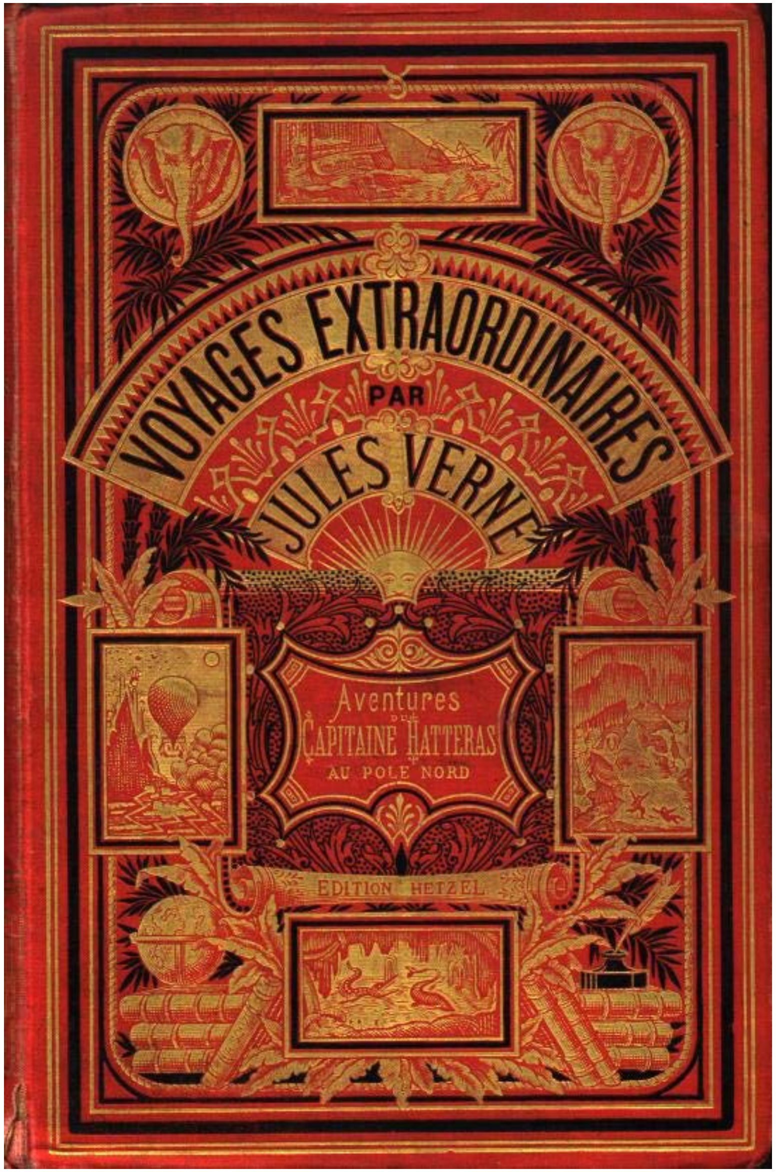
GOCE: 1700 days of flight operations

… and science for a lifetime



GOCE: 1700 days of flight operations

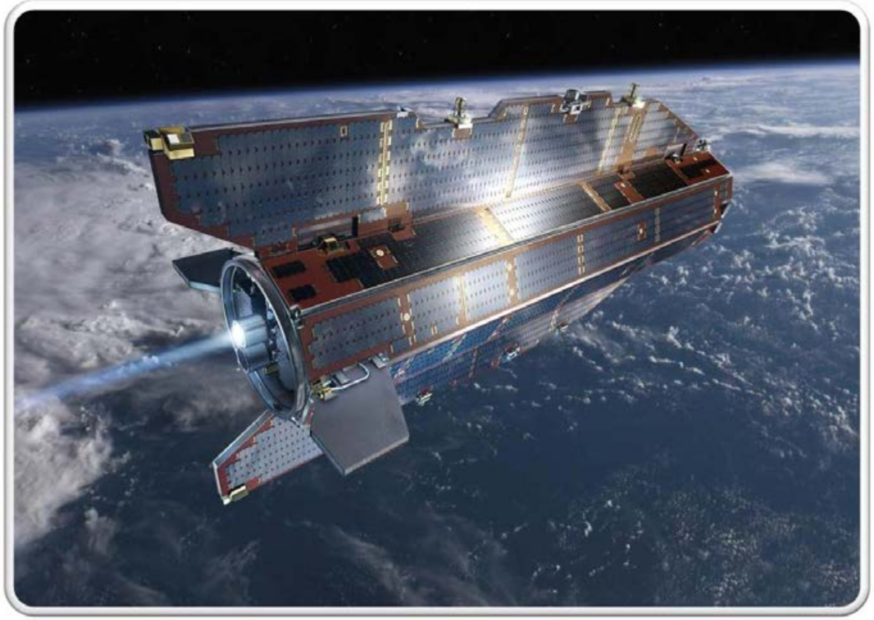
… and science for a lifetime

- Around the world for 1700 days
- After we ran out of fuel: de-orbiting & re-entry
- Results and their context: what has GOCE taught us?
- What next?

report on 1700 days of exciting flight ops

DOCUMENT

GOCE *End-of-Mission Operations Report*

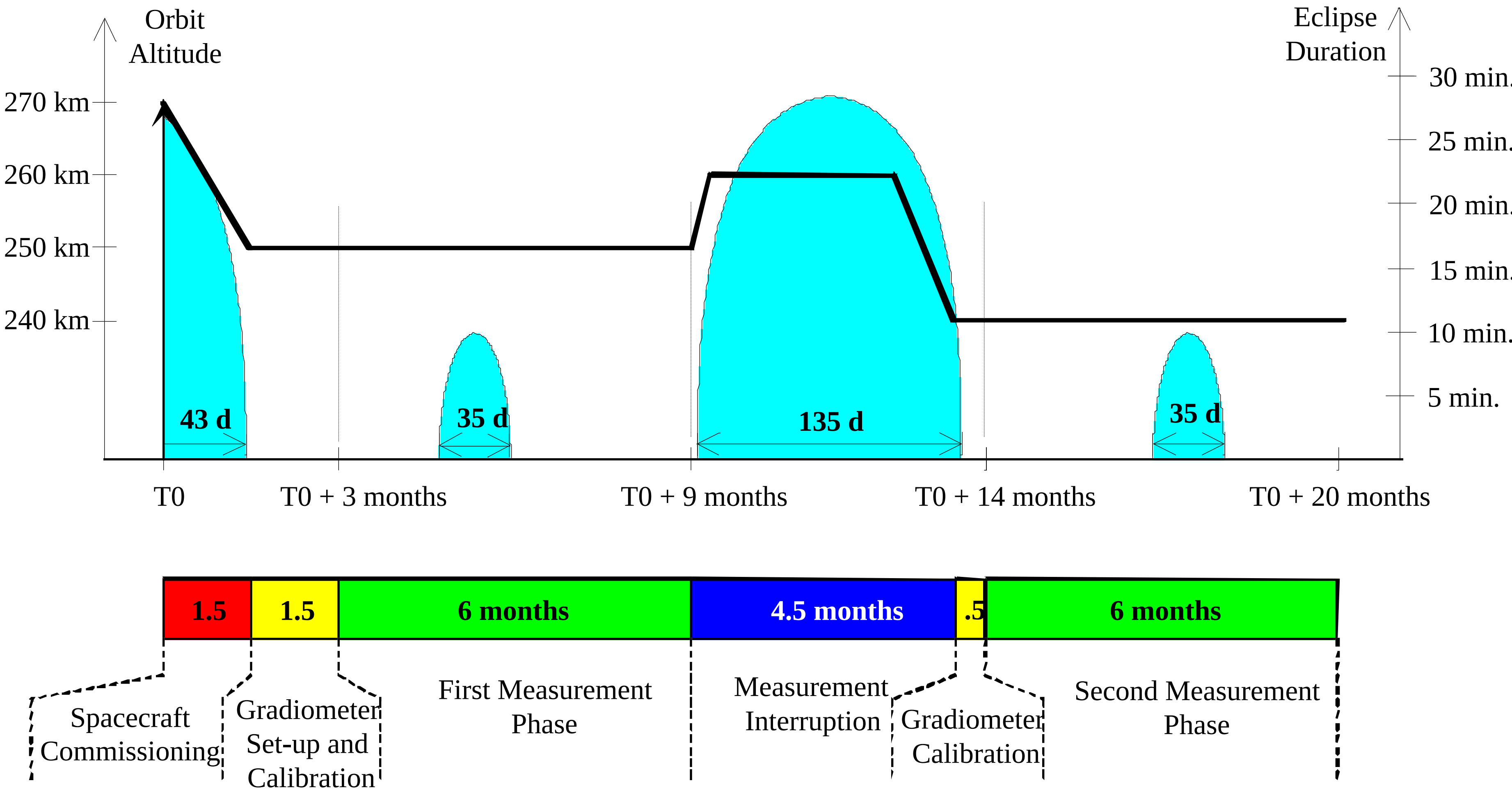


Prepared by	GOCE Flight Control Team (HSO-OEG)
Reference	GO-RP-ESC-FS-6268
Issue	1
Revision	0
Date of Issue	07/02/2014
Status	Authorised
Document Type	RP
Distribution	

see

earth.esa.int/goce

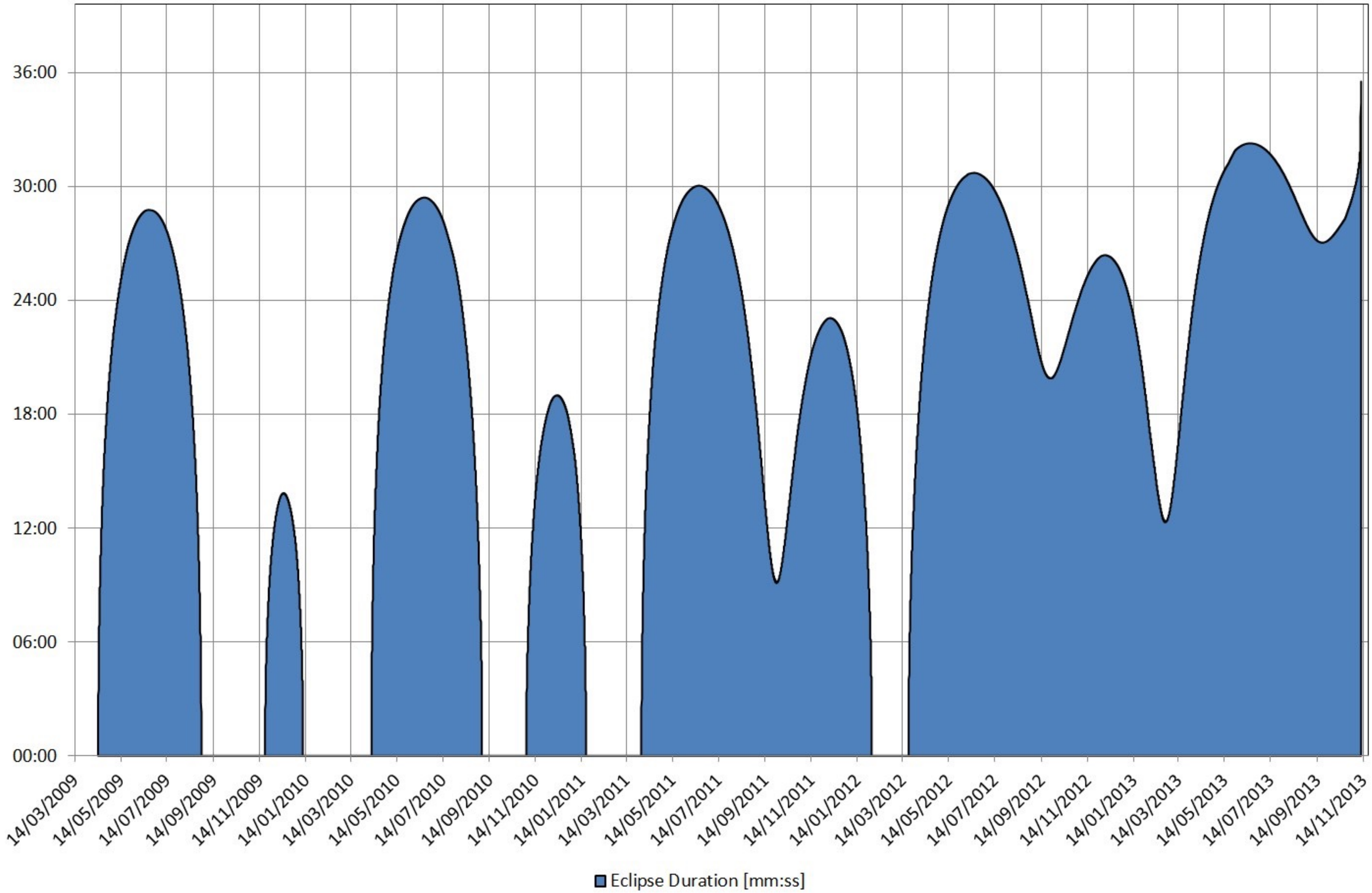
- Planned mission: ’20 months all inclusive’
- 2 ‘measurement’ phases of six months - with propellant resources for 3


Orbit Altitude
270 km
260 km
250 km
240 km
Eclipse Duration
30 min.
25 min.
20 min.
15 min.
10 min.
5 min.
43 d
35 d
135 d
35 d
T0
T0 + 3 months
T0 + 9 months
T0 + 14 months
T0 + 20 months
1.5
1.5
6 months
4.5 months
.5
6 months
Spacecraft Commissioning
Gradiometer Set-up and Calibration
First Measurement Phase
Measurement Interruption
Gradiometer Calibration
Second Measurement Phase

- Planned mission: ’20 months all inclusive’
- 2 ‘measurement’ phases of six months - with propellant resources for 3

