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# IMPROVING THE PASSIVE DOPPLER GEOLOCATION SYSTEM THROUGH EXTENSION OF THE DATA RECEPTION NETWORK

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**ABSTRACT.** The main goal of this work is to show an investigation on the improvement of the newly developed Doppler based Brazilian geographic location system using the data reception network software. The Doppler data measurement set of a single satellite pass and a single DCP (Data Collecting Platform), considering a network of ground reception stations, is named as the data reception network. Thus, increasing the terrestrial reception stations around the Brazilian territory, will allow an increment in the coverage and amount of data collected. Consequently the accuracy of the computed locations would also increase as well as the reliability figures. The results and analyses were obtained under two conditions: the first one used both ideal simulated and real conditions to compare results from the same satellite passes, DCP and two known ground reception stations, the second one used ideal simulated conditions from measurements of one DCP transmitter, three ground stations and two satellites. Results using such database were quite satisfactory. The achieved study showed the importance of additional terrestrial reception stations spread over the Brazilian territory, to increase the measurements amount, as well as to get more valid and precise locations.

**Keywords**: Brazilian network, geographical location, satellites, Doppler shift.

**RESUMO.** O objetivo deste trabalho é apresentar uma investigação preliminar da precisão nos resultados do sistema de localização geográfica de transmissores desenvolvido utilizando o *software* da rede brasileira de coleta de dados. Um conjunto de medidas de desvio Doppler de uma única passagem do satélite, considerando uma Plataforma de Coleta de Dados (PCD) e uma rede de estações de recepção terrestres, é denominado uma rede de recepção de dados. Assim, a rede brasileira de coleta de dados com o uso de múltiplas estações de recepção permitirá o incremento na quantidade de dados coletados com conseqüente melhora na precisão e na confiabilidade das localizações fornecidas. Consequentemente uma maior quantidade de localizações válidas e mais precisas. Os resultados e análises foram obtidos sob duas condições: na primeira foi considerada uma condição prática com dados reais e dados ideais simulados, para comparar os resultados considerando a mesma passagem do satélite, transmissor e duas estações de recepção conhecidas; na segunda foram consideradas as condições ideais simuladas a partir de medidas de um transmissor fixo, três estações de recepção e dois satélites. Os resultados utilizando a rede de recepção de dados foram bastante satisfatórios. O estudo realizado mostrou a importância da instalação de novas estações de recepção terrenas distribuídas no território nacional, para um aumento na quantidade de medidas e consequentemente uma maior quantidade de localizações válidas e mais precisas.

**Palavras-chave**: rede brasileira, localização geográfica, satélites, efeito Doppler.

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## INTRODUCTION

Nowadays there are more than 600 (fixed and moving) Data Collecting Platforms (DCP) transmitting several types of payload data (meteorological, hydrological, agricultural, deforestation, $CO_2$ gas concentration, and others) through LEO (Low Earth Orbit) satellites. In Brazil, near real-time geographical location of transmitters (Sousa, 2000; Sousa et al., 2001, 2003) and its monitoring through satellites is used to track displacements and habits of animals by fixing mini-transmitters on them (Muelbert et al., 2000); to monitor oceanographic buoys for scientific research (Kampel et al., 1997); to monitor emergency location and rescue of aircraft and ships (Techno-Sciences, 2000), and others. Similar approaches are followed elsewhere (French, 1986; Itoigawa et al., 1996; Okamoto et al., 1999). The Brazilian network for reception of satellite-relayed data composed by several terrestrial reception stations is spread over different areas of the Brazilian territory. The relay satellite measures the Doppler shift suffered by the DCP transmitted signal, which in turn, together with the payload data, downlinks the Doppler measurements to ground receiving stations. Such Doppler shift measurements are freely available (passive), being further processed to compute the DCP location through the location software.

The data reception network software uses an ordering selection method that merges the collected Doppler shift measurements through the stations network in a single file. The pre-processed and validated measurements encompass the DCP signal transmission time and the Doppler shifted signal frequency received on board the satellite. Thus, the assembly into a single file of the whole measurements collected, considering a given satellite pass, will contain more information about the full Doppler curve while decreasing the amount of measurement losses, as a consequence of an extended visibility between the relay satellite and the reception stations.

