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Swarm density assimilation in DTM

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SWAMI project objectives

Space Weather Atmosphere Model and Indices

- To develop a model of the whole atmosphere (MOWA) with a science as well as operations-focused approach (MCM). Two existing models of the atmosphere, the UM and the DTM, will be extended and blended to produce this unique new whole atmosphere model, which shall provide estimates of both climatology and space weather variability.

- To provide new high-cadence geomagnetic indices, 'Hp*xx*', including its nowcast and predictions to be used in the UM and DTM.

- To develop steps, including provision of software, model output, or data sharing facilities, to transition the improved model system into operations.

SWAMI: DTM2018

DTM2018 is an intermediate model that, compared with DTM2013, is based on:

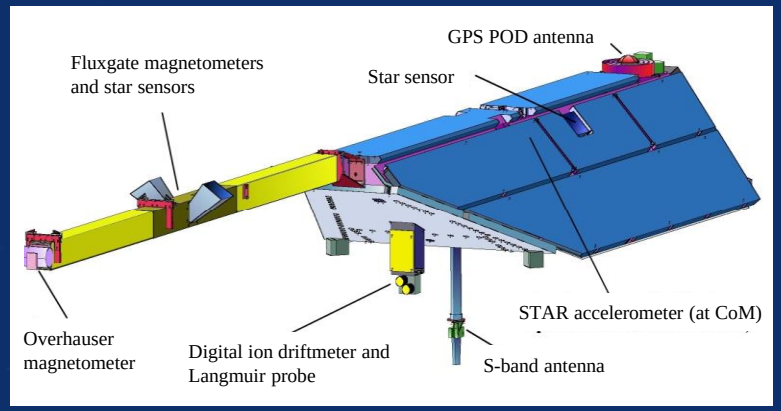
- Same algorithm and drivers (DTM2019: Hp_{xx} geomagnetic index)
- More data, different preprocessing (*no scaling*)
- Better data correction and editing
- Iterative model development

Total density data

Data: CHAMP, GRACE and GOCE

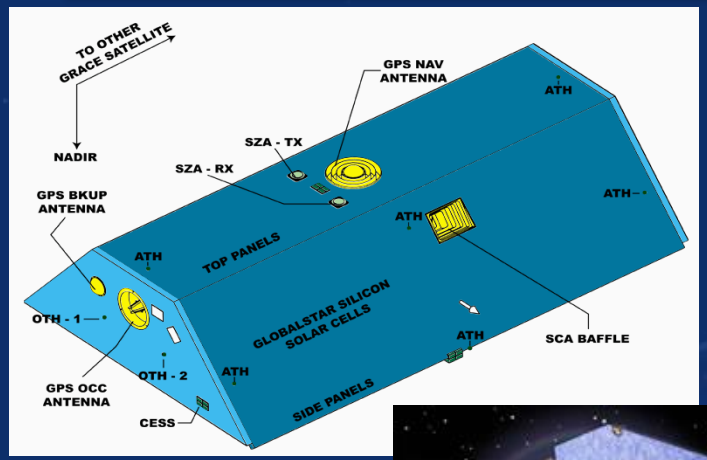
CHAMP (2000-2010):

- ***STAR resolution: $3 \cdot 10^{-9}$ m/s²/Hz$^{0.5}$***
- GPS and SLR
- inclination: 87°
- Altitude: 460-300 km



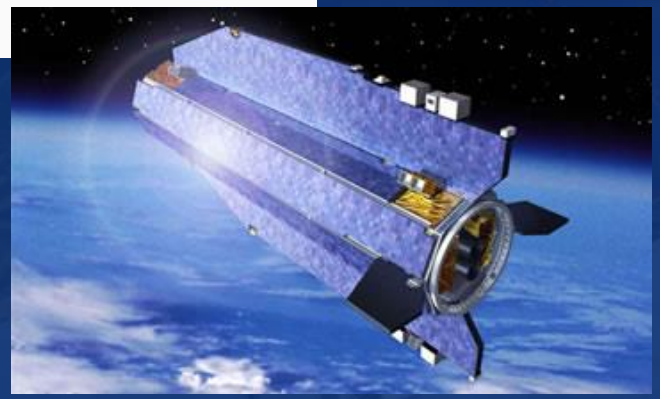
Stella (POE)

(1994-2016)



GRACE (2002-2016):

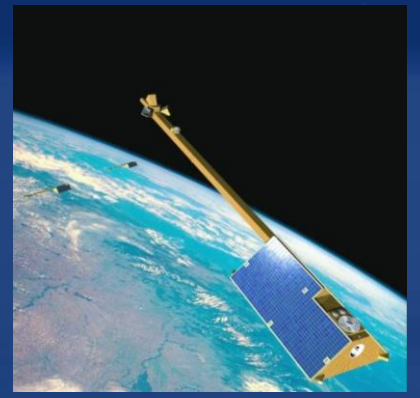
- ***SuperSTAR resolution: $1 \cdot 10^{-10}$ m/s²/Hz$^{0.5}$***
- GPS and SLR
- inclination: 90°
- Altitude: 490-450 km



GOCE (2009 – 2013):

