Establishing Metrics for Model Evaluation of Neutral Density

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Including Tables and Figures from paper in preparation for special issue of AGU Space Weather Journal on the Cape Canaveral validation workshop outcome being prepared by Bruinsma et al.

Thermosphere upper atmosphere models

	Type	drivers	Hor.resolution, step
NRLMSISE-00	SE	F10.7 ; ap	30°, 3 hr
JB2008	SE	S10, F10.7, M10, Y10 ; Dst, ap	30°, 1 hr
DTM2013	SE	F30 ; Kp	30°, 3 hr
TIEGCM	FP		
CTIPe	FP		
GITM	FP		
??			

Datasets selected for model assessment

	Period	Altitude (km)	Sampling	Precision (%)
CHAMP	05/2001 – 08/2010		10 s	2-?%
GRACE	01/2003 – 7/2016		5 s	2-?%
GOCE	11/2009 – 10/2013	270-180	10 s	1-3%
Swarm	06/2014 – 05/2017	450	10 s	5%*
Global (Emmert)				?
Stella	01/2000 – 12/2016	815	24h	5-15%
Starlette	01/2000 – 12/2016	800	24h	5-20%

Selected annual periods
low (2007), medium (2012), high (2001) solar activity

The 81-day mean solar radio flux F10.7
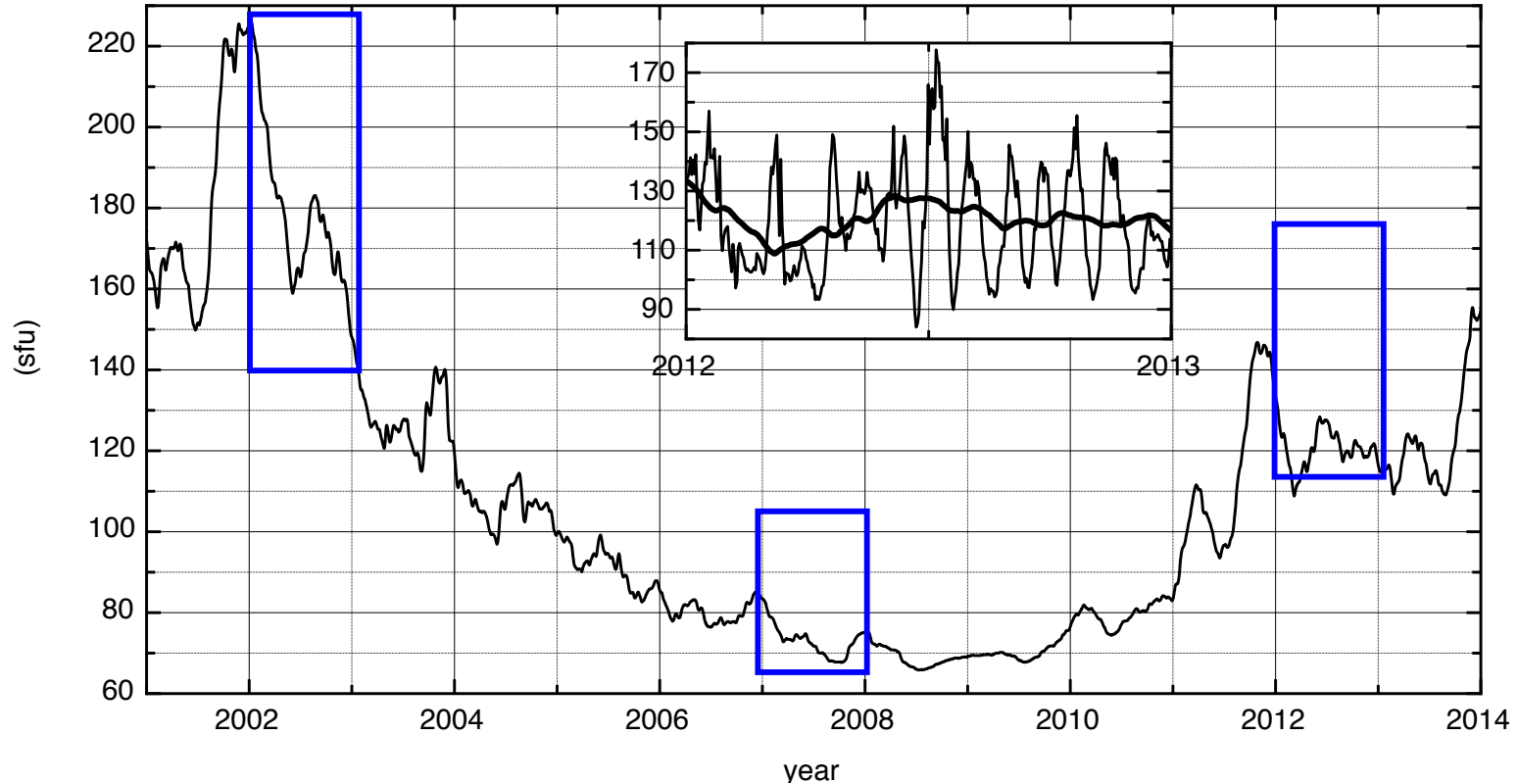
Selected storm periods

