Modeling the barotropic response of the Mediterranean sea level to atmospheric pressure forcing

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Introduction and Problems

An important characteristic of the Earth's atmosphere, with direct impact on the marine environment and Earth's gravity field, are the variations of the atmospheric pressure as it often determines wind and weather patterns across the globe.

Variations in atmospheric pressure and especially low atmospheric systems affect the values of radar altimeter sea level anomalies (SLA).

This response of sea level is translated to the Inverse Barometer (IB) correction given by the altimeters within their geophysical data records.

Objectives

This work examines the sea level response to atmospheric pressure change over short time scales (such as ten days) and examines if the total barometer correction given by the altimeter is close to the expected response (- 1 cm/mbar) of sea level to atmospheric pressure change.

A regional multiple regression analysis between sea level anomalies, atmospheric pressure and wind speed components from the Live Access Server (LAS) of NOAA is carried out to model the barotropic response of the Mediterranean to atmospheric wind and pressure forcing.

Finally, in order to investigate the IB effect in the frequency domain, a spectral transfer function has been computed through the Fourier transforms of sea level and pressure.

Available data

The focus is on single mission altimetry data from Jason-2 in the along track direction (pass 196) for a period of fifty days (6 cycles) between October and December 2013.

This period was characterized by extremely low-pressure fields over the Mediterranean Sea and especially in the area of the Ionian and Adriatic Seas.

Pass 196 consists of ~100-140 observations for each cycle, starting from northern Libya, passing East of Malta and crossing the Ionian and Adriatic Seas.

The data have been downloaded from the RADS server (DEOS Radar Altimetry Data System) in the form of SLAs relative to EGM2008 (in the MT system), after applying all the necessary geophysical and instrumental corrections.

Atmospheric pressure data and wind speed data for the period under study were available from the LAS of NOAA and provided at four times per day intervals in a grid format.

Statistics of Jason-2 SLAs per cycle. [Unit: cm]

cycle	Date and time	values	min	max	mean	std
194	15/10 09:45	88	-7.43	8.60	-0.13	±3.73
195	25/10 07:44	107	-13.45	9.72	1.94	±4.45
196	04/11 05:42	149	-7.71	9.77	2.08	±3.61
197	14/11 03:41	131	-10.76	26.03	12.21	±7.44
198	24/11 01:39	134	3.10	31.42	18.11	±5.35
199	03/12 23:38	146	-22.48	8.86	-9.36	±6.88

Statistics of IB corrections per cycle. [Unit: cm]

194	min	max	mean	std
total	-8.81	-5.63	-7.70	±1.09
local+global	-9.81	-7.14	-8.71	±0.94
IB calculated	-6.67	-5.17	-6.18	±0.62

