A machine learning approach for Greenland ice sheet altimetric mass balance

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Greenland Ice Sheet Mass Balance (1992–2020) From Calibrated Radar Altimetry

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Abstract We present the first 1992–2020 record of Greenland Ice Sheet (GrIS) mass balance derived from multisatellite Ku-band altimetry. We employ an empirical approach as an alternative detailed to radar-propagation modeling, and instead convert elevation changes observed by radar altimetry into mass changes using spatiotemporal calibration fields. This calibration field is derived from a machine learning approach that optimizes the prediction of a previously published mass balance field as a function of ice sheet variables. Our mass balance record shows a GrIS contribution of 12.1 ± 2.3 mm sea-level equivalent since 1992, with more than 80% of this contribution occurring after 2003. Our record also suggests that the 2017 hydrological year is the first year in the 21st century which, within uncertainties, the GrIS was in balance. Overall, the 28-year radar-derived mass balance record we present highlights the potential of the method to provide operational mass balance estimates derived from multisatellite Ku-band altimetry.

Plain Language Summary Earth's land ice masses are shrinking due to climate change. The Greenland Ice Sheet (GrIS) has been a major contributor to sea-level rise in recent years. Earth-observing satellites have enabled us to monitor ice-sheet changes, but common problems for these estimates of ice-sheet mass balance are mission gaps and changing instrumentation. Since 1991, the European Space Agency has used the same instrumentation for satellite radar altimeters in orbits applicable for monitoring the GrIS. Additionally, before retiring one satellite altimeter, a replacement has been commissioned with a sufficient timespan of overlapping measurements to estimate offsets between satellites. The resulting satellite altimetry record can be processed to provide a lengthy, and consistent, record of ice-sheet elevation and volume changes. Here, we apply machine learning to convert radar-derived volume changes to radar-derived mass changes. This novel mass balance record shows a contribution from the GrIS to global sea level rise of 12.1 ± 2.3 mm since 1992, with more than 80% of this contribution originating after 2003. The method we present is an alternative to modeling both radar propagation and firn compaction, and provides a path toward operational mass-balance estimates from satellite altimetry.

Key Points:
- Novel estimate of Greenland Ice Sheet mass balance from calibrated multisatellite Ku-band altimetry
- Total eustatic sea-level rise contribution of 12.1 ± 2.3 mm from the ice sheet since 1992
- Atmospheric circulation can shift ice-sheet mass balance by 3σ within 5 years

Supporting Information:
- Supporting Information S1

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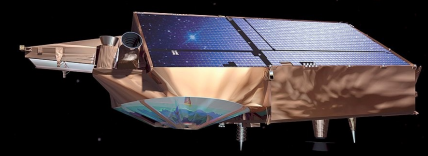

