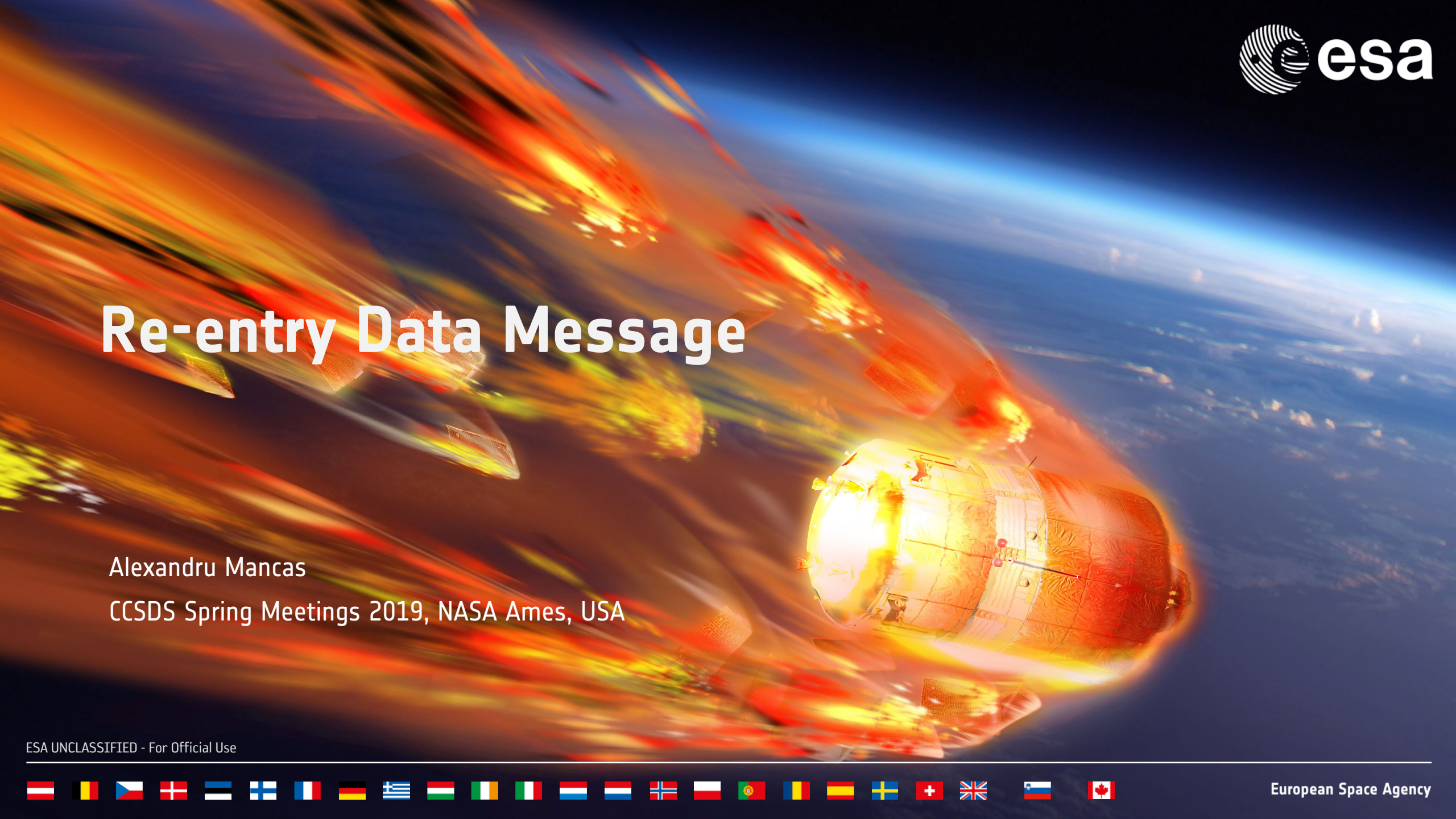

Re-entry Data Message

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CCSDS Spring Meetings 2019, NASA Ames, USA

