

Minor Planet Center: data processing challenges

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Abstract. The Minor Planet Center receives up to several million astrometric observations of minor planets and comets each month. Given the volume of observations, the sheer number of known objects against which to possibly match, the shortness of the time interval over which each object was likely observed, and the uncertainties in the positions, and occasionally possible errors in times, reported, a number of data processing challenges present themselves. These include: Identifying observations of objects reported as new with already known objects; linking together sets of observations from different nights which may belong to the same object; determining if a set of observations has been assigned to the wrong object; determining if an object with a very short arc is possibly a Near-Earth object; prioritizing newly discovered objects in order of need of follow up; and, efficiently matching one or more observations with known objects.

Keywords. Minor planets, asteroids, comets: general, surveys, astrometry, ephemerides

1. Introduction

The Minor Planet Center (MPC), is the single worldwide location for receipt and distribution of positional measurements (astrometry) of minor planets, comets and outer irregular natural satellites of the major planets. The MPC is responsible for the identification, designation and orbit computation for all of these objects. This involves maintaining the master files of observations and orbits, assigning the discovery credit of each object, and announcing discoveries via electronic circulars and an extensive website/database (<http://minorplanetcenter.net>). The MPC operates at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts USA, under the auspices of Division F of the International Astronomical Union.

As of September 2015, the MPC database includes approximately 133 million astrometric observations, 700,000 minor planet orbits, and 7500 comet orbits (at multiple apparitions) for 3800 comets. Additionally, a separate table of 10 million undesignated single-night observations is maintained. Both web form and web service interfaces exist to allow users to query the database.

Up to several million astrometric observations are received each month via the internet. They are validated, then processed in near real time. The observations come in batches whose formats are checked and whose observations are run through a number of other routine checks such as departure from great circle motion, prior publication, single observations, near duplicates, etc. Some or all of a batch of observations may be returned to its sender if they fail one or more of the checks. After the observations have been validated, they are processed to produce orbits of newly discovered objects or used to update the orbits of known objects.

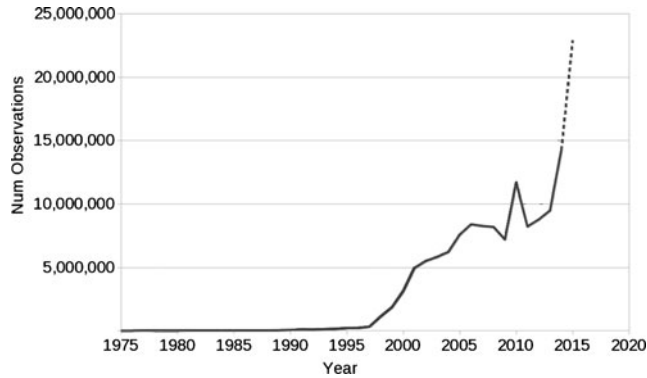


Figure 1. Observations received per year, during the period 1975 to 2015.

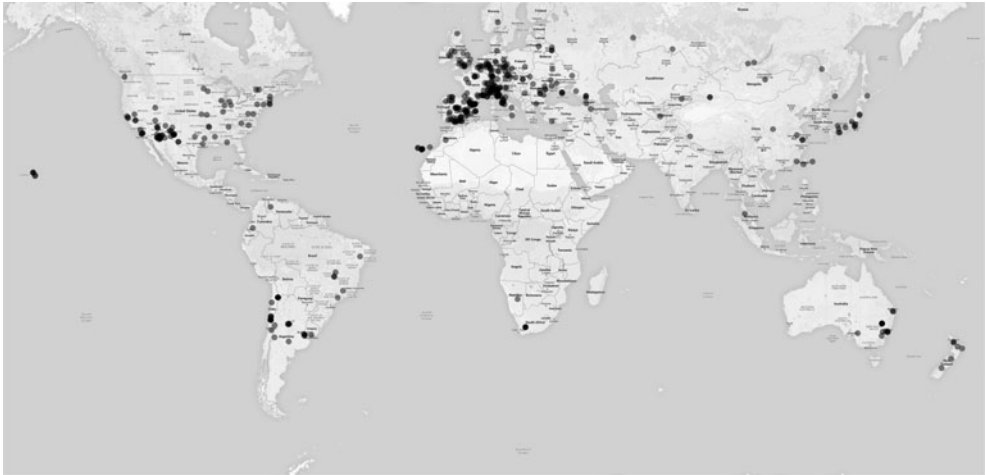


Figure 2. Locations of observatories (black dots) that contribute astrometry to the MPC. Note dearth of observatories in Central and Western Asia, as well as the Southern Hemisphere.

The number of observations received by the MPC has been increasing rapidly of late (Fig. 1), and is expected to increase several fold times when additional sky surveys such as ATLAS (Tonry 2011) and LSST (Tyson 2002) come online. Processing, and performing the necessary bookkeeping on, such a vast quantity of incoming data will in itself become an interesting challenge.

