Ifremer

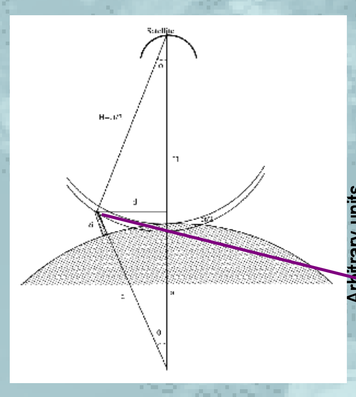
OSTST SAN DIEGO 2011.

Antarctic icebergs Distribution 2002-2011

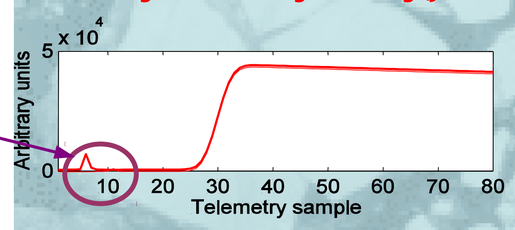
Tournadre J. Ardhuin-Girard Fanny IFREMER, FRANCE, LOS, Plouzané France
Legrèsy Benoît, CNRS, LEGOS,Toulouse, France

Tournadre et al (2008) presented a method of detection of iceberg in HR (20Hz) altimeter waveforms. We present an improvement of the method that allows, assuming a constant iceberg freeboard elevation and constant ice backscatter coefficient, to estimate the iceberg area and the distribution of the volume of ice on a monthly basis. The complete Jason-1 archive (Versionc) covering the 2002-2010 period was processed to produce a small iceberg (length<2km) data base for the southern ocean. It gives a description of the small iceberg distribution at unprecedented time and space resolutions. The icebergs size follows a log-normal distribution with a mean of 630 m. The strong seasonal cycle of icebergs size reflects the melting of icebergs during the austral summer (estimated at 1.5 m/day). The total volume of ice in the southern ocean has a annual mean value of about 400±120 Gt, i.e. ~35% of the volume of large icebergs. It can thus play a significant role in the injection of freshwater in the ocean. The distribution of the ice volume which has strong seasonal cycle presents a very high spatial and temporal variability which is very contrasted in the three ocean basins (South Atlantic, Indian and Pacific oceans). The analysis of the relationship between small and tabular icebergs shows that a majority of small icebergs are directly associated with the tabular ones but that vast regions, such as the eastern branch of the Wedell Gyre, exists where the transport of ice is done only by the smaller ones.

Iceberg detection



EX. signature of single iceberg (Jason WF)

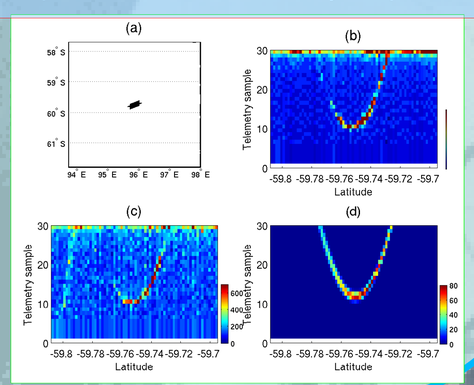


Peak of σ before the mean sea level

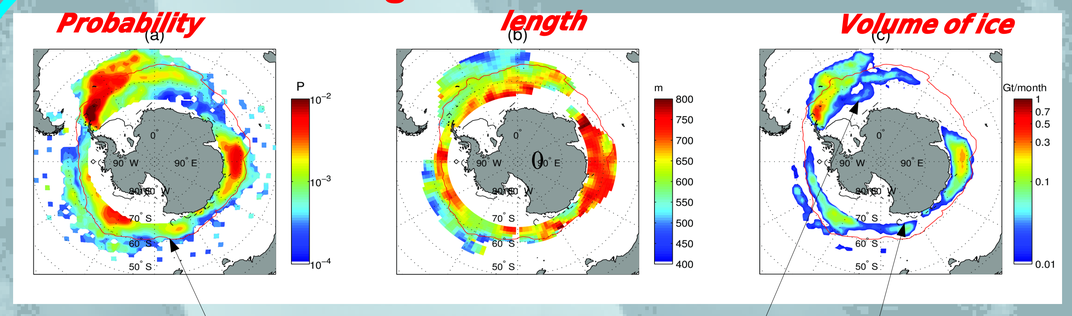
Targets emerging from the sea (iceberg, ships, lighthouse) : detectable signature in the noise part of Altimeter WF [*Tournadre et al , 2008*]. In the waveform space the signature is a parabola determined by the orbital parameters.
Detection algorithm: detection of parabola in the noise part of the WF. Works only in open water.

