

Projected increases in surface melt and ice loss and their potential feedbacks for the Northern and Southern Patagonian Icefields



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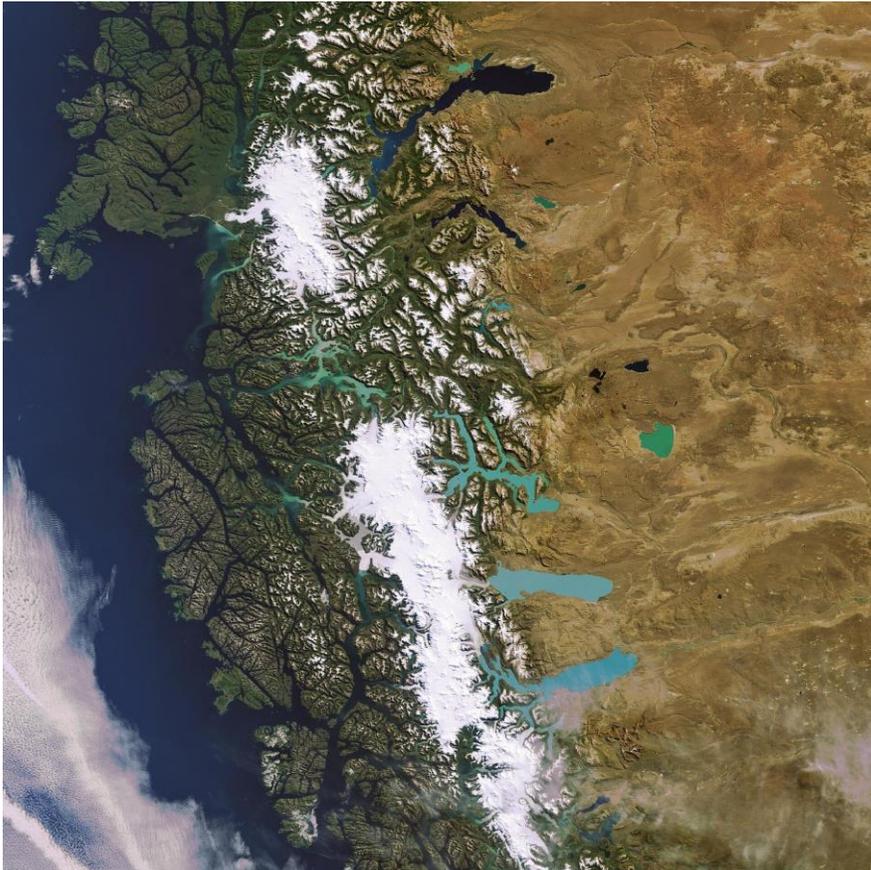


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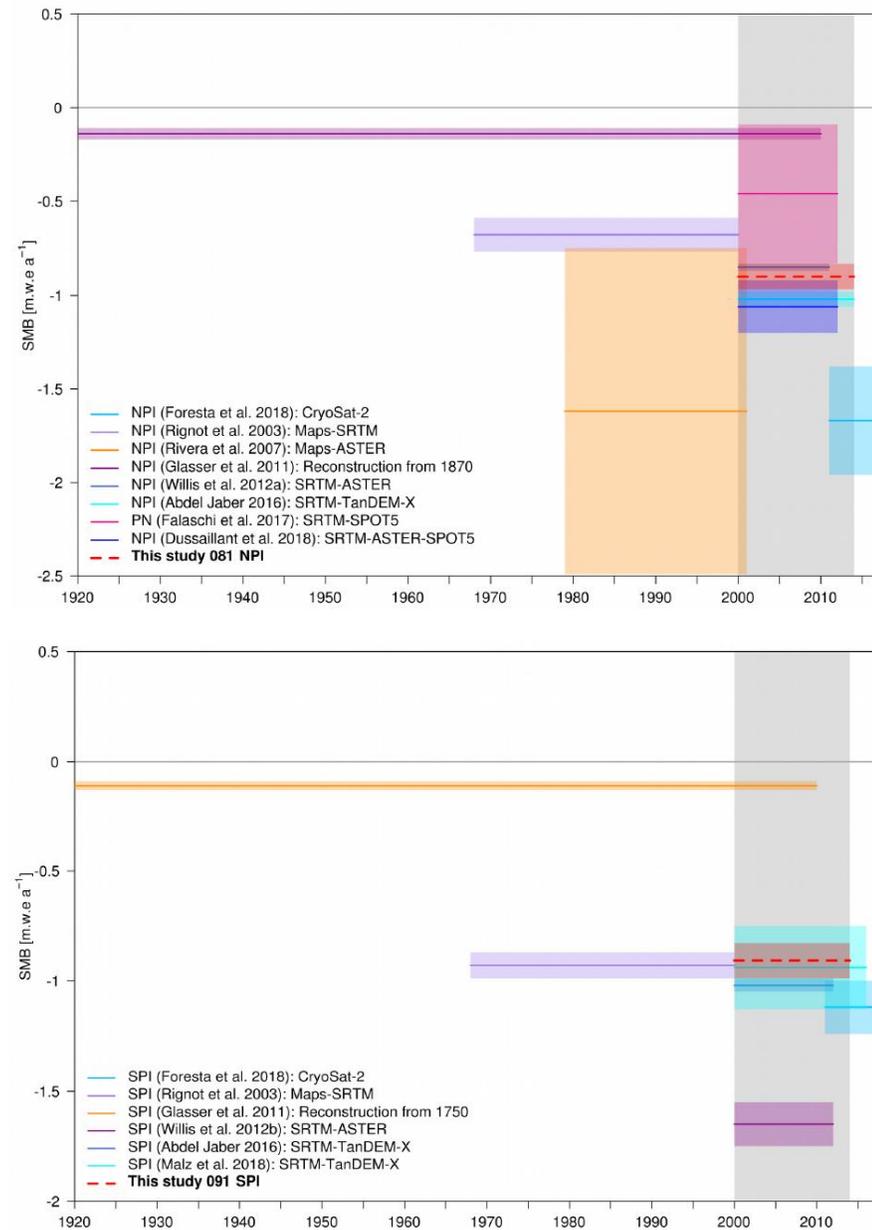


