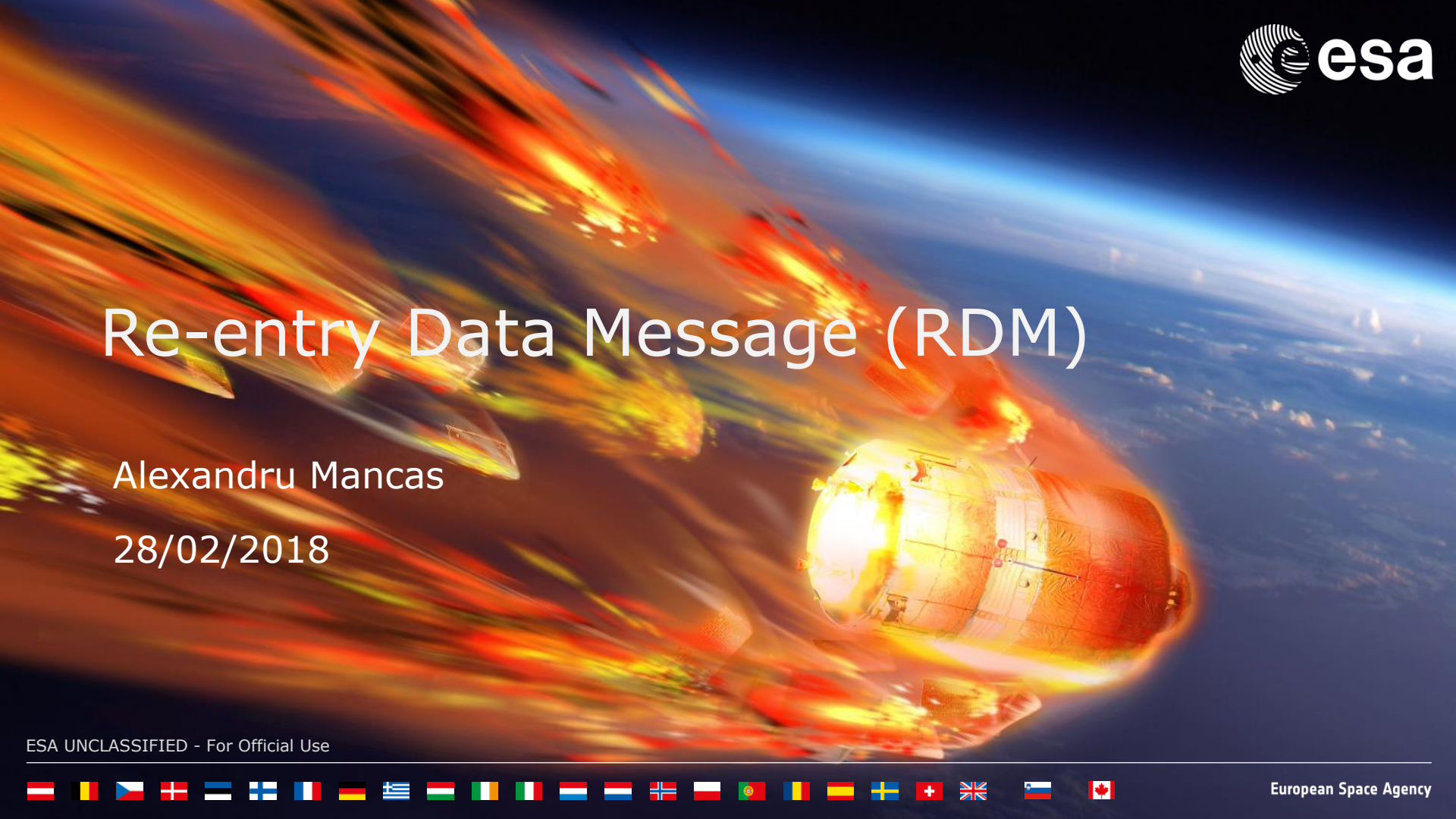

Re-entry Data Message (RDM)

Alexandru Mancas

28/02/2018

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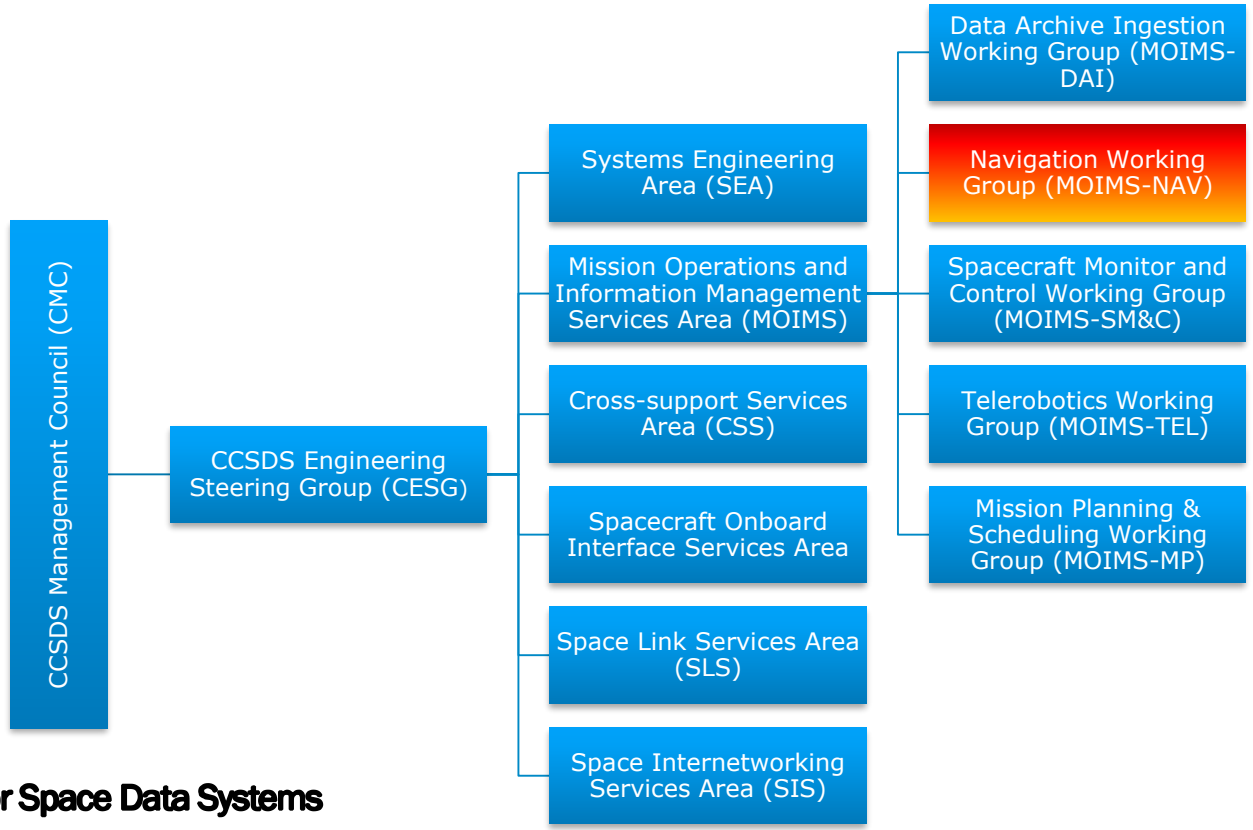
Overview

