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On the possible use of satellite fixed positions for Argo profiles in case of GPS failures

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Abstract

INCOIS had deployed iridium based PROVOR Bio-Argo floats obtained from NKE, France. These floats are fitted with GPS for obtaining accurate position of the Argo profiles. However there are cases where in the GPS fitted with the Argo floats tend to give wrong positions owing to unknown reasons. In this present work we discuss the possibilities of using the Iridium satellite fixed position in case of GPS failures. For this, analysis was done by comparing the GPS and satellite fixed profiles positions of good floats. These statistics can be used for using the satellite fixed position in case of GPS failures. For each comparison the satellite fixed position with least circular error probability (CEP) radius was chosen. The study suggested that on a average the satellite fixed positions tend to differ from the GPS fixed positions by 0.03 degrees. CEP radii are found to be consistent with the difference between satellite fixed position and GPS position. Based on this we suggest a quality flag of 2 for positions with CEP radius <=4 and flag 4 for any other positions.

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Abstract

INCOIS had deployed iridium based PROVOR Bio-Argo floats obtained from NKE, France. These floats are fitted with GPS for obtaining accurate position of the Argo profiles. However there are cases where in the GPS fitted with the Argo floats tend to give wrong positions owing to unknown reasons. In this present work we discuss the possibilities of using the Iridium satellite fixed position in case of GPS failures. For this, analysis was done by comparing the GPS and satellite fixed profiles positions of good floats. These statistics can be used for using the satellite fixed position in case of GPS failures. For each comparison the satellite fixed position with least circular error probability (CEP) radius was chosen. The study suggested that on a average the satellite fixed positions tend to differ from the GPS fixed positions by 0.03 degrees. CEP radii are found to be consistent with the difference between satellite fixed position and GPS position. Based on this we suggest a quality flag of 2 for positions with CEP radius <=4 and flag 4 for any other positions.

1. Introduction

Argo is an international project which is conducted in cooperation with meteorological and oceanographic organizations of many nations, WMO and IOC (Argo Science Team, 2001; Ravichandran et al., 2004). Argo reached its target of building up a global ocean monitoring system consisting of 3,000 Argo floats by 2007. Argo float measures temperature and salinity (T/S) profiles from the sea surface down to 2,000 m depth and transmit those data via the ARGOS satellite system every 5/10 days. With the completion of Argo float network in 2007, one lakh T/S profiles in the global ocean are being reported every year. The no of floats deployed by 26 nations and European Union together in the world ocean is more than 3500. INCOIS is responsible for Indian floats, and as of May, 2014 contributed 322 floats to the global Argo float network. All the Argo float data is distributed to meteorological organizations around the world via the Global Telecommunication System (GTS) within 24 hrs after reception and served to observe the oceanic state and to forecast climate changes. In addition INCOIS performs additional high quality control called as the delayed mode quality process to the Argo float data. This is done once the acquired data from the float crosses 6 months. This is done in scientific way and the data is released within 6 months via internet with no additional charge to the user community.

India have deployed different Argo floats procured from various manufacturers. The details of the float types and manufacturers are given in the table below (as of May 2014).

SNo	Float Type	Manufacturer	Additional Sensors	Total No
1.	APEX-8C/9A	Web Research Corp	• Near Surface Temperature mission (NST) + CTD • SBE-Dissolved Oxygen (DO) + CTD • Anderra DO + CTD • Only CTD Total	15 14 2 172 203
2.	APEX-Iridium (9I)	Web Research		25

		Corp		
3.	PROVOR	Metocean	• SBE-CTD • FSI-CTD	15 2
4.	PROVOR-CTS-3	NKE	• Only CTD	10
5.	ARVOR-L	NKE	• Only CTD	42
6.	Bio-Argo	NKE	• Chla, DO, FLBB + CTD	18
7.	ARVOR-I	NKE	• Only CTD	7

Table 1: Types and Number of Indian Argo floats.

Data from these floats is transmitted via two ways. One set of floats use the ARGOS constellation of satellites onboard NOAA for transmission of the data. The other set of them use IRIDIUM satellites to communicate the data measured by the floats. APEX-Iridium floats use RUDICS, while the NKE floats communicate the data in Short Burst Data (SBD) format. These iridium floats are equipped with GPS for obtaining better position of the measured profile. The positions set by the APEX-9I floats are all found to be of good quality, while the positions from some of the NKE floats seem to be having error.

