Cryosat-2 SAR and SARin contribution to Height System Unification in Greece

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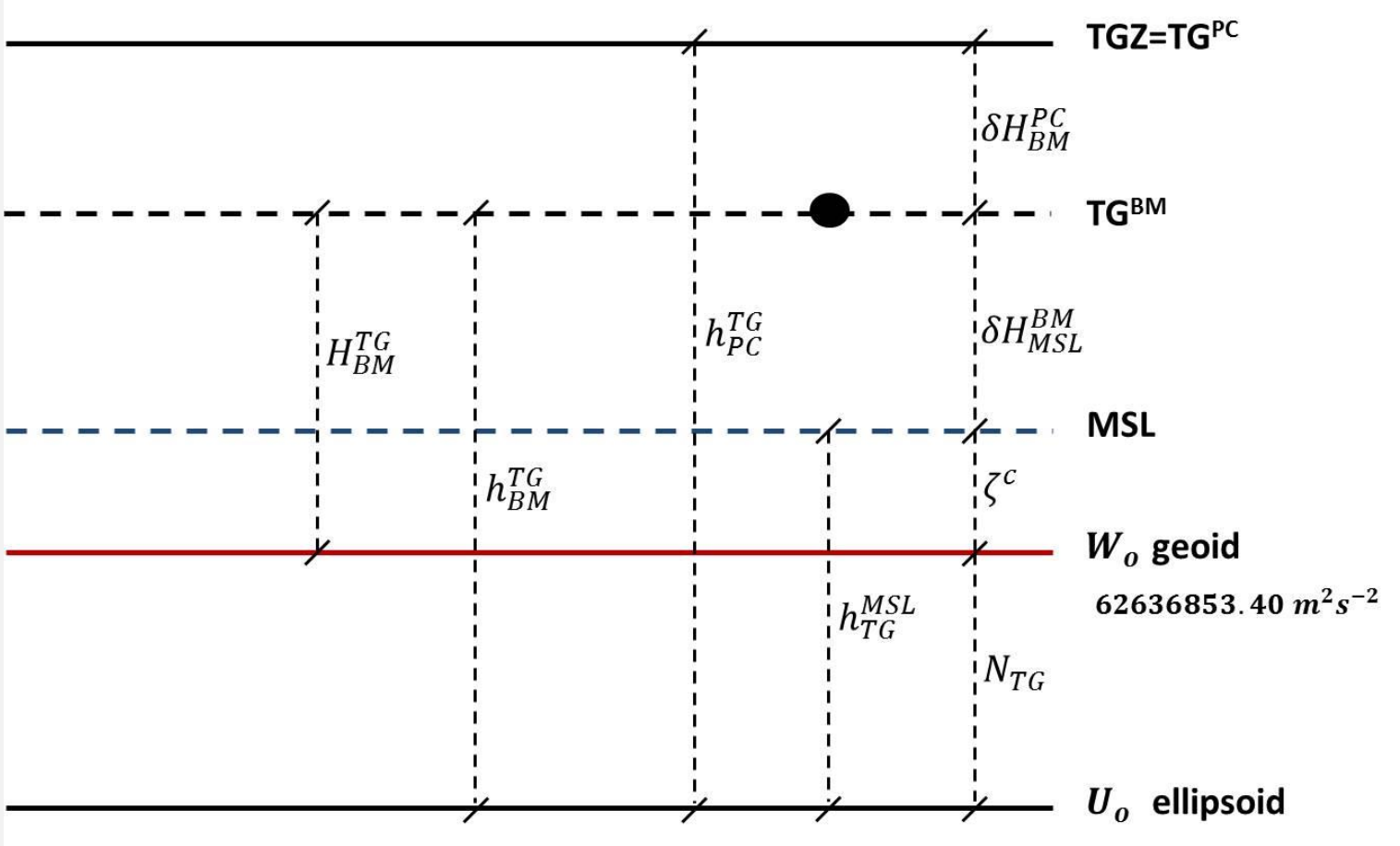
Rationale and outline

- For HSU ellipsoidal heights at BMs and/or TGs are needed
- Only a few number of TGs have collocated GNSS observations (SONEL)
- …..while many areas do not have GNSS infrastructure at all
- Nevertheless, HSU is needed as a tool for scientific and mainly engineering applications
- Satellite altimetry provides the opportunity to estimate ellipsoidal heights (almost) all over the world, irrespective of site location

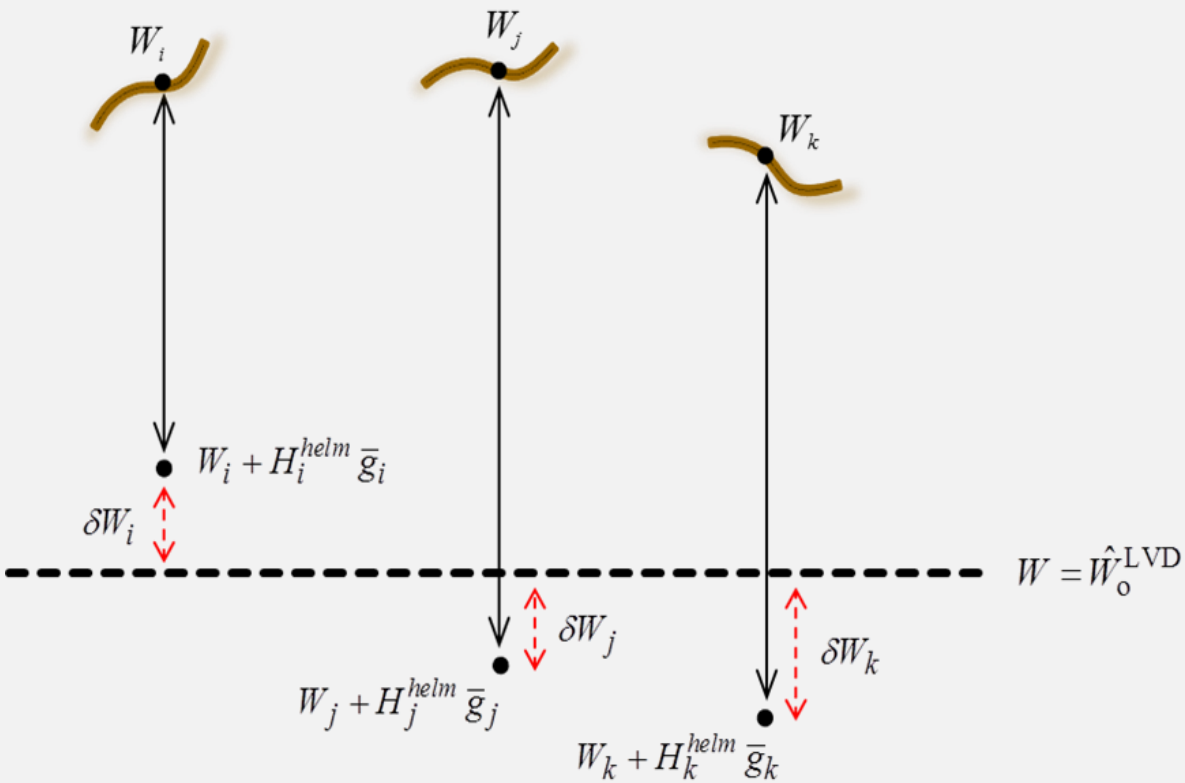
Necessity of the project and goals

To define the VRS and realize the VRF, link with ellipsoidal heights at the TG locations is needed



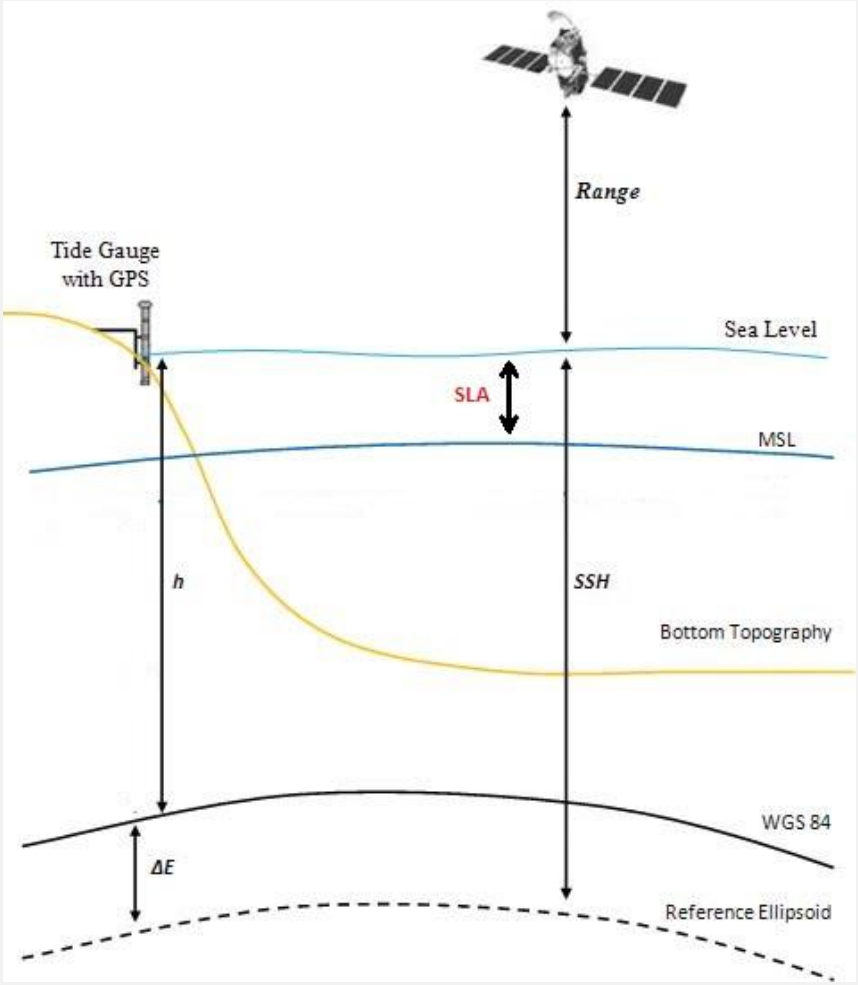
Necessity of the project and goals

Then HSU can be carried out employing all leveling, geoid, gravity, and TG data



Zero-height geopotential value determination from a network of stations (after Grigoriadis et al. 2014)

Data availability

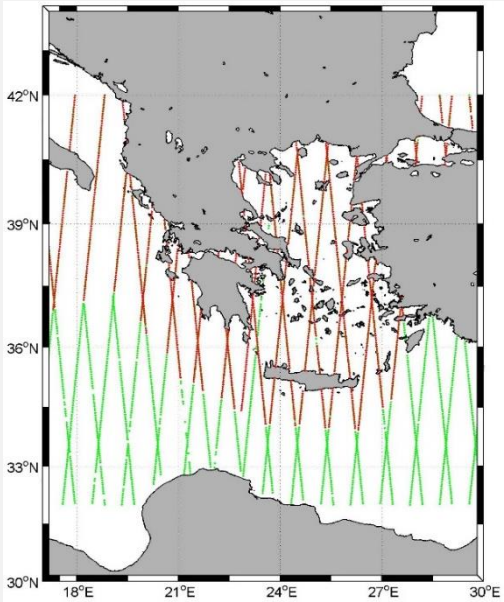


Singh et al. (2013)

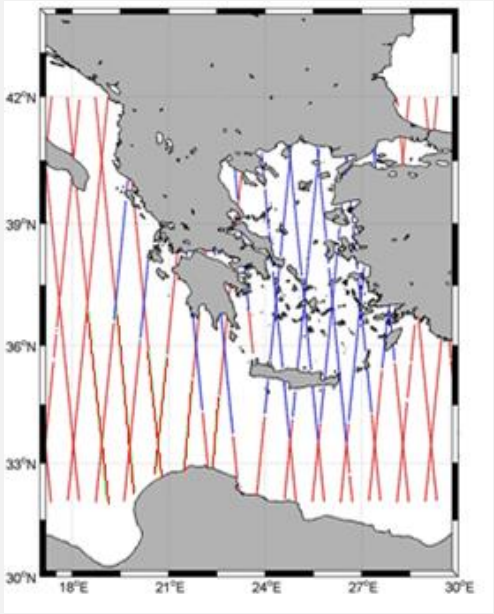
SLA values (August 2010 – December 2016)

LRM (2010-2015) - RADS
SAR (2010-2015) - SARVATORE
SARin (2016) - SARVATORE

Cycle 36



Cycle 75 until now



LRM ***SAR*** ***SARin***

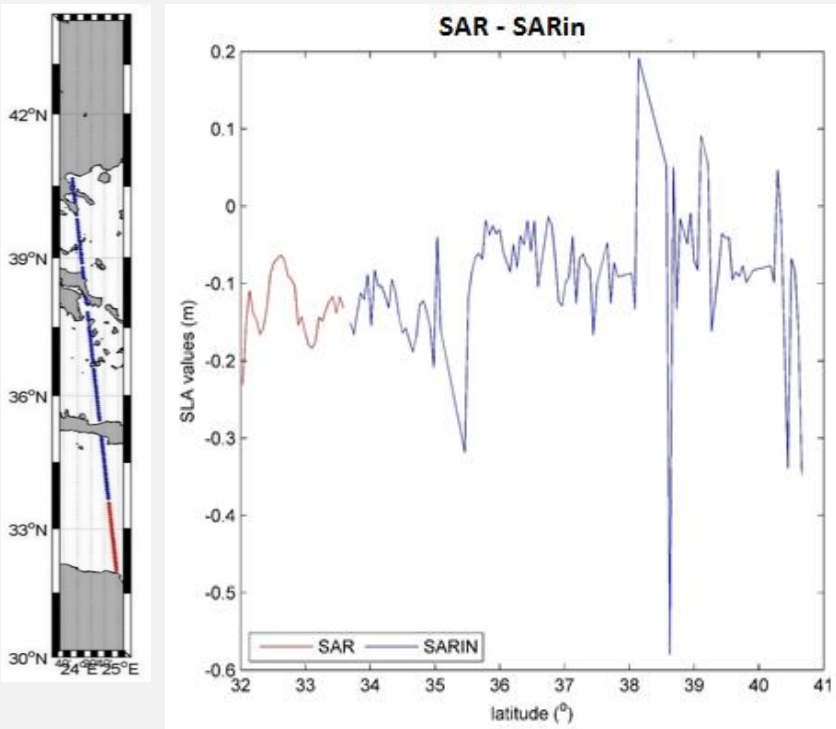
Data availability

- RADS : all corrections - except IB
- SARVATORE : all corrections - except IB/SSB
- SARVATORE Processing Options: Zero-padding, extended analysis window (256 range bins), re-tracking on coastal zone
- IB corrected - SLA values [-0.5,0.5] m → rejected

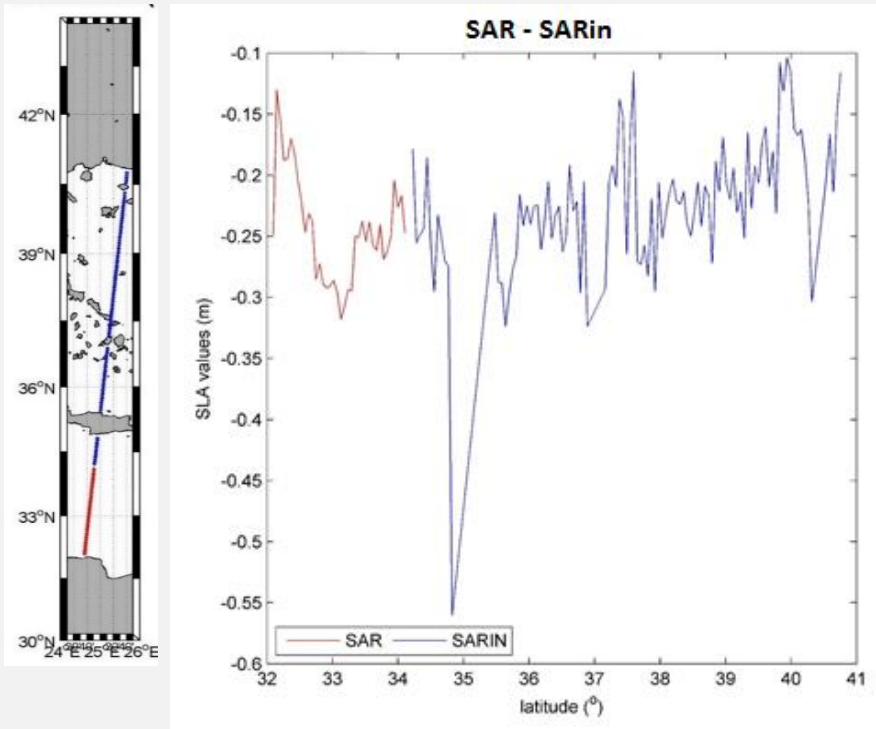
[cm]	LRM [171143]	SAR [111792]	SARin [11570]
min	-50.00	-49.99	-49.79
max	49.60	49.66	49.81
mean	-2.64	-7.33	-11.04
std	12.71	13.33	12.44
rms	12.99	15.21	16.63

