MINISTERIO DE FOMENTO

Puertos del Estado

Comparison of CODAR SeaSonde HF Radar operational waves and currents measurements with Puertos del Estado buoys. Final report.

Marta Alfonso, Enrique Álvarez and José Damián López.

Puertos del Estado.

March 2006.

Contents

Abstract

Puertos del Estado, the Harbour Authorities of A Coruña and Vigo and the engineering company Qualitas Instruments, signed in April 2005 an agreement to carry out the installation of two CODAR Seasonde HF Radars at the Galician Coast in the lighthouses of Finisterre and Silleiro. The objective is to analyse HF Radar technology as a complementary component of the other ocean observing networks of Puertos del Estado in relation with ocean future monitoring strategies. Measurements have been carried out between November 2005 and February 2006 during a representative three months period. This report presents the results of the comparison done between data of different instruments, HF Radar and buoys. The results of the experience are, mainly, the following:

- The HF Radar system operated properly during the whole experience period.
- Agreement between HF Radar and Silleiro buoys measurements were satisfactory.
- Measurement outputs were intregated in Puertos' web page showing, in real time, currents fields and currents and waves time series in buoys nearness.
- The system tested is mature for operational applications.

1 Introduction

SeaSonde HF radar delivers complementary information to the existing operational measuring network of Puertos del Estado and this motivated the start of an experience in Galicia on 2005. The experience was designed with these main objectives:

- Validate the data obtained by the HF radar by comparing with moored buoys the parameters of vectors currents and waves direction, period and height.
- Describe the benefits of the technology for harbour management, safe navigation and search and rescue.
- Promote discussion and serve as a basis of further analysis and articles.

In this report the procedures and results of the validation are presented. The validation period stared at 19 November 2005 and finished at 17 February 2006. The instrumentation used in the validation have been the following:

- HF radar Long Range SeaSonde located in the lighthouses of Finisterre (A Coruña) and Silleiro (Pontevedra). Both systems were operating at 4.86 MHz with bandwith of 30 KHz.
- Seawatch deep water buoy (ext. buoy) with DWR sensor for waves and UCM-60 sensor for currents measurement.
- Waverider shallow water buoy (int. buoy) for scalar waves measurement.

2 Previous considerations

2.1 Currents analysis considerations

The currents analysis uses data from both SeaSonde sites and the deep water buoy (ext. buoy). The currents sampling time of SeaSonde is different from buoy. This is due to difference of the measurement's physics: while long range hf radar is based on Bragg waves' echo distanced up to 200 km from the antenna, the buoy ultrasonic currentmeter is based in the difference in transit time between two opposites direction ultrasonics waves pulsed at same time from transducers distanced about 10 cm. Briefly, the radar hf needs, for a 4-5 MHz frequency and 3 cm/s of radial velocity resolution a time series of 1024 seconds (20 min), several spectra and radial maps must be averaged to avoid the statistical noise, producing a sample every hour, and independent sample every 3 hours. On the other hand, the ultrasonic sensor pulses every 0.5 sec, averages during 10 min, obtaining an independent sample every hour.

In order to use the same time window for the comparison we have applied a temporal filter to buoy data, this is, the components u and v of the buoy of each hour is averaged with the hour before and the hour after (moving window). The spatial horizontal variability is taken into account and radar currents are biliearly interpolated from the four points closer to the ext. buoy in the radar's map grid (6021 to 6024 in figure 1).

The inertial and subinertial currents from ext. buoy and radar were computed and compared to provide additional insight to the study.

2.2 Waves analysis considerations

The waves analysis uses data from Silleiro SeaSonde site and from both buoys. The SeaSonde waves data comes from the second order Bragg peak information of one range cell, that means that the measure area has to be considered as a partial ring centered in radar site, which width is the range resolution (5 km for 4-5 MHz). In the experience it was used only data from cell located between 10-15 km (see figure 2).

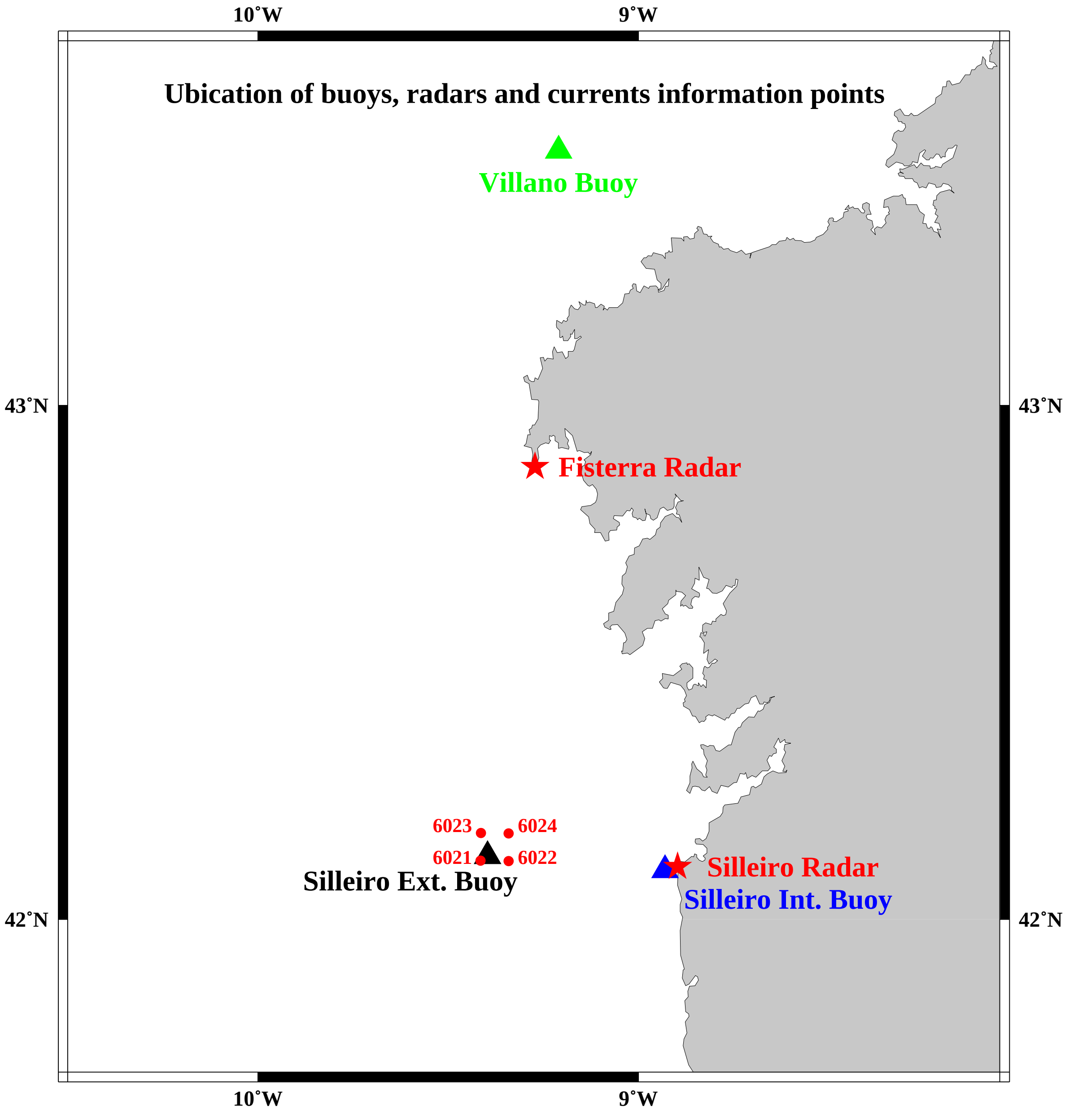


Figure 1. Location of radars, buoys and currents measurement points.

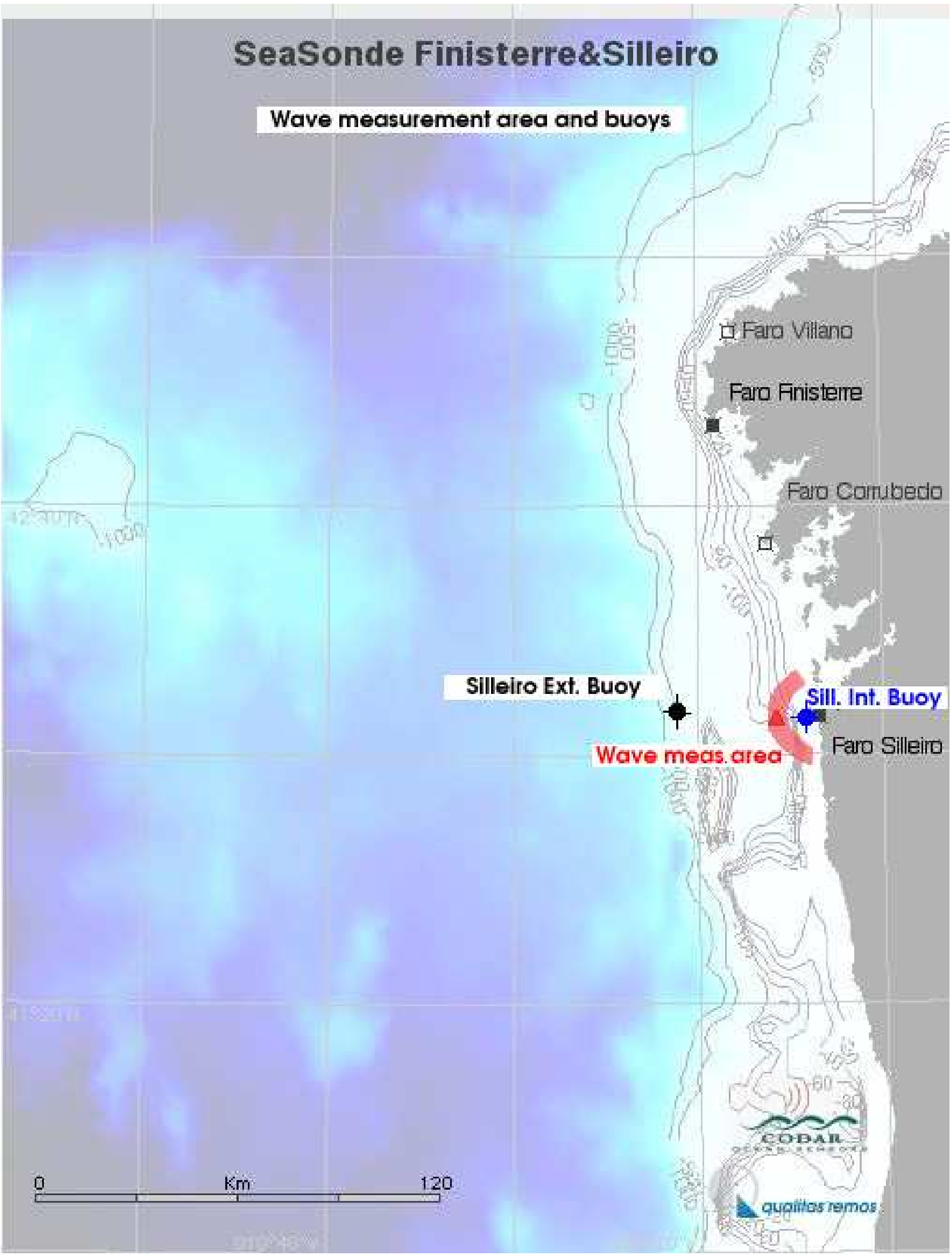


Figure 2. Location of buoys and waves measurement area.

3 Statistics applied

Supose we have two series of data: $\{X(t_i); i = 1, ..., N\}$ and $\{Y(t_i); i = 1, ..., N\}$. To compare both sets we have selected the following statistical variables:

- Mean value of X series:

$$\overline{X} = \mathbf{E}[X] = \frac{1}{N}\sum_{i=1}^{N} X(t_i) \tag{1}$$

- Mean value of Y series:

$$\overline{Y} = \mathbf{E}[Y] = \frac{1}{N}\sum_{i=1}^{N} Y(t_i) \tag{2}$$

- Linear regression:

  · Regression line slope:

$$m = \frac{\mathbf{E}[X\,Y] \;-\; \mathbf{E}[X]\,\mathbf{E}[Y]}{\mathbf{E}[X^2] - \mathbf{E}[X]^2} \tag{3}$$

  · Ordinate in the origin:

$$b = \overline{Y} - m\overline{X} \tag{4}$$

- Correlation index:

$$IC = \frac{\mathbf{E}[X\,Y] \;-\; \mathbf{E}[X]\,\mathbf{E}[Y]}{\{\,\mathbf{E}[X^2] - \mathbf{E}[X]^2\,\}^{\frac{1}{2}}\;\{\,\mathbf{E}[Y^2] - \mathbf{E}[Y]^2\,\}^{\frac{1}{2}}} \tag{5}$$

- Root mean square difference:

$$RMSDif = [\,\frac{1}{N}\sum_{i=1}^{N}(Y(t_i) - X(t_i))^2\,]^{\frac{1}{2}} \tag{6}$$

- Bias.

$$Bias = \overline{Y} - \overline{X} \tag{7}$$

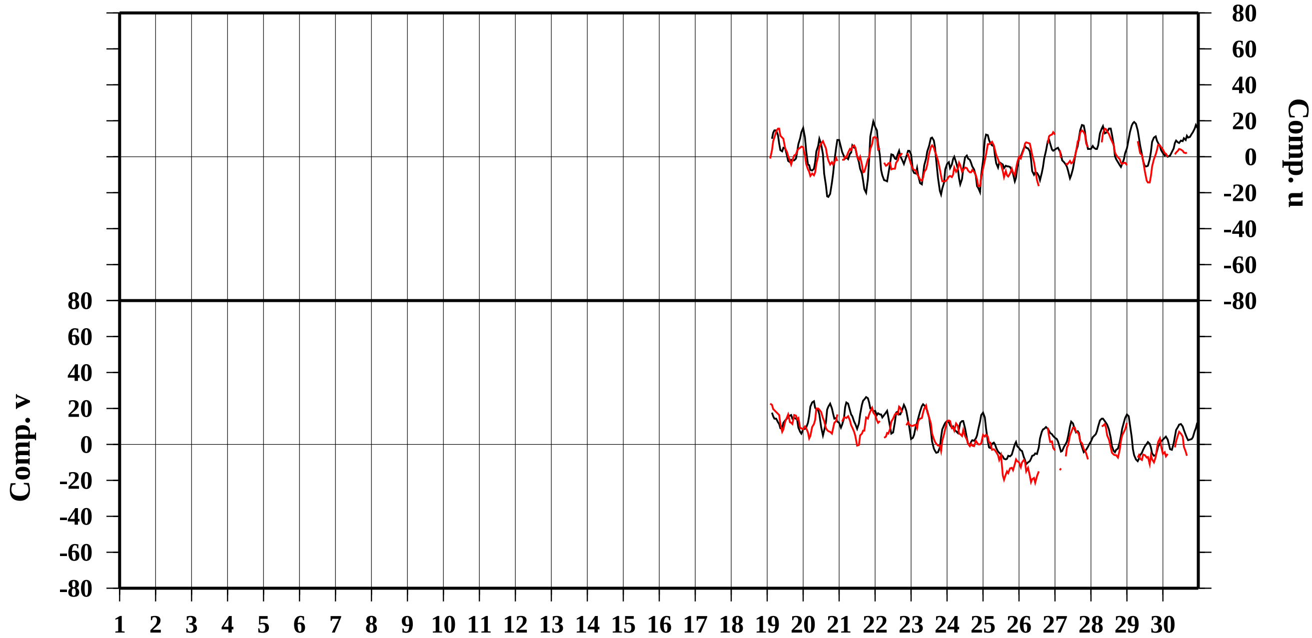
- Scatter index:

