Accelerated Mass Loss from Greenland Ice Sheet: Links to Atmospheric Circulation in the Arctic

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Background

- Satellite remote sensings have suggested that GrIS mass loss has accelerated.

✓-21.9±1 Gt/yr^2 from 1992 to 2009 (Rignot et al., 2011)

✓-30±11 Gt/yr^2 from Apr. 2002 to Feb. 2009 (Velicogna, 2009)

✓-8.3±6.5 Gt/yr^2 from Mar. 2003 to Feb. 2010 (Schrama and Wouters, 2011)

✓-18.6 Gt/yr^2 , -8.8 Gt/yr^2 and -14.8 Gt/yr^2 from Aug. 2002 to Aug. 2011 (Svendsen et al., 2013)

Background

- Causes of the acceleration are not certain

$$\Delta M_{T_0}^{T} = \int_{T_0}^{T} (P - S - R)dt - \int_{T_0}^{T} Ddt$$

Surface mass balance (SMB)
= precipitation (P)-sublimation (S)-meltwater runoff (R)
Ice discharge (D)

✓ van den Broeke et al. (2009) – decrease P, increase R and D

✓ Sasgen et al. (2012) – decrease P is important in the south Greenland

✓ Wouters et al. (2013) - observational periods are too short to distinguish SMB and D from the acceleration

Objectives

- Estimate of the current GrIS mass loss acceleration rate.
- Find causes of the acceleration.
- Suggest future sea level rise scenario

Method and Data

- Greenland's ice mass variations

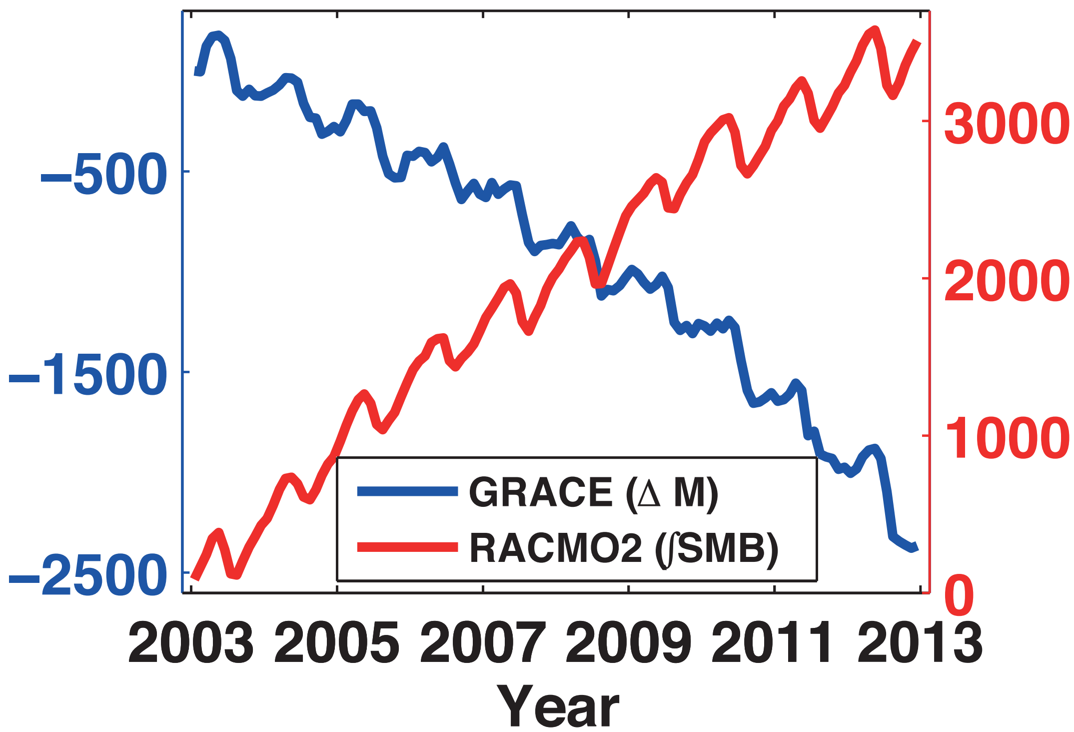
$$\Delta M_{T_0}^{T} = \int_{T_0}^{T} (P - S - R)dt - \int_{T_0}^{T} Ddt$$

- GRACE for ΔM and RACMO2 (van den Broeke, ,2009) for SMB (P-S-R).
- The typical data reduction procedures for ΔM; C_{20} from SLR (Cheng and Tapley, 2004), GIA correction (Paulson et al., 2007), de-striping (Swenson and Wahr, 2006) and a 300km Gaussian smoothing.
- RACMO2 SMB (~11km) is reproduced with the same spatial resolution of GRACE ΔM (~300km); convert SMB grids into SH degrees and orders up 60, apply 300km Gaussian smoothing and then converting back to latitude-longitude grids

