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Update of the South-Atlantic Anomaly corrective model for JASON-1 DORIS data using the maps of energetic particles from the CARMEN dosimeter onboard JASON-2

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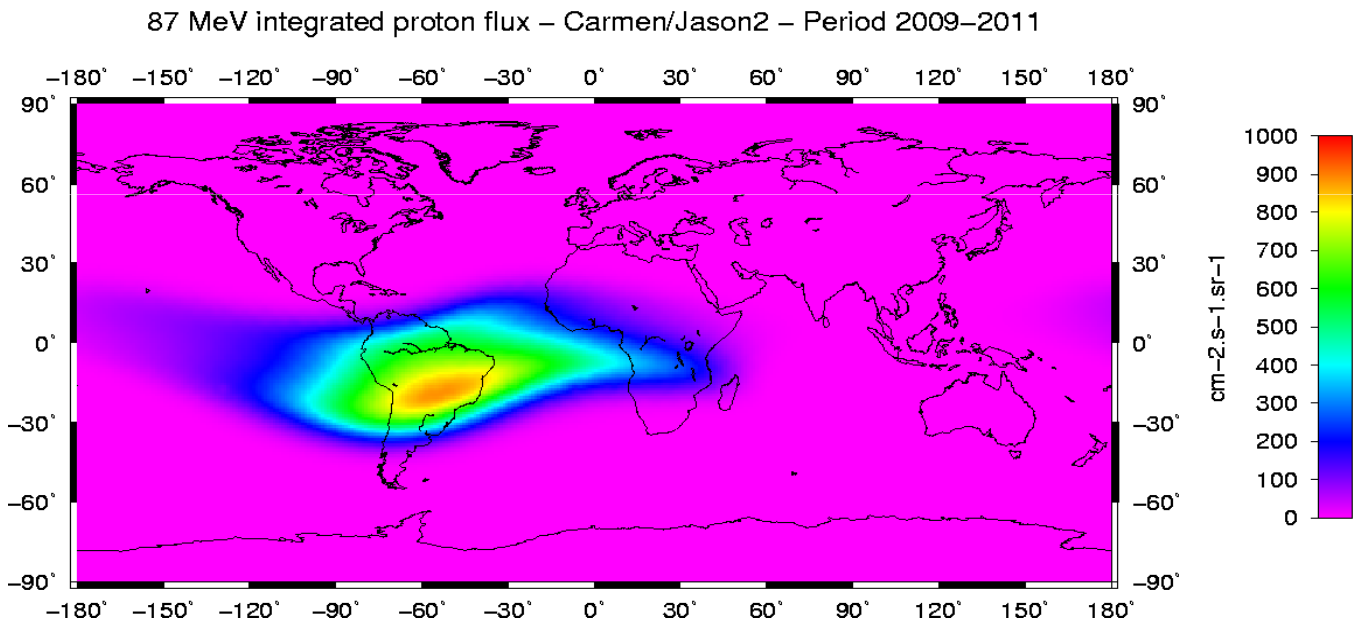
South Atlantic Anomaly effect

The sensitivity of the ultra stable oscillator (USO) of DORIS/Jason-1 to the high energy protons trapped in the Van Allen belts is now well known. This sensitivity causes a fluctuation of the frequency when the satellite crosses the area of the South-Atlantic Anomaly (SAA). The principal consequence is the impossibility of using the measurements of the DORIS beacons located in the SAA area for cm-precision positioning since the real frequency of the on-board oscillator is varying rapidly in that area.

