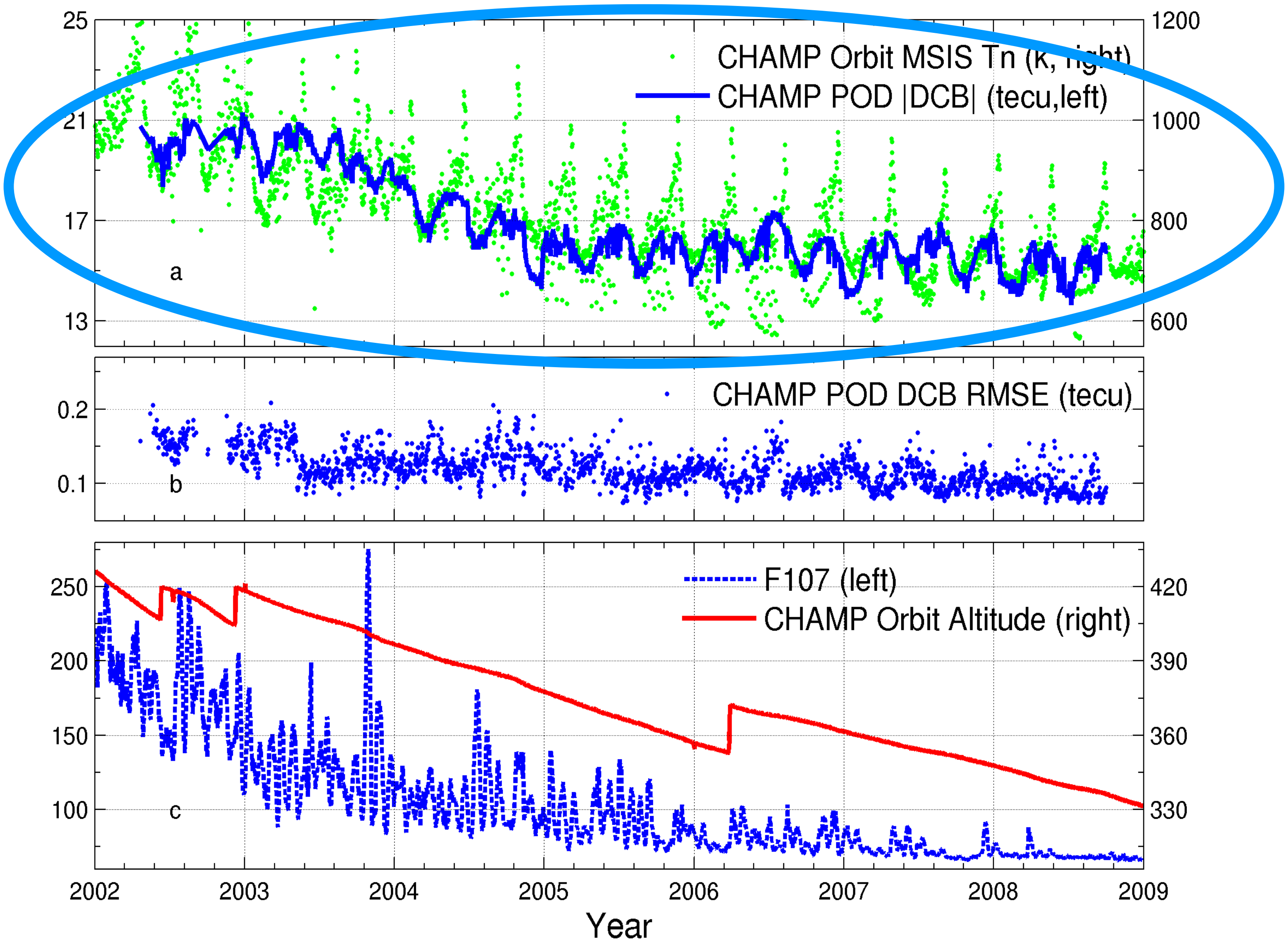
LEO based GNSS process mainly include:

- **cycle slip detection;**
- **Multi path calibration;**
- **Leveling of phase TEC to pseudo-range TEC;**
- **Differential Code Bias (DCB) estimation: spherical symmetry assumption**



