Global glacier volume projections under high-end climate change scenarios

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The Paris Agreement

Hold global warming to well below 2°C and to "pursue efforts" to limit it to 1.5°C but …

PERSPECTIVE

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Paris Agreement climate proposals need a boost to keep warming well below 2 °C

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The Paris climate agreement aims at holding global warming to well below 2 degrees Celsius and to "pursue efforts" to limit it to 1.5 degrees Celsius. To accomplish this, countries have submitted Intended Nationally Determined Contributions (INDCs) outlining their post-2020 climate action. Here we assess the effect of current INDCs on reducing aggregate greenhouse gas emissions, its implications for achieving the temperature objective of the Paris climate agreement, and potential options for overachievement. The INDCs collectively lower greenhouse gas emissions compared to where current policies stand, but still imply a median warming of 2.6–3.1 degrees Celsius by 2100. More can be achieved, because the agreement stipulates that targets for reducing greenhouse gas emissions are strengthened over time, both in ambition and scope. Substantial enhancement or over-delivery on current INDCs by additional national, sub-national and non-state actions is required to maintain a reasonable chance of meeting the target of keeping warming well below 2 degrees Celsius.

2.6-3.1 degrees based on intended carbon contributions

nature climate change

LETTERS

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Less than 2 °C warming by 2100 unlikely

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The recently published Intergovernmental Panel on Climate Change (IPCC) projections to 2100 give likely ranges of global temperature increase in four scenarios for population, economic growth and carbon use[1]. However, these projections are not based on a fully statistical approach. Here we use a country-specific version of Kaya's identity to develop a statistically based probabilistic forecast of CO_2 emissions and temperature change to 2100. Using data for 1960–2010, including the UN's probabilistic population projections for all countries[2–4], we develop a joint Bayesian hierarchical model for Gross Domestic Product (GDP) per capita and carbon intensity. We find that the 90% interval for cumulative CO_2 emissions includes the IPCC's two middle scenarios but not the extreme ones. The likely range of global temperature increase is 2.0–4.9 °C, with median 3.2 °C and a 5% (1%) chance that it will be less than 2 °C (1.5 °C). Population growth is not a major contributing factor. Our model is not a 'business as usual' scenario, but rather is based on data which already show the effect of emission mitigation policies. Achieving the goal of less than 1.5 °C warming will require carbon intensity to decline much faster than in the recent past.

is a specific version of the IPAT equation, Impact = Population × Affluence × Technology. We use data from 1960 to 2010 on GDP per capita and carbon intensity for most countries. We build a joint Bayesian hierarchical statistical model for GDP per capita and carbon intensity in most countries, and combine it with the UN probabilistic population projections to produce a predictive distribution of quantities of interest to 2100. We develop a probabilistic forecast of global temperature increase by combining them with the relationship between cumulative CO_2 emissions and temperature used by the IPCC[15].

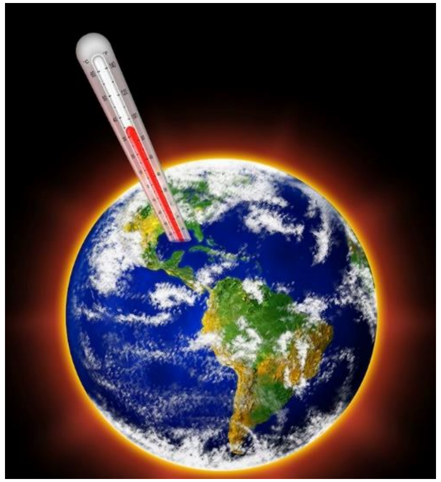
For GDP per capita we use a Bayesian hierarchical model for all countries based on the idea of a world technology frontier (represented by the US for the period of our data), towards which countries may converge[16]; see Supplementary Fig. 1. The frontier is modelled by a random walk model with constant drift[17,18]. This allows countries with high current growth rates to continue growing fast in the short to medium term, while avoiding unrealistically high long-term forecasts.

To model carbon intensity, we note that most countries have reached a peak intensity; subsequently their carbon intensity has been trending downwards, as illustrated in Fig. 1. Note that we posit

2-4.9 degrees with only a 5% chance of staying below 2 degrees

Working towards “The JULES-integrated impacts model”

