MEERKAT EMAIL MANUAL

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APPROVAL

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CHANGE LOG

Reason for change	Issue Nr	Revision Number	Date
Added RMS and Discovery Station in Chapter 3. Added Station Selector Plot in Section 4.2.	2.0		19/05/2023
Added mailing list for mitigation activities	3.0		21/07/2023
Added mailing list for fireball activities	4.0		22/05/2024
New features from Meerkat 2.0: RMS std, Impact velocity, Impact flight path angle, Earth's shadow entry time, computation time in Dashboard plot	5.0		03/10/2025

CHANGE RECORD

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DISTRIBUTION

Name/Organisational Unit

Table of Contents

1. INTRODUCTION

This document explains the content of the emails sent by the Meerkat Asteroid Guard software. The second chapter describes the list of emails that can be received. The third chapter discusses the information reported in the email. The fourth chapter explains Meerkat plots. The emails are automatically sent to the users subscribed to the Meerkat mailing list.

2. MEERKAT EMAILS LIST

Meerkat system provides three different mailing lists. The first one is meant for observers. It has lower thresholds, and it includes close approaches results. The second mailing list is tailored specifically for individuals interested in mitigation activities. Thus, emails are only sent if a notable object with a higher impact score has been found by Meerkat. The third mailing list is tailored for individuals interested in fireball detection activities. In this case, emails are sent for all the objects found by Meerkat with a very high impact score.
All the emails contain the same plots and the same data.

2.1. Observers mailing list

These emails are sent checking impact score and close approach distance thresholds. Automatic emails sent by the Meerkat system are identified with type tags, including:

- [New]: new object with impact score larger than 0.01 (IP in email subject).
- [New]: new object with the close approach distance to the geocenter less than 7 Earth radii (DCA in email subject). This close approach distance is the weighted mean of the possible distance of closest approach.
- [Upd]: updates for object with impact score larger than 0.01 (IP in email subject).
- [Upd]: updates for object with close approach distance to the geocenter less than 7 Earth radii (DCA in email subject).
- [Rmv]: object removed from NEOCP list. This email is sent only if a previous email was already sent for the reported object.
- [Clr]: clear email for an object that dropped below notification limit, thus with an impact score less than 0.01 or close approach distance larger than 7 Earth radii. This email is sent only if a previous email was already sent for the reported object.

2.2. Mitigation mailing list

These emails are sent checking impact score and Impactor Size (diameter of the asteroid considering only impacting solutions) thresholds. Automatic emails sent by the Meerkat system are identified with type tags, including:

- [New]: new object with impact score larger than 0.1 (IP in email subject) and Impactor Size larger than 5 meters.
- [Upd]: updates for object with impact score larger than 0.1 (IP in email subject) and Impactor Size larger than 5 meters.
- [Rmv]: object removed from NEOCP list. This email is sent only if a previous email was already sent for the reported object.
- [Clr]: clear email for an object that dropped below notification limit, thus with an impact score less than 0.1 or Impactor Size less than 5 meters. This email is sent only if a previous email was already sent for the reported object.

2.3. Fireball mailing list

These emails are sent checking impact score threshold. Automatic emails sent by the Meerkat system are identified with type tags, including:

- [New]: new object with impact score larger than 0.9 (IP in email subject).
- [Upd]: updates for object with impact score larger than 0.9 (IP in email subject).
- [Rmv]: object removed from NEOCP list. This email is sent only if a previous email was already sent for the reported object.
- [Clr]: clear email for an object that dropped below notification limit, thus with an impact score less than 0.9. This email is sent only if a previous email was already sent for the reported object.

3. MEERKAT EMAILS DATA

Meerkat emails contain the following information:

Email subject

In the subject of [Upd] and [New] emails, some scores are reported.

For impacting cases: IP, GEO, H_imp.

For close approach cases: DCA, GEO, H_NEO

Attribute	Description	Unit
IP	See Imp in Scores table.	-
GEO	See GEO in Scores table.	-
DCA	See DCA in Scores table.	Earth radii
H_imp	See “Weighted mean H” in Impact Data table.	mag
H_NEO	Weighted mean absolute magnitude of all NEO solutions.	mag

Scores

Most important object scores.

