Application of IONOLAB-CIT to Central Europe for Regional Tomographic Reconstruction of Ionospheric Electron Density

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INTRODUCTION

- Estimation of 3D electron density in the ionosphere is a crucial problem for investigating the ionospheric effects on electromagnetic propagation.
- Two important tools are generally used for investigating the ionosphere:

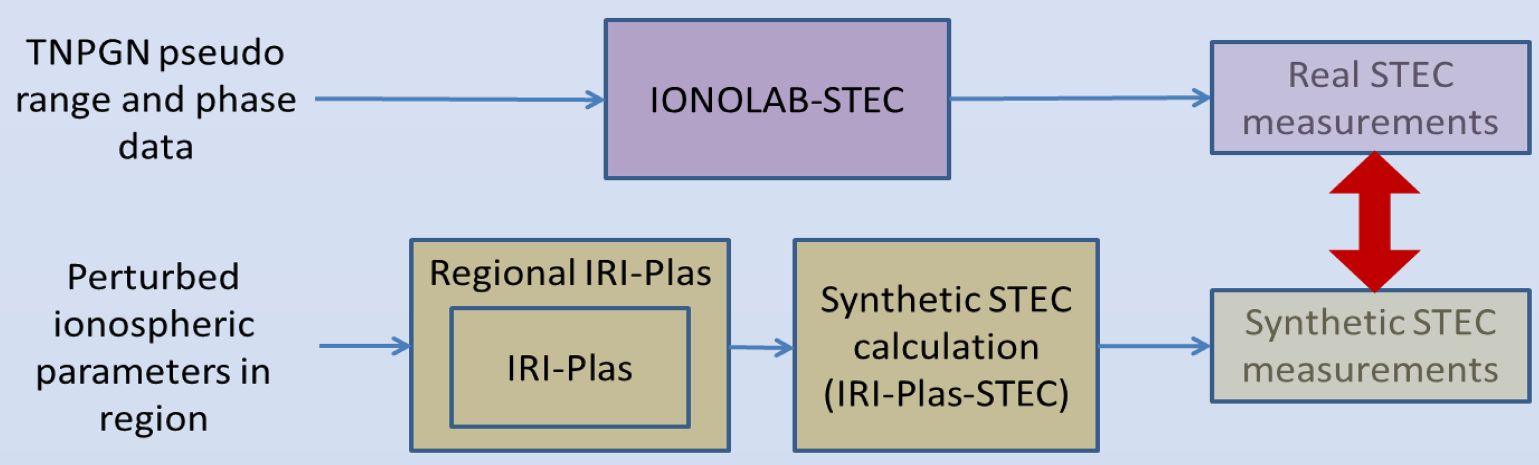
↓ *GPS-TEC measurements*
  - widely used in ionospheric studies
  - very sparse and non-uniform for employing 3D tomography methods (ill-conditioned problem)

↓ *Ionospheric models like IRI-Plas*
  - can estimate monthly averages of 3D electron density distributions
  - not generally compliant to the real measurements obtained from GPS receivers.

- In this study, a novel method for estimating the 3D electron density distribution in the ionosphere by using both GPS measurements over Central Europe.
- Proposed method **perturbs** default **ionospheric parameters** used in IRI-Plas model over a region of interest by using parametric perturbation surfaces, and **iteratively searches for the best physically feasible 3D electron density distribution**, which is compliant with the GPS-TEC measurements.

PROBLEM DEFINITION

Find the optimum **perturbation values** on the selected ionospheric parameters in a region, such that, the resultant 3D electron density distribution generates synthetic STEC values similar to the real GPS-TEC measurements.