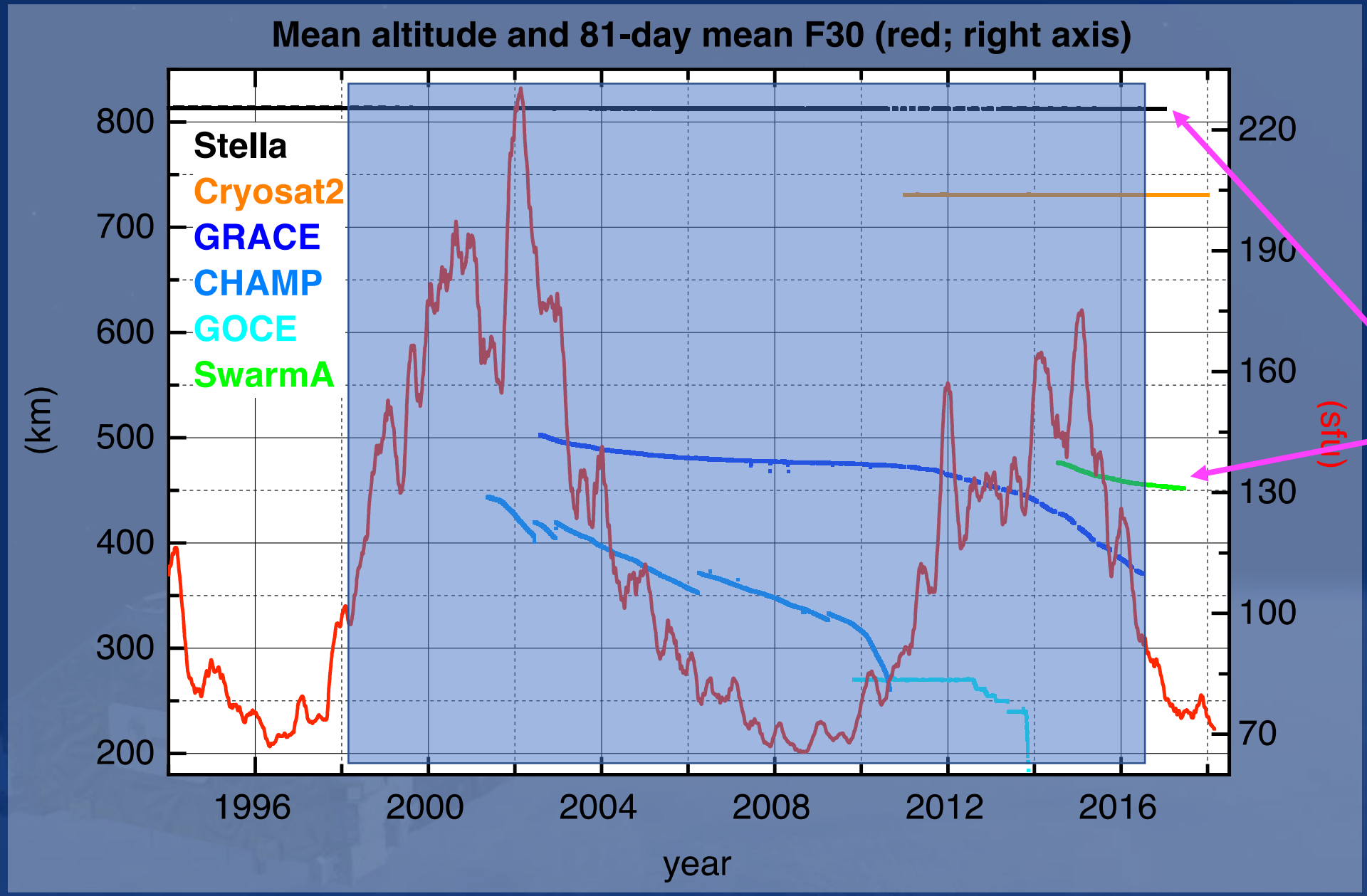
- ***Acc. resolution: $1 \cdot 10^{-12}$ m/s²/Hz$^{0.5}$***
- ***ion propulsion***
- GPS and SLR
- inclination: 96.5°
- Altitude: 255-225 km

Swarm ('GPS Acc')



(7/2014 – 7/2017)

Total density data



Impact of Swarm:

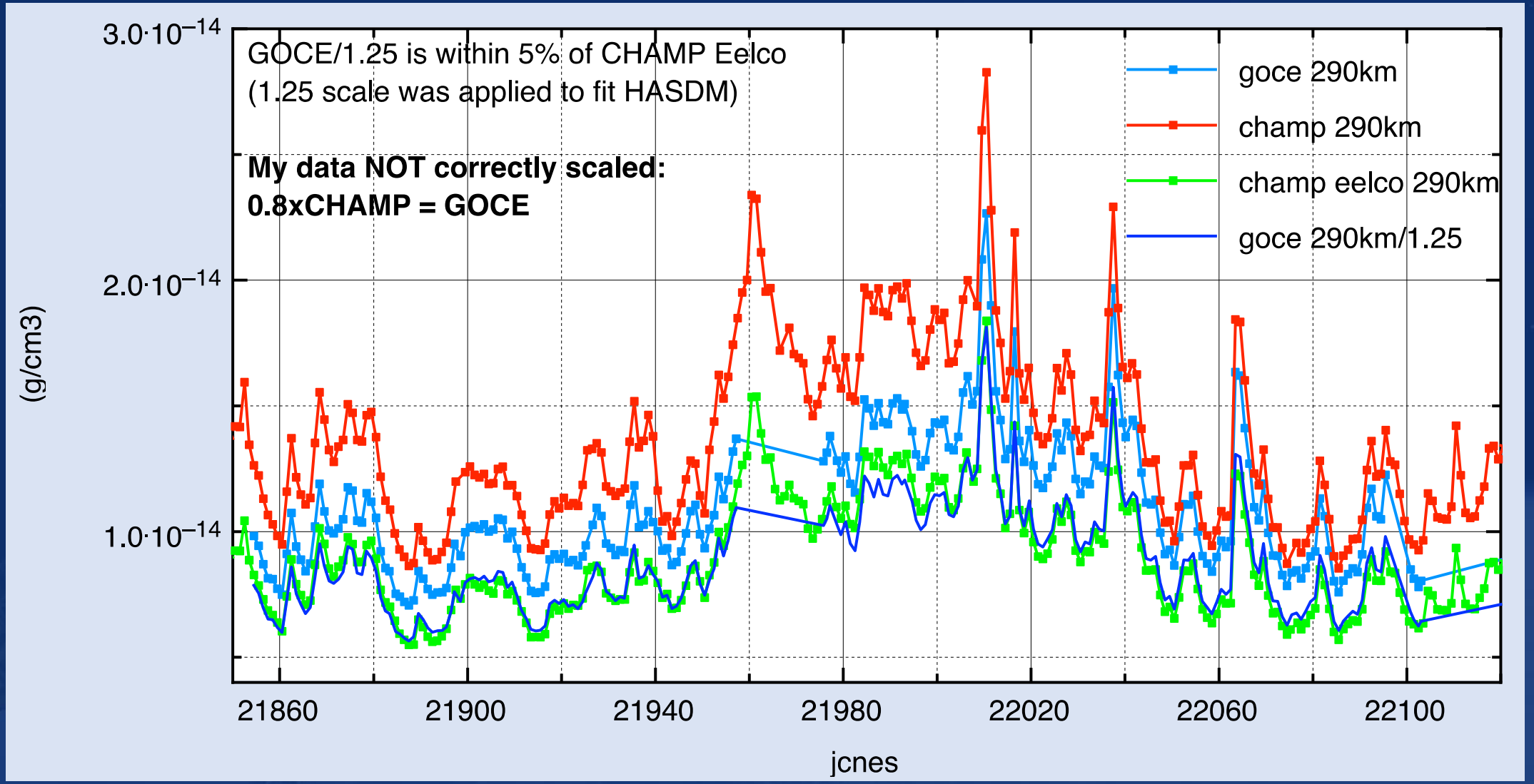
Only *Stella* (‘high’) and *SwarmA* (‘low’)

Scaling of data

CHAMP and GOCE (November 2009 – June 2010): daily-mean density at 290 km

Determination of scale factors is necessary but complicated due to:

- Altitude
- Epoch
- LST



Scaling of data

Scaling applied in this version:

GOCE V1_5 (ESA / E. Doornbos) (1.00)
CHAMP (E. Doornbos) (1.00)
SwarmA (ESA / E. Doornbos) (1.00)

GRACE scaled to GOCE, CHAMP, and SwarmA

2002-2005 : 0.76
2006 : 0.73
2007 (<9/10) : 0.70
9/2009-2016 : 0.70

NB: Data rejected for 10/2007 - 9/2009

Stella (1.00)

What do you mean, 'scale' of density data?!

