GNSS/Acoustic positioning of acoustic beacons on the seafloor using an autonomous surface vehicle

Example from the FOCUS experiment offshore Sicily (Italy)

E. Lenhof [1], J-Y. Royer [1], V. Ballu [2], P. Sakic [3], C. Poitou [1], M. Beauverger [1], T. Coulombier [2], D. Dausse [2], G. Jamieson [4], P-Y. Morvan [4], M-A. Gutscher[1]

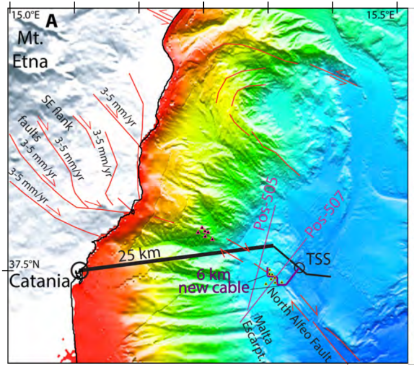
[1]Geo-Ocean, [2]LIENSs, [3]GFZ, [4]iXblue

Vienna (Austria), 24 May 2022

0 Outline

1 Overview of the FOCUS project

- Offshore Sicily, Italy
- Assess use of optical fiber cable to study movements of active submarine fault
- Calibrate laser interferometry observations with geodetic seafloor stations
- More details in Gutscher et al. presentation at 14:16

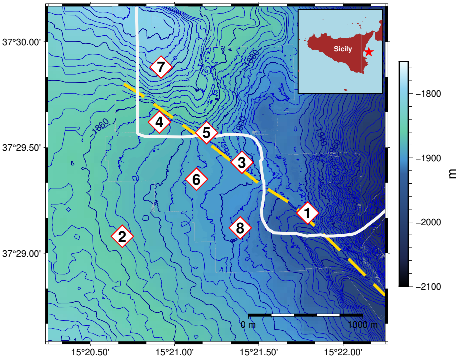


Study area with optical fiber (black and purple lines) and geodetic array (yellow triangles) [1]

1 Seafloor geodetic stations

- iXblue Canopus acoustic beacons
- 2.5 - 3m above seafloor
- Pressure, temperature, inclinometer, celerometer sensors

Geodetic stations deployed during cruise FOCUS-X1



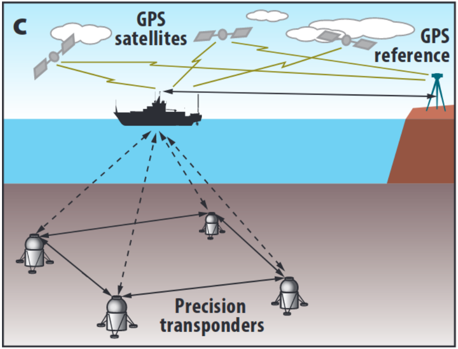
Geodetic network on both sides of North Alfeo strike-slip fault (yellow)

- Relative distancemetry and absolute positioning (GNSS/A) is performed

2 Principle of GNSS/A positioning

Absolute positioning of seafloor point(s) requires :

- Absolute positioning of surface vessel by GNSS antenna
- Positioning of seafloor stations relative to vessel acoustic antenna
- Vessel attitude and lever-arm between antennas



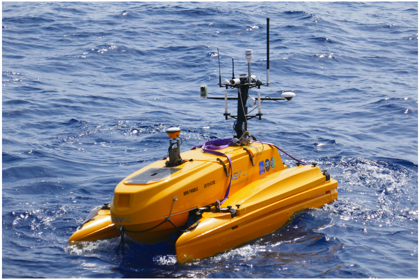
GNSS/A schematic representation [2]

2 Difficulties to overcome

- Precise high-rate GNSS positioning of offshore moving antenna
  - Precise Point Positioning with Ambiguity Resolution
- Precise lever-arm measurements
  - The smaller the better
- Sound speed variability
  - Multiple CTD profiles
  - Surface vehicle trajectories to minimize errors [3, 4, 5]
  - Estimate sound speed horizontal gradient together with station positions [6, 7]
- Additional constraints
  - Station depth from pressure measurements
  - Inter-station distances from relative positioning
  - Information from INS in GNSS positioning