Method and Data

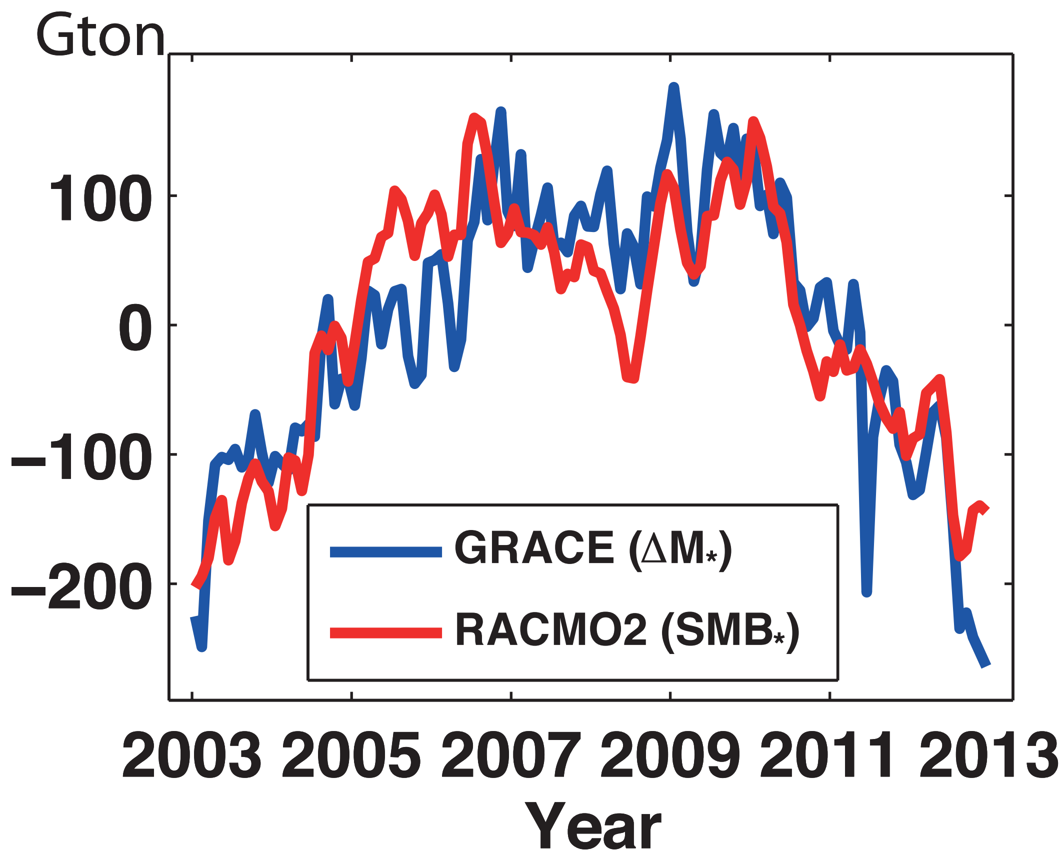
- Scale factor is estimated by the least square fitting of the smoothed to the unsmoothed RACMO2 SMB, 1.60
- Apply the scale factor for both ΔM and SMB

Results – Continental scale



✓ The linear trend from Mar 2003 to Feb 2010 is -196 Gt/yr, which is very close to the previous estimate, -201 Gt/yr during the same period (Schrama and Wouters, 2011)