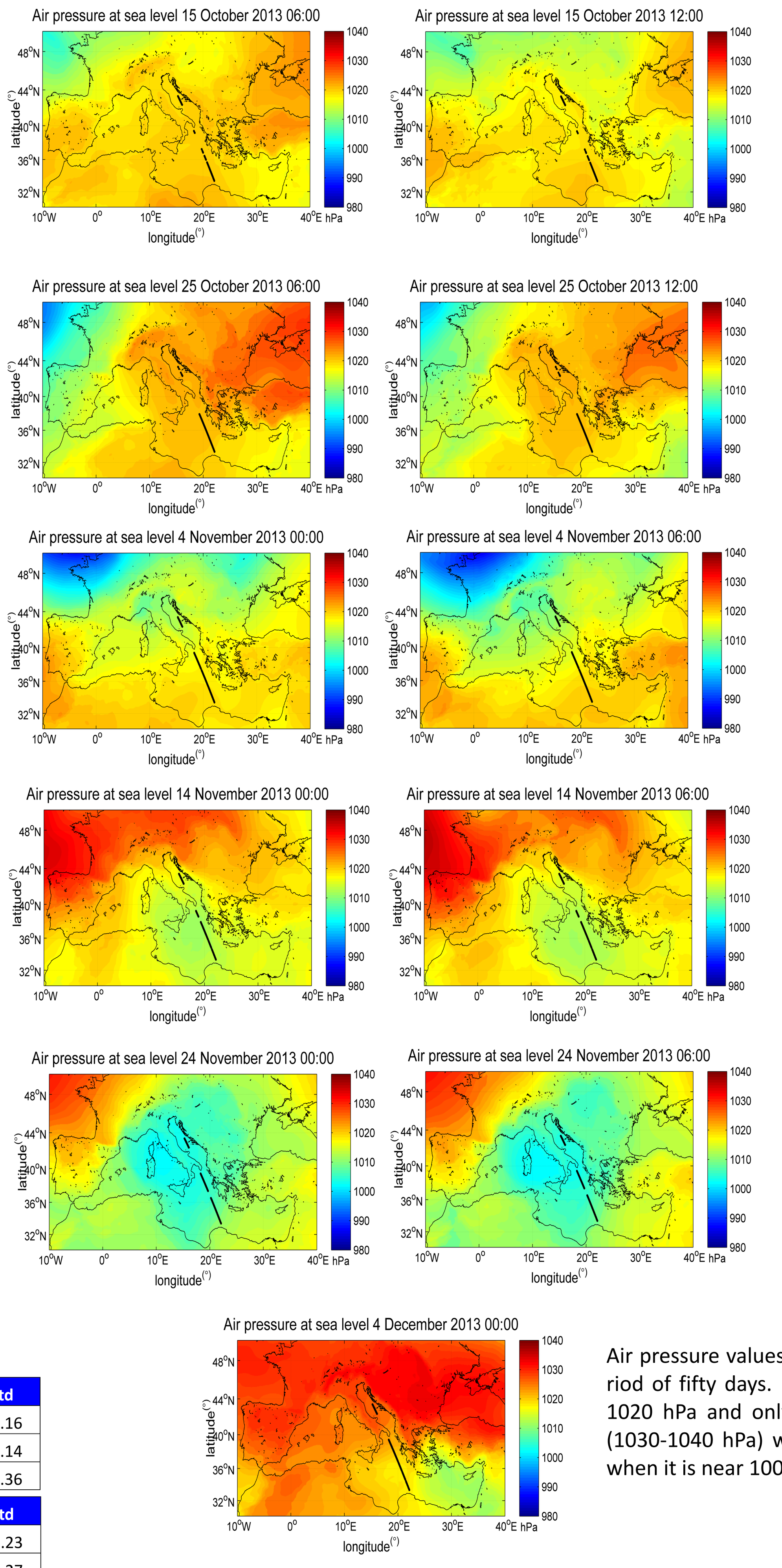
197	min	max	mean	std
total	-10.37	0.00	-2.04	±3.16
local+global	-2.73	4.10	2.17	±2.14
IB calculated	-2.69	1.79	0.69	±1.36

195	min	max	mean	std
total	-11.28	-8.31	-9.50	±0.67
local+global	-12.01	-7.50	-10.73	±0.44
IB calculated	-8.65	-6.67	-7.50	±0.53

198	min	max	mean	std
total	1.93	13.25	6.24	±3.23
local+global	3.50	10.66	7.34	±2.27
IB calculated	3.78	9.75	7.31	±2.10

196	min	max	mean	std
total	-11.12	-3.15	-8.22	±2.46
local+global	-8.51	1.47	-5.27	±3.02
IB calculated	-6.67	3.28	-3.85	±3.09

199	min	max	mean	std
total	-12.12	-6.36	-8.07	±1.95
local+global	-12.26	-4.26	-6.64	±2.71
IB calculated	-12.63	-4.68	-7.12	±2.87



Air pressure values at sea level vary from 1000 to 1040 hPa in this period of fifty days. For mot dates air pressure value is close to 1010-1020 hPa and only in 4 December the highest values are observed (1030-1040 hPa) while the smallest one is observed ten days earlier when it is near 1000 hPa.

Figure 1: Air pressure at sea level for the cycles 194-199.

For cycles 194 and 195 an interesting agreement is found between the consecutive records of the satellite. A mean separation between the cycles 196-197 is evidenced, of the order of ~20 cm for the southern part of the pass while this separation is observed and in cycles 198 and 199.