$$SI = \frac{RMSDif}{\overline{X}} \tag{8}$$

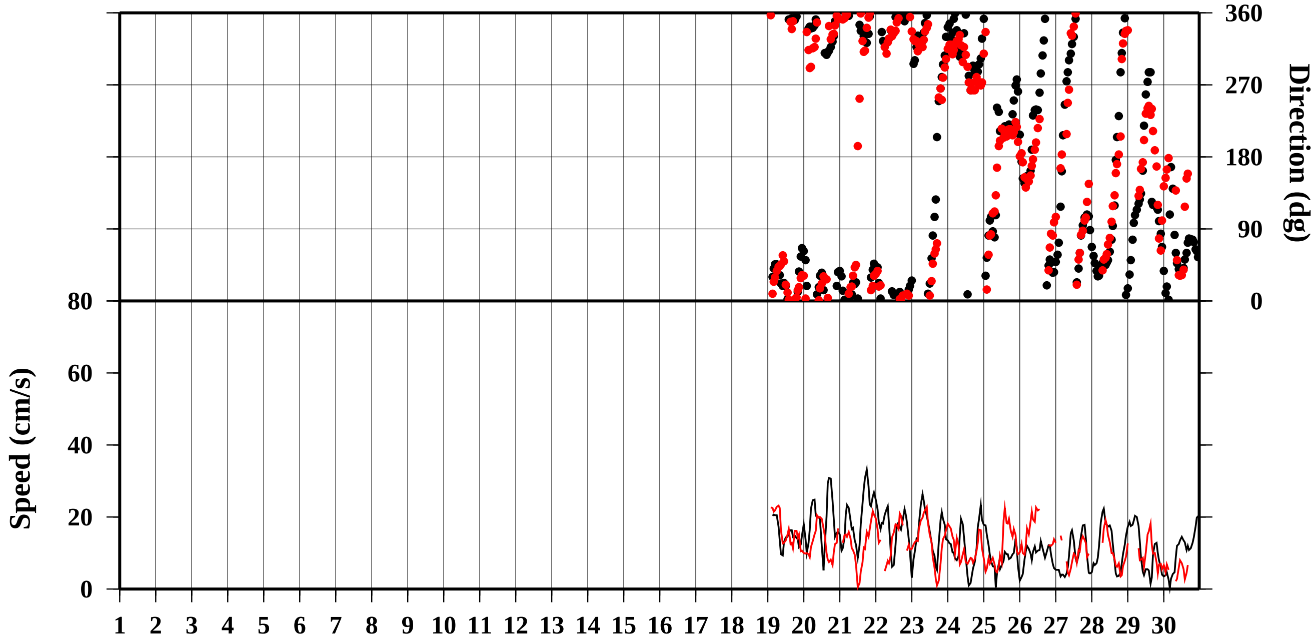
4 Currents results

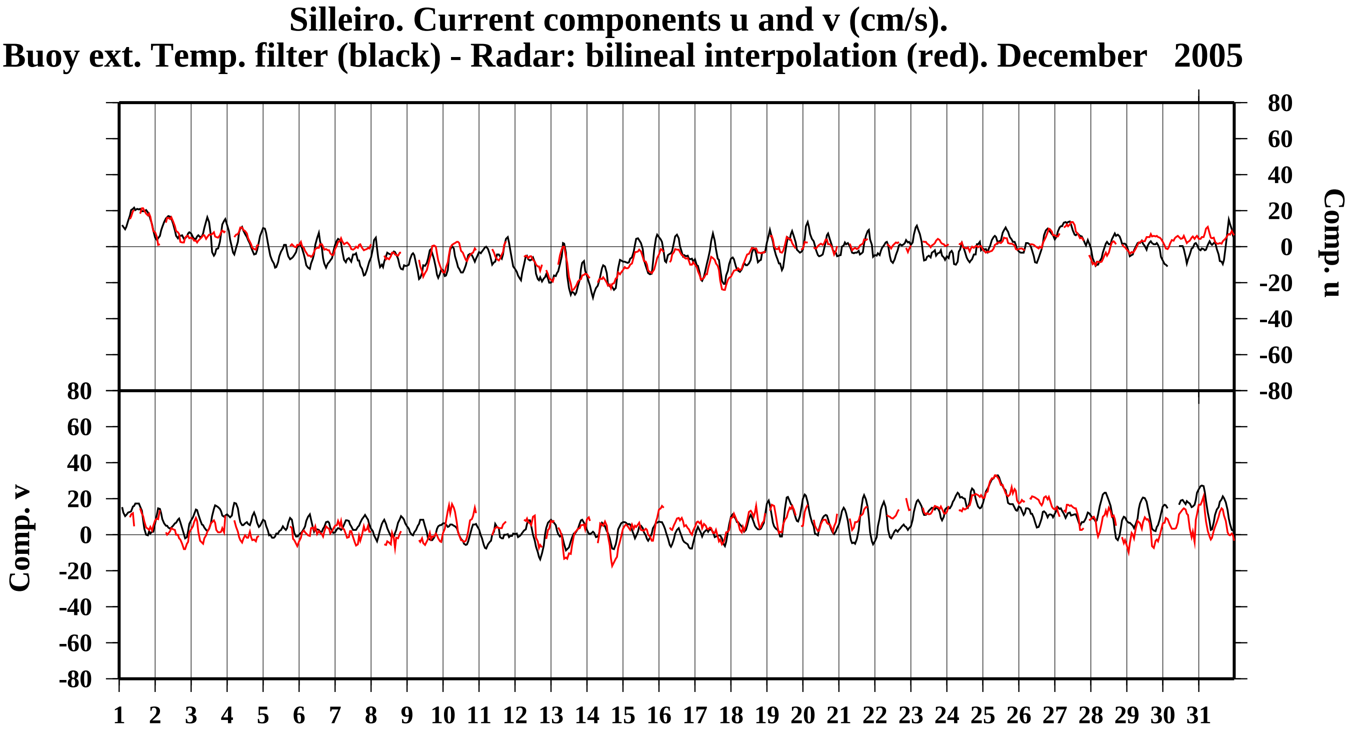
4.1 Time series graphs

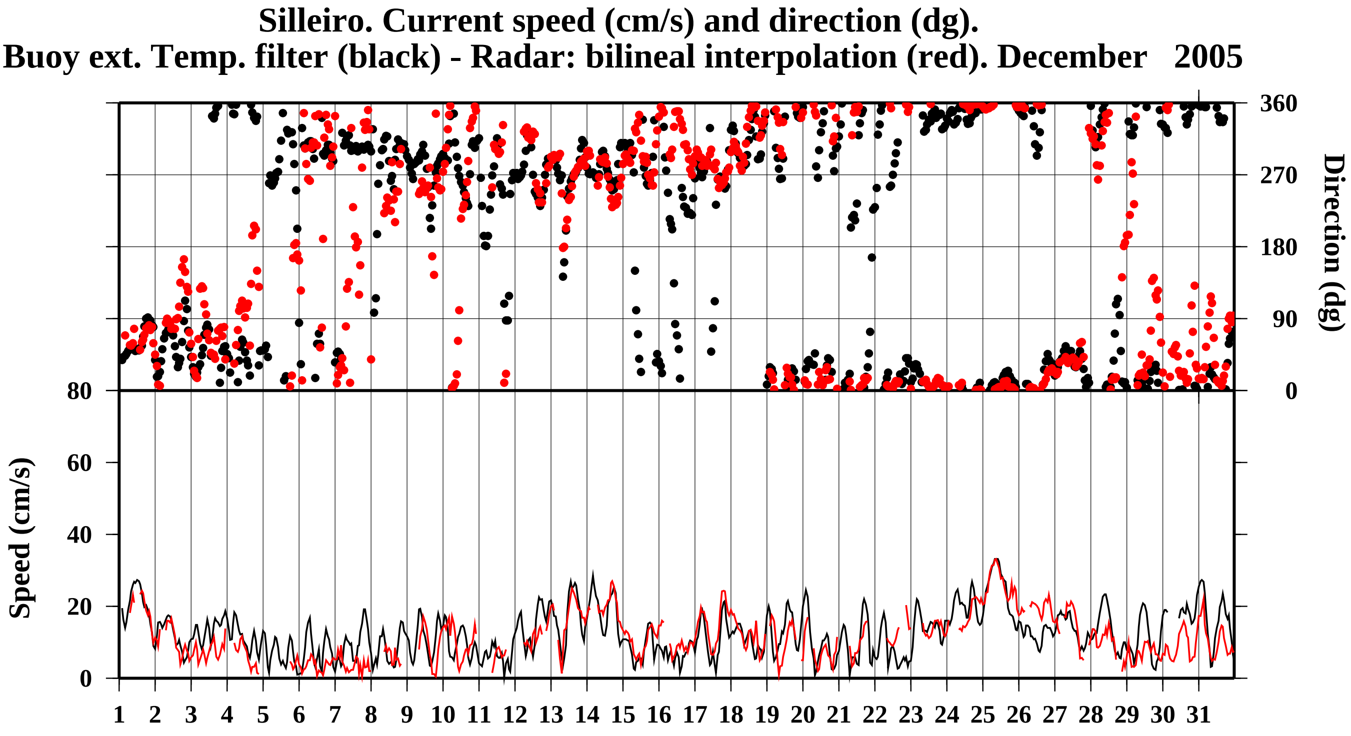
Silleiro. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005

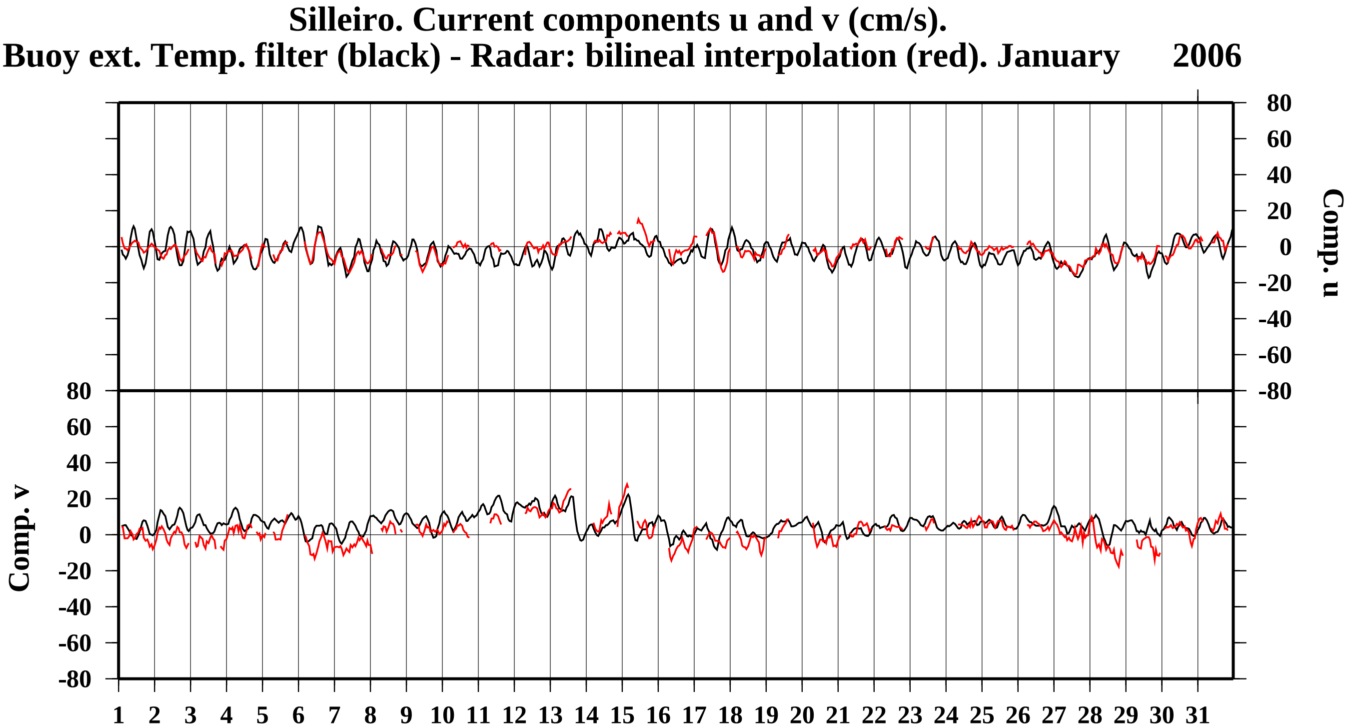


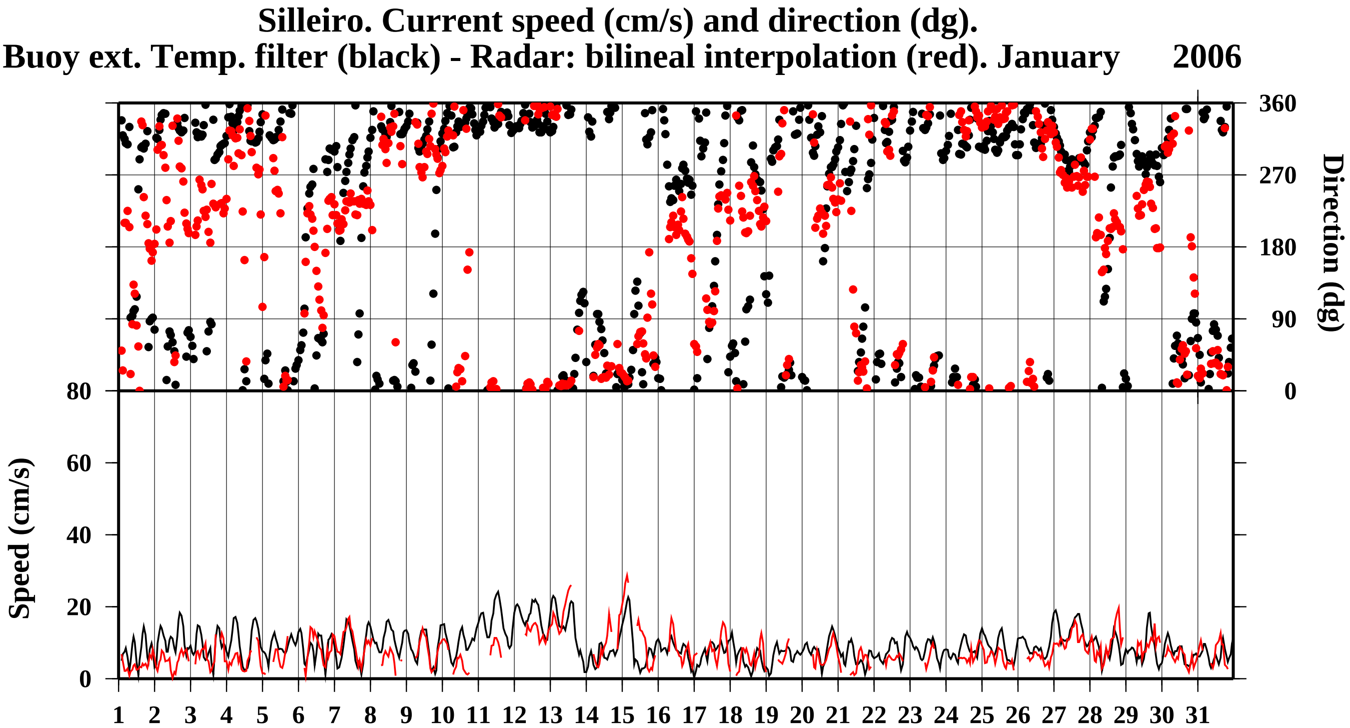
Silleiro. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005



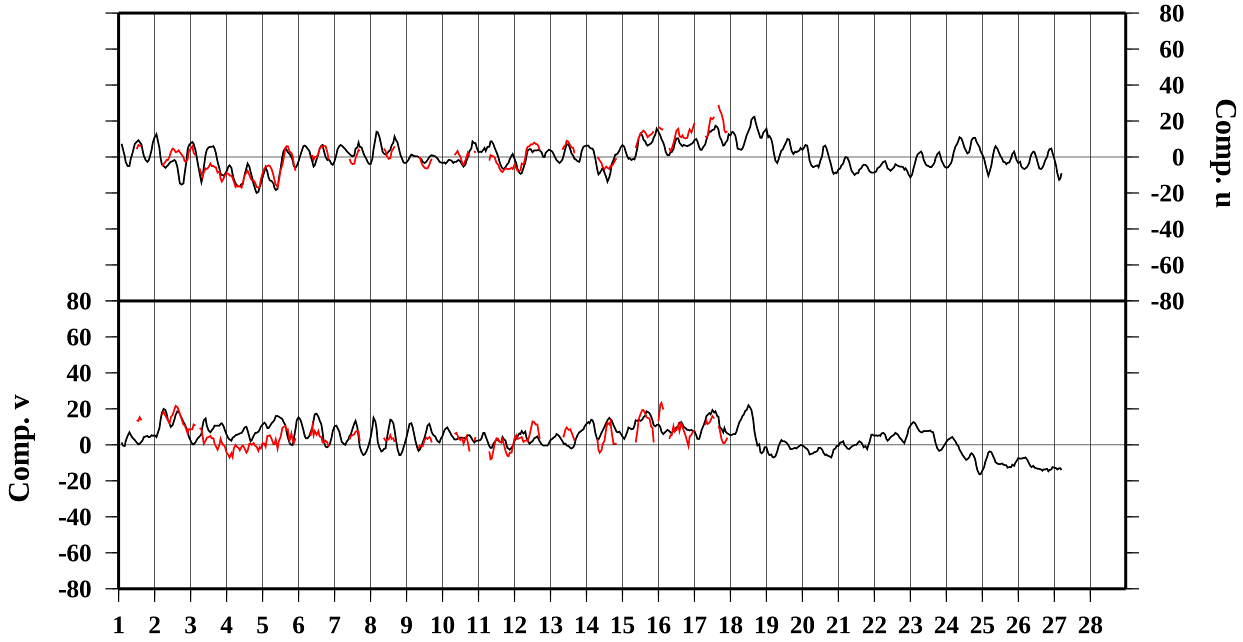

Silleiro. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005
Comp. u
Comp. v
80
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31


Silleiro. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005
Direction (dg)
360
270
180
90
0
Speed (cm/s)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

