Improving Argos Doppler Location with Kalman Filtering - Advantages for Argo Floats

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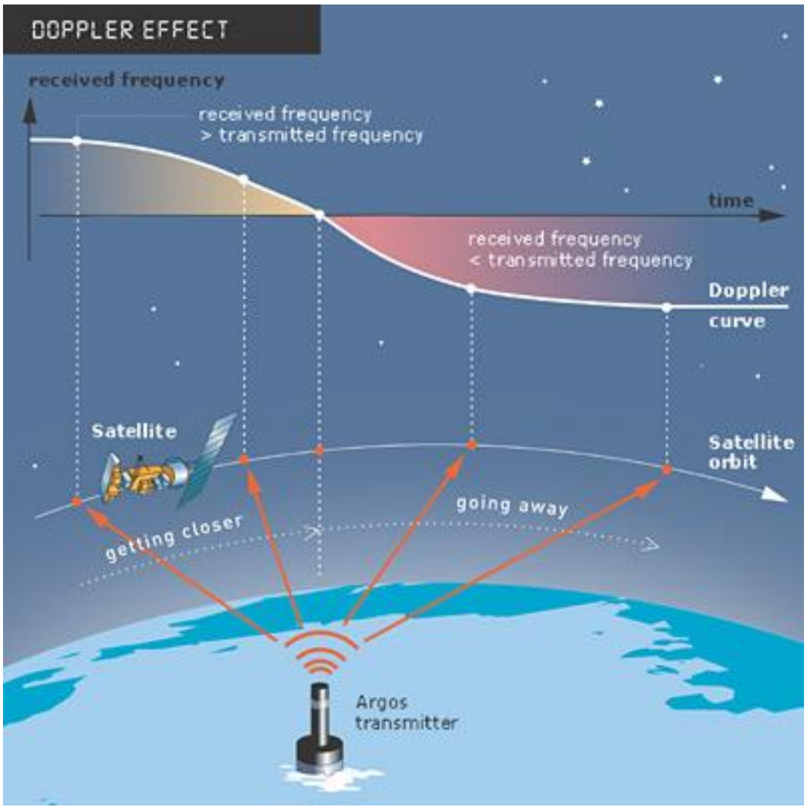
1. Introduction

Argos platforms, like Argo floats, automatically transmit messages which are received by satellites and relayed to Argos processing centers to compute a transmitter's location using the Doppler Effect on transmission frequency. Until March 2011, locations were computed from all the messages received during a satellite pass by a Least Square method.



CLS has developed in 2010 a new location processing algorithm for Argos. The new technique continues to measure the Doppler frequency shift while introducing two significant additions: the integration of platform dynamics and the use of a Kalman filter to calculate positions.

This new processing technique using Kalman filtering makes it possible to distribute more positions and to improve accuracy. These improvements are particularly significant for applications like animal tracking application with Argos, where relatively few messages are received with each satellite pass.

2. Advantages of the new method

More positions:

In the case of Argo floats, the new processing technique makes it possible to distribute up to 12% more positions. This improvement is due to:

- Good positions no more filtered: some previously discarded positions are now considered to be valid by the new processing system's quality control. In some particularly cases (i.e. sub-trace passes) geometric positions computed with the Least Square method was previously filtered (see Argos user's manual chapter 3.2). As the Kalman method is using the last(s) known positions for its calculation, the geometric localization is no longer used.

- Quality Control and accuracy improved: Thanks to new technique of quality controls (more realistic) and a better accuracy in the calculation, more good positions are now validated by the Kalman filtering method.

More accuracy:

CLS measured positioning errors for both calculation methods on several hundred Argos/GPS platforms, by comparing the Argos positions with the GPS fixes more precise (estimated error < 100m). For location classes 1, 2 and 3 (with at least four messages collected in one satellite pass), the median error in positioning was reduced by nearly 20% with the Kalman method.

These error of measurements also demonstrated that the new technique is more robust when it comes to unrealistic positions: it corrects them by bringing them closer to the platform's trajectory or eliminates them completely. This means that the dispersion of positioning errors is now weaker.

