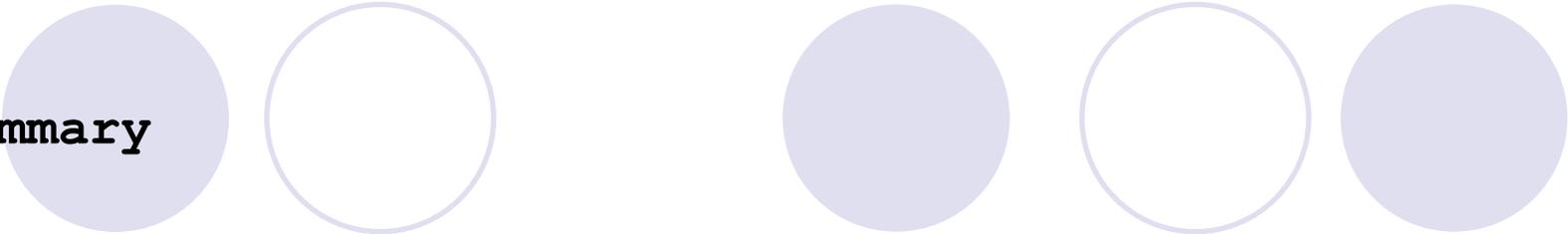


Relative signal strengths from
SLR tracking of the different
retro-reflector targets onboard
HEO satellites using the
fullrate data set

Matthew Wilkinson and Graham Appleby

NERC Space Geodesy Facility, UK



Summary

- Introduction
- Different High Earth Orbiting (HEO) satellite targets
- Return rates from fullrate data
 - Defining the 'return rate' and forming a value
 - What variables affect the return rate?
 - Reducing the impact of these variables
- Analysis of the Herstmonceux and Yarragadee fullrate data from 2007
- Plots of return rate against elevation and corrections
- Comparison of CompassM1 target and individual retro-reflectors to the other HEO satellites
- Conclusion

Introduction

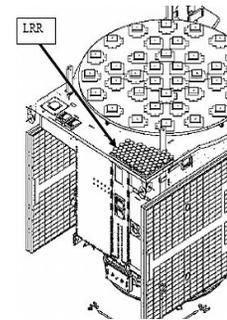
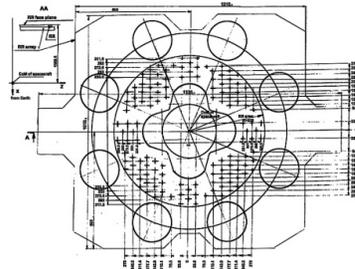
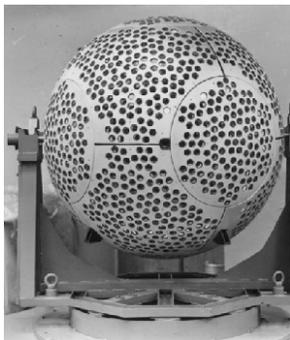
- The ILRS Missions Working Group requested a tracking campaign for March 2009 encouraging stations to increase tracking of the CompassM1 satellite and the other HEO satellites.
- The aim was to test and compare the effectiveness of the relatively small array of **un-coated cubes** on the COMPASS-M1 satellite with respect to the three GLONASS, two GIOVE, two GPS and two ETALON geodetic satellites currently supported.
- This work follows a preliminary report presented at the Missions Working Group and Analysis Working Group meetings in April 2009 at the EGU.



The CompassM1 retro-reflector array. 31.6 x 28cm, 42 cubes of 33mm diameter of fused silica.

Introduction

- CompassM1 is the only HEO satellite to use un-coated retro-reflectors
- The GPS, Giove, Etalon and Glonass retro-reflectors were built by the Russian Institute for Space Device Engineering. Each is made from fused-quartz with the back reflective surfaces coated with aluminium.
- For the different satellites, the retro-reflector arrays are arranged in different shapes and sizes.



Relative signal strengths

- The fullrate data files on CDDIS and EDC from contributing stations contain all successful returns from satellite laser ranging separated into satellite and station folders.

```

070110109136293112525979709005132908473664944146380386895
070110109136293120025974709005132908352664979146379590865
0701101091362931279259807090051329082316690141463787959335
070110109136293155026048709005132907787665141146375800255
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0701101091362931790257527090051329074886665146373763045
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5320 98482880 3617350 4670 19 162595 -4 400
5320 98482880 3617349 4670 19 162595 -4 400
5320 98482880 3617349 4670 27 162595 -4 400
5320 98482880 3617347 4670 15 162595 -4 400
5320 98482880 3617347 4670 19 162595 -4 400
5320 98482880 3617347 4670 23 162595 -4 400
5320 98482880 3617347 4670 65 162595 -4 400
5320 98482880 3617346 4670 95 162595 -4 400
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5320 98482880 3617344 4670 68 162595 -4 400
5320 98482880 3617344 4670 29 162595 -4 400
5320 98482880 3617344 4670 118 162595 -4 400
5320 98482880 3617344 4670 41 162595 -4 400
5320 98482880 3617343 4670 18 162595 -4 400
5320 98482880 3617343 4670 86 162595 -4 400
5320 98482880 3617343 4670 66 162595 -4 400
5320 98482880 3617343 4670 66 162595 -4 400
5320 98482880 3617343 4670 84 162595 -4 400
5320 98482880 3617342 4670 30 162595 -4 400
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5320 98482880 3617342 4670 33 162595 -4 400

```

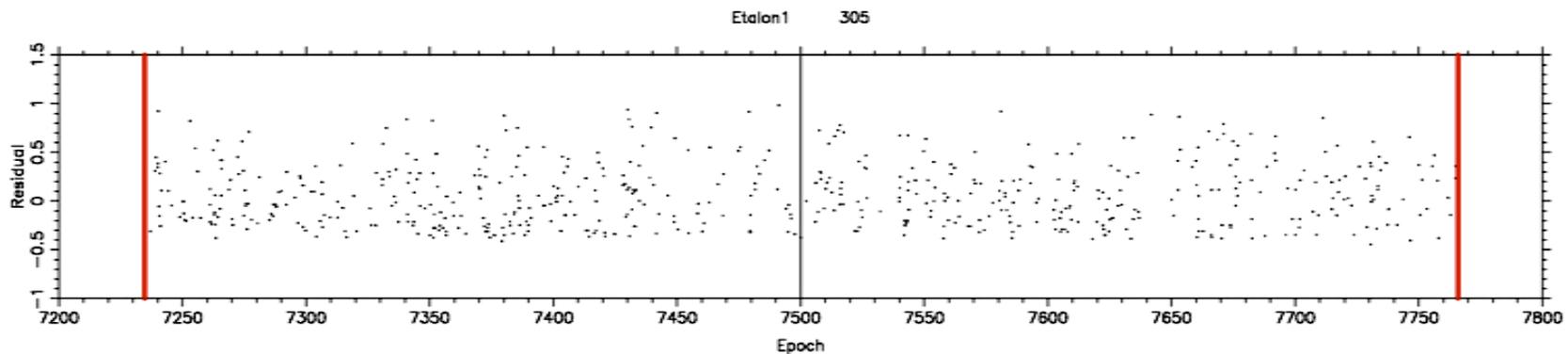
- A return rate can be calculated as the number of observation entries in the fullrate file within a time interval over the expected number of shots during this period.

$$\text{Return rate} = \frac{\text{Number of observations}}{\text{Number of laser fires}}$$

- The fullrate data used in this study was from **2007 onwards**.
- The CompassM1 and GioveB datasets include data from the beginning of SLR tracking, December 2008, and May 2008 respectively.

Relative signal strengths

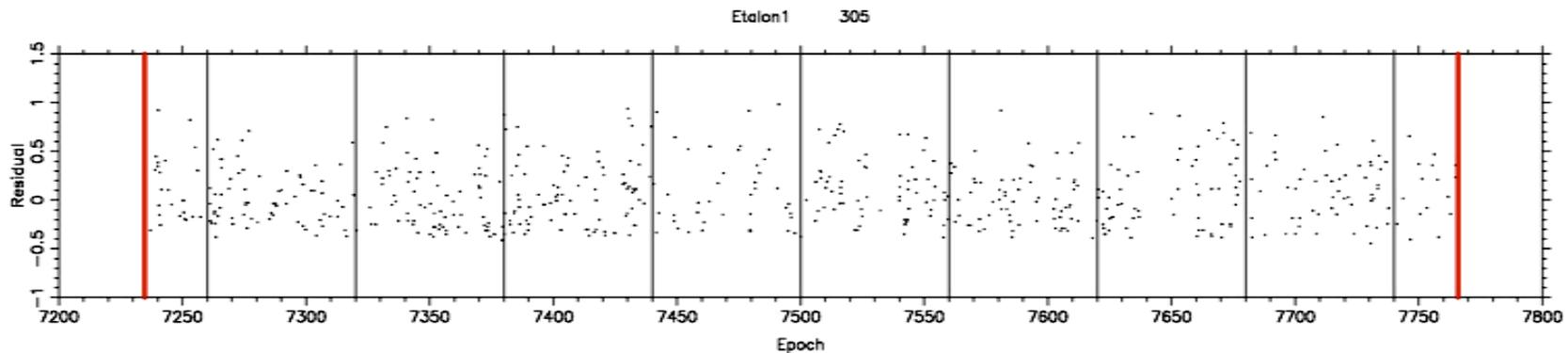
- Return rates in this investigation use the maximum and minimum epochs in a bin and the interval between the two to calculate the number of expected fires, dependant on the firing rate.



- Instead of the 300 second normal point bin, a 60 second bin was used to best avoid any gaps in data. Further to this data gaps of greater than 15 seconds were removed.

Relative signal strengths

- Return rates in this investigation use the maximum and minimum epochs in a bin and the interval between the two to calculate the number of expected fires, dependant on the firing rate.



- Instead of the 300 second normal point bin, a 60 second bin was used to best avoid any gaps in data. Further to this data gaps of greater than 15 seconds were removed.