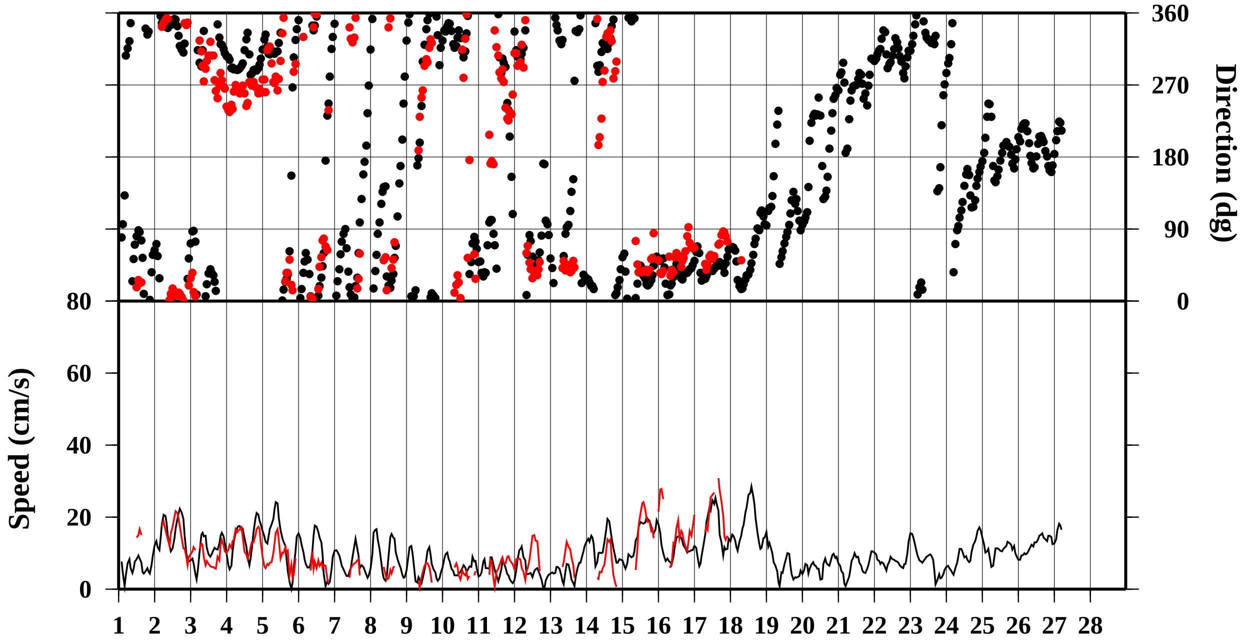

Silleiro. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006
Comp. u
Comp. v
80 60 40 20 0 -20 -40 -60 -80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31


Silleiro. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006
Direction (dg)
360 270 180 90 0
Speed (cm/s)
80 60 40 20 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

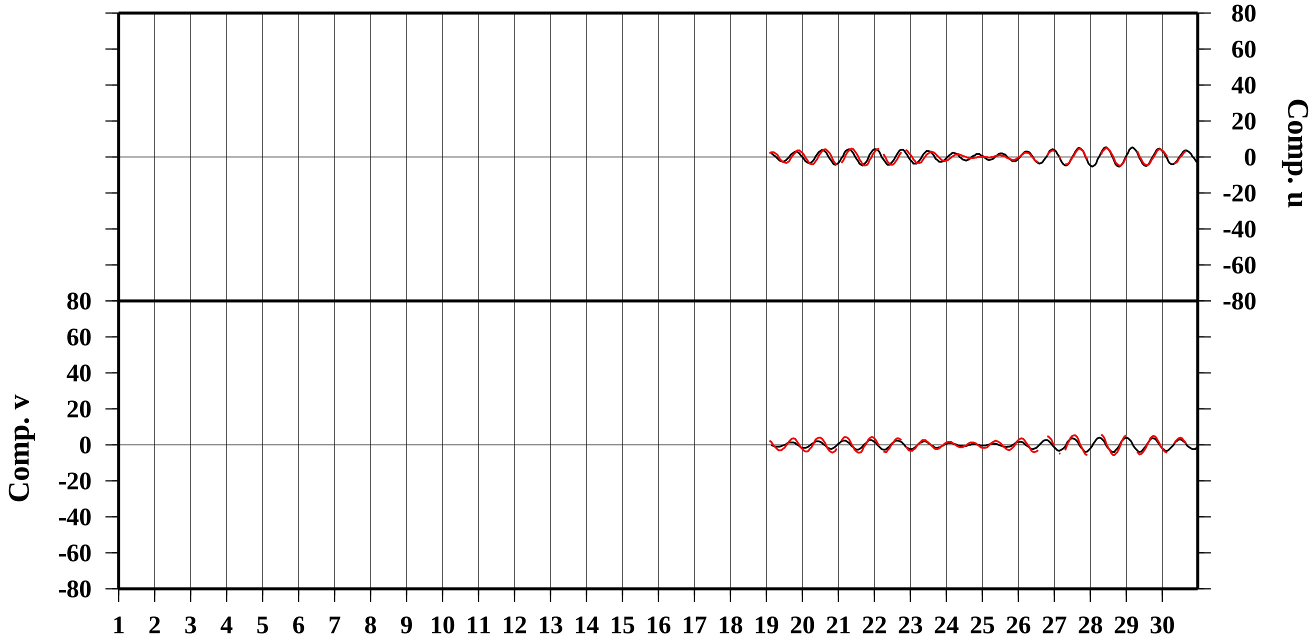
Silleiro. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006



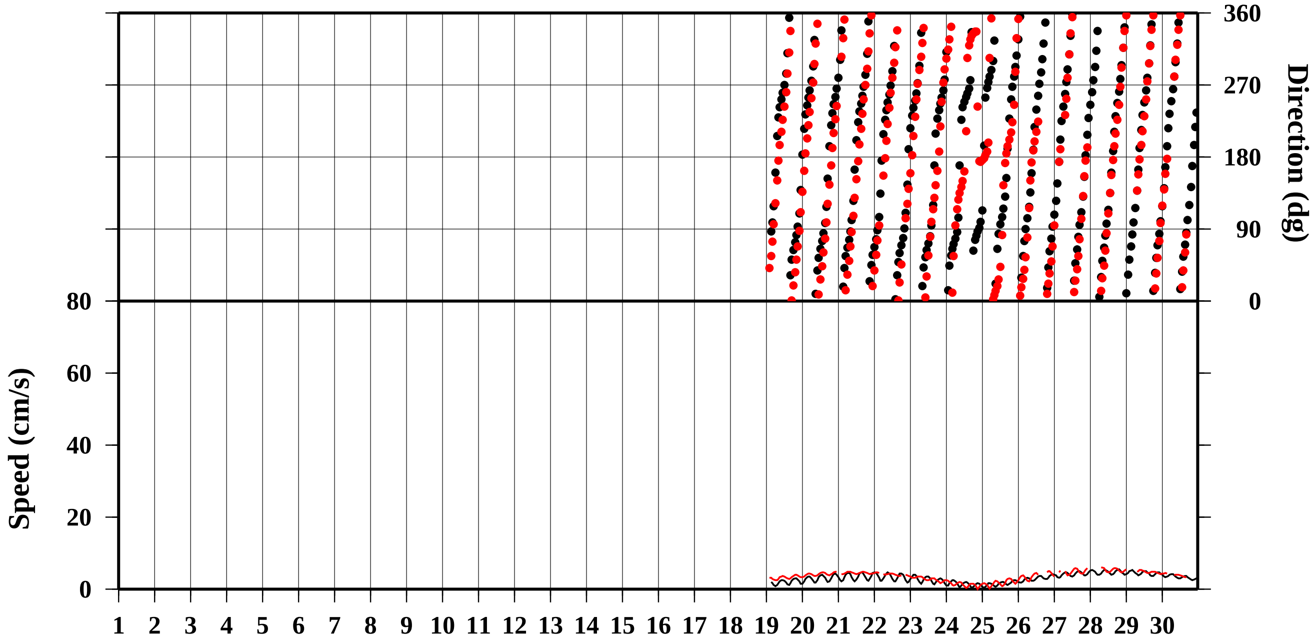
Silleiro. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006



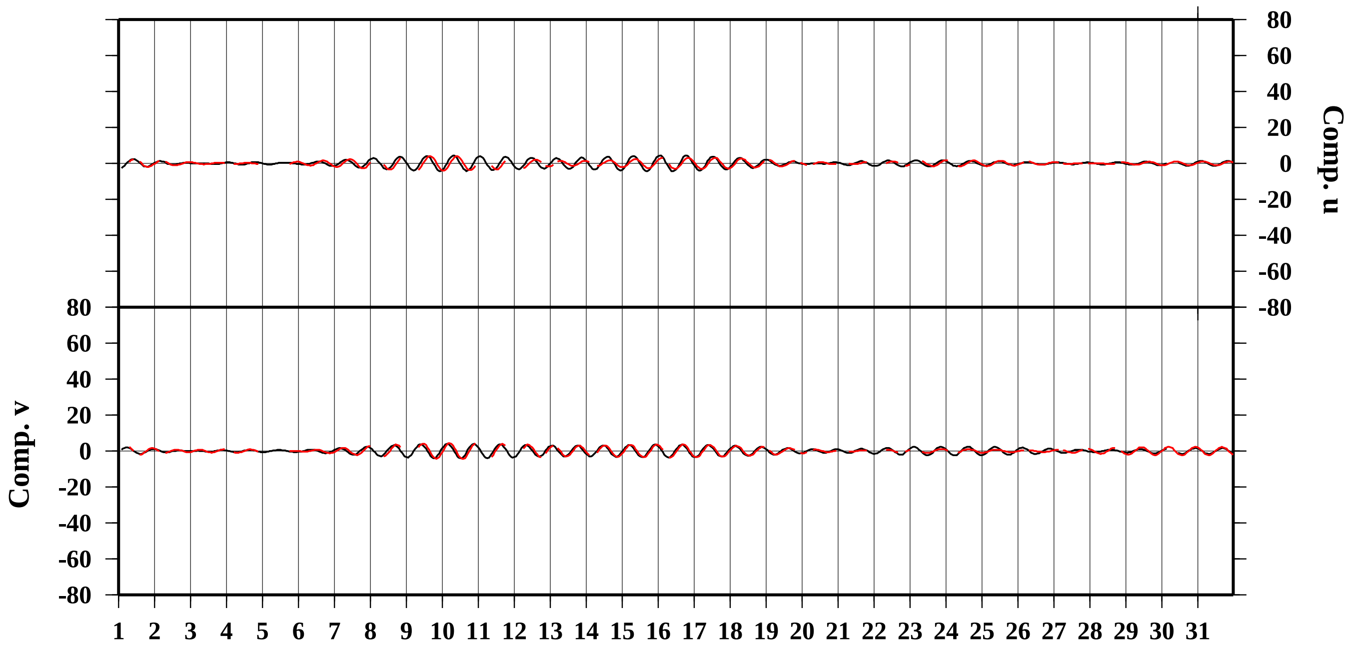
Silleiro inertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005



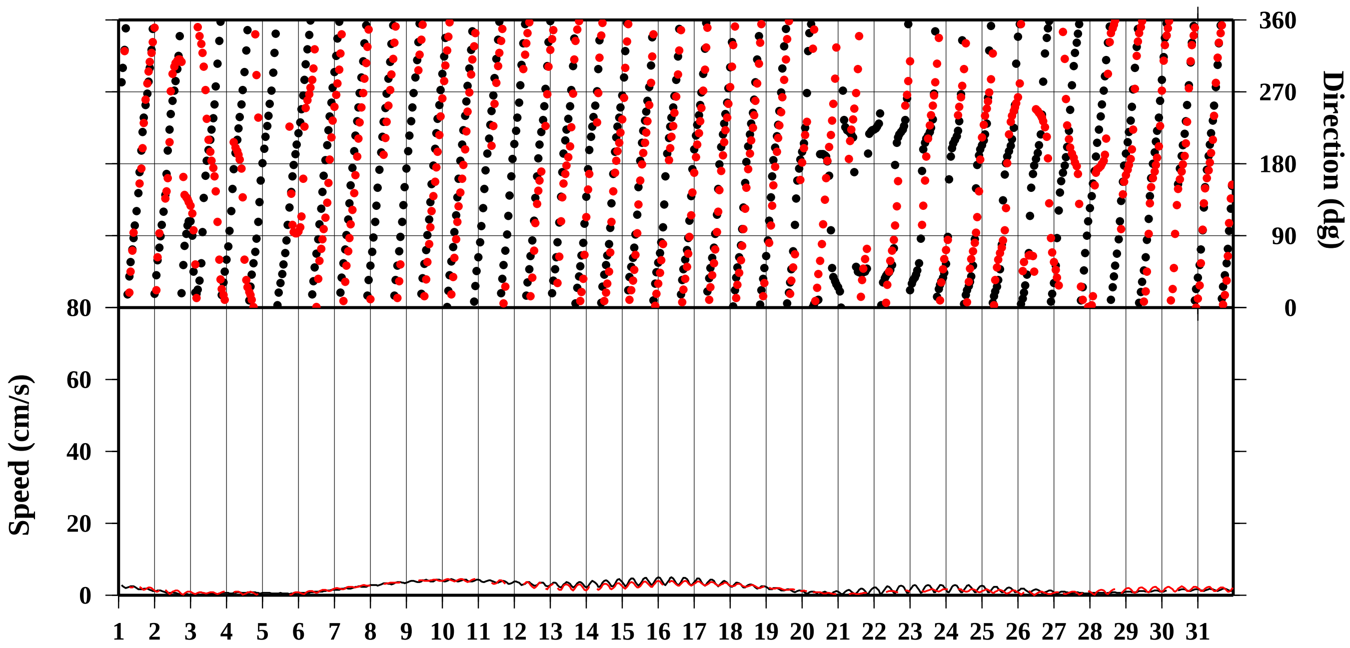
Silleiro inertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005



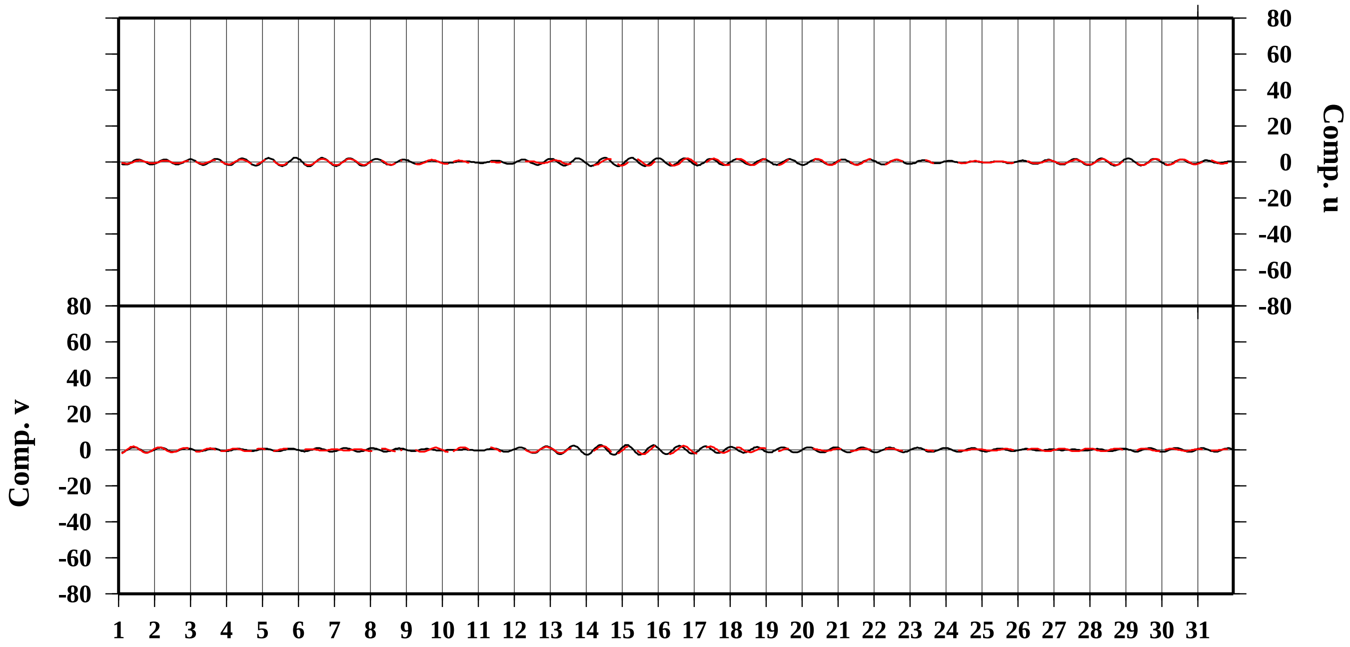
Silleiro inertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005



