WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Understanding Climate Change in the Mountains
IPROMO 2020

28.09.2020

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

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Overview

- Introduction;
- Climate Change in the mountains;
- Climate Normals;
- Observations and data - the foundation for understanding;
- Next steps.

Palcacocha glacier lake, Peru Courtesy C Huggel (Switzerland)

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Interaction

- Q&A – during the presentation;
- Chat – monitored;
- 3 questions.

Courtesy: J Fiddes (Switzerland)

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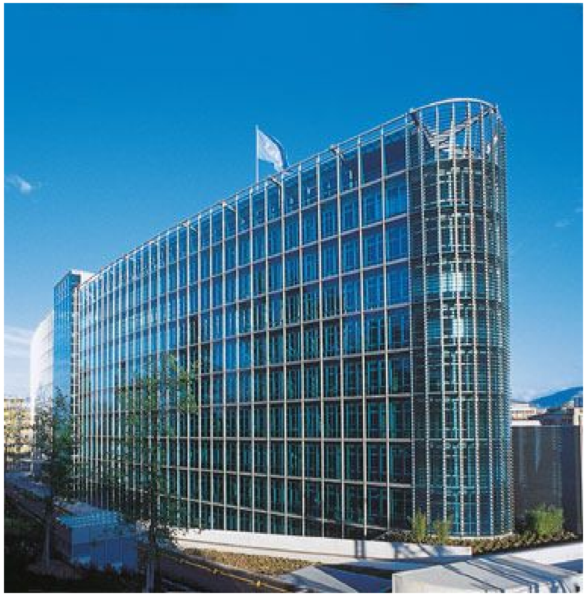
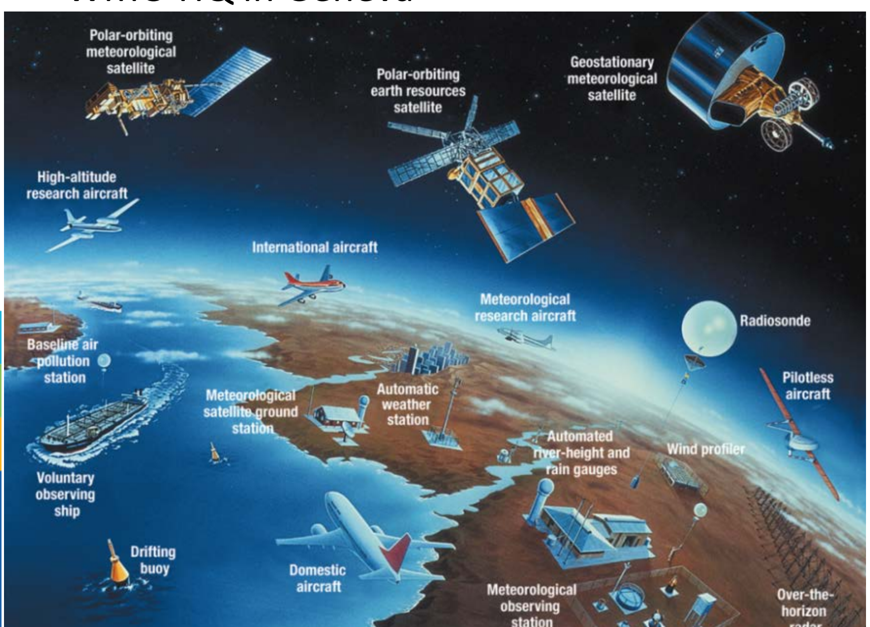
World Meteorological Organization



WMO HQ in Geneva



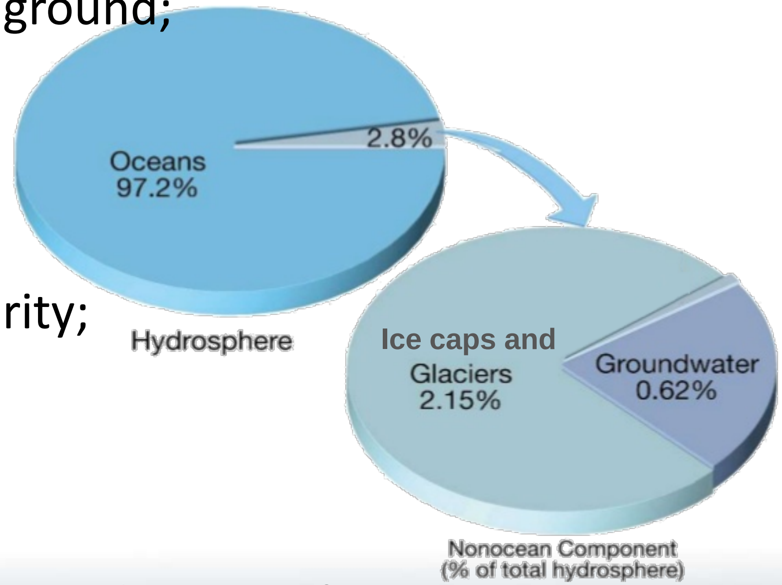
WMO – **UN Specialized Agency**

- **Intergovernmental body** that facilitates worldwide cooperation on **monitoring and predicting changes in weather, climate, water and other environmental conditions** through the exchange of data, information and services, standardization, application, research and training and capacity building.
- 193 Members

Bow River flood 2013, Canada; courtesy J Pomeroy

The mountains and the cryosphere

- “kryos” = icy cold
- snow, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground;
- Nearly 100 countries have cryosphere;
- Important for
  - Water resources, agriculture/food security;
  - Infrastructures, hydropower;
  - Ecosystems, weather;



- Sensitive indicator of climate change (glacier melt, permafrost thaw, changes in snowfall, raising snow line, etc).

