Potential way to mitigate the second order ionospheric effect in neutral RO retrievals: preliminary evaluations

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Outline

- Overview of ionospheric 2nd order effect in neutral atmospheric retrievals.

- Two potential methods to mitigate:
  - 1: Ray tracing through models: Is the ionospheric model accurate enough to calibrate the 2nd order effect?
  - 2: Regression on the first order: is it feasible?

Ionospheric 2nd order effect

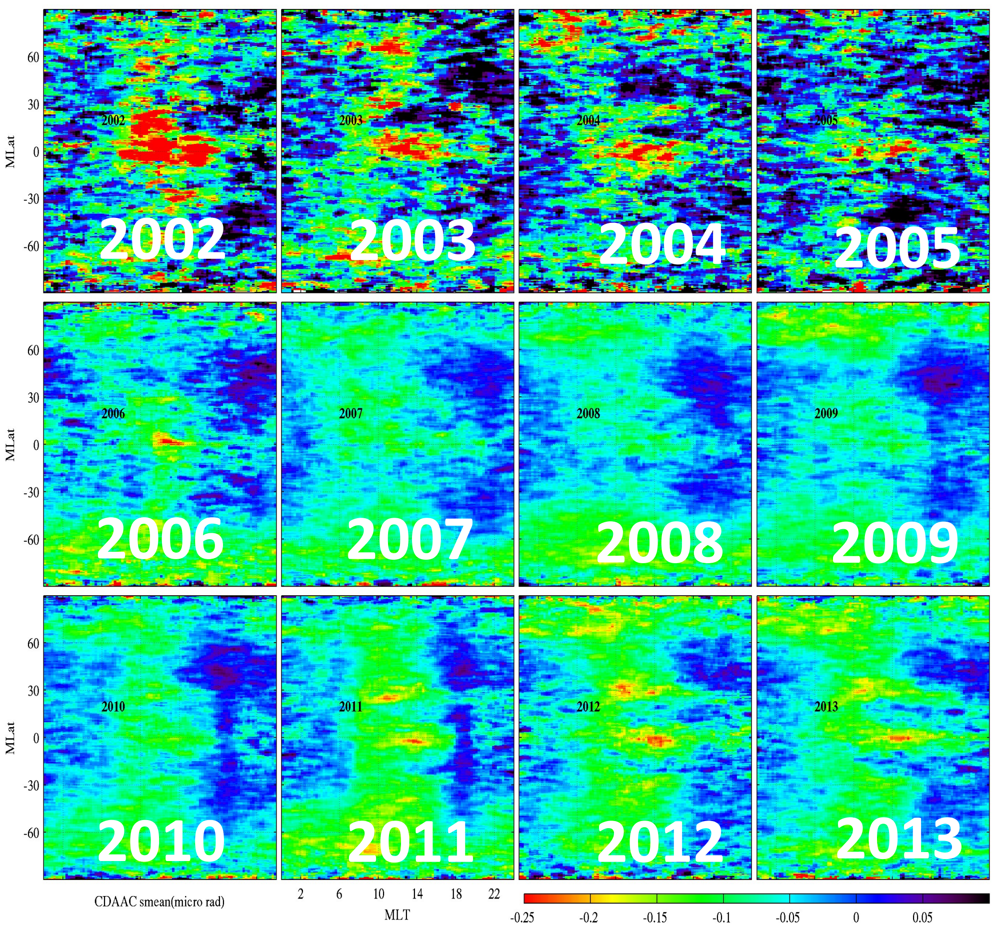
- Here we consider the large-scale 2nd residual, not the small-scale 2nd residual (usually 100-1000 times larger than the large-scale residual).
- Linear combination of bending angle is used to calibrate the 1st order ionospheric effect, the 2nd order effects come from (Mannucci, 2011):
- main reason for the 2nd order effect: L1 and L2 rays travel different trajectories; the effect is reduced but not eliminated by combining L1 and L2 at the same impact parameter (Vorob'ev and Krasil'nikova)
- other reasons: higher-order terms in the Appleton-Hartree equation (mainly the term with geomagnetic field)
- Assumption n=1 at LEO substantially affects L1 and L2 BA, but is eliminated after the 1st order correction; the 2nd order effect substantially depends on this assumption (must be calculated consistently with the calculation of the obs. BA)

