# Calculating the Re-Entry Probability for a given Area of Interest

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# Overview

# Introduction

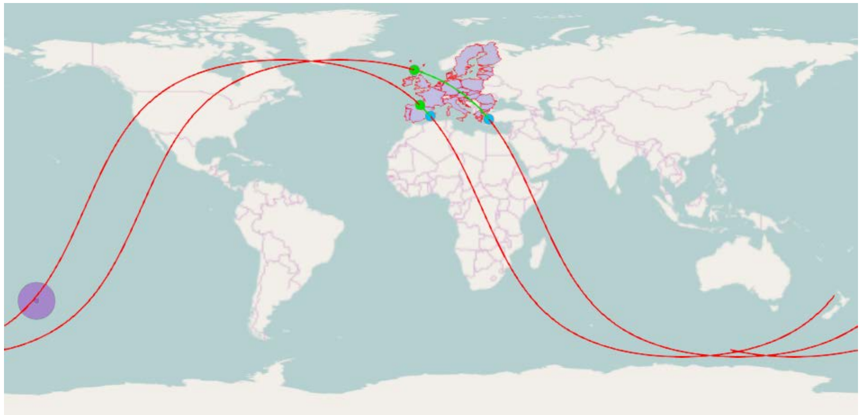
Re-Entry calculations are part of daily business at GSSAC

Development of an analysis mode

- Reduce number of false positive alerts
- Calculate re-entry probability for a given area of interest

Approach:

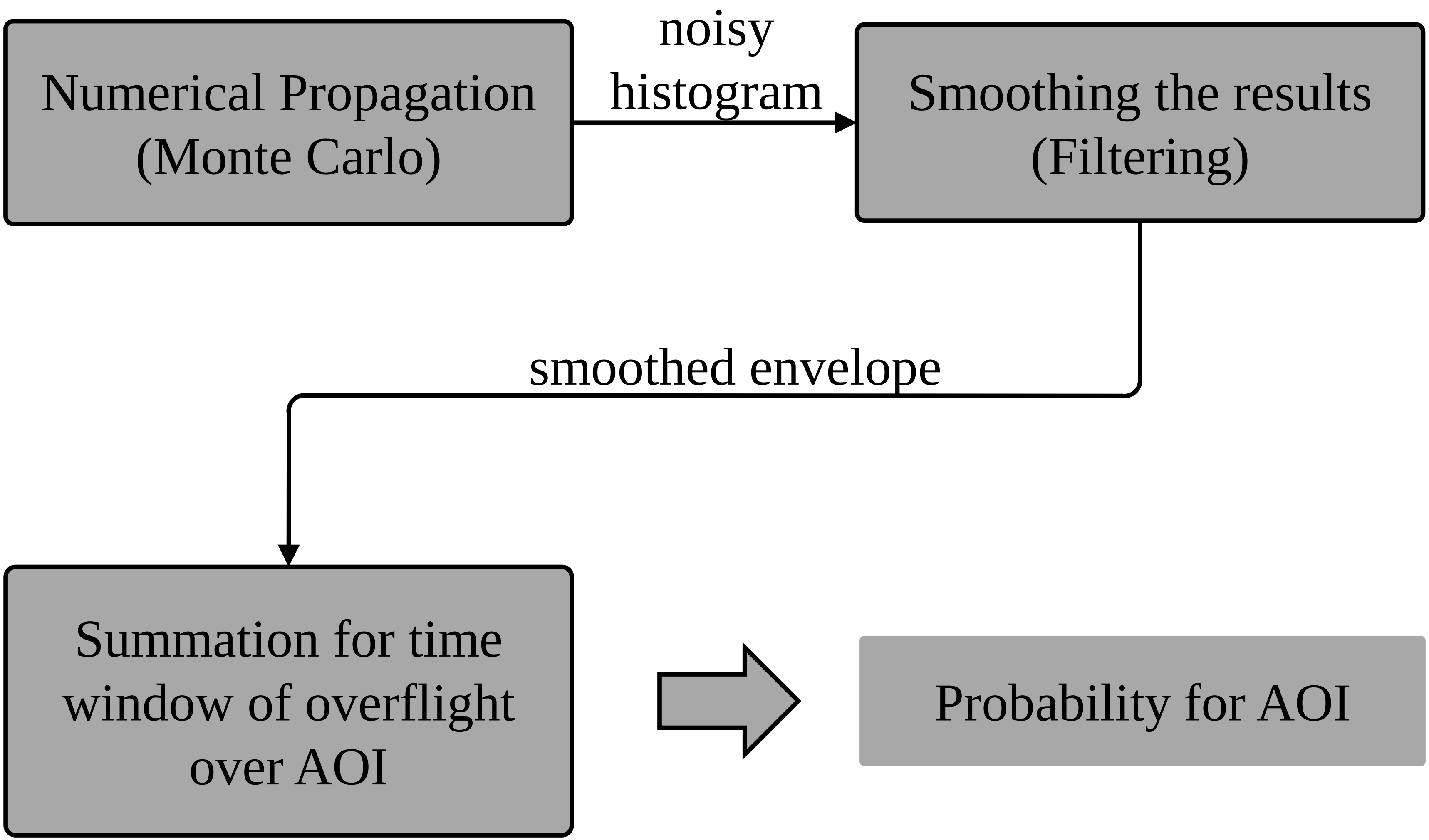
- Monte Carlo Simulations
- Combined with filter techniques



Currently:

- Use TIP from JSpoC

# Sequence of Operations



# Monte Carlo Simulations

Analysis mode can run various number of MC simulations

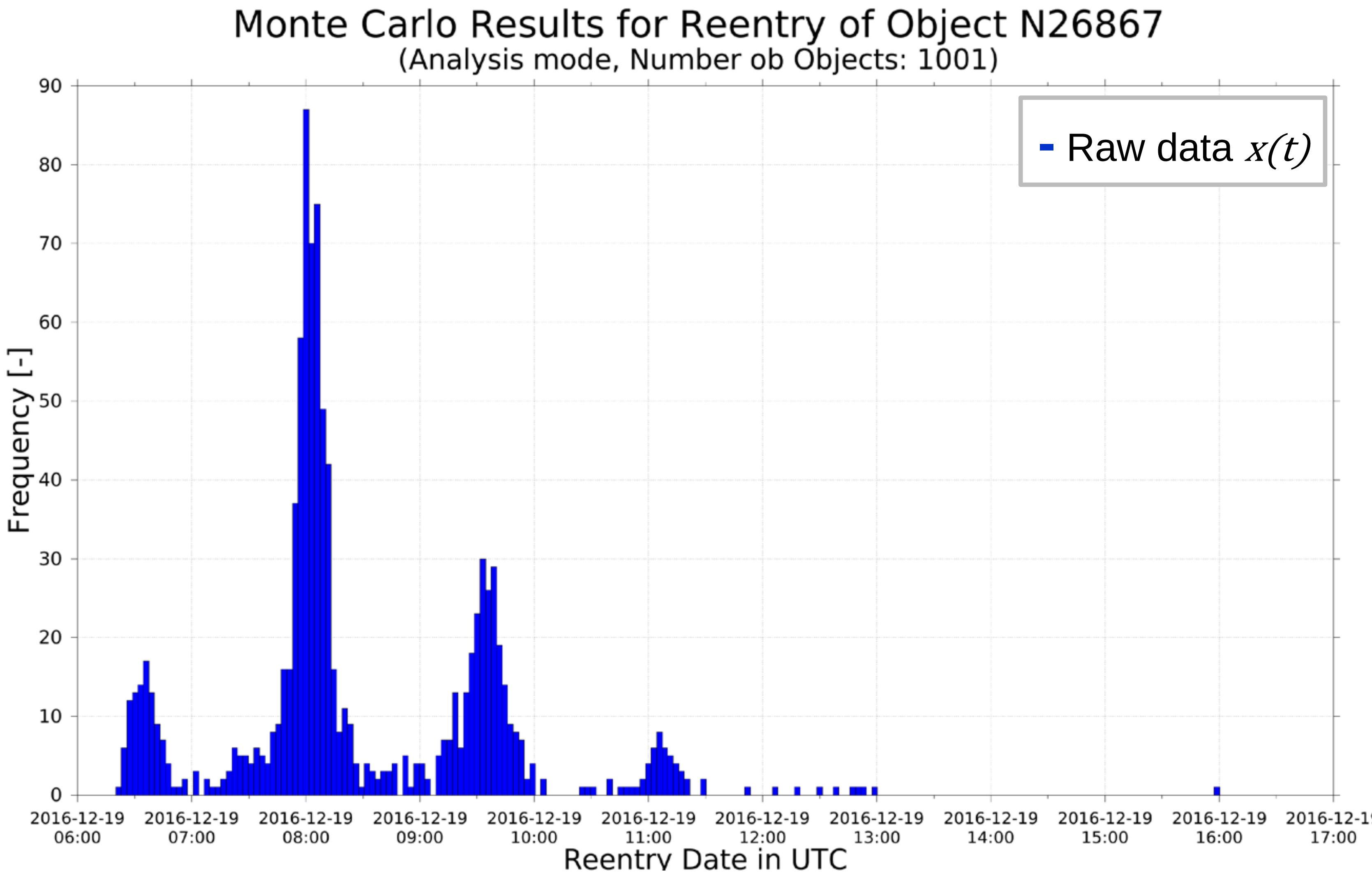
Applying a independent normal distribution to

- Satellite Position
- Satellite Velocity
- Ballistic Coefficient
- Solar Radiation Pressure Coefficient

Tests have shown that 1000 MC runs result in a sufficient number of data sets (re-entry COIW + position)

Characteristic curve for a remaining life time less than one day

# Monte Carlo Simulations




Luftwaffe
Wir. Dienen. Deutschland.

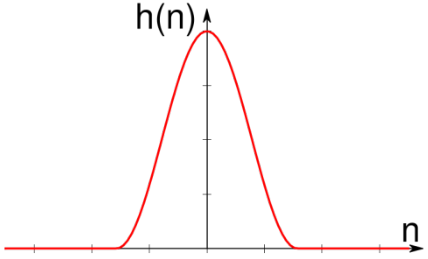
DLR

# Filter Techniques

A raised cosine filter was implemented to reduce the noise of the derived MC data

- Non-negative impulse response (NNIR) filter
- Leaned on Hann function

$$h(n) = cos\left(n \cdot \frac{f_c}{f_s} \cdot 2\pi\right) + 1$$

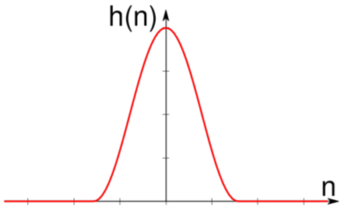



Function has to be normalised and cut at its first minimum to get a low-pass filter.

$$h(n) = 0 \; \forall \; |n| > \frac{1}{2}\frac{f_s}{f_c}$$

# Filter Techniques

$$h(n) = cos\left(n \cdot \frac{f_c}{f_s} \cdot 2\pi\right) + 1$$




Cut-off frequency $f_c$ is depended on the shape of the current orbit and will be calculated by using a FFT

- Aim is to find the envelope of the derived MC data

Sample frequency $f_s$ is depend off the time difference of the raw histogram data: $f_s = \frac{1}{dt}$

Applying the filter on the raw data leads to the smoothed probability distribution $p(t)$

$$x(t) \longrightarrow \boxed{h(n)} \longrightarrow p(t)$$

# Re-Entry Probability

Received probability distribution is located in the time domain

- The time window of an overflight can be used to calculate re-entry probability for the given area of interest

$$p_{\mathrm{win}} = \sum_{t=t_{\mathrm{start}}}^{t_{\mathrm{end}}} \mathrm{p}(t)$$

If there is more than one overflight the probabilities of the separate windows have to be added up

A probability corresponding to the time of the overflight is calculated to make results comparable

# Re-Entry Probability

Example for overflights over the EU:

