FRENCH PIRATA CRUISES S-ADCP DATA PROCESSING

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Abstract

In the framework of the PIRATA program, several types of observations are carried out in the Tropical Atlantic during yearly cruises, including Shipboard Acoustic Doppler Current Profilers (SADCP) data. The present note is a brief review of the SADCP data processing methodology applied for 8 PIRATA cruises by using CASCADE software. To illustrate the processing steps and demonstrate the CASCADE software capabilities, an example of SADCP data processing obtained from PIRATA-FR24 cruise has been shown. This data set is made available on the PIRATA website and will also be used in the framework of the EU PREFACE program (see http://preface.b.uib.no/).

Introduction

The PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) observing network is a contribution to the GOOS (Global Ocean Observing System), GCOS (Global Climate Observing System), and the GEOSS (Global Earth Observing System of Systems), endorsed by the international program CLIVAR (CLImate VARiability and predictability). Launched in 1997 thanks to a multinational cooperation between France (IRD and Météo-France), Brazil (INPE) and USA (NOAA), PIRATA mostly maintains 18 meteo-oceanographic buoys (ATLAS system; see www.pmel.noaa.gov/tao/ for detail) by carrying out yearly cruises for their servicing (Bourlès et al., 2008). In France, PIRATA is recognized as a National Observatory ("Service National d'Observation"), and yearly cruises also allow, in addition to ATLAS buoys servicing, to carry out different opportunity operations (e.g. ARGO autonomous profilers deployments) and to get several types of observations along repeated track lines, including oceanic currents from Ship mounted Acoustic Doppler Current Profiler (SADCP; see http://www.brest.ird.fr/pirata/index_fr.php). After a brief reminder of ADCP principle and a description of main characteristics of SADCP instrument onboard different research vessels used for PIRATA cruises, we present the SADCP data processing that has been applied for 8 PIRATA cruises carried out from 2007 to 2014, by using the CASCADE (Chaîne Automatisée de Suivi des Courantomètres Acoustiques Doppler Embarqués) software (Le Bot et al., 2011). An example of SADCP data processing obtained from one PIRATA cruise is also shown.

Shipboard Acoustic Doppler Current Profilers (SADCP)

2.1 Principle

We recall here the principle of the ADCP measurements, in order to better understand the data processing steps detailed afterwards.
ADCP estimates horizontal and vertical velocity of flowing water with sound, using the principle of Doppler Effect. It does so by emitting « pings» of acoustic signal at a known and constant frequency into the water. The acoustic pulses ricochet off small particles suspended in the moving water (plankton, sediments, or other solid particles) and reflect back to the transducer with a slightly changed frequency. The ADCP uses the Doppler frequency shift of this backscattered signal measured by the transducer to measure the fluid velocity along the beam path. For measuring the three velocity components of the current, ADCP usually uses four beams inclined from the vertical plane at an angle θ (called 'beam angle') and pointing in different directions. In this configuration, ADCP estimates horizontal and vertical velocities and also an error used to qualify the data. The determination of the Doppler frequency is made by considering the ensemble of signal in time windows, which define cells or 'bins'. The accuracy of the measure, the vertical resolution and the acoustic noise, depends on the ADCP's type (Broadband or Narrowband) and on the frequency of the SADCP instrument (typically: 38, 75, 150, 300, 600 or 1200 kHz). Low frequency systems provide long range and low resolution measurements, while high frequency systems have shorter ranges with much higher resolution.

2.2 ADCP onboard PIRATA research vessels

Table 1 below presents the summary of the 8 cruises carried out from 2007 to 2014 in the framework of the PIRATA program, and the frequency of ship-mounted SADCP instrument used for each cruise. For the 4 first cruises onboard the R/V L'Antéa, an Ocean Surveyor 75 kHz system was used while it was a broad-band 150 kHz system for the 4 last cruises onboard the R/V Le Suroit. The 75 kHz ADCP are suited for a range about twice as deep as the 150 kHz (about 600 meters in broad-band mode). The standard deviation of velocity data obtained using broad-band ADCPs are significantly lower than that for narrow-band ADCPs, but the range is shallower. For all these PIRATA cruises, the vertical profiling resolution was nominally 8 m (= bin size) for the 150 and 75 kHz ADCPs. For additional background and references on the oceanographic application of shipboard ADCPs, see e.g. Firing and Hummon (2010).

