Atmospheric density calibration using satellite drag observations

Eelco Doornbos (TU Delft)
Heiner Klinkrad (ESA/ESOC)

Second European Space Weather Week
Tuesday, 15 November, 2005

TU Delft
Delft University of Technology

Outline

- Applications of empirical neutral thermosphere density models for satellite orbit determination
- Two ESA/ESOC contract studies:
  - Density model calibration feasibility study
  - Near real-time density calibration based on two-line element (TLE) orbit data

TU Delft

Empirical thermosphere neutral density models

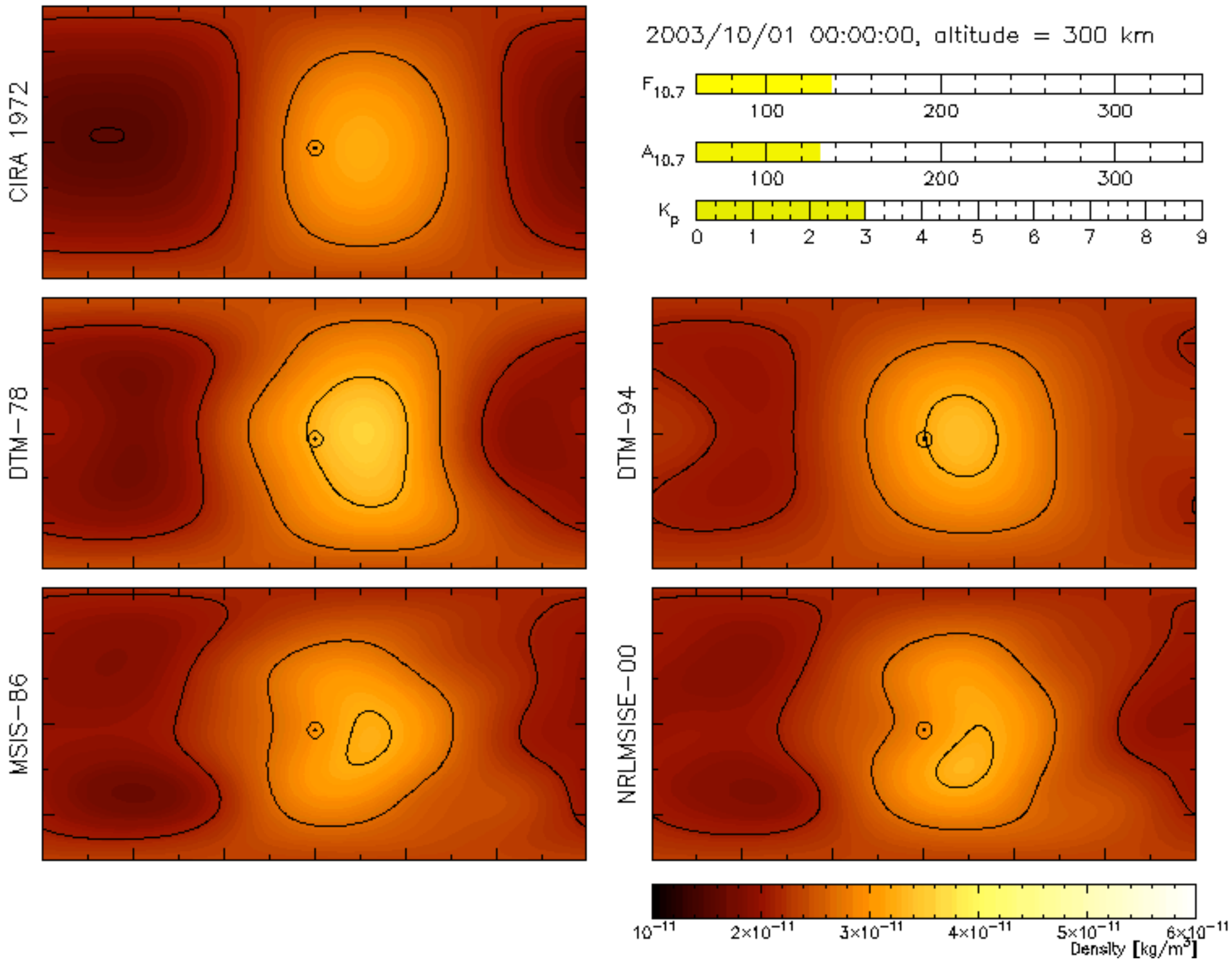
- Models: Jacchia, DTM78, DTM94, MSIS-86, NRLMSIS-00
- Based on correlation of neutral density and temperature with space weather proxies (F10.7, and Ap or kp).
- Density predictions are based on F10.7 and Ap predictions

TU Delft

Density models recent research

- Expansion of density database, including CHAMP accelerometer data
- Improved space weather proxies offering (slightly) better correlations (Mg-II index, Solar 2000 E10.7)
- No real improvements for orbit applications...