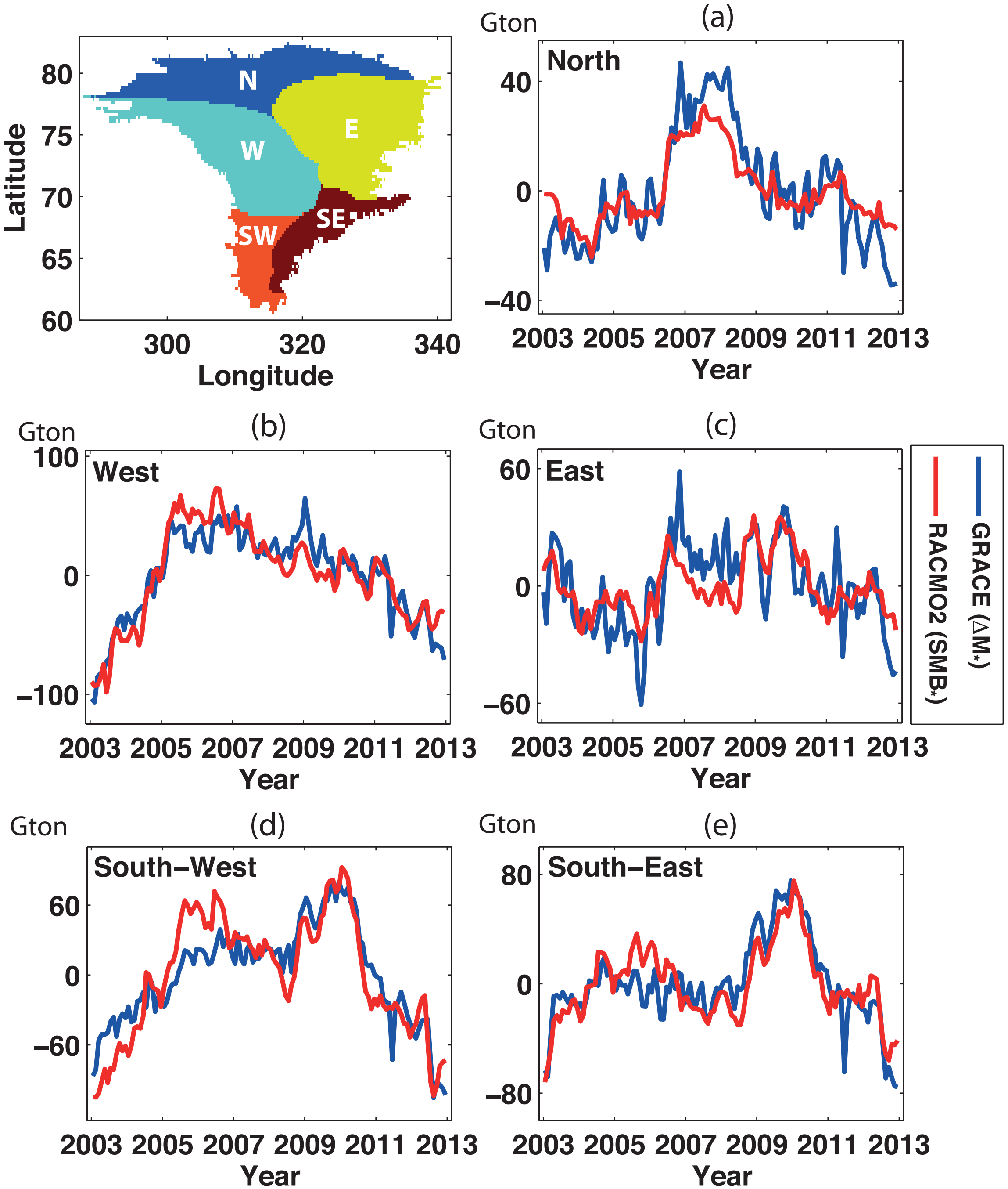
Results



✓ The acceleration rates in ΔM_* and SMB_* from 2003 to 2012 are -12.5±1.8 Gt/yr^2 and -10.9±1.6 Gt/yr^2, respectively.

✓The correlation coefficients between the two is 0.86

✓ Ice dynamic is relatively minor in the acceleration.



