Space Weather Atmosphere Model and Indices SWAMI

The H2020 project SWAMI: Development of a Whole Atmosphere Model and Kp Indices
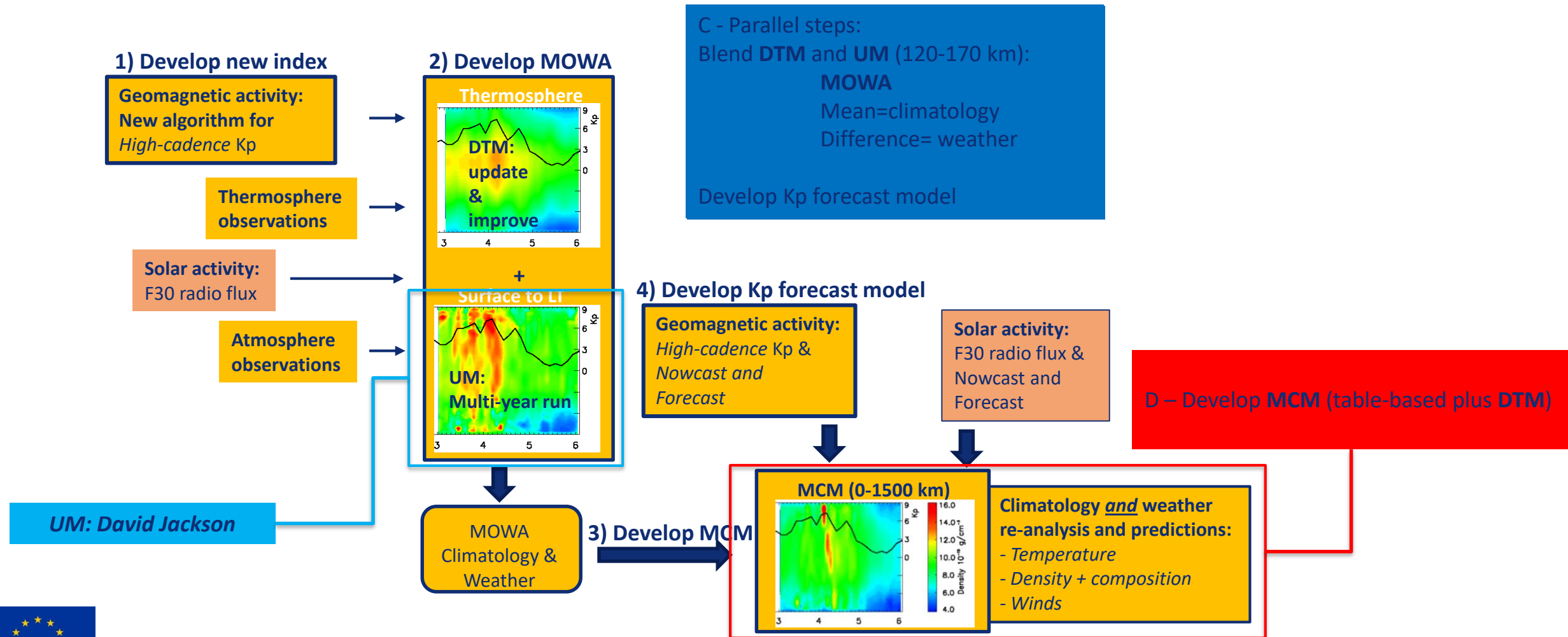
The DTM thermosphere model

Sean Bruinsma, CNES, Toulouse, France

David Jackson, Met Office, Exeter, United Kingdom

Claudia Stolle, GFZ Potsdam, Germany

Sandra Negrin, Deimos Space, Tres Cantos, Spain

WA Modelling Workshop
Deimos Space, Tres Cantos
13 June 2018

- **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.**
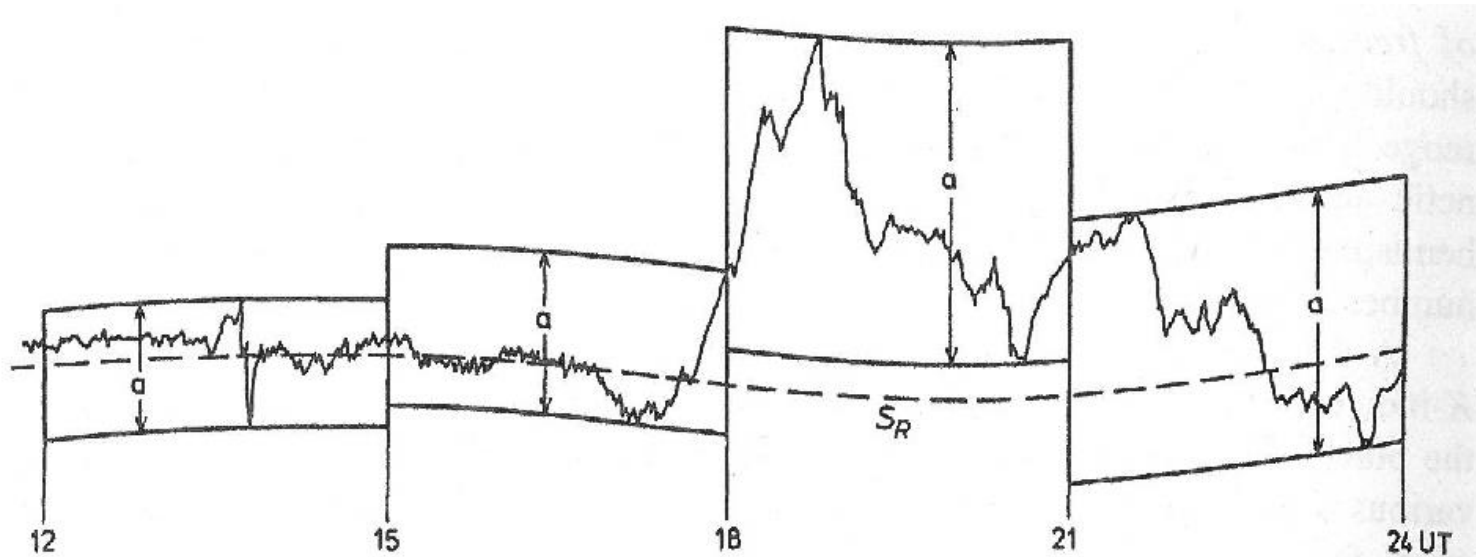
1) Develop new index