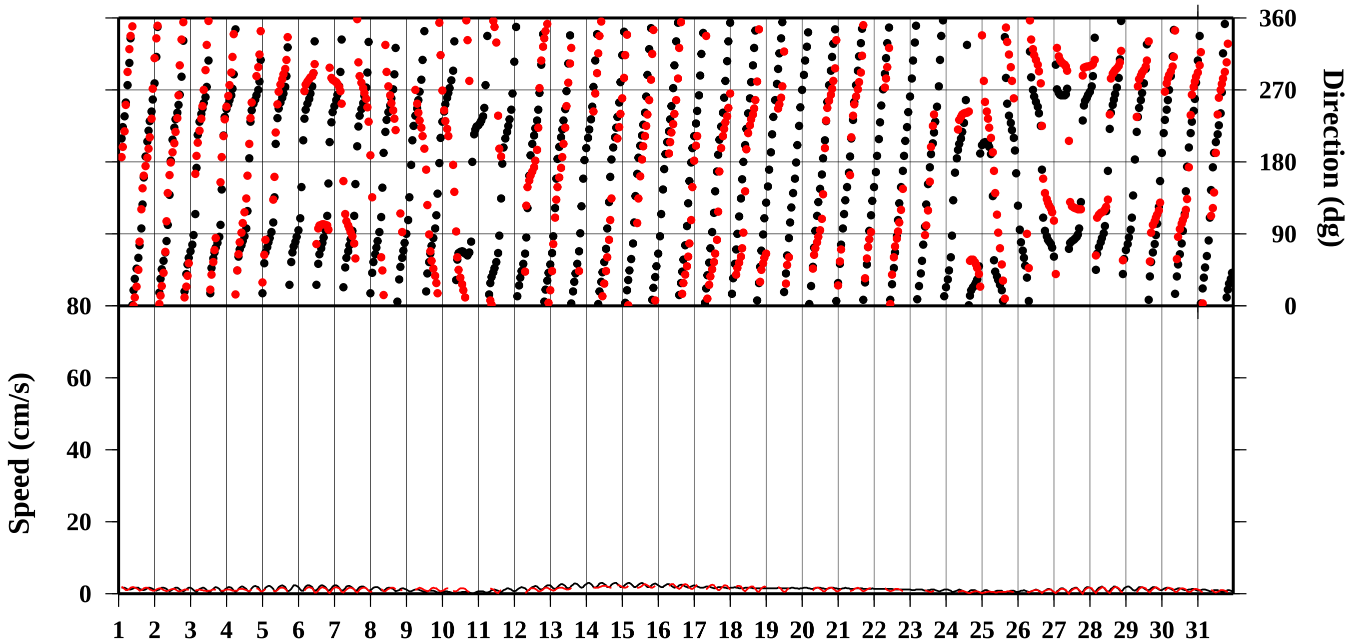
Silleiro inertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005



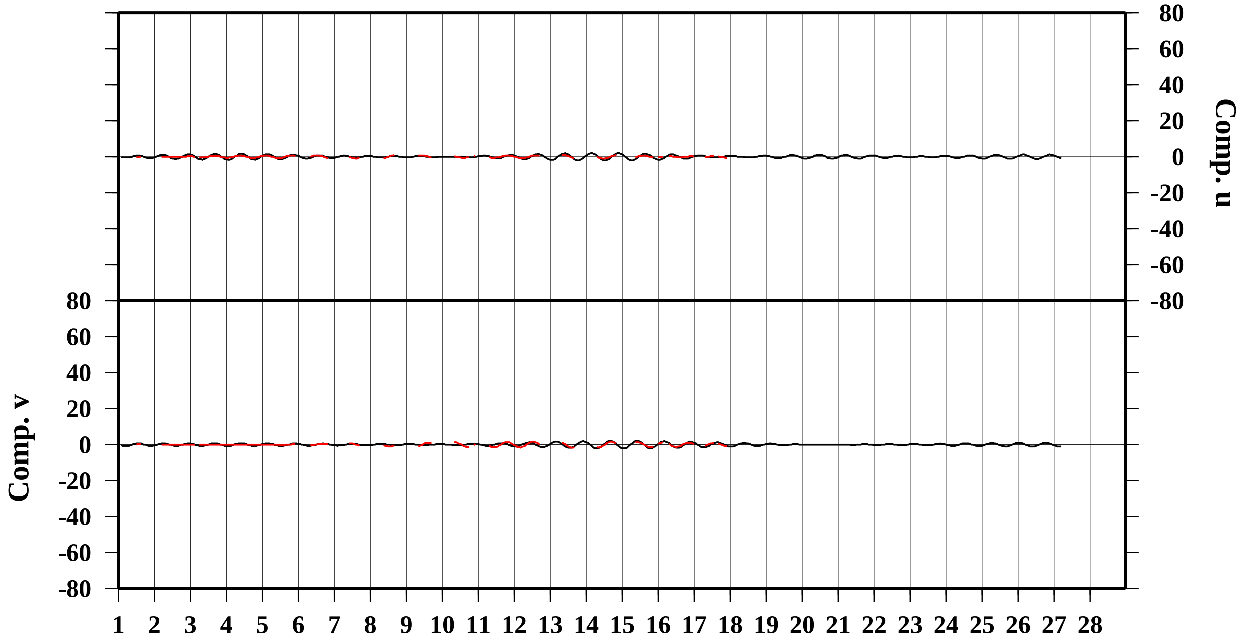
Silleiro inertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006



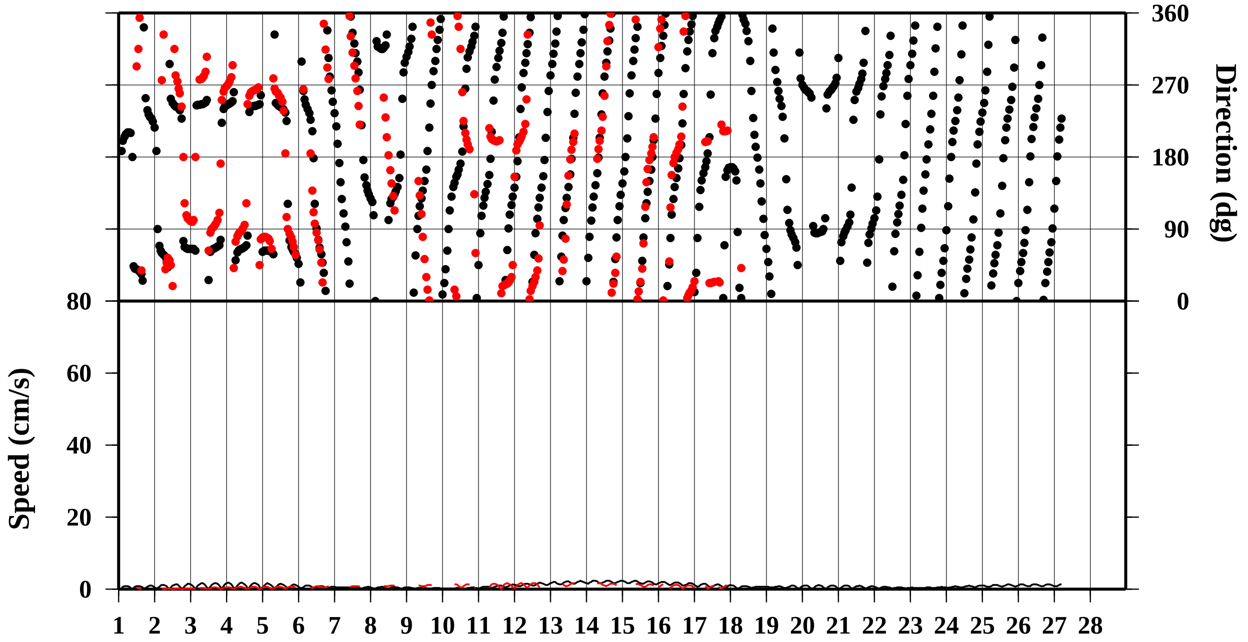
Silleiro inertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006



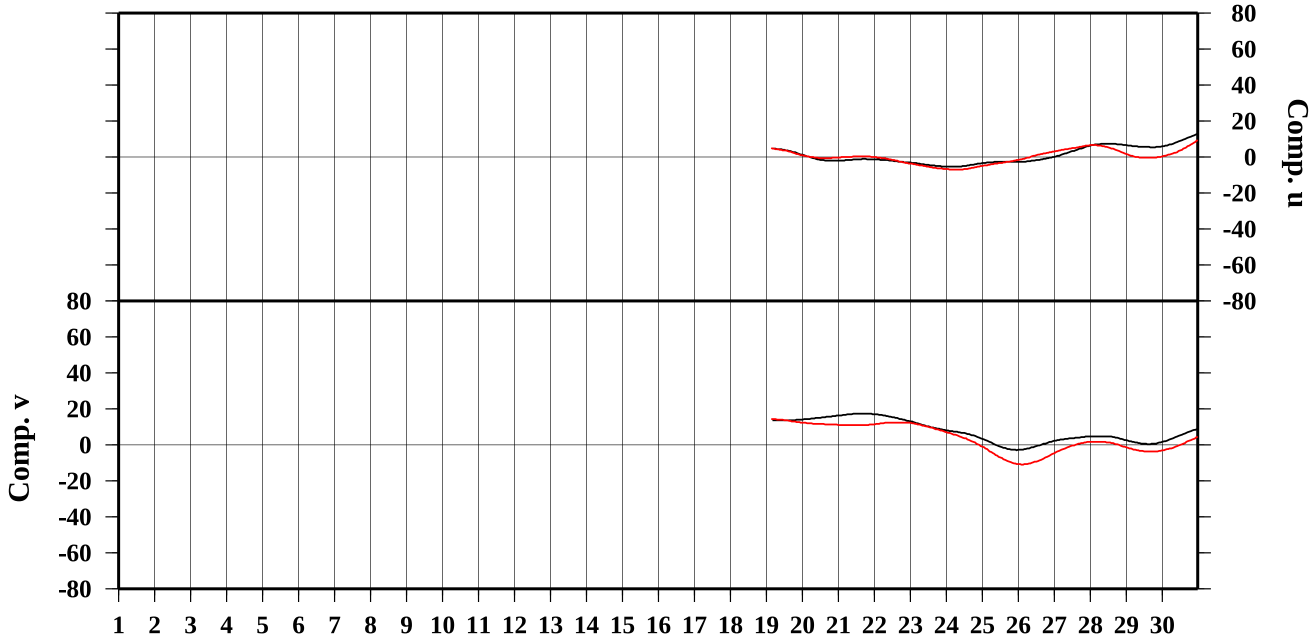
Silleiro inertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006



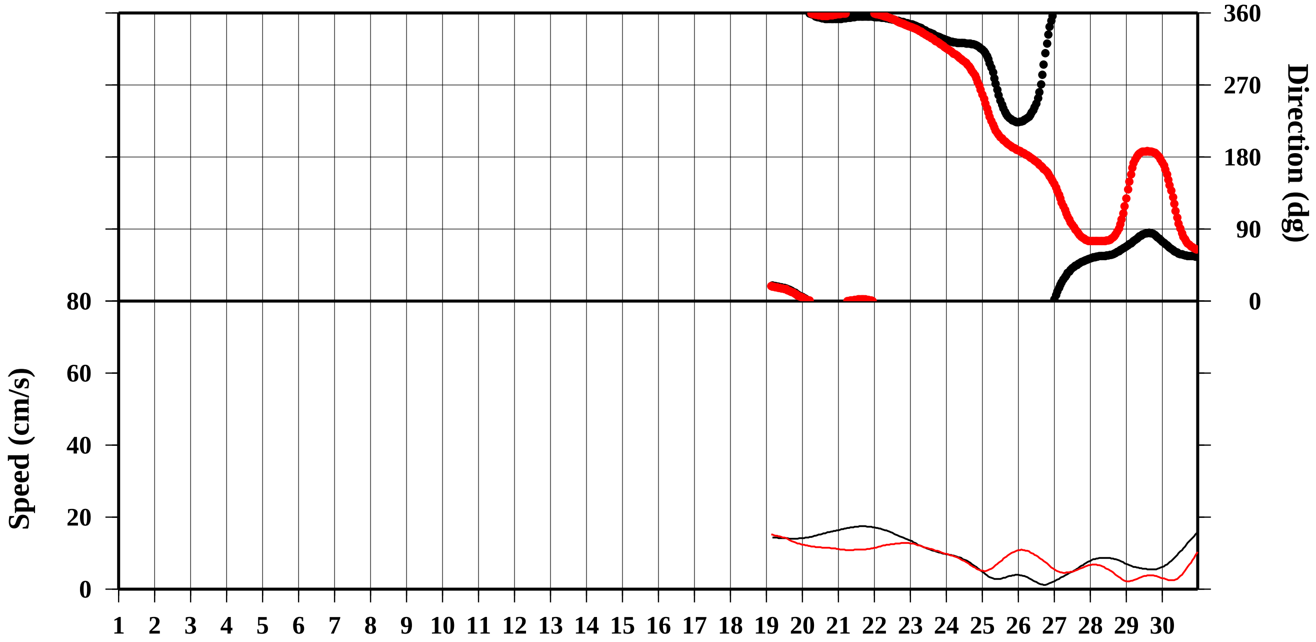
Silleiro inertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006



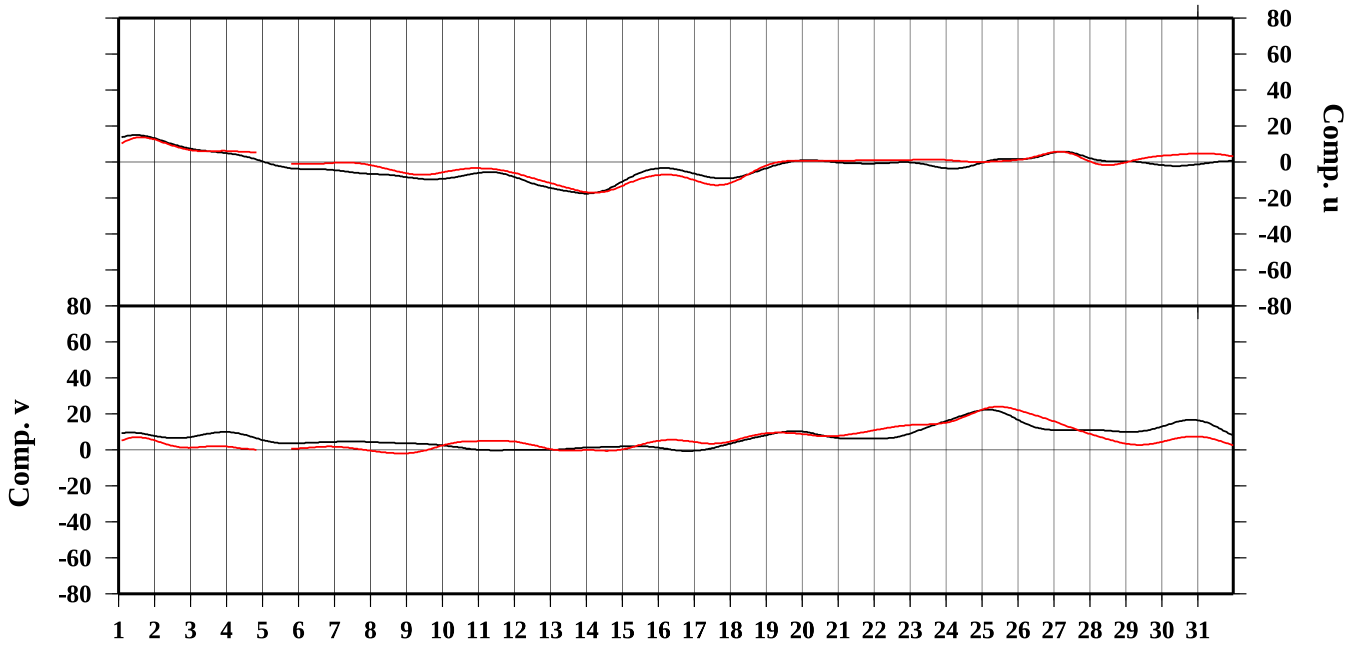
Silleiro subinertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005



