



# Developing systems for ionospheric data assimilation

Making a quantitative comparison between observations and models

A.C. Bushell, 5<sup>th</sup> European Space Weather Week, Brussels, 20<sup>th</sup> November 2008



# Collaborators & Contributors

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- **Institute of Atmospheric Physics, ASCR, Prague**
  - Jan Lastovicka, Petra Sauli, Josef Boska
- **GEO6 project**
  - FP6 (via **GNSS Supervisory Authority**)
  - Miquel Garcia (**Starlab**) - tomography
  - B.Nava (**Abdul Salam ICTP, Trieste**) - artificial Galileo data.



# Contents

This presentation covers the following areas

- Introduction
- GEO6 Project: Ionosphere – Gravity wave detection
- GEO6 Project: Ionosphere – Investigating GNSS ionospheric data assimilation
- Conclusions



# Developing operational systems

- **Monitoring & forecasting the state of the ionosphere** is a significant component for **Space Weather service** provision, a primary activity strand of **Space Situational Awareness**
- **Meteorological services** (e.g. Met Office) could potentially plug a gap in provision of **routine analyses** of the **ionosphere & thermosphere**
- **Operational centres** would require **infrastructure** for:
  - Acquiring observations in reliable and timely manner
  - Processing observations in a data analysis system to produce an analysis state
  - Running forecasts with a physical upper atmosphere model
  - Making output available for downstream products and end-user applications

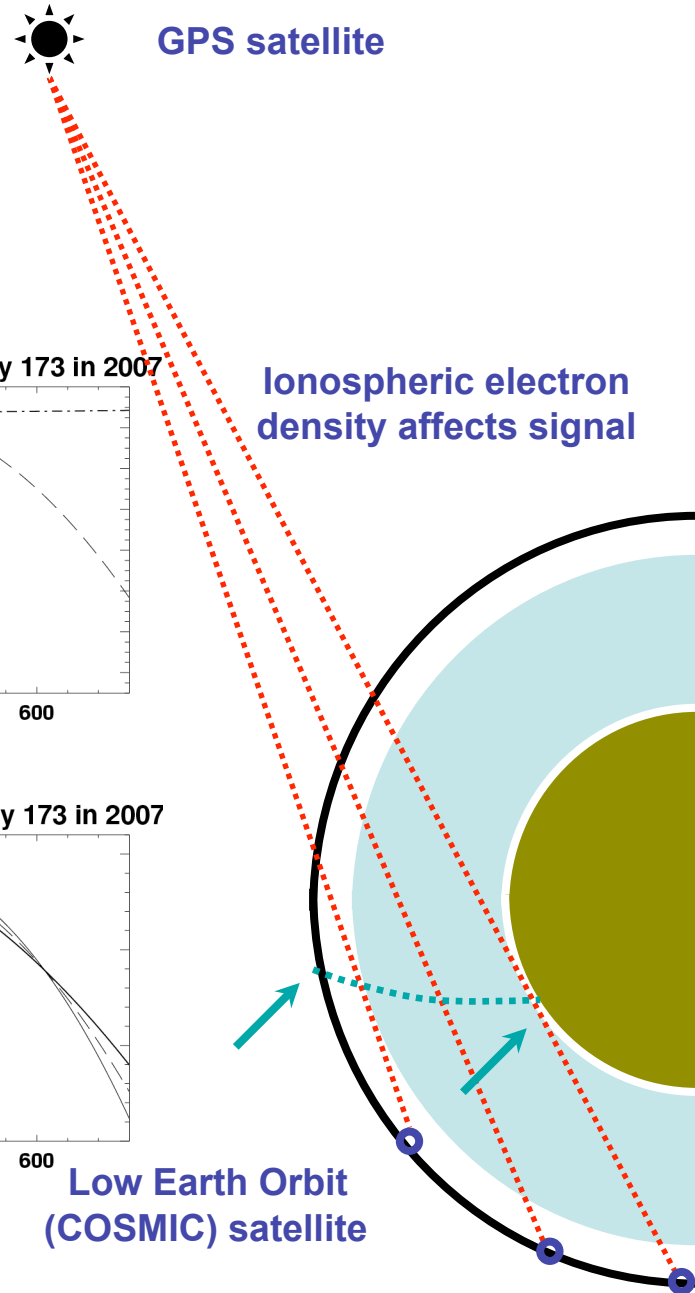


# FP6 Project GEO6 (Galileo)

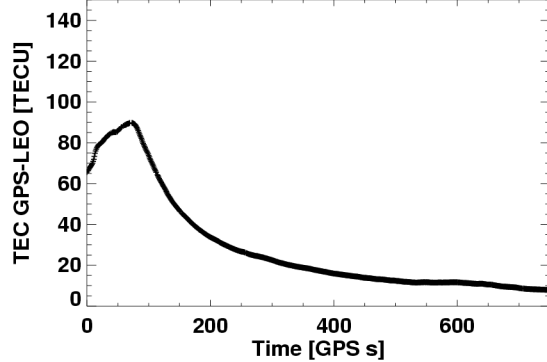
- Sponsored by GNSS Supervisory Authority
- Explore new applications of the Galileo Global Navigation Satellite System for the Scientific User Community
- Priority Application 2 – Ionosphere
  - Exploitation of GNSS Radio Occultation data
  - Gravity Wave Detection
  - Investigating GNSS Ionospheric Data Assimilation
- Expect publication in near future.

