Memo

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Onderwerp
Visualizing changes of the Antarctic Ice Sheet

1 Visualizing changes of the Antarctic Ice Sheet

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This memo describes a visualization method created in the context of the program KPP Kustbeheer. The sea-level rise is measured at the Dutch coast. The trend of this rise is periodically reported in the Dutch sea-level monitor (Baart et al., 2018). The trends and other indicators of this report are used for coastal policy. The indicator “current sea-level rise” at the Dutch coast is used to define the limits of the volume of gas extraction below the Wadden and to estimate the volume of nourishments that keep the Dutch coast in line with sea-level rise.

A visualization with a trend line represents the current rate of sea-level rise. This figure is also often used to discuss the current state of how the climate is doing and whether we should be concerned (de Winter, 2019; Speksnijder, 2019). Although the current sea-level rise is a relevant indicator for the Dutch coast, it is not intended to present a message of concern. In this memo, we describe an alternative visualization for presenting a message about the relevant changes for concern that are occurring today and will affect the Dutch coast.

There are several sources of sea-level rise. There are two main sources of potential extreme sea-level rise, the Greenland Ice Sheet (with a mass equivalent of 7m sea-level rise) and the Antarctic Ice sheet (with a mass equivalent of 58m sea-level rise), whereas glaciers can contribute 0.5m (Oppenheimer et al., 2019). Even though the mass loss of the Greenland Ice Sheet is currently the main contributor to global sea-level rise, due to the gravitation effect, the melting of the Antarctic Ice Sheet is our main concern (Slangen et al., 2014). The gravitation effect pulls water towards large ice masses. If these ice masses shrink the pulling reduces and the water moves away. If we zoom into Antarctica and look at the combined figure of the inverse fingerprint and current mass loss (based on the GRACE and GRACE-FO missions), we can see that the current mass loss is not uniform and that the inverse fingerprint (how much mm of sea-level rise do we expect to occur at the Dutch coast, relative to the mm of “sea-level rise equivalent” mass loss) is also varying along the Antarctic coast.

The Amundsen Sea Embankment is currently the area with the highest mass loss. This area, marked as D in Figure 1, is the location of the Smith, Haynes, Thwaites, and Pine Island Glaciers that connect to the ocean side by side. Here we’ll focus on the latter two. These glaciers contribute about 5% of current sea-level rise (Lhermitte et al., 2020; Shepherd et al., 2018). Based on the analysis of sediment cores it is known that the mass loss of the Pine Island Glacier started after an unusual El Niño event in the 1940s (Smith et al., 2017). The Thwaites Glacier is currently the fastest moving glacier in Antarctica. It has varied greatly over the last 70 years. Since the B22 iceberg came loose in 2002, ice loss accelerated

(Stammerjohn et al., 2015). From the perspective of current mass loss, we will focus our visualization on the Thwaites Glacier in the context of the Amundsen Sea Embankment. This is an area that is important to the Dutch coast because it is expected that each cm of sea-level rise equivalent mass loss will also end up at the Dutch coast.

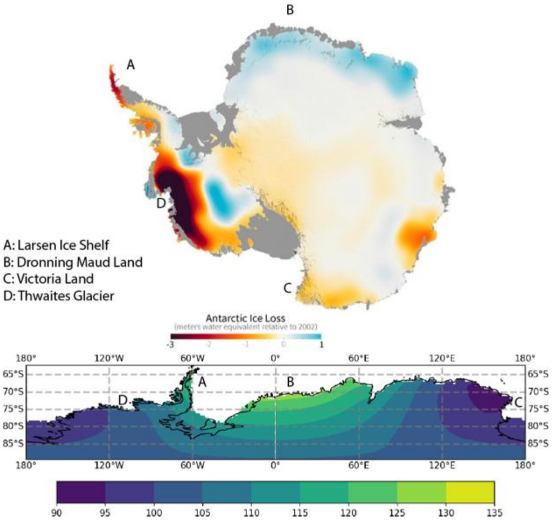


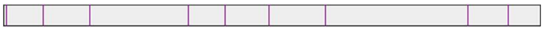
Figure 1: Current (2002-2016) mass loss of Antarctica (top) (src: gracefo.jpl.nasa.gov) and the inverse fingerprint (relative contribution to sea-level rise) for the Dutch coast (src: Dewi le Bar @ KNMI).

Summarizing, here our goal is to find an effective visualization of the changes of the most relevant areas of the Antarctic Ice Sheet for Dutch sea-level rise. Effective in this context is that the visualization is interpreted consistently (different people interpret the visualization in the same way) and gives an accurate qualitative impression of the current state of the relevant area of the ice sheet (whether there is ice mass loss). We defined the Thwaites Glacier as a relevant area because of the significant contribution to the current mass change and affects the sea level at the Dutch coast, taking into account gravitation effects.