Geomagnetic activity:
New algorithm for
High-cadence Kp

Thermosphere
observations

Solar activity:
F30 radio flux

Atmosphere
observations

2) Develop MOWA

Thermosphere

DTM:
update
&
improve

+

Surface to LT

UM:
Multi-year run

C - Parallel steps:
Blend **DTM** and **UM** (120-170 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

D – Develop **MCM** (table-based plus **DTM**)

UM: David Jackson

MOWA
Climatology &
Weather

3) Develop MCM

MCM (0-1500 km)

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

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

$$a = 0 \ldots 5 \ldots 10 \ldots 20 \ldots 40 \ldots 70 \ldots 120 \ldots 200 \ldots 330 \ldots 500 \text{ nT} \ldots$$
$$K = \quad 0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \cdot \quad 7 \quad 8 \quad 9$$

Geomagnetic activity index K

o Only regard horizontal components

o Subtract quiet curve from magnetogram

o Determine range (it is a **Range** index)

o Translate range into quasi-logarithmic K value (see table)

o **K**: "**K**ennziffer" (= planetary index)

o 3-hourly index, values from 0, 1, … to 9

o Previously hand-scaled, now algorithms to derive it from 1-minute data

o 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)

Variations of all Kp Stations, 2017-09-07
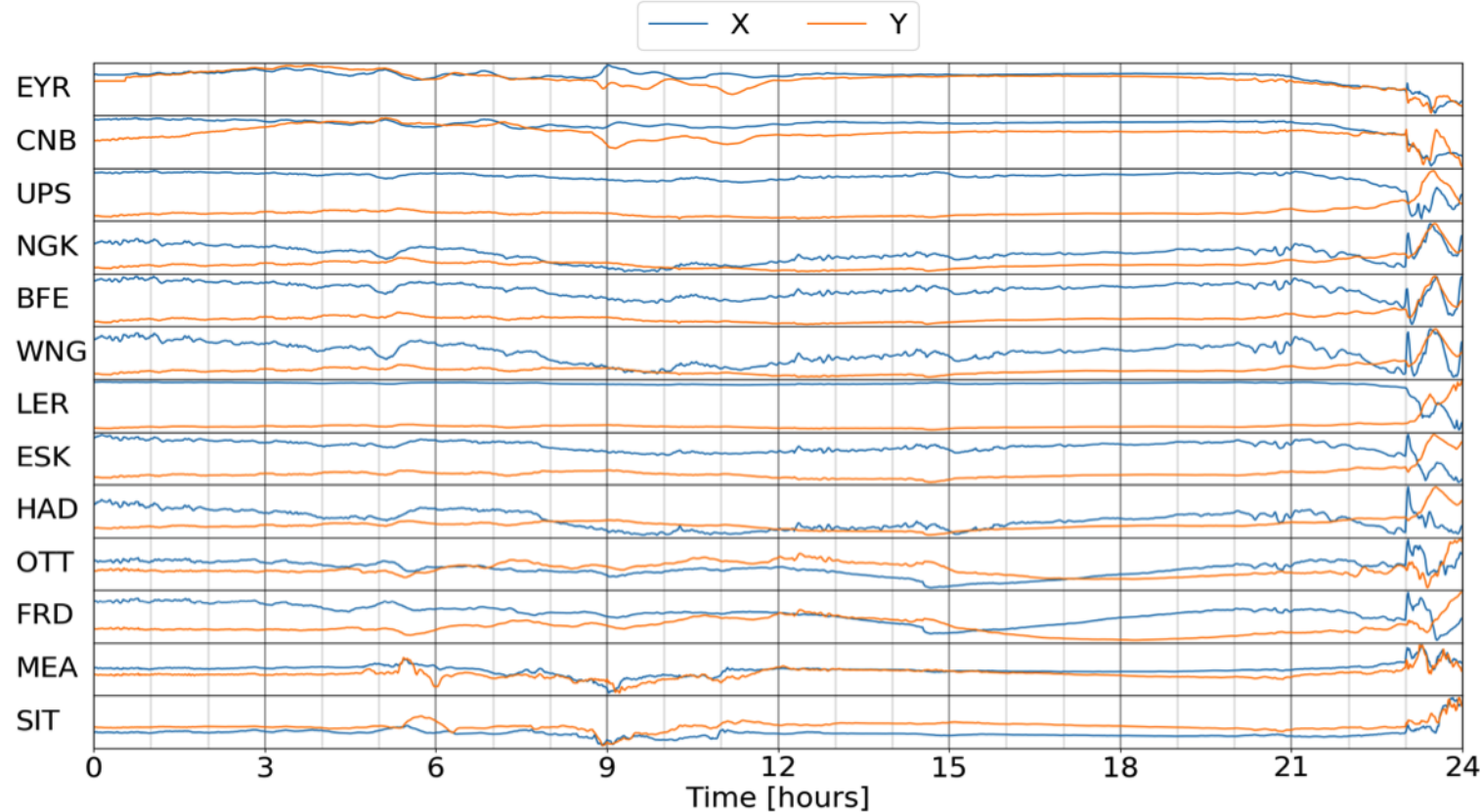
Developing H and Hp: new, high-cadence, K and Kp-like indices

o H is the local index

o Hp is the planetary index (following algorithm for calculating Kp from K)

o H90, H60, H30 and Hp90, Hp60, Hp30 are indices for 90, 60 and 30 minutes cadence, respectively

o 90 minutes LEO orbital period

o 60 minutes popular with users

o 30 minutes just to investigate properties

o A clear advantage of a high-cadence index is the improved time resolution to better define timing of geomagnetic activity, especially onset time.