Date	Min Dst (nT)	Max ap/Kp
29/03 – 03/04/2001	-387	
18/07 – 31/07/2004	-170	
17/01 – 20/01/2005		
20/01 – 23/01/2005		
07/05 – 10/05/2005		
14/05 – 17/05/2005		
29/05 – 01/06/2005		
08/07 – 14/07/2005		
23/08 – 26/08/2005		
08/09 – 19/09/2005		
08/03 – 11/03/2012	-131	
16/03 – 20/03/2013	-132	
31/05 – 04/06/2013	-119	
21/06 – 24/06/2015	-204	

Metrics (linear space)

- **IDL post-processing** (standard IDL functions)

- **R**: correlation coefficient is a measure of the degree of linear relationship betw

$$R = \text{CORRELATE } (Model, Obs)$$

- **RMSE**: root mean square error is a quadratic scoring rule which measures the the error (i.e., the difference between values predicted by a model and the valu

$$RMSE = \sqrt{\left(\sum \uparrow \blacksquare ((Obs - Model)/Obs\,\right)}$$

- **BIAS**: determines whether results are consistently too high or too low relative value of the measured or estimated variable.

Fedrizzi et al., 2012

2012 GOCE/CTIPe Comparisons: Along Orbit vs. Orbit Averaged
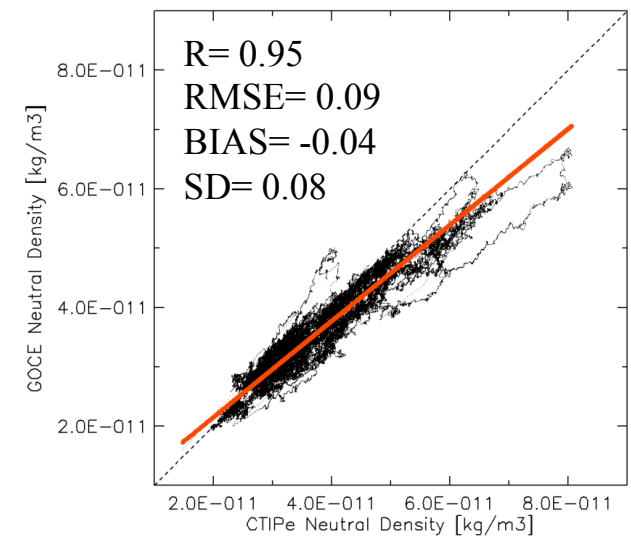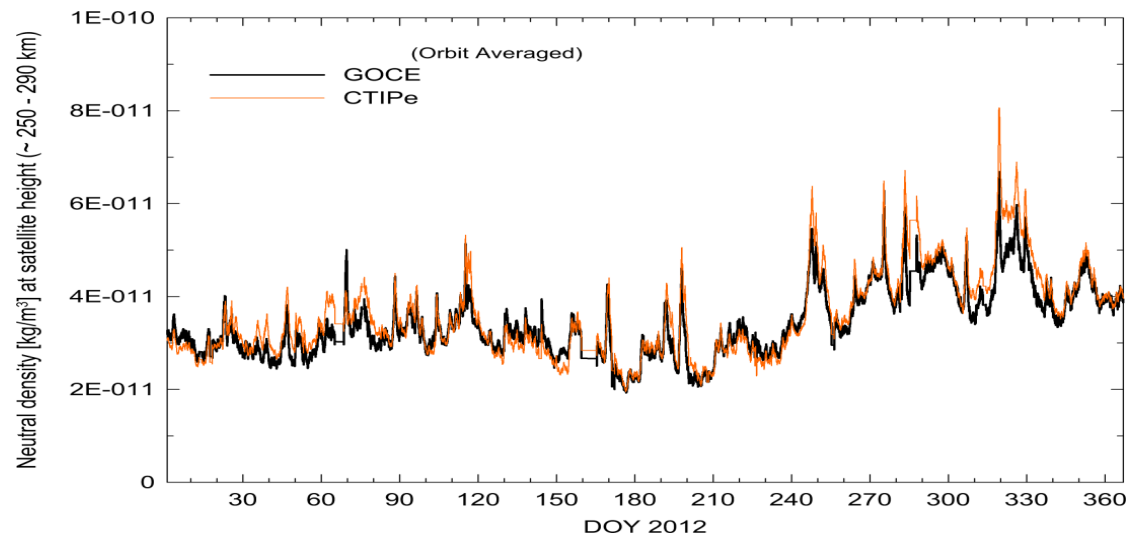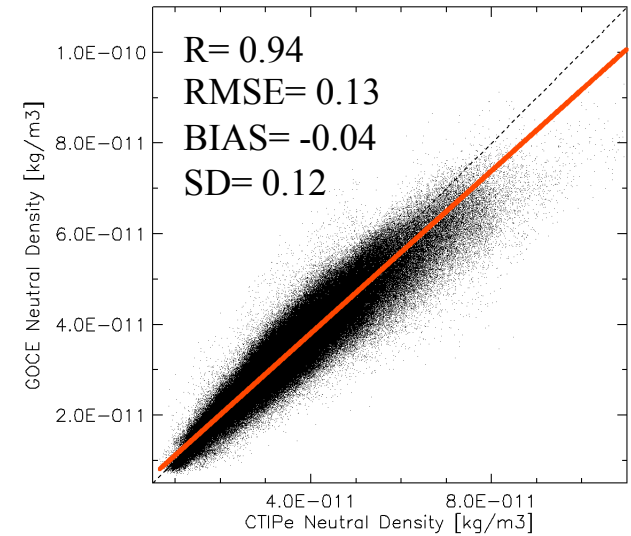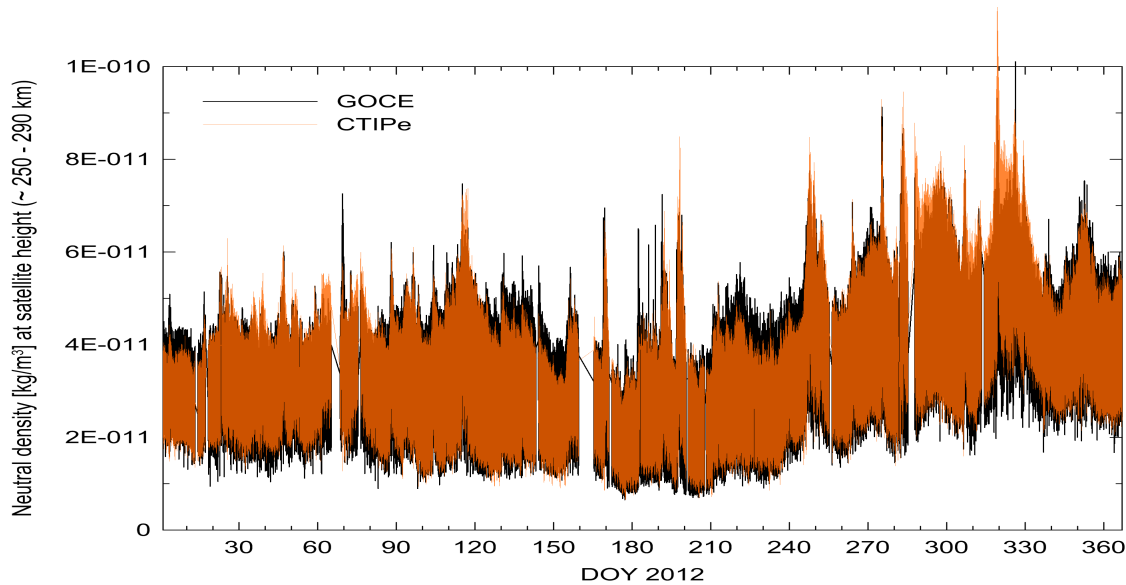
GOCE data provided by Eelco Doornbos and Sean Bruinsma