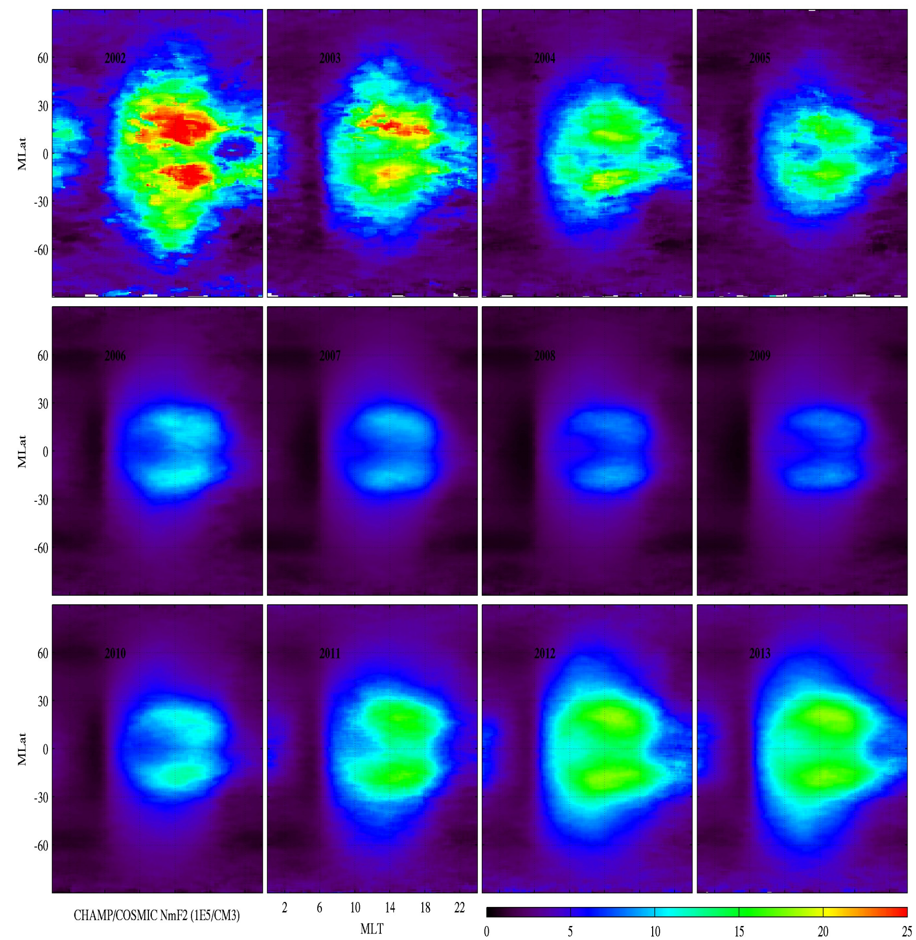
Ionospheric 2nd order effect

- Important for climate studies, negligible for weather applications.
- Related to ionospheric ionization level, higher in solar maximum, higher in daytime
- Related to the degree of spherical asymmetry of ionosphere.
- Contributions from both E and F layers.

Left: Yearly MLT-MLat variation of mean deviation between observed bending angle and NCAR climatology model between 60-80 km (median: -0.04 μrad)