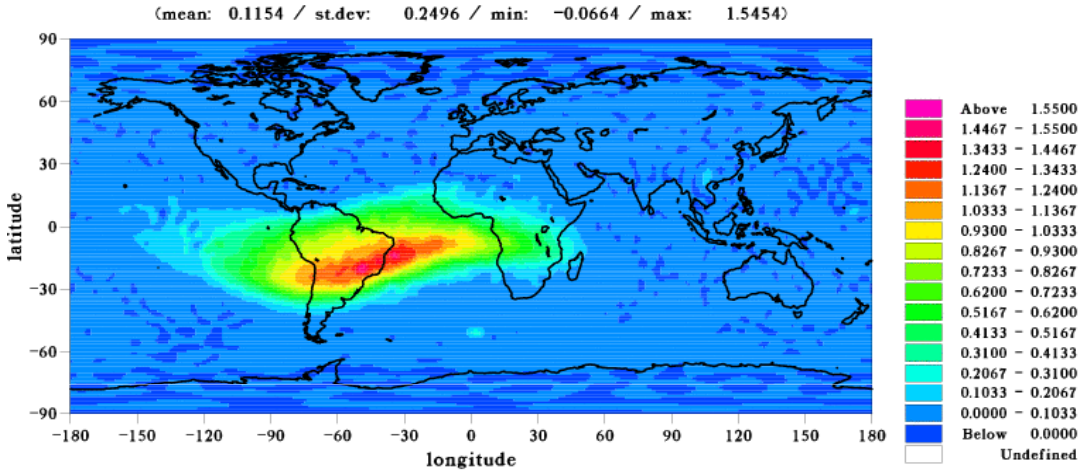


Definition of corrective model for JASON-1 DORIS data

The model involves :

-the physical source of the perturbations of the DORIS oscillator:

•1◦ × 1◦ geographical map of the mean SAA intensity at the altitude of Jason-1 (1,300 km)



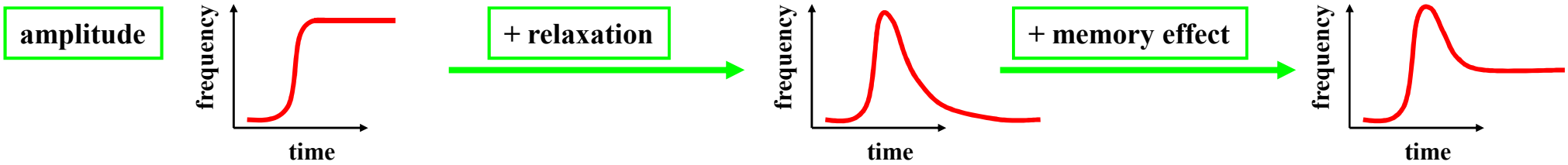
This grid can then be interpreted only in a relative way. Since the mean value of the grid and the mean value of the A parameter are one to-one correlated, an additional condition had to be imposed in order to enable solving for both the grid and the A parameter. This arbitrary condition was that the grid maximum value be 1.5.

-the response of the oscillator to this excitation, through a set of parameters that can vary with time

• A: amplitude factor relating the dose received by the quartz oscillator to the dose exposure

• τ : time constant of the relaxation behaviour

• μ: memory effect coefficient



Definition of corrective model for JASON-1 DORIS data

Principle of the model

•Determination of the SAA onboard frequency signal

1) Determination of precise orbits of all DORIS satellites

combination of all satellites except Jas1→ station parameters

Jason1 → orbit dynamical parameters

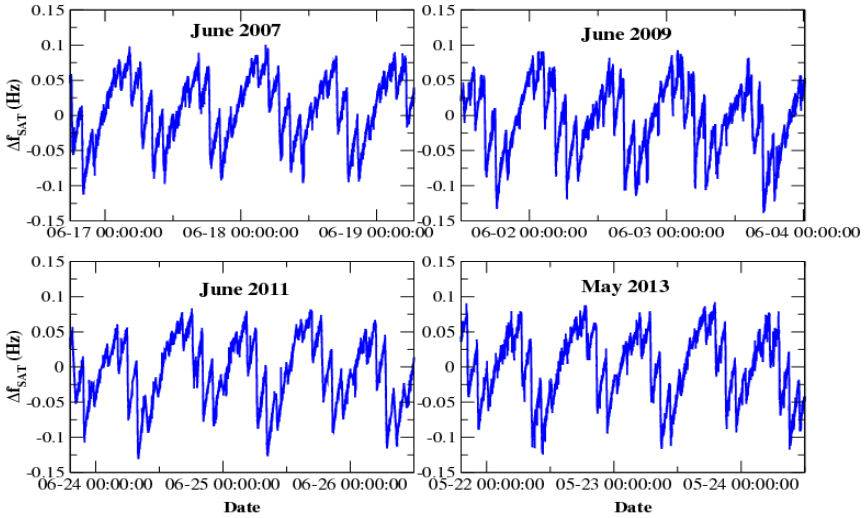
2) Determination of measurement residual

we have fixed station parameters and Jason-1 orbit (of step 1)