1. Introduction to CCSDS
2. Need and rationale for a Re-entry Data Message
3. Current status
4. Examples of use
5. Future plans
6. Q&A session

Consultative Committee for Space Data Systems

- CCSDS is a multi-national forum for the development of communications and data systems standards for spaceflight
- Founded in 1982 by the world's major space agencies
- Formally affiliated with the International Organization for Standardization (ISO TC20/SC13)
- www.ccsds.org – general web site of the CCSDS



CCSDS
The Consultative Committee for Space Data Systems

CCSDS Navigation Working Group

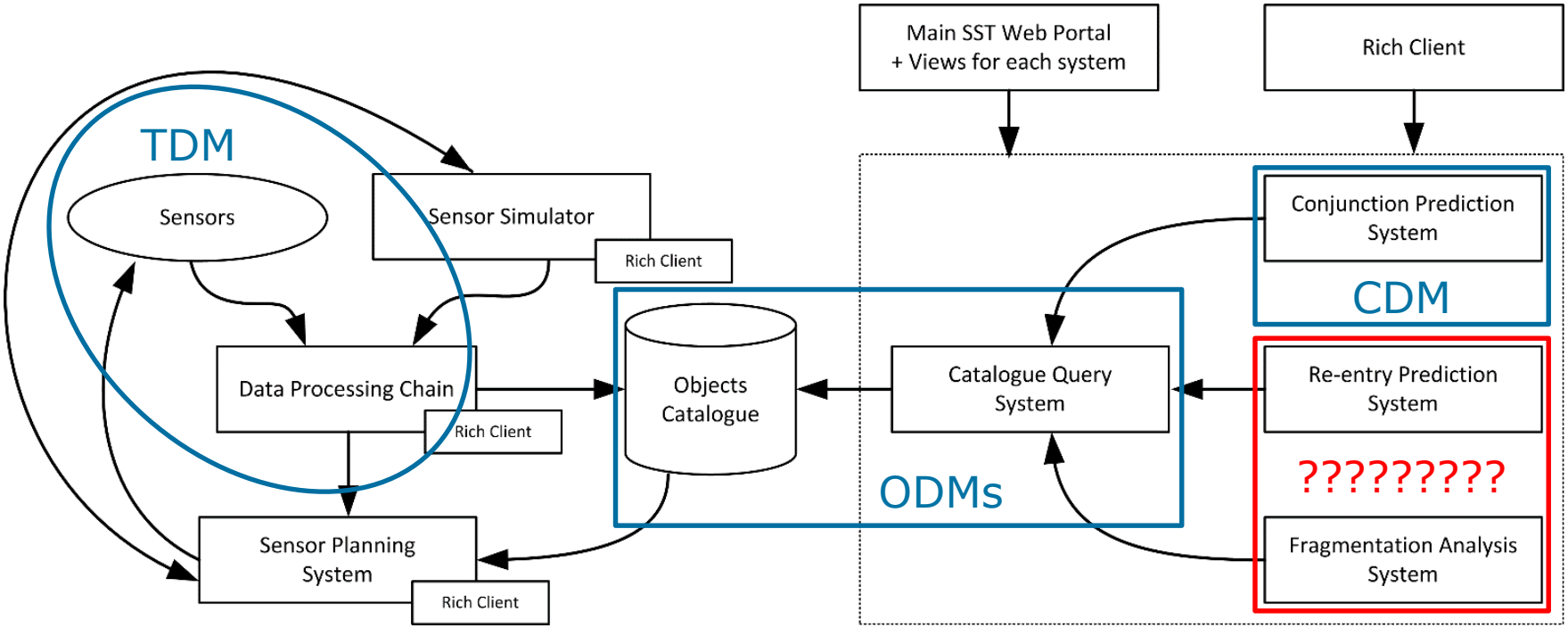
- the Navigation Working Group is chartered to produce CCSDS Recommendations related to the formatting and **exchange** of flight dynamics data
- exchanging data in standardised formats facilitates rapid processing of complex data
- CCSDS Standards related to SST:
  - Tracking Data Message (TDM)
  - Orbit Data Messages (ODM)
  - Conjunction Data Message (CDM)
  - Re-entry Data Message (RDM)
- KVN or XML versions

Need and rationale






Standardisation gap



Requirements

Mandatory:

- provide remaining orbital lifetime
- specify controlled/uncontrolled
- work for arbitrary central body
- no need to model re-entry to use
- specify owner and operator
- prev/next message
- provide ground impact location and epoch
- info about observations used in OD

Optional:

- extensible
- consistent with other CCSDS messages
- contain one state vector
- covariance
- modelling used
- spacecraft parameters

Universal CCSDS NAV requirements:

- digital, plain text, platform independent
- readable by humans and computers
- identify message and object …

RDM Red Book 1 – contents

- follows the typical NDM approach:
  - header – standard CCSDS NAV header
  - **one** data segment
    - metadata
    - data
- consistency kept as much as possible with existing messages (CDM, OPM)
- not always possible due to CDM-OPM inconsistency (OPM prevailed)

RDM Red Book 1 – metadata – the boring stuff

Mandatory

- object name
- international designator
- center name
- time system
- epoch t_0

Optional

- comment
- catalog name
- object designator
- object type
- object owner
- object operator
- ephemeris name
- previous/next message info