Mission	Inclination (°)/Altitude(km)/mass(kg)	GPS Receiver type	Operation years	POD antenna normal	Multipath RMSE (C/A, m)	Leveling error mean (tecu)	DCB RMSE mean (tecu)
COSMIC FM4	72/700-800/70	Blackjack	2006-	75° off the zenith	0.30	0.12	0.69
CHAMP	87.3/460-330/522	Blackjack	2000-2009	zenith	0.20	0.19	0.11
GRACE-A	89/~495/432	Blackjack	2002-	zenith	0.42	0.31	0.14
SAC-C	98.2/~710/467	Blackjack	2000-	zenith	0.42	0.60	0.87
TerraSAR-X	97.44/~514/1230	IGOR	2007-	zenith	0.29	0.15	0.09
Metop-A	98.7/~820/4093	GRAS	2006-	zenith	0.15	0.09	0.16

✓ **Satellite environmental temperature effects on the Differential Code Bias (DCB) estimation: CHAMP DCB drift aggress well with orbit neutral temperature variation**



Key parameters of the global ionospheric data assimilation model used in this study

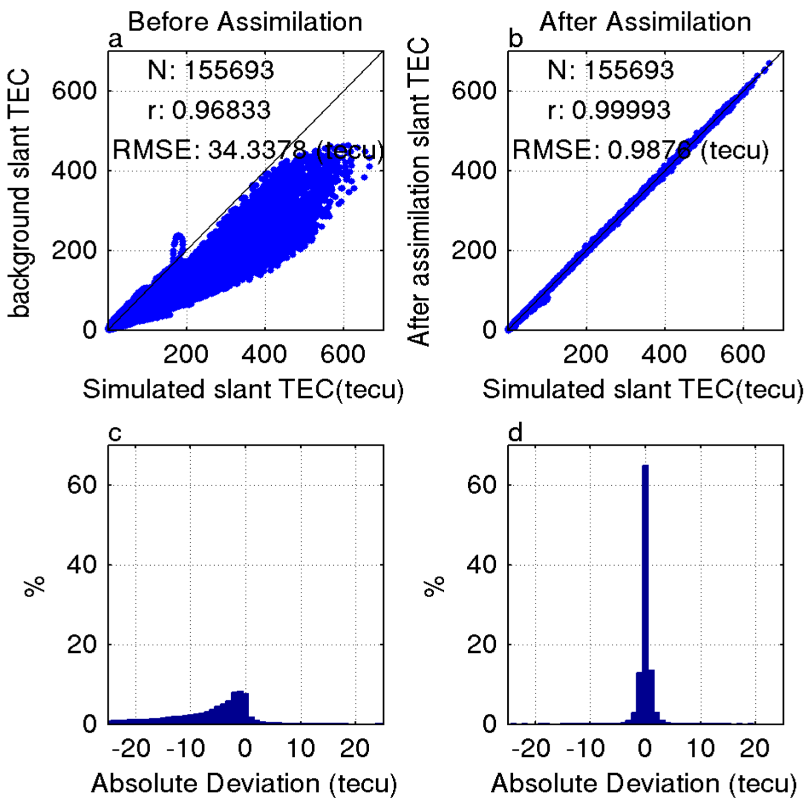
- **Background model:** empirical model (NeQucik, IRI), easy to add other(theoretical) models
- **Space Resolution:** flexible, 2.5 latitude, 5 longitude, 20 km altitude in this study.
- **Background correlation and error:** Gaussian correlation, cutoff when dlat>10, dlon>20, and dalt>60; square of background Ne.
- **Observation correlation and error:** un-correlated; 1% of background error.
- **Time resolution:** flexible, 1 hour in this study.
- **Altitude range:** flexible, 80-2000 km in this study, plasmasphere is calibrated by a simple H+ model.
- **Solve method:** Kalman Filter.
- **Inversion of innovation covariance:** restarted GMRES (generalized minimal residual) iteration method.
- **Input:** GNSS rinex files, IGS GIM, LEO orbit, GNSS orbit, navigation of Glonass (to get the frequency number). flexible to add different kind observations.
- **Data down-sampling and quantity control:** flexible. TEC range restriction; remove duplicate GPS ray.
- **Output:** global 3-D grid electron density.