✓ Scale factors are re-estimated for each basin

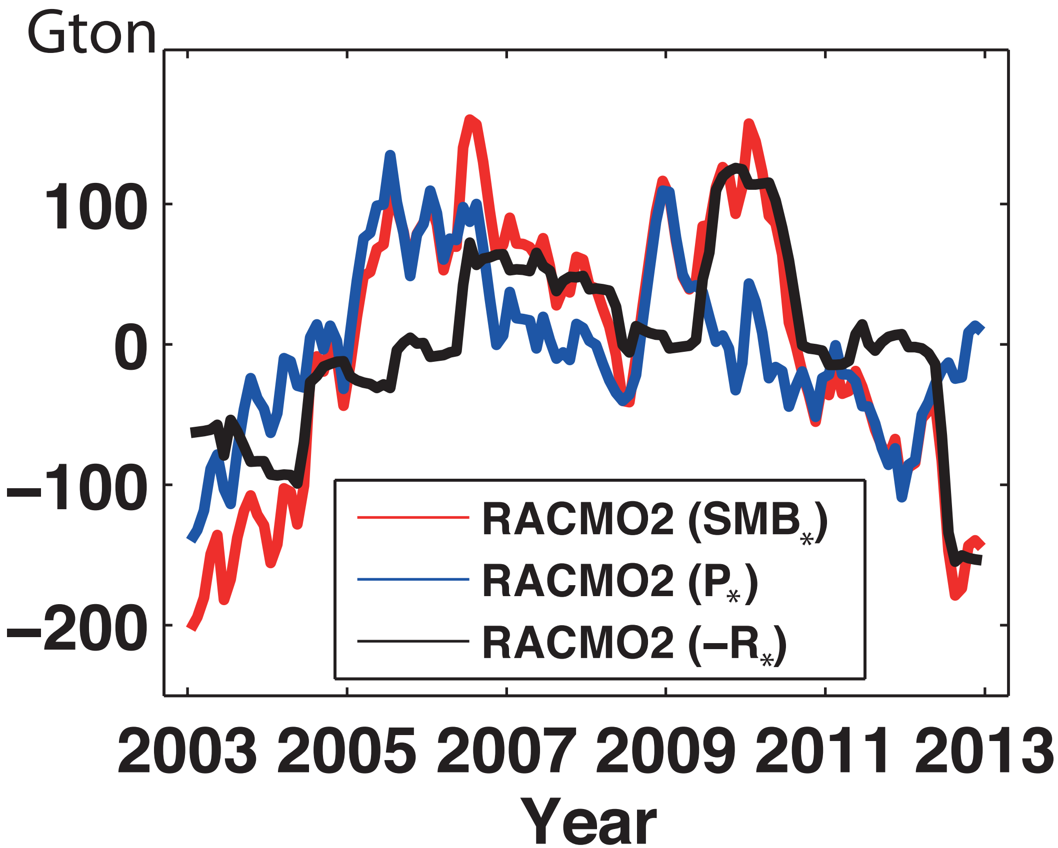
✓ This regional changes are consistent with Chen et al. (2011)

Conclusions (3-1)

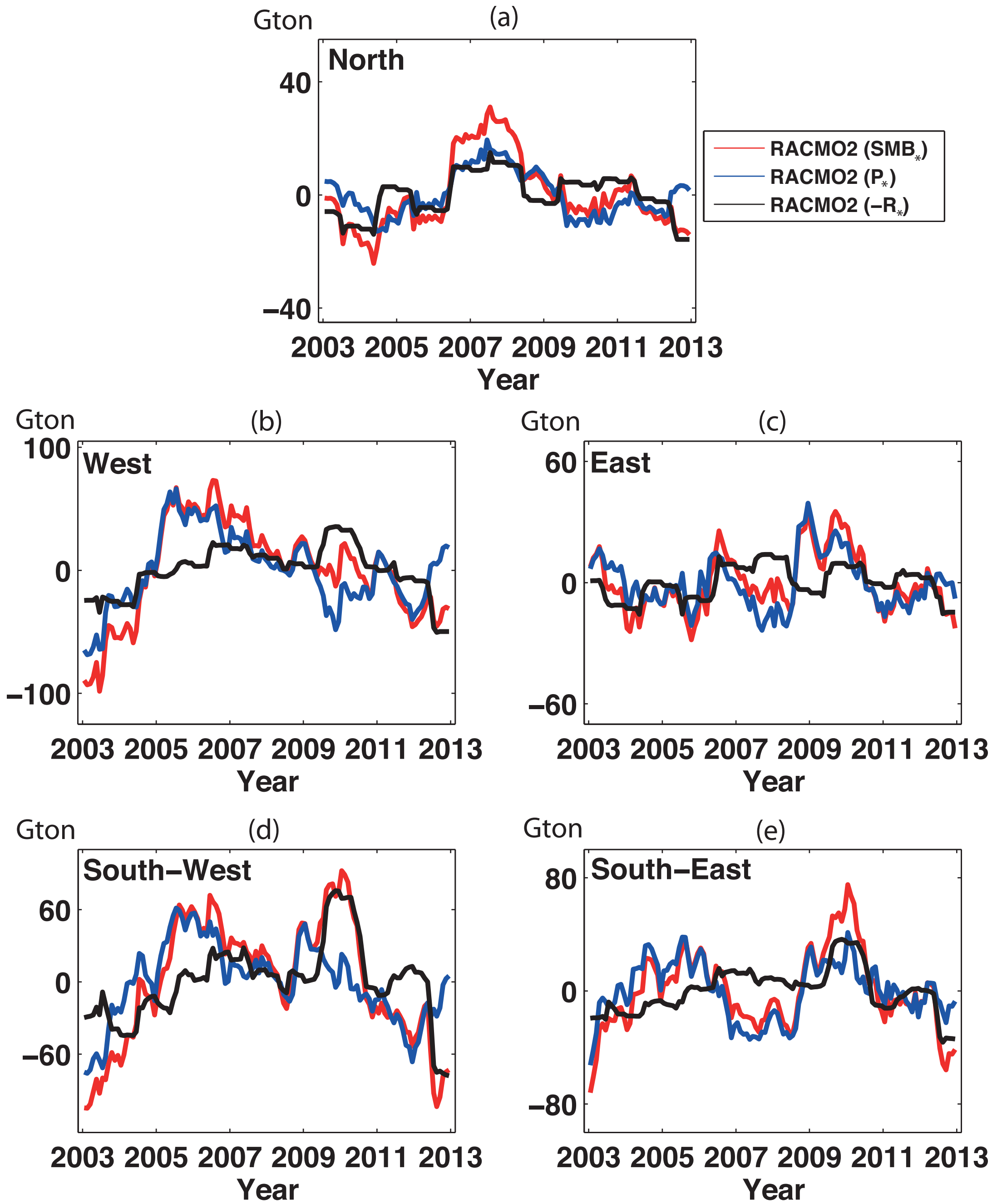
- Estimate of the current GrIS mass loss acceleration rate
  ✓ -12.5±1.8 Gt/yr2 (from 2003 to 2012).
- Find causes of the acceleration
  ✓ SMB explain the most acceleration, -10.9±1.6 Gt/yr^2

