Post-EPS altimeter mission orbit determination and tide aliasing

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Introduction

The aim of the study is to suggest optimal orbit candidates for a new Post-EPS (EUMETSAT Polar System) altimeter mission planned around 2020 and onward. After more than 15 years of continuous and accurate space altimetry, it is worth questioning old strategies, and trying to define the best choices for future missions, based on the experience of previous missions and on the requirements from data users.
Optimising future altimeter missions is indeed a complex problem. Many conflicting requirements, constraints and issues must be taken into account. The orbit geometry determines the geographical coverage, the space/time sampling by the altimeter measurements and the type of applications that can be addressed. While defining a new altimeter mission, it is thus of highest importance to optimise the orbit parameter. Particularly the aliasing of tides is a crucial issue: it was one of the drivers of the choice of the TOPEX/Poseidon-Jason's orbit. Nowadays tidal signals are well known in deep ocean. However some issues remain in coastal areas and internal tides are not determined accurately. Aliasing of tides by altimeter sampling remains a challenge as it may pollute other signal estimations, particularly in the aliasing band of 40-90 days and the semi-annual/annual band.

Aliasing of tides

* Determined by orbit repeat period
* Aliasing needs to be studied as a function of inclination for tides whose period is an integer fraction of days (K1,S1,P1K2,S2),
* As a function of cycle duration for other tides (O1,Q1,M2,N2 …)
* Presented by J.P. Berthias at the OST strategic workshop, 2008
* **Good aliasing frequency is 2 cpy minimum (T/P, SWOT)**

Separability of waves

* Time to separate 2 constituents is given by the Rayleigh criteria
* **Time to separate 2 constituents needs to be minimized**
* **Consider mission lifespan limitation**

Post-EPS orbit selection criteria :

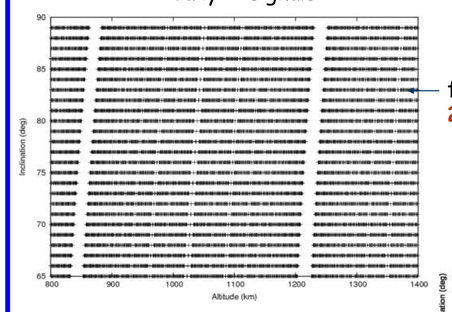
* Tidal aliasing issues
  - No sun-synchronous orbits (to allow aliasing of daily signals)
  - Consider main tides + some non-linear tides
  - K1 alias is important
  - No aliasing at annual or semi-annual frequencies
  - No aliasing to very long period
    - Good aliasing frequency is over 2 cpy
  - Good separability of major tides constituents
* Good mesoscale observability
  - Scales of ~150 km, ~15 days
  - 3-4 days subcycles are preferred
* Climate issues
  - Need to avoid the [4..9 cpy] aliasing band
  - No aliasing at annual or semi-annual frequencies + good separation with Sa Ssa
  - No aliasing close to 3 or 6 cpy (60 days climate signals)
* Low altitudes to reduce mission costs

Global recommendations from analysis of passed/planned altimeter missions (GFO,TP,Jason,Envisat,Sentinel3, …)

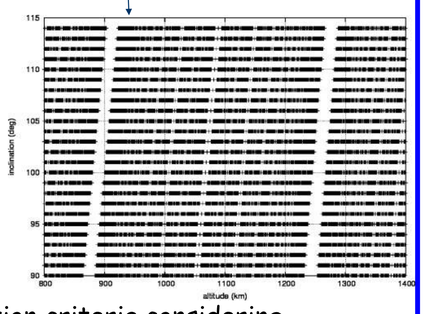
*** Payload characteristics need to be optimised**

*** Raw recommendations for optimisation of orbit geometry**

- Altitude between 800 and 1400 km (Berthias 2008)
- Air-drag and solar radiation exposure trade-off
- Repeat cycle between 10 and 35 days (mesoscale observation + Long term continuity challenge)
- High inclination to get more polar ocean observations
- No sun-synchronous orbits because they do not allow aliasing of daily signals



=> > 44000 possible orbit candidates for Post-EPS :**22304 prograde orbits + 22848 retrograde orbits**