For the NKE floats, the position corresponding to the measured profile is given in the "Vector Technical Parameter Data" by the float. The following information is given w.r.t to each of the profile (shown here for a sample case):

GPS latitude (°)	12
GPS latitude (minutes)	9
GPS latitude (in minutes fractions (4th))	9409
GPS latitude orientation (0=North 1=South)	0
GPS longitude (°)	88
GPS longitude (minutes)	41
GPS longitude (minutes fractions (4th))	6134
GPS longitude orientation (0=East 1=West)	0
GPS valid fix (1= valid 0=not valid)	1

Table 2. Sample GPS information provided by the float via Vector Technical Parameter Data.

The GPS latitude orientation is used to know whether the profile belongs to northern or southern hemisphere. However the validity of the position is known only by the GPS valid fix information. However if the GPS valid fix is set to 0 (not valid), what exactly to be done is not clearly mentioned in the manual. It is interesting to note that apart from the position by the GPS, the IRIDIUM satellite do fix the position of the float while it is transmitting the data using the Doppler Shift method. Our intension in this work is to check how good this position is in comparison to GPS position and in case need with what accuracy this position can be used in place of the GPS fixed position.

INCOIS had first deployed 9 PROVOR-BioArgo floats in the Indian Ocean which communicates the data via SBD format. Out of these 9 floats 3 floats have developed problems with the GPS and started to communicate bad data. The "GPS valid fix" information for all these float profiles are found to be set to 0 indicating not a valid fix. Even though these floats were deployed in Indian Ocean, owing to the wrong fixes, the data sets are shown as belonging to Bolivia. Hence to check for an alternative, comparison between GPS and satellite fixes are done and some conclusions are drawn which are discussed in details below. The remainder of the work is arranged as follows: section 2 describes in detail about GPS error accuracy and precision, section 3 describes about comparison between GPS and satellite fixes and summary &conclusions are given in section 4.

2. GPS Accuracy, Errors & Precision (Courtesy: http://www.radio-electronics.com/info/satellite/gps/accuracy-errors-precision.php)

One of the key points and advantages of GPS is its accuracy. The GPS errors can be reduced to a sufficiently small level that the system provides excellent results in commercial applications as well as the much higher level of accuracy obtainable by US military users.

GPS accuracy is far greater than anything that was previously available, and it is sufficiently accurate for most applications. However there are GPS errors that have been significant for some applications and much work has been undertaken to reduce the level of GPS errors to a level where they are insignificant.

It is found that if GPS positions are logged over a period of time, the positions indicated will be scattered over an area as a result of the measurement errors. The plot of the dispersion of the indicated points is called a scatter plot, and it is this indication that manufacturers of GPS receivers use to determine the accuracy of the GPS equipment. The scatter plot is then analysed statistically to provide an indication of the GPS accuracy performance for the receiver.

2.1 GPS accuracy & precision

The term GPS accuracy is a rather over-used term. However it can be said that the levels of GPS accuracy are extremely high these days, even for civilian use GPS units.

It is also worth defining the difference between accuracy and precision:

- ***GPS accuracy:*** The accuracy refers to the degree of closeness the indicated readings are to the actual position.
- ***GPS precision:*** Is the degree to which the readings can be made. The smaller the circle of unknown the higher the precision.

The difference between accuracy and precision is described visually in the diagram below.