RDM Red Book 1 – metadata – more interesting

- controlled re-entry (M)
- reference frame (O)
- reference frame epoch (O)
- gravity model (O)
- atmospheric model (O)
- solar flux prediction (O)
- n-body perturbations (O)
- solar radiation pressure (O)
- Earth tides (O)
- in-track thrust (O)
- re-entry disintegration (O)
- impact uncertainty method (O)

RDM Red Book 1 – data – the basics

divided into multiple data blocks:

- atmospheric re-entry data
- ground impact and burn-up data
- state vector – same as OPM
- covariance matrix – same as OPM
- object physical parameters – same as OPM
- OD parameters – same as CDM
- user defined parameters

only mandatory keywords are **orbit lifetime** and **re-entry altitude**

RDM Red Book 1 – data – atmospheric re-entry

- orbit lifetime (days) – for long term predictions
- lifetime dispersion (%) – for long term predictions
- re-entry altitude – arbitrarily defined (eg 150 km)
- nominal re-entry epoch – for short term predictions
- re-entry window start and end – allows asymmetric dispersion

- orbit lifetime servers a dual purpose
  - specify whether long and short term prediction used
  - for long term actually give the orbit lifetime

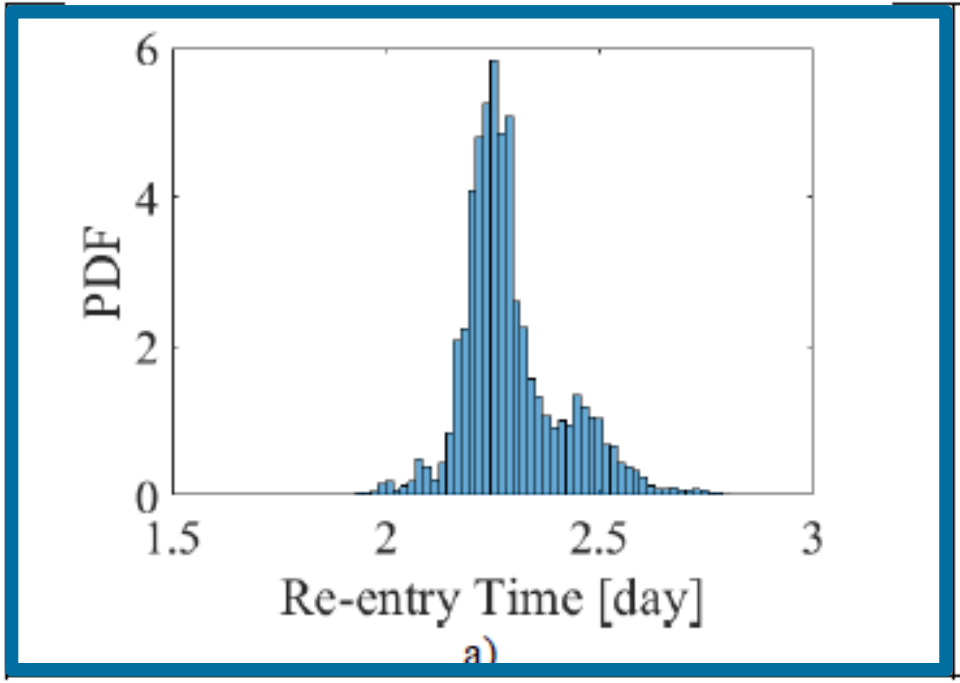
RDM Red Book 1 – data – ground impact & burn-up

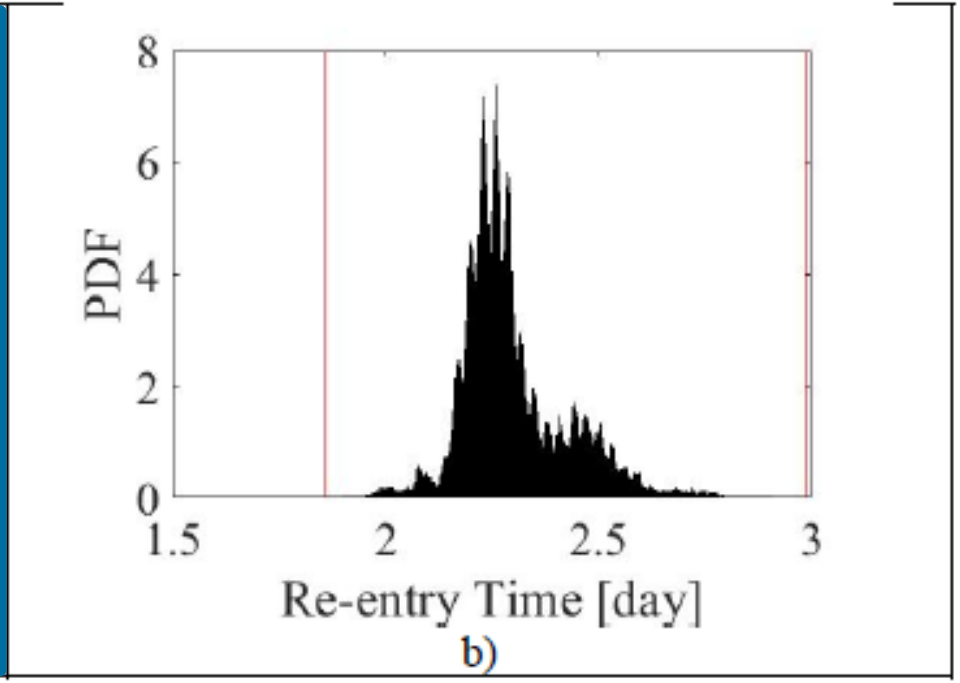
- probability of: impact, burn-up, break-up, land impact, and casualty
- nominal (predicted) impact epoch + impact window start/stop
- impact reference frame
- nominal impact location (lon, lat, alt)
- (up to) 3 impact location confidence intervals:
  - confidence level (%)
  - lat/lon start/stop along track -> interpolate ground track
  - width in the cross-track direction (km)

RDM Red Book 1 – data – user defined parameters

- user defined parameters allowed, but use is not encouraged
- USER_DEFINED_x, eg
  USER_DEFINED_THE_THING_WE_REALLY_NEED = 666.66 [m]
- allows people to tailor standard to own use while still staying compliant