- Actual flight: 4.5y of near-continuous science operations
- No distinction between eclipse or sunlit periods
- Flawless operation of drag-free control system

eclipse phases as encountered



- Planned mission: ’20 months all inclusive’
- 2 ‘measurement’ phases of six months - with propellant resources for 3

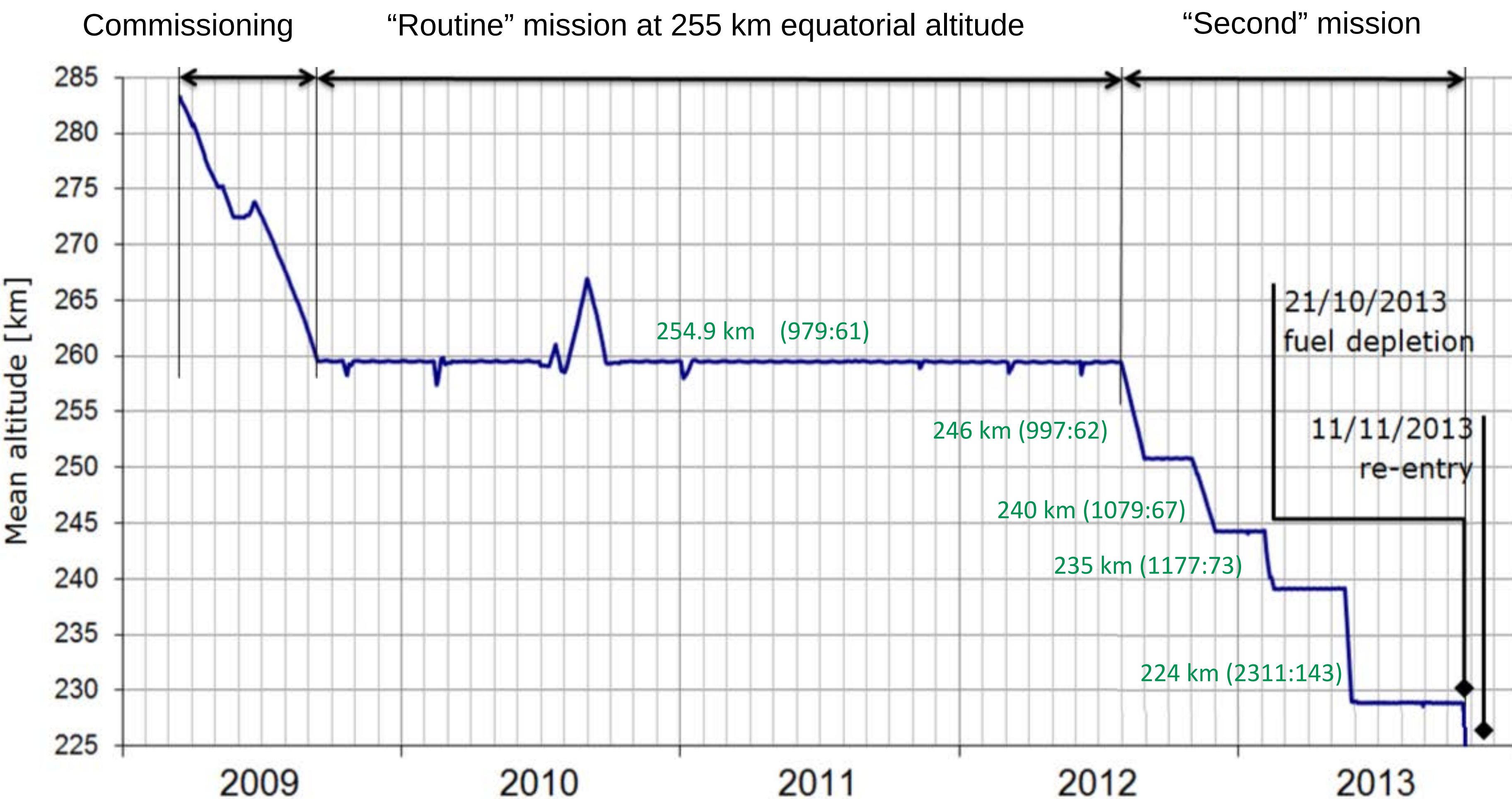
- Actual flight: 4.5y of near-continuous science operations
- No distinction between eclipse or sunlit periods
- Flawless operation of drag-free control system

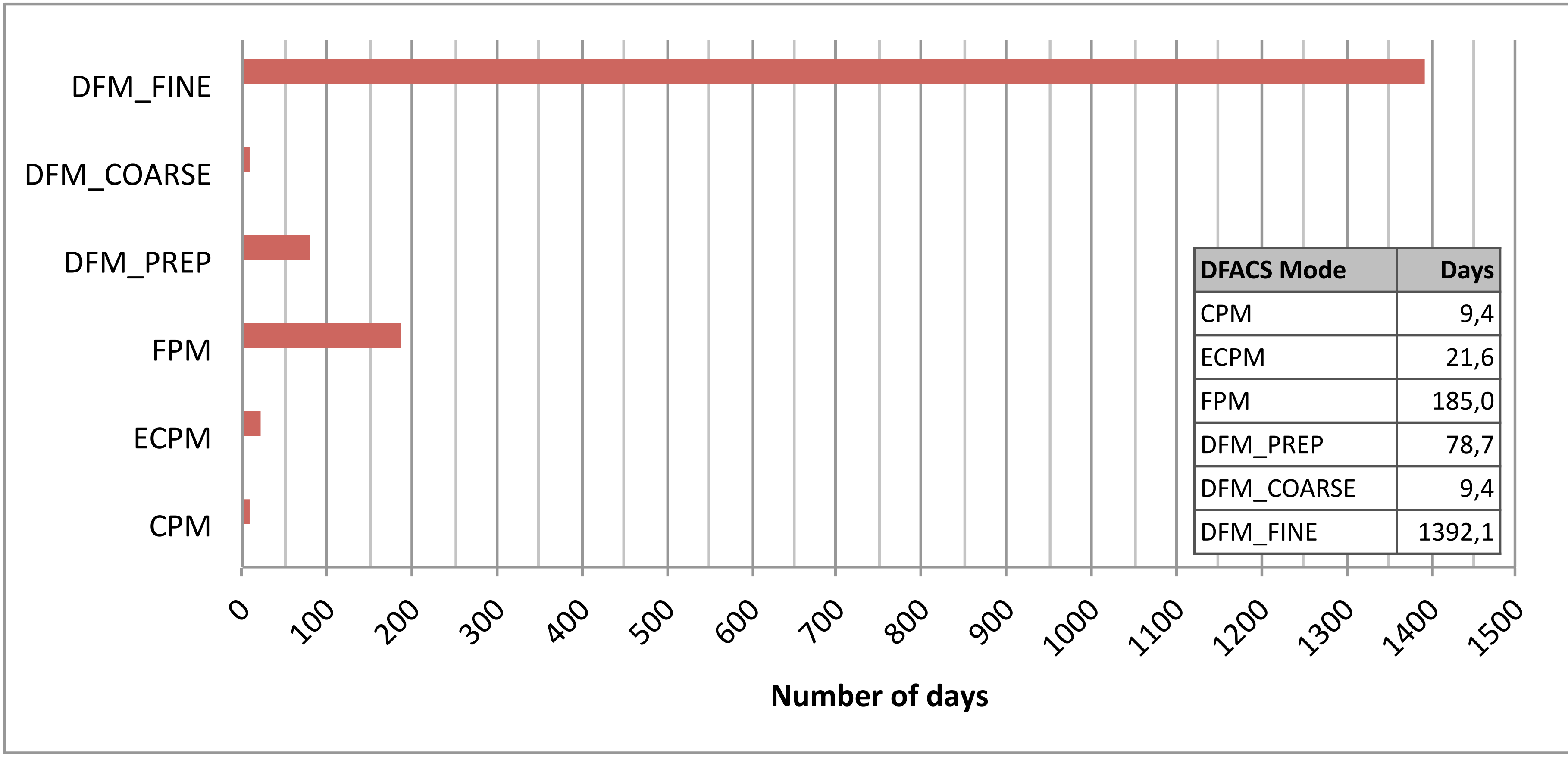
- Celebrating today a highly successful joint undertaking of ESA, European industry and science

actual altitude history

Mean spherical altitude

(subtract 5 km for equatorial altitude)



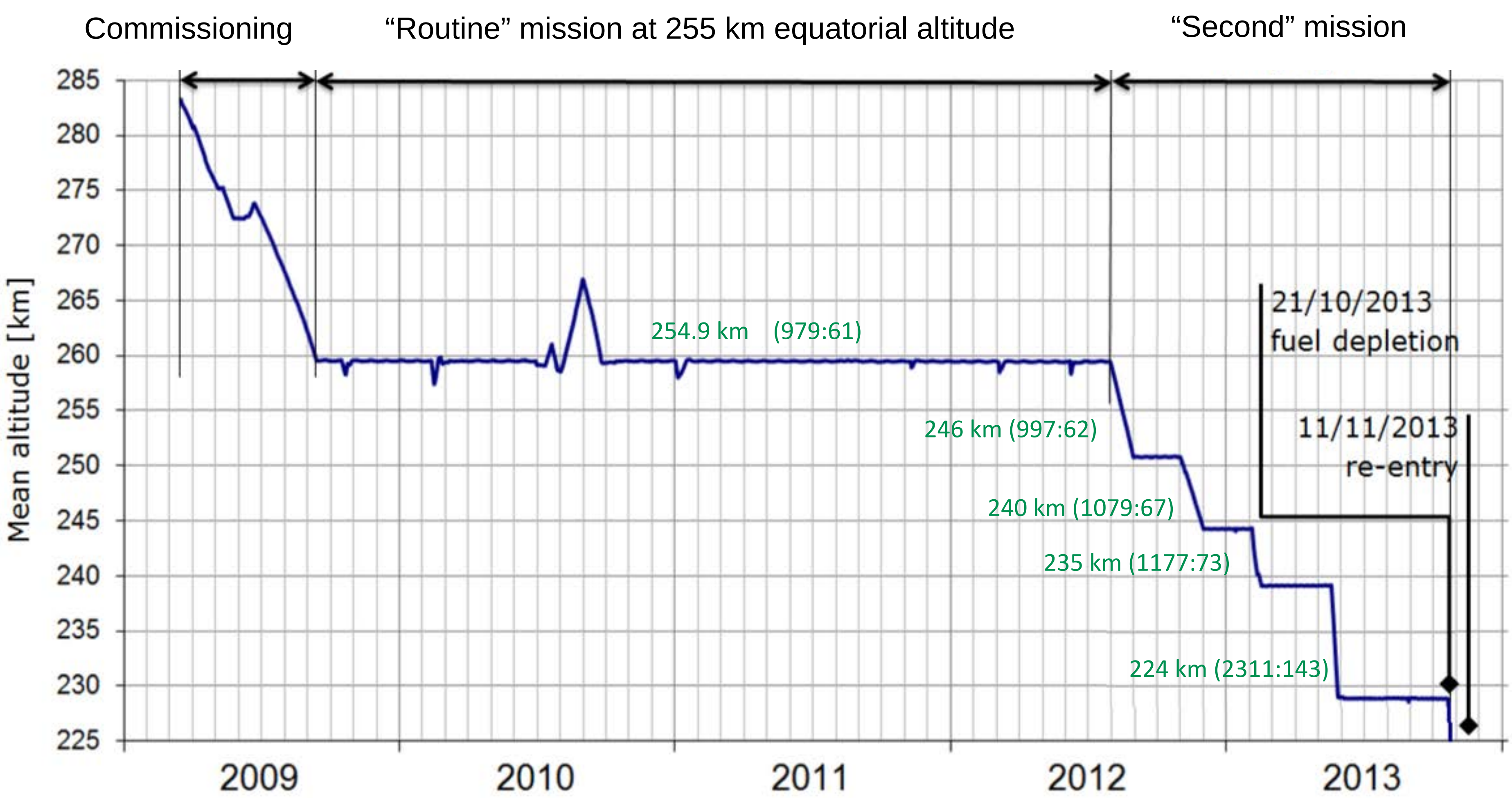


DFACS Mode	Days
CPM	9,4
ECPM	21,6
FPM	185,0
DFM_PREP	78,7
DFM_COARSE	9,4
DFM_FINE	1392,1

DFM = drag-free mode

Mean spherical altitude

(subtract 5 km for equatorial altitude)



satellite performance - science service interruptions

from	to	#days	event
16/10/09	26/10/09	11	Fallback due to IPA SW crash + playback data corruption
12/02/10	02/03/10	19	CDMU failure
20/03/10	24/03/10	5	EGG SW crash + electrodes reconfiguration
30/06/10	06/07/10	7	IPA SW crash + EGG reconfiguration
08/07/10	06/10/10	91	No TM anomaly
02/01/11	19/01/11	18	SSTI state vector anomaly
08/02/11	10/02/11	3	EGG SW crash + FEEU desynchronisation
23/09/11	26/09/11	4	EGG SW crash
09/11/11	11/11/11	3	Fallback due to IPA SW crash
05/03/12	08/03/12	4	Safe Mode #4 (sudden PASW restart)
07/06/12	13/06/12	7	Safe Mode #5 (loss of attitude control due to EGG ASH1 anomaly)
13/01/13	14/01/13	2	Fallback due to IPA SW crash
02/02/13	07/02/13	6	EGG ASH1 anomaly and loss of attitude control in recovery
05/05/13	06/05/13	2	EGG ASH1 anomaly
29/08/13	30/08/13	2	Fallback due to IPA SW crash

