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# TOWARDS BETTER DESCRIPTION OF SOLAR ACTIVITY VARIATION IN IRI TOPSIDE ION COMPOSITION MODEL


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# Outline

- Introduction
- IRI ion composition models (TTS-03 and DY-85) and the solar activity variation of the ion composition
- Ion composition data
  - consistency of C/NOFS, AE-C, AE-E, IK-24 measurements
- Improved empirical ion composition model (TBTion-13) and its validation with respect to the upper transition height ($H_t$).
- Conclusions

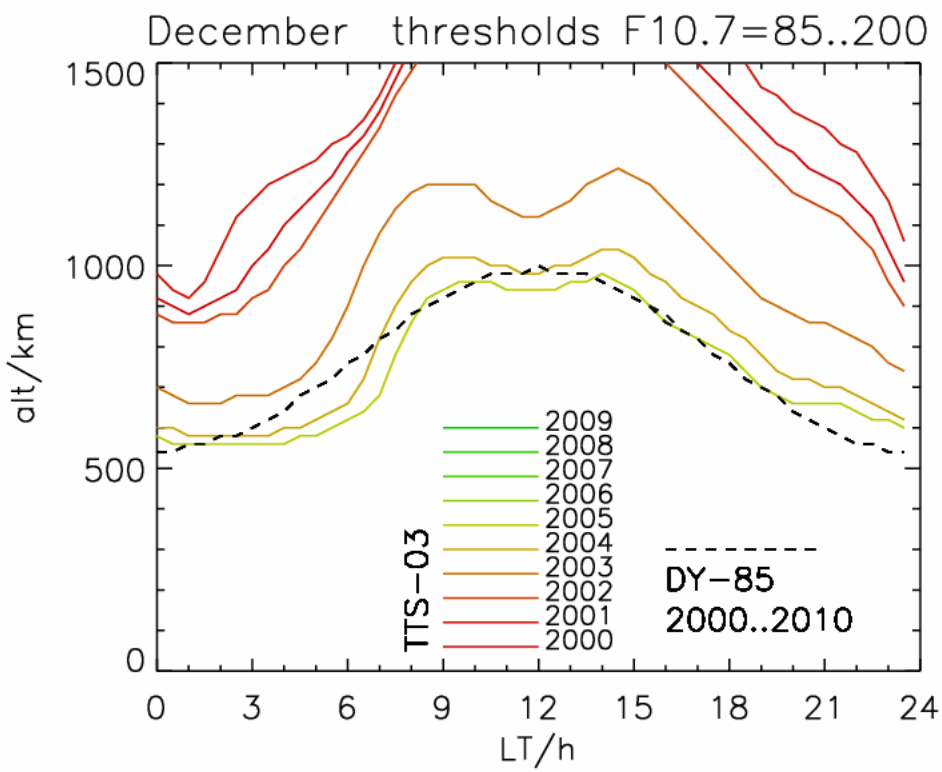
# Introduction

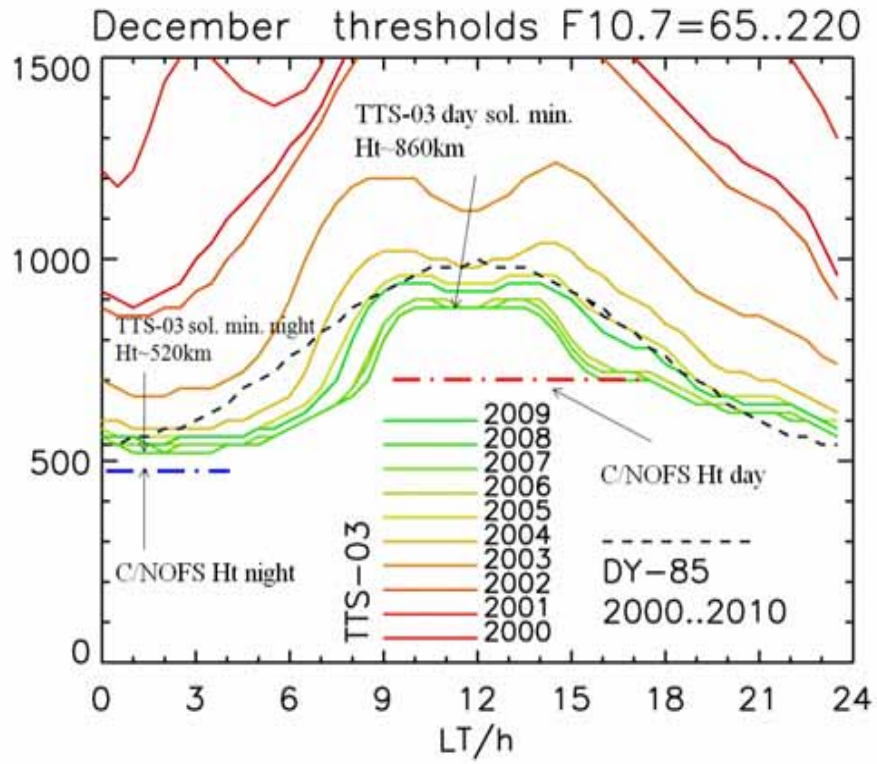
IRI ion composition models for the topside (relative density of $O^+$, $H^+$, $He^+$, $N^+$ in dependence on geophysical parameters) :
TTS-03 (Triskova et al., 2003)
DY-85 (Danilov and Yaichnikov, 1985)

2008-2009 unusually low solar minimum (min. F10.7 about 65)
C/NOFS ion composition measurements:
Heelis et al., 2009, and Klenzing et al.,2011 found very low upper transition height $H_T$ (from $O^+$ to $H^+$) (for 2008 at Equator: ~480km - night, 700km – day) that it is lower than IRI predicts.

In this presentation we investigate this issue and try to find possible IRI correction or solution. We deal with possible improvement of the TTS-03 model. DY-85 values will be shown only for comparison.

IRI 2007 IRI 2012




Equatorial upper transition height from the IRI2007/TTS-03 and IRI2012/TTS-03 (removed upper and lower threshold F10.7=85 and 200) model (solid color lines) and from the DY-85 model for years from 2000 (solar maximum) to 2009 (solar minimum). $H_T$ from DY-85 exhibits no dependence on solar activity and at daytime is about 1000km. $H_T$ from TTS-03 shows a dramatic change; the lowest daytime values at solar minimum are about ~860km for IRI2012/TTS-03 which is still above values from the C/NOFS measurements. This means that IRI ion composition models overestimate the fraction of $O^+$ or/and underestimate the fraction of $H^+$ in the topside ionosphere during very low solar activity (F10.7 about 65).

