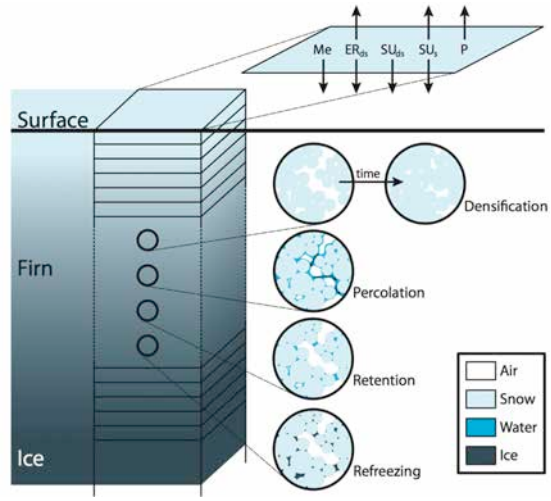
Advanced Training Course on Remote Sensing of the Cryosphere
Leeds (UK), 12-16 September 2016

Challenges of modelling surface mass balance

Michiel van den Broeke
Institute for Marine and Atmospheric Research, Utrecht University (IMAU)

How do we define surface mass balance (SMB)?

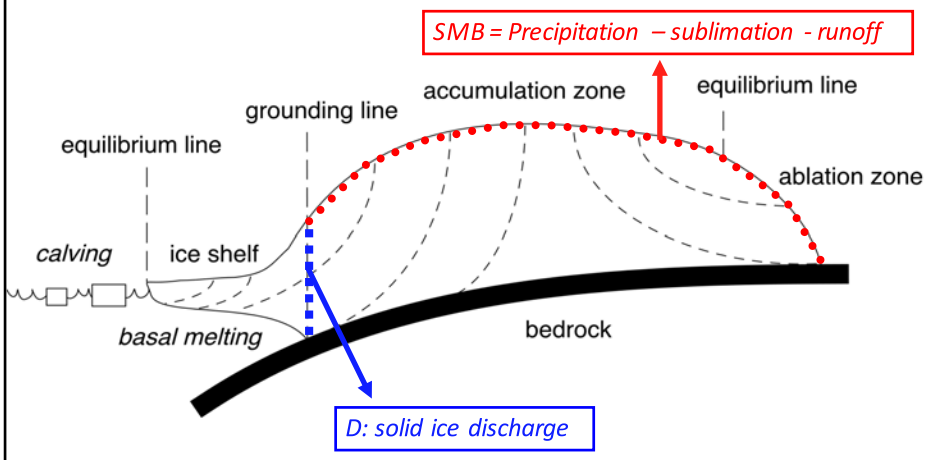


Here: the sum of surface *and* internal mass balance (*climatic mass balance* or *firn mass balance*)

Ligtenberg, PhD thesis, 2014

Mass Balance = Surface Mass Balance – Discharge

MB = dM/dt = SMB – D



SMB is challenging: not one, but three balances!

Ice sheet mass balance (MB)

MB = Surface mass balance – Discharge [Gt yr^{-1}]

Surface mass balance (SMB)

SMB = Precipitation – Sublimation – Runoff - Erosion [Gt yr^{-1}]

Liquid water balance (LWB)

Runoff = Rain + Condensation + Melt – Refreezing – Retention [Gt yr^{-1}]

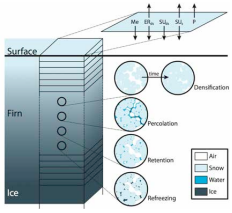
Surface energy balance (SEB)

$M = SW_{net} + LW_{net} + H + L + G_s$ [W m^{-2}]

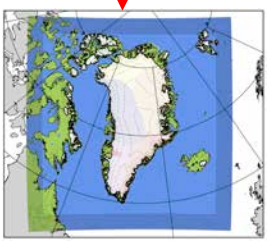
J. Paul Getty Museum

Combine EO, in situ observations and SMB modelling

Firm model

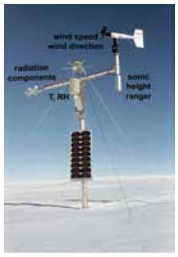


Climate model



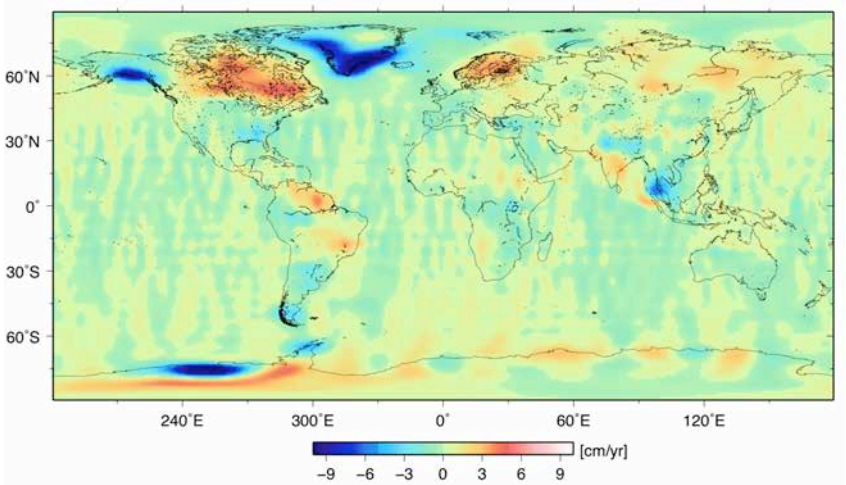
Remote sensing

Evaluation
Calibration
Spatial/temporal extension



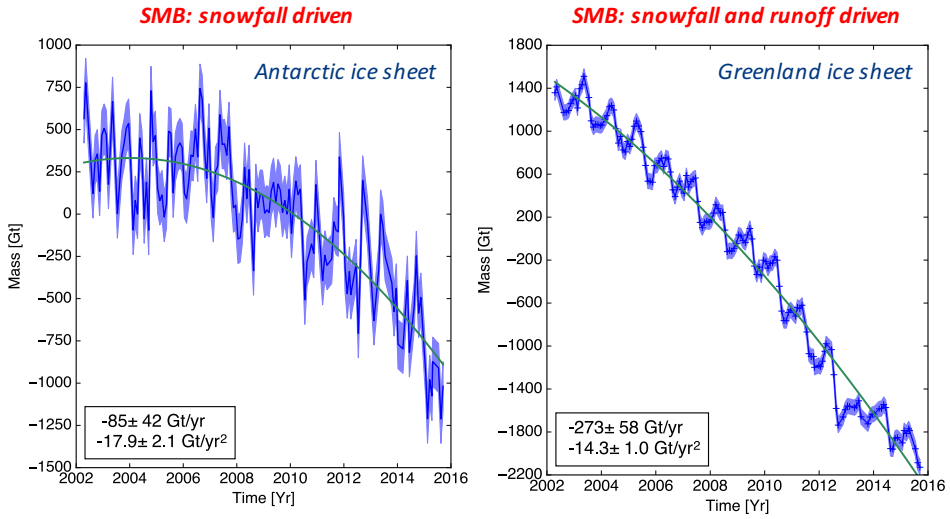
In situ observations

GRACE mass trends (2003-2012)