# GEO6 Observations: GPS Radio Occultation

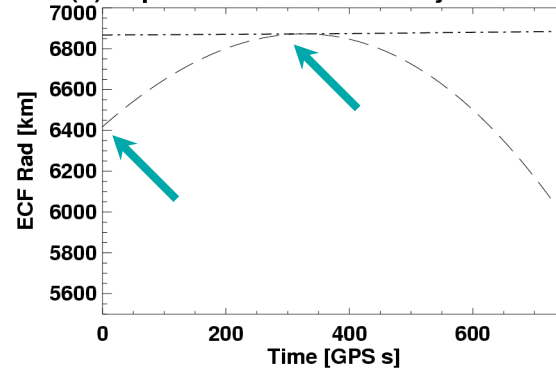
Constellation Observing System for  
Meteorology, Ionosphere, Climate



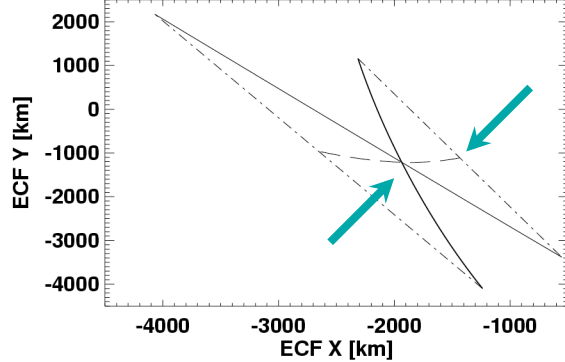
(a) COSMIC PoD : 0000Z Day 173 in 2007



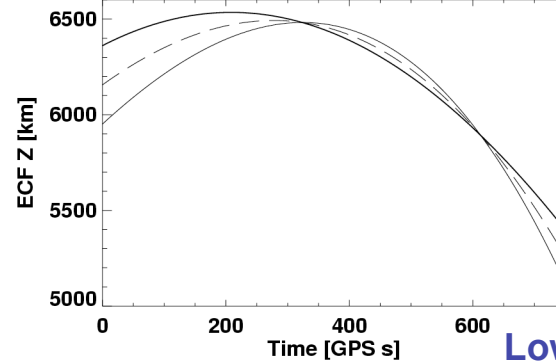
(b) Impact Radius : 0000Z Day 173 in 2007



