# "HIGH RATE GPS POSITIONING , JASON ALTIMETRY AND MARINE GRAVIMETRY - MONITORING THE ANTARCTIC CIRCUMPOLAR CURRENT (ACC) THROUGH THE DRAKE CAMPAIGNS. "


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*I would like to dedicate this work in the memory of my mentor and supervisor Dr. Yves Menard and to promise him that this work will stand on the level of his memory !!*


## Abstract


The Drake campaign which took place from Jan 14, 2006 – 08 Feb, 2006 has been a very successful mission in collecting a wide range of GPS and marine gravity data all along JASON altimetry ground track n° 104. The same campaign will be repeated in 2009 along 028 and 104 JASON-2 ground track. The *Drake Passage* (DP) chokepoint is not only well suited geographically, as the *Antarctic Circumpolar Current* (ACC) is constricted to its narrowest extent of 700 km, but observations and models suggest that dynamical balances are particular effective at this area. Furthermore the space geodesy observations and their products provided from several altimetry missions (currently operating ENVISAT, JASON 1 and 2, GFO, ERS ⅓ and other plannified for the future such as Altika, SWOT) require the cross comparison with independent geodetic techniques at the DP.

The current experiment comprises a kinematic GPS and marine gravimetry Cal/Val geodetic approach and it aims to :

•validate with respect to altimetry data and surface models such a kinematic high frequency GPS technique for measuring sea state and *sea surface height* (SSH),

•compare the GPS SSH profiles with altimetry *mean dynamic topography* (MDT) and *mean sea surface* (MSS) models,

•give recommendations for future "offshore" Cal/Val activities on the ground tracks of altimeter satellites such as JASON-2, GFO, Altika etc.

•and determine the mean surface profile of the geostrophic current and associated velocity field.

The high frequency GPS SSH profiles are derived using two different GPS kinematic software, GINS (CNES) and TRACK (MIT).

The campaign took place aboard the *research vessel* (RV) "Polarstern" of the *Alfred-Wegener-Institut* (AWI). The expedition, which principally was a mutli-sensor oceanographic experiment, was named ANTARKTIS-XXIII/3 (ANT-XXIII/3) of the RV "Polarstern" (Provost 2007). The ship had room for approximately 40 scientists and 44 crewmembers. The CNES – LEGOS research team (Ménard et al. 2005) participated in the ANT-XXIII/3 on the ship's voyage from Puntas Arenas (Chili) to O'Higgins (Antarctica) measuring gravity and GPS SSH time-series all along JASON's 104th ground track (**Fig. 1**). The same campaign will take place in 2009 from Mars 21, 2009 - Apr 09, 2009 under the name ANT-XXV/4. Along with the multi-sensor oceanographic expedition the complex geodetic GNSS technique will provide a precise kinematic 3D positioning of a floating tracer (e.g. ship, buoy) with respect to distant fixed reference geodetic points as was tentatively proposed by Menard et al. (2005). This technique was used and demonstrated previously but over close distances to fixed reference stations, especially in the altimetric calibration sites of Senetosa in Corsica (Bonnefond et al 2003), Bass Strait, in Australia (Watson et al. 2004), the T/P California off-shore platform in the US (Haines et al. 2003) and the most recent one on the Gavdos island of Crete in Greece (Pavlis and Merticas, 2007). In the present case such a technique is extended to a larger area and it is used to determine the absolute sea surface *Dynamic Topography* (DT), the *Sea Surface-Height* (SSH) and derived geostrophic current parameters.

In the present paper we focus on the principal and the evaluation of the GPS technique (Fig. 2). In order to validate the processed GPS SSH time-series using the two independent GPS software, collocated sessions with a tide gauge (TG) are also being analysed. Finally the perspectives and the general outlook of the next steps are presented.