Relative signal strengths

- There are a number of factors that influence the observed return rate:
 - Individual station ability
 - **Separate analysis for individual stations**
 - Atmospheric transparency
 - **Averaged over large amounts of data**
 - Beam divergence
 - **Settings kept the same for all HEOs over time**
 - Satellite range
 - **To be corrected for**
 - Filtering of the return signal and detection thresholds
 - **Data entries removed so that the all data is comparable**
 - Retro-reflector targets
 - **Remaining dominant variable in analysis**

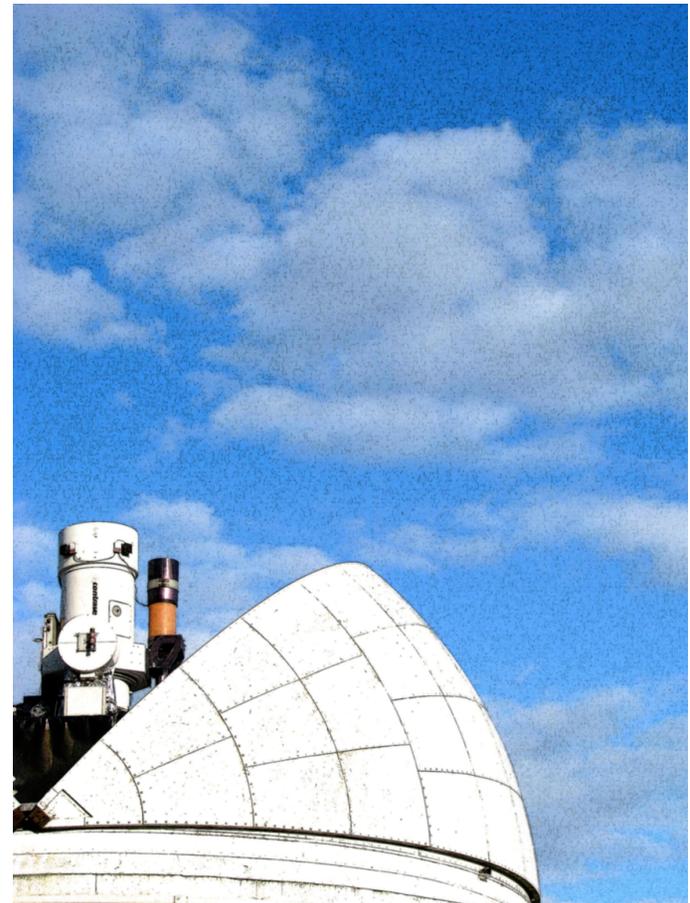
Relative signal strengths

- In the following plots the resulting return rates are presented plotted against elevation.
- The Etalon satellite datasets are combined together.
- The GPS datasets are combined together
- The Glonass datasets (Glonass99, Glonass 102 and Glonass 109) are combined together.
- The Giove satellites have different retro-reflector targets and are treated independently.

Relative signal strengths

Herstmonceux, UK

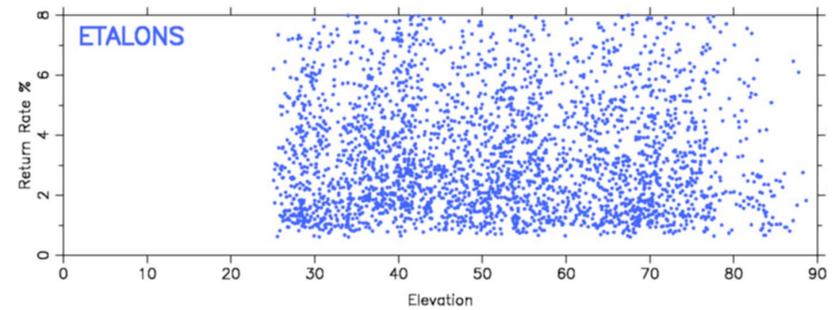
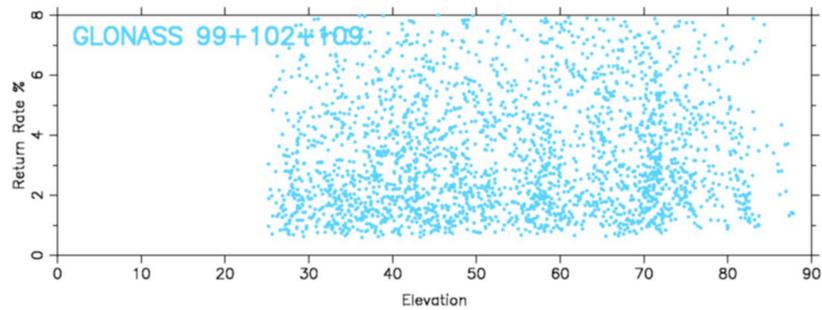
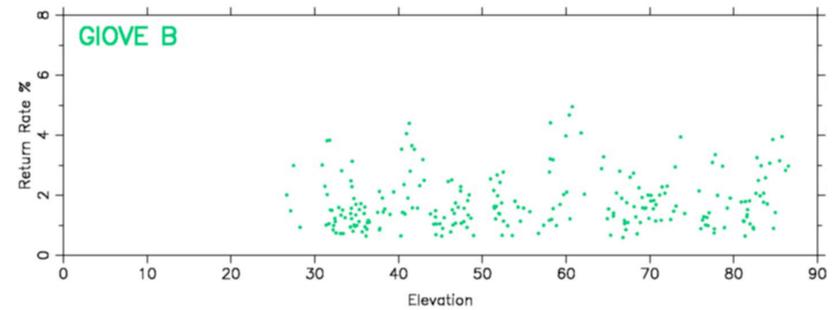
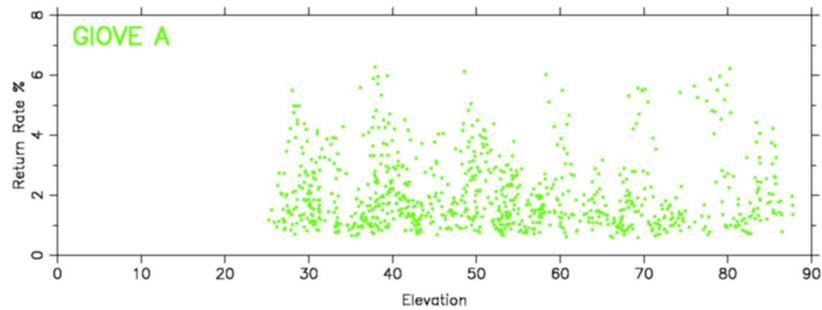
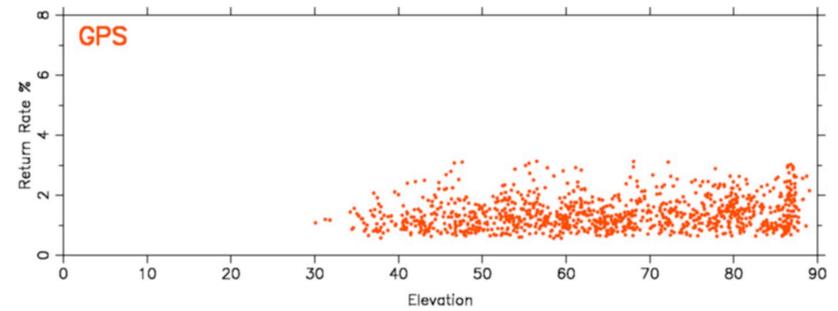
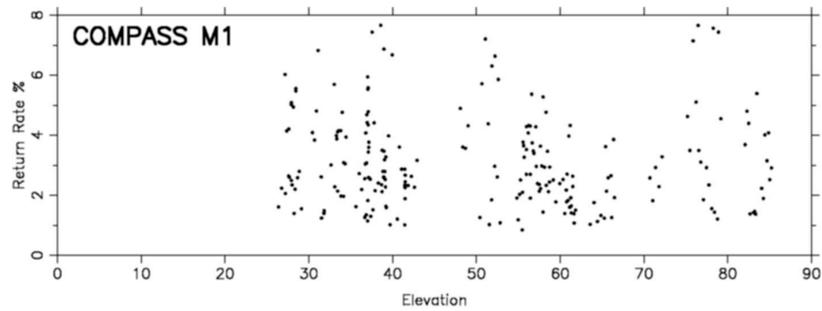
- Herstmonceux firing rate is effectively 24Hz using the semi-train.
- All Daytime data is excluded in this analysis as this was collected using the Narrowband filter
- All kHz tracking is excluded
- All data collected using Neutral Density filters was excluded.



Relative signal strengths

Herstmonceux, UK

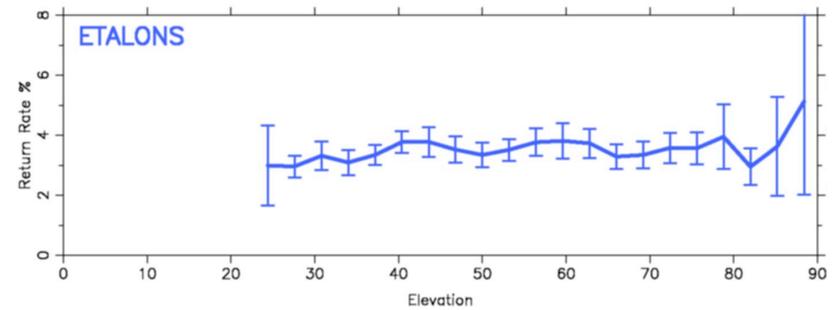
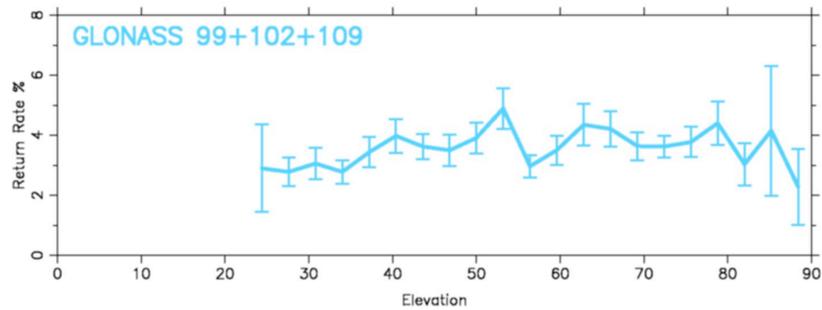
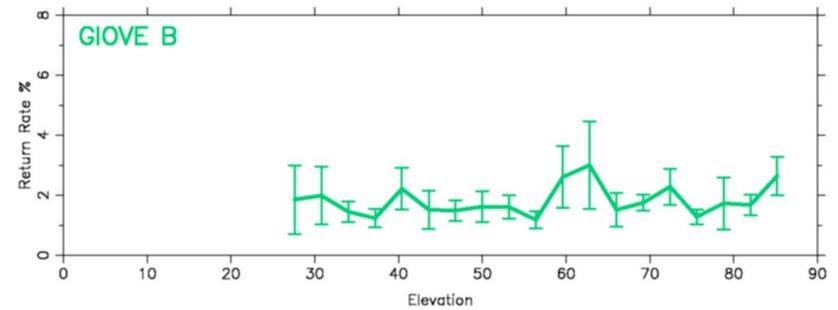
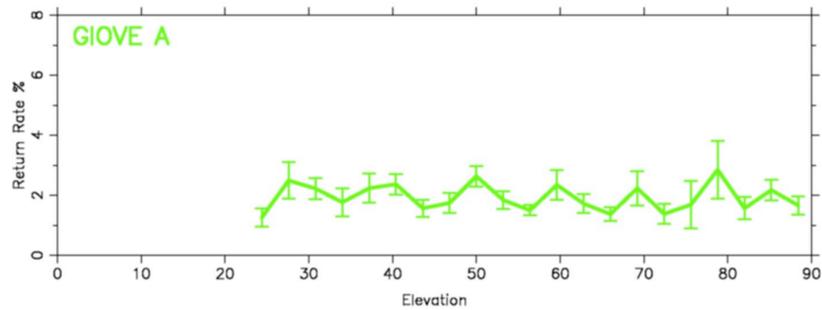
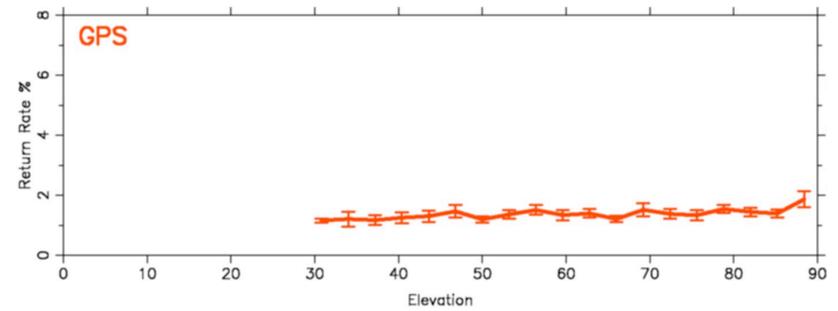
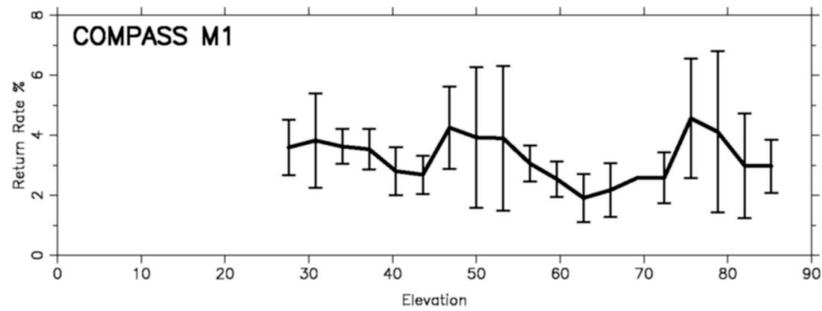
Return rates from the Herstmonceux SLR station from 2007