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Introduction

1. Current status of the Re-entry Data Message
2. Prototyping
3. Red Book
4. Next Steps and schedule
5. Summary and conclusions

RDM current status

- Agency Review successfully completed in 2018
- prototyping by ESA/ESOC and DLR/GSOC in late 2018 and early 2019
- 3 independent prototypes developed:
  - ESA/ESOC: output of Re-entry Prediction System as XML RDM
  - ESA/ESOC: conversion between XML and KVN RDMs
  - DLR/GSOC: output of Re-entry Prediction System as KVN RDM
- prototyping successful; KVN2XML converter able to read/convert all messages provided
- one technical change to the Red Book: ORBIT_LIFETIME_CONFIDENCE changed to ORBIT_LIFETIME_CONFIDENCE_LEVEL – name and description not clear enough in Red Book 1.3
- multiple editorial changes in the Red Book: switching from annexes to the SANA registry for some keyword values, fixing typos and inconsistencies, etc.

Prototyping – overview and general approach (1)

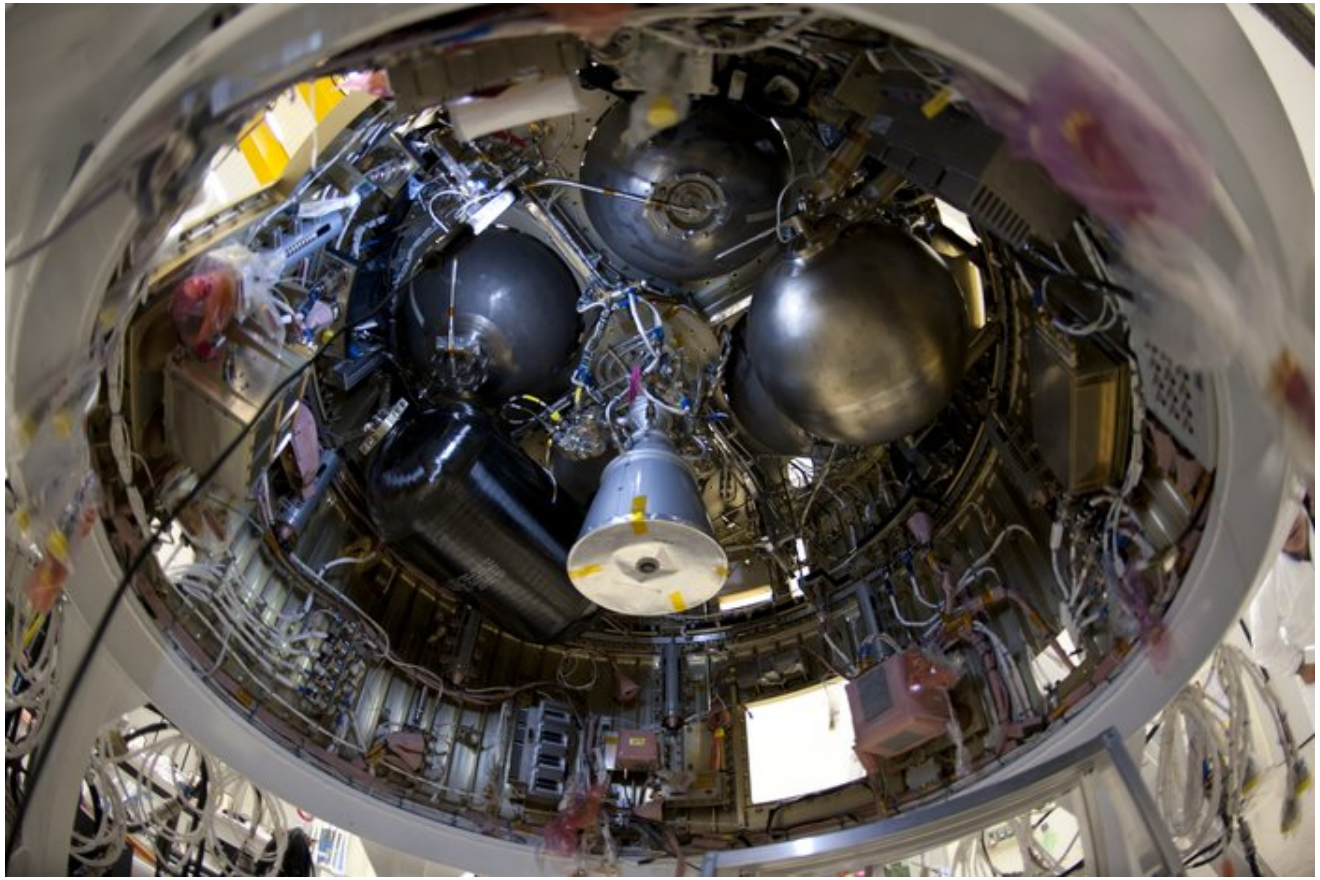
- **2** prototyping agencies: ESA/ESOC and DLR/GSOC
- existing re-entry prediction systems were used, modified to write RDMs (more details on the ESA approach in later slides)
- additional RDN KVN2XML converter based on existing CCSDS NDM-handling libraries (no sharing of code between the prototypes; different programming languages) ➤ **3** prototypes
- the KVN2XML converter was used to process RDMs