# Possible problems and solutions

- Problem in solar activity description of the ion composition in the TTS-03 model
- Inconsistency of the C/NOFS data and data used for the TTS-03 model (AE C&E) for the same solar activity conditions?
- We tried to revise TTS-03 model and to check consistency of AE C&E and C/NOFS data

# TTS-03 model

Empirical model of $O^+$, $H^+$, $He^+$, $N^+$ relative densities

(Triskova et al., 2003)

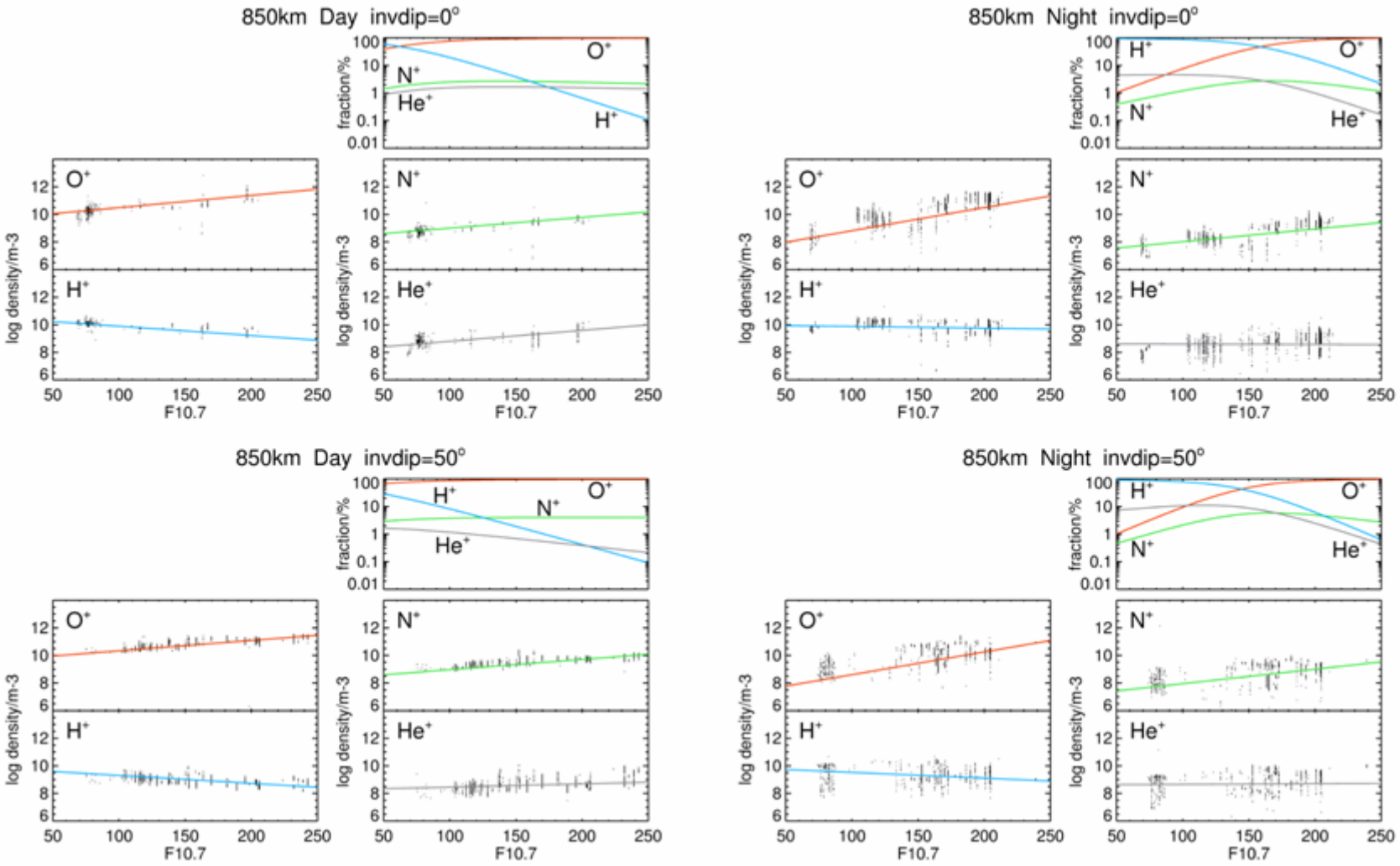
Data used (relative density)

| solar activity | average F10.7 | satellite | altitude km | inclination deg | time period | ion mass spectrometer |
|---|---|---|---|---|---|---|
| maximum | 200 | IK-24 | 500 - 2500 | 83 | Nov 1989 - May 1991 | Bennett |
| minimum | 85 | AE-C | 350 - 1150 | 68 | Dec 1973 - Nov 1974 | Bennett + magnetic |
| minimum | 75 | AE-E | 350 - 1150 | 20 | Dec 1975 - Oct 1976 | Bennett + magnetic |

The full model consists of sub-models for individual altitude ranges and seasons:

IK24: 550 ± 80 km, 900 ± 100 km, 1500 ± 150 km, and 2250 ± 250 km
AE: 400 ± 50 km, 650 ± 80 km, and 1000 ± 150 km
Linear interpolation of relative ion densities in solar activity (F10.7 index)
TTS-03 was validated using OGO-6 and ISS-B ion mass spectrometer data (Truhlik et al., 2003)