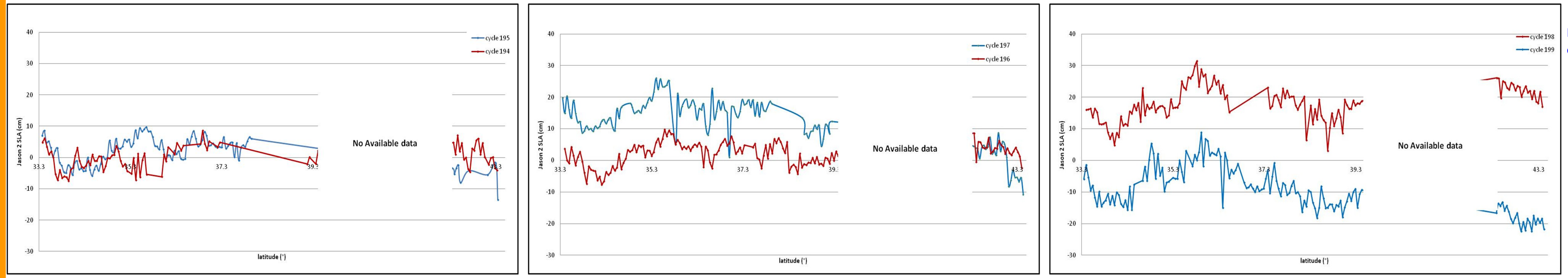


Figure 2: Jason 2 pass 196 SLAs for cycles 194, 195 (left) cycles 196, 197 (center) and cycles 198, 199 (right)

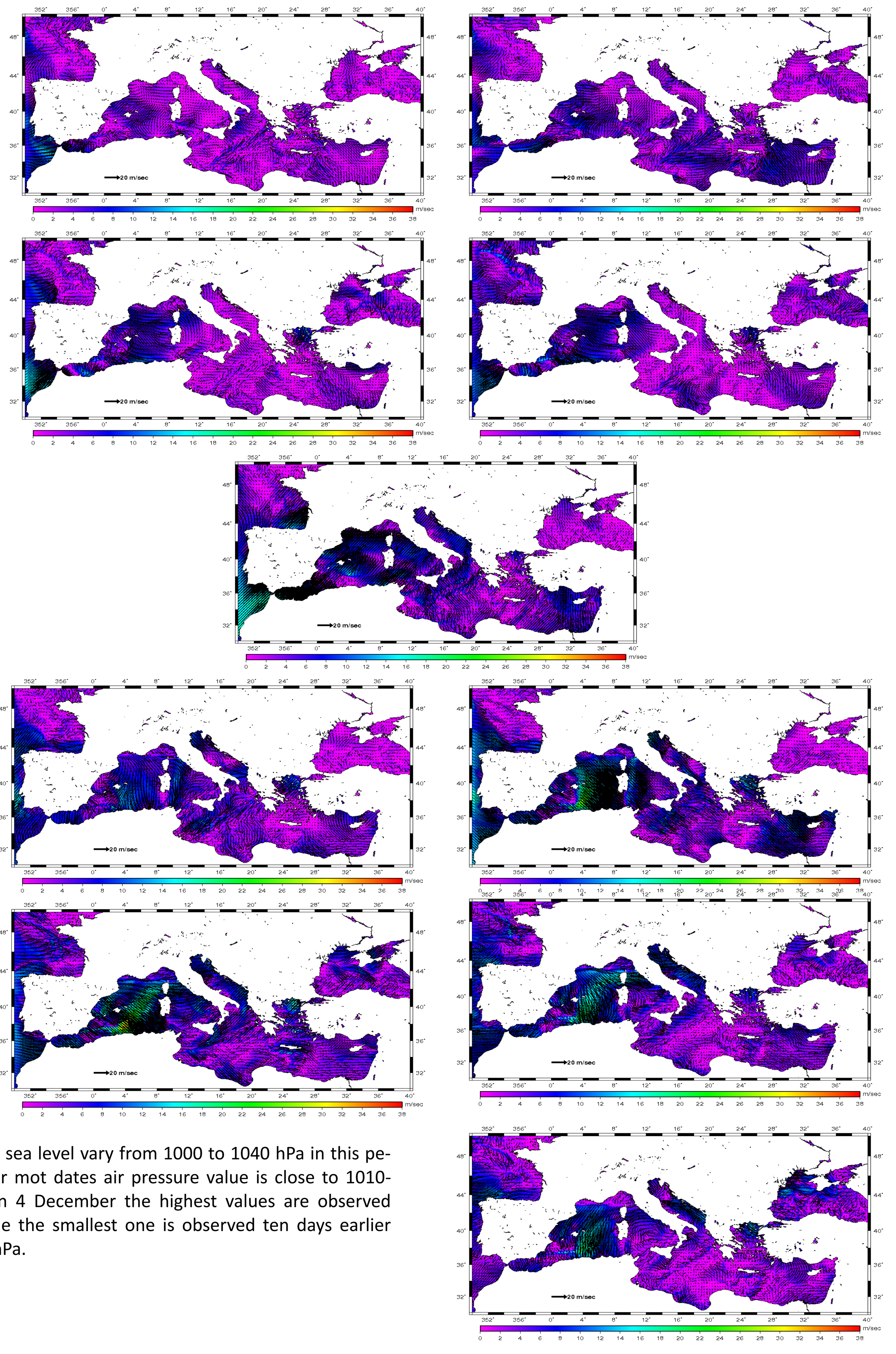
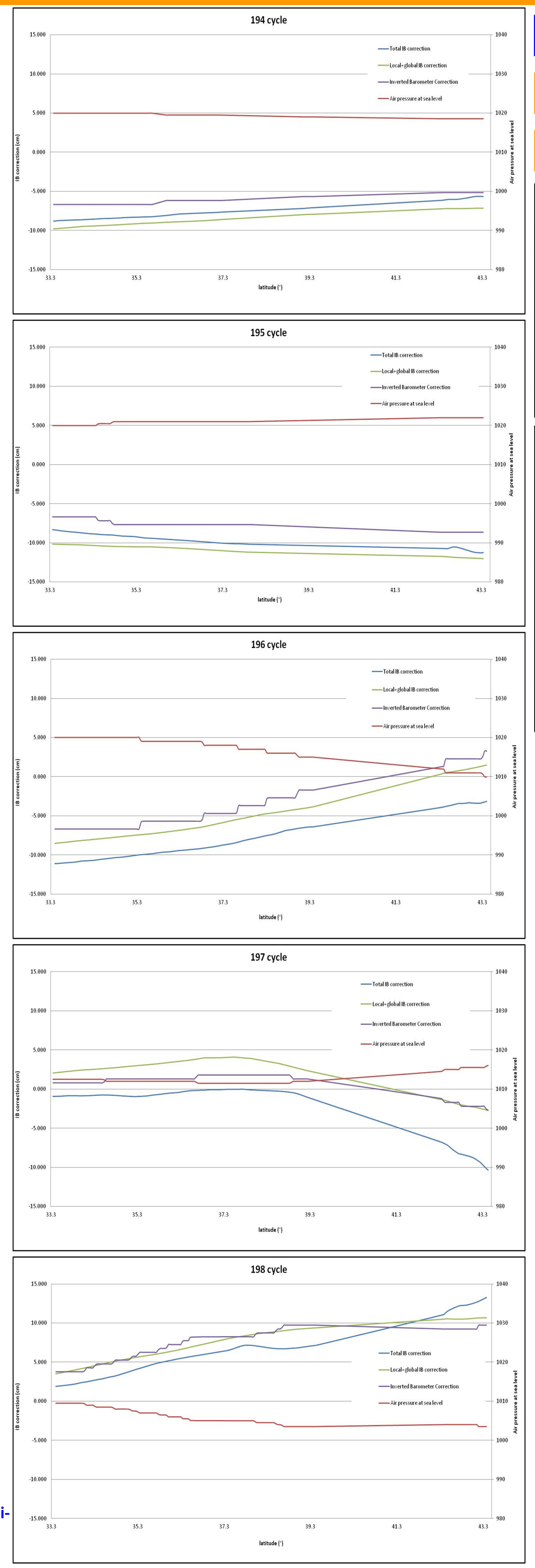