Relative signal strengths

Herstmonceux, UK

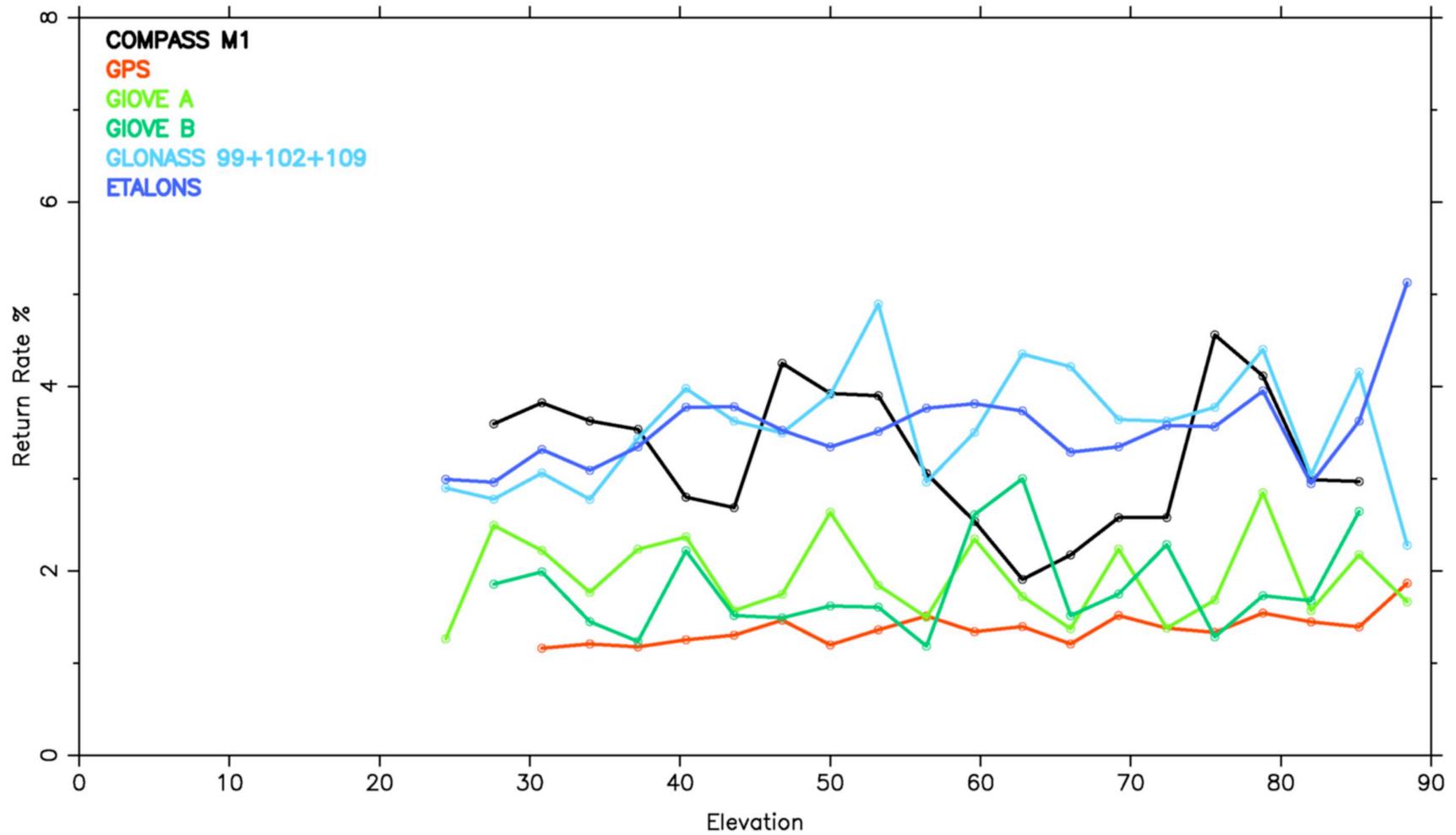
Return rates from the Herstmonceux SLR station from 2007



Relative signal strengths

Herstmonceux, UK

Average Return Rate vs Elevation for HEO satellites from Herstmonceux since 2007.00 at 24Hz



Relative signal strengths

- Return rate is dependent upon the satellite range as a R^4 relation. The distances to the satellites are:

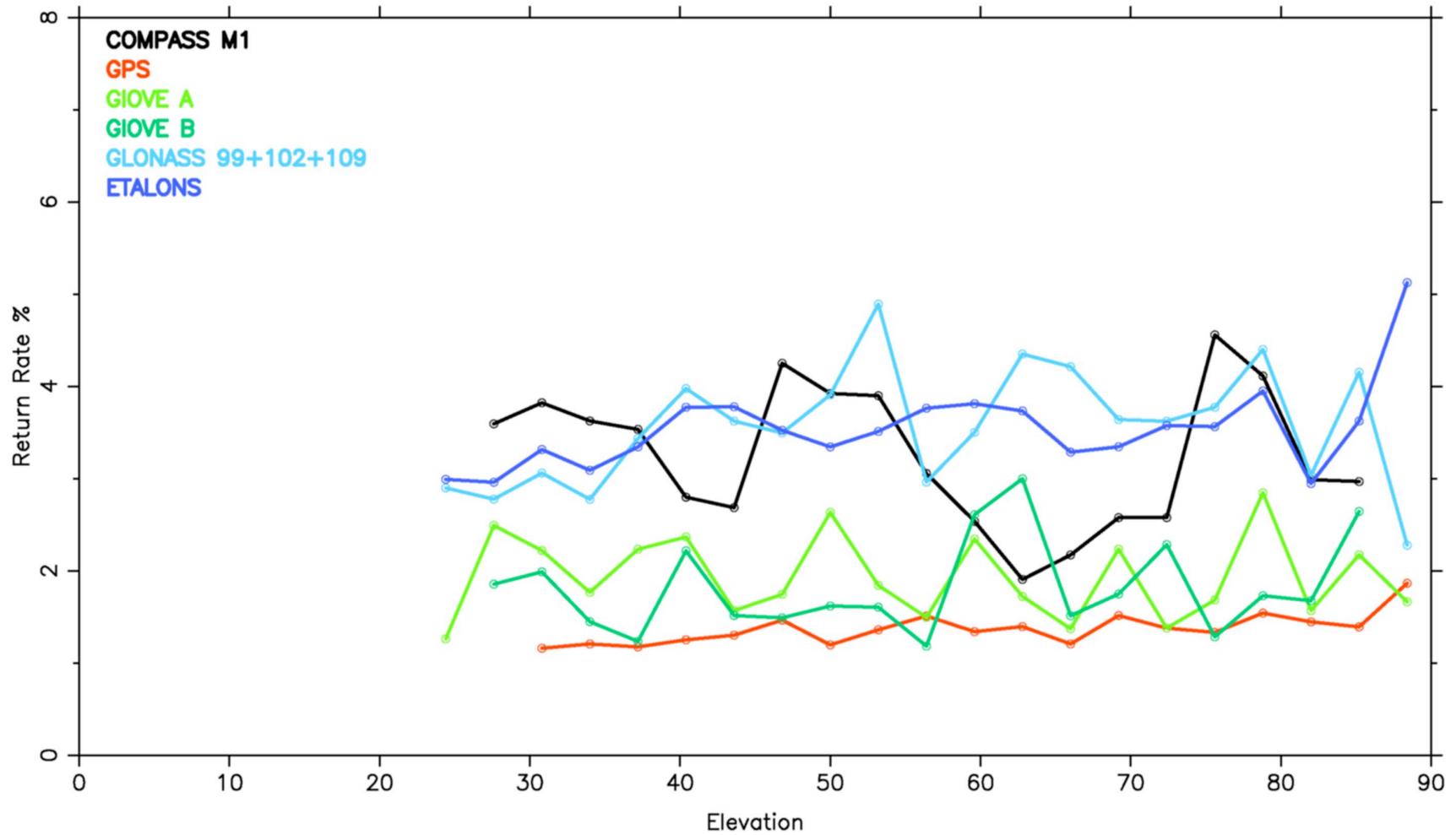
CompassM1	21 500 km
Etalon 1 + 2	19,135 km
GioveA	23 916 km
GioveB	23 916 km
Glonass99 + 102 + 109	19,140 km
GPS35 + 36	20,030 km

- The return rates can therefore each be scaled according to the average range. The following results are normalised to a distance approximately that of Compass M1 range in the Zenith.