- designed to follow the typical approach for ESA re-entry predictions:

  use TLEs as input for long-term predictions, switch to dedicated observations + OD determinations for short-term predictions

Prototyping – overview and general approach (2)

- divide-and-conquer approach:
    1. KVN to XML and back conversion: catch-all case for any unused/not-needed keywords by the other cases + user defined keywords
    2. long-term prediction
    3. short-term prediction
    4. ground impact
    5. ground impact uncertainty
- all cases used **2012-006K (AVUM R/B)** as the re-entering object

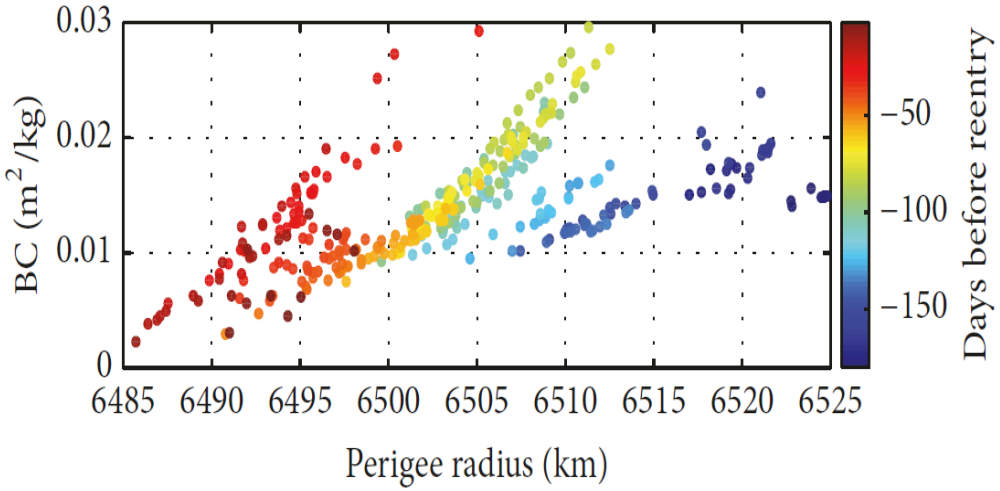


Prototyping – ESA Re-entry Prediction System (1)