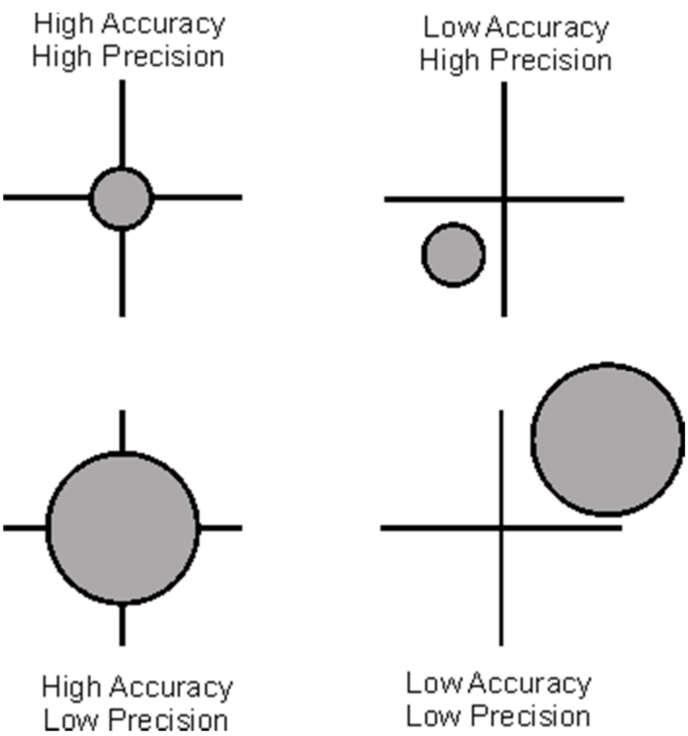

Fig 1.GPS accuracy and precision (Courtesy: http://www.radio-electronics.com/info/satellite/gps/accuracy-errors-precision.php)

Prior to the de-activation of the Selective Availability accuracies to within around 100 metres could be obtained. Afterwards, accuracies to within 15 metres could typically be obtained. This depended on many factors including the number and position of the satellites as well as the design of the receiver - parallel multi-channel receivers are able to provide significant improvements over earlier systems.

2.2 Understanding GPS accuracy specifications

Specification of the GPS accuracy for various receivers is subject to much marketing terminology as each manufacturer is trying to show their equipment to its best. Also GPS accuracy is difficult to describe, especially in simple terms and in data sheets where space is at a premium. However for the typical SatNavs used in automobiles, the accuracy is sufficient to enable the receiver to track the position against the known map stored in the SatNav.

In addition to this it is necessary to remember that GPS accuracy specifications are determined under ideal conditions - in an open sky with more than sufficient satellites to gain a good fix, and in open country where there is no possibility of reflections that could give rise to inaccuracies. Real operating conditions are rarely this good.

As the errors are subject to statistical spreads they are often expressed in terms of the 95th percentile, i.e. 95% of the data generated will be better than the stated value, and 5% outside it, or as the 50th percentile where 50% of the data is inside the specified value, and 50% outside.

On top of this, there are two common terms associated with GPS accuracy specifications:

- ***CEP - Circular Error Probability:*** GPS accuracies specified as CEP refer only to the horizontal plane, i.e. position on a map. CEP is defined as the radius of a circle centered on the true value that contains 50% of the actual GPS measurements. So a receiver with 10 metre CEP accuracy will be within ten metres of the true position 50% of the time. The circle of radius indicating the 95% probability is often referred to as R95, i.e. R95 is the CEP with the radius of the 95% probability circle.

- ***SEP - Spherical Error Probability:*** GPS accuracies specified as SEP refer to both horizontal and vertical planes. For a 50th percentile, half the data points or positions would fall within a sphere of this radius.

When viewing the accuracy specifications of a consumer GPS receiver, accuracy specifications in the form "Real-Time Accuracy <10 Metre CEP" may be seen. This means that under ideal conditions (which may be specified in the spec sheet), the GPS receiver will indicate the location to within 10 metres of the true location 50% of the time. This specification is for the horizontal accuracy as SEP was not quoted. Typically the vertical accuracy will be 2 to 3 times worse than the horizontal accuracy.

2D GPS accuracy, i.e. horizontal accuracy may also be specified in terms of DRMS, Distance Root Mean Square this is a single number that can express the GPS equipment. This is the square root of the average of the squared horizontal position errors. There is a 65% probability of the position being within the actual probability circle.

$$\text{DRMS} = \sqrt{\sigma_x^2 + \sigma_y^2}$$

The concept of RMS accuracy can be taken further. It is possible to change the DRMS formula to give twice the DRMS of the horizontal position errors. In other words the circle defined gives the 95% probability of the real position falling within the circle defined. The 2DRMS circle is twice the radius of the DRMS circle. Similarly the 3DRMS circle gives the 97.5% probability and is three time the radios of the DRMS circle.

$$\text{2DRMS} = 2\sqrt{\sigma_x^2 + \sigma_y^2}$$

$$\text{3DRMS} = 3\sqrt{\sigma_x^2 + \sigma_y^2}$$

GPS error sources

There are a number of ways in which errors can creep in to the overall GPS system. These are well known and documented.

- ***Propagation errors:*** There are errors introduced as the signal slows as it passes through the ionosphere and troposphere. However it is only possible to estimate the average errors that are likely to be encountered. Any local conditions may alter the validity of these calculations.

