THE NEED FOR DATA IN ATMOSPHERE MODELS

TOTAL DENSITY, COMPOSITION, INDICES - *AND MORE*

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COMET ORB / ENV / OPS
13 May 2022

Outline

1. Thermosphere model development. Example: DTM2020

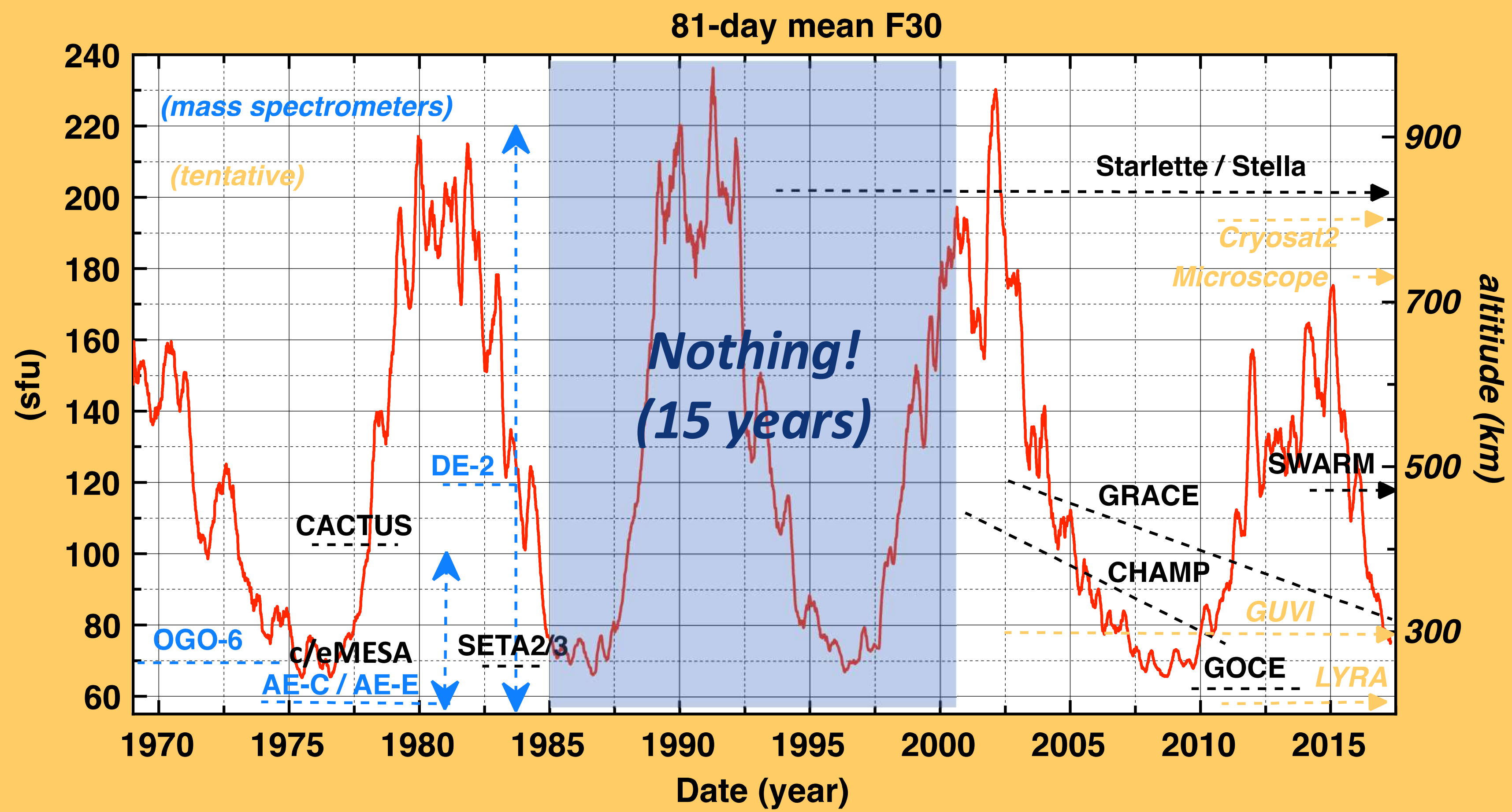
2. Reasons for relatively slow progress in thermosphere model improvement

3. A possible way forward

2 - Data used in the construction of DTM *(sparse data)*

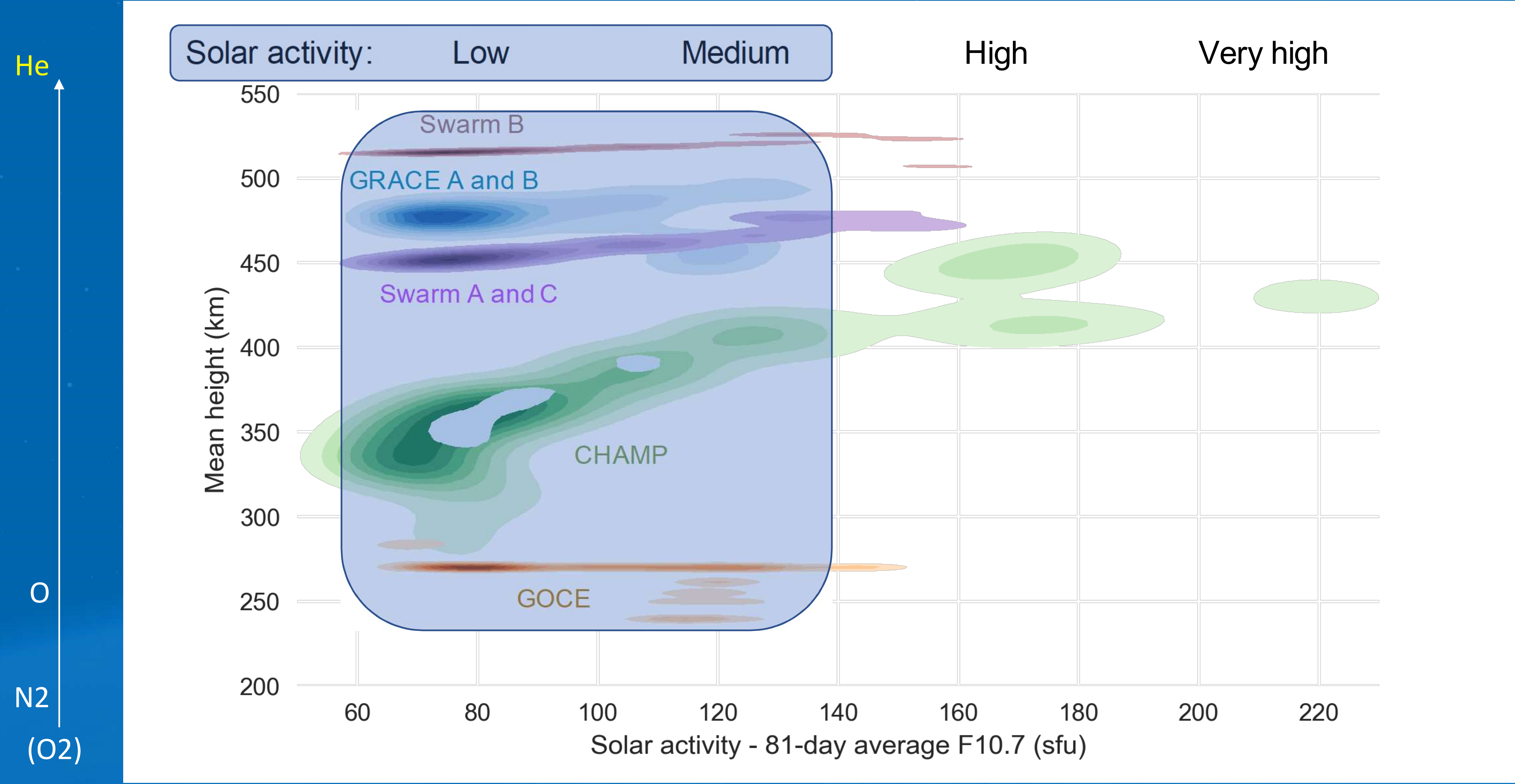
Hi-Res accelerometer density observations, but very sparse:
- Below 250 km
- Above 500 km
- For cycle max

Spectrometer data:
- Biased
- Eccentric orbits
- Before EUV (SEM)
- No recent data