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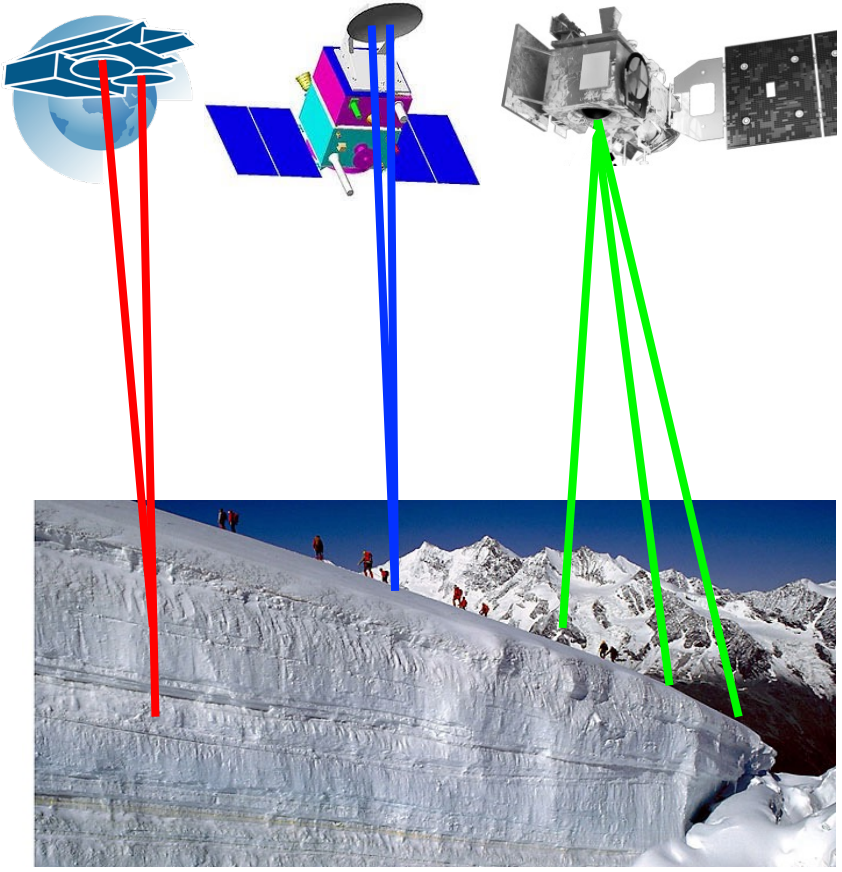
Greenland ice sheet altimetry – The challenge

Volume to mass conversion

Ku-band

Ka-band

LiDAR



RA-MB

LA MB

GMB

IO-MB

Mass change rate [Gt / year]

200
0
-200
-400
-600
-800

Cumulative Mass [Tt]

1
0
−1
−2
−3
−4
−5

Sea Level Rise [mm]

−2
0
2
4
6
8
10
12

1995
2000
2005
2010
2015
2020
Year

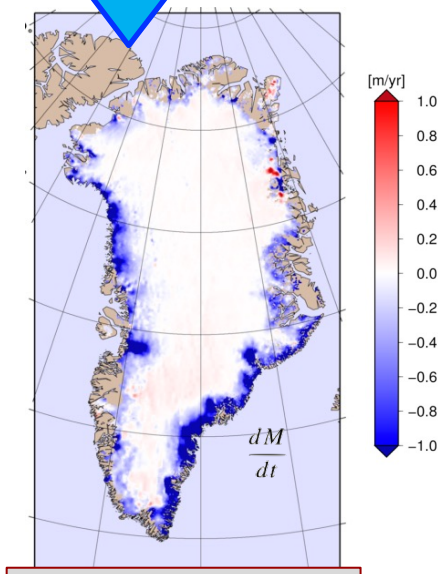
Climatological average

1995
2000
2005
2010
2015
2020

Year

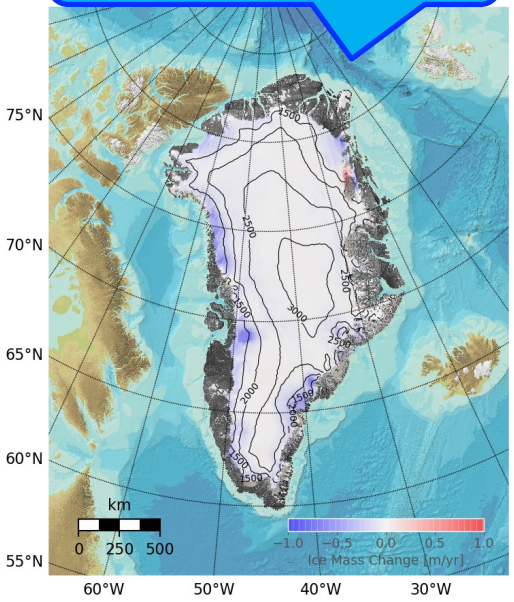
Greenland ice sheet mass balance - Surface penetration correction approach.