- ESA provides re-entry support services to its member states and has responsibility for ESA-registered objects; international involvement in IADC
- Automated re-entry predictions at ESA:
  - Since 1999: LASCO (Lifetime Assessment of Catalogued Objects) ➤ fully automated lifetime and re-entry predictions
  - 2013 ➤ LASCO data distributed via e-mail
  - 2014 ➤ RAPID tool for more accurate predictions
  - 2016 ➤ web-based data distribution: https://reentry.esoc.esa.int
- atmospheric models: NRLMSISE-00, GOST-2004 (daily or hourly Ap, F10.7), DTM-2013 (hourly Kp, F30)
- space weather model: ESA SOLMAG (short-term daily prediction, long-term monthly prediction, very short term SIDC expert prediction – 3 days)

Prototyping – ESA Re-entry Prediction System (2)

- Automatic daily run, based on available orbital states:
  - Long-term: LASCO
  - Less than 1 month: RAPID
    - FOCUS: CD estimation
    - OrbGen: numerical propagation
- Manual predictions: RAPID
  - Different sources of data, if raw: OD
  - Variations (MC):
    - # of TLE used
    - TLE used as last state
    - solar activity

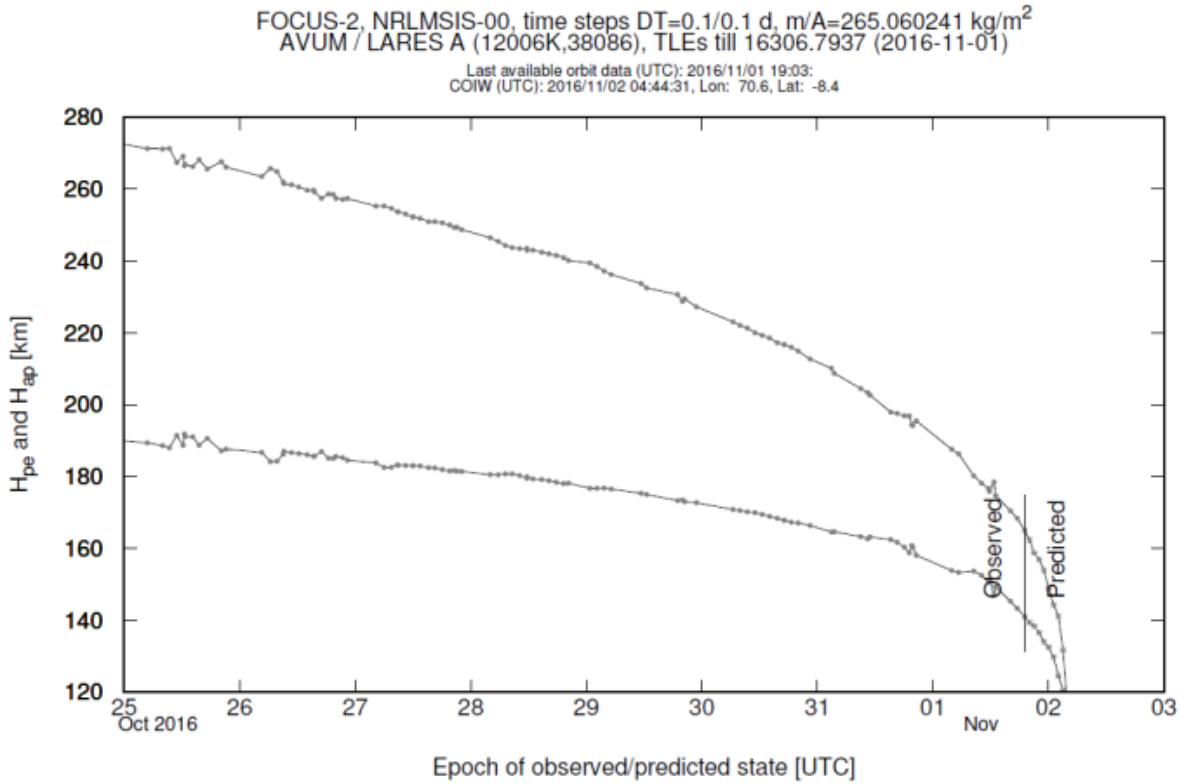


Prototyping: ESA Re-entry Prediction System (3)