(c) TEC Path : 0000Z Day 173 in 2007

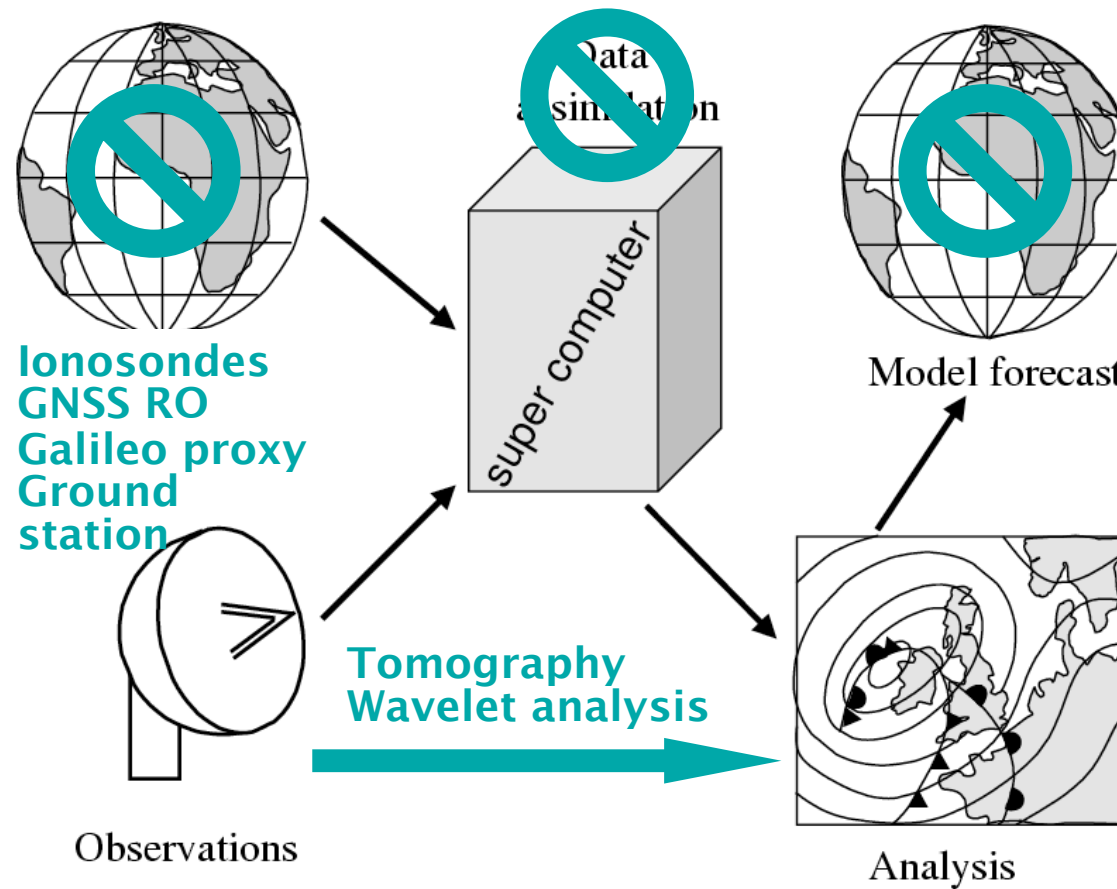


(d) TEC Z location : 0000Z Day 173 in 2007

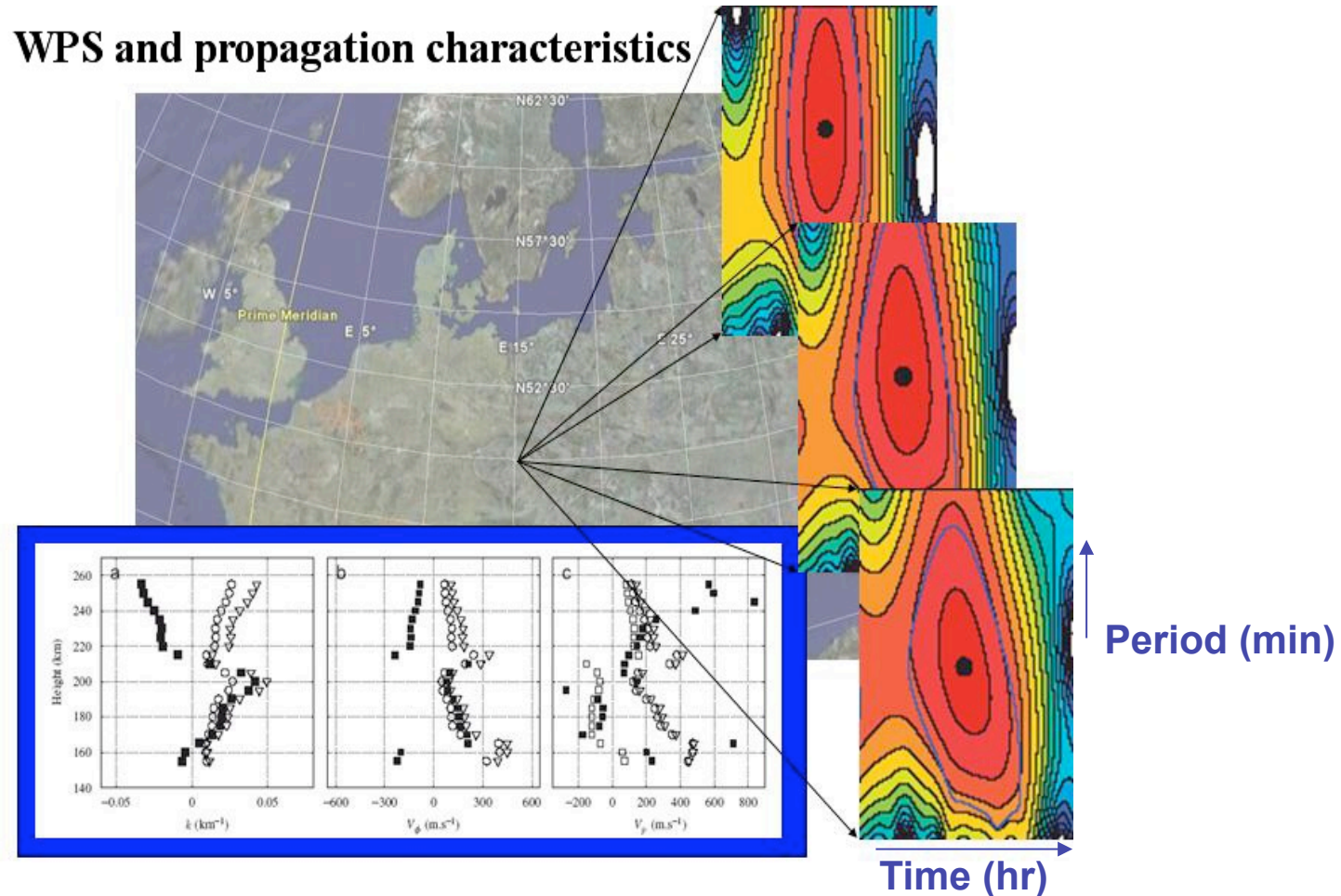




# Components of a data assimilation & forecast system (GEO6 Gravity wave detection)

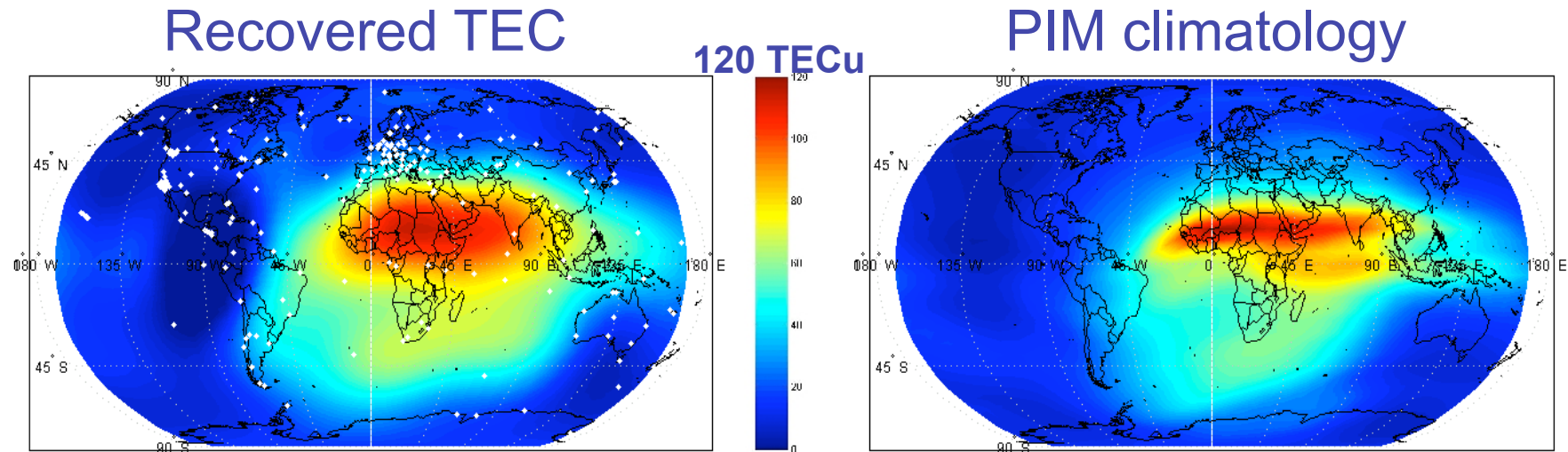


# Gravity Wave Detection



**Fig. 1. Example output of the 3-D computer code/toolbox calculations. Coloured figures – results of wavelet analysis for different heights of one event Black-and-white panels – vertical profile of wave number, phase speed, packet (group) speed of three different gravity waves.**

# Tomography – new approach H-representation



**n=8 ca 22° horizontal, 100km vertical**

Fig. 2. (Left) Recovered TEC with  $n=8$  (204 coefficients,  $a=20$ ), using ground data (IGS stations appear as white dots) and all LEO data (over 10,000 measurements). (Right) Ionosphere modelled with PIM.