TU Delft


2003/10/01 00:00:00, altitude = 300 km
F10.7
100
200
300
A10.7
100
200
300
Kp
0
1
2
3
4
5
6
7
8
9
CIRA 1972
DTM−78
DTM−94
MSIS−86
NRLMSISE−00
10−11
2×10−11
3×10−11
4×10−11
5×10−11
6×10−11
Density [kg/m3]

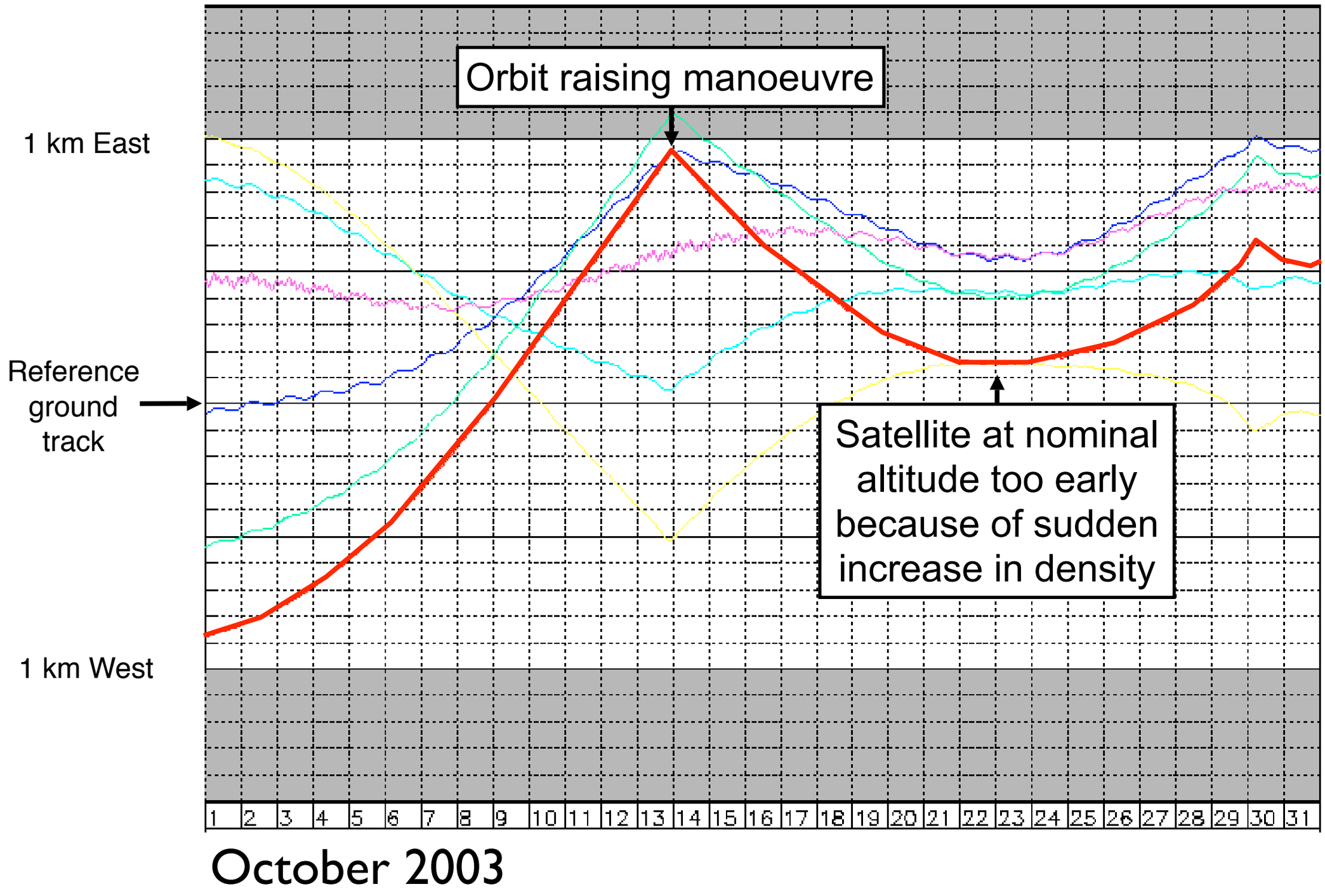
TU Delft

Applications of thermosphere models in orbit determination

- Collision avoidance (space debris)
- Re-entry analysis
- Ground-track maintenance
- Precise orbit determination