1. Background

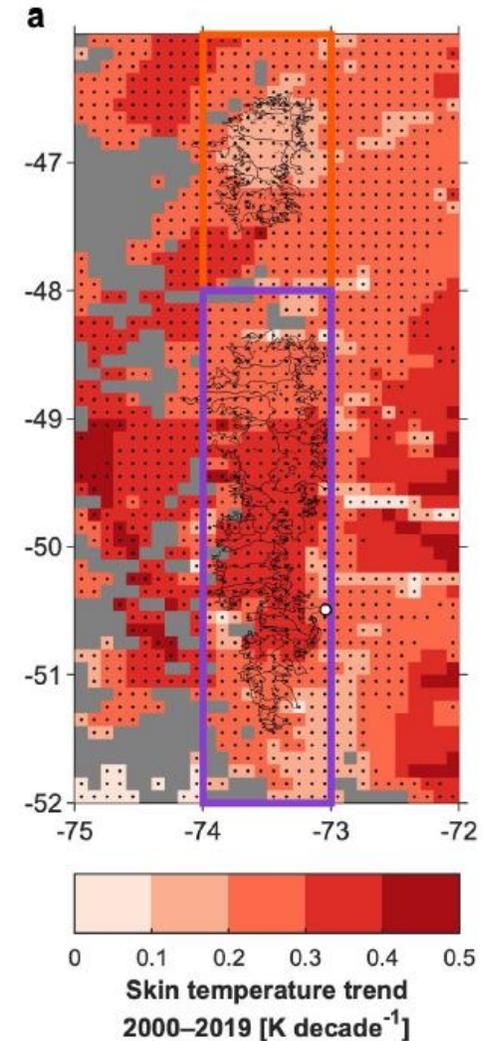
Patagonia (40°S-55°S) is the region of South America with the largest glaciers, most of which shrinking rapidly including the Icefields.



Ice loss (Braun et al., 2019)



Air temperature increase

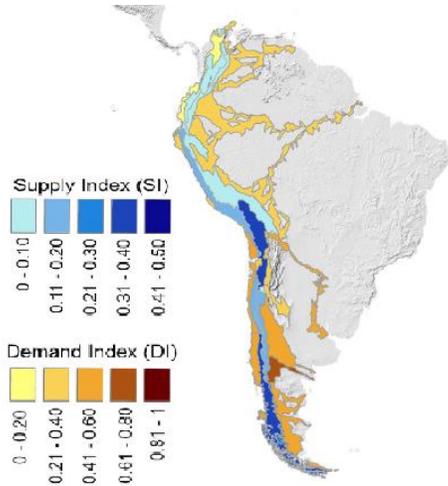
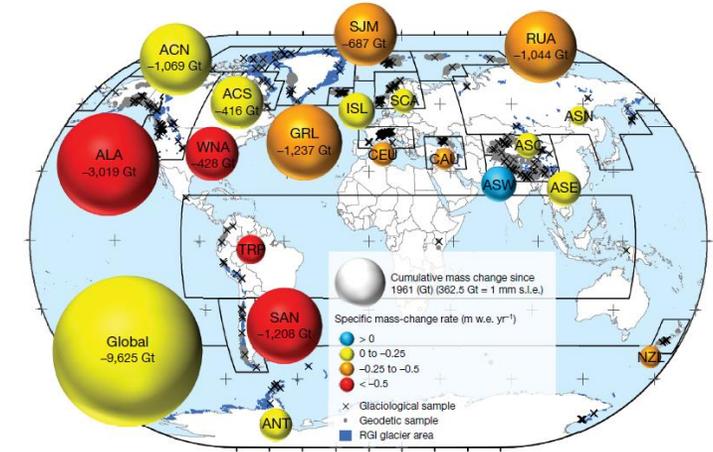


Minowa et al. (2021)

2. Why to assess the future response of the Patagonian Icefields?

Worldwide implications:

- Concern exists in relation to their sea-level rise contribution (Zemp et al., 2019).