Aerodynamic coefficient

$$a_{drag} = -\frac{1}{2} C_D \frac{A}{m} r v^2$$

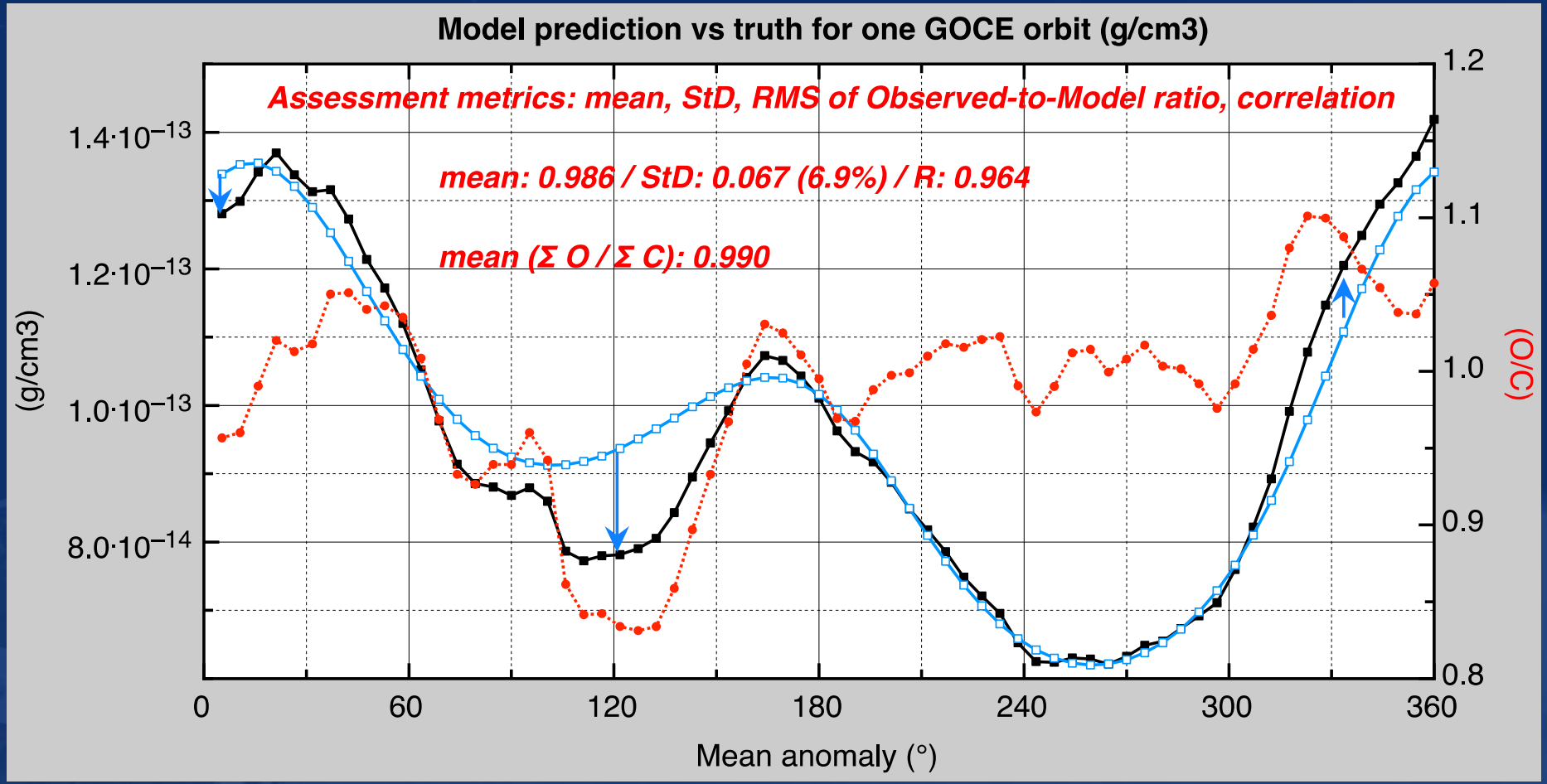
Surface in ram direction

Metrics

Metrics to quantify model improvement are selected and benchmarks are established:

Mean, StD and R are computed on several <u>time scales:</u>

- **Annual**
- **27-days**
- **Daily**
- **Orbit**



Scaling of data: DTM2013

DTM2013 was constructed with data scaled to the HASDM model:

	mean O/C	StD	R
GOCE (O/C all data)	0.98	11.6%	0.978
CHAMP (annual O/C)	1.02	19.6%	0.931
GRACE (annual O/C)	1.06	22.4%	0.928
SwarmA (O/C all data)	0.78	25.5%	0.962
Stella (annual O/C)	0.97	19.5%	0.925

Scaling of data: DTM2013 biases

DTM2013 was constructed with data scaled to the HASDM model:

With the present (not) scaled datasets:

	mean O/C		StD	R
GOCE (O/C all data)	0.98	0.79	11.6%	0.978
CHAMP (annual O/C)	1.02	0.76	19.6%	0.931
GRACE (annual O/C)	1.06	*0.77**	22.4%	0.928
SwarmA (O/C all data)	0.78	0.78	25.5%	0.962
Stella (annual O/C)	0.97	0.97	19.5%	0.925

** scaled to GOCE, CHAMP, and SwarmA*

Results of the preliminary DTM2018 model

The model was elaborated in 3 iterations:

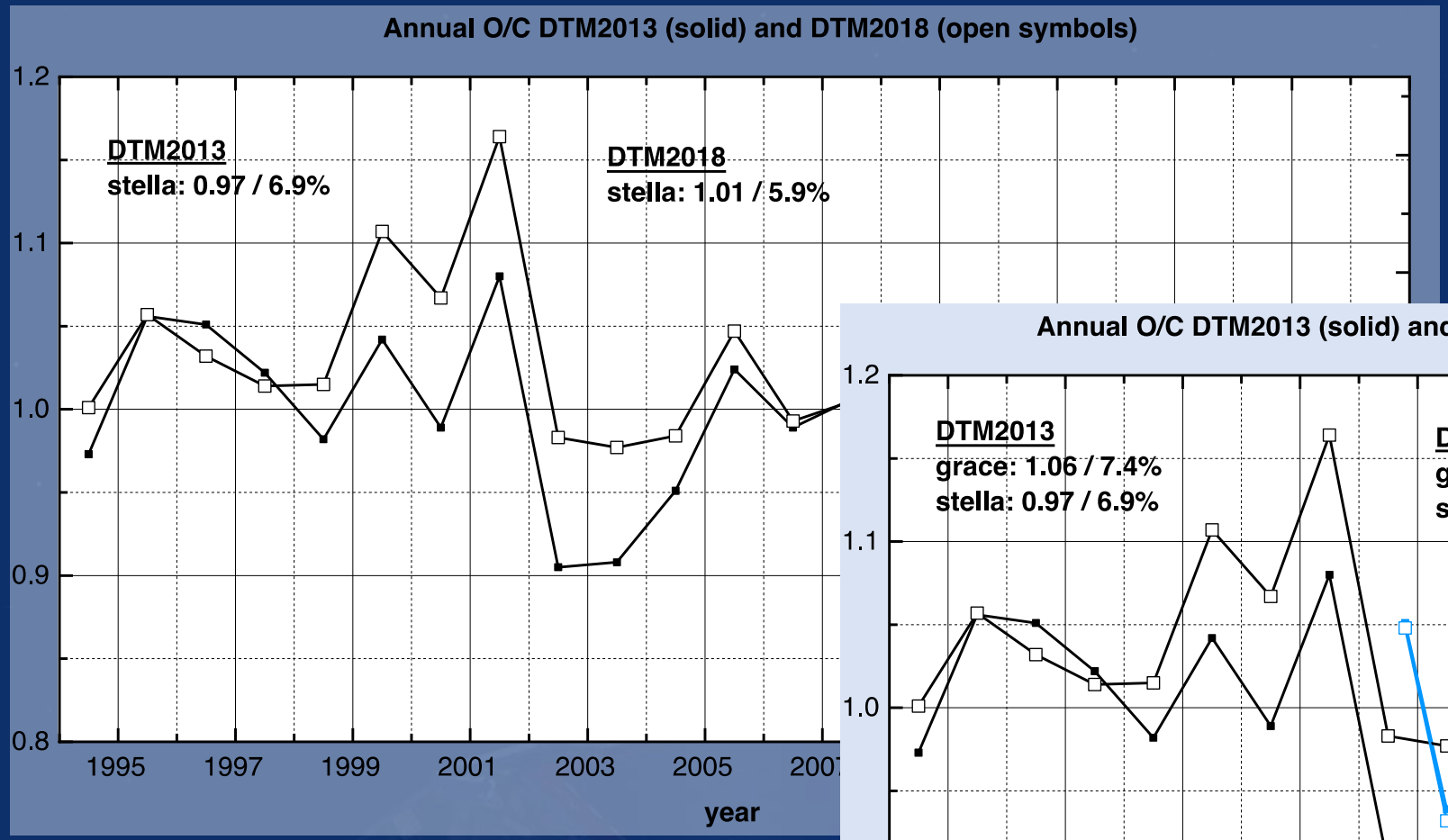
Apriori	Estimate	Data	Result
DTM2013	*O and N2*	GOCE, CHAMP 2001-2005 & 2008-2010	DTM_ON2
DTM_ON2	*He*	GRACE, Stella, SwarmA	DTM_ON2He
DTM_ON2He	*T, O, N2, He*	All	**DTM2018**