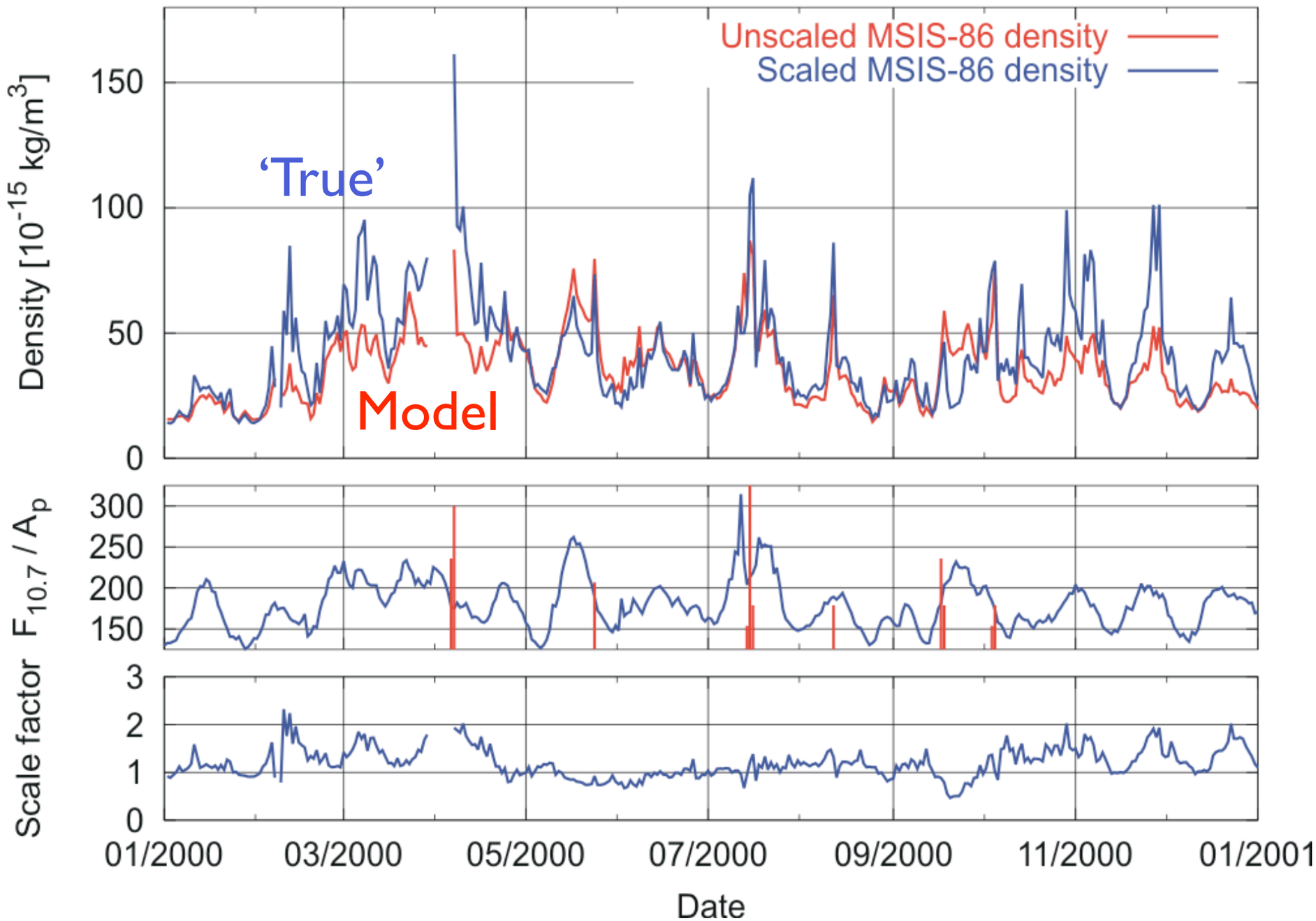
TU Delft

ERS-2 ground track maintenance



TU Delft

ERS-2 density from precise orbit tracking



TU Delft

Thermosphere density calibration

- US Air Force Space Command initiatives:
  - HASDM (High-Accuracy Satellite Drag Model)
  - Sapphire Dragon (HASDM 2)
- Based on US Air Force Space Surveillance Network (SSN) tracking data
- SSN tracking data and resulting models are not available to outside users

