Revisiting land motion and sea level trends in the north-eastern Adriatic Sea with satellite altimetry and tide gauge data

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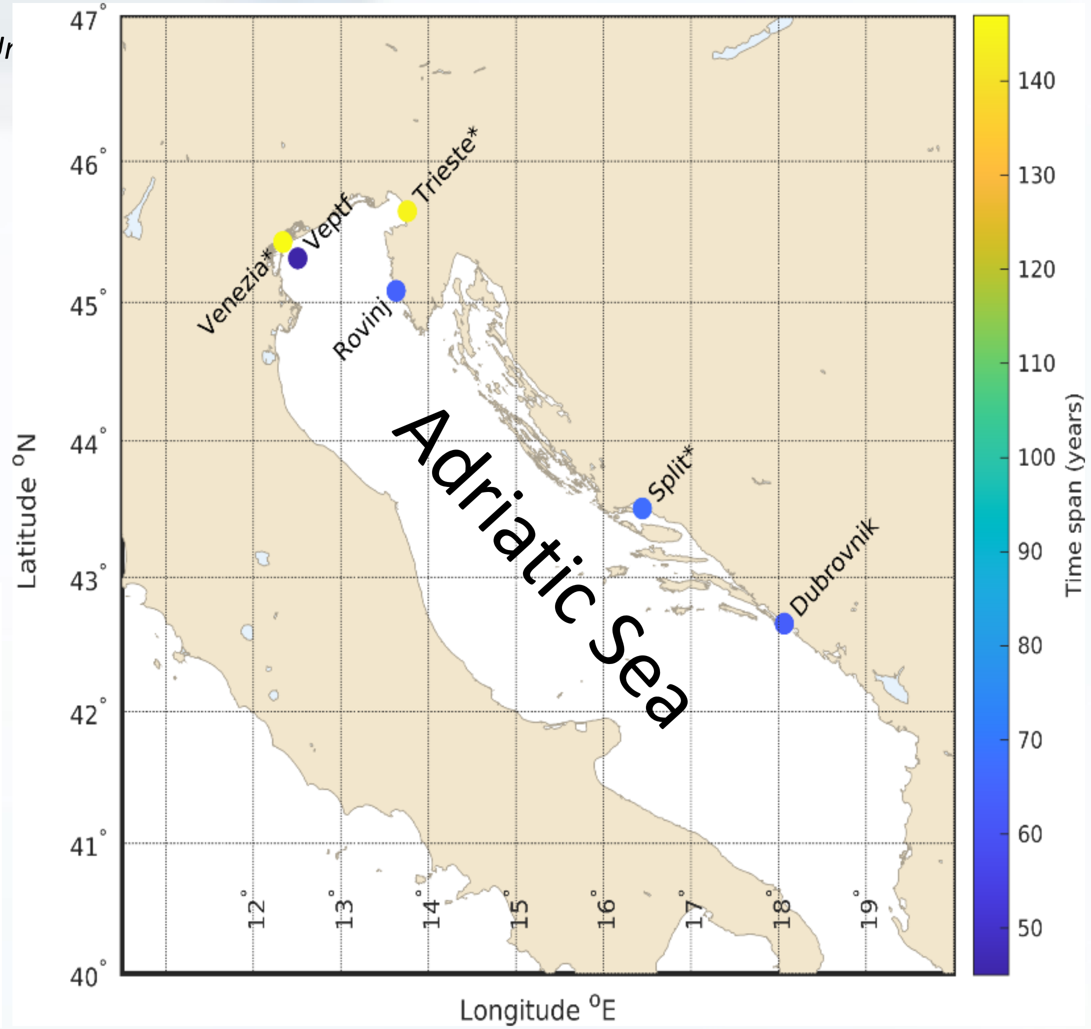
Objectives

- Optimal estimation of the vertical land motion (VLM) at some tide gauge location, using two different state-of-the-art altimetry dataset of sea level anomaly (SLA, 1993-2018) and tide gauge observations of sea level (SL, 1974-2018)
- Compare VLM results with GPS observations where available and reliable
- Estimate absolute sea level trend in the Adriatic on longer periods (1974-2018)

Adriatic Sea: one of the most exposed places in the Mediterranean Sea to the sea level rise and to storm surge related risks. An ideal place for validating coastal altimetry products and study short-to-mid term aspects of climate change

OUTLINE:

- Sea Level Anomaly from altimetry datasets SLCCI and C3S
- Sea Level in situ datasets from tide gauges
- Vertical Land Motion from in situ CGPS
- Methods
- Results: VLM and absolute SL trend estimates
- Summary