Greenland	Month	Year	Latitudinal Range	Research Vessel	SADCP (KHz)
PIRATA-FR16	5 - 6	2007	0° - 15°N	L'Antéa	OS75
PIRATA-FR17	6 - 7	2007	10°S - 5°N	L'Antéa	OS75
PIRATA-FR18	9 - 10	2008	10°S - 15°N	L'Antéa	OS75
PIRATA-FR20	9 - 10	2010	10°S - 15°N	L'Antéa	OS75
PIRATA-FR21	5 - 6	2011	10°S - 15°N	Le Suroit	BB150
PIRATA-FR22	3 - 5	2012	10°S - 15°N	Le Suroit	BB150
PIRATA-FR23	5 - 6	2013	10°S - 15°N	Le Suroit	BB150
PIRATA-FR24	4 - 5	2014	10°S - 15°N	Le Suroit	BB150

Table1: Summary of the 2007-2014 PIRATA oceanographic cruises and frequency used by SADCP for each cruise

To estimate the absolute current velocity in earth coordinates, one needs to remove the ship movement using the best navigation data available (position, speed, tilt, heading). This information is provided by specific instruments that depend upon the ship. During the PIRATA cruises addressed here, the ship's position, pitch, roll and heading onboard the R/V Le Suroit are measured by an inertial navigation system based on fiber-optic gyroscope technology which integrated GPS information, whereas they are provided by an optical gyrocompass and motion sensor parted from a high precision GPS system onboard the R/V L'Antéa. The transformation from beam ADCP to earth coordinates is performed using the Vessel-Mounted Data Acquisition System (VmDAS). VmDAS is the constructor's software (RDI's software) used for RDI ADCP acquisition. It generates files containing averages mono-ping ADCP data and best navigation data available. The ADCP velocities recorded are relative to the ship, in earth coordinates and averaged in time: FILE.STA files for 'Short Term Average' with 2 minutes averages and FILE.LTA files for 'Long Term Average' with 10 minutes averages, for instance. These files are then processed and analyzed by the Matlab CASCADE software ("Chaîne Automatisée de Suivi des Courantomètres Acoustiques Doppler Embarqués"). The following section presents the CASCADE software and gives a brief review of the basic post-cruise processing steps realized after the cruise.

Processing and quality checks of SADCP data

The data processing software: CASCADE

CASCADE is a Matlab software developed by the Laboratory of Physical Oceanography (Le Bot et al., 2011) in order to process Vessel-mounted ADCP data collected along vessel transects. The programs have been specifically tested for Windows and Linux and can be downloaded from: http://wwz.ifremer.fr/lpo/Le-Laboratoire/Actualites/CASCADE-V6.2. It is used in different research organisms and has been implemented in operational mode by the data center SISMER ("Systèmes d'Informations Scientifiques pour la MER") at IFREMER. Regular updates of the software are made in order to take into account the users feedbacks and the suggestions of improvements.

The CASCADE inputs files are the binary FILE.STA/FILE.LTA files obtained from the acquisition software VmDAS. In our case, we used the version 6.2 of CASCADE to analyze and process the SADCP data collected during 8 PIRATA cruises carried out between 2007 and 2014 in the eastern tropical Atlantic **(see table 1)**. In the following section, we describe briefly the main processing steps of CASCADE software.