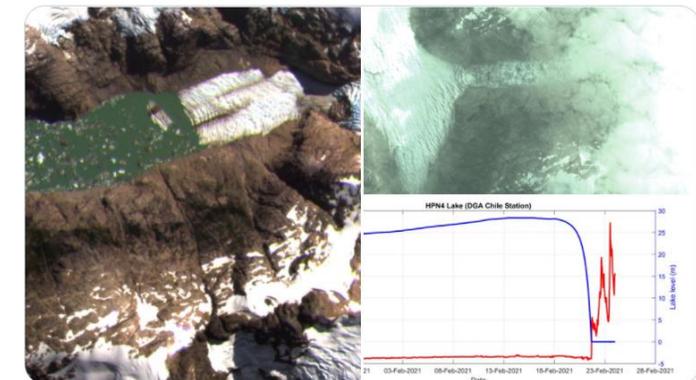
Regional implications:

- An increase demand on water resources for irrigation, domestic consumption and industrial activities has been recognized in southern South America and glacier meltwater are recognized as one of the main supplies (Immerzeel et al., 2020).

Local implications:

- Increase in both area and number of glacial lakes (Loriaux et al., 2013, Wilson et al., 2018, Shugar et al., 2020).
- Increase in landslide occurrence and glacial-lake outburst flood (GLOFs) events (Dusaillant et al., 2010, Wilson et al., 2018, Iribarren-Anacona et al., 2015).
- Increase in debris-covered area over ice surfaces (Glasser et al., 2016).
- Impacts on aquatic ecosystem and sediment dynamics (Gutierrez et al. 2015; Quiroga et al., 2016).

Claudio Bravo Lechuga @C_BravoLechuga · Feb 24
 HPN4 lake GLOF event in the Northern Patagonian Icefield, @planetlabs images 15 and 23 February, monitored by DGA Chile station cooperativa.cl/noticias/pais/... More info on the evolution of this lake realglacier.blogspot.com/2021/02/03-feb-2021.html



3. Aim

- to model the surface glacier mass balance response to future climate change on the Patagonian Icefields.

4. Materials and Methods

Approach: focus is on modelling the future response of both Icefields under two pathway scenarios using a regional climate model

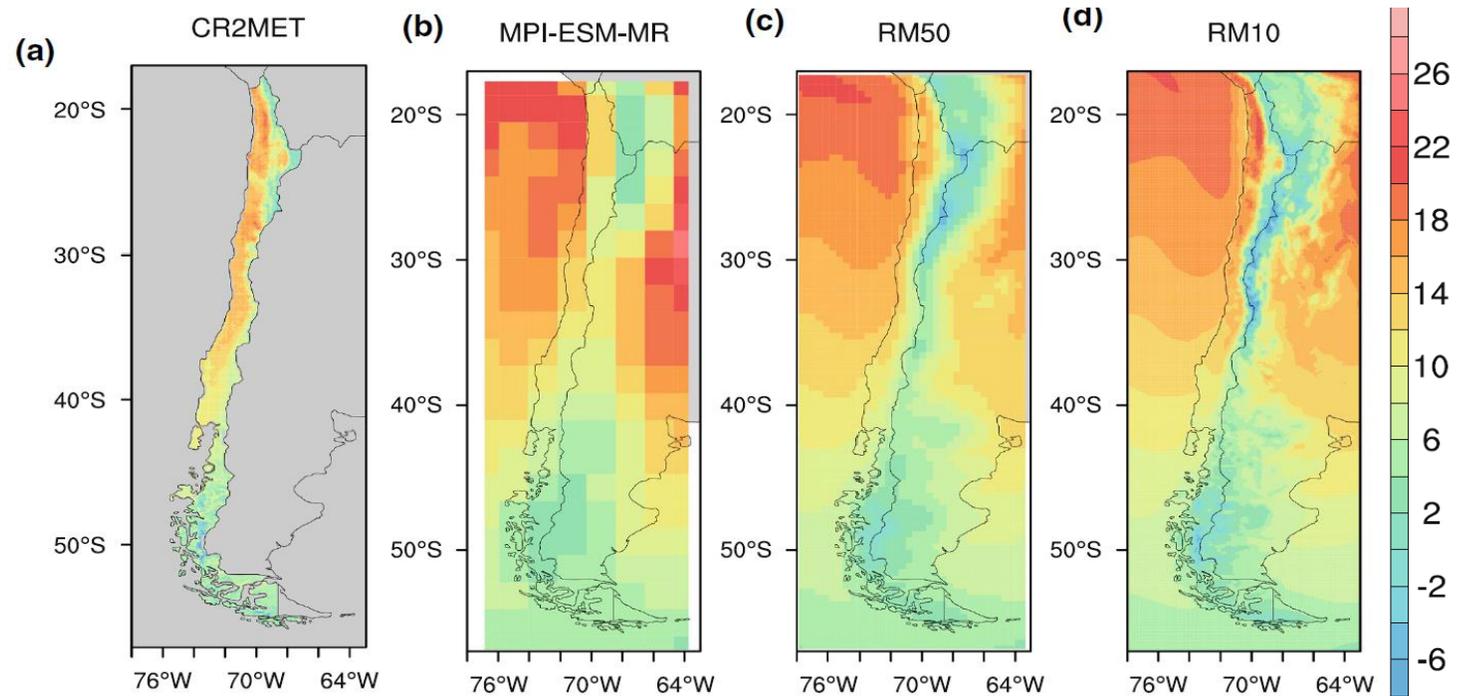
- RegCM4.6/MPI-ESM-MR Earth System Model (Bozkurt et al., 2019).
- Daily data. ~10 km spatial resolution
- Historical period (1976-2005).
- RCP (2006-2050) 2.6 and 8.5.