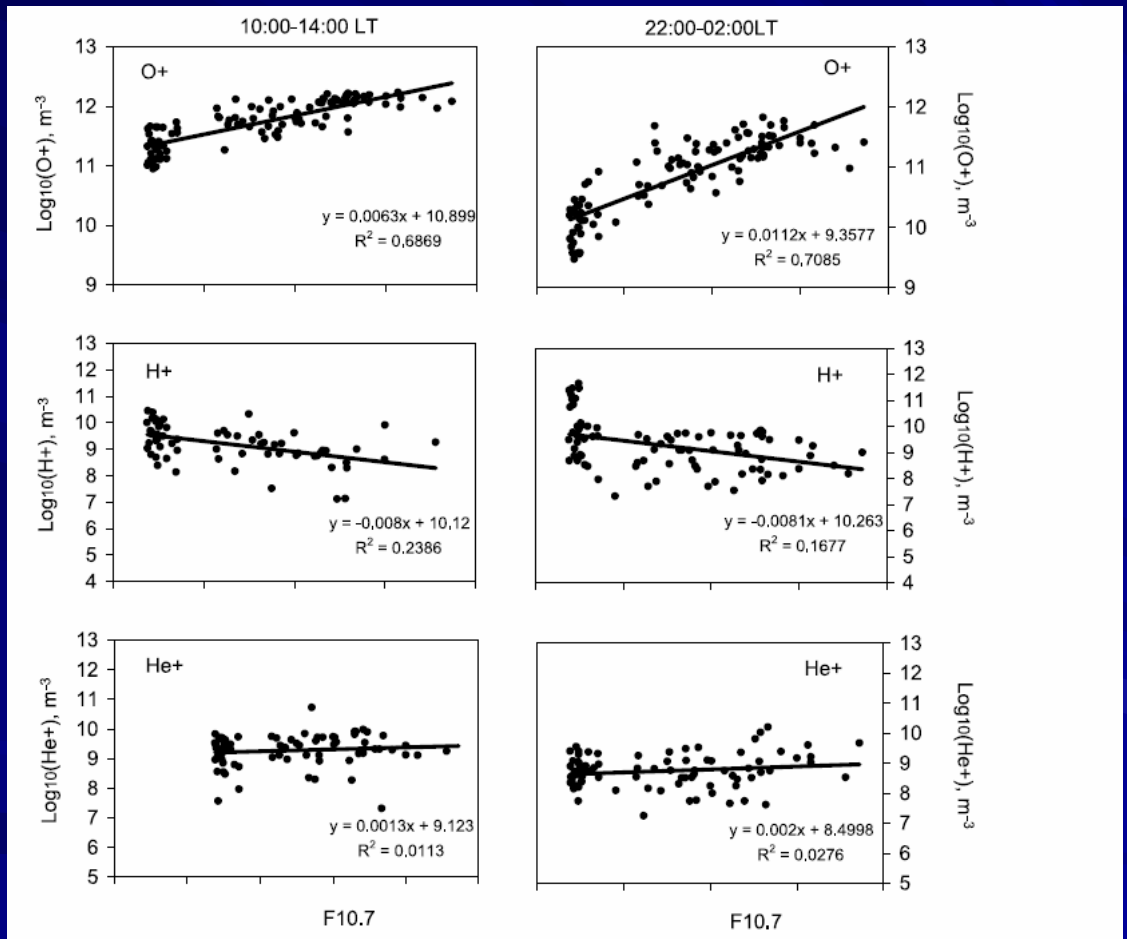
# Solar activity dependence I




Absolute densities of individual ions on log scale are close to linear dependence on solar activity (F10.7 index). Dependence of the logarithm of the individual ion densities from Atmosphere Explorer C&E and Intercosmos 24, and of the relative ion densities on the solar activity level characterized by the actual day values of the F10.7 index. Example for equinox, equator±15deg, mid-latitudes 50±15deg, altitude of 850±90 km, daytime and nighttime. Points-measured values, lines-values fitting. (Truhlik et al., Ann. Geophys, 2005)

# Solar activity dependence II

Borgohain and Bhuyan JGR, 2010

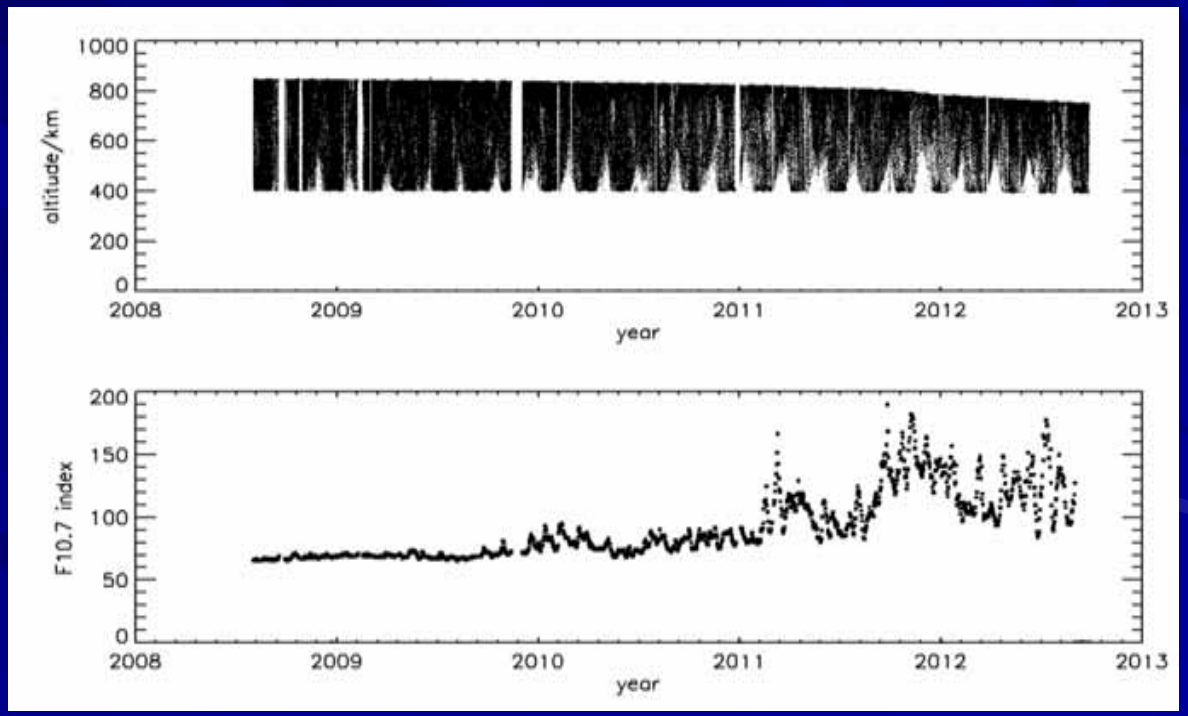



Variation of monthly average daytime (1000–1400 LT) and nighttime (2200–0200 LT) ion density observed by the SROSS C2 and FORMOSAT-1 satellites with $F_{10.7}$ cm solar flux within ±2.5° of dip latitude.

