Annex II Methodology of Monitored Parameters
[The methodology for collecting data and calculating the monitored parameters is given as follows:

Broadcast Ephemeris Accuracy (Orbit and Clocks)
The same process for two parameters, SIS URE and SIS UTC is used in the first half of steps to calculate Broadcast Ephemeris Accuracy. The reference is IGS final orbit and clock for GPS and GLONASS, while the reference for other GNSSs is substituted by the postprocessing final product generated by the each provider or provider nominating organization. [NOTE: need discussion, likely for GPS and GLONASS, it is desireble that the combined IGS final product is used for the calculation for other GNSS. However, there is no official product in IGS though MGEX is trying to establish those products into IGS reguler product.]

Algorithm description.

- Conduct the following calculations at an agreed-upon frequency throughout a day, such as once per 30 seconds, per minute, or per five minutes. All time calculations will be based on GNSS time.
- Apply the following algorithm only to satellites that are deemed "healthy". The term "healthy" refers to the satellite being made available by GNSS operators for use in generating position and time solutions.
- Obtain broadcast ephemeris and clock data from the navigation message for each satellite in the GNSS at the time of interest (meaning, navigation data is available at the time selected, and the signal is marked as healthy).
- Calculate the navigation message satellite position, $(xeph,\ yeph,\ zeph)$, and clock states at the time of interest based on broadcast ephemeris and clock data.
- Obtain precise ephemeris and clock states from IGS for the time of calculation.
- Calculate the satellite precise position, $(xref,\ yref,\ zref)$, and clock states at the time of calculation based on precise ephemeris and clock data.
- For Orbit accuracy
    - Three dimantional position error is calculated
      $Orb\_acc3d{=}xref{-}xeph2{+}yref{-}yeph2{+}zref{-}zeph2$
    - Or each component in the satellite orbit coordinate, radial, along- and cross-track direction is calculated after coordinate transformation.
- For Clock accuracy

- To be provided
- NOTE: How to treat the difference between the reference time of broadcast ephemeris clock offset parameters and ICG clock offset is to be discussed.

SIS User Range Error

This section describes the calculation of the signal-in-space user range error for a given user location. The algorithm follows that used in the document “GPS Navstar Ephemeris/Clock Estimation Training (September 1993)” and “An Analysis of GPS Performance for 2014”, published by the Space and Geophysics Laboratory Applied Research Laboratories, University of Texas at Austin. The algorithm is based on a comparison of the satellite positions and clocks derived from the broadcast ephemeris against the satellite positions and clocks as contained in the IGS precise ephemeris (considered as the “truth” source). This is a useful approach, but one that has specific limitations, the most significant of which is that precise ephemeris does not well reflect the effect of individual discontinuities or large effects over a short time (such as a frequency step or clock runoff).

Algorithm description.

- Conduct the following calculations at an agreed-upon frequency throughout a day, such as once per 30 seconds, per minute, or per five minutes. All time calculations will be based on GNSS time.
- Apply the following algorithm only to satellites that are deemed “healthy”. The term “healthy” refers to the satellite being made available by GNSS operators for use in generating position and time solutions.
- Obtain broadcast ephemeris and clock data from the navigation message for each satellite in the GNSS at the time of interest (meaning, navigation data is available at the time selected, and the signal is marked as healthy).
- Calculate the navigation message satellite position and clock states at the time of interest based on broadcast ephemeris and clock data.
- Obtain precise ephemeris and clock states from IGS for the time of calculation.
- Calculate the satellite precise position and clock states at the time of calculation based on precise ephemeris and clock data.
- Compute instantaneous user range error as the projection of the satellite position and clock errors (difference between precise position and clock state and broadcast position and clock state) along the line-of-sight between the satellite and the given geographical user location.

SIS UTC Offset Error

Computation of GNSS-UTC Offset Error involves collecting the broadcast UTC offset values from each of the GNSS and comparing them to GNSS-UTC offset "truth" values.

Determination of UTC Offset

Obtain the GNSS-UTC offset values by extracting the GNSS-UTC offset parameters from GNSS broadcast navigation message and calculating the offset in accordance with the applicable GNSS interface control document. Note that at any given time, the GNSS-UTC Offset calculated may differ between satellites within a given GNSS due to the different times each satellite is uploaded. Average the GNSS-UTC Offset values to obtain a single GNSS-UTC Offset average value.