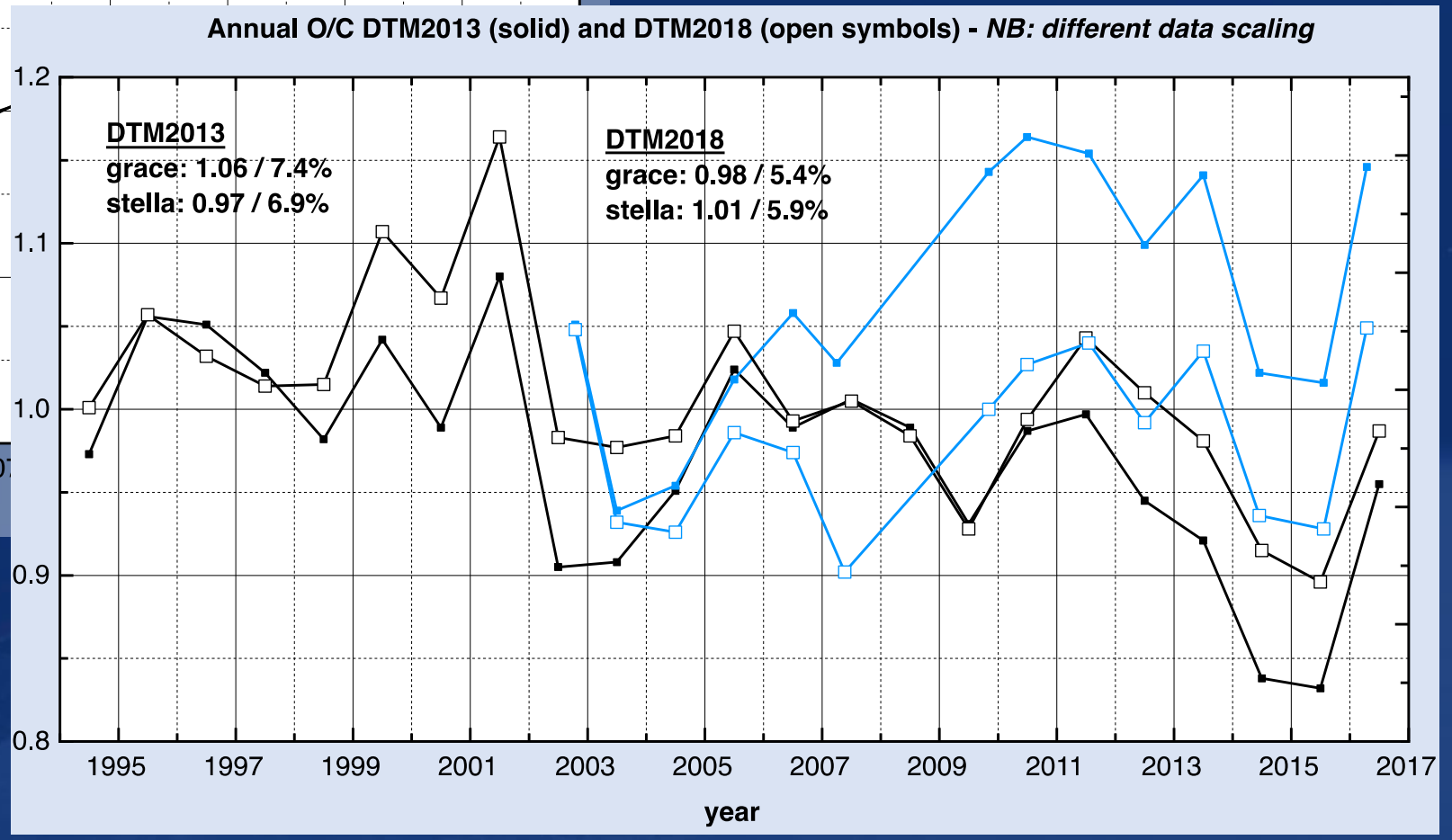
Results of the preliminary DTM2018 model

DTM2013 with the ('HASDM' scaled) datasets:
DTM2018 with the ('TU Delft' scaled) datasets:

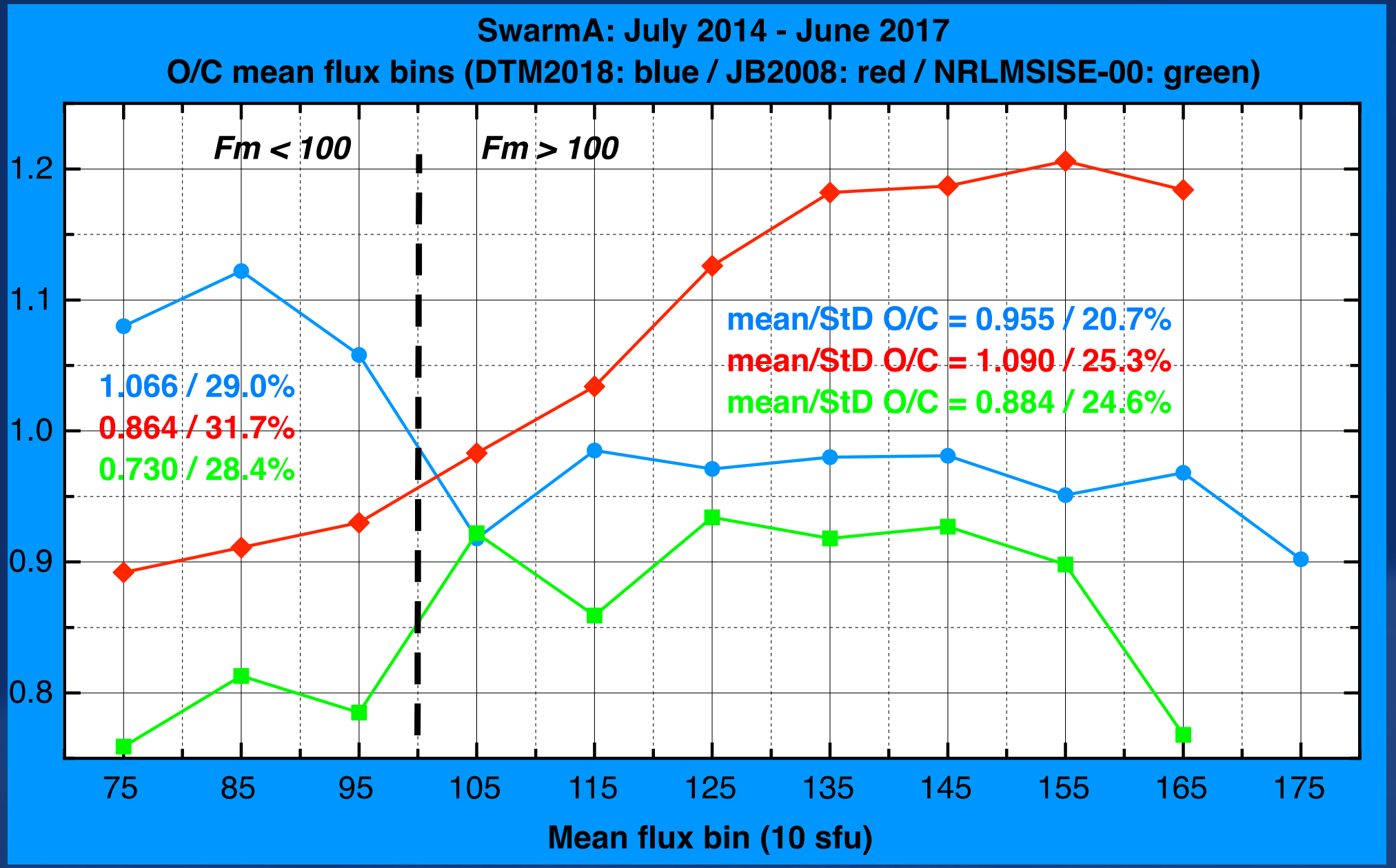
	mean O/C		StD		R	
GOCE (O/C all data)	0.79	1.01	11.6%	10.3%	0.978	0.984
CHAMP (annual O/C)	0.76	1.01	19.6%	17.5%	0.931	0.943
GRACE (annual O/C)	0.77	0.98	22.4%	21.2%	0.928	0.936
SwarmA (O/C all data)	0.78	1.00	25.5%	24.9%	0.962	0.964
Stella (annual O/C)	0.97	1.01	19.5%	18.8%	0.925	0.933

Results of the preliminary DTM2018 model





Results of the preliminary DTM2018 model



Summary and outlook

DTM2018 is an intermediate model:

- More data were assimilated, and CHAMP, SwarmA & GOCE were used *without* scaling
- More precise than DTM2013
- Model predicts lower densities

SwarmA GPS-densities:

- Is the only data source since 2016 above 400 km, and below Stella (815 km)
- Are less precise when mean solar activity drops below 100 sfu
- Will, hopefully, soon be compared with high-res GRACE-FO data.