In [Clr] emails, two “Scores” sections are reported: “Scores new” with the results of the last computation and “Scores old” with the results of the previous computation.

In [Rmv] emails, only the “Scores old” section is reported, containing the results of the last computation.

Attribute	Description	Unit
Imp	Earth impact score, considering both heliocentric and geocentric impactors $Imp \in [0;1]$	-
GEOImp	Earth impact score, considering only geocentric impactors $GEOImp \in [0;Imp]$	-
NEO	Near-Earth object score $NEO \in [0;1]$	-
GEO	Geocentric object score $GEO \in [0;1]$	-

DCA	Weighted mean of distance of closest approach to geocenter. This value is reported only for close approach cases.	Earth radii
TCA	Weighted mean of time of closest approach. This value is reported only for close approach cases.	UTC
RMS min	Minimum of weighted Root Mean Square error of topocentric range–range rate grid.	-
RMS std	Standard deviation of the weighted Root Mean Square error of the topocentric range–range rate grid. This metric is used to measure the flatness of the grid fitting contours. If the value is high, it indicates that the systematic ranging has likely found a good solution. If the value is low, the grid shows little variation, suggesting that no good solution exists. This could lead to a false positive with a high impact score.	-

Impact data This section is reported only for objects with impact score above the threshold.		
95% early TImp	Earliest impact date and time of the impacting 95% confidence region. NOT the general earliest possible impact date and time!	UTC
95% late TImp	Latest impact date and time of the impacting 95% confidence region. NOT the general latest possible impact date and time!	UTC
Weighted mean TImp	Weighted mean impact date and time of all impacting solutions.	UTC
95% large H	Largest absolute magnitude of the impacting 95% confidence region. NOT the general largest possible magnitude!	mag
95% low H	Lowest absolute magnitude of the impacting 95% confidence region. NOT the general lowest possible magnitude!	mag

Weighted mean H	Weighted mean absolute magnitude of all impacting solutions.	mag
95% low d	Lowest object diameter of the impacting 95% confidence region. NOT the general smallest possible diameter!	m
95% large d	Largest object diameter of the impacting 95% confidence region. NOT the general biggest possible diameter!	m
Weighted mean d	Weighted mean object diameter of all impacting solutions.	m
Min imp vel	Minimum impact velocity computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found.	km/s
Max imp vel	Maximum impact velocity computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found.	km/s
Median imp vel	Median impact velocity computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found.	km/s
Min imp FPA	Minimum impact flight path angle computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found. FPA $\in$ [-90;+90]	deg
Max imp FPA	Maximum impact flight path angle computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found. FPA $\in$ [-90;+90]	deg
Median imp FPA	Median impact flight path angle computed from all impacting Monte Carlo samples. Computed if Imp > 0.6. Defaults to nan if solution not found. FPA $\in$ [-90;+90]	deg

Observations Observational data. In [Clr] emails, only “Observations new” section is reported, with the results of the current computation. In [Rmv] emails, only “Observations old” section is reported, with the results of the last computation.		
NObs	Number of observations.	-
ObsArc	Observation arc.	hours
LastRA	Last observed right ascension in tracklet file.	deg
LastDec	Last observed declination in tracklet file.	deg
LastV	Last observed apparent magnitude in tracklet file.	mag
Discovery station	Discovery station code	-
TShadow early	Time entering the Earth’s shadow umbra for the earliest impacting Monte Carlo sample (UTC ISOT). Computed if Imp > 0.6. Defaults to nan if solution not found.	UTC
TShadow median	Time entering the Earth’s shadow umbra for the median impacting Monte Carlo sample (UTC ISOT). Computed if Imp > 0.6. Defaults to nan if solution not found.	UTC
TShadow late	Time entering the Earth’s shadow umbra for the latest impacting Monte Carlo sample (UTC ISOT). Computed if Imp > 0.6. Defaults to nan if solution not found.	UTC

Current (median) data Object data referred to the reported epoch. This epoch is rounded at the closest XX:30 (hh:mm) time. This section is not reported for [Clr] and [Rmv] emails.		
Epoch	Current ephemeris	UTC
RA	Current median right ascension	deg
Dec	Current median declination	deg
Unc	Current 1-sigma plane-of-sky position uncertainty	arcmin
Rate	Current plane-of-sky rate of motion	arcsec/min
V	Current visual magnitude	mag

4. MEERKAT EMAIL PLOTS

4.1. Score Dashboard Plot

The top row of the dashboard shows information about Earth impacting solutions, the middle row focuses on near-Earth object solutions and the bottom row on properties from non-NEO object classes.