Two altimetry SLA processing chains: ESA and Copernicus C3S

Gridded monthly means of SLA[1,2] @¼ degrees **1993-2015** from the ESA Sea Level Climate Change Initiative (**SLCCI**) project:

It is produced by the Climate Change Initiative project on "Sea Level" (SLCCI) of the European Space Agency (ESA). It is an improved set of reprocessed satellite-based sea level products, aimed at being a reference for climate studies

- Multimission: TOPEX/Poseidon, Jason-1, Jason-2, ERS-1, ERS-2, GeoSat Follow-On (GFO), Envisat, SARAL/AltiKa and CryoSat-2
- Processing: editing, cross-calibration, homogeneous corrections, removal of global and regional biases, homogenization of long-spatial-scale errors, monthly optimal interpolation gridding
- Climate data record designed to be the reference for climate-related sea level studies

Gridded daily means of SLA[3] @0.125 degrees **1993-2018** from the Copernicus Climate Change Service (**C3S**):

Climate Change Service

C3S provides this state-of-the-art, climate-oriented dataset of SLA for the Mediterranean Sea at 0.125 deg. resolution grid. Up-to-date altimeter standards are used to estimate the SLA with a mapping algorithm specifically dedicated to the Med Sea. Monthly means were obtained from daily means.

- Obtained using a stable two-satellite constellation of altimeters and homogeneous corrections and standards in time
- Processing: editing, cross-calibration, homogeneous corrections, removal of global and regional biases, homogenization of long-spatial-scale errors, optimal interpolation gridding
- Climate data record designed to be the up-to-date extension of the SLCCI SLA dataset to nowadays

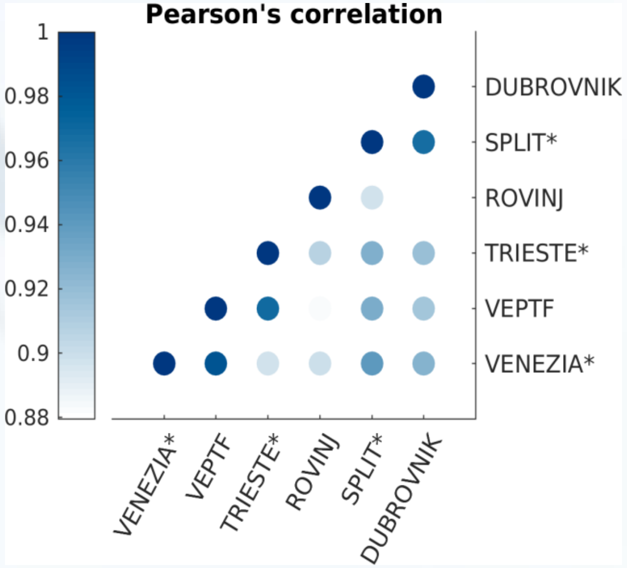
- The SLCCI project has developed consistent altimeter corrections in order to produce a homogeneous and stable global sea level product. The operational production of the climate-oriented global sea level product has now been taken over by the C3S. The main difference is that all available satellites have been included in the SLCCI product, whereas a stable number of two altimeters is used for the C3S product: this contributes to increase the stability of the sea level record, especially on a regional scale[4]
- Dynamic Atmospheric Correction (DAC) **from CNES AVISO+** was re-added to both SLA datasets in order to obtain a sea level comparable to TG monthly means observations
- TOPEX-A drift in 1990-1998 was corrected neither in the SLCCI product nor in the C3S product[2,3]
- Satellite altimetry sea level observations are referenced to the ellipsoid, which is an absolute reference system

(1) *DOI: 10.5270/esa-sea_level_cci-MSLA-1993_2015-v_2.0-201612*
(2) *Legeais et al.: DOI: 10.5194/essd-10-281-2018, 2018*
(3) *http://datastore.copernicus-climate.eu/documents/satellite-sea-level/D3.SL.1-v1.2_PUGS_of_v1DT2018_SeaLevel_products_v2.4.pdf*
(4) *Legeais, J.F., personal communication*

Six tide gauge SL from PSMSL[1,2] and other authorities[3,4]

The tide gauge data was retrieved from the Permanent Service for Mean Sea Level, the Tide Forecast and Early Warning Center of the Venice Municipality and from the Trieste section of the CNR-ISMAR Institute.
The mutual Person's linear correlation coefficient is always > 8.5