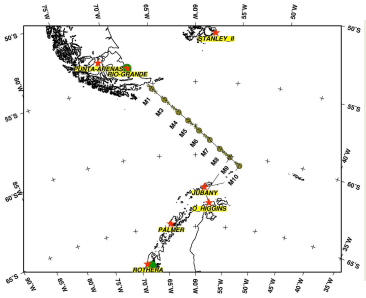




**Figure 1** : (Up) The 2006 Drake campaign along the 104th ground track of JASON. Moorings (M1-M10) and CTD sections are drawn. The tide gauge (TG) network collocated with GPS is illustrated in red stars and in green circles are collocated DORIS stations.

**The geodetic data** set collected during the 2006 Drake campaign comprises :
56 GPS-buoy sessions of 2-3 hours-interval at 1-Hz;
23 days-interval of continuous GPS-ship sessions at 1-Hz from 2 Trimble 5700 receivers equipped with 2 TRM41249.00 antennas and an Ashtech Z-12 receiver equipped with an ASH700700.B antenna.
23 days-interval of continuous GPS observations from the following stations : EACF (BR) at 1-Hz, RIOG (AR, IGb00) at 1-Hz, PARC (CH, ex-IGb00) at 1-Hz, PALM (US, ITRF00) at 1-Hz, SMRT (AR, ITRF00) at 30s, JUBY (AR) at 30s, OHI3 (CH, IGb00) at 1-Hz;
and a marine gravity profile from a KSS31 sea gravimeter.

### *The Floating Line (FL) calibration (Fig. 2)*

During the first phase of the project, a number of GPS buoy deployments took place in the harbour of Punta Arenas, in Jubany and O'Higgins on the Antarctic Peninsula, and during open-sea sessions to measure the on-board GPS antenna positions with respect to the instantaneous sea level, referred as the *Floating Line* (FL) henceforth. The setup is illustrated in **Figure 2**. An accurate calibration of the vessel's FL is required in order to use the on-board GPS antennas for measuring the SSH in a consistent reference frame, like ITRF2000 or ITRF2005. Moreover, while the ship is cruising on its track fuel consumption can significantly change the FL. Thus frequent GPS buoy-ship sessions were accomplished at every CTD, ADCP, XBT and mooring survey (Fig. 1).

The FL of the RV "Polarstern" is defined as :

$$FL = h_{bat} - h_s + FL_b \Rightarrow \quad (1)$$
$$SSH_{bat} = h_{bat} - FL$$

Where $h_s$ and $h_{bat}$ are the ellipsoidal heights of the buoy and ship GPS-antenna phase center respectively and $FL_b$ is the buoy's floating line. The buoy was used with two different configurations during the 2006 campaign; we calculated two different floating lines $FL_b$ :

**1 life-saver FL = 9.2 cm**
**2 life-savers FL = 21.8 cm**

**In the next step we can associate the ship's GPS antenna height to the geoid and the MDT through (Fig. 2) :**

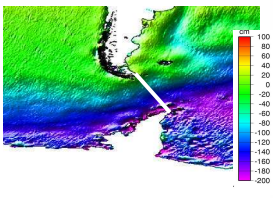
$$h_{bat} = N + FL + \zeta_t + \zeta_c + v \quad (2)$$

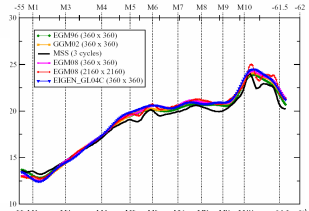
Where: N is the geoid undulation, $\zeta_t$ is the time dependent sea surface topography and $\zeta_c$ is the QSST and $v$ is errors.

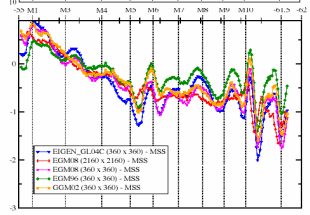
**Table 1 : The « Polarstern » FL determination in the open sea (Buoy – Ship common sessions)**