# Polar orbital ring – penalizing high- $n$ spherical harmonics

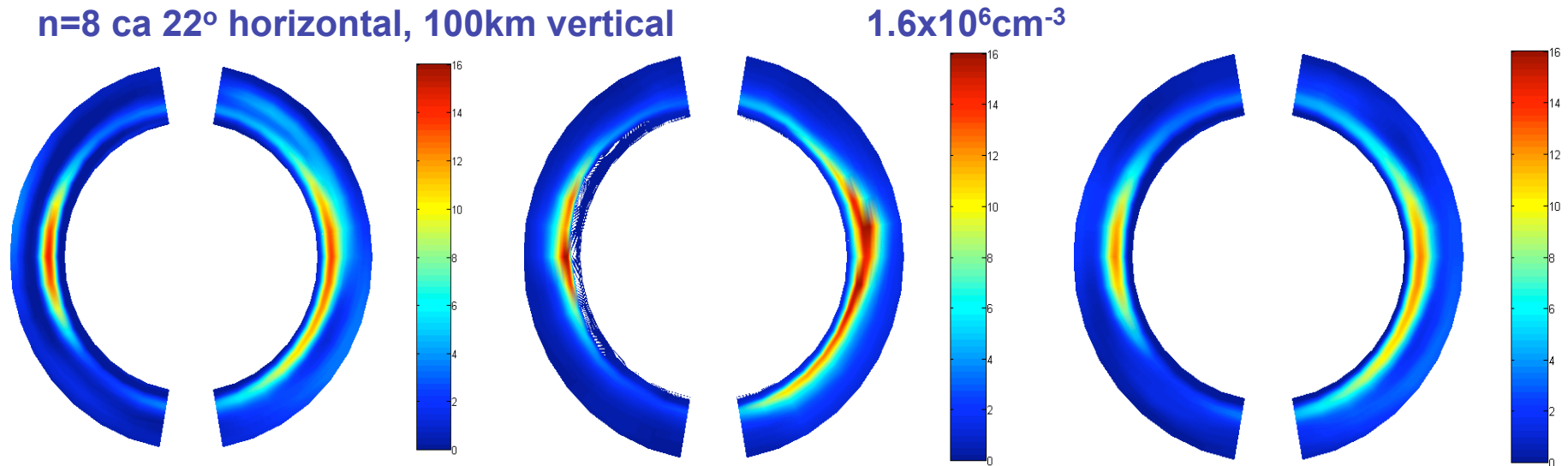


Fig. 3. Solution with an H-representation of order  $n=8$  (204 unknowns,  $a=10$  km) with GNSS-R data (left), reference truth (middle) and with a  $n$ -constraint (of  $\lambda[n^2]$  type) (right). No ground data has been used. Altitude spans from 0 to 1,000 km of altitude. Units are  $10^{11}$  electrons/ $\text{m}^3$ .