This software is integrated with the developed geographical location system that uses the method of near real-time (just after data reception) geographic location of transmitters through satellites. In the following sections we outline the modeling of the geographical location problem, using the Doppler shift measurements and the satellite dynamic motion. After that, we show the obtained results and analysis with table and figures under two conditions: the first condition using both ideal and real conditions to compare results from real live data and simulated Doppler shift measurements from the same fixed known DCP transmitter, the Brazilian Data Collection Satellite (SCD-2, 25° inclination) passes and both Brazilian Cuiabá and Alcântara reception stations; the second one using ideal conditions from simulated Doppler shift measurements of one DCP transmitter placed in the center of Brazil, three reception stations configuring ideal geometry, and the SCD-2 (Brazilian Data Collecting Satellite-2) and NOAA-15 (National Oceanic and Atmospheric Administration) satellites.

## GEOGRAPHICAL LOCATION USING DOPPLER SHIFT MEASUREMENTS

In the Brazilian Environmental Data Collection System, the satellite works as a message retransmitter (bent pipe transponder). Therefore, a communication link between a Data Collection Platform (DCP) and a reception station is established through one of the satellites. When the transmitter and the reception station are inside the satellite visibility circle of around 5000 km diameter for 5° minimum elevation angle, the nominal UHF frequency signals periodically sent by the transmitter are received by the satellite and immediately (real-time) sent down to the reception station. The platforms installed on ground (fixed or mobile) are configured for transmission intervals of between 40 to 220 seconds. In a typical condition, in which both transmitter and receiver are close enough, this period can last up to 10 minutes. The DCP messages retransmitted by the satellites and received by the Cuiabá and Alcântara stations are sent to the Data Collection Mission Center located at Cachoeira Paulista, for processing, storage and dissemination to the users, as Figure 1.

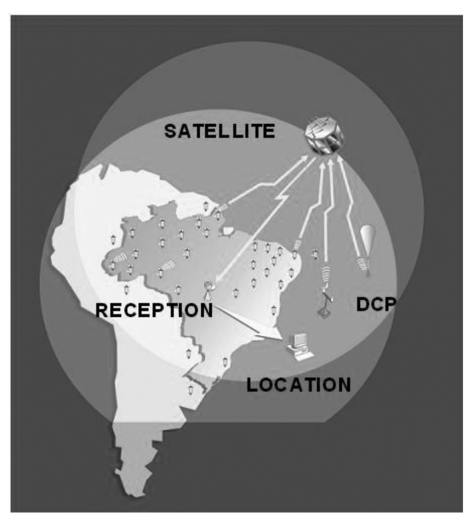


**Figure 1** – Brazilian Environmental Data Collection System and Cuiabá and Alcântara station visibility circles.

The difference between the received signal frequency and the nominal frequency supplies the Doppler shift. The basic principle of transmitter location considers that for each signal transmitted a location cone is obtained (Fig. 2). The satellite is in the cone vertex and its velocity vector $V$ lies in the symmetry axis. Two different cones of location intercept the surface and its intersection contains two possible transmitter positions. To find which of the two positions is the correct one, additional information is required, as for example, the knowledge of an initial position. A second overpass removes any uncertainties.

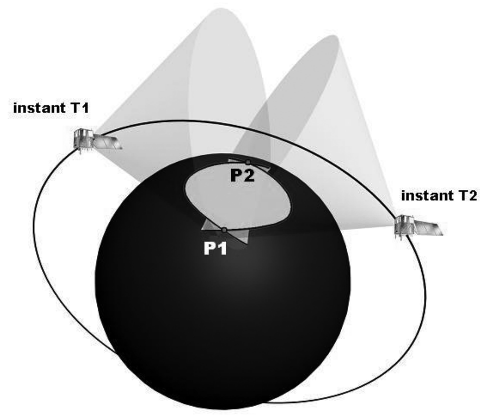


**Figure 2** – Location cones.

The transmitter geographic location can be determined by means of the Doppler shift of the transmitted frequency due to the relative velocity between the satellite and the transmitter. The satellite velocity relative to the transmitter $(V \cos\alpha)$ in vacuum conditions, denoted by $\dot{\rho}$, is given by the Doppler effect (Resnick, 1968) equation as follows:

$$\dot{\rho} \;=\; \left[\frac{(f_r - f_t)}{f_t}\right] c\,, \tag{1}$$

where $f_r$ is the frequency value as received by the satellite; $f_t$ is the reference frequency sent by the transmitter; $(f_r - f_t)$ is the Doppler shift due to the relative velocity satellite-transmitter; $c$ is the speed of light; $\alpha$ is the angle between the satellite velocity vector $V$ and the transmitter position relative to the satellite. The Doppler shift observations are modeled by:

$$y \;=\; h(x) + v\,, \tag{2}$$

where $y$ is the set of Doppler shifts measured; $v$ is the observation noise, and $h(x)$ is the non-linear function (Aksnes et al., 1988) relating the measurements to the location parameters and function of the satellite ephemeris, that is,

$$\begin{aligned} h(x) \;=\; & \frac{\left[(x-X)(\dot{x}-\dot{X}) + (y-y)(\dot{y}-\dot{Y}) + (z-Z)(\dot{z}\dot{Z})\right]}{\sqrt{(x-X)^2 + (y-Y)^2 + (z-Z)^2}} \\ & + b_0 + b_1 \delta t \end{aligned} \tag{3}$$

where $(x, y, z)$ and $(X, Y, Z)$ are the satellite and transmitter position coordinates, $b_0$ is the bias and $b_1$ is the drift of the Doppler curve. The set of measurements are then processed by the least squares method based on Householder orthogonalization (Lawson & Hanson, 1974; Golub & Van Loan, 1989). The whole procedure and the algorithm details can be found in Sousa (2000) and Sousa et al. (2003).

## DATA DESCRIPTION

In order to get the results of Table 1 a simulator was developed. The simulator emulates data files arising from the satellite passages over the Earth reception stations. Fortran language was used to code the algorithm. The inputs to the simulator include the satellites ephemeris (given in two-lines format), the initial and final dates to be simulated, the transmission rate, white noise and systematic errors (biases), as well as the position of the transmitter and of the reception station. The output files generated by the simulator contain all the simulated Doppler shift measurements spanning the passage of the satellites in the specified time interval corresponding to the input transmitter and satellite data.

To simulate the Doppler shift measurements, it was used the Doppler shift equation, corrupted by noise and bias:

$$\delta \;=\; -\frac{(f_t \dot{\rho})}{c} + b + w$$

where $\delta$ is the Doppler shift, $\dot{\rho}$ is the speed of the satellite with respect to the transmitter, $f_t$ is the transmitted frequency, $c$ is the speed of the light, $b$ is the bias term and $w$ is the white noise term.

## RESULTS AND DISCUSSION FOR SIMULATED AND REAL DATA

In this section we show a comparison of location results using ideal (simulated Doppler measurements without considering errors, i.e. no noise and no bias, which is an ideal but non realistic condition) and actual data corresponding to a fixed DCP transmitter #32356 (18.4342°S, 309.5918°E) relaying data through the SCD-2 satellite to the Brazilian Cuiabá (center of Brazil) and Alcântara (near Equator) reception stations. The used transmission burst for this transmitter was 90s (one single Doppler shift measurement every 90s) for 10 minutes passes (overflies) of SCD-2 satellite. The SCD-2 ephemeris was provided by the Control Center of INPE (*Instituto Nacional de Pesquisas Espaciais*). The data were gathered from May 06 to 16, 2006.

The comparison between the location errors using actual (collected) and ideal (simulated) measurements for a network of two stations (Cuiabá and Alcântara) is given in Table 1 (Kuga et al., 2007). The first and the second columns represent the day and hour from each satellite passage.