- Molnya 3-51on 19.12.2016

| # | start | end | probability | rel. probability |
|---|---|---|---|---|
| 1 | 07:24:21 | 07:32:55 | 0.0152 | $2.96 \cdot 10^{-05}$ 1/s |
| 2 | 09:04:01 | 09:05:36 | 0.0023 | $2.42 \cdot 10^{-05}$ 1/s |
| Σ | | | 0.0175 | $2.87 \cdot 10^{-05}$ 1/s |

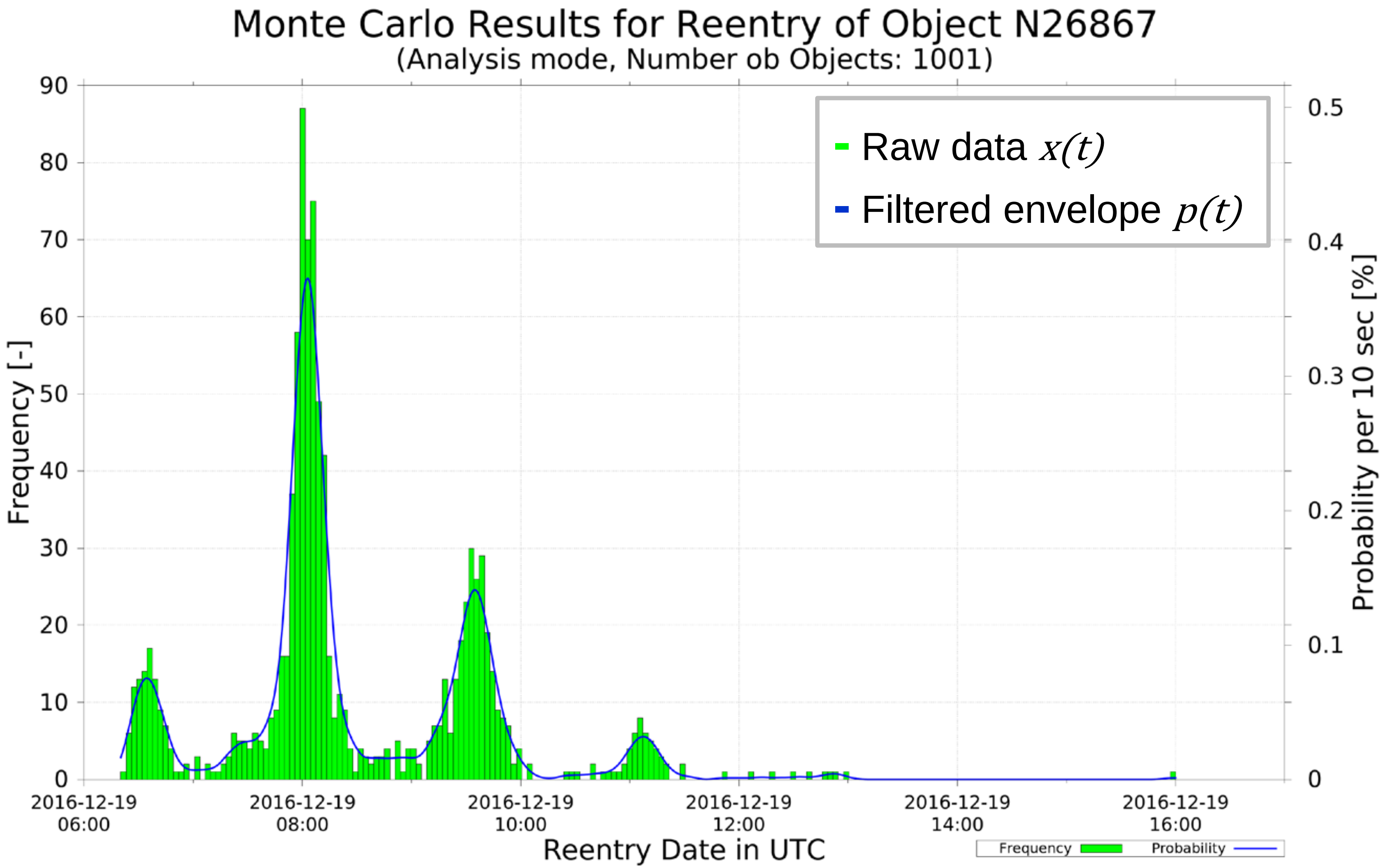
More simulations are needed to set a suitable threshold