Exemple of iceberg signature and detection

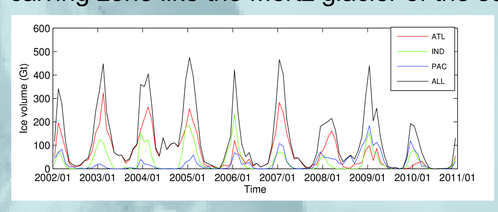
Jason-1 archive processed from Cycle 1 to 310
53000 icebergs detected in the Southern Ocean
Database of location, time of the Echo and backscatter



Iceberg distribution 2002-2010

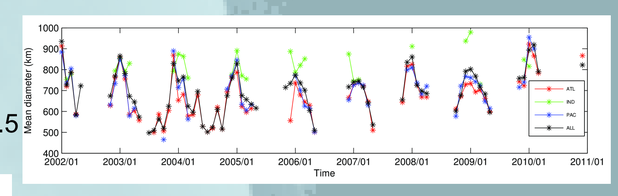


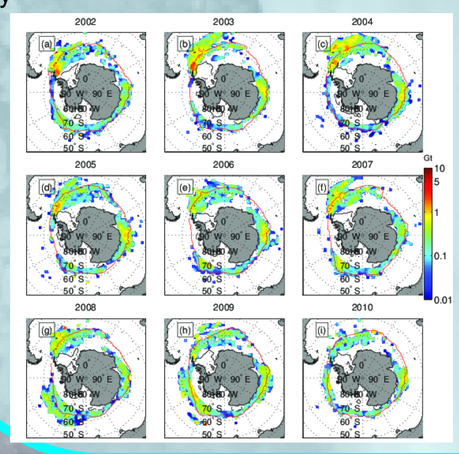
Three probability maxima one in each basin ***SA*** (South Atlantic) ***SI*** (South Indian) and ***SP*** (South Pacific). More than 50% of the ice in the SA. Larger icebergs in the SI. Decrease of icebergs size with latitude reflecting deterioration. In the SA, two main icebergs alleys one corresponding to ACC the other to the eastern branch of the Wedell gyre. A lot of detail of the calving zone like the Mertz glacier of the secondary P maximum near Balleny islands.



Monthly volume of ice from 2002 to 2010.
Large seasonal cycle and large inter-annual variability. Large differences between the three basins. Mean maximum volume of about 400 Gt +/- 120 Gt, about 35% of the volume of large icebergs (1089+-300Gt) *(Silva et al 2006)*

Time variability of icebergs size in the 3 basins
Maximal in austral summer then decay as icebergs deteriorate. Melting estimated to 1.5 m/day



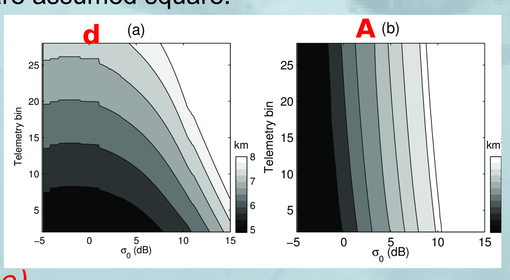


Mean annual volume of ice from 2002 to 2010.
Shows the extreme variability of the distribution of small icebergs in the southern ocean.
Part of this variability results from the presence of large tabular icebergs like in 2008-2009 in the SP.
In the SA the northernmost limit of iceberg extent much further north than the maximum sea ice extent (red line from AMSR).
2010 characterizes by an extremely low number of icebergs.

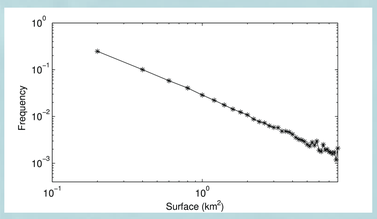
Estimation of icebergs area

For climatology, ocean circulation modeling, impact on biology, the *volume of ice is the key parameter*. The method is improved to include an estimate of the iceberg surface.
Detection gives 2 parameters (range (t_{ech}) and backscatter σ_{ice}) depending on distance from nadir (*d*), iceberg area (*A*), iceberg freeboard elevation (*h*) and iceberg surface backscatter (σ_1). Two parameters, 4 unknowns, hypotheses necessary.
Freeboard fixed to 28 m, i.e. thickness of 250 m (Gladstone et al 2001)
Surface backscatter of icebergs 19 dB (Tran et al 2008 Legresy et al 2005).
Analytical model of WF used to compute the signature of icebergs as a function of distance from nadir (0 to 12 km), and area (0.01 to 9 km²), icebergs are assumed square.