No composition data since 1983

2 - Data used in the construction of DTM *(sparse data)*

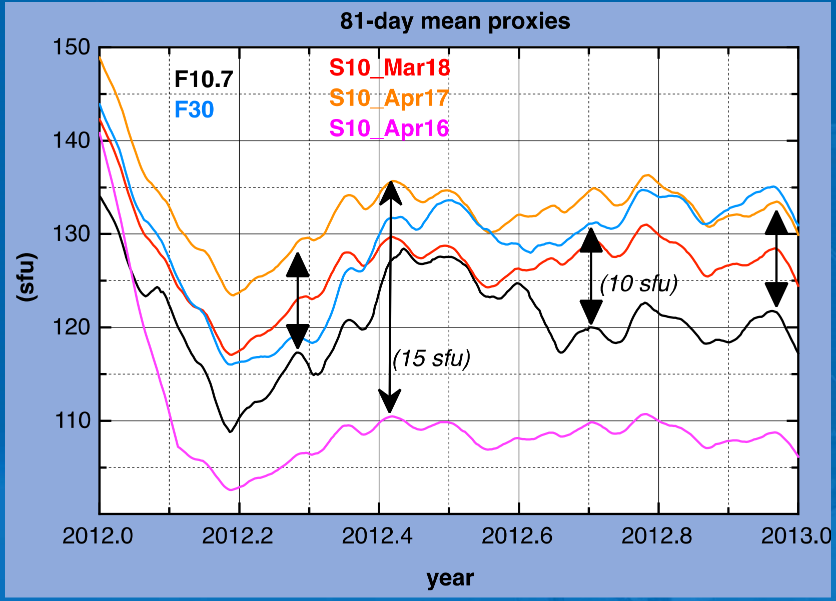


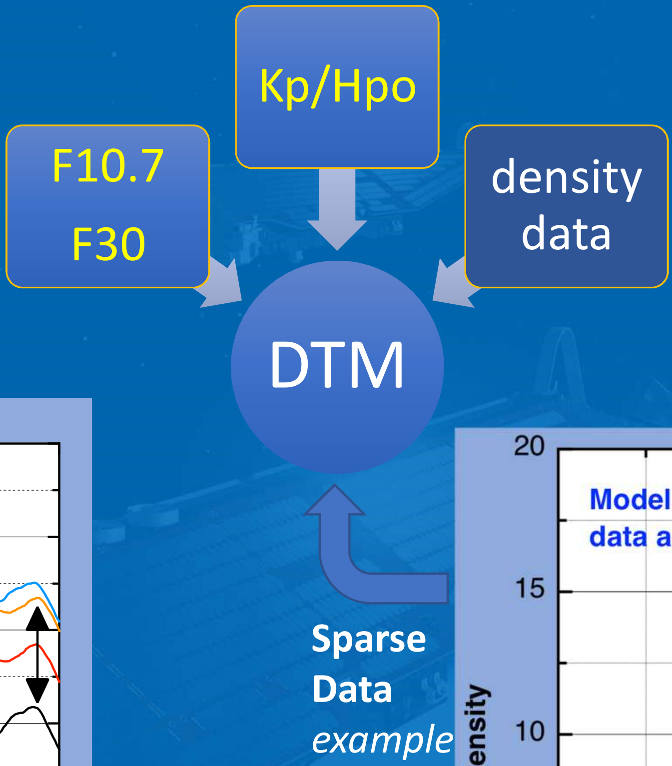
Courtesy: TU Delft, Siemes and Doornbos

2 - Data used in the construction of DTM

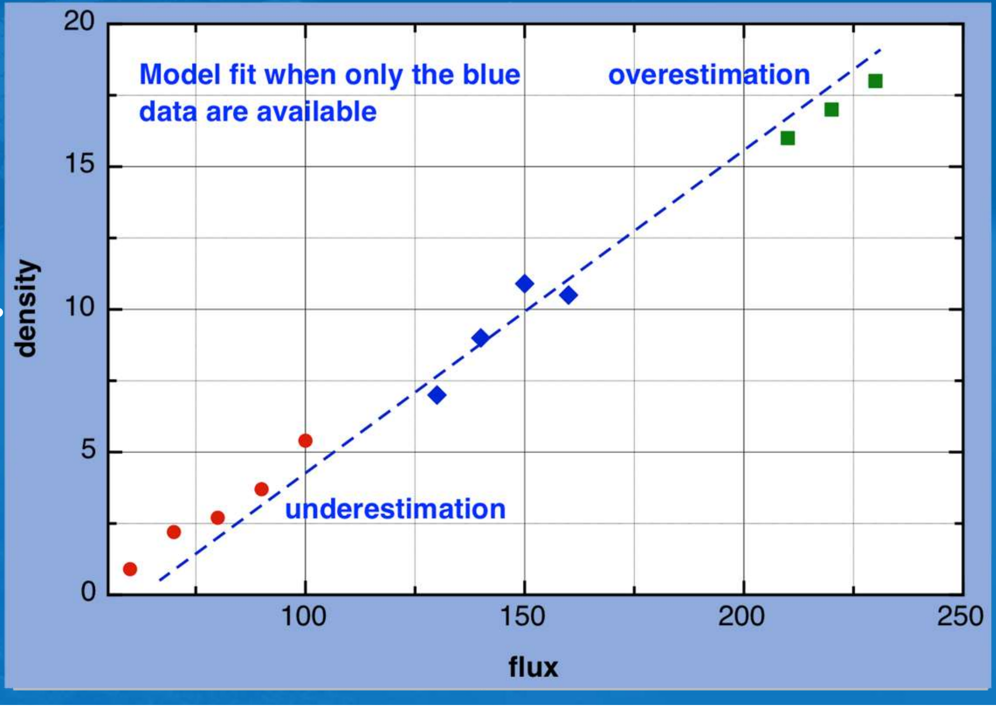
To develop a model you need: Temperature, density and composition data, and drivers.

Solar and geomagnetic input is considered "truth"
(we use proxies, so incorrect)





Density data preprocessing:
- **Editing (threshold, 3σ, ...), filtering**
- **Selection**
- **Scale corrections (*satellite model*)**



2 - Data used in the construction of DTM

Two DTM2020 models were developed: one version compatible with operations, the other not *yet*

DTM

DTM2013:
F30 & Kp
'old' DB

DTM2019:
F30 & Kp
intermediate DB

"OPERATIONA
- same algori
- drivers: F10
- *complete database 1970-2019*

Site at Bialkow observatory, University of Wroclaw: 27 April

ESA has contracted a Polish consortium to construct and operate a radio telescope to measure F10.7 and F30.
10 May: antenna installation
17 May: first tests

Data will be made available on the ESA SWE portal.

(Hp60 already available @GFZ)

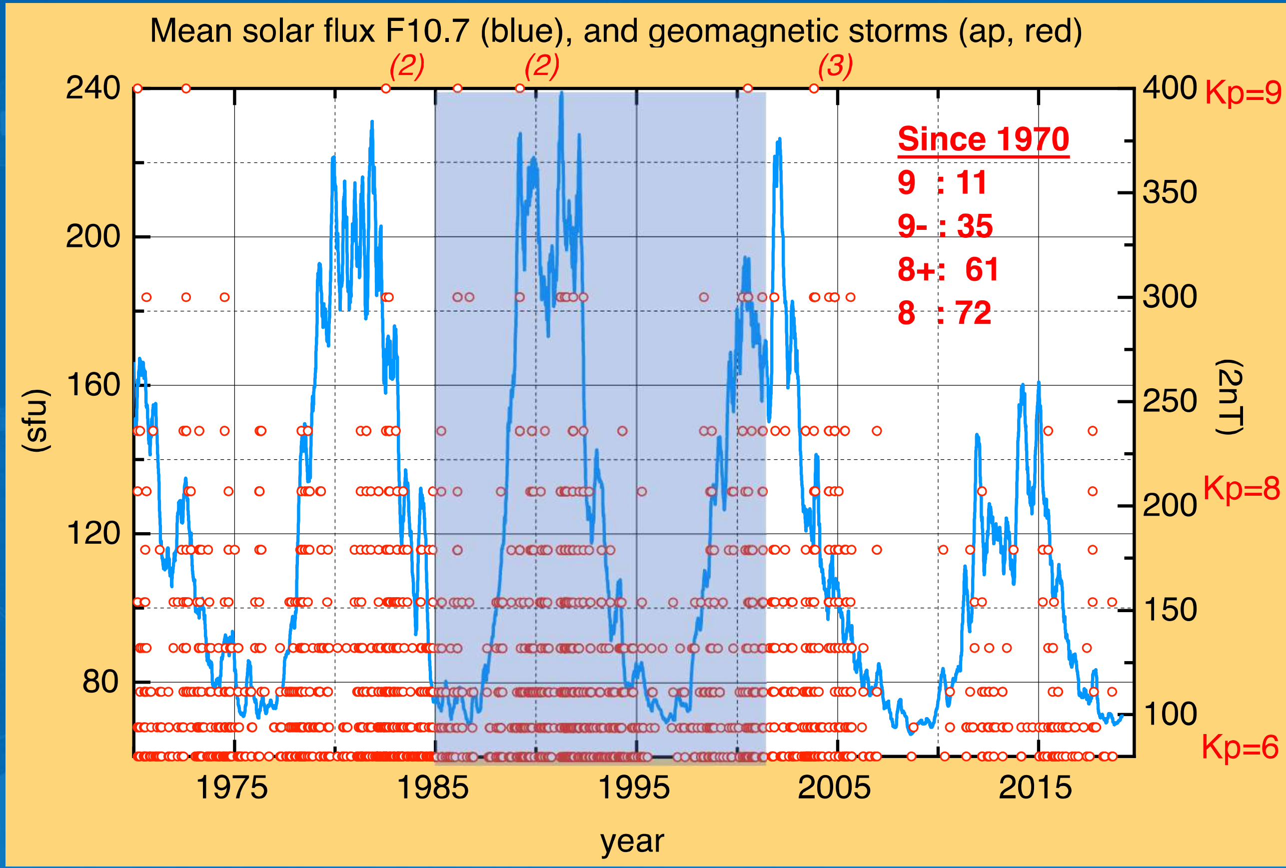
orithm
Hp60
- *database 2000-2019*

Intermediate:
F30 & Kp
Complete DB

2 - Data used in the construction of DTM *(sparse data & few events)*

Slow and fast temporal variations:

- Solar cycle (≈11 years)
- Season (6 months & 12 months)
- Active regions (months)
- Solar rotation (≈27 days)
- Corotating Interaction Regions (9&13.5 days)
- Solar/geomagnetic storms (hours – days)
- Solar flares (hours)



Since 2001, about *10* extreme storms – and at best *2* satellites operating each storm:
Only *2* altitudes & local time planes observed!