Climate change



Glacier scheme

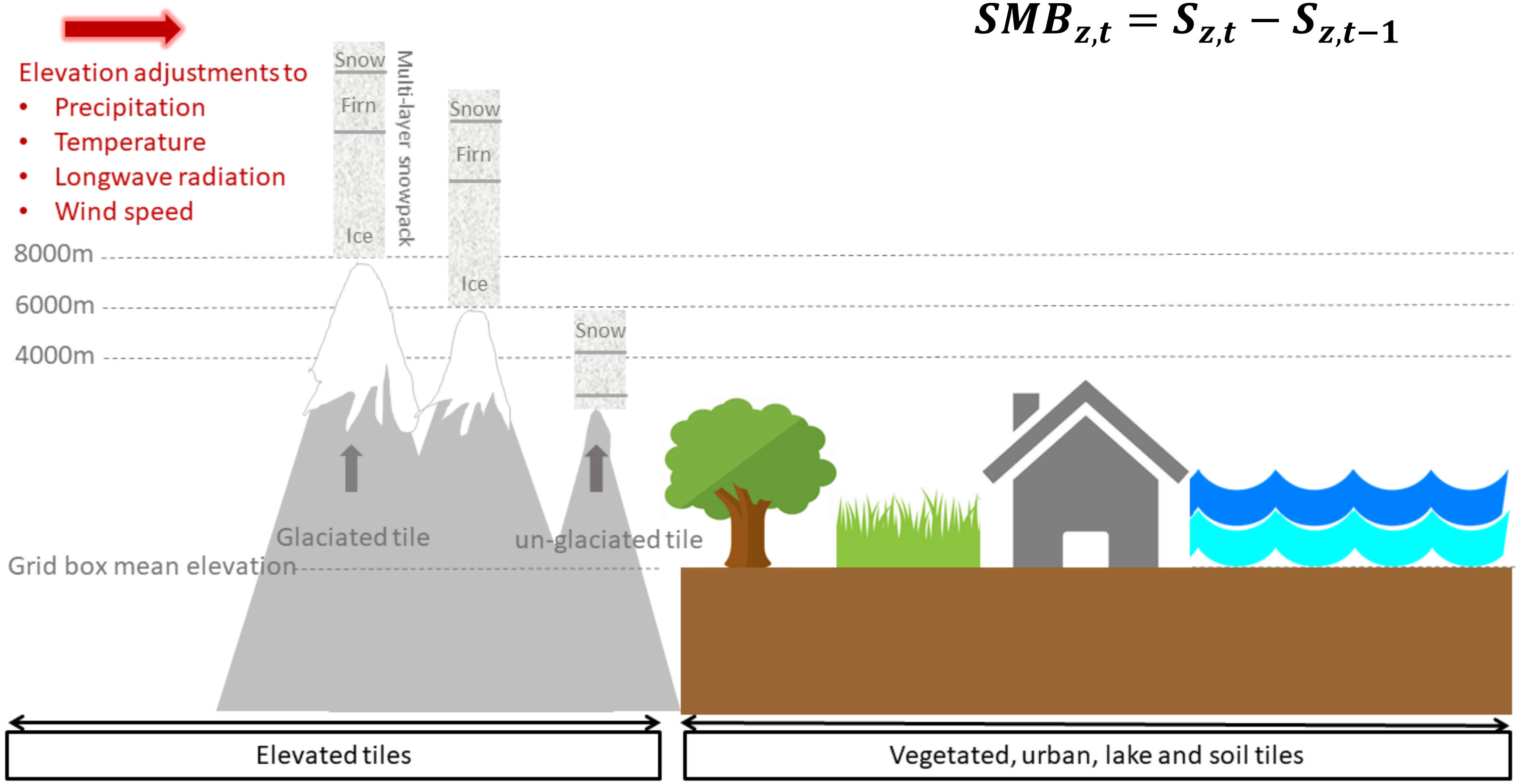
River routing (TRIP/RFM)

Irrigation demand

Crop (wheat, soybean, maize and rice)

Elevation-dependent mass balance model (version 4.7)

$$SMB_{z,t} = S_{z,t} - S_{z,t-1}$$



Elevated tiling – Robin Smith, NCAS, Reading
Climate adjustments – Andy Wiltshire, Met Office

Adjust climate for elevation

- Set elevation bands (for example 0:250:9000m)

Lapse rate adjust

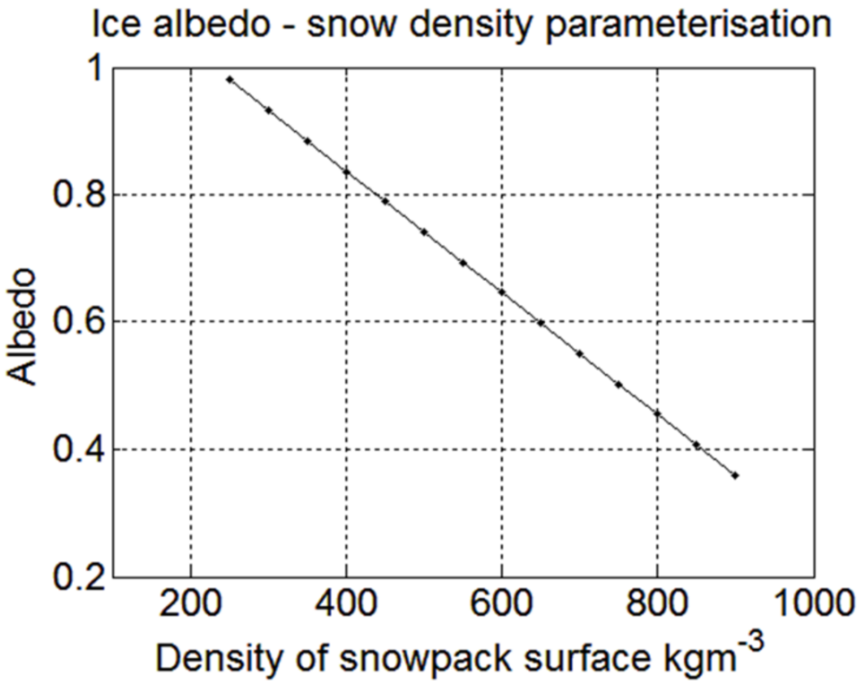
- Air temperature ($^oCm^{-1}$) tuneable
- Precipitation (%/100m) tuneable. Convert rain to snow if $T_z < 0^oC$
- Downward longwave radiation is adjusted for elevation