**Table 1** – Comparison of location results using ideal and real live data conditions.

| May 2006 | | Simulated data | | | Actual data | | |
|---|---|---|---|---|---|---|---|
| Day | Hour | CBA | ALC | CBA+ALC | CBA | ALC | CBA+ALC |
| 06 | 01 | 0.05 | 0.21 | 0.08 | 27.38 | — | **1.41** |
| 06 | 02 | 1.38 | 0.84 | 1.12 | — | 87.74 | 0.39 |
| 08 | 19 | 0.72 | 0.28 | 0.22 | 106.08 | 354.40 | **4.51** |
| 08 | 22 | 0.02 | 0.18 | 0.08 | 0.76 | 2.31 | 1.25 |
| 09 | 20 | 0.12 | 0.08 | 0.11 | 0.35 | 57.00 | 0.41 |
| 09 | 23 | 0.41 | 0.38 | 0.38 | 2.36 | — | 2.60 |
| 10 | 21 | 0.21 | 0.37 | 028 | 0.75 | — | 0.55 |
| 11 | 00 | 0.30 | 0.53 | 0.09 | 2.44 | — | 2.88 |
| 11 | 16 | 0.14 | 0.17 | 0.20 | 1.17 | — | 1.41 |
| 11 | 18 | 0.10 | 0.12 | 0.05 | 1.75 | 1.62 | 1.48 |
| 11 | 20 | 0.11 | 0.12 | 0.10 | 20.00 | 84.97 | **2.65** |
| 11 | 22 | 0.22 | 0.14 | 0.10 | 1.03 | 2.13 | 1.92 |
| 12 | 01 | 0.21 | 0.32 | 0.26 | 1.41 | 2.35 | 1.70 |
| 12 | 19 | 0.25 | 0.03 | 0.16 | 2.22 | 1.23 | 1.25 |
| 13 | 20 | 0.11 | 0.13 | 0.02 | — | 1073.33 | **1.53** |
| 13 | 22 | 0.37 | 0.66 | 0.13 | 26.74 | 502.38 | 3.62 |
| 15 | 22 | 0.43 | 0.41 | 0.41 | 21.35 | 1.25 | 1.08 |
| 16 | 00 | 0.18 | 0.28 | 0.17 | 39.14 | 14.15 | **1.09** |
| 16 | 21 | 0.75 | 0.44 | 0.60 | 1.46 | — | 2.51 |
| 16 | 23 | 0.19 | 0.16 | 0.12 | 1.68 | 23.02 | 1.49 |

The third and fourth columns represent the location errors (km) using simulated Doppler shift data from the known DCP #32356 using single Cuiabá (CBA) or Alcântara (ALC) reception Stations. The fifth column shows location error (km) using the data reception network software, which processes both (CBA and ALC) data.

The sixth and seventh columns represent the locations error (km) using actual measured data, the same reception stations (CBA and ALC) and DCP at the same simulated period. Finally the last column shows location error (km) using the data reception network software, which processes both (CBA and ALC) data.

We can observe from Table 1 that the results from simulated data were better than from actual data, as expected. The columns of actual data without results, symbol (—), means that there were insufficient data to compute a location. When we used the data reception network software to merge data from both reception stations, it was possible to have improved results as shown in the upright column in Table 1 (actual data, CBA+ALC). Remarkable improvements can be noticed, for instance, on D06 H01 (to be read day 06, hour 01), D08 H19, D11 H20, D13 H20, D13 H22, and D16 H00 (all boldfaced).

Considering the valid location results using ideal and actual data, respectively, we obtained the mean location error (km) of $0.313 \pm 0.319$ and $5.066 \pm 9.115$ using only Cuiabá reception station. Using solely the Alcântara station the mean location error (km) was $0.292 \pm 0.207$ and $6.074 \pm 9.483$, respectively. Using the data reception network software, which processes and merges both (CBA and ALC) data, the mean location error (km) was of $0.225 \pm 0.257$ and $1.806 \pm 1.086$ for ideal and real data respectively. In the location using real data the improvement using merged data from both stations is remarkable, the standard deviation decreased from about 9.5 km to about 1.1 km.