Figure 3: Wind speed vector at 10 meters above ground on the same hour and date with Air pressure values. In November 4, the wind speed is a mean field estimated between the 00:00 and the 06:00 field.



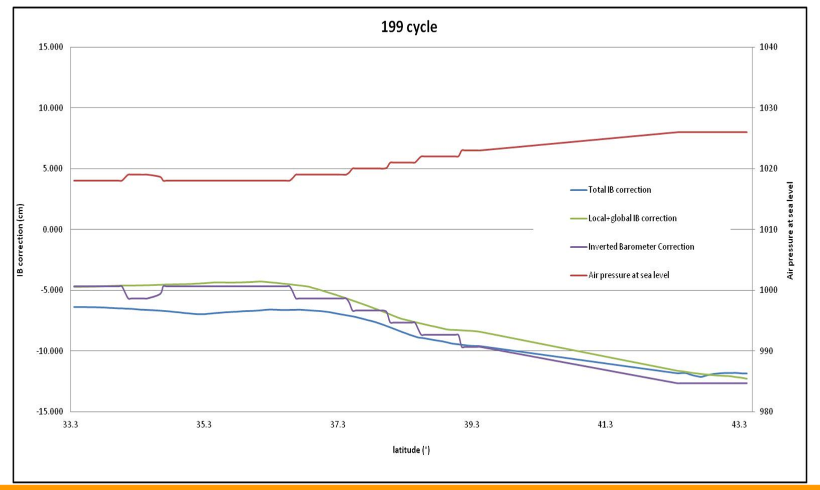


Figure 4: Air pressure at sea level and various IB corrections for all cycles.