# C/NOFS ion composition data

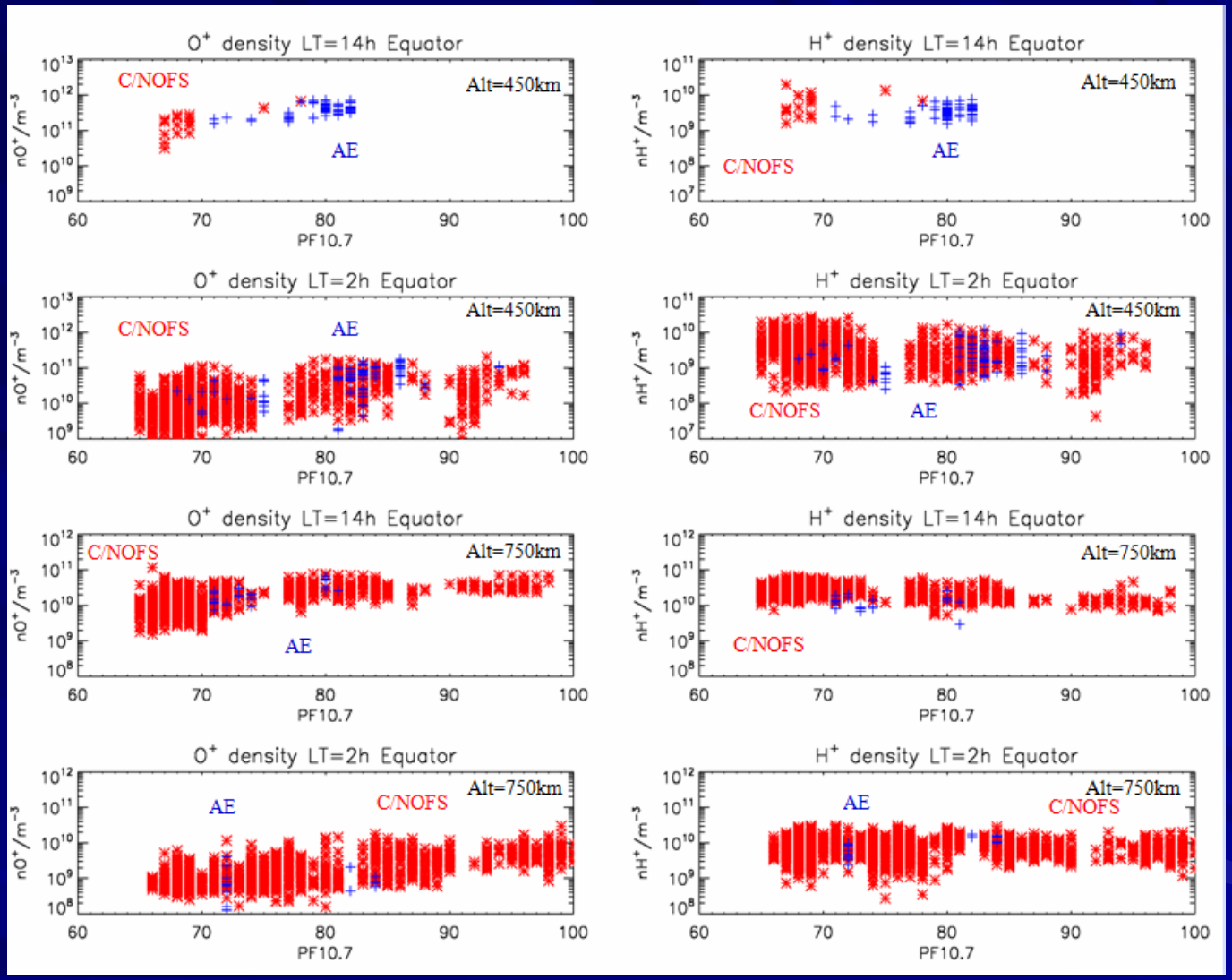
C/NOFS satellite:
Launch date April 16, 2008
Perigee 405km, apogee 853km
inclination 13 deg

Experiment:
CINDI IVM/RPA
Ion density, ion composition ($O^+$, $H^+$, $He^+$), drift
http://cindispace.utdallas.edu/
August 2008-
Data from diplat=0 deg ±5 deg used