3 The FOCUS-G1 cruise

- 25, 26 and 27 August 2021 with N/O Thetys II

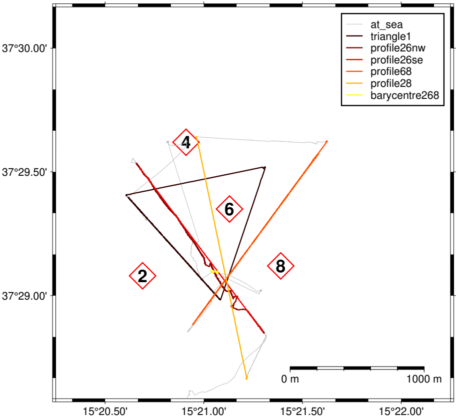


ASV Pameli

N/O Thetys II

- GNSS/A from ASV
  - silent (electrical propulsion)
  - compact (3m x 1.6m)
  - reduced electromagnetic noise
  - maneuverability
- CTD profiles (1800m and 300m) from vessel

3 GNSS-A experimental set up



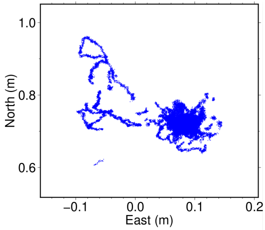
ASV tracks during GNSS/A acquisition

- Acoustics : USBL Gaps-M7
- GNSS : Trimble antenna connected to SPS855 and PolarX5 receivers with G/R/E/C constellations
- CTD : RBRconcerto[3]
- GNSS/A positioning of beacons 2, 4 (out of order), 6 and 8
- Different tracks tested :
  - Inverted triangle (before 4 failure revealed)
  - Barycenter of 2, 6 and 8
  - Equidistant from pairs of beacons (2-6, 2-8, 6-8)

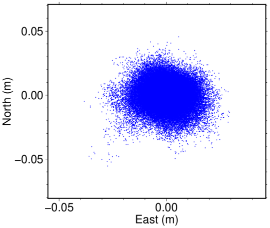
3 GNSS processing

- Raw GNSS quality check with G-Nut/Anubis [8] to compare kinematic marine to static land antenna :
  - similar with ASV at sea (slides 16 and 17)
- For cm accuracy on seafloor, cm accuracy on surface is required
  - D-GNSS not precise enough (baseline > 25 km)
  - PPP-AR with CSRS-PPP [9], GINS [10] and PRIDE PPP-AR [11]

IGS station BRST offsets between ITRF coordinates [12] and

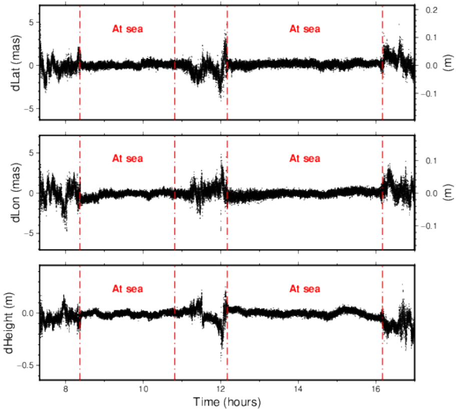


D-GNSS solution computed with RTKLIB, IGN-RGP station LPPZ as base station (baseline ∼ 25km)



PPP solution computed with CSRS-PPP

3 PPP processing comparison

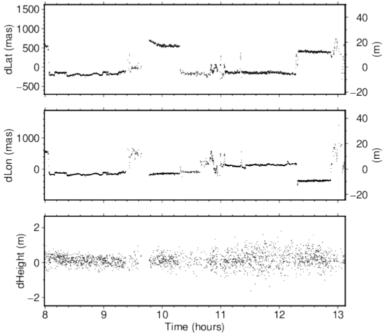


Differences[1] between GINS and CSRS-PPP solutions on 25-08-2021

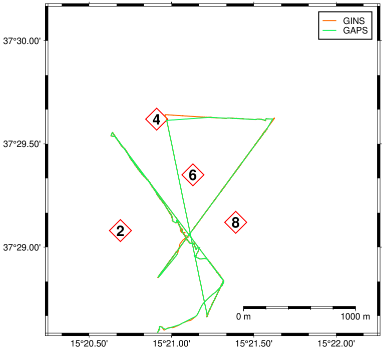
- Poorer results when Pameli was on vessel deck
- Accurate PPP based on good ambiguity resolution percentage and RMS (slides 18 to 21)
- GINS and CSRS-PPP solutions agree at centimeter level (slides 22 and 24)
- PRIDE PPP-AR solutions display strange behaviour (slide 23)