3) Conversion of measurement residual in offset frequency

Δfsat (*in Hz on 2GHz)*

SAA onboard frequency Δfsat



•Determination of the parameters

Using the SAA Jason1 map:

-Amplitude (Hz/day)= Map_SAA(lat,lon) x Amplitude (t)

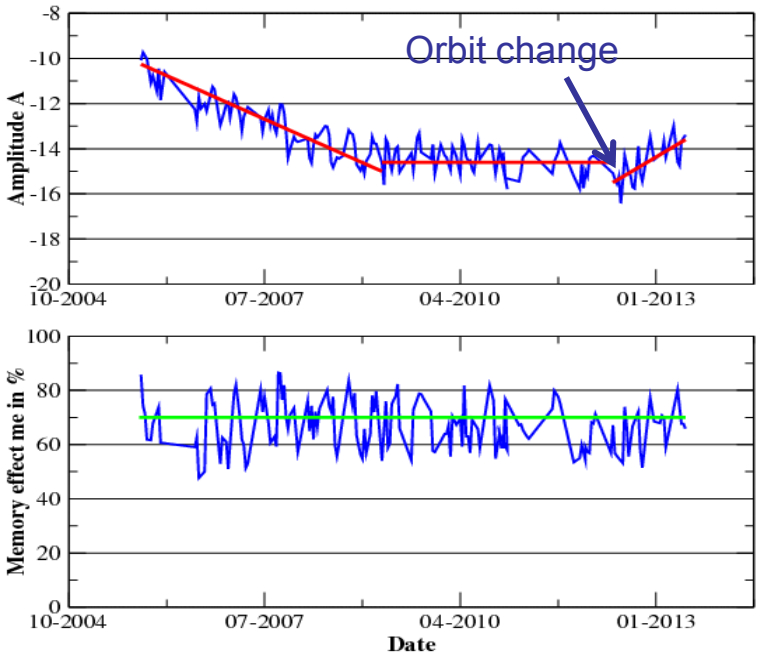
linear regression, a constant and linear regression corresponding to the orbit change in 2012

-Time constant of the relaxation behaviour τ

fixed to 40 mn

-Memory effect me

we find me=0.7



Using of JASON-1 DORIS data corrected for ITRF2014

•Context

- The model was added to the POD standards for the Jason-1 series of altimeter mission and by others POD groups as GSFC and ESA
- In the frame of new ITRF realization (DORIS data used : 1993-2014) we proposed to include Jason-1 SAA corrected data to the DORIS multi-satellite solution in order to fill the gap in the data for the orbits of inclination 66° during the period from the end of TOPEX (November 2004) to the start of Jason-2 (July 2008)

•Impact on the orbit

We processed Jason-1 DORIS data from November 2004 to July 2008 with and without SAA correction

Orbit Results	DORIS RMS (mm/s)	Data number	Orbit differences RMS3D
with SAA model	0.311	37655	< 5mm
Without SAA model	0.325	36842	

the SAA model leads to decrease significantly the RMS of orbit residuals (5%) and to increase the validated measurements