Right: Yearly MLT-Mlat variation of NmF2 observed by CHAMP/COSMIC

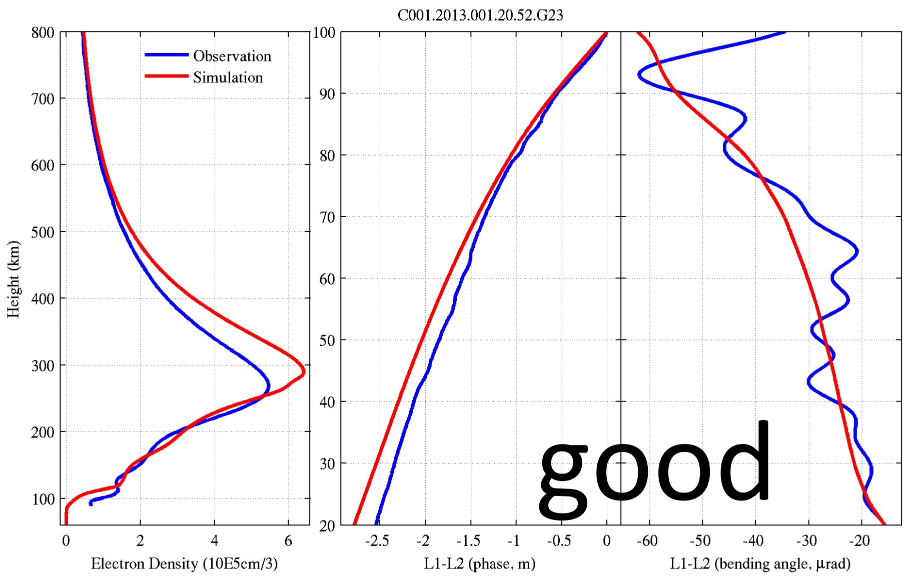


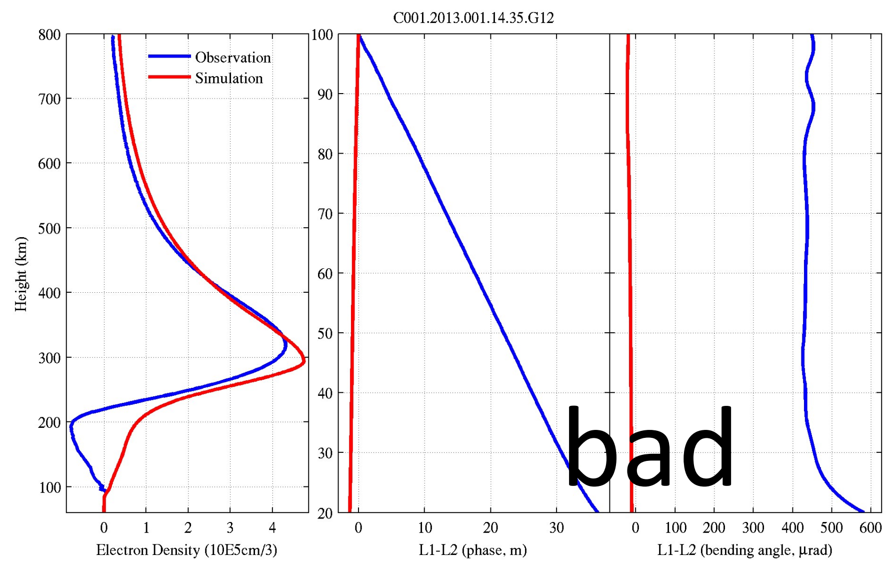


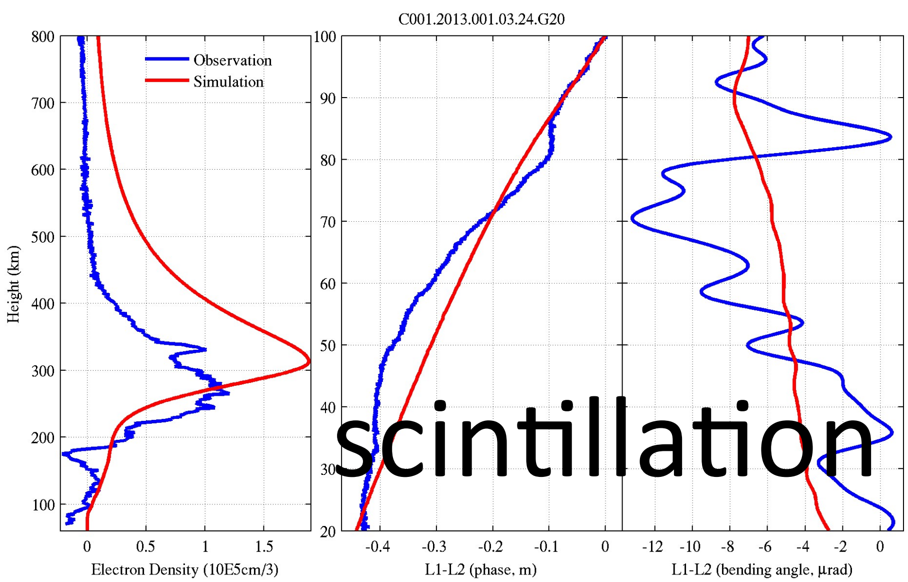
Evaluation of the ionospheric model accuracy

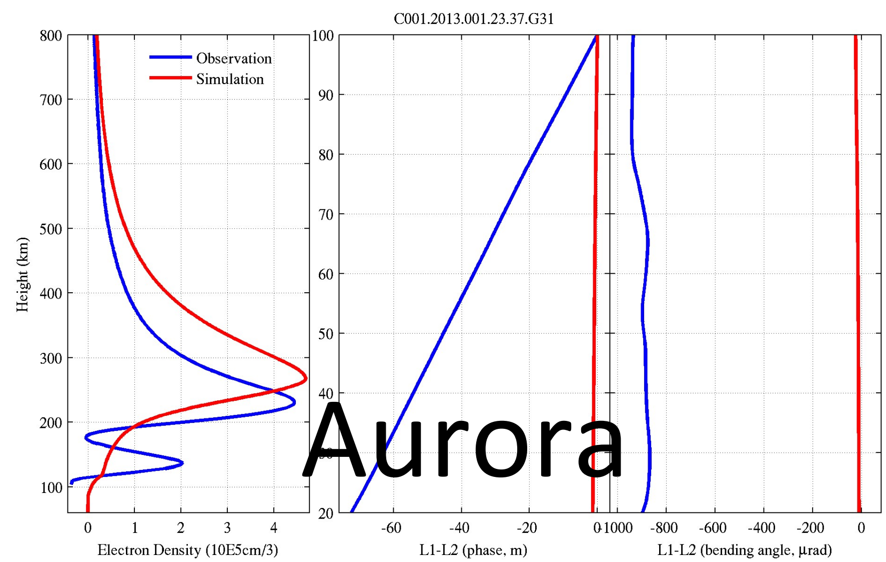
- Method: comparison of L1-L2 bending angle between real observations and model results.
- Ray tracing tool: EGOPS, full 3D ray tracing (written by Stig Syndergaard).
- Ionospheric model: International Reference Ionosphere 2007.
- 3 quiet days were selected for comparison:
  - 2002.096, F107=207, CHAMP
  - 2008.091, F107=79, CHAMP
  - 2013.001, F107=114, COSMIC