2 Methods

There are several datasets available that can be used to visualize the mass changes of the Thwaites Glacier. Due to the remote location and harsh conditions (monthly mean temperatures at the coast vary from -26 degrees to -2 degrees Celsius), the main source of information is through remote sensing.

Remote sensing datasets that are available and commonly used for visualizing changes in Antarctica are listed in the table below. To create a visualization that is comprehensible for a wide audience the optical images are in general the first choice. The main limitation of using optical is that half of the year Antarctica is hidden in darkness. The radar images are available all year and can scan through clouds. Lidar data is collected in profiles, which are useful for estimating height changes, but less so for visualization. The GRACE measurements are good to show mass changes but don't have enough resolution to see details in a regional area. Based on this overview we focus on visualizing with the radar images from Sentinel-1.

Measurement	Mission	Resolution	Revisits 2019
Optical	Landsat 8 & Sentinel 2a, b	~10-30m	
Radar	**Sentinel1**	**~10m**	
Lidar	ICESat-2	~0.7m (along track)	Every 40 days
Gravitational	GRACE FO	~110km	 (ocean product)

To transform the data into a visualization, we define a process of several steps. This process is represented in Figure 2. The raw sentinel measurements are transformed into gridded products. We start our analysis from this gridded product, which contains reflectance images for different polarity combinations. The dataset is filtered for the location of interest.

The Sentinel 1 satellite does not take a picture of the whole earth at the same time. It flies at a height of 693km and takes a swath (a band of images) of 250km wide. This band only covers part of our area of interest. To have a complete image of the area we combine several images into one by aggregating the images over the last running 12 days using a max aggregation. This is similar to keeping a lens open for 12 days, resulting in a long exposure shot.

The advantage of optical images is that the collected spectral measurements can be represented as a true color image, representing the data as an image as it would appear to a human observer. For radar images, where only one band of information is measured no such transformation exists. To be able to make a perceptual intuitive visualization we remap the reflectance to a colormap that corresponds to the perception of the water, ice, snow dimension (Thyng et al., 2016), transforming the reflectance mosaic to a perceptual mosaic.

The region that we want to visualize has an area of approximately 350 by 400 km. Yet we want to zoom into areas in the order of a kilometer. This requires to render high-resolution frames (~340 megapixels). These frames are transformed into a high-resolution video. The edge of the region of interest is blurred using a transparent channel in the video. We split the video into separate videos of 512x512 resolution to make it loadable and zoomable. These video frames are stored in a public cloud bucket using a common TMS/WMTS tiling scheme. The final step is to adapt client-side map rendering software to load video tiles instead of image tiles and to play them in sync. This was implemented as a website using both leaflet and mapbox-gl libraries. For a detailed description of the technical details see (Dimopoulos, 2019).