Ablation, Energy Balance Model (EBM):

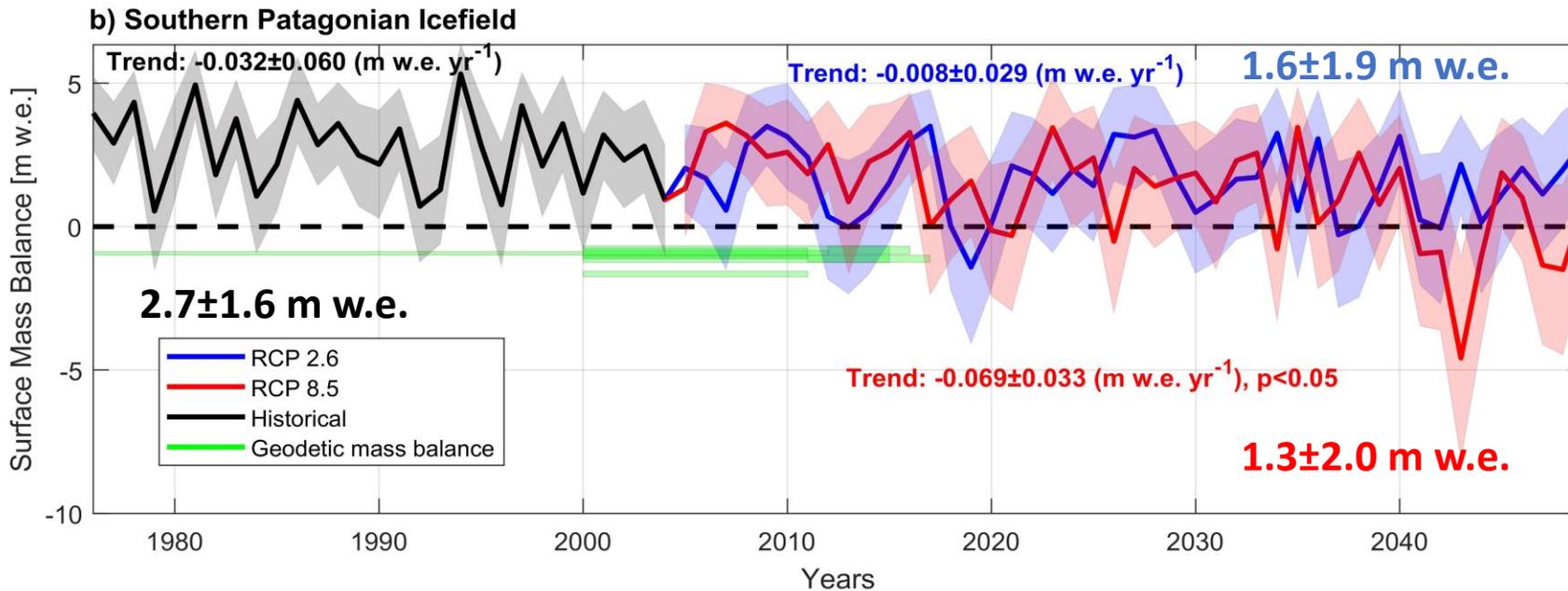
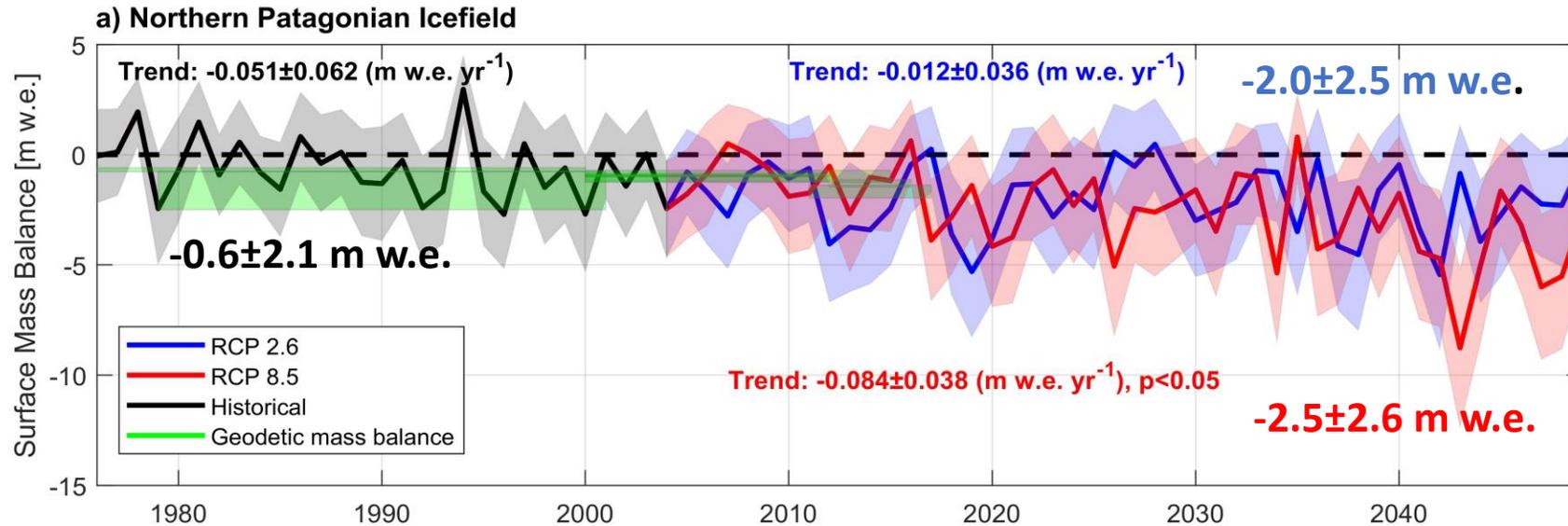
$$Q_m = (1 - \alpha) S_{in} + L_{in} + L_{out} + Q_h + Q_l + Q_r$$