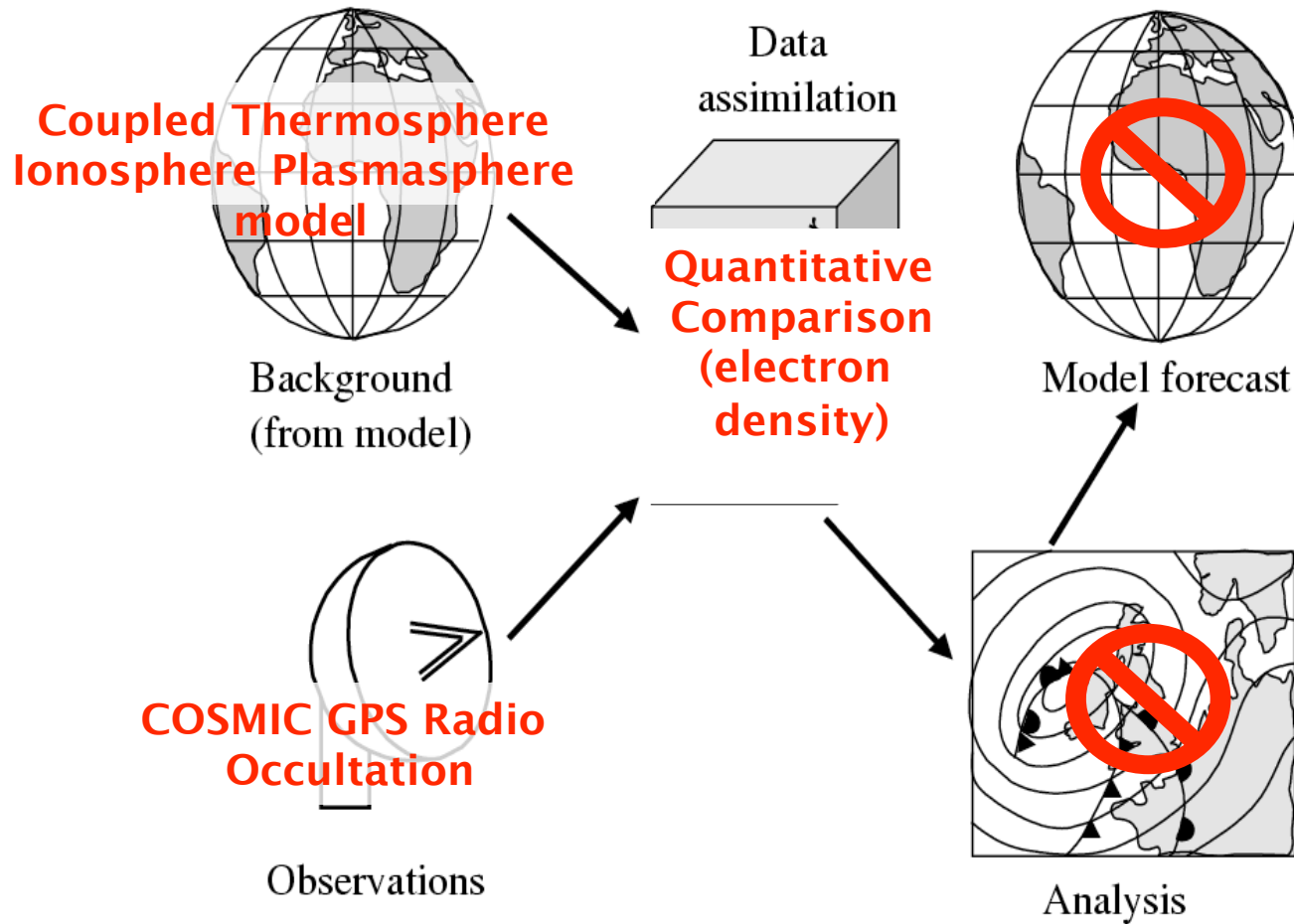


# GWD Conclusions

- Simulated Galileo electron density profiles & ionosonde data for pronounced GW events produced
- 2-D AGW toolbox publicised at <http://www.ufa.cas.cz/html/climaero/sauli.html>
- H-representation tomography would allow detection of medium-scale Travelling Ionospheric Disturbances
- Need higher spatio-temporal coverage to obtain smaller scale GWs or acoustic waves with periods O(minutes) using 3-D toolbox. Galileo data should make procedure viable.



# Components of a data assimilation & forecast system (Investigating GNSS Ionospheric DA)



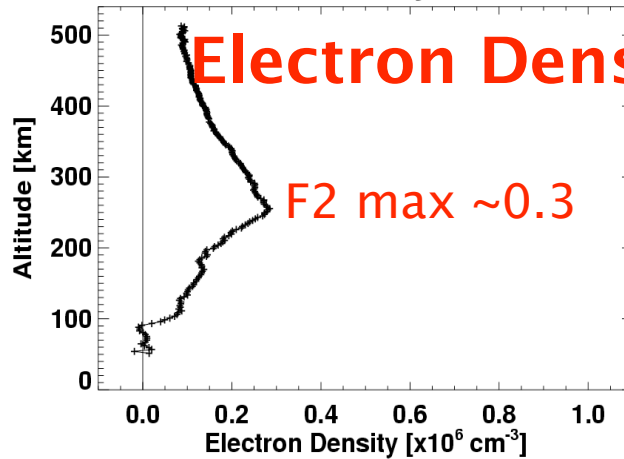




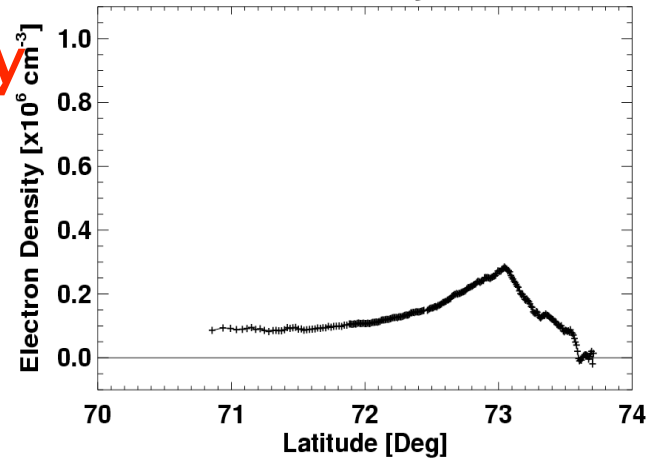
# GEO6 Observations: Results

Source: COSMIC Data Analysis & Archival Center (CDAAC)