=> Need to define some selection criteria considering user/experts requirements : tides, climate, mesoscale, mission cost …

⇒ **All those criteria are very constraining : trade-off and priorities are needed …**

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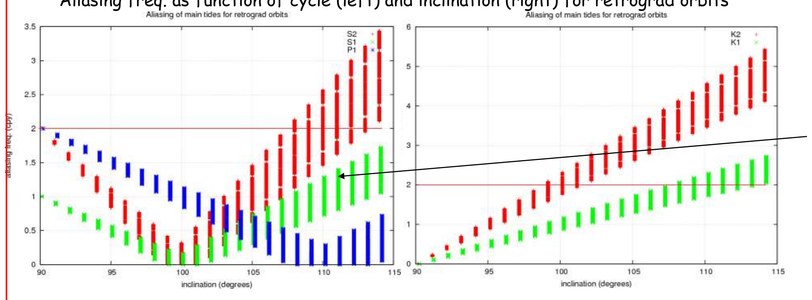
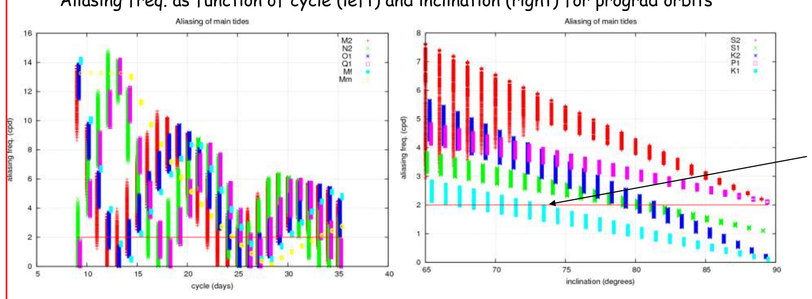
First strategy : tide aliasing is a priority = most aliasing freq. > 2cpy + good separability criteria

Aliasing freq. as function of cycle (left) and inclination (right) for retrograd orbits



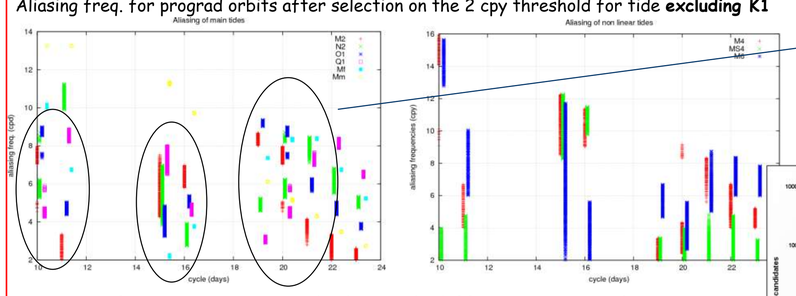
=> None retrograd orbit is selected due to P1 and S1 bad alias

Aliasing freq. as function of cycle (left) and inclination (right) for prograd orbits



=> **K1 alias is very restrictive in terms of inclination : < 72 °**

Aliasing freq. for prograd orbits after selection on the 2 cpy threshold for tide **excluding K1**



=> **1433 orbits candidates remain :**
- Repeat cycles around 10-11, 15-16, 19-23 days
- Inclinations until 81° are suitable
- Need more criteria for selection : **separability**

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Number of remaining orbits which match different separability criteria between 3 years (zero) and infinity (which means no selection with this criterion), for different aliasing criteria (considering K1 or not) and for optimised 2-satellite orbits or not.
Separability is a very restricting criteria => need trade off and to define most important waves to consider …

Second strategy : tide aliasing is **not** a priority as tides already well known + climate purposes are a priority (good separability criteria with Sa+ Ssa + less alias in [4-9 cpy] as possible) + mesoscale observation is a priority (3-4 days sub-cycles only)

32 remaining orbits candidates with a 4 days sub cycle, K1 alias > 2 cpy, altitude below 1150 km and aliasing score below 400. Scores depend on the aliasing performances of the orbits for climate, tides purposes: the smaller is better:

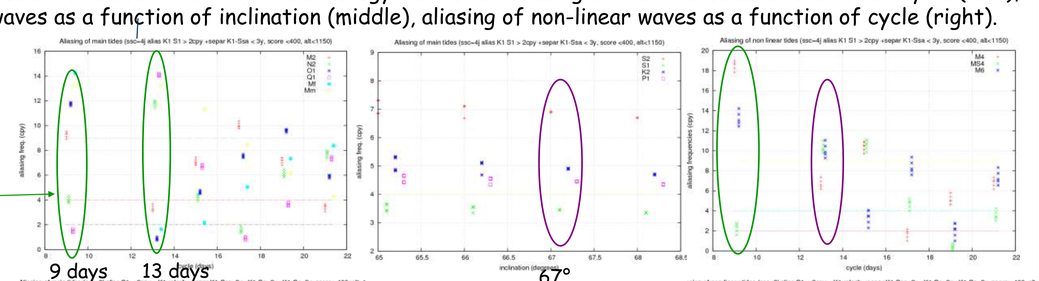
Score=
+ 10000 for bad aliasing of M2 or S2 : such orbits are ruled out.
+ 100 for bad aliasing for all other waves
+ 10 if the time separability with Sa or Ssa is greater than 5 years, for all waves
+ 1 if the aliasing frequency is in the 4-9 cpy band (40-90 days)
+ 0.01 if the aliasing frequency is around 3 cpy (120 days)
+ 0.001 if the aliasing frequency is around 6 cpy (60 days)

ssc4j_score400_alt1150												
nb rev.	frac rev.	cycle	inclination	altitude (km)	CYCLE	S1	K2S	N2	K1L	M4	S2	M2	score
13	2	9	65	1127,825	8,916596	106,908522	75,575739	94,560963	151,151479	19,442802	53,454274	38,885605	103
13	7	9	65	921,305	8,910605	99,676867	68,544733	84,338088	137,089466	20,462781	49,838444	40,925561	205
13	3	13	65	1124,54	12,879398	106,792743	75,460073	30,730588	150,920147	56,748111	53,396384	113,496222	204,01
13	10	13	65	924,379	12,871011	99,783617	68,645736	31,9218	137,291471	49,623971	49,89182	99,247942	214
13	4	15	65	1110,782	14,860215	106,307972	74,9769	85,06107	149,953799	34,719769	53,153999	51,9592	17
13	11	15	65	937,322	14,851828	100,233764	69,072541	93,526352	138,145083	37,54337	50,116893	49,144979	16
13	4	17	65	1122,802	16,8422	106,731454	75,398886	249,543637	150,797772	192,52997	53,36574	36,913535	328
13	13	17	65	926,007	16,831417	99,840314	68,699413	191,402053	137,398826	367,460914	49,920168	35,278765	327
13	5	19	65	1112,124	18,823017	106,355173	75,023865	60,349841	150,04773	73,082015	53,177599	50,705841	108,002
13	14	19	65	936,055	18,812234	100,189659	69,030659	56,604723	138,061318	62,867987	50,094841	53,69048	218,002
13	5	21	65	1121,727	20,805002	106,693586	75,361096	46,657472	150,722192	51,764782	53,346806	103,529563	10,001
13	16	21	65	927,016	20,791822	99,875281	68,732529	49,396142	137,465058	59,239534	49,937652	118,479068	11,012
13	7	9	66	922,326	8,913054	102,512948	71,255992	88,239659	142,511984	20,032956	51,256486	40,065911	214
13	10	13	66	925,398	12,874544	102,621575	71,361003	31,408803	142,722006	52,395505	51,310799	104,791011	214
13	4	15	66	1111,727	14,863947	109,251446	77,938856	81,770571	155,877712	33,596405	54,625736	53,31657	18
13	11	15	66	938,336	14,855879	103,079308	71,804452	89,235739	143,608904	36,124011	51,539666	50,465546	17,01
13	13	17	66	927,026	16,836033	102,679147	71,416693	212,614578	142,833386	264,537444	51,339585	35,960724	318
13	5	19	66	1113,068	18,827742	109,299442	77,987717	62,149813	155,975434	78,67741	54,649734	49,501292	108,012
13	14	19	66	937,069	18,817368	103,034443	71,760918	58,328685	143,521837	67,351185	51,517233	52,22635	208,002
13	16	21	66	928,034	20,797522	102,714866	71,451257	48,172921	142,902514	55,756623	51,357445	111,513247	10,011
13	7	9	67	923,365	8,915522	105,536693	74,211879	92,551021	148,423758	19,618002	52,768359	39,236005	103
13	10	13	67	926,436	12,878103	105,647156	74,321166	30,908641	148,642332	55,517733	52,82359	111,035467	214,01
13	11	15	67	939,369	14,859961	106,11268	74,782761	85,295534	149,565523	34,799253	53,056353	51,868995	17
13	13	17	67	928,063	16,840683	105,705767	74,379192	239,323504	148,758384	206,339155	52,852896	36,674622	318
13	14	19	67	938,102	18,822541	106,06702	74,737413	60,174081	149,474826	72,561575	53,033522	50,830584	118,002
13	16	21	67	929,071	20,803264	105,74202	74,415095	47,000972	148,830191	52,640323	52,871022	105,280646	10,001
13	7	9	68	924,425	8,918007	108,765971	77,445651	97,338202	154,891301	19,217327	54,382999	38,434653	103,01
13	10	13	68	927,495	12,881687	108,878344	77,559647	30,421017	155,119294	59,060291	54,439185	118,120583	204,011
13	11	15	68	940,422	14,864071	109,351707	78,040946	81,665959	156,081892	33,560448	54,675867	53,362732	18
13	13	17	68	929,121	16,845367	108,937904	77,620108	273,964721	155,240216	168,930913	54,468965	37,422403	228
13	14	19	68	939,156	18,827751	109,305356	77,993739	62,153436	155,987479	78,689186	54,652691	49,498994	108,012
13	16	21	68	930,128	20,809047	108,974707	77,657481	45,87755	155,314963	49,836643	54,487367	99,673287	10,011