2 - Data used in the construction of DTM *(driver for solar activity)*

What is the 'best' (*representative of UV/EUV, calibrated, permanent and reliable*) proxy for solar EUV activity? → Based on our studies: 30 cm radio flux (F30)

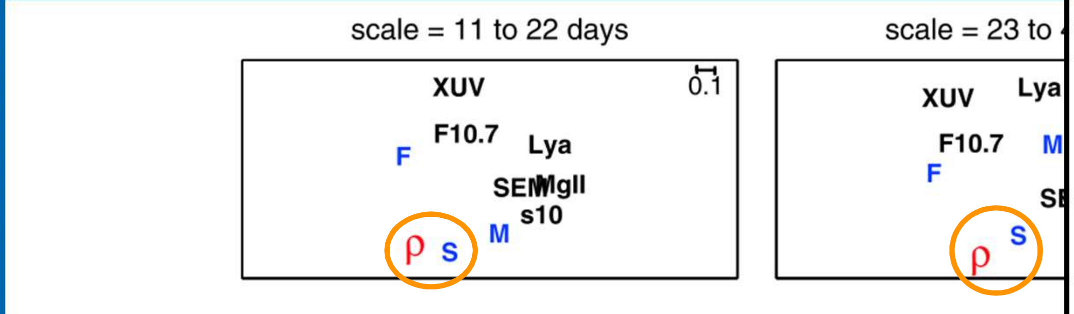


Figure 3. Correspondence maps for three characteristic scales. RMS error; axes have no immediate meaning. Characters corre

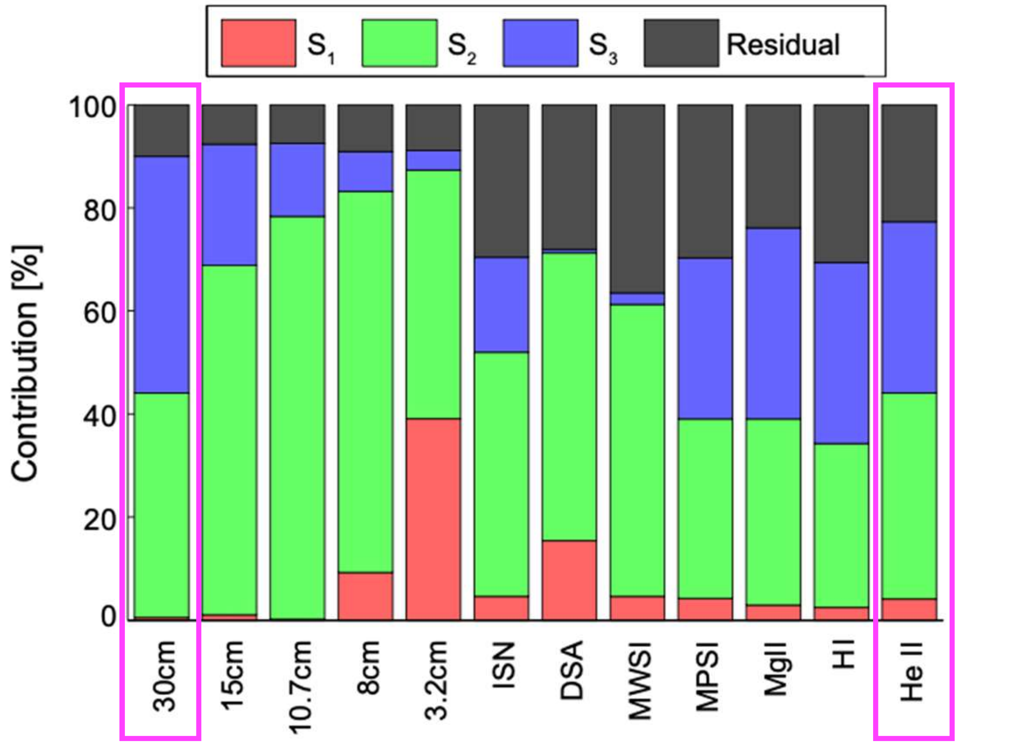


Figure 8. Relative contribution of each of the three sources to the five radio fluxes and to seven common solar proxies. For each quantity, the sum of the contributions has been normalised to 100%.

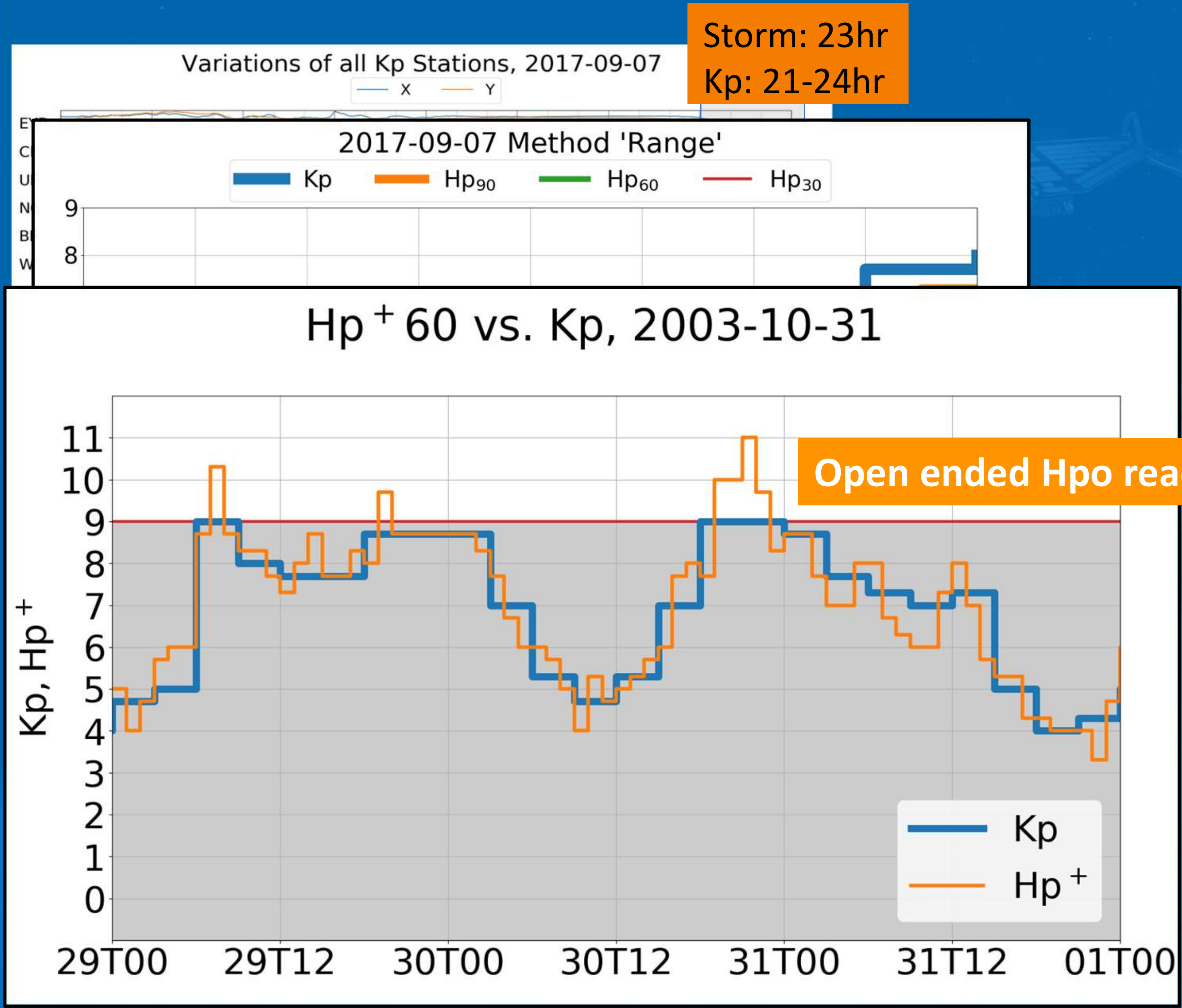
Best result: S (He II)

But serious calibration issues! (*e.g. S10 in JB2008*)

So we continued looking and testing:

F30 is closest to He II in terms of gyroresonance (S2) and Bremsstrahlung (S3)

2 - Data used in the construction of DTM *(driver for geomagnetic activity)*



Open ended Hpo reaches 11o during Halloween storm

Hpo: Kp-like, open-ended, 30&60-minutes

- High-cadence **Hpo60** (60min resolution)
- based on local H60 values from the 13 Kp-observatories

<u>Operational service for Hpo started 08/2020</u>
(@GFZ)