Reminder: For each location for which at least four messages are received during a satellite pass, an estimated error is calculated. The error is assumed to be isotropic and hence characterized by a single number called the radius of error. It corresponds to one standard deviation (sigma) of the estimated location error. The location class is attributed based on the radius of error. The location class and associated error is sufficient for many applications.

Class	Type	Estimated error*	Number of messages received per satellite pass
3	Argos	< 250m	4 messages or more
2	Argos	250m < < 500m	4 messages or more
1	Argos	500m < < 1500m	4 messages or more

3. How it works

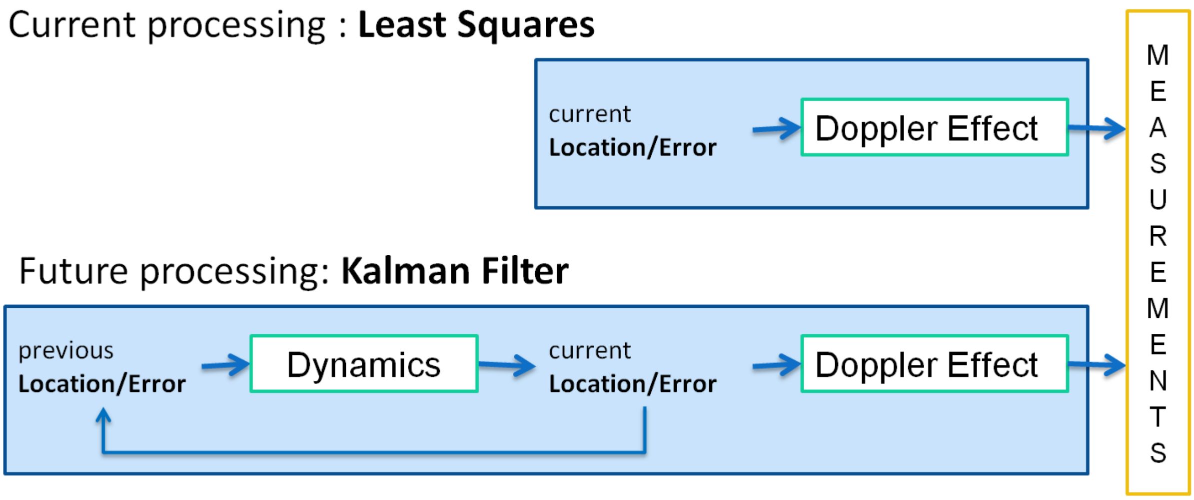
A movement model for all platforms:

The dynamics of a platform tracked using the Argos system is essentially unknown: from its previous position, a platform can move in any direction and the distance likely covered increases with time. A "random walk" mathematical model is the most appropriate method for taking this into account (Rudnick, et al., 2004). The model's job is to predict the next position and its error based on previously calculated positions:

• Knowing that the platform can move almost anywhere since its previous position, it is best to consider that the platform has "on average" not moved at all. In other words, that the next position is equal to the previous position.
• Since distance increases with time, uncertainty about the location or about the error estimation also increases from the last position.

The rate at which the uncertainty surrounding the predicted location increases is a function of the maximum speed of the platform. The higher the maximum speed is, the faster the uncertainty grows. The default maximum speed for an Argo float is 5 meters per second.

Random walk is the most robust model for mobile tracking, because a minimal hypothesis about platform behavior is made. Coherent tracks are produced since dynamics are taken into account, making it possible to accumulate information on past positions, whether or not they come from the same satellite. To sum it up, the new technique is similar to the multi-satellite location process.