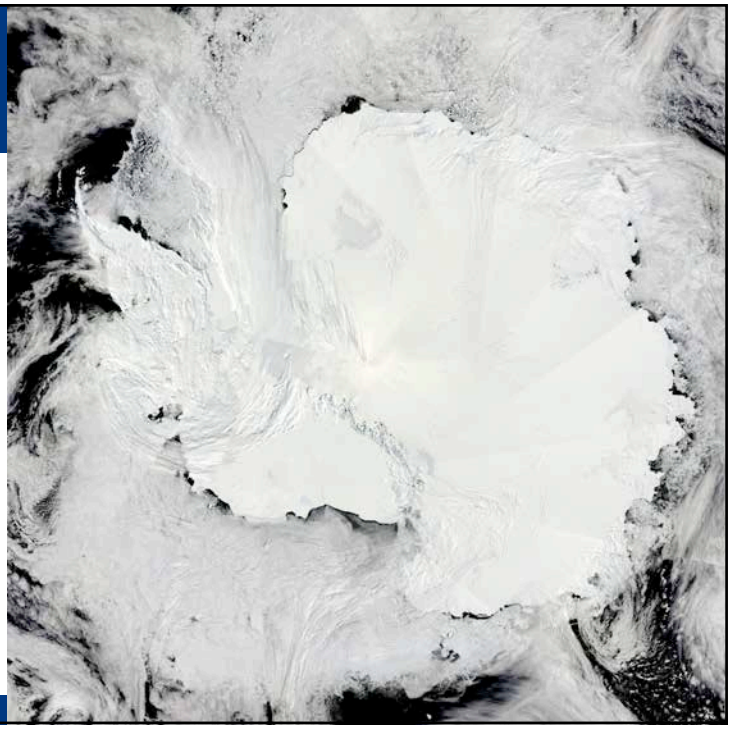
Courtesy: Bert Wouters

13 years of ice sheet mass changes from GRACE



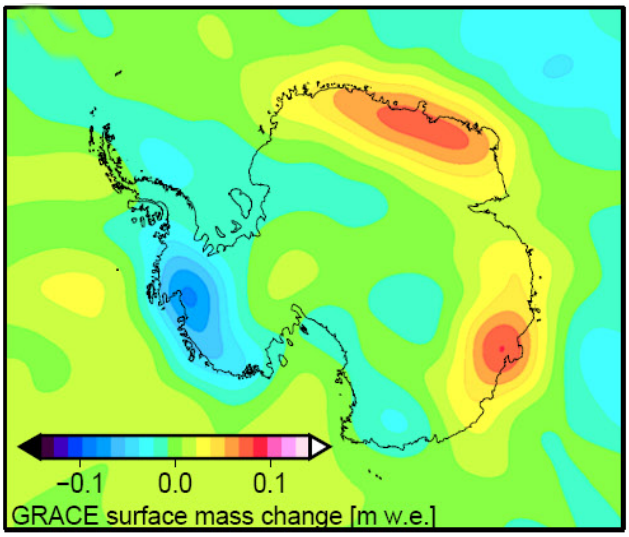
Velicogna and others, 2015

The 'simpler' case: Antarctica



NASA/MODIS

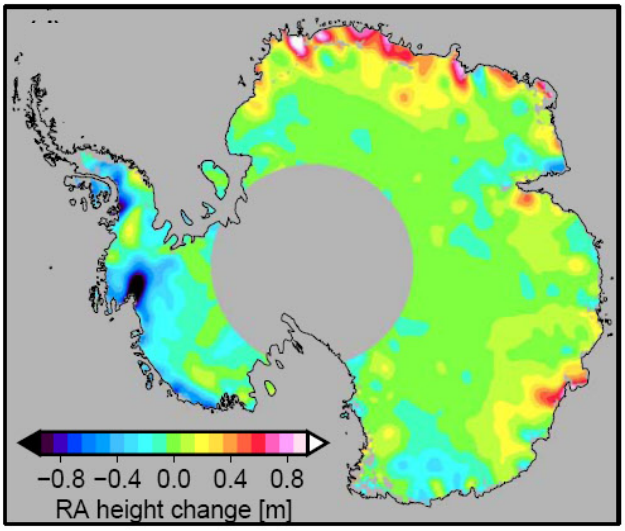
Added value of SMB modelling: a case study for Antarctica



Mass changes in 2009 from GRACE

Martin Horwath

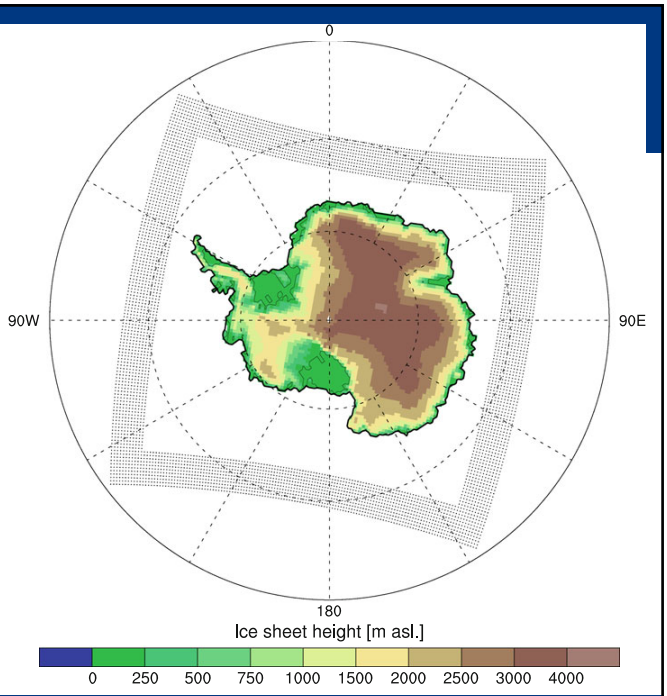
Added value of SMB modelling: a case study for Antarctica