TG name	Lat	Lon	Data (%)	Time span	Length (Year)
VENEZIA*	45.431	12.336	97	1872 – 2018	147
VEPTF	45.314	12.508	100	1974 – 2018	45
TRIESTE*	45.647	13.760	89	1875 – 2018	145
ROVINJ	45.083	13.628	99	1955 – 2018	64
SPLIT*	43.507	16.442	100	1952 – 2018	67
DUBROVNIK	42.658	18.063	99	1956 – 2018	63



- TG SL observations are measured with respect to relative references: usually a benchmark in the TG cabin or nearby
- Processing: X0-filtering for VENEZIA2 and VEPTF
- Trends errors are calculated taking into account serial correlation, and are given with 95% confidence interval.

(1) Holgate et al. (2013), Journal of Coastal Research, 29, 3, 493 – 504, doi:10.2112/JCOASTRES-D-12-00175.1
(2) Permanent Service for Mean Sea Level (PSMSL), 2020, data retrieved 08 Apr 2020 from http://www.psmsl.org/data/obtaining/.
(3) VENEZIA and VEPTF TG data kindly provided by the Tide Forecast and Early Warning Center of the Venice Municipality and PSMSL*
(4) TRIESTE kindly provided by CNR-ISMAR section of Trieste*

Geocentric surface velocities from CGPS at four tide gauges from the Nevada Geodetic Laboratory(1), SONEL(2) and ISPRA(3)

CGPS STATION	LAT	LON	V up NGL (MIDAS) (mm yr^{-1})	Record Length & span (Year)	V up SONEL (mm yr^{-1})	Record Length & span (Year)	V up ISPRA (mm yr^{-1})	Record Length & span (Year)	Vup Pooled mean (mm yr^{-1})
VENEZIA PSAL	45.431	12.337	-1.70 ± 0.80	6 (2014-2020)	-	-	-1.46 ± 0.09	5 (2010-2015)	-1.59 ± 0.65
TRIESTE TRIE	45.710	13.764	-0.52 ± 0.45	17 (2003-2020)	0.20 ± 0.26	10 (2003-2013)	-	-	-0.25 ± 0.52
SPLIT SPLT	45.507	16.438	0.45 ± 0.68	8 (2004-2012)	-0.25 ± 0.34	8 (2004-2012)	-	-	0.10 ± 0.64
DUBROVNIK DUBR	42.650	18.110	-1.99 ± 0.80	12 (2000-2012)	-	-	-	-	-1.83 ± 0.70(4)
DUBROVNIK DUB2	42.650	18.110	-1.94 ± 0.89	8 (2012-2020)	-	-	-	-	

Several solutions are nowadays available on-line for the Continuous GPS monitoring of selected locations, in particular near TGs: SONEL (Université La Rochelle) and Nevada Geodetic Laboratory (University of Nevada). Values of VLM are sometimes very different from centre to centre, and in any case they are often calculated on a limited time-span.
For Venice we report also the solution obtained by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), which performs continuous checks on the benchmarks of the geodetic network around the CGPS station of VENEZIA PSAL.

(1) Blewitt et al. (2018), Eos, 99, https://doi.org/10.1029/2018EO104623
(2) On-line: https://www.sonel.org/-GPS-.html
(3) Baldin G., Crosato F., (2017), ISPRA, Quaderni - Ricerca Marina, 10/2017, Roma
(4) Pooled mean of DUBR and DUB2 («Cochrane Handbook for Systematic Reviews of Interventions», 2° Ed., DOI:10.1002/9781119536604)

Methods 1

- The **SLCCI** and **C3S** gridded time-series of **SLA** monthly means, were compared to the TG SL observations, also organized in monthly mean time series
- The altimeter grid point associated with the TG was decided on the base of the distance and of the maximum correlation
- Another experiment was attempted associating to the TG time series the mean of all the altimeter grid points in the distance range of 10-50 km, and farer than 10 km from coast (to avoid orographic disturbances). No very profound differences were found in this case, and the results have been omitted

We compared the slopes (trends) of the SLA time series derived from the altimetry and SL from the TGs:

- For the altimetry datasets the DAC correction was re-applied to SLA
- For both altimetry and tide gauge time series the annual/inter-annual cyclic variations were subtracted
- In order to get an optimal estimate of the geocentric vertical motion at the TGs, we use the technique developed by Kuo et al.[(1)], perfected by Wöppelmann and Marcos[(2)] and based on the solution of the linear inverse problem with constraints (Menke[(3)])