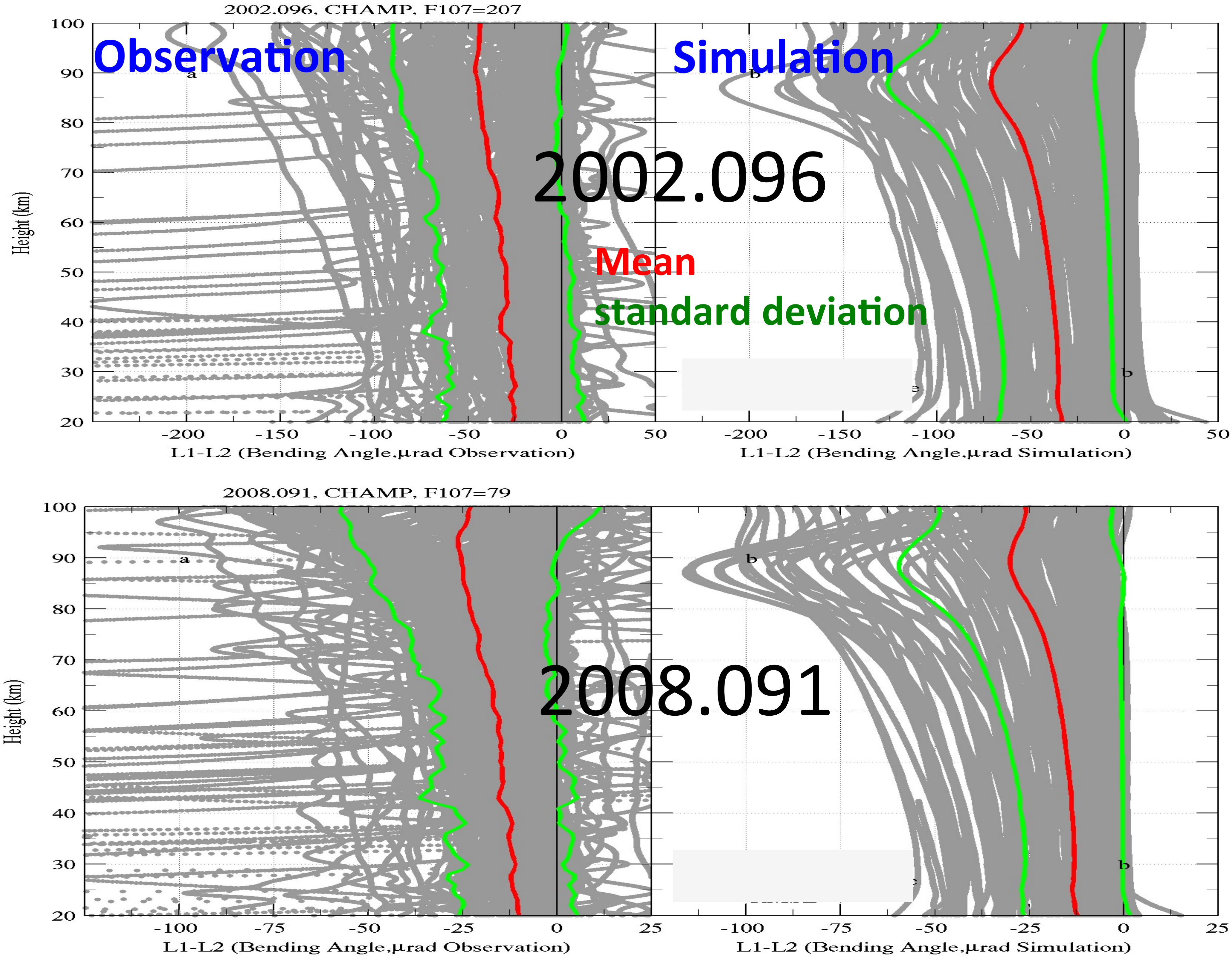
Comparison examples





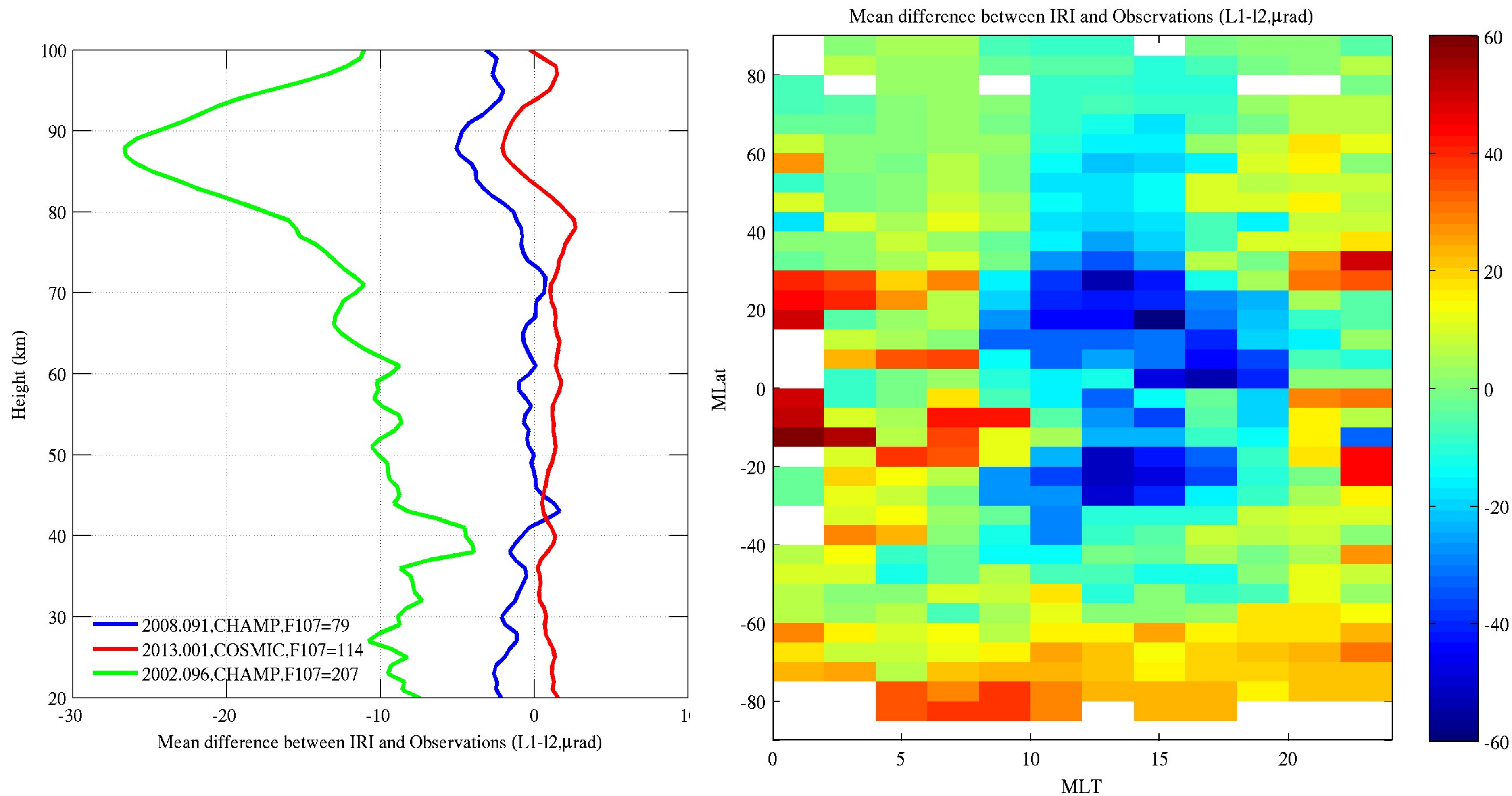





2002.096, CHAMP, F107=207
Observation
Simulation
2002.096
Mean
standard deviation
Height (km)
L1-L2 (Bending Angle,μrad Observation)
L1-L2 (Bending Angle,μrad Simulation)
2008.091, CHAMP, F107=79
2008.091