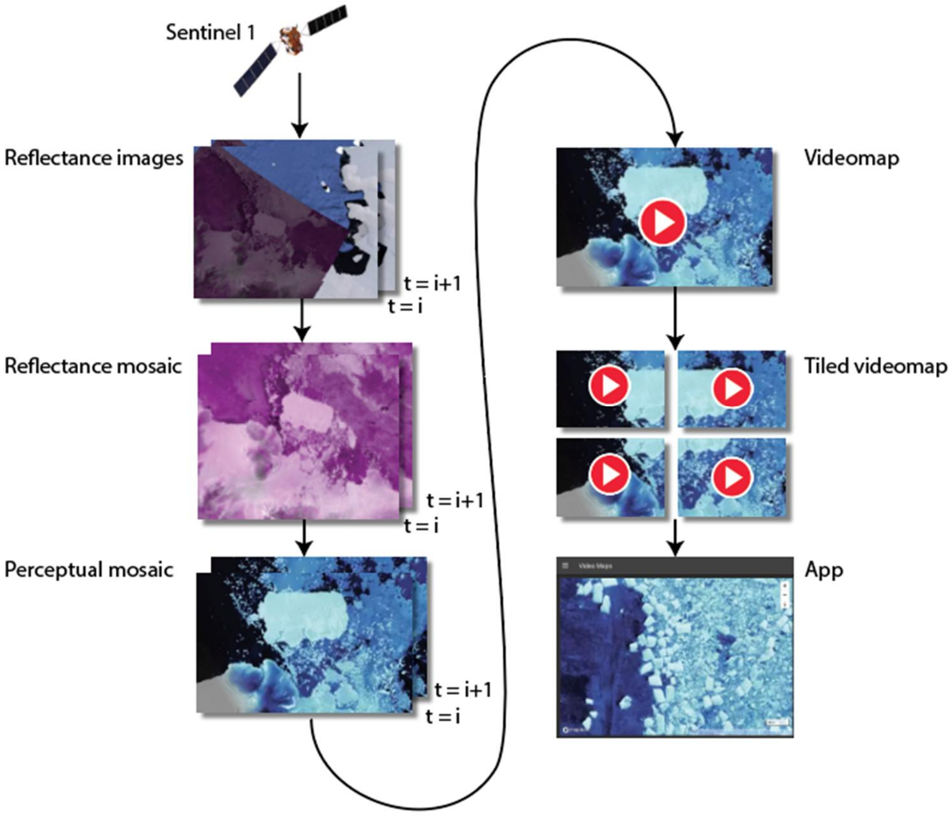


Figure 2: Process from measurements to visualisation

3 Results

The resulting application is available in a public website[1]. This website shows the videomap and three other videomaps. The concept behind this map was presented at the AGU conference (Baart et al., 2019).

Below are four frames to give an impression from the zoomed-out version to zoomed in at the highest resolution . The videomap shows the evolution of the B22A iceberg half stranded. Several events shake up the fractured icebergs and now and then all the sea ice, up to the glacier tongues disappears. The ice tongues drift into the sea and the ice that reaches the sea appears to be pushed together. For a detailed discussion on the processes that occur in the Amundsen Sea Embankment with similar styled videos see (Lhermitte et al., 2020).

Scripts to generate this visualization have been made publicly available[2]. Tools to generate tiled videos are also made available[3]. Also, the source code for the website is made available [4]. This website makes use of an extended version of mapbox-gl[5].

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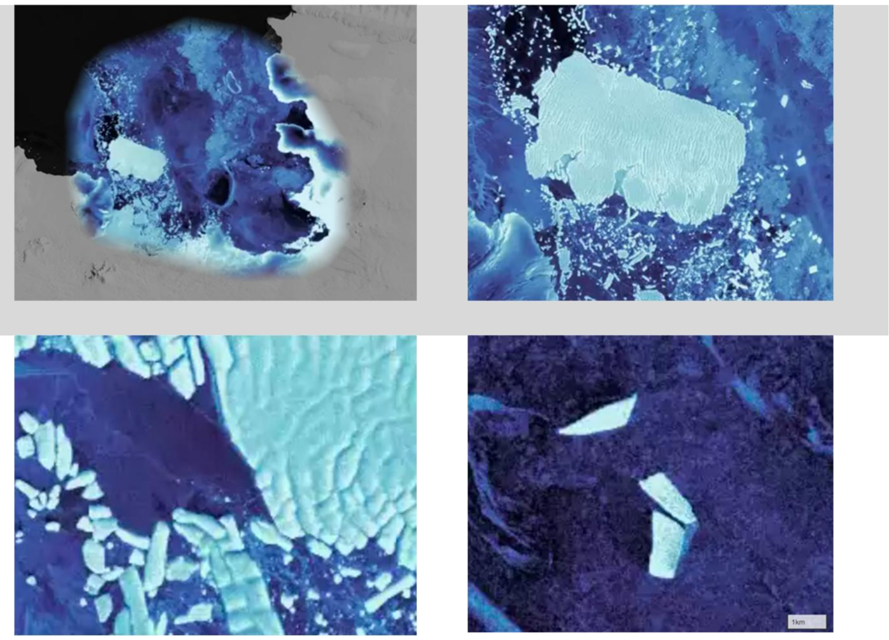
[1] https://videomap.netlify.app/#/map/glacier
[2] https://github.com/gena/ee-code-editor-archive/blob/master/paper-video-tiles/s1-ice
[3] https://github.com/openearth/videomap
[4] https://github.com/openearth/videomap-stories
[5] https://github.com/gena/mapbox-gl-js/tree/tiled-video



4 Discussion and conclusion

Here we present a new method to visualize data using tiled videomaps. These provide a zoomable video of the current (last 5 years) of ice loss at the area that is most relevant for the Netherlands. This results in an easy-to-understand visualization of some of the processes (glacier flow, sea-ice loss, fracturing) that contribute to the current mass loss We hope that this can contribute to ongoing discussions on the current state sea-level rise inducing processes.

The results are not intended to estimate mass loss or to quantify the rate of the changes. For this mass loss changes estimated using GRACE provide a more relevant indicator, see for example (Shepherd et al., 2018).

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