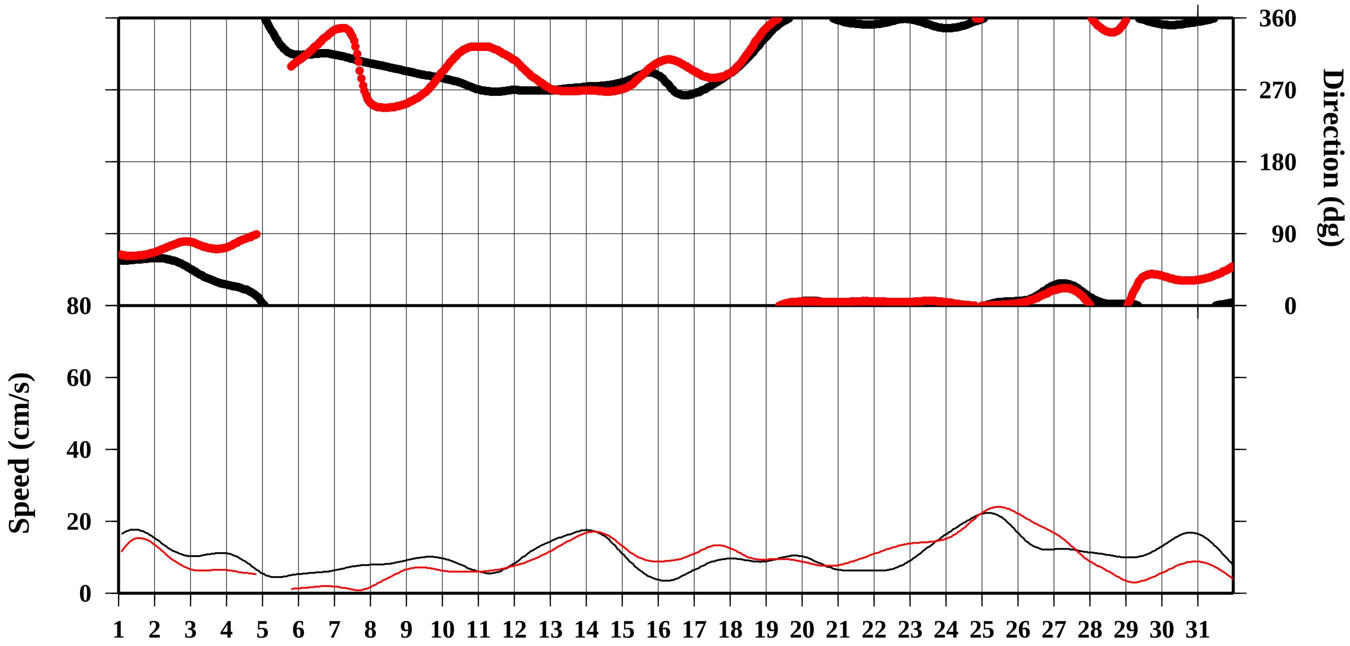
Silleiro subinertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). November 2005

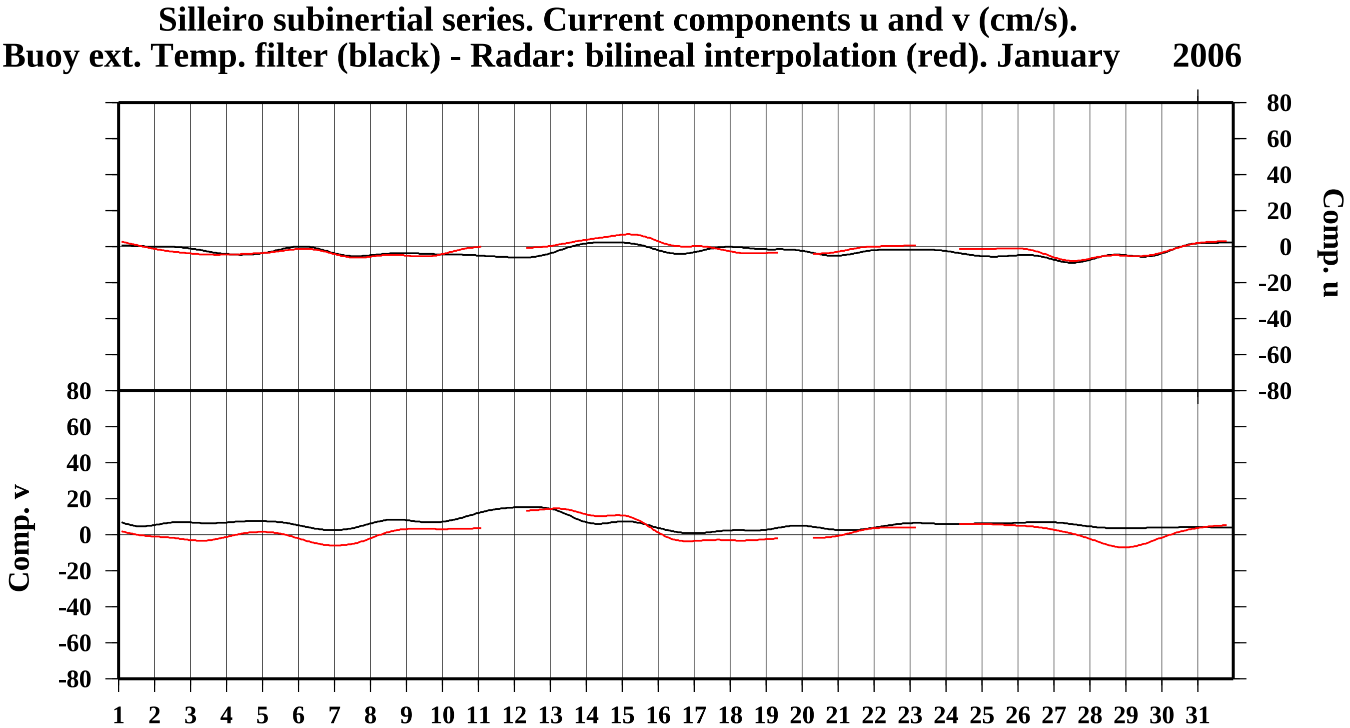


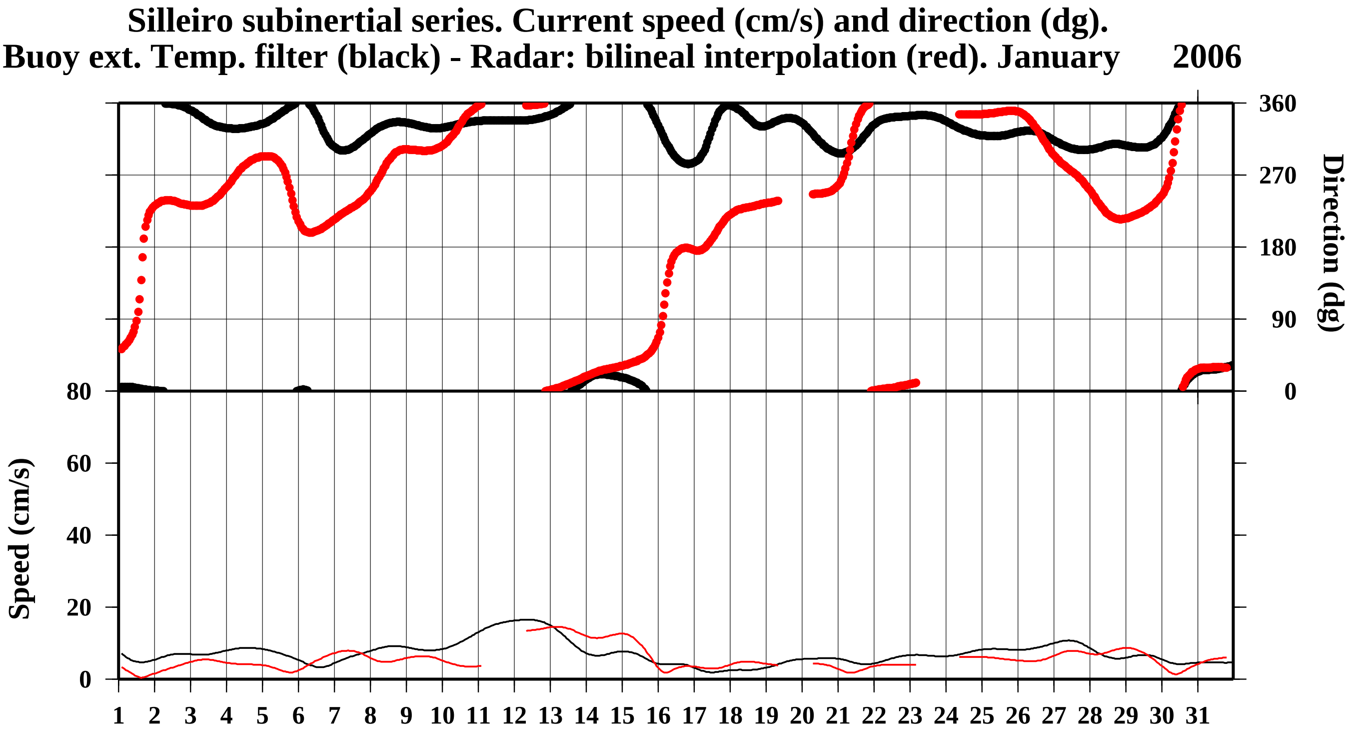
Silleiro subinertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005

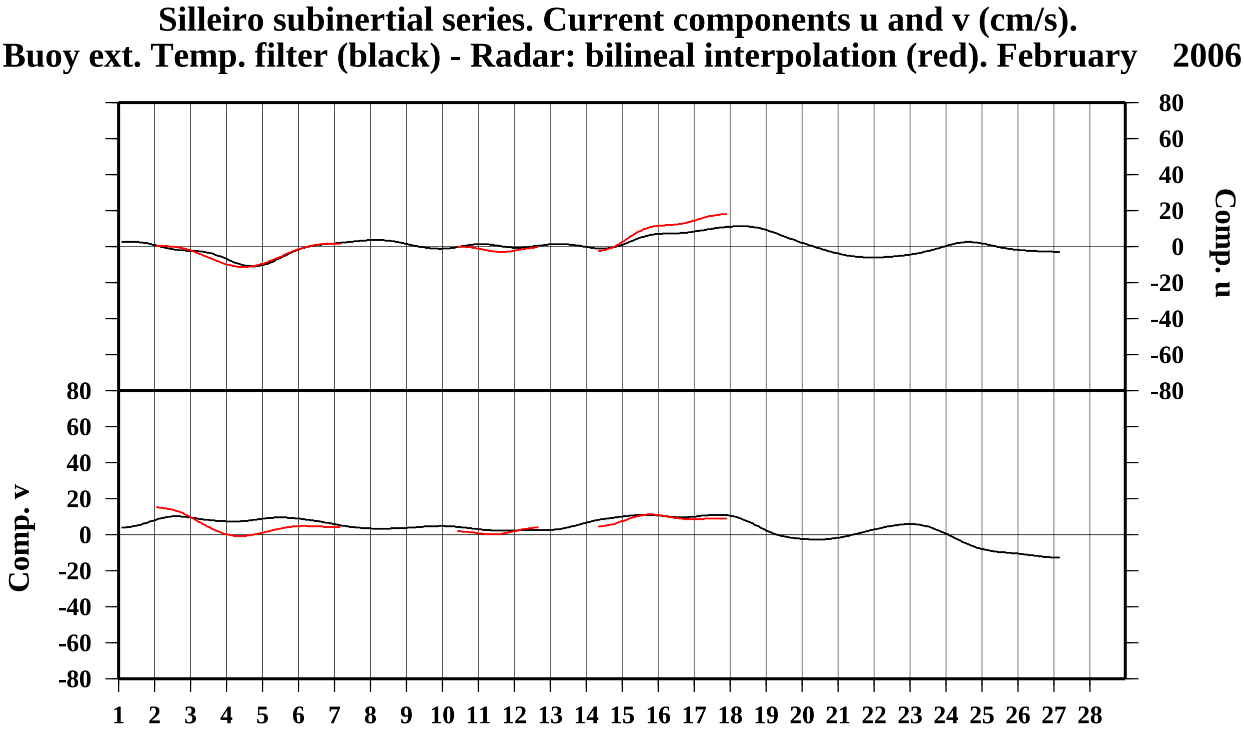


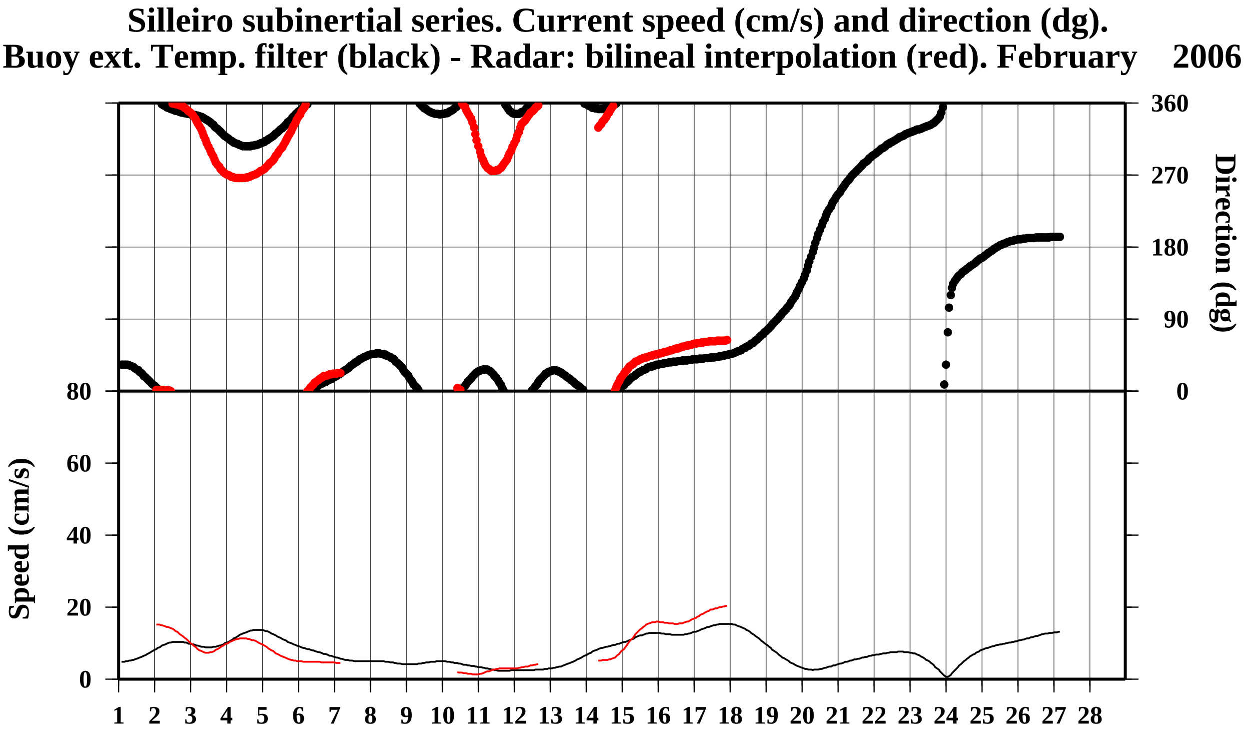
Silleiro subinertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). December 2005



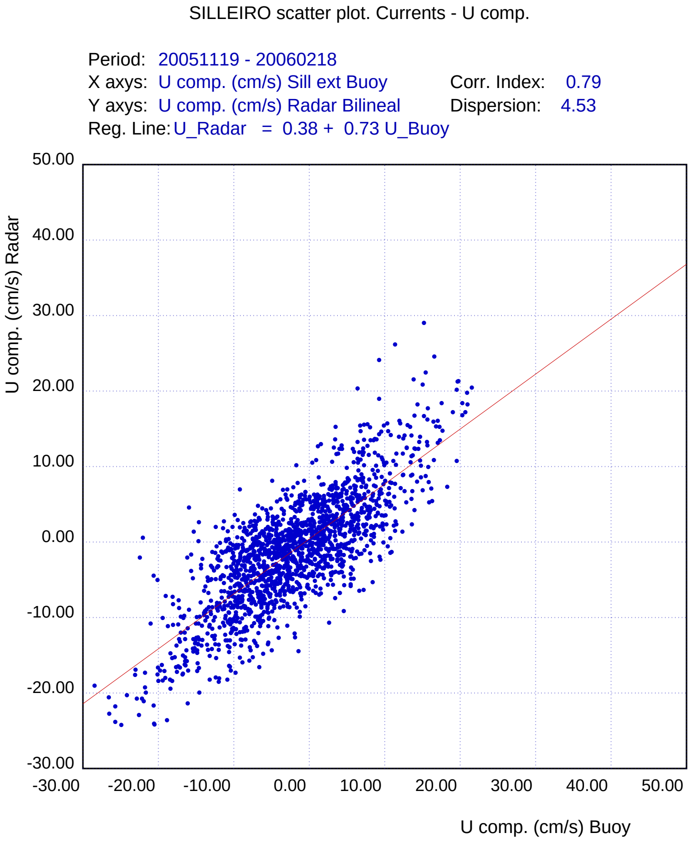

Silleiro subinertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006
Comp. u
Comp. v
80
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