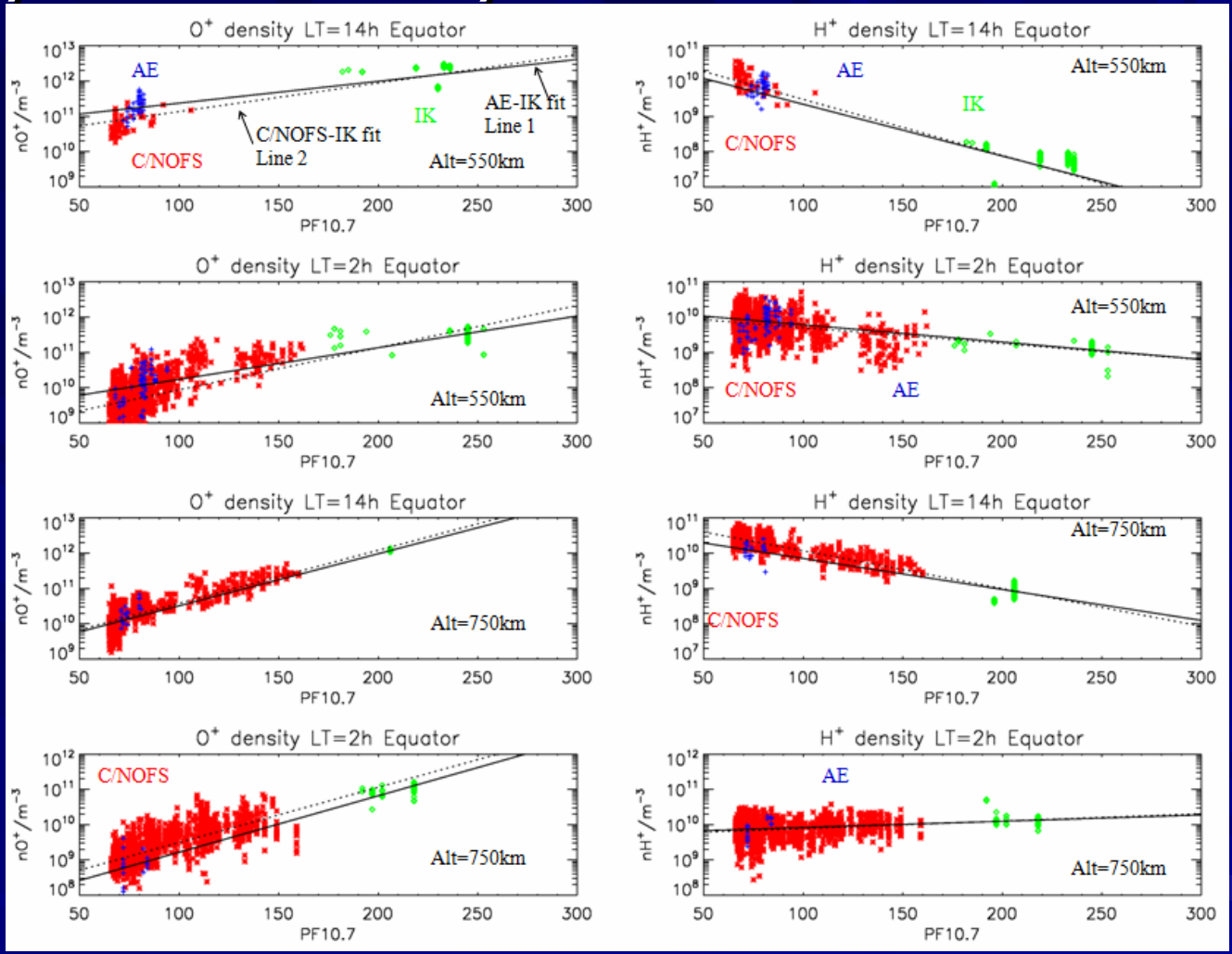

Year-altitude data coverage and corresponding solar activity

# AE vs. C/NOFS Data consistency



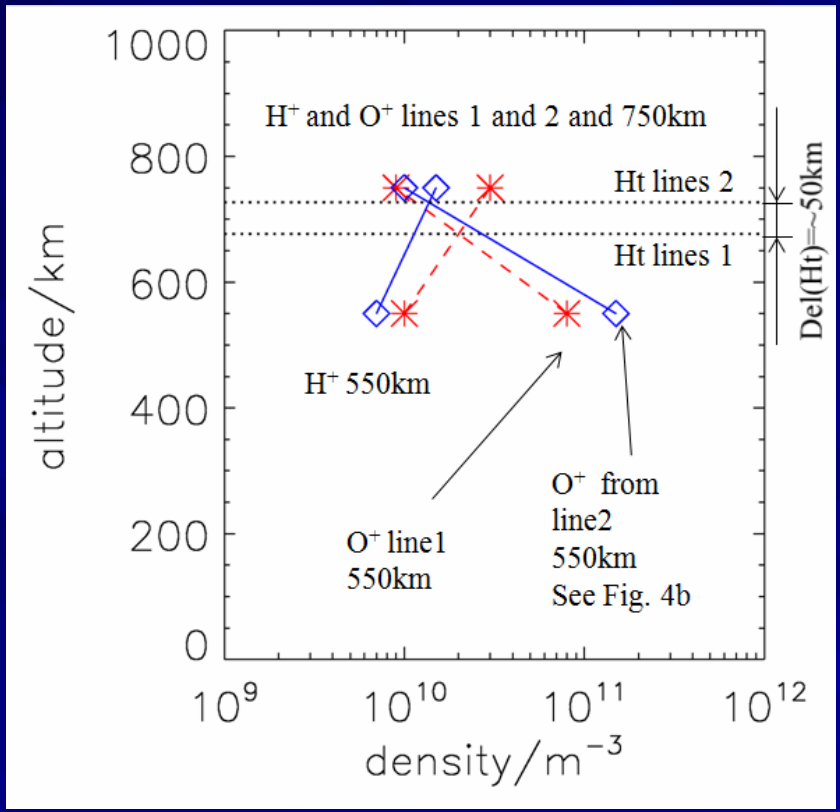

Data ($O^+$and $H^+$density) from C/NOFS (red) and AE (blue) vs. solar activity (for day, night and two altitude ranges) from a “low solar activity” (PF10.7=65-100) interval. The values do not show any substantial inconsistency and for the same PF10.7 both measurements are generally within the same scattered region.

# AE, C/NOFS, IK vs. solar activity




The same as previous plot but added data from high solar activity (IK-Intercosmos 24) and the lower altitude was increased to 550km due to the IK orbit. More compressed scale on x axis reveals some minor inconsistency between C/NOFS and AE (e.g. day, 550km). Solid line (line 1) shows a linear fit of AE and IK data. Dashed line (line 2) shows the fit of C/NOFS and IK data. Generally small differences between both lines found.

# Error in determination of the Upper transition height – estimation from data




An estimation of a possible error of the upper transition height from both linear fits from previous figure for the lowest solar activity (PF10.7=65) and daytime.

# Improved TTS-03 model (TBTion-13)

Empirical model of $O^+$, $H^+$, $He^+$, $N^+$ densities

Data used - absolute density (mass spectrometer measurement calibrated to simultaneous Ne from RPA or Langmuir probe)

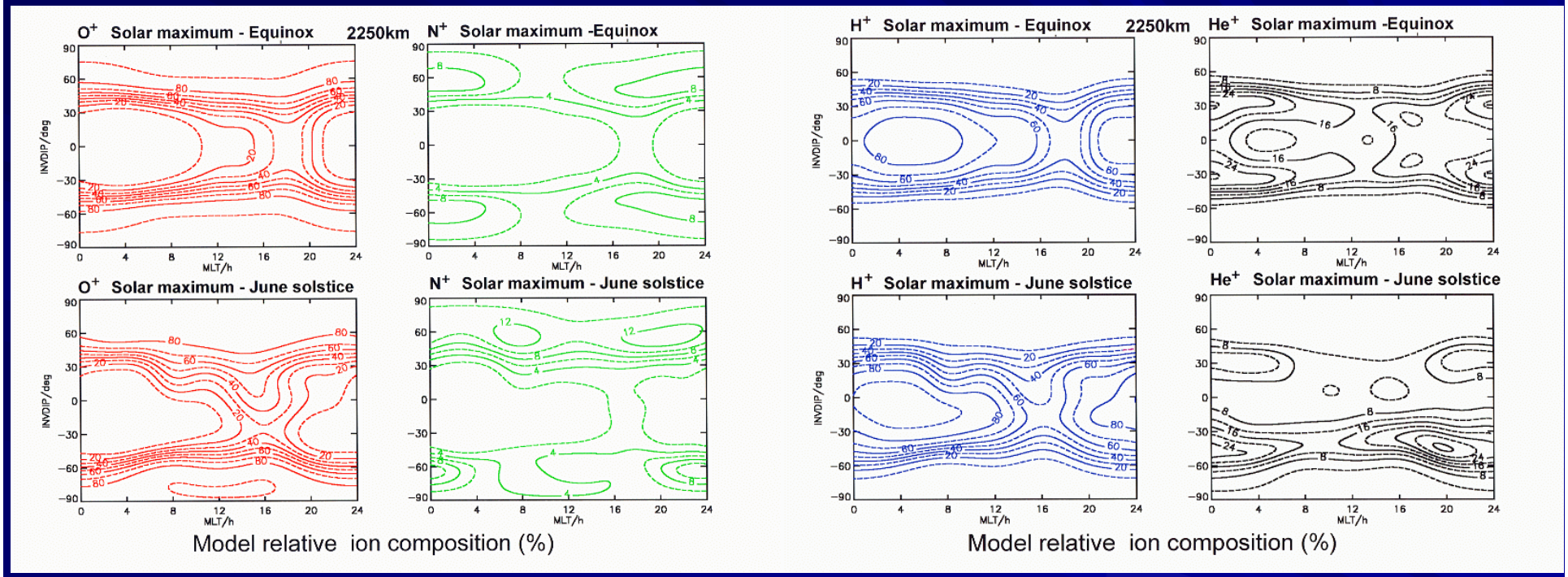
We have revised AE and IK databases (created in 2001) – more data found ☺