Mean deviation of IRI from observations in terms of L1-L2 Bending angle

MLT-MLat: 2013.001



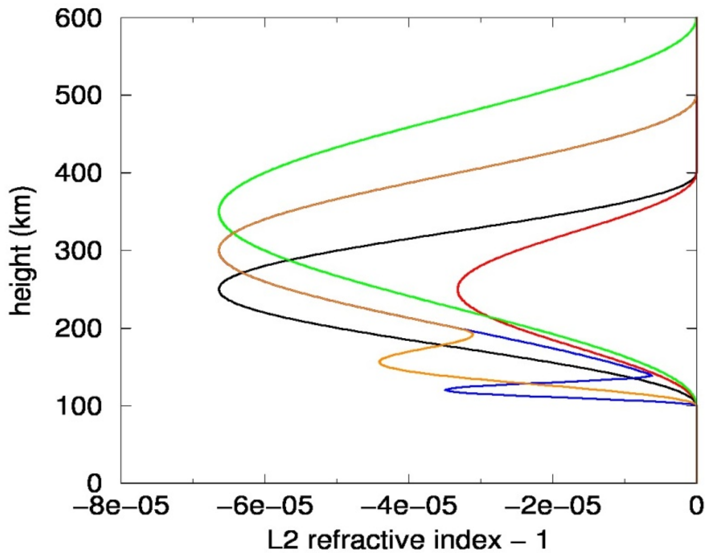
Regression method

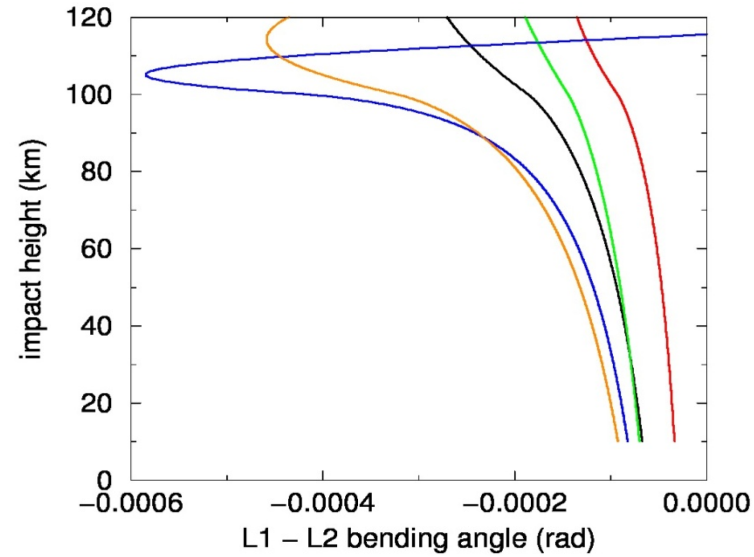
- Regression method has been widely used to improve the 2nd order ionospheric effect for ground based GNSS observations.
- Tool: CDAAC ray-tracing (low-noise), analytical representation of refractivity and gradients.
- Two cases: spherically-symmetric and asymmetric ionosphere were tested.

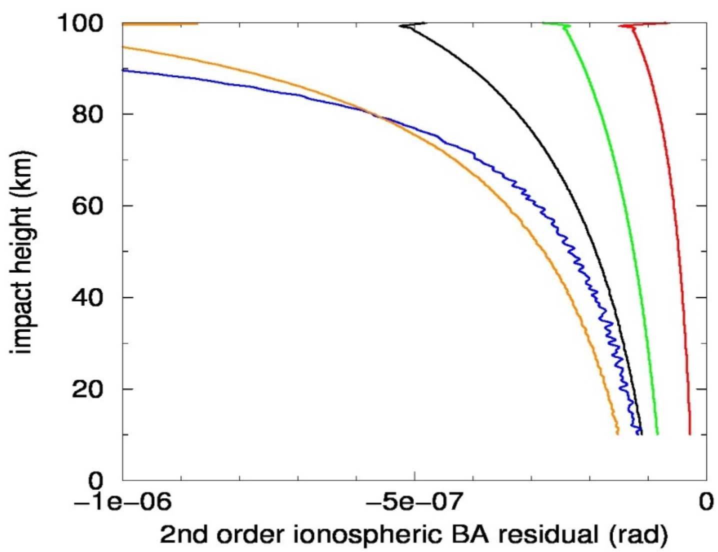
Modeling of the 2nd order ionospheric residual for spherically-symmetric Ne