Perturbation surfaces

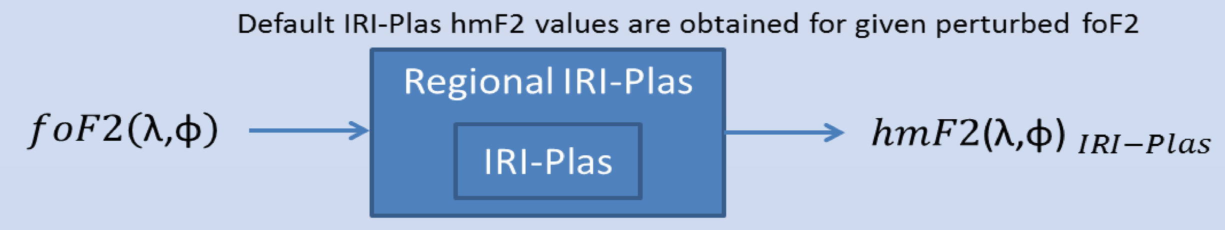
$$f(\lambda,\phi) = m_1\lambda' + m_2\phi' + m_3$$
$$h(\lambda,\phi) = m_4\lambda' + m_5\phi' + m_6$$

Perturbed ionospheric parameters

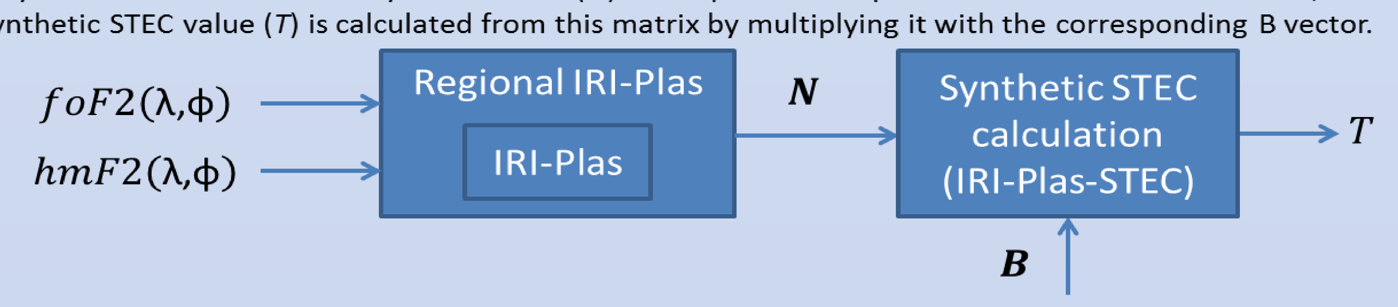
$$foF2(\lambda,\phi) = foF2\,(\lambda,\phi)_{\,IRI-Plas} + f(\lambda,\phi)$$
$$hmF2(\lambda,\phi) = hmF2\,(\lambda,\phi)_{\,IRI-Plas} + h(\lambda,\phi)$$

λ : latitude, ϕ : longitude, λ' : normalized latitude [-1, 1], ϕ' : normalized longitude [-1, 1]

Default IRI-Plas hmF2 values are obtained for given perturbed foF2



A synthetic 3D electron density distribution (N) is computed from perturbed foF2 and hmF2 values, then any synthetic STEC value (*T*) is calculated from this matrix by multiplying it with the corresponding B vector.



Objective: Minimize the following cost function

$$C = \frac{\|\boldsymbol{M}-\boldsymbol{T}\|}{\|\boldsymbol{M}\|} + \rho\,\frac{\|\boldsymbol{H}-\boldsymbol{H}'\|^2}{\|\boldsymbol{H}\|^2}$$