The top left ring shows the impact score as a thick ring. Red marks heliocentric impactors (most likely NEOs), while dark grey indicates the fraction of geocentric impactors (most likely artificial satellites) and light grey non-impacting solutions. The inner, small ring only considers impacting solutions, in order to provide better differentiation of heliocentric and geocentric impactors. The impact score, displayed within the circle, combines heliocentric and geocentric impact solutions.

The top centre plot shows the impact scores as a function of the impact time, in bins of 2 hours and over a timespan of 48 hours. The epoch below the plot indicates the zero point, which is always the latest observation of the object. If the current computation time is within the 48 hour window, it is marked on the plot in blue.

The top right ring presents the estimated size distribution of the objects, only considering impacting solutions. The value in the ring is the weighted mean diameter for impactors.

The middle left ring characterises how the NEO solutions are split into standard NEO classes (Interior-Earth object, Apollo, Aten and Amor). The value written inside the ring is the Interior-Earth object score.

The middle right ring presents again the size distribution of the object, only considering NEO solutions (geocentric solutions are not considered here). The value in the ring is the weighted mean diameter for NEOs.

The lower left ring visualizes how the different orbital solutions are distributed among all Asteroid classes. The value in the ring is the NEO score.

The lower centre ring presents the distribution into Comet classes, as defined by Levison. The value in the ring is the ISO score, a rough indicator of the possible interstellar nature of the object.

The lower right ring visualizes the diameter of the size distribution of the object, considering the full grid (with geocentric solutions). The value in the ring is the weighted mean diameter.

4.2. Station Selector Plot

The plot shows the detection probability as contour lines, depending on the epoch and the field of view (FoV). The detection probability values are not station-specific but geocentric. The abscissa axis can be found on the bottom of the plot showing the time after the computation. Another abscissa axis can be found on top the plot showing the time in UTC. An additional vertical dashed line gives the epoch of computation.
The small panel at the bottom shows the cumulative impact score as background colour and the impact score per hour as graph.

4.3. Systematic Ranging Plot

The plot shows the topocentric range – topocentric range rate grid, used to determine the various scores for the objects. The left panel displays the weighted astrometric root-mean square error as a contour plot. The right panel displays the absolute magnitude as a contour plot. The outer blue area at top, right and bottom marks interstellar solutions, which are excluded from the computation. The blue area on the left, aligned with the 0 km/s mark, indicates geocentric solutions. The red region marks Earth impacting solutions, while yellow is occasionally used for Sun impacting solutions and orange for Moon impacting ones. The green area indicates the 95% confidence region, following the posterior probability density, determined by the SR software.

4.4. Sample Scatter Plot

The upper left panel shows the geocentric semi-major axis and eccentricity. The background shows the artificial satellite density for each hexagon, useful to immediately identify if a geocentric solution corresponds to a region that is populated with many artificial objects. The coloured crosses indicate the location where some typical orbital classes of artificial objects concentrate in this space. The light grey area marks the region of where objects orbiting in the vicinity of the Sun-Earth Lagrange point 2 objects are expected to fall. The dark grey dots are the samples produced by the SR software following the posterior probability distribution.

The upper right panel shows a similar plot with respect to the geocentric semi-major axis and inclination. It is following the same colour conventions of the upper left panel.
The lower left panel shows the heliocentric semi-major axis and eccentricity. In this case, the background shows the various asteroid type regions. The black line indicates the threshold defining near-Earth objects. The samples are plotted in the respective asteroid type colours.
The lower right panel shows the heliocentric semi-major axis and inclination. The squares show the approximate location of the Hungaria and Phocaea groups. The samples are again plotted in the respective asteroid type colours.

4.5. Impact Plot

The plot shows the impact position of each sample on Earth. The colour indicates the impact time. The red triangle represents the discovery station.