It is found that the ionised particles in the ionosphere will tend to slow radio signals travelling through it. This will alter the triangulation calculations for the GPS receiver. Also refractive index changes in the troposphere will have a similar, if small, effect.

- ***Signal multipath:*** Errors can be introduced when signals are reflected of buildings of geographical entities such as large rocks, etc. As the less direct path will be longer and take extra time, this can add errors into the system if the receiver recognises the reflected signal.
- ***Receiver clock errors:*** As the clock inside the receiver will be nowhere near as accurate as the four atomic clocks on board the satellite, this can introduce some small errors.
- ***GPS satellite orbit errors:*** Holding the satellite in an exact orbit is a real challenge. Deviations from the positions given in the ephemeris data - ephemeris errors will translate into GPS receiver position errors.
- ***Number of satellites visible:*** Obviously the more satellites that can be seen and can be used to provide readings, the more triangulation points are obtained and the greater the level of certainty and accuracy.
- ***Satellite position geometry:*** The geometry of the satellite positions can have an impact on the GPS errors. The optimum situations occur when the satellites have wider angles relative to each other. Poorer readings are obtained when the satellites have small angels between them. A measure of this known as DOP or Dilution of Precision is explained below.

2.3 Dilution of Precision, DOP

The dilution of precision or DOP figure is used to give a simple characterisation of the geometry of the satellites being used for a fix. As the satellite geometry has an impact on the accuracy of the reading the DOP figure provides a useful guide. When using triangulation techniques, the distance from known points is used to determine the position of the target point. The distance from the known points forms a circle around each known point, and where the circles intersect, there is the target. The optimum accuracy is achieved when the angles to the known points are near right angles to each other. The same is true for the triangulation techniques used with satellites.

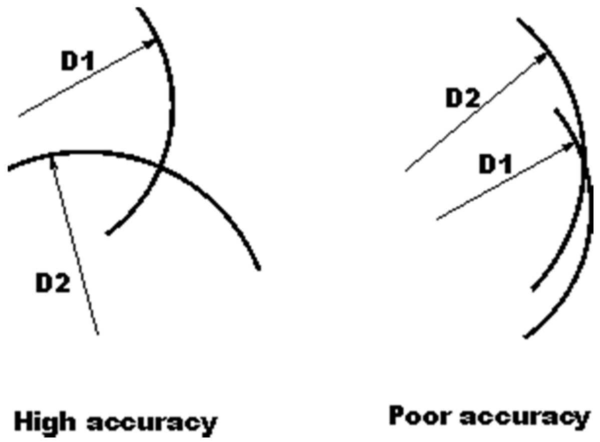

Fig 2.Triangulation Accuracy and GPS DOP (Courtesy: http://www.radio-electronics.com/info/satellite/gps/accuracy-errors-precision.php)

It can be seen that where the satellites are well separated, the distance lines from the satellite intersect at right angles giving a clear point of intersection. Where the satellites are close together, the distance lines intersect with a small angle and it is more difficult to determine the exact point of intersection.

The dilution of precision, DOP is related to the volume formed by the intersection of the points of the user satellite vectors, with the user at the centre of the sphere.

Larger volumes of cones, the better the intersection of the distance lines and this gives smaller DOP values which in turn generally relate to better position accuracy. Conversely smaller volumes of cones where the satellites are closer together give smaller cone volumes and larger DOP values which indicates poorer accuracy.

Although the DOP is a useful estimate of the likely accuracy and precision related to the satellite positions, this is not the only source of error as can be seen from the list above. Sometimes other abbreviations may be seen: HDOP, VDOP, PDOP, and TDOP are abbreviations for Horizontal, Vertical, Positional (3D), and Time Dilution of Precision.

DOP Value	Rating	Comment
1	Ideal	Highest possible confidence level
1 - 2	Excellent	At this level of DOP, all but the most exacting measurements should be met
2 - 5	Good	This level represents the lowest level of confidence for making business decisions
5 - 10	Moderate	Measurements made would be adequate for most applications but could be improved
10 - 20	Fair	Represents a low confidence level. Any measurements should be treated with caution
> 20	Poor	At this level of DOP there will be significant levels of inaccuracy and error.

Table 3. Details of dilution of precision.

2.4 Summary of typical GPS accuracy levels

The accuracy expected to be obtained using a GPS receiver will vary according to the overall system used. While accuracy level actually achieved will depend upon many factors, typical estimations of the level of GPS accuracy can be given.