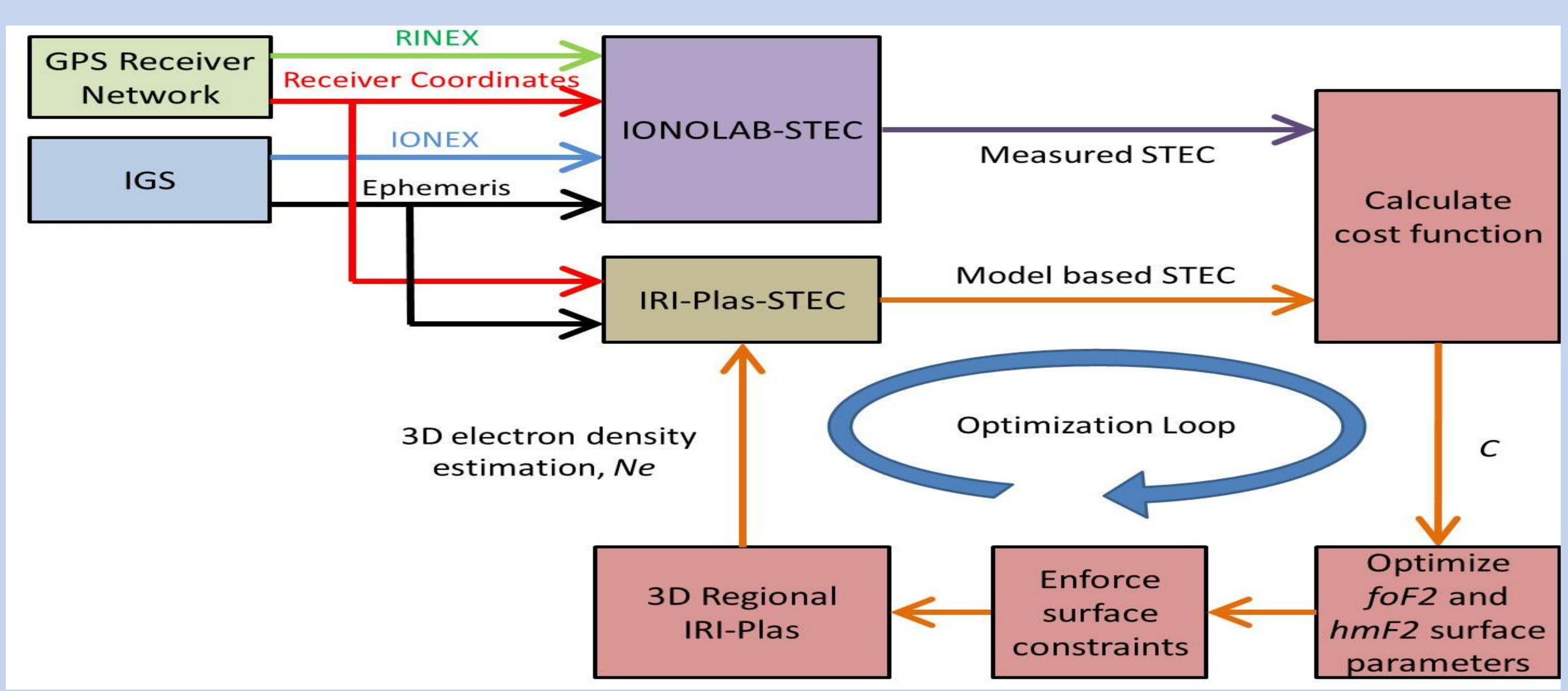
Difference between measured and calculated STEC values (first term)

Deviation from physical relation between foF2 and hmF2 values (second term)

Relaxation parameter (used as 3 in simulations) (ρ)

$\boldsymbol{M}$: The array containing measured GPS-TEC (IONOLAB-STEC).
$\boldsymbol{T}$: The array containing synthetic GPS-TEC (IRI-Plas-STEC).
$\boldsymbol{H}$: The array containing perturbed $hmF2$ values.
$\boldsymbol{H}'$: The array containing default $hmF2$ values for given perturbed $foF2$ values from IRI-Plas.