From the figure 4, it is obvious that air pressure is inverse to IB correction. The IB correction varies from –15 cm to 15 cm and three types of IB correction are presented.

Total IB given by the altimeter, the sum of local and global IB correction also given by the altimeter and the inverted Barometer correction as it is calculated by the equation given in AVISO handbook for JASON2: IB= -9.948 *(P_{atm} - 1013.3)

Small differences (2 – 5 cm) are observed between the corrections. In some cycles the global value of IB was not available and as result the sum is equal to the local correction.

Moreover, the barometer correction given by the altimeter is close to the expected response (-1 cm/mbar) of sea level to atmospheric pressure change.

Regional multiple regression analysis

3 regression coefficients $sla = b_1 p + b_2 v_x + b_3 v_y$

5 regression coefficients $sla = b_1 p + b_2 v_{x-2} + b_3 v_{x+2} + b_4 v_{y-2} + b_5 v_{y+2}$

cycle	b_1 (cm/mbar)	b_2 (m/s)	b_3 (m/s)
194	-0.108 ± 0.131	0.265± 0.541	1.645 ±1.202
195	0.041 ± 0.153	2.341 ± 0.660	-0.541 ± 0.42
196	0.139 ± 0.126	0.110 ± 0.306	0.117 ± 0.241
197	1.166 ± 0.082	1.149 ± 0.445	1.789 ± 0.272
198	1.970 ± 0.421	-0.032 ± 0.582	-0.246 ± 0.72
199	-1.122 ± 0.145	-1.104 ± 0.260	1.540 ± 0.342

cycle	b_1 (cm/mbar)	b_2 (m/s)	b_3 (m/s)	b_4 (m/s)	b_5 (m/s)
194	-0.163±0.150	-0.667±1.048	0.933±1.931	1.817±2.429	0.182±2.309
195	0.088±0.115	-3.624±1.374	3.772±1.442	6.491±1.806	-6.647±1.875
196	0.088±0.234	-2.741±0.579	2.416±1.321	1.327±1.147	-0.857±1.478
197	1.189±0.086	1.231±0.735	0.162±0.714	0.434±1.566	1.318±1.655
198	1.530±0.511	-2.280±1.357	1.972±1.239	0.675±0.984	-0.216±1.013
199	-1.071±0.130	-2.289±0.843	1.178±0.870	0.553±0.893	1.248±0.840

Two different approaches for the linear regression between sea level, wind speed and atmospheric pressure have been used.

The first one with three regression coefficients and the second with five regression coefficients. In the 3-coefficients case they represent atmospheric pressure and two wind speed components, one in the West-East and another in the North-South direction, for the point under consideration. In the 5-coefficients there are two additional wind speed components for the preceding and following points.

In both cases, the coefficient for atmospheric pressure for cycle 199 gets closer to the -1 cm/mbar while cycles 197 and 198 present values close 1 cm/mbar. The coefficients b_2 to b_5 for the wind stress tend to have comparable magnitudes and opposite signs

For cycle 197 the magnitude of the coefficients get smaller values signalling the pass of the atmospheric low in the area.

For Cycles 197, 198 and 199 the high-value of b1 dictates that the SLA is mainly atmosphere-drives. Contrary to that for Cycle 194, 195 and 196 b1 is very low signalling that the SLA variation is due to other phenomena (salinity, temperature, etc.)