Overview of ADCP data cleaning stages in CASCADE

Complete cleaning of ADCP data requires several steps. CASCADE first converts the FILE.STA/FILE.LTA files generated by VmDAS software into a single NetCDF file containing all the information but also the absolute current velocities in earth coordinates calculated from the relative and ship velocities. From this NetCDF file, the user can add important external ancillary data (like estimations of bathymetry and barotropic tide for example), flag the velocity data according to adjustable parameters, estimate and apply rotations of the ADCP coordinate system to realign it with the ship system, and, finally, smooth the data in time and/or depth. At the end of the cleaning stage, the three components of the absolute current velocity (U, V, W) are flagged 1 (good), 2 (dubious) or 3 to 9 (bad). The cleaning and correction are an iterative process. Automatic and visual quality checks of the data help the user to choose the best cleaning parameters and the best ADCP correction (misalignment/amplitude) if needed. It is also possible to flag suspect data manually between two dates or two ensembles. When the current data are supposed to be the best, the user can create section and/or station files. These files contain the absolute current velocities re-averaged in space (for the section file) or time (for the station file). From these averaged section/station files, user can plot the absolute velocities as vectors or contouring plots.

Example of processed SADCP data obtained from PIRATA-FR24 cruise.

In this section, an example of PIRATA SADCP data processed with CASCADE software is presented, i.e. the data collected during the leg1 of the PIRATA-FR24 cruise from April 9 to May 22, 2014 aboard the R/V Le Suroit from Dakar (Senegal) to Abidjan (Ivory Coast) **(figure 1)**. The velocity and direction of the currents were measured along the route by a BB150 SADCP **(table 1)**, able to investigate the current field down to nearly 250 m. For this cruise, data were acquired with a blanking interval of 4m and vertical bin size of 8m and were preliminary processed onboard with the VmDAS software. Only the data processed after the cruise by CASCADE software (version 6.2) from VmDAS FILE.STA files (pings averaged in two minutes ensembles) are presented.

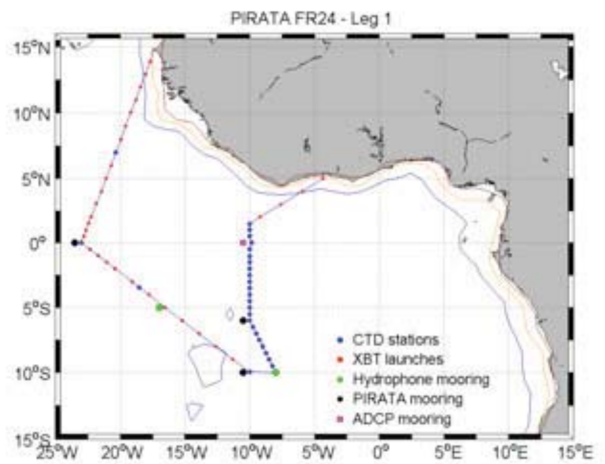

Figure 1: Track of the leg1 of PIRATA-FR24 cruise.