Accumulation:

Phase Partitioning Methods (PPM, Bravo et al., 2019)

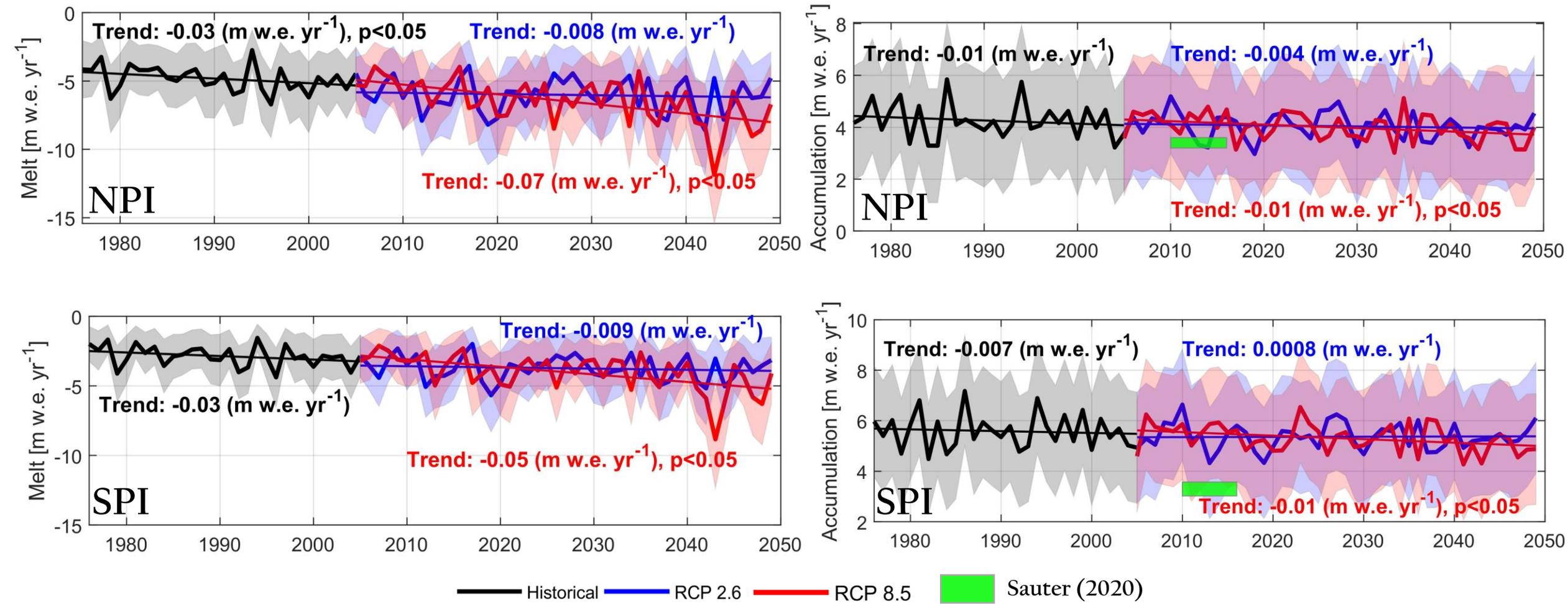


5. Results: Modelling the surface mass balance



- For the historical period, the mean SMB was negative in the NPI, in agreement with previously published geodetic mass balances in comparable periods.
- The NPI will be characterized by a notable negative SMB until 2050.
- No agreement with the geodetic mass balance.
- The SPI will continue to gain mass but with lower values compared to the historical period.

6. Results: Components of the surface mass balance



The variance of the annual SMB depends largely on the ablation (R^2 0.88 and 0.94 for the NPI and SPI respectively) rather than accumulation (R^2 of 0.57 and 0.73).

7. Results: Frontal ablation

Zeroth-order assumption

Frontal ablation

recent past = future

NPI: 2.4 Gt yr⁻¹ (1975-2016)

Minowa et al. (2021): 2.5 Gt yr⁻¹ (2000-2019)

SPI: 46 Gt yr⁻¹ (1975-2016)

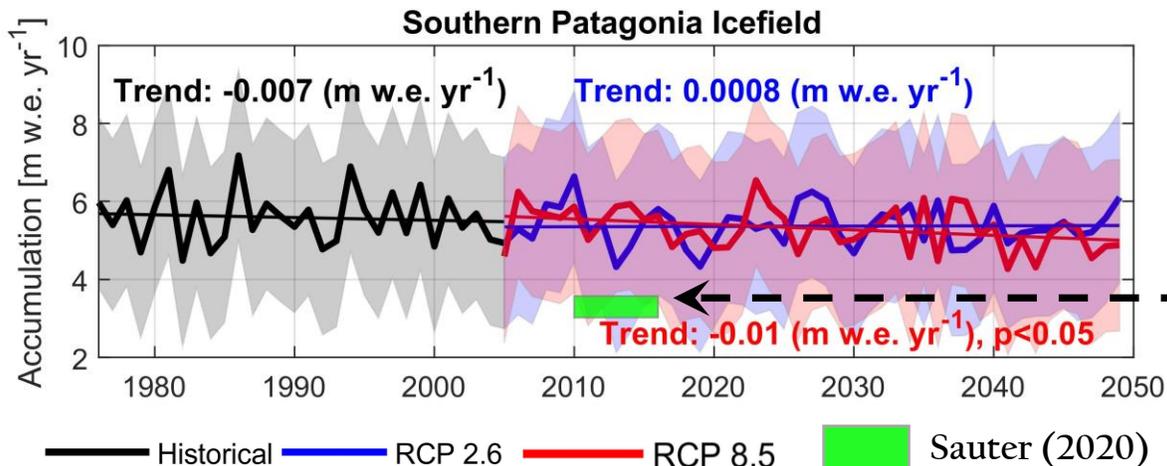
Schaefer et al. (2015): 40 Gt yr⁻¹ (1975-2000)
55 Gt yr⁻¹ (2000-2011)

Minowa et al. (2021): 22 Gt yr⁻¹ (2000-2019)

Frontal ablation is computed as the difference between surface mass balance and geodetic mass balance (Schaefer et al., 2015).