| solar activity | average F10.7 | satellite | altitude km | inclination deg | time period | ion mass spectrometer |
|---|---|---|---|---|---|---|
| maximum | 200 | IK-24 | 500 - 2500 | 83 | Nov 1989 - May 1991 | Bennett |
| minimum | 85 | AE-C | 350 - 1150 | 68 | Dec 1973 - Nov 1974 | Bennett + magnetic |
| minimum | 75 | AE-E | 350 - 1150 | 20 | Dec 1975 - Oct 1976 | Bennett + magnetic |

The full model consists of sub-models for individual altitude ranges and seasons

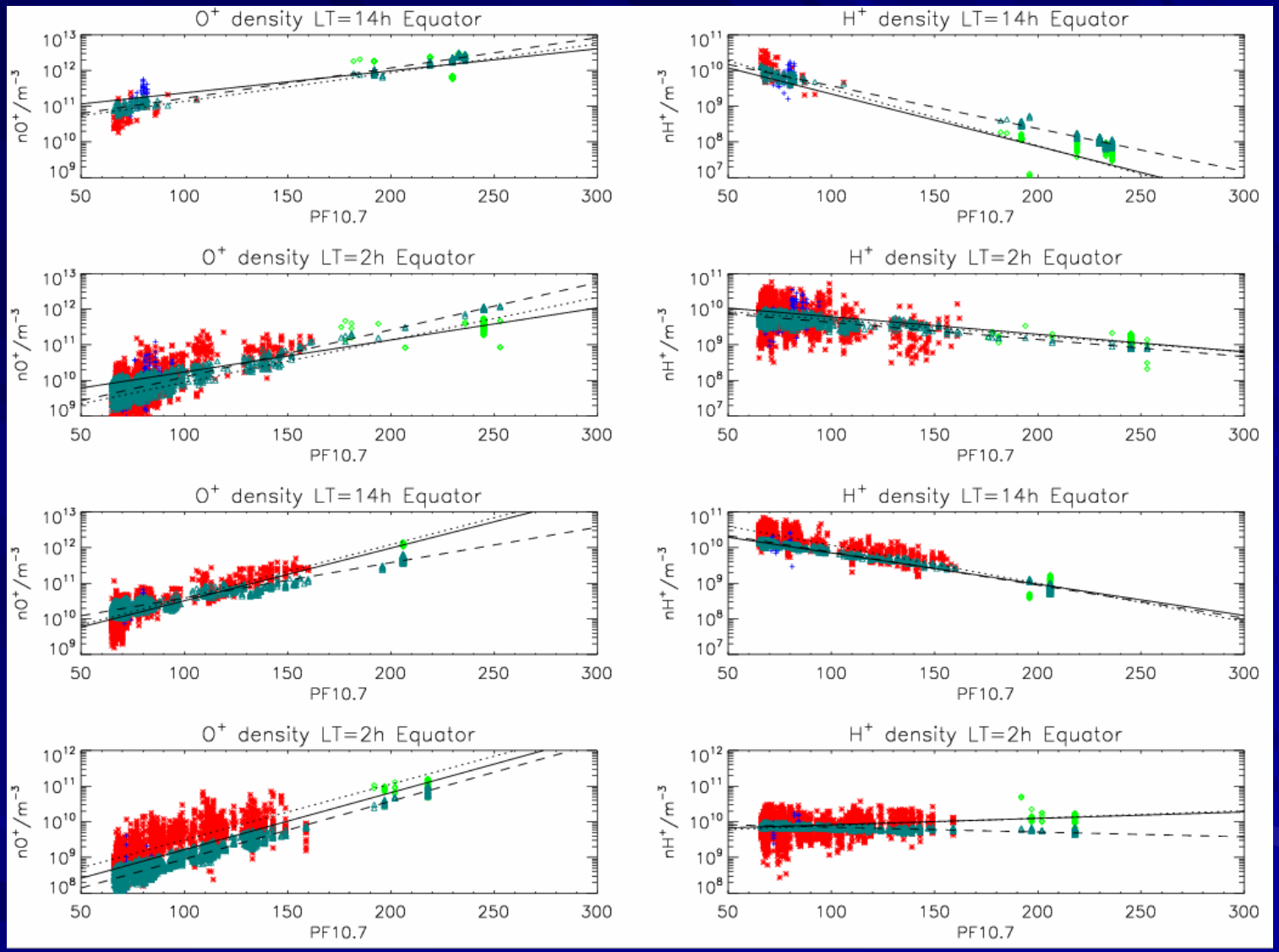
IK24: 550 km, 900 km, 1500 km, and 2250 km
AE: 400 km, 550km, 750 km, and 1000 km
Linear interpolation in log of absolute ion densities
Normalization to obtain relative density (for IRI):
Ni~n(O+)+n(H+)+n(He+)+n(N+)