satellite performance - science service interruptions

from	to	#days	event
16/10/09	26/10/09	11	Fallback due to IPA SW crash + playback data corruption
12/02/10	02/03/10	19	CDMU failure
20/03/10	24/03/10	5	EGG SW crash + electrodes reconfiguration
30/06/10	06/07/10	7	IPA SW crash + EGG reconfiguration
08/07/10	06/10/10	91	No TM anomaly
02/01/11	19/01/11	18	SSTI state vector anomaly
08/02/11	10/02/11	3	EGG SW crash + FEEU desynchronisation
23/09/11	26/09/11	4	EGG SW crash
09/11/11	11/11/11	3	Fallback due to IPA SW crash
05/03/12	08/03/12	4	Safe Mode #4 (sudden PASW restart)
07/06/12	13/06/12	7	Safe Mode #5 (loss of attitude control due to EGG ASH1 anomaly)
13/01/13	14/01/13	2	Fallback due to IPA SW crash
02/02/13	07/02/13	6	EGG ASH1 anomaly and loss of attitude control in recovery
05/05/13	06/05/13	2	EGG ASH1 anomaly
29/08/13	30/08/13	2	Fallback due to IPA SW crash

satellite performance - science service interruptions

from	to	#days	event
16/10/09	26/10/09	11	Fallback due to IPA SW crash + playback data corruption
12/02/10	02/03/10	19	CDMU failure
20/03/10	24/03/10	5	EGG SW crash + electrodes reconfiguration
30/06/10	06/07/10	7	IPA SW crash + EGG reconfiguration
08/07/10	06/10/10	91	No TM anomaly
02/01/11	19/01/11	18	SSTI state vector anomaly
08/02/11	10/02/11	3	EGG SW crash + FEEU desynchronisation
23/09/11	26/09/11	4	EGG SW crash
09/11/11	11/11/11	3	Fallback due to IPA SW crash
05/03/12	08/03/12	4	Safe Mode #4 (sudden PASW restart)
07/06/12	13/06/12	7	Safe Mode #5 (loss of attitude control due to EGG ASH1 anomaly)
13/01/13	14/01/13	2	Fallback due to IPA SW crash
02/02/13	07/02/13	6	EGG ASH1 anomaly and loss of attitude control in recovery
05/05/13	06/05/13	2	EGG ASH1 anomaly
29/08/13	30/08/13	2	Fallback due to IPA SW crash

satellite performance - science service interruptions

from	to	#days	event
16/10/09	26/10/09	11	Fallback due to IPA SW crash + playback data corruption
12/02/10	02/03/10	19	CDMU failure
20/03/10	24/03/10	5	EGG SW crash + electrodes reconfiguration
30/06/10	06/07/10	7	IPA SW crash + EGG reconfiguration
08/07/10	06/10/10	91	No TM anomaly
02/01/11	19/01/11	18	SSTI state vector anomaly
08/02/11	10/02/11	3	EGG SW crash + FEEU desynchronisation
23/09/11	26/09/11	4	EGG SW crash
09/11/11	11/11/11	3	Fallback due to IPA SW crash
05/03/12	08/03/12	4	Safe Mode #4 (sudden PASW restart)
07/06/12	13/06/12	7	Safe Mode #5 (loss of attitude control due to EGG ASH1 anomaly)
13/01/13	14/01/13	2	Fallback due to IPA SW crash
02/02/13	07/02/13	6	EGG ASH1 anomaly and loss of attitude control in recovery
05/05/13	06/05/13	2	EGG ASH1 anomaly
29/08/13	30/08/13	2	Fallback due to IPA SW crash

No TM anomaly **was a real threat to the success of the mission, after having lost the nominal computer earlier**

NEWS SCIENCE & ENVIRONMENT

7 September 2010 Last updated at 22:31

Share

Goce gravity satellite 'caught the cold'

By Jonathan Amos
Science correspondent, BBC News

The flagship European Earth observation satellite Goce was knocked offline because some of its onboard systems got too cold as it circled the planet.

Goce flies lower than any other scientific satellite

The spacecraft is on a mission to make the most precise maps yet of how gravity varies across the world.

But when a fault appeared in its one fully functional computer, the flow of science data to the ground stopped.

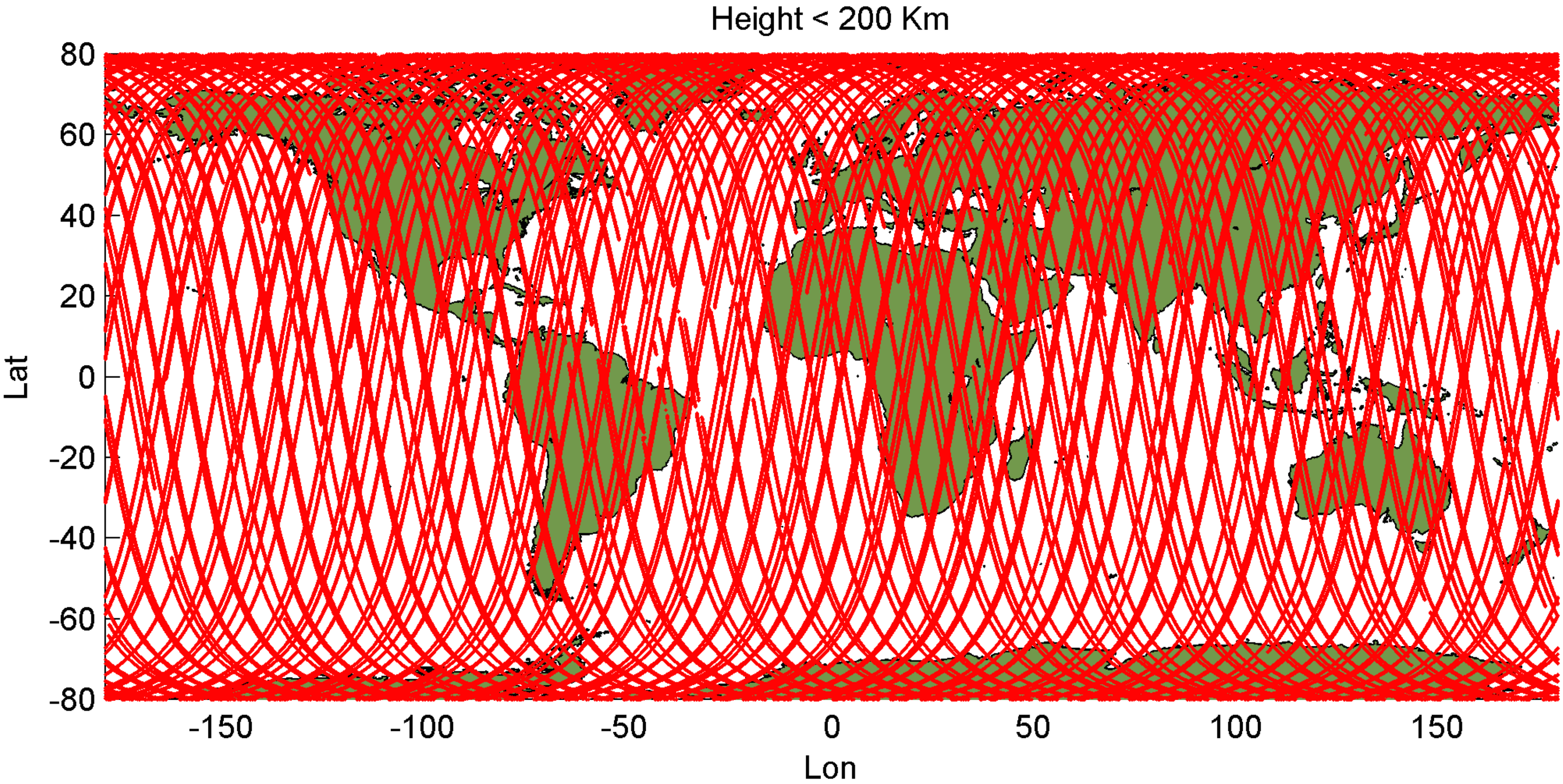
Controllers managed to recover the situation only when they turned the heat up inside the satellite.