(1) *Kuo, C. Y., C. K. Shum, A. Braun, and J. X. Mitrovica (2004), Geophys. Res. Lett., 31, L01608 DOI: 10.1029/2003GL019106*

(2) *Wöppelmann, G., and Marcos, M. (2012), J. Geophys. Res., 117, C01007, DOI: 10.1029/2011JC007469*

(3) *Menke, W. (1989), Geophysical Data Analysis: Discrete Inverse Theory,289 pp., Academic, San Diego, Calif.*

Methods 2 - The Linear Inverse Problem with constraints (LIP)

The rate of absolute vertical land movement at tide gauge *i* is given by the difference between the absolute sea level change rate and the relative sea level change rate at the same place:

a) $\dot{\boldsymbol{u}}_i = \dot{\boldsymbol{g}}_i - \dot{\boldsymbol{s}}_i$

$\dot{g}_i$, $\dot{s}_i$= **absolute** and **relative** sea level change **rates** at the tide gauge *i* in the altimetry era; dot means time differentiation. In practice, $\dot{g}_i$ is measured by the altimeter, and $\dot{\boldsymbol{s}}_i$ by the tide gauge limited to the same altimetry time span.

This equation is sufficient to obtain an estimate of the VLM rates at each tide gauge[(1)]. However with often strong uncertainties. Solution: introduce the rate of relative vertical motion between two nearby tide gauges: $r\dot{u}_{ij} = (\dot{g}_i - \dot{s}_i)$ - $(\dot{g}_j - \dot{s}_j)$ which reduces to:

b) $\boldsymbol{r\dot{u}_{ij}} = \dot{\boldsymbol{s}}_j$ - $\dot{\boldsymbol{s}}_i$

if $\dot{g}_i = \dot{g}_j$, i.e., if the absolute sea level change rate is the same at the two different locations.

As in general the rates $\boldsymbol{r\dot{u}_{ij}}$ have much smaller errors, they can be used to reduce the overall error in the $\dot{\boldsymbol{u}}_i$. This is done by putting the N equations (**a**) in matrix form:

c) $G \cdot \dot{\boldsymbol{u}} = \boldsymbol{d}$; $\dot{\boldsymbol{u}} = \begin{pmatrix} \dot{u}_1 \\ \vdots \\ \dot{u}_N \end{pmatrix}$; $\boldsymbol{d} = \begin{pmatrix} \dot{g}_1 - \dot{\boldsymbol{s}}_1 \\ \vdots \\ \dot{g}_N - \dot{\boldsymbol{s}}_N \end{pmatrix}$; $G = I_N$

and the M<N equations (**b**) as constraints to the linear system:

d) $F \cdot \dot{\boldsymbol{u}} = \boldsymbol{h}$; $\boldsymbol{h} = -F \cdot \begin{pmatrix} \dot{\zeta}_1 \\ \vdots \\ \dot{\zeta}_N \end{pmatrix}$;

$\dot{\boldsymbol{\zeta}}_i$ **relative SL rate of the whole TG$_i$ life** (> alimetry era)

$$F = \begin{bmatrix} 1 & -1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & -1 & 0 & \cdots & 0 \\ & \cdots & & & \cdots & \\ 0 & 0 & 0 & \cdots & 1 & -1 \end{bmatrix}$$ constraints design matrix

The constraints can be chosen arbitrarily, but they have to be linearly independent so that the rank of the matrix F is <=N-1, and that the condition expressed in b) is true ($\dot{g}_i - \dot{g}_j = 0$).

(1) Cazenave, A., K. Dominh, F. Ponchaut, L. Soudarin, J. F. Crétaux, and C. Le Provost (1999), Geophys. Res. Lett., 26, 2077–2080, doi:10.1029/1999GL900472

IBF Istituto di Biofisica ISPRA ISP Istituto di Scienze Polari

Methods 3 - The Linear Inverse Problem with constraints (LIP)

The linear system **c) + d)** is simoultaneously solved with the use of Lagrange multipliers[(1)]:

$$\begin{bmatrix} G^T \cdot G & F^T \\ F & 0 \end{bmatrix} \begin{pmatrix} \dot{\boldsymbol{u}} \\ \boldsymbol{\lambda} \end{pmatrix} = \begin{pmatrix} \boldsymbol{d} \\ \boldsymbol{h} \end{pmatrix}$$

By using the generalized inverse of the matrix $\begin{bmatrix} G^T \cdot G & F^T \\ F & 0 \end{bmatrix}$.

Errors are calculated with the associated covariance matrix.