[1] 1 mas $\sim$ 3cm on Earth surface at the Equator

3 PPP/real-time navigation comparison



Differences between GINS post-processed solution and GAPS real-time navigation[1] on 26-08-2021

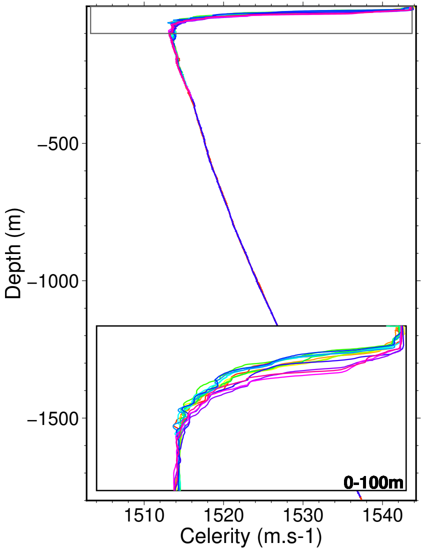


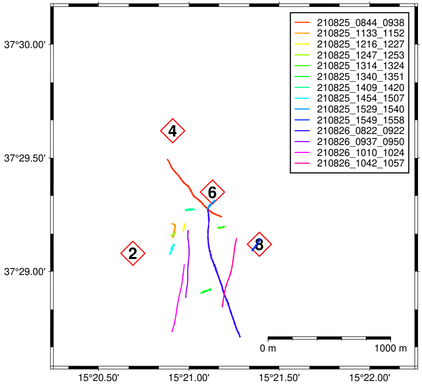
GINS solution along GAPS real-time navigation on 26-08-2021

- As expected, PPP is more precise than real-time navigation
- Real-time navigation subject to INS outages and errors

[1] Using EGM2008 [13] for altitude/height conversion

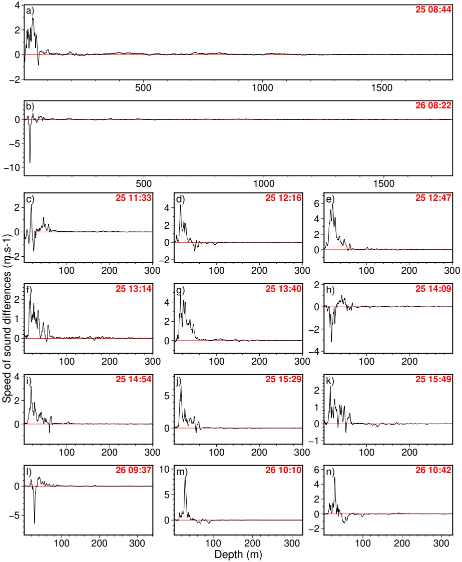
4 CTD observations





Vessel drifting during CTD profiles

4 SSP rapid variations

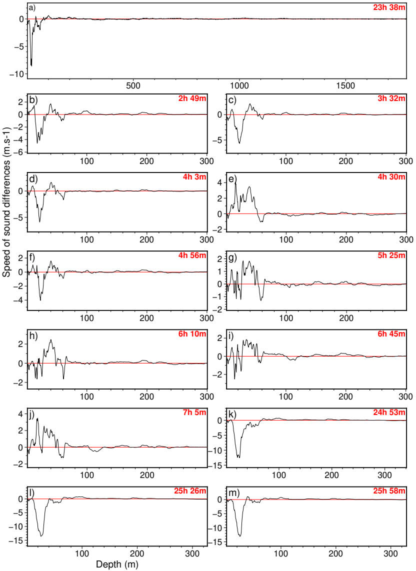


Sound-speed [14] differences between down and up measurements of same profile

a) 210825_0844_0938 b) 210826_0822_0922
c) 210825_1133_1152 d) 210825_1216_1227
e) 210825_1247_1253 f) 210825_1314_1324
g) 210825_1340_1351 h) 210825_1409_1420
i) 210825_1454_1507 j) 210825_1529_1540
k) 210825_1549_1558 l) 210826_0937_0950
m) 210826_1010_1024 n) 210826_1042_1057