$$LW \downarrow = \varepsilon_{cs} \sigma T_z^{\ 4}$$

ε_{cs} is the clear sky emissivity, σ is Stefan-Boltzmann constant and T_z elevated air temperature.

- Linearly scale wind speed

Albedo scheme, (Greuell and Konzelmann,1994)



Use snow scheme if density > firn density

$$\alpha = \alpha_i + (\boldsymbol{\rho_{ss}} - \rho_i)\left(\frac{\alpha_s - \alpha_i}{\rho_s - \rho_i}\right)$$

- $\boldsymbol{\rho_{ss}}$ is the density of the top 10cm of the snowpack > firn density
- α_s maximum albedo of fresh snow (0.98 0.7), α_i albedo of ice (0.36 0.25), ρ_s is the density of fresh snow (250kgm^{-3})and ρ_i is the density of ice (910kgm^{-3})
- New parameter aicemax (similar to amax but for ice)

Initialisation

- Elevated ice tile fraction

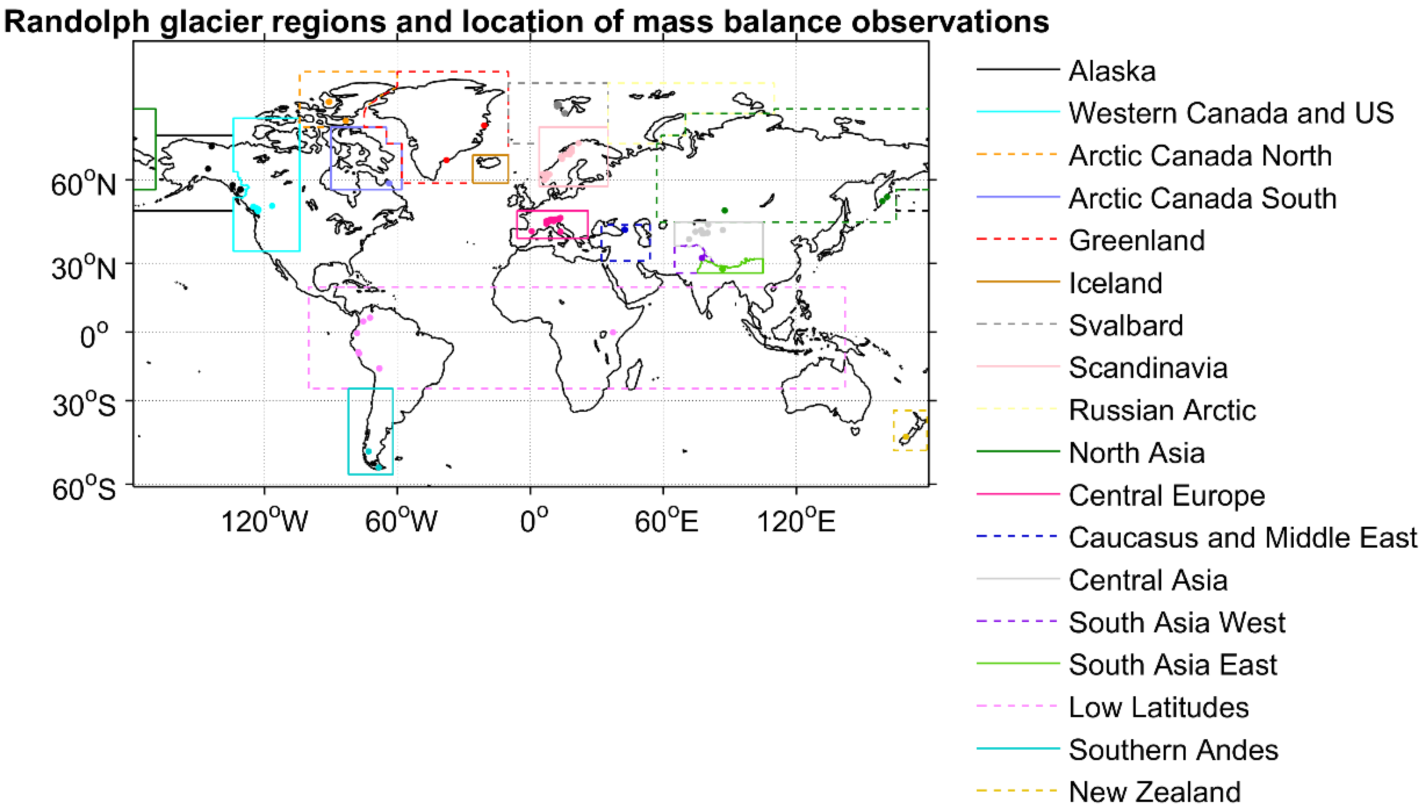
$$\boldsymbol{frac_{ice(n)} = \frac{RGI\_area(n)}{gridbox\_area(n)}}$$

