# CryoSat-2: A new perspective on Antarctica

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**\*** Antarctic ice sheet mass imbalance

**Amundsen Sea sector** 

**\* Antarctic Peninsula** 

#### **Primary Mission Goals**

- Determination of regional and basin-scale trends in perennial Arctic sea ice thickness and mass
- Determination of regional and total contributions to global sealevel of the Antarctic and Greenland ice sheets

#### **Secondary Mission Goals**

- Observation of seasonal cycle and variability of Arctic and Antarctic sea ice mass and thickness
- Observation of variation in thickness of the world's ice caps and glaciers



#### **Global Sampling**

- 92 degree orbit inclination to survey Arctic Sea Ice and Antarctic and Greenland ice sheets
- 369 day repeat with 30 day sub cycle provides dense across track sampling and captures temporal change

#### **Fine Resolution**

- SAR mode improves along track resolution, designed to pick out leads
- SARIn mode improves across track resolution, designed for rugged terrain





- Launched April 8 2010
- 4+ years of continuous operation
- Novel technology: first SAR and SARIN altimeter in Earth space
- Platform and Payload fully compliant to system requirements
- SIRAL exceeding technical performance
- Housekeeping unit failure Sept 2013, switched to redundant power
- Ground segment evolving to accommodate new products and demand
- High data availability (98%)
- Mission extended to Feb 2013





- Level 2 elevation
   evaluated wrt ICESat &
   GPS
- 83 cm bias in East Antarctica
- 40 cm bias at Salar de Uyuni (Borsa et al.)
- Difference attributed to ku-band penetration



80

- Level 3 elevation rates evaluated wrt IceBridge
- 21 cm/yr bias in West Antarctica
- $\sigma_{CS2} = 16 \text{ cm/yr}$
- $\sigma_{OIB} = 17 \text{ cm/yr}$
- $\sigma_{ACC} = 38 \text{ cm/yr}$
- Difference explained by commission & omission errors





**Table 1.** The Area, Mean Accumulation Rate, Estimated Snowfall Variability, Average Elevation Rate, and Estimated Mass Imbalance of Antarctic Drainage Basins (Numbered 1–27) and of Regions of Ice Dynamical Imbalance (IDI) (see Figure 1) from 2010 to 2013<sup>a</sup>

	Observed Area <sup>b</sup>	Mean lce Accumulation Rate <sup>c</sup>	Snowfall Variability <sup>d</sup>	Mean Elevation Rate	Mass Imbalance
Basin	(km <sup>2</sup> )	(cm/yr)	(cm/yr)	(cm/yr)	(Gt/yr)
East Antarctica	9,499,900	11.6	1.0	$\textbf{0.1}\pm\textbf{0.2}$	$-3\pm36$
West Antarctica	1,705,175	26.0	4.4	$-$ 9.8 $\pm$ 0.3	$-134 \pm 27$
Antarctic Peninsula	167,325	67.6	32.4	$-25.6\pm2.5$	$-$ 23 $\pm$ 18
Antarctica	11,372,400	14.8	1.2	$-1.9\pm0.2$	$-\textbf{159} \pm \textbf{48}$

<sup>a</sup>Few regions exhibit elevation fluctuations that are large in comparison to expected snowfall variability over the 3 year survey. The boldface signifies subtotal (East Antarctica, West Antarctica, and Antarctic Peninsula) and total (Antarctica) values. <sup>b</sup>Derived from the map of *Zwally et al.* [2012].

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<sup>c</sup>Derived from *Vaughan et al.* [1999] and assuming an ice density of 917 kg m<sup>-3</sup>.

<sup>d</sup>Following the method of *Wingham et al.* [1998] and assuming a snow density of  $350 \text{ kg m}^{-3}$ .



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Basin	Observed Area <sup>b</sup> (km <sup>2</sup> )	Mean Ice Accumulation Rate <sup>c</sup> (cm/yr)	Snowfall Variability <sup>d</sup> (cm/yr)	Mean Elevation Rate (cm/yr)	Mass Imbalance (Gt/yr)
Totten IDI	20,225	69.7	36.6	-52.2 ± 1.2	$-10 \pm 3$
Kamb IDI	51,150	12.9	6.7	$46.2 \pm 0.4$	22 ± 1
Getz IDI	33,200	37.5	19.4	$-70.4 \pm 1.1$	$-22 \pm 3$
Thwaites IDI	91,850	44.5	22.8	-37.5 ± 0.5	$-32 \pm 8$
PSK IDI	20,950	37.9	19.6	$-117.5 \pm 1.3$	-25±2
Pine Island IDI	96,800	47.7	24.5	$-59.4 \pm 0.4$	$-53 \pm 9$
Ferrigno IDI	5,950	74.4	38.2	$-123.7 \pm 2.7$	-7±1

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### **\*** Amundsen Sea sector



- Antarctic Peninsula least well surveyed region by all 3 geodetic techniques
- >1000 basins
- Complex terrain
- Gaps in data
- Variability in glacier
   behaviour an obstacle to interpolation and extrapolation



- CS2 provides 60 % coverage
- Perform guided interpolation to fill areas of omission
- Leads to estimated volume rate of -55 km<sup>3</sup> yr<sup>-1</sup> (2010-2014)





Rate of loss has increased from 20 km3/yr in 2002 to 50 km3/yr today



Elevation rate (m/yr)

+1

-1



- Standard CS2 level 2 product is from point of closest approach (POCA)
- Over sloping terrain

   (>0.5deg, typical of ice sheet margins), SARIn
   echoes map a swath
   across the ground track
- Swath width up to 10km
- 75-fold increase in volume of elevation data
- <1m accuracy compared to airborne data





• CS2 swath elevation density vastly superior to POCA



• CS2 swath domain sampling vastly superior to POCA



• CS2 swath dh/dt misfit comparable to POCA

![](_page_24_Figure_2.jpeg)

## \* Swath altimetry CS2 POCA 5 km grid

![](_page_25_Figure_1.jpeg)

-3

#### CS2 swath 1 km grid

![](_page_25_Figure_3.jpeg)

![](_page_26_Picture_0.jpeg)

- First assessment of entire (>96%) Antarctic ice sheet
- Fivefold improvement in sampling of ice sheet margins
- Certainty comparable to 19-years of conventional altimetry
- Shows conventional altimetry prone to omission bias in some sectors
- Mass loss from Antarctica has increased over time
- CS2 land ice mission objectives accomplished
- 500m DEM's & 1km dh/dt are both in sight

![](_page_27_Figure_0.jpeg)