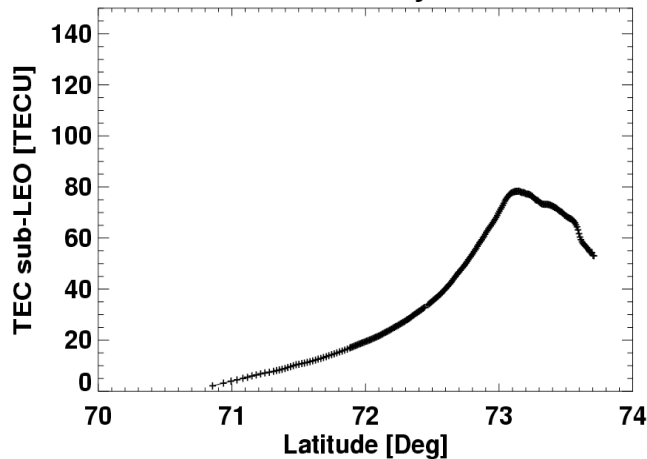
COSMIC : 0000Z Day 173 in 2007



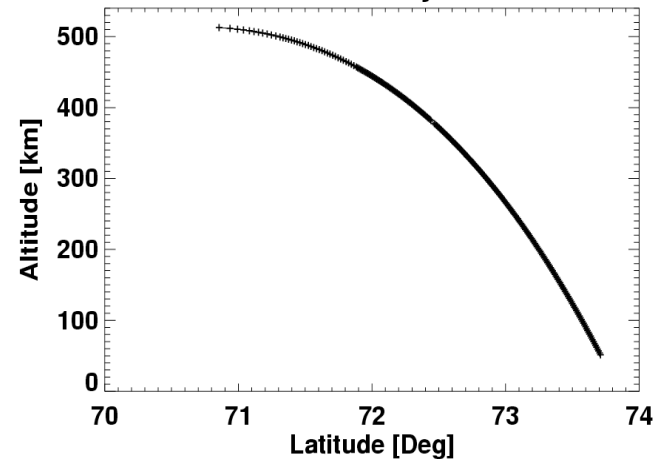
COSMIC : 0000Z Day 173 in 2007



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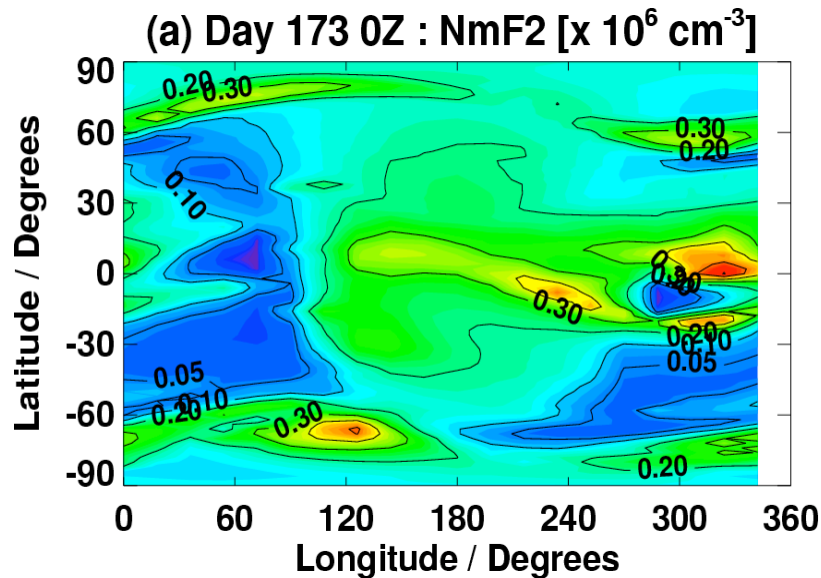
COSMIC : 0000Z Day 173 in 2007



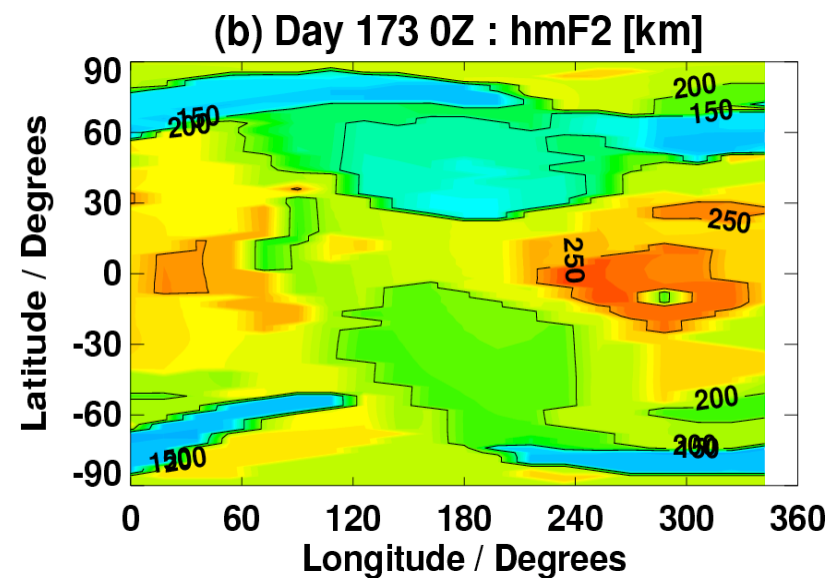


# GEO6 Models: Solar Min Experiment

Value of maximum electron density



Height of maximum electron density



## CTIP model

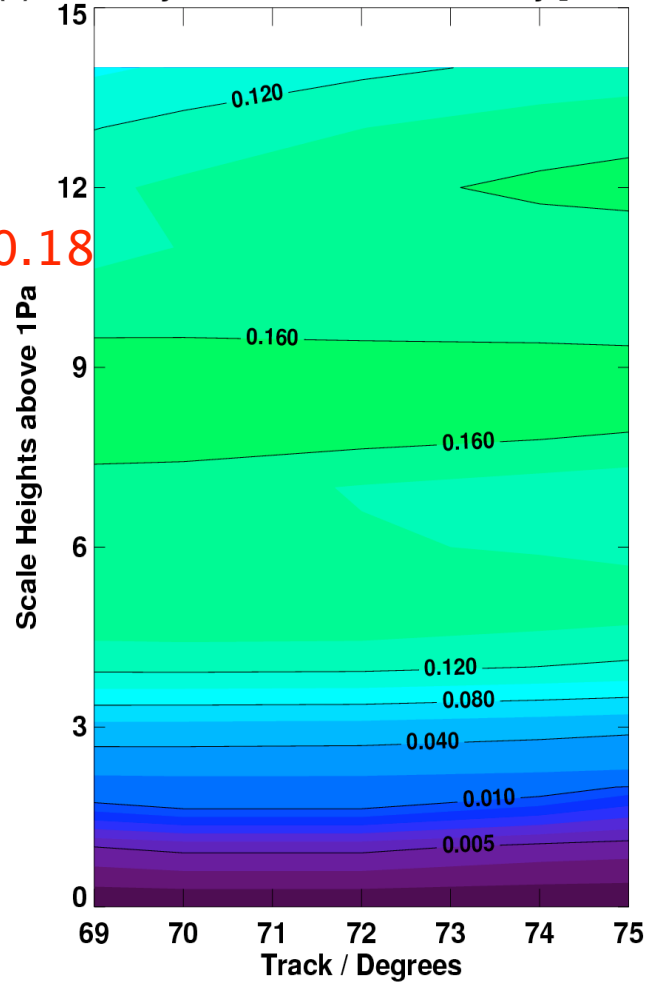
- Global Thermosphere (geographic)
- $18^\circ \times 2.5^\circ$
- Flux tubes (geomagnetic grid)
- 1min timestep
- June 2007 Solstice case