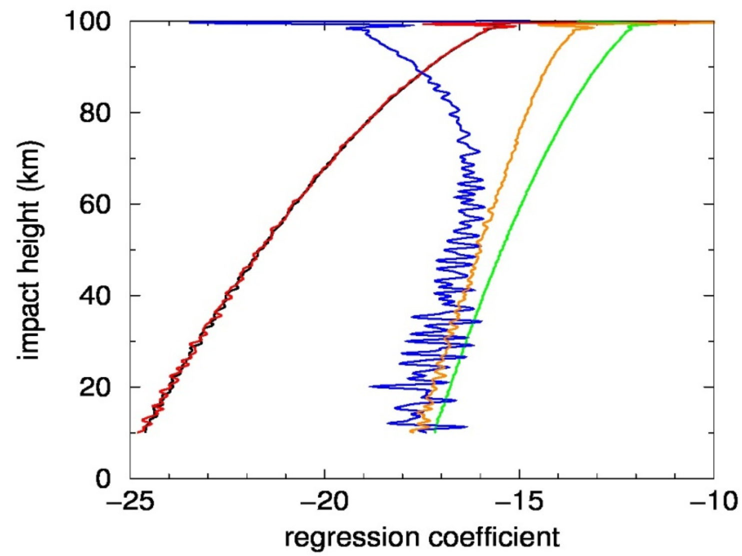
$L4 = L1 - L2$; $LC = (f1^2 L1 - f2^2 L2) / (f1^2 - f2^2)$; $LR = LC - L(\text{neutral})$ - 2nd order residual

- contribution of the neutral atmosphere is negligible (a model is not required)
- contribution of the E-layer is significant
- local regression: LR = - **C** * (L1 - L2)^2; **C** - regression coefficient