Elevation changes in 2009 from Envisat

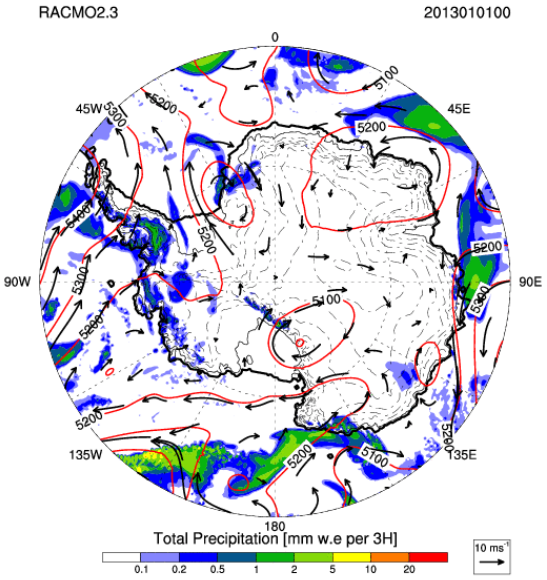
Martin Horwath

Regional climate model domain



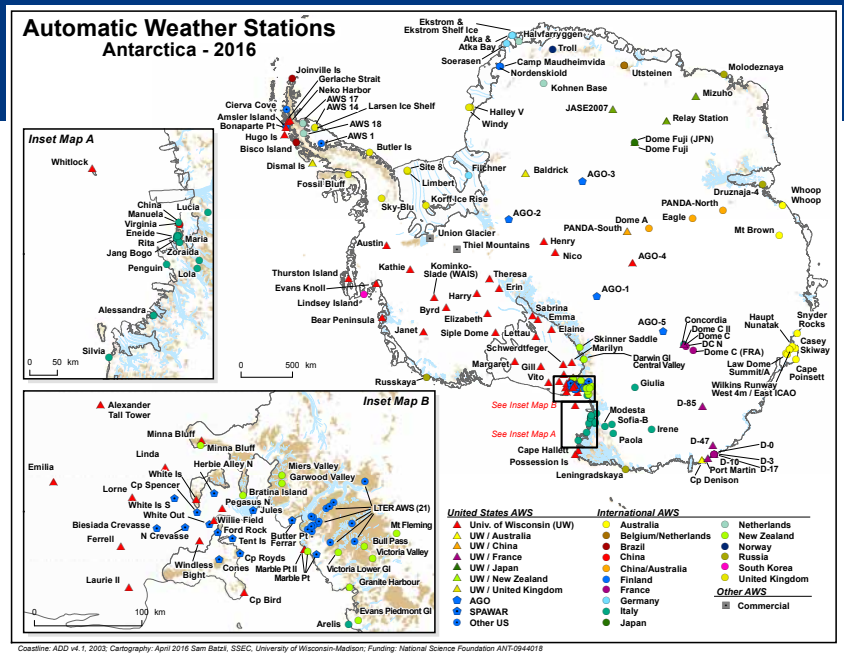
27 km resolution

Modelled 3-hourly precipitation



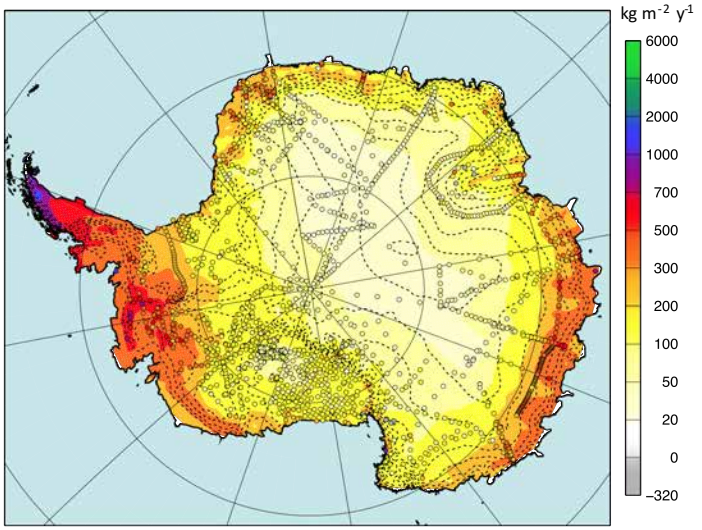
Run: RACMO2.3/ANT
Resolution: 27 km

Courtesy: Melchior van Wessem



University of Wisconsin, Madison

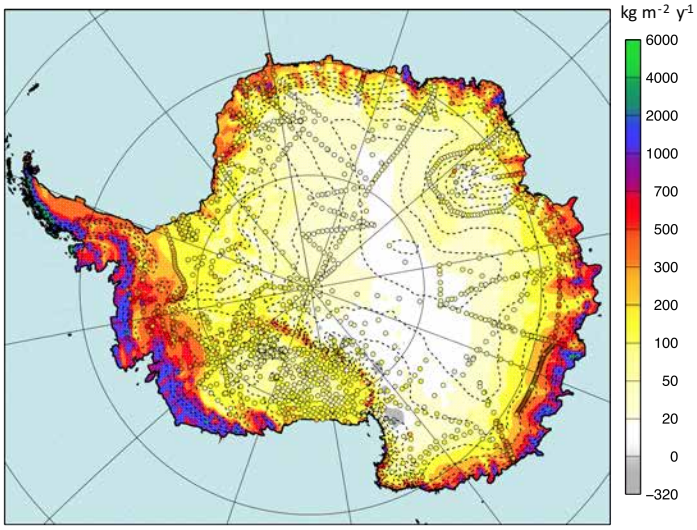
Observation-based accumulation map



Circles: ≈ 1200 obs.

Data: Arthern and others, 2006

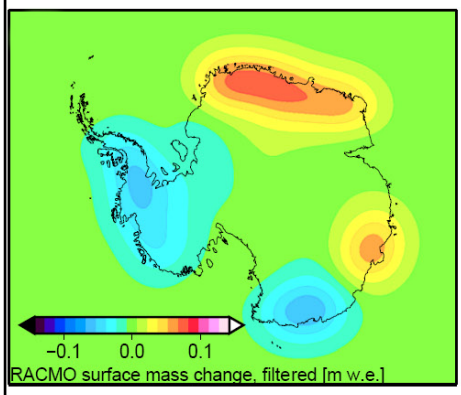
Modeled Antarctic surface mass balance

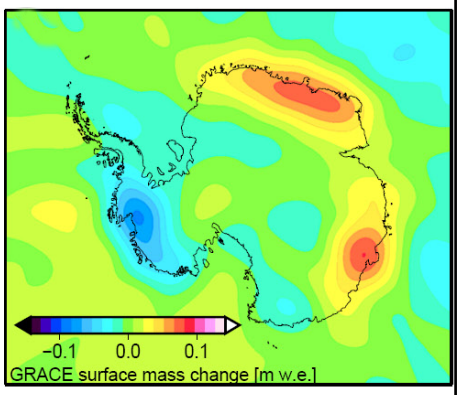


Run: RACMO2.1/ANT
Period: 1979-2011
Resolution: 27 km
Circles: ≈ 1200 obs.

Data: Lenaerts and others, 2012

Compare SMB to GRACE mass anomalies

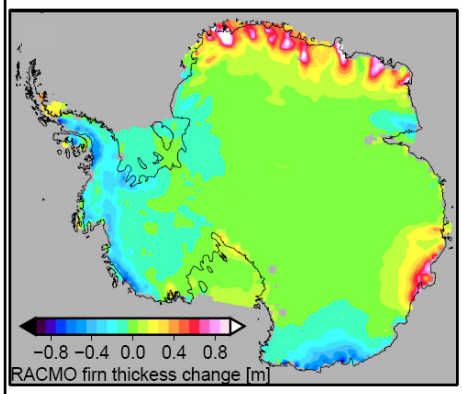


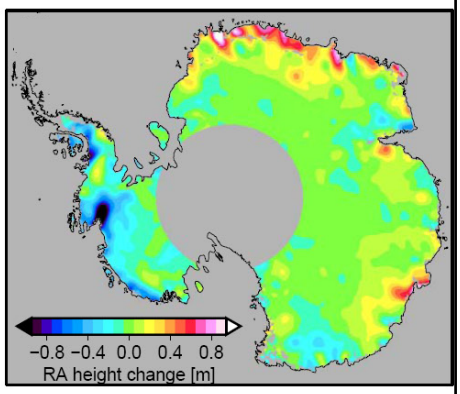


Filter SMB field from regional climate model RACMO to same resolution as GRACE

Martin Horwath

Compare modelled snow depth change to altimetry





Convert snowfall anomalies to firn thickness change, using a firn model

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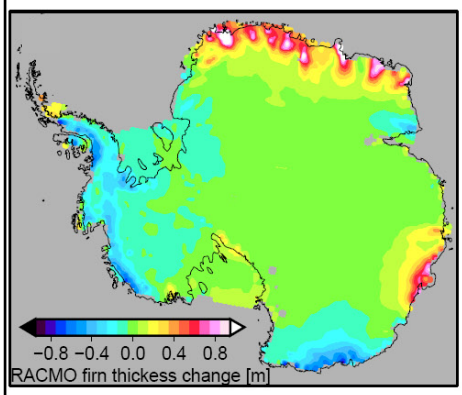
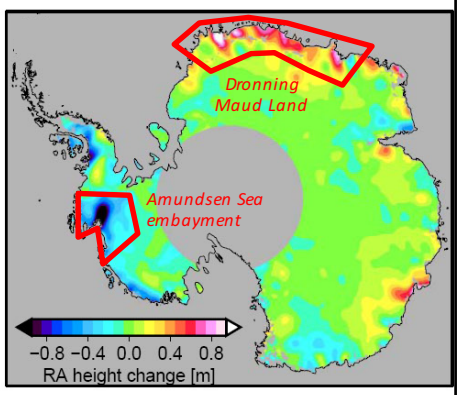
Compare modelled snow depth change to altimetry