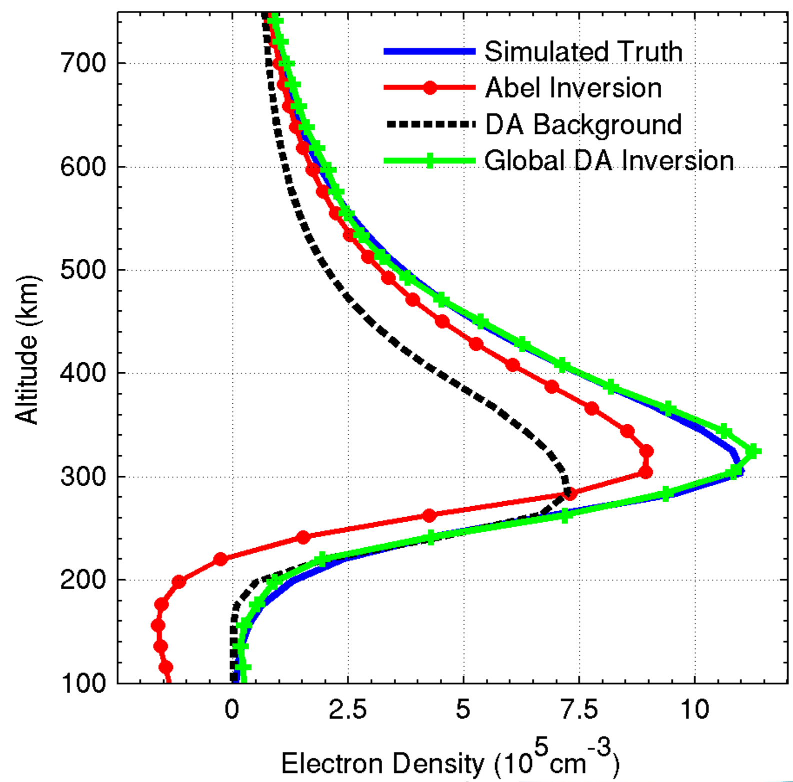
✓ Simulation:

- suppose ~1100 occultations during 2009.266 occur simultaneously.
- Simulation model: NeQuick (F107);Background: IRI (F107+40)
- Assimilate these occultations and ground based GNSS observation into the model

✓ Evaluation:

- Interpolate the electron density after assimilation to the tangent point of radio occultation events, compare with the corresponding Abel retrieved results .