GPS system	Expected GPS accuracy (metres)
GPS with S/A activated	±100
GPS without S/A activated	±15
GPS with WAAS	±3
Differential GPS	±5

Table 4. Typical accuracy levels with different GPS systems

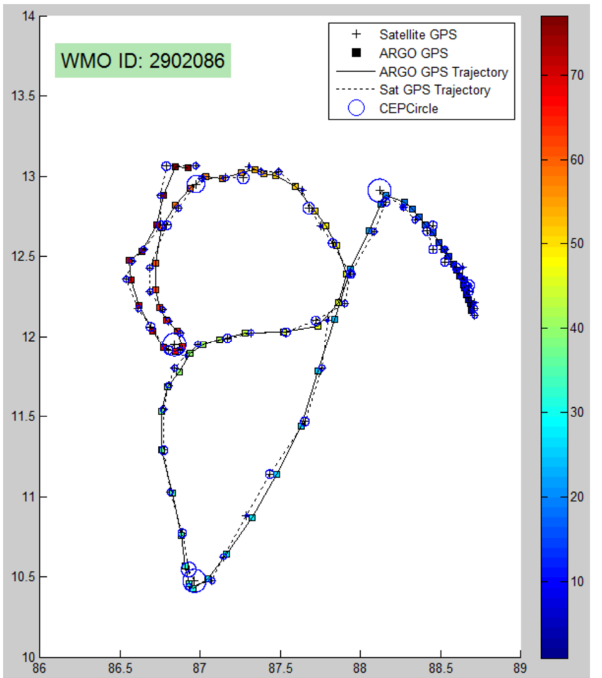

Fig 3.Trajectories of the float with WMOID-2902086 during its life time. Solid line indicate GPS trajectory and dashed lines indicate the Satellite fix trajectory. Circles indicate the CEP radius.

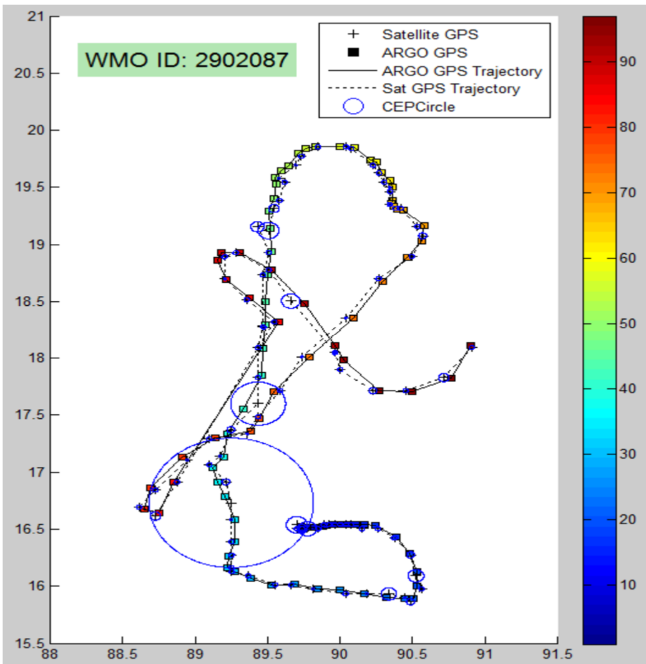

Fig 4. Same as in Fig 3 but for the float with WMOID-2902087.