Determination of GNSS-UTC Truth Value

Obtain from a trusted source the daily GNSS-UTC offset values. Candidate sources for each of the GNSS is as follows:
GPS: USNO (http://www.usno.navy.mil/USNO/time/gps/usno-gps-time-transfer)
GLONASS: TBD
Galileo: TBD
BeiDou: TBD
IRNSS: TBD

Determination of GNSS-UTC Offset Error

The comparison between the broadcast GNSS-UTC offset and the GNSS-UTC offset truth value must be done in a common time domain. For example, if the truth values are daily values, then the GNSS-UTC offset from broadcast data must be computed as a daily value for purposes of comparison.
To compute a daily broadcast GNSS-UTC offset, do the following:

- Once a day at the pre-selected time obtain from each spacecraft the UTC parameters broadcast and compute the GNSS-UTC Offset.
- Difference the daily Broadcast UTC Offset with the GNSS-UTC Truth Value to obtain the GNSS-UTC Offset Error.

PDOP

Position dilution of precision is a measure of the GNSS constellation geometry at a given time for a given location. For the purposes of this document, PDOP values are generated for points spread out evenly over the earth and throughout all times of day. This involves first determining a grid of points on the earth surface for which to compute

PDOP values, then computing the PDOP values over the day at each of these points.

Determination of Global Grid Points

The objective of this algorithm is to generate the latitude and longitude of a sequence of points equal distances apart for all or a specified portion of the globe, given an input of the start and stop points and the desired distance between points. This algorithm is used to generate points for performing geometry computations across any desired area at any required discrete density. The reason for using this algorithm is to ensure an even distribution of points over the assessment area. A conventional latitude/longitude degree increment weights a performance assessment erroneously towards the higher latitudes. Note that the algorithm does generate small latitude residuals at the prime meridian that slightly distort the equal spacing need. The size of the residual grows directly as a function of the grid spacing. At a 1°grid spacing, the maximum latitude residual at any given longitude results in a deviation of less than 12 kilometers in the nominal distance between the first and last points. This algorithm is taken from the document “GPS Civil Signal Monitoring Performance Specification (April 2009)”.

In this algorithm, latitude increments from 0° to 90° north of the equator, and 0° to -90° south of the equator. Longitude begins at 0° at the Greenwich Meridian, and increments to 360° counterclockwise as viewed from the North Pole.

STEP 1. Define grid spacing.

This value represents the distance to use between points in the grid. Input can be defined either in terms of degrees or kilometers. At the equator, 111.1395 kilometers equals 1°. Note that if this input is specified in terms of degrees, the number of degrees requested will only apply at the equator. This is due to the fact that the number of kilometers per degree longitude decreases as latitude increases. At 80° latitude, 1° equals approximately 19 kilometers. The convention of “degrees” is used for this implementation.

INITIALIZE_INCREMENT_DEGREES = ________ (Degrees)
INCREMENT_KM = 111.3195 × INITIALIZE_INCREMENT_DEGREES

STEP 2. Define start and stop points in degrees latitude and longitude.

Note that the algorithm will use the starting longitude as the reference, and return to it for the next latitude increment. The algorithm is intended to increment in a northeasterly direction. The end longitude should be larger than the start longitude. To ensure this, add 360° to the end longitude. The end latitude should be larger than the start latitude.

START_LAT = ________ (Degrees)   START_LONG = ________ (Degrees)
END_LAT = ________ (Degrees)   END_LONG = ________ (Degrees)

j = 0
k = 0
LONGITUDE(j=0) = START_LONG
LATITUDE(k=0) = START_LAT

STEP 3. Perform geometry or position solution computations at starting point, and for each {j,k} increment.

From this algorithm's perspective, it doesn't matter if a single solution is performed at this point before incrementing to the next, or if all solutions over the specified time interval are computed.

STEP 4. Compute the number of longitude increments required at the current latitude.

