The H2020 project SWAMI (Space Weather Atmosphere Model and Indices)

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Project objectives

- 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.

Project approach

1) Develop new index

Geomagnetic activity:
New algorithm for
High-cadence Kp

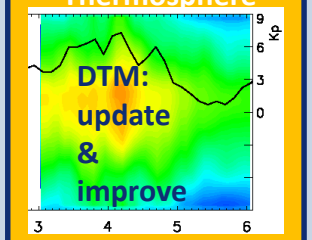
Thermosphere observations

Solar activity:
F30 radio flux

Atmosphere observations

2) Develop MOWA

Thermosphere



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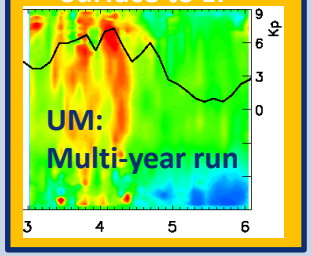
Surface to LT



MOWA
Climatology &
Weather

3) Develop MCM

C - Parallel steps:
Blend **DTM** and **UM** (120-160 km):
MOWA
Mean=climatology
Difference= weather

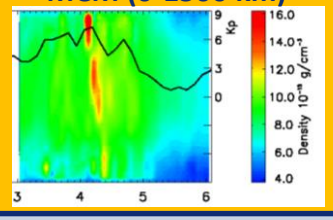
Develop Kp forecast model

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

D – Develop **MCM**
(Spherical Harmonics / 4D-Table plus **DTM**)

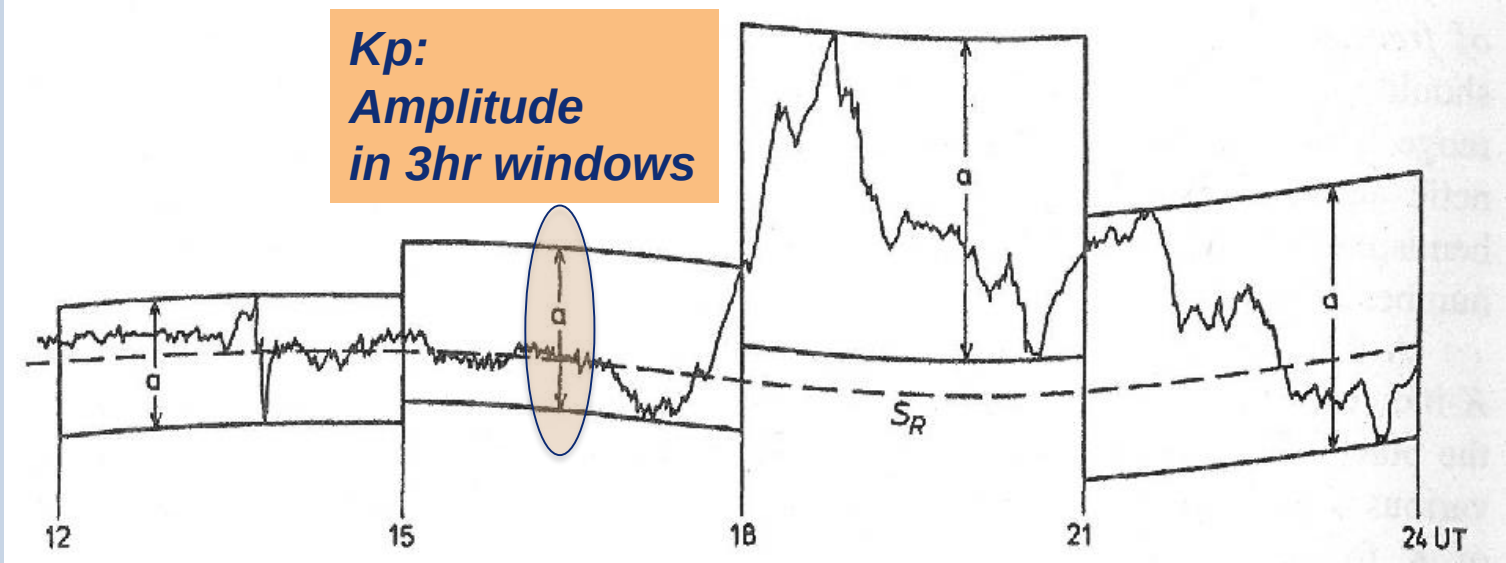


Fig. 1. Record section for 12 h (four 3-h intervals) to illustrate the elimination of the regular daily variation S_R (indicated by the *dashed curve*). The difference between the lower and upper envelopes of the actual trace, parallel to S_R, determines the maximum disturbance range a within every 3-h interval

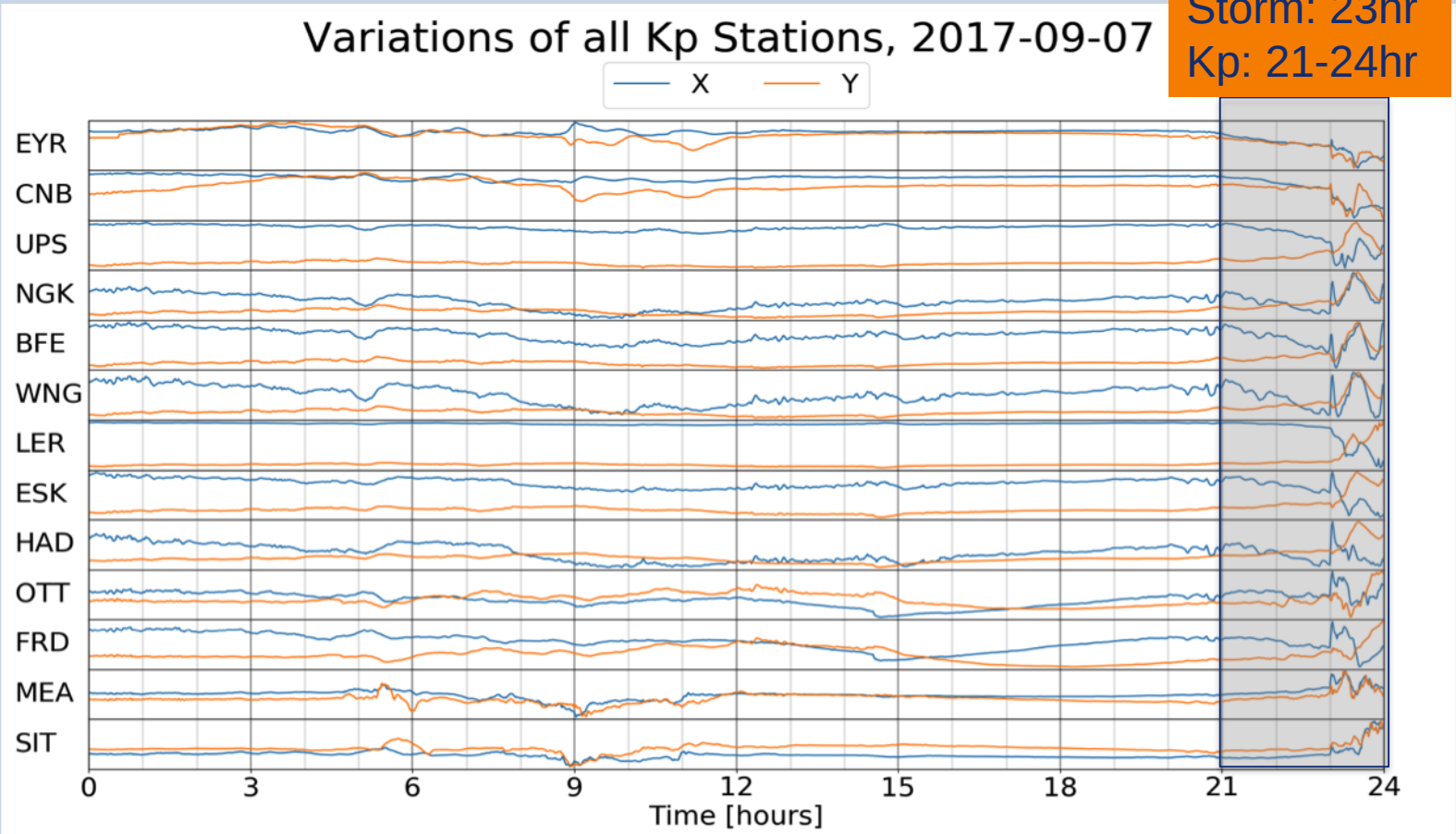
a =	0 …	5 …	10 …	20 …	40 …	70 …	120 …	200 …	330 …	500 nT …
K =	0	1	2	3	4	5	6	7	8	9

Geomagnetic activity index K

- Only regard horizontal components
- Subtract quiet curve from magnetogram
- Determine range (it is a **Range** index)
- Translate range into quasi-logarithmic K value (see table)
- ***K***: "**K**ennziffer"
  (= planetary index)
- 3-hourly index, values from 0, 1, … to 9
- Previously hand-scaled, now algorithms to derive it from 1-minute data
- IAGA: Method to determine K considered good if disagreement with an established method is maximum 20 % of values by a maximum K difference of 1

Fig: Siebert (1996)