Relative signal strengths

Herstmonceux, UK

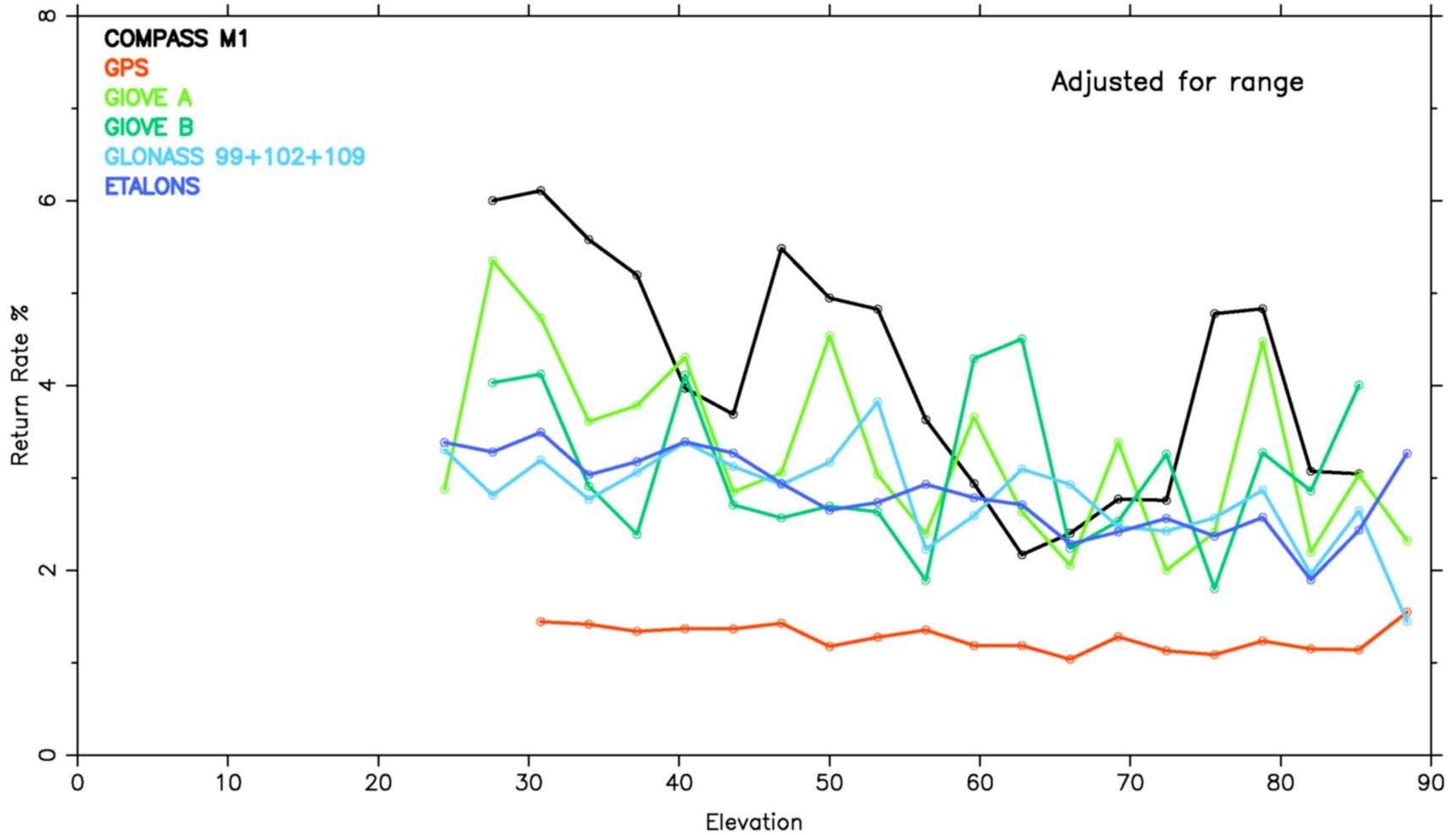
Average Return Rate vs Elevation for HEO satellites from Herstmonceux since 2007.00 at 24Hz



Relative signal strengths

Herstmonceux, UK

Average Return Rate vs Elevation for HEO satellites from Herstmonceux since 2007.00 at 24Hz



Relative signal strengths

Yarragadee, Australia

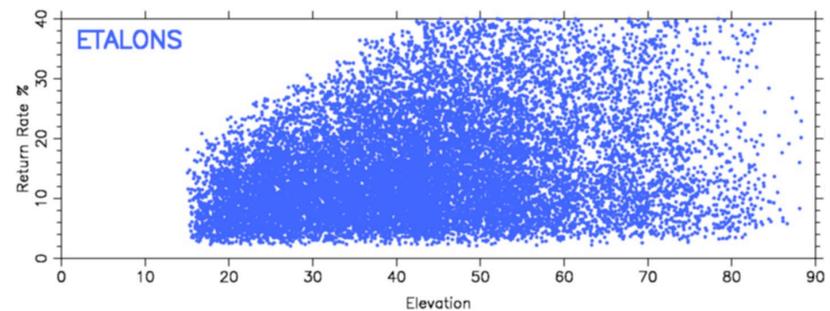
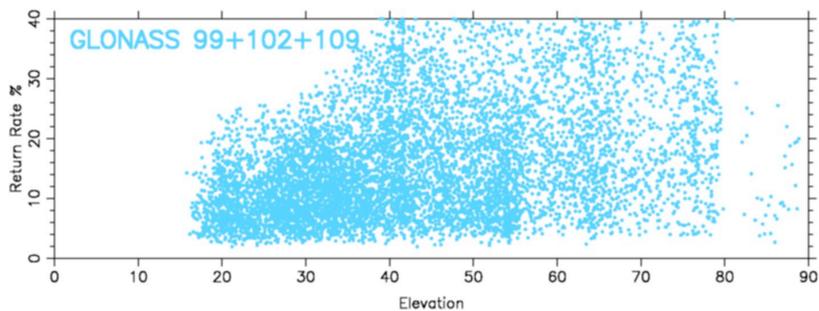
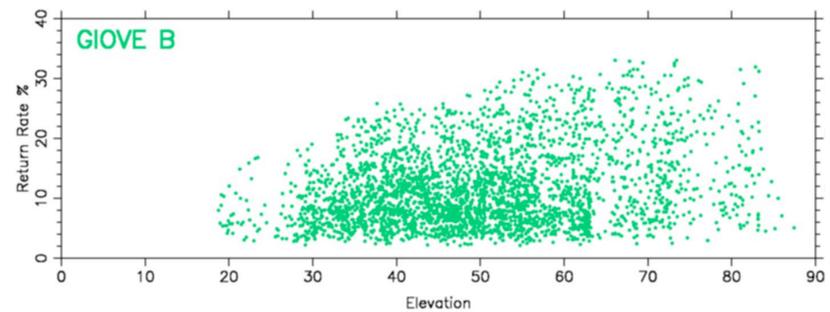
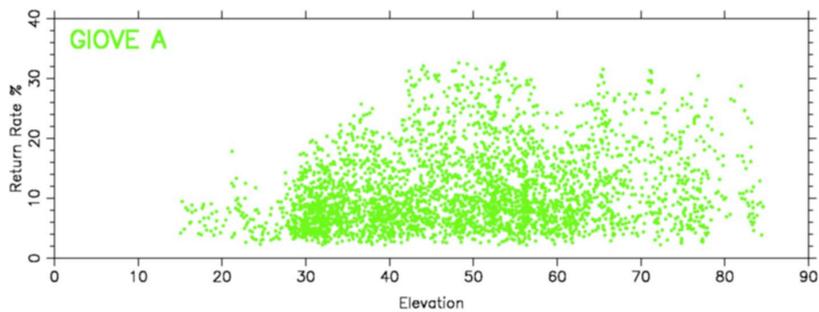
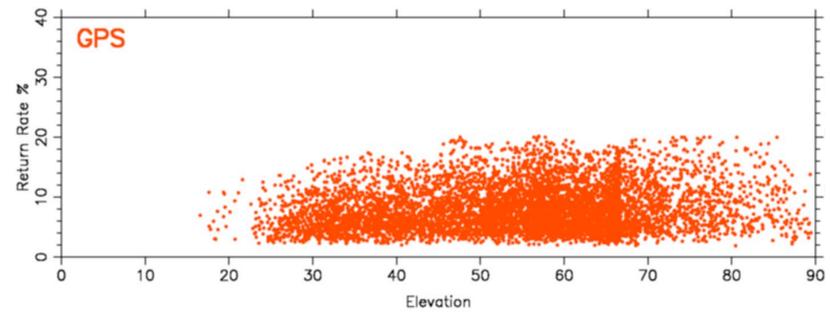
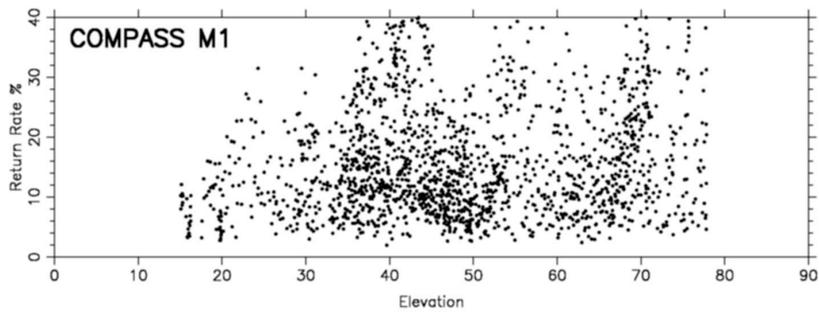
- Yaragadee is the most productive site in the ILRS network.
- In July 2009 a new MCP tube was installed using a voltage of 3000V and allowing daytime HEO observations. This data was not included in this analysis.
- The previous MCP used a voltage of 3600V which was increased to 3700V for most GPS passes and some other difficult GNSS passes.
- In this period no daytime observations of HEOs were made.
- The firing rate is 4Hz for HEO satellites.
- ND filters would only rarely be used.