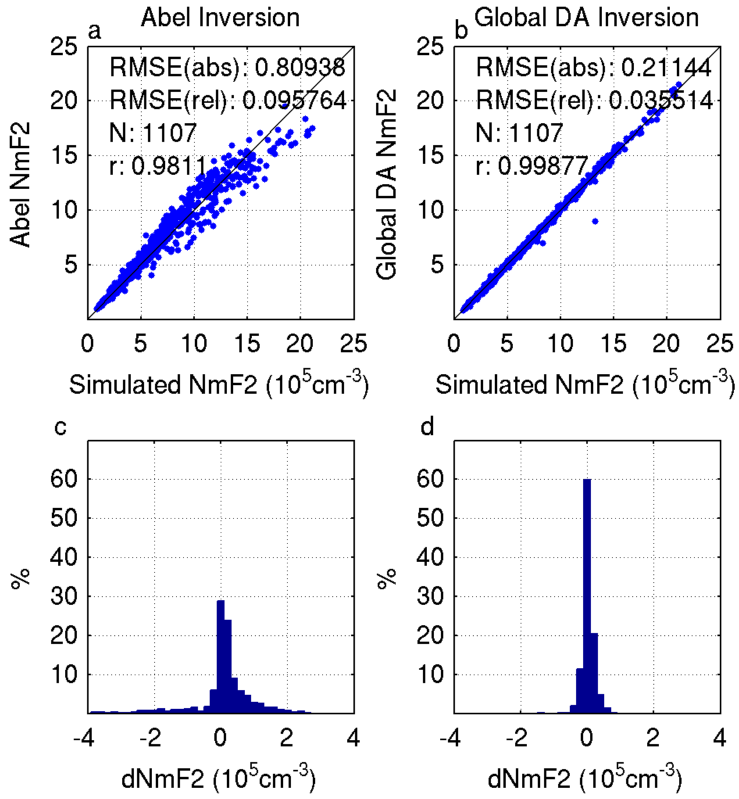


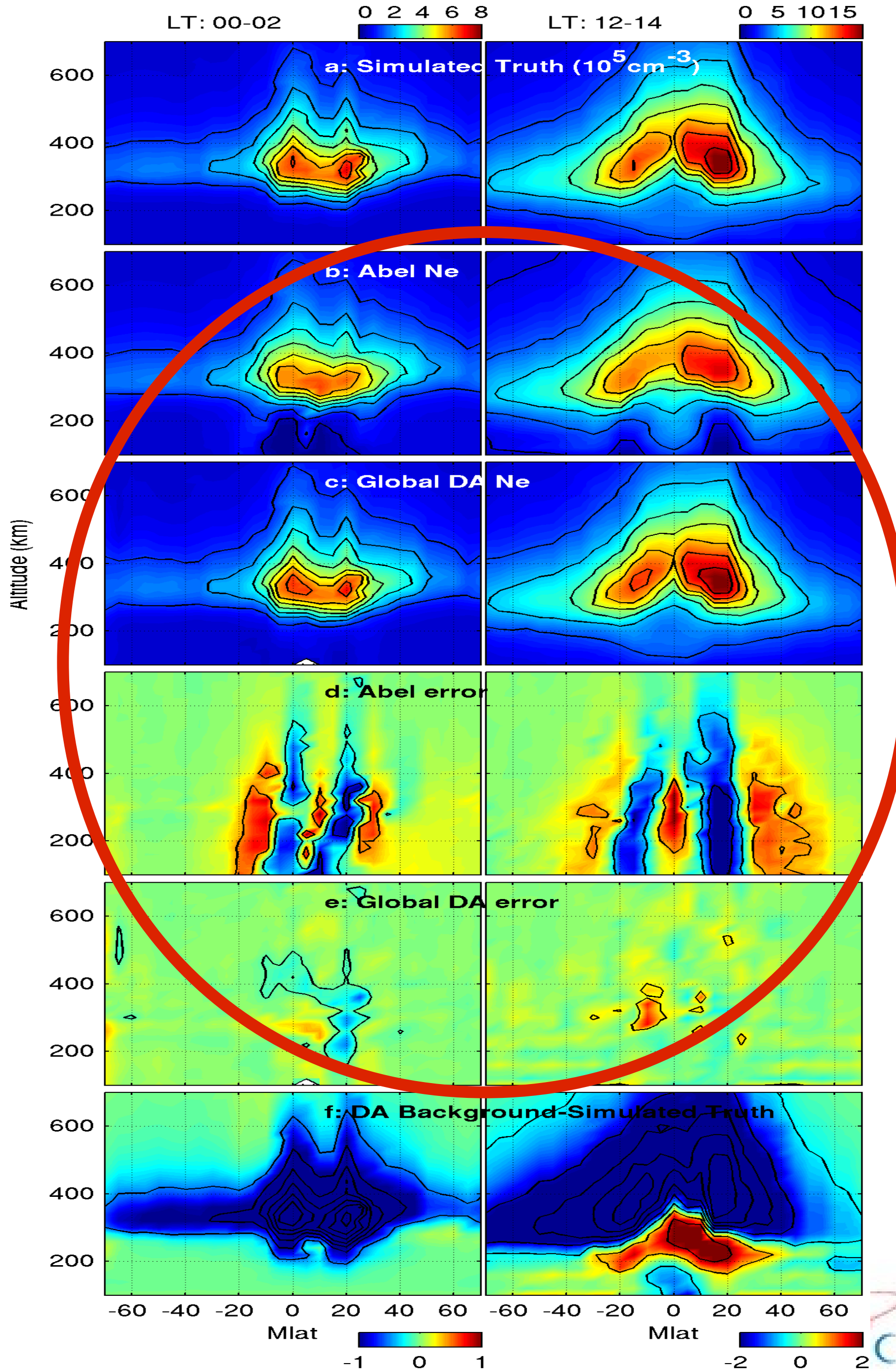


✓ **Simulating the improved effect of global data assimilation on the electron density retrieval (compared with Abel inversion):**

left: NmF2 comparison

right: Error comparison





Conclusion:

✓ **Global assimilation inversion aided by ground slant TEC:**

- **Simulation results show good performance either in F or E region. Less systematic error than Abel inversion.**
- **A possible method for COSMIC-2.[sufficient data are available]**
- **Generate high level data product: global 3-D Ne**