•Impact on the positioning

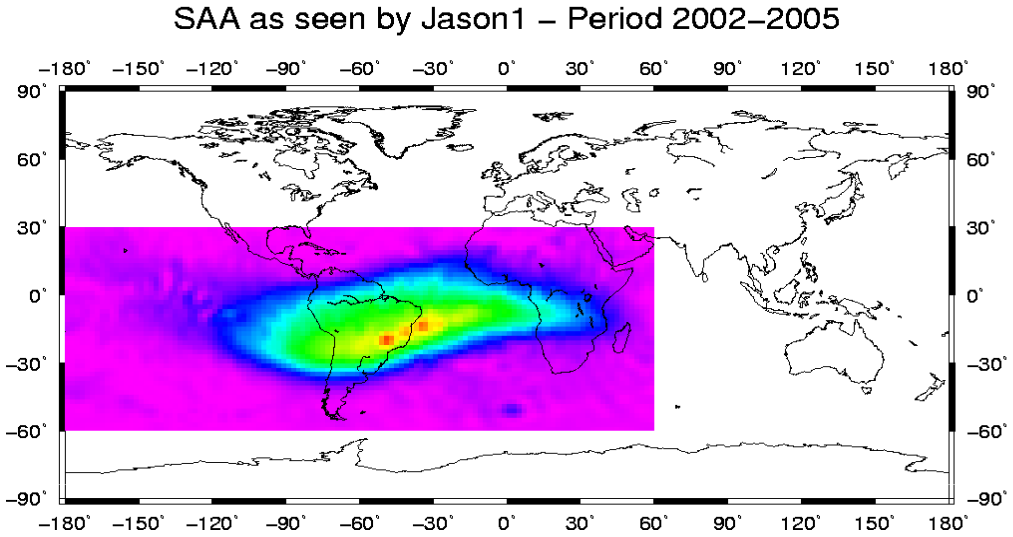
We computed a weekly multi-satellite solution with and without Jason-1 and we compare with CATREF these weekly solutions to the ITRF2008:

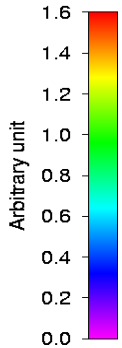
when the Jason-1 satellite is added to the multi-satellite solution

- the stability of the geocenter Z-translation is improved :**STD of 11.5 mm against 16.5 mm**
- the X and Y pole estimates differences relative to IERS C04 series are reduced by nearly 10 percent over the time span from November 2004 to July 2008.

SAA corrective model for Jason-1 by using CARMEN map

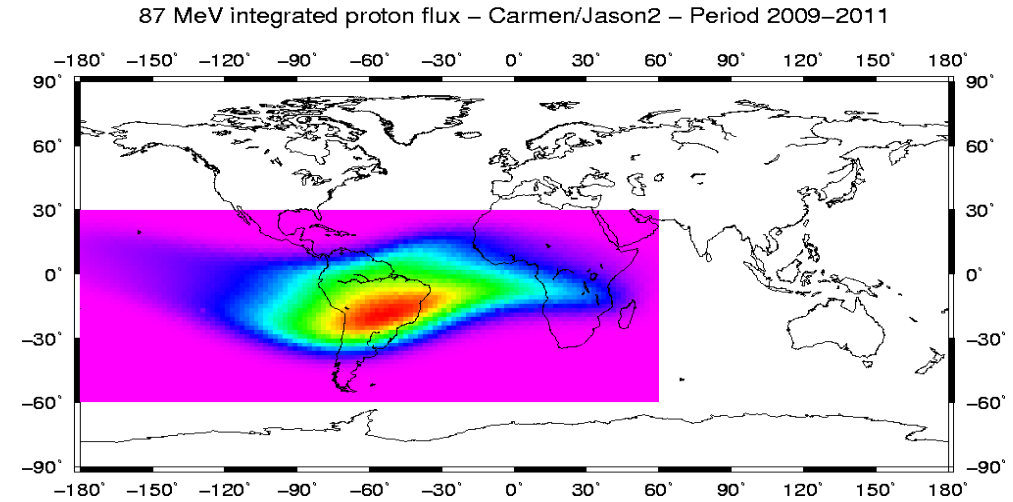
Correlation study of the SAA grid from DORIS data and from CARMEN data

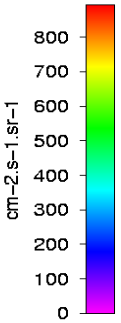




SAA Grid from Jason-1 DORIS data

•1°x1° grid (2002-2005)
(converted in 2°x2° grid for this study)





SAA Grid from Jason-2 CARMEN data

- 5 energy band tested
63, 76, 87, 97 and 138 MeV
- 4 annual grids (2x2°)
from 2009 to 2012
and a mean grid 2009-2011 (2x2°)
for 87 MeV and 138 Mev