Bias: – mean of model-to-observation

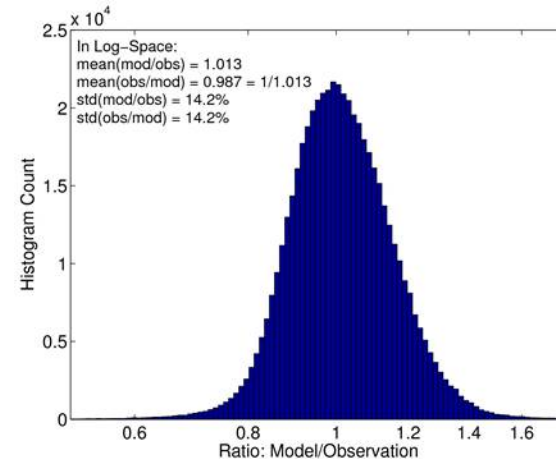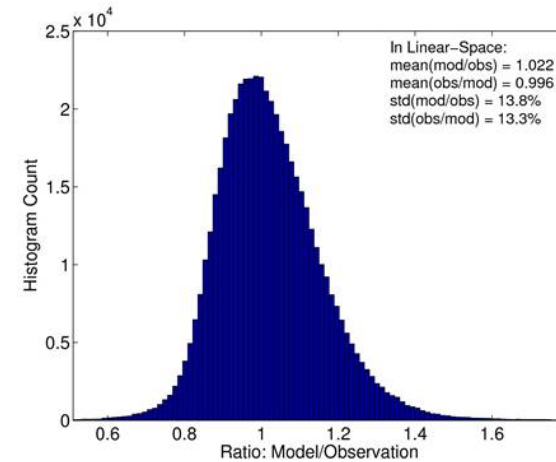$$\mu(m/o) = \exp\left(\frac{1}{N}\sum_{n=1}^{N}\ln\frac{\rho_{m,i}}{\rho_{o,i}}\right)$$

Root Mean Square Error:

$$\text{RMSe} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\ln\frac{\rho_{m,i}}{\rho_{o,i}}\right)^2}$$

Standard deviation of model-to-observation :

$$\sigma(m/o) = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\ln\frac{\rho_{m,i}}{\rho_{o,i}} - \ln\mu(m/o)\right)^2}$$

$$\text{RMSe}^2 = \ln(\mu(m/o))^2 + \sigma(m/o)^2.$$

In Linear-Space:
mean(mod/obs) = 1.022
mean(obs/mod) = 0.996
std(mod/obs) = 13.8%
std(obs/mod) = 13.3%

In Log-Space:
mean(mod/obs) = 1.013
mean(obs/mod) = 0.987 = 1/1.013
std(mod/obs) = 14.2%
std(obs/mod) = 14.2%

In linear space (upper figure)
distribution skewed

Metrics Comparison 2012 orbit average (linear vs log space)

	Linear space	Log space
Bias:	1.0388	1.0355
Root Mean Square Error:	0.092	0.087
Standard deviation:	0.084	0.080