- Suggest future sea level rise scenario

Results



- ✓ The acceleration rates in P_* and $-R_*$ from 2003 to 2012 are -4.6±1.3 Gt/yr^2 and -6.3±1.3 Gt/yr^2, respectively.
- ✓ Before the extreme melting years of 2010 and 2012, the acceleration rates in P_* and $-R_*$ from 2003 to 2009 are -9.9±2.8 Gt/yr^2 and -2.6±2.4 Gt/yr^2, respectively.



✓ P_* is a larger contributor than $-R_*$ to the acceleration from 2003 to 2009, but the situation is reverse after extreme melting in 2010 and 2012

Conclusions (3-2)

- Estimate of the current GrIS mass loss acceleration rate

  ✓ -12.5±1.8 Gt/yr2 (from 2003 to 2012).

- Find causes of the acceleration

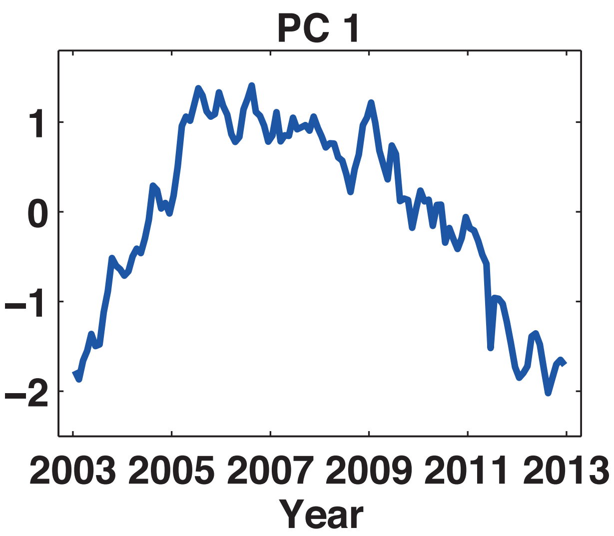
  ✓ Decrease in SMB explain the most acceleration, -10.9±1.6 Gt/yr^2

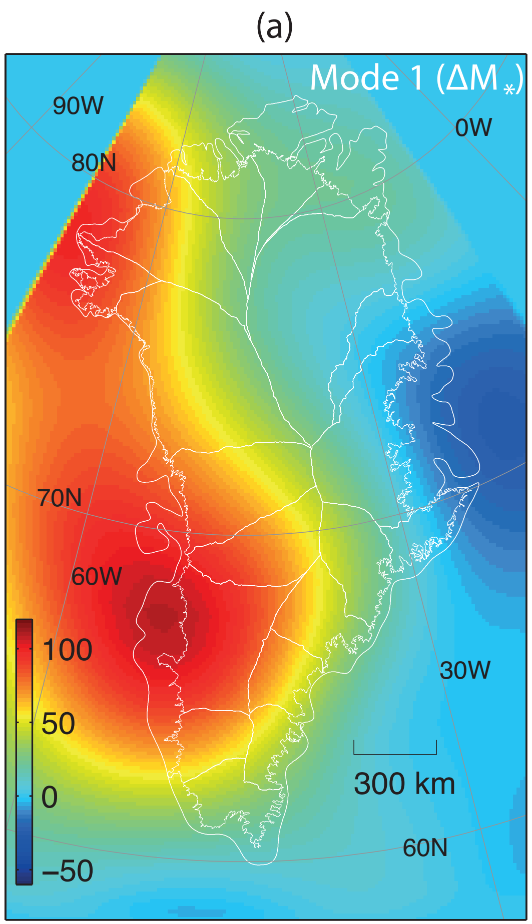
  ✓ The contribution from runoff is emerging in the most recent years, 2010 and 2012