RGI_area from Randolph Glacier Inventory Version 6 (RGI6)

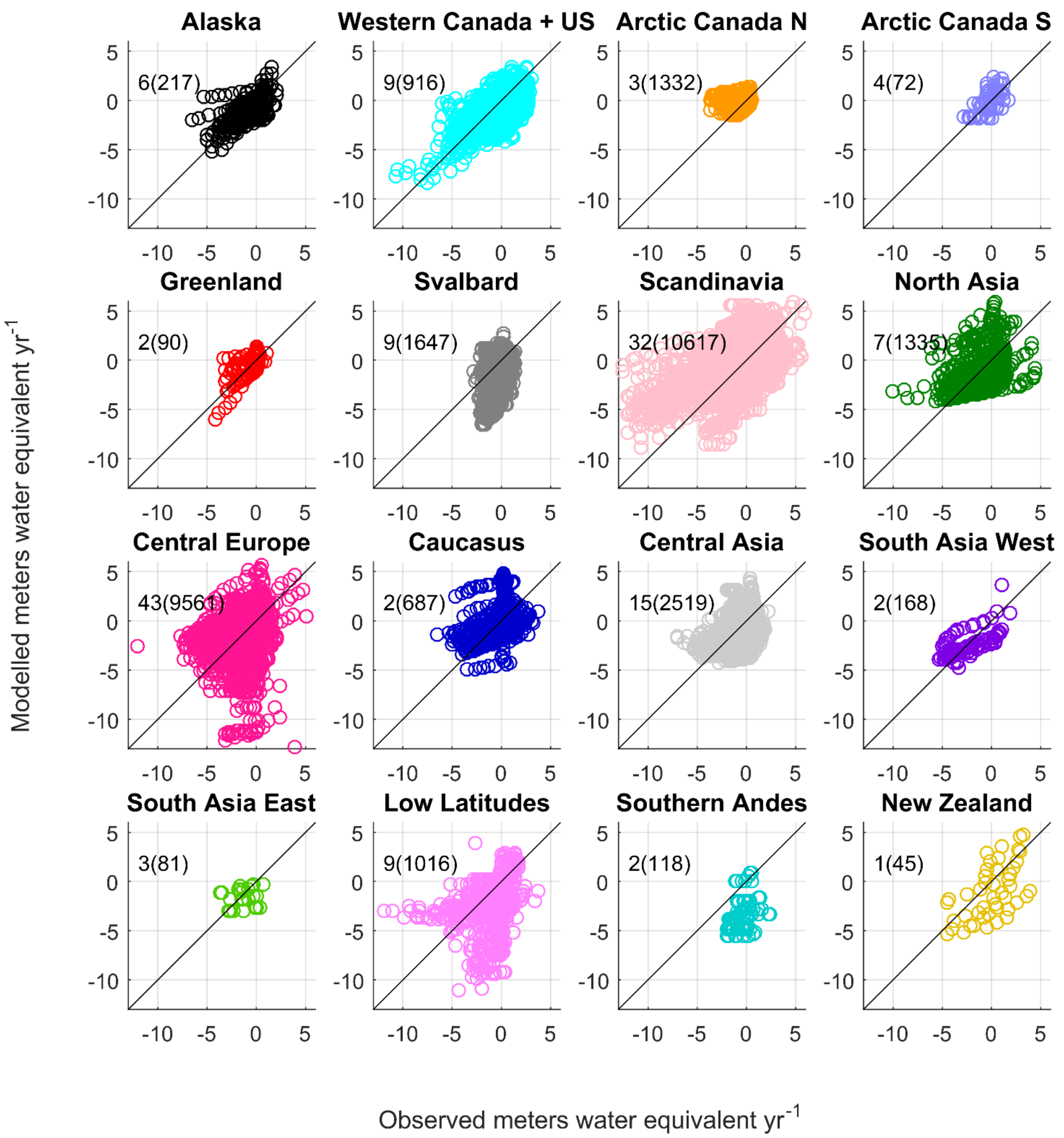
- Snowpack properties (10 levels)
  - snow_ds
    - Future RGI6 thickness
    - Calibration 1000m never depletes
  - snow_ice
    - Future runs RGI6
    - Calibration large enough to not deplete (1000m x density ice)
  - snow_liq = 0
  - rgrain (50µm surface), 2000µm bottom)
  - tsnow – 10 year spin up top = Jan bottom = annual