Bias investigation between

- **SAR and SARin modes**



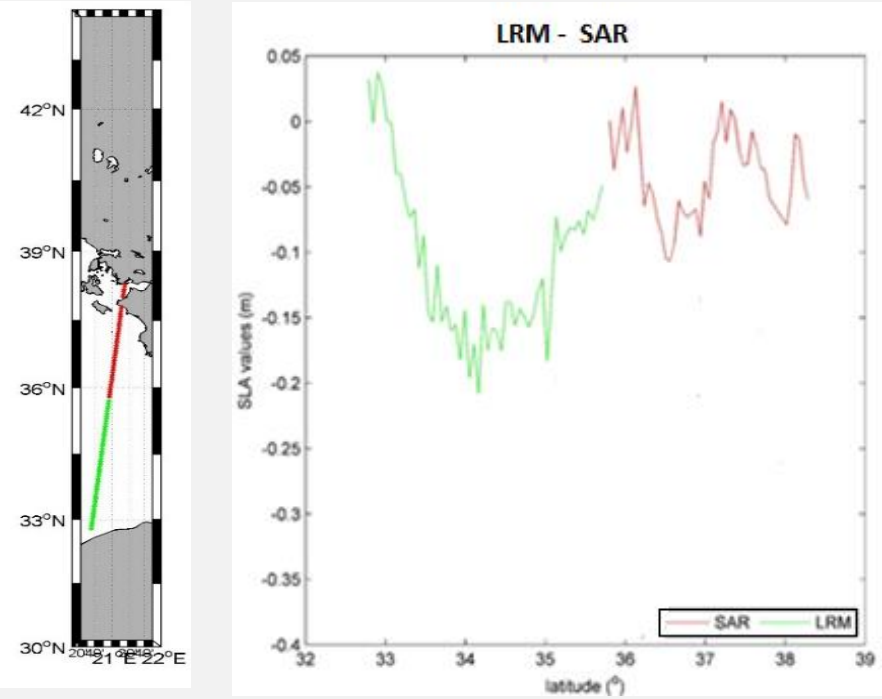
Cycle 74 – pass 738



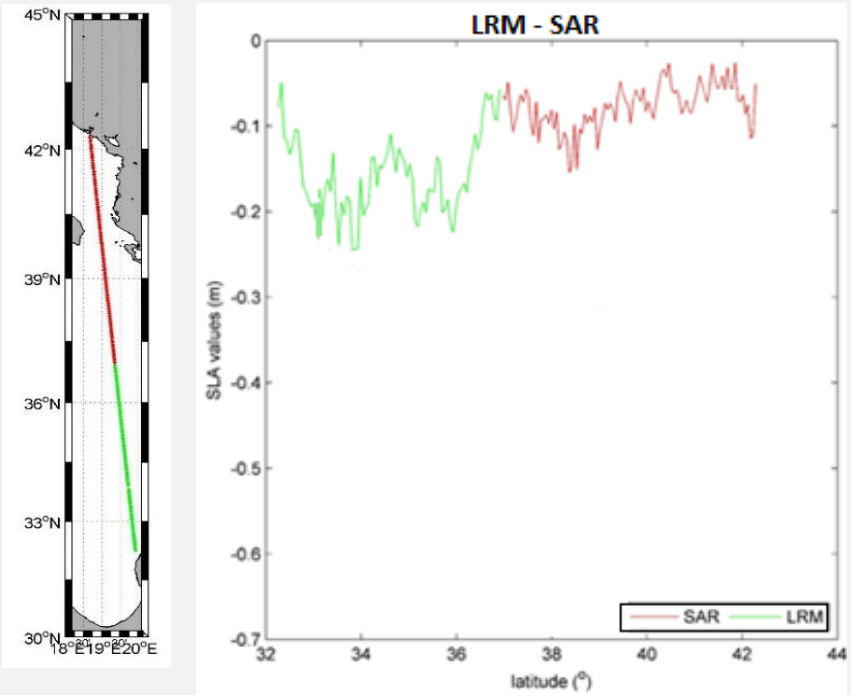
Cycle 74 – pass 607

Bias investigation between

- **SAR and LRM modes**



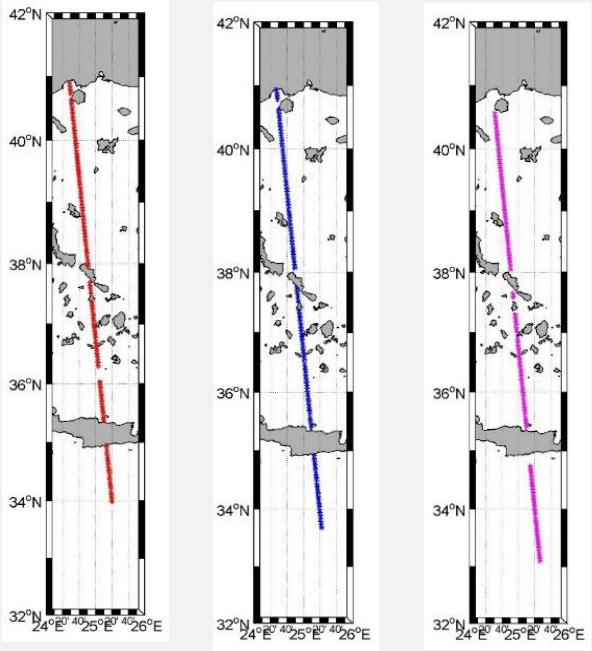
Cycle 74 – pass 188

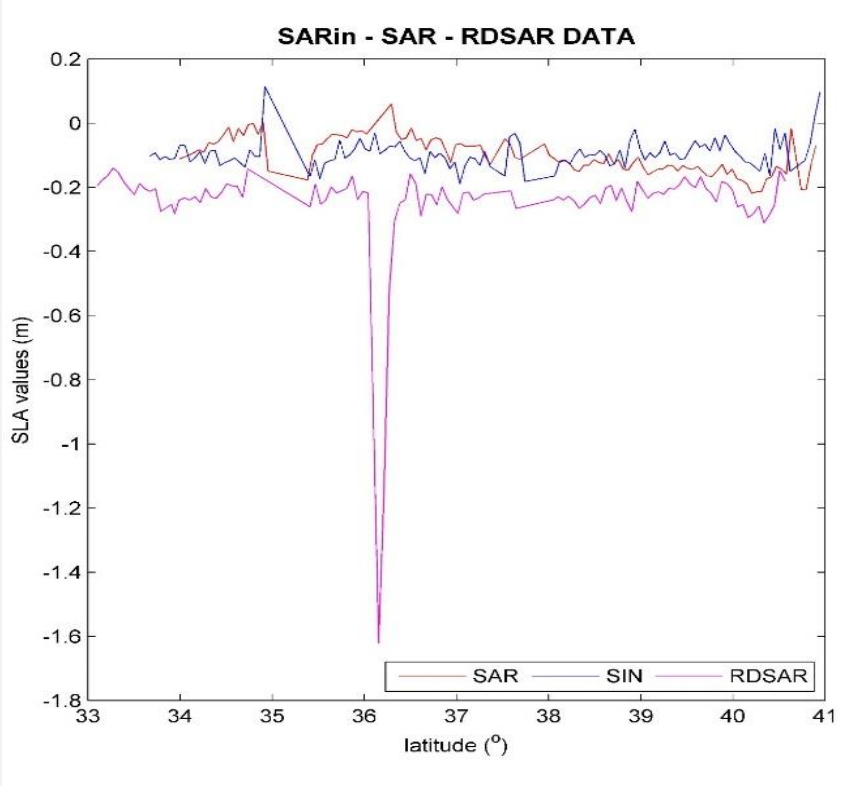


Cycle 74 – pass 173

Evaluation of SAR – SARin – RDSAR data in Greece

January : cycle 36 (SAR, RDSAR) - cycle 75 (SARin)





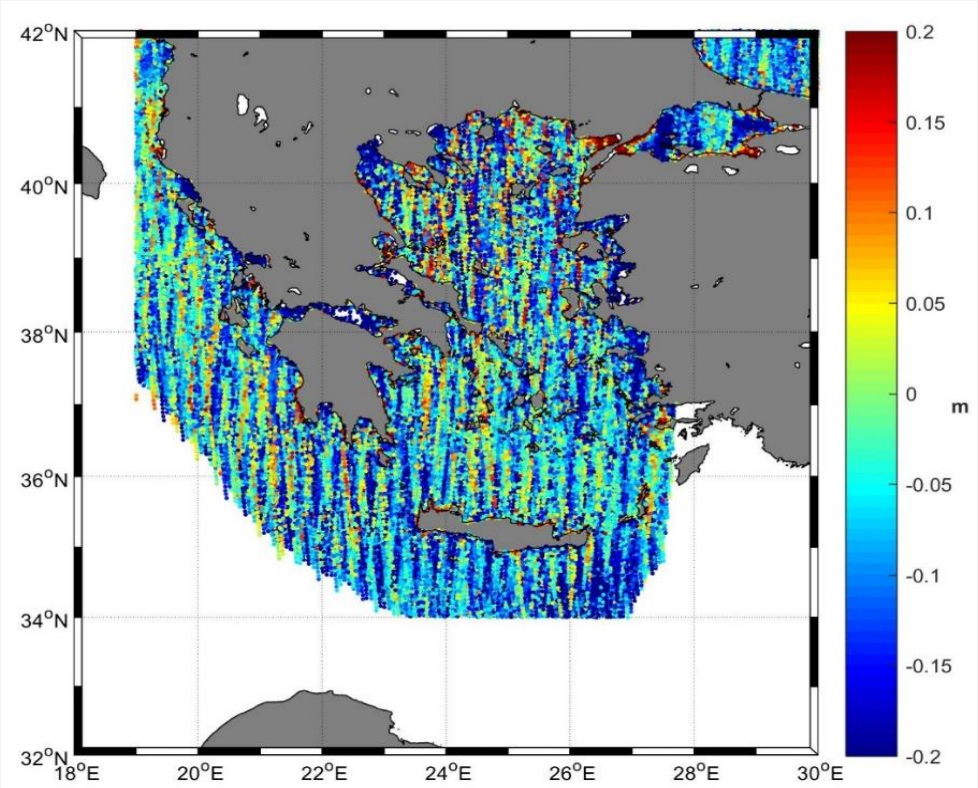
Evaluation of SAR – SARin – RDSAR data in Greece

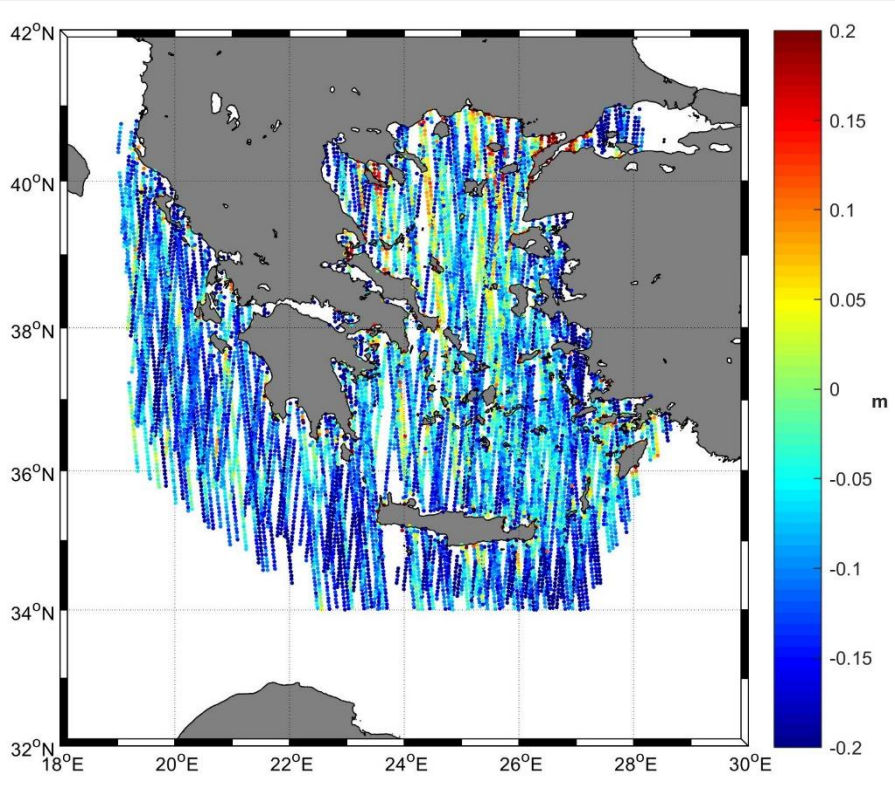
[cm]	#607 - January			#607 - February		
	2013 – cycle 36		2016 – cycle 75	2013 – cycle 37		2016 – cycle 76
	RDSAR	SAR	SARin	RDSAR	SAR	SARin
min	-162.20	-21.87	-18.98	-31.31	-55.34	-30.24
max	-14.00	5.90	11.43	0.70	2.17	1.02
std	±17.83	±5.58	±4.44	±5.33	±6.14	±6.28
mean	-25.28	-10.03	-9.62	-18.98	-13.64	-13.09
rms	±30.94	±11.47	±10.59	±19.54	±14.96	±14.52

[cm]	#738 - March			#607 - April		
	2013 – cycle 38		2016 – cycle 77	2013 – cycle 39		2016 – cycle 78
	RDSAR	SAR	SARin	RDSAR	SAR	SARin
min	-11.50	-74.26	-130.29	-100.60	-24.21	-26.26
max	29.10	13.72	25.54	9.80	9.34	6.92
std	±6.92	±8.78	±13.07	±12.80	±4.75	±5.77
mean	5.94	-6.00	-16.99	-7.36	-5.51	-2.47
rms	±9.12	±10.64	±21.44	±14.77	±7.28	±6.28

[cm]	#738 - May		
	2013 – cycle 40		2016 – cycle 79
	RDSAR	SAR	SARin
min	-123.10	-99.37	-44.36
max	18.30	9.94	13.23
std	±13.84	±10.39	±7.48
mean	-5.36	-10.31	-12.79
rms	±14.84	±14.64	±14.82

Cryosat-2 Data in the Aegean Sea 2010 - 2016





σ_{SAR} = 11.01 cm

~ 111000 pts.

σ_{SARin} = 9.24 cm

~ 11000 pts.