# Results

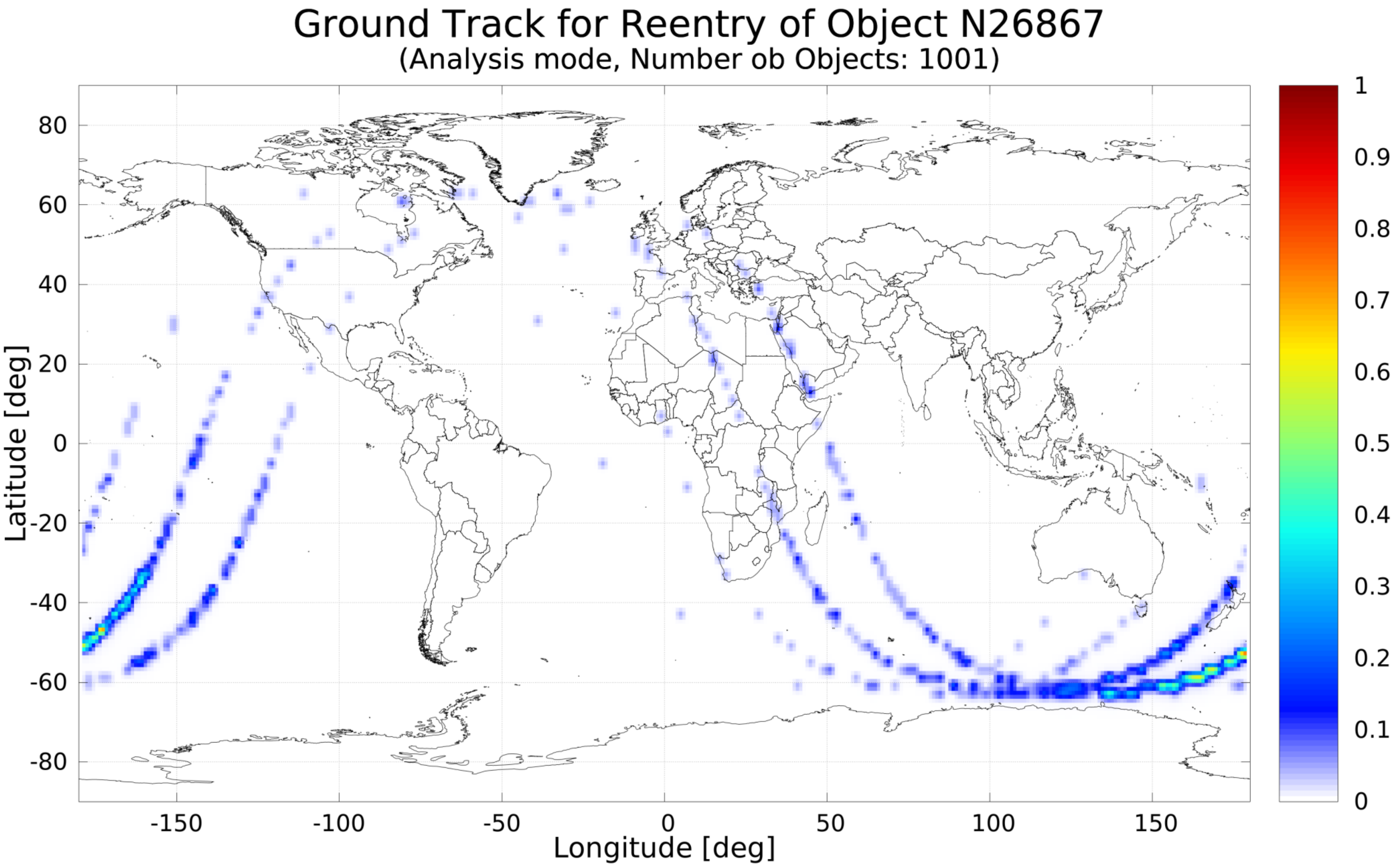
Example: **Eccentric Orbit**

| Name | Value |
|---|---|
| satellite name | MOLNIYA 3-51 |
| International Designator | 2001-030A |
| NORAD ID | 26867 |
| decay day | 2016-12-19 |
| decay time (TIP) | 06:43:00 |
| orbit data epoch | 2016-12-18T23:45:22 |
| Period | 99.55 min |
| Inclination | 62.42° |
| Apogee | 1400.09 km |
| Perigee | 88.55 km |
| Eccentricity | 0.09216 |

# Results


Monte Carlo Results for Reentry of Object N26867
(Analysis mode, Number ob Objects: 1001)
Raw data x(t)
Filtered envelope p(t)
Frequency [-]
Probability per 10 sec [%]
Reentry Date in UTC
2016-12-19 06:00
2016-12-19 08:00
2016-12-19 10:00
2016-12-19 12:00
2016-12-19 14:00
2016-12-19 16:00
0
10
20
30
40
50
60
70
80
90
0
0.1
0.2
0.3
0.4
0.5
Frequency
Probability

# Results



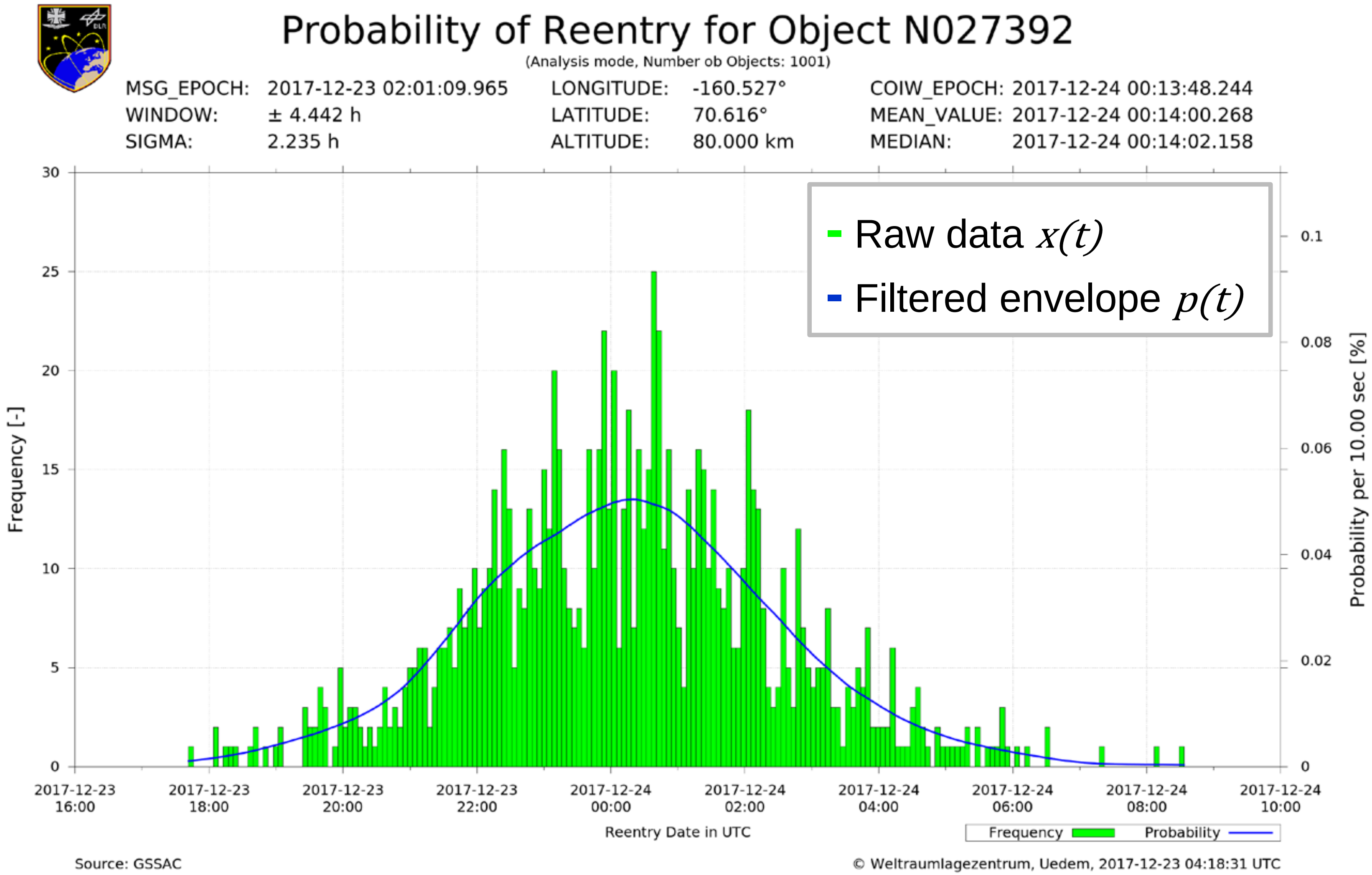
Ground Track for Reentry of Object N26867
(Analysis mode, Number ob Objects: 1001)
Latitude [deg]
80
60
40
20
0
-20
-40
-60
-80
Longitude [deg]
-150
-100
-50
0
50
100
150
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