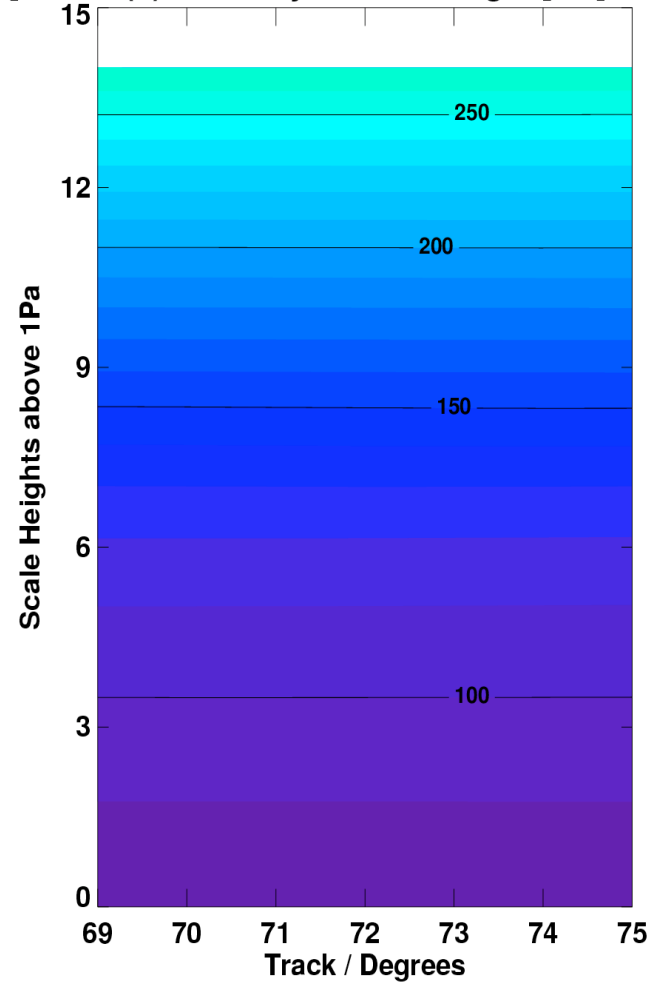
# GEO6 Models: Results

F2 max ~0.18

(a) CTIP Day 173 00Z Electron Density [ $\times 10^6 \text{ cm}^{-3}$ ]

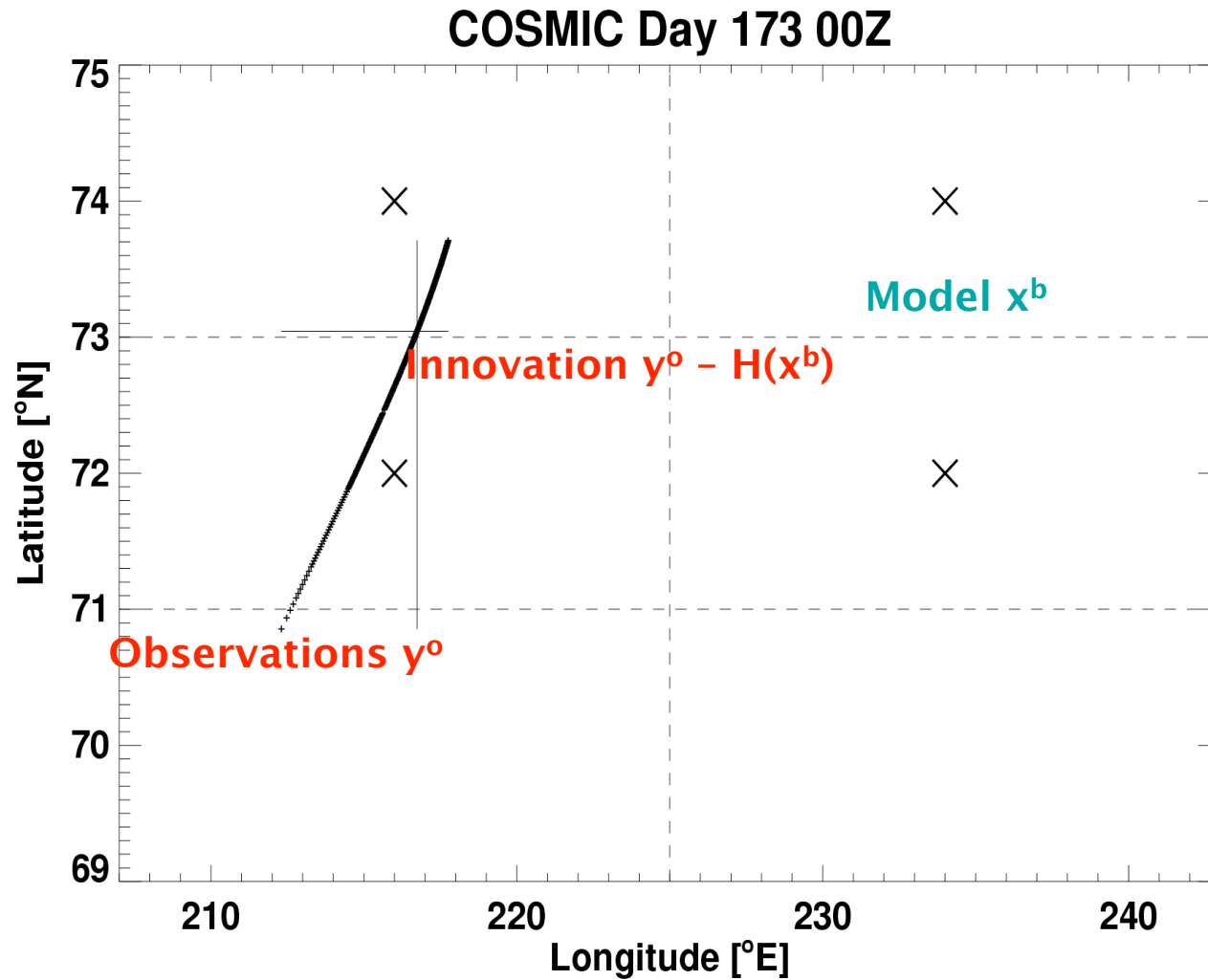


(b) CTIP Day 173 00Z Height [km]