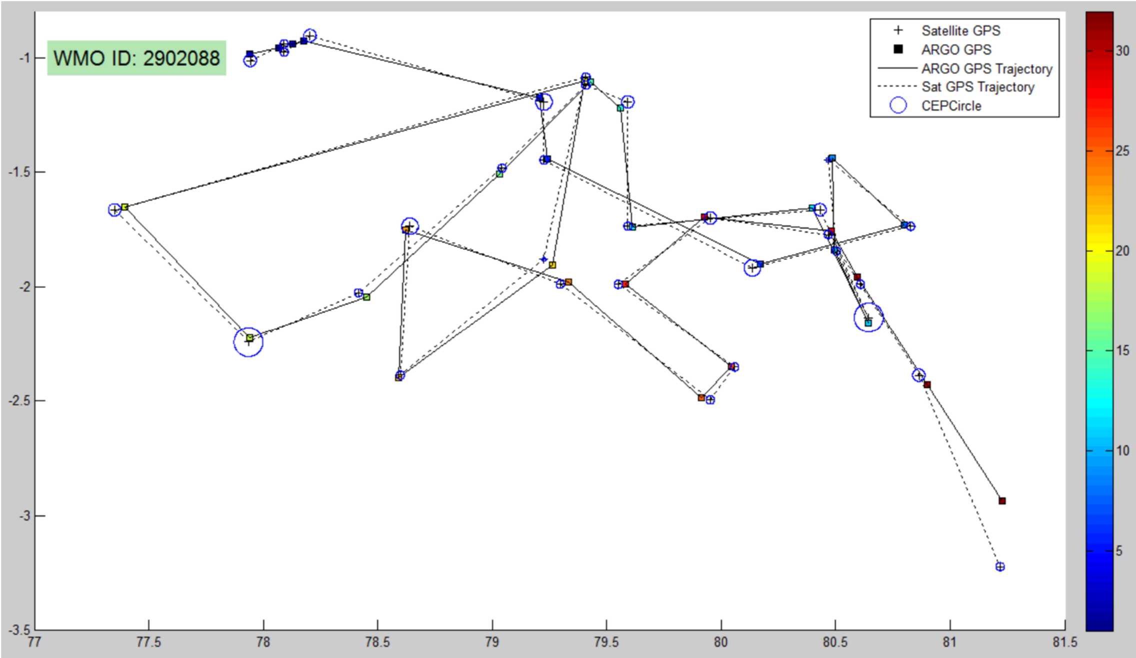

Fig 5. Same as in Fig 3 but for the float with WMOID-2902088.

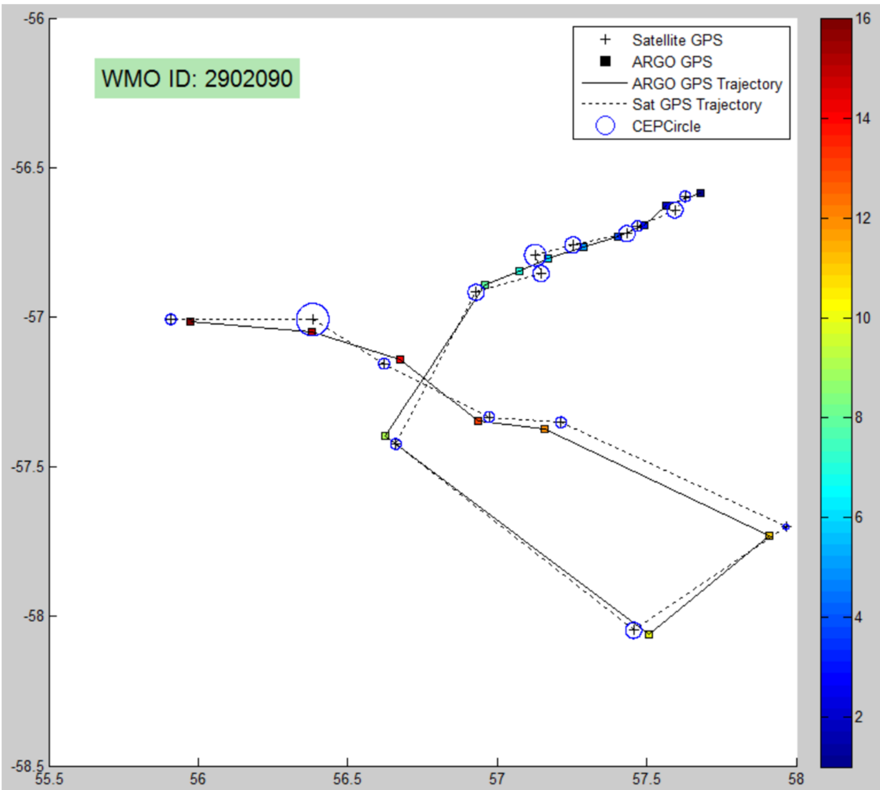

Fig 6. Same as in Fig 3 but for the float with WMOID-2902090.