2017-09-07 Method 'Range'
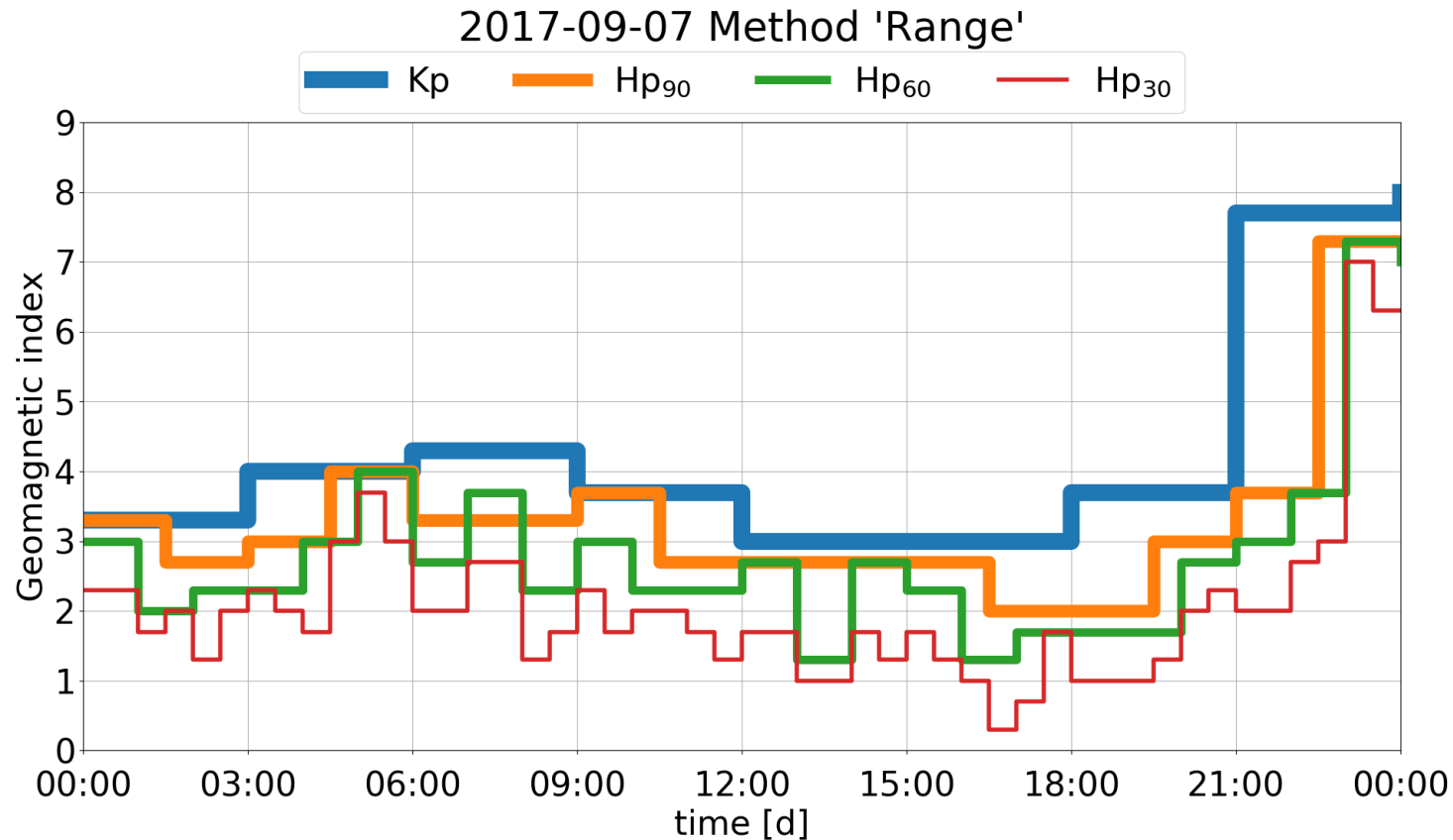
General problem of high-cadence range indices

o If we just keep the algorithm for K and use it for lower time resolution, then the resulting values are generally lower

o Such values can not reasonably be used for models that have been developed using Kp

o Either, 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.

Model predictions at 250 km, Kp < 2:
- o 2009-12-14 (mean F10.7 = 75 sfu)
- o 2011-12-14 (mean F10.7 = 144 sfu)

<u>DTM is a semi-empirical model:</u>
- Low resolution
- Easy and fast in use (*point-wise predictions*)
- Relatively accurate
- Climatology

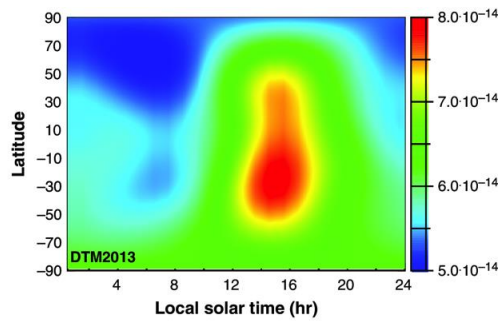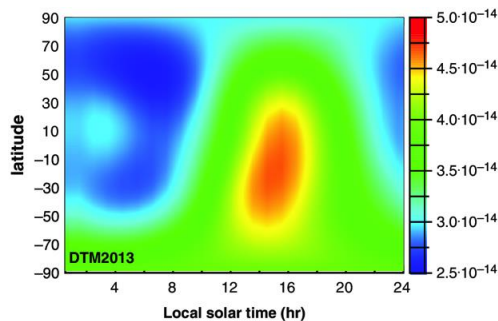Temperature and constituents (i.e., the winter Helium bulge is present) are modeled:

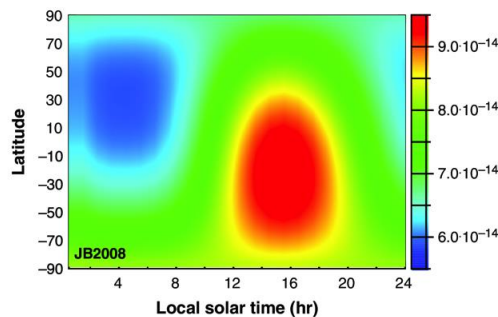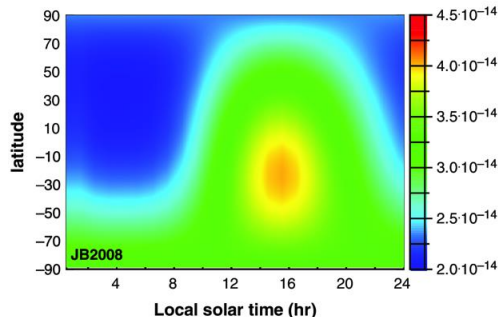*Concentration at 120 km*   *Height function*

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

Spherical harmonics
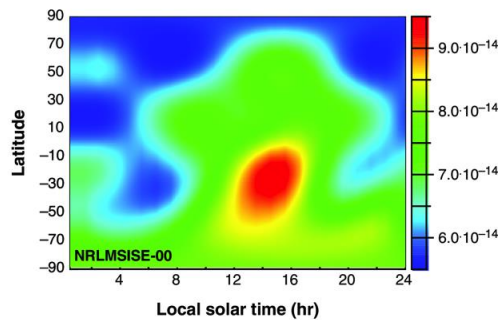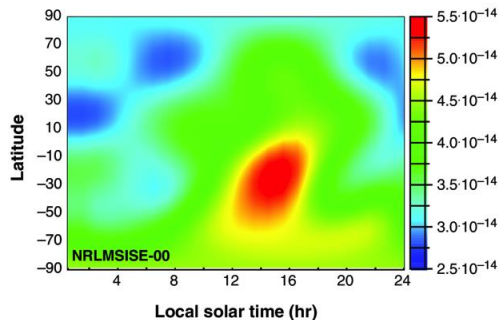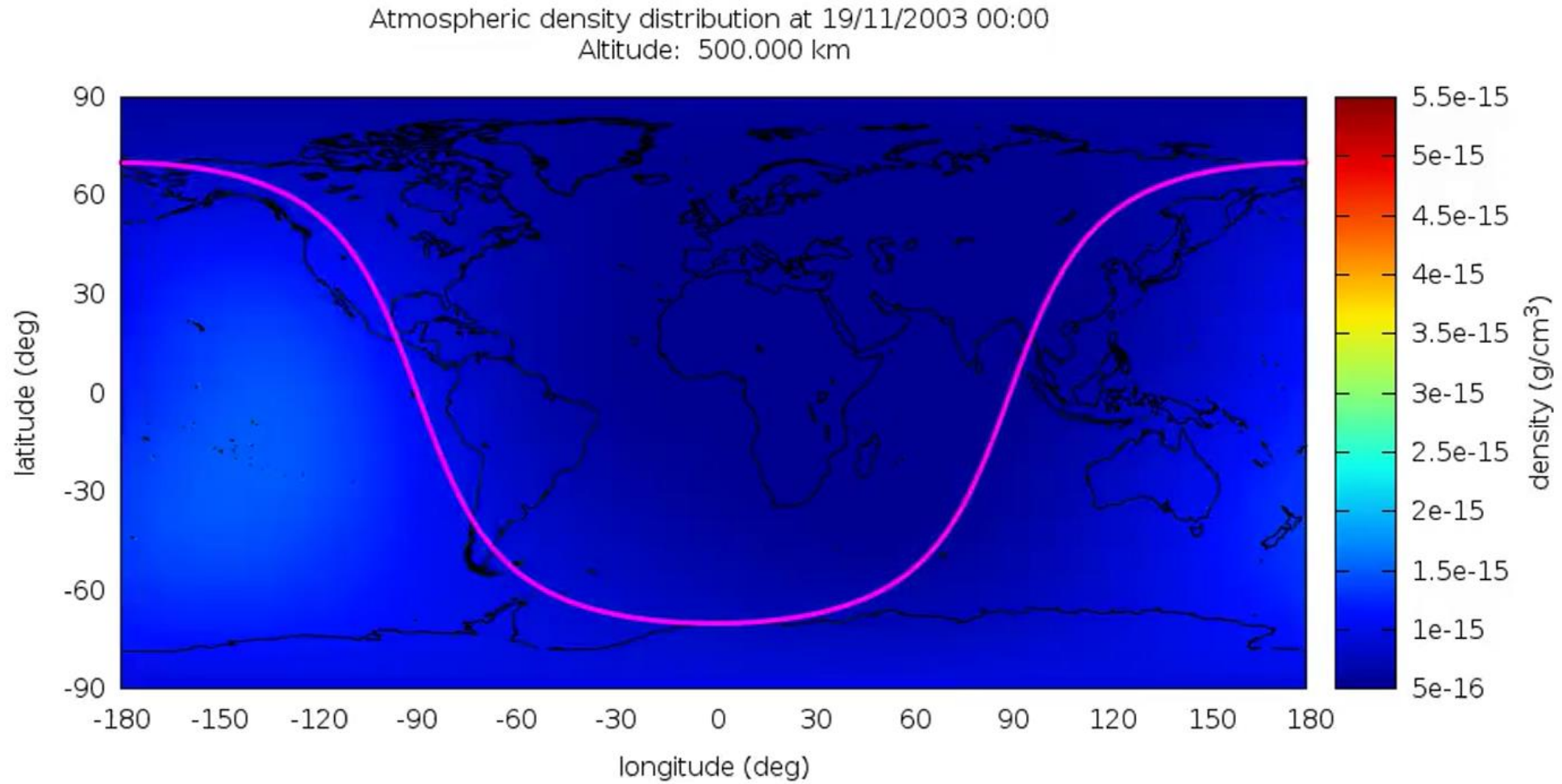
Atmospheric density distribution at 19/11/2003 00:00
Altitude: 500.000 km