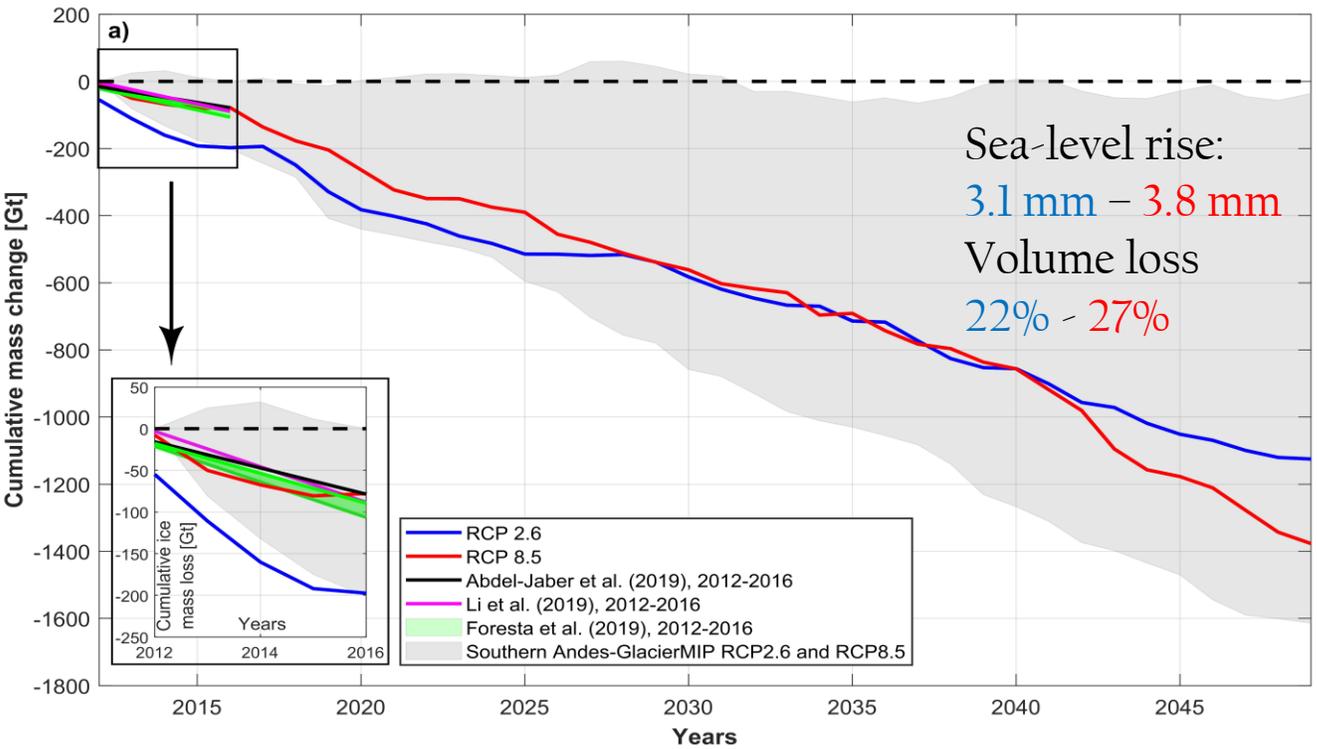
For the NPI, we derive a total frontal ablation contribution of 2.4 Gt yr⁻¹ in accordance with the robust estimation by Minowa et al. (2021) which estimated 2.5 Gt yr⁻¹.

The frontal ablation estimated by Minowa et al. (2021) in the SPI reaches 21.6 Gt yr⁻¹, which is far lower than our estimation and previous ones. To match this value, the SMB in the SPI must decrease ~ 1.5 m w.e. This reduction is in the SMB uncertainty range and could be associated mainly with the high uncertainty in define the actual accumulation.



If this is the case, the actual accumulation rate in the SPI will be close to the estimated by Sauter (2020) between 2010 and 2016, which is in the lower bound of the present estimation.

8. Results: Projected contribution to sea level-rise



Comparison of estimated sea-level contribution from the Patagonian Icefields by several authors. Data correspond to the annual rate estimate for the respective period.

Cumulative mass change estimated for both icefields combined between 2012 and 2050. For comparison purposes, data from GlacierMIP is showed (grey area). GlacierMIP ice mass loss corresponds to all the models runs under scenarios RCP2.6 and 8.5 computed for the Southern Andes RGI region. Ice mass loss estimations by Abdel-Jaber et al. (2019), Foresta et al.(2019) and Li et al. (2019) for the four first years (2012-2016) are also shown. Inset, corresponds to a detailed view of this period. Total equivalent sea-level contribution to year 2050 and ice loss volume is indicated.

	NPI	SPI	
Glasser et al. (2013)	0.0018 mm yr ⁻¹	0.005 mm yr ⁻¹	LIA-2010
Rivera et al. (2002)	0.032 mm yr ⁻¹		1945-1996
Rignot et al. (2003)	0.042 mm yr ⁻¹		1968/75-2000
Rignot et al. (2003)	0.105 mm yr ⁻¹		1995-2000
Chen et al. (2007)	0.078 mm yr ⁻¹		2002-2006
Li et al. (2019)	0.066 mm yr ⁻¹		2002-2016
Schaefer et al. (2013)	0.016 mm yr ⁻¹		21 st Century
This work	0.091 mm yr ⁻¹		2012-2050
	0.024 mm yr ⁻¹	0.067 mm yr ⁻¹	