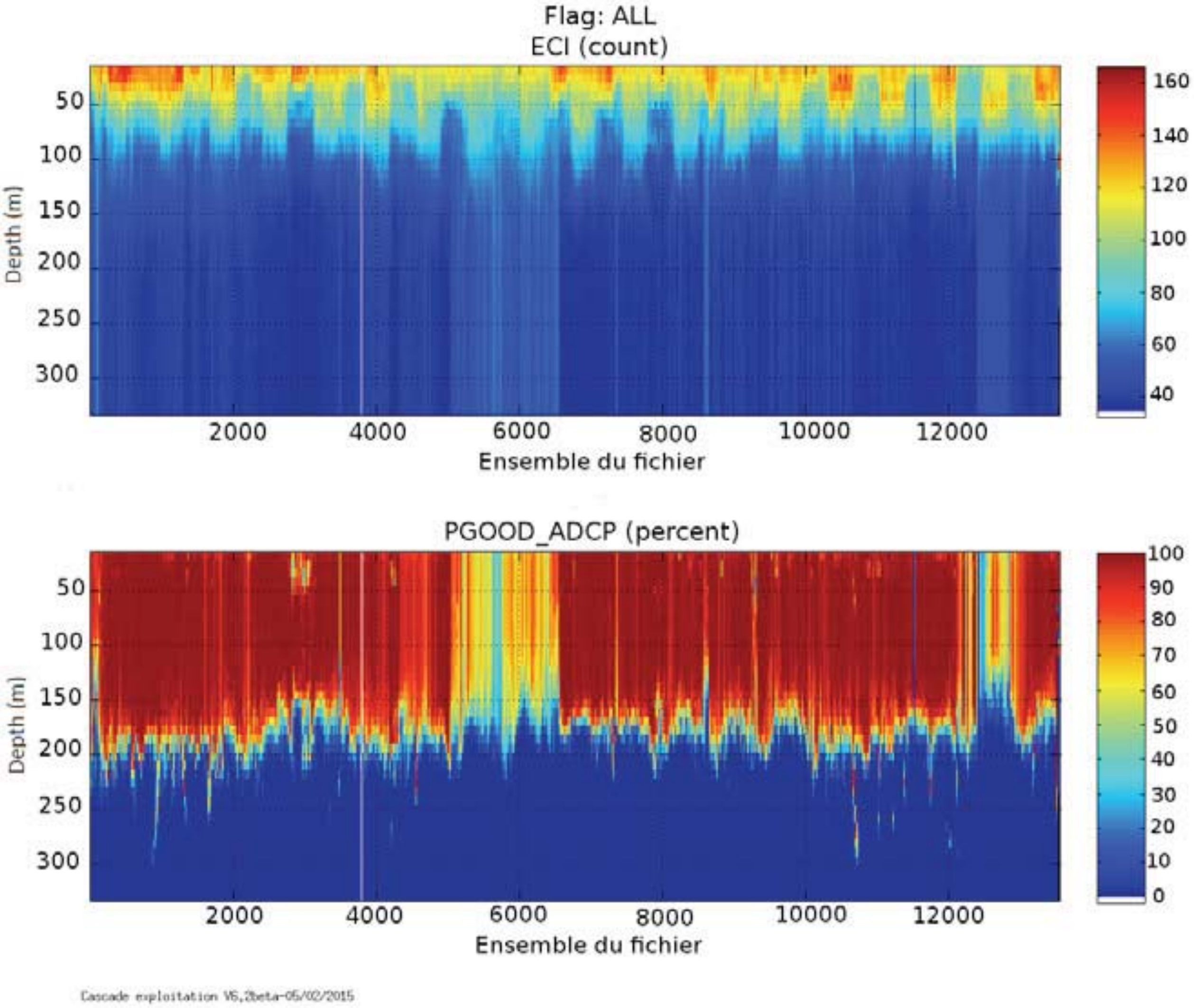

Figure 2: Mean Echo Intensity (upper plot) and percentage of good data (lower plot).

Some controls about the quality of the data can be made before the processing. The Percent Good variable plotted on figure 2 represents the percentage of pings using the four beams for each two-minute average ensemble. Data are considered as acceptable data when the percentage is > 10 %. The percentage of good data is highest for the bins near the surface and rapidly falls below 50 % at some depth. This feature is the basic profile usually observed and indicates that the ADCP data quality for this cruise is rather good. Nevertheless, a decrease of the percentage of good data happens locally for shallow cells (around the ensembles 6000 and 12500), associated to a low echo intensity, indicating that the signal-to-noise for these water cells is also low, maybe due to the presence of passive backscatters. The CASCADE cleaning data step gives the following result:

Flag	Meaning	Percent on the whole ensembles
1	Good data	55.86 %
2	Doubtful data	0.89 %
3	Bad data: median filter over 20 ensembles beyond 3 standard deviations.	0 %
4	Vertical shear > 0.2 s^{-1}	0 %
5	Vertical current speed > 100 cm/s PGOOD_ADCP < 10%	0 %
6	Horizontal current speed component > 4 m/s	0 %
7	Missing data	43.25 %
8	Data under the bottom (bottom ping)	0 %
9	Manual invalidation between 2 ensembles	0 %

Table 2: Flags attributed to the PIRATA-FR24 SADCP data (leg1 only) using CASCADE software.