| | | Unfiltered | | Low - pass Filtered at 60 s | | Low - pass Filtered at 120 s | |
|---|---|---|---|---|---|---|---|
| *Date* | *Section* | *mean (m)* | *std (m)* | *mean (m)* | *std (m)* | *mean (m)* | *std (m)* |
| 17/01/2006 | TRM1 - BM03 | 20,994 | 1,116 | 21,094 | 0,0791 | 21,094 | 0,069 |
| 18/01/2006 | TRM1 - BC18 | 20,782 | 1,29 | 20,608 | 0,175 | 20,6083 | 0,171 |
| 19/01/2006 | TRM1 - BM04 | 20,838 | 0,842 | 20,838 | 0,239 | 20,838 | 0,236 |
| 20/01/2006 | TRM1 - BC20 | 22,221 | 1,302 | 22,22 | 0,91 | 22,221 | 0,9 |

**Comparisons of geoid profiles to JASON altimetry.**

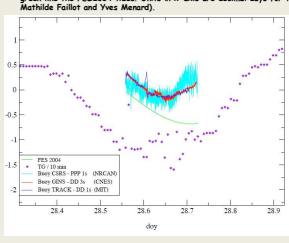



| *Geoid model* | *min* | *max* | *mean* |
|---|---|---|---|
| EGM06 (360 x 360) | -1.39 | 0.47 | -0.25 |
| EGM08 (2160 x 2160) | -1.65 | 0.65 | -0.47 |
| EGM08 (360 x 360) | -1.74 | 0.79 | -0.47 |
| GGM02C (360 x 360) | -1.59 | 0.84 | -0.37 |
| EIGEN_04GLC (360 x 360) | -2.0 | 0.88 | -0.48 |

**The GPS-TG collocated session at O'Higgins observatory. The purple pointed line illustrates the TG readings for every 10 min. The red line illustrates the GPS – buoy ellipsoidal height variations as calculated from GINS (CNES) GPS software in DD, the blue line represents those calculated from TRACK (MIT) GPS software in DD, the cyan line represents the solutions from the CSRS (NRCAN) PPP GPS software while the green line the FES2004 tides. Units in x-axis are decimal days for the Feb 28, 2006 and in y-axis are in meters (The photo is taken from Mathilde Faillot and Yves Menard).**





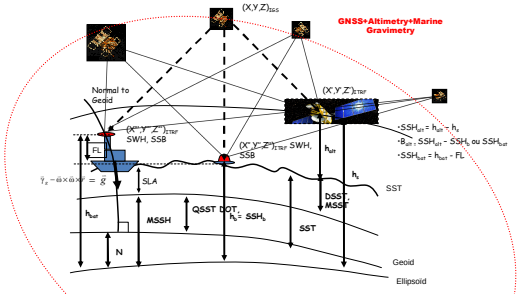


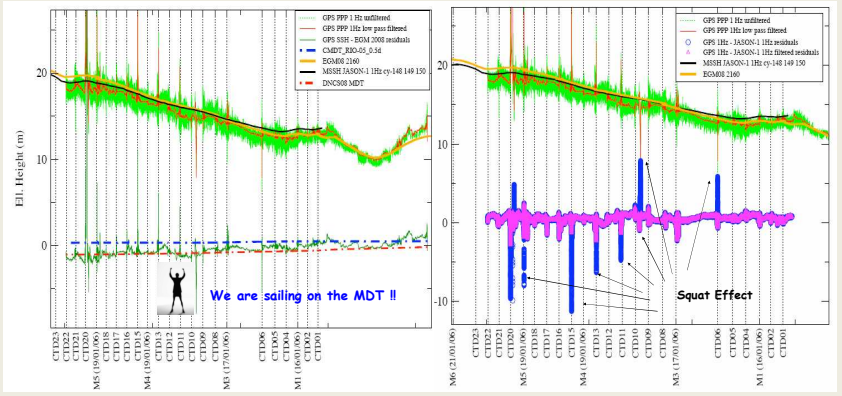

**Figure. 2.** Representation of the altimetric, gravimetric and GNSS combination technique. **SLA** – *Sea Level Anomaly*, **MSSH** – *Mean Sea Surface Height*, **QSST** – *Quasi- Stationary Sea Surface topography (constant over short time periods)* ~ **DOT** – *Dynamic Ocean Topography*, **DSST** - *Dynamic or time dependent Sea Surface Topography* , **SSH** – *instantaneous Sea Surface Height*, **SST** – *Sea Surface Topography*, **ISST** – *Instantaneous Sea Surface Topography*, **MSS** – *Mean Sea Surface*, **MSST**- *Mean Sea Surface Topography* ~ **DSST** - *Dynamic Sea Surface Topography (time-varying)*.