# Local time vs. latitude

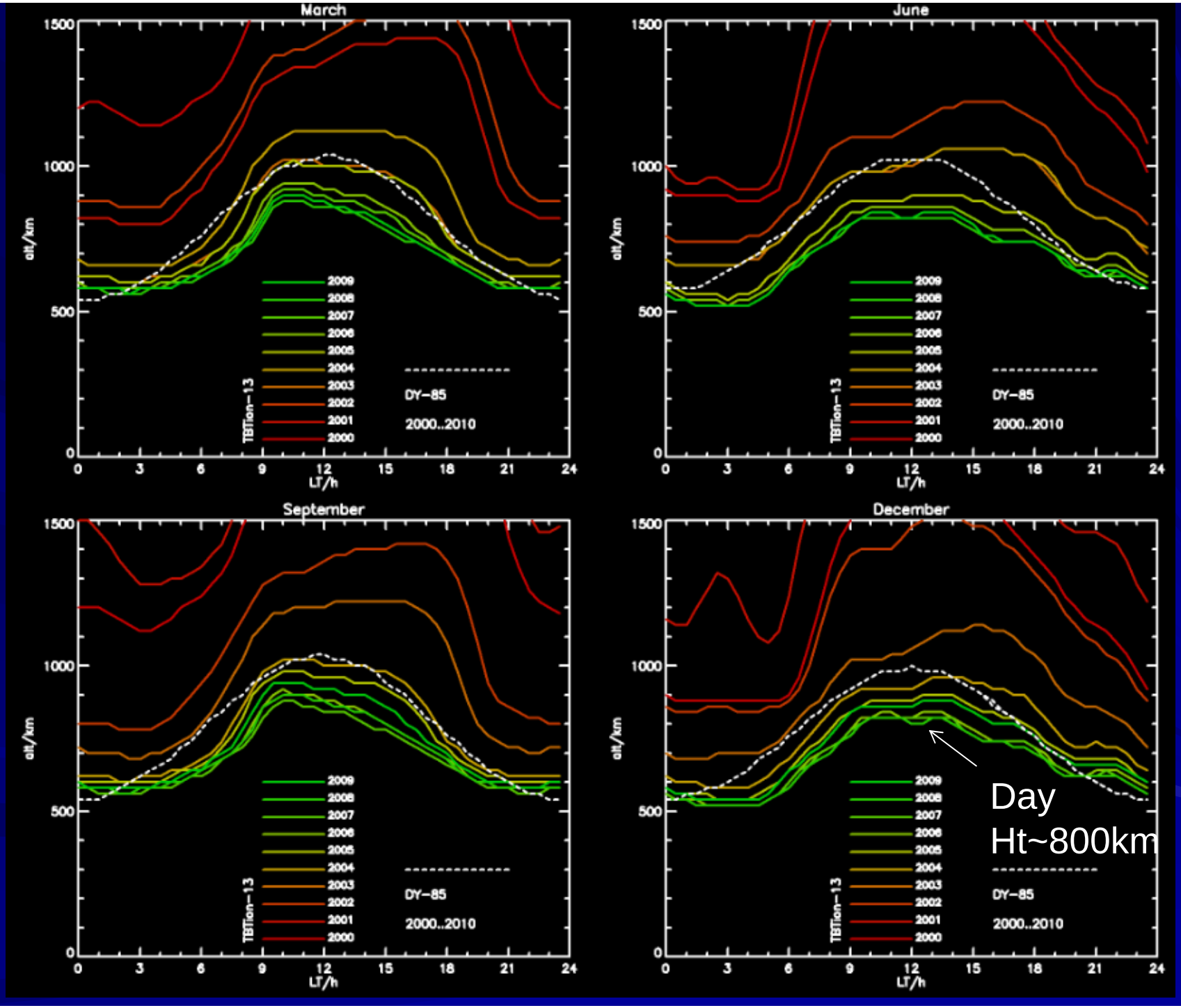



Example of contour plots of the TBTion-13 model

# AE, CNOF/S, IK and TBTion-13 vs. F10.7

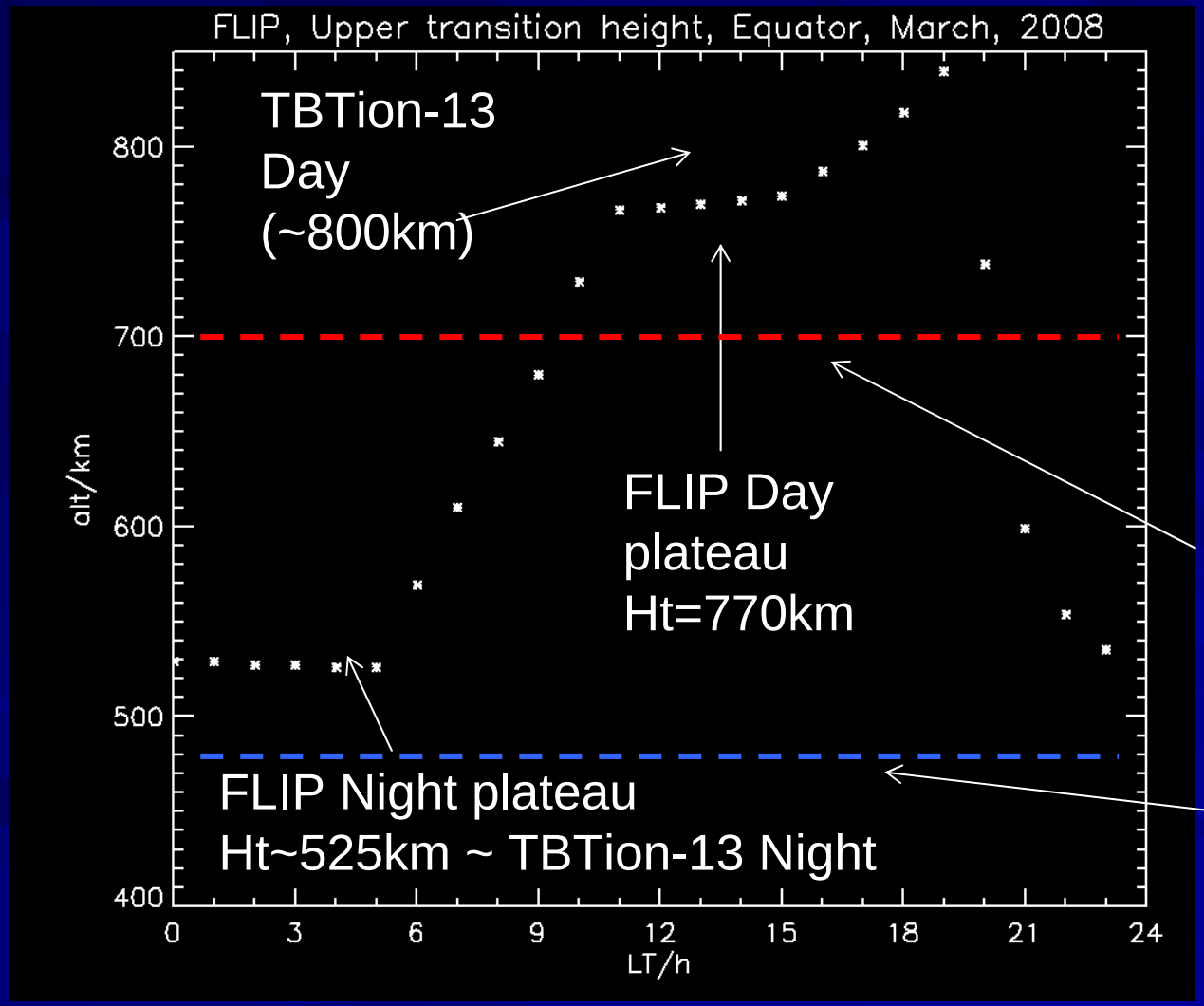



Solid line shows a linear fit of AE and IK data. Dashed line shows the fit of C/NOFS and IK data. Turquoise points show model values calculated for the same conditions as measured values (long dashed line). Generally a satisfactory agreement among the lines found.