Convert snowfall anomalies to firn thickness change, using a firn model

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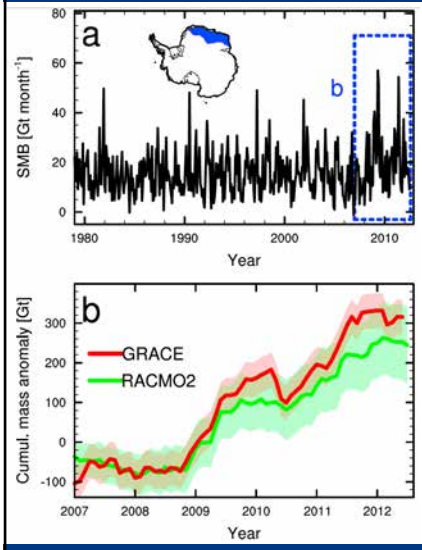
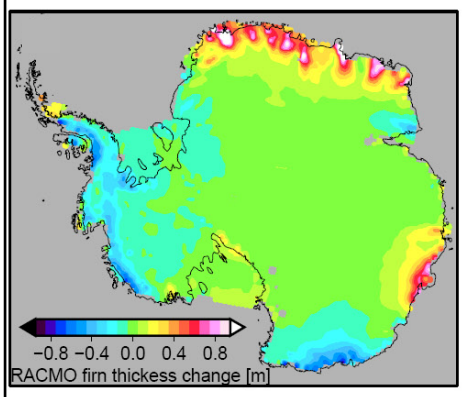
Dronning Maud Land, East Antarctica

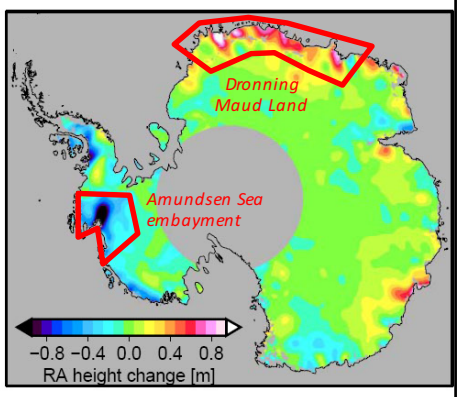


a) SMB from regional climate model
b) Cumulative SMB anomaly vs. GRACE

Lenaerts and others, 2013

Compare modelled snow depth change to altimetry





Convert snowfall anomalies to firn thickness change, using a firn model

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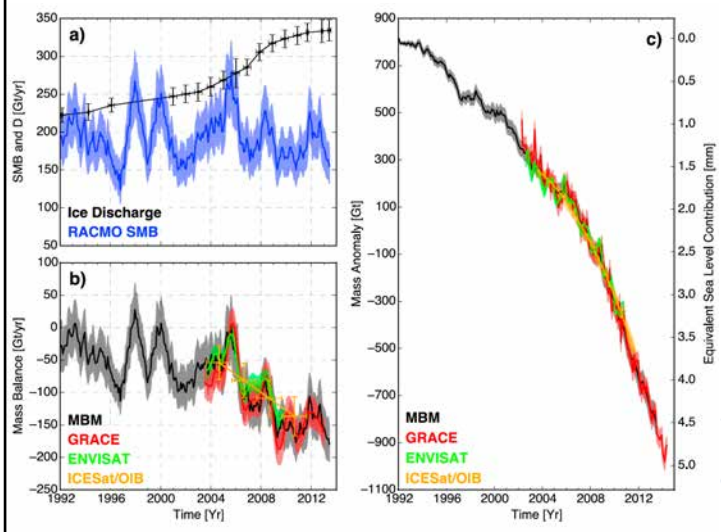
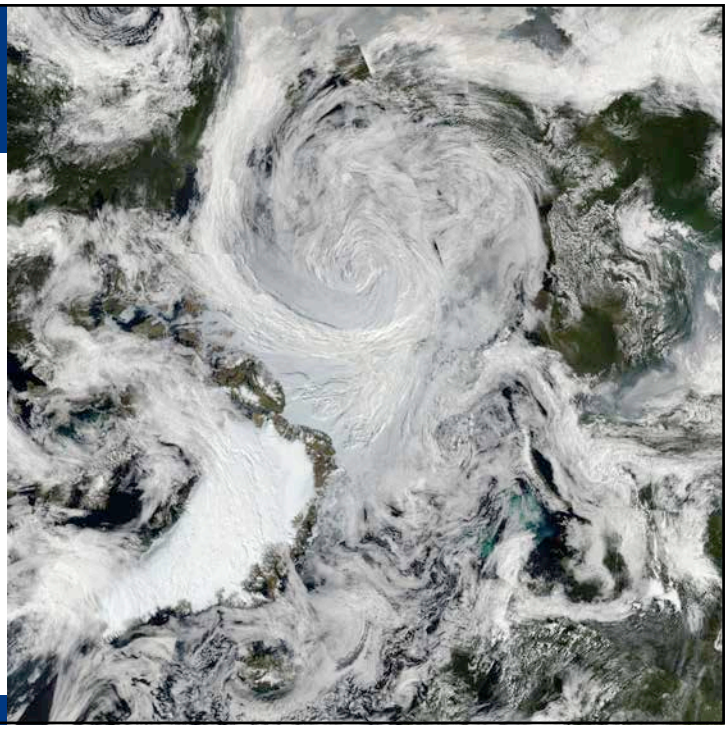
Amundsen Sea embayment, West Antarctica