We know the mass balance in the ICEsat-era



LS Sørensen, SB Simonsen, K Nielsen, P Lucas-Picher, G Spada, G Adalgeirsdottir, R Forsberg, R., and CS Hvidberg **Mass balance of the Greenland ice sheet (2003–2008) from ICESat data – the impact of interpolation, sampling and firn density** The Cryosphere (2011) doi: 10.5194/tc-5-173-2011

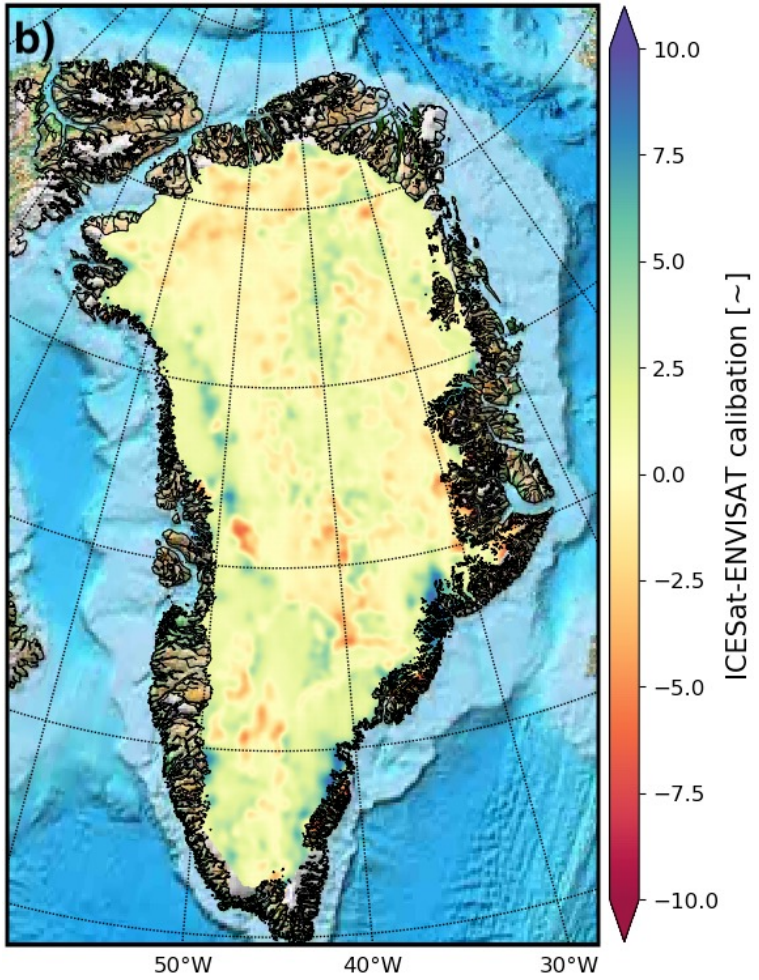
An initial guess for the Radar based MB, by simple snow/ice approximations