Remaining orbits candidates after selection on the 2nd strategy's criteria : aliasing of main waves as a function of cycle (left), aliasing of other main waves as a function of inclination (middle), aliasing of non-linear waves as a function of cycle (right).

4 days sub-cycle + K1 > 2cpy : **32 orbits**

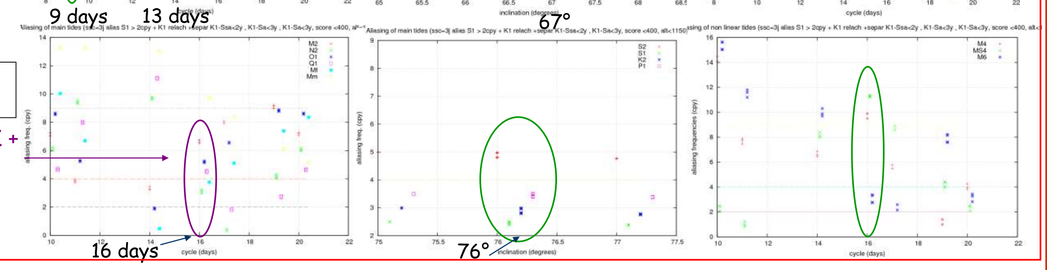
Climate criteria OK



9 days 13 days 67°

3 days sub-cycle + K1 < 2cpy : **23 orbits**

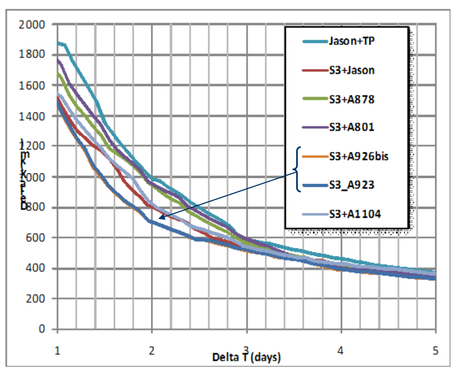
Climate criteria nearly OK + Tides aliasing not too bad