Calibrating present day mass balance

Parameter	Range
Fresh snow albedo (VIS)	0.99 - 0.7
Fresh snow albedo (NIR)	0.85 - 0.6
Ice albedo (VIS)	0.7 – 0.05
Ice albedo (NIR)	0.6 – 0.05
Temperature lapse rate	3 – 9.8 $^{o}K\ km^{-1}$
Precipitation gradient	0 – 25 %/100m
Wind speed scale factor	1 - 5

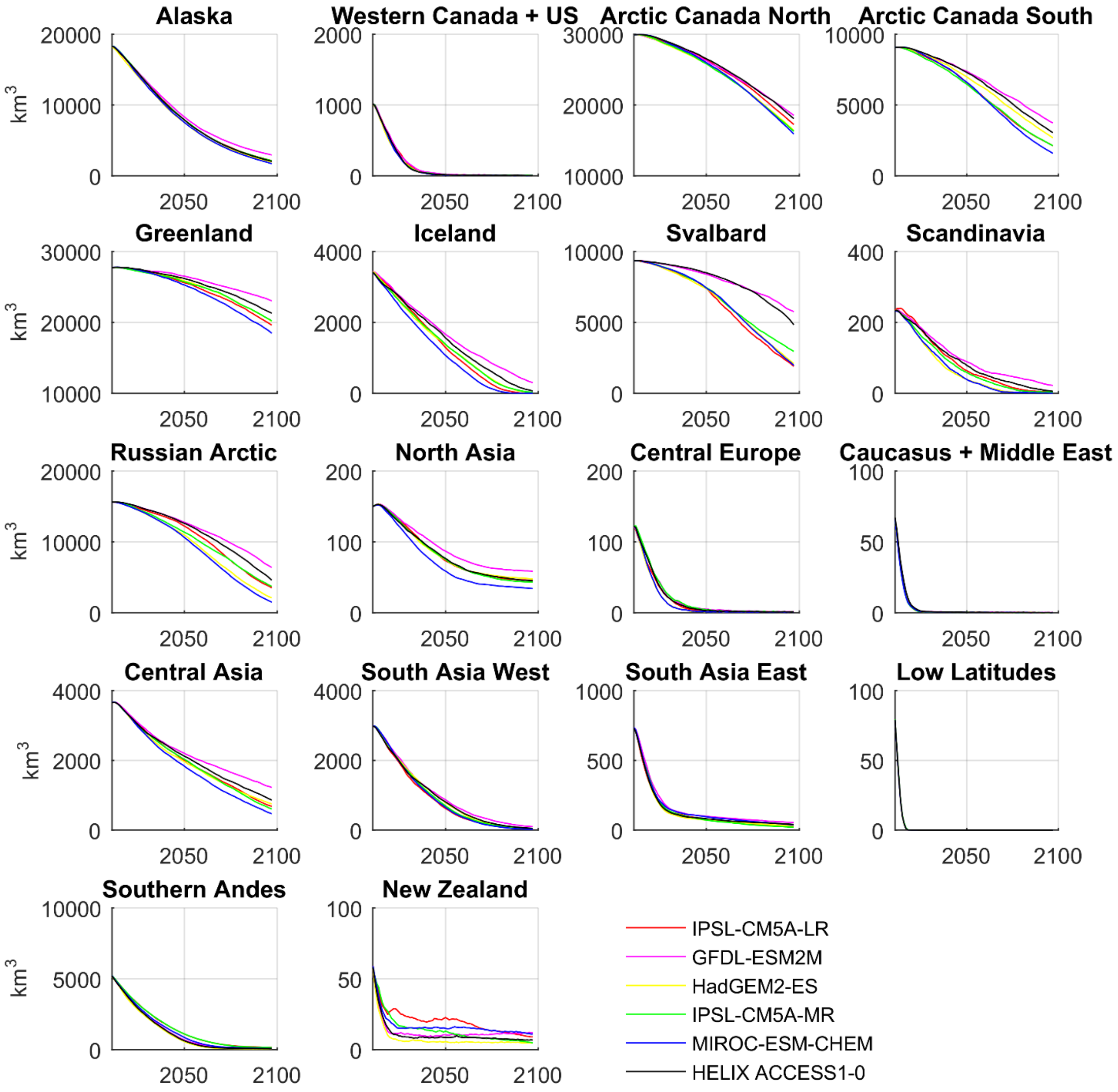


- 198 combinations selected using Latin Hyper Cube Sampling
- RUN with WATCH Era-interim data 1980-2014
- Parameter ranges from literature
- Best parameter sets selected by minimising RMSE