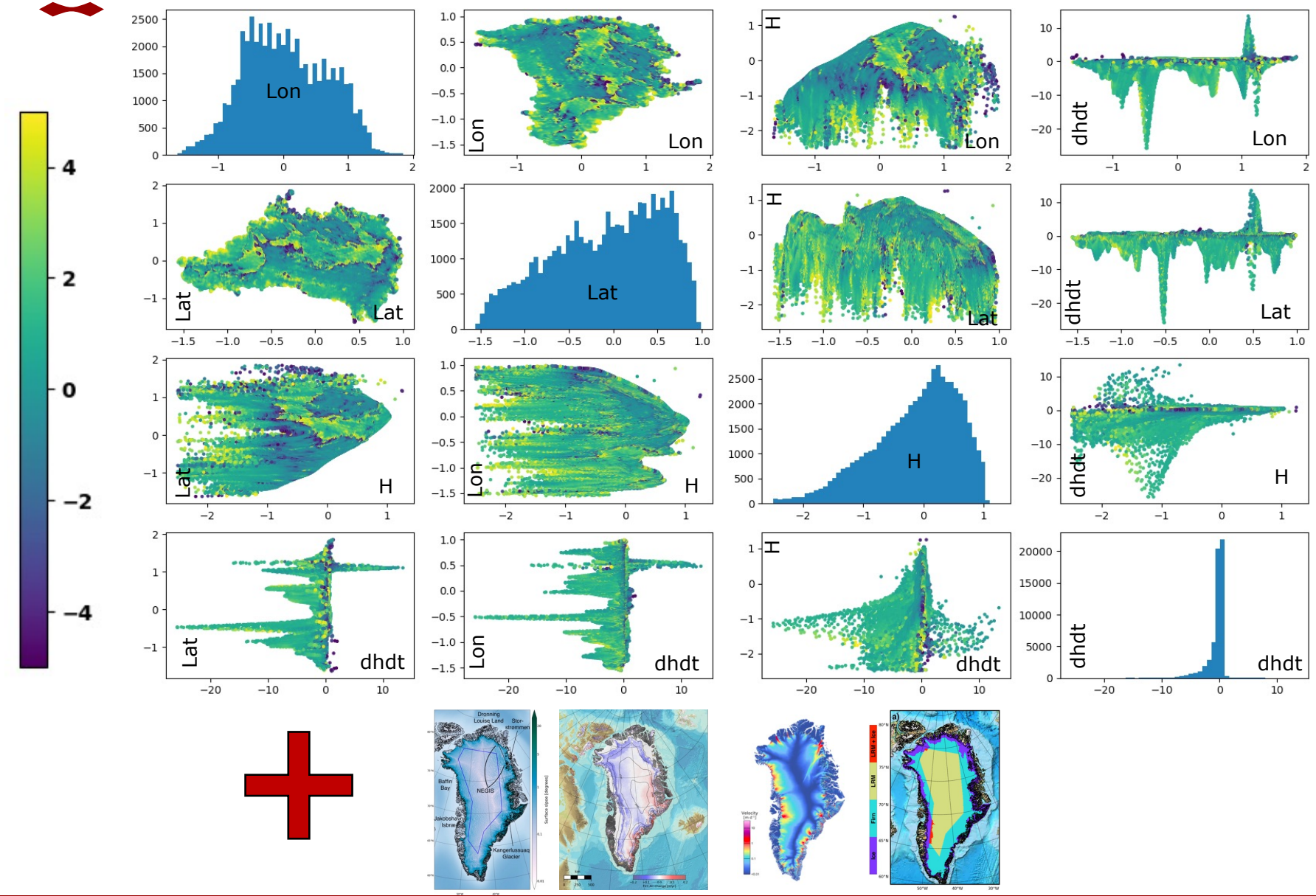
2003-2009
Conversion field

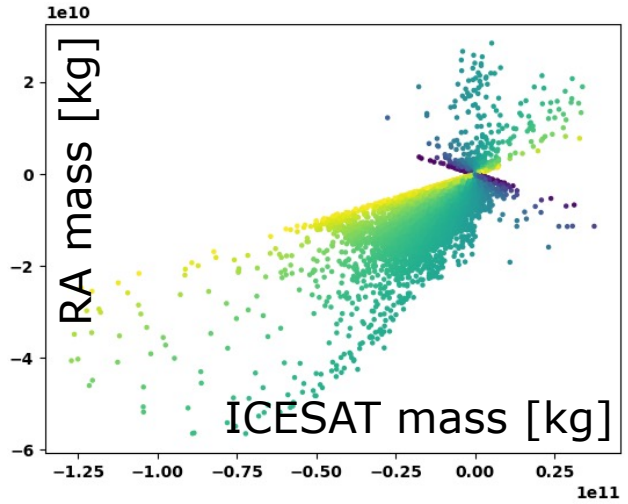
$$ICE_{Scale} = \frac{Mass\ balance\ _{ICESat}}{Mass\ balance\ _{Radar}}$$

=



Greenland ice sheet mass balance
- Surface penetration correction approach.