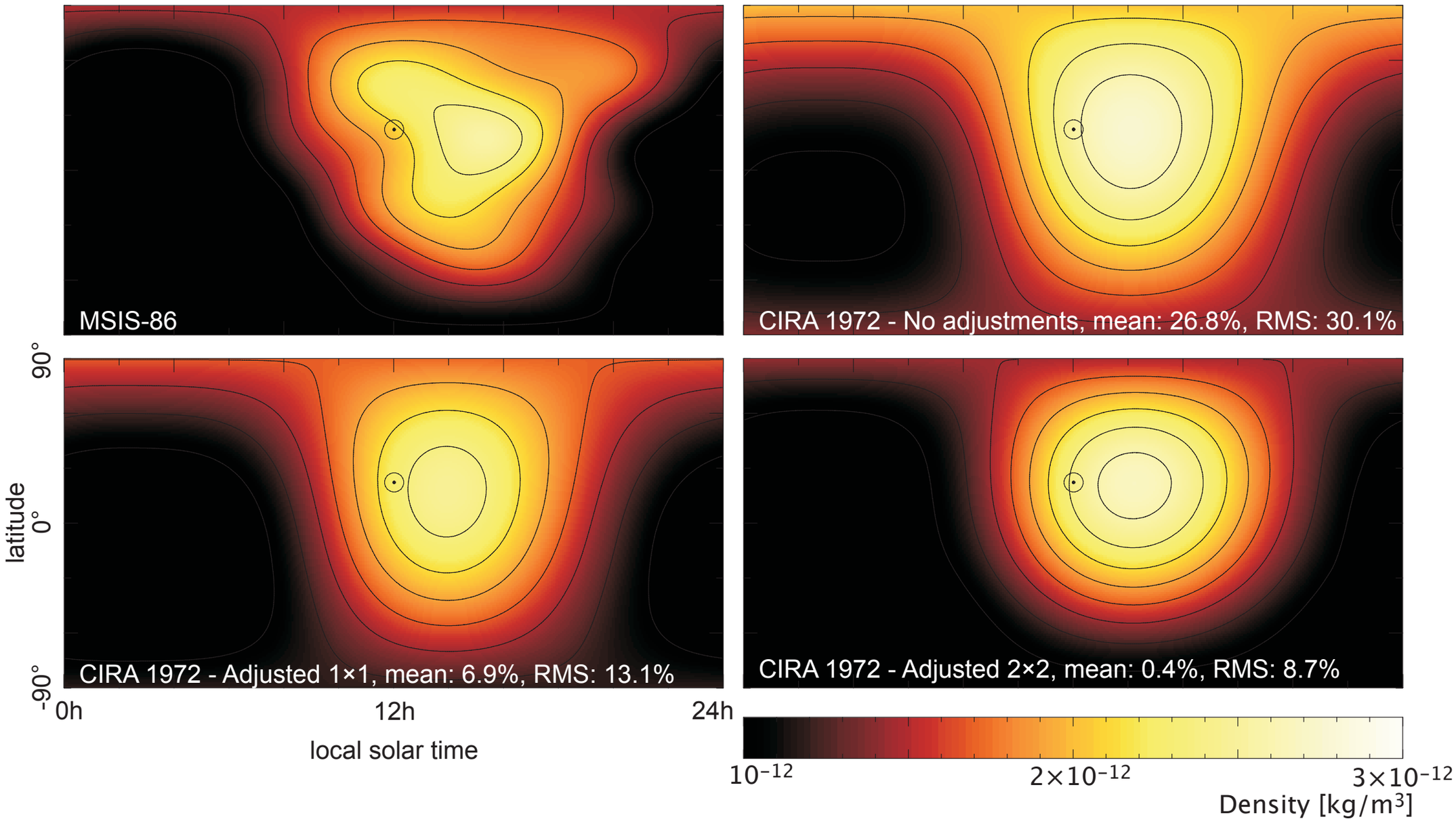
TU Delft

Feasibility study on density model calibration for ESOC

- Inventory of possible data sources:
  - Precise tracking: GPS, DORIS, SLR (around 5-10 satellites)
  - Accelerometer measurements (2 or 3 satellites)
  - Two-Line Element data (many objects, from SSN tracking)
- Inventory of error sources:
  - Satellite ballistic coefficients (drag coefficient, area / mass)
  - Other forces, winds
- Model calibration simulation study

