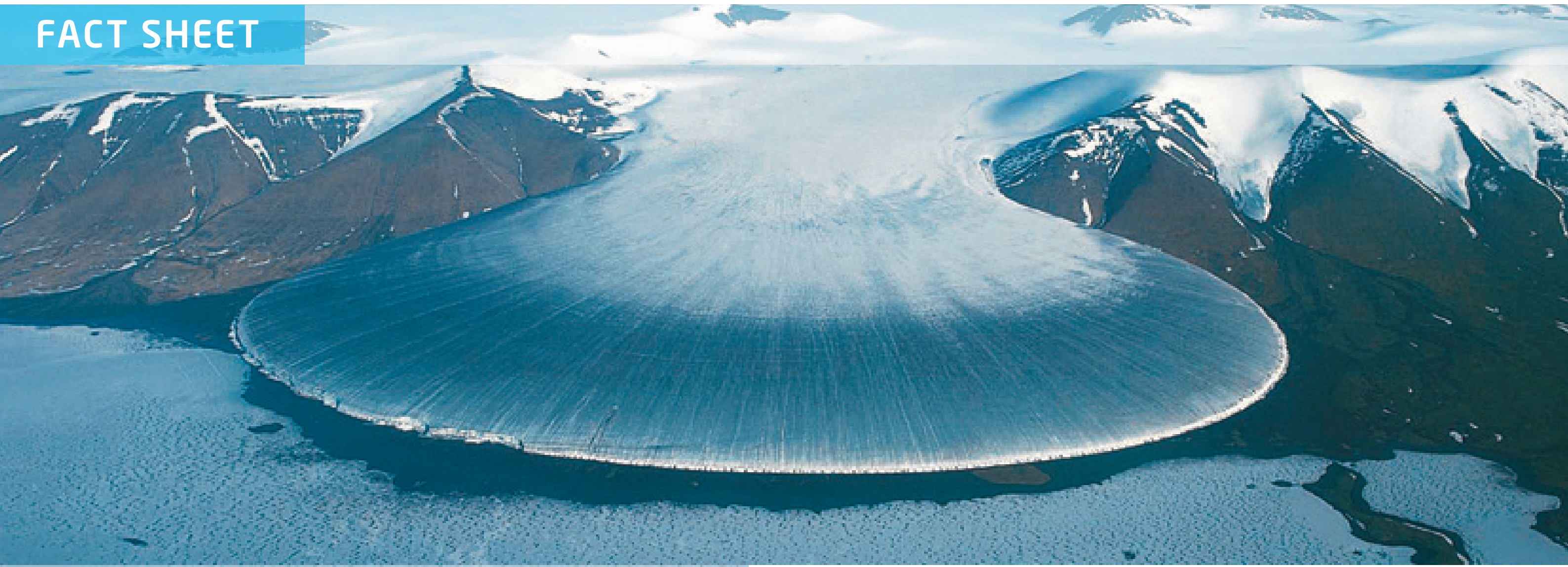
FACT SHEET



OUR CURRENT KNOWLEDGE OF:

Ice sheets

What is the current status of research?

Changes in the mass of polar ice sheets are of considerable significance for society since they influence the sea level and conditions in the ocean. They are a consequence of the internal dynamics of ice and a response of the "ice sheet" system to extreme changes, such as those in the ocean and atmosphere.

It has now been verified that ice sheets and glaciers are losing mass worldwide. This trend towards loss of mass is clear and shows that the ice masses were responsible for more than half of the annual rise in sea level in the period from 2005 to 2010 (see Table 1). Expressed in numbers, the share of the global rise in sea level accounted for by the Greenland and Antarctic ice sheets was approximately 1 millimetre a year. By means of three different, independent methods, investigations are looking at how much the ice sheets contribute to the sea level: they all result in the same picture.