Similar values in linear and log space, same interpretation
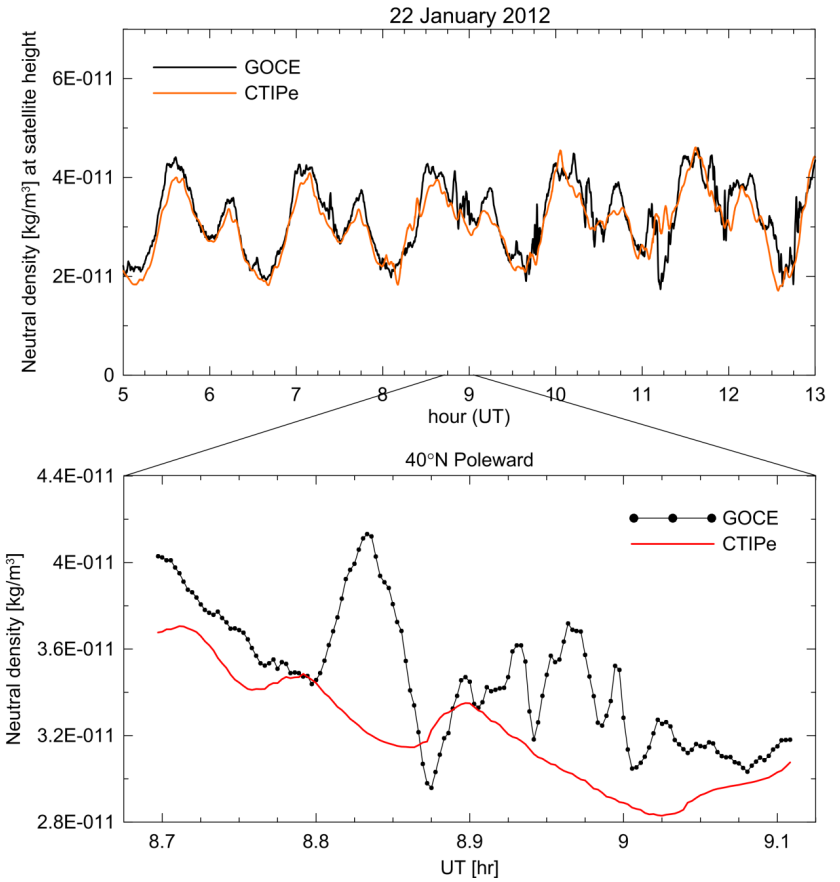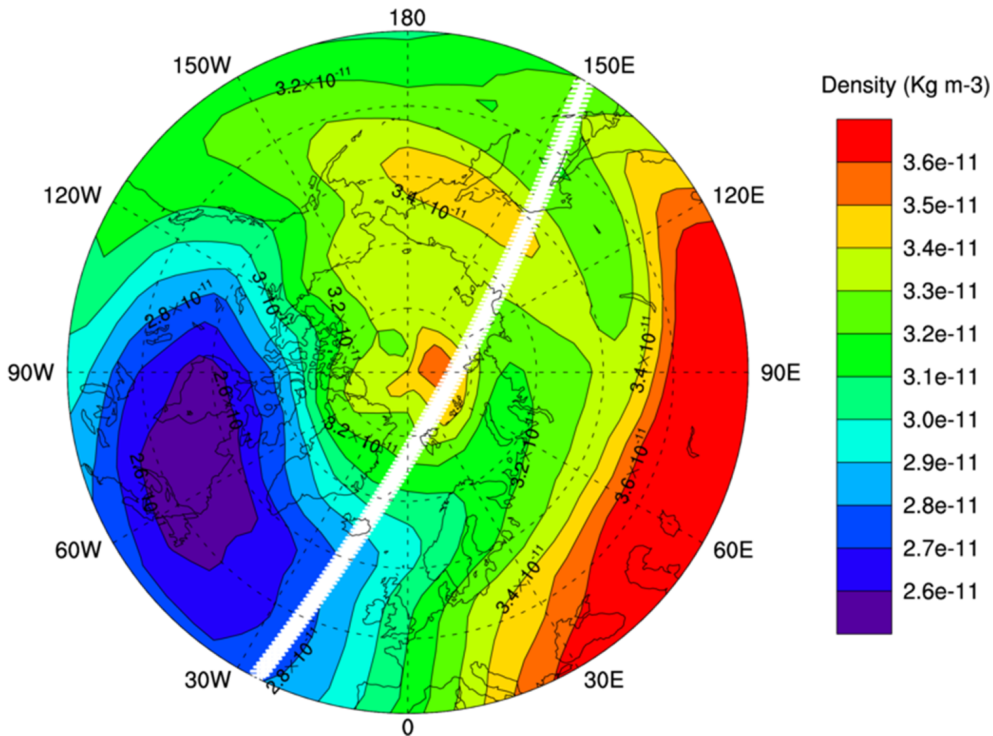
Example of specific orbit periods