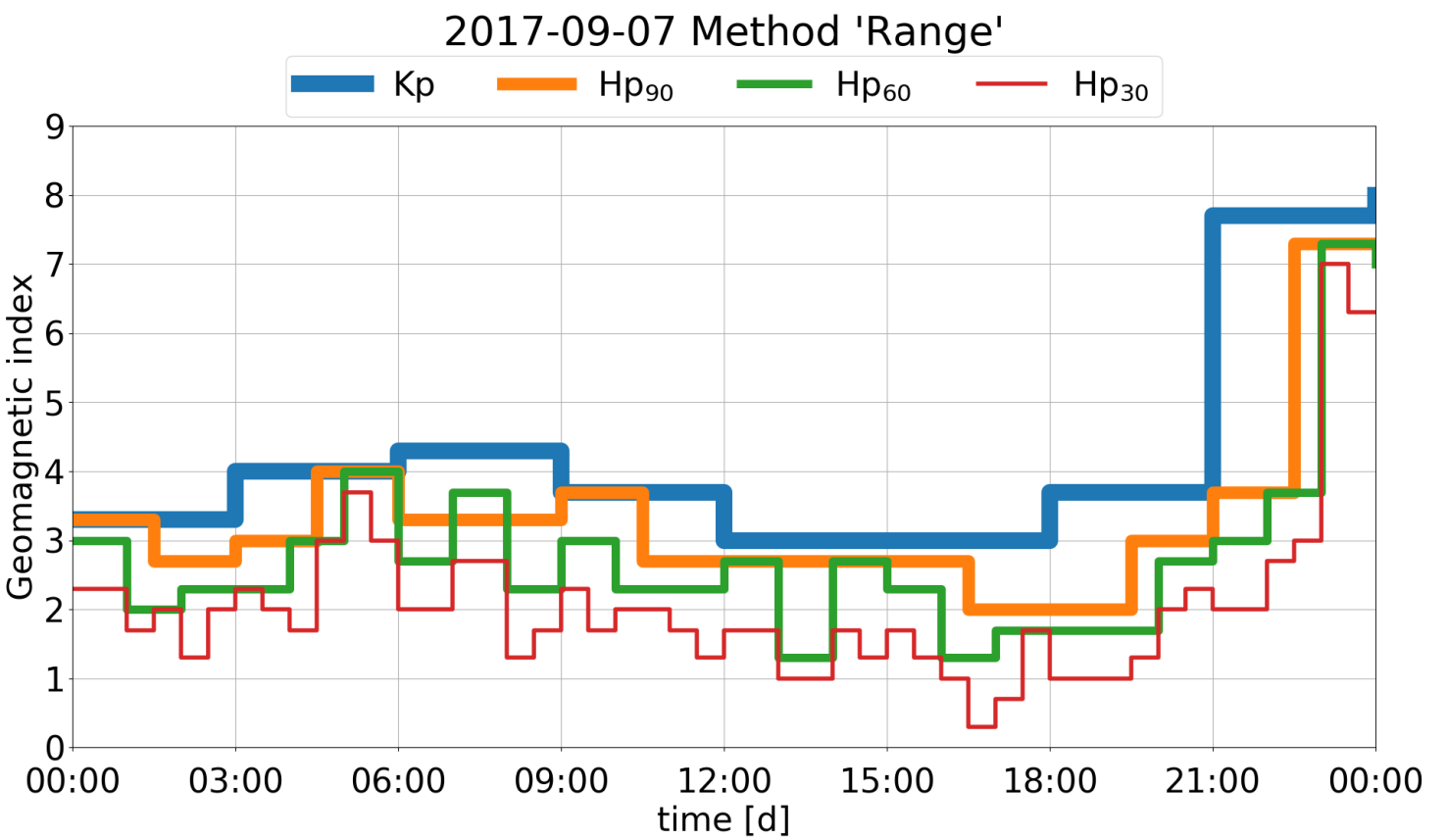
Hp_{xx} geomagnetic indices



Developing H and Hp: new, high-cadence, K and Kp-like indices

- H is the local index
- Hp is the planetary index (following algorithm for calculating Kp from K)
- H90, H60, H30 and Hp90, Hp60, Hp30 are indices for 90, 60 and 30 minutes cadence, respectively
- 90 minutes LEO orbital period
- 60 minutes popular with users
- 30 minutes just to investigate properties
- A clear advantage of a high-cadence index is the improved time resolution to better define timing of geomagnetic activity, especially onset time.

Hp_{xx} geomagnetic indices



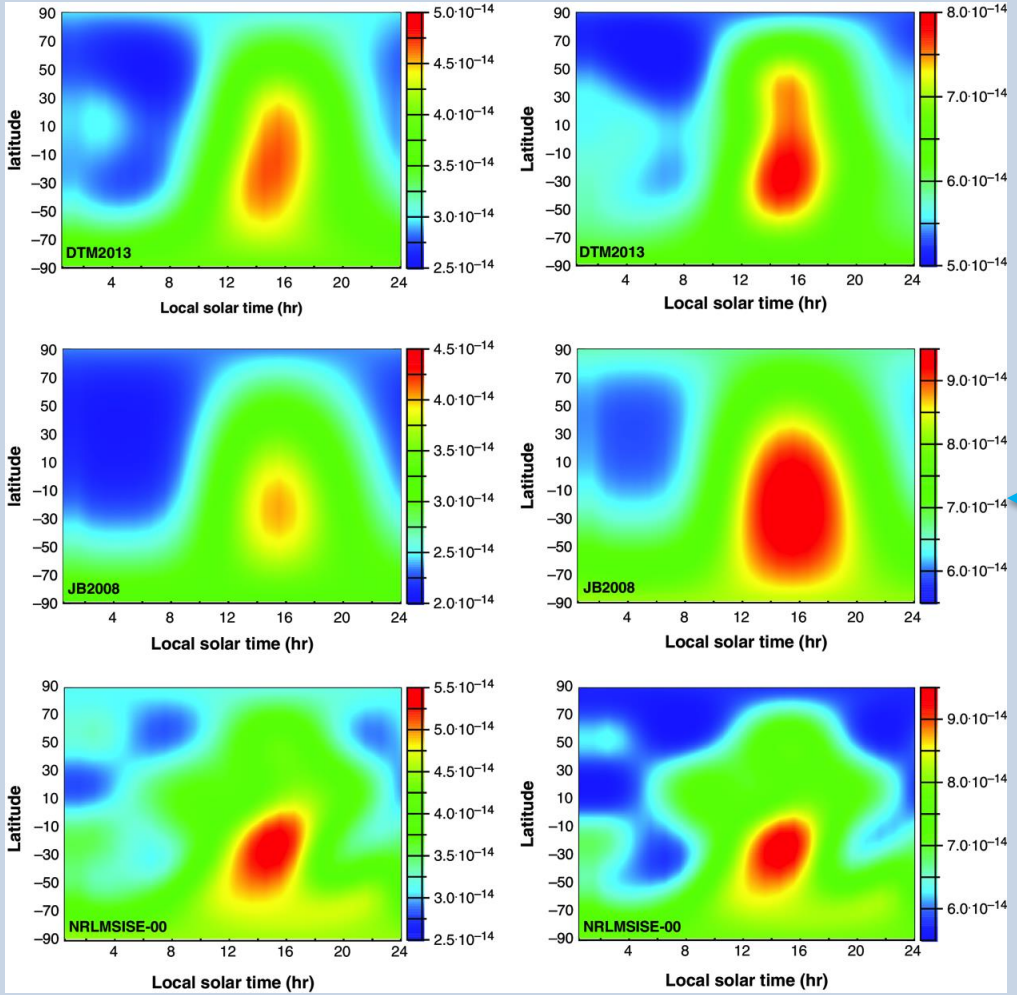
General problem of high-cadence range indices

- If we just keep the algorithm for K and use it for lower time resolution, then the resulting values are generally lower
- Such values cannot reasonably be used for models that have been developed using Kp
- New models have to be developed, or the algorithm for high-cadence index needs to be modified to result in an index with a Kp-like frequency distribution.

DTM2013

JB2008

NRLMSISE-00



Model predictions at 250 km, Kp < 2:

- 2009-12-14 (mean F10.7 = 75 sfu)
- 2011-12-14 (mean F10.7 = 144 sfu)

DTM is a semi-empirical model:

- Low resolution
- Easy and fast in use (*point-wise predictions*)
- Relatively accurate
- Climatology

Temperature and constituents (i.e., the winter Helium bulge is present) are modeled:

Concentration at 120 km

Height function

$$\rho(z) = \sum_i \frac{m_i}{N_A} c_i(120\ \text{km}) f_i(z) \exp(G_i(L))$$

Spherical harmonics

DTM model: data

Data used in the construction of:	DTM2013	DTM2018
✓CHAMP	05/2001 - 08/2010	
✓GRACE	01/2003 - 12/2011	08/2002 - 12/2016
✓GOCE	11/2009 - 05/2012	11/2009 - 10/2013
✓Starlette & Stella	01/1994 - 12/2012	01/1994 - 12/2016
✓Deimos-1	03/2010 - 09/2011	
✓CACTUS	07/1975 - 01/1979	
✓OGO6 (T)	06/1969 - 08/1975	
✓DE-2 (T, He, O, N2)	08/1981 - 02/1983	
✓AE-C (N2)	01/1974 - 04/1977	
✓AE-E (T, He, O)	12/1975 - 05/1981	
✓ Swarm	(-)	04/2014 – 07/2017
✓ Cryosat2	(-)	01/2012 – 12/2017 (*maybe*…)

And possibly:

- GUVI, LYRA O/N2?
- Microscope?
- Dellingr?
- GOLD O/N2 & T?
- SABER NO?
- APOD?
- …?