H2020 SWAMI website

http://swami-h2020.eu

Total density data

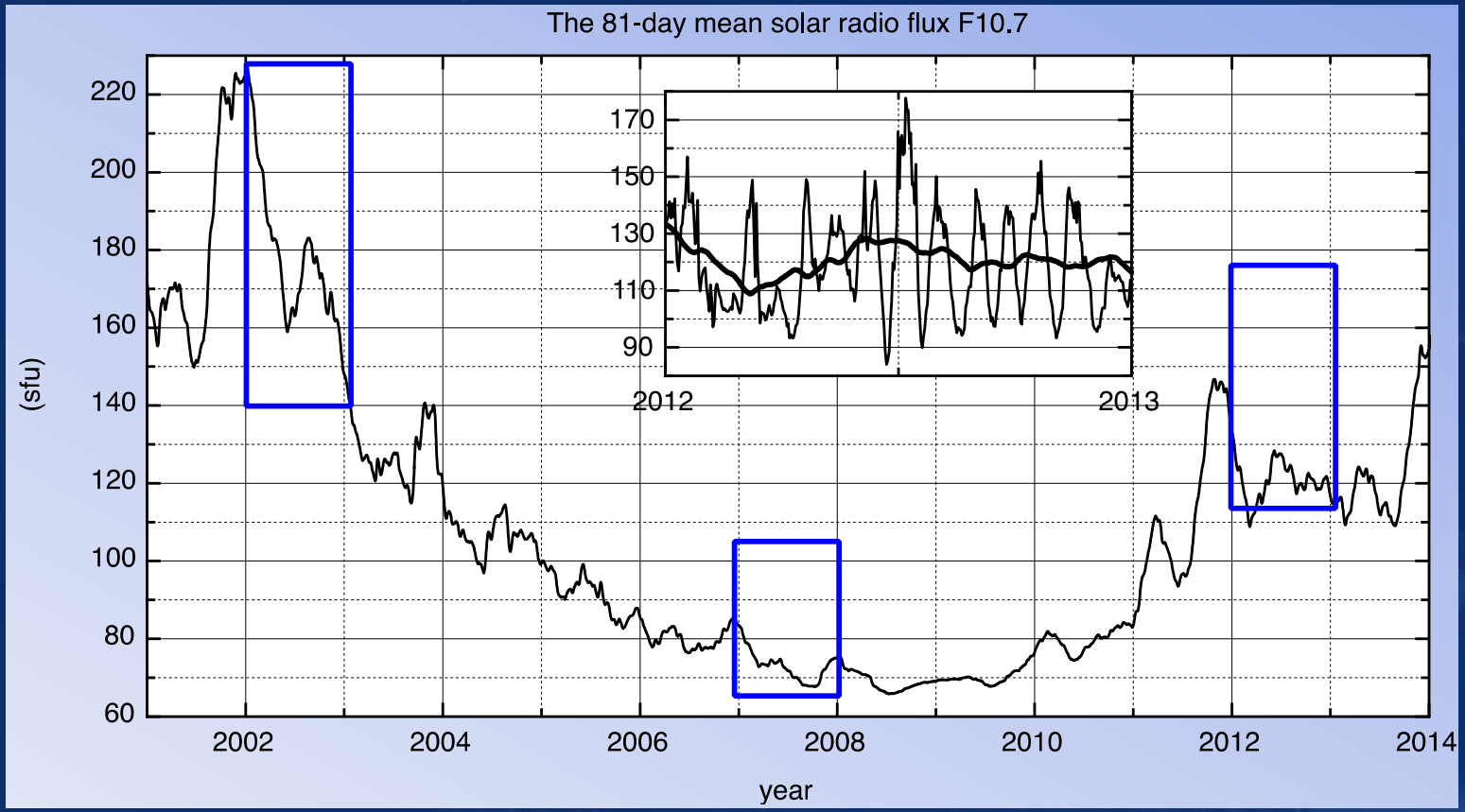
	Period	Altitude (km)	i	LST 24h LST	cadence	Precision (%)
CHAMP	05/2001 – 08/2010	450 - 250	87°	0 - 24 120 - 130 days	80 s	1-4%
GRACE	08/2002 – 07/2016	490 - 300	89°	0 - 24 120 - 160 days	80 s	2-6%
GOCE	11/2009 – 10/2013	270 - 180	96°	6-8 & 18-20	80 s	1-3%
SwarmA	06/2014 – 05/2017	450 - 440	89°	0 - 24 135 days	10 s	5%*
TLE (Emmert)	01/1967 – 12/2013	250, 400, 550	-	-	24h	?
Stella	01/2000 – 12/2016	815	93°	9-15 & 21-3	24h	5-15%
Starlette	01/2000 – 12/2016	800	49°	0 - 24 200	24h	5-20%

NB: Filtered and down-sampled

Not yet available: these POE derived mean densities

	Period	Altitude (km)	i
Cryosat2	2011 – 2017	717	92°
Aqua/Aura	2002 - ?	700	98°
TanDEM-X TerraSAR-X	2010 - ?	500	97°