The following figures depict the importance of a full Doppler curve reconstitution and the extended data reception network. For the sake of illustration, we used the satellite pass from Table 1 corresponding to May, day 06 at 02:02 hours. Figure 3 shows the full Doppler curve considering actual data from Cuiabá (circle symbol) and Alcântara (triangle symbol) reception stations.

We notice that Cuiabá has only 2 data points, insufficient for a location; and Alcântara has 4 data points, all with negative sign, which yielded around 88 km location error (Table 1). When we merge the whole data set (Fig. 3), the full Doppler curve is better observed and the location error drops (improves) drastically to 0.39 km.

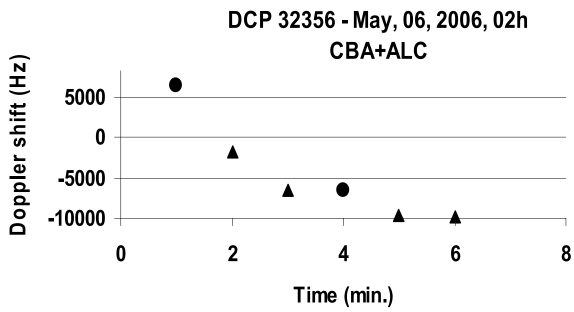


**Figure 3** – Doppler curve from May 06, 2006 at 02:00 hours using actual live data and Cuiabá (●) and Alcântara (▲) reception stations.

## RESULTS AND DISCUSSION FOR SIMULATED IDEAL GEOMETRY

Next we shows the results using ideal conditions from simulated Doppler shift measurements of a DCP transmitter located in the center of Brazil with latitude value of 12°S and longitude value of 310°W as illustrated in Figure 3. We also used three simulated ground reception stations configuring a nearly ideal geometry (Fig. 4) and the SCD-2 and NOAA-15 satellites with orbit geometry as in Figure 5.

Tables 2 and 3 show results using SCD-2 and NOAA-15 satellites respectively. Considering SCD-2 satellite we obtained 20 (twenty) valid passes during 02 to 07 November 2006 when the three stations received messages simultaneously, and 6 (six) valid passes considering NOAA-15 satellite. The first column represents the three simulated reception stations (Fig. 4) and the last two columns show the mean location error with its standard deviation when the transmission sampling rates were 120s and 10s, respectively.

There were more satellite passages using the equatorial satellite SCD-2 (about 8 per day) than the polar satellite NOAA-15 (about 3 to 4 per day), as expected.

Comparing Tables 2 and 3, the mean location error from the three simulated reception stations considering a transmission sampling burst every 10s was better than that every 120s. This shows clearly the importance of having a high DCP transmission sampling rates to gather more Doppler data and to a better location result. The obtained location results using NOAA-15 satellite were better than that using SCD-2 satellite. This occurred because we introduced random noise errors at the level of 0.1 Hz to NOAA-15, and 1 Hz to SCD-2 in the Doppler shift measurements, consistent with their corresponding on board oscillator stability (Sousa, 2000).

**Table 2** – Mean location error from November 2006 using SCD-2 satellite.

| | Mean location error (km) | |
|---|---|---|
| | 120s | 10s |
| STA 1 | $0.649 \pm 1.449$ | $0.189 \pm 0.521$ |
| STA 2 | $0.444 \pm 1.003$ | $0.149 \pm 0.249$ |
| STA 3 | $0.410 \pm 0.456$ | $0.094 \pm 0.072$ |
| STA 1 + STA 2 + STA 3 | $0.237 \pm 0.301$ | $0.104 \pm 0.272$ |

**Table 3** – Mean location error from November 2006 using NOAA-15 satellite.

| | Mean location error (km) | |
|---|---|---|
| | 120s | 10s |
| STA 1 | $0.037 \pm 0.019$ | $0.013 \pm 0.008$ |
| STA 2 | $0.032 \pm 0.031$ | $0.013 \pm 0.008$ |
| STA 3 | $0.050 \pm 0.053$ | $0.007 \pm 0.008$ |
| STA 1 + STA 2 + STA 3 | $0.022 \pm 0.013$ | $0.007 \pm 0.010$ |