- Highly unstable upper layer (0-80m)
- Variations exponentially decrease with depth (slide 25)
- SSP differences independent from time and displacement during CTD profiles (slide 27)
- SSP variability as a stochastic process ?? (slides 28 to 30)

4 SSP variations over experiment



Sound speed [14] profile differences between 210825_0844_0938 and
a) 210826_0822_0922 b) 210825_1133_1152
c) 210825_1216_1227 d) 210825_1247_1253
e) 210825_1314_1324 f) 210825_1340_1351
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i) 210825_1529_1540 j) 210825_1549_1558
k) 210826_0937_0950 l) 210826_1010_1024
m) 210826_1042_1057

- Up to 13 m.s-1 day-to-day differences in the upper 80 meters due to temperature variations (slide 31)
- At depth, sound-speed variations between CTDs remain small (slide 32)
- Temporal density of CTDs is too small to evidence periodic SSP variations

5 Summary

- GNSS/A positioning from an ASV has many advantages :
  - Compact system providing good quality data
  - High maneuverability enabling various and precise trajectories
- PPP improves the GNSS solution to cm level
  - CSRS-PPP and GINS better than PRIDE PPP-AR
- SSP is highly variable in the upper water layer (0-80m)
- Yet to be done :
  - Reprocess GAPS data with PPP solution
  - Determine barycenter position jointly using 3 beacons
  - Determine beacon position from equidistant tracks
  - Assess the effects of sound speed variability

References and supplemental material are available in the uploaded presentation

Thank you for your attention

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6 Raw GNSS quality check with Anubis on IGS static stations

Station	Date	Duration	G cs	E cs	R cs
BRST	2021/12/01	23:59:59	4129	5700	1230
BRST	2021/12/02	23:59:59	4718	6049	1204
BRUX	2021/12/01	23:59:59	1029	2989	1810
BRUX	2021/12/02	23:59:59	840	2551	1910

G C1 mp	G C2 mp	E C1 mp
27.3	14.5	16.0
26.8	14.1	15.4
15.3	5.2	12.3
15.2	5.2	12.0

Raw data analysis of stations BRUX and BRST[1] on two days : number of cycle slips (cs) and multi-path observation (mp) in meters

[1] High-rate data available at : https://www.epncb.oma.be/_networkdata/data_access/highrate/

6 Raw GNSS quality check on ASV at sea

- Using observations from Pameli in water only

Receiver	Date	Duration	G cs	E cs	R cs
Septentrio	2021/08/25	07:49:59	4250	932	430
Septentrio	2021/08/26	05:14:59	4257	307	741
Trimble	2021/08/25	07:49:59	220	n/a	715
Trimble	2021/08/26	05:14:59	88	n/a	591

G C1 mp	G C2 mp	E C1 mp
11.8	4.4	9.0
10.4	4.9	9.2
25.5	15.5	n/a
25.3	15.0	n/a

Raw data analysis of mobile antenna : number of cycle slips (cs) and multi-path observation (mp) in meters

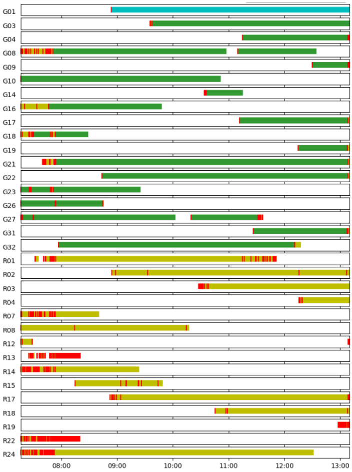
6 GNSS processing ambiguity resolution

Rec	Date	GINS	SCRS-PPP	PRIDE PPP-AR
Sept	08/25	90.5 (19G+16E)	77.14 (24G)	$\sim$ 80 (18G+14E+19C)
Sept	08/26	96 (16G+13E)	73.89 (21G)	$\sim$ 90 (15G+13E+16C)
Trim	08/25	0 (23G)	76.85 (24G)	$\sim$ 90 (22G)
Trim	08/26	0 (18G)	95.47 (18G)	$\sim$ 85 (17G)