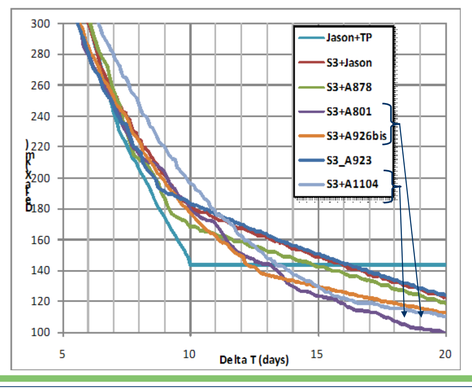
16 days 76°

Summary of orbits candidates proposed for Post-EPS, on purely tides aliasing criteria (blue), and while relaxing tides criteria and considering climate criteria (green):

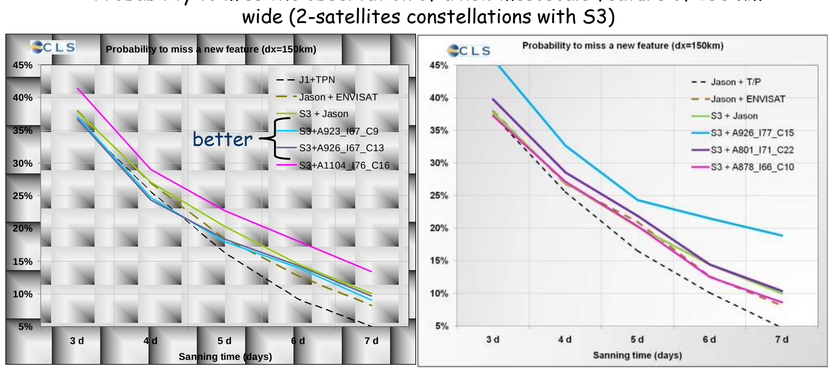
	Altitude (km)	Inc (deg)	Cycle (days)	Exact repeat cycle (days)	Tide Aliasing	Tide separability (years)	Optimisation for 2 satellites	Sub-cycle (days)	S1 aliasing (days)	rev/day
A878_i66_c10	**878.731**	**66**	**10**	**9.901936**	**K1 included**	**3.5 y**	**no**	**1**	**100.97**	**13+9/10**
A1150_i72_c11	1150.317	72	11	10.917843	No K1	4 y	yes	5	132.89	13+2/11
A964_i74_c19	964.879	74	19	18.860482	No K1	5 y	yes	3	135.18	13+13/19
A835_i75_c19	835.619	75	19	18.860551	No K1	5 y	yes	1	135.25	14+1/19
A1076_i68_c11	1076.855	68	11	10.904653	no K1, but alias K1>2cpy afterall	6y	yes	3	114.36	13+4/11
A801_i71_c22	**801.857**	**71**	**22**	**21.810438**	**K1 inluded**	**6 y**	**no**	**7**	**115.05**	**14+3/22**
A1361_i65_c11	1361.612	65	11	10.905338	K1 included	6 years	yes	3	115.20	12+7/11
A912_i70_c11	912.147	70	11	10.905479	K1 included	8 years	yes	5	115.37	13+9/11
A822_i68_c15	822.474	68	15	14.858551	K1 included	8 years	yes	1	105.04	14+1/15
A1104_i76_c16	**1104.802**	**76**	**16**	**15.895629**	**K1<2cpy**	-	**no**	**3**	**152.3**	**13+5/16**
A923_i67_c9	**923.365**	**67**	**9**	**8.915522**	**K1>2cpy**	-	**no**	**4**	**105.53**	**13+7/9**
A926_i67_c13	**926.436**	**67**	**13**	**12.878103**	**K1>2cpy -**	-	**no**	**4**	**105.64**	**13+10/13**



Approximate space/time scales resolved with post-EPS candidates (2-satellites constellations with S3)



Probability to miss the observation of a new mesoscale feature of 150 km wide (2-satellites constellations with S3)



Conclusions – Perspectives

* Selection on tidal/climate considerations allowed proposing a few orbits candidates for Post-EPS
* Preliminary characterisation of the orbits has been made : geometrical analysis of observable space/time scales, mesoscale structure observation …
* Any more recommendation from the experts to be taken into account within the orbit selection ?
* All the orbits candidates will be evaluated more in depth (planned work)
  - HF signals
  - Other applications: Mesoscale, MSL, climate variations of the ocean
  - Mission costs
  - POD

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OSTST meeting
Nice, November 2008
EUMETSAT