Related Stories

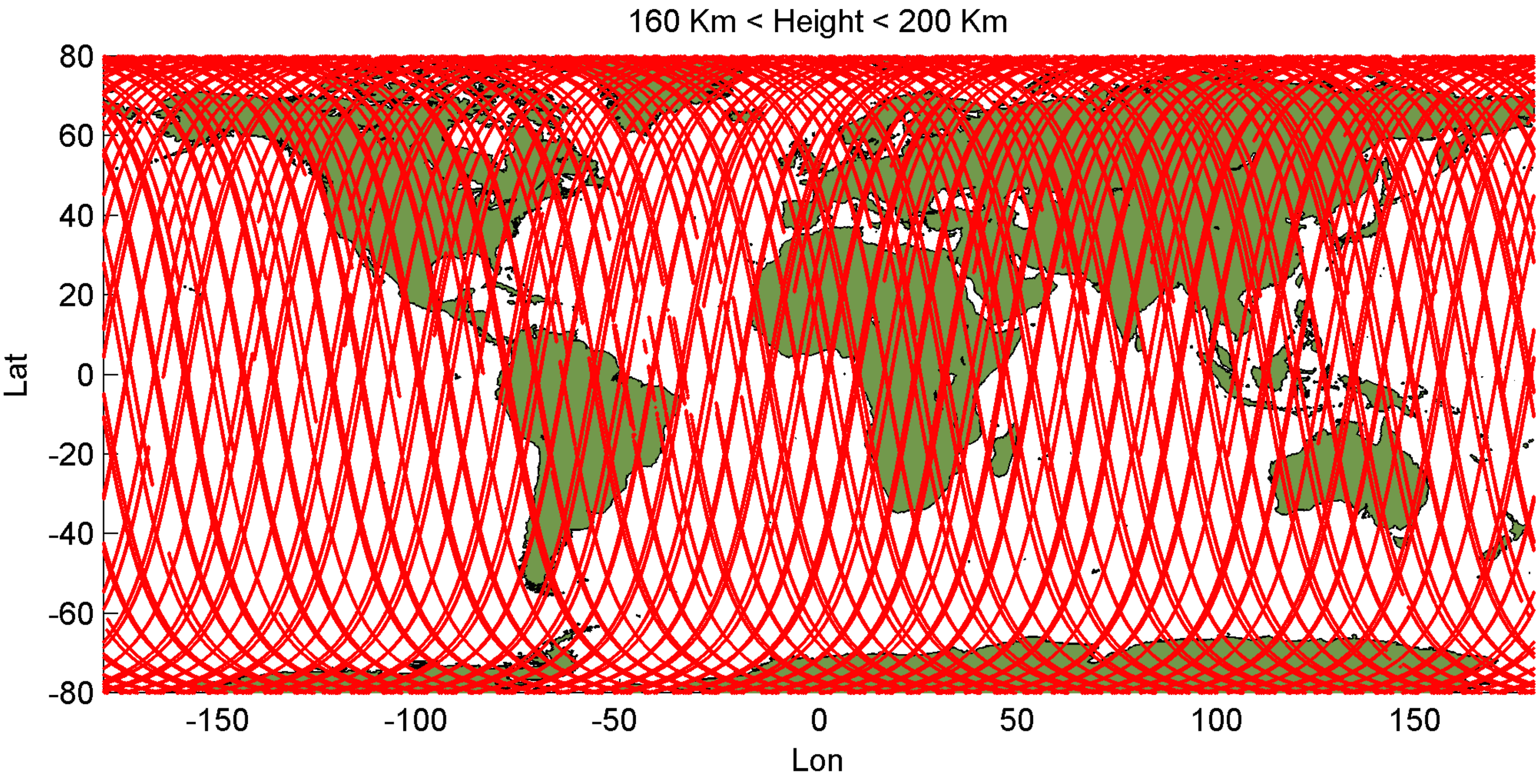
Top Storie

NHS staff to fly o
Labour 'still party
Memorial due for
14 injured in hote

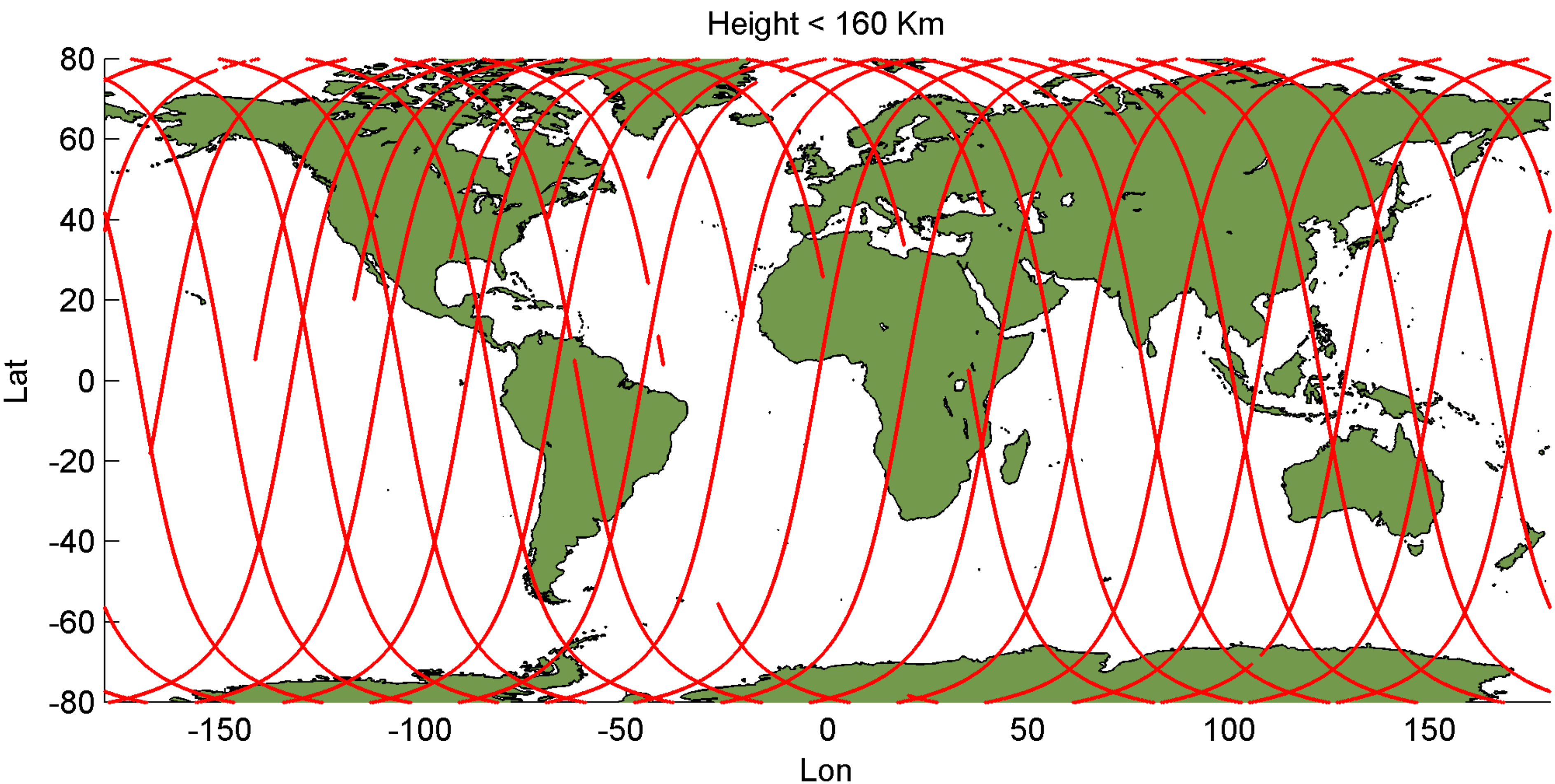
Features


Height < 200 Km
80
60
40
20
0
-20
-40
-60
-80
Lat
-150
-100
-50
0
50
100
150
Lon

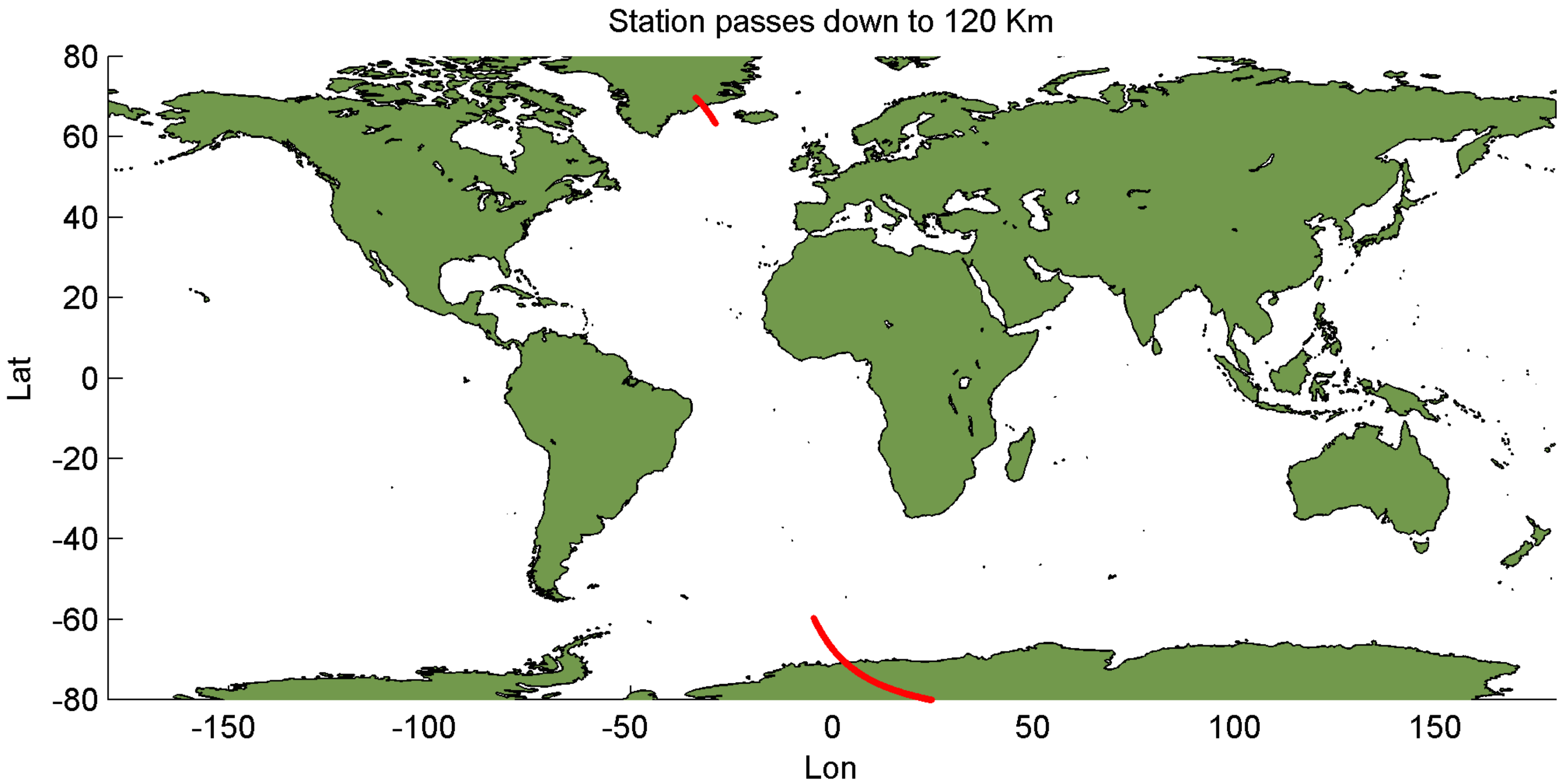
data availability



data availability



data availability



- Some 23,000 catalogued objects (>10cm) have re-entered since 1958
  - 1 to 2 catalog objects per day (d > 10cm)
  - 1 to 2 potential survivor objects per week (d > 1m)

- ESA Space Debris Mitigation Requirements:

  In case the total casualty risk is larger than 10^{-4}, uncontrolled re-entry is not allowed. Instead, a controlled re-entry must be performed such that the impact foot-print can be ensured over an ocean area, with sufficient clearance of landmasses and traffic routes.

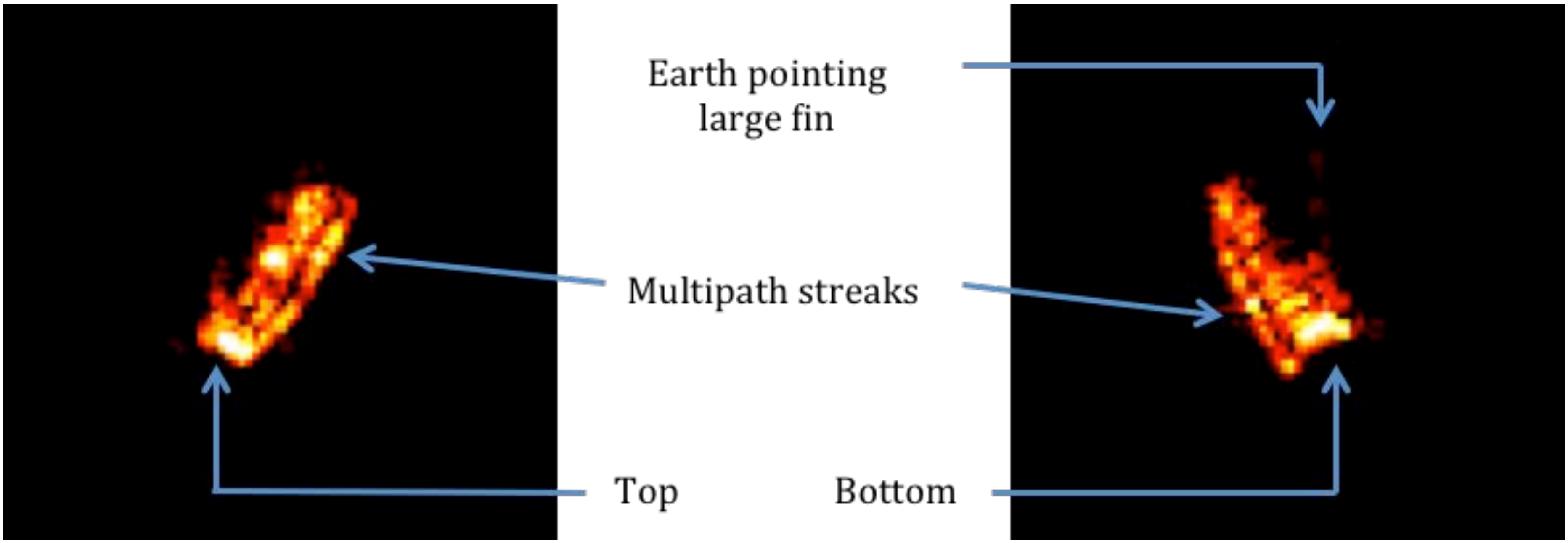
- Need for a good understanding of the physical process governing orbital decay and re-entry break-up, especially for the implementation of future missions

research opportunities: tracking and prediction

- On request ESA provides predictions for uncontrolled re-entry events to national alert centres
- Since uncontrolled re-entries normally concern inactive objects, active (ground-based) sensors are used
- Inter-Agency Debris Coordination Committee pools sensors to enrich prediction results
- GOCE performed a re-entry with no orbit control (i.e., uncontrolled in the above sense) while recording positional and attitude data
- GOCE re-entry therefore is a reference for the validation of
  - ground based orbit and attitude measurements (radar, optical, SLR)
  - orbit & attitude dynamic predictions