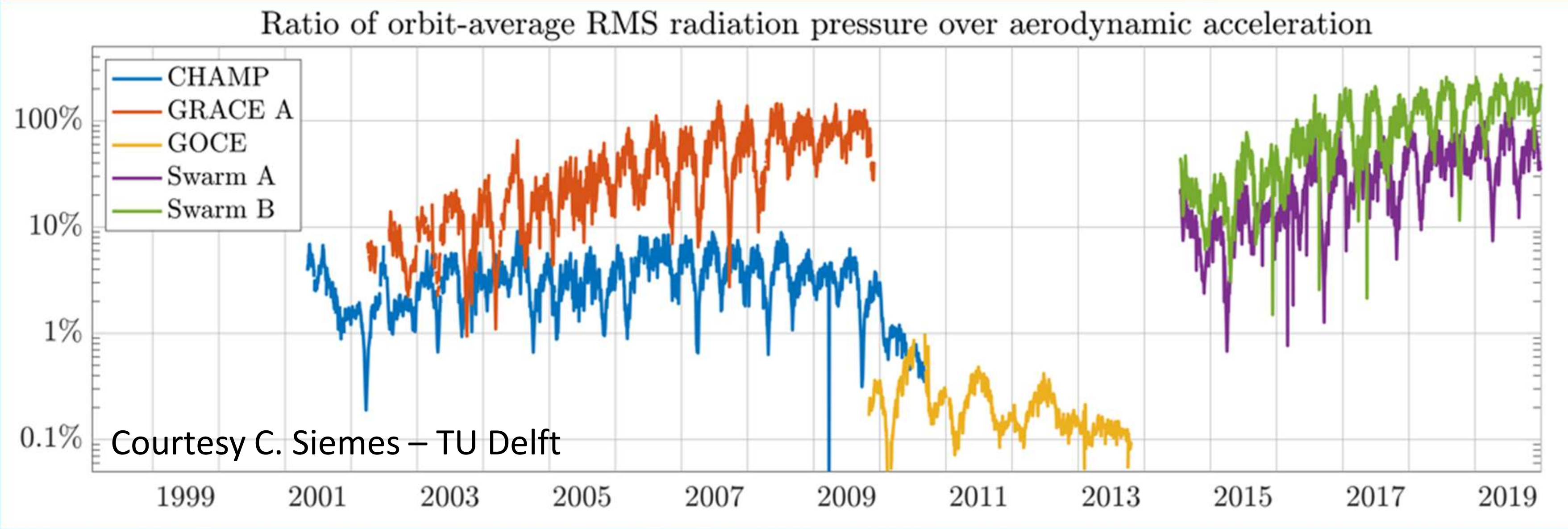
The causes for the slow progress

1. simple and coarse modeling algorithm in case of semi-empirical models, GCMs not fitted to density data,
2. model errors due to sparseness/errors/inconsistencies in the compiled density data,
3. the solar and geomagnetic indices used are *proxies* with low temporal resolution,
4. errors in the predictions of the solar and geomagnetic indices,
5. errors in the satellite model (e.g., shape, mass, and notably aerodynamic coefficient).

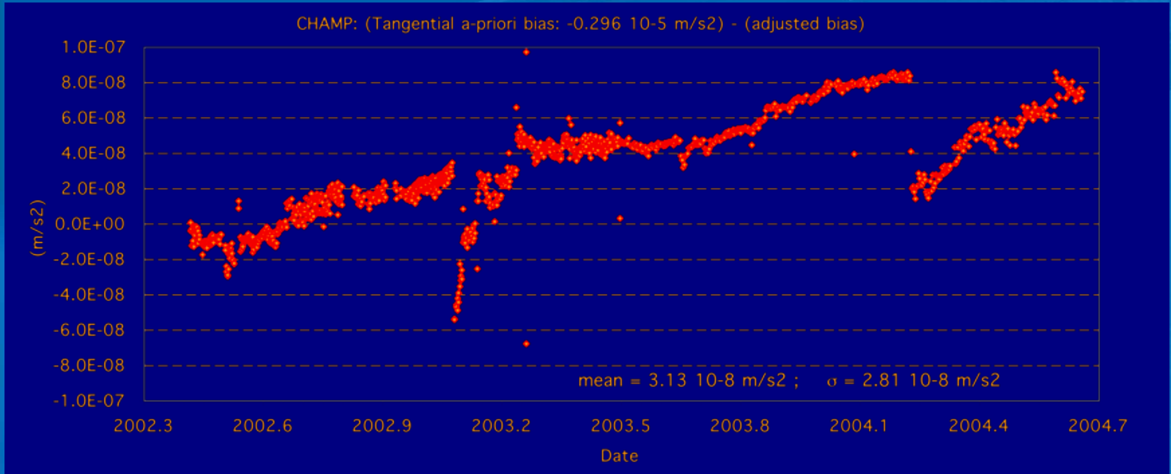
The causes for the slow progress - #2 (errors in the data)

Two examples

1) Solar radiation pressure must be modeled to infer density. The impact of an error increases with altitude.



Courtesy C. Siemes – TU Delft



2) Accelerometers require calibration. The mean bias in the along-track direction of CHAMP is 10x bigger than the signal. Difficult to delineate bias and scale.

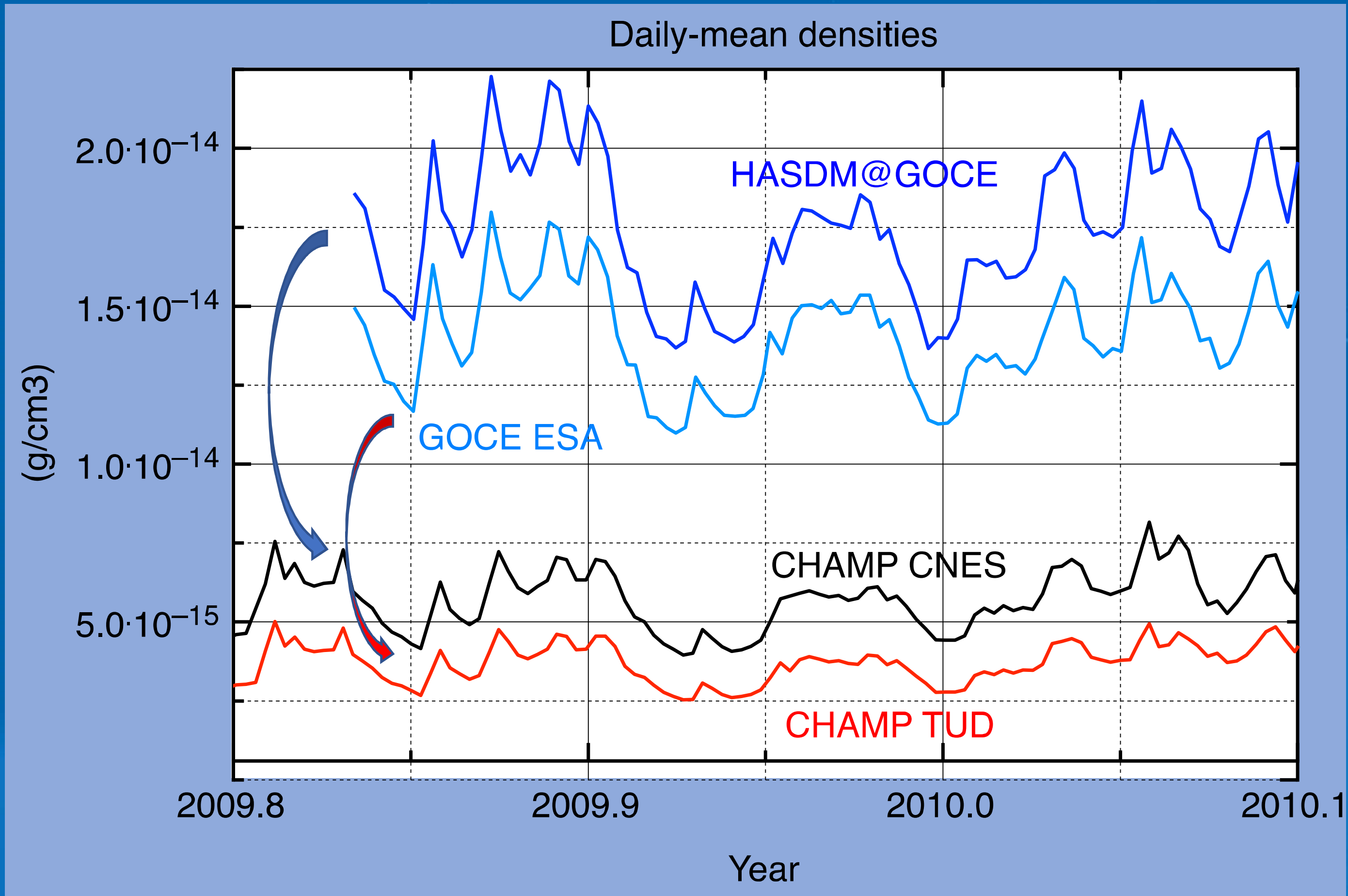
Calibration equation:

$a_{(calibrated)}$ = bias + scale$\cdot a_{(measured)}$

	Average values applied to CHAMP/ STAR		GRACE-A	
T:	bias = $-0.296\cdot10^{-5}$ ms^{-2}	scale = 0.833	bias = $-0.117\cdot10^{-5}$ ms^{-2}	scale = 0.957
N:	bias = $-0.341\cdot10^{-6}$ ms^{-2}	scale = 0.833	bias = $-0.285\cdot10^{-4}$ ms^{-2}	scale = 0.962
R:	Model (due to instrumental problems)		bias = $-0.532\cdot10^{-6}$ ms^{-2}	scale = 0.968

The causes for the slow progress - #2 (inconsistent data)

GOCE@270km & CHAMP@350km



Consistency:

- ✓ **HASDM & CNES**
- ✓ **ESA & TUD**

HASDM & TUD

What causes these differences?