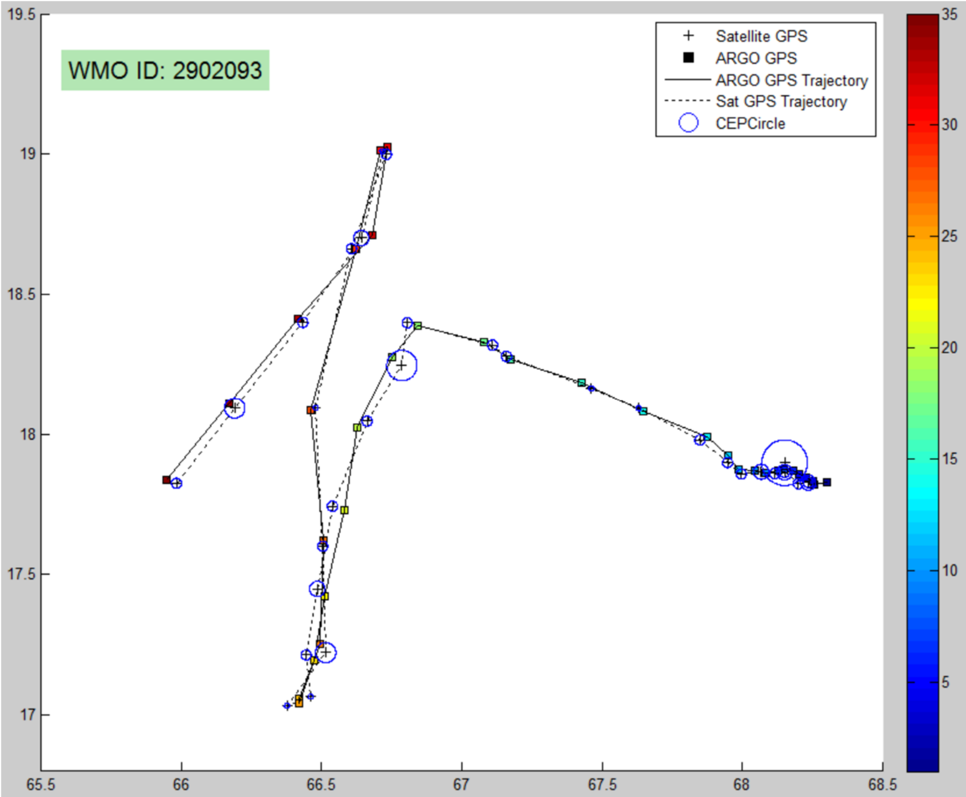

Fig 7. Same as in Fig 3 but for the float with WMOID-2902093.

3. Comparison between GPS and Satellite fixes

As mentioned before the GPS fix is given encoded in the "Vector Technical Parameter Data" along with the profiles information and sent via the SBD mails. The satellite fix is given in the mail through with the SBD data is communicated. Along with the fix a circular error probability (CEP) information is also provided. CEP radius means an estimate of accuracy of the unit position in kilometer. In order to check the credibility of satellite fix in case of error in the GPS, comparison is done between GPS and satellite fixes for floats with good GPS fixes. The information derived from this can be used in case of the bad GPS floats. For this 5 PROVOR-BioArgo floats were considered. Figures 3-7 shows the trajectories of both the GPS and satellite fixes during the life time (considered for this study) overlaid on each other. The circles found around the satellite fixes correspond to the CEP radius reported by the satellite. Comparison of trajectory between GPS and IRIDIUM Satellite is done with the smallest CEP radius of all positions observed during drifting on the surface in each cycle. In most of the cases the satellite fixes compared well with that of the GPS fixes. However there are cases where the satellite fixes are found to be bad. However this is restricted to few locations only. Further the following examination is done:

- The distance between GPS and Satellite fix.
- The relation between this distance with CEP radius.