IONOLAB-CIT

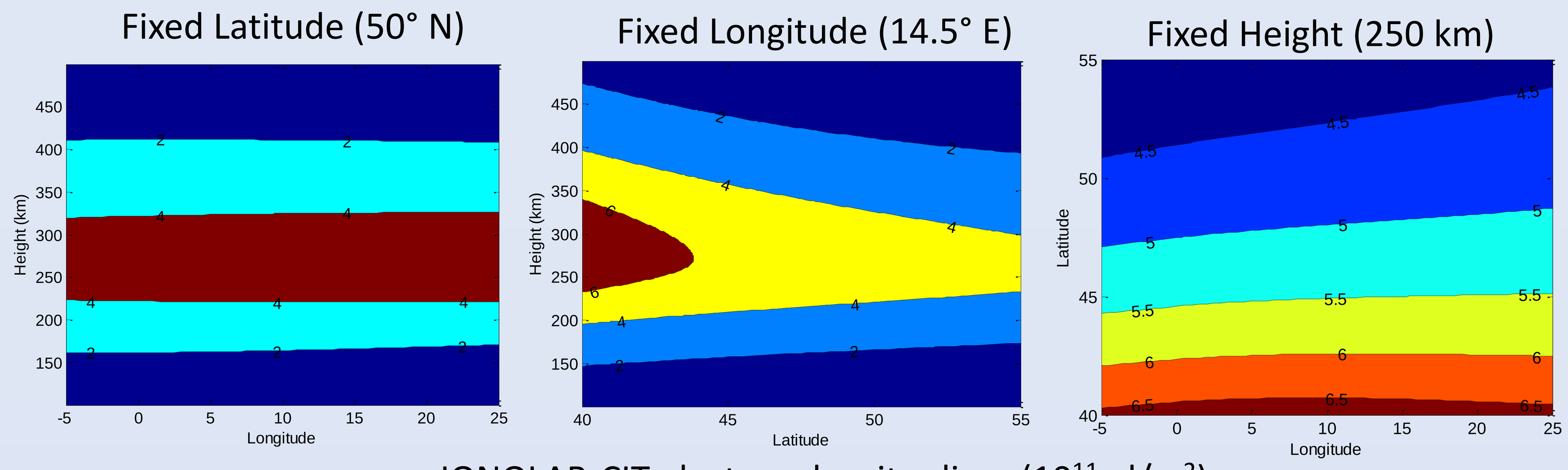


RESULTS

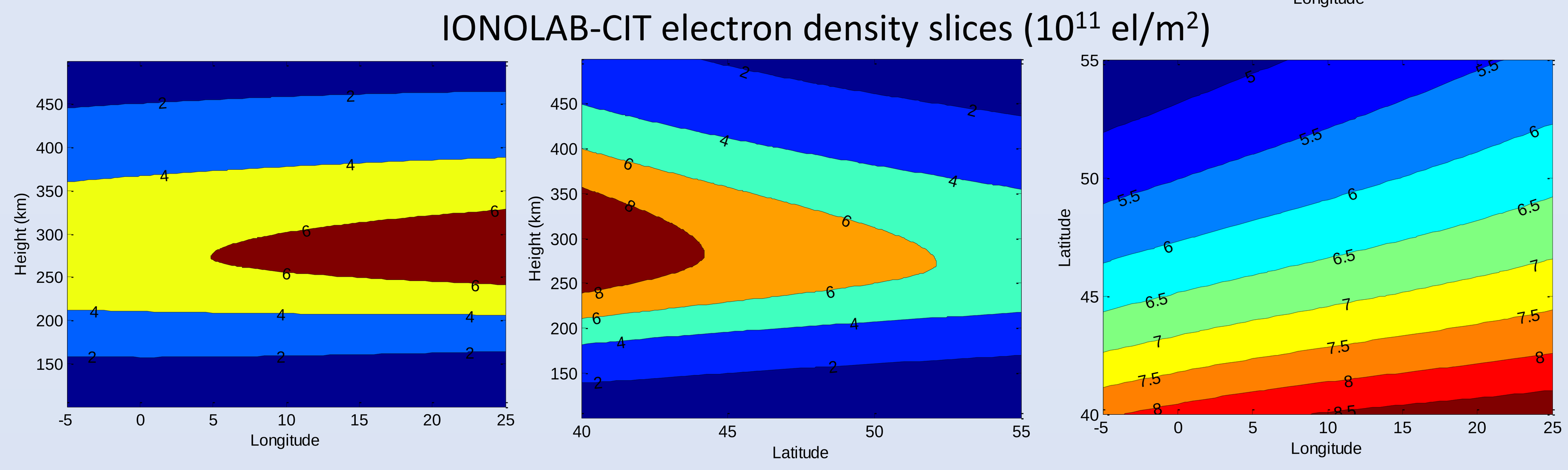
(17 April 2011, 13:00 GMT, Calm)