Wöppelmann and Marcos[(2)] used a strategy to further reduce the errors on the time series contributing to the rates ***d*** and ***h***: instead of calculating the error on the differences of the rates ($d_i = \dot{g}_i - \dot{s}_i$; $h_{ij} = \dot{\zeta}_j - \dot{\zeta}_i$), they calculated the error on the rates of the differenced time series: in such a way the formal error is lower.

(1) *Menke, W. (1989), Geophysical Data Analysis: Discrete Inverse Theory,289 pp., Academic, San Diego, Calif.*

(2) *Wöppelmann, G., and Marcos, M. (2012), J. Geophys. Res., 117, C01007, DOI: 10.1029/2011JC007469*

However, still exists the limitation posed by different absolute sea level rates in forming "homogeneous" relative VLM rates between TG and TG.

In this study we try to overcome this limitation with a change of variables, redefining the rates of absolute and relative sea level change rates by the ***local absolute sea level rate ($\dot{g}_i$)*** :

$$\dot{g}_i \rightarrow \dot{g}'_i = \dot{g}_i - \dot{g}_i = 0$$
$$\dot{s}_i \rightarrow \dot{s}'_i = \dot{s}_i - \dot{g}_i$$
$$\dot{\zeta}_i \rightarrow \dot{\zeta}'_i = \dot{\zeta}_i - \dot{g}_i$$
$$\dot{u}_i = \dot{g}_i - \dot{s}_i = \dot{g}_i - \dot{g}_i + \dot{g}_i - \dot{s}_i = \dot{g}'_i - \dot{s}'_i$$

VLM rates $\dot{\boldsymbol{u}}_i$ are unaltered by this change of variable.

We hope also that this work will help to clarify the role of the limitation imposed by eq. b), i.e. the assumption that the relative differences of the TG–TG time series are valid as long as the absolute sea level trends at the TGs are comparable.

Results 1: 1993-2015

SLCCI altimetry dataset (1993-2015)

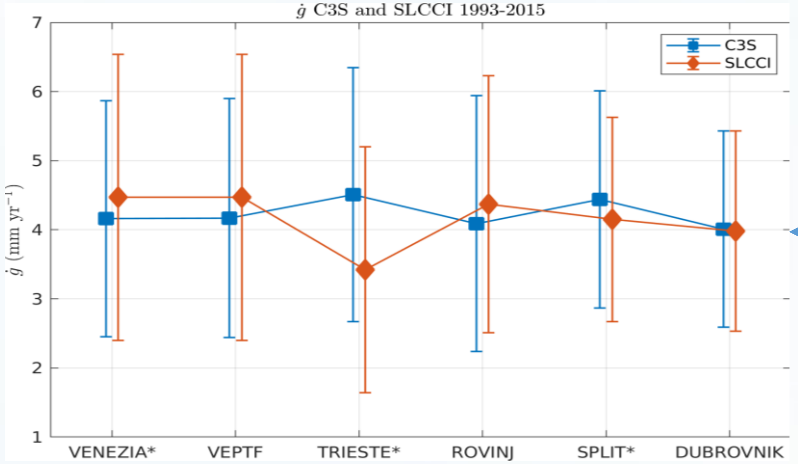
TG name	ALT ($\dot{g}$)	TG^{Alt} ($\dot{s}$)	TG^{TG} ($\dot{\zeta}$)	ALT-TG^{Alt} ($\dot{g}$-$\dot{s}$)[1]	LIP ($\dot{u}$)$_{LIP}$	LIP$_{cov}$ ($\dot{u}$)$_{LIPcov}$	GPS ($\dot{u}$)$_{GPS}$
VENEZIA	4.47 ± 2.07	6.08 ± 2.08	3.29 ± 0.82	-1.61 ± 0.91	-1.02 ± 0.41	-0.70 ± 0.41	-1.59 ± 0.65
VEPTF	4.47 ± 2.07	6.44 ± 2.07	3.83 ± 0.81	-1.97 ± 0.93	-1.54 ± 0.47	-1.21 ± 0.47	-
TRIESTE	3.42 ± 1.78	4.49 ± 1.98	2.40 ± 0.74	-1.07 ± 0.74	-0.14 ± 0.36	-0.86 ± 0.36	-0.25 ± 0.52
ROVINJ	4.37 ± 1.86	1.91 ± 2.04	1.61 ± 0.73	2.46 ± 1.04	0.65 ± 0.39	0.87 ± 0.39	-
SPLIT	4.15 ± 1.48	4.15 ± 1.87	2.45 ± 0.72	-0.00 ± 0.76	-0.18 ± 0.36	-0.17 ± 0.36	0.10 ± 0.64
DUBROVNIK	3.98 ± 1.45	4.67 ± 1.70	2.80 ± 0.63	-0.69 ± 0.70	-0.55 ± 0.50	-0.71 ± 0.50	-
Pooled mean	***4.14 ± 1.80***	***4.62 ± 1.96***	***2.73 ± 0.75***	***-0.48 ± 0.85***	***-0.46 ± 0.42***	***-0.46 ± 0.42***	***-0.58 ± 0.60***