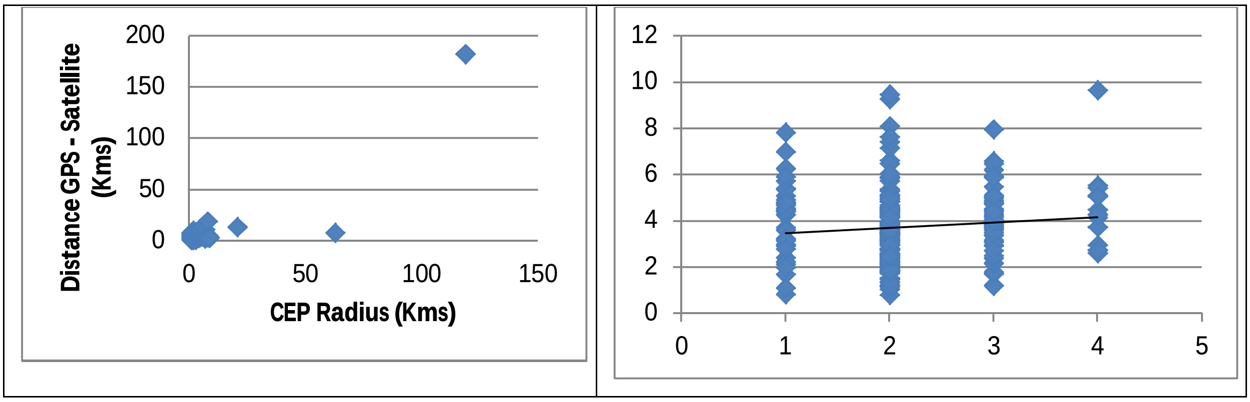

Fig 8. Scatter plot of CEP radius vs. distance between GPS and Satellite fixes with smallest CEP radius positions.

It is observed that CEP radiuses are relatively consistent with distances between GPS and IRIDIUM Satellite fixes (Fig 8a). The smallest CEP radiuses corresponding to all positions observed during drifting of the float on the surface in each cycle are observed to be within 10 km barring a couple of positions (Fig 8b). However it is observed that CEP radiuses are inconsistent with distances of GPS-Satellite fixes when CEP radiuses are within 5km. Figure 9 shows the frequency distribution of smallest CEP radius for all the profiles obtained while the float is on the surface and drifting.

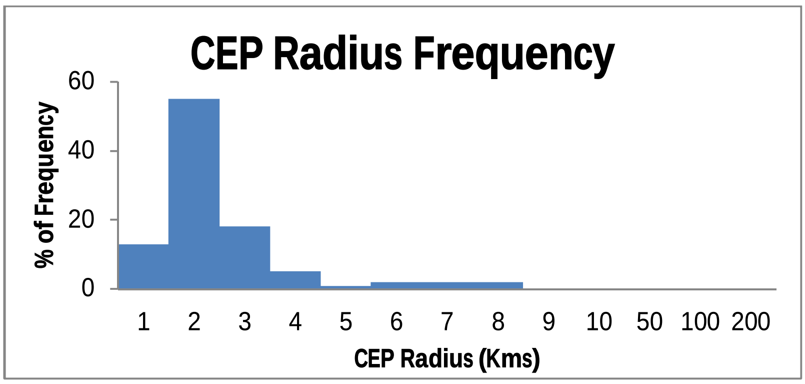

Fig 9. Frequency distribution of CEP radius.

It is observed that 55% of the time CEP radius is 2 km and the average distance between GPS and Satellite fixes is 3.5 km (Fig 8). Over all 91% of data is attributed to the CEP radius between 1 - 4 km and during this time the average distance between GPS and Satellite fixes is observed to be 3.7 km. The information about different CEP radii and the average distance between the GPS and Satellite fixes are tabulated in table 5.

CEP Radius	GPS - Sat Average Distance (km)
1	4
2	3.5
3	4
4	4.6
5	7
6	4.56
7	4.56
8	7.36
9	2.5
>=10	67.5

Table 5. Information about CEP radius and the average distance between the GPS and Satellite fixes.

From the above one can observe that satellite fixed position can be conveniently used in case of faulty GPS as the distance between the GPS and Satellite fixes is observed to be less than 3.5 Km on an average.

4. Summary and Conclusions

INCOIS has deployed Iridium based floats equipped with GPS for obtaining best possible positions for the observed temperature and salinity profile. How due to unknown reasons some of the GPS fitted on to these floats were found to be malfunctioning giving wrong positions. This causes the loss of valuable T/S profiles. IRIDIUM satellites also fix position of the float while it is on the surface transmitting the T/S profile data. This information can be handy in case of faulty GPS. A comparison is done between the GPS and Satellite fixes of profile positions. All the surface fixes during a profile transmission is taken and the one with least CEP radius is chosen. Comparison is done between this and the GPS fixed position. More than 91% of the cases it is observed that a CEP radius of 1 - 4 Km is associated with all the satellite fixes. With this CEP radius the average distance between GPS and satellite fixed positions is observed to be 3.5 Km. Hence we propose that for any profile with faulty GPS the satellite fixed position can be used if the CEP radius is within 4 Km and quality flag of 2 can be associated. For all other cases the satellite fix can be used with a quality flag of 4.

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