- **Satellite model**
- **Cd model**

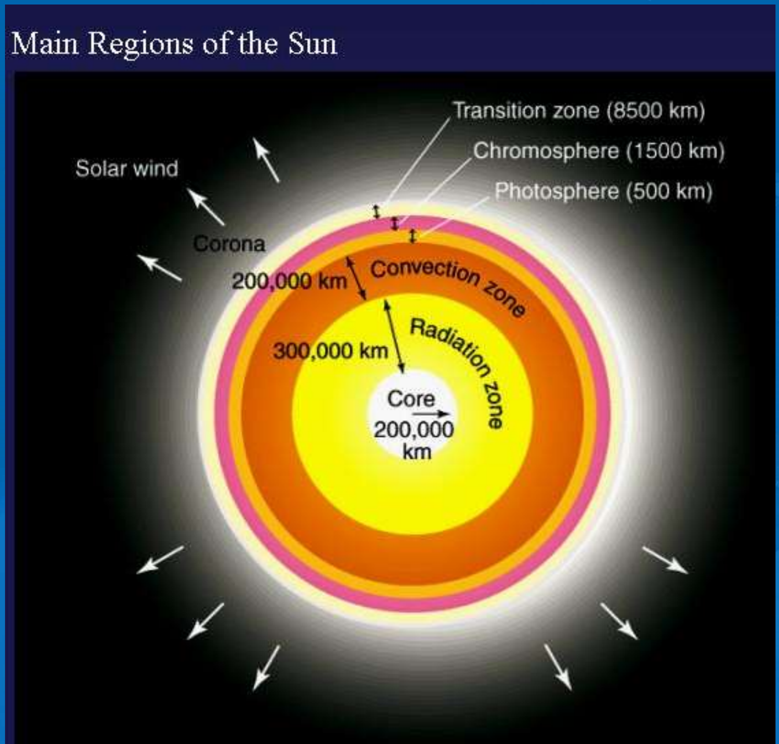
(item #5)

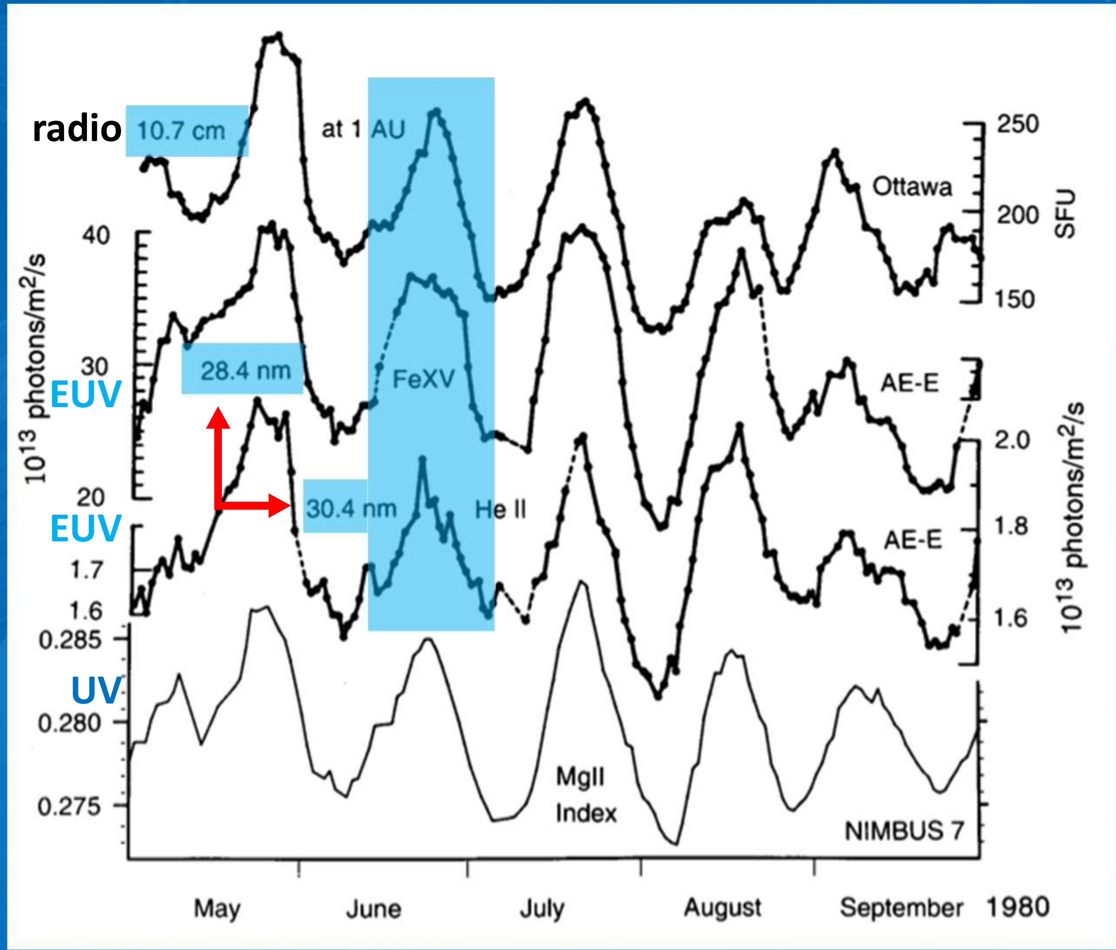
The causes for the slow progress - #3 (proxies - solar)

No EUV at the surface…
we use proxies

Proxy:
measurement that mimics variations of another observable → **EUV**

Solar flux (F10.7 & F30): daily measurements
(*only 1 station : in Canada & Japan respectively*)

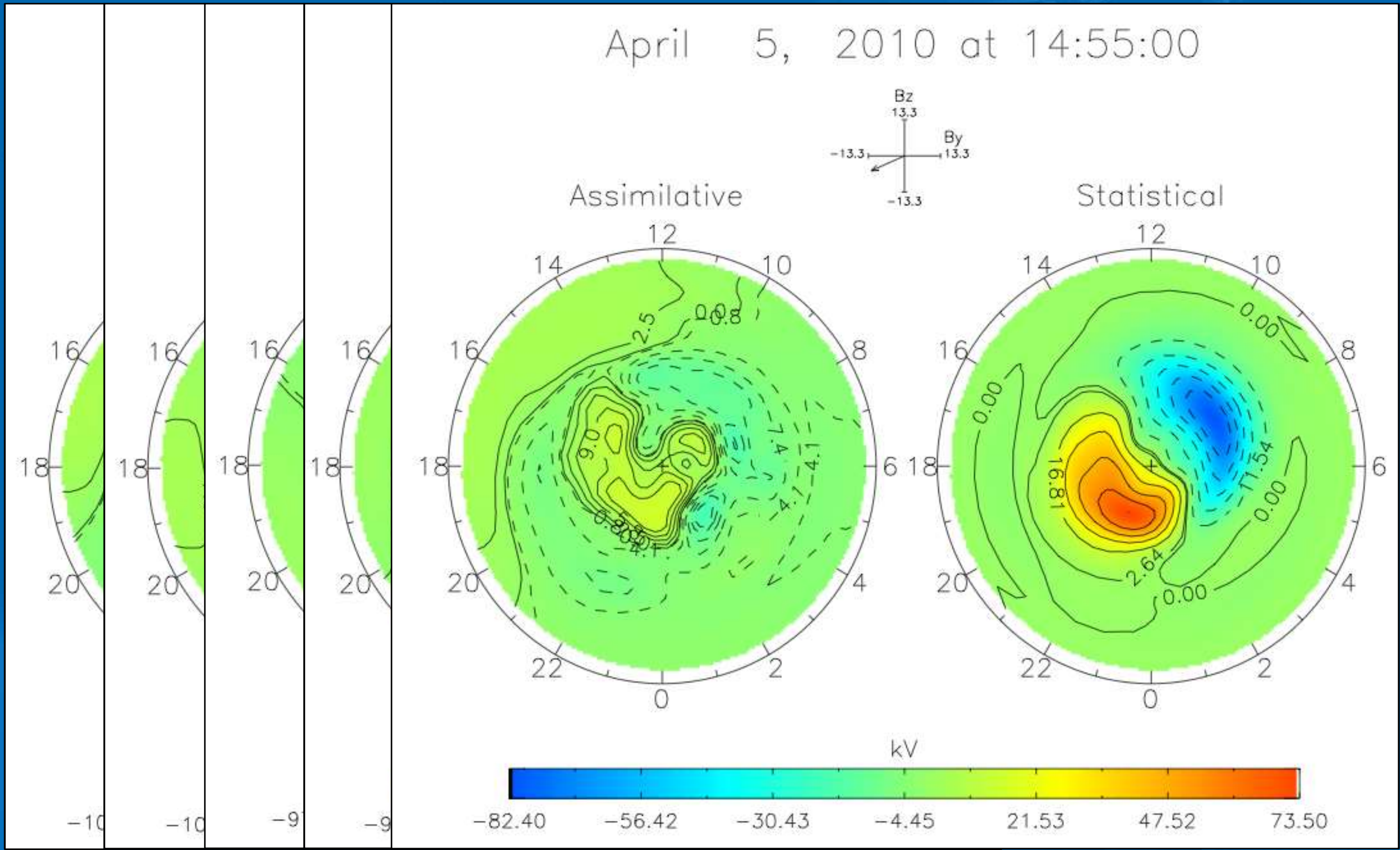




The causes for the slow progress - #3 (proxies - geomagnetic)

Proxy for energy deposition due to solar wind (Joule heating and particle precipitation)

Proxy:
measurement that mimics variations of another observable → **Kp, Hpo**



Kp (3hr), Hpo and Dst (1hr):
→ ***Planetary indices***

GCMs more often use Weimer or AMIE* as drivers
→ ***High resolution***

But still large differences:
Statistical vs Assimilative

**** Assimilative Mapping of Ionospheric Electrodynamics***

The causes for the slow progress - #4 (forecasting)