Relative signal strengths

Yarragadee, Australia

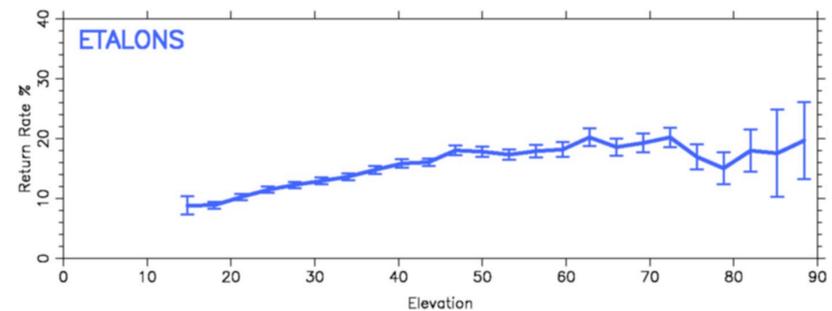
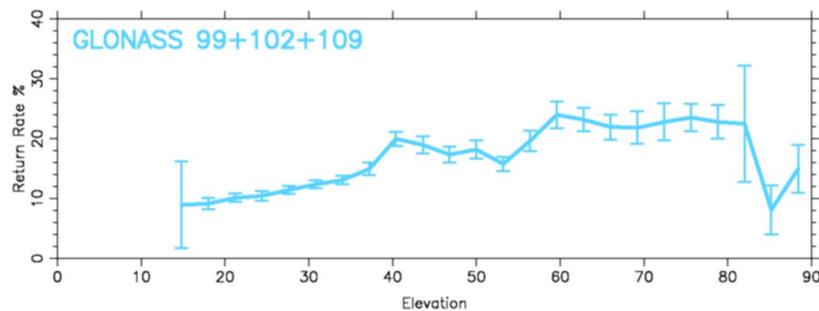
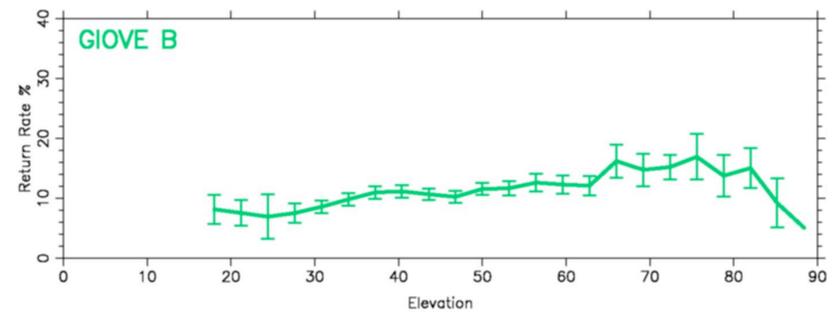
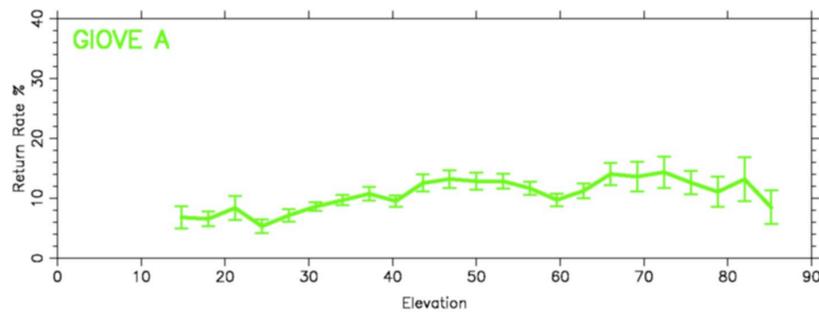
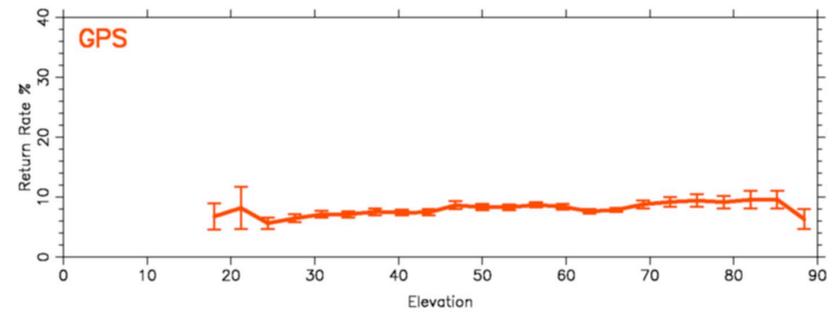
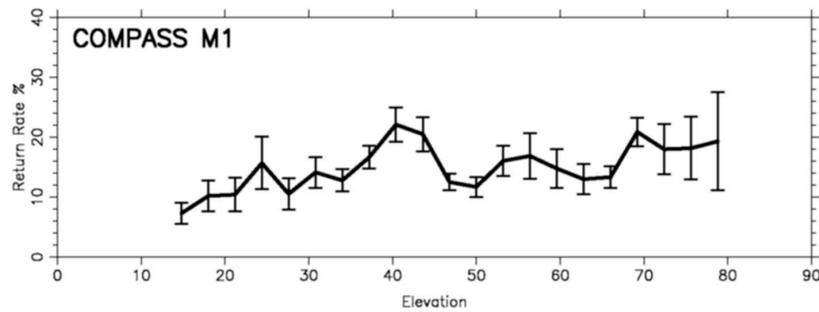
Return rates from the Yarragadee SLR station from 2007



Relative signal strengths

Yarragadee, Australia

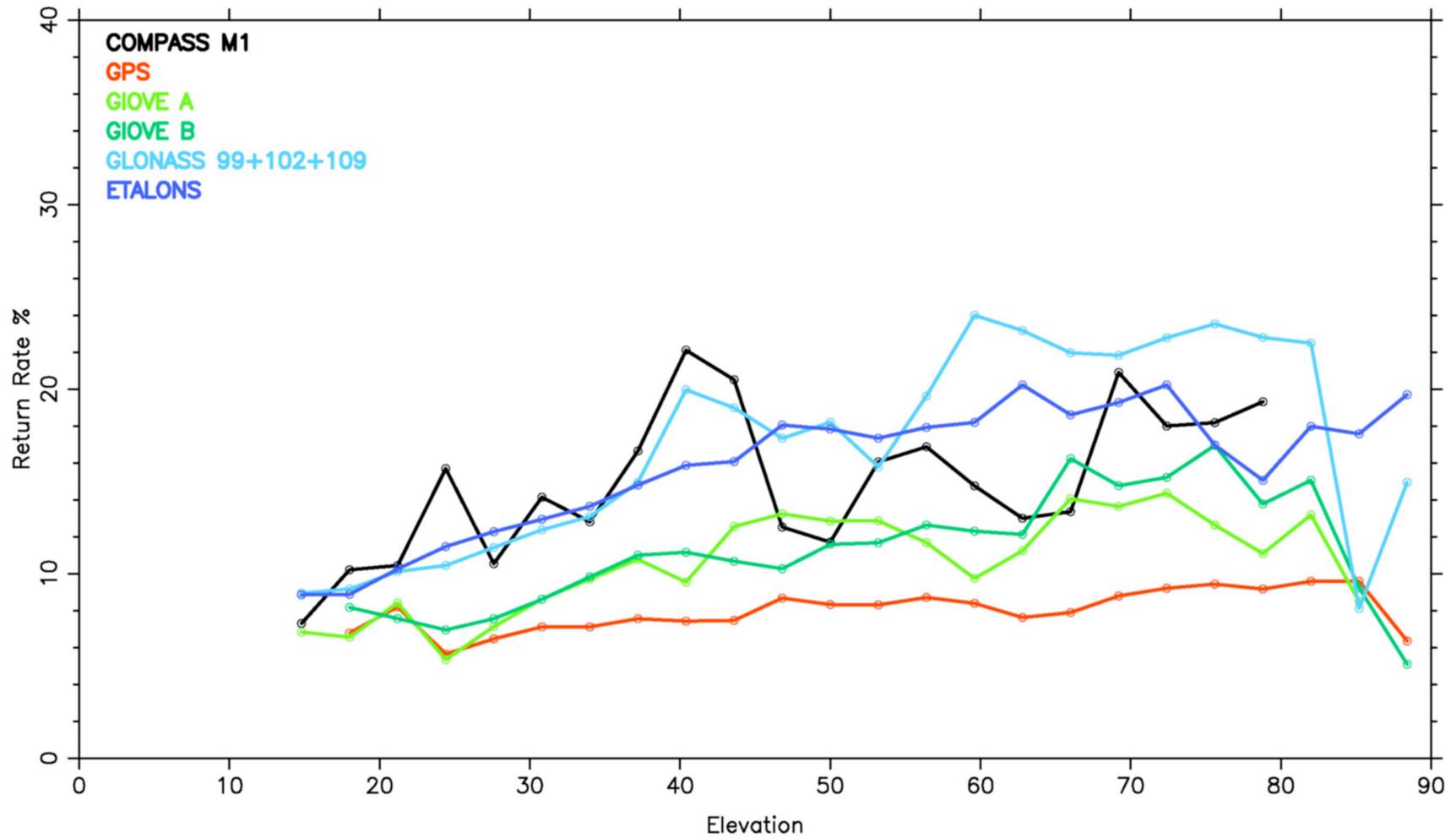
Return rates from the Yarragadee SLR station from 2007