The data are also corrected from barotropic tide (using the model TPX0 7.2 (Egbert and Erofeeva, 2002)) and horizontally and vertically smoothed. To detect misalignments or navigation errors, it is possible to plot comparison of absolute current velocities averaged on the reference layer, “en route” versus “in stations” (not shown). A misalignment can also be identified when a correlation of the amplitude and direction of the ship velocity with those of the absolute current velocity is noticed **(figure 3)**. For this part of the cruise neither misalignment nor navigation errors have been detected.

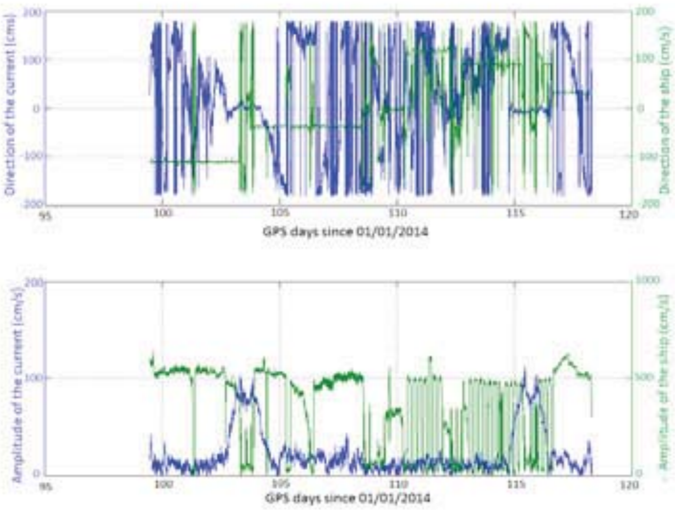

Figure 3: Upper panel: direction of ship (green line) and direction of the current estimated from ADCP (blue line) ; lower panel: amplitude of the ship (green line) and amplitude of the current estimated from ADCP (blue line).

For each strait or segment of interest, an average section of the velocity is calculated. For this cruise four 5km average-sections are defined from 2-minutes average files **(see figure 4)**. Figure 5 shows the vector plots of the 2 minutes horizontal velocities obtained from 18 m to 98 m depth (left) and from 98 m to 202 m depth (right) averaged every 5 km along the sections 1-4 of the ship track. Only the data affected to the flag 1 are used.

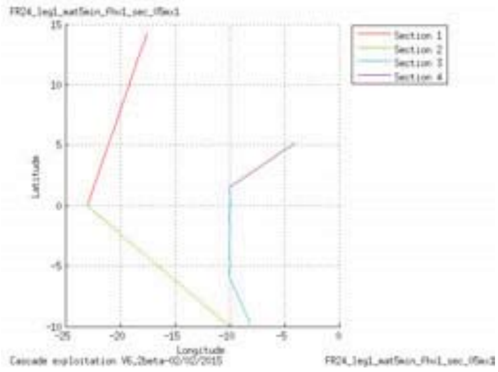

Figure 4: Sections along the leg1 of PIRATA-FR24 track.

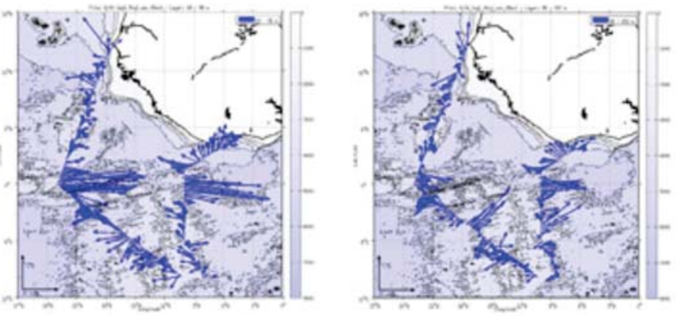

Figure 5: Vector plots of the 5km averaged horizontal current along the leg1 of PIRATA-FR24 cruise’s track averaged from 18 to 98 meters depth (left) and from 98 to 202 meters depth (right) superimposed on the bathymetry of the area. The arrows are displayed every 5 data points.