Space Weather (Warren et al., 2017)

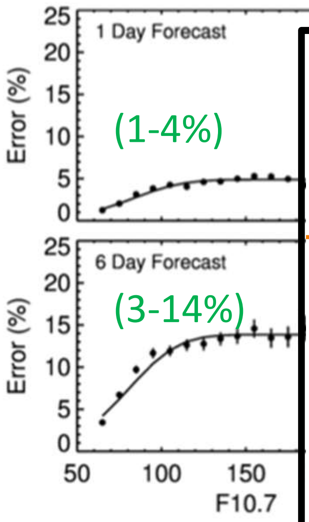
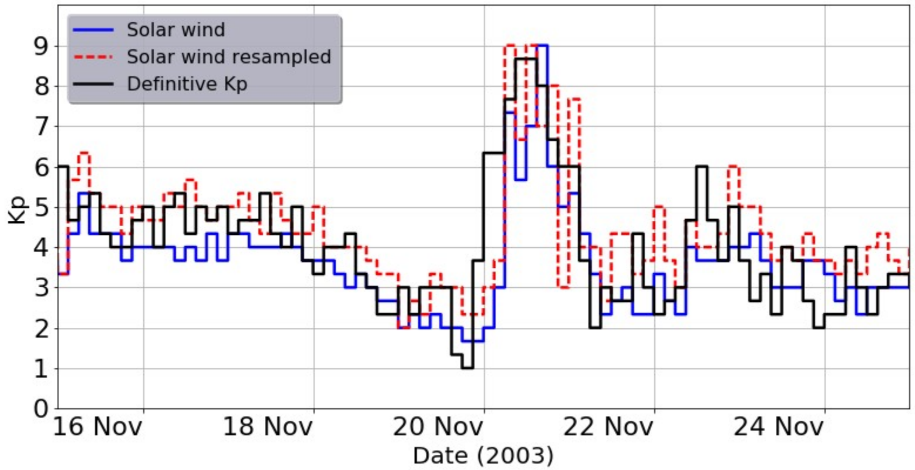


Figure 5. Forecast error as a function of level of so
from binning the residuals from each forecast by l
parametric fit to the observed residuals for each fo
uncertainties for a given forecast. (bottom) Examp
solar activity for four different forecast days. The e
(see text for details).

Rebalancing IV **(because so few storms in the database)**



- Example of a forecast **with** and **without resampling** for a 3h horizon.
- Without resampling, the model based on the solar wind (blue) systematically underestimates Kp.

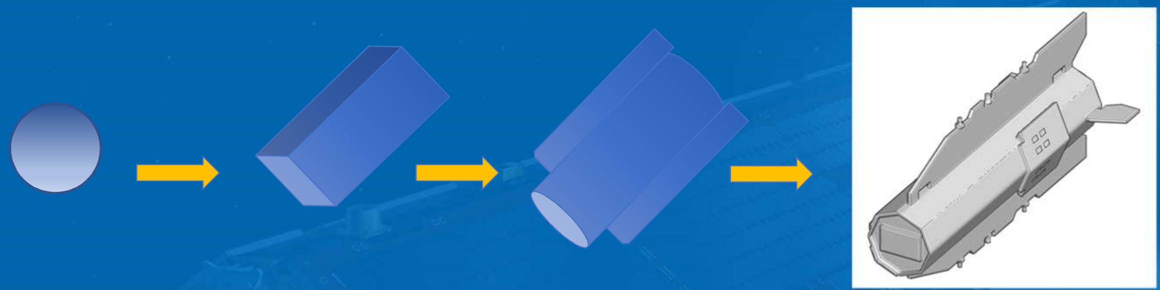
The causes for the slow progress - #5 (satellite model)

*There is no standard, nor a clear consensus within the community, on how **aerodynamic drag** should be computed*

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

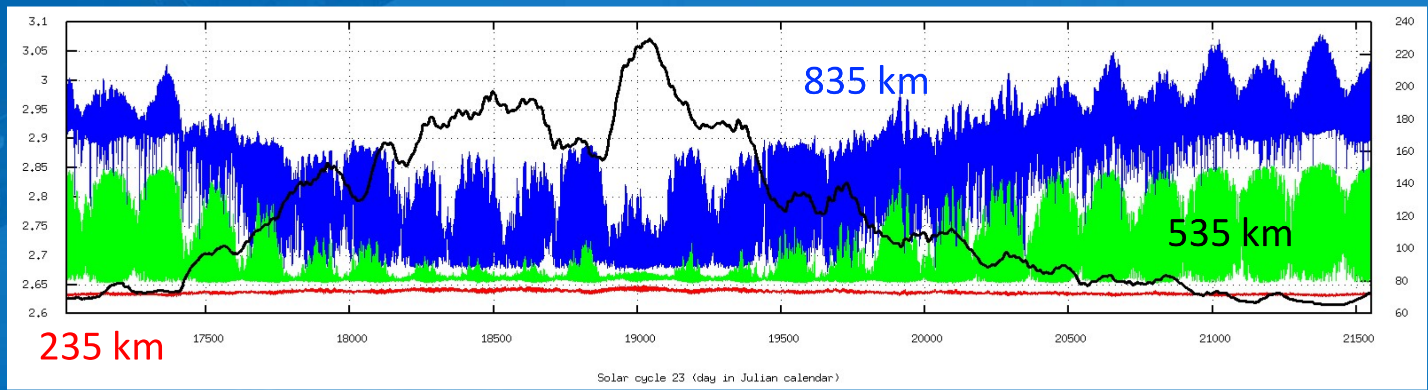
Differences in the drag calculation are due to:

- Level of approximation of the satellite model (sphere, number of panels, undocumented changes, mass,…)



- Aerodynamic coefficient model

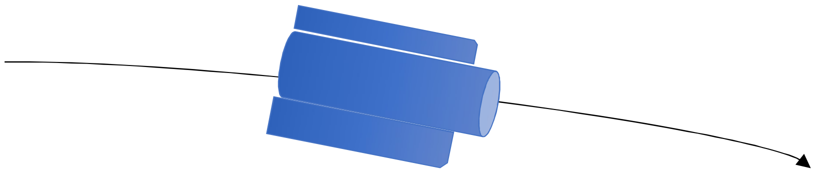
C_D of a sphere and Sentman model over one solar cycle for 3 altitudes



The causes for the slow progress - #5 (satellite model)

What is the problem?

1 – Infer density, and ingest (<u>Here: CNES-GS</u>)



$$\rho = -\frac{2\, a_{drag}\, m}{C_D\, A\, v^2}$$

Model (e.g. DTM2020)

2 – Compute orbit (<u>*not* CNES-GS</u>)

Model(ρ)

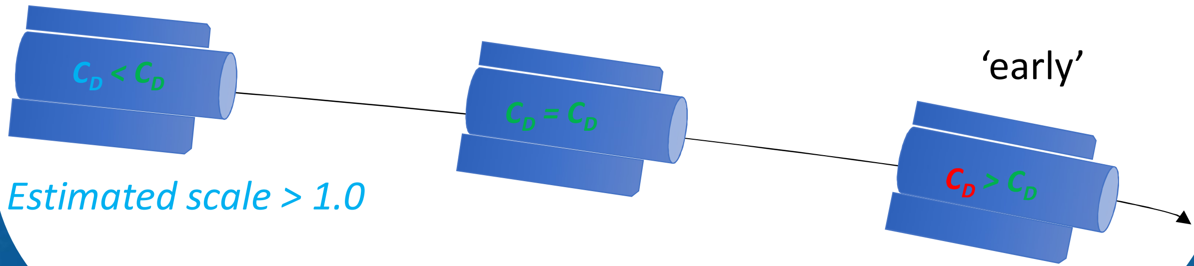
$C_D = C_D$ $\qquad a_{drag} = -{}^{1}/_{2}\; C_D\, \frac{A}{m}\, \rho\, v^2$

$C_D < C_D$ $\qquad a_{drag} = -{}^{1}/_{2}\; C_D\, \frac{A}{m}\, \rho\, v^2$

$C_D > C_D$ $\qquad a_{drag} = -{}^{1}/_{2}\; C_D\, \frac{A}{m}\, \rho\, v^2$

‘late’

‘early’



Estimated scale > 1.0

estimated scale < 1.0

The causes for the slow progress – status

1. simple and coarse modeling algorithm in case of semi-empirical models, GCMs not fitted to density data,

Does not appear to be the limiting factor *yet,* and GCMs with DA are being tested

2. model errors due to sparseness/errors/inconsistencies in the compiled density data,

Well-distributed data needed, accurately processed *(continuous, calibrated, satellite model)*

3. the solar and geomagnetic indices used are *proxies* with low temporal resolution,

Issues with solar EUV data *(calibration);* geomagnetic indices are global proxies

4. errors in the predictions of the solar and geomagnetic indices,

Can be improved for solar proxies, but geomagnetic activity forecast horizon very limited

5. errors in the satellite model (e.g., shape, mass, and notably aerodynamic coefficient).

Shape and mass should be correct for spacecraft *(debris!),* but no standard for C_D

A possible way forward

Concurrent temperature, composition and density data (spectros+accelerometer *on the same mission*)

accurate satellite model – ground tests!