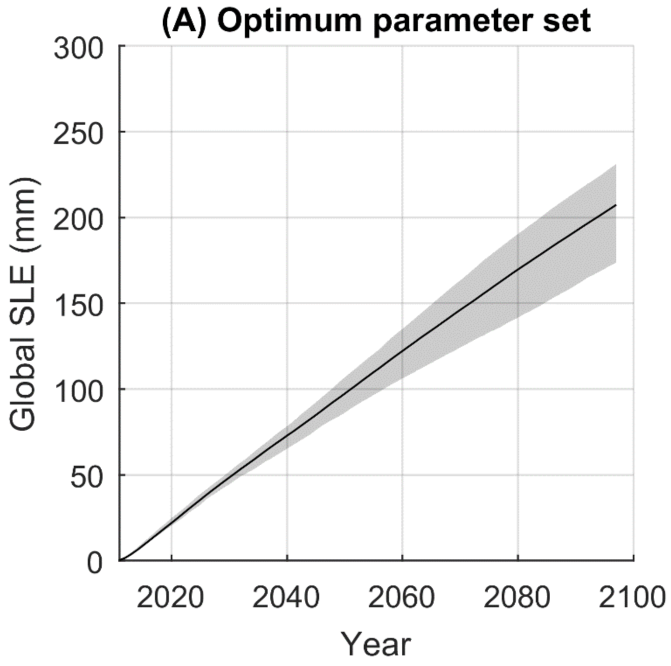
Alaska
6(217)
Western Canada + US
9(916)
Arctic Canada N
3(1332)
Arctic Canada S
4(72)
Greenland
2(90)
Svalbard
9(1647)
Scandinavia
32(10617)
North Asia
7(1335)
Central Europe
43(9561)
Caucasus
2(687)
Central Asia
15(2519)
South Asia West
2(168)
South Asia East
3(81)
Low Latitudes
9(1016)
Southern Andes
2(118)
New Zealand
1(45)
Modelled meters water equivalent yr^{-1}
Observed meters water equivalent yr^{-1}

End of century glacier volume changes

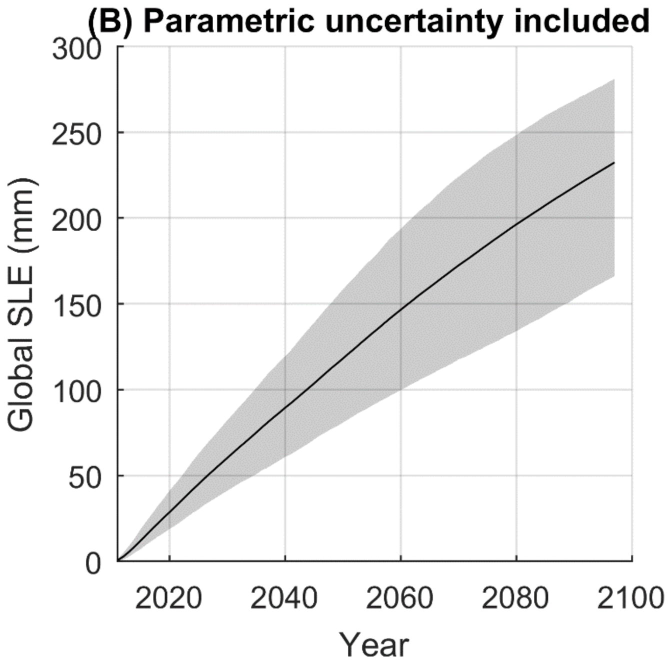


- Downscaled CMIP5 data using HadGEM3-A
- Subset of six CMIP5 RCP8.5 models that pass 1.5 and 2°C during this century
- 215 ± 20mm which is higher than 188mm (Radic et al. 2014) and 136±23mm (Huss and Hock 2015) caused mainly by greater contributions from Alaska, Southern Andes and the Russian Arctic

Global sea level rise projections



215 mm (range 57mm)



227mm (range 115mm)

Glacier Model Intercomparison Project

Background and motivation

Currently, glaciers (here defined as all glaciers other than the ice sheets) contribute approximately just as much to global sea level as the Antarctic and Greenland ice sheets combined, and will continue to be important contributors during the 21st century. They are also important regulators of seasonal water availability in many regions, and both growing and shrinking glaciers may cause geohazards. Hence, it is essential to develop accurate predictive tools of the glaciers' response to climate variability and change suitable for regional to global scales.

Goals and Objectives of GlacierMIP

The overall goal is to provide – for the first time - a framework for a coordinated intercomparison of global-scale glacier mass change models to foster model improvements and reduce uncertainties in global glacier projections.