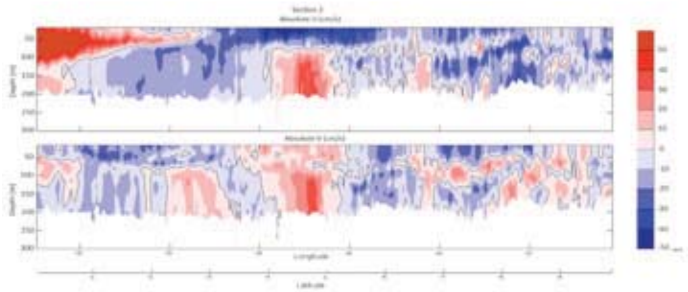

Figure 6: Vertical distribution of zonal and meridional current (in cm/s) function of longitude along section 2 from April 21 2014 to April 27 2014 during the leg1 of the PIRATA-FR24 cruise.

Several interesting features of the flow field can be observed in this presentation of the data: an eastward current is well visible on the 18-98 m average plot (figure 5, left) in the range 2°S – 2°N. It corresponds to the Equatorial Under-Current (EUC), a quasi-permanent feature of the zonal equatorial circulation in both the Atlantic and Pacific oceans (see e.g. Philander, 1973 ; Wyrtki and Kilonsky, 1984). The EUC is strongly attenuated bellow 100m depth (figure 5, right), as already shown in recent studies dedicated to the EUC and using some PIRATA ADCP measurements (e.g. Arhan et al., 2006; Kolodziejczyk et al., 2009, 2014). CASCADE software gives also the possibility to plot vertical distribution of velocities along each section, as illustrated by figure 6 that shows these distributions along the section 2. We can see that the EUC exhibits a core depth between 25 and 100m between 23°W and 22°W, with maximum core speeds in the range of 50-60 cm/s. Around 17°W below 100m depth is the subsurface SEUC (South Equatorial Under Current) (see e.g. Schott et al., 1998). Above it, we can observe the westward surface-intensified flow of the cSEC (central South Equatorial Current).

Data archiving and data access

The set of SADCP processed data from these 8 PIRATA oceanographic cruises are made available on the ftp website: ftp://ftp.ifremer.fr/ifremer/ird/pirata/pirata-data/ . For each cruise, different files are available:

- NetCDF data files - Raw data and processed data (date/time, latitude, longitude, depth, horizontal and vertical absolute current, navigation data...).
- UNIX tar files containing figures (section map, images and vector plots of the sections).
- Report which contains information about data collection, quality checks, processing procedures applied to data and problems encountered with the data.

The files are also archived and directly downloadable on the SISMER portal (under Data access http://www.ifremer.fr/sismer/index_UK.htm)

Conclusion

During each yearly oceanographic PIRATA cruise, current measurements are carried out in the Tropical Atlantic (from 0 to 700 m max). These current-meter measurements made using ADCP require relatively complex processing and checking, taking into account navigational parameters and ship's attitude. In this note, a brief review of processing methodology by using the CASCADE software applied to SADCP data obtained from the 8 2007-2014 PIRATA cruises has been made. Thus, CASCADE allows computing the ancillary data (such tide and bathymetry), flags, re-computing data for a given misalignment and/or amplitude, smoothing the data according to time or/and depth, defining sections or stations with a spatial or temporal sampling and providing graphical display of the data. The processing steps realized by CASCADE software have become increasingly automated, nevertheless they do not replace a scientific analysis and human judgment that is still required for the final product. To illustrate the processing steps and demonstrate the CASCADE software capabilities, an example of SADCP data processing obtained from PIRATA-FR24 cruise in April-May 2014 has been shown. Once processed, the SADCP data are available for the scientific community as soon as possible via internet. PIRATA data sets have already allowed numerous studies carried out by several French laboratories, focusing on the oceanic processes and data assimilation technique, especially in the frame of the operational MERCATOR global Ocean forecasting system.

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