IRI-Plas electron density slices (10^{11} el/m^2)

Fixed Latitude (50° N) | Fixed Longitude (14.5° E) | Fixed Height (250 km)



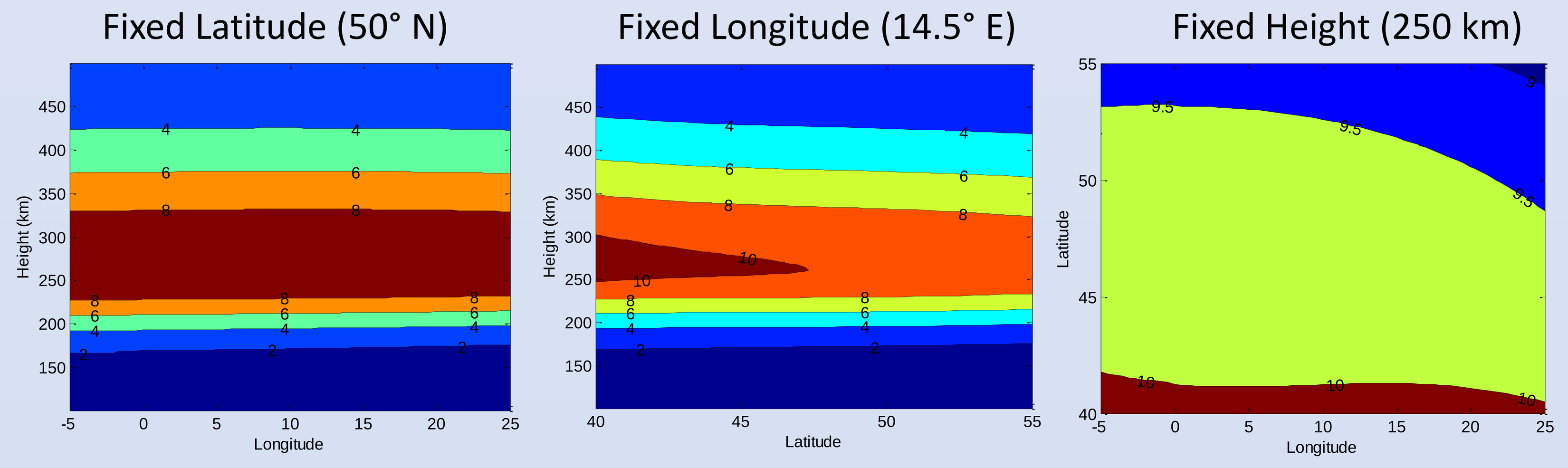
IONOLAB-CIT electron density slices (10^{11} el/m^2)