The specific objectives are:

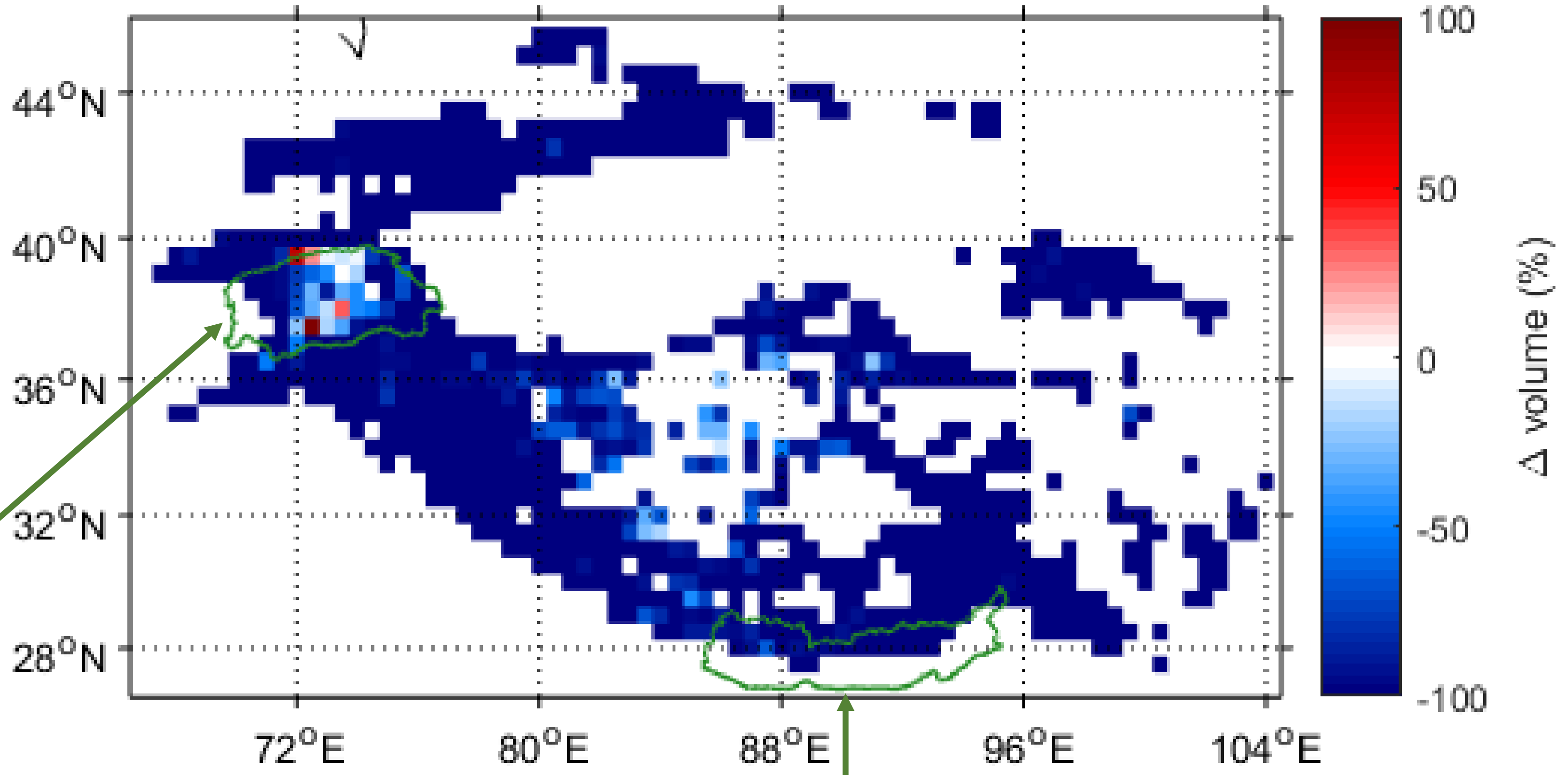
1. to coordinate a model intercomparison of existing state-of-the-art large-scale glacier models with respect to decadal to century scale glacier mass change projections (and possibly century scale past reconstructions),
2. to identify current model deficiencies and data needs, and work towards a new generation of global-scale glacier models that allow more accurate projections
3. to work closely with other internationally coordinated activities/organizations such as the Ice Sheet Model Intercomparison Project for CMIP6, ISMIP6, to ensure our data outputs follow shared standards, or the IACS Working Groups on the "Randolph Glacier Inventory and Infrastructure for Glacier Monitoring", and "Glacier Ice Thickness Estimation") to ensure that necessary data for initial and boundary conditions of the experiments are available.
4. to disseminate results through publications and presentations at conferences and workshops.

Our goals will be achieved through a community-based definition of standardized experiment designs, forcing data, and deliverable output variables, as well as the definition of deadlines, milestones and deliverables.