# Results

## Example: **Circular Orbit**

| Name | | Value |
|---|---|---|
| satellite name | | GRACE 2 |
| International Designator | | 2002-012B |
| NORAD ID | | 27392 |
| decay day | | 2017-12-24 |
| decay time (TIP) | | 00:16:00 |
| orbit data epoch | 2017-12-23T02:01:10 | 2017-12-23T22:49:47 |
| Period | | 87.14 min |
| Inclination | | 88.97° |
| Apogee | | 134.03 km |
| Perigee | | 131.42 km |
| Eccentricity | | 0.00020 |

# Results



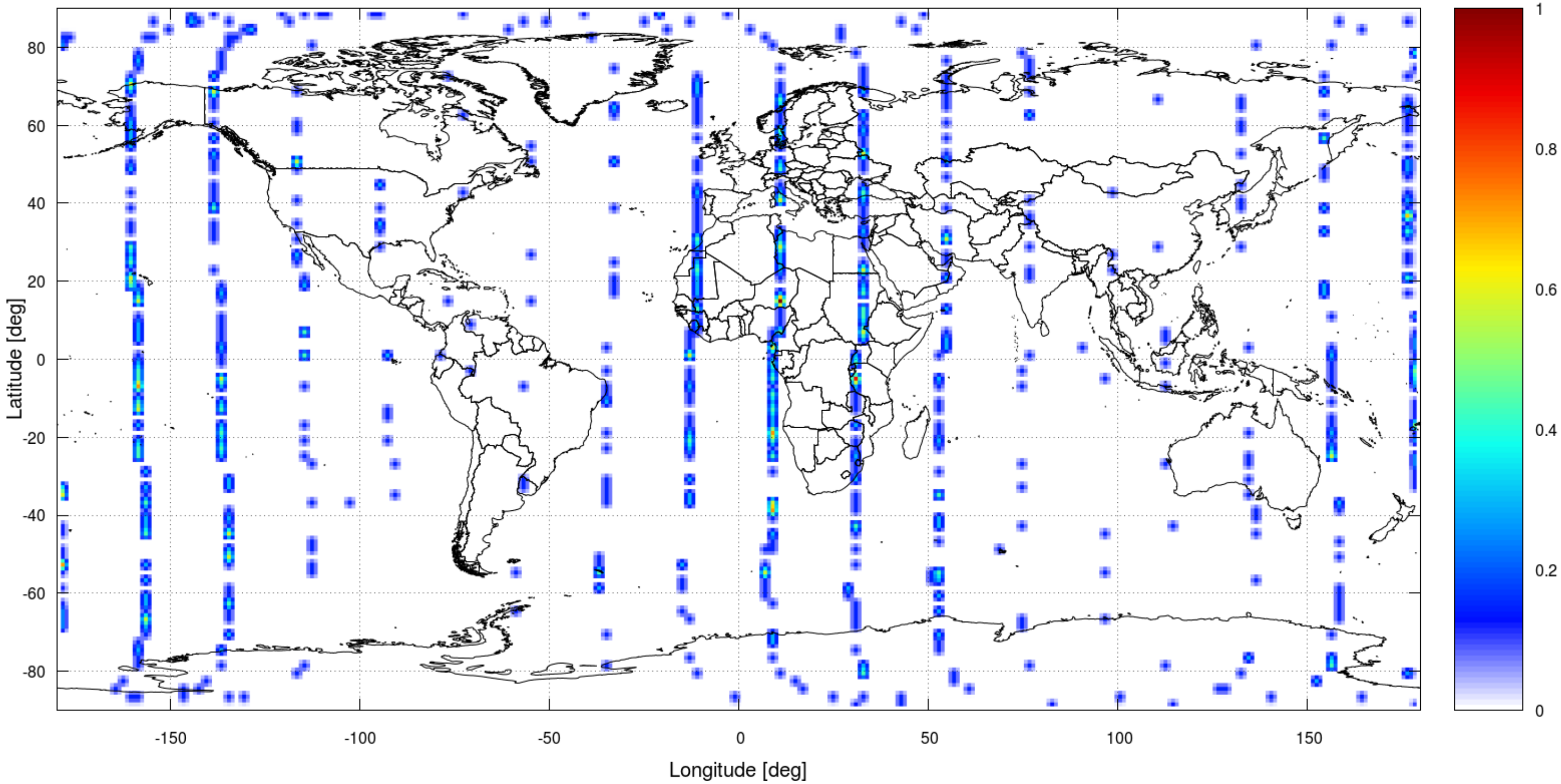
Probability of Reentry for Object N027392
(Analysis mode, Number ob Objects: 1001)
MSG_EPOCH: 2017-12-23 02:01:09.965
WINDOW: ± 4.442 h
SIGMA: 2.235 h
LONGITUDE: -160.527°
LATITUDE: 70.616°
ALTITUDE: 80.000 km
COIW_EPOCH: 2017-12-24 00:13:48.244
MEAN_VALUE: 2017-12-24 00:14:00.268
MEDIAN: 2017-12-24 00:14:02.158
Raw data x(t)
Filtered envelope p(t)
Frequency [-]
Probability per 10.00 sec [%]
Reentry Date in UTC
Frequency
Probability
Source: GSSAC
© Weltraumlagezentrum, Uedem, 2017-12-23 04:18:31 UTC