SAA corrective model for Jason-1 by using CARMEN map

Correlation study of the SAA grid from DORIS data and from CARMEN data

Method of comparison

- determination of the correlation coefficients between both grids
- looking for the energy band having the best agreement with Jason-1 map
- determination of the coefficients by adjusting in latitude and longitude per 2° grid step
  looking for the max correlation by taking into account geographical offsets
- adjusting by least square to calculate the scale factor k between both grids
  (Carmen) Grid = k x (Jason-1) Grid

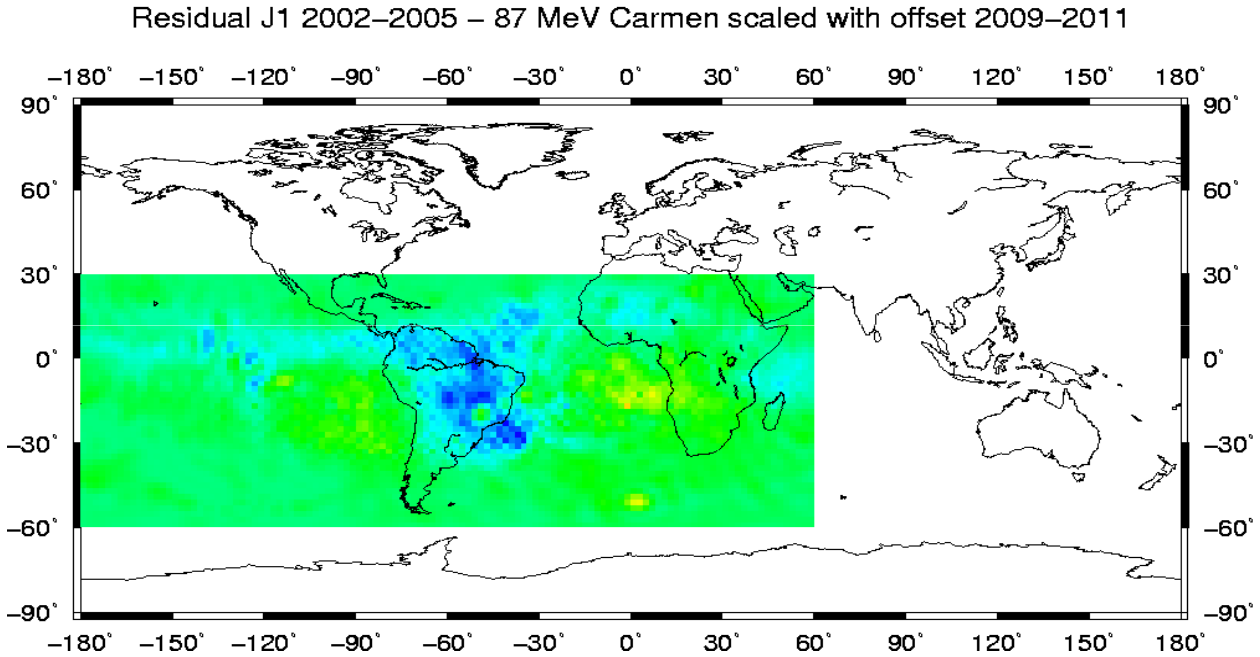
Carmen Grids (MeV)		Jason-1 Grid (2002-2005)			
		Offset latitude	Offset longitude	Correlation coefficient	Scale factor K
Mean 2009-2011	87	0	6	98.58	631.54
	138	-2	8	98.05	385.42
Year 2011	63	0	6	98.35	827.09
	76	0	6	98.45	730.46
	87	0	6	98.56	632.78
	97	-2	4	98.25	566.15
	138	-2	8	98.04	386.96

SAA corrective model for Jason-1 by using CARMEN map

Correlation study of the SAA grid from DORIS data and from CARMEN data

Residual map between Jason-1 map and the mean 87Mev CARMEN map with 6° latitude offset

Residual = (Jason-1) Grid – 1/k (Carmen) Grid



- Residuals are homogeneous on the SAA area
- SAA maximum slightly higher on the Jason-1 grid