Computed (blue) and Observed (red) density, and density ratio O/C (black)
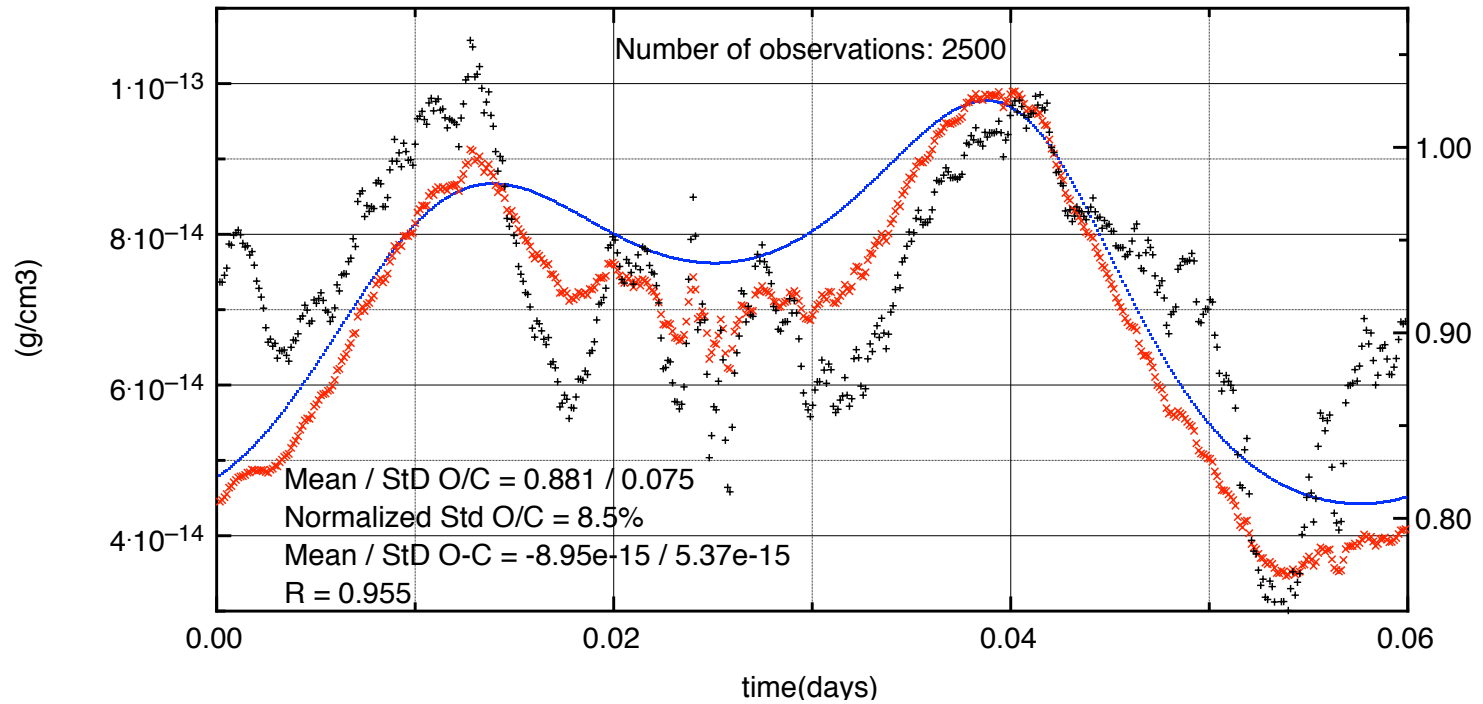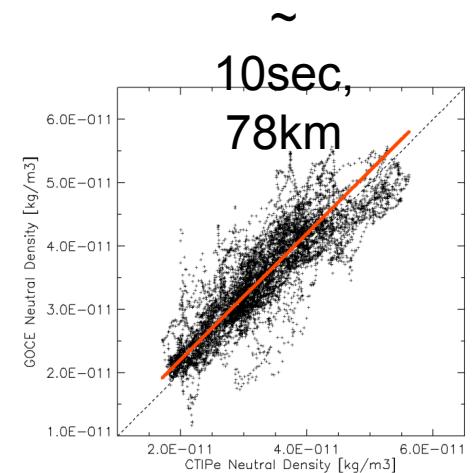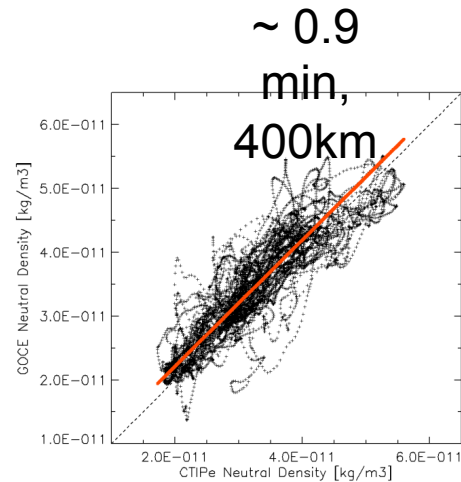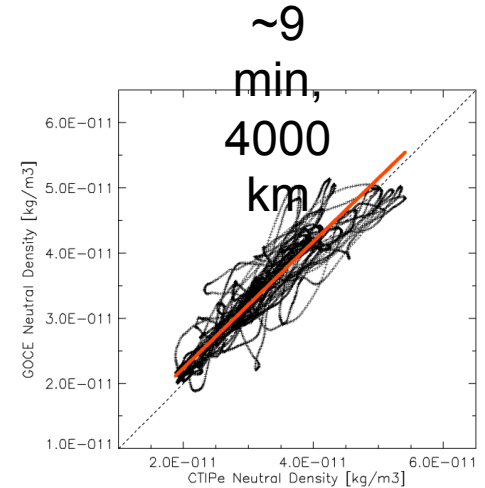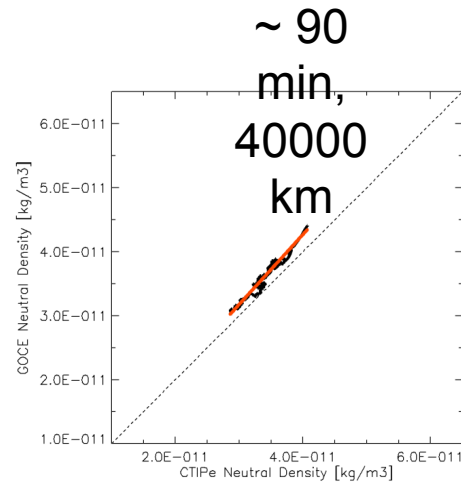
Neutral Density Spatial and Temporal Scales