# Results

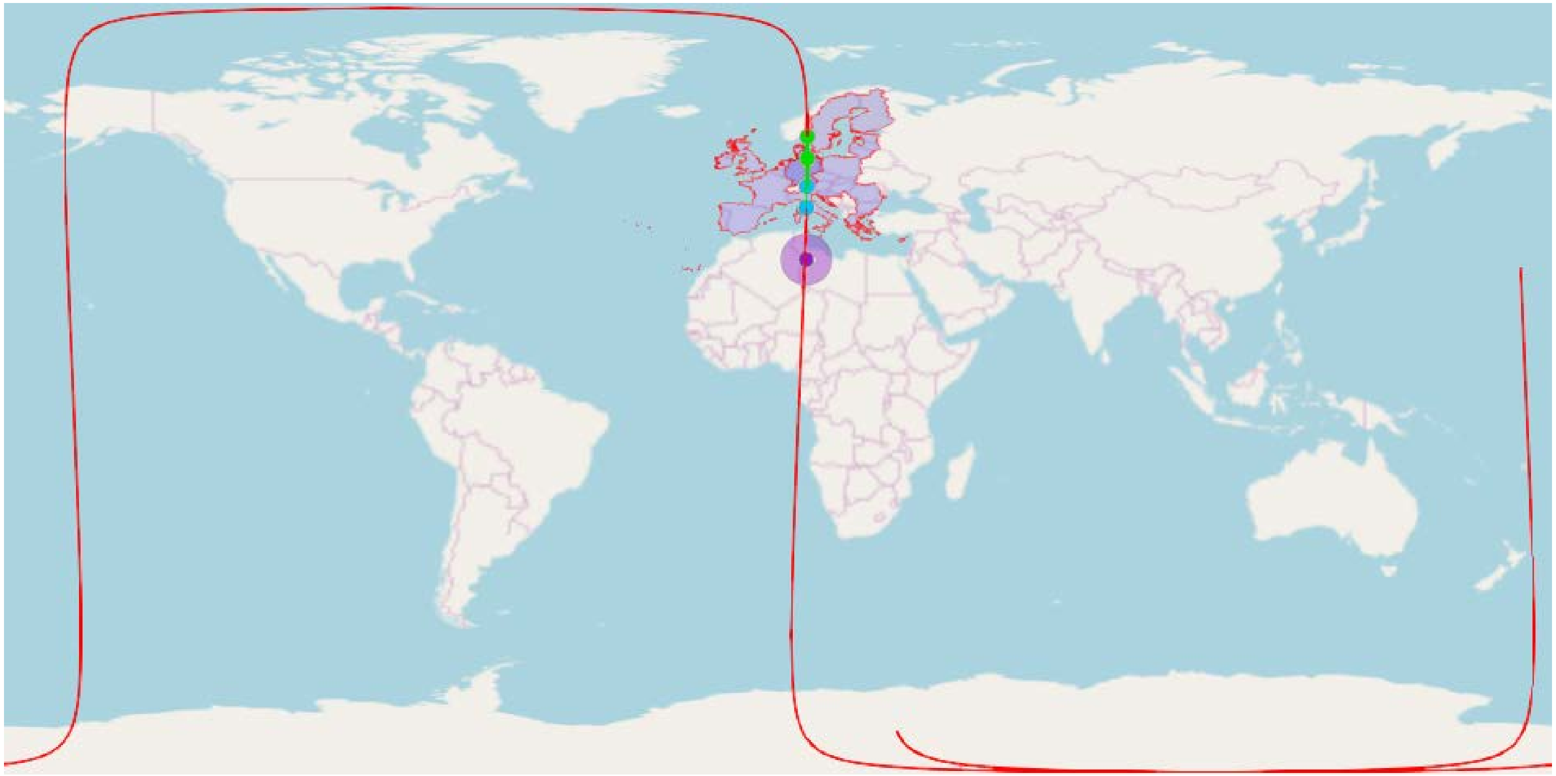
## Ground Track for Reentry of Object N027392

(Analysis mode, Number ob Objects: 1001)