a) SMB and D
b) MB = SMB – D
c) Cumulative MB

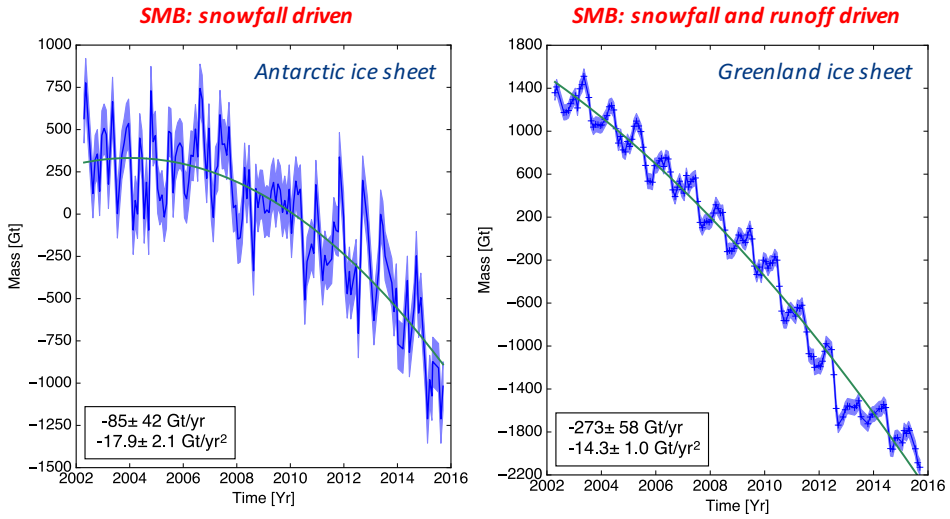
Sutterley and others, 2014

The 'harder' case: Greenland



NASA/MODIS

13 years of ice sheet mass changes from GRACE



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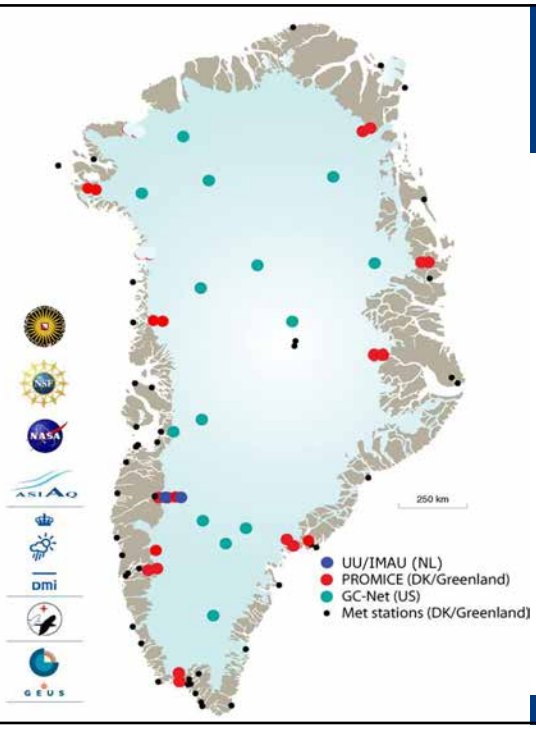
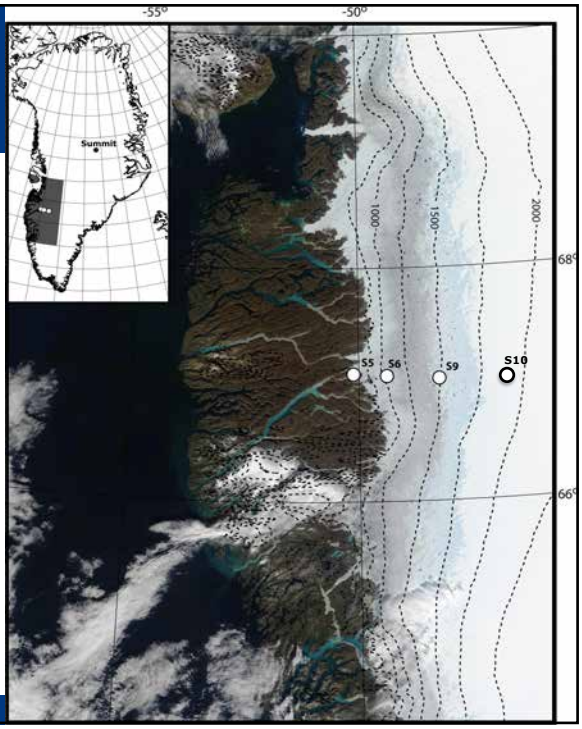
J. Paul Getty Museum

Greenland automatic and manned weather stations



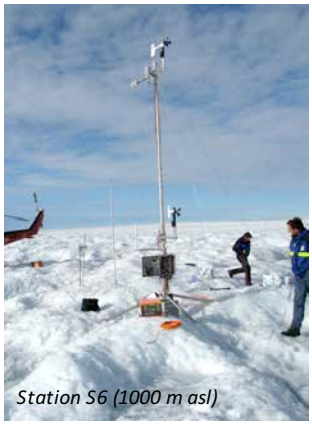
Adapted from GEUS

K-transect, west Greenland

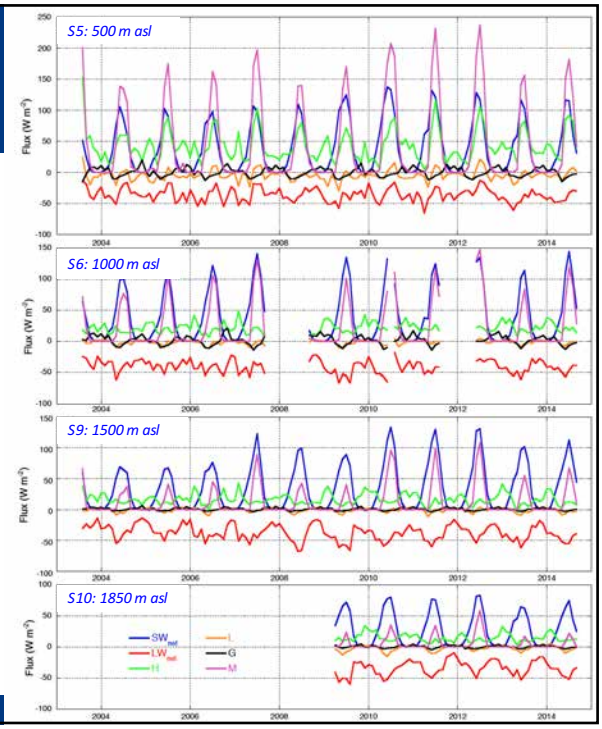


NASA/MODIS

Greenland surface energy balance

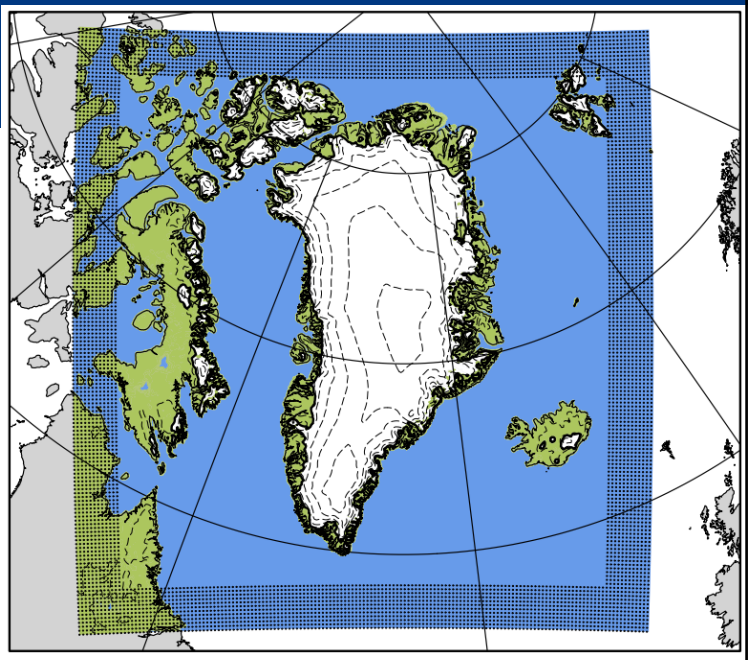


Station S6 (1000 m asl)