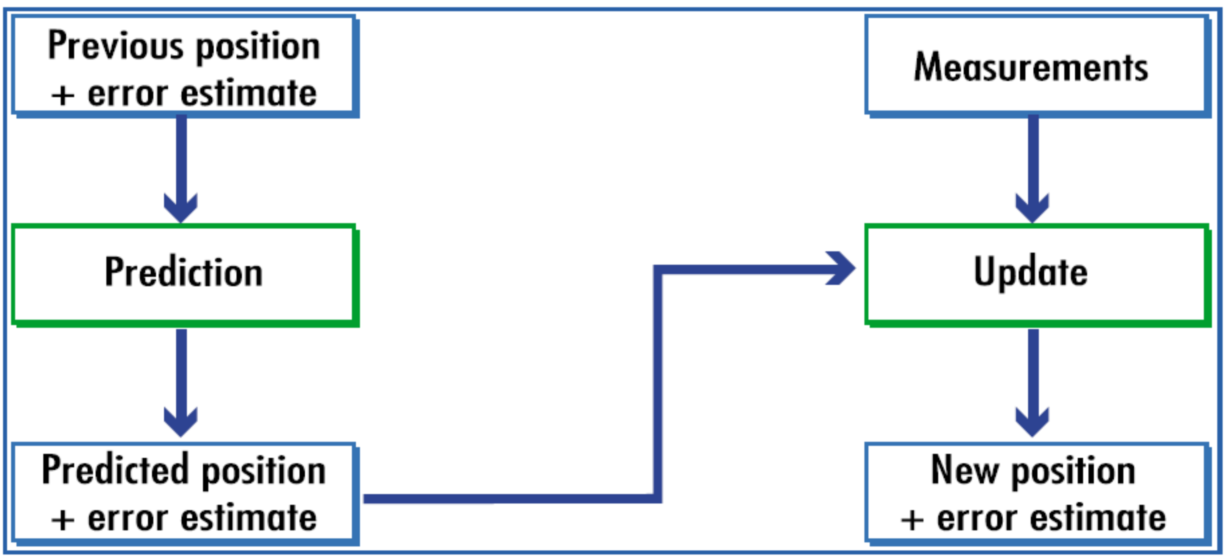
A positioning algorithm based on Kalman filters:

With a least squares analysis (method used until now to estimate platform positions and transmission frequency), at least four messages must be received per satellite pass to produce an error estimate. Furthermore, at least two messages must be received per satellite pass to produce a position. The Kalman filter is a flexible and robust method that overcomes these limitations by taking into account platform dynamics. Kalman filters have proven to be particularly useful when it comes to tracking mobiles, and major improvements have occurred since the method was developed in the 1960s (Julier, et al., 1997) (Van Der Merwe, et al., 2001a).

Kalman filtering is a 2-step process:

• The filter predicts the next position and its estimated error based on the previous position and its estimated error, using a random walk model,

• The filter calculates the new position and its estimated error by updating the predicted position using frequency measurements acquired during the satellite pass.



4. Validation process

The new location processing has been subject to intensive operational testing for all Argos applications (animal tracking, buoys, floats, boats…). The tests were designed to gather comparative data between Argos and GPS positions for Argos platforms equipped with GPS receivers.

To date, several hundred platforms and 112,000 Argos positions have been tested to compare the two processing systems (Least Square and Kalman Filter) and determine positioning errors. This extensive comparison between Argos positions and GPS fixes (serving as reference) has demonstrated what the new algorithm can do and has generated the confidence needed to make this new service operational.

Concerning the validation on Argo floats, there is no Argo float using the Argos communication system with a GPS receiver on board. In cooperation with the Argo Technical Coordinator (JCOMMOPS) we decided to reprocess all Argos locations with the new method for a representative sample of Argo floats since January 2008 and compare results obtained with the previous method in same conditions (in delayed time processing). The results of this reprocessing and comparisons are shown in the following chapters of this document.

5. Representative sample of floats for validation tests

In order to validate precisely the new method, CLS in cooperation with JCOMMOPS have chosen a representative sample of Argos platforms, included Argo floats in nominal cases but also in extreme situation as beached floats or iced over floats.18 Argo floats, listed in the table below, have been selected.