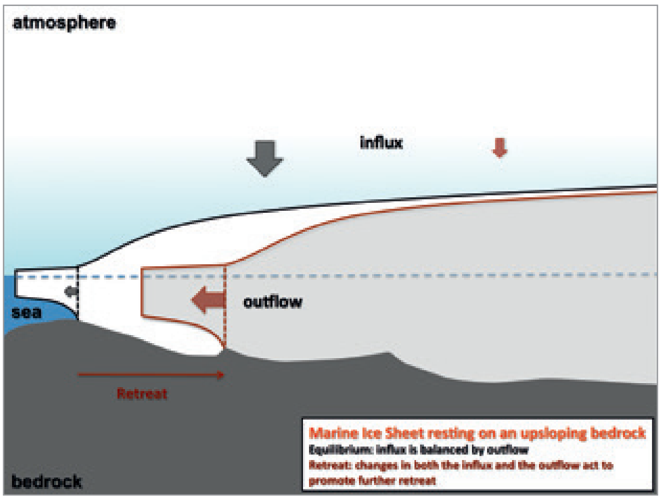
It is also a fact that glaciers in the marginal regions of Greenland and the Antarctic have significantly increased their flow speed. One example: The mean annual speed of the Jakobshavn Isbrae on the west coast of Greenland yields a 1992 to 2012 speedup of 286 percent. In the year 2012 he reached a speed of more than 17 kilometres a year. For this reason

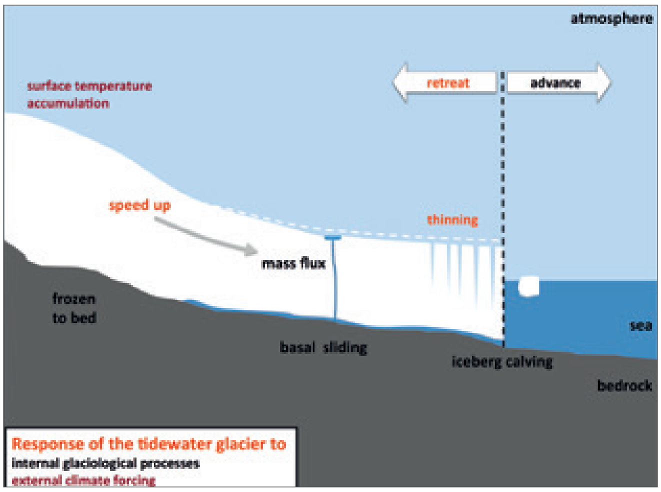
	1992-2000 Gt/a	2000-2011 Gt/a	2005-2010 Gt/a	2005-2009 mm/a SLE
Greenland	-51 ± 65	**-211 ± 37**	**-263 ± 30**	**+0.73 ± 0.08**
Antarctic	-48 ± 65	**-87 ± 43**	**-81 ± 37**	**+0.23 ± 0.10**
Antarctic Peninsula	-8 ± 17	**-29 ± 12**	**-36 ± 10**	**+0.10 ± 0.03**
West Antarctic	**-38 ± 32**	**-85 ± 22**	**-102 ± 18**	**+0.28 ± 0.05**
East Antarctic	-2 ± 54	26 ± 36	**58 ± 31**	**-0.16 ± 0.09**
Greenland + Antarctic	-100 ± 92	-298 ± 58	**-344 ± 48**	**0.96 ± 0.13**
Glaciers & Ice sheerts				**0.83 ± 0.37** (2005-2009)

Table 1: Overview of the losses in mass of the ice sheets in Greenland and the Antarctic. All data are in gigatons per year and relate to the periods indicated in the table header in each case. (Table: A. Humbert, AWI, Data basis: Shepherd et al., 2012 und Oerlemans, pers. comm., IPCC 2013)

glaciers like it transport more ice to the bordering ocean and thus increasingly contribute to the rise in sea level. Aside from the acceleration, however, changes in snow accumulation also have to be taken into account in the question as to loss of mass. In Greenland, for instance, the loss of mass on the surface of the ice sheets is extremely pronounced due to increased melt water discharge.

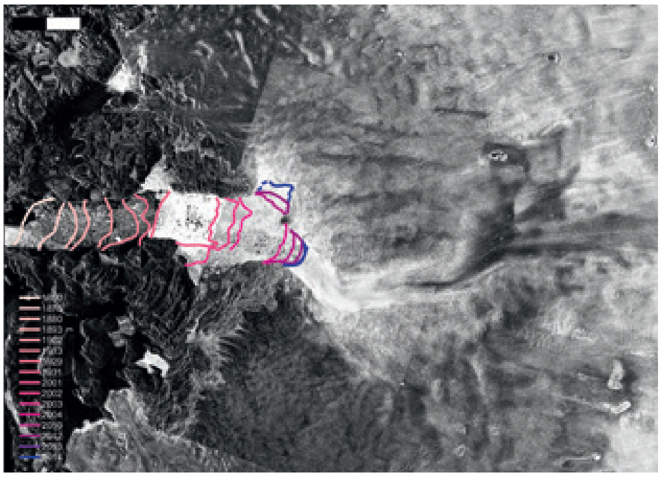
Substantial changes in the ice sheets are driven by interactions with ocean water on the bottom of freely floating ice masses, ice shelves. Higher melt rates caused by changes in the ocean dynamics may