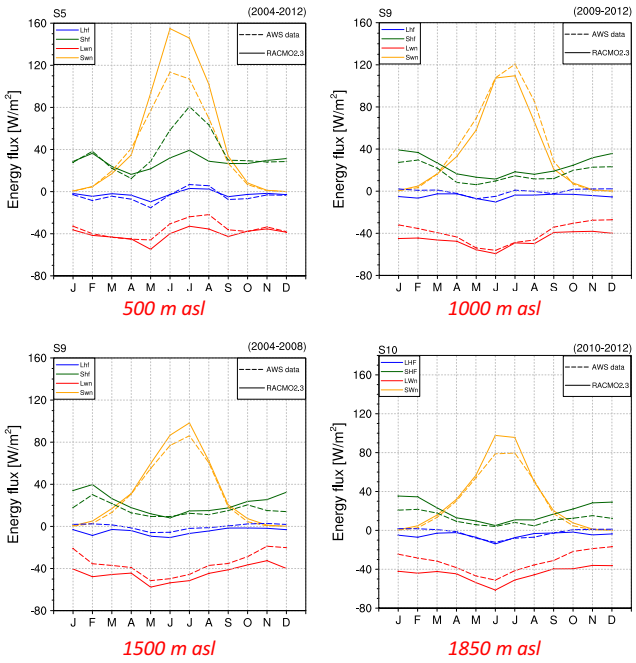
Courtesy: Peter Kuipers Munneke

Regional climate model



11 km resolution

Model evaluation: surface energy balance

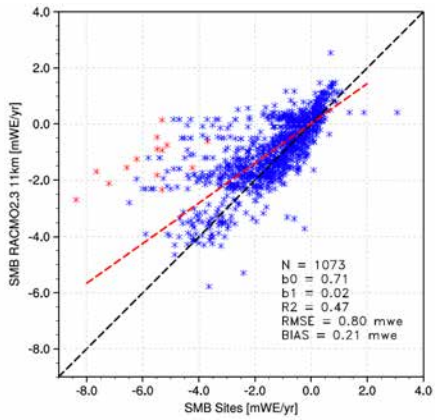


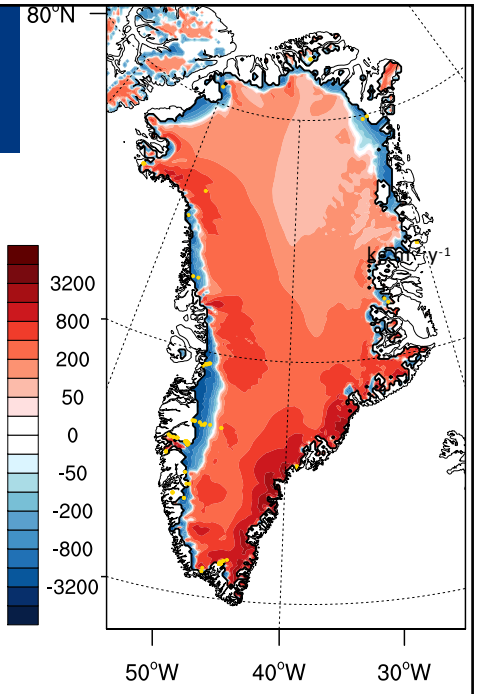
500 m asl | 1000 m asl

1500 m asl | 1850 m asl

Noël and others, 2015

Modeled evaluation: surface mass balance

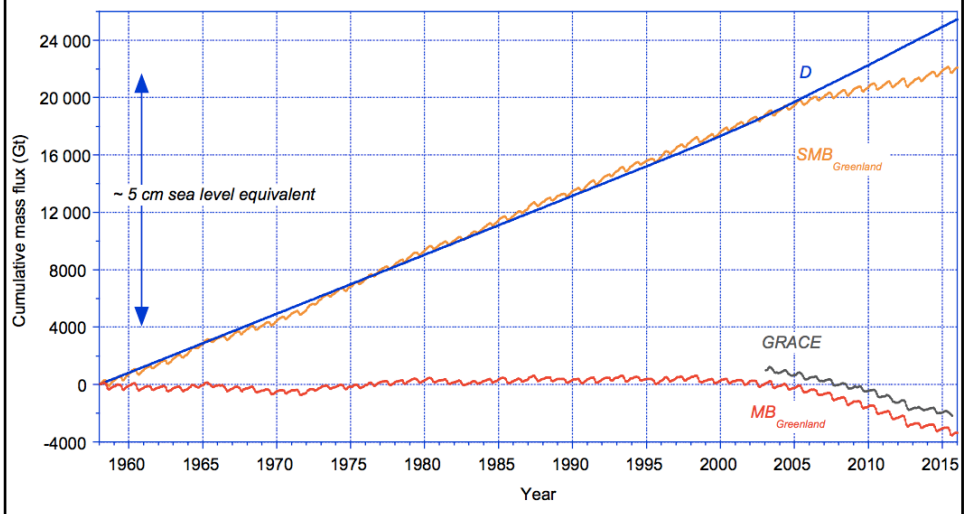




Run: RACMO2.3/GR
Period: 1958-2014
Resolution: 11 km

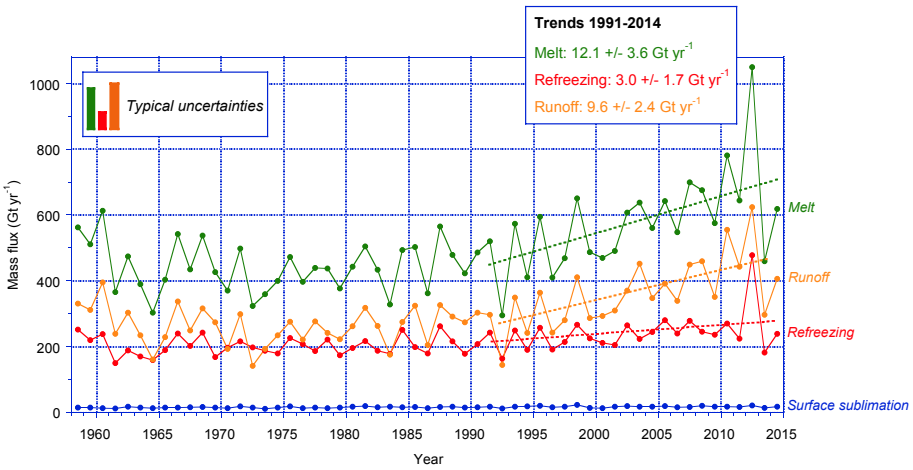
Noël and others, 2016

Greenland cumulative mass balance (1958-2014)



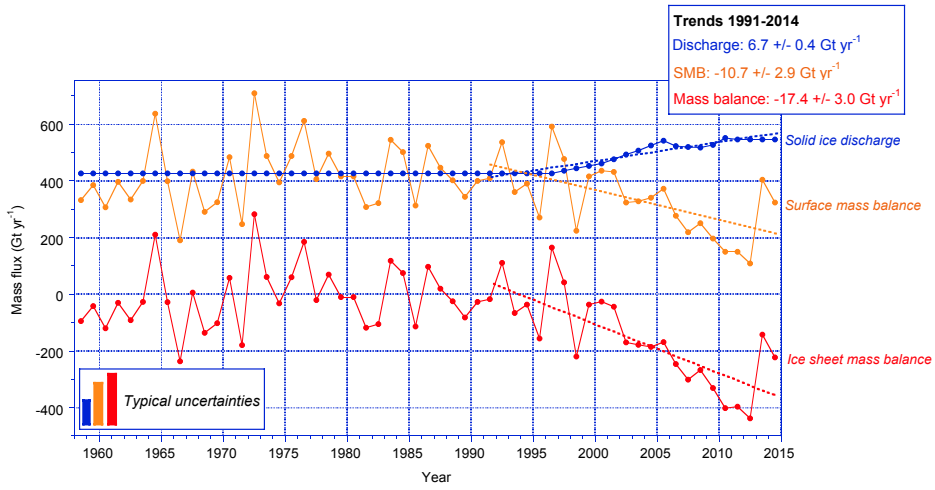
Van den Broeke and others, 2016

Modelled Greenland ice sheet melt/runoff (1958-2014)