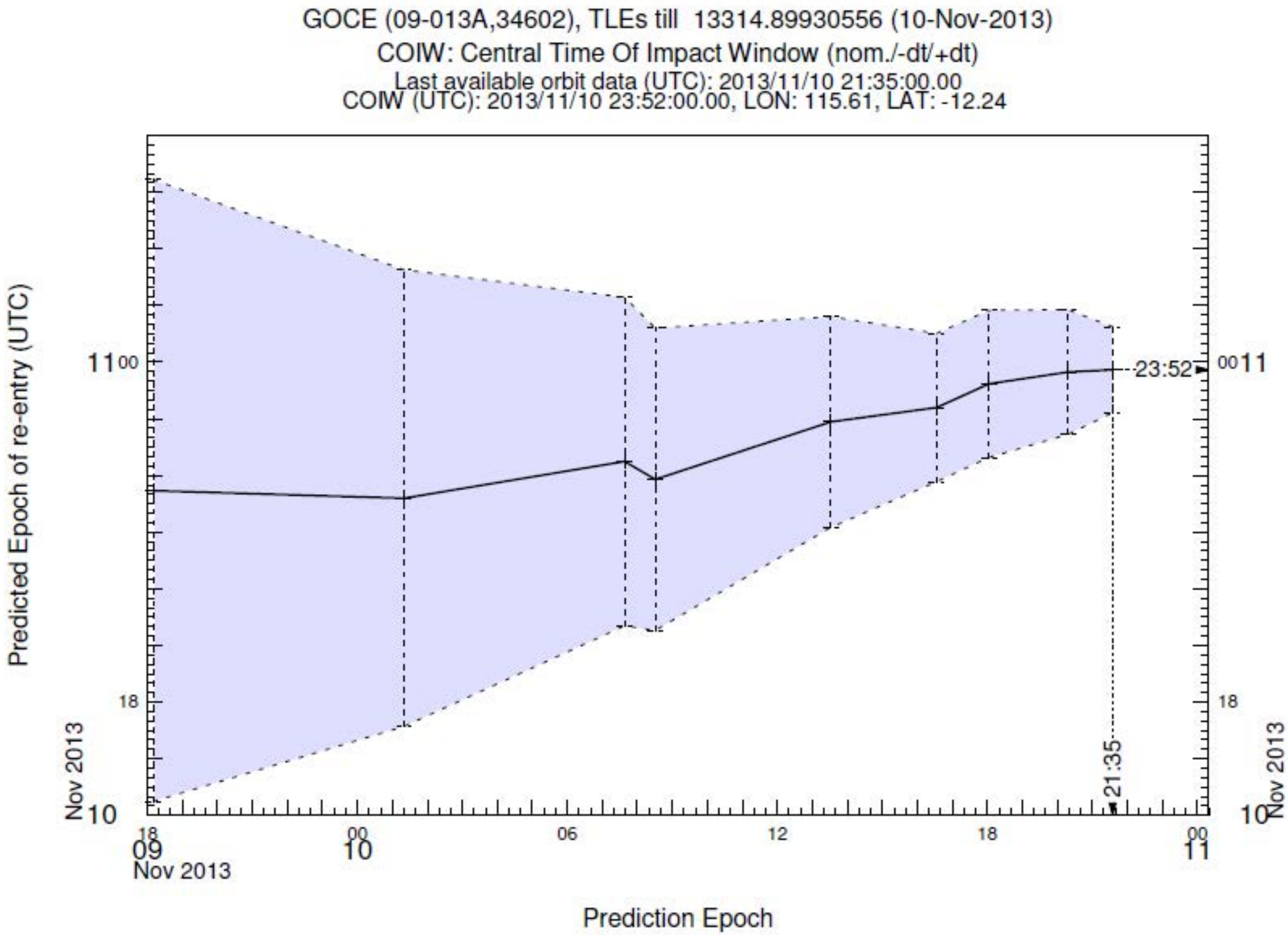
ground-based imagery of GOCE

ground-based imagery of GOCE during de-orbiting phase

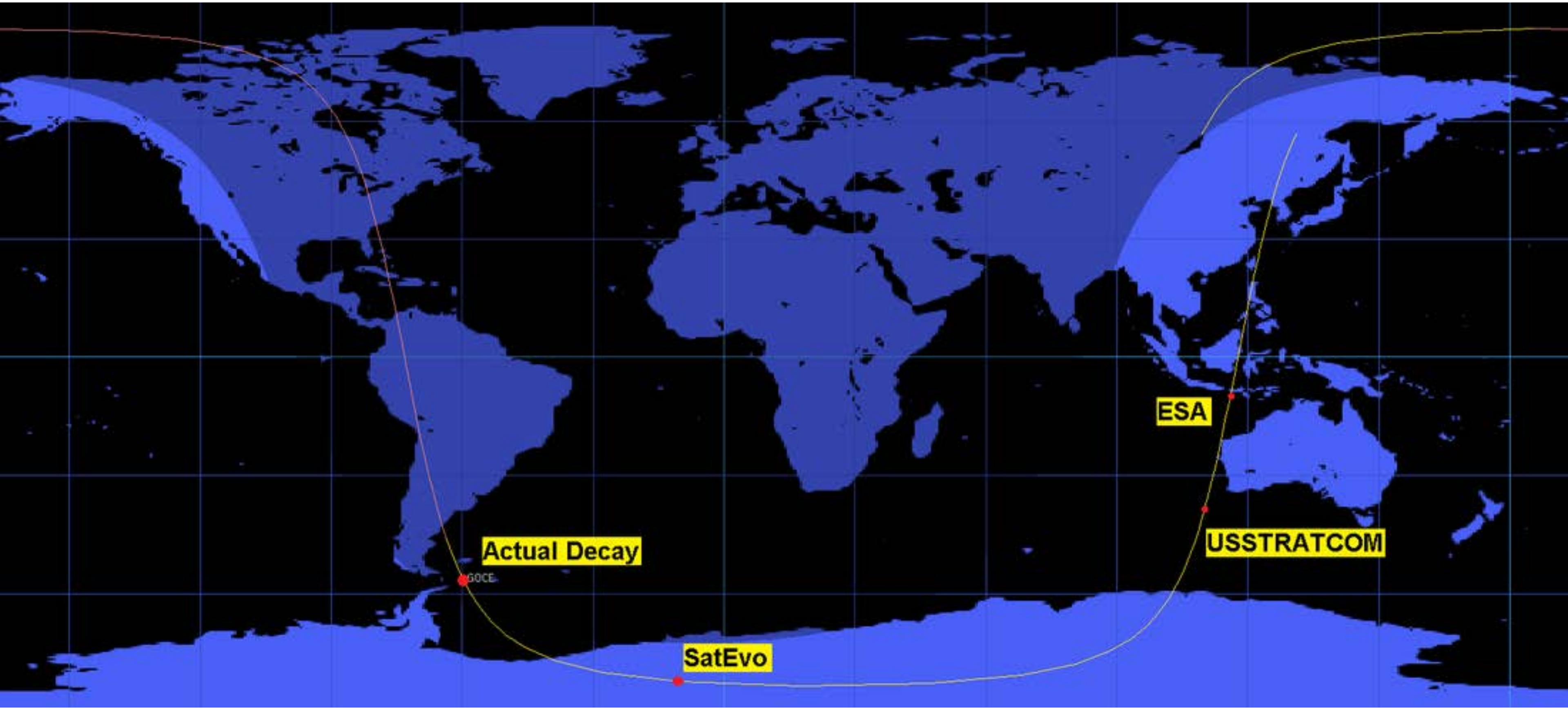


Courtesy: Fraunhofer Institute

evolution of the prediction window



why are the re-entry data important?



[00:16 UTC]: Re-entry confirmed (visual and by radar/IR sensors)
[23:03 UTC]: SatEvo computes decay at 0:09 UTC on November 11
[22:13 UTC]: Last ESA Re-Entry Prediction: 22:50 to 00:50 UTC
[21:43 UTC]: Last USSTRATCOM Re-Entry Prediction: November 10, 2013 - 23:58 UTC +/-2 hours

Re-entry predictions difficult; all predictions had significant uncertainties; satellite kept “flying”
—> political interest in space debris issues, casualty risk mitigation, social responsibility of all ‘space’, etc.

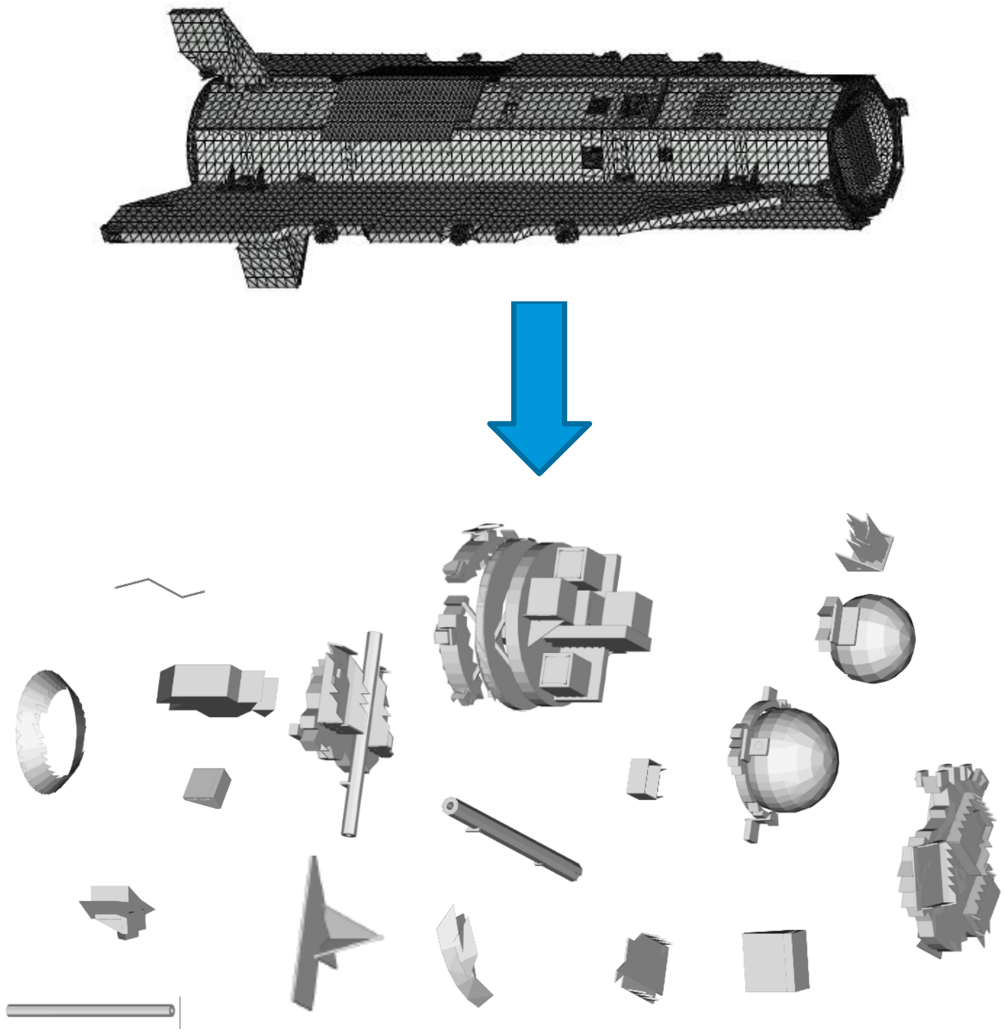
research opportunities: re-entry & break-up

- In order to determine on-ground risk (also prior to mission implementation) ESA uses dedicated software tools to simulate the re-entry break-up process

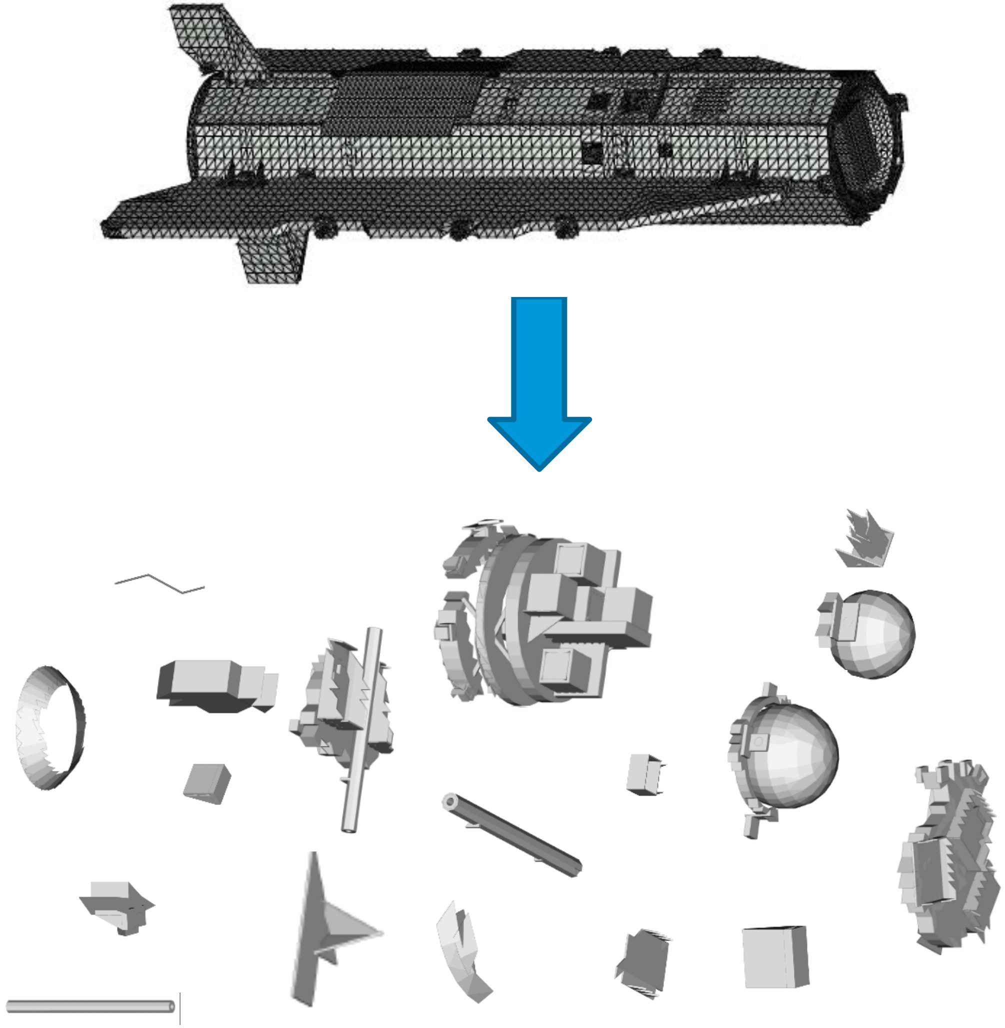
- Simulations consider the aerodynamic and aerothermal effects that occur as a result of the spacecraft/atmosphere interaction

- GOCE re-entry data down to nearly 100 km help validate such simulations (although GOCE was a very special design):
  - decay rate (from TM and ground observations)
  - attitude motions (from TM)
  - temperature of selected components (sensor TM)