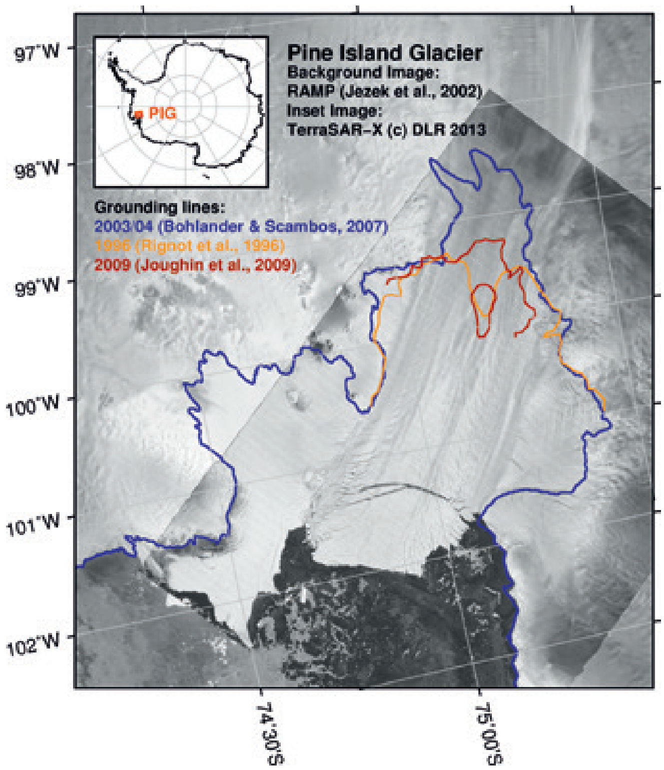


These two infographics show the current changes in the ice sheets in Greenland and the Antarctic. Large outlet glaciers that flow directly into the sea and at the front of which icebergs calve are called tidewater glaciers. It is presumed that they display cyclic flow characteristics which can be attributed to internal processes of ice dynamics and are not or only weakly coupled to the climate on short time scales.
On longer time scales, however, the future of glaciers is always influenced by the climate. That is why it is important to distinguish between changes in ice dynamics and climate-related changes so as to be able make statements regarding the stability of these glaciers and their contribution to the mass balance and thus to the sea level. The dynamics of these glaciers are still understood only to a small degree. Major processes, like basal sliding and the related hydrology as well as the processes that cause the calving of icebergs, are therefore the subject of current scientific work. (Infographics: AWI)

thin out the ice shelves. As a consequence, their restraining force on the glaciers that feed them declines, as a result of which the glaciers accelerate and transport more ice to the ocean. It has been possible to verify the flow of warm water masses under the ice shelves, particularly in the regions of Greenland and Antarctica in which glaciers accelerate in speed. Likewise, a thinning out of the ice shelves has been observed at places where warm water masses meet the continental shelf.



This TerraSAR-X satellite image displays how far the calving line of the Jakobshavn Isbrae glacier on the west coast of Greenland has retreated between the years 1875 and 2015. On its edge this glacier flows through a narrow valley towards the sea. That's why it is called outlet glacier. (Image: DLR/AWI)



These TerraSAR-X satellite images of the Pine Island Glacier in the West Antarctic displays the positions (marked in colour) of the glacier's grounding line. The grounding line is the transition from land ice to the floating ice shelf. At the moment the Pine Island Glacier displays very high thinning rates that have an impact far into the land ice. One example: in the period from 2003 to 2007 thinning rates of up to 6 metres/year were measured at its grounding line. (Figure: DLR/RAMP/AWI)

In the West Antarctic the loss of mass takes place in the Amundsen Sea and along the Antarctic Peninsula. After the glaciers on the Antarctic Peninsula were seemed to be extensively in equilibrium during the

1990s, they are now accelerating due to the breakup of individual ice shelves and the retreat of calving fronts. Glaciers are therefore losing a significant amount of mass. Although the area of the glaciers on the Antarctic Peninsula only makes up a small portion of the Antarctic continent (around 4 percent), they currently contribute about 25 percent to the total loss of mass in the Antarctic.

The majority of the loss of mass in the Antarctic is caused by a few glaciers in the Amundsen Sea that are accelerating rapidly (for example, the Pine Island Glacier, see figure on left). Slight increases in mass in the eastern Antarctic are due in part to unusually heavy precipitation (e.g. Dronning Maud Land).