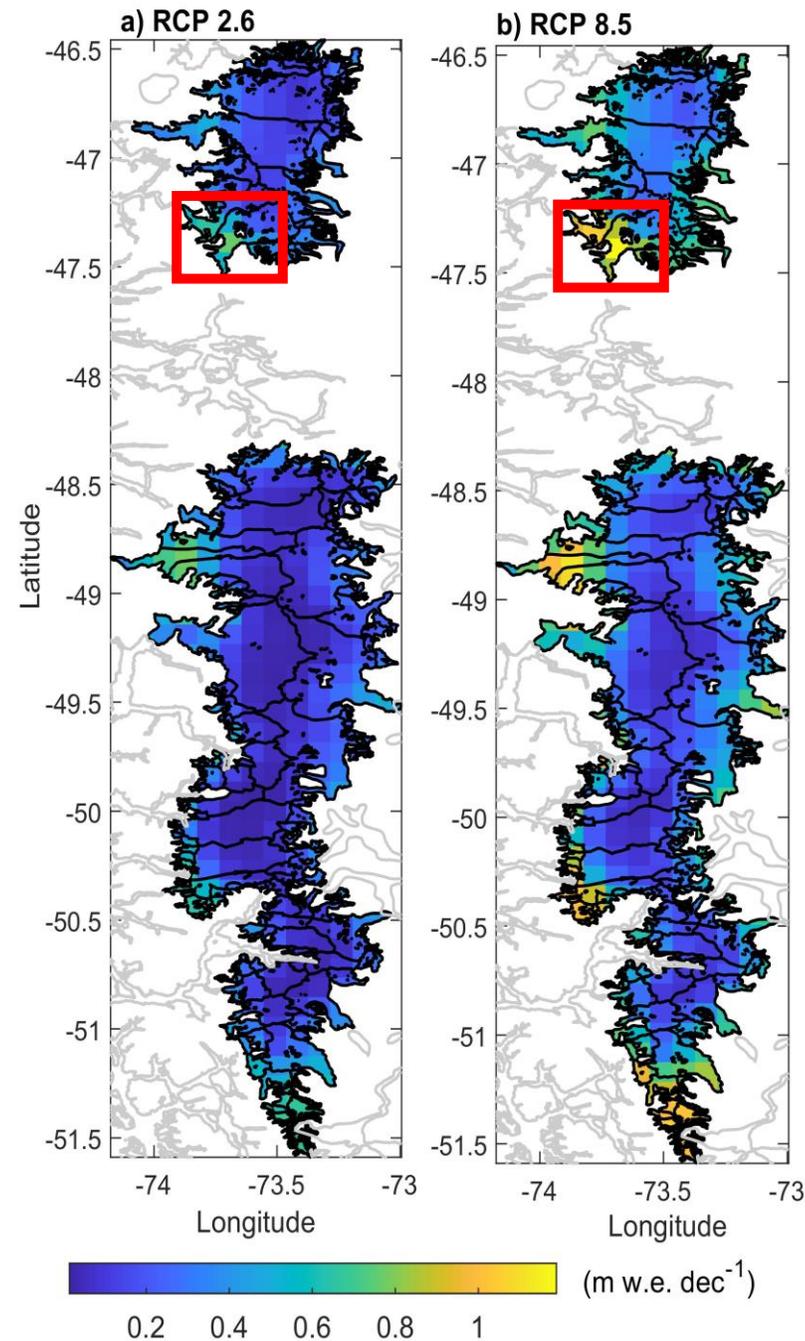
9. Feedbacks

Not accounted in the modelling (future work?):

- Debris cover area increase (Glasser et al., 2016)
- Supraglacial lake (Lo Vecchio et al., 2019)
- Nunataks area increase (Carrión et al., in preparation)

The main reason for the decrease in SMB is related to projected increases in meltwater, which in turn could trigger other mechanisms of glacier mass loss associated with ice dynamics and frontal ablation in glaciers with calving fronts (e.g. Minowa et al. 2017, 2021).

It is expected that the ice loss of some glaciers will be faster due to the presence of meltwater which acting as an ice loss positive feedback. For instance, Steffen and Acodado glaciers (red square), where a higher rate of melt increase is modelled, shows the most negative elevation changes in the NPI (Abdel-Jaber et al., 2019). Additionally, the frequency of GLOF in this area has increased in the last few years.



Spatially distributed melt trends over the Patagonian Icefields estimated with the EBM. Trends are from the hydrological year 1976/77 to 2049/50, following after 2005 the pathway scenario RCP 2.6 (a) and the pathway scenario RCP8.5 (b). Black lines are the glacier basins and grey lines are coastlines. All the grid points are significant ($p < 0.05$).

10. Key messages

The Patagonian Icefields in 2021:

Accumulation is still not well constrained. Models overestimate the accumulation especially in the SPI (Why the precipitation seems to be better represented in the NPI compared to the SPI?)

The atmospheric signal in the overall glacier mass loss it is more evident in the NPI (negative geodetic and surface mass balance) than in the SPI (negative geodetic mass balance and positive surface mass balance).

The Patagonian Icefields in 2050:

Lower surface mass balance for both Icefields. Negative in the NPI and positive (or barely negative) in the SPI.

Sea-level rise between 3.1 and 3.8 mm due to Patagonian Icefields ice loss between 2012 and 2050.

A total volume reduction for both Icefields between 22% and 27% is projected under the RCP2.6 and RCP8.5 respectively.

The main reason for the decrease in SMB is related to projected increases in meltwater, which in turn could trigger other mechanisms of glacier mass loss associated with ice dynamics and frontal ablation in glaciers with calving fronts.

Questions?



¡Muchas gracias!

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