8

Data used in the construction of: <u>DTM2013</u>   <u>DTM2018 additional</u>

✓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

<u>And possibly:</u>

- **GUVI, LYRA O/N2?**
- **Microscope?**
- **Dellingr?**
- **GOLD O/N2 & T?**
- **SABER NO?**
- **APOD?**
- **Cryosat2?**
- **…?**
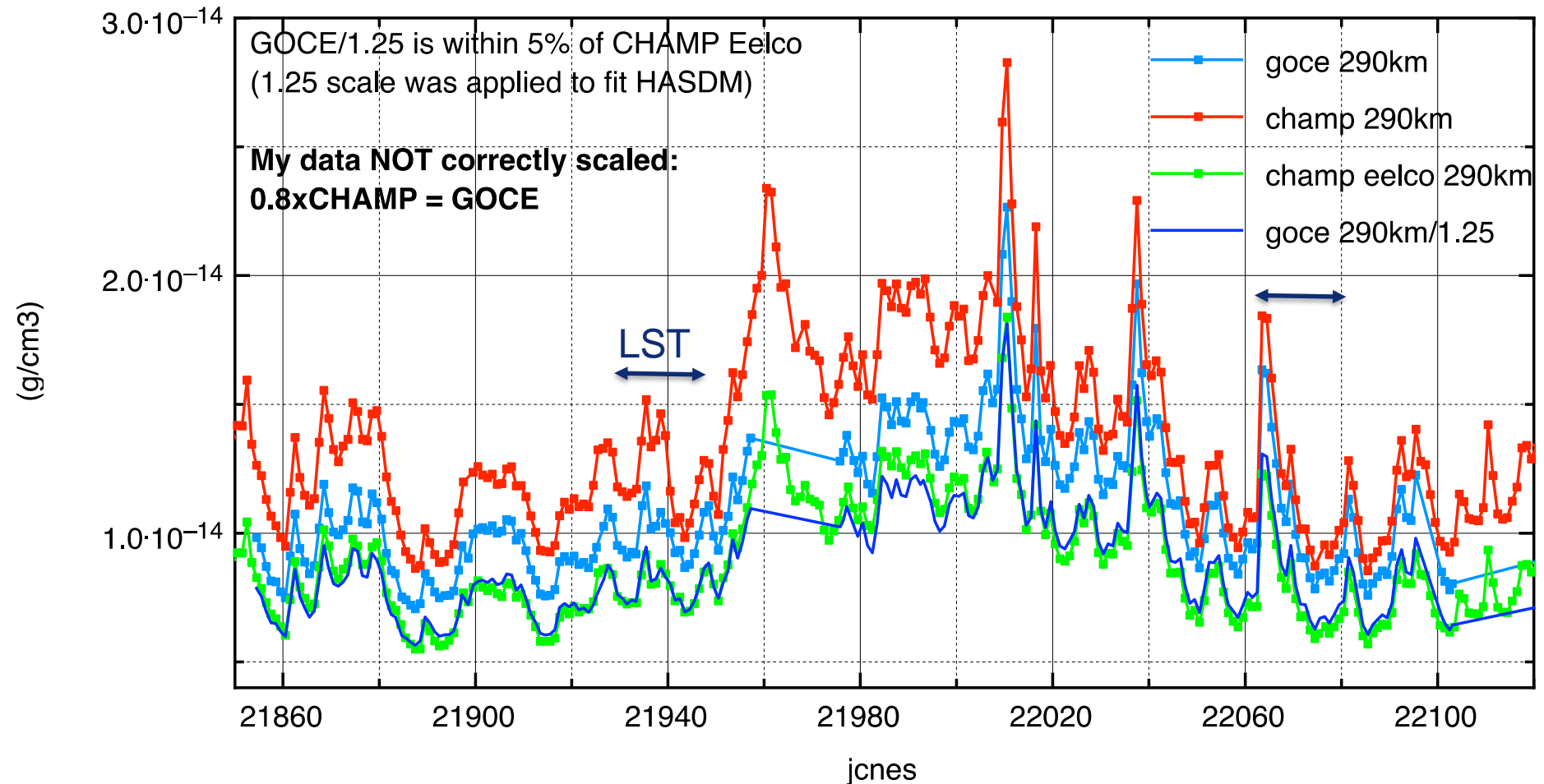
Very few Hi-Res density observations:
- Below 200 km
- Above 500 km
- For strong cycle max

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

81-day mean F30

(mass spectrometers)

(tentative)

OGO-6

AE-C / AE-E

CACTUS

DE-2

SETA2

(sfu)

DE2 Helium (16-30 August 1981)

altitude (km)

latitude

Determination of consistent scale factors is necessary but complicated due to:
- Altitude
- Epoch
- LST

daily mean density at 290 km (with JB2008)

GOCE/1.25 is within 5% of CHAMP Eelco
(1.25 scale was applied to fit HASDM)

My data NOT correctly scaled:
0.8xCHAMP = GOCE

Legend:
- goce 290km
- champ 290km
- champ eelco 290km
- goce 290km/1.25

And consequences for model assessment:
bias is a subjective result

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

rmse_ln:	0.087
bias_ln:	0.966
sd_ln:	0.079
(DTM bias_ln:	1.227)