research opportunities: re-entry & break-up

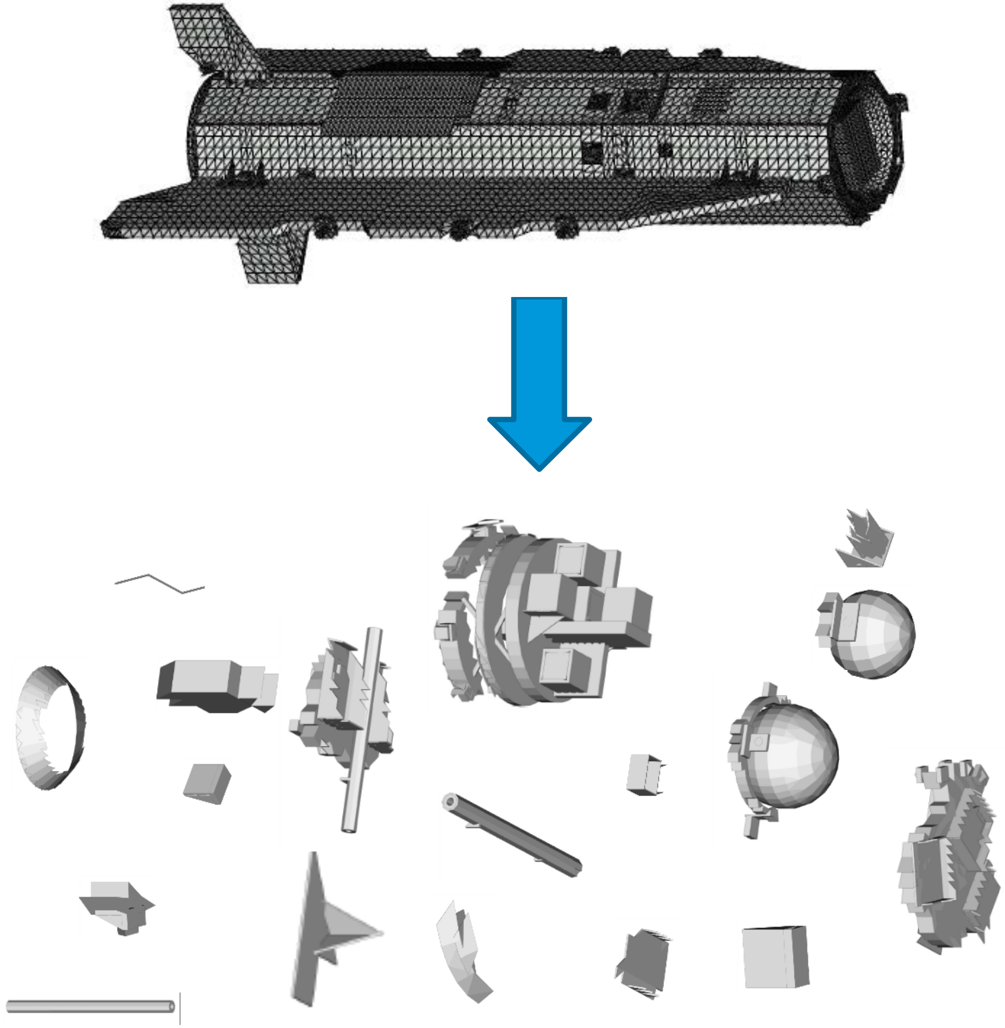


Spacecraft modelling
—> simplified model



Spacecraft modelling
—> simplified model

Aerodynamic analysis
—> forces and torques

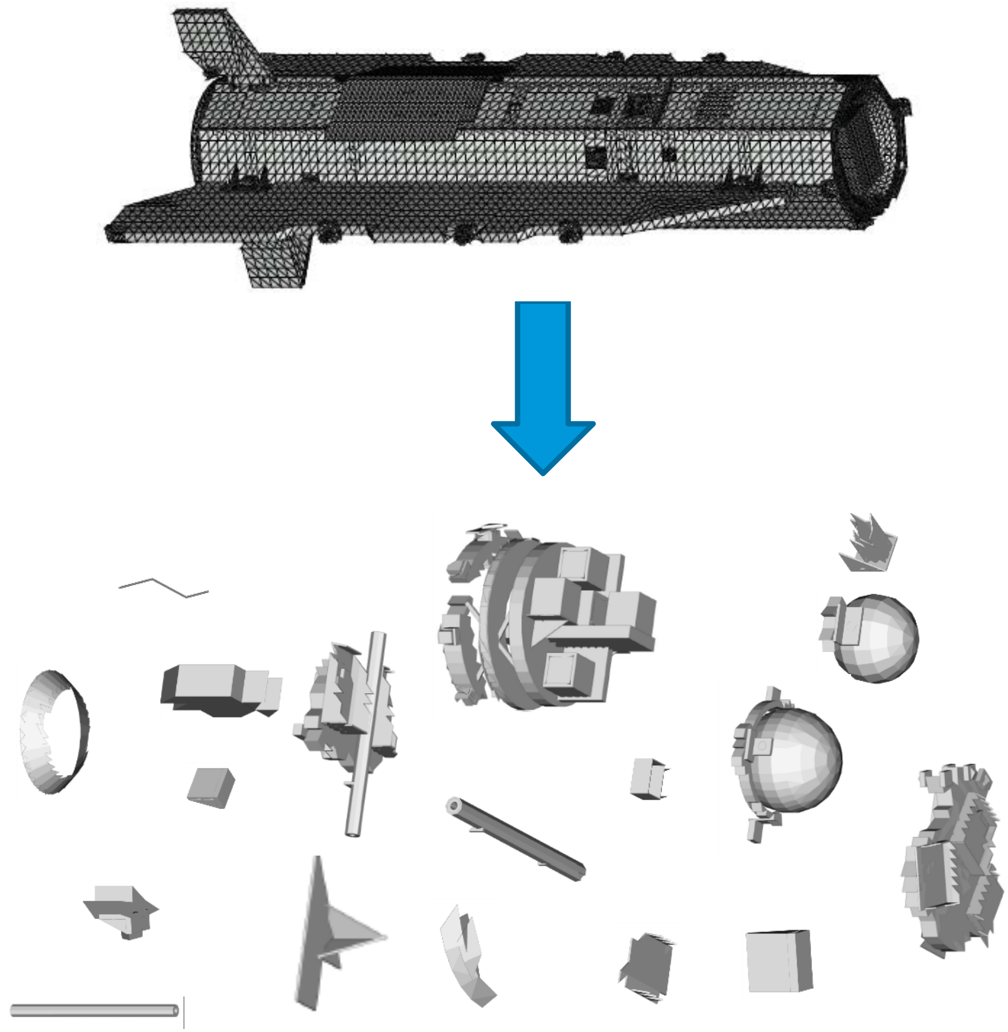


research opportunities: re-entry & break-up

Spacecraft modelling
—> simplified model

Aerodynamic analysis
—> forces and torques

Dynamic analysis
—> trajectory and attitude motion

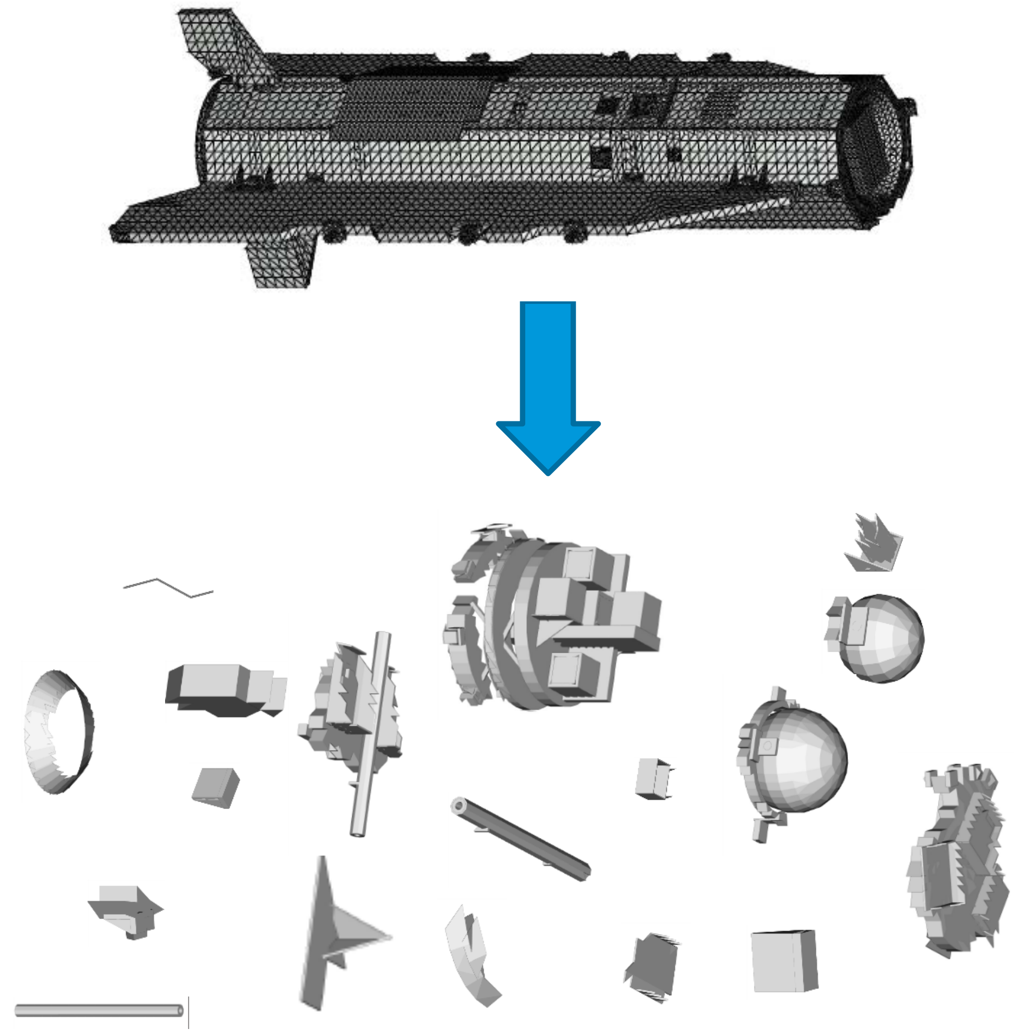


Spacecraft modelling
—> simplified model

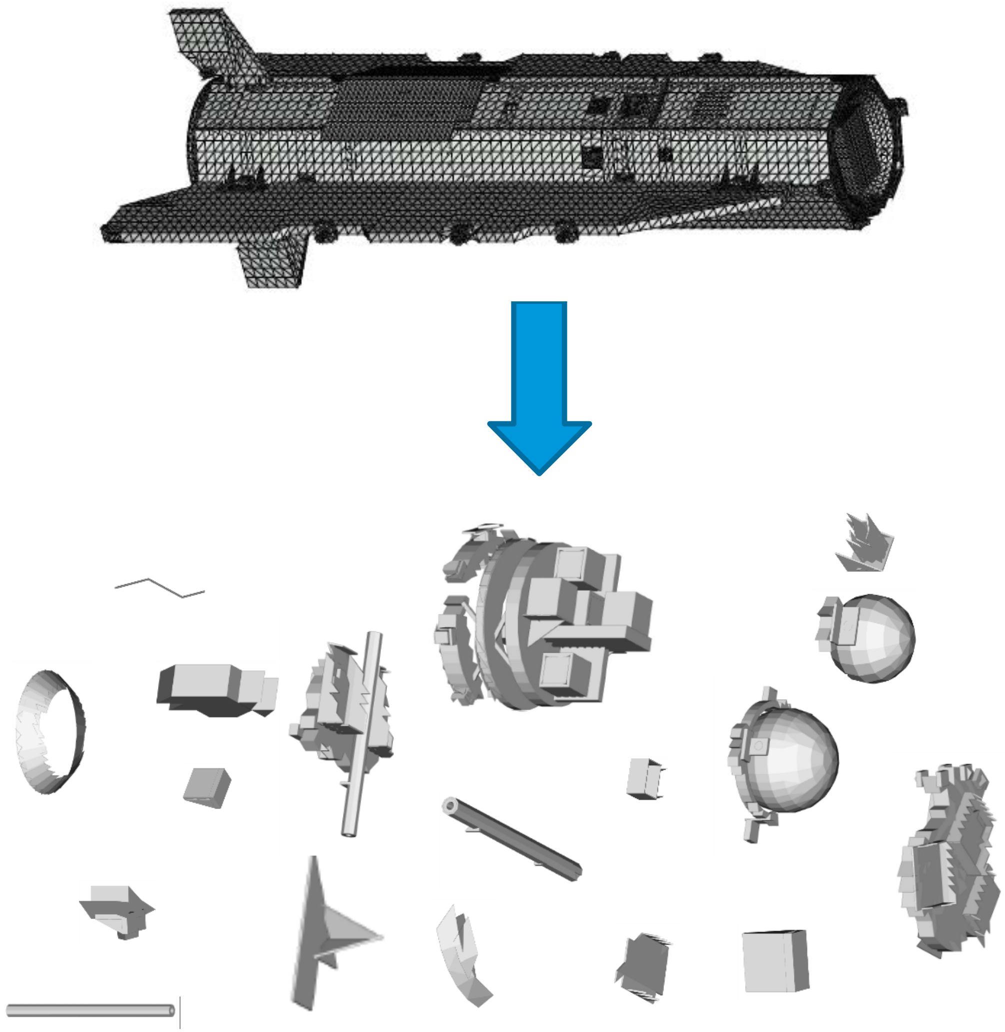
Aerodynamic analysis
—> forces and torques

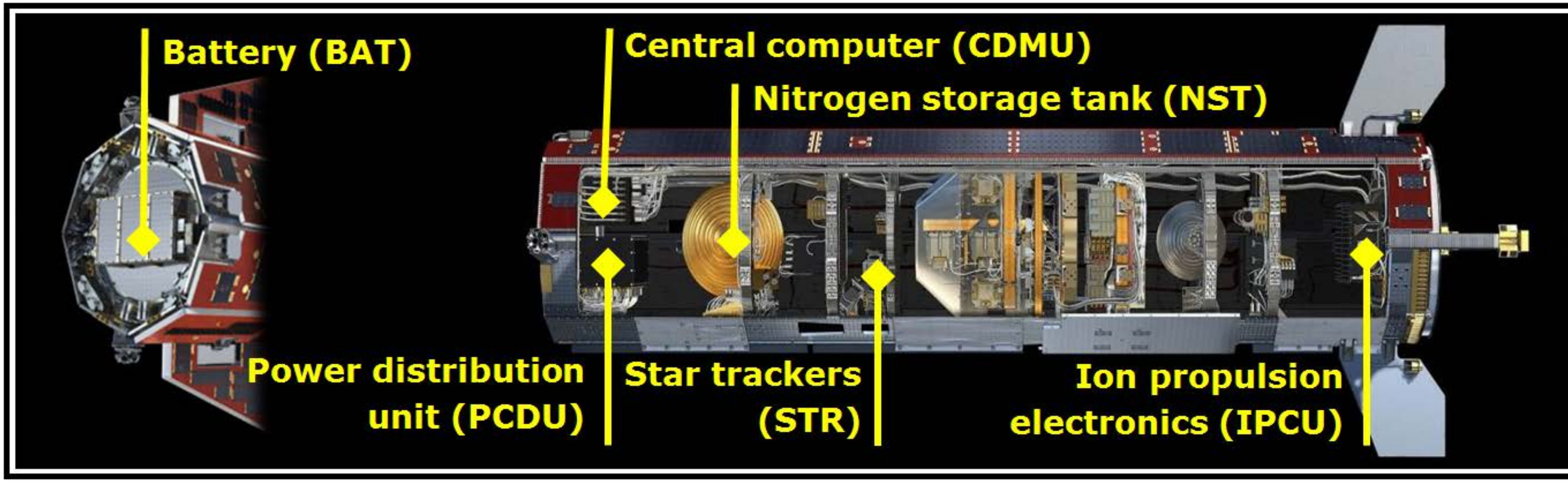
Dynamic analysis
—> trajectory and attitude motion

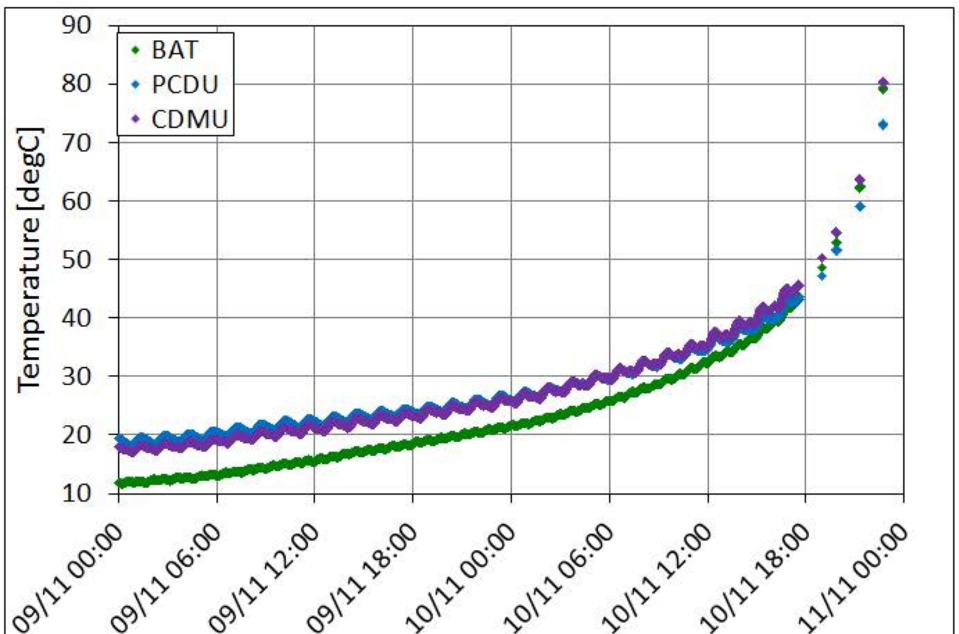
Aerothermal analysis
—> heating and melting