SAA dynamical evolution

West: secular variation of the magnetic field ~0.3°/year

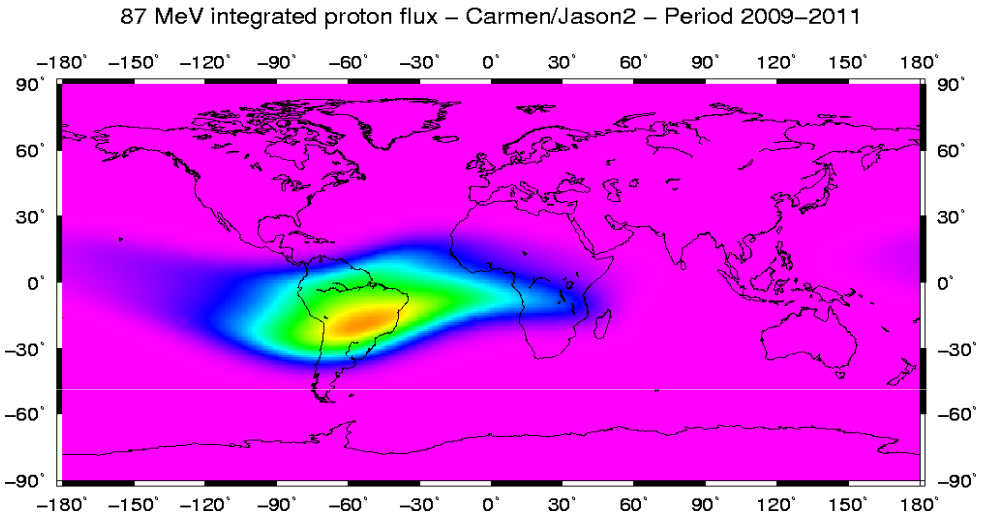
Since 2011 year SAA diminution : beginning of the solar cycle 24

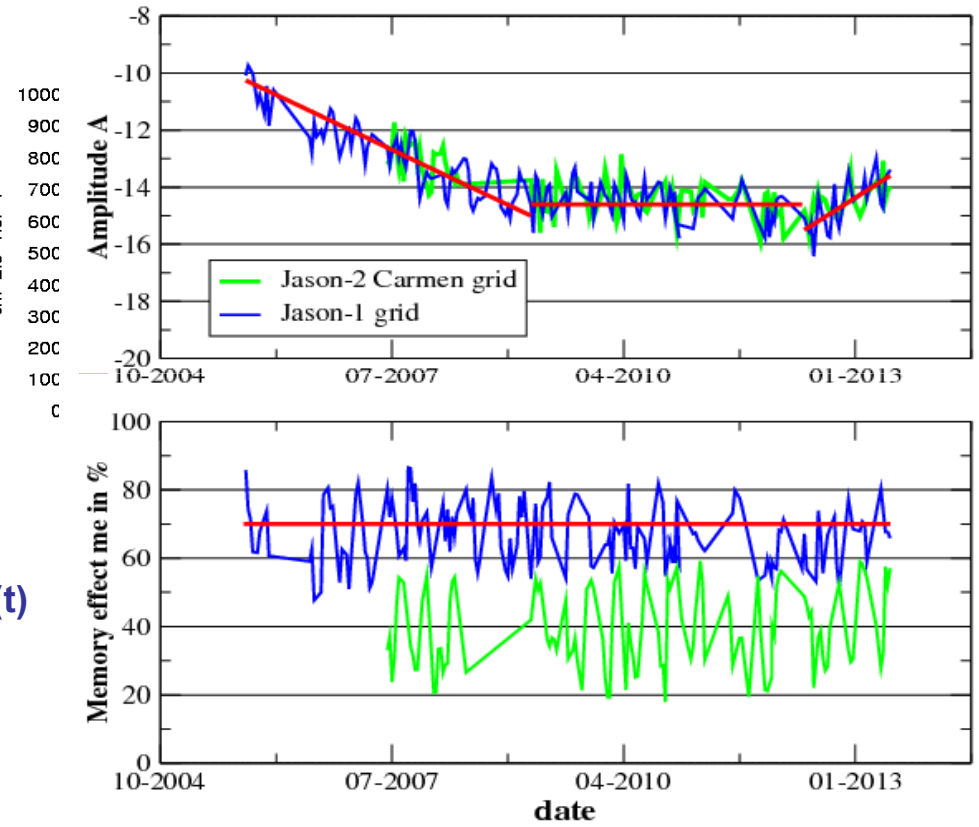
SAA corrective model for Jason-1 by using CARMEN map