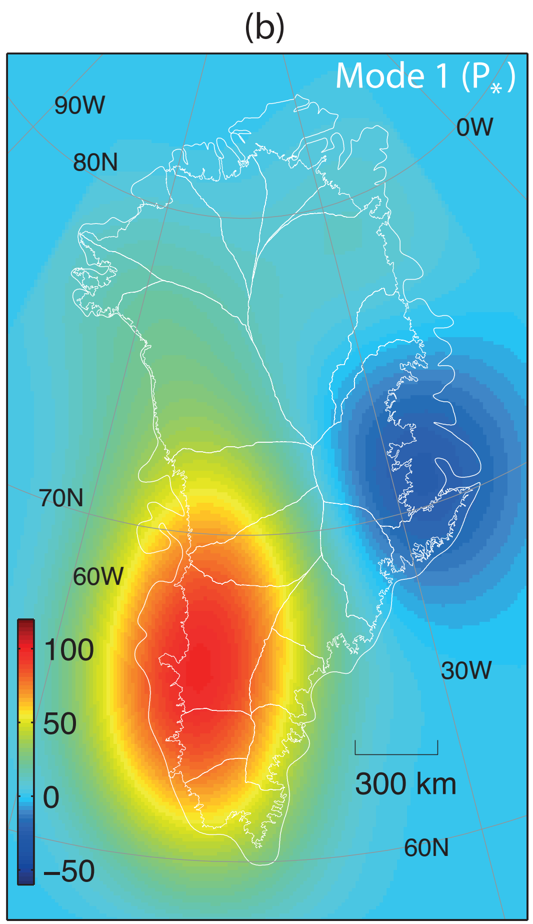
  ✓ Before extreme melting years (2010 and 2012), decrease in P (quadrature pattern in cumulative P) is the main cause of the SMB decrease.