Open call for participation

The 4-year activity was started in February 2015. Modelers performing global-scale modeling are invited to participate in the model intercomparison. Participants are

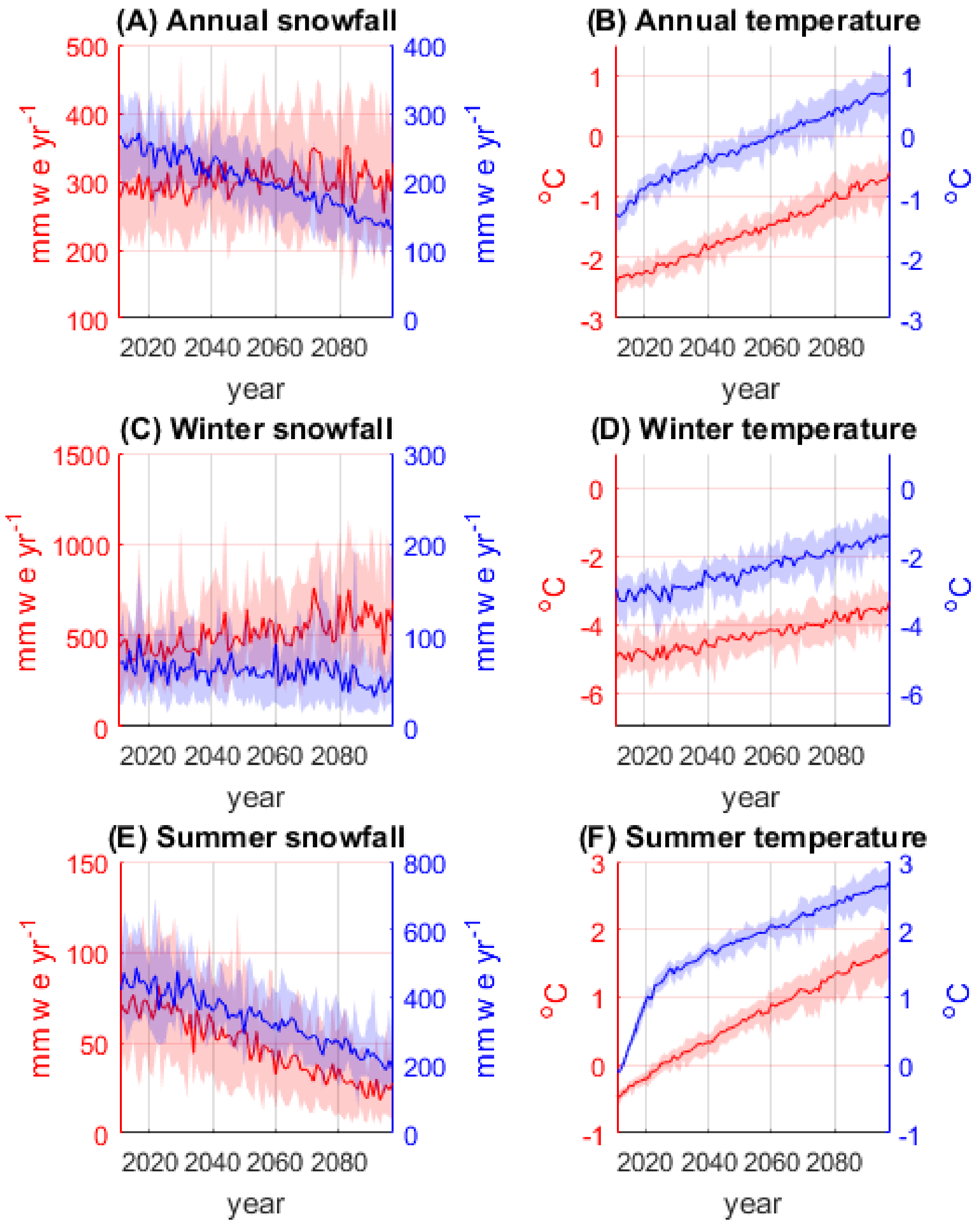
End of the century volume changes



Pamir (winter accumulating glaciers)

Eastern Himalayas (summer accumulating glaciers)

Explanation for Pamir mass gain



Pamir region
Eastern Himalaya

- Glaciers in Eastern Himalaya accumulate mass in summer – snowfall is decreasing
- Glaciers in the Pamir regions accumulate mass in winter – snowfall is slightly increasing
- Pamir region (red) is colder than Eastern Himalaya (blue)

Pros and cons of JULES-glacier

- Elevated ice can not share a gridbox with other tiles – can not mix ice and vegetation tiles
- Not fully coupled to the atmosphere
- Simple physics
  - No ice flow - glacier area is fixed
  - Albedo ~ surface density i.e. glaciers are clean - no debris
  - simple treatment of wind speed

- Full energy balance
- Linked to land surface model – crop (wheat, soybean, maize and rice), river routing, irrigation scheme.

Thank you