March
June
September
December
alt/km
LT/h
TBTion-13
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
DY-85
2000..2010
Day
Ht~800km

# Equatorial $H_t$ from the FLIP model

preliminary simulation made for March equinox




Field Line Interhemispheric Plasma (FLIP) model
(e.g. Richards, 2001; Richards, 2002)
Includes:
-Continuity and momentum equations along the field line for $O^+$, $H^+$, $He^+$, and $N^+$.
-Energy balance equations for electrons and ions. Geometry of tilted offset dipole
-Two stream photoelectron model
-Photochemical equilibrium below 500km for ions $NO^+$, $O_2^+$, $N_2^+$, $O^+(^2P)$, and $O^+(^2D)$
- Continuity and momentum equations for minor neutral species NO, $O(^1D)$, $N(^2D)$, and $N(^4S)$ from 100 to 500km in each hemisphere
Inputs:
-EUV from EUVAC model
-Neutral densities and temperature from MSIS-86 model
--ExB drift from Scherliess-Fejer model

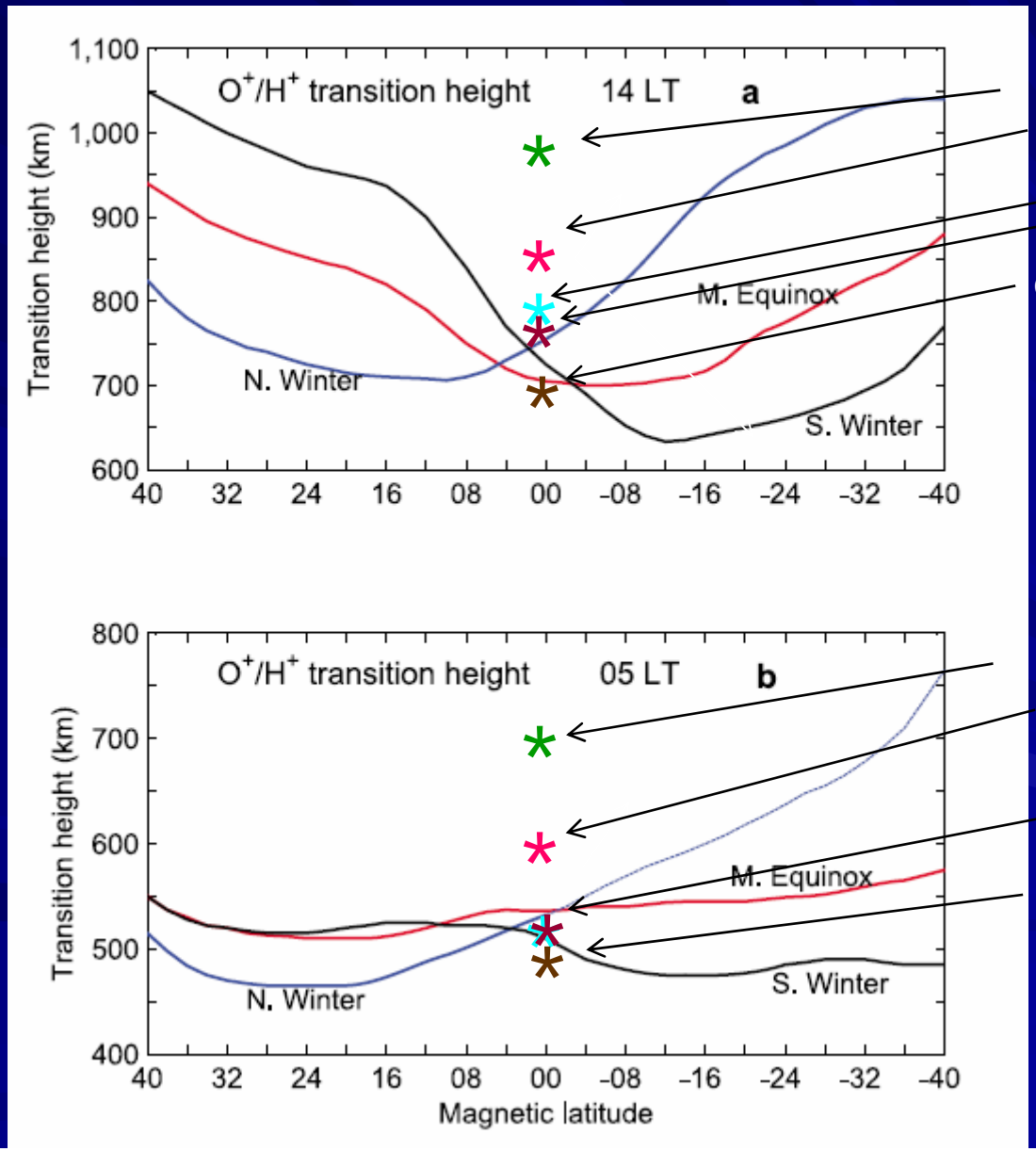
C/NOFS Day
Klenzing et al.
2011

C/NOFS Night
Klenzing et al.
2011

# Comparison with SUPIM (equator)

Balan et al.
JGR, 2012

ExB drift
2009:
Stoneback et al.,
JGR, 2011




DY-85 and IRI2007/TTS-03

IRI2012/TTS-03

TBTion-13

FLIP (equinox)

CNOFS Klenzing et al., 2011

DY-85

IRI2007/TTS-03

IRI2012/TTS-03

TBTion-13

FLIP (equinox)

CNOFS Klenzing et al., 2011

# Conclusions

- Reported large differences between IRI and C/NOFS equatorial upper transition height (1000km vs 700km) (Klenzing et al., 2011) showed a problem of the IRI ion composition model (both TTS-03 and DY-85) which were not constructed for such a low solar activity like 2008-2009 solar minimum.
- We have proposed improvement of the TTS-03 model called TBTion-13 model based on absolute ion densities and which employs linear interpolation in log of absolute densities of individual ions.
- Difference of the Ht from the TBTion-13 model and of the Ht from the C/NOFS is less than 100km. Difference of the Ht from the model and the estimation from the measured data is about 50km, which is probably due to the limited resolution of the global model.
- Equatorial Ht from TBTion-13 is in better agreement with the results of theoretical models (FLIP and SUPIM) than the TTS-03 and DY-85 models.