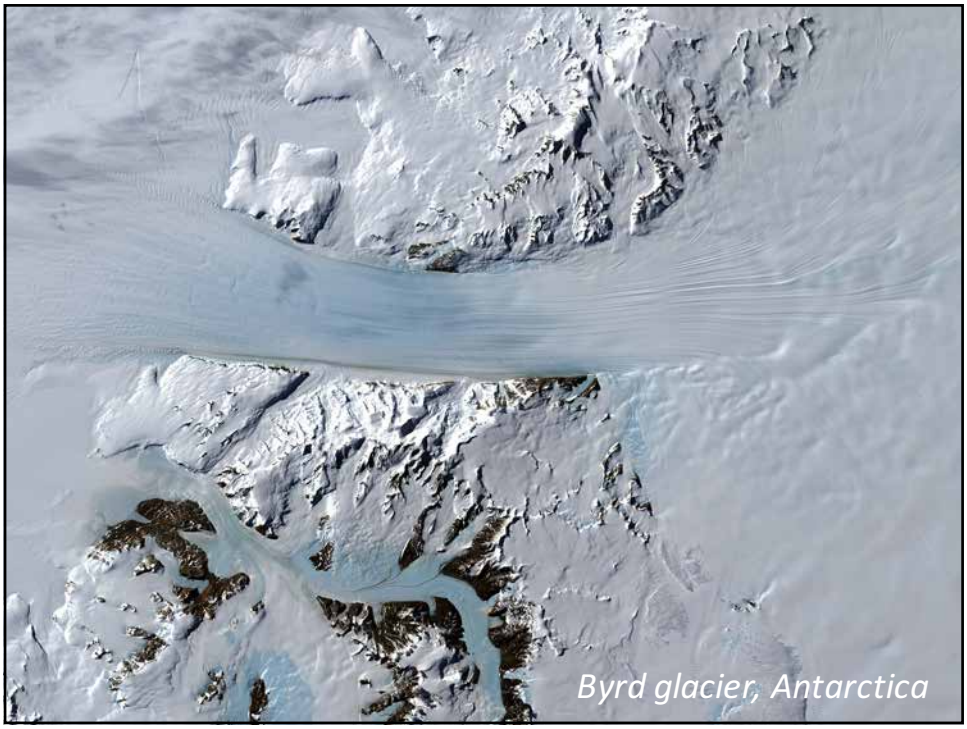


Van den Broeke and others, 2016

Modelled Greenland ice sheet mass balance (1958-2014)

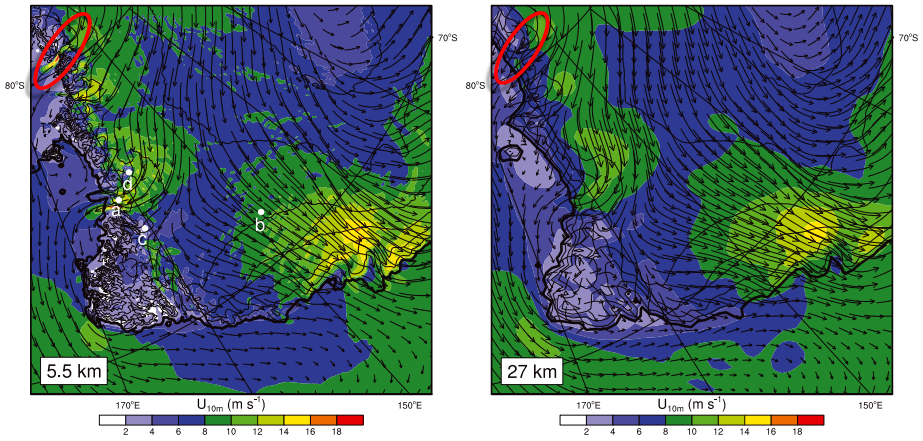


Van den Broeke and others, 2016



Impact of model resolution on net snow accumulation

Byrd glacier basin



Lenaerts and others, 2012

Impact of model resolution on net snow accumulation

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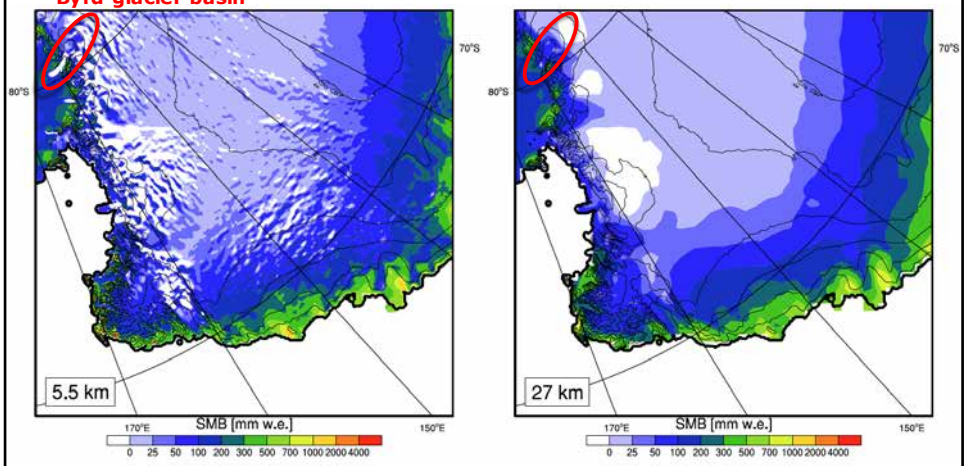

Lenaerts and others, 2012

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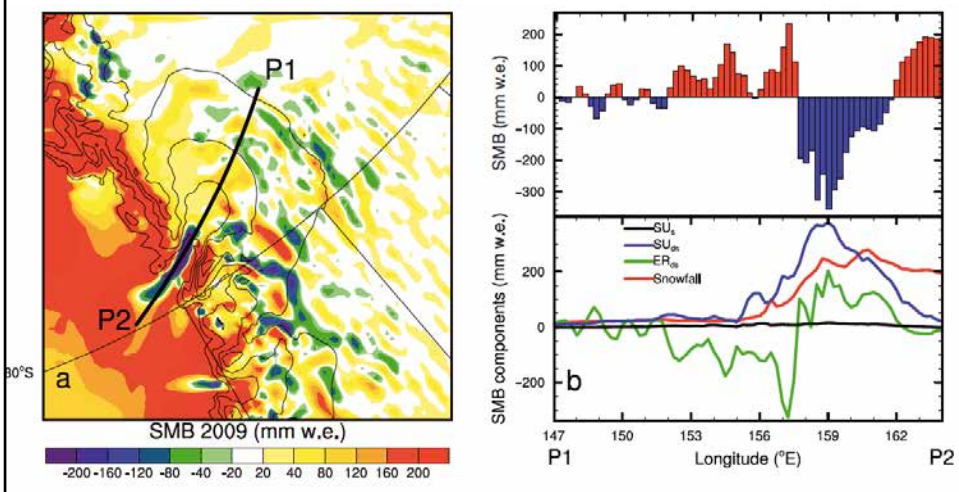
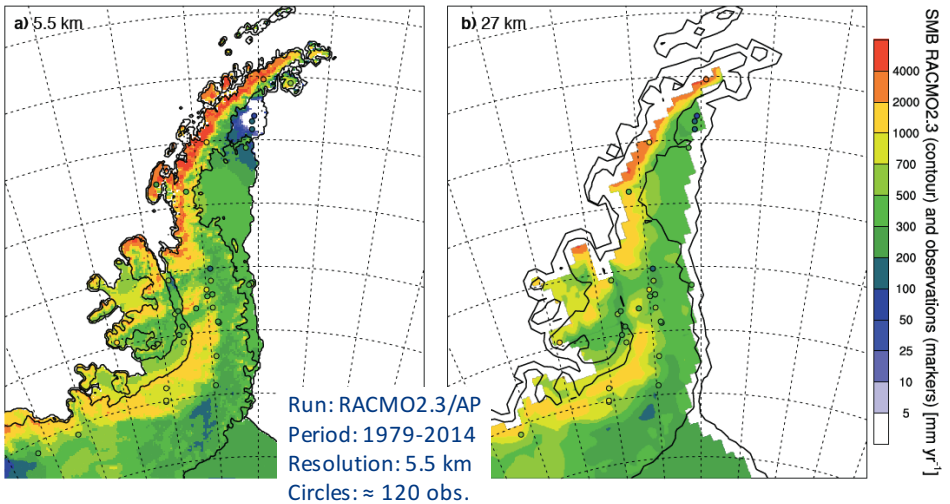