TU Delft

Adjustment using 100 simulated TLE orbits



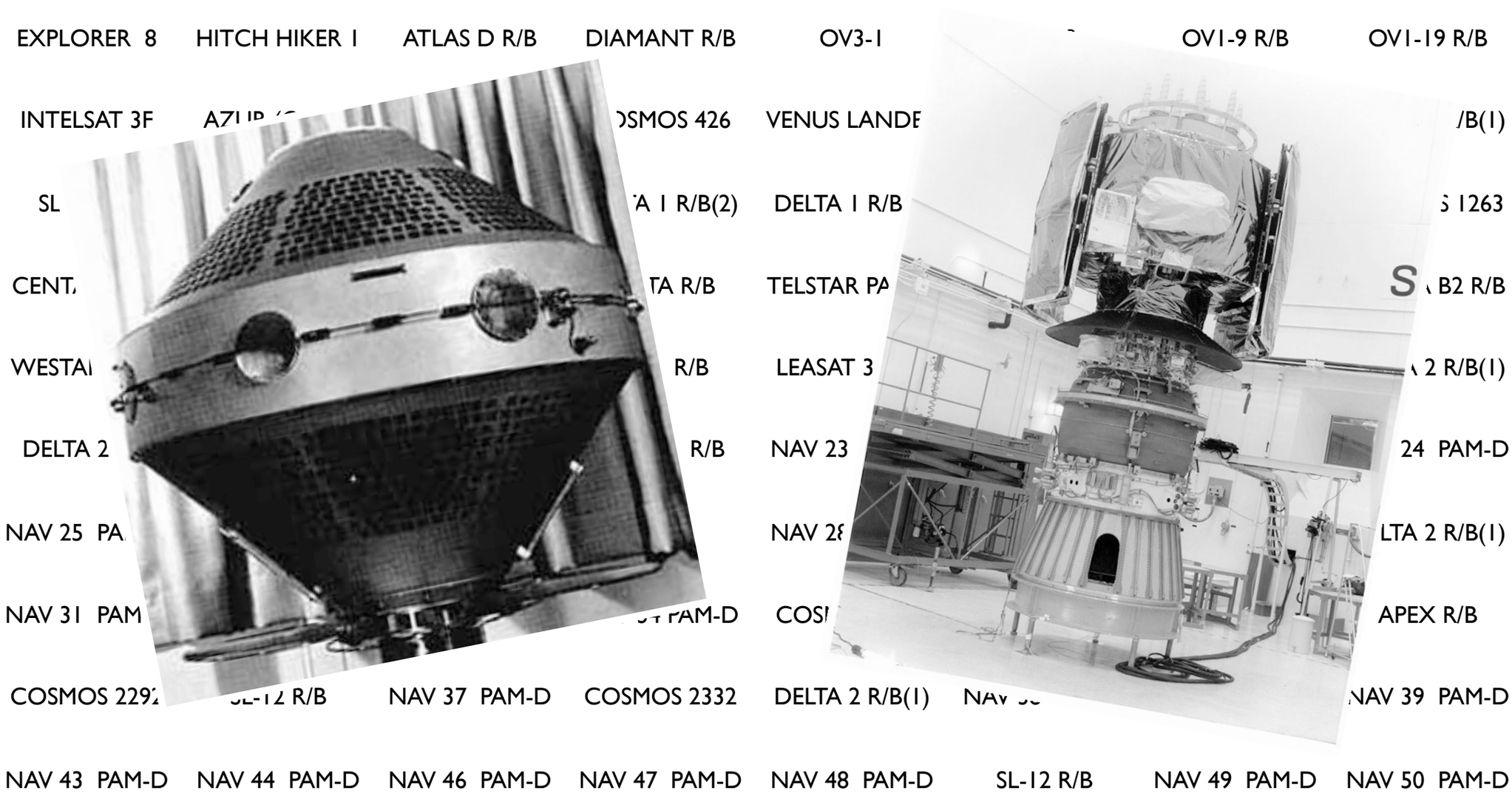
TU Delft

TLE to density processing

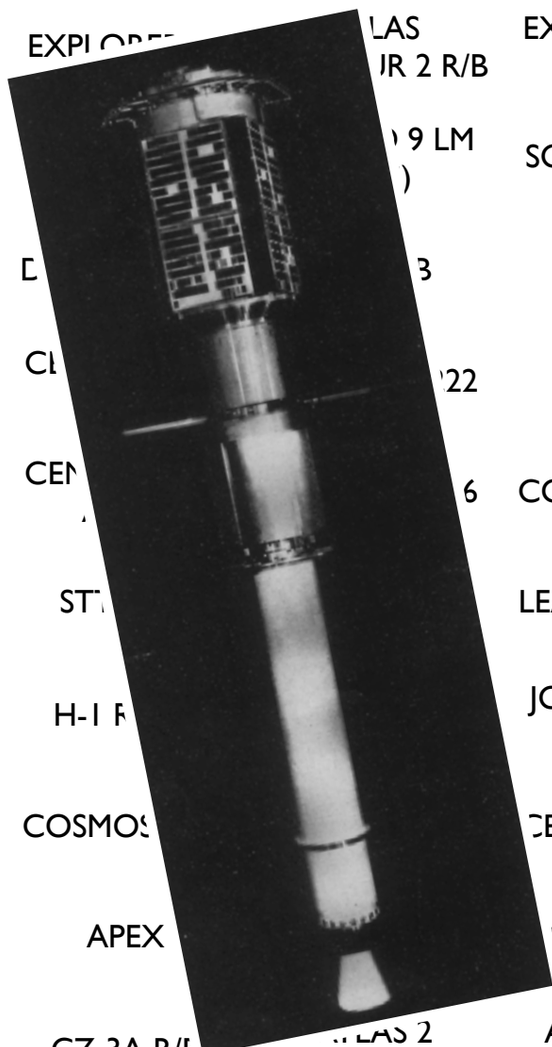
- Algorithm from Picone, Emmert and Lean, 2005 (JGR).
- List of objects with stable ballistic coefficient obtained from Bruce Bowman (US AFSPC).
- Estimated ballistic coefficient by assuming MSIS-86 ratio over one year equals 1.0.
- HWM-93 (Hedin) wind model applied.