Actual use case – GOCE re-entry prediction study



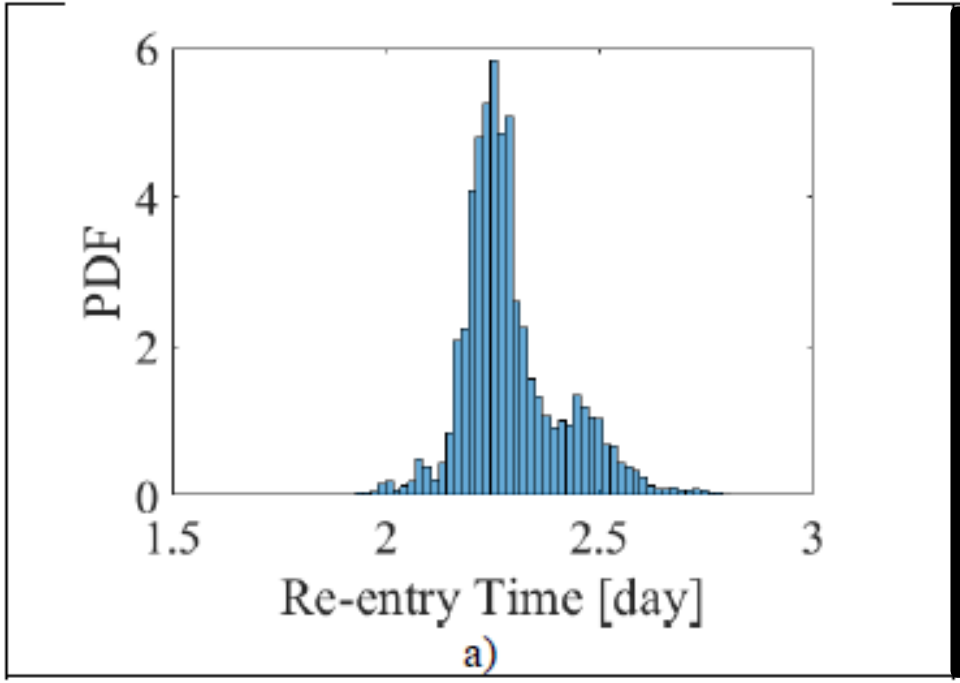


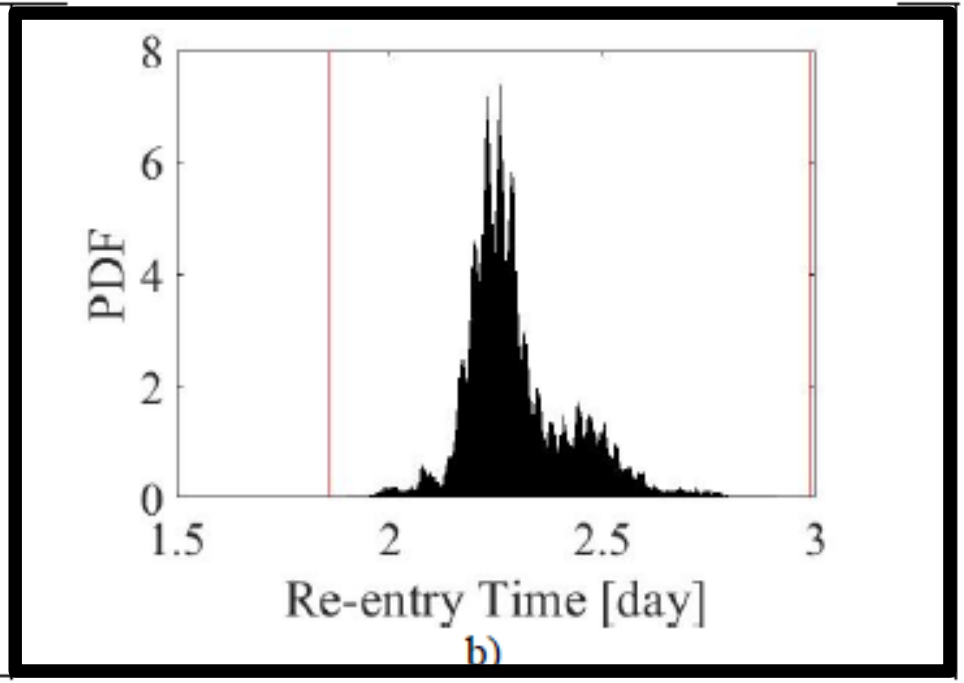
peaks in the detailed plot are not random!

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-02-02T09:48:34.00
ORIGINATOR                  = ESA
MESSAGE_ID                  = ESA/20180202-001

OBJECT_NAME                 = GOCE
INTERNATIONAL_DESIGNATOR    = 2009-013A
CATALOG_NAME                = SATCAT
OBJECT_DESIGNATOR           = 34602
OBJECT_TYPE                 = PAYLOAD
OBJECT_OWNER                = ESA
OBJECT_OPERATOR             = ESA
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2013-11-09T03:00:00.00
REF_FRAME                   = ICRF

GRAVITY_MODEL               = EGM-96: 9D 9O
ATMOSPHERIC_MODEL           = JACCHIA
SOLAR_FLUX_PREDICTION       = MONTE CARLO
N_BODY_PERTURBATIONS        = NO
SOLAR_RAD_PRESSURE          = NO
EARTH_TIDES                 = NO
INTRACK_THRUST              = NO
RE_ENTRY_DISINTEGRATION     = NO

COMMENT Short term re-entry prediction results
ORBIT_LIFETIME              = 2.28            [d]
REENTRY_ALTITUDE            = 80.0            [km]
NOMINAL_REENTRY_EPOCH       = 2013-11-11T09:43:12
REENTRY_WINDOW_START        = 2013-11-11T01:19:12
REENTRY_WINDOW_END          = 2013-11-11T22:12:00
```

```
COMMENT State vector at T0
EPOCH                    = 2013-11-09T03:00:00
X                        =  2570.526925    [km]
Y                        =   -78.492266    [km]
Z                        = -6022.949749    [km]
X_DOT                    =  6.787037515    [km/s]
Y_DOT                    = -2.470288138    [km/s]
Z_DOT                    =  2.925871310    [km/s]