Relative signal strengths

Yarragadee, Australia

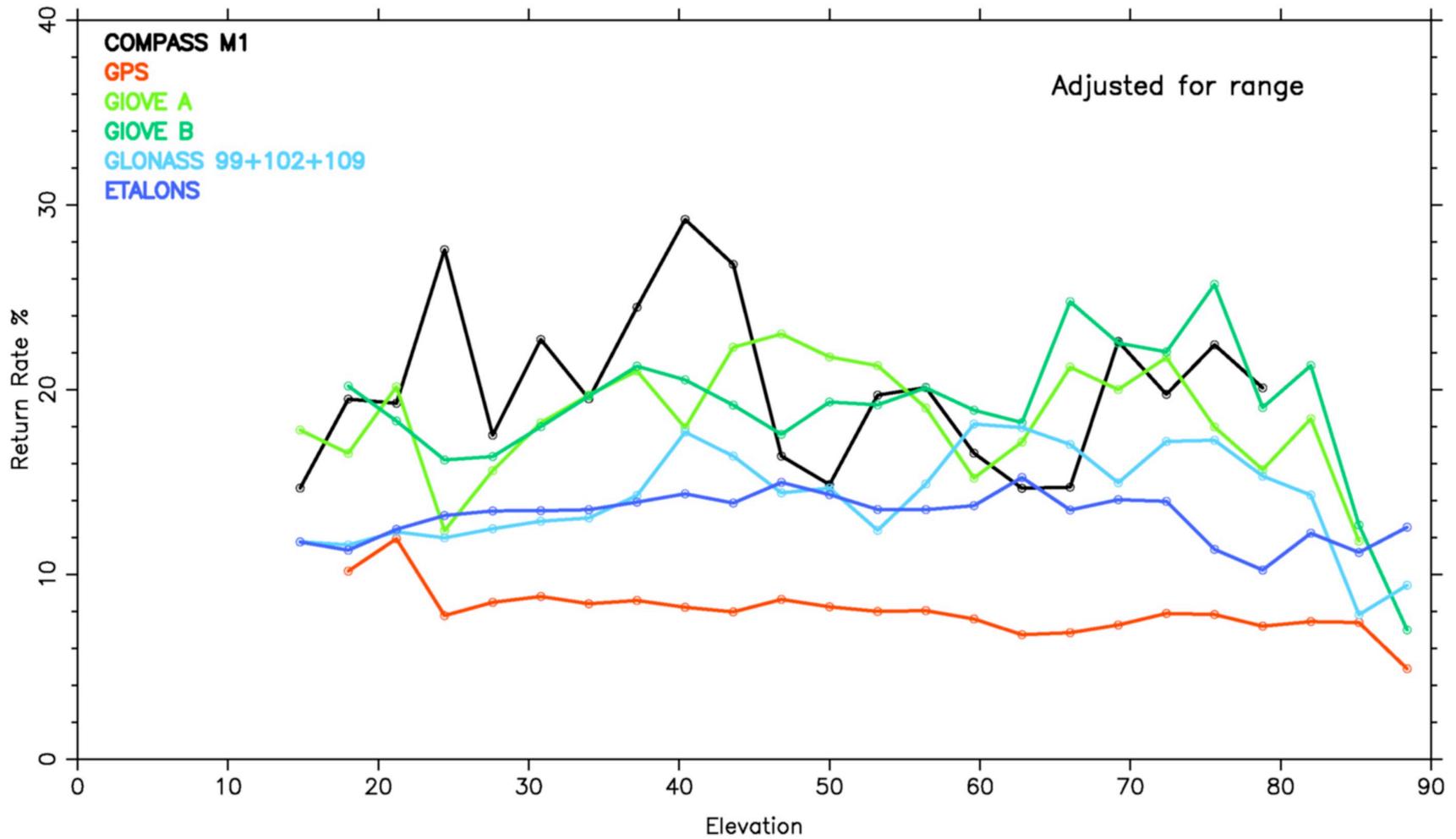
Average Return Rate vs Elevation for HEO satellites from Yarragadee since 2007.00 at 4Hz



Relative signal strengths

Yarragadee, Australia

Average Return Rate vs Elevation for HEO satellites from Yarragadee since 2007.00 at 4Hz



Relative signal strengths

- The retro-reflector targets have the following:

	No. cubes	Cube Diameter	Retro Target Area
CompassM1	42	3.3cm	359.2cm ²
Etalon 1 + 2	65.8 effectively ± 3.9 [#]	2.86cm*	422.7cm ²
GioveA	76	2.86cm*	488.2cm ²
GioveB	67	2.86cm*	430.4cm ²
Glonass99 + 102 + 109	112	2.86cm *	719.5cm ²
GPS35 + 36	32	2.86cm *	205.6cm ²

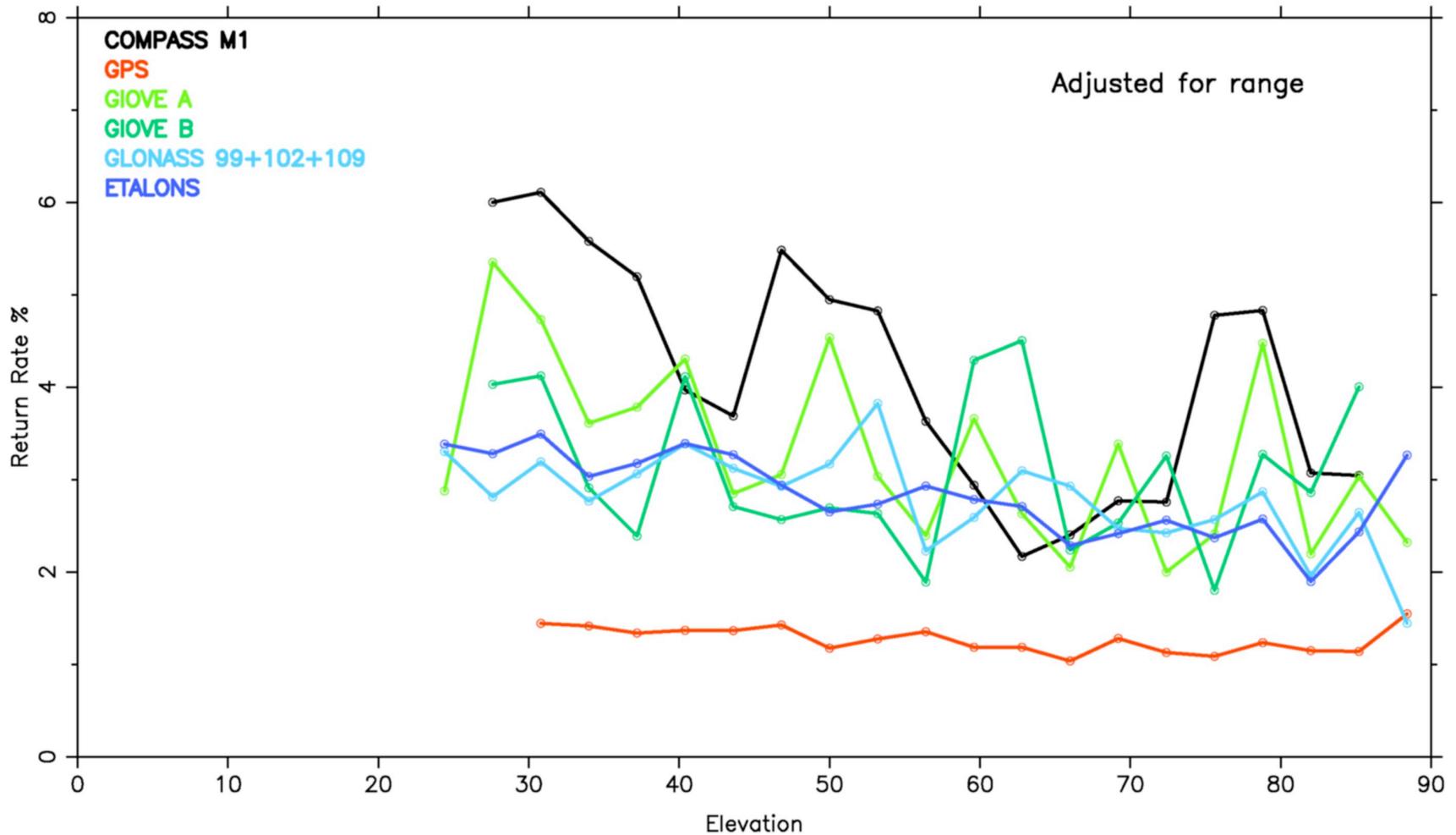
[#] Mironov et al "Etalon-1,-2 Center of Mass Correction and Array Reflectivity" 8th ILRS Workshop, Maryland, 1992

* Degnan, J.J., Pavlis, E.C., "Laser Ranging to GPS Satellites with Centimeter Accuracy", GPS World, Vol. 5, no. 9 Sept. 1994

Relative signal strengths

Herstmonceux, UK

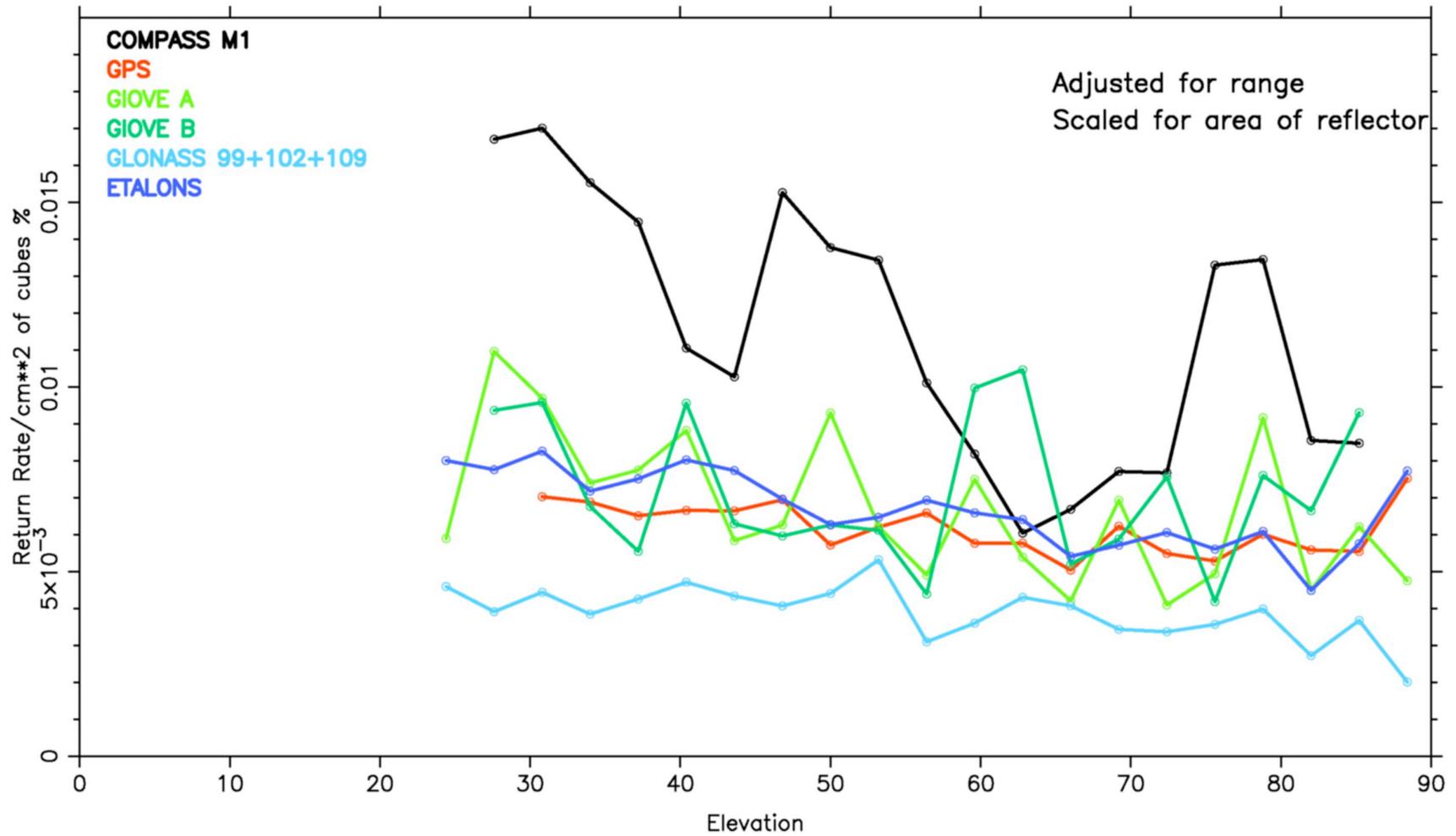
Average Return Rate vs Elevation for HEO satellites from Herstmonceux since 2007.00 at 24Hz