Determination of the parameters

-Using the SAA CARMEN Jason-2 map

with scale factor and longitude shift of 6°





- Model parameters

- **Amplitude (Hz/day)= Map_SAA(lat,lon) x Amplitude (t)**
  the amplitude parameter is similar for both grids

- **Time constant of the relaxation behaviour τ**
  with Jason-1 map τ is fixed to 40 mn
  with CARMEN map τ is fixed to 60 mn

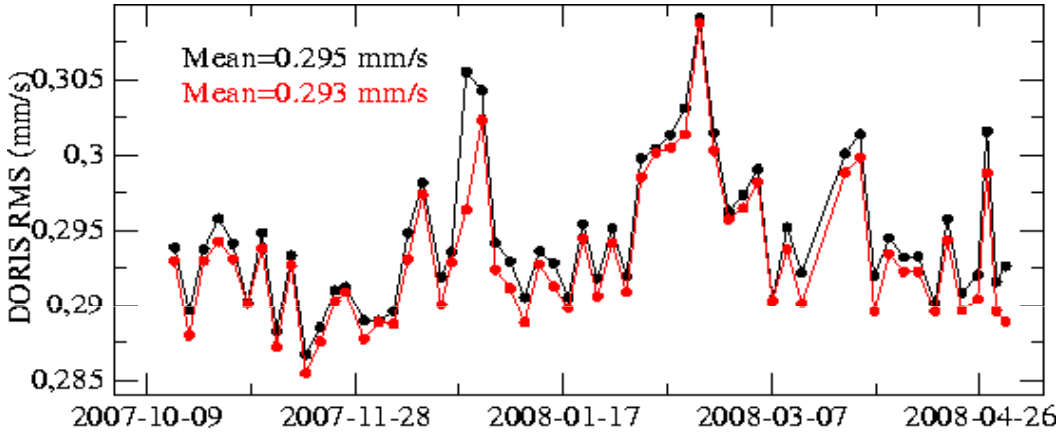
- **Memory effect me**
  with Jason-1 map me=0.7
  with CARMEN map me=0.4

SAA corrective model for Jason-1 by using CARMEN map

•Impact on the orbit:

We have processed 25 weeks (from July 2007 to May 2008) of two sets of Jason-1 DORIS data:
- data has been corrected by applying the SAA model based on the CARMEN map
- data has been corrected by the model based on the Jason-1 map.

DORIS RMS of fit of the orbit determination



With SAA data corrective model :
using Jason-1 map in black
using CARMEN Jason-2 map in red

The orbit residuals are systemically lower with CAMEN map but the differences are small

•Impact on the positioning

We also computed a weekly Jason-1 single satellite solution over the same 25 weeks by using the two DORIS data corrected sets.
We compared with CATREF these weekly solutions to the ITRF2008
- the weighted RMS of fit for stations by component, shows that the WRMS are slightly lower when using the model based on the CARMEN map
-the SAA map determined from DORIS data was very realistic and gave a good estimate of the SAA perceived by Jason-1.

CONCLUSION AND PERSPECTIVE

Using of JASON-1 DORIS data corrected for ITRF2014
when the Jason-1 satellite is added to the multi-satellite solution
- the stability of the geocenter Z-translation is improved :**STD of 11.5 against 16.5 mm**
- the X and Y pole estimates differences relative to IERS C04 series are reduced by nearly 10 percent over the time span from November 2004 to July 2008.

Updating the Jason-1SAA corrective model by using CARMEN maps showed:
- the SAA map determined from DORIS data was very realistic and gave a good estimate of the SAA perceived by Jason-1. We demonstrated that the DORIS derived map is physical, so there is no added benefit in rederiving corrections from the CARMEN data
- even by using the CARMEN map the correction is not complete

We plan to improve the SAA correction by correcting the DORIS data directly from the SAA onboard frequency signal observed (a filtering will be necessary)

We have submitted a paper on SAA models in ASR Special Issue on DORIS:
"Update of the corrective model for Jason-1 DORIS data in relation to the South Atlantic Anomaly and a corrective model for SPOT-5"