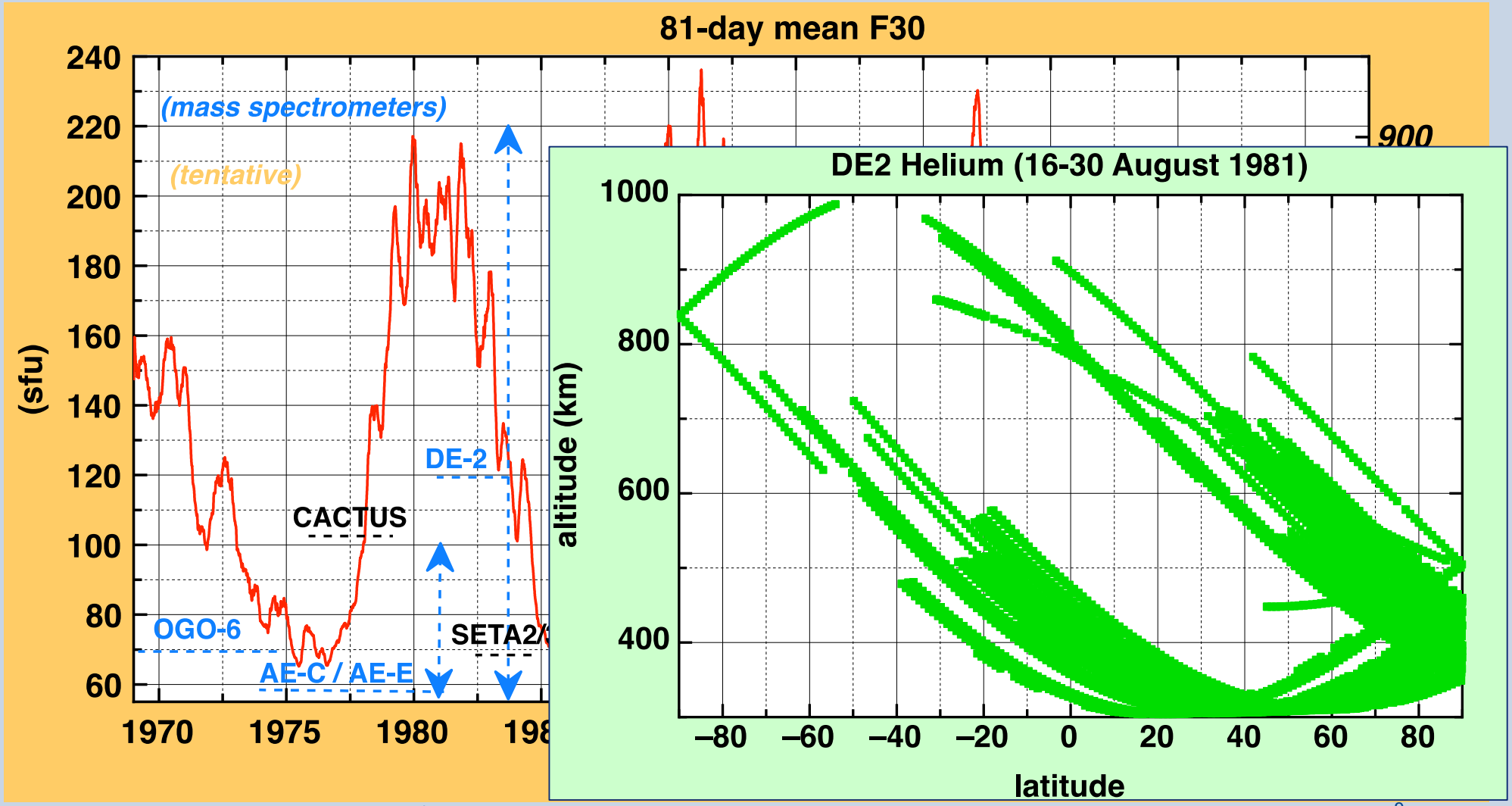
DTM model: data

Very few Hi-Res density observations:

- Below 200 km
- Above 500 km
- For strong cycle max

Spectrometer data:

- Biased
- Eccentric orbits
- Before EUV (SEM)
- No current data (satellite model!)