Periods and specific events for comparisons

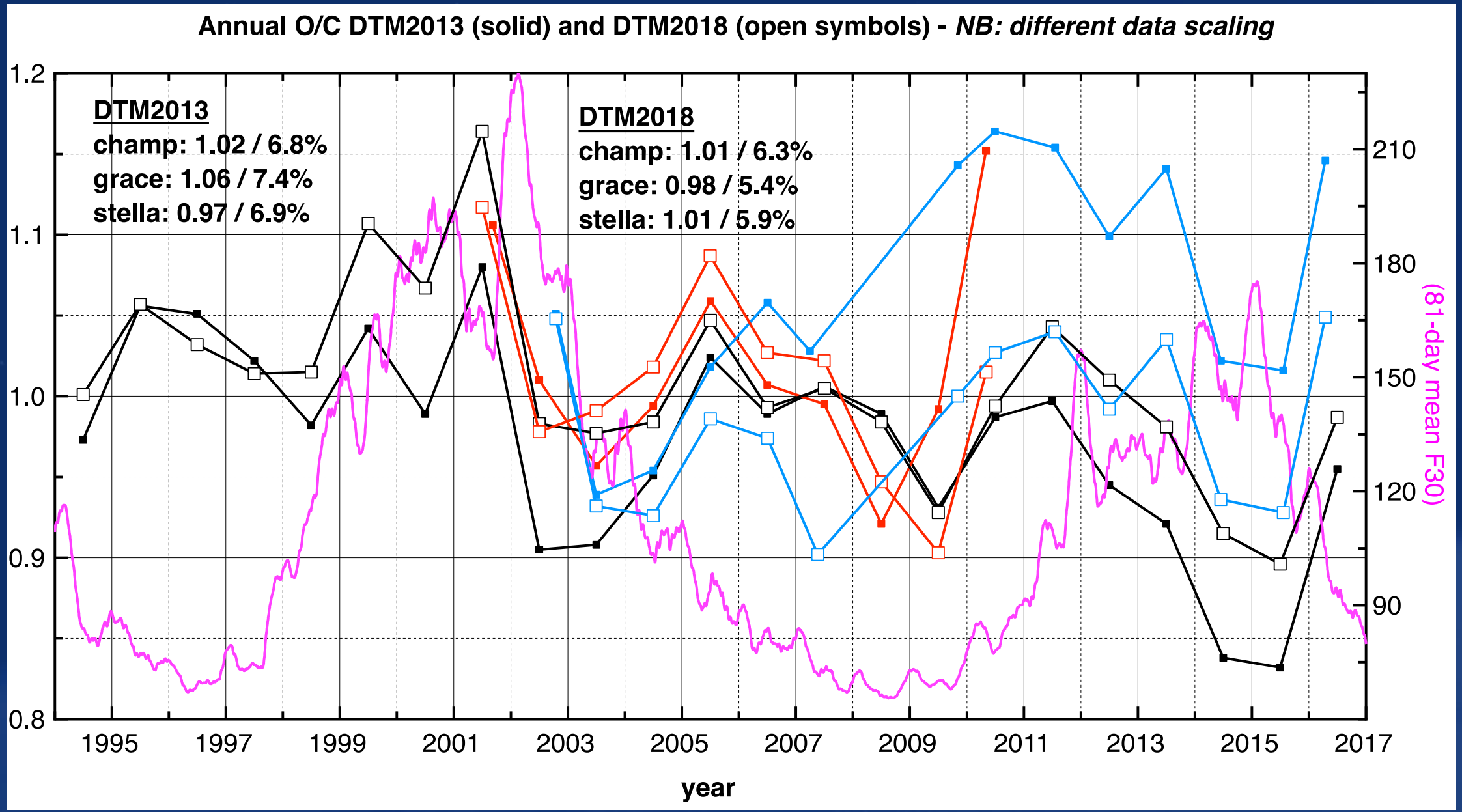


Three complete years were selected (2002, 2007, 2012) in order to asses e.g., seasonal and 27-days solar variations, as well as specific storm events.

14 storms + Oct&Nov 2003 storms:

Date	Min Dst (nT)	Max ap/Kp
29/03 – 03/04/2001	-387	300 / 9-
18/07 – 31/07/2004	-170	300 / 9-
17/01 – 20/01/2005	-103	179 / 8-
20/01 – 23/01/2005	-105	207 / 8
07/05 – 10/05/2005	-127	236 / 8+
14/05 – 17/05/2005	-263	236 / 8+
29/05 – 01/06/2005	-138	179 / 8-
08/07 – 14/07/2005	-92	94 / 6+
23/08 – 26/08/2005	-216	300 / 9-
08/09 – 19/09/2005	-147	179 / 8-
08/03 – 11/03/2012	-131	207 / 8
16/03 – 20/03/2013	-132	111 / 7-
31/05 – 04/06/2013	-119	132 / 7
21/06 – 24/06/2015	-204	236 / 8+

Results of the preliminary DTM2018 model



SWAMI: project diagram

1) Develop new index

Geomagnetic activity:
New algorithm for
High-cadence Kp

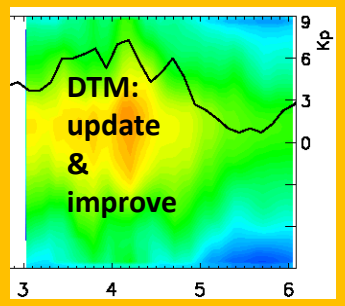
Thermosphere observations

Solar activity:
F30 radio flux

Atmosphere observations

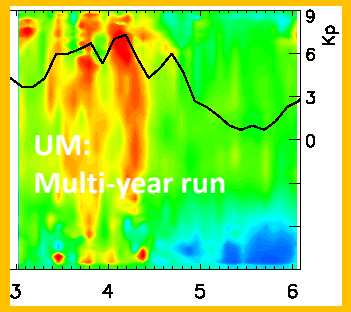
2) Develop MOWA

Thermosphere



+

Surface to LT



MOWA
Climatology & Weather

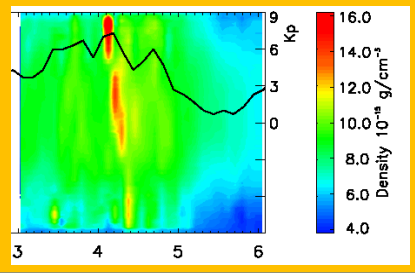
3) Develop MCM

4) Develop Kp forecast model

Geomagnetic activity:
High-cadence Kp &
Nowcast and
Forecast

Solar activity:
F30 radio flux &
Nowcast and
Forecast

MCM (0-1500 km)



Climatology *and* weather re-analysis and predictions:
- *Temperature*
- *Density + composition*
- *Winds*

Scaling of data

GRACE and SwarmA (June 2015): daily-mean density at 450 km

Determination of scale factors is necessary but complicated due to:

- Altitude
- Epoch
- LST