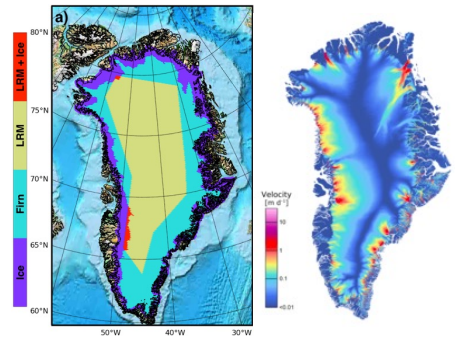
Testing supervised machine learning technics

- Nearest Neighbors
- SGD (linear regression)
- Decision Tree
- Random Forest
- Neural Net (MLP Regression)
- AdaBoost

Greenland ice sheet mass balance

Supervised machine learning

AdaBoost



Ku-band Radar Altimetry
- Calibrated time series

Mass change rate [Gt / year]

Sea Level Rise [mm]

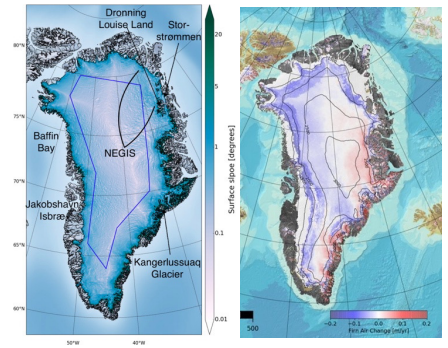
Cumulative Mass [Tt]

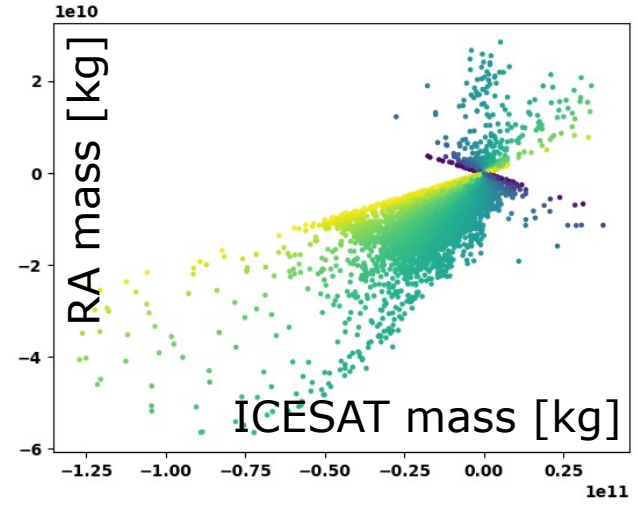
RA-MB
LA MB
GMB
IMBIE

Year

GRACE-GMB [Gt/yr]

Radar-VMB [Gt/yr]