Ellipsoidal height prediction at BMs

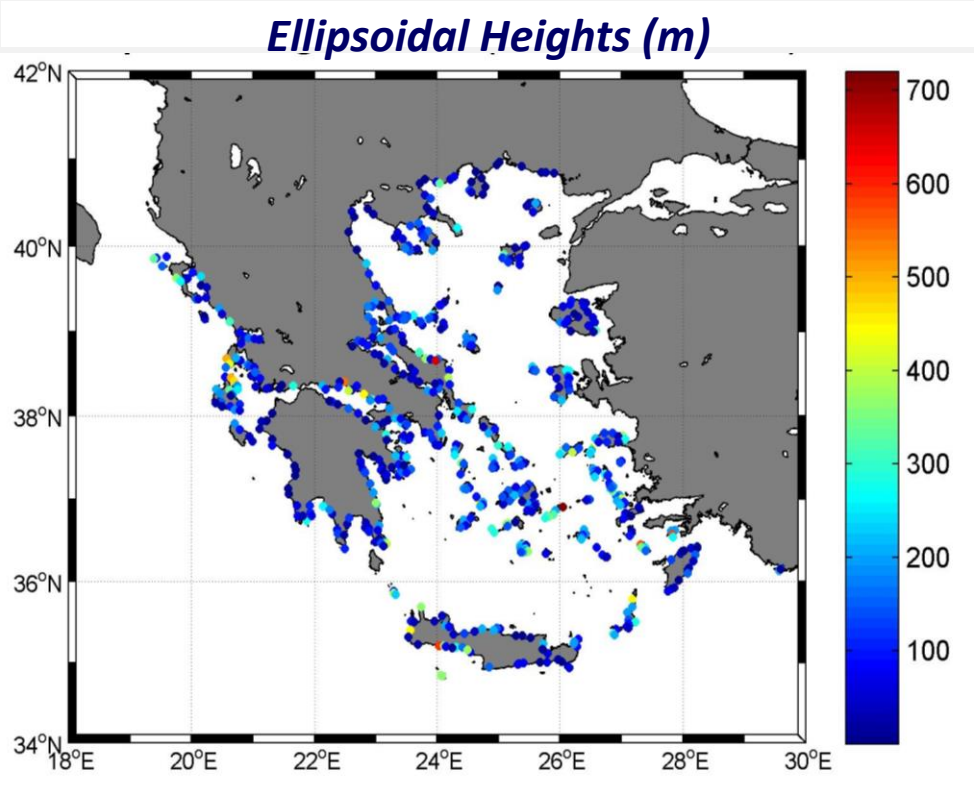
- 1D low pass filtering
- 2D low pass filtering
- Non-corrected SSB
- SSB corrected -> 4% SWH
- Linear – Nearest – Cubic interpolation

Prediction methods

- ✓ Cubic interpolation
- ✓ Least Squares Collocation

Ellipsoidal height prediction at BMs

602 BMs – 1 km from coastline



- Orthometric Heights : Helmert-type
  - σ_H= 0.1-1 cm (1σ) (formal)
  - σ_H= 3-8 cm (1σ) (realistic – a-posteriori)

- Ellipsoidal Heights : GPS measurements (Hepos project, 2008)
  - σ_{hor}= 1-4cm (1σ)
  - σ_{vert}=2-5 cm (1σ)

$$\hat{h} = MSS + SLA + H$$

Ellipsoidal height prediction at BMs

Cubic interpolation

A) 2D FILTERING – GRID 3’ – INTERPOLATION SLAs AT BMs – ADD MSS AT BMs

B) 2D FILTERING – GRID 3’ – ADD MSS AT GRID – INTERPOLATION MSS+SLA AT BMs

C) GRID 3’ – INTERPOLATION SLAs AT BMs – ADD MSS AT BMs

D) GRID 3’ – ADD MSS AT GRID – INTERPOLATION MSS+SLA AT BMs

E) GRID 3’ – 2D FILTERING – INTERPOLATION SLAs AT BMs – ADD MSS AT BMs

F) GRID 3’ – 2D FILTERING – ADD MSS AT GRID – INTERPOLATION MSS+SLA AT BMs

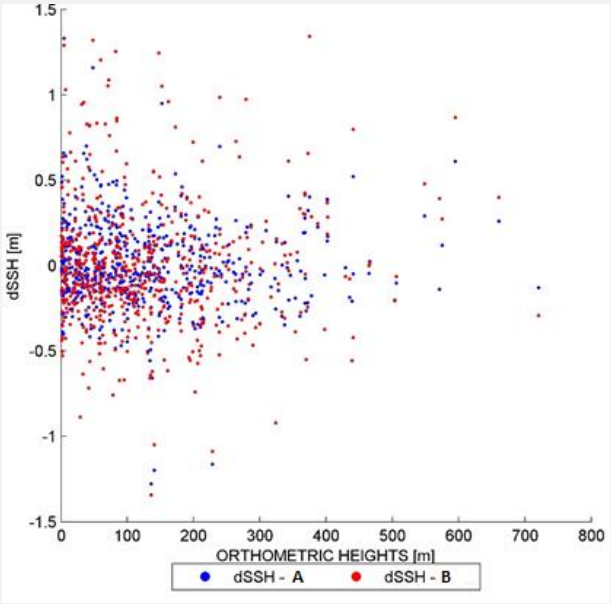
Ellipsoidal height prediction at BMs

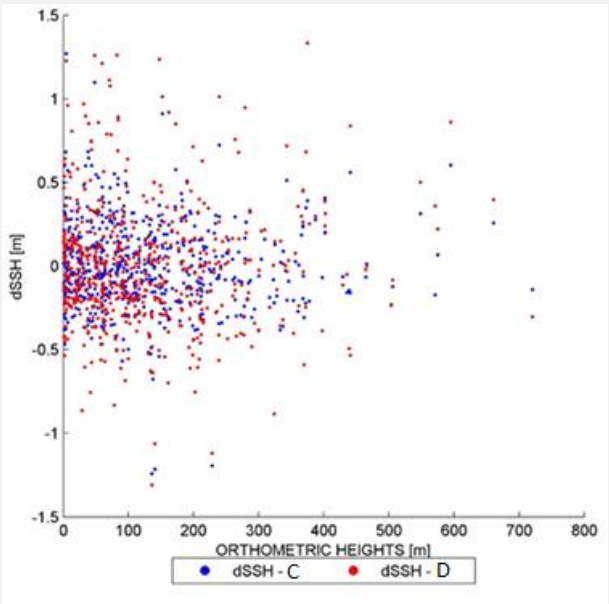
Cubic interpolation

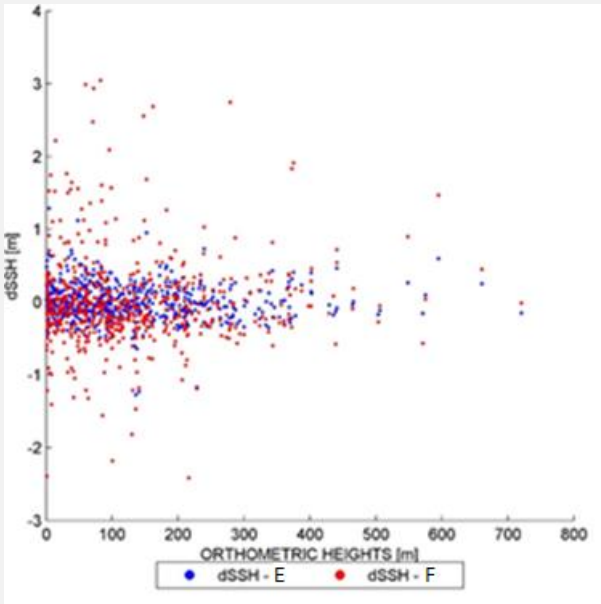
[cm]	A		B		C	
std	±23.76		±24.00		±25.72	
mean	-74.14		-71.91		-71.85	
	±10 cm [40.86%]	**±20 cm [69.77%]**	**±10 cm [39.87%]**	**±20 cm [69.10%]**	**±10 cm [33.22%]**	**±20 cm [62.79%]**
std	±5.75	±10.22	±5.74	±10.32	±5.81	±10.97
mean	-0.87	-2.65	-0.76	-2.52	-0.95	-2.07
rms	±5.82	±10.56	±5.79	±10.62	±5.89	±11.16
[cm]	**D**		**E**		**F**	
std	±35.84		±24.93		±61.71	
mean	-67.76		-74.26		-60.34	
	±10 cm [24.42%]	**±20 cm [51.16%]**	**±10 cm [41.80%]**	**±20 cm [70.02%]**	**±10 cm [21.59%]**	**±20 cm [37.54%]**
std	±5.45	±11.49	±5.12	±10.69	±5.70	±11.04
mean	-0.63	-0.94	-1.01	-1.81	-0.72	-1.71
rms	±5.49	±11.53	±5.22	±10.84	±5.75	±11.17

Ellipsoidal height prediction at BMs

Cubic interpolation – Differences between predicted and initial SLA values



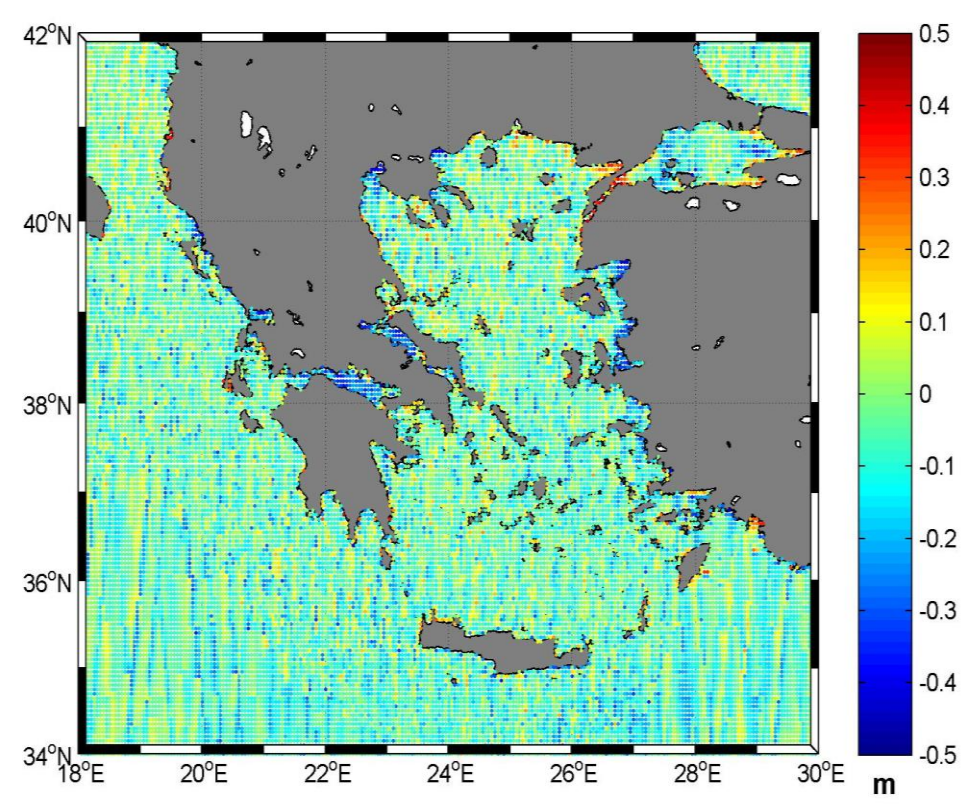


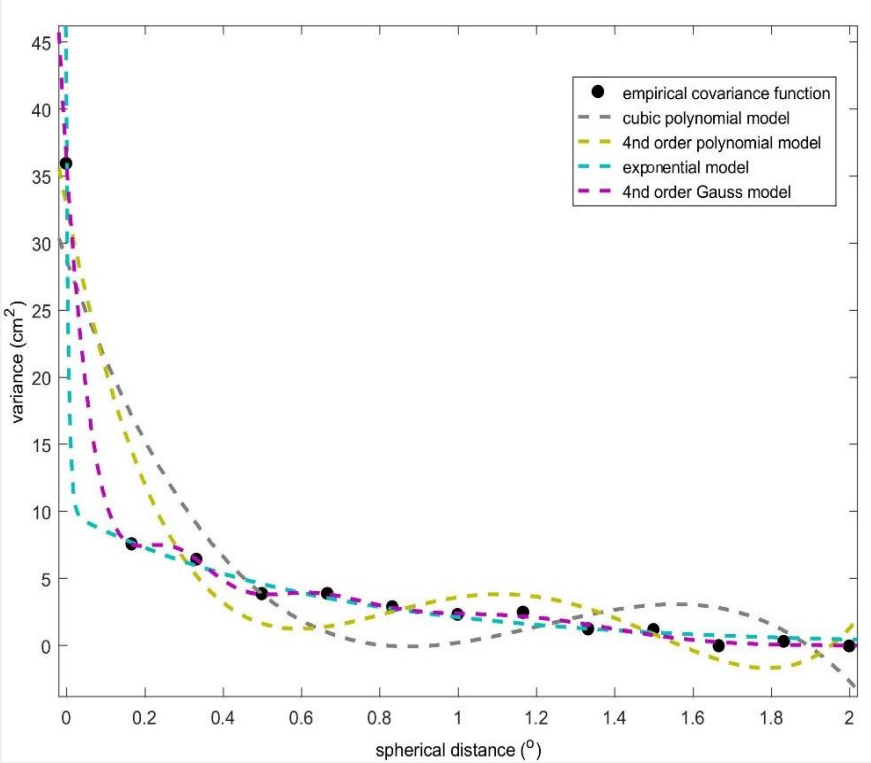


no correlation between prediction accuracy and topography

Ellipsoidal height prediction at BMs

Least Squares Collocation – Gridded data (CASE E)





Ellipsoidal height prediction at BMs

Least Squares Collocation – Gridded data (CASE E)

Remove Local Vertical Offset : -74.26 cm

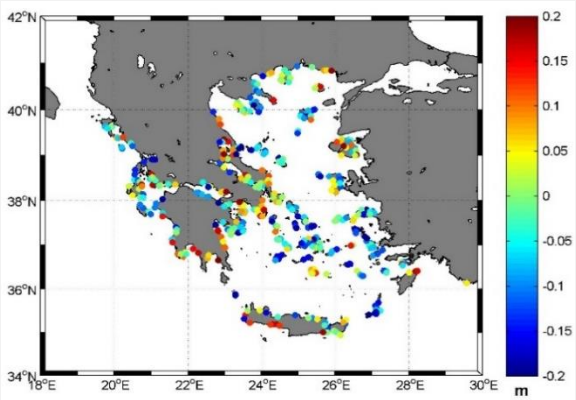
[cm]	Exponential model		3rd order polynomial model		4th order polynomial model		4th order Gauss model	
std	±23.45		±26.01		±25.49		±23.46	
mean	-77.63		-75.83		-75.67		-77.64	
	±10 cm [42.03%]	**±20 cm [69.77%]**	**±10 cm [37.20%]**	**±20 cm [62.46%]**	**±10 cm [36.54%]**	**±20 cm [62.46%]**	**±10 cm [42.03%]**	**±20 cm [69.77%]**
std	±5.47	±10.18	±10.41	±10.32	±5.89	±10.19	±5.48	±10.18
mean	-0.59	-2.56	-1.14	-2.30	-0.39	-2.39	-0.59	-2.57
rms	±5.50	±10.50	±10.48	±10.57	±5.90	±10.47	±5.51	±10.50

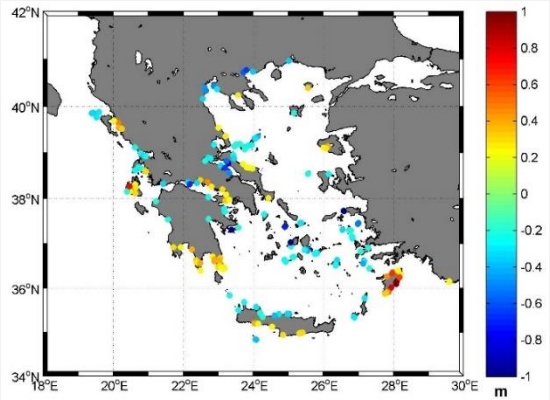
Remove Local Vertical Offset : - 64.91 cm

[cm]	Exponential model		3rd order polynomial model		4th order polynomial model		4th order Gauss model	
	±10 cm [29.73%]	**±20 cm [57.97%]**	**±10 cm [25.91%]**	**±20 cm [53.32%]**	**±10 cm [25.41%]**	**±20 cm [53.65%]**	**±10 cm [29.90%]**	**±20 cm [57.97%]**
std	±5.74	±10.27	±5.51	±10.91	±5.31	±10.69	±5.78	±10.27
mean	-2.20	-5.15	-1.38	-3.84	-1.41	-4.04	-2.13	-5.16
rms	±6.15	±11.49	±5.68	±11.57	±5.50	±11.43	±6.17	±11.49