The mean location errors for simulated conditions using the ideal data reception scenario were 0.237 km (transmission rate of 120s) and 0.104 km (transmission rate of 10s) considering SCD-2 satellite and three reception stations. For NOAA-15 satellite the locations were 0.022 km (transmission rate of 120s) and 0.007 km (transmission burst of 10s). It can be noted that the standard deviation using 120s sampled data improved with usage of 3 stations in all the cases, whereas for 10s sampled data the improvement is not pronounced. Thus it is implied that at rough sampling rates (e.g. one Doppler data every 120s), which is the case for most of the transmitters, the extension of the data reception network will improve the performance of the location system.

## CONCLUSION

The performance of the geographic location system was presented for extended reception stations. Since the algorithm is still under tests the analysis was done considering fixed transmitters with well-known location, so that the location results can be evaluated. It can be observed the good performance of the data reception network for both the simulated and the actual case.

Besides, the results show the importance of additional terrestrial reception stations spread over the Brazilian territory to improve the geometrical coverage between satellite and DCPs, in order to increase the number of Doppler measurements collected during the passage of the satellite, and to better recover the full Doppler curves, yielding as a consequence valid and improved locations.

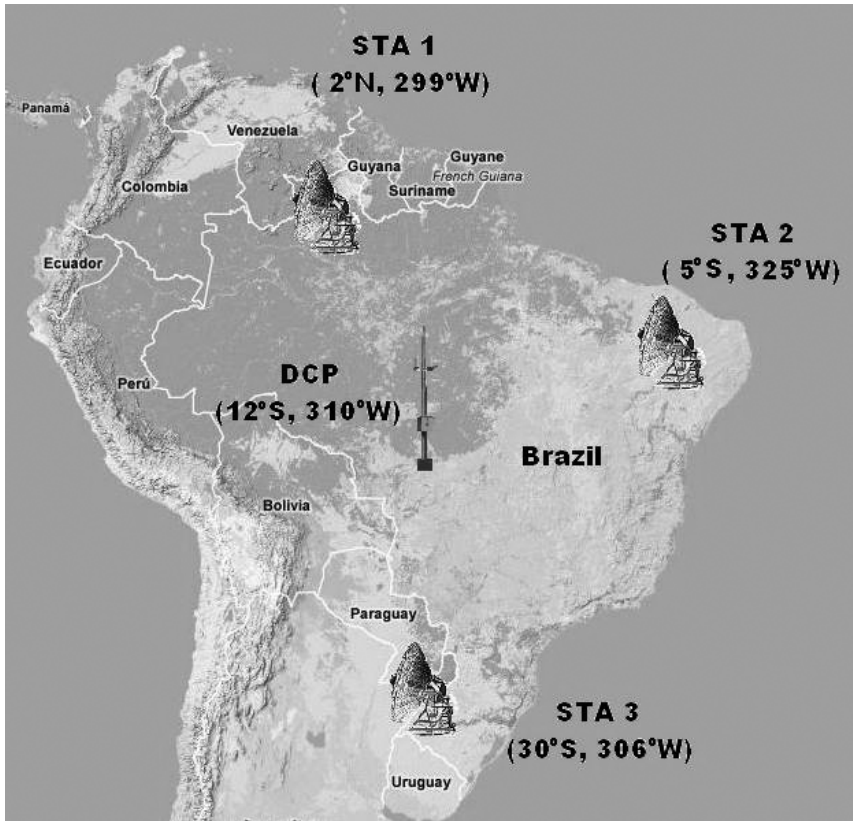


**Figure 4** – Reception stations configuring ideal geometry.

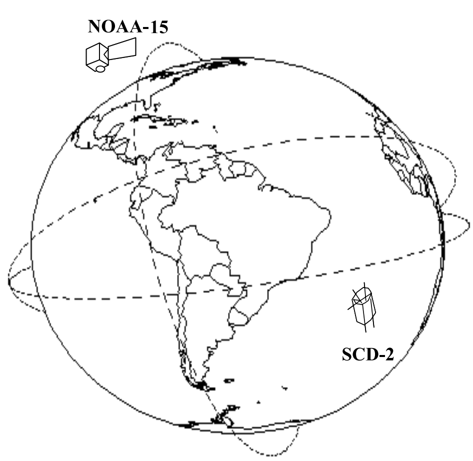


**Figure 5** – Space segment (SCD-2 and NOAA-15).

## REFERENCES

AKSNES K, ANDERSEN PH & HAUGEN E. 1988. A precise multi-pass method for satellite Doppler positioning. Celestial Mechanics and Dynamical Astronomy, 44: 317–338.

FRENCH J. 1986. Tracking animals by satellite. Electronics and Power, 32(7): 508.

GOLUB G & VAN LOAN FC. 1989. Matrix computations. Baltimore, Johns Hopkins. 642 pp.

ITOIGAWA N, MINAMI T, KANAZAWA T, IMAKAWA S & YASUDA J. 1996. Geographical movements of free-ranging male Japanese monkeys. Argos Newsletter, 51: 13.