Relative signal strengths

Herstmonceux, UK

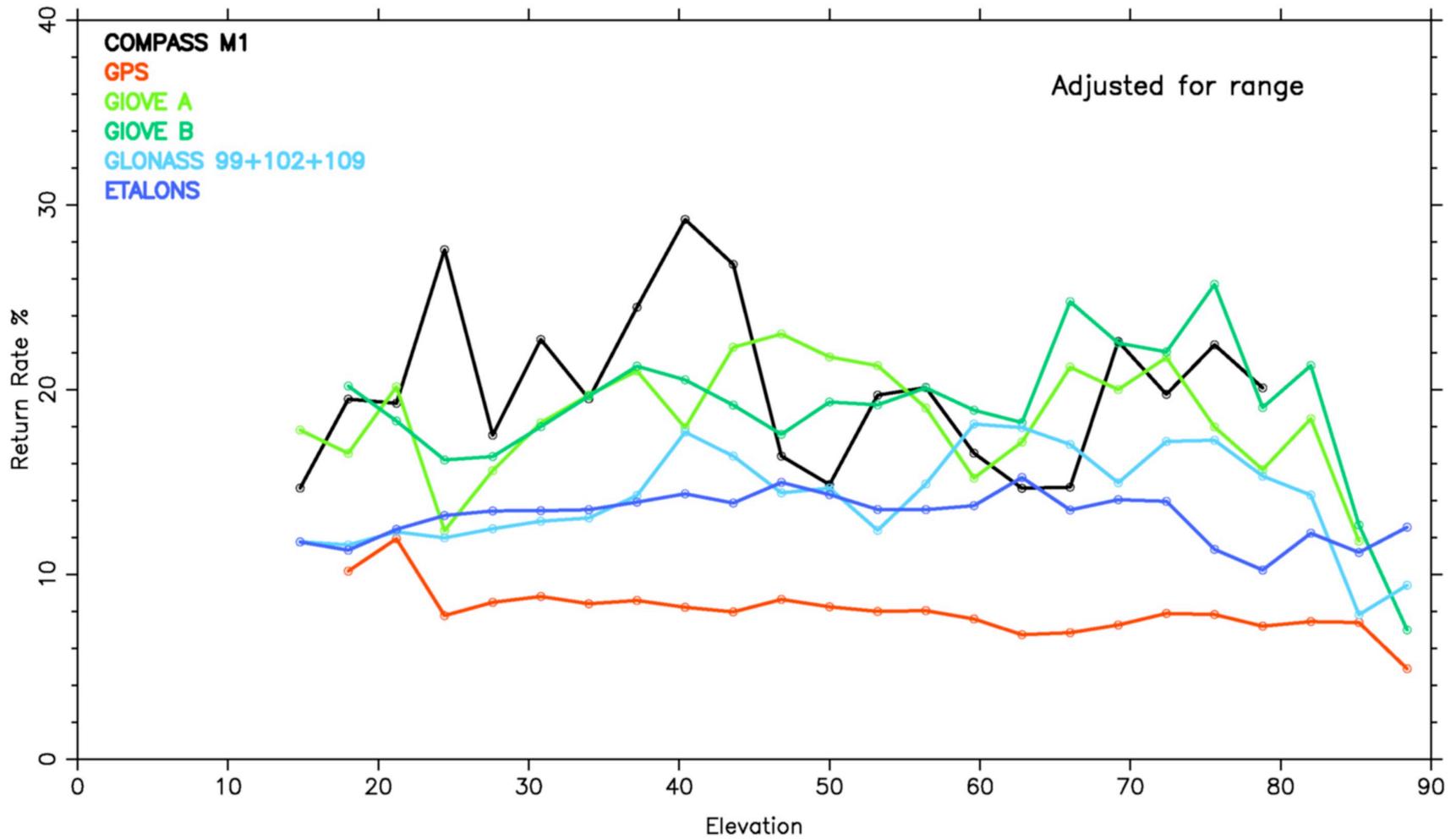
Average Return Rate vs Elevation for HEO satellites from Herstmonceux since 2007.00 at 24Hz



Relative signal strengths

Yarragadee, Australia

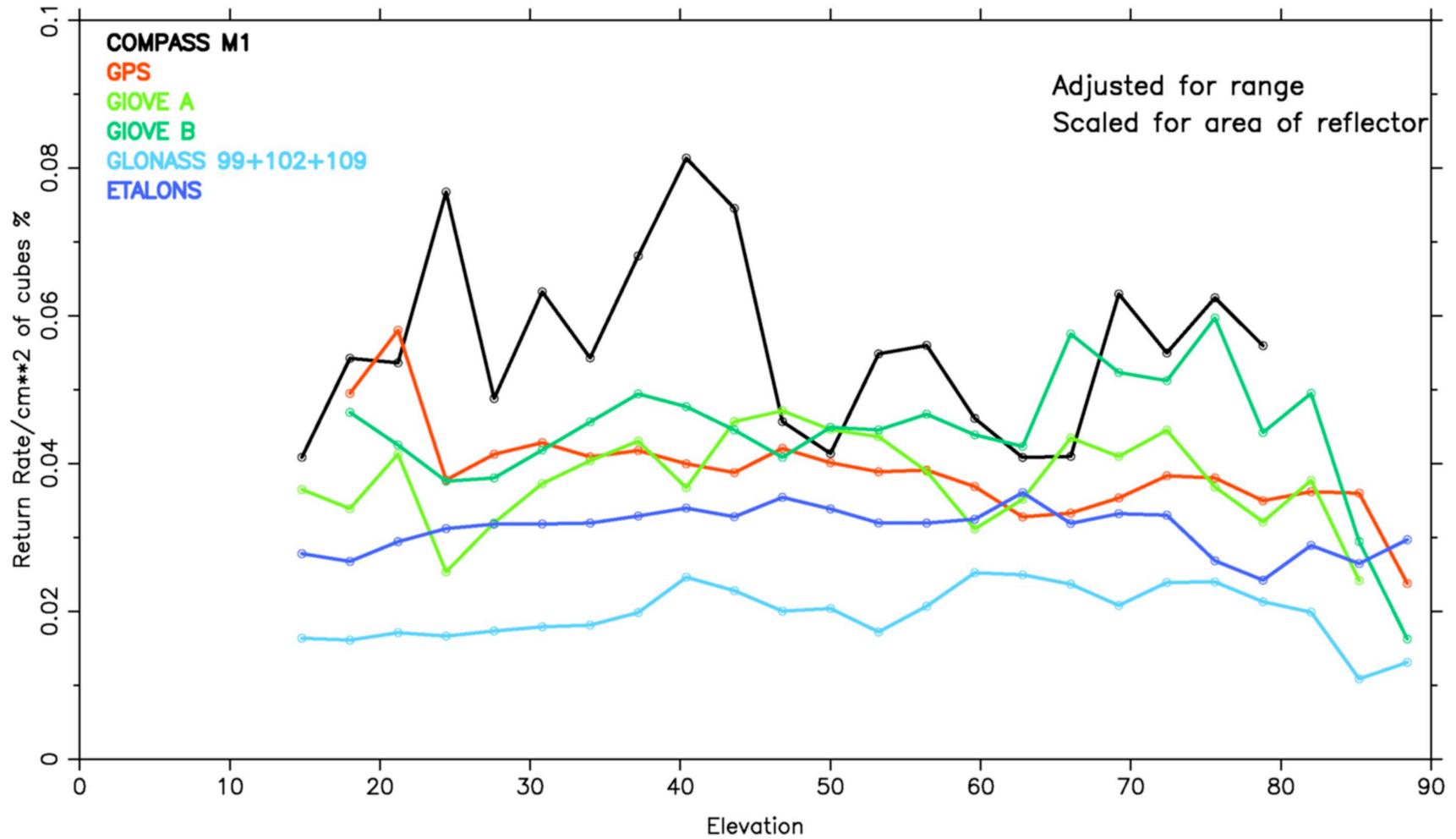
Average Return Rate vs Elevation for HEO satellites from Yarragadee since 2007.00 at 4Hz



Relative signal strengths

Yarragadee, Australia

Average Return Rate vs Elevation for HEO satellites from Yarragadee since 2007.00 at 4Hz



Relative signal strengths

- Estimate of return signal as a percentage of that from the CompassM1 target and per cm² of the targets

	Target Area cm ²	Herstmonceux %	Herstmonceux per cm ² %
Etalon 1 + 2	422.7	66.3 ± 12.5	56.4 ± 18.5
GioveA	435.1	78.7 ± 14.4	57.9 ± 14.4
GioveB	383.6	66.9 ± 17.7	55.9 ± 17.7
Glonass99 + 102 + 109	719.5	66.3 ± 12.8	33.1 ± 12.8
GPS35 + 36	205.6	28.7 ± 12.3	50.2 ± 12.3

Relative signal strengths

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GPS35 + 36	205.6	28.7 ± 12.3	50.2 ± 12.3

Relative signal strengths

- Estimate of return signal as a percentage of that from the CompassM1 target and per cm² of the targets

	Target Area cm ²	Yarragadee %	Yarragadee per cm ² %
Etalon 1 + 2	422.7	66.5 ± 5.4	56.3 ± 11.4
GioveA	435.1	93.8 ± 7.0	69.0 ± 7.0
GioveB	383.6	95.3 ± 7.1	79.6 ± 7.1
Glonass99 + 102 + 109	719.5	70.6 ± 6.0	35.2 ± 6.0
GPS35 + 36	205.6	37.4 ± 5.8	65.4 ± 5.8

Relative signal strengths

- Estimate of return signal as a percentage of that from the CompassM1 target and per cm² of the retro-reflector areas

	Target Area cm ²	Yarragadee %	Yarragadee per cm ² %
Etalon 1 + 2	422.7	66.5 ± 5.4	56.3 ± 11.4
GioveA	435.1	93.8 ± 7.0	69.0 ± 7.0
GioveB	383.6	95.3 ± 7.1	79.6 ± 7.1
Glonass99 + 102 + 109	719.5	70.6 ± 6.0	35.2 ± 6.0
GPS35 + 36	205.6	37.4 ± 5.8	65.4 ± 5.8