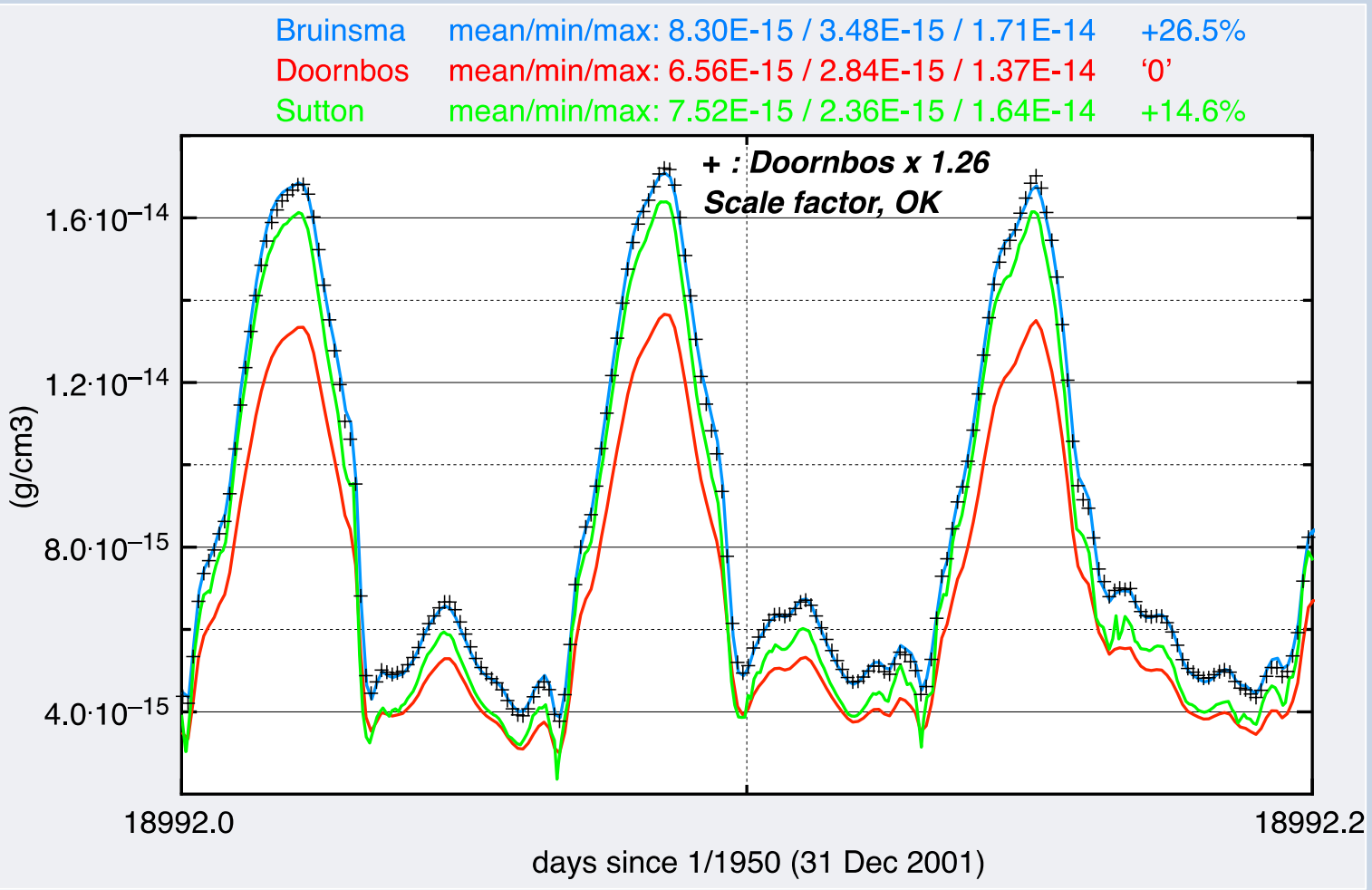


Example: CHAMP densities from different sources

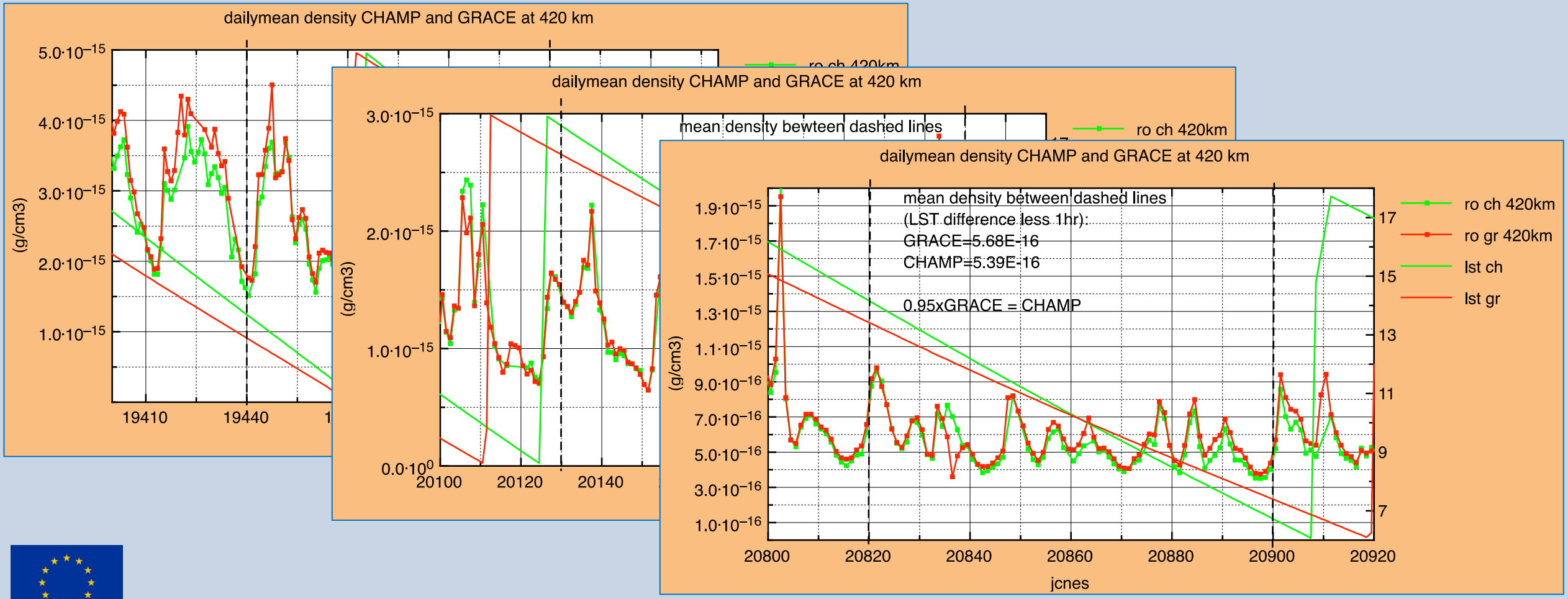
Density data, computed with different software…
can be quite different!

(due to satellite model)

But datasets must be consistent before model adjustment:
scaling is required



GRACE and CHAMP at 420 km (2002, 2005, 2007)

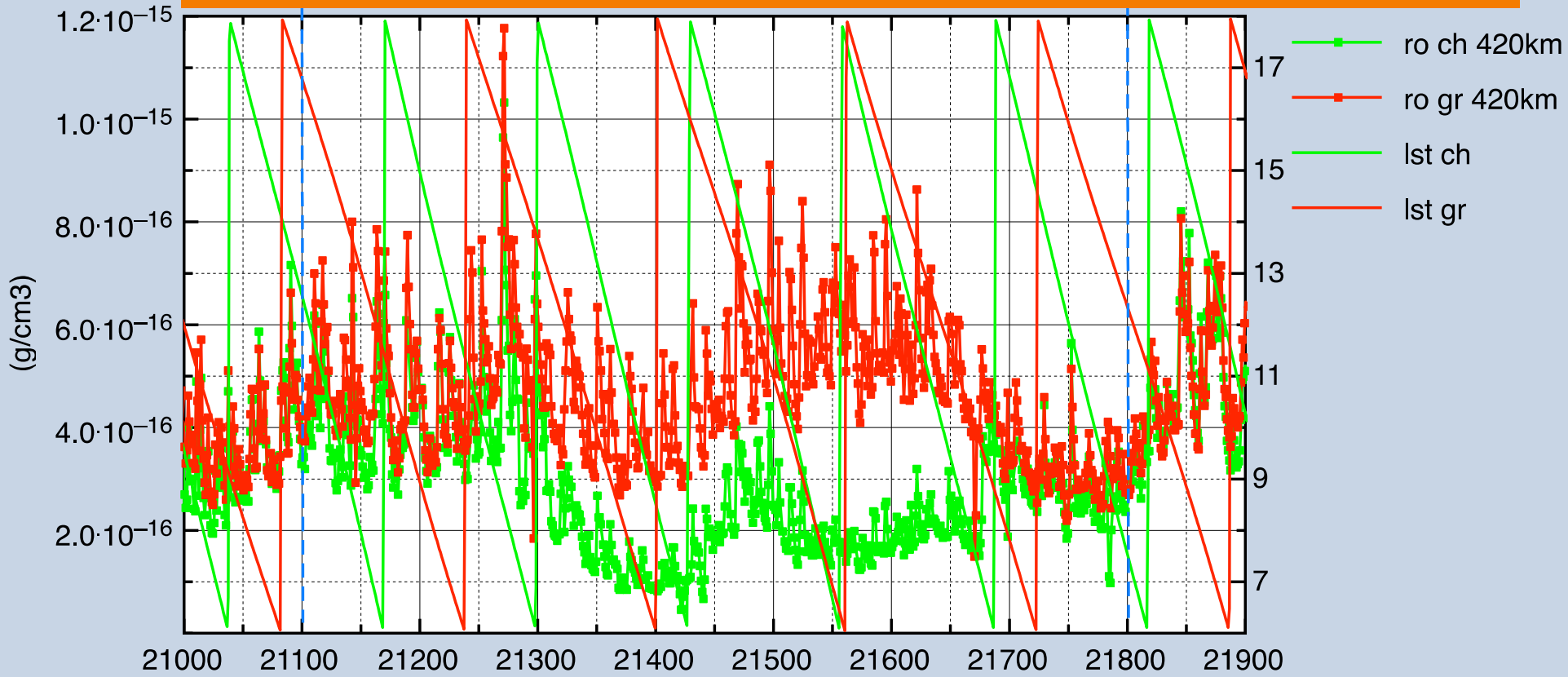


Determination of consistent scale factors is necessary but complicated due to:

- Altitude
- Epoch
- LST

GRACE and CHAMP at 420 km (July 2007 – Dec 2009)

Reject GRACE from October 2007 – September 2009



DTM model: data scaling

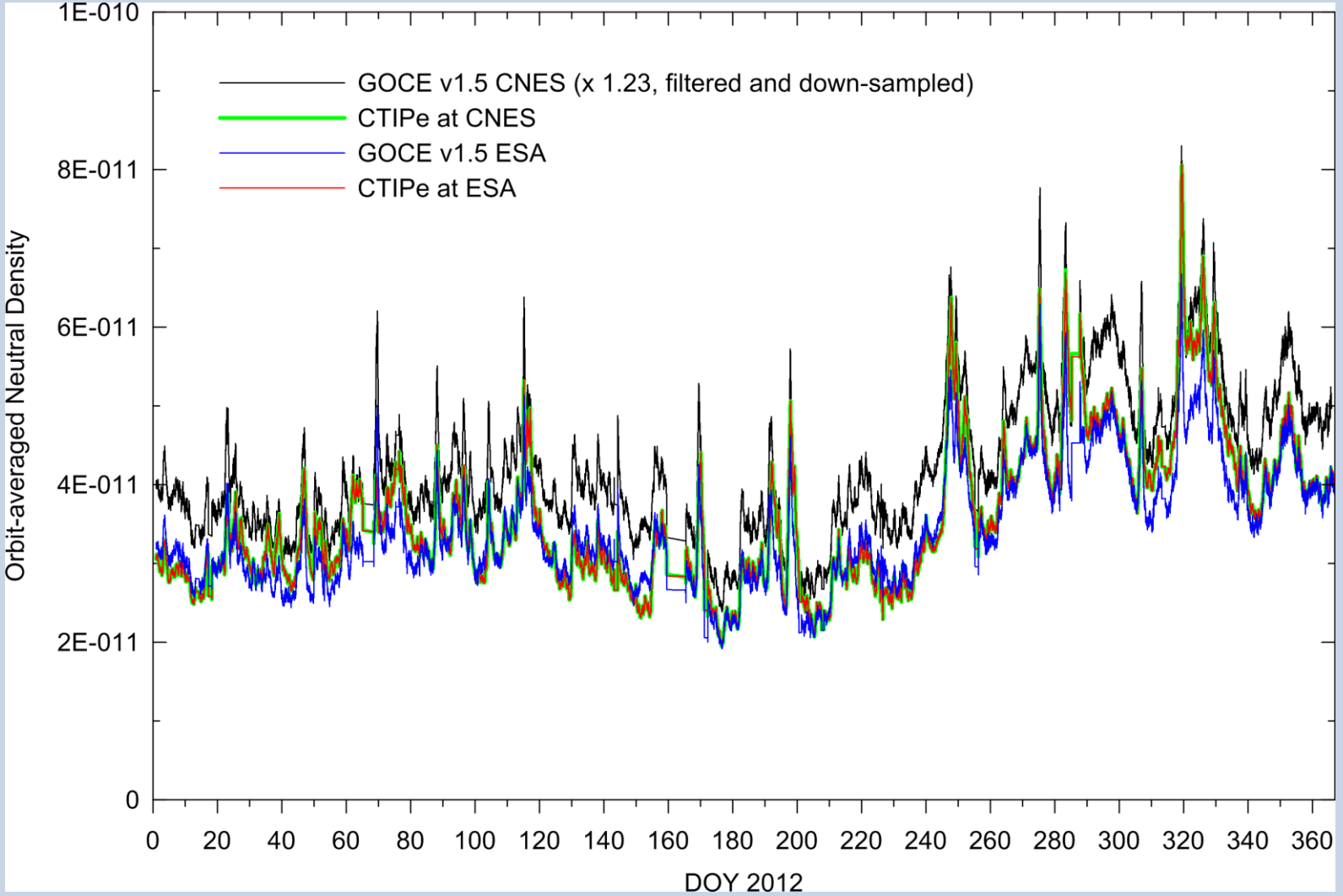
A consequence for model assessment:
bias is a subjective result