Argos ID	WMO ID	Deployment date	Model	Organization	Characteristics
5558	Q6900612	04/10/2008	Provor	UK	Stuck on surface (Arctic Sea)
6109	Q6900603	01/08/2007	Provor	UK	North Atlantic area
22847	Q6900235	04/12/2004	Provor	Coriolis	Bay of Biscay area
25184	Q5900387	21/08/2003	Apex	JAMSTEC	South Pacific area
26575	Q7900014	17/12/2002	Apex	AWI	Ice float in Antarctica area
27284	Q1900230	05/08/2003	Apex	IFM GEOMAR	Beached in Somalia
27922	Q3900233	05/04/2004	Apex	PMEL	Pacific equatorial area
29812	Q2900439	23/11/2004	Apex	KMA	Noisy transmission area (Sea of Japan)
30491	Q5900440	23/10/2003	Solo	SCRIPPS	Mirror locations - Pacific equatorial area
30712	Q6900543	16/10/2007	Nemo	BSH	40 days without transmission - Atlantic area
35504	Q6900453	05/07/2006	Apex	MEDARGO	Mediterranean Sea area
36733	Q1900054	28/11/2002	Apex	UW	8 years old float - South Indian ocean area
53211	Q5901134	22/11/2005	Apex	CSIRO	South Pacific area
57076	Q4900630	12/06/2005	Apex	WHOI	North Pacifica area
59022	Q3900548	22/01/2006	Apex	PMEL	Pick-up by a boat + travels in plane
63660	Q1900605	11/04/2006	Provor	Coriolis	Noisy transmission area (East of Med. Sea)
67212	Q4900473	27/02/2007	Apex	UW	Ice float in Antarctica area

Table 1: List of floats included in the test validation sample

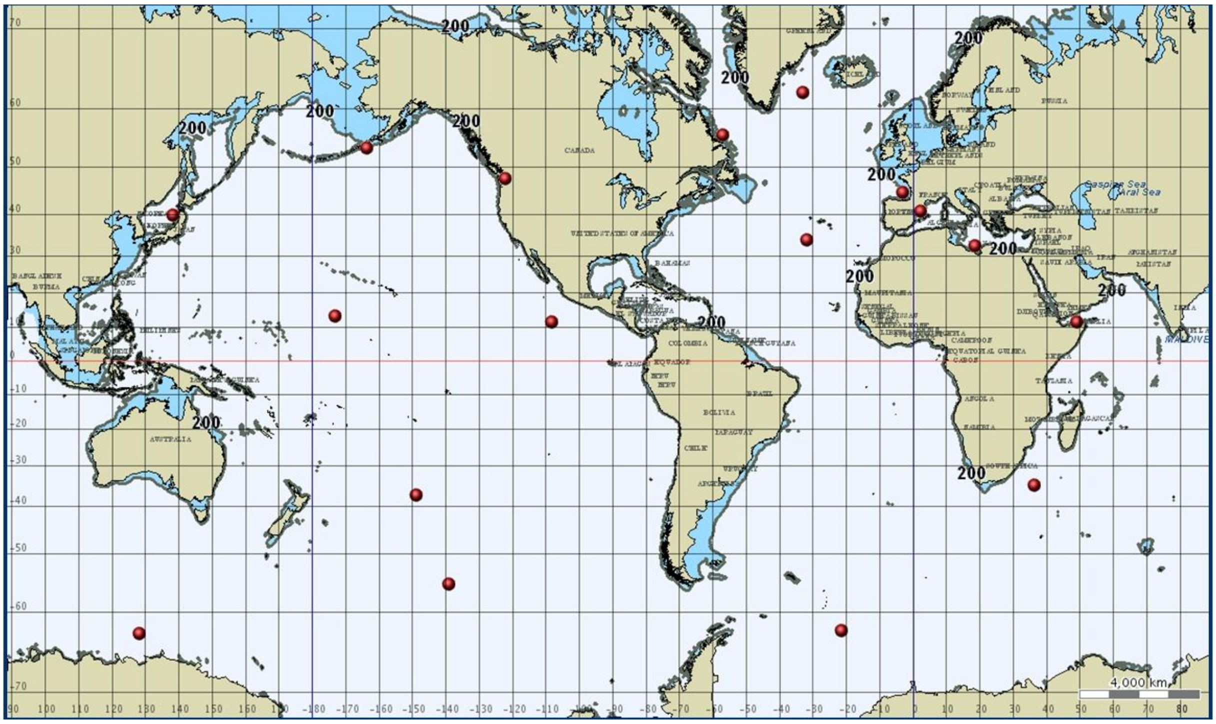


Figure 1: Last Argos locations of floats chosen for new Argos location method validation tests

The 18 floats of the test validation sample have been reprocessed with both methods between 1 January 2008 and 1 October 2010. More than 20,000 Argos positions have been tested to compare the both Argos location calculation methods for Argo floats (table 2).