What don't we know yet?

In many places we currently lack key parameters to be able to understand the dynamics of the present-day system and assess future changes. An example of this is the melt rates on the bottom of the ice shelves and floating tongues of Greenland's outlet glaciers (when ice sheets flow on their edge through narrow valleys towards the sea, these glaciers are called outlet glaciers).

One of the great unknowns in the question regarding the contribution of ice sheets to the future sea level is the stability of marine ice sheets and related to that the retreat rate of the grounding line. This is the line at which the land ice lying on the ground turns into a floating ice shelf. In some regions large sections of the bedrock are below the sea level (marine) and slope off towards the land ice. We know that these prerequisites hold the potential for a situation in which ice sheets may become unstable. For individual systems, such as the West Antarctic Ice Sheet, however, we cannot say whether they are currently stable or whether the present changes lead to unstable conditions.

The processes right at the grounding line are of great importance for the dynamics of marine ice sheets and their contribution to the sea level. In addition to observation of these developments, therefore, it is very important for our numerical models to map the processes on the grounding line and their temporal behaviour as precisely as possible. Current studies show, on the one hand, that a model resolution on a magnitude of around 1 kilometre and less is required for this purpose. On the other hand, it is evident that models based on approximation solutions of momentum balance do not adequately map the physics on these scales.

The calving line of the Filchner-Ronne ice shelf in the Weddell Sea, Antarctic (Photo: R. Timmermann, AWI)

The models that have been used thus far to determine the future mass balance of the ice sheets are based for the most part on such approximation solutions. They employed coarse grids and have not been able to verify correct treatment of the grounding zone. It is therefore important to significantly improve these and other models so we can forecast the extent of the rise in sea level more precisely in future.

Another challenge is that simulations of the physical processes involved (<1 km) also require knowledge of the topography of the bedrock on which the ice sheets are situated – and at an appropriately high resolution as far as possible. Today, however, this information is only available to us from a few regions in the Antarctic. Moreover, it is extensively unknown where the ice lies on rock and where on sediment. The volume of melt water and its spatial distribution additionally depend on the thermal state of the ice at its base. These basal properties determine how the ice slides over the ground. Along with calving, sliding is thus one of the major unsolved problems in ice sheet and glacier research.

Calving of icebergs plays an essential role in connection with ice shelves in the Antarctic and the dynamics of Greenland outlet glaciers. It has become evident in recent years that a combination of two processes takes place here: (1) Water from the lakes that form on the surface of the ice sheet seeps through the ice via melt channels, reaches the bottom of the ice and runs from there to the grounding line of these glaciers. (2) After getting there, the melt water rises and leads to a melting process on the bottom of the floating ice – a process that in turn influences calving.

What do we have to do in order to map these processes in models? We ice modellers are faced by the immense challenge of finding ways to map the formation of melt channels and the subsequent melting processes in our models within the next decade. At the same time we need a calving law that incorporates this process. On-ly in this way we will be able to map the acceleration of glaciers in models and thus make forecasts that are reliable and accurate.

By means of what methods do we want to fill the gaps?

We need two different approaches: one is to observe processes and elements of the system (e.g. subglacial melt channels) on a scale that is not feasible for us today. We will be able to refine the present methods in terms of their spatial resolution only to a limited degree. This means new approaches are necessary here. At the same time we will employ state-of-the-art research equipment and measuring instruments in extensive measuring programmes so as to determine, for example, the ice thickness and thus the bedrock geometry, too, in greater detail.

It is equally important to create a basis that, by means of observation of various glaciological parameters, enables us to understand the present-day dynamics of the ice sheets and utilise them as a reference for assessment of future changes. To do so, we have to define key regions in which we monitor representative outlet glaciers, ice flows and ice shelves so as to identify changes at an early stage.

The second method involves a new approach of numerical modelling. Numerical models of varying complexity can be applied at different spatial resolutions so as to quantify the impacts of the physical processes on the movement of the ice and thus the loss in mass of ice flows and glaciers.

Contact the AWI expert

Professor Angelika Humbert
Phone: +49 (0) 471 4831-1834
E-mail: Angelika.Humbert@awi.de

Imprint: Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Am Handelshafen 12, 27570 Bremerhaven, Germany
Publisher: Karin Lochte (Director)

Editors: Sina Löschke, Kristina Bär (E-mail: medien@awi.de)
Cover photo: Hans Oerter, AWI
Expert photos: AWI