COMMENT Position/velocity cov matrix at T0
CX_X                     = 0.25000000 [km**2]
CY_X                     = 0.00000000 [km**2]
CY_Y                     = 0.25000000 [km**2]
CZ_X                     = 0.00000000 [km**2]
CZ_Y                     = 0.00000000 [km**2]
CZ_Z                     = 0.25000000 [km**2]
CX_DOT_X                 = 0.00000000 [km**2/s]
CX_DOT_Y                 = 0.00000000 [km**2/s]
CX_DOT_Z                 = 0.00000000 [km**2/s]
CX_DOT_X_DOT             = 0.00000025 [km**2/s**2]
CY_DOT_X                 = 0.00000000 [km**2/s]
CY_DOT_Y                 = 0.00000000 [km**2/s]
CY_DOT_Z                 = 0.00000000 [km**2/s]
CY_DOT_X_DOT             = 0.00000000 [km**2/s**2]
CY_DOT_Y_DOT             = 0.00000025 [km**2/s**2]
CZ_DOT_X                 = 0.00000000 [km**2/s]
CZ_DOT_Y                 = 0.00000000 [km**2/s]
CZ_DOT_Z                 = 0.00000000 [km**2/s]
CZ_DOT_X_DOT             = 0.00000000 [km**2/s**2]
CZ_DOT_Y_DOT             = 0.00000000 [km**2/s**2]
CZ_DOT_Z_DOT             = 0.00000025 [km**2/s**2]

COMMENT Spacecraft parameters used
MASS                     = 1002.152 [kg]
DRAG_AREA                = 1.6286 [m**2]
DRAG_COEFF               = 3.5
```

Actual use case – GOCE re-entry prediction study





peaks in the detailed plot are not random!

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-02-02T09:48:34.00
ORIGINATOR                  = ESA
MESSAGE_ID                  = ESA/20180202-001

OBJECT_NAME                 = GOCE
INTERNATIONAL_DESIGNATOR    = 2009-013A
CATALOG_NAME                = SATCAT
OBJECT_DESIGNATOR           = 34602
OBJECT_TYPE                 = PAYLOAD
OBJECT_OWNER                = ESA
OBJECT_OPERATOR             = ESA
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2013-11-09T03:00:00.00
REF_FRAME                   = ICRF

GRAVITY_MODEL               = EGM-96: 9D 9O
ATMOSPHERIC_MODEL           = JACCHIA
SOLAR_FLUX_PREDICTION       = MONTE CARLO
N_BODY_PERTURBATIONS        = NO
SOLAR_RAD_PRESSURE          = NO
EARTH_TIDES                 = NO
INTRACK_THRUST              = NO
RE_ENTRY_DISINTEGRATION     = NO

COMMENT Short term re-entry prediction results
ORBIT_LIFETIME              = 2.28          [d]
REENTRY_ALTITUDE            = 80.0          [km]
NOMINAL_REENTRY_EPOCH       = 2013-11-11T09:04:37
REENTRY_WINDOW_START        = 2013-11-11T01:19:12
REENTRY_WINDOW_END          = 2013-11-11T22:12:00
```

```
COMMENT State vector at T0
EPOCH                    = 2013-11-09T03:00:00
X                        =  2570.526925 [km]
Y                        =   -78.492266 [km]
Z                        = -6022.949749 [km]
X_DOT                    =  6.787037515 [km/s]
Y_DOT                    = -2.470288138 [km/s]
Z_DOT                    =  2.925871310 [km/s]

COMMENT Position/velocity cov matrix at T0
CX_X                     = 0.25000000   [km**2]
CY_X                     = 0.00000000   [km**2]
CY_Y                     = 0.25000000   [km**2]
CZ_X                     = 0.00000000   [km**2]
CZ_Y                     = 0.00000000   [km**2]
CZ_Z                     = 0.25000000   [km**2]
CX_DOT_X                 = 0.00000000   [km**2/s]
CX_DOT_Y                 = 0.00000000   [km**2/s]
CX_DOT_Z                 = 0.00000000   [km**2/s]
...
<<extra covariance lines removed>>
...
CZ_DOT_Z_DOT             = 0.00000025   [km**2/s**2]

COMMENT Spacecraft parameters
MASS                     = 1002.152     [kg]
DRAG_AREA                = 1.6286       [m**2]
DRAG_COEFF               = 3.5

COMMENT User defined value for each probability
peak
USER_DEFINED_SCENARIO_PROBABILITY = 0.42
```