Argos ID	WMO ID	LS positions	KF positions
5558	Q6900612	4507	4750
6109	Q6900603	1295	1383
22847	Q6900235	200	212
25184	Q5900387	1578	1736
26575	Q7900014	364	388
27284	Q1900230	346	352
27922	Q3900233	1041	1103
29812	Q2900439	1104	1183
30491	Q5900440	1546	1683
30712	Q6900543	605	663
35504	Q6900453	1380	1475
36733	Q1900054	852	916
53211	Q5901134	1258	1396
57076	Q4900630	1993	2163
59022	Q3900548	693	748
63660	Q1900605	509	569
67212	Q4900473	1275	1398
	Total	**20546**	**22118**

Table 2: Number of Argos positions reprocessed by calculation method for each float

6. Results and comparison

Each float has been reprocessed with the new method and compare with the previous one. All results are downloadable on the JCOMMOPS website at this page: ftp://ftp.jcommops.org/Argo/ARGOS. For each floats, the following five files are available:

- A file ***.kalman.csv** that contains positions computed with the Kalman filtering algorithm and a ***.leastsquares.csv** which contains the positions computed with the least squares algorithm;
- A file ***.stat.csv** that contains statistics on number of positions available in both ***. csv** file before;
- Both files ***.kalman.kml** and ***.leastsquares.kml** to view the trajectories with Google Earth.

The name of these 5 files consists of the Argos ID number, date of start and end date of reprocessing (DD-MM-YYYY). Example: 63660_01-01-2008_01-10-2010 identifies the Argos ID 63660 reprocessed between 01/01/2008 and 01/10/2010.

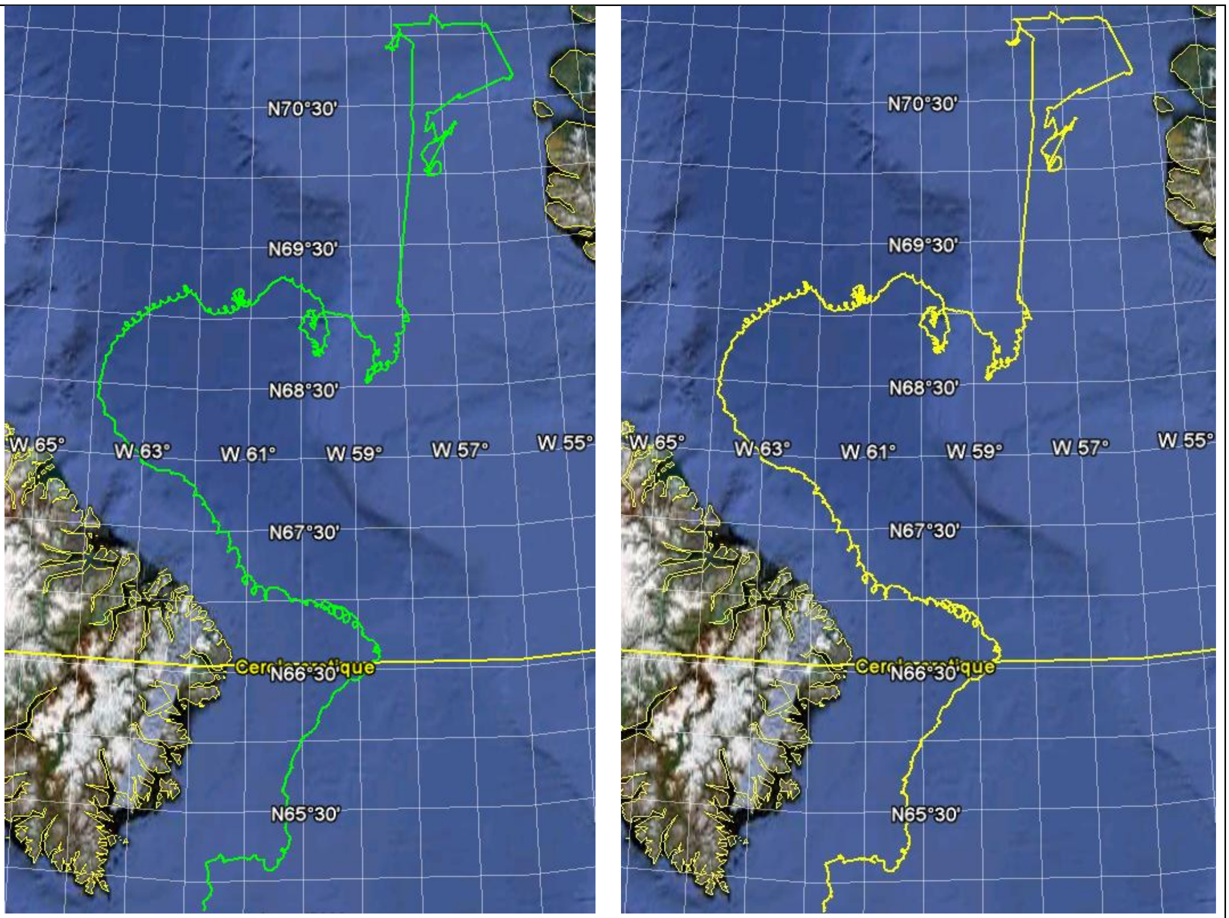
The comparison of both methods shows that:

- Trajectories computed with both methods are very similar (Figure 2)

- Some bad positions (call mirror positions) are filtered with the Kalman filtering method (Figure 3)

- More positions are computed with the new method, + 7.7% in average (Table 3): they are from positions that had been filtered with the least squares before and now quality control tests succeed.

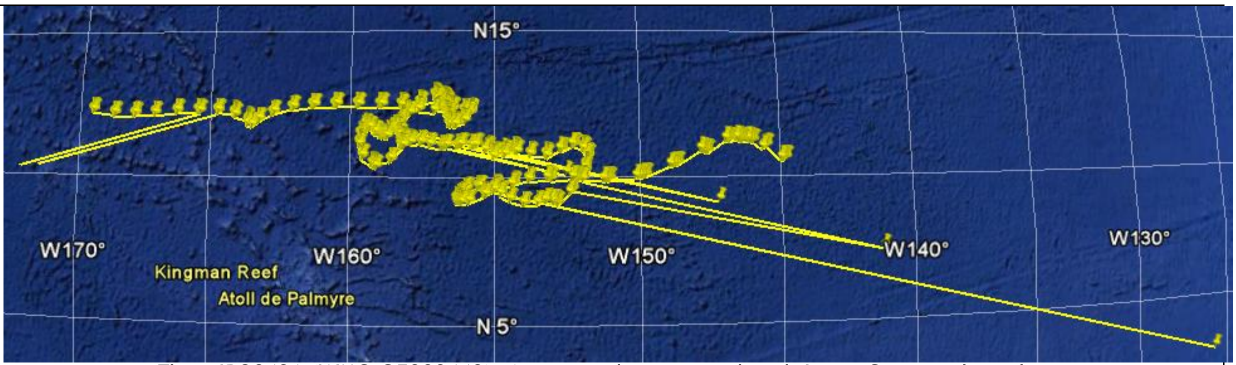
- More accuracy on Argos positions: +138.1 % of class 3 locations in average, (Table 3).



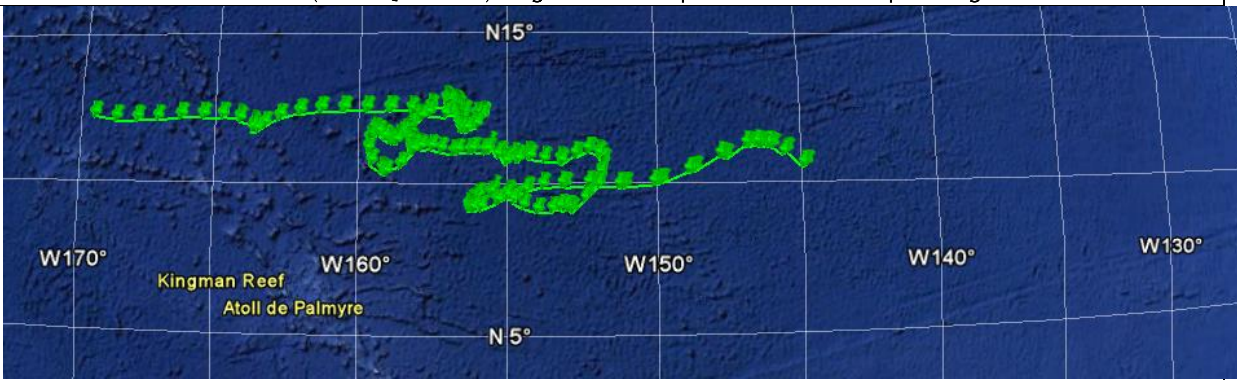
Argos track computed with Kalman filtering algorithm