Measurements at altitudes below 200 (O_2,N_2,dT), 250 (N_2,O), 400 (O), 500 (O,He), 800 km (O,He - *EO sats*)

constellation (*cubesats?*) – accurate C_D model also required

Calibrated and reliable EUV measurements (e.g. He II), 6hr cadence

regular rocket under flight calibration campaigns with the *same* instruments

And: international coordination of the above 'observing system' – WMO?

But large obstacles remain in forecasting:

Solar activity for horizon > 5 days

Geomagnetic activity for horizon > 12hr

If all data in near-real-time ⟹ Model+Data Assimilation (DA) is achievable

allows correcting thermosphere state, e.g. for driver error, or lack of driver

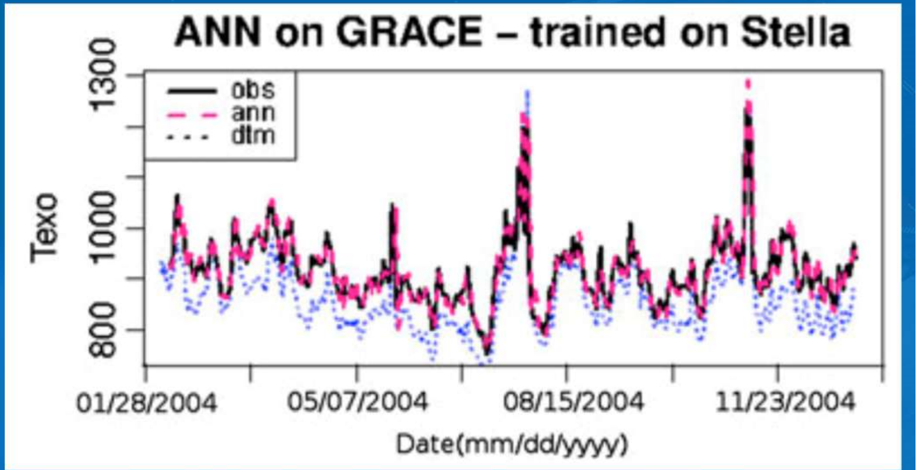
A possible way forward: DTM + Data Assimilation

	Altitude (km)	eccentricity	inclination	Time frame
GOCE	270	0.002	97°	1/2010 – 12/2012
CHAMP	450 – 350	0.001	87°	5/2001 – 12/2009
GRACE	490 – 460	0.002	89°	4/2003 – 12/2009
Starlette	*815*	*0.021*	*50°*	*1/1994 – 12/2009*
Stella	800	0.001	99°	1/1994 – 12/2009

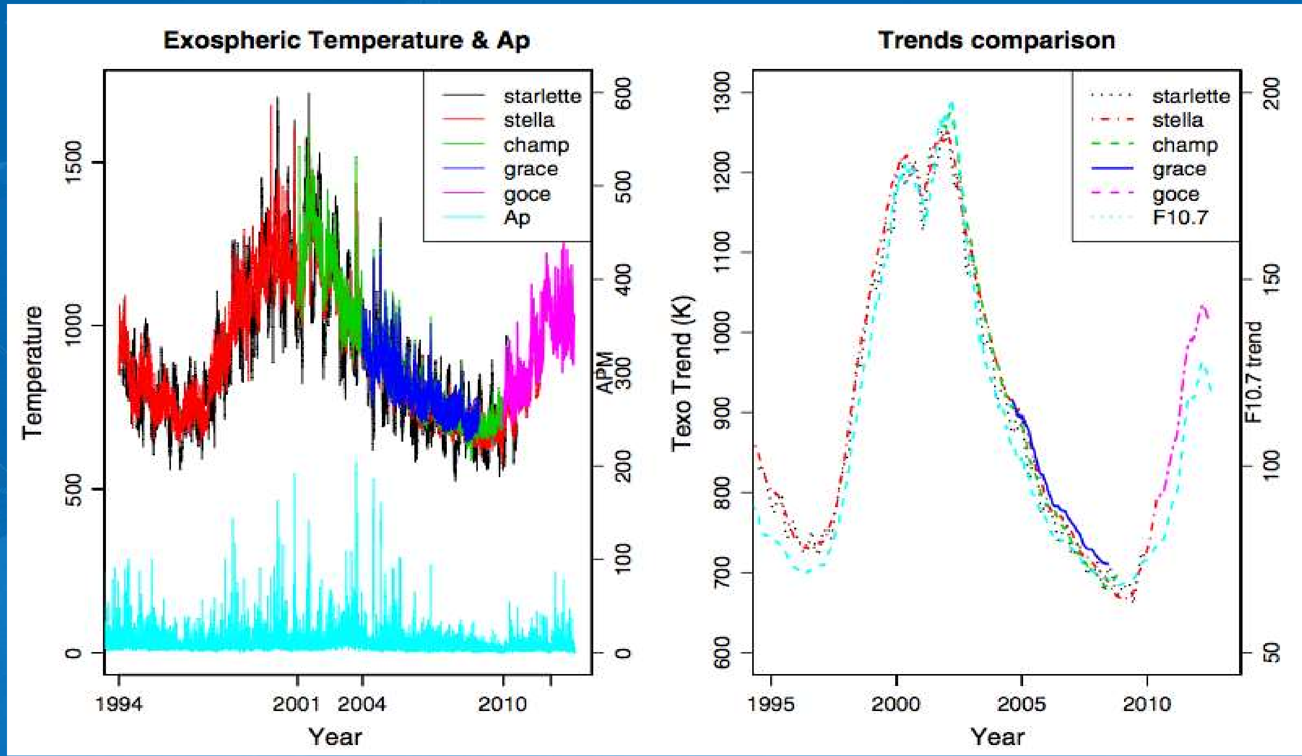
USAF: HASDM
(classified)
~80 objects, hourly updates

Reduce model bias through computation and forecast of exospheric temperature corrections

Comparisons of 1-day forecasts:



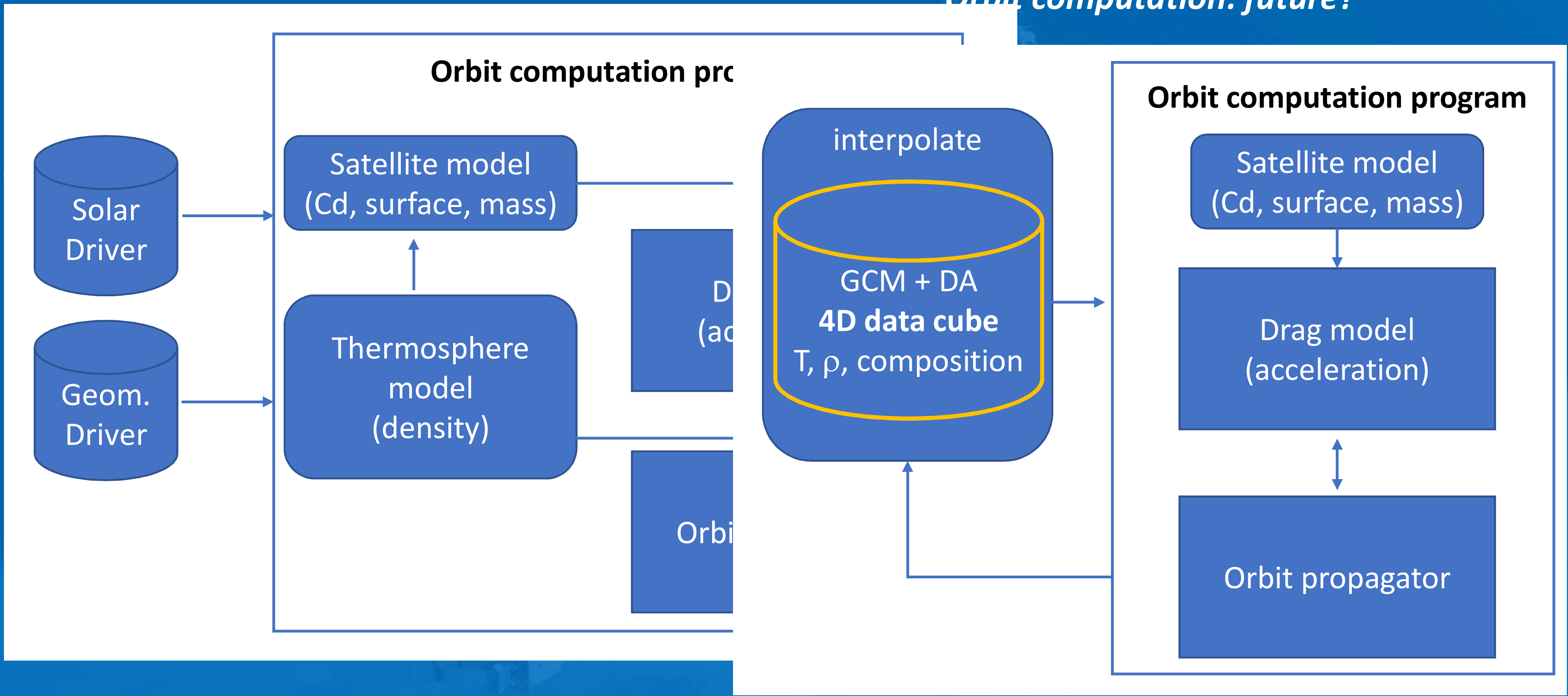
(prototype developed in FP7 project ATMOP)



A possible way forward: GCM + Data Assimilation

Orbit computation: present situation

Orbit computation: future?



Space weather research: COSPAR-ISWAT

ISWAT - International Space Weather Action Teams

Keywords

Join forces to advance space weather understanding and capabilities to alert and shield society!