CTIPe Neutral Density at 265km
22-Jan-2012 08:55UT

22 January 2012

40°N Poleward

GOCE small scale fluctuations not captured by CTIPe model -> drivers, model resolution?
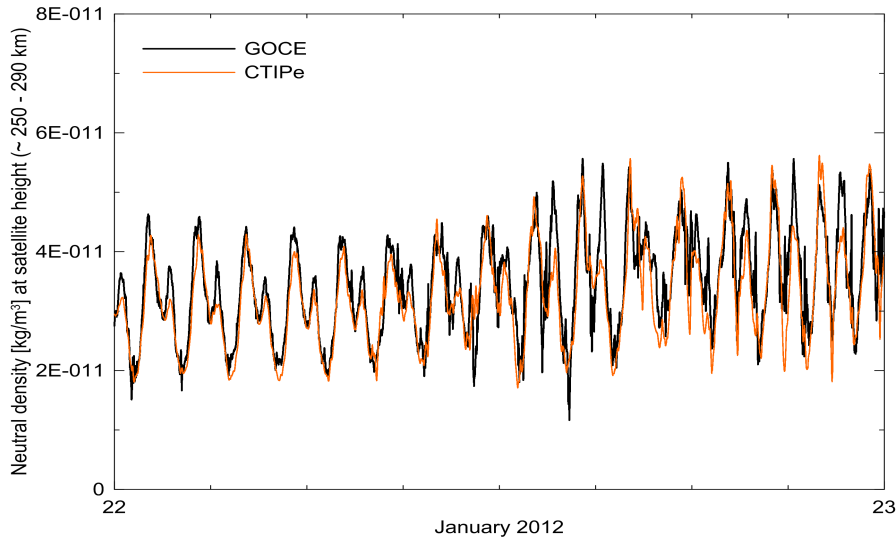
WINDOW (km)	R	RMSE	BIAS	SD
40000	0.986	0.060	0.059	0.015
4000	0.915	0.105	0.057	0.089
400	0.880	0.128	0.057	0.116
78	0.875	0.131	0.057	0.120

Neutral Density Spatial and Temporal Scales (cont'd)

Running Average Window:
GOCE (black), CTIPe (red)

~ 90 minutes, 40000km

~ 9 minutes, 4000km

~ 0.9 minutes, 400km

~ 10 seconds, 78km

Neutral density [kg/m³] at satellite height (~ 250 - 290 km)

Fractional DOY in 2012
(22 Jan 2012, ~ 08:00 to 09:30UT)