**Comparison of GPS SSH filtered PPP estimates to JASON-1 mean SSH profile of cycles 148 149 150**

| | *With outliers* | | | | *With major outliers rejection* | | | |
|---|---|---|---|---|---|---|---|---|
| *transect 1* | *min* | *max* | *mean* | *std* | *min* | *max* | *mean* | *std* |
| 17/01/2006 - 20/01/2006 | -66,4162 | 7,84672 | 0,124 | 0,637 | -2,8 | 2,449 | 0,157 | 0,432 |

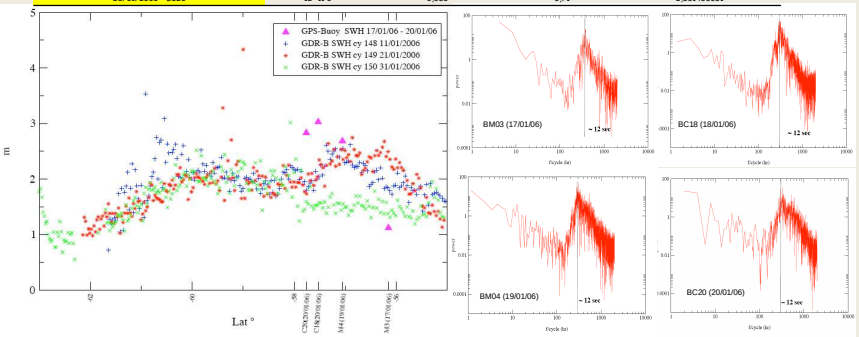
**Comparison of GPS SSH filtered PPP estimates to MDT models and the mean SSH profile of cycles 148 149 150**

| *transect 1* | *MDT model* | *mean* | *std* |
|---|---|---|---|
| 17/01/2006 - 20/01/2006 | CMDT RIO-05 | 0,385 | 0,067 |
| | DNCS08 MDT | -0,808 | 0,203 |
| | GPS 1Hz MDT | -0,292 | 0,714 |



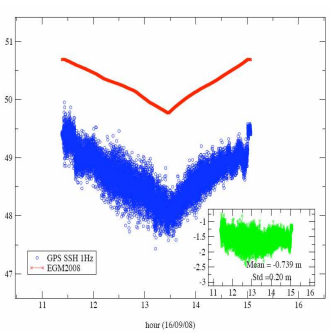

**Significant Wave Height from the GPS buoy and comparison to Altimetry**

| | *Period* | *sigma GPS bouy (port session) (m)* | *sigma Res (m)* | *SWH (m)* |
|---|---|---|---|---|
| 17/01/2006 - BM03 | 12 -11 s | 0,055 | 0,285 | 1,118570516 |
| 18/01/2006 - BC18 | 12 -11 s | 0,055 | 0,759 | 3,028018494 |
| 19/01/2006 - BM04 | 12 -11 s | 0,055 | 0,673 | 2,682995341 |
| 20/01/2006 - BC20 | 12 -11 s | 0,055 | 0,71 | 2,831466051 |




### The preparation for the 2009 Campaign

**In collaboration with the « Observatoire de Banuyls sur Mer » we have accomplished a preliminary campaign in order to test our new material for the Drake 2009 campaign. During this experiment a new buoy which was constructed in collaboration with the UTAS university was calibrated. Furthemore a radar altimetry system will be installed aboard Polastern in order to have more independent determination of the ship's FL and draft calculation. This will be useful to cross - compare to GPS and to eliminate more effectively the "squat effect" of the GPS SSH time series**





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