- ESA RPS developments for Re-entry Data Message prototyping:
  - output of the ESA RPS in one row in a database containing all the re-entry predictions
  - column in the database changed to match RDM keywords
  - Python tool developed (using the ESA pyDISCOS library for accessing the database) that generates one XML RDM for each desired entry in the database
  - all changes made are operational, ie ESA will be able to produce/distribute RDMs once the Blue Book is published
- KVN2XML converter:
  - reuses existing (Fortran) libraries for NDM handling (both KVN and XML)
  - integrated with navigation/flight dynamics software in use at ESA

Prototyping: selected re-entry – 2012-006K

- 3 TIRA tracks (used for OD), 3 EISCAT tracks
- Confirmation of re-entry time by pieces found on ground (in south India)



Prototyping: long-term prediction (test case #2)

- ESA prepared one OPM based on TLEs ~ 1 year before re-entry
- ingested by both ESA/ESOC and DLR/GSOC re-entry prediction systems
- both re-entry prediction systems ran their standard prediction process from here on and produced one RDM (XML for ESA, KVN for DLR) each for the re-entry

- results were as expected:
  - orbit lifetime in each message inside the other message's lifetime window
  - ESA KVN2XML converter was able to read/convert both messages
- one issue encountered: ORBIT_LIFETIME_CONFIDENCE not interpreted correctly ➤ change in the Red Book to ORBIT_LIFETIME_CONFIDENCE_LEVEL

Prototyping: short-term prediction (test case #3)

- ESA prepared one OPM with OD results from 2 TIRA tracks of 2012-006K
- ingested by both ESA/ESOC and DLR/GSOC re-entry prediction systems
- both re-entry prediction systems ran their standard prediction process from here on and produced one RDM (XML for ESA, KVN for DLR) each for the re-entry

- results were as expected:
  - re-entry epoch inside the other message's re-entry window
  - ESA KVN2XML converter was able to read/convert both messages
  - ESA and DLR use different modelling for almost everything and different re-entry altitudes ➤ metadata section very useful
- one issue encountered : ORBIT_LIFETIME_CONFIDENCE not interpreted correctly ➤ change in the Red Book to ORBIT_LIFETIME_CONFIDENCE_LEVEL

Prototyping: ground impact location (test case #4)