C3S altimetry dataset (1993-2015)

TG name	ALT ($\dot{g}$)	TG^{Alt} ($\dot{s}$)	TG^{TG} ($\dot{\zeta}$)	ALT-TG^{Alt} ($\dot{g}$-$\dot{s}$)[1]	LIP ($\dot{u}$)$_{LIP}$	LIP$_{cov}$ ($\dot{u}$)$_{LIPcov}$	GPS ($\dot{u}$)$_{GPS}$
VENEZIA	4.16 ± 1.71	6.08 ± 2.08	3.29 ± 0.82	-1.93 ± 0.79	-0.94 ± 0.42	-1.01 ± 0.42	-1.59 ± 0.65
VEPTF	4.17 ± 1.73	6.44 ± 2.07	3.83 ± 0.81	-2.27 ± 0.81	-1.46 ± 0.48	-1.52 ± 0.48	-
TRIESTE	4.51 ± 1.84	4.49 ± 1.98	2.40 ± 0.74	0.02 ± 0.71	-0.05 ± 0.37	0.23 ± 0.37	-0.25 ± 0.52
ROVINJ	4.09 ± 1.85	1.91 ± 2.04	1.61 ± 0.73	2.18 ± 1.17	0.73 ± 0.40	0.60 ± 0.40	-
SPLIT	4.44 ± 1.57	4.15 ± 1.87	2.45 ± 0.72	0.29 ± 0.70	-0.10 ± 0.37	0.11 ± 0.37	0.10 ± 0.64
DUBROVNIK	4.01 ± 1.42	4.67 ± 1.70	2.80 ± 0.63	-0.66 ± 0.62	-0.46 ± 0.51	-0.69 ± 0.51	-
Pooled mean	***4.23 ± 1.69***	***4.62 ± 1.96***	***2.73 ± 0.75***	***-0.40 ± 0.82***	***-0.38 ± 0.43***	***-0.38 ± 0.43***	***-0.58 ± 0.60***

(1) Direct calculation of the VLM from the difference $(\dot{g}_i - \dot{s}_i)$ as in Cazenave et al. (1999)

- *SLCCI altimetry SLA rates at the six TGs: general agreement apart from TRIESTE, which has much lower SLA rate in the SLCCI dataset w.r.t. the other TGs and with respect to C3S → effect of SLCCI lower resolution or C3S specific regionalization?*
- *$\dot{u}$ calculated from the difference between ALT and TG rates are similar for SLCCI and C3S, apart from Trieste and Split which exhibit significantly different behaviours.*
- *$\dot{u}$ calculated with LIP are similar across all TGs in the two datasets*
- *$\dot{u}$ calculated with LIP$_{cov}$ are more differenced in the two datasets*
- The dispersion of the $\dot{u}$ *estimate is lower in the constrained problem (LIP, LIP$_{cov}$) w.r.t. the direct problem: the mean std error passes from 0.80 mm/yr (ALT-TG) to 0.40 in the LIP*
- *For Rovinj, both datasets (C3S and SLCCI) give LIP VLM much lower than the standard method (ALT-TG). Unfortunately no GPS present nearby Rovinj*
- *GPS observations for Dubrovnik do not reflect the effective movement of the TG → GPS too far?*