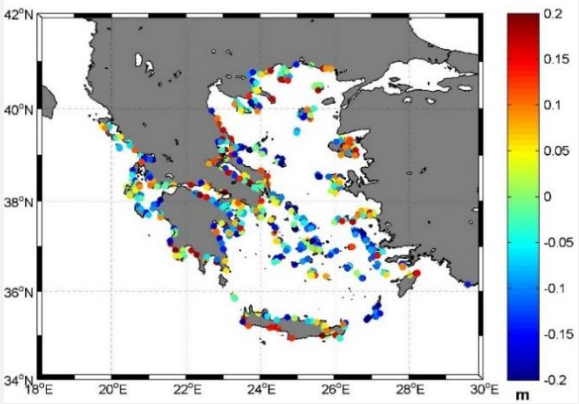
Ellipsoidal height prediction at BMs

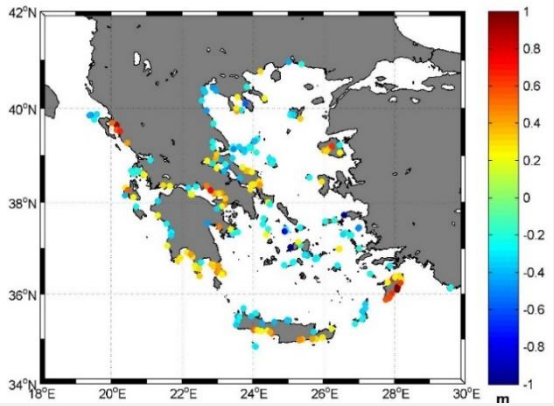
Dh ≤ ±20 cm (left) and Dh ≥ ±20 cm (right)





Exponential model [420/602]

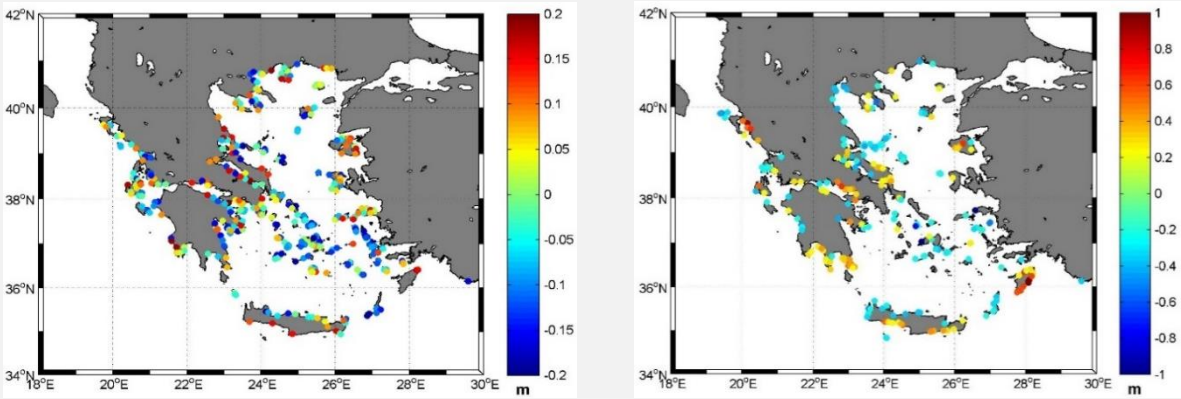




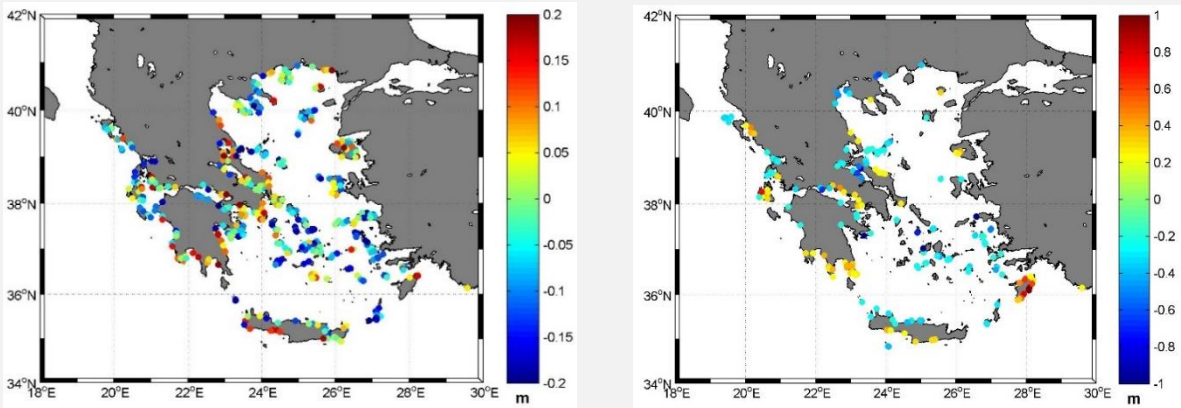
3nd order polynomial model [376/602]

Ellipsoidal height prediction at BMs

Dh ≤ ±20 cm (left) and Dh ≥ ±20 cm (right)



4th order polynomial model [376/602]

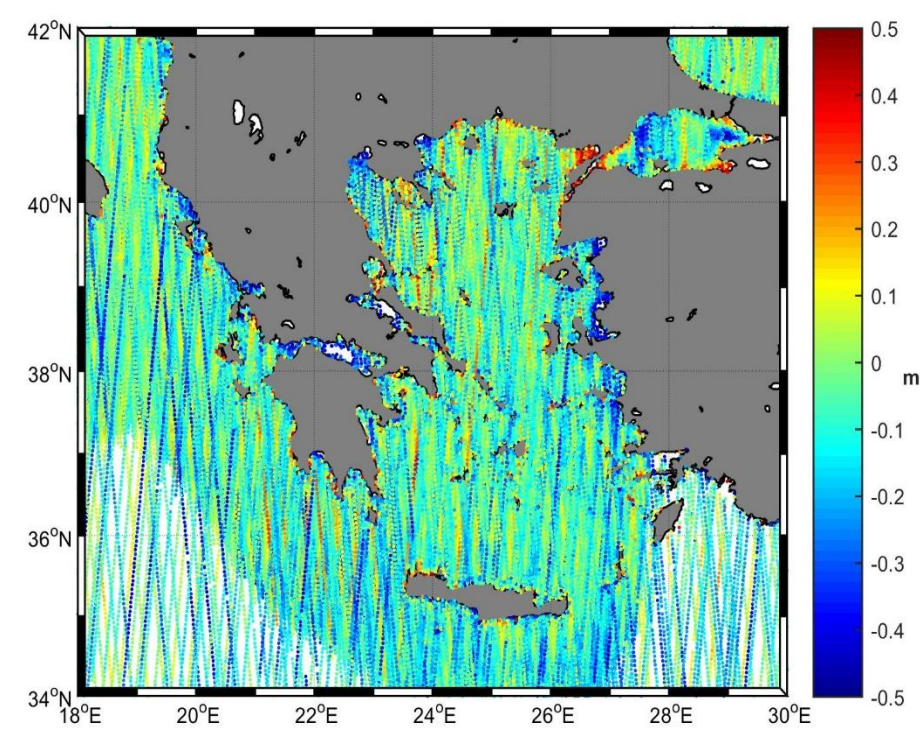


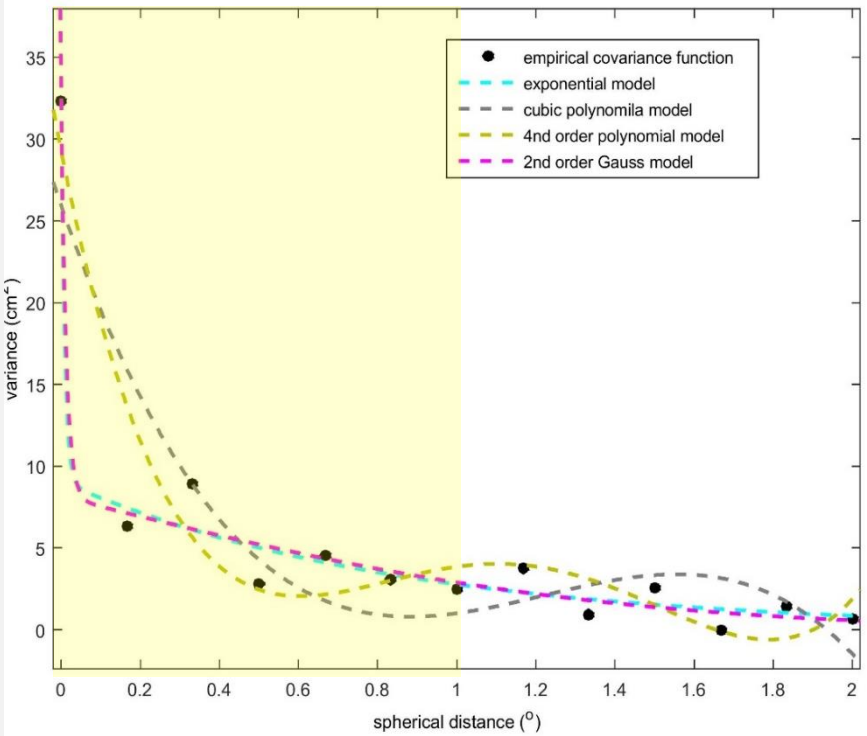
4th order Gauss model [420/602]

no correlation between prediction accuracy and topography

Ellipsoidal height prediction at BMs

Least Squares Collocation – Irregular data





Ellipsoidal height prediction at BMs

Least Squares Collocation – Irregular data

Remove Local Vertical Offset : -74.26 cm

[cm]	Exponential model [532/602]		3rd order polynomial model [197/602]		4th order polynomial model [353/602]		2nd order Gauss model [431/602]	
std	±22.54		±76.28		±66.31		±23.95	
mean	-76.49		-74.7		-25.21		-44.14	
	±10 cm [35.88%]	**±20 cm [61.46%]**	**±10 cm [3.65%]**	**±20 cm [6.81%]**	**±10 cm [8.80%]**	**±20 cm [17.11%]**	**±10 cm [27.91%]**	**±20 cm [48.50%]**
std	±5.58	±10.55	±6.11	±11.42	±5.74	±10.88	±5.54	±10.71
mean	-0.48	-2.20	-1.38	-1.25	0.31	0.00	-0.49	-1.72
rms	±5.60	±10.78	±6.26	±11.49	±5.75	±10.88	±5.56	±10.85

Remove Local Vertical Offset : -64.91 cm

[cm]	Exponential model [532/602]		3rd order polynomial model [197/602]		4th order polynomial model [353/602]		2nd order Gauss model [431/602]	
	±10 cm [26.08%]	**±20 cm [51.50%]**	**±10 cm [2.32%]**	**±20 cm [7.48%]**	**±10 cm [8.64%]**	**±20 cm [17.11%]**	**±10 cm [21.60%]**	**±20 cm [42.03%]**
std	±5.65	10.52	±5.78	±10.85	±5.82	±12.86	±5.82	±11.50
mean	-1.92	-4.62	-1.65	-3.74	-0.98	1.03	-1.27	-1.26
rms	±5.97	11.49	±6.01	±11.47	±5.90	±12.90	±5.96	±11.57

Ellipsoidal height prediction at BMs

Least Squares Collocation – Irregular vs. gridded data

Remove Local Vertical Offset : -74.26 cm

[cm]	Exponential model [532/602]		Exponential model (gridded)	
std	±22.54		±23.45	
mean	-76.49		-77.63	
	±10 cm [35.88%]	**±20 cm [61.46%]**	**±10 cm [42.03%]**	**±20 cm [69.77%]**
std	±5.58	±10.55	±5.47	±10.18
mean	-0.48	-2.20	-0.59	-2.56
rms	±5.60	±10.78	±5.50	±10.50

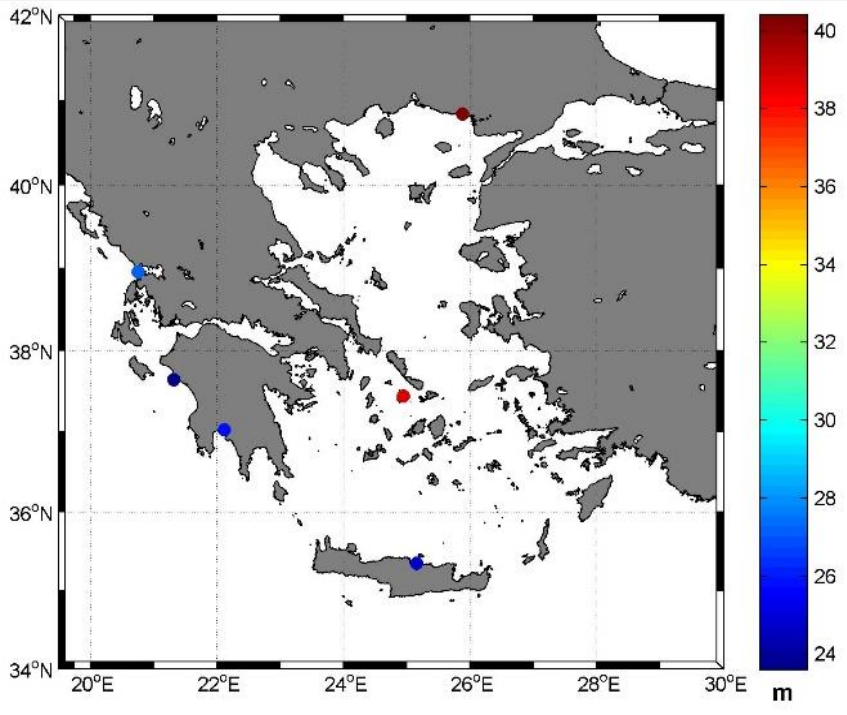
Remove Local Vertical Offset : -64.91 cm

[cm]	Exponential model [532/602]		Exponential model (gridded)	
	±10 cm [26.08%]	**±20 cm [51.50%]**	**±10 cm [29.73%]**	**±20 cm [57.97%]**
std	±5.65	10.52	±5.74	±10.27
mean	-1.92	-4.62	-2.20	-5.15
rms	±5.97	11.49	±6.15	±11.49

Ellipsoidal height prediction at TGs

Tide gauges in Greece (SONEL)

$$\hat{h} = MSS + SLA$$



PSMSL ID	Latitude(°)	Longitude(°)	Station
1238	40.84414	25.87827	ALEXANDROUPOLIS
634	35.34848	25.15269	IRAKLION
411	37.02368	22.11584	KALAMAI
1240	37.64482	21.31968	KATAKOLON
410	38.95908	20.75663	PREVEZA
1234	37.43997	24.94581	SIROS

PSMSL ID	Ellipsoidal Heights [m]	
	Tide free system	Mean tide system
1238	40.419	40.402
634	24.705	24.705
411	25.761	25.756
1240	23.607	23.600
410	27.055	27.044
1234	38.634	38.628

Altimetric data -> mean tide system
Tide gauges data -> tide free system

$$h^{MT} = h^{TF} + 0.62\left(0.099 - 0.296\sin^2\varphi\right)$$

Cubic interpolation – Gridded data (CASE E)

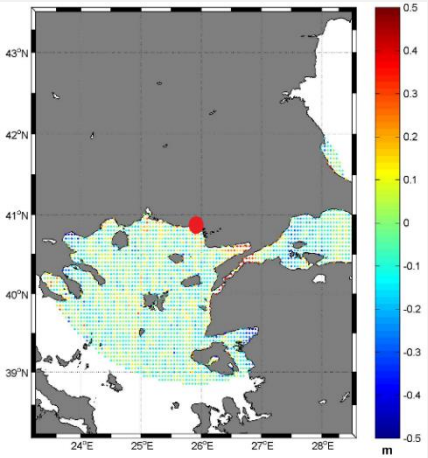
[unit: m]						LVD (-74.26 cm)		LVD (–64.91 cm)	
PSML ID	$h_{INITIAL}$	DTU13 MSS	SLA	$h_{INITIAL}$ - MSS	$h_{INITIAL}$ - (MSS+SLA)	$h_{INITIAL}$ - MSS	$h_{INITIAL}$- (MSS+SLA)	$h_{INITIAL}$- MSS	$h_{INITIAL}$- (MSS+SLA)
1238	40.402	40.869	-0.005	-0.467	-0.462	0.276	0.281	0.182	0.187
634	24.705	25.29	0.081	-0.585	-0.666	0.158	0.077	0.064	-0.017
411	25.756	26.441	0.091	-0.685	-0.775	0.058	-0.032	-0.036	-0.126
1240	23.600	24.275	0.033	-0.675	-0.708	0.068	0.035	-0.026	-0.059
410	27.044	27.872	-0.139	-0.828	-0.689	-0.085	0.054	-0.179	-0.04
1234	38.628	39.296	0.05	-0.668	-0.719	0.075	0.024	-0.019	-0.07
Statistics			min	-0.828	-0.775	-0.058	0.024	-0.179	-0.126
			max	-0.467	-0.462	0.158	0.281	0.182	0.187
			std	±0.120	±0.108	±0.120	±0.108	±0.120	±0.108
			mean	-0.651	-0.67	0.091	0.073	-0.002	-0.021
			rms	±0.662	±0.678	±0.150	±0.130	±0.120	±0.110