GOCE v1.5 ESA & CTIPe (O/C):

rmse:	0.087
bias:	0.966
sd:	0.079
(DTM bias:	1.227)

GOCE HASDM scale & CTIPe (O/C):

rmse:	0.196
bias:	1.200
sd:	0.079
(DTM bias:	0.982)
(NRLMSISE-00 bias:	1.036)



DTM model: data scaling

DTM2013 scale, Option 1: CHAMP scaled to GOCE*1.25, GRACE to CHAMP, and SwarmA to GRACE
(*GOCE*1.25: scaled to HASDM*)

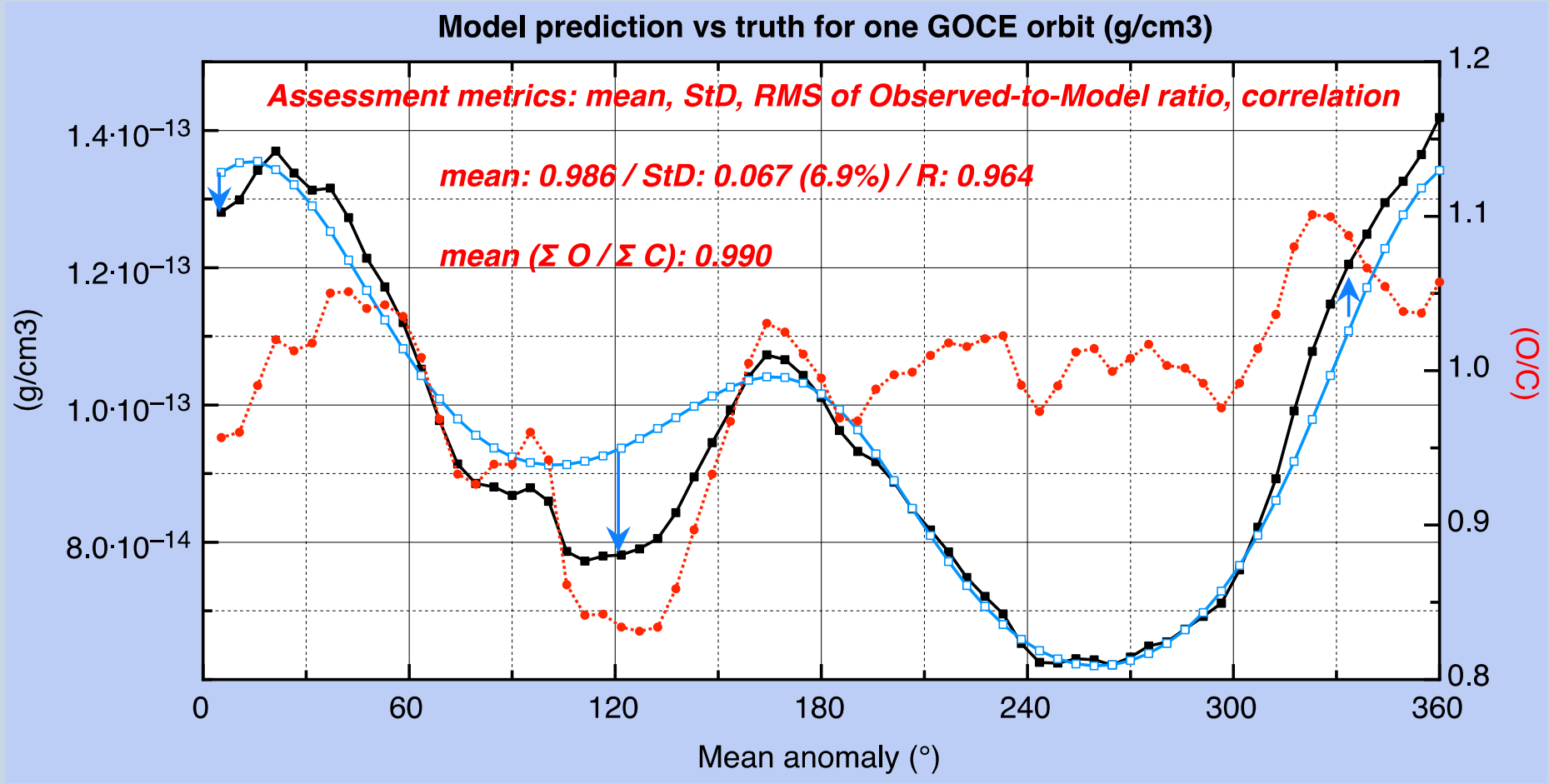
Smaller ρ ← Option 2: CHAMP (TU Delft), GRACE scaled, GOCE (ESA) and SwarmA (ESA)

Smaller ρ ← *Ideally, Option 3:*
New data are being prepared by E. Doornbos et al. (TU Delft) based on new geometry models; densities from GOCE/CHAMP/GRACE/SwarmA are inferred in a consistent way, and consequently data scaling should not be necessary.
But not available yet….

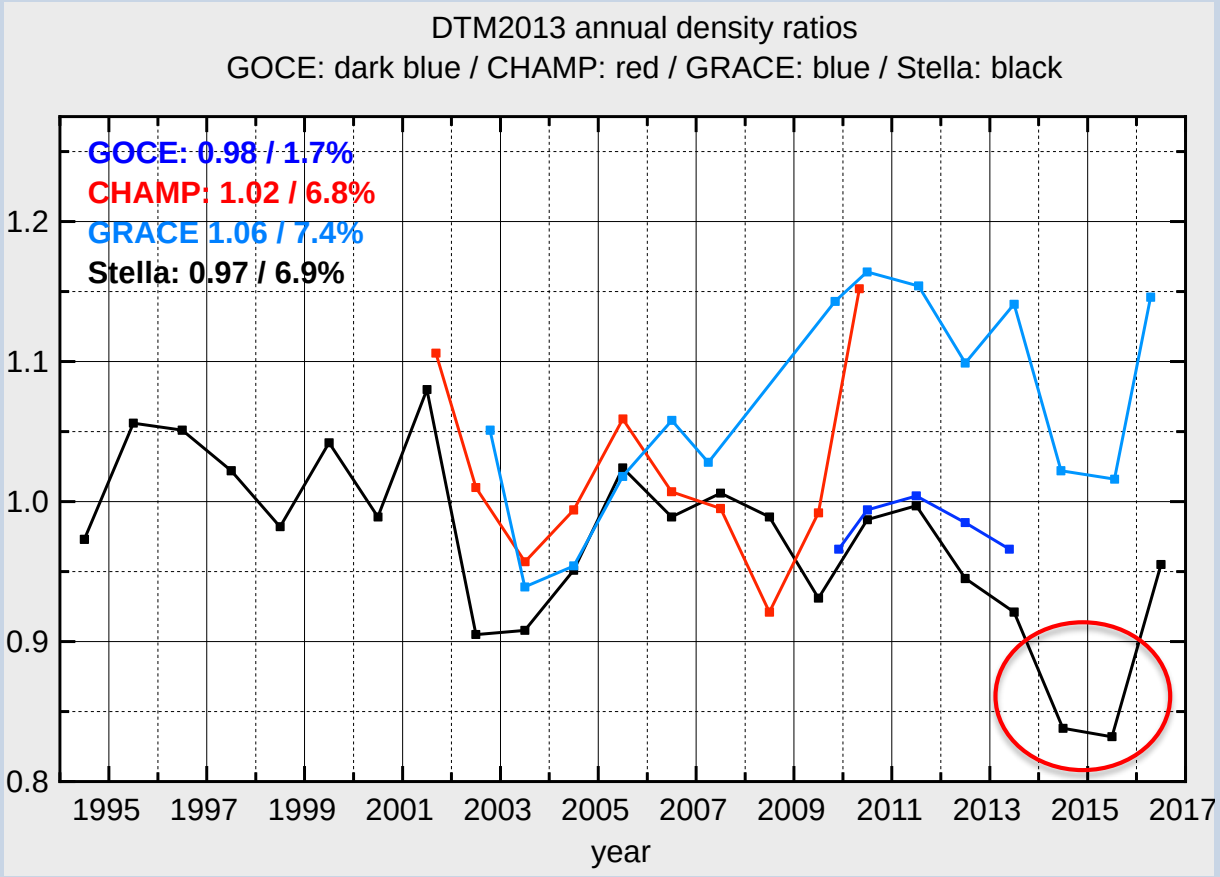
Metrics to quantify model improvement are selected and benchmarks are established:

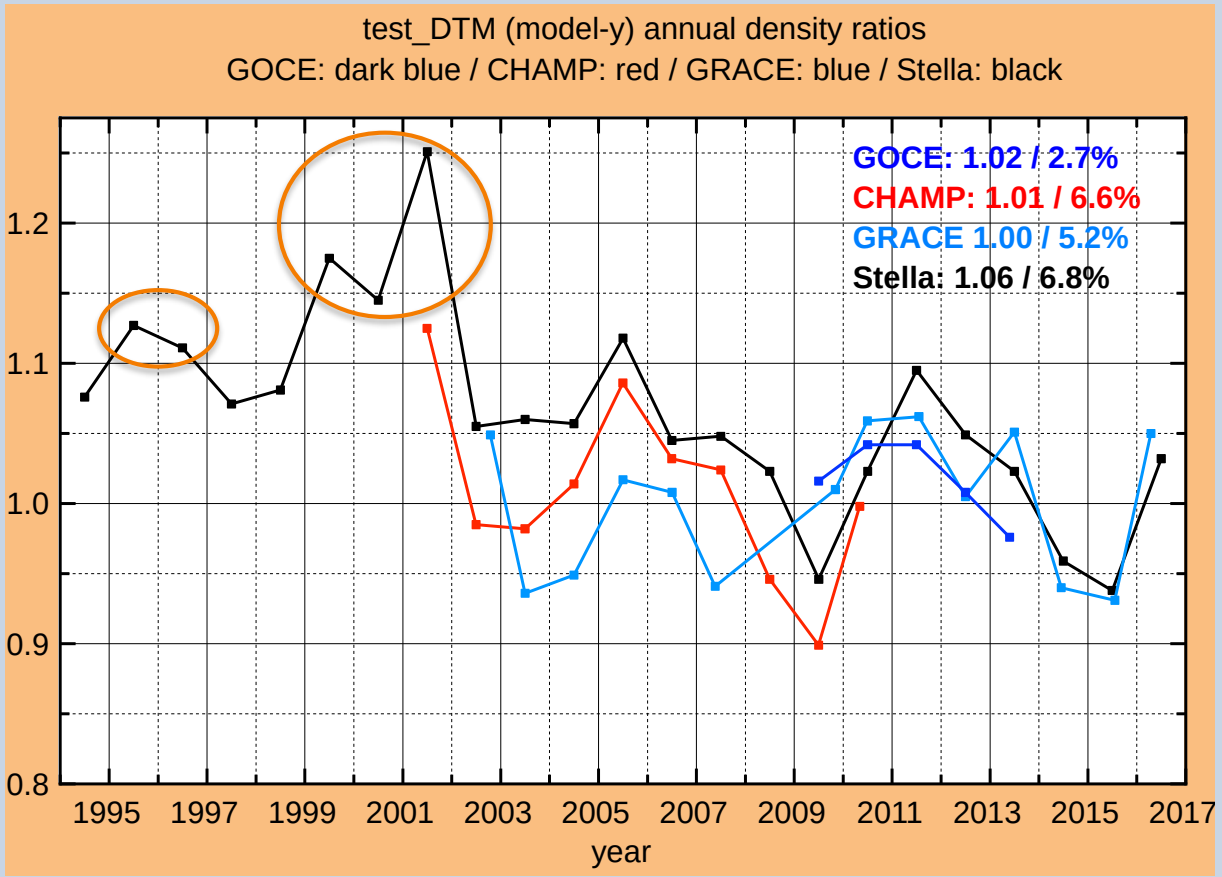
Mean and StD are computed on several time scales:

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



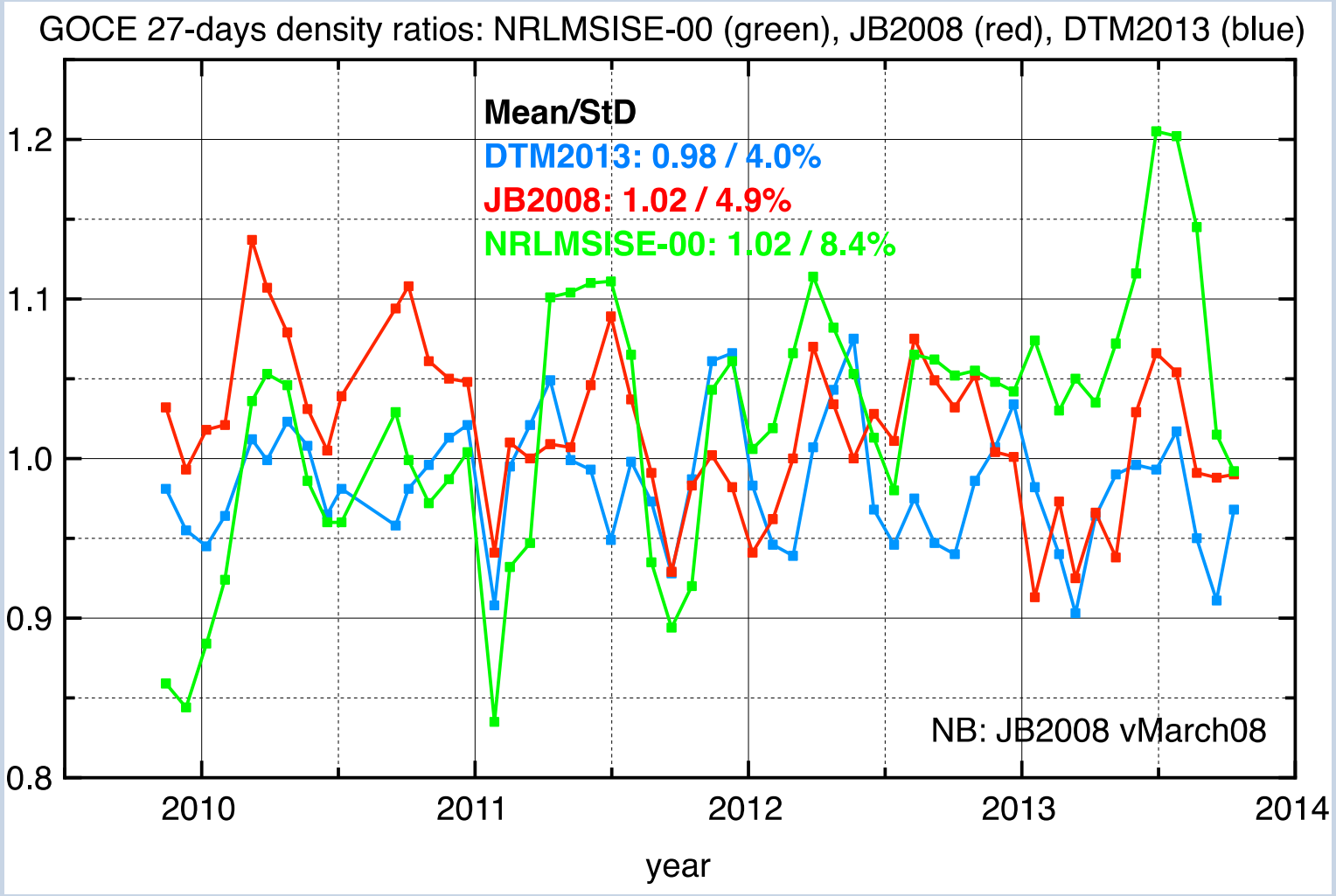
Present status: test model with scaling Option 2 (*~25% smaller densities*!)