Percentage of observations with fixed ambiguities for different software, receivers and date

- Lower value for SCRS-PPP with Septentrio as there is no ambiguity duration threshold to delete short ambiguities when multiple cycle slips occur
- Wrong GNSS C2X/L2X signals selected in Trimble receiver configuration, cannot be fixed with GINS C2W/L2W products

6 CSRS-PPP ambiguities[1]

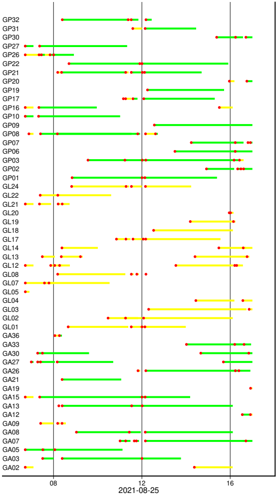


Trimble receiver on 26-08-2021

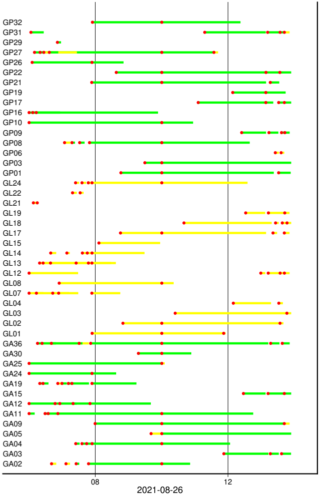
Septentrio receiver on 26-08-2021

[1] Reference ambiguity, Fixed ambiguity, Float ambiguity, New ambiguity

6 GINS ambiguities[1]



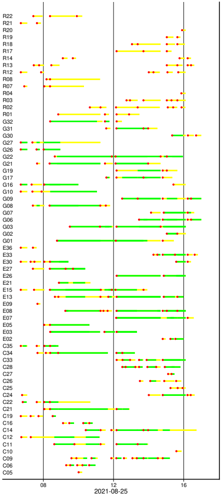
Septentrio receiver on 25-08-2021



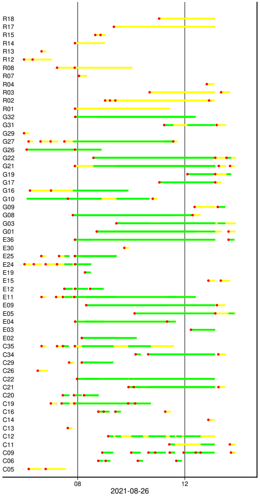
Septentrio receiver on 26-08-2021

[1] Fixed ambiguity, Float ambiguity, New ambiguity

6 PRIDE PPP-AR ambiguities[1]



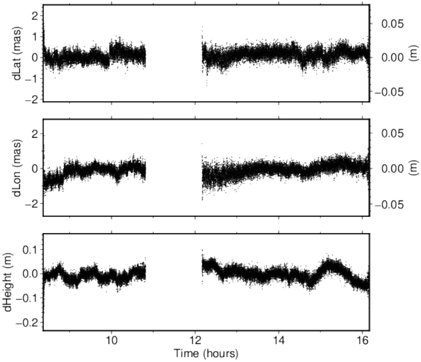
Septentrio receiver on 25-08-2021



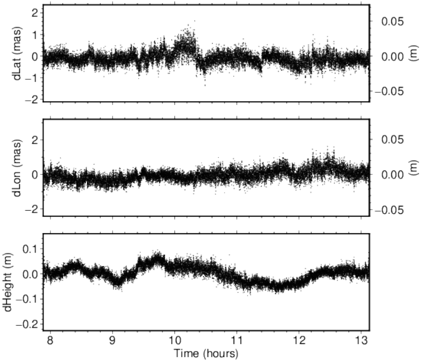
Septetrio receiver on 26-08-2021

[1] Fixed ambiguity, Float ambiguity, New ambiguity