Cubic interpolation – Gridded data (CASE E)

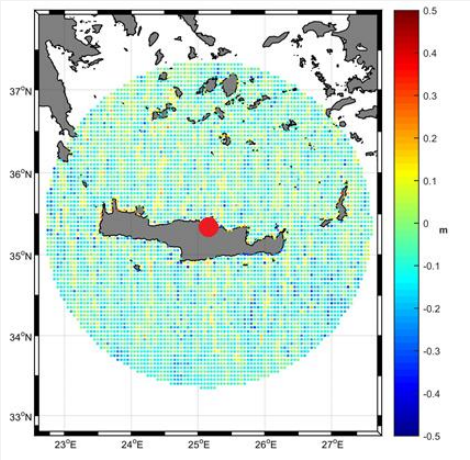
[unit: m]						LVD (-74.26 cm)		LVD (–64.91 cm)	
PSML ID	$h_{INITIAL}$	DTU13 MSS	SLA	$h_{INITIAL}$ - MSS	$h_{INITIAL}$ - (MSS+SLA)	$h_{INITIAL}$ - MSS	$h_{INITIAL}$- (MSS+SLA)	$h_{INITIAL}$- MSS	$h_{INITIAL}$- (MSS+SLA)
1238	40.402	40.869	-0.005	-0.467	-0.462	0.276	0.281	0.182	0.187
634	24.705	25.29	0.081	-0.585	-0.666	0.158	0.077	0.064	-0.017
411	25.756	26.441	0.091	-0.685	-0.775	0.058	-0.032	-0.036	-0.126
1240	23.600	24.275	0.033	-0.675	-0.708	0.068	0.035	-0.026	-0.059
410	27.044	27.872	-0.139	-0.828	-0.689	-0.085	0.054	-0.179	-0.04
1234	38.628	39.296	0.05	-0.668	-0.719	0.075	0.024	-0.019	-0.07
Statistics			min	-0.828	-0.775	-0.085	-0.032	-0.179	-0.126
			max	-0.585	-0.666	0.158	0.077	0.064	-0.017
			std	**±0.088**	**±0.041**	**±0.088**	**±0.041**	**±0.088**	**±0.041**
			mean	-0.688	-0.711	0.055	0.032	-0.039	-0.062
			rms	0.694	0.713	±0.103	±0.052	±0.096	±0.075

Ellipsoidal height prediction at TGs

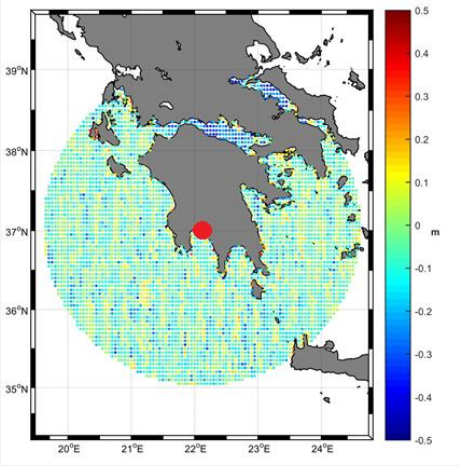
Least Squares Collocation – Gridded data (CASE E), radius 2°



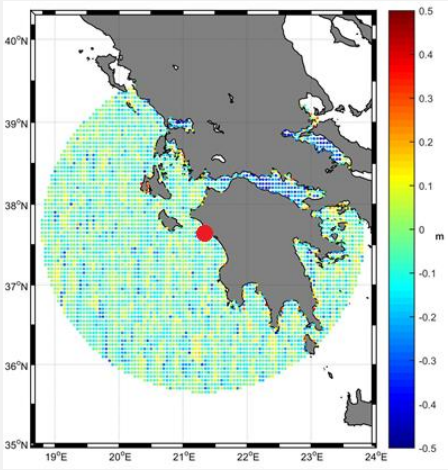
ALEXANDROUPOLIS



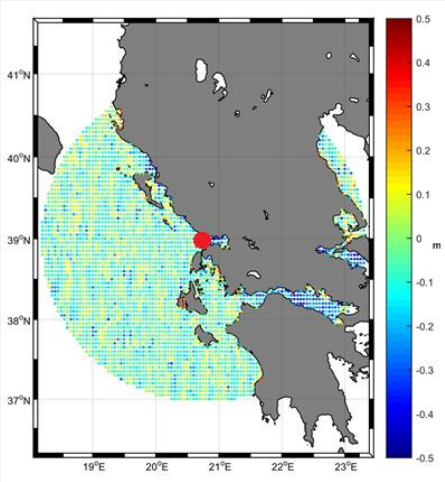
IRAKLION



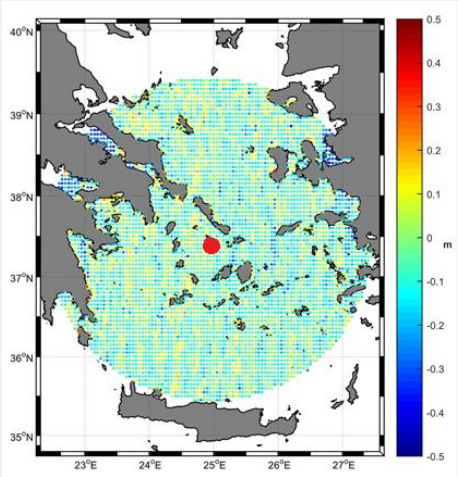
KALAMAI



KATAKOLON



PREVEZA



SIROS

Ellipsoidal height prediction at TGs

Least Squares Collocation – Gridded data (CASE E), radius 2°

PSMSL ID	Exponential model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	2.44E-05	-0.467	**0.276**	**0.182**
634	1.22E-02	-0.597	0.145	0.052
411	5.32E-05	-0.685	0.058	-0.036
1240	1.31E-03	-0.676	0.066	-0.027
410	-1.84E-04	-0.828	-0.085	-0.179
1234	1.63E-03	-0.670	0.073	**-0.021**
	min	-0.828	-0.085	-0.179
	max	-0.467	0.276	0.182
	std	±0.118	±0.118	±0.118
	mean	-0.654	0.089	-0.005
	rms	**±0.664**	**±0.148**	**±0.119**

PSMSL ID	4th order Gauss model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	2.23E-14	-0.467	**0.276**	**0.182**
634	1.07E-02	-0.596	0.147	0.053
411	-2.63E-10	-0.685	0.058	-0.036
1240	1.40E-04	-0.675	0.067	-0.026
410	-1.90E-10	-0.828	-0.085	-0.179
1234	2.08E-03	-0.670	0.073	**-0.021**
	min	-0.828	-0.085	-0.179
	max	-0.467	0.276	0.182
	std	±0.119	±0.119	±0.119
	mean	-0.653	0.089	-0.004
	rms	**±0.664**	**±0.148**	**±0.119**

Ellipsoidal height prediction at TGs

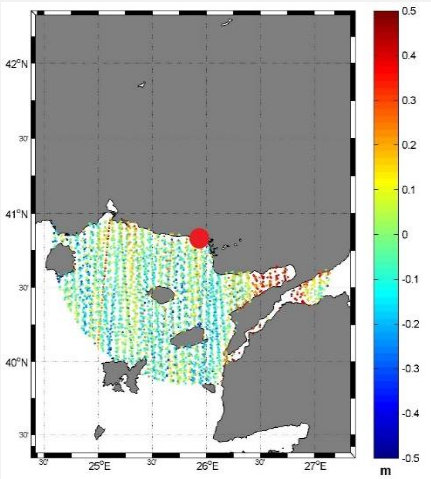
Least Squares Collocation – Gridded data (CASE E), radius 2°

PSMSL ID	3rd order polynomial model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	0.077	-0.544	**0.198**	**0.105**
634	0.086	-0.671	0.072	-0.022
411	0.128	-0.813	-0.071	-0.164
1240	0.056	-0.731	**0.012**	-0.082
410	-0.140	-0.688	0.055	-0.039
1234	0.100	-0.768	-0.025	-0.119
	min	-0.813	-0.071	-0.164
	max	-0.544	0.198	0.105
	std	±0.093	±0.093	±0.093
	mean	-0.702	0.040	-0.053
	rms	**±0.709**	**±0.102**	**±0.108**

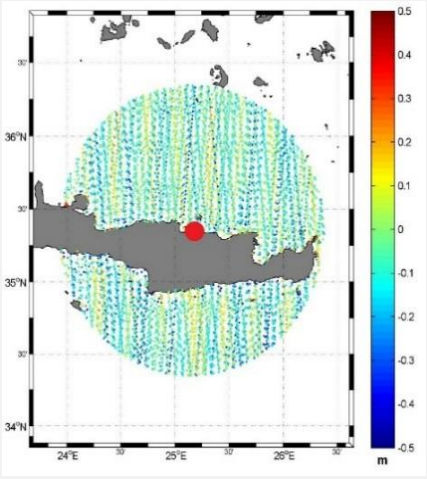
PSMSL ID	4th order polynomial model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	0.093	-0.560	**0.182**	0.089
634	0.081	-0.666	0.077	**-0.017**
411	0.121	-0.806	-0.063	**-0.157**
1240	0.055	-0.730	0.012	-0.081
410	-0.137	-0.691	0.051	-0.042
1234	0.088	-0.756	-0.014	-0.107
	min	-0.806	-0.063	-0.157
	max	-0.560	0.182	0.089
	std	±0.085	±0.085	±0.085
	mean	-0.702	0.041	-0.053
	rms	**±0.707**	**±0.094**	**±0.100**

Ellipsoidal height prediction at TGs

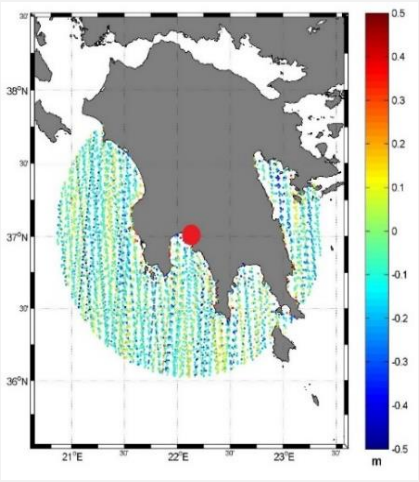
Least Squares Collocation – Irregular data, radius 1°



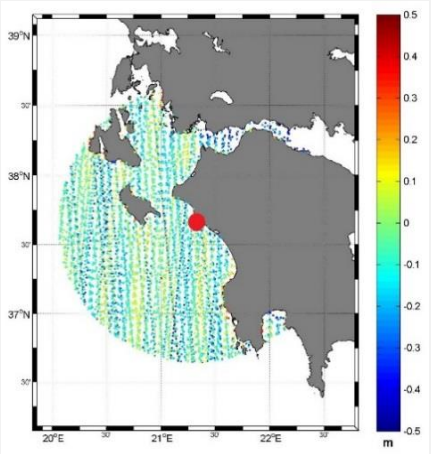
ALEXANDROUPOLIS



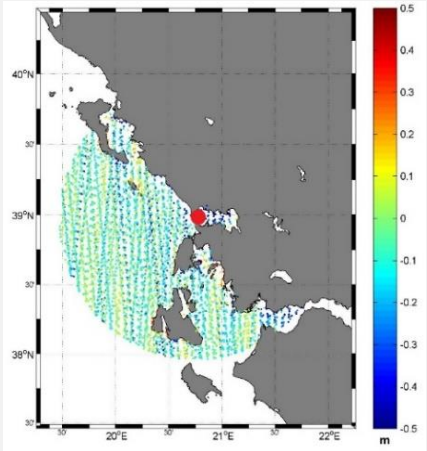
IRAKLION



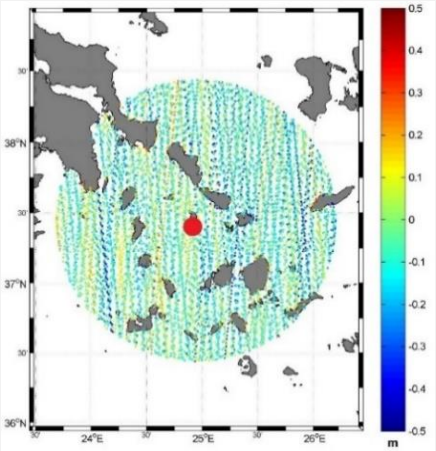
KALAMAI



KATAKOLON



PREVEZA



SIROS

Ellipsoidal height prediction at TGs

Least Squares Collocation – Irregular data, radius 1°

PSMSL ID	Exponential model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	-	-	-	-
634	-	-	-	-
411	-2.04E-04	-0.685	0.058	-0.036
1240	-8.27E-03	-0.667	0.076	-0.018
410	-4.34E-04	-0.828	-0.085	-0.178
1234	-	-	-	-
	min	-0.828	-0.085	-0.178
	max	-0.667	0.076	-0.018
	std	±0.088	±0.088	±0.088
	mean	-0.726	0.016	-0.077
	rms	**±0.732**	**±0.090**	**±0.117**

PSMSL ID	2nd order Gauss model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	-	-	-	-
634	-	-	-	-
411	-6.58E-08	-0.685	0.058	-0.036
1240	-6.22E-03	-0.669	0.074	-0.020
410	-1.14E-05	-0.828	-0.085	-0.179
1234	-	-	-	-
	min	-0.828	-0.085	-0.179
	max	-0.669	0.074	-0.020
	std	±0.088	±0.088	±0.088
	mean	-0.727	0.015	-0.078
	rms	**±0.733**	**±0.089**	**±0.117**

Ellipsoidal height prediction at TGs

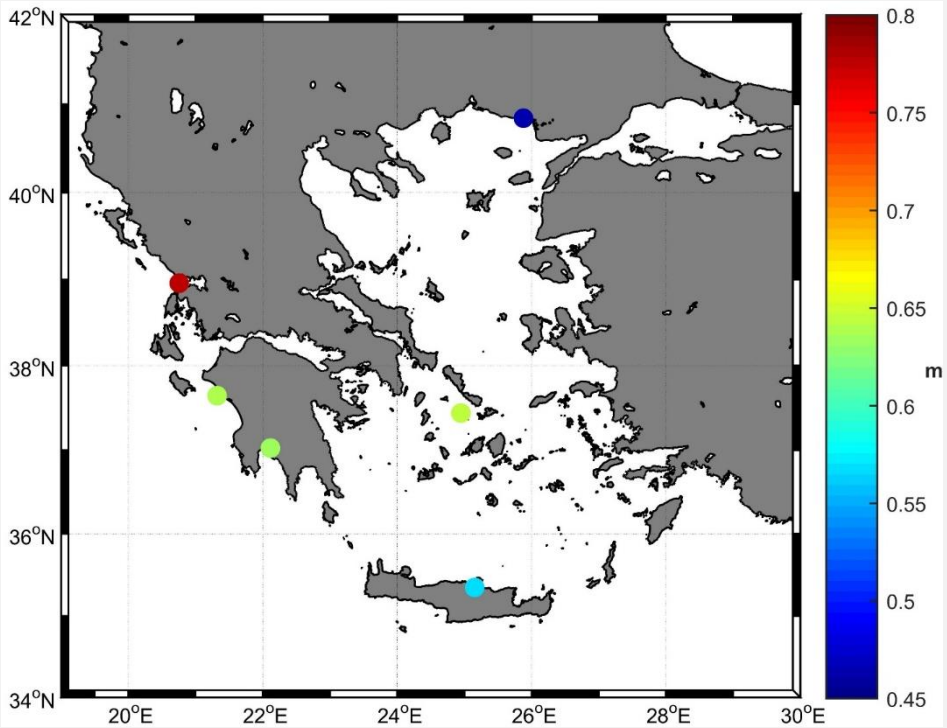
Least Squares Collocation – Irregular vs. gridded data