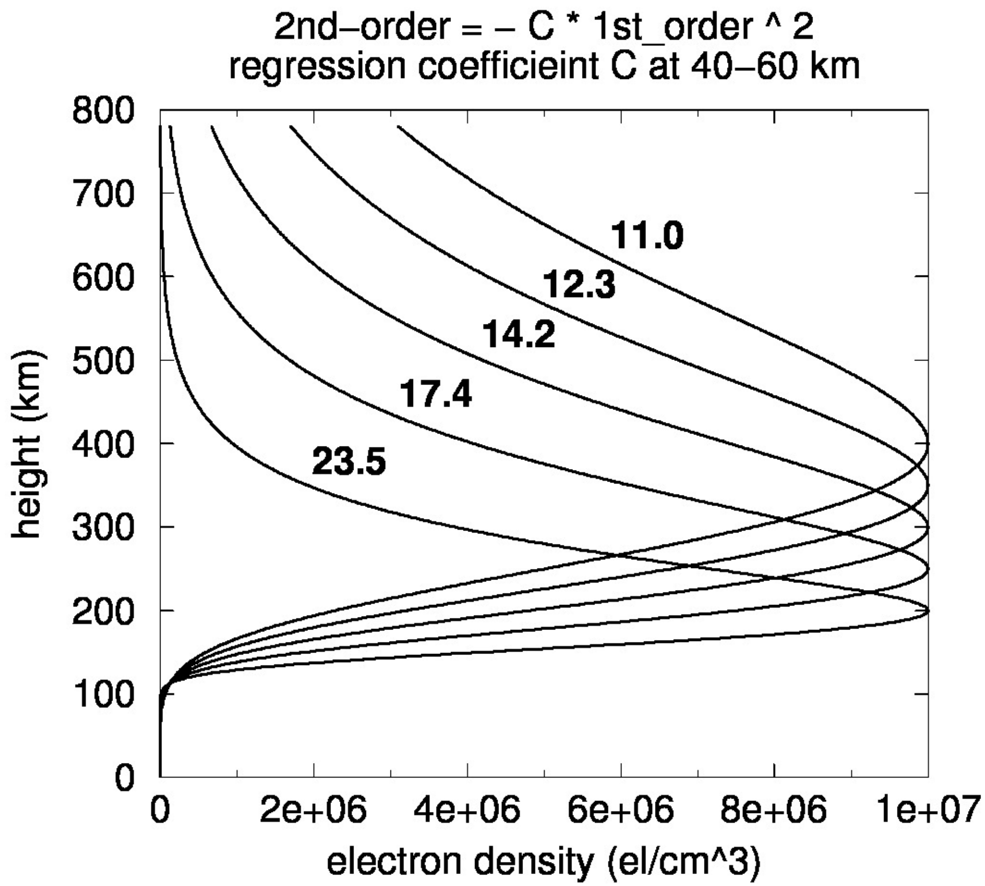






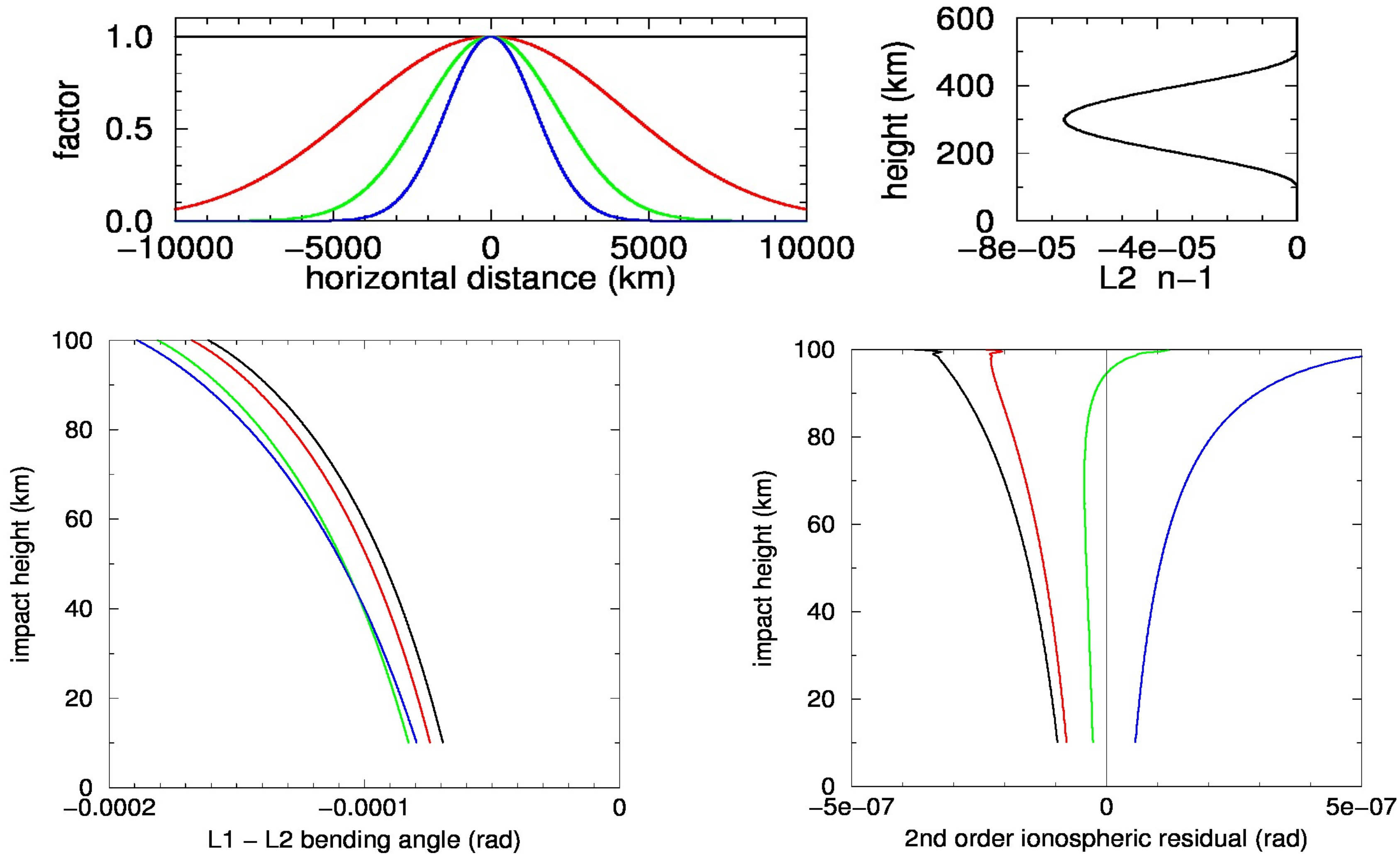
Regression coefficient for a Chapman layer

Changes about twice when HmF2 changes from 200 to 400 km



Modeling of the 2nd order ionospheric residual for non-spher.-symm. Ne

- refractivity = 10^6 [n(z)-1] x factor (horizontal distance)
- for horizontal scales of the ionospheric structure of about several thousands km, the regression of LR on $L4^2$ fails (LR may even change sign); this result needs further verification



Conclusions

- IRI model is not accurate enough to provide reasonable 1st order correction, so it won't provide accurate 2nd order calibration. However, an accurate high resolution ionospheric specification via data assimilation is still possible in the future with a lot of data. Challenge: how to specify E layer more accurately and ray trace through sharp E layers

- Regression approach: provides accuracy about 50% for spher.-symm. Chapman model (HmF2 ~ 200 - 400 km); fails for a certain model of hrizontal inhmogeneity: however, this needs further investigation

Conclusions (cont.)

- Validation of the 2nd order correction (problems):
- direct validation: datasets for comparison do not exist;
- indirect validation: (by use of 11-year solar or diurnal cycle) residual ionospheric effects are mixed with climate trends or tides, how to separate?
- validation by an ionospheric model: valid for that model.