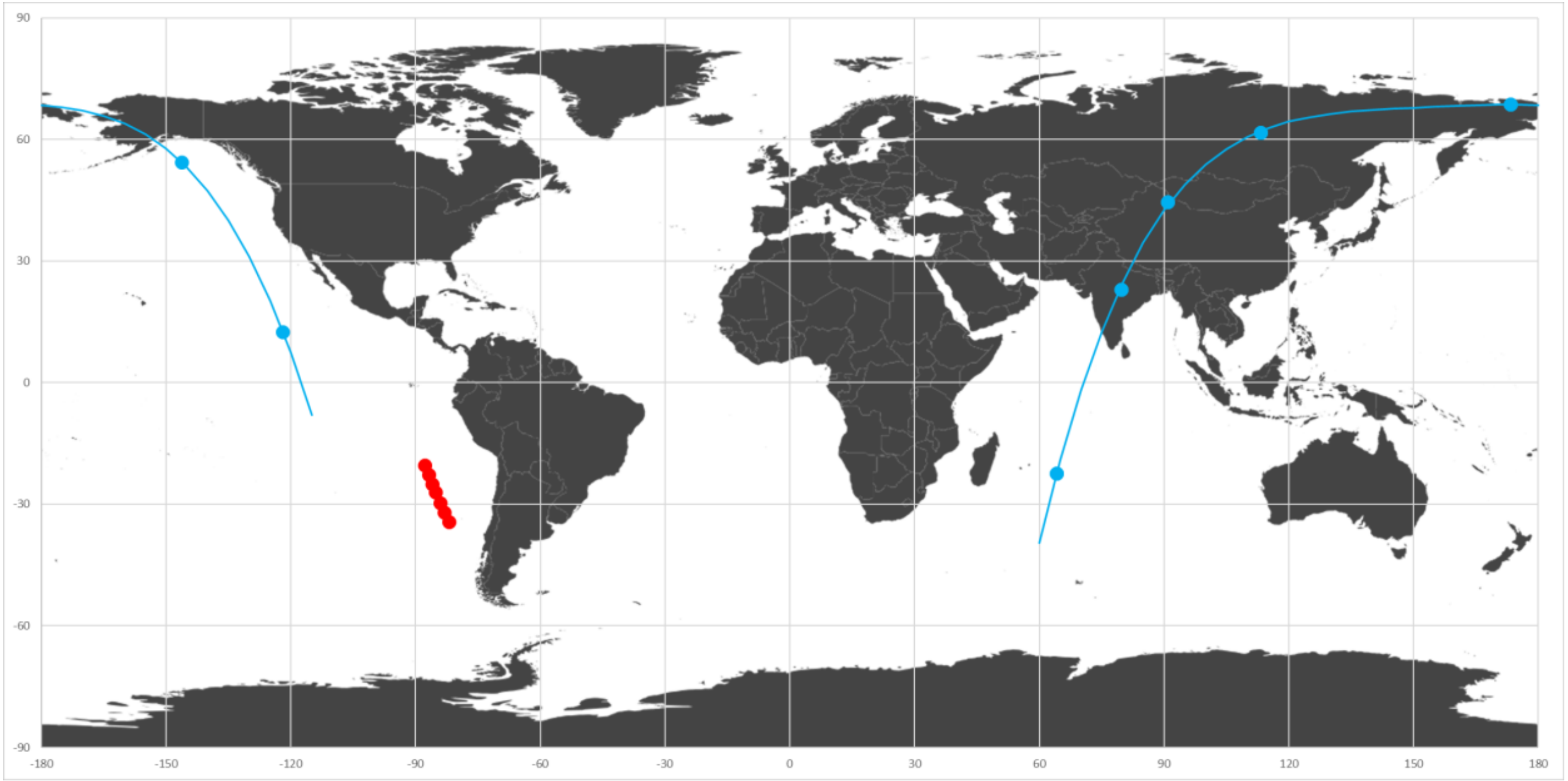
- ESA prepared one OPM with OD results from 2 TIRA tracks of 2012-006K (same as test case #2)
- ingested by both ESA/ESOC and DLR/GSOC re-entry prediction systems
- both re-entry prediction systems ran their standard prediction process from here on and produced one RDM (XML for ESA, KVN for DLR) each for the re-entry

- results were as expected:
  - impact epoch inside the other message's impact window
  - ESA KVN2XML converter was able to read/convert both messages
  - different impact locations, but impact windows were still large
- one issue encountered : ORBIT_LIFETIME_CONFIDENCE not interpreted correctly ➤ change in the Red Book to ORBIT_LIFETIME_CONFIDENCE_LEVEL

Prototyping: ground impact location uncertainty (test case #5)

- ESA prepared one OPM with OD results from 2 TIRA tracks of 2012-006K (same as test case #2)
- ingested by both ESA/ESOC and DLR/GSOC re-entry prediction systems
- both re-entry prediction systems ran their standard prediction process from here on and produced one RDM (XML for ESA, KVN for DLR) each for the re-entry

- results were as expected:
  - ESA KVN2XML converter was able to read/convert both messages
  - different impact locations, but impact windows were still large
- different approach in impact location window estimation, the DLR impact window is much smaller and 0.5 or 1.5 orbits before the ESA impact
- one issue encountered : ORBIT_LIFETIME_CONFIDENCE not interpreted correctly ➤ change in the Red Book to ORBIT_LIFETIME_CONFIDENCE_LEVEL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Prototyping summary and conclusions

Based on this operational diversity and the positive test results, the RDM prototyping effort successfully addresses the Blue Book promotion criteria. It is thus proposed to approve the Re-entry Data Message as a CCSDS Recommended Standard.