Relative signal strengths

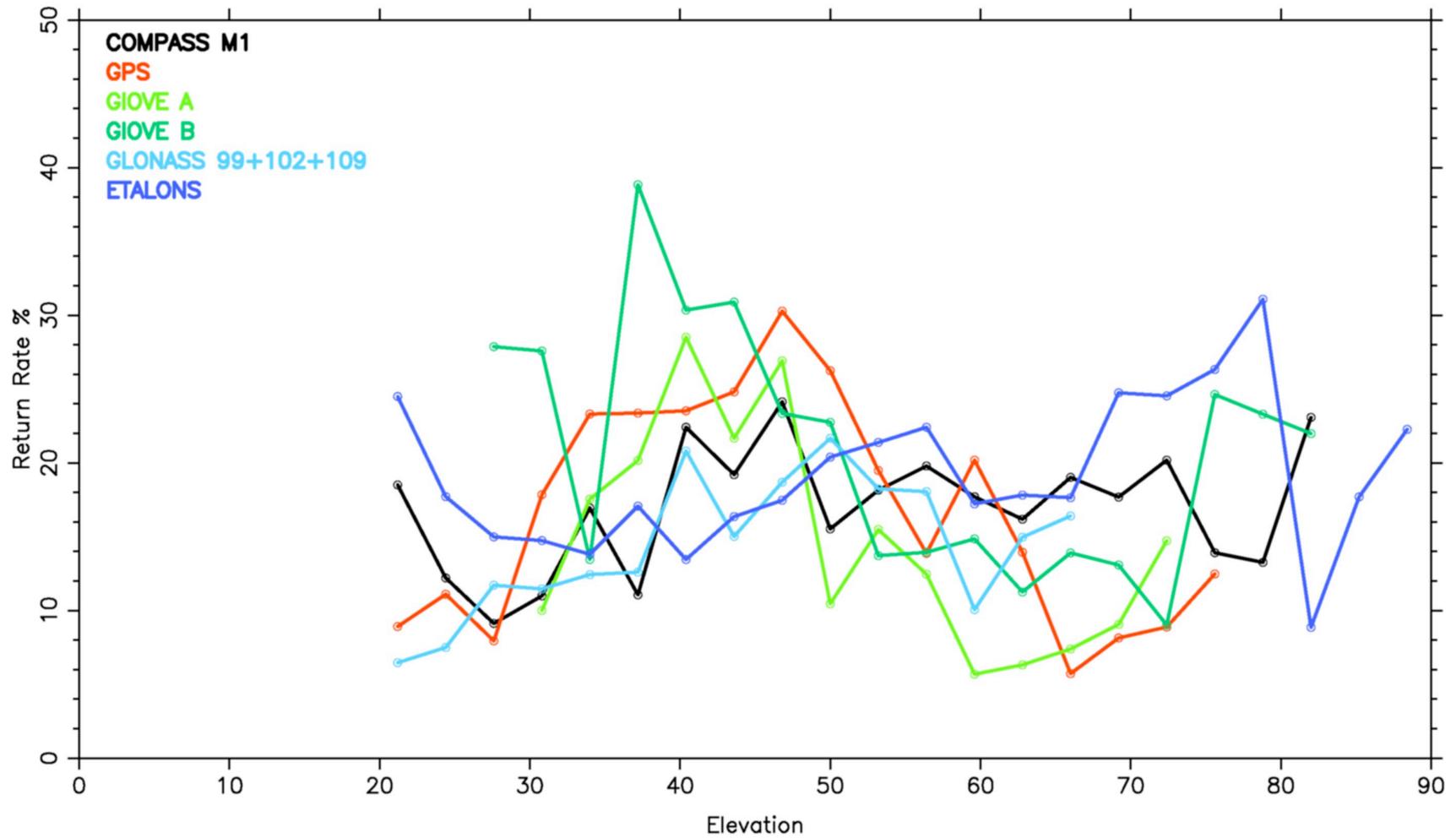
- Estimate of return signal as a percentage of that from the CompassM1 target and per cm² of the targets

	Target Area cm ²	Yarragadee %	Yarragadee per cm ² %
Etalon 1 + 2	422.7	66.5 ± 5.4	56.3 ± 11.4
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Glonass99 + 102 + 109	719.5	70.6 ± 6.0	35.2 ± 6.0
GPS35 + 36	205.6	37.4 ± 5.8	65.4 ± 5.8

Relative signal strengths

Monument Peak, USA

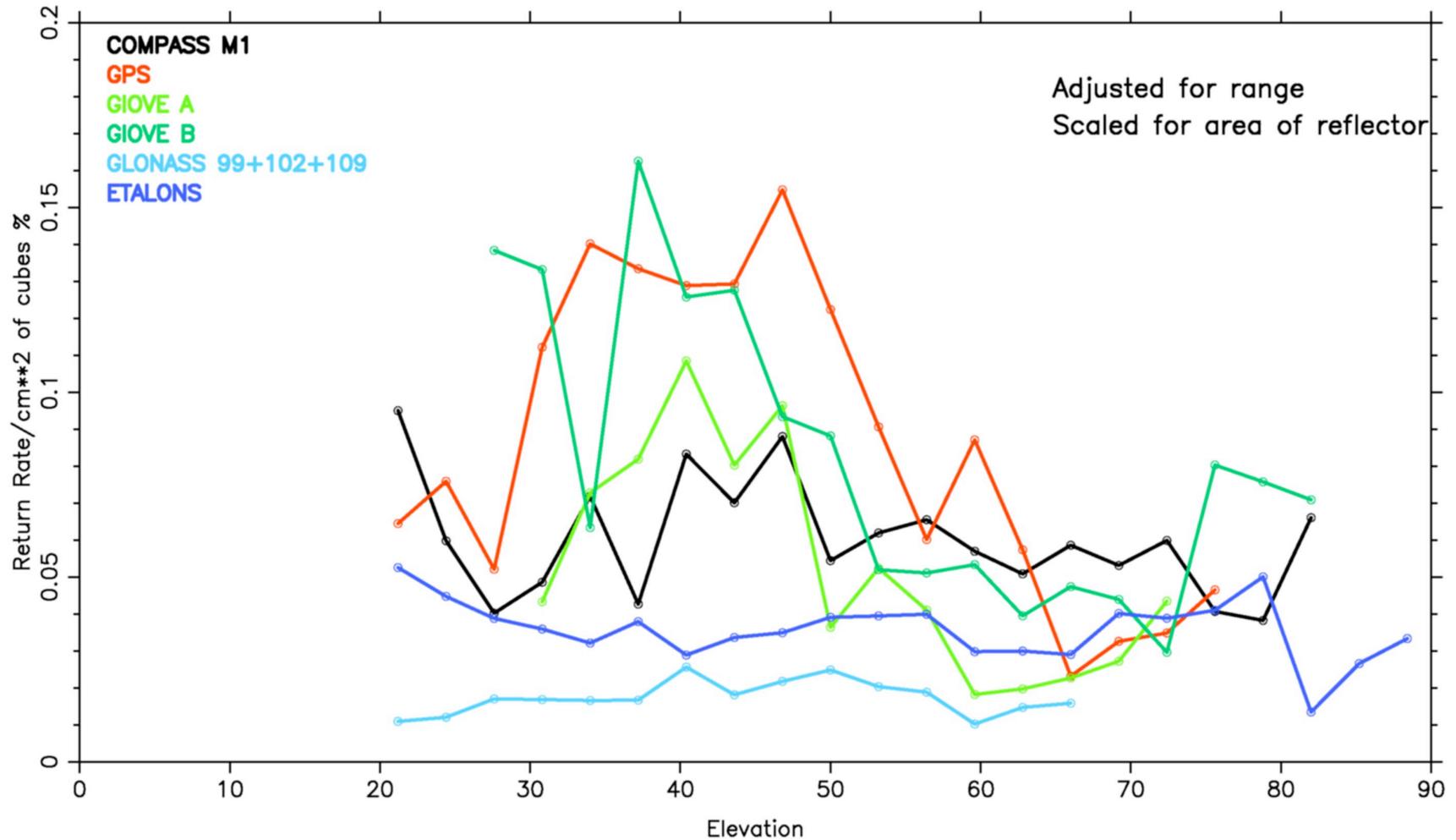
Average Return Rate vs Elevation for HEO satellites from Monument Peak since 2007.00 at 5Hz



Relative signal strengths

Monument Peak, USA

Average Return Rate vs Elevation for HEO satellites from Monument Peak since 2007.00 at 5Hz



Relative signal strengths

- Estimate of return signal as a percentage of that from the CompassM1 per cm² of the retro-reflector targets

	No. cubes	Herstmonceux per cm ² %	Yarragadee per cm ² %	Monument Peak per cm ² %	McDonald per cm ² %
Etalon 1 + 2	65.8	56.4 ± 18.5	56.3 ± 11.4	58.4 ± 15.7	56.5 ± 20.4
GioveA	76	57.9 ± 14.4	69.0 ± 7.0	98.7 ± 16.7	75.1 ± 16.5
GioveB	67	55.9 ± 17.7	79.6 ± 7.1	104.1 ± 15.9	86.2 ± 18.6
Glonass99 + 102 + 109	112	33.1 ± 12.8	35.2 ± 6.0	29.3 ± 12.8	31.9 ± 17.9
GPS35 + 36	32	50.2 ± 12.3	65.4 ± 5.8	171.7 ± 14.7	103.5 ± 17.5

Relative signal strengths

- Estimate of return signal as a percentage of that from the CompassM1 per cm² of the retro-reflector targets

	No. cubes	Herstmonceux per cm ² %	Yarragadee per cm ² %	Monument Peak per cm ² %	McDonald per cm ² %
Etalon 1 + 2	65.8	56.4 ± 18.5	56.3 ± 11.4	58.4 ± 15.7	56.5 ± 20.4
GioveA	76	57.9 ± 14.4	69.0 ± 7.0	98.7 ± 16.7	75.1 ± 16.5
GioveB	67	55.9 ± 17.7	79.6 ± 7.1	104.1 ± 15.9	86.2 ± 18.6
Glonass99 + 102 + 109	112	33.1 ± 12.8	35.2 ± 6.0	29.3 ± 12.8	31.9 ± 17.9
GPS35 + 36	32	50.2 ± 12.3	65.4 ± 5.8	171.7 ± 14.7	103.5 ± 17.5

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Conclusions

- Analysis of the full rate dataset confirms the experience of the SLR observer that the GPS is a more difficult target and the new CompassM1 satellite is more successful.
- The return signal from the CompassM1 target is approximately 1.5 times stronger than the Glonass, Etalon and GioveB targets and 3 times stronger than the GPS targets.
- The CompassM1 has the highest return rate per unit array area.
- The return signals from the Etalon, GPS and Giove satellites per cm^2 are approximately 50% of the CompassM1 signal.
- The Glonass satellite return signal per cm^2 is approximately 30%.