2. Observation Coordination

Astrometry for minor planets and comets is received from observatories distributed around the globe (Fig. 2). Also, there have been space-based satellite missions, such as NEOWISE (Mainzer *et al.* 2011), which have made significant contributions of astrometry of both new and known minor planets and comets.

Some observatories undertake systematic survey programs to search for new objects, while others specialize in performing equally important follow up observations of newly discovered and previously known objects.

Considering how briefly a time span over which some objects might be observable, it is desirable to cover the entire observable sky to a reasonably faint magnitude in as short a period of time as possible. However, there are not presently sufficient resources

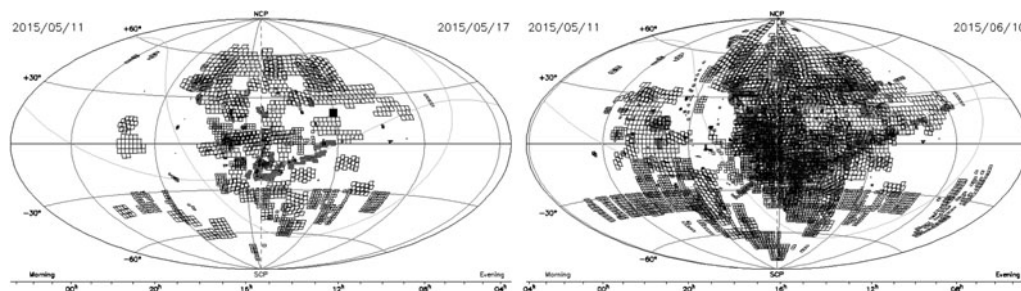


Figure 3. Sky coverage during one week (left), and one month (right) in May-June 2015.

to do so. This then raises the issue of coordination among surveys in order to increase sky coverage, as well as among follow up programs to reduce redundancy.

As a rule of thumb, most sufficiently bright objects would likely be detected if the entire sky were scanned within the course of a week. Figure 3 (left) is typical of the coverage currently being accomplished in one week's time. Even after an entire lunation, gaps in coverage frequently remain (Fig. 3 right). Sky coverage maps are available at the MPC sky coverage web page: <http://minorplanetcenter.net/iau/SkyCoverage.html>

The issue of observation coordination – taking into account factors such as observatory locations, weather conditions, telescope/detector capabilities, desired coverage, galactic plane confusion, and optimal cadence – could certainly stand some close examination, perhaps applying relevant insights gleaned from the field of operations research.

3. Near Earth Object Discovery and Confirmation

Of particular interest of late are the so called “Near-Earth Objects” (NEOs), whose orbits bring them near the vicinity of the Earth. The MPC has a web page – the NEO Confirmation Page (NEOCP) at http://www.minorplanetcenter.net/iau/NEO/toconfirm_tabular.html – whose purpose is to present observations, nominal and possible variant orbits, and ephemerides of newly discovered objects which might be NEOs. In most cases the initial observations tend to cover too short an arc to definitively determine whether or not the object is in fact a NEO.

Observations of an object are processed by a program – *digest2* (Keys 2011) – which attempts to determine the likelihood that the object is a NEO. If a certain threshold is exceeded, the object is placed on the NEOCP, and its likelihood value is converted into its initial desirability score. Information is updated whenever additional observations are received. Furthermore, the desirability score is adjusted in order to provide guidance as to the need for any further observations of the object in the immediate future.

Follow up observation resources are limited, so it is important to try and avoid the occurrences of false positive as well as true negative initial possible NEO determinations. False positive cases are those where an object is initially thought to be a NEO, is placed on the NEOCP, but subsequent observations reveal that the object has a non-NEO orbit. True negative cases are those where an object is initially thought to be a non-NEO and therefore does not appear on the NEOCP, but incidental follow up observations in fact reveal it to be a NEO. In the first case, resources could have been better used targeting other objects; and in the second case, some objects that deserved immediate follow up were ignored due to their absence from the NEOCP. Thus, tweaking the determination of what does or does not appear on the NEOCP is important. Also, the algorithm for adjusting the desirability score is rather simplistic and could stand refinement.