- 5 test cases prototyped covering all RDM keywords (including user-defined) and all foreseen use cases for the RDM (long-term prediction, short-term prediction, ground impact location and location uncertainty);
- data exchange and RDM reading successful – results between the two re-entry prediction systems can be different due to the different monitoring; the more complex the re-entry simulation the more different the results (long-term very similar, but location uncertainty different)
- differences not due to RDM!!!

RDM Red Book – overview of changes

changes between Red Book 1 (final) and Red Book 1.5:

- editorial changes/clarifications due to Agency Review: separate medium and long-term re-entries in nomenclature, define controlled re-entry
- switched to SANA registries for “approved” values of most keywords (most of annex B has been removed – only for COV_REF_FRAME for now)
- added/changed keywords (**before prototyping**): DRAG_PARAMETERS_SOURCE, DRAG_PARAMETERS_ALTITUDE, REENTRY_UNCERTAINTY_METHOD, ORBIT_LIFETIME_WINDOW_START/_END, ORBIT_LIFETIME_CONFIDENCE(_LEVEL), WET_/DRY_MASS, HAZARDUOS_SUBSTANCES
- clarified values for lat/lon
- fixed typos and inconsistencies (eg “long-term” instead of “long term”)
- clarified some normative requirements where the wording was not 100% clear

RDM Red Book – changes from 1.3 to 1.5

- Red Book 1.4 internal to the prototyping team
- look at pdf with tracked changes to 1.3 (Word unable to compare 1.0 and 1.5)

RDM Red Book – Blue Book changes?

- did not receive any CRMs to 1.3 or 1.5 (TBC)
- technical content extremely mature and stable
- two things that could lead to changes:
  - SANA registry for covariance reference frames is published – remove Annex B completely – *could be covered by a corrigendum, depending on the timeline*
  - any typos/inconsistencies/etc identified – proofreading not my strongest skill

Next steps and schedule

- update Red Book and Yellow Book (if needed)
- update XML schema with ORBIT_LIFETIME_CONFIDENCE_LEVEL
- update ndmxml-1.0-master.xsd with RDM
- test the schemas

- WG vote
- send to AD/secretariat/etc ➤ CMC/CESG(?) polls
- approval ➤ drinks at the Fall Meetings in Darmstadt

- check and update schedule on CWS

Summary and conclusions

- prototyping completed, Yellow Book 99.99 % done
- Red Book 99.99 % done (the last 0.01 % is always the hardest)
- XML schemas need to be updated
- need to decide on covariance reference frames SANA registry use (now or technical corrigendum)
- need to decide on vote and schedule