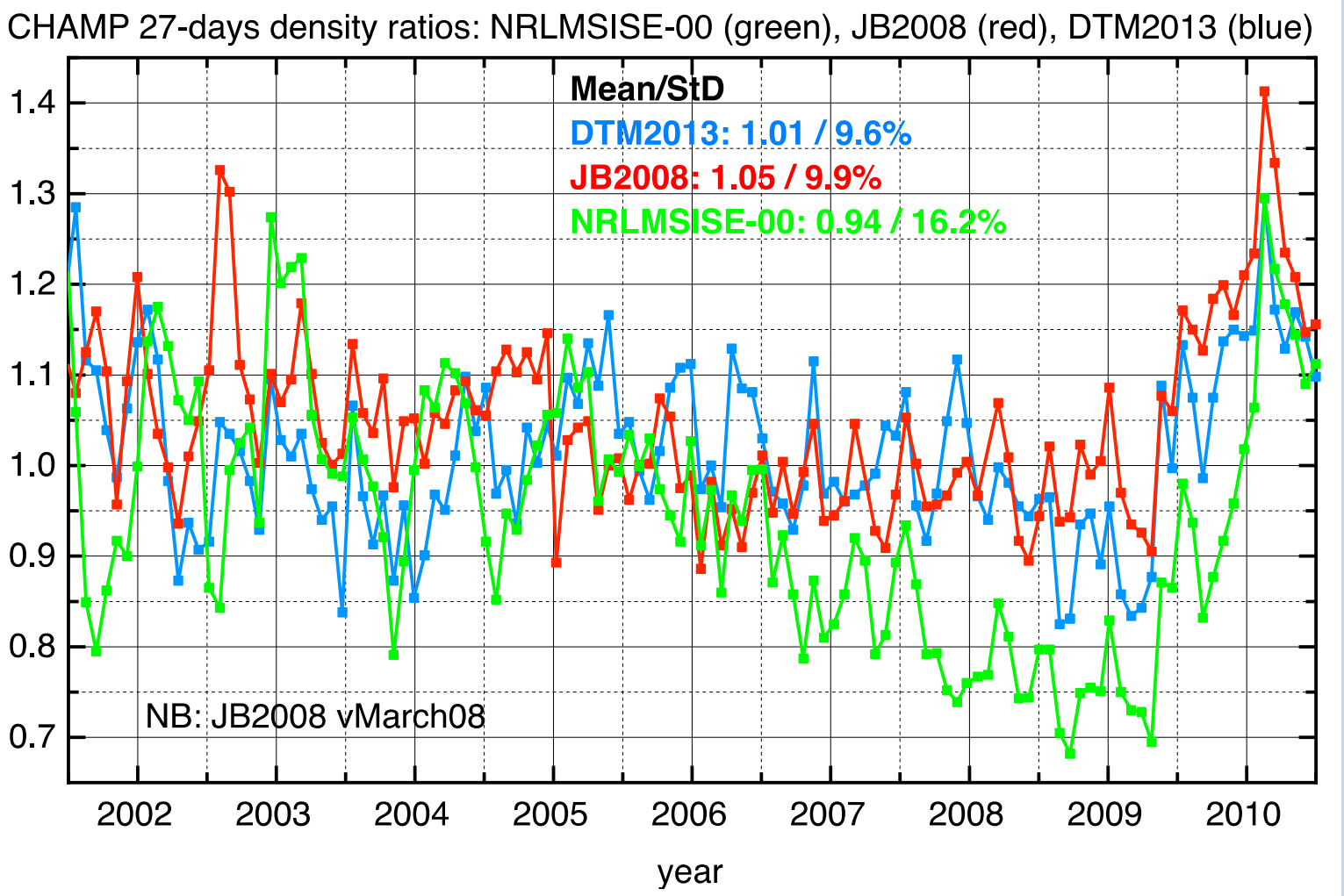
Benchmark examples: 27-day time scale

GOCE
250 km



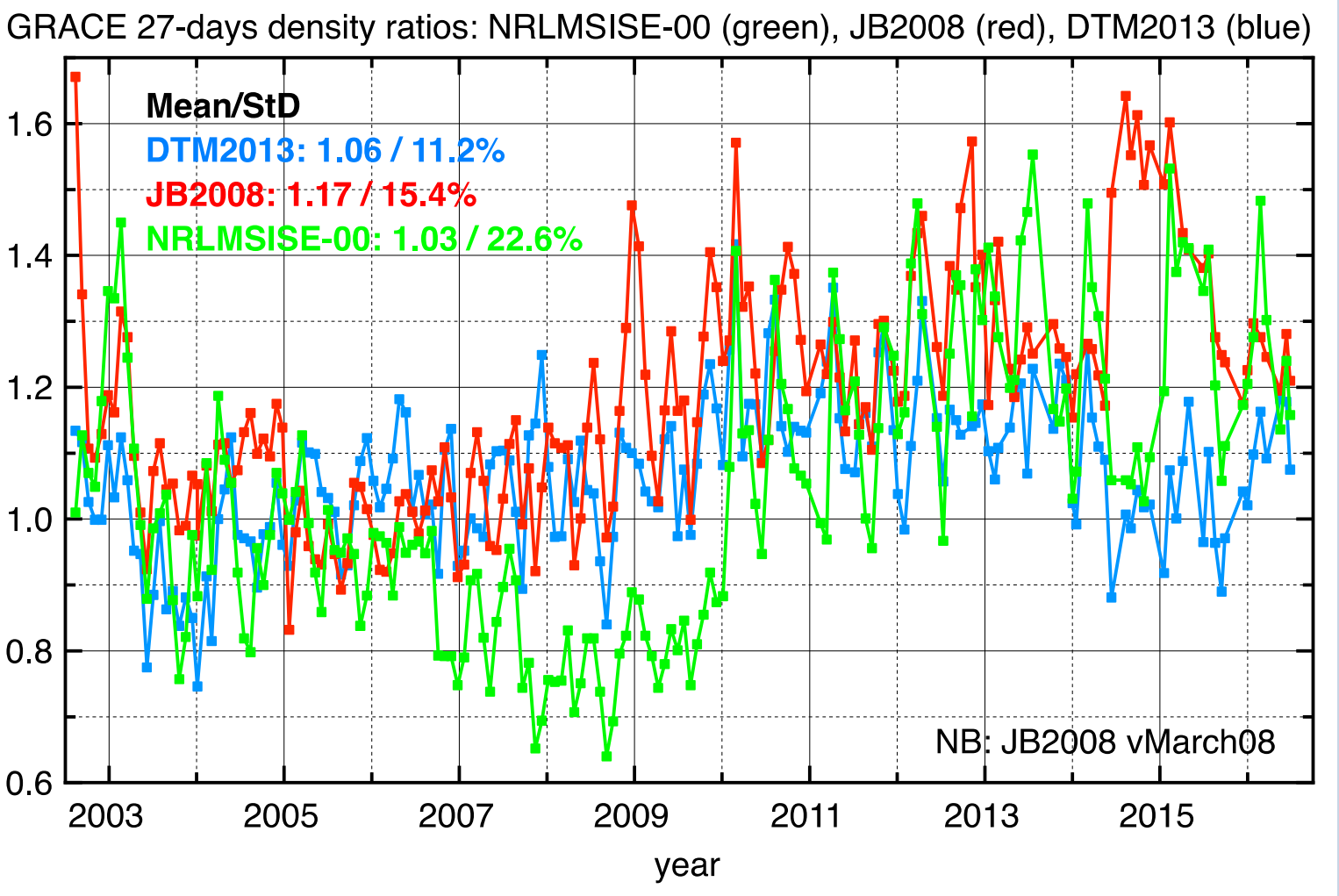
Benchmark examples: 27-day time scale

CHAMP
400-300 km



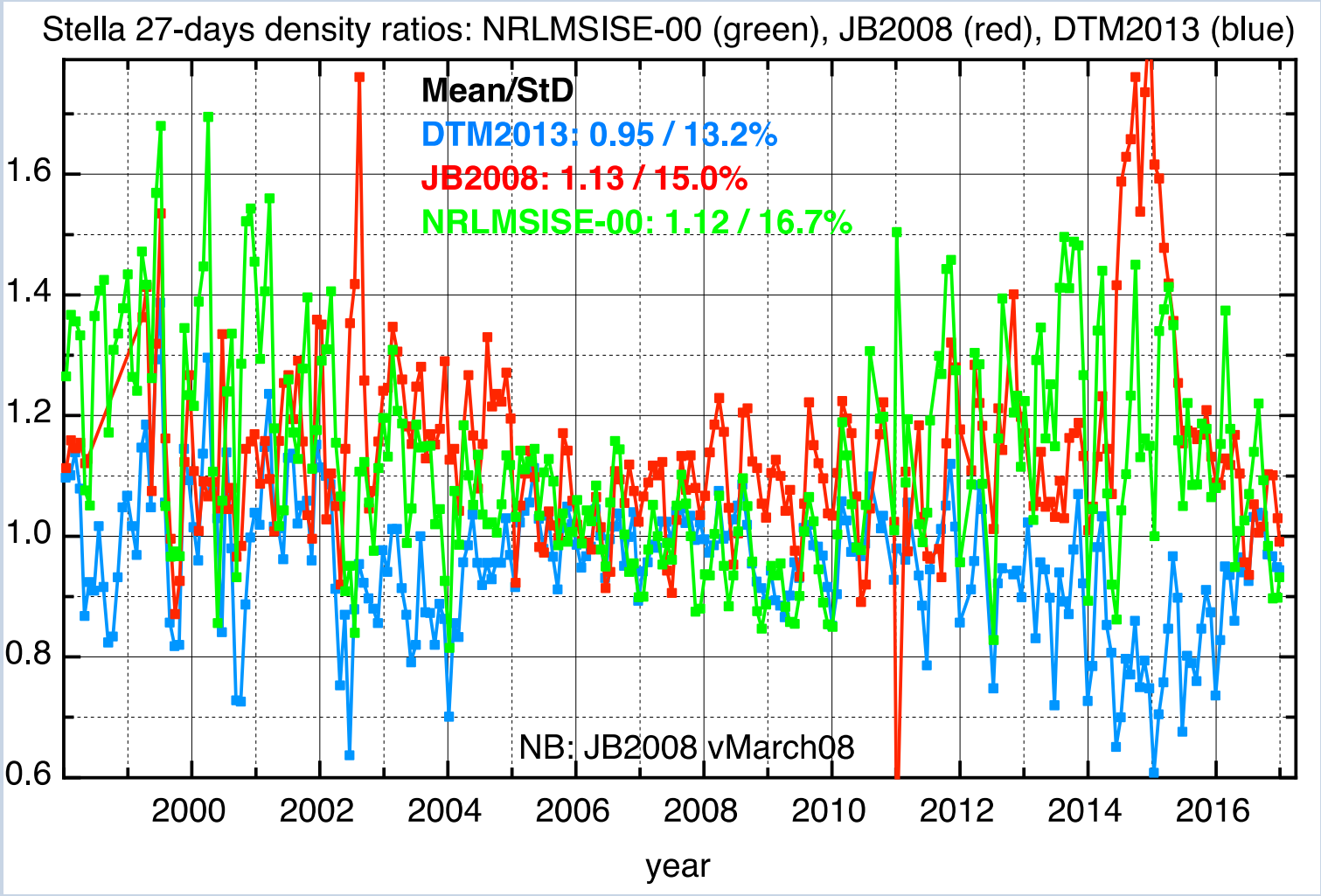
Benchmark examples: 27-day time scale

GRACE
480-330 km

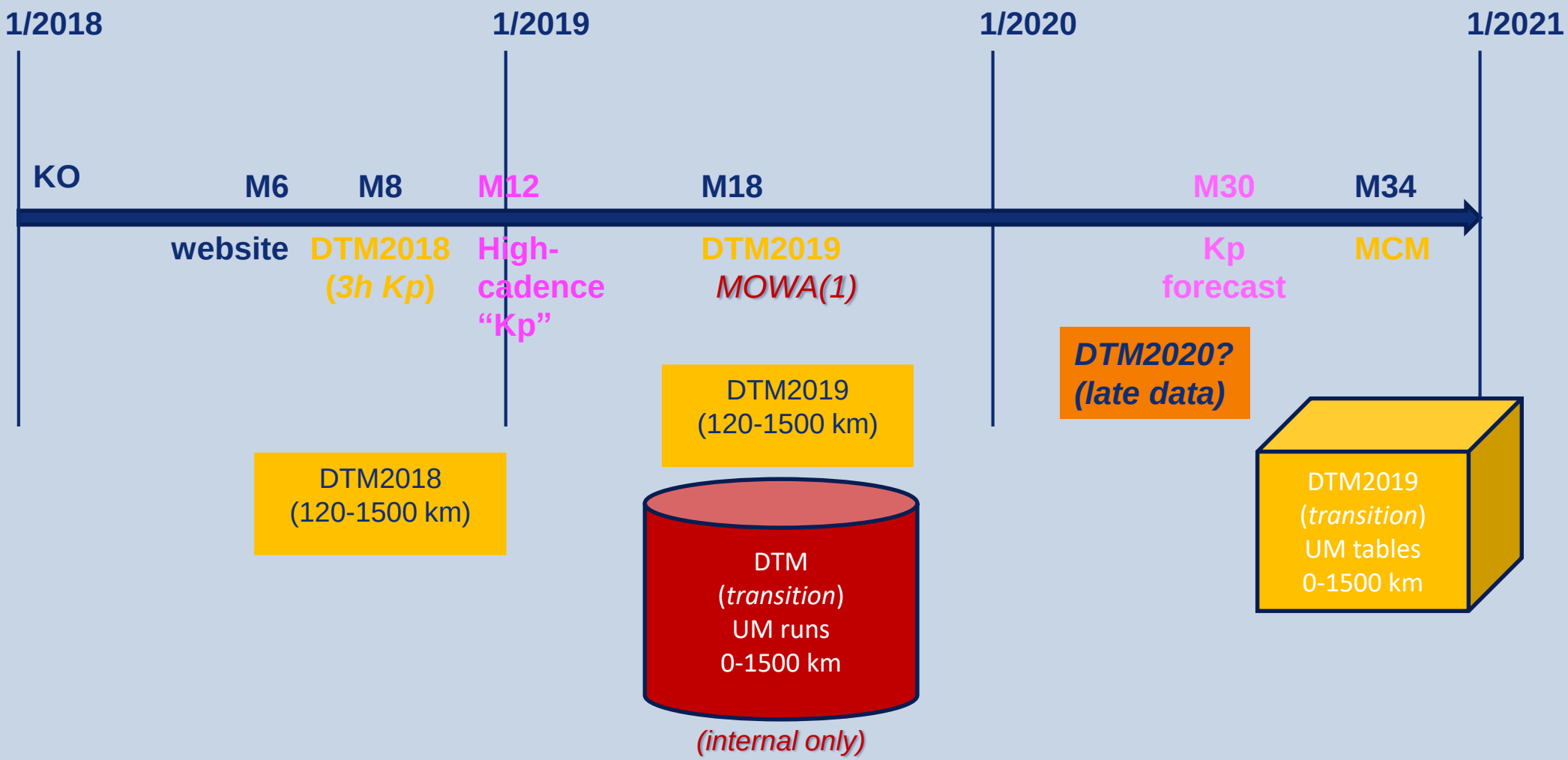


Benchmark examples: 27-day time scale

Stella
815 km