Argos track computed with Least Square algorithm

Figure 2: Comparison of both Argos location methods for Argo float ID5558 (WMO: Q6900612)



Float ID30491 (WMO Q5900440) Argos track computed with Least Square algorithm



Float ID30491 (WMO Q5900440) Argos track computed with Kalman filtering algorithm

Figure 3: Mirror location has been cancelled with Kalman filtering method

Argos ID	Characteristics	Δ Class 3 (%)	Δ Class 2 (%)	Δ Class 1 (%)	Δ all classes (%)
5558	Stuck on surface (Arctic Sea)	118.88	-30.23	-49.55	5.39
6109	North Atlantic area	165.04	-25.57	-39.83	6.8
22847	Bay of Biscay area	146.88	-12.12	-33.33	6
25184	South Pacific area	106.26	-31.16	-26.96	10.01
26575	Ice float in Antarctica area	50	-27.01	-45.45	6.59
27284	Beached in Somalia	18.06	-15.94	-48	1.73
27922	Pacific equatorial area	180.68	-26.62	-35.37	5.96
29812	Noisy transmission area (Sea of Japan)	97.54	-15.04	-39.74	7.16
30491	Mirror locations - Pacific equatorial area	145.99	-29.07	-24.53	8.86
30712	days without transmission - Atlantic area	142.11	37.14	-29.88	9.59
35504	Mediterranean Sea area	69.83	-30.14	-32.11	6.88
36733	8 years old float - South Indian ocean area	284	-7.05	-38.98	7.51
53211	South Pacific area	252.78	-18.26	-24.04	10.97
57076	North Pacifica area	181	9.2	-37.15	8.53
59022	Pick-up by a boat + travels in plane	90.64	-25.63	-27.59	7.94
63660	Noisy transmission area (East of Med. Sea)	103.51	-2.93	-27.37	11.79
67212	Ice float in Antarctica area	194.68	-12.96	-36.22	9.65
Average		**138.11**	**-15.49**	**-35.06**	**7.73**

Table 2: Variation in % of Argos positions numbers by location class [Kalman - Least Square]

7. Conclusion

Here below are the main benefits of the new Argos location method for the Argo program:

• More positions: up to 12% more positions,
• Better accuracy: up to 250% more class 3 positions,
• Automatic correction or elimination of all unrealistic positions.

For these reasons, CLS and JCOMMOPS recommended to the Argo community to switch all Argo floats in the same time on the new Argos location calculation. It's important to note that the establishment of the new method will cause no changes on Argos data distribution formats. Positions will be distributed in the same format via the usual data distribution channel.

As the new algorithm permanently replaces the preceding one in the real-time Argos processing system, the location data from the old processing method will not be still available.

A scientific paper on Improving Argos Doppler Location with State-Space Modeling and Kalman Filtering is in preparation at CLS and will be soon published.

Next step:

The new location processing system is now able to calculate positions using as few as one message per satellite pass. These positions are considered to be Class B. The median error for these positions varies between one and three kilometers, based on the platform type. Note that this kind of locations is distributed in real-time especially for wildlife trackers who are getting very few Argos messages by satellite pass. This kind of locations is not displayed for Argo floats because enough good positions are available and they could make noisy trajectories.

However a study is in course at CLS on the possibility to propose a new optional service for Argo users with an Argos location delayed mode processing. This post processing would allow the distribution of locations computed with less than 4 messages (Argos location classes 0, A and B) for Argo floats. This new delayed mode service would permit to:

- Have more Argos locations and more accuracy on delayed mode trajectories,
- Use locations closer to the real float surfacing position,
- Get more location s with error estimates (provide now for all classes) especially useful for float recovery with few messages collected by satellite pass.

8. References

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