PSMSL ID	Exponential model (irregular) [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	-	-	-	-
634	-	-	-	-
411	-2.04E-04	-0.685	0.058	-0.036
1240	-8.27E-03	-0.667	0.076	**-0.018**
410	-4.34E-04	-0.828	**-0.085**	**-0.178**
1234	-	-	-	-
	min	-0.828	-0.085	-0.178
	max	-0.667	0.076	-0.018
	std	±0.088	±0.088	±0.088
	mean	-0.726	0.016	-0.077
	rms	**±0.732**	**±0.090**	**±0.117**

PSMSL ID	4th order polynomial model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	0.093	-0.560	**0.182**	0.089
634	0.081	-0.666	0.077	**-0.017**
411	0.121	-0.806	-0.063	**-0.157**
1240	0.055	-0.730	0.012	-0.081
410	-0.137	-0.691	0.051	-0.042
1234	0.088	-0.756	-0.014	-0.107
	min	-0.806	-0.063	-0.157
	max	-0.560	0.182	0.089
	std	±0.085	±0.085	±0.085
	mean	-0.702	0.041	-0.053
	rms	**±0.707**	**±0.094**	**±0.100**

Time-series construction/analysis

Local vertical offsets of TGs



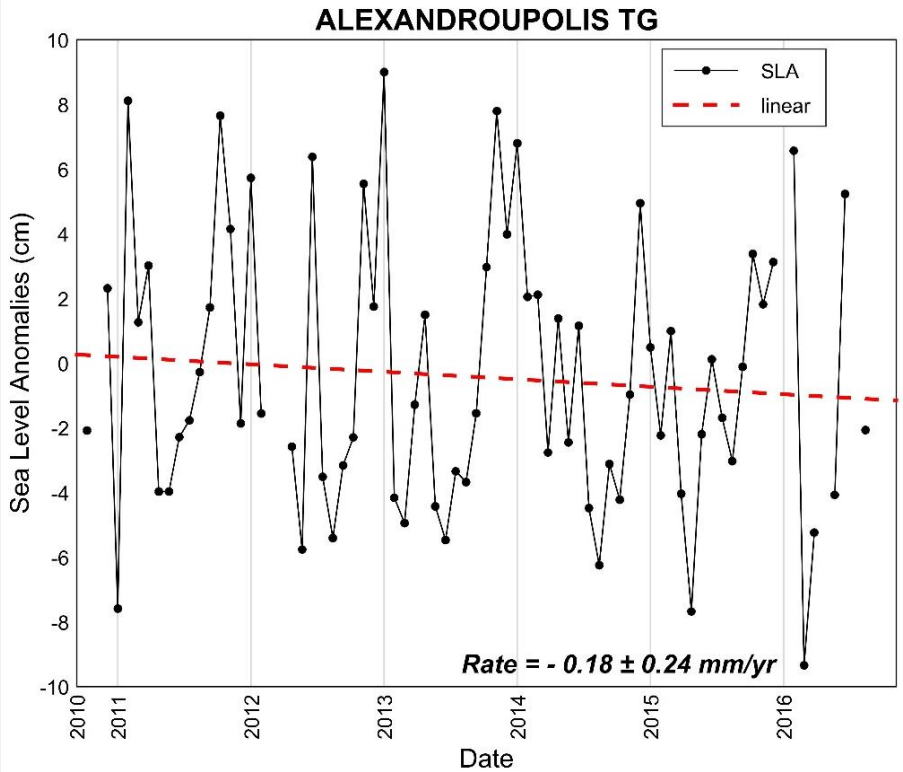
Cubic interpolation per cycle

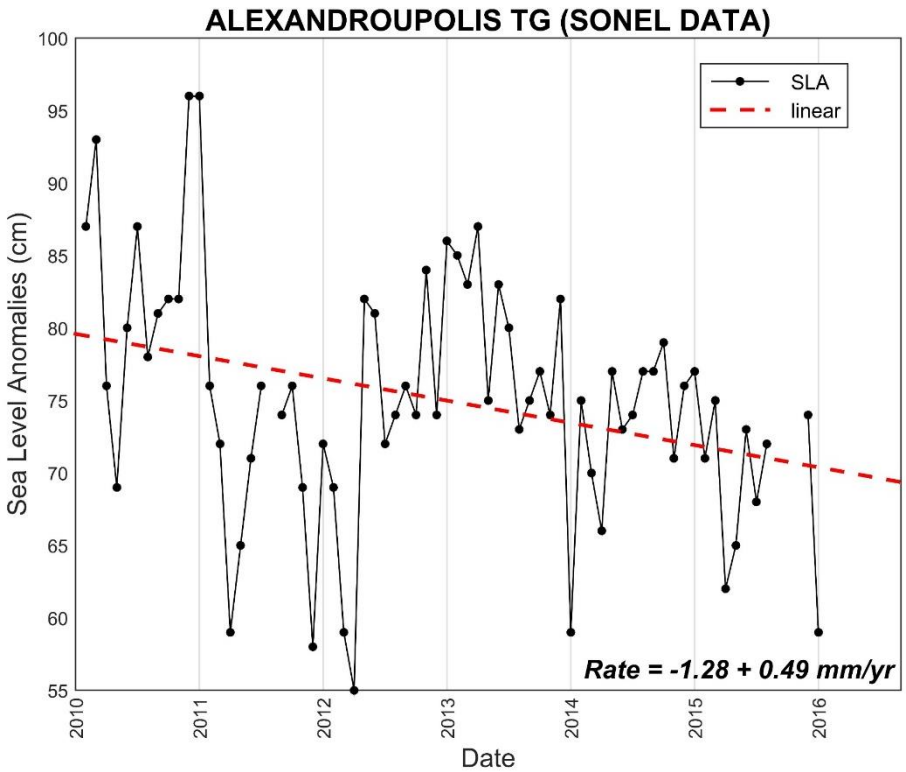
- ✓ **Gridded along track SLA data**
- ✓ **2D low pass filtering**
- ✓ **prediction at BMs**

$$LVO = h_{initial} - h_{estimated}$$

Time-series construction/analysis

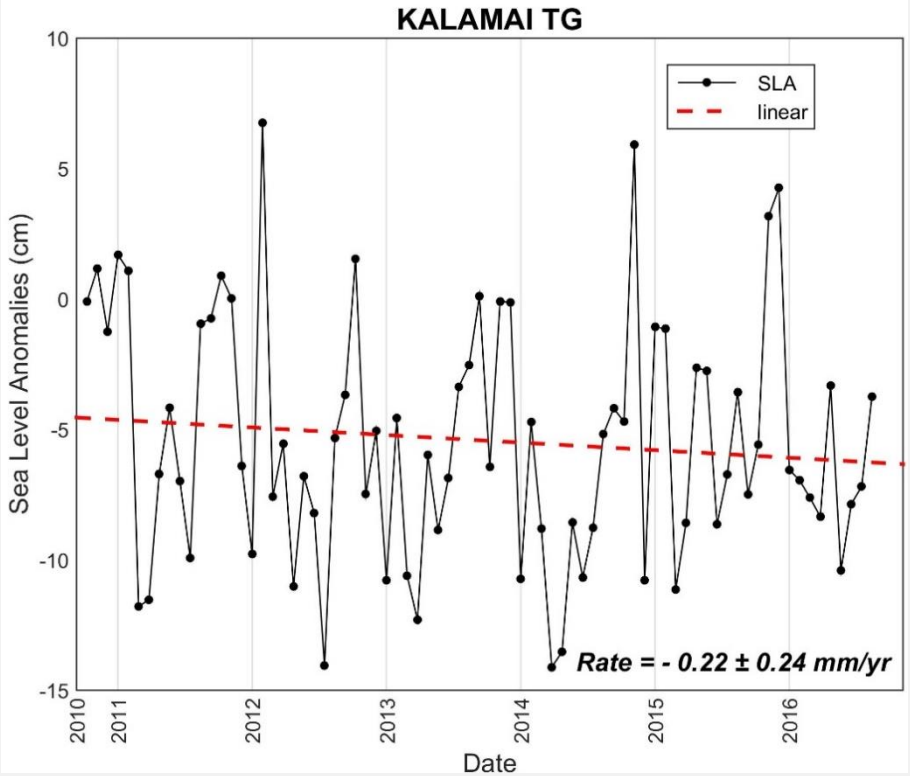
TGs check points

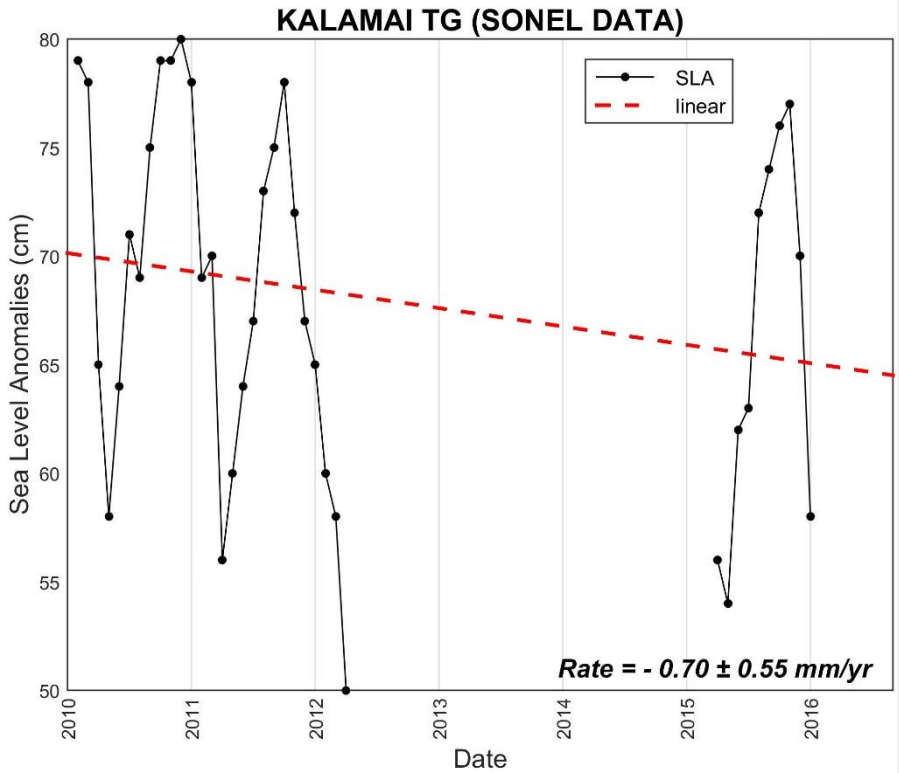




Time-series construction/analysis

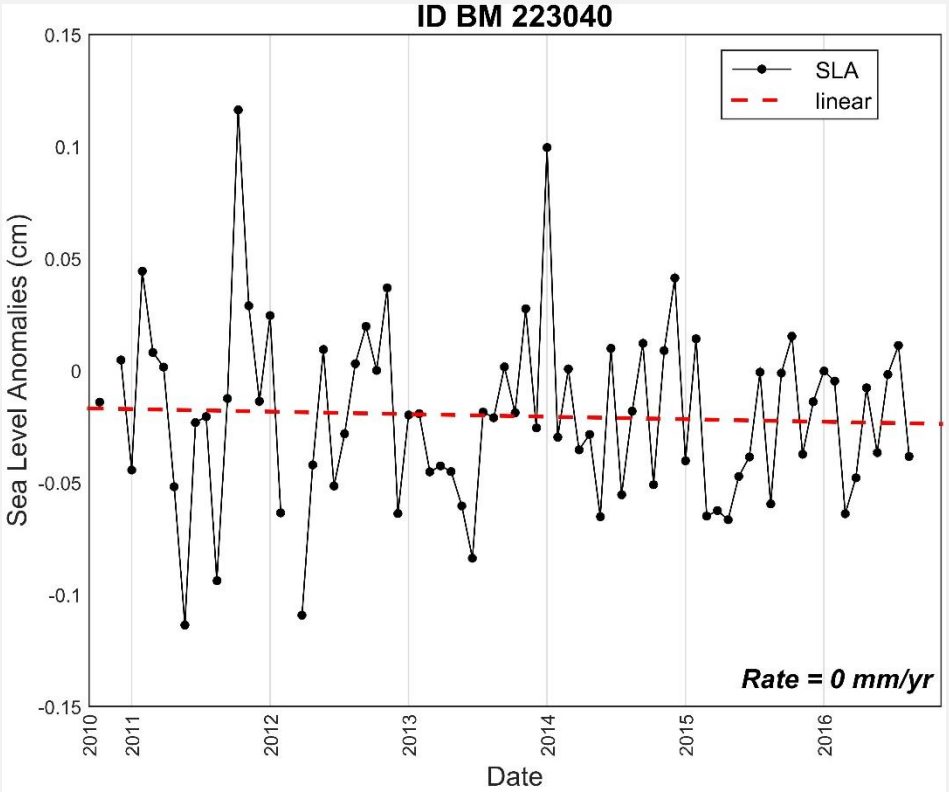
TGs check points

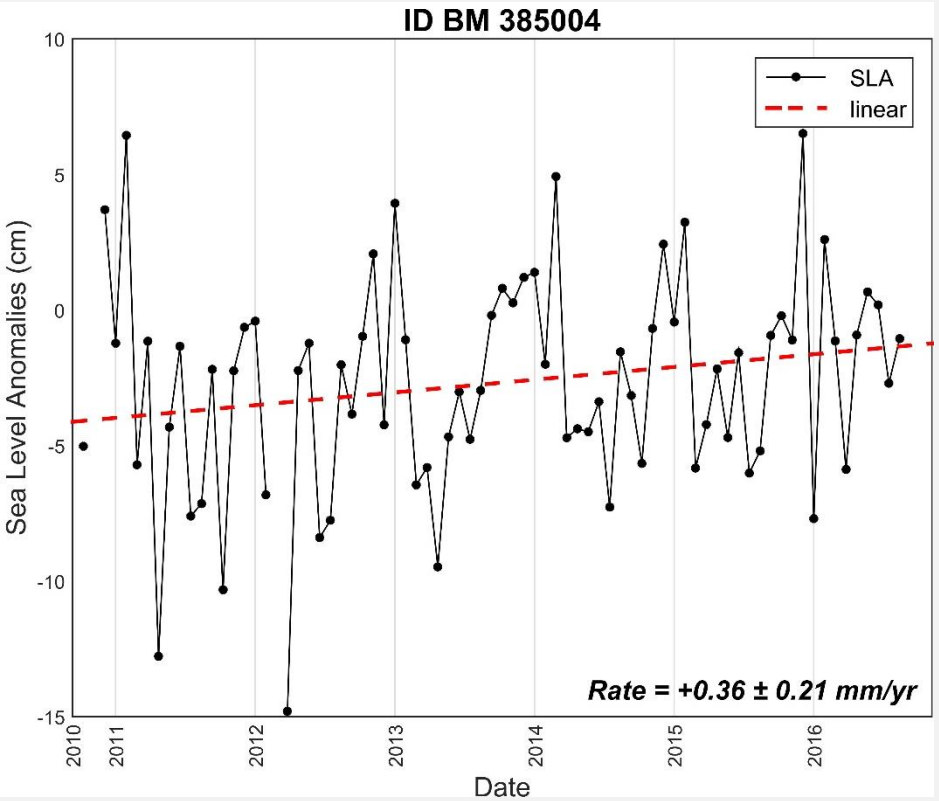




Time-series construction/analysis

BMs check points

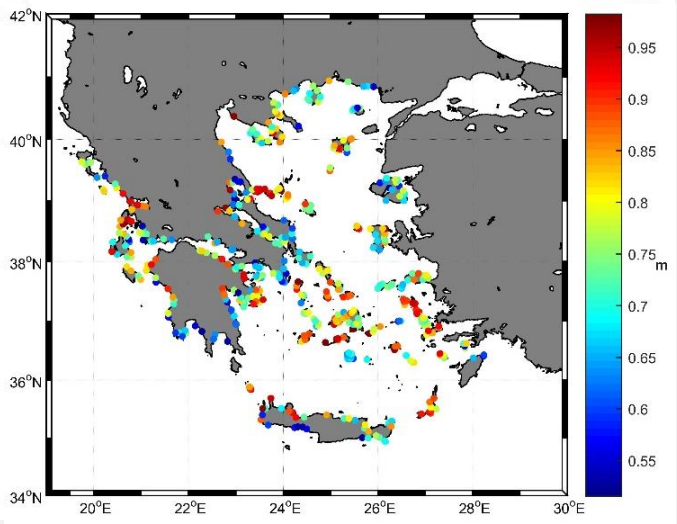




Time-series construction/analysis

Local vertical offsets
(Jason ellipsoid, MT and IAG W_o)