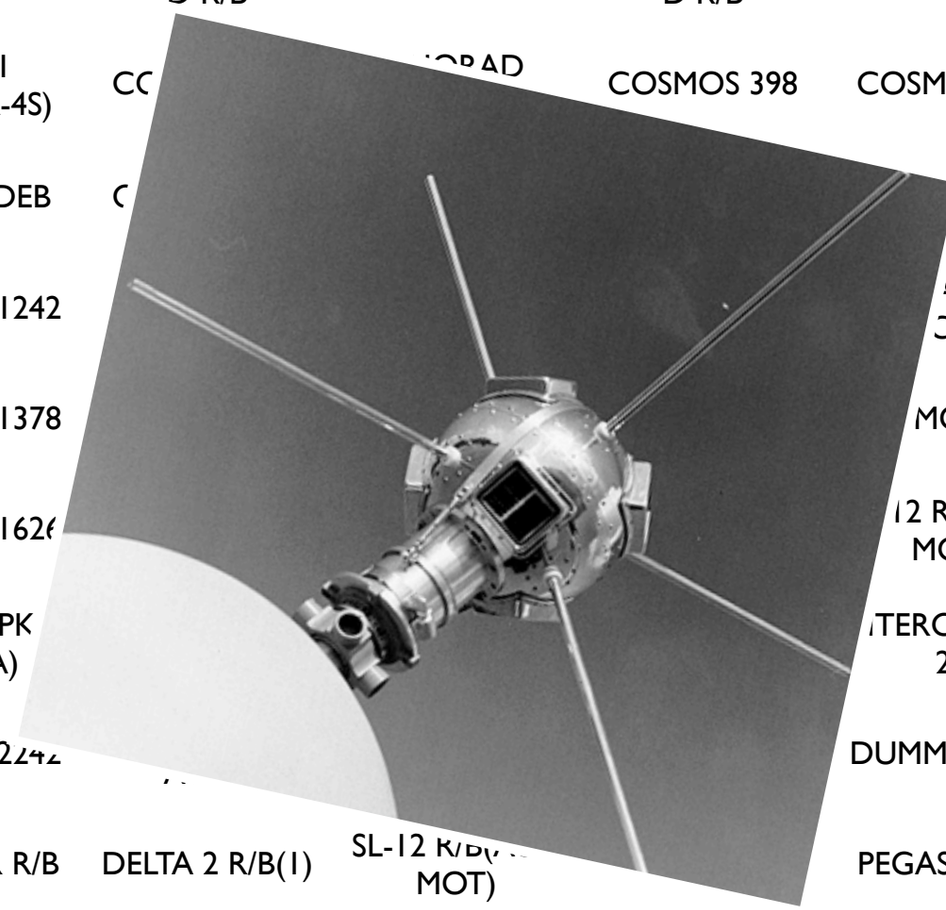
TU Delft

80 TLE objects with stable B



90 TLE objects with unstable B



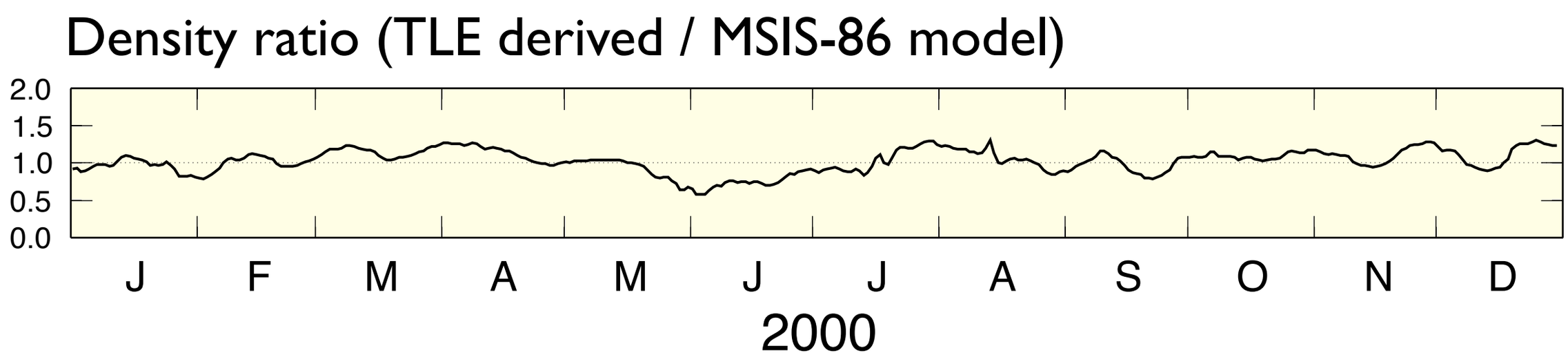


VANGUARD 1	EXPL	LAS JR 2 R/B	EXPLORER 26 (EPE-D)	OV1-2	THOR AGENA D R/B	SCOUT B R/B	ATLAS AGENA D R/B	OV1-9
DIAMANT R/B		9 LM)	SCOUT B R/B	OSUMI (LAMBDA-4S)	CC		COSMOS 398	COSMOS 405
COSMOS 434	D	B	SL-8 R/B	DELTA 1 DEB	C			/B(2)
COSMOS 1220	CL	22	SL-8 R/B	COSMOS 1242				AUR R/B C-56
COSMOS 1315	CEN	6	COSMOS 1356	COSMOS 1378				MOS 1441
DELTA 1 R/B(1)	ST		LEASAT 1 PKM	COSMOS 1626				12 R/B(AUX MOT)
EXOS D	H-1 F		JCSAT 2 PKM (SSUS-A)	LEASAT 5 PK (SSUS-A)				ITERCOSMOS 25
COSMOS 2221	COSMOS		CENTAUR R/B	COSMOS 2242				DUMMY MASS
SL-12 R/B(AUX MOT)	APEX		CZ-3A R/B	CENTAUR R/B	DELTA 2 R/B(1)	SL-12 R/B(MOT)		PEGASUS R/B
M-5 R/B	CZ-3A R/B	ATLAS 2 CENTAUR R/B	ATLAS 2AS CENTAUR R/B	DELTA R/B(1)	CXO R/B(1)	FREGAT RB/ CLUSTER 2	DM-F3	ATLAS 2A CENT R/B