Results– P_* vs ΔM_*

Combined EOF for P_* and ΔM_* for the co-variability

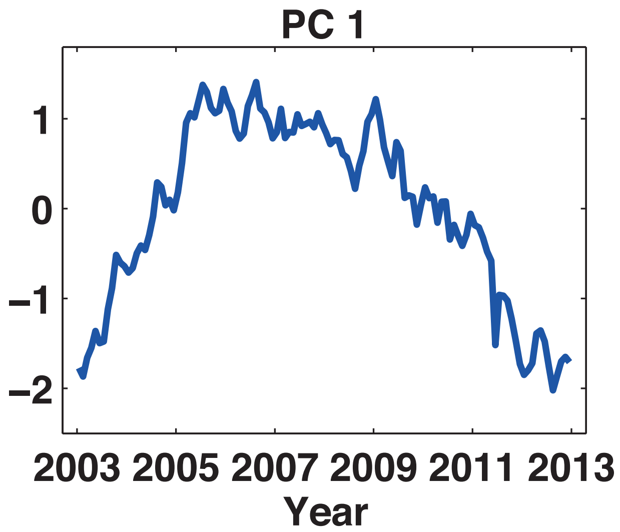


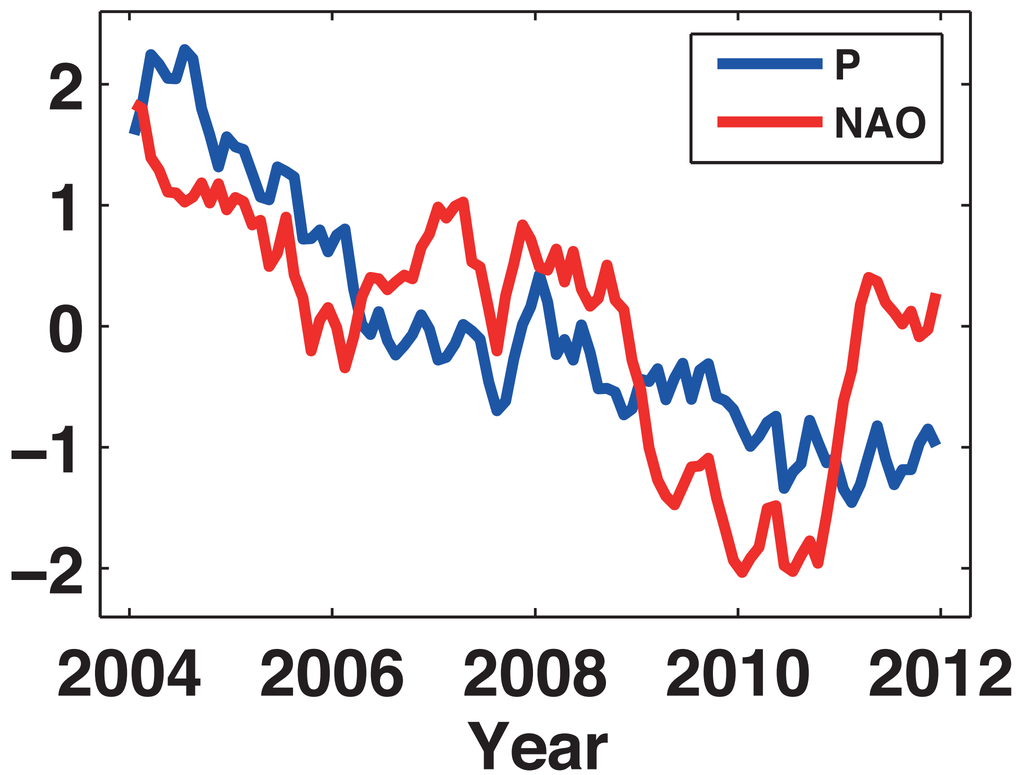




Results– P vs NAO

• We examine the correlation between precipitation and the North Atlantic Oscillation (NAO). Previous findings already indicated that the NAO influences Greenland precipitation rate (Appenzeller et al., 1998).