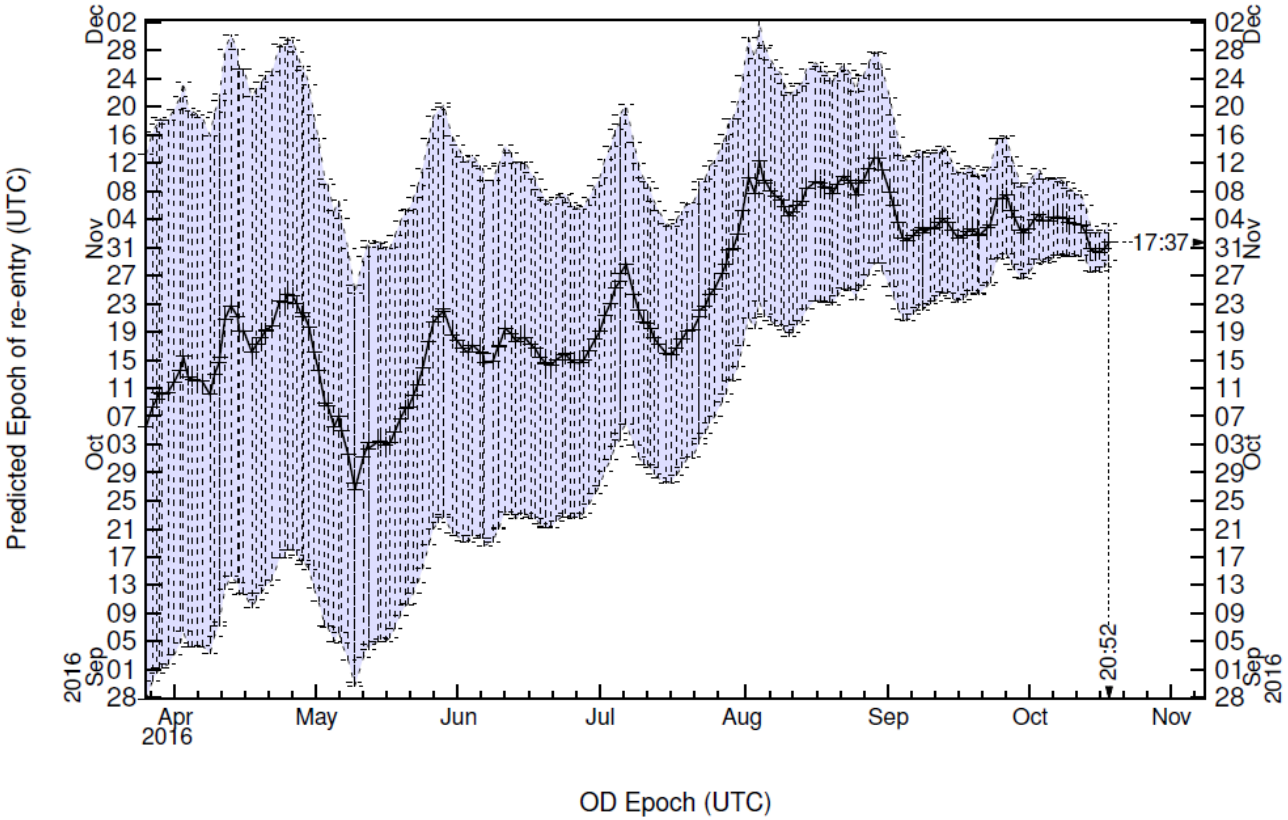
```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-02-02T09:48:34.00
ORIGINATOR                  = ESA
MESSAGE_ID                  = ESA/20180202-001

OBJECT_NAME                 = GOCE
INTERNATIONAL_DESIGNATOR    = 2009-013A
CATALOG_NAME                = SATCAT
OBJECT_DESIGNATOR           = 34602
OBJECT_TYPE                 = PAYLOAD
OBJECT_OWNER                = ESA
OBJECT_OPERATOR             = ESA
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2013-11-09T03:00:00.00
REF_FRAME                   = ICRF

GRAVITY_MODEL               = EGM-96: 9D 9O
ATMOSPHERIC_MODEL           = JACCHIA
SOLAR_FLUX_PREDICTION       = MONTE CARLO
N_BODY_PERTURBATIONS        = NO
SOLAR_RAD_PRESSURE          = NO
EARTH_TIDES                 = NO
INTRACK_THRUST              = NO
RE_ENTRY_DISINTEGRATION     = NO

COMMENT Short term re-entry prediction results
ORBIT_LIFETIME              = 2.28          [d]
REENTRY_ALTITUDE            = 80.0          [km]
NOMINAL_REENTRY_EPOCH       = 2013-11-11T10:27:49
REENTRY_WINDOW_START        = 2013-11-11T01:19:12
REENTRY_WINDOW_END          = 2013-11-11T22:12:00
```

```
COMMENT State vector at T0
EPOCH                    = 2013-11-09T03:00:00
X                        =  2570.526925 [km]
Y                        =   -78.492266 [km]
Z                        = -6022.949749 [km]
X_DOT                    =  6.787037515 [km/s]
Y_DOT                    = -2.470288138 [km/s]
Z_DOT                    =  2.925871310 [km/s]

COMMENT Position/velocity cov matrix at T0
CX_X                     = 0.25000000   [km**2]
CY_X                     = 0.00000000   [km**2]
CY_Y                     = 0.25000000   [km**2]
CZ_X                     = 0.00000000   [km**2]
CZ_Y                     = 0.00000000   [km**2]
CZ_Z                     = 0.25000000   [km**2]
CX_DOT_X                 = 0.00000000   [km**2/s]
CX_DOT_Y                 = 0.00000000   [km**2/s]
CX_DOT_Z                 = 0.00000000   [km**2/s]
...
<<extra covariance lines removed>>
...
CZ_DOT_Z_DOT             = 0.00000025   [km**2/s**2]

COMMENT Spacecraft parameters
MASS                     = 1002.152     [kg]
DRAG_AREA                = 1.6286       [m**2]
DRAG_COEFF               = 3.5

COMMENT User defined value for each probability
peak
USER_DEFINED_SCENARIO_PROBABILITY = 0.37
```

Actual use case: 2012-006K

- both long term and short-term (including impact location predictions)
- AVUM Rocket Body
- re-entered in November 2016 over the Indian Ocean

AVUM / LARES A (12006K,38086), TLEs till 16292.8699 (2016-10-18)
COIW: Central Time Of Impact Window (nom./-dt/+dt)
Last available orbit data (UTC): 2016/10/18 20:52:47.70
COIW (UTC): 2016/10/31 17:37:35.20, LON: 16.65, LAT: 64.04