The equatorial radius of the Earth (r) equals 6378.137 kilometers.

$$INCREMENT\_DEGREES(k) = \frac{360}{2\pi r \cos LATITUDE(k)} \times INCREMENT\_KM$$

$$LONG\_INCREMENT\_NUMBER(k) = INTEGER\left[\frac{END\_LONG - START\_LONG}{INCREMENT\_DEGREES(k)}\right]$$

STEP 5. Increment longitude by the LONG_INCREMENT_NUMBER value.

If the current increment exceeds the count, reset the longitude to START_LONG, and increment the latitude (STEP 6).

j = j+1
If j < LONG_INCREMENT_NUMBER (k)
LONGITUDE (j=j+1) = [LONGITUDE (j) + INCREMENT_DEGREES(k)]mod 360

If j ≥ LONG_INCREMENT_NUMBER(k), THEN
j = 0
LONGITUDE(j=0) = START_LONG

STEP 6. Compute latitude step size in degrees, and the latitude count.

If the latitude count is exceeded, the process is complete and the entire grid has been computed.
Note that this algorithm begins with the lowest latitude, and works to the greater latitude. If the
global case is being evaluated, use (-90° + LAT_INCREMENT_DEGREES) as the latitude start point and (90° - LAT_INCREMENT_DEGREES) as the latitude end point.
LAT_ INCREMENT_DEGREES = INITIALIZE_ INCREMENT_DEGREES

$$LAT\_INCREMENT\_NUMBER = INTEGER\left[\frac{END\_LAT - START\_LAT}{LAT\_INCREMENT\_DEGREES}\right]$$

k=k+1
If k < LAT_INCREMENT_NUMBER
LATITUDE(k+1) = LATITUDE(k) + LAT_INCREMENT_DEGREES

If k ≥ LAT_INCREMENT_NUMBER STOP

Computation of PDOP Values

Individual PDOP values for each GNSS constellation are calculated for a given time and location in accordance with the PDOP definition in Annex I of this document. The positions for the GNSS receivers will be the grid points assigned in the “Determination of Global Grid Points” section. The positions for the GNSS satellites will be calculated in accordance with the applicable GNSS interface control documents using the most recent ephemeris and clock data taken from the broadcast navigation messages in each GNSS. Calculation times can vary according to project agreements. For example, at the beginning of the project, the time interval could be set to once every 5 minutes, and then after the process is established could be speeded up to be once per minute or once per 30 seconds. The PDOP calculations for each GNSS will be calculated using matching time and location point sets to ensure uniformity in calculation and to permit easy comparison.

The calculations stated above establish the core set of PDOPs to be calculated. Once this core set is implemented, additional calculations can be added such as calculation of other DOP types (VDOP, HDOP, etc.), statistics for PDOPs (mean, 95%, maximum, etc.), and regional designations (Europe, Indian subcontinent, North America, etc.). This process is in keeping with Terms of Reference guidance, to start with a limited set of parameters and expand to additional capabilities in subsequent phases.

]

Annex III Roadmap for IGMA

[

This section is intended to describe the desired roadmap for the IGMA as it moves through the trial project and eventually toward permanent implementation. A discussion needs to be held within the IGMA Task Force to decide what elements should be in the Roadmap and the relative priority of each element. What follows is a candidate list of elements to include, but not in any particular order of importance or priority. Through discussions, elements will be added, deleted, or modified, and the relative priority order will be established in order that a coherent roadmap can be established.

Candidate Elements:

- Technical improvements
    - Implement computation of four parameters for each GNSS using manual postprocessing
    - Implement automated postprocessing
    - Implement automated near realtime processing
    - Expand computation of four parameters to obtain statistics (e.g., RMS, 95%, maximum, global average)
    - Implement accessible data on ICG website
    - Implement graphic display of GNSS performance over time (line graphs)
    - Implement multi-GNSS computations to reflect hybrid service
    - Add parameters beyond the original four
        - add user level performance monitoring such as user positioning error
    - Add real-time monitoring and analysis function
    - Add accessment function after performance standard for each GNSS is defined and opens it to the public
    - Add accessment function for performance with using multi-GNSS constellation after performance standard for milti GNSS is defined and opens it to the public
- Programmatic steps
    - Complete the trial project and summarize the results
    - Implement a permanent IGMA
    - Implement a permanent ICG portal to access IGMA results

]