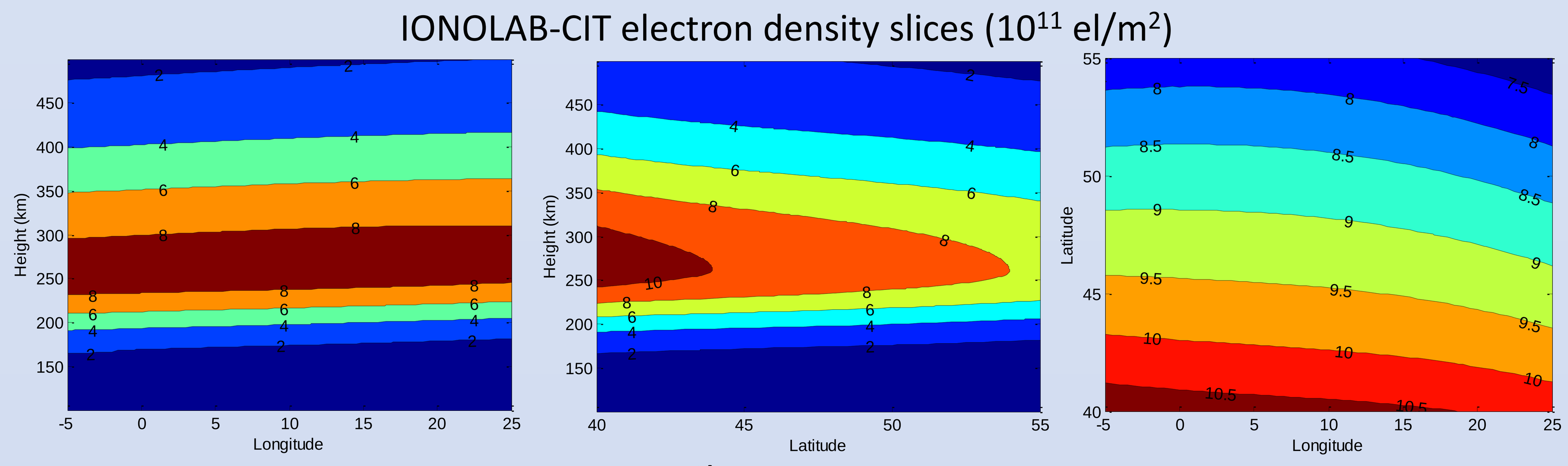
(25 October 2011, 13:00 GMT, Disturbed)

IRI-Plas electron density slices (10^{11} el/m^2)

Fixed Latitude (50° N) | Fixed Longitude (14.5° E) | Fixed Height (250 km)