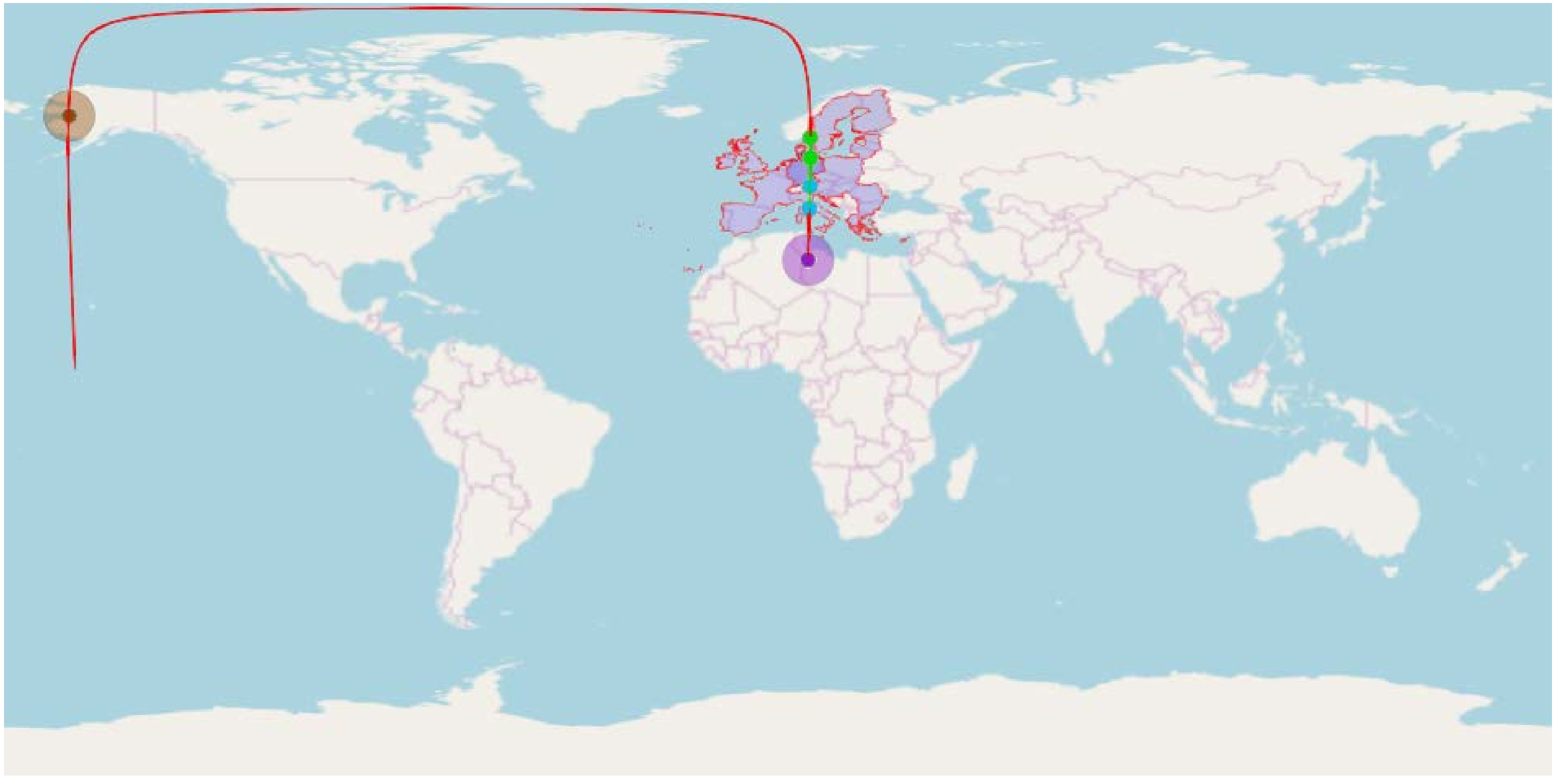
| | | | | | |
|---|---|---|---|---|---|
| MSG_EPOCH: | 2017-12-23 02:01:09.965 | LONGITUDE: | -160.527° | COIW_EPOCH: | 2017-12-24 00:13:48.244 |
| WINDOW: | ± 4.442 h | LATITUDE: | 70.616° | MEAN_VALUE: | 2017-12-24 00:14:00.268 |
| SIGMA: | 2.235 h | ALTITUDE: | 80.000 km | MEDIAN: | 2017-12-24 00:14:02.158 |