Differences[1] between GINS and SCRS-PPP Septentrio solutions on



25-08-2021

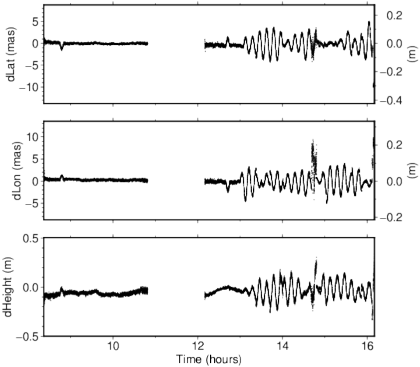


26-08-2021

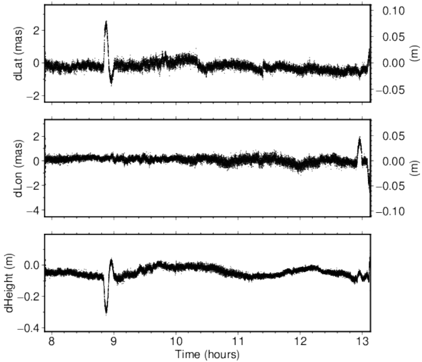
[1] 1 mas ∼ 3cm on Earth surface at the Equator

6 Software solutions comparison

Differences[1] between GINS and PRIDE PPP-AR Septentrio solutions on



25-08-2021 after outliers (> 10mas) removal

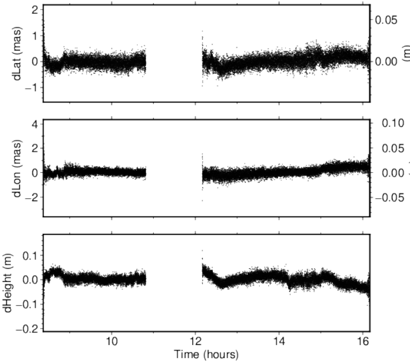


26-08-2021

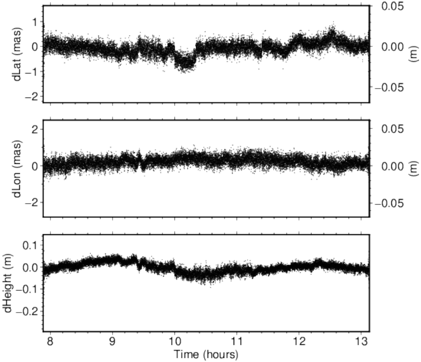
[1] 1 mas $\sim$ 3cm on Earth surface at the Equator

6 Antenna solutions comparison

Differences[1] between Trimble and Septentrio solutions with



CSRS-PPP on 25-08-2021



GINS on 26-08-2021

[1] 1 mas ∼ 3cm on Earth surface at the Equator

6 SSP rapid variations

Differences between down and up measurements of same profile

a) 210825_0844_0938 b) 210826_0822_0922 c) 210825_1133_1152 d) 210825_1216_1227 e) 210825_1247_1253
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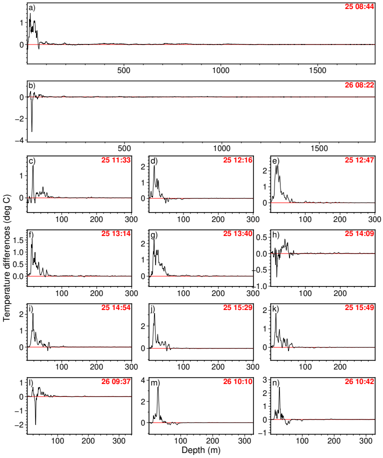
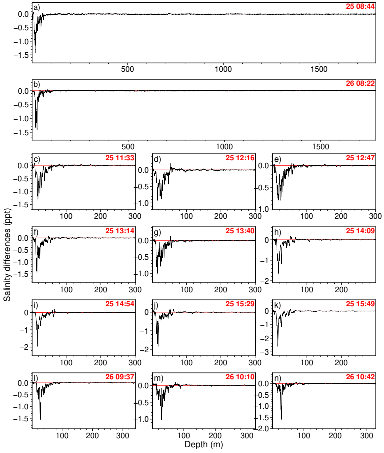
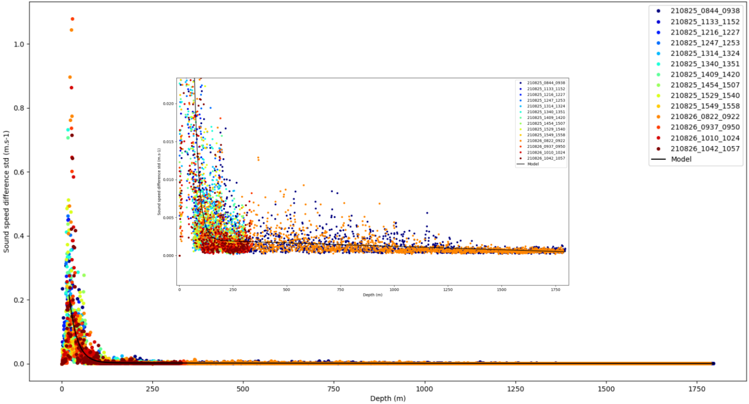