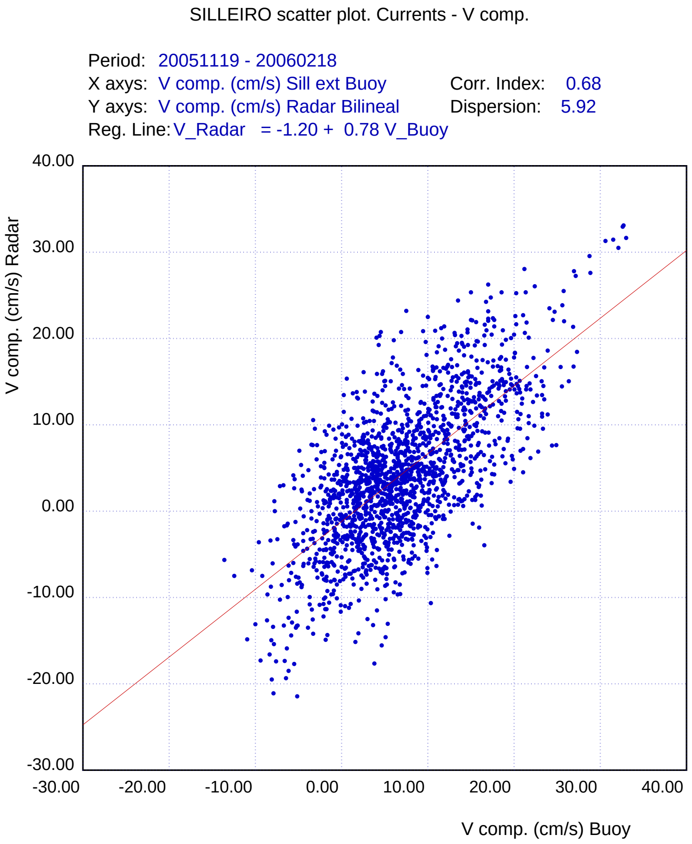

Silleiro subinertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). January 2006
Direction (dg)
360
270
180
90
0
Speed (cm/s)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

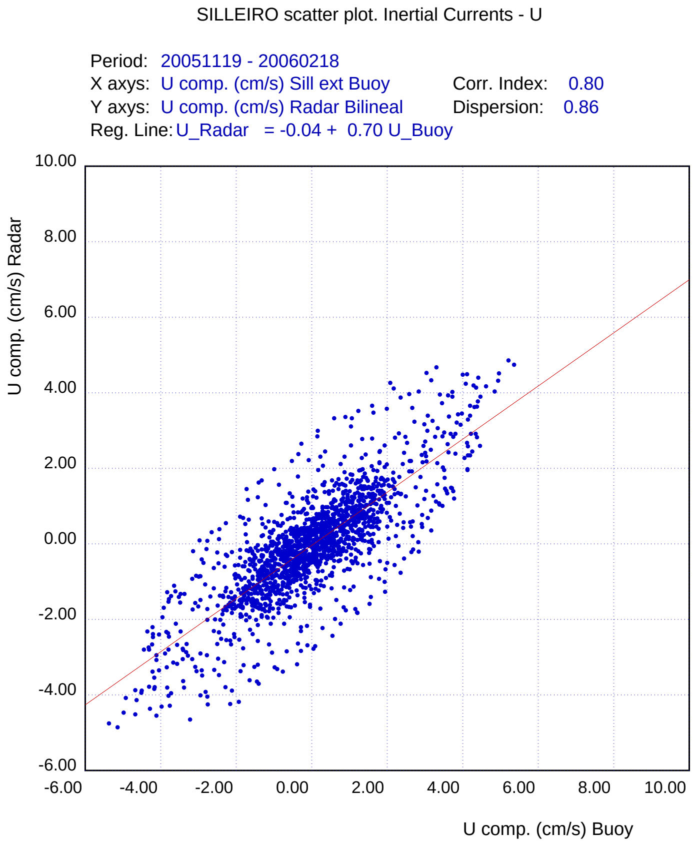

Silleiro subinertial series. Current components u and v (cm/s).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006
Comp. u
Comp. v
80
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

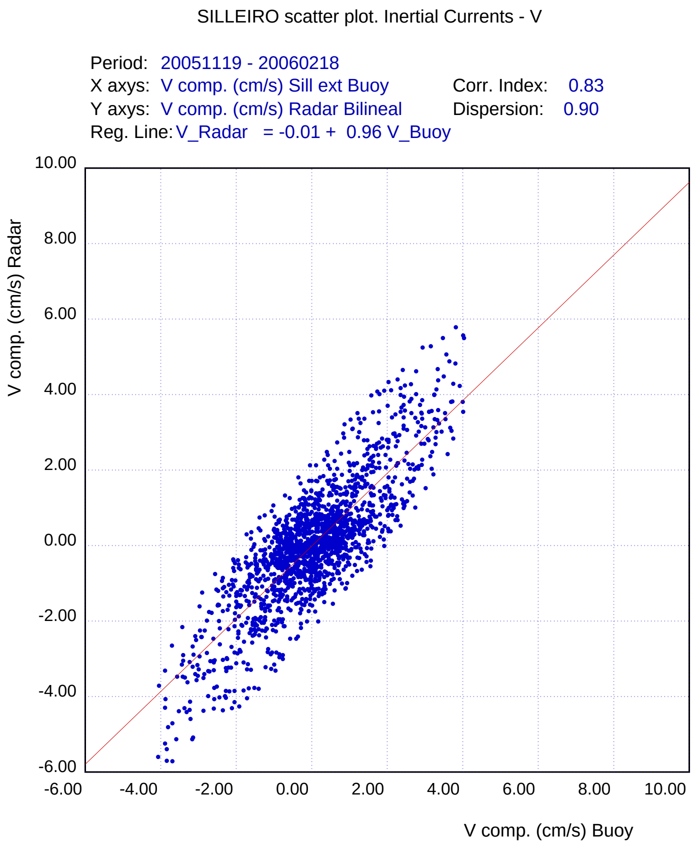

Silleiro subinertial series. Current speed (cm/s) and direction (dg).
Buoy ext. Temp. filter (black) - Radar: bilineal interpolation (red). February 2006
Direction (dg)
360
270
180
90
0
Speed (cm/s)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

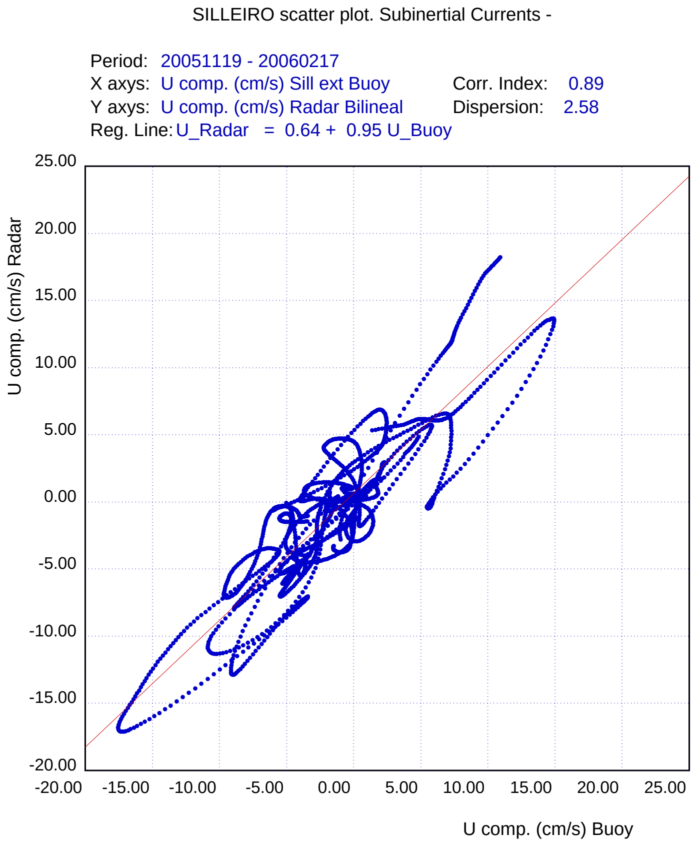
4.2 Scatter plots and statistics

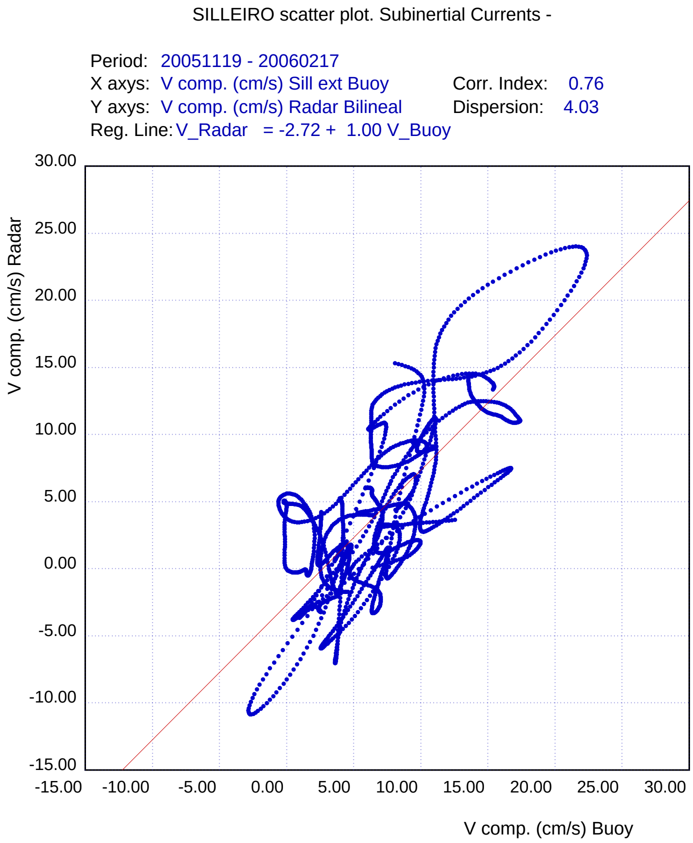





SILLEIRO scatter plot. Inertial Currents - U
Period: 20051119 - 20060218
X axys: U comp. (cm/s) Sill ext Buoy
Corr. Index: 0.80
Y axys: U comp. (cm/s) Radar Bilineal
Dispersion: 0.86
Reg. Line: U_Radar = -0.04 + 0.70 U_Buoy
U comp. (cm/s) Radar
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
U comp. (cm/s) Buoy


SILLEIRO scatter plot. Inertial Currents - V
Period: 20051119 - 20060218
X axys: V comp. (cm/s) Sill ext Buoy
Corr. Index: 0.83
Y axys: V comp. (cm/s) Radar Bilineal
Dispersion: 0.90
Reg. Line: V_Radar = -0.01 + 0.96 V_Buoy
V comp. (cm/s) Radar
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
V comp. (cm/s) Buoy


SILLEIRO scatter plot. Subinertial Currents -
Period: 20051119 - 20060217
X axys: U comp. (cm/s) Sill ext Buoy
Corr. Index: 0.89
Y axys: U comp. (cm/s) Radar Bilineal
Dispersion: 2.58
Reg. Line: U_Radar = 0.64 + 0.95 U_Buoy
U comp. (cm/s) Radar
U comp. (cm/s) Buoy
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00


SILLEIRO scatter plot. Subinertial Currents -
Period: 20051119 - 20060217
X axys: V comp. (cm/s) Sill ext Buoy
Corr. Index: 0.76
Y axys: V comp. (cm/s) Radar Bilineal
Dispersion: 4.03
Reg. Line: V_Radar = -2.72 + 1.00 V_Buoy
V comp. (cm/s) Radar
V comp. (cm/s) Buoy
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00

SILLEIRO CURRENTS STATISTICS

-- buoyft-buoy: comparison between data from Silleiro ext buoy with and without temporal filter.

-- buoyft-radar: comparison between data from Silleiro ext buoy with temporal filter and radar with bilineal interpolation.

SILLEIRO CURRENTS STATISTICS.

U COMPONENT	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyft-buoy	-1.393	-1.391	0.967	1.038	0.054	2.156	0.002	-1.549	2399
buoyft-radar	-2.033	-1.095	0.788	0.728	0.385	5.110	0.938	-2.513	1741

V COMPONENT	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyft-buoy	5.965	5.966	0.978	1.028	-0.165	1.593	0.001	0.267	2399
buoyft-radar	6.906	4.220	0.682	0.785	-1.198	6.672	-2.686	0.966	1741

CURRENT SPEED	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyft-buoy	10.816	11.284	0.951	1.010	0.357	1.966	0.468	0.182	2399
buoyft-radar	11.328	10.190	0.599	0.586	3.551	5.465	-1.139	0.482	1741

SILLEIRO CURRENTS STATISTICS

-- inertial cur: comparison between inertial currents from Silleiro ext buoy and radarhf.

-- subinertial : comparison between subinertial currents from Silleiro ext buoy and radarhf.

SILLEIRO CURRENTS STATISTICS.

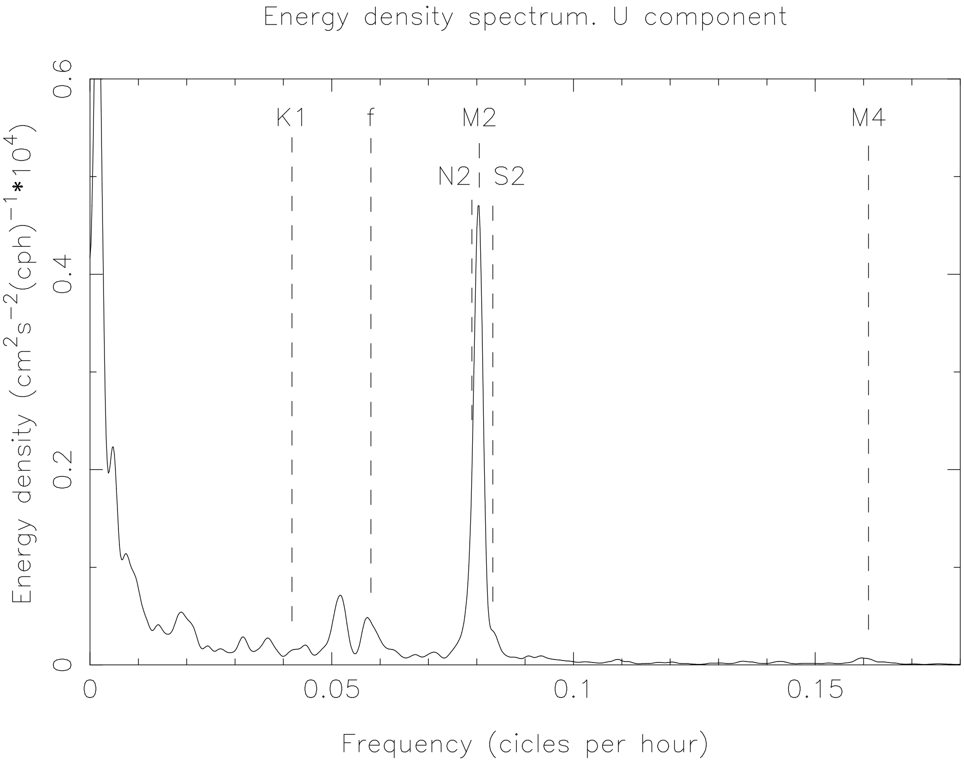
U COMPONENT	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
inertial cur	-0.028	-0.059	0.790	0.708	-0.039	1.024	-0.030	-36.434	1467
subinertial	-2.024	-1.290	0.880	0.866	0.463	2.645	0.734	-1.307	1673

V COMPONENT	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
inertial cur	0.058	0.054	0.842	1.008	-0.005	0.927	-0.004	16.060	1467
subinertial	6.697	3.941	0.767	1.002	-2.770	4.972	-2.756	0.743	1673

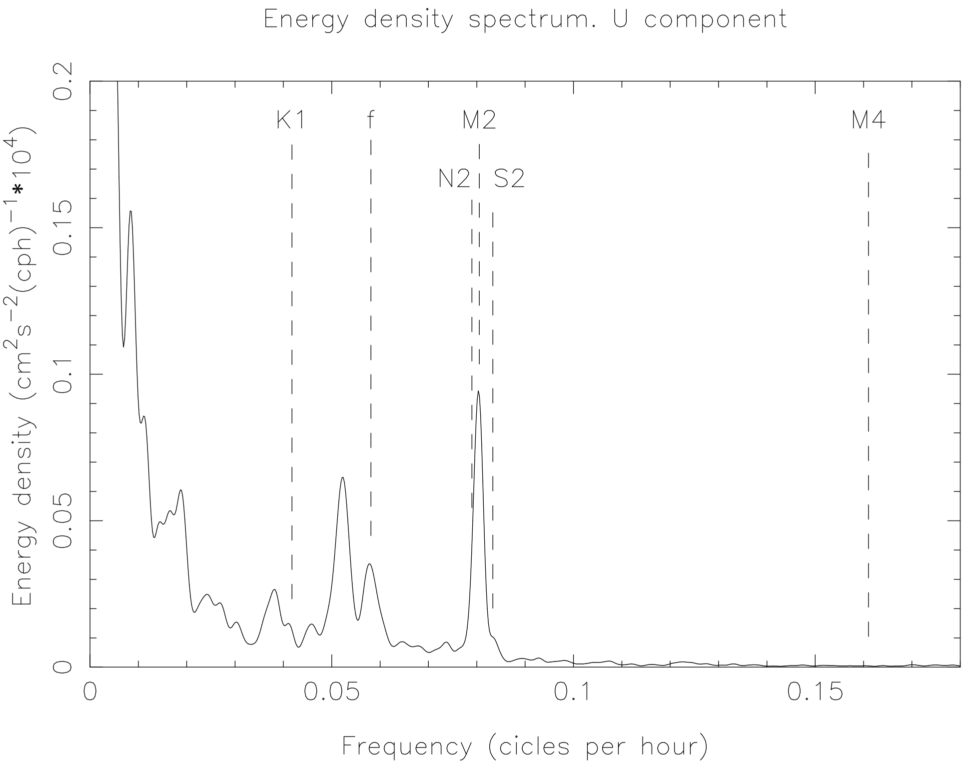
CURRENT SPEED	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
inertial cur	1.889	1.925	0.828	0.912	0.203	0.680	0.037	0.360	1467
subinertial	9.068	7.966	0.705	0.765	1.027	3.631	-1.102	0.400	1673