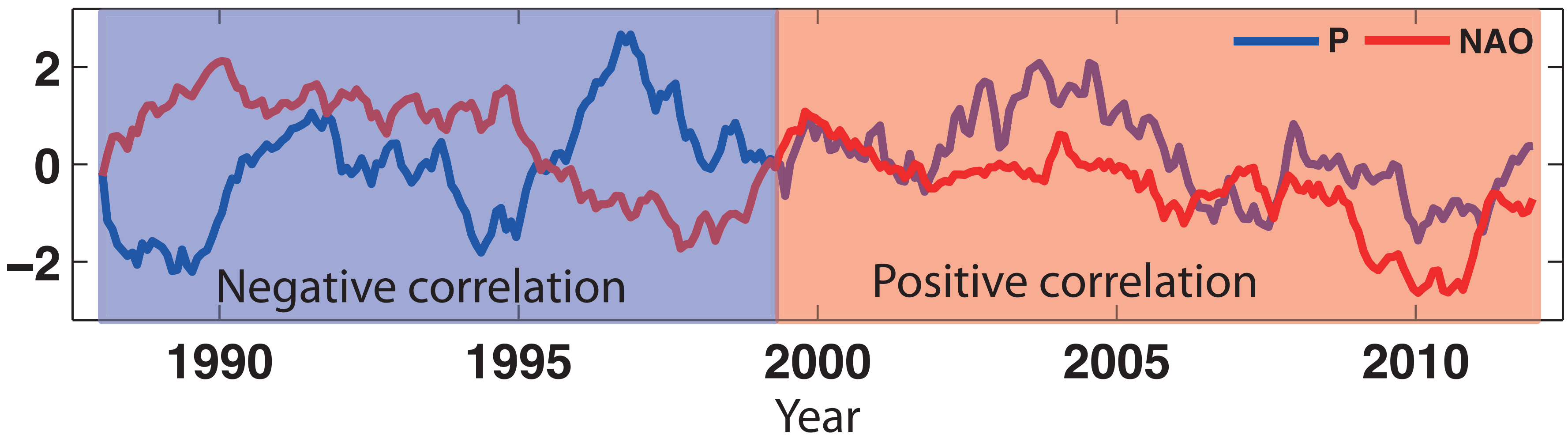


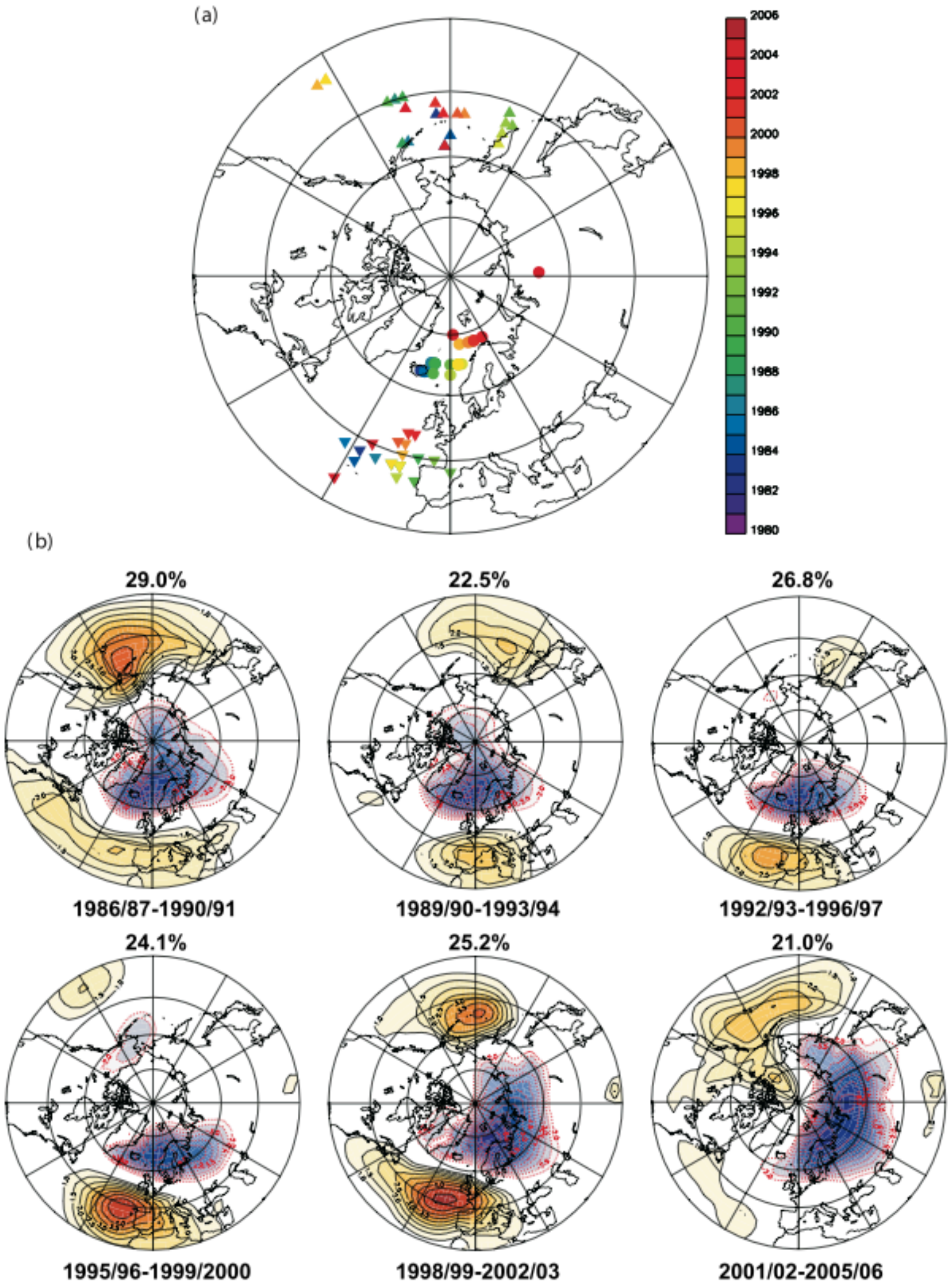
Results– P vs NAO

• Previous studies (Appenzeller et al., 1998; Johannessen et al., 2005) showed that Greenland precipitation is negatively correlated with NAO before 21st century.

• This study shows the positive correlation after GRACE era, since 2002.

• The correlation change might be related to the spatial redistribution of atmospheric circulation patterns in the Arctic. Since 1986, the poleward center of NAO patterns shifted from the Icelandic Sea to the Eurasian Arctic coast, and this progressive eastward shift was abrupt since the beginning of the 21st century (Zhang et al., 2008)





Zhang et al. (2008)

Conclusions (3-3)

- Estimate of the current GrIS mass loss acceleration rate
  ✓ -12.5±1.8 Gt/yr2 (from 2003 to 2012).
- Find causes of the acceleration
  ✓ Decrease in SMB explain the most acceleration, -10.9±1.6 Gt/yr^2
  ✓ Before extreme melting years (2010 and 2012), decrease in P is the main cause of the SMB decrease.
  ✓ The contribution from runoff is emerging in the most recent years, 2010 and 2012
- Suggest future sea level rise scenario
  ✓ It is cautious to project future sea level rise from the recent satellite observations (Wouters et al., 2013) because a part of acceleration in GrIS mass loss is associated with precipitation decrease driven by NAO, and the connection between precipitation and NAO in Greenland is suggested to undergo change.