Lenaerts and others, 2012

Enhanced dynamical downscaling

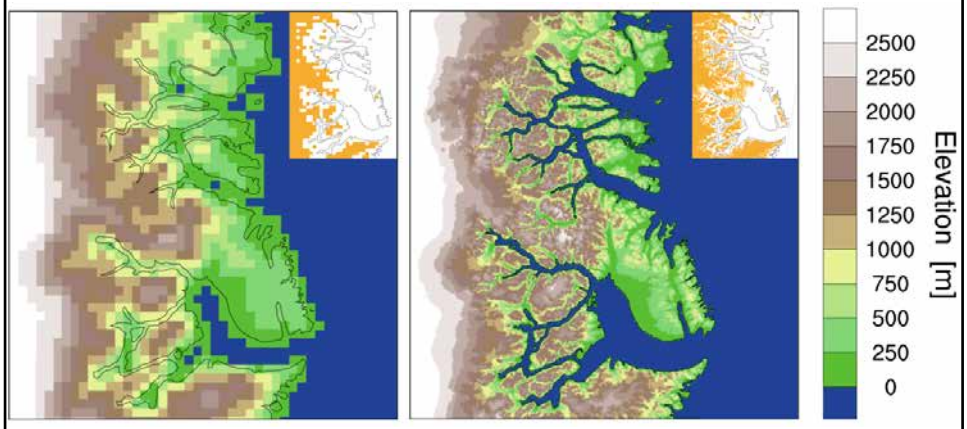


Courtesy: Melchior van Wessem

East Greenland: individual glaciers not resolved

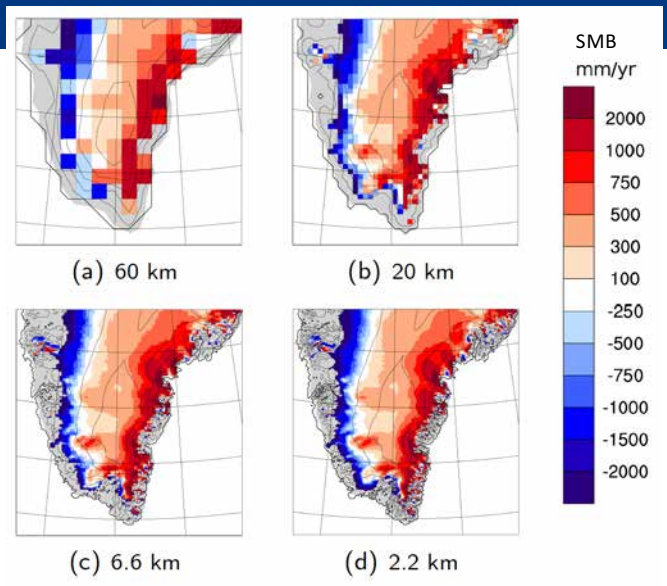
11 km resolution

1 km resolution



Noël and others, 2016

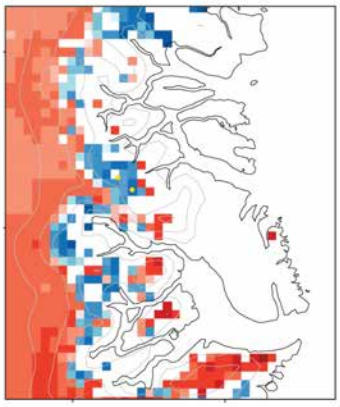
Enhanced dynamical downscaling



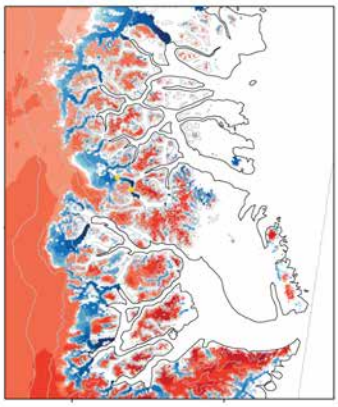
Courtesy: Willem Jan van de Berg

Enhanced statistical downscaling

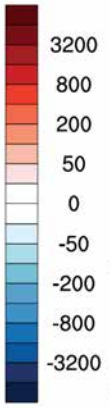
RACMO2.3 (11 km), East Greenland



Statistically downscaled to 1 km



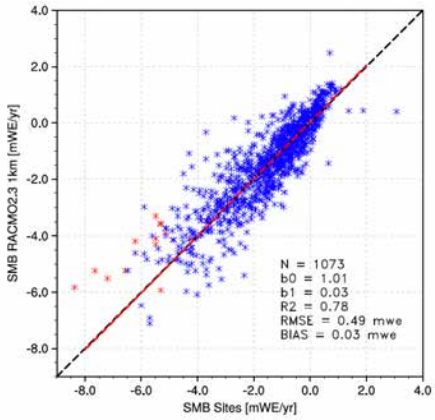
SMB (mm yr^{-1})



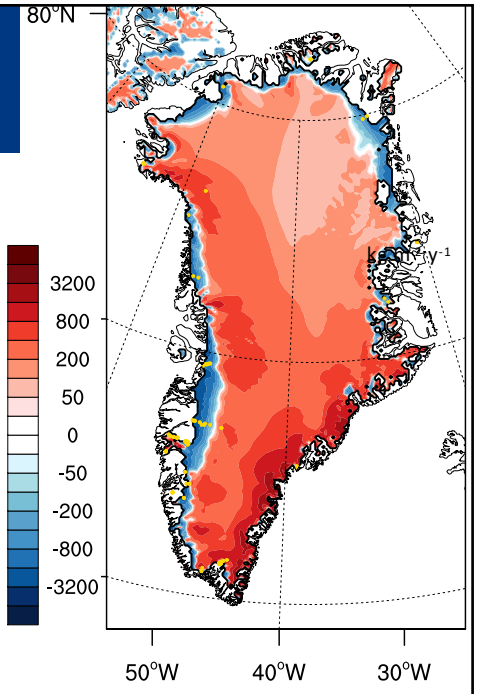
(Based on GIMP, Howat and others, 2014)

Noël and others, 2016

Modeled Greenland surface mass balance



Run: RACMO2.3/GR
Period: 1958-2014
Resolution: 11 km



Noël and others, 2016

Outlook

Observations

Focus on accurate radiation and turbulence measurements!

New generation of autonomous weather stations

New generation of satellites: GRACE-2, ICESat-2

Models

Further improve existing atmospheric climate models (clouds)

Further improve existing snow models (heterogeneous percolation)

Move to global model systems (coupled ice sheet models)

Improve prognostic albedo schemes (dust, black carbon, bio-albedo)