Temperature



Salinity

6 SSP rapid variations

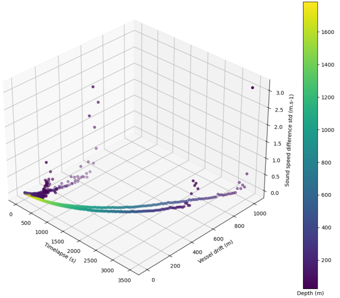


Standard deviation of sound speed differences between down and up measurements of same profile, over 1m depth layers, Model $\sim 0.5 * exp(-z/20) - 1e^{-6}z + 0.003$

6 SSP rapid variations

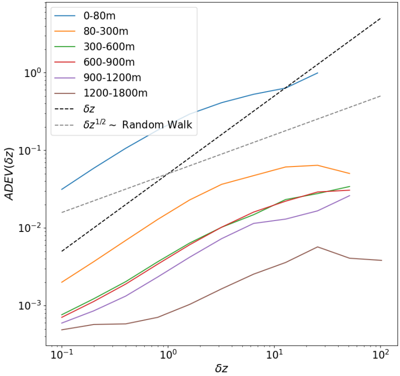
	Depth	Timelapse	E drift	N drift	Mean	Std
Depth	x	0.12	-0.04	-0.04	-0.32	-0.79
Timelapse	0.12	x	0.93	0.88	0.11	0.18
E drift	-0.04	0.93	x	0.84	0.17	0.34
N drift	-0.04	0.88	0.84	x	0.07	0.28
Mean	-0.32	0.11	0.17	0.07	x	0.36
Std	-0.79	0.18	0.34	0.28	0.36	x

Spearman correlation between indicators of sound speed differences between down and up measurements of same profile

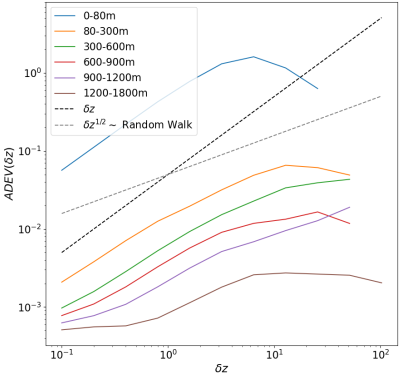


Standard deviation of sound speed differences between down and up measurements of same profile, over 10m depth layers

6 SSP rapid variations



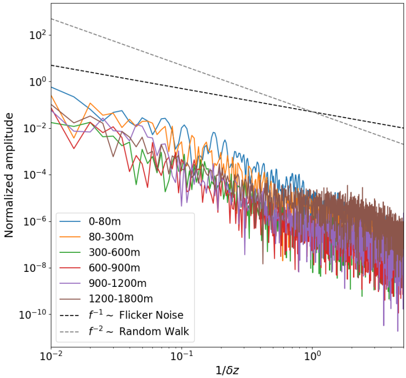
Allan deviation of profile 210825_0844_0938 over different depth layers



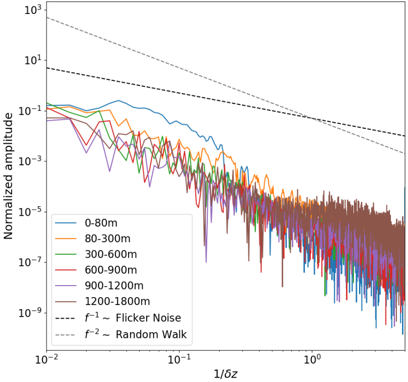
Allan deviation of profile 210826_0822_0922 over different depth layers