Timeline and products



Website

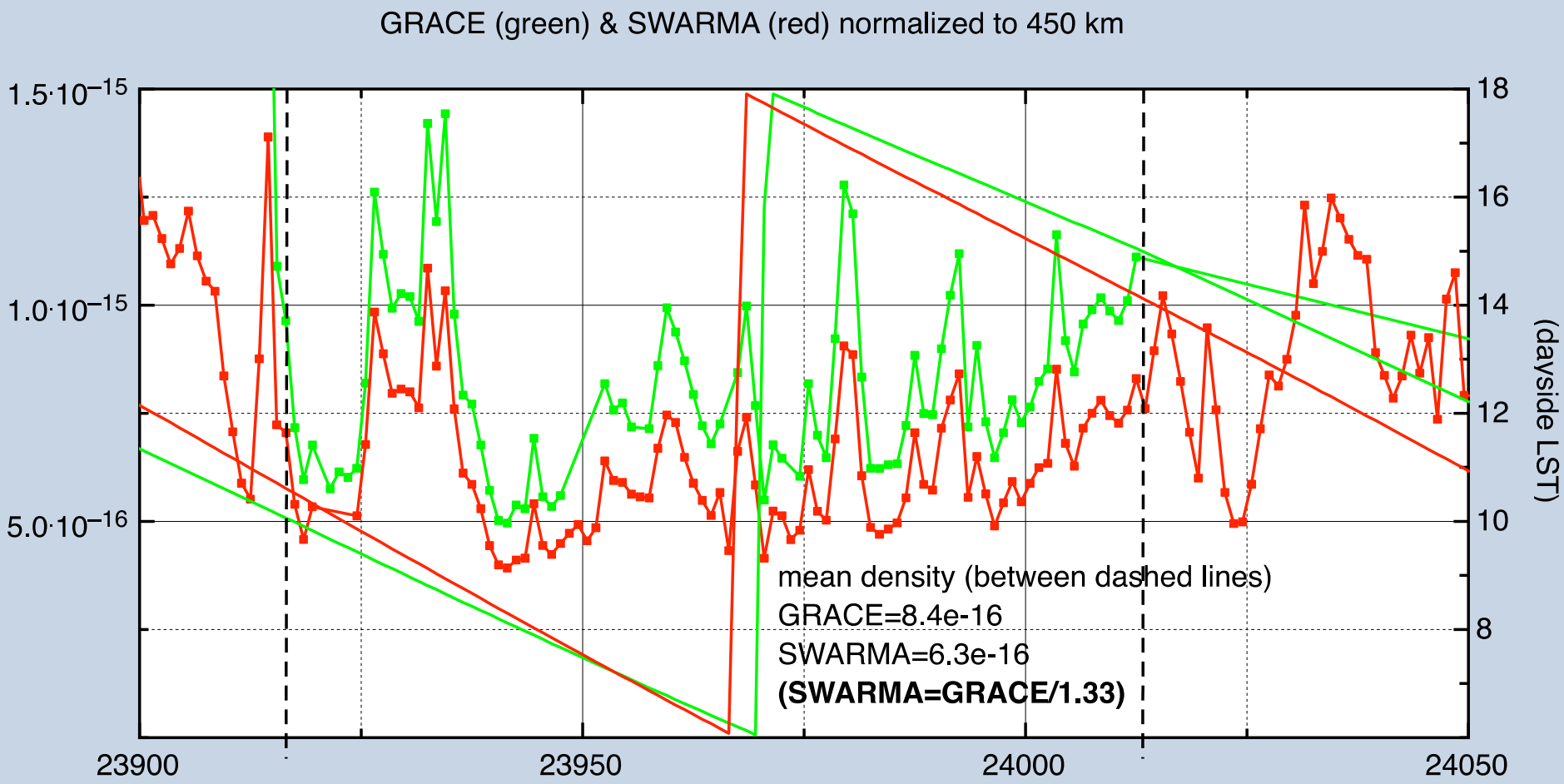
http://swami-h2020.eu

Back up slides

GRACE and SwarmA at 450 km (June 2015)

Determination of consistent scale factors is necessary but complicated due to:

- Altitude
- Epoch
- LST



GOCE and CHAMP at 290 km (Jan & May 2010)

Determination of consistent scale factors is necessary but complicated due to:

- Altitude
- Epoch
- LST