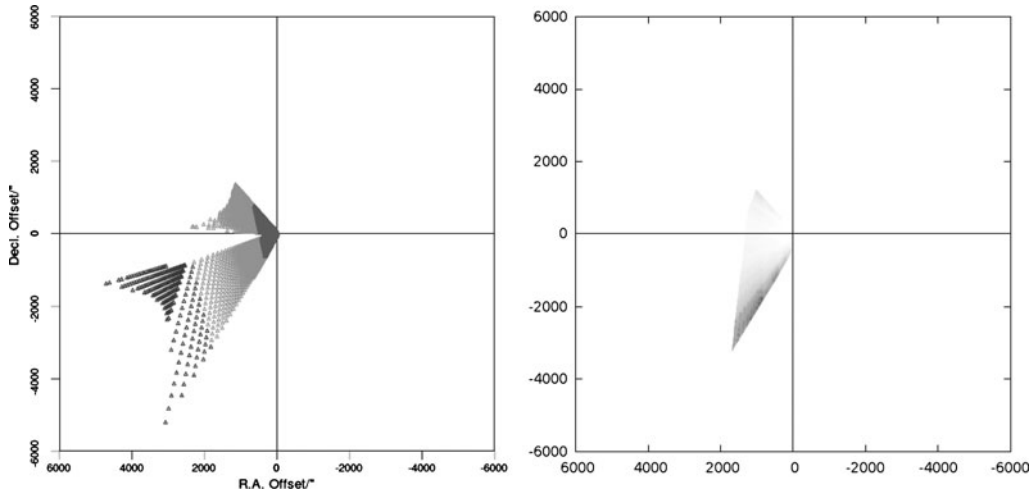


Figure 4. An uncertainty map showing the variant orbit offsets (left), and expected offsets based on a hypothetical solar system model (right).

After an object is observed over an arc sufficient to determine a preliminary orbit, it is assigned a provisional designation, removed from the NEOCP; and the observations, orbit and an ephemeris are communicated to subscribers via Minor Planet Electronic Circulars (MPECs).

Another point of interest regarding follow up observations regards the practical issues which arise when follow up attempts result in non-detections. How should non-detections be communicated: field corners and magnitude limit, perhaps? Should variant orbits corresponding to the non-detection ephemeris positions be eliminated? Observations of a newly discovered object on a subsequent night or two are usually sufficient to determine a rough preliminary orbit that is hopefully accurate enough to allow the object to be locatable in the near term and thence lead to further refinements in the computed orbital elements. What should be done, however, in cases where objects which were thought to have been seen during the first couple of nights do not appear to be where they were expected to be some time later?

4. Uncertainty Maps

For observations of possible NEOs which cover a very short arc – typically less than a day – site specific maps can be generated which plot the offsets in position of variant orbits from a nominally chosen orbit. The variant orbits are computed using distance-velocity systematic ranging. Due to the short arc and uncertainty in the astrometric measurement reductions, without further follow up observations, it is difficult to determine which of the variant orbits, if any, is correct.

As time passes, the uncertainty in the expected position of such an object may tend to grow considerably. Consequently, in order to give observers the best chance of locating the object in the hours and days following the submission of initial astrometry, it is desirable to consider ways in which the uncertainty maps could be improved upon.

One idea currently under development at the MPC is to apply a hypothetical model of the solar system (e.g. Grav, *et al.* 2007) to the variant orbits. The resultant map weights the variant orbits according to the expected count of objects in the corresponding model bins. Figure 4 gives an example of an uncertainty map, along with a smoothed plot in

which the variant orbits have been so weighted. The suggested follow up search area is potentially greatly reduced. Of course, the accuracy of the model dictates the efficacy of such an approach.

5. Identifications

The process of linking together observed tracklets – perhaps separated by some number of nights, or linking a set of observations to an already known object, or determining that what was thought to be two or more distinct objects are in fact a single object – all of these activities can be thought of as falling under the umbrella of making identifications.

Linking of tracklets is attempted by fitting generalized Vaisala orbits to sets of tracklet pairs. There are currently over 3 million tracklets in the ever growing single night observations data base table. Trying to speculatively link tracklet pairs by such a brute force method is very time consuming and highly inefficient.

Trying to link observations to known objects involves looking for small residuals between the expected positions of known objects and the observations. This is done simply by fitting the observation positions onto the plane of the orbit of a known object by adjusting the mean anomaly to correspond to the times of the observations.

Misidentifications do occasionally crop up and are generally only caught when additional observations indicate that some prior subset of observations in fact don't fit the revised orbit.

6. Minor Planet Checker

Observers sometimes have occasion to want to know which minor planets or comets are near a given position on a given date and time. The MPC has a service which performs this quicklook duty, called MPChecker (available at <http://minorplanetcenter.net/cgi-bin/checkmp.cgi>). For the current epoch, it computes the position of each known object at each specified time and checks whether the object lies within the specified radius. For epochs prior to the current one, precomputed sets of elements for objects with perturbed orbits are generated at 200-day intervals (except 40-day intervals for recent dates and 2-day intervals for NEOs).

When run on a current day run-of-the-mill single core processor, it takes approximately 7 CPU seconds to try and match a position/time against 700,000 orbits. As the number of discoveries increases, obviously so too do the number of orbits to match against. Additionally, as new survey programs become established, the number of minor planet checker requests will tend to grow. This has the potential to place a strain on computing resources. A faster minor planet checker would be a welcome gift to the community.

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