- Parabolic shape interpreted as a low decay Markov process [15]

6 SSP rapid variations



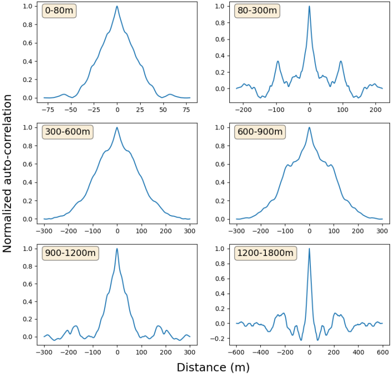
Lomb-Scargle periodogram of profile 210825_0844_0938 over different depth layers



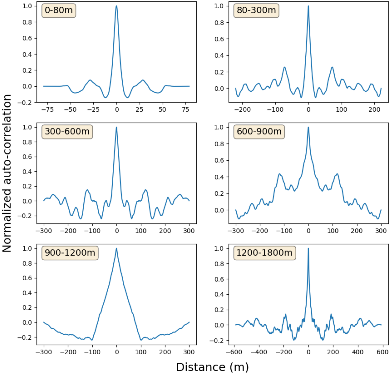
Lomb-Scargle periodogram of profile 210826_0822_0922 over different depth layers

- Typical shape of a random walk or a Markov process

6 SSP rapid variations



Auto-correlation of profile 210825_0844_0938 over different depth layers



Auto-correlation of profile 210826_0822_0922 over different depth layers

- Random walk or Markov process are good approximations for some layers

Profile differences between 210825_0844_0938 and

a) 210826_0822_0922 b) 210825_1133_1152 c) 210825_1216_1227 d) 210825_1247_1253 e) 210825_1314_1324
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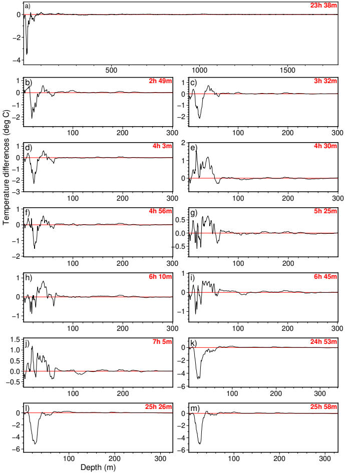
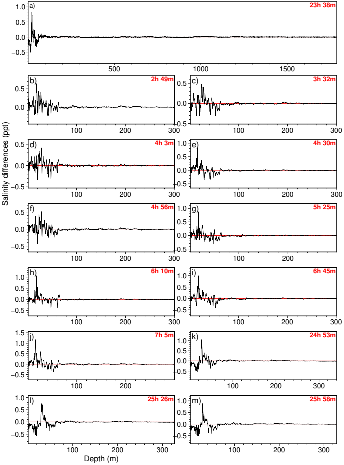
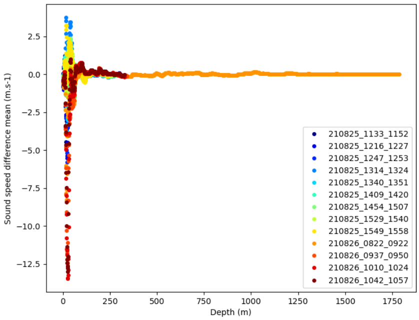


Temperature

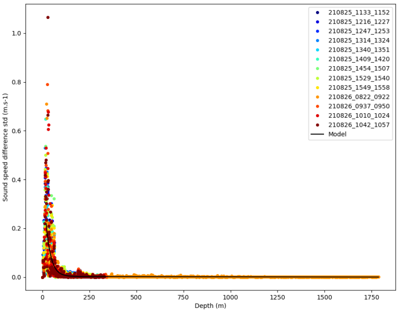


Salinity

6 Variations between SSPs



Mean of sound speed differences with respect to 210825_0844_0938 profile, over 1m depth layers



Standard deviation of sound speed differences with respect to 210825_0844_0938 profile, over 1m depth layers

Model $\sim 0.5 * exp(-z/20) - 1e^{-6}z + 0.003$

Bibliography :

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