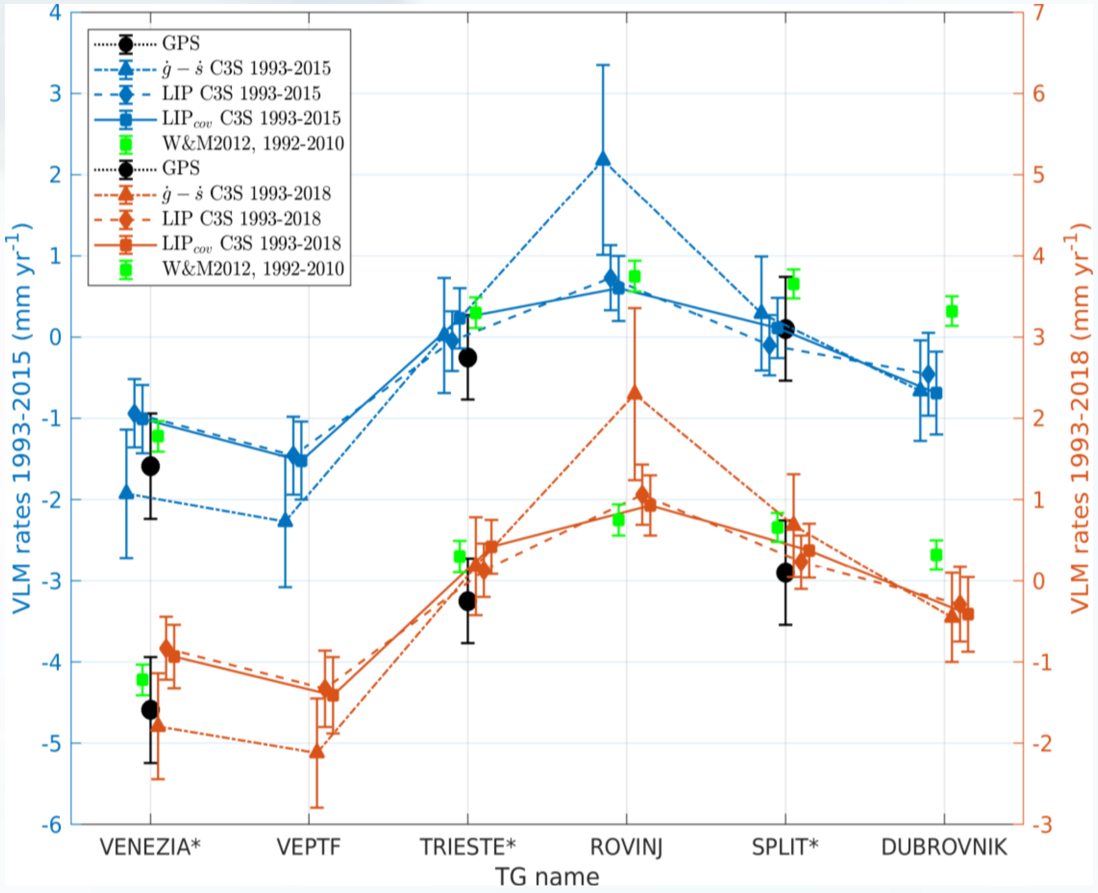


Results 2: 1993-2018

C3S altimetry dataset (1993-2018)

TG name	ALT ($\dot{g}$)	TG^{Alt} ($\dot{s}$)	TG^{TG} ($\dot{\zeta}$)	$ALT\text{-}TG^{Alt}$ ($\dot{g}$-$\dot{s}$)[1]	LIP $(\dot{u})_{LIP}$	LIP_{cov} $(\dot{u})_{LIPcov}$	GPS $(\dot{u})_{GPS}$
VENEZIA	3.36 ± 1.45	5.15 ± 1.73	3.26 ± 0.73	-1.79 ± 0.65	-0.83 ± 0.39	-0.93 ± 0.39	-1.59 ± 0.65
VEPTF	3.38 ± 1.46	5.50 ± 1.73	3.78 ± 0.73	-2.12 ± 0.67	-1.33 ± 0.47	-1.41 ± 0.47	-
TRIESTE	3.75 ± 1.58	3.56 ± 1.66	2.30 ± 0.67	0.18 ± 0.60	0.13 ± 0.33	0.42 ± 0.33	-0.25 ± 0.52
ROVINJ	3.33 ± 1.58	1.03 ± 1.85	1.36 ± 0.71	2.30 ± 1.06	1.06 ± 0.37	0.93 ± 0.37	-
SPLIT	3.60 ± 1.36	2.92 ± 1.65	2.20 ± 0.66	0.68 ± 0.63	0.23 ± 0.33	0.37 ± 0.33	0.10 ± 0.64
DUBROVNIK	3.34 ± 1.22	3.79 ± 1.48	2.69 ± 0.58	-0.45 ± 0.55	-0.29 ± 0.46	-0.41 ± 0.46	-
Pooled mean	**3.46 ± 1.45**	**3.66 ± 1.69**	**2.60 ± 0.68**	**-0.20 ± 0.71**	**-0.17 ± 0.40**	**-0.17 ± 0.40**	**-0.58 ± 0.60**