Time of the echo $t_{ech}=f(d,A)$
Iceberg backscatter $\sigma_{iceb}=g(d,A)$
estimated from the modeled waveforms.
Inverse model $d=m(t_{ech},\sigma_{iceb})\quad A=l(t_{ech},\sigma_{iceb})$
Model shows that backscatter saturates around 15 dB for icebergs larger than 8km².
Value close to observed mean max backscatter.



Rescaled histogram of iceberg area (log scale)



Lognormal distribution with mean area of 0.73km², mean length of 630 m. Same order as values from *Romanov et al 2011*

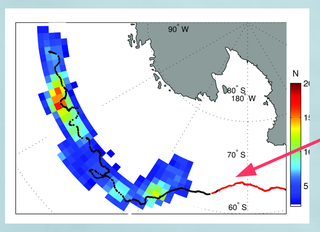
Estimation of the volume of ice

From iceberg database: estimation on regular polar stereographic grid of Probability **P** of presence of iceberg, mean surface **A**, **N** of valid sample.
Volume ***V***: Probability of presence x mean surface x Thickness (250m)x surface of the grid cell (**Δx**Δ**y**) divided by the area o the altimeter swath within the cell ($\mathbf{A}_{SW}$)

$$V(i,j,t)=\frac{A(i,j,t)P(i,j,t)N(i,j,t)H_T\Delta x\Delta y}{A_{SW}N(i,j,t)}=P(i,j,t)A(i,j,t)H_T\frac{\Delta x\Delta y}{A_{SW}}$$

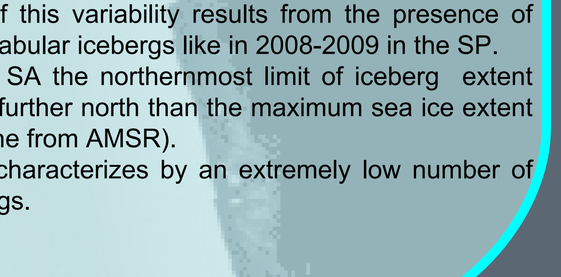
Relation with giant tabular icebergs

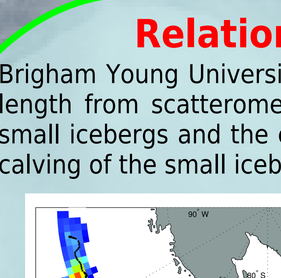
Brigham Young University Antarctic iceberg data:tracks of icebergs larger than 5-6 km length from scatterometer data. Used to compute the minimum distance between a small icebergs and the closest contemporary large iceberg. Proxy for the probability of calving of the small iceberg from a large one.



Number of small icebergs detected along the trajectory of the C19a tabular iceberg from Brigham Young University Antarctic iceberg data base in 2008-2009. The red line indicates the C19a trajectory in sea ice and the black line in open water.
The number of small icebergs calved from C19a varies from 2-3 /10days to 20/10days.

Ratio of small detected icebergs closer than 200 km to a large one and mean distance .
Two regimes:
1: ex Scotia Sea, along the Antarctic coast in the SI ocean, and in the SP around 60°S: proximity between small and large icebergs, in these areas the small icebergs either calved from the large ones or in the same regions of Antarctica, then drift along similar paths either calved from the large ones or in the same regions of Antarctica, then drift along similar paths
2- no direct relationship between the small and large. mean distance >800 km. Transport of ice due solely to small icebergs drifting over very long distances.





Estimation of mean fresh water flux in the southern ocean from small icebergs
The difference between the maximum and minimum of the volume of ice observed during one year used as a proxy to the available fresh water. Similar patterns as the one obtained from numerical model, but higher values especially in the Eastern branch of the Wedell Gyre.

CONCLUSION & PERSPECTIVE

Detection of small icebergs over 9 years, Estimation of icebergs area and of the volume of ice in the Southern Ocean. Unprecedented description of the time and space variability of icerbergs distribution. Small icebergs act as a diffusive process of ice from large tabular icebergs. They carry about 35% of the total volume of ice from icebergs. Estimation of fresh water flux from icebergs.
Extension to Topex/Poseidon, Jason2 Envisat archive in the near future