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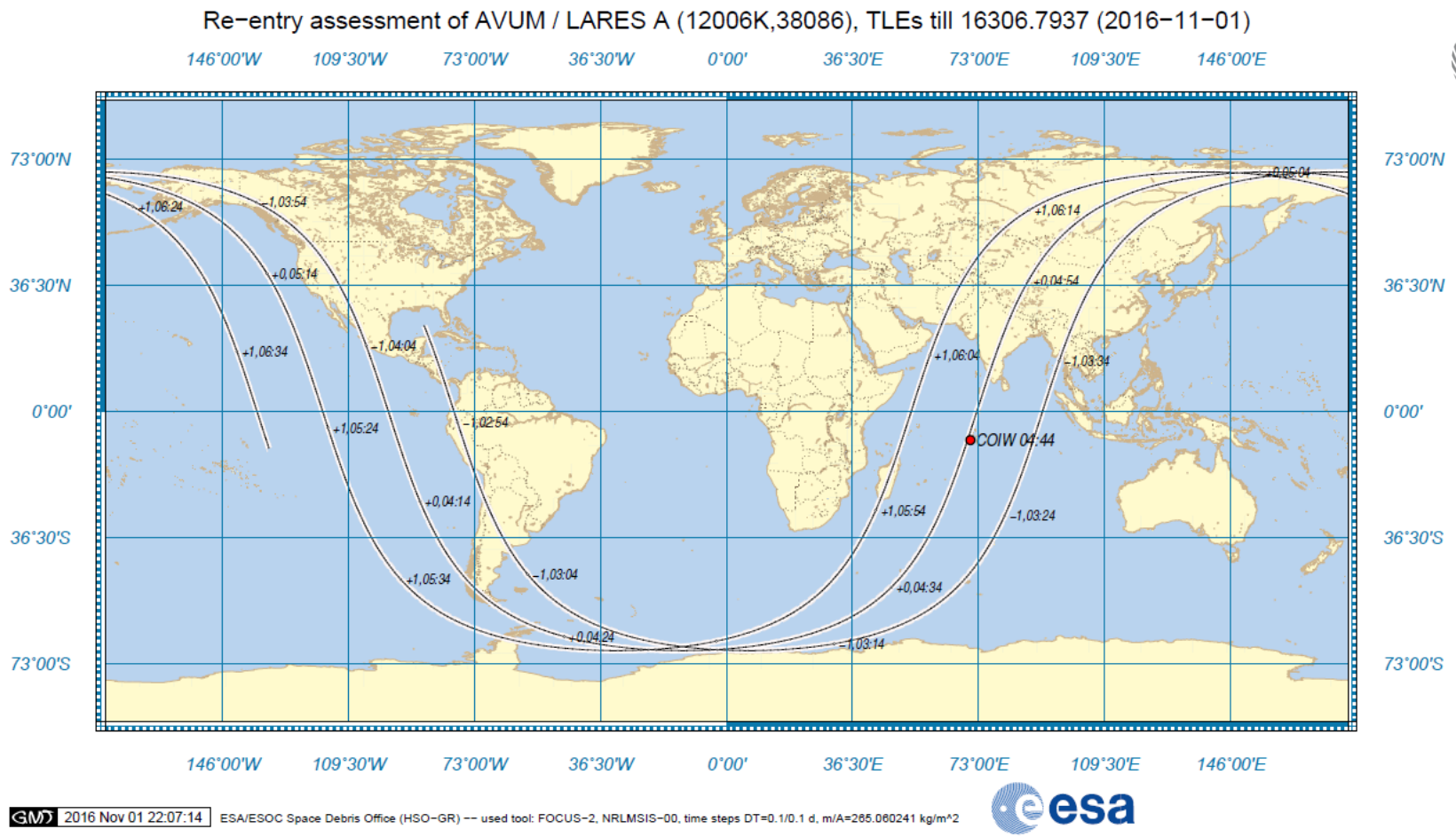
```
CCSDS_RDM_VERS            = 1.0
CREATION_DATE             = 2018-02-02T15:53:34.00
ORIGINATOR                = ESA
MESSAGE_ID                = ESA/20180202-004

OBJECT_NAME               = VEGA-01 AVUM
INTERNATIONAL_DESIGNATOR  = 2012-006K
CATALOG_NAME              = SATCAT
OBJECT_DESIGNATOR         = 38086
OBJECT_TYPE               = ROCKET BODY
OBJECT_OWNER              = ESA
OBJECT_OPERATOR           = ESA
CONTROLLED_REENTRY        = NO
CENTER_NAME               = EARTH
TIME_SYSTEM               = UTC
EPOCH_TZERO               = 2016-04-01T12:00:00.00

COMMENT Long term re-entry prediction results
ORBIT_LIFETIME            = 193          [d]
REENTRY_ALTITUDE          = 80.0         [km]
NOMINAL_REENTRY_EPOCH     = 2016-10-11T12:00:00
REENTRY_WINDOW_START      = 2016-09-03T12:00:00
REENTRY_WINDOW_END        = 2016-11-20T12:00:00
```

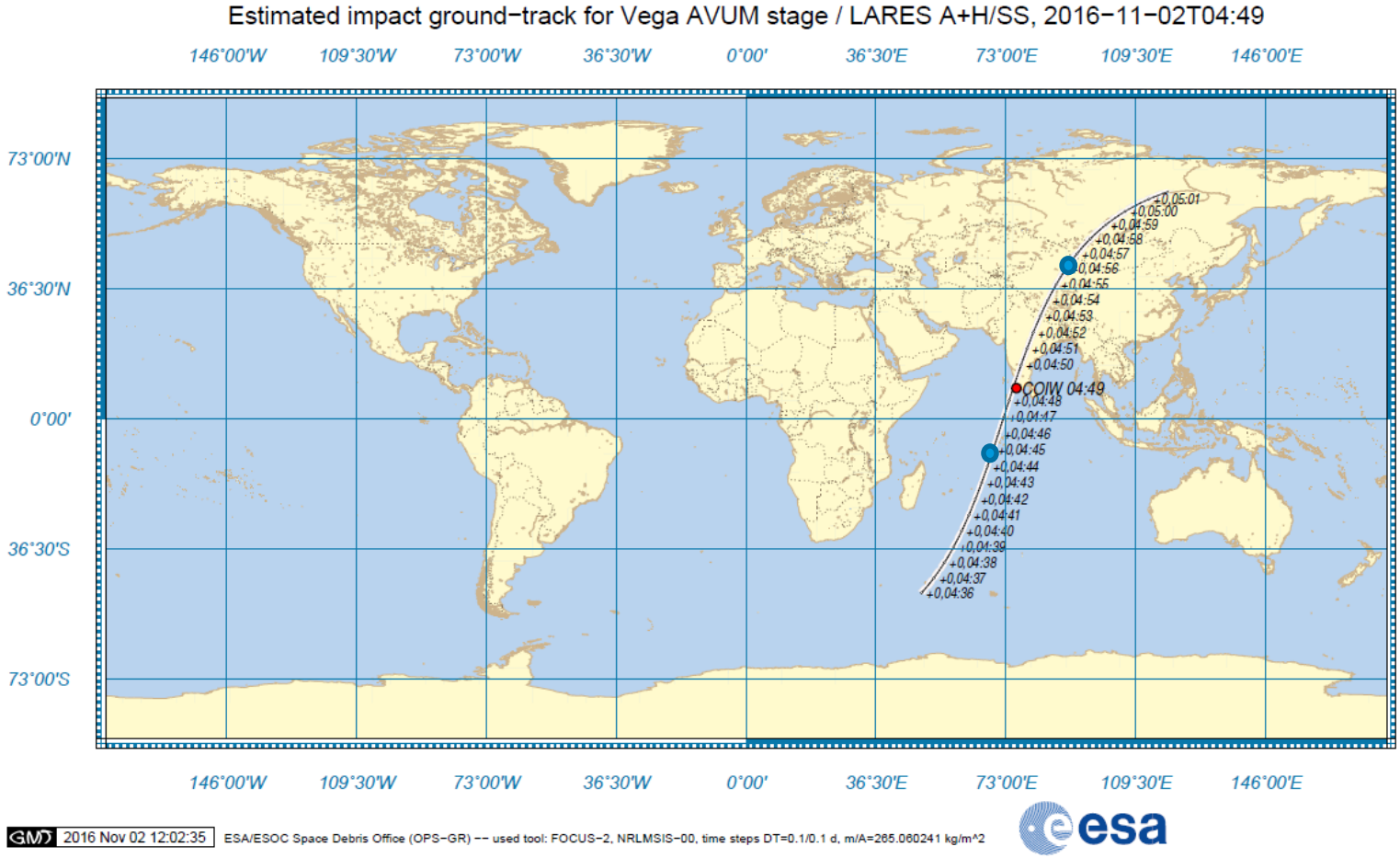
```
CCSDS_RDM_VERS            = 1.0
CREATION_DATE             = 2018-02-02T15:53:34.00
ORIGINATOR                = ESA
MESSAGE_ID                = ESA/20180202-004

OBJECT_NAME               = VEGA-01 AVUM
INTERNATIONAL_DESIGNATOR  = 2012-006K
CATALOG_NAME              = SATCAT
OBJECT_DESIGNATOR         = 38086
OBJECT_TYPE               = ROCKET BODY
OBJECT_OWNER              = ESA
OBJECT_OPERATOR           = ESA
CONTROLLED_REENTRY        = NO
CENTER_NAME               = EARTH
TIME_SYSTEM               = UTC
EPOCH_TZERO               = 2016-05-01T12:00:00.00

COMMENT Long term re-entry prediction results
ORBIT_LIFETIME            = 169          [d]
REENTRY_ALTITUDE          = 80.0         [km]
NOMINAL_REENTRY_EPOCH     = 2016-10-17T12:00:00
REENTRY_WINDOW_START      = 2016-09-11T12:00:00
REENTRY_WINDOW_END        = 2016-16-20T12:00:00
```