4.3 Currents spectra

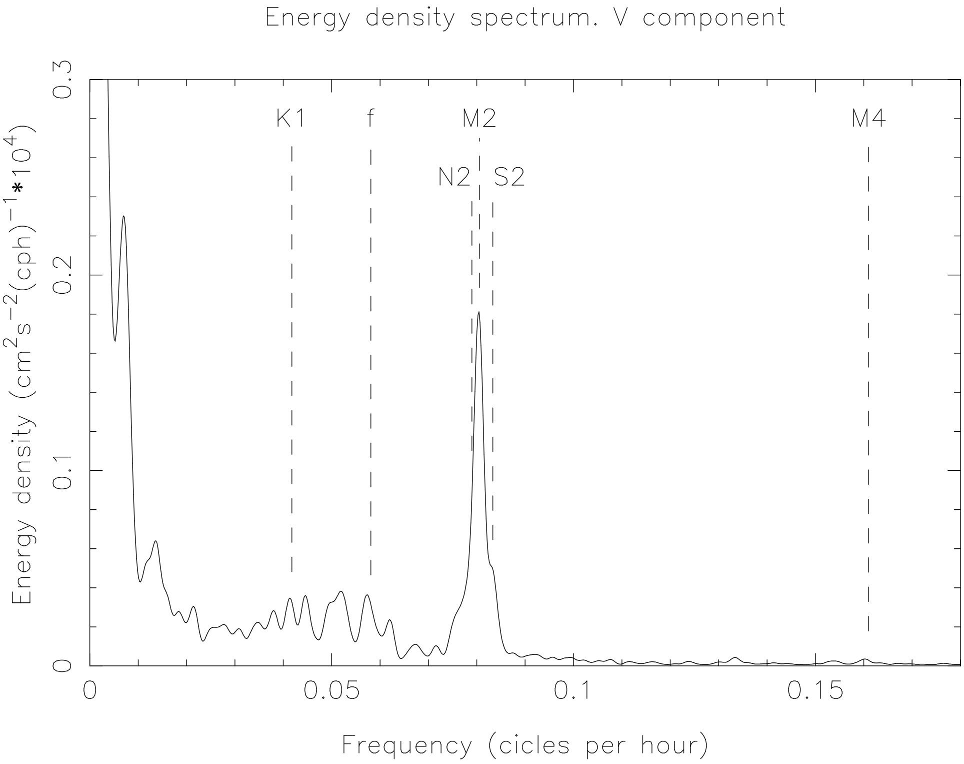
Silleiro Buoy with temp. filter. Period: 19-November-2005 / 17-February-2006 .



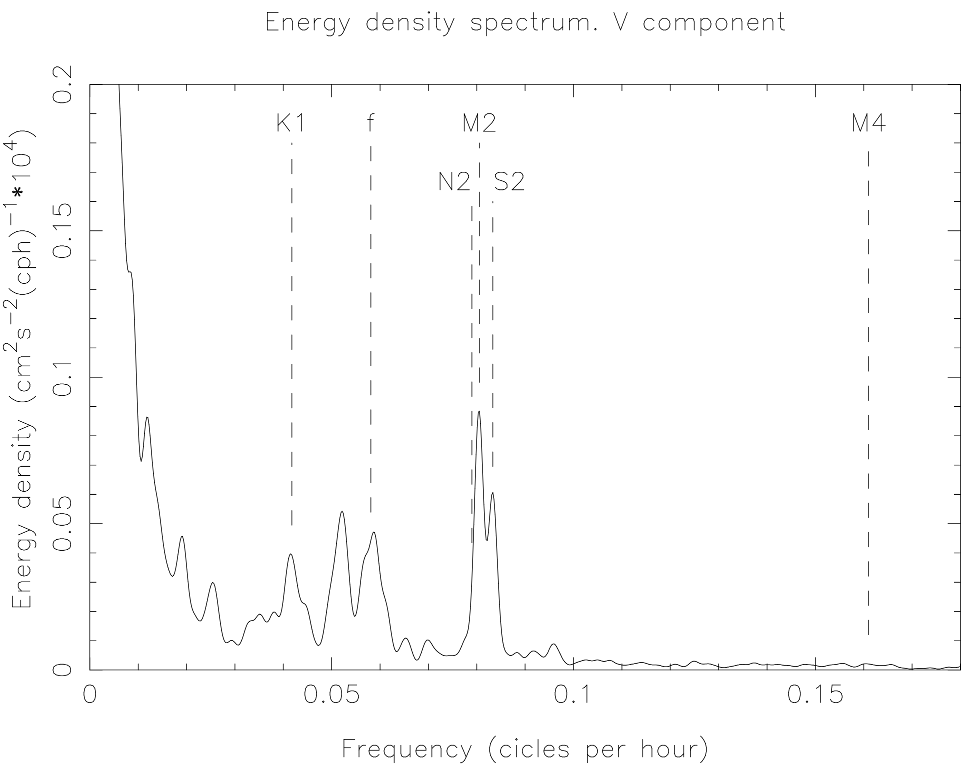
Silleiro radar with bilinear int. Period: 19-November-2005 / 17-February-2006 .



Silleiro Buoy with temp. filter. Period: 19-November-2005 / 17-February-2006 .

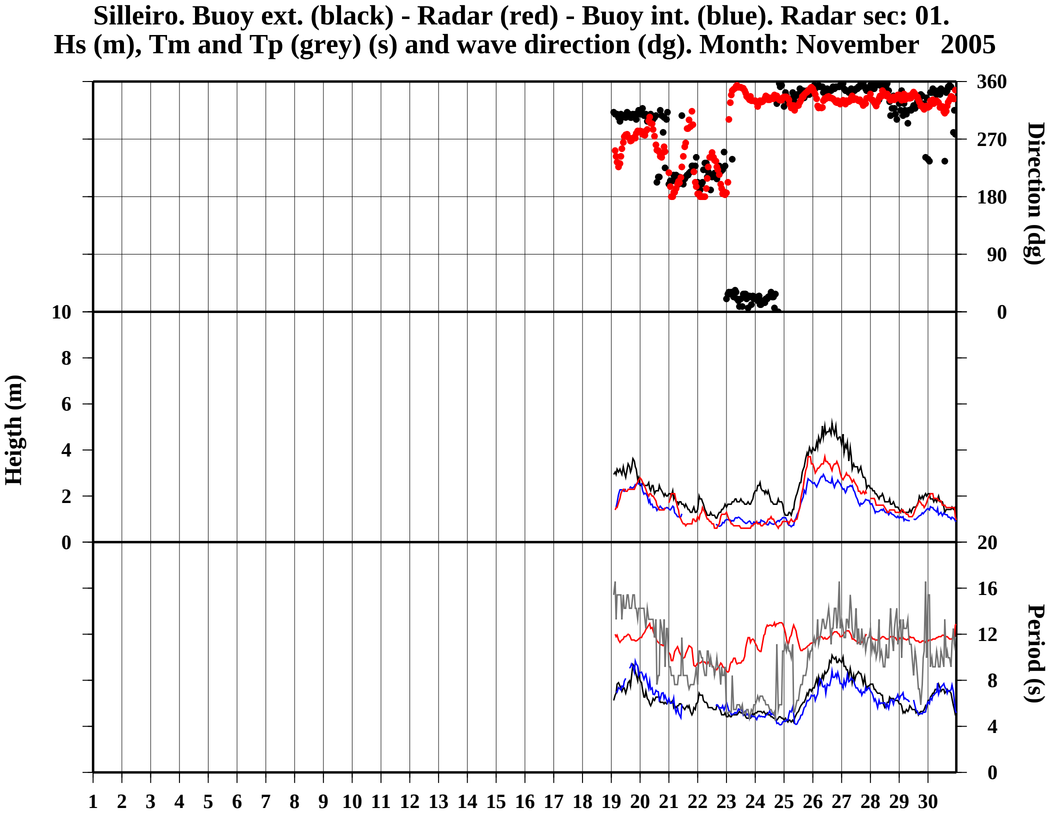


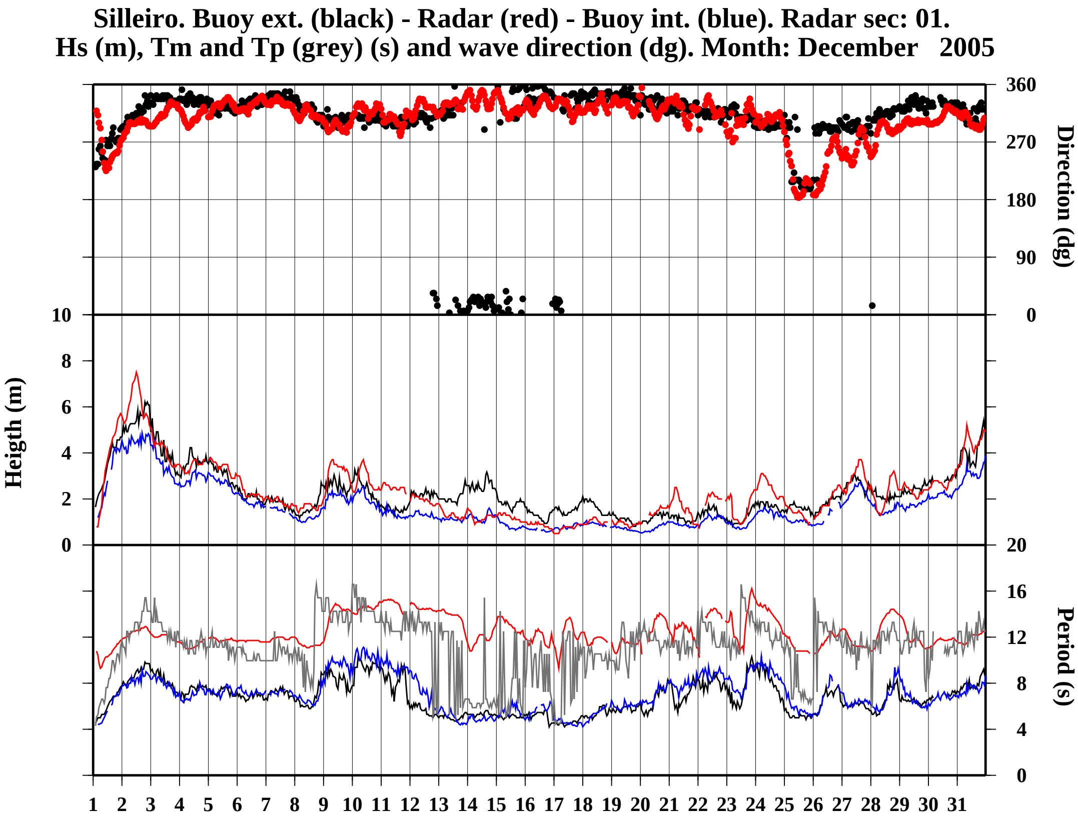
Silleiro radar with bilinear int. Period: 19-November-2005 / 17-February-2006 .



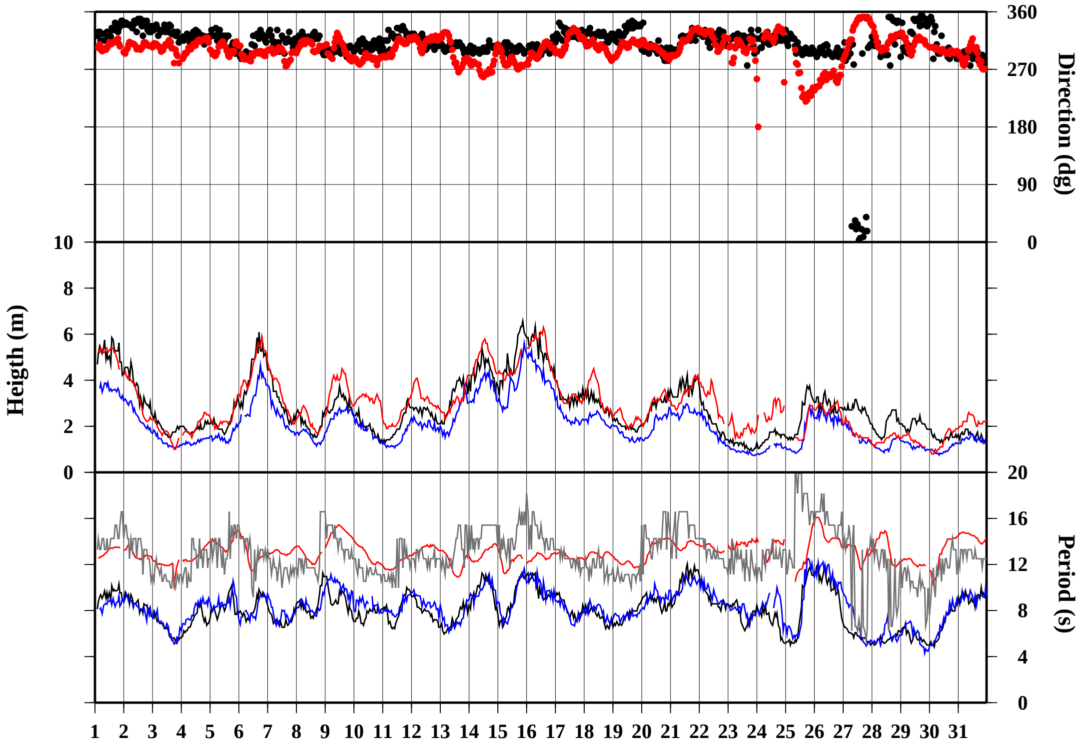
5 Waves results

5.1 Time series graphs

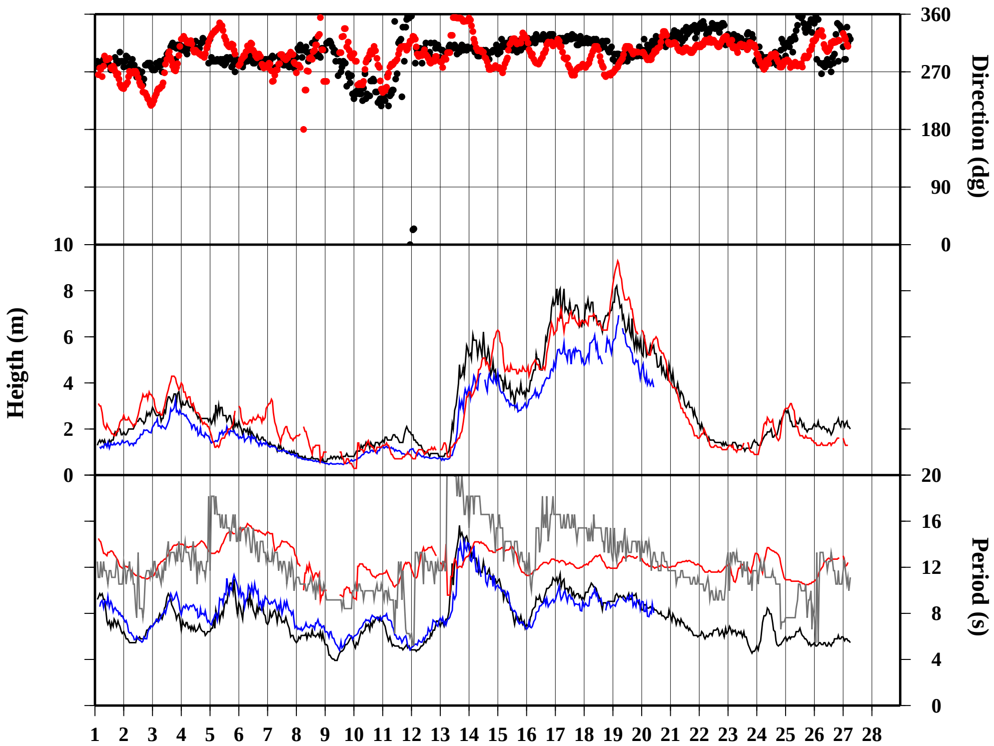




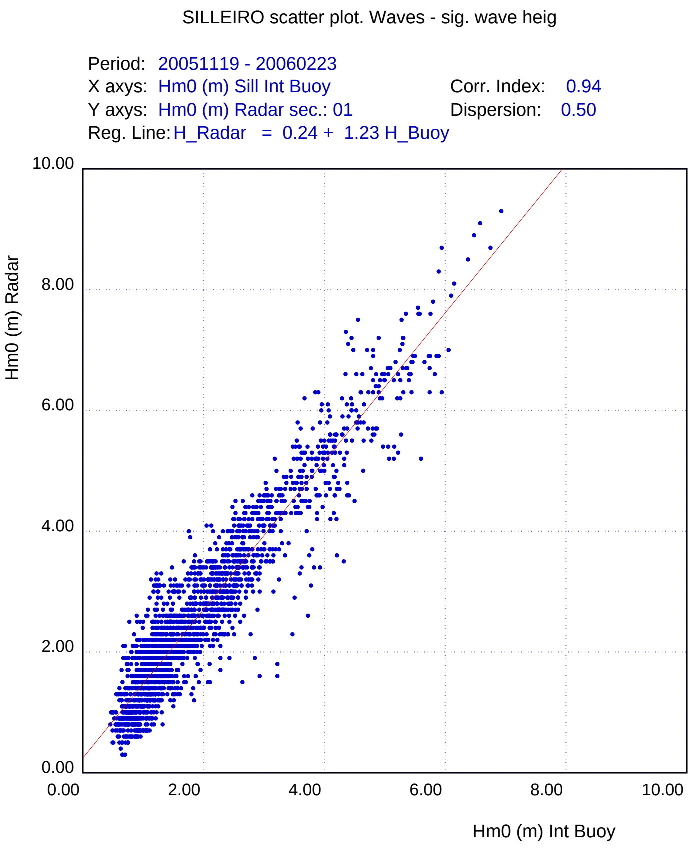
Silleiro. Buoy ext. (black) - Radar (red) - Buoy int. (blue). Radar sec: 01.
Hs (m), Tm and Tp (grey) (s) and wave direction (dg). Month: January 2006