$$\delta\widehat{W}_o^{Gr\ LVD} = -66.84\ \mathrm{cm}$$



TGs check points

6 TGs -> -62.00 cm

4 TGs -> -62.04 cm (except ALEXANDROUPOLIS and PREVEZA)

BMs check points

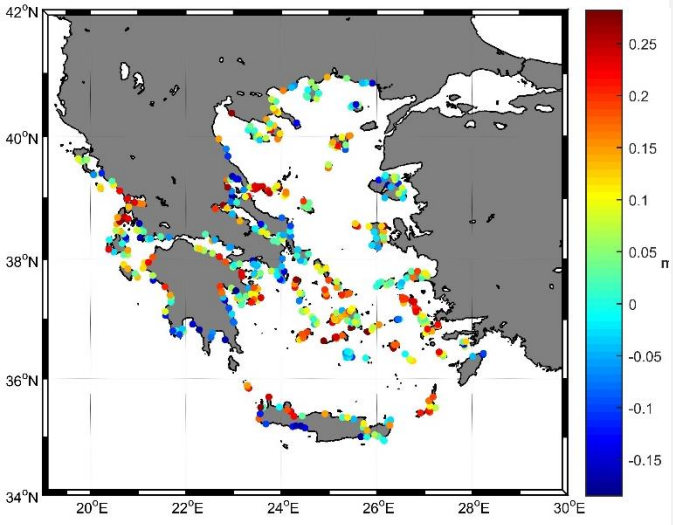
602 BM -> -74.95 cm

1σ test (std=23.5 cm) -> 465 BMs, new offset -> -76.47 cm

Time-series construction/analysis

Local vertical offsets
(GRS80 ellipsoid, MT and IAG W_o)

$$\delta\widehat{W}_o^{Gr\ LVD} = +3.16\ \mathrm{cm}$$



TGs check points

6 TGs -> +8.00 cm

4 TGs -> +8.04 cm (except ALEXANDROUPOLIS and PREVEZA)

BMs check points

602 BM -> -4.95 cm

1σ test (std=23.5 cm) -> 465 BMs, new offset -> -6.47 cm

Conclusions

- No-bias during alternation of altimeter modes (LRM, SAR, SARIN)
- RDSAR –> high observation noise (std > ±10 cm)
- SAR/SARin –> new information closer to the coast – high observation noise
- Remove SSB – altimetry data need to be corrected

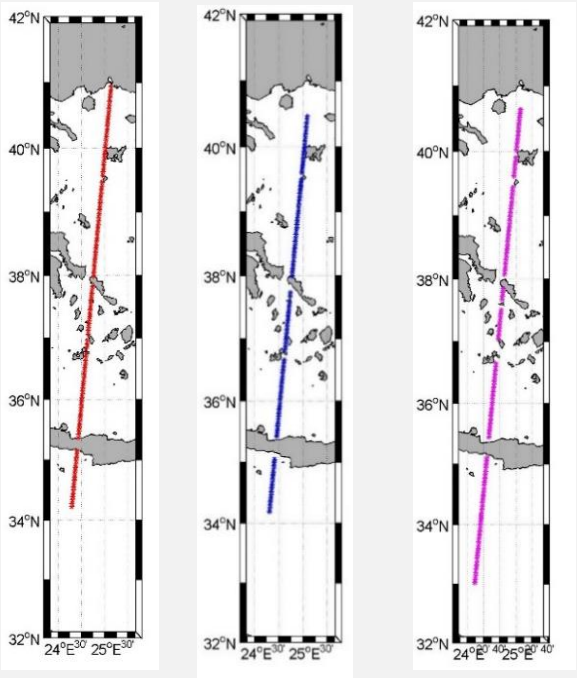
Conclusions

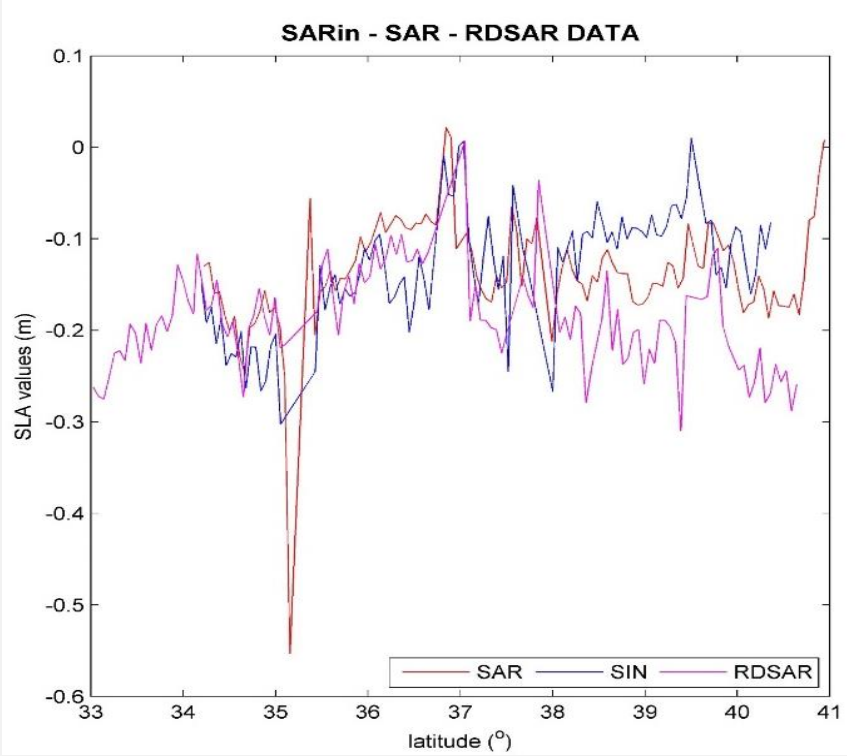
- Cubic interpolation – LSC (exponential and Gauss 4th order models)
- Data : 2D low pass filtering on grid
- Prediction accuracy ≈ 5 cm, Δh< ±10 cm for more than ½ BMs
- 4-8 cm accuracy in the $\delta\widehat{W}_o^{Gr\ LVD}$ compared to the best estimate for the Greek LVD. Looks promising!
- Calculation of LVD Offset (602 BMs) : -4.95 cm (GRS80, MT)
- Little or no correlation between topography and prediction accuracy
- LSC: prediction accuracy is related to distance from prediction point and quality of altimetric observations

Back-up slides

Evaluation of SAR – SARin – RDSAR data in Greece

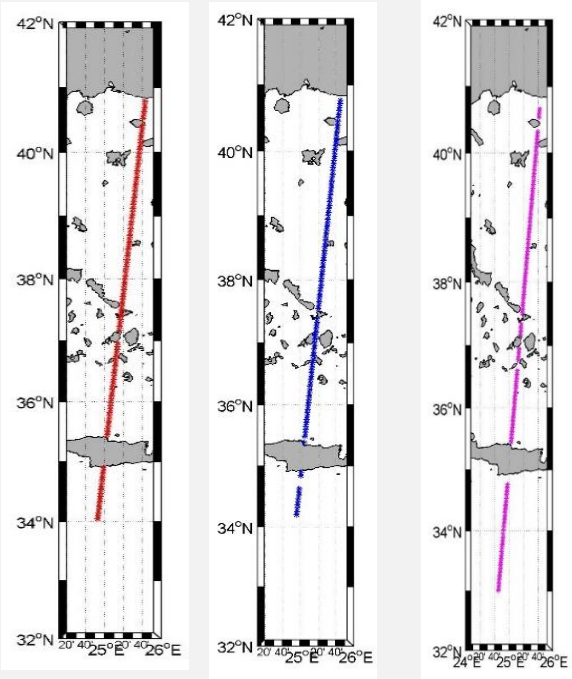
February : cycle 37 (SAR, RDSAR) - cycle 76 (SARin)

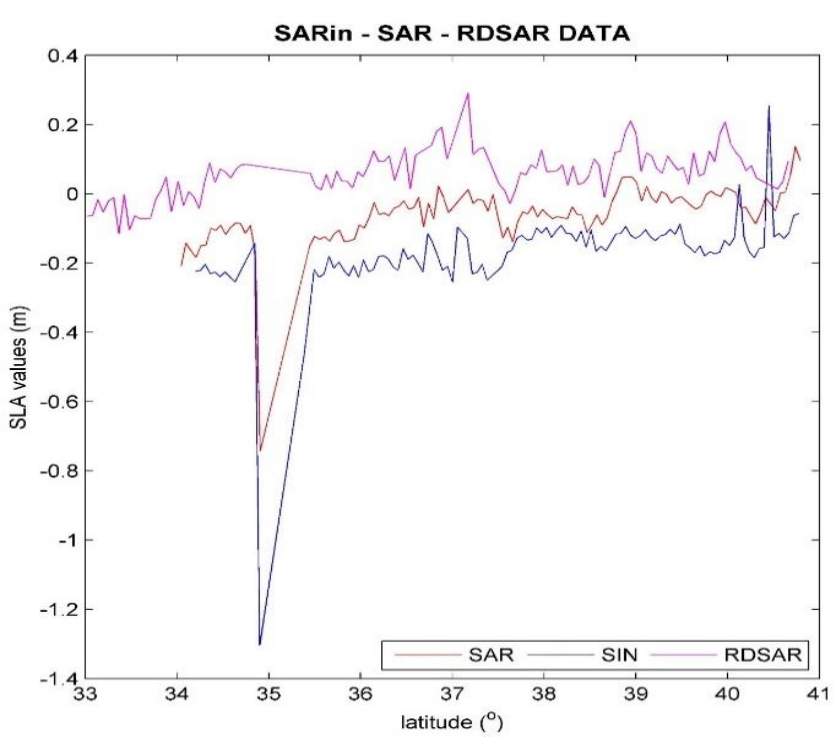




Evaluation of SAR – SARin – RDSAR data in Greek region

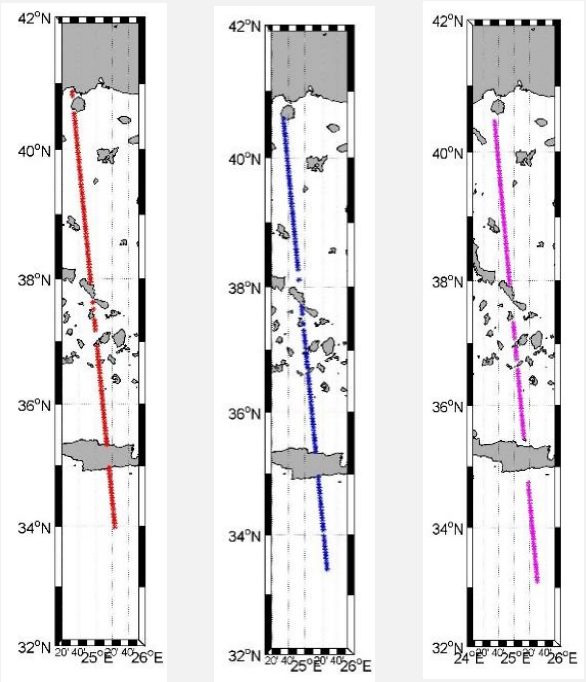
March : cycle 38 (SAR, RDSAR) - cycle 77 (SARin)

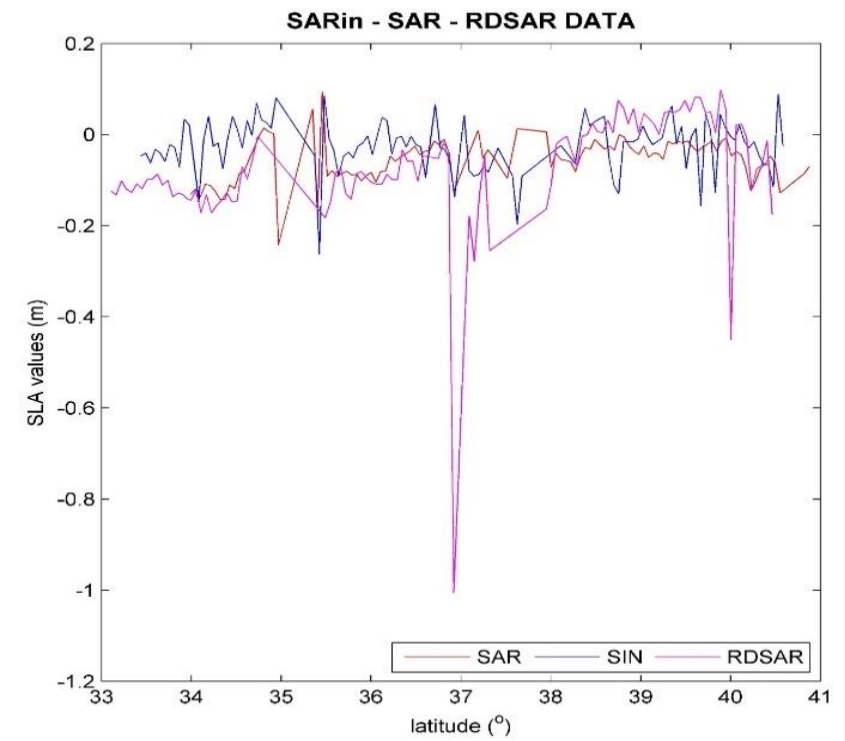




Evaluation of SAR – SARin – RDSAR data in Greek region

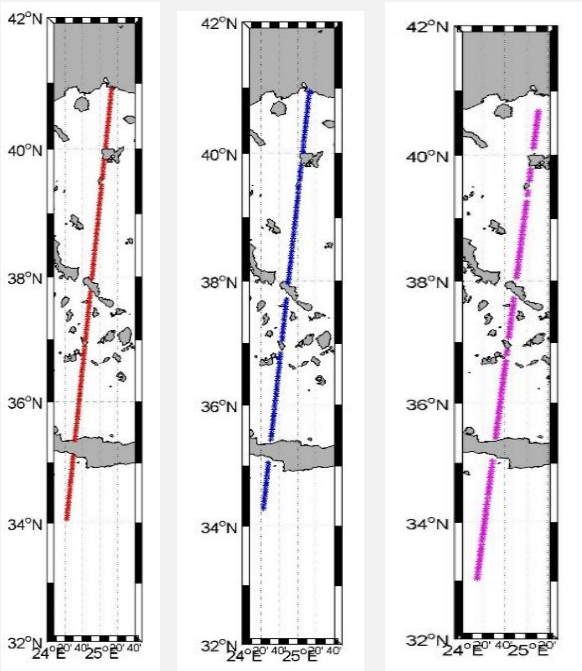
April : cycle 39 (SAR, RDSAR) - cycle 78 (SARin)