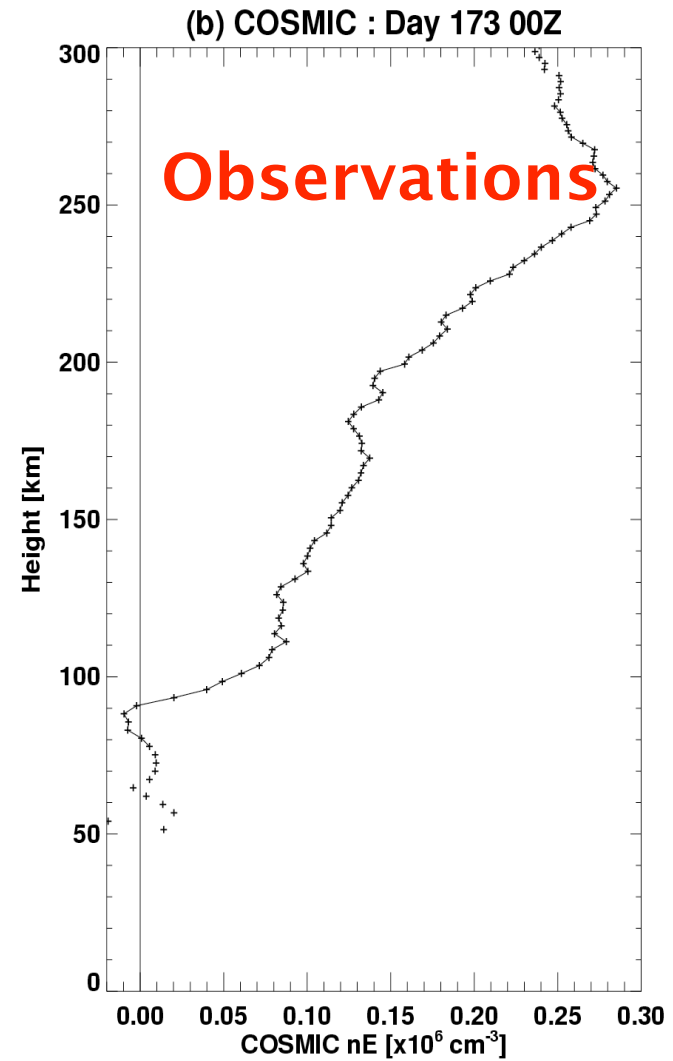
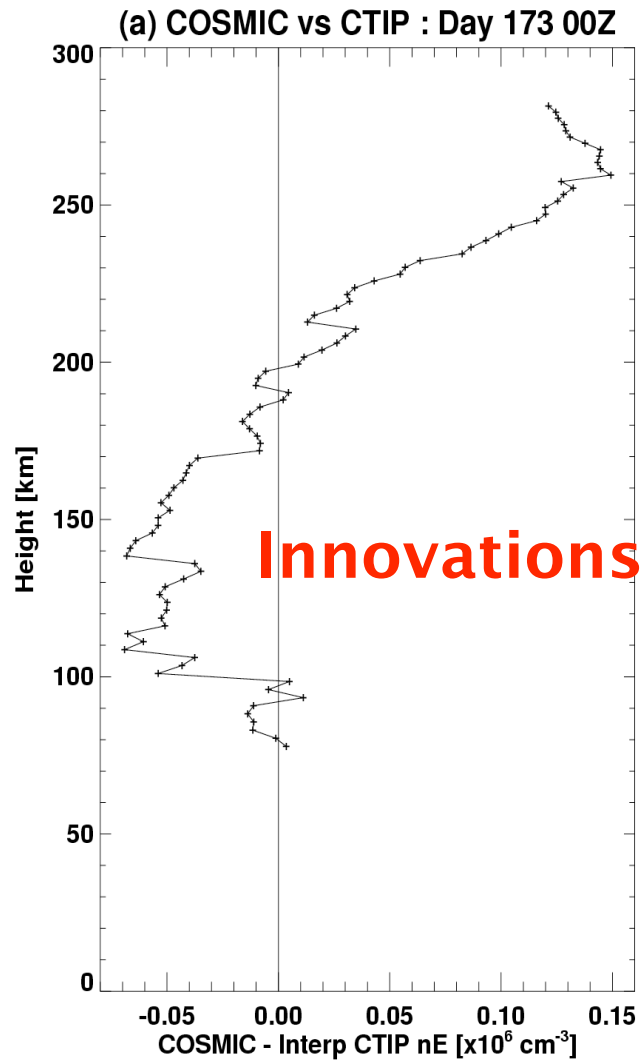


# GEO6 Comparison: Matching





# GEO6 Comparison: Results





# Categorized options for future activities

- Obtaining observations
- Upper atmosphere model experimentation
- External drivers and coupling
- Quantitative comparison
- Developing an observation operator
- Data assimilation



# GEO6 Recommendations

- “GSA consider the advantages of funding activity to catalyse development of operational ionospheric data assimilation systems ... and, if appropriate, take steps to enable FP7 support for such activity.”
- In the absence of a “system in place to exploit Galileo-derived RO data on the ionosphere” , recommend that GSA address this “by undertaking or sponsoring some exploration of the possible systems via which ionospheric RO data might be provided to the scientific UC.”



Met Office



# Questions and answers