GOCE HASDM scale & CTIPe (O/C):

rmse_ln:	0.196
bias_ln:	1.200
sd_ln:	0.079
(DTM bias_ln:	0.982)
(NRLMSISE-00 bias_ln:	1.036)
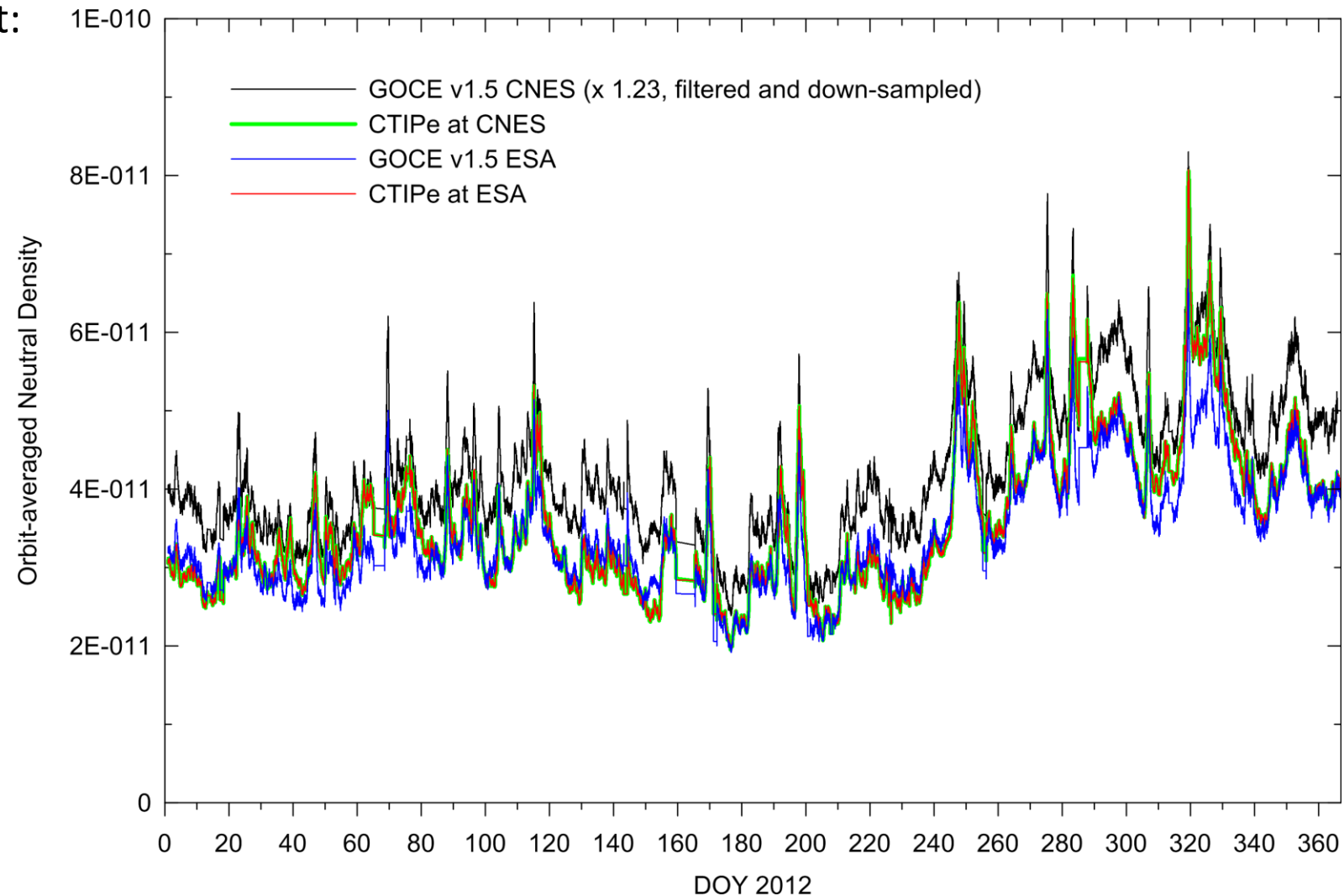
Scheme 1: same scaling as DTM2013 (e.g. GOCE * 1.25)

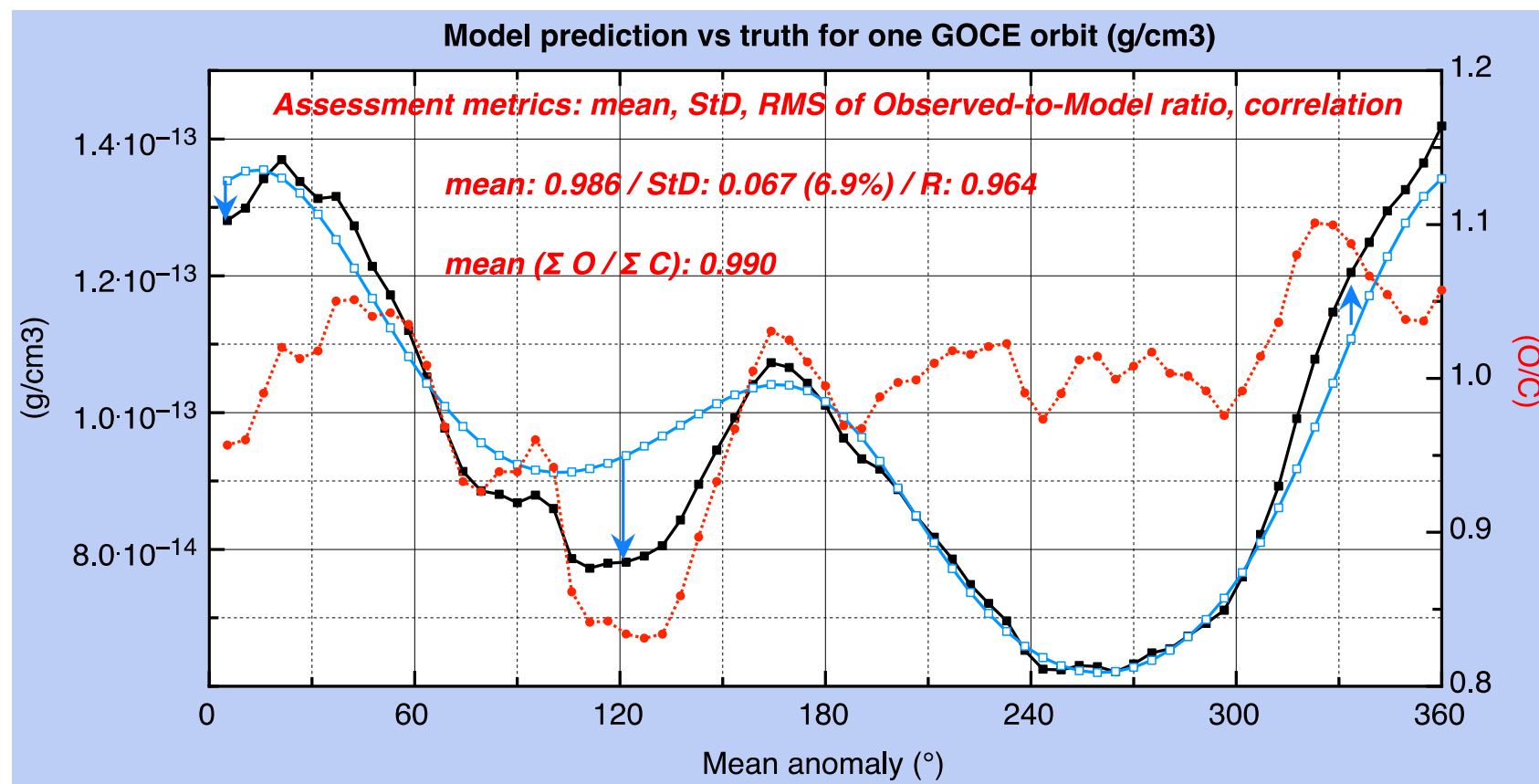Scheme 2: CHAMP scaled to GOCE*1.25, GRACE to CHAMP and SwarmA (ESA)