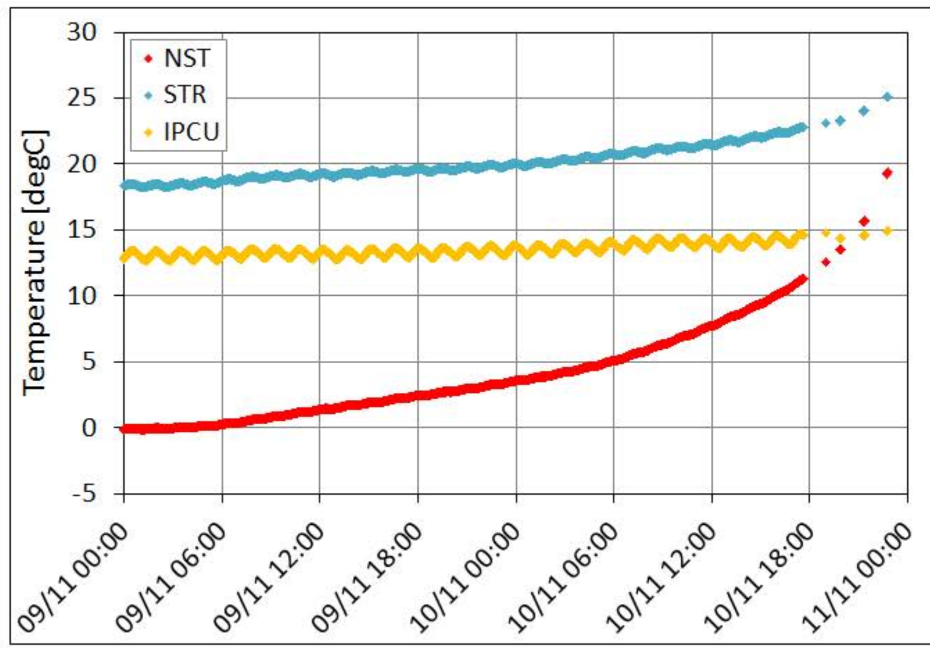


Spacecraft modelling —> simplified model
Aerodynamic analysis —> forces and torques
Dynamic analysis —> trajectory and attitude motion
Aerothermal analysis —> heating and melting
Fragmentation analysis —> structural fracture and separation due to melting

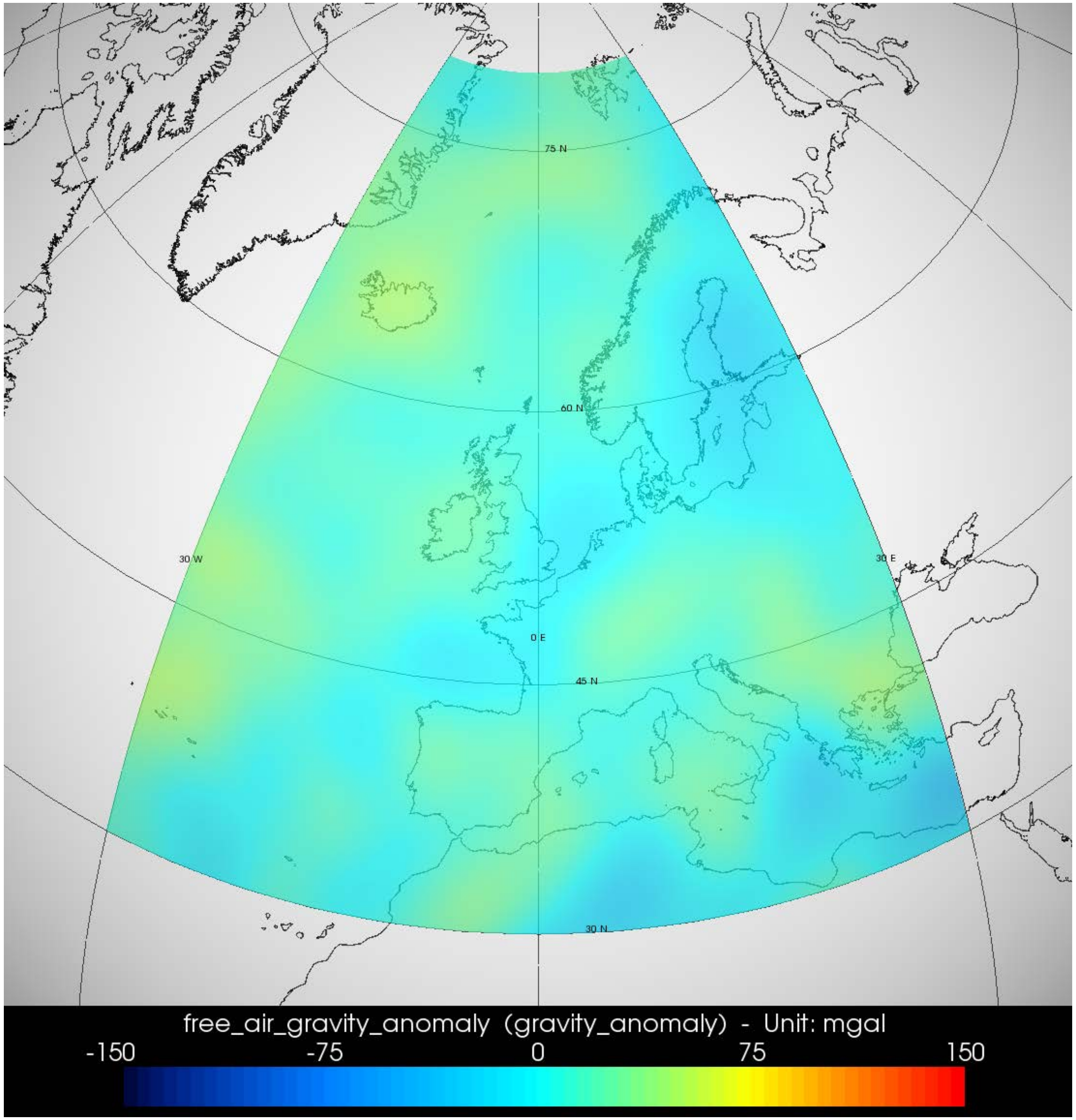



Battery (BAT)
Central computer (CDMU)
Nitrogen storage tank (NST)
Power distribution unit (PCDU)
Star trackers (STR)
Ion propulsion electronics (IPCU)

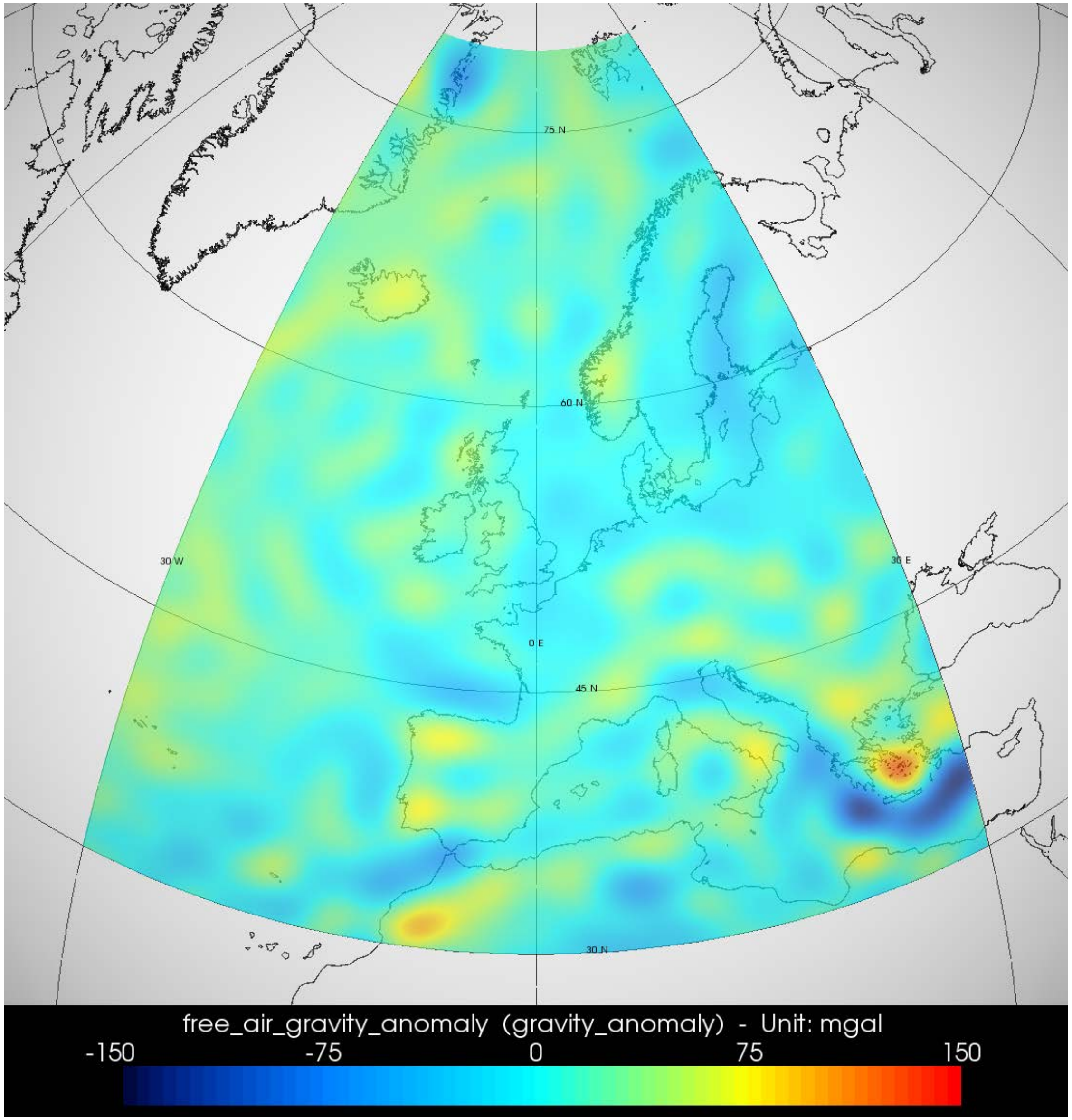

BAT
PCDU
CDMU
Temperature [degC]
90
80
70
60
50
40
30
20
10
09/11 00:00
09/11 06:00
09/11 12:00
09/11 18:00
10/11 00:00
10/11 06:00
10/11 12:00
10/11 18:00
11/11 00:00


NST
STR
IPCU
Temperature [degC]
30
25
20
15
10
5
0
-5
09/11 00:00
09/11 06:00
09/11 12:00
09/11 18:00
10/11 00:00
10/11 06:00
10/11 12:00
10/11 18:00
11/11 00:00