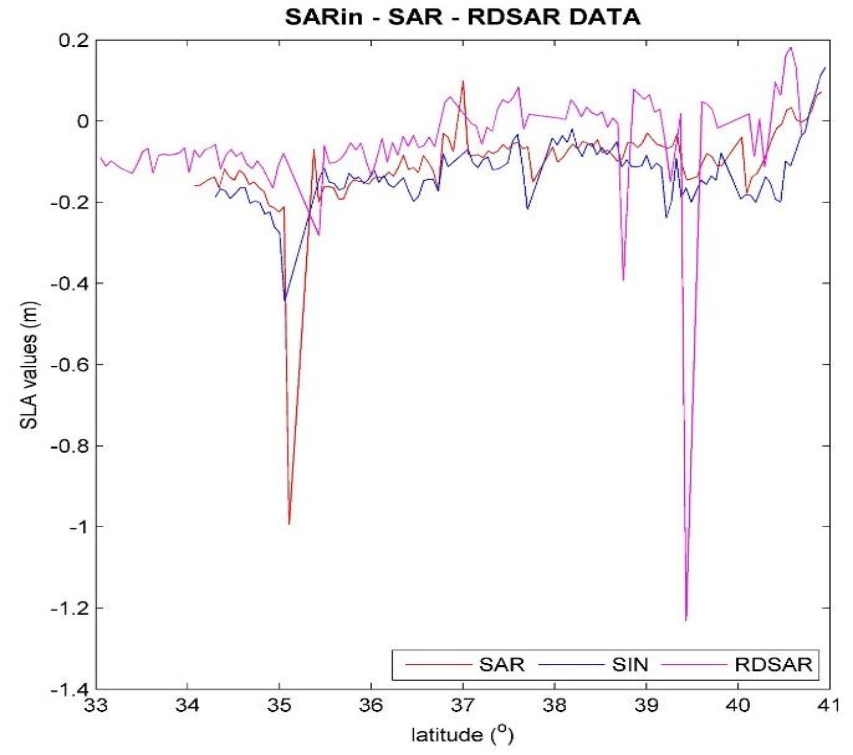




Evaluation of SAR – SARin – RDSAR data in Greek region

May : cycle 40 (SAR, RDSAR) - cycle 79 (SARin)





Ellipsoidal height prediction at TGs

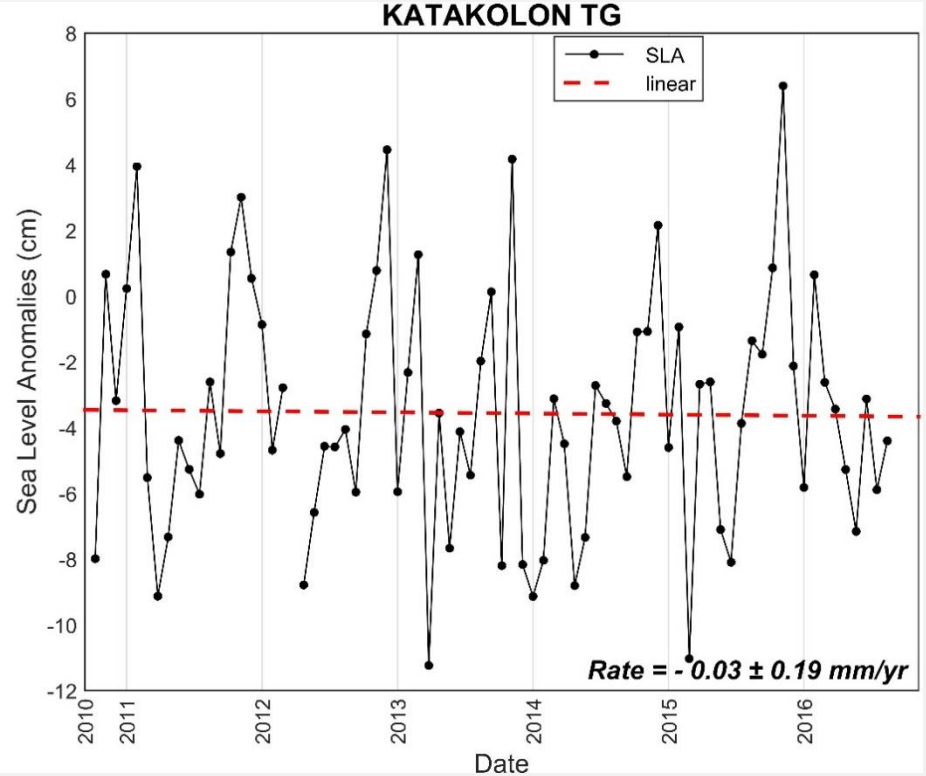
Least Squares Collocation – Irregular data, radius 1°

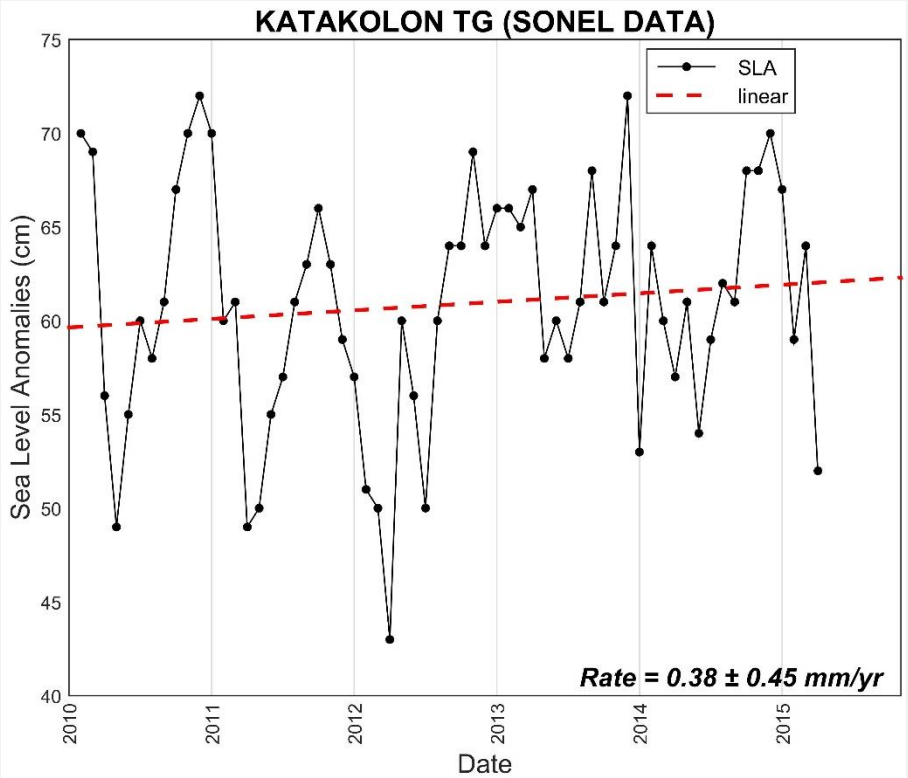
PSMSL ID	3rd order polynomial model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	-	-	-	-
634	-	-	-	-
411	0.309	-0.994	**-0.252**	-0.345
1240	-1.472	0.797	1.540	1.446
410	2.176	-3.004	**-2.261**	**-2.355**
1234	-	-	-	-
	min	-3.004	-2.261	-2.355
	max	0.797	1.540	1.446
	std	±1.902	±1.902	±1.902
	mean	-1.067	-0.324	-0.418
	rms	**±2.180**	**±1.929**	**±1.947**

PSMSL ID	4th order polynomial model [unit: m]			
	SLA	h-(MSS+SLA)	Remove LVD -74.26 cm	Remove LVD -64.91 cm
1238	-	-	-	-
634	-	-	-	-
411	-0.636	-0.049	**0.694**	0.600
1240	-0.014	-0.661	0.081	**-0.012**
410	0.508	-1.336	-0.594	**-0.687**
1234	-	-	-	-
	min	-1.336	-0.594	-0.687
	max	-0.049	0.694	0.600
	std	±0.644	±0.644	±0.644
	mean	-0.682	0.060	-0.033
	rms	**± 0.938**	**±0.647**	**±0.645**

Time-series construction/analysis

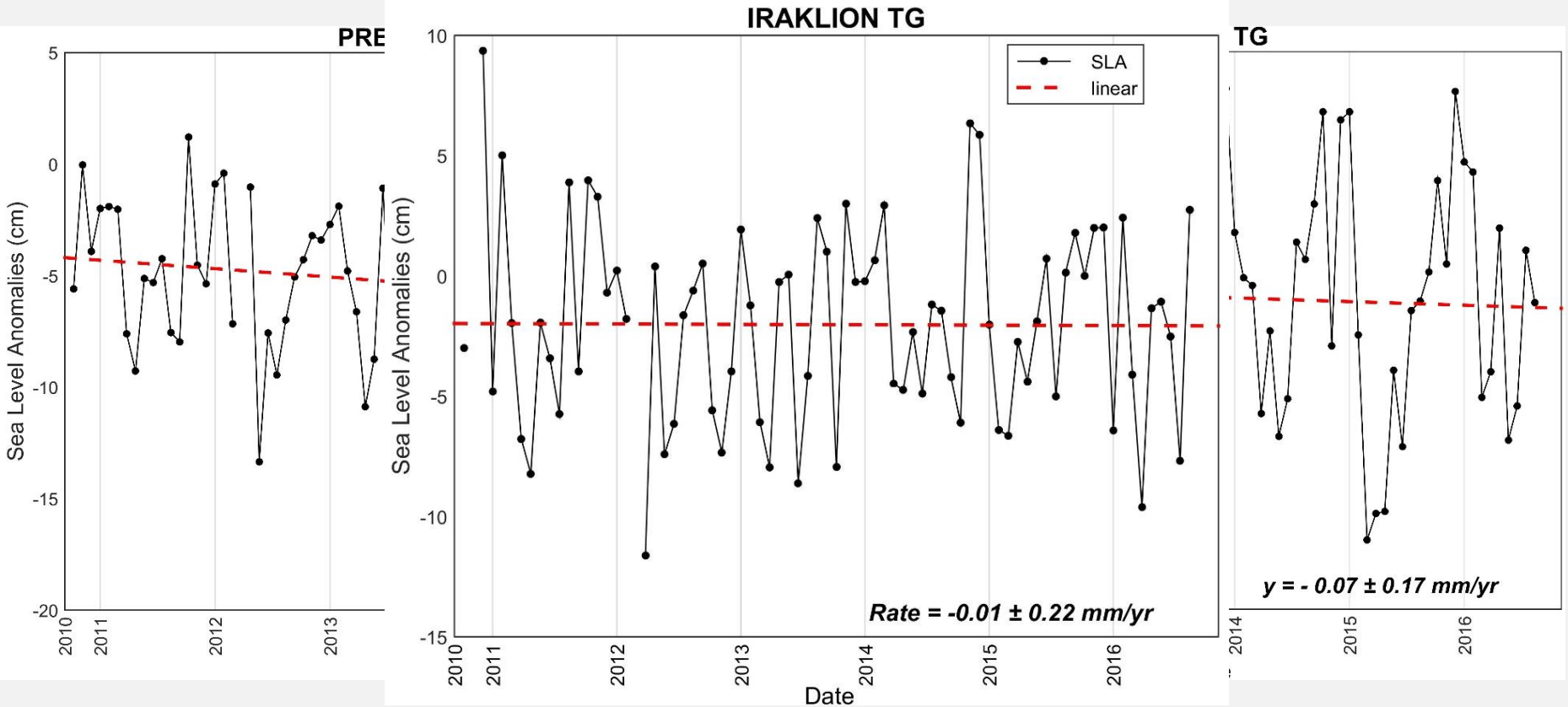
TGs check points





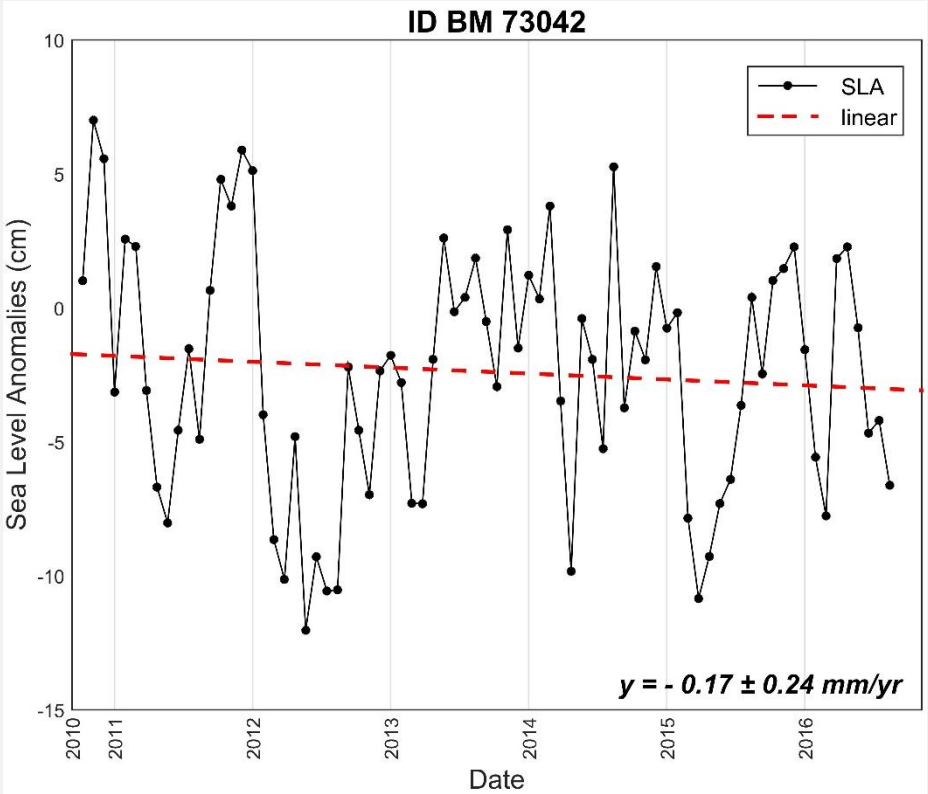
Time-series construction/analysis

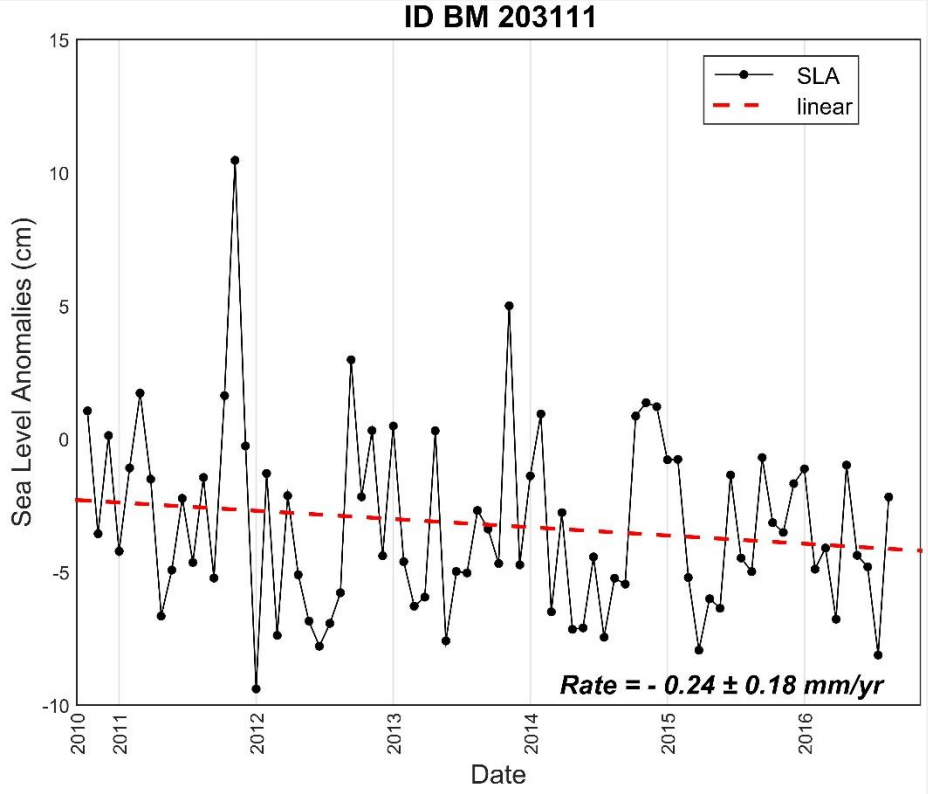
TGs check points



Time-series construction/analysis

BMs check points





Time-series construction/analysis

BMs check points