Workshop Output Form to be submitted (max. 4 pages)

Title of workshop: W 2.3B Consequences of climate change for the cryosphere

Prepared by

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* Workshop participants that have submitted contributions to the workshop

General questions to please be answered in the workshop reporting

1) What was the focus of the workshop? Methodological issues and advancements or thematic issues (systems knowledge, transformation knowledge, target knowledge). Please check and fill in the matrix in the output section.

Methodological issues and advancements	**Thematic issues**		
	System knowledge	Transformation knowledge	Target Knowledge

WORKSHOP QUESTION: What are the key remaining unknowns about how the snow, glaciers and permafrost across the mountains of the world will change in the coming century?

- **Not sure where this sits in the matric table.**
- **Generally this topic was probably too broad to focus a discussion – better to pin it down from the workshop proposal stage to a specific question e.g. What cryospheric measurements do we need to target and why?**
- **Nevertheless it was an interesting discussion.**

2) Which key points were discussed in the workshop as a whole? (This should be more a synthesis and not simply a summary of the key points in each presentation)

We discussed what are key knowledge gaps for the participants research, some are listed below:

- deeper statistical understanding needed to analyze increasing climate and snowfall/snow evolution model data outputs
- predicting snow might be broadly more 'problematic' than predicting glaciers
- snow studies may be underutilizing the potential of satellite radar products to derive snow properties to supplement snow extent
- but otherwise essential snow properties such as SWE rely on (sometimes poorly validated) snow models

- critical scarcity of data on basic glacier properties required for model validation/calibration in some regions (e.g. NZ and Andes)
- step change in glacier remote sensing observations thanks to new satellites (e.g. Sentinel-2), but quality of DEMs still a challenge (causing mismatches in orthorectifying these images) – thereby limiting the potential applied benefit
- discontinuous permafrost distribution based on modeling potential – still fairly inaccurate, and has consequences for other parts of the mountain system – needs new investigations e.g. machine learning applications

Then we sought opinions of all attendees on critical challenges in quantifying the (a) present and (b) future state of the cryosphere and identifying (c) key impacts of the changing cryosphere on society.

3) What is your opinion on the current state of knowledge concerning your topic(s) (focusing on mountain regions)? *Please check and fill in the matrix on the following page.*

Drawing on Christians notes on the speakers presentations, our panel discussion and the post-it note contributions of all participants, Lindseys synthesis of the whole workshop is below:

Not new, but fundamentally we are vulnerable to uncertainty in future climate modeling – **are we communicating our specific needs to that community**?

- particularly mountain climate gradients
- cryosphere-atmosphere feedbacks

There is room for work to **improve global DEMs so that the quality of Sentinel 2 imagery can be capitalized upon** – this may apply to many mountain disciplines.

Global analyses are needed:

- particularly these are lacking for snow products, and it as noted that glacier science is 'doing better' in this respect
- but from the glacier side we note that care and caution is needed in applying these uncritically – e.g. RGI still contains some alignment issues, and errors and some of these issues are then inherited into associated products e.g. global debris cover mask and global thickness
- more transparent error assessment of these products in needed to help downstream users understand any potential limitations in using the product
- there remains a funding gap for supporting global mapping efforts like improving RGI and/or developing GIs for different time slices.

There is still need for **deeper process understanding from detailed field measurements**, e.g. to guide choice of appropriate snow model, or to understand the role of 'complicating' factors such the interaction of organisms and cryosphere (e.g. bioalbedo).

Broad suggestion that **data shortages could be addressed by more open data sharing** – we are perhaps not capitalizing on the available (field) data as it is not openly/freely available.

Order of uncertainty in main cryospheric components seems to be:

1) snow (particularly SWE and how climate change might alter circulation, precipitation patterns and phase)
2) permafrost (how much and how much does it matter, and issues with gas emissions and hazards all seem 'relatively' poorly constrained, badly represented in hydrological models of glacierized catchments, also potential impacts on water quality)
3) glaciers (recent effort have improved the understanding, but there are critically data scarce regions and issues with uncrtitical global/regional assessments that might not adequately account for processes or might be inheriting upstream errors

Main cryosphere related **social impacts** were identified as

(1) hydrological (re. planning for peak water, changes in seasonal delivery, flood prediction)
    - hydrological interaction of cryopsheric runoff with groundwater is poorly understood
(2) hazards associated with glacier change
    - climate change dependency of cryospheric hazard potential is also poorly understood

Other impacts mentioned: tourism/water quality/biological effects of changing hydrology, and how changing cryosphere could affect planned sustainable development, also how some cryosphere engineering (e.g. in ski resorts) produces environmental contamination.

Lindsey – sorry, I did not complete the table below

Overall assessment of the state of:

What is your personal opinion on the current state of knowledge concerning the topic(s) addressed in your workshop. Please tick the appropriate field. Brief explanations are appreciated.

State of knowledge	Very good	Good	Poor	Very poor	Not appropriate	*Comments*
Global						
Regional						*Which region?*
Scattered case study-based knowledge						*Where?*
Knowledge about past states/trends						
Knowledge about current situation						
Knowledge about future states/trends/thresholds						
Knowledge about the system						
Knowledge about shaping pathways to more sustainable development (transformation knowledge)						
Knowledge about envisaged goals (target knowledge)						