KAMPEL M, STEVENSON MR & ASSIREU AT. 1997. Heat transport estimates in the surface layer of the Antarctic polar front using a satellite tracked drifter – first results. In: International Congress of the Brazilian Geophysical Society, 5., São Paulo. Proceedings... São Paulo: Brazilian Geophysical Society – SBGf, 1: 99–102.

KUGA HK, SOUSA CT & VILHENA DE MORAES R. 2007. Improving the passive Doppler geolocation system through extension of the data reception network. In: International Symposium of the IAA on Small satellites for Earth observation, 6., Proceedings... Berlin: International Academy of Astronautics, Apr. 23-26, 2007, 8 pp., IAA-B6-0721P. CD-ROM.

LAWSON LC & HANSON JR. 1974. Solving least squares problems. New York, Prentice Hall. 340 pp.

MUELBERT MMC, ROBALDO RB, MARTINEZ PE, BIANCHINI A & SETZER AW. 2000. Movimentos sazonais de elefantes-marinhos do sul (*Mirounga leonina L.*) da Ilha Elefante, Shetland do Sul, Antártica, observados através de telemetria de satélite ("Seasonal motion of marine elephants from south of Elephant Island”). In: Seminário sobre Pesquisas Antárticas, 7., (“7th Seminar on Antarctic Research”), São Paulo: Instituto de Geociências, USP, IAG, p. 38.

OKAMOTO T, HAYASHI T, HOSOKAWA S & YOKOYAMA K. 1999. Positioning of the signal source based on Doppler shift in uplink signals received by a satellite. In: International Astronautical Congress, 50, Amsterdam, 1999. Proceedings, IAF. Paper B. 4.05, p. 1–6.

RESNICK R. 1968. Introduction to special relativity. New York: John Wiley. 248 pp.

SOUSA CT. 2000. Geolocalização de Transmissores com Satélites usando Desvio Doppler em Tempo-Quase-Real. (“Geographic Location of Transmitters with Satellites using Doppler Shift in Near real-time”) (in Portuguese) PhD Dissertation, São José dos Campos, INPE, 185 pp.

SOUSA CT, KUGA HK & SETZER AW. 2001. Geo-Location of transmitters using real data, Doppler shifts and Least Squares. In: ROSER HP, VALENZUELA A & SANDAU R. (Ed.). Small Satellites for Earth Observation. Berlin, Wissenschaft und Technik Verlag, 1: 327–330.

SOUSA CT, KUGA HK & SETZER AW. 2003. Geo-Location of transmitters using real data, Doppler shifts and Least Squares. Acta Astronautica, 52(9): 915–922.

TECHNO-SCIENCES. 2000. COSPAS/SARSAT Program. Available in: <http://www.technosci.com>. Access on: Oct. 19, 2000.

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