last impact prediction from ESA SDO (@10km altitude)

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-02-02T15:53:34.00
ORIGINATOR                  = ESA
MESSAGE_ID                  = ESA/20180202-004

OBJECT_NAME                 = VEGA-01 AVUM
INTERNATIONAL_DESIGNATOR    = 2012-006K
CATALOG_NAME                = SATCAT
OBJECT_DESIGNATOR           = 38086
OBJECT_TYPE                 = ROCKET BODY
OBJECT_OWNER                = ESA
OBJECT_OPERATOR             = ESA
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2016-11-01T19:00:00.00
ATMPSPHERIC_MODEL           = NRLMSISE-00
REENTRY_DISINTEGRATION      = NONE
IMPACT_UNCERTAINTY_METHOD   = NONE
```

```
COMMENT Short term re-entry prediction results
ORBIT_LIFETIME              = 0.31          [d]
REENTRY_ALTITUDE            = 120.0         [km]
NOMINAL_REENTRY_EPOCH       = 2011-11-0-2T3:25:42:00.0

COMMENT Ground impact data
PROBABILITY_OF_IMPACT       = 1.0
IMPACT_REF_FRAME            = WGS84
NOMINAL_IMPACT_EPOCH        = 2016-11-02T04:44:00.0
NOMINAL_IMPACT_LON          = 70.30265      [deg]
NOMINAL_IMPACT_LAT          = -7.30187      [deg]
```



impact prediction from JSpOC (@80km altitude)

+ added confidence intervals

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-02-02T15:53:34.00
ORIGINATOR                  = ESA
MESSAGE_ID                  = ESA/20180202-004

OBJECT_NAME                 = VEGA-01 AVUM
INTERNATIONAL_DESIGNATOR    = 2012-006K
CATALOG_NAME                = SATCAT
OBJECT_DESIGNATOR           = 38086
OBJECT_TYPE                 = ROCKET BODY
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2016-11-01T19:00:00.00
ATMPSPHERIC_MODEL           = NRLMSISE-00
REENTRY_DISINTEGRATION      = NONE
IMPACT_UNCERTAINTY_METHOD = ANALYTICAL

COMMENT Short term re-entry prediction results
ORBIT_LIFETIME              = 0.31          [d]
REENTRY_ALTITUDE            = 120.0         [km]
NOMINAL_REENTRY_EPOCH       = 2011-11-0-2T3:25:42:00.0
```

```
COMMENT Ground impact data
PROBABILITY_OF_IMPACT       = 1.0
IMPACT_REF_FRAME            = WGS84
NOMINAL_IMPACT_EPOCH        = 2016-11-02T04:49:00.0
NOMINAL_IMPACT_LON          = 72.41129
NOMINAL_IMPACT_LAT          = 9.954546

IMPACT_1_CONFIDENCE         = 35            [%]
IMPACT_1_START_LON          = 70.302650     [deg]
IMPACT_1_START_LAT          = -7.301870     [deg]
IMPACT_1_STOP_LON           = 88.306452     [deg]
IMPACT_1_STOP_LAT           = 42.177778     [deg]
IMPACT_1_CROSS_TRACK        = 20            [km]

IMPACT_2_CONFIDENCE         = 99            [%]
IMPACT_2_START_LON          = 56.153846     [deg]
IMPACT_2_START_LAT          = -48.666667    [deg]
IMPACT_2_STOP_LON           = 119.752809    [deg]
IMPACT_2_STOP_LAT           = 63.266667     [deg]
IMPACT_2_CROSS_TRACK        = 30            [km]
```

Future of the RDM

- since re-entry prediction services are in their infancy, future directions are uncertain
- practical experience and actual user input needed
- different use cases (ie IADC campaign and SST services) can approach things from different angles

- latest draft available at CCSDS CWE (no login required to download the file)

Q&A