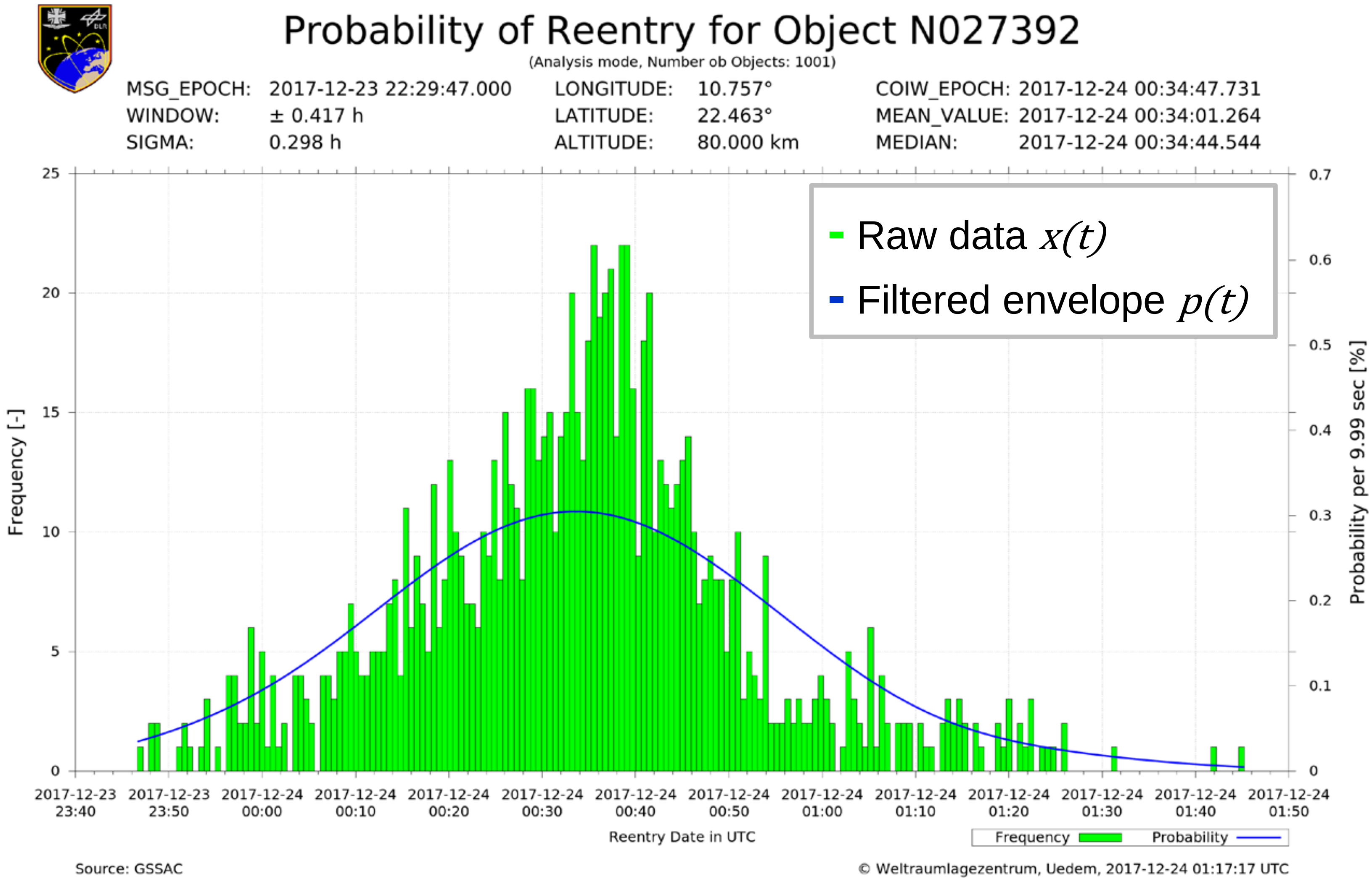
# Results



# Results



# Results



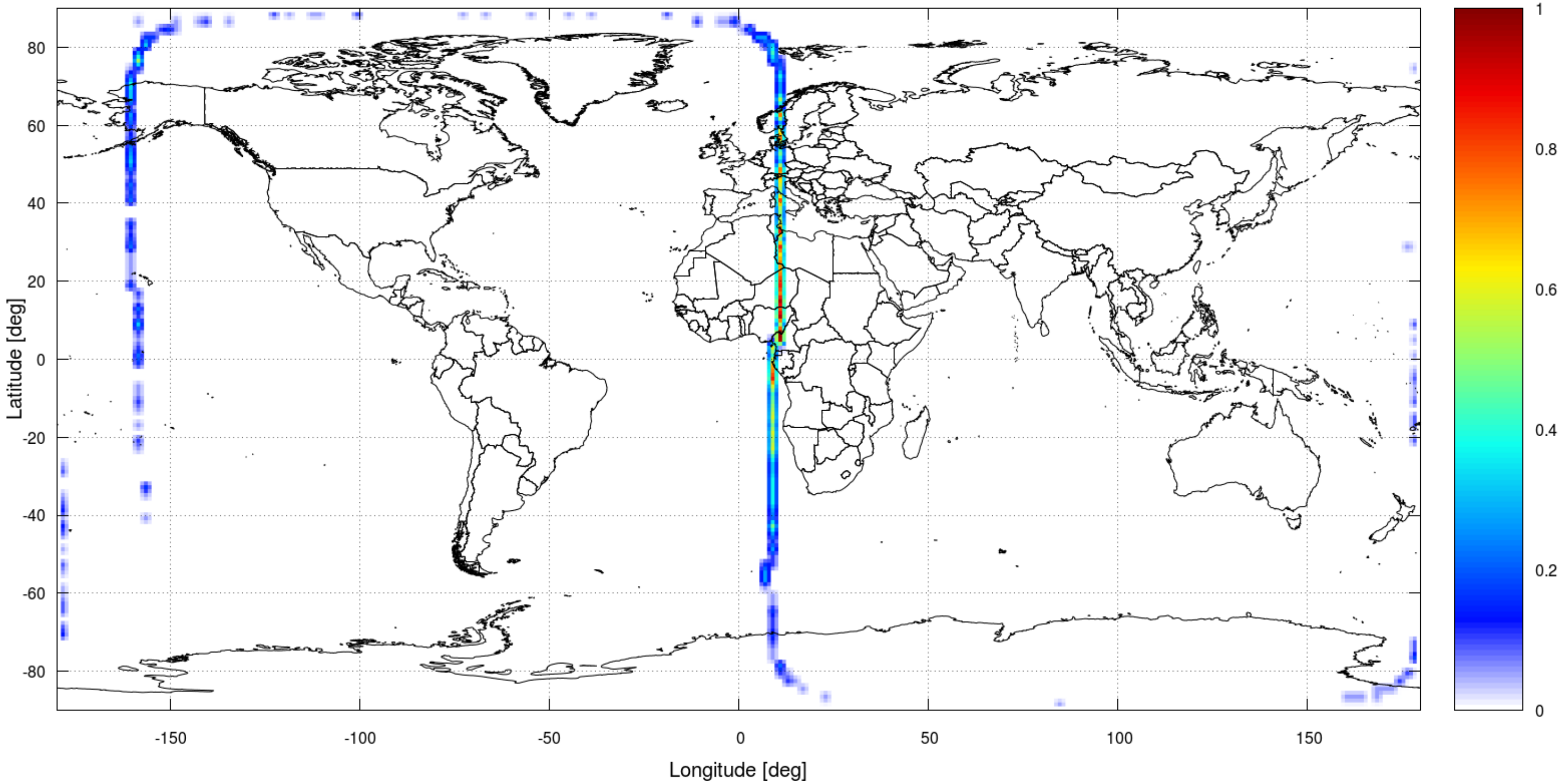
Probability of Reentry for Object N027392
(Analysis mode, Number ob Objects: 1001)
MSG_EPOCH: 2017-12-23 22:29:47.000
WINDOW: ± 0.417 h
SIGMA: 0.298 h
LONGITUDE: 10.757°
LATITUDE: 22.463°
ALTITUDE: 80.000 km
COIW_EPOCH: 2017-12-24 00:34:47.731
MEAN_VALUE: 2017-12-24 00:34:01.264
MEDIAN: 2017-12-24 00:34:44.544
Raw data x(t)
Filtered envelope p(t)
Frequency [-]
Probability per 9.99 sec [%]
Reentry Date in UTC
Frequency
Probability
Source: GSSAC
© Weltraumlagezentrum, Uedem, 2017-12-24 01:17:17 UTC

# Results

## Ground Track for Reentry of Object N027392

(Analysis mode, Number ob Objects: 1001)

| | | | | | |
|---|---|---|---|---|---|
| MSG_EPOCH: | 2017-12-23 22:29:47.000 | LONGITUDE: | 10.757° | COIW_EPOCH: | 2017-12-24 00:34:47.731 |
| WINDOW: | ± 0.417 h | LATITUDE: | 22.463° | MEAN_VALUE: | 2017-12-24 00:34:01.264 |
| SIGMA: | 0.298 h | ALTITUDE: | 80.000 km | MEDIAN: | 2017-12-24 00:34:44.544 |



# Conclusion

The results show potential to improve the prediction and assessment of re-entries

- Even more reliable with better input values
- Calculations should start at around one day before the final re-entry

In the future it is planned to use the following inputs:

- Covariance information derived from OD
- Variation of ballistic coefficient

A threshold for the re-entry probability shall be derived by analyzing more re-entry events.

# Thank you for your attention