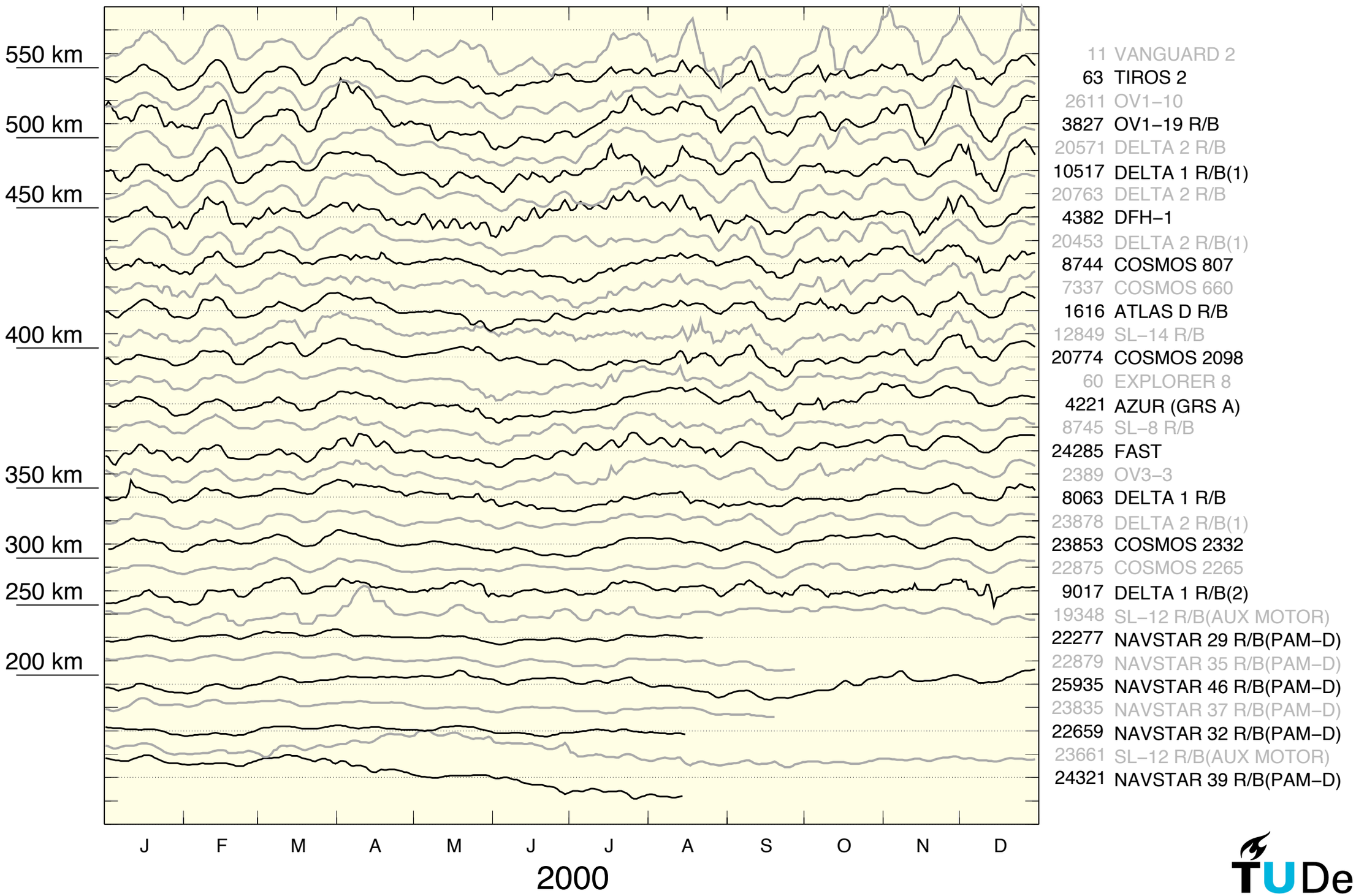
TU Delft

Density ratio time series

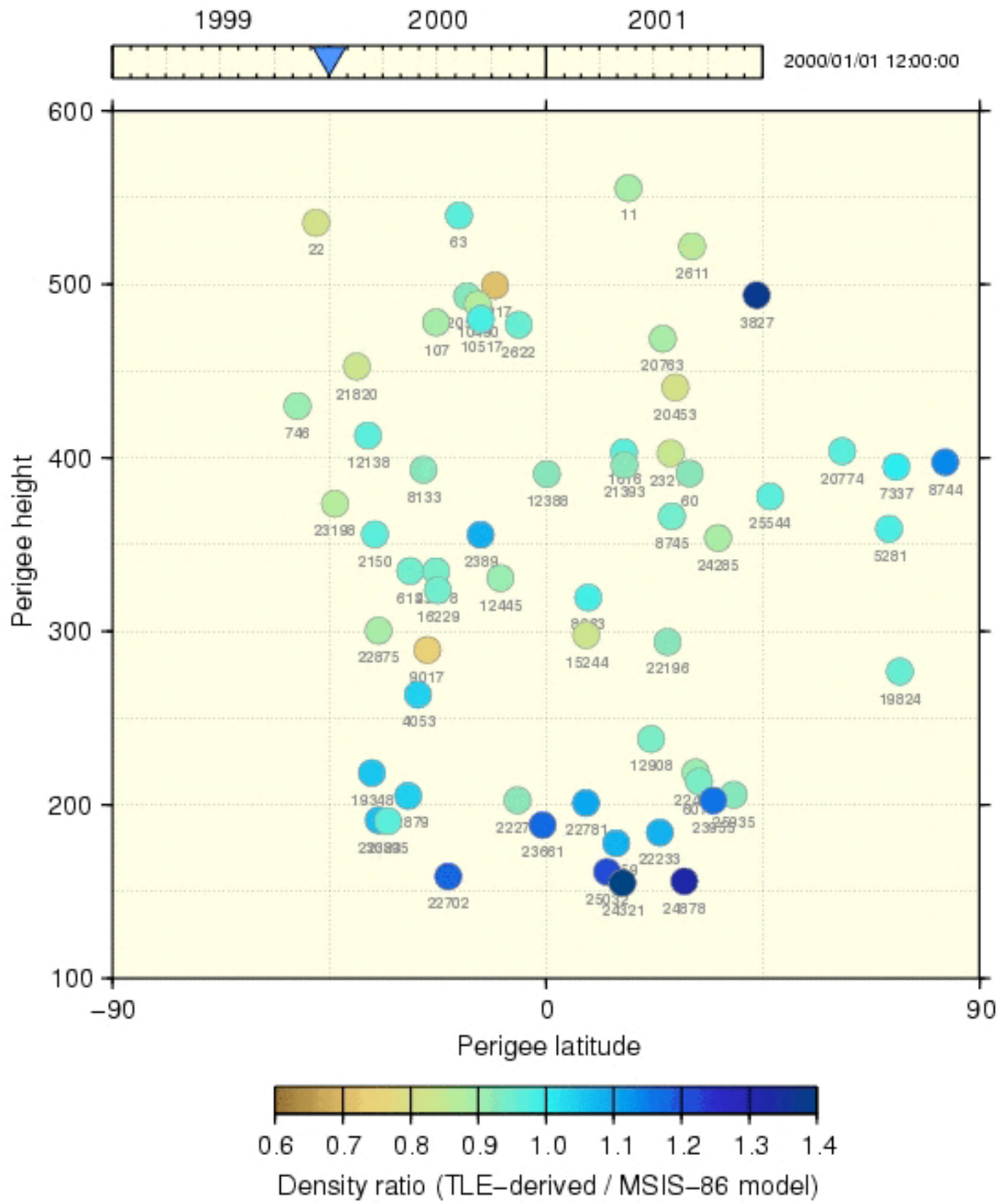
Example:
Explorer-8 2002



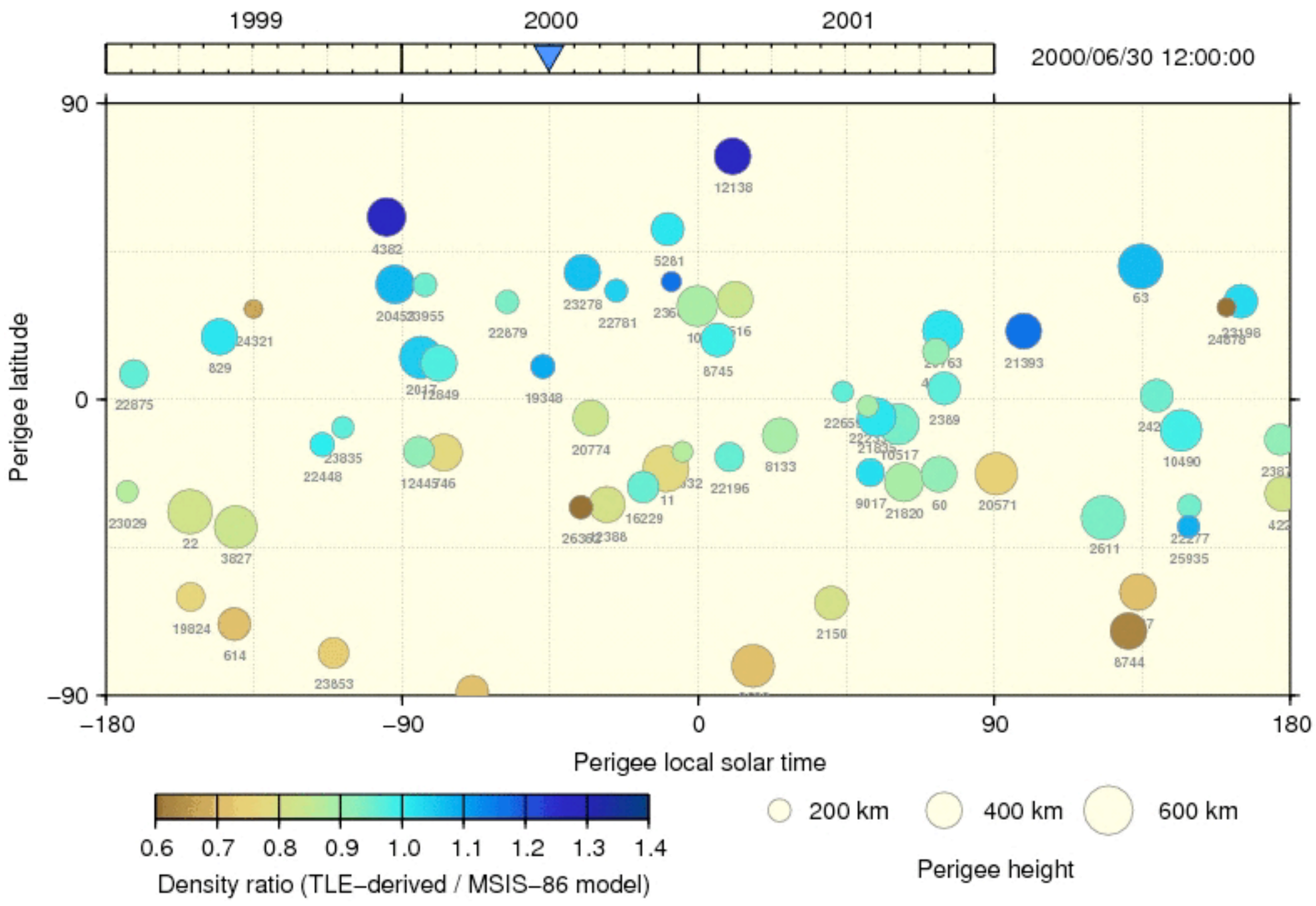
Density ratio time series
Offset and sorted by perigee height



TU Delft


1999
2000
2001
2000/01/01 12:00:00
Perigee height
Perigee latitude
Density ratio (TLE–derived / MSIS–86 model)
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

TU Delft


1999
2000
2001
2000/06/30 12:00:00
90
0
−90
Perigee latitude
−180
−90
0
90
180
Perigee local solar time
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Density ratio (TLE−derived / MSIS−86 model)
200 km
400 km
600 km
Perigee height

TU Delft

Outlook

- Improve TLE data processing performance
- Investigate and implement calibration algorithms
- Calibrated model to be installed at ESOC in June 2006
- Include accelerometer and precise tracking derived data
  - Future ESA missions: GOCE, SWARM

TU Delft

Conclusions

- Progress towards an open near real-time calibrated density model
- Using and comparing complementary data sources
  - Precise tracking, accelerometry and TLEs
- For use in satellite orbit determination and space weather research

TU Delft