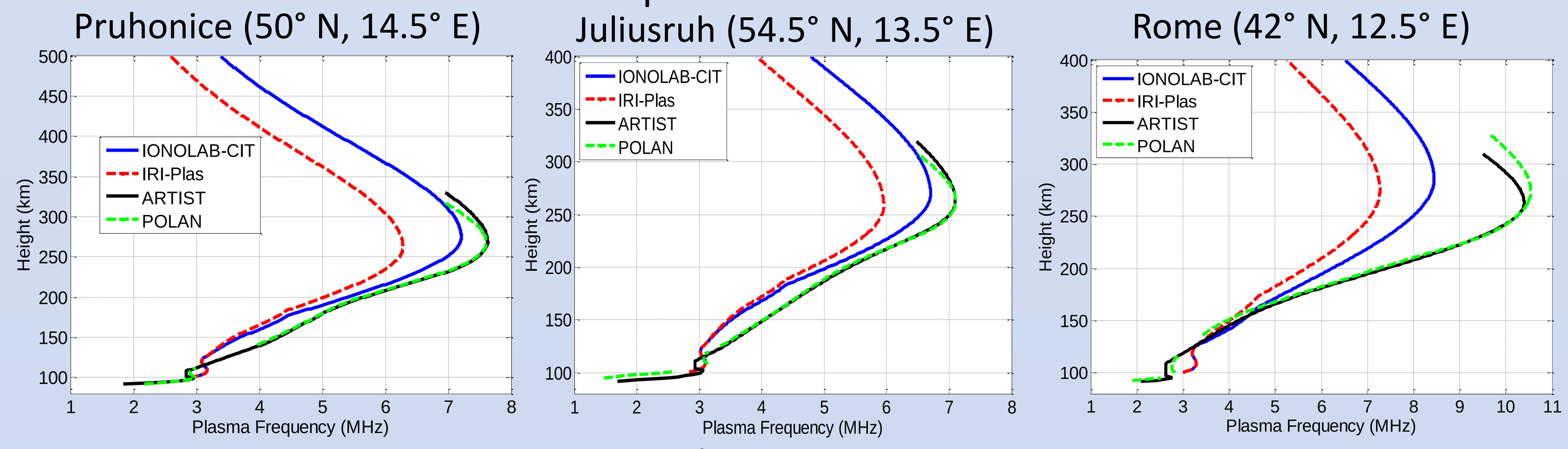


IONOLAB-CIT electron density slices (10^{11} el/m^2)



17 April 2011 13:00 GMT

Pruhonice (50° N, 14.5° E) | Juliusruh (54.5° N, 13.5° E) | Rome (42° N, 12.5° E)



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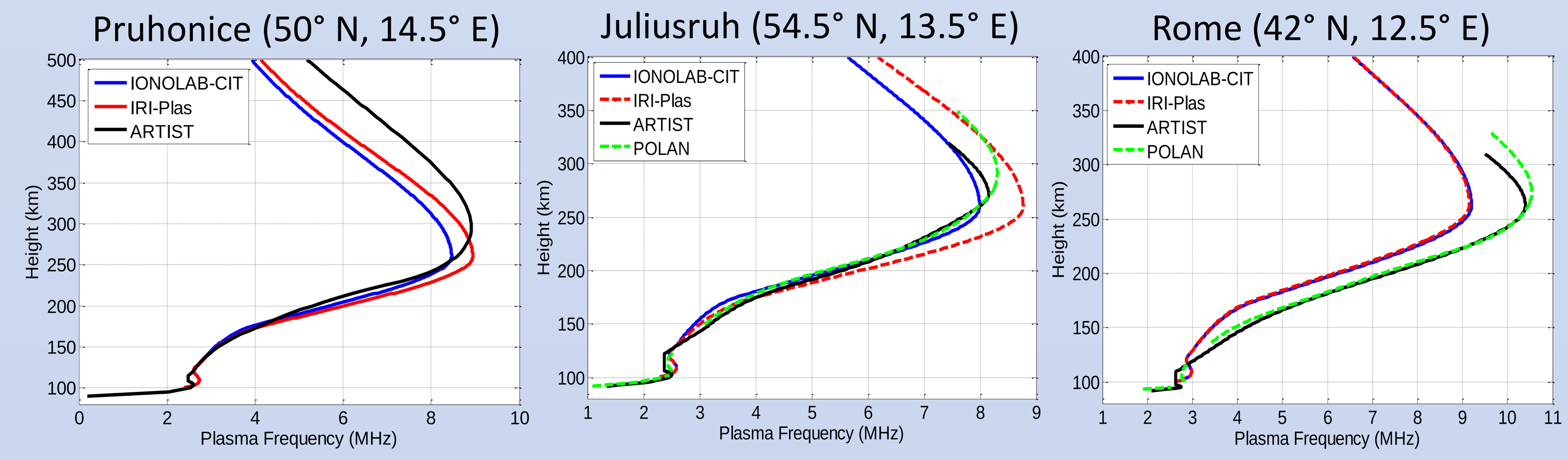

CONCLUSION

- Input parameters of IRI-Plas model are tuned in a way that the resulting 3D electron density profile is in compliance with GPS based STEC measurements and the input parameters are in compliance with each other.
- ***foF2* and *hmF2* values over Europe** are both represented with additive surface models with 3 parameters. The problem is reduced to a **6-parameter optimization** problem.
- **BFGS optimization method** is used for solving the optimization problem.
- Results show that the proposed methodology provides 3D electron density distributions compliant with both real GPS STEC measurements, and ionosonde measurements.
- Future works may consider temporal correlation of the optimization parameters which isn't involved in this study.

Acknowledgement

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