HOME | JOIN ISWAT | HOW WE WORK | NEWS, EVENTS, ACTIVITIES | CONTACT US

IMPORTANT ANNOUNCEMENT: In face of the recent evolution of the COVID pandemics and of the related travel restrictions, we are postponing the in-person I... Meeting to 26-30 September, 2022.

Mini-ISWAT Roadmap Status Review and Preparation Virtual Working Meeting I: March 30 - April 1, 2022 (click here for LIVE AGENDA)

- Links to presentations, Chats and meeting recordings are from the LIVE AGENDA

LATEST NEWS:

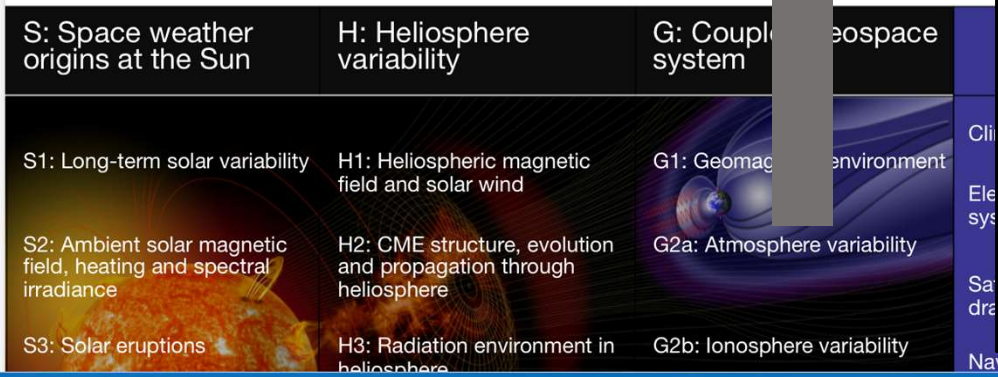
COSPAR SPACE WEATHER ROADMAP 2022 (*click here for details*)

- Announcements of Special Issues of *Advances in Space Research*
  - **COSPAR Space Weather Roadmap 2022 Research and Applications Announcement**:
    ** Please note that we have granted an extension for the first Topical Issue to 18th March 2022 **
  - COSPAR Space Weather Roadmap 2022 Achievements **and Goals Announcement**: deadline 30 June 2022
    - Click here for *Roadmap Preparation Page*

ISWAT WORKING MEETINGS (upcoming, ongoing and recent):

- Mini-ISWAT Roadmap Status Review and Preparation Virtual Working Meeting II: Tentative dates: May18 - May 20, 2022 (click here for details, TBC
- Mini-ISWAT Roadmap Status Review and Preparation Virtual Working Meeting I: March 30 - April 1, 2022 (click here for details)
- COSPAR ISWAT2022 Working Meeting, Coimbra, Portugal (in-person), 26-30 September, 2022
- COSPAR ISWAT2021 Virtual Working Meeting: Towards Community-Driven Living COSPAR Space Weather Roadmap
- Mini-ISWAT Virtual Meeting Series, Feb - Jun 2021 (*click here for details*)
- COSPAR ISWAT Inaugural Working Meeting, February 10-14, 2020 (*click here to view plenary presentations, including teams*
- COSPAR Scientific Assembly, Sydney, Australia, January 28 - February 4, 2021 (click here for details of PSW events)

The COSPAR ISWAT initiative is a global hub for collaborations addressing challen... oss the field of sp...



H2: CME structure, evolution and propagation through heliosphere

- **H2-01:** CME Arrival Time and Impact Working Team (Leads: C. Verbeke <cgjmverbeke@gmail.com>, M. L. Mays <m.leila.mays@nasa.gov>)
- **H2-02:** Magnetic Profiles of Interplanetary CMEs (Lead: Christina Kay ckay314@gmail.com)
- **H2-03:** CME model evaluation through synthetic observations (Lead: Luke Barnard <l.a.barnard@reading.ac.uk>, Tanja Amerstorfer <tanja.amerstorfer@oeaw.ac.at>)

H3: Radiation environment in heliosphere

- **H3-01:** SEP Validation (Leads: Katie Whitman kathryn.whitman@nasa.gov, Phil Quinn philip.r.quinn@nasa.gov, Hazel Bain hazel.bain@noaa.gov, Ian Richardson ian.g.richardson@nasa.gov, Mark Dierckxsens Mark.Dierckxsens@aeronomie.be, M. Leila Mays, m.leila.mays@nasa.gov); SEP Scoreboard (Leads: M. Leila Mays m.leila.mays@nasa.gov, Mark Dierckxsens Mark.Dierckxsens@aeronomie.be)
- **H3-02**: The Suprathermal Seed Population in the Interplanetary Medium (Lead: Maher Dayeh maldayeh@swri.edu
- **H3-03:** Heliophysics for Artemis and Beyond (Lead: Alexa Halford Alexa.J.Halford@nasa.gov Brian Walsh bwalsh@bu.edu Eddie Semones edward.j.semones@nasa.gov)

H4: Space Weather at other planets/ planetary bodies

- **H4-01:** Understanding the physics of Space Weather at planetary bodies (Lead: Reka Winslow rwinslow@guero.sr.unh.edu)
- **H4-02:** Towards Solar System robotic and human exploration (Lead: TBD, POC: Insoo Ju, Insoo.Jun@jpl.nasa.gov)

G1: Geomagnetic environment

- **G1-01**: Geoelectric field and GIC modelling Working Team **(**Lisa Rosenqvist <lisa.rosenqvist@foi.se>)
- **G1-02**: Mid-to-Low-Latitude Space Weather Effects (Katariina Nykyri, Embry-Riddle Aeronautical University, USA <nykyrik@erau.edu>)
- **G1-03:** Auroral Precipitation and High Latitude Electrodynamics (AuroraPHILE) (Lead: Bob Robinson robert.m.robinson@nasa.gov Katie Garcia-Sage katherine.garcia-sage@nasa.gov)
- **G1-04:** MHD models of the geomagnetic environment and their capability to reproduce small scale GIC source processes (Lead: Daniel Welling daniel.welling@uta.edu)

G1-05: Understanding the Geomagnetic Response to CMEs (Lead: Chigo Ngwira cngwira@astraspace.net)

G2a: Atmosphere variability

- **G2A-01:** Thermosphere Model Assessment and Improvement (Lead: Sean Bruinsma <sean.bruinsma@cnes.fr>)
- **G2A-02**: Space Weather and Lower Atmosphere (Lead: Jia Yue jia.yue@nasa.gov)
- **G2A-03**: Satellite Aerodynamic Modeling (Lead: Piyush Mehta piyush.mehta@mail.wvu.edu)

G2b: Ionosphere variability

- **G2B-01**: TechTIDE Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects (Lead: Anna Belehaki <belehaki@noa.gr>)
- **G2B-02**: Ionospheric Plasma Irregularities and Their Impact on Trans-ionospheric Radio Waves. (Lead: Wojciech Miloch w.j.miloch@fys.uio.no)
- **G2B-03**: LW-Sun-Ionosphere nexus (Lead: Dr. Shanmugha Sundaram G A ga_ssundaram@cb.amrita.edu)
- **G2B-04**: Ionospheric perturbation indices and scales (Lead: Norbert Jakowski norbert.jakowski@dlr.de)
- **G2B-05**: Ionosphere Plasma Density: NmF2/foF2, hmF2, TEC (Lead: Ioanna Tsagouri tsagouri@noa.gr)
- **G2B-06**: Global and Regional Ionospheric Total Electron Content (Lead: Ludger Scherliess ludger.scherliess@usu.edu)
- **G2B-07**: HamSCI: Ham Radio Science Citizen Investigation (Lead: Nathaniel Frissell nathaniel.frissell@scranton.edu Phil Erickson pje@mit.edu)
- **G2B-08:** Ground-based and space borne HF-VHF ionospheric investigations (Lead: Hanna Rothkaehl hrot@cbk.waw.pl Maaijke Mevius mevius@astron.nl)
- **G2B-09**: Ionospheric Scoreboard Development (Lead: Katherine Garcia-Sage katherine.garcia-sage@nasa.gov)
- **G2B-10**: Modelling and Forecasting Ionospheric TEC/Scintillations based on Artificial Intelligence Methods (Lead: Devanaboyina Venkata Ratnam dvratnam@kluniversity.in Pasumarthi Babu Sree Harsha harry9harsha@gmail.com Gampala Siva Vara Prasad gsivavaraprasad@gmail.com)

G3: Near-Earth radiation and plasma environment

- **G3-01**: Radiation Effects at Aviation Altitudes (Leads: Kent Tobiska <ktobiska@spacenvironment.net>, Matthias Meier <matthias.meier@dlr.de>)
- **G3-02**: Surface Charging Effects and the Relevant Space Environment (Leads: Natalia Ganushkina <ganuna@umich.edu>, Joseph Minow <joseph.minow@nasa.gov>)
- **G3-03**: On Total Dose Effects (Leads: Insoo Jun <insoo.jun@jpl.nasa.gov>, Timothy Guild <timothy.b.guild@aero.org>)
- **G3-04**: Internal Charging Effects and the Relevant Space Environment (Leads: Yuri Shprits <yuri.shprits@gfz-potsdam.de>, T. Paul O'Brien <paul.obrien@aero.org>)
- **G3-05**: Solar Energetic Particle Population in Geospace (Lead: Valeriy Tenishev vtenishe@umich.edu)