Re-entry Data Message

BACK-UP SLIDES

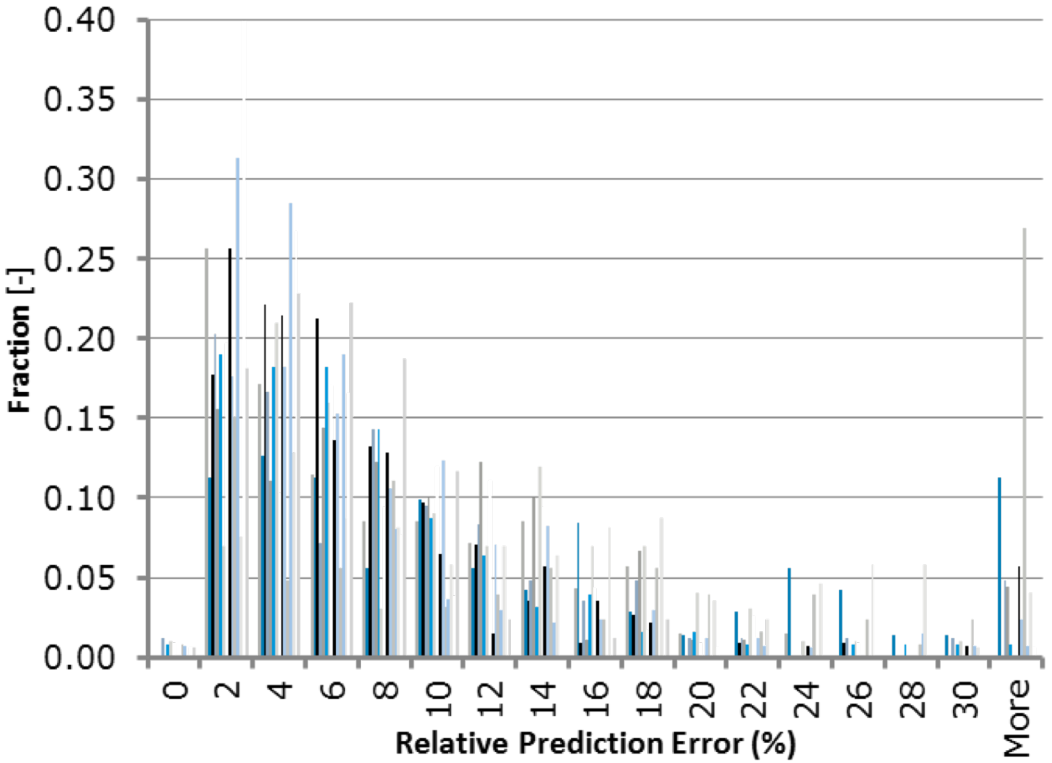
Uncontrolled Re-entry

Short term (2 weeks prior to reentry) uncertainties:

- Attitude variations
- Density variations
- Orbit determination uncertainties

Long term this uncertainties leads to uniform distributions in longitude and orbit position.

Spacecraft characteristics and atmospheric properties influence the **time** of re-entry.

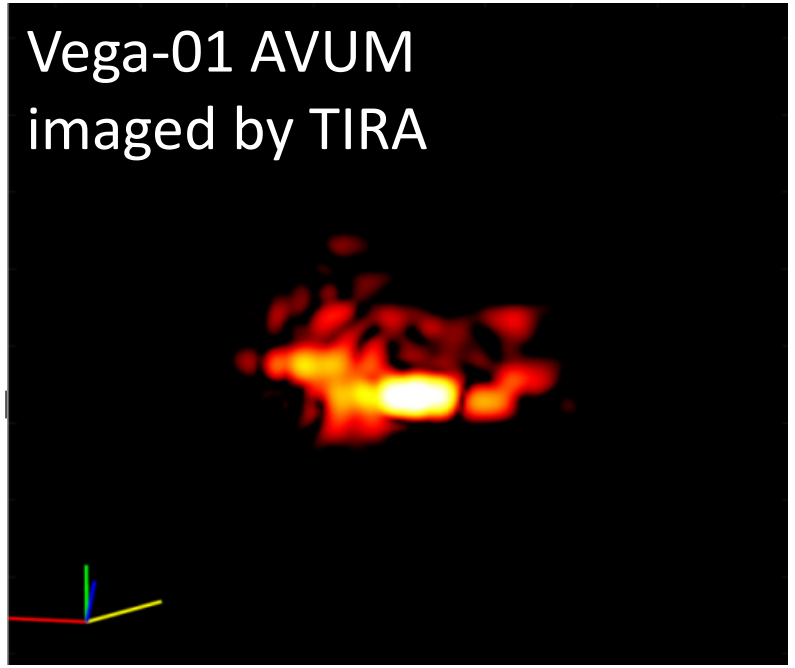


Practicalities of a re-entry: manual work

- Until 2 days before re-entry: daily predictions
- Last 2 days: constant monitoring of new data, predictions every few hours

Data used:

- TLEs from international partners
- Tracking sensor passes, possibly with imaging→ intrinsic rotatio



Typical difficulties of a re-entry prediction:

- Solar activity (real vs. predicted); under-prediction of storms
- Inaccurate atmosphere models
- Different sources of data, OD, filtering, …
- Very last states tend to be noisy