Smaller ρ ← Scheme 3: CHAMP and GRACE scaled to GOCE (ESA) and SwarmA (ESA)

Smaller ρ ← Scheme 4:
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….

Scheme 1: negligible improvement, abandon

Scheme 2: test models are developed and assessed. Ongoing activity (8/2018)

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

Model prediction vs truth for one GOCE orbit (g/cm3)

Assessment metrics: mean, StD, RMS of Observed-to-Model ratio, correlation

mean: 0.986 / StD: 0.067 (6.9%) / R: 0.964

mean (Σ O / Σ C): 0.990

Benchmark example GOCE & DTM2013: time scales (*4yr – ½ orbit*)

Mean O/C all data: 0.993

StD of:

annual O/C time series:	0.014
monthly time series:	0.037
daily time series:	0.061
½ rev time series (dusk):	0.069
½ rev time series (dawn):	0.078
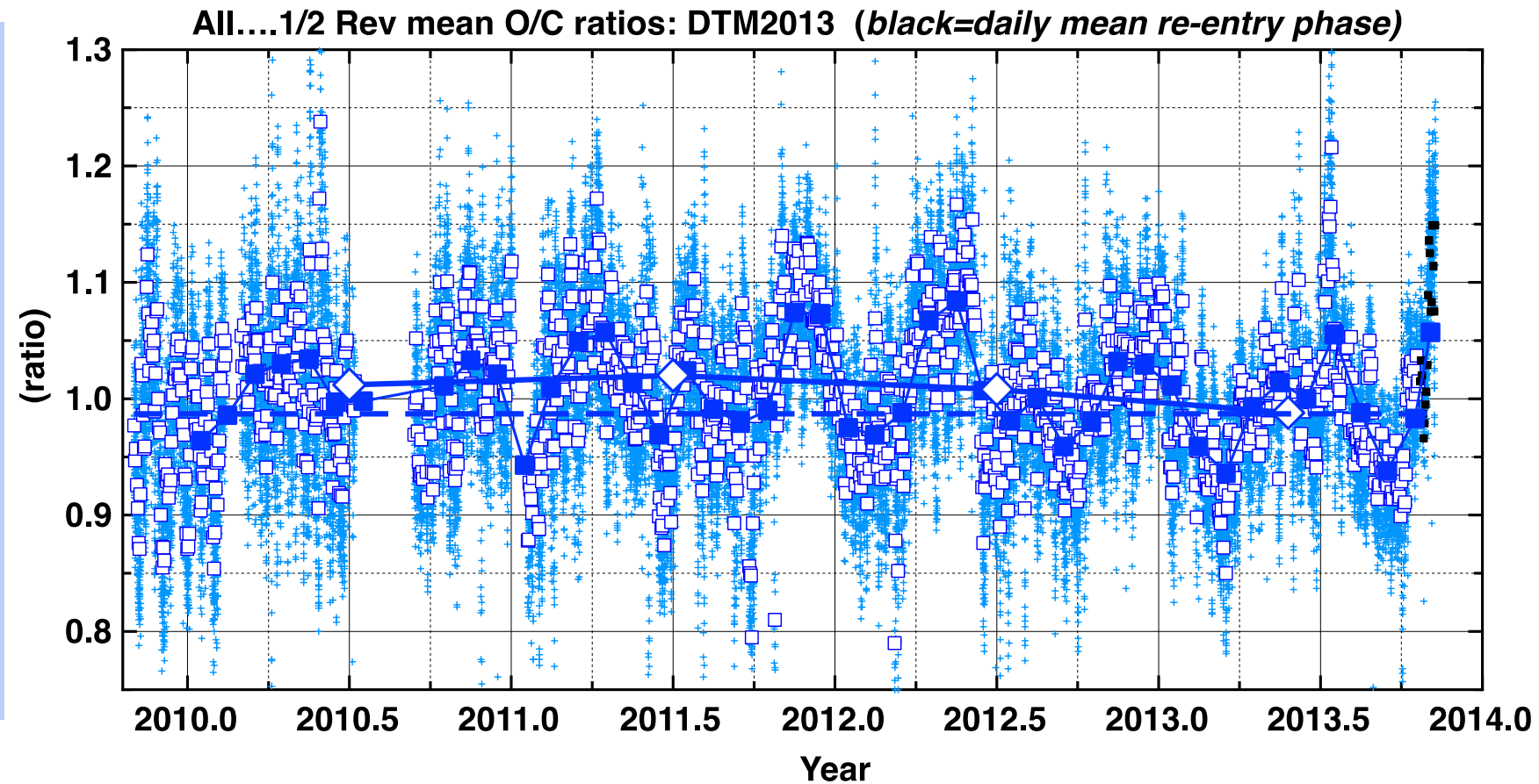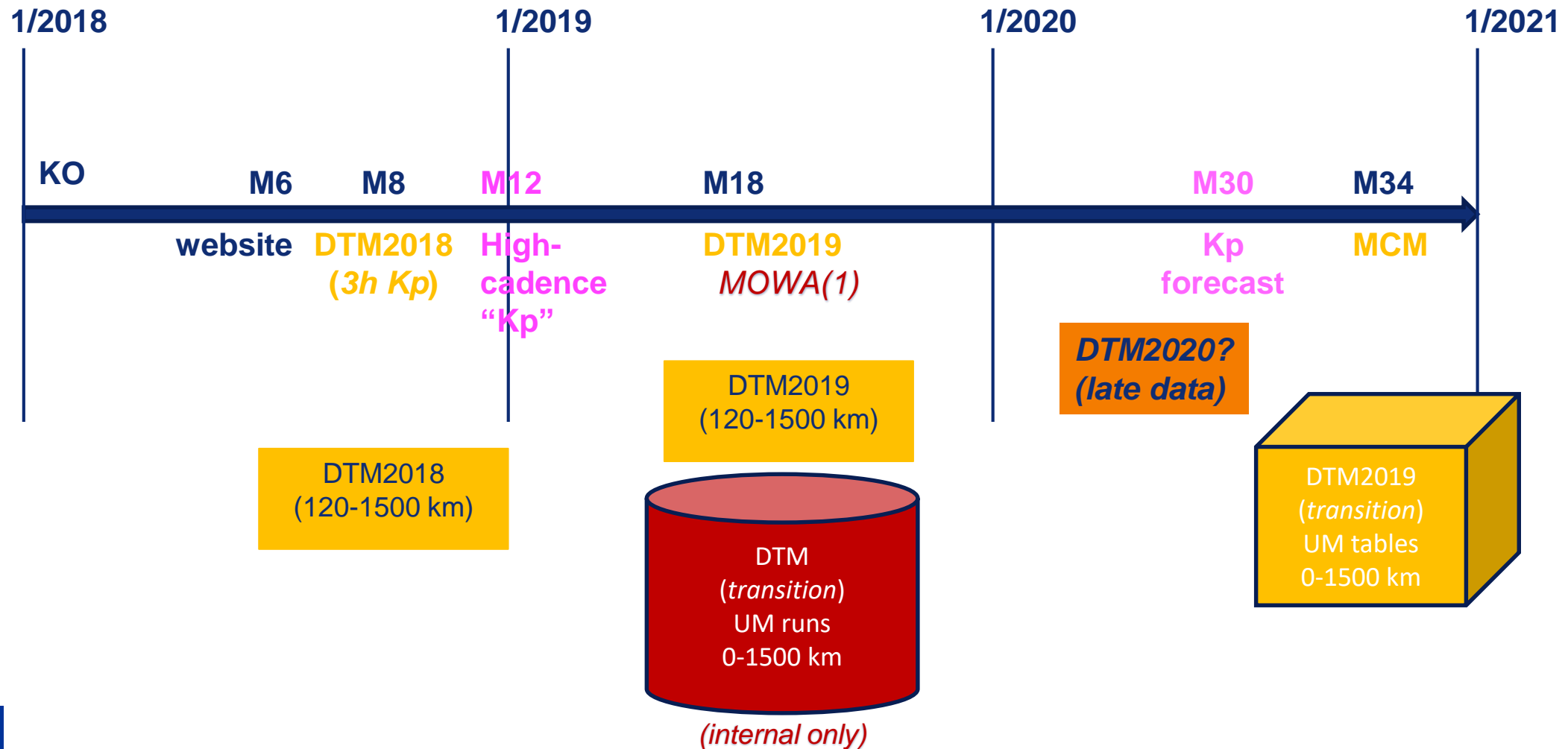
All….1/2 Rev mean O/C ratios: DTM2013 (*black=daily mean re-entry phase*)

(Idem for CHAMP, GRACE…)

1/2018   1/2019   1/2020   1/2021

KO

M6   M8   M12   M18   M30   M34

website   DTM2018   High-cadence "Kp"   DTM2019   Kp forecast   MCM

DTM2018 (*3h Kp*)

MOWA(1)

DTM2019 (120-1500 km)

DTM2018 (120-1500 km)

DTM2020? (late data)

DTM (*transition*) UM runs 0-1500 km

(internal only)

DTM2019 (*transition*) UM tables 0-1500 km

http://swami-h2020.eu

Neutral density models used in operations and research

The full altitude range of 0-1500 km is important (*all replies*!)

Density error estimate is requested as error bar or percentile
- Accuracy requirement is not quantified
- Also requested: temperature & error, horizontal winds, composition, pressure

Neutral density forecast on all horizons (day, week, month, solar cycle)
- Most found the forecast accurate
- Most need predictions for both average and storm conditions
- No requirement on continuity of service

Model output requested as: point-wise, altitude profile, grid

Survey-based recommendations for the new geomagnetic indices, Hp, with higher temporal resolution

✓ Temporal resolution: 60 minutes (Hp60)

✓ Data format: tab (simple text format of 3-hourly Kp index)

✓ Index update rate: less then 3 hours

✓ Forecast horizon: 6 and 72 hours

✓ Interest in: definitive, nowcast and forecast

✓ Most frequent purpose: data analysis and modelling

Thank you