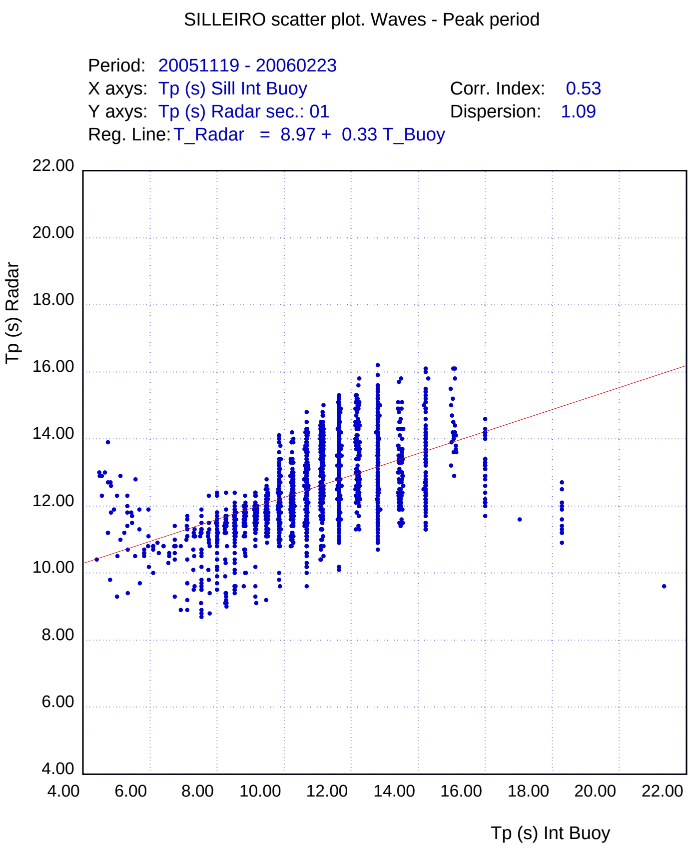


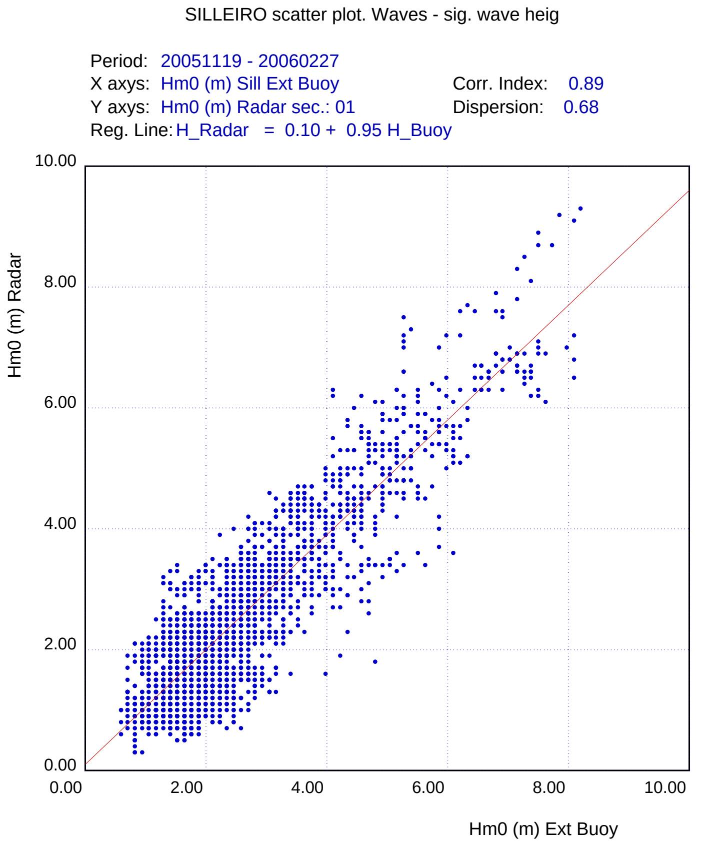
Silleiro. Buoy ext. (black) - Radar (red) - Buoy int. (blue). Radar sec: 01.
Hs (m), Tm and Tp (grey) (s) and wave direction (dg). Month: February 2006

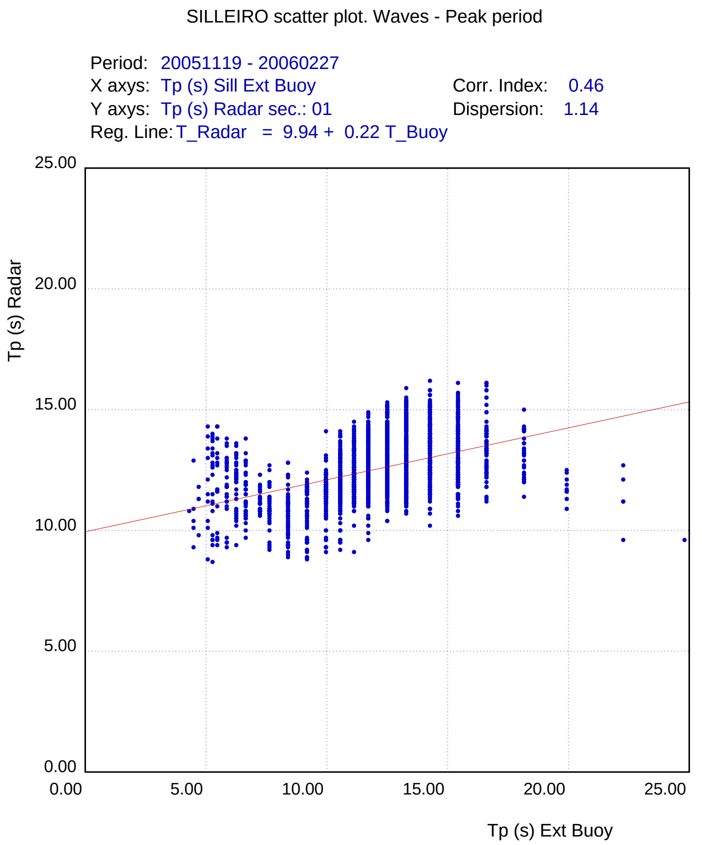


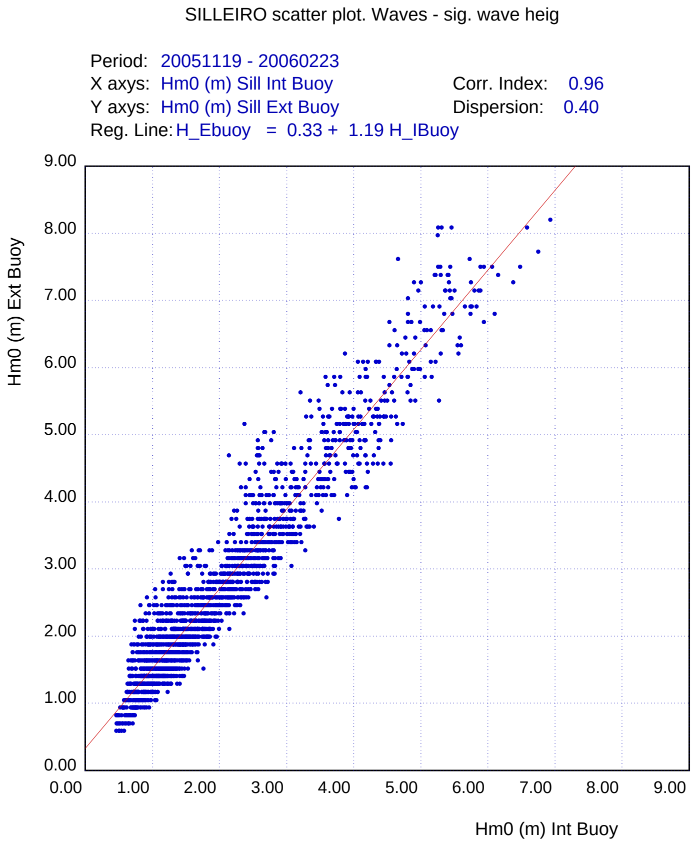
5.2 Scatter plots and statistics



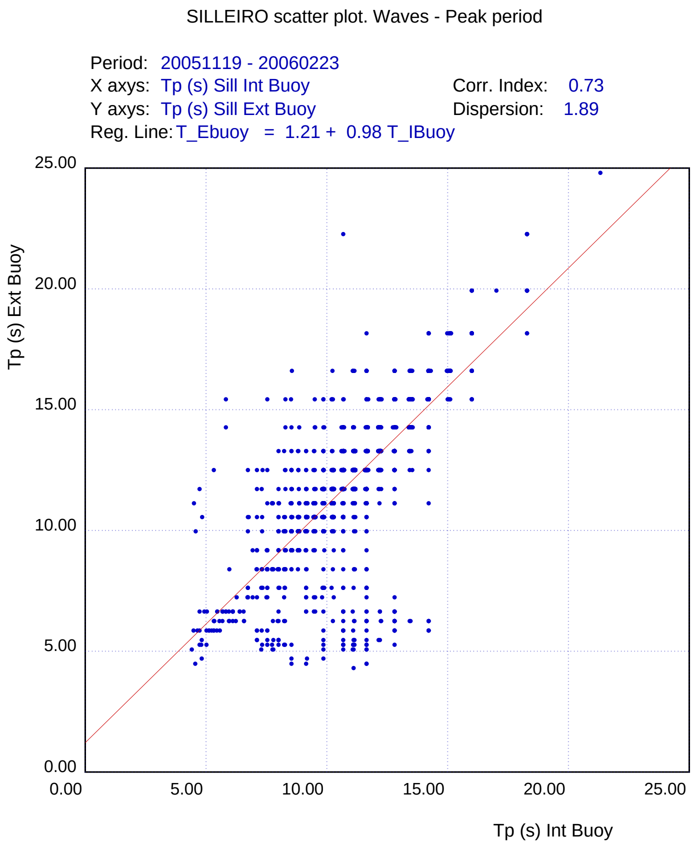



SILLEIRO scatter plot. Waves - sig. wave heig
Period: 20051119 - 20060227
X axys: Hm0 (m) Sill Ext Buoy
Y axys: Hm0 (m) Radar sec.: 01
Reg. Line: H_Radar = 0.10 + 0.95 H_Buoy
Corr. Index: 0.89
Dispersion: 0.68
Hm0 (m) Radar
Hm0 (m) Ext Buoy
0.00
2.00
4.00
6.00
8.00
10.00


SILLEIRO scatter plot. Waves - Peak period
Period: 20051119 - 20060227
X axys: Tp (s) Sill Ext Buoy
Y axys: Tp (s) Radar sec.: 01
Reg. Line: T_Radar = 9.94 + 0.22 T_Buoy
Corr. Index: 0.46
Dispersion: 1.14
Tp (s) Radar
Tp (s) Ext Buoy
0.00
5.00
10.00
15.00
20.00
25.00



SILLEIRO scatter plot. Waves - sig. wave heig
Period: 20051119 - 20060223
X axys: Hm0 (m) Sill Int Buoy
Y axys: Hm0 (m) Sill Ext Buoy
Reg. Line: H_Ebuoy = 0.33 + 1.19 H_IBuoy
Corr. Index: 0.96
Dispersion: 0.40
Hm0 (m) Ext Buoy
Hm0 (m) Int Buoy
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00



SILLEIRO scatter plot. Waves - Peak period
Period: 20051119 - 20060223
X axys: Tp (s) Sill Int Buoy
Y axys: Tp (s) Sill Ext Buoy
Reg. Line: T_Ebuoy = 1.21 + 0.98 T_IBuoy
Corr. Index: 0.73
Dispersion: 1.89
Tp (s) Ext Buoy
Tp (s) Int Buoy
0.00
5.00
10.00
15.00
20.00
25.00

SILLEIRO WAVES STATISTICS

-- buoyI-buoyE: comparison between Silleiro int buoy (closer to the coast) and Silleiro ext buoy.

-- buoyE-rad01: comparison between Silleiro ext buoy and radar sector 01.

-- buoyI-rad01: comparison between Silleiro int buoy and radar sector 01.

SILLEIRO WAVES STATISTICS.

PARAM: HM0	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyI-buoyE	1.941	2.634	0.961	1.185	0.333	0.829	0.693	0.427	2194
buoyE-rad01	2.619	2.589	0.892	0.950	0.101	0.689	-0.030	0.263	2354
buoyI-rad01	1.959	2.645	0.943	1.224	0.247	0.893	0.686	0.456	2155

PARAM: TP	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyI-buoyE	10.991	12.012	0.728	0.982	1.218	2.151	1.021	0.196	2194
buoyE-rad01	11.904	12.502	0.465	0.222	9.858	2.500	0.598	0.210	2354
buoyI-rad01	10.997	12.578	0.526	0.327	8.985	2.366	1.581	0.215	2155

SILLEIRO WAVES STATISTICS. HM0_radarhf > 2.

PARAM: HM0	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyI-buoyE	1.815	2.503	0.941	1.133	0.446	0.801	0.688	0.441	1741
buoyE-rad01	3.020	3.183	0.844	0.730	0.977	0.653	0.162	0.216	1024
buoyI-rad01	2.322	3.186	0.873	0.972	0.929	0.997	0.865	0.429	1022

PARAM: TP	X mean	Y mean	CorrInd	Slope	b	RMSDif	Bias	Sca.Ind	N
buoyI-buoyE	10.830	11.740	0.665	0.911	1.878	2.187	0.909	0.202	1741
buoyE-rad01	12.690	12.453	0.515	0.434	6.945	1.736	-0.237	0.137	1024
buoyI-rad01	11.301	12.462	0.558	0.543	6.327	1.881	1.161	0.166	1022

6 Comments about the results

The main conclusion in this validation is that the comparison has revealed a quite good concordance between measurements. The numbers obtained in the statistical results are the expected in a good comparison. In spite of that, we want to stand out some clear tendencies in order to investigate the source of the discrepancies. Our comments about the results are the following:

- The numbers obtained in the statistical results are the expected in a good comparison with correlation indexes of 0.8 in current U component, 0.7 in current V component and up to 0.9 in wave height.
- The current spectra and the comparison of currents in different bands show that both radar and Ext. buoy are measuring currents forced by similar mechanisms. Alike statistics are obtained from high (inertial) and low (subinertial) frequencies.
- In currents comparisons U component shows better results that V component in agreement with some problems found in Finisterre radar installation.
- Radar information coverage is rather good in waves (97%) but low in currents (72%) in the buoy nearness.
- The radar wave measurement area is located just before the coastal shelf limit, so we can, a priori, expect wave heigths higher in radar measurements that in Sillerio Int. buoy. These higher wave heights must ocurr when waves come from sector SW-NW and must be similar to Silleiro Ext. buoy but not higher. Radar wave heigths must be, however, more similar to Sillerio Int. buoy wave heights when directions are closer to North due to the coast effect. This behaviour is well reproduced by the results but heigths seem to be slightly overestimated with about 1 meter in some peaks over Ext. buoy measurements (see, for instance, 02/12/2005 or 19/02/2006).
- Wave period estimations from radar measurements are very stable but maybe too smooth and seem to be incapable to reproduce sudden changes in periods. This situation can be due to the fact that the estimator used for radar period (centroid) does not work well with bimodal sea states and very probably we have two peaks in the spectra when these changes in periods ocurr (see, for instance, storm between 13/02/2006 and 20/02/2006, with radar period below even the buoys mean period).
- Some strange oscillations are showed in radar wave directions. They seem to be related to a tidal effect (daily oscillations?).