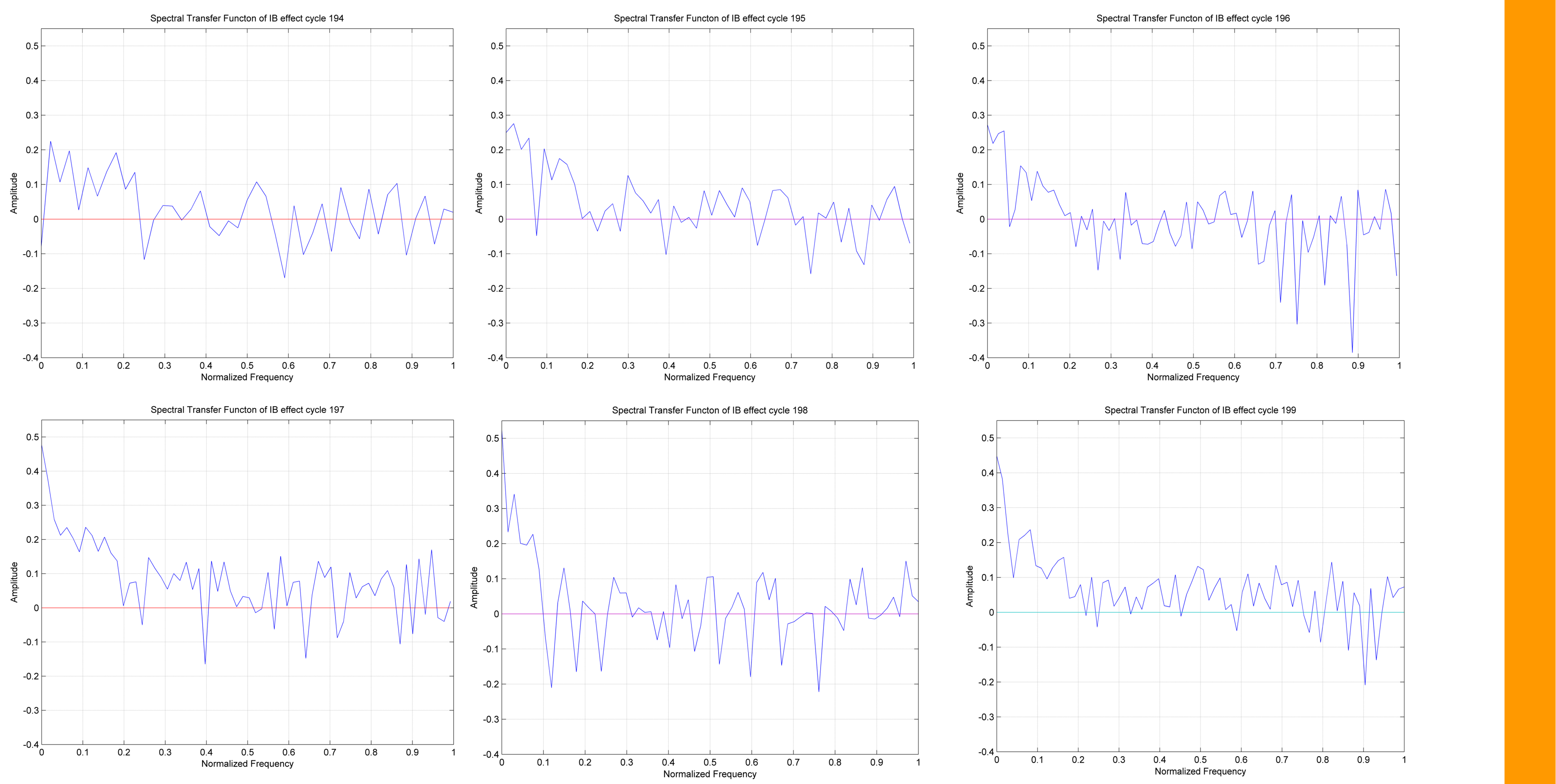


Figure 5: Spectral Transfer Function of IB for cycles 194-199.

To investigate the IB effect in the frequency domain, a spectral transfer function has been computed through the Fourier transforms of sea level and pressure. In cycles where air pressure gets the minmax values (198-199) the transfer function present large discrepancies and large values while in cycles where air pressure values were stable the transfer function gets values close to zero. The coherency between SLA and air-pressure for Cycles 197, 198 and 199 is close to 50% and reduces to 10-20% for cycles 195, 196 and 197.

Conclusions

- At short scales of 10 days an agreement between the consecutive LA records of the satellite is observed. Differences between them, from cycle to cycle, can be attributed to extreme high and low pressure fields or high wind speeds.
- Generally , the total IB correction given by the altimeter is closed to the expected one of –1 cm/mbar and all types of IB corrections present similar values.
- Trough multiple regional analysis, it is obvious that in regions with large discrepancies in air pressure the b_1 coefficient is close to –1 cm/bar. The effect of wind forcing is obvious in areas with stable air pressure as the other coefficients tend to have large values.
- The transfer function of IB presents large values and discrepancies when air pressure gets the minmax values and gets values close to zero when the air pressure is stable. There is large coherency between the SLA and atmospheric pressure when there is an atmospheric low, whereas it reduces to 10-20% when the SLA variation is not related to atmospheric forcing

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