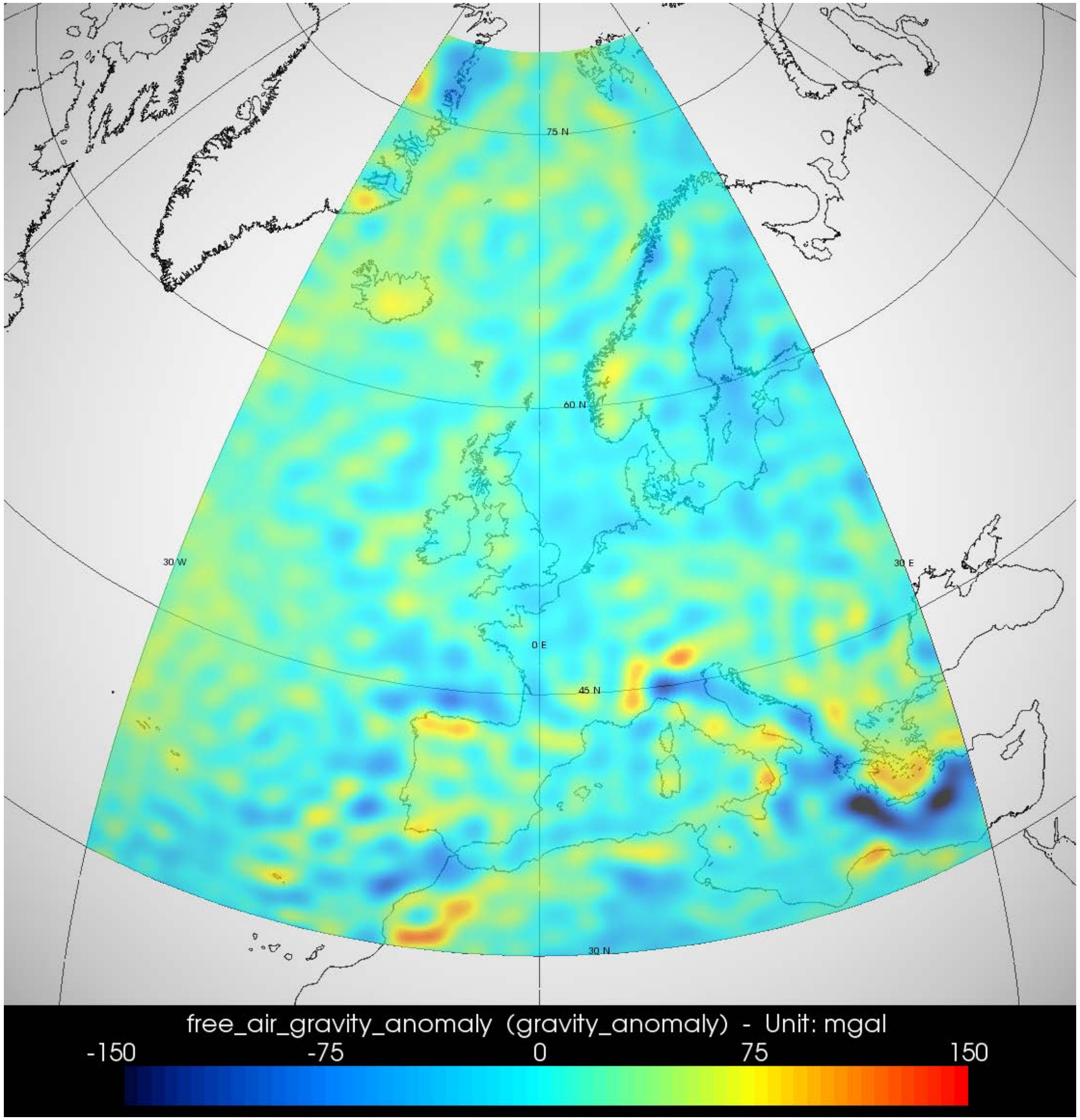
gravity field model before and now



in 1996

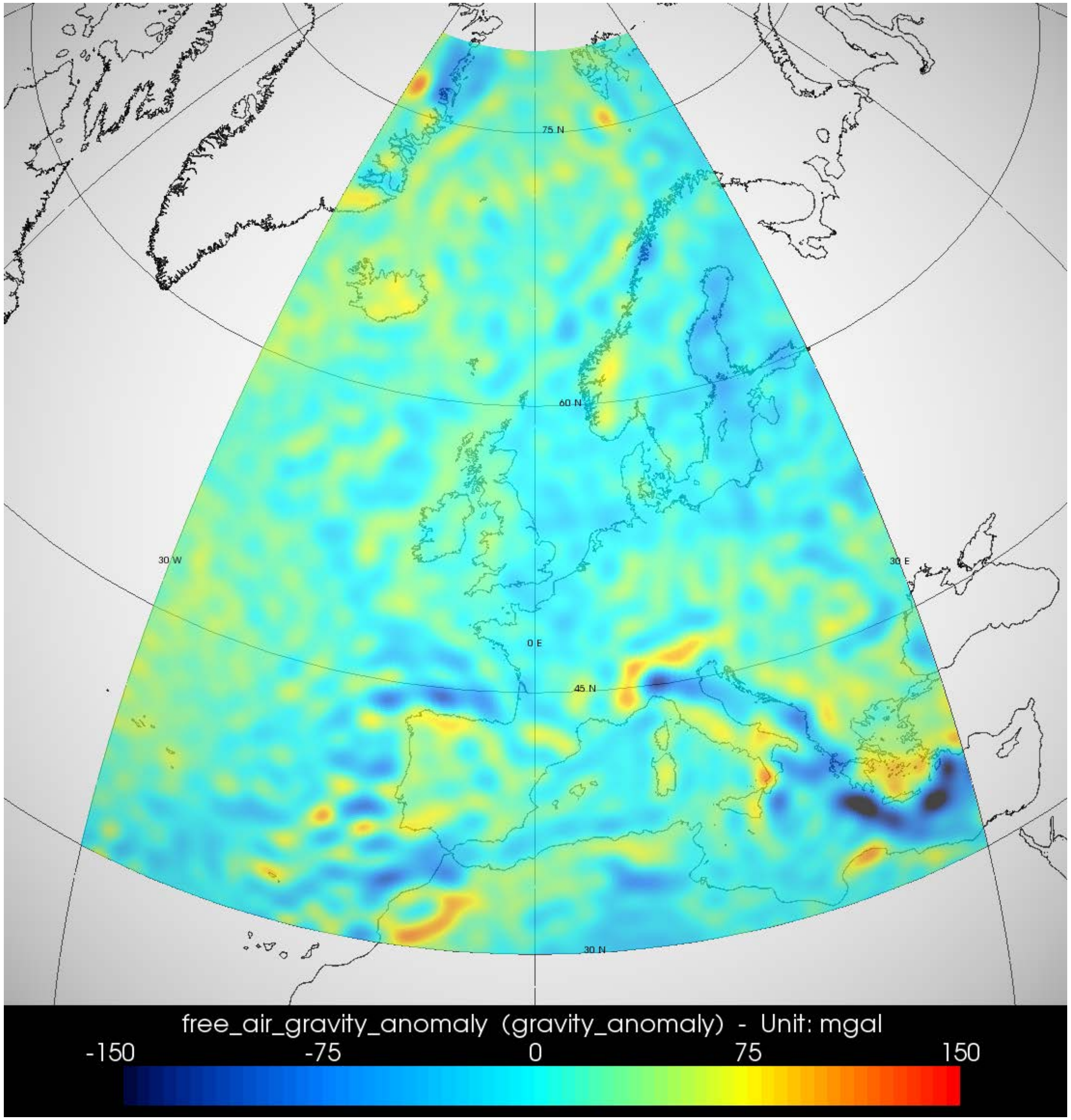

75 N
60 N
45 N
30 N
30 W
30 E
0 E
free_air_gravity_anomaly (gravity_anomaly) - Unit: mgal
-150
-75
0
75
150

after CHAMP

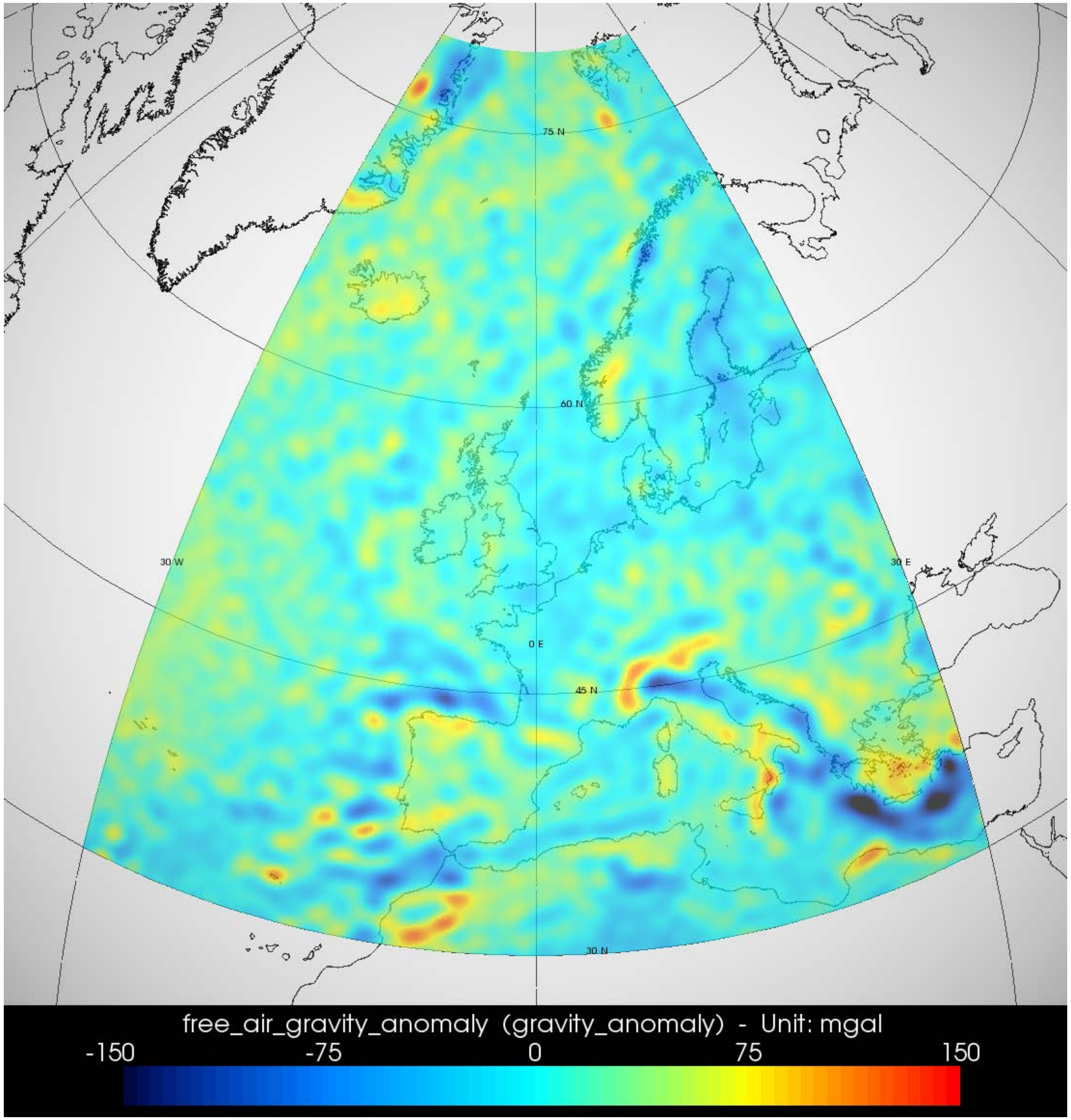


GRACE 2010
(still flying)

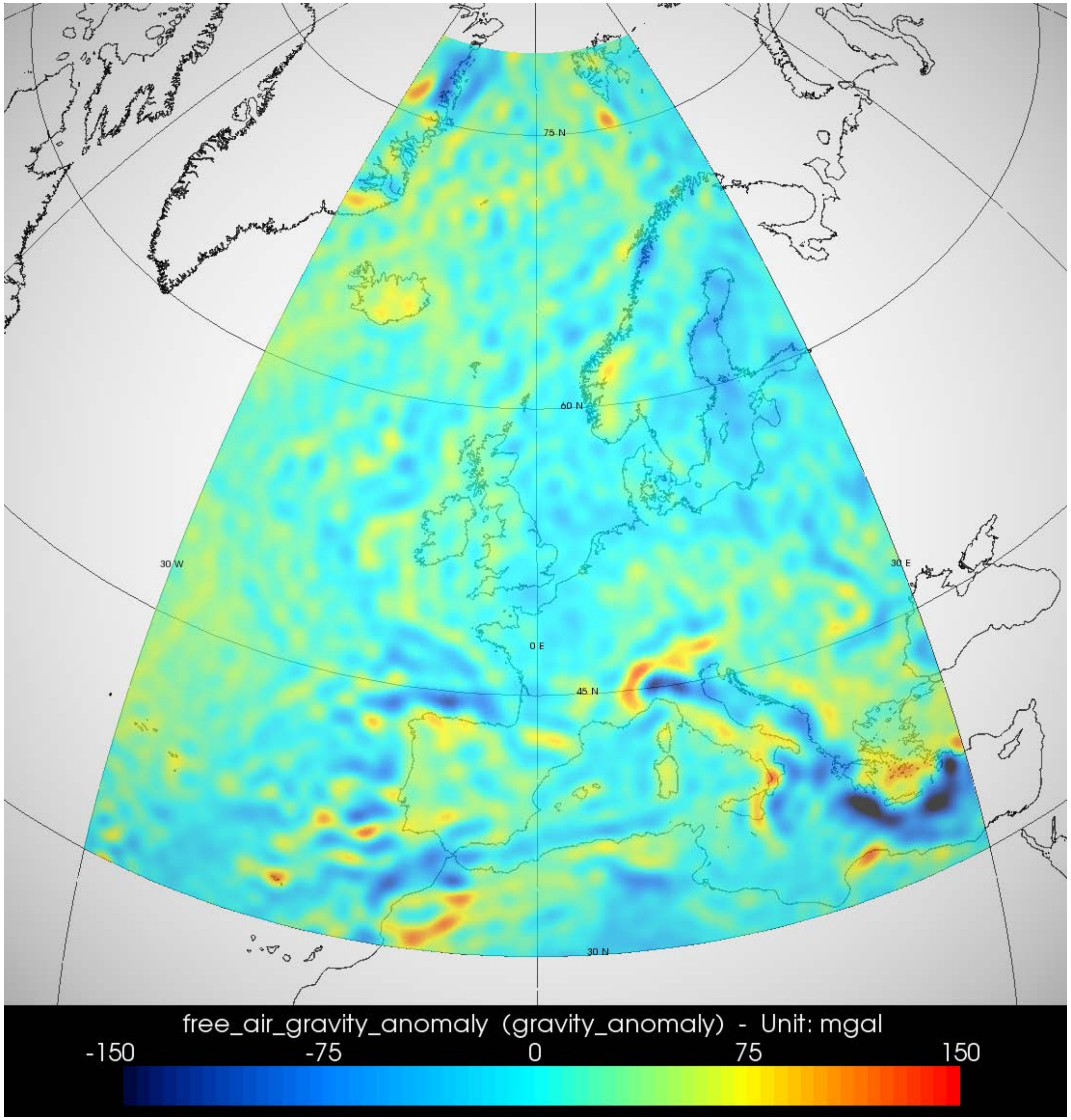
gravity field model before and now



GOCE Release 1
(2 months data)



GOCE Release 3



GOCE Release 5 (all GOCE data)

collection of science highlights

freshly available on

iBook Store

conclusions

- *Voyage extraordinaire* of GOCE has exceeded all expectations, and provided some thriller drama during its 1700 days of flight
- Fascinating 'second mission' from August 2012 to Nov 2013
- Spectacular de-orbiting & re-entry data
- A good number of 'surprise' discoveries
- Gravity data from GOCE will be hard to beat in terms of spatial resolution. Direct measurements of gravity gradients is extremely useful for earth science.
- Scientists and space agencies are working to define the requirements and technical solutions for the next step in space-based observations of gravity (mass variations) from space
- Exploitation of GOCE data for Earth system understanding is still only at the beginning