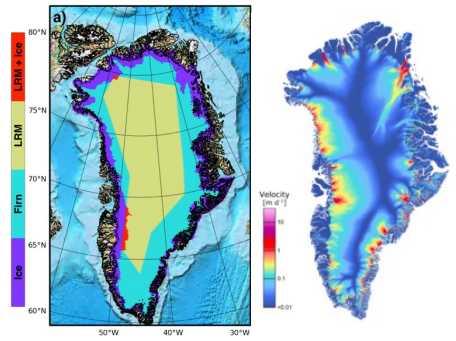




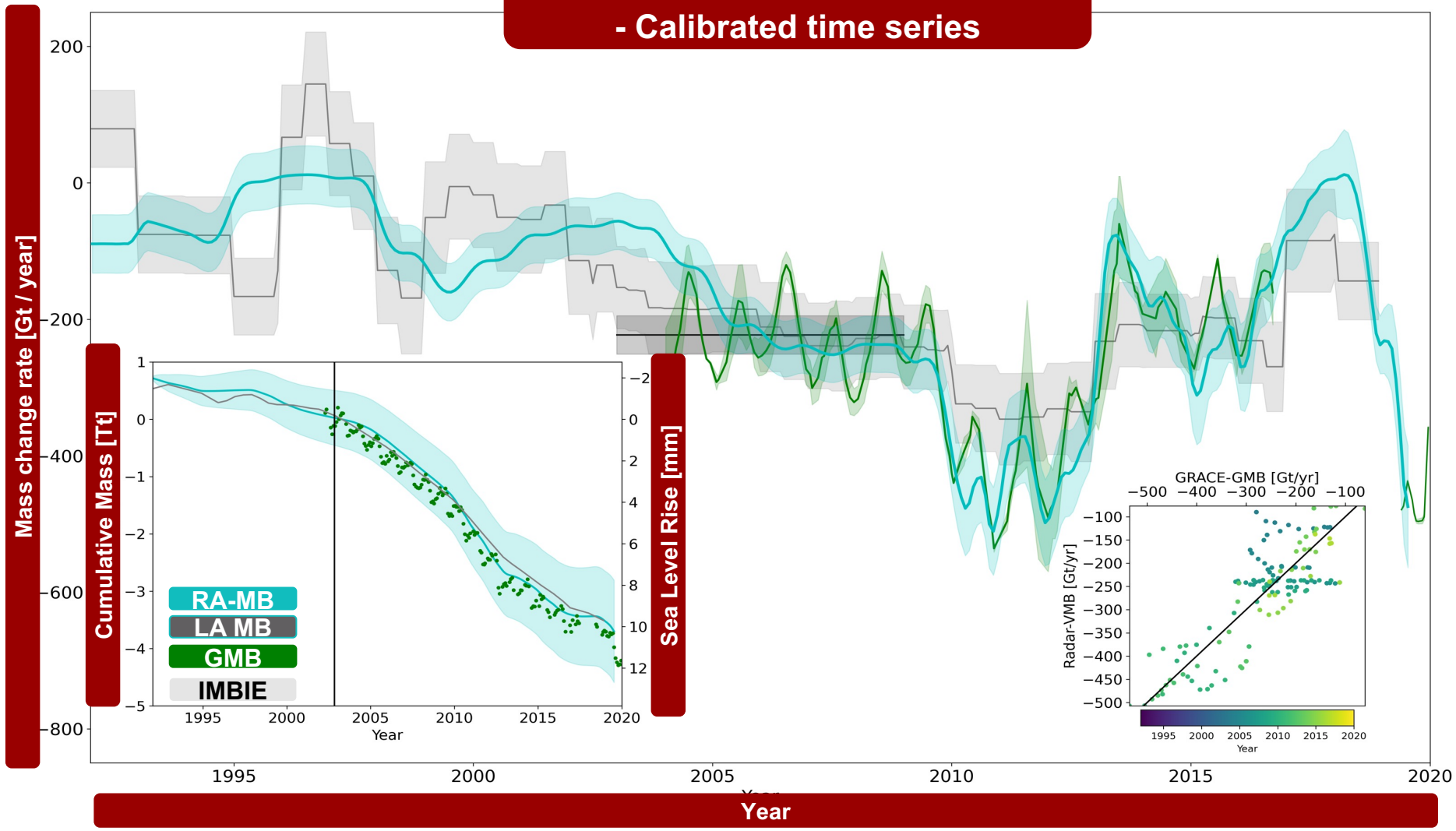
Greenland ice sheet mass balance

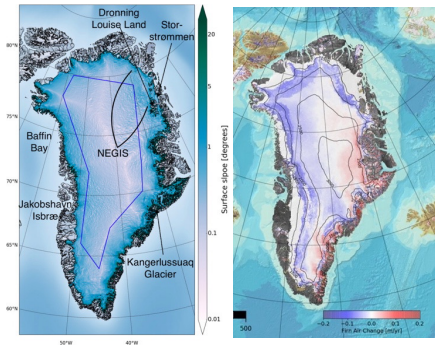
Supervised machine learning

AdaBoost



Ku-band Radar Altimetry
- Calibrated time series





Greenland ice sheet mass balance from 1992- 2020:

12.1±2.3 mm sea-level equivalent since 1992

More than 80% of this contribution occurring after 2003

DTU

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