- *The extension of only 3 years (2016, 2017 and 2018) of the C3S dataset involves a reduction of absolute and relative sea level change rates (see Table). As expected, VLM rates remain almost unchanged (see Table) as they derive from the differences of absolute and relative SL changes, as seen by comparing VLMs results of the two different periods (1993-2015) and (1993-2018) (see Figure)*
- *The agreement of the LIP-derived VLMs with GPS is good (Figure)*
- *Agreement is found also with previous study of Woppelmann and Marcos (2012) (Figure)*
- *Variability of LIP-derived VLMs is lower than that of the direct method*



(1) Direct calculation of the VLM from the difference ($\dot{g}_i - \dot{s}_i$) as in Cazenave et al. (1999)

Results 3: 1974-2018 absolute SL trend along N-E coast of the Adriatic Sea

Rates of absolute sea level change at the TGs: calculated as the sum of the relative sea level change and the VLMs derived in this study for the whole record length of the corresponding TGs: $\dot{g} = \dot{u} + \dot{\zeta}$

$\dot{u}$ is the VLM calculated with the LIP_{cov} method

$\dot{\zeta}$ is the relative SL rate derived from TG time series extending back in time, before altimetry. As the VLM rates have been obtained using TG observations since 1974, the results are intended valid in 1974-2018

Location	$\dot{\zeta} - LIP_{cov}$
VENEZIA*	2.33 ± 0.83
VEPTF	2.37 ± 0.86
TRIESTE*	2.71 ± 0.75
ROVINJ	2.29 ± 0.80
SPLIT*	2.57 ± 0.74
DUBROVNIK	2.28 ± 0.74
Pooled mean	2.43 ± 0.80
Sample mean	**2.43 ± 0.18**

- *There is strong agreement between rates at different TGs. Even if all individual estimates have "bulky" dispersions of the order 0.8 mm/yr, the sample standard deviation is much lower: 0.18 mm/yr*
- *The sample mean is 2.43 mm/yr in the period 1974-2918*
- *Previous work reported 1.36 ± 0.13 mm/yr (Wöppelmann & Marcos, 2012): seems to indicate an acceleration in the regional absolute sea level change rate*

Conclusions

We have estimated VLM, relative SL and absolute SL ***trends and errors*** *at six locations* ***in the Adriatic Sea****; we have used* ***two different measuring systems*** *(tide gauges and satellite altimetry),* ***integrating the information*** *and comparing the results with a third measuring system (GPS), in order* ***to maximize the knowledge, qualitatively and quantitatively****. We have* ***assessed*** *two different* ***altimetry*** *products (ESA* ***SLCCI*** *and Copernicus* ***C3S****) specifically processed for climate studies. We have compared the results with the* ***direct method*** *(subtracting the relative from the absolute sea level rates) and as a* ***constrained linear inverse problem****, which permits to* ***simoultaneously solve for the rates of all TGs****. We extended the LIP method in the case of variable absolute sea level rates at the TG, to obtain a sharper methodology for sea level studies, overcoming the limitation of the LIP method. We used this method to* ***derive absolute sea level rates*** *of the six TGs considered in the N-E Adriatic Sea.*

We found that:

- *The two altimetry products, SLCCI and C3S, supply very similar results, except for Trieste (probably because SLCCI has lower resolution than C3S, and is not regionalized)*
- *VLM rates obtained with the LIP approach have less dispersion than the direct method (ALT-TG, Cazenave et al. 1999). Errors on the VLM rates are of the order of 0.4 mm yr^{-1}*
- *Overall, for the Adriatic Sea we obtain a consistent representation of VLM and absolute sea level change rates. VLM rates are confirmed by those derived from 3 CGPS stations. Self-consistency of absolute sea level change rates obtained by summing VLMs and relative SL rates brings confidence in the methodology*
- ***To be considered:***
- *The SLCCI and C3S datasets cover slightly different periods*
- *The SLCCI and C3S products are generated from different processing chains, have different spatial and temporal resolutions, and C3S relies on a* mapping algorithm specifically dedicated to the Mediterranean Sea
- GPS data span very different time periods, but always shorter than altimetry and TGs time series; sometimes it is difficult to understand if CGPS stations do effectively reflect the tide gauge movement

Open questions:

- *Open question 1: can we use this strategy to analyze sea level rates in other regions of the Mediterranean Sea or elsewhere?*
- *Open question 2: how can we maximize the exploitation of the existing CGPS stations in this context, and improve the integration of the available measurement systems?*