MOUNTAIN CRYOSPHERE: recreation, scientific research, environmental, education, resource, and cultural **values**

	Glacier	Snow	Permafrost/seasonally frozen ground	Glacier lakes
Water Supply	Irrigation and water domestic use; Hydropower	Irrigation and domestic use; Hydropower; Feed and food production, llivestock	Contribution to groundwater and runoff	Drinking water; Water resource
Sociocultural	Tourism, religion, sport, aesthetic value	Tourism, religion, sport, aesthetic value		Tourism, religion, sport, aesthetic value
Regulations	Climate (Albedo, cold water) Runoff regulation	Climate (Albedo, cold water) Runoff regulation	Prevention of rockfall and landslides Climate: organic carbon storage hydrological cycle: infiltration of rain/meltwater into the soil, groundwater	Water storage
Habitat	Flora, fauna, microorganisms, iconic species	Flora, fauna, microorganisms, iconic species	Microorganisms Constraining rooting zones of flora and habitat for fauna;	Habitat for cold water aquatic ecosystems
Disservice (risks)	Ice and rock avalanches, Loss of water resources	Snow avalanches and storms	Degradation/thawing of permafrost (infrastructure damage, sediment flow, slope instability, rock avalanches, increase GHG emissions)	GLOFs Loss of water storage

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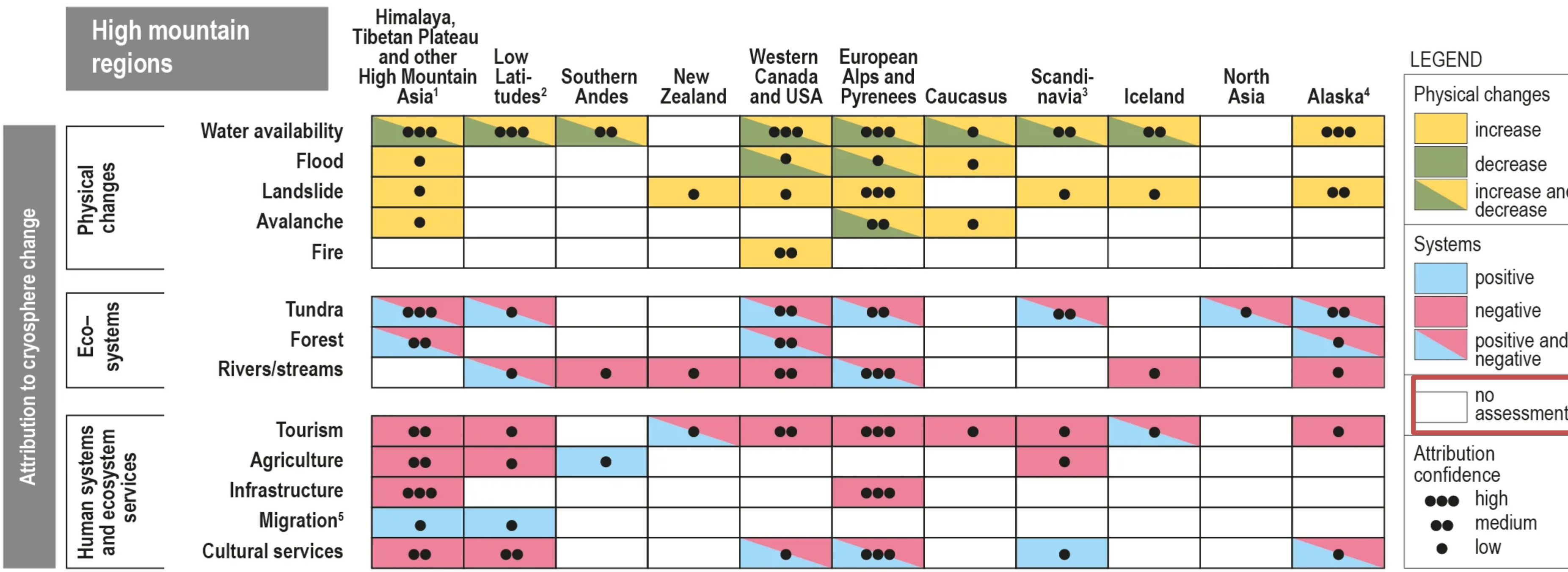
In central Chile and central-western Argentina, the seasonal **snow that accumulates each winter in the Andes represents a crucial water resource** for sustaining human consumption, agriculture, hydro-electric generation and numerous industrial activities in the adjacent lowlands

Observed physical changes and impacts in high mountain regions over past decades that can at least partly be attributed to changes in the cryosphere



[1] includes Hindu Kush, Karakoram, Hengduan Shan, and Tien Shan; [2] tropical Andes, Mexico, eastern Africa, and Indonesia;
[3] includes Finland, Norway, and Sweden; [4] includes adjacent areas in Yukon Territory and British Columbia, Canada;
[5] Migration refers to an increase or decrease in net migration, not to beneficial/adverse value.

Figure 2.8.
Confidence levels refer to confidence in attribution to cryospheric changes.
No assessment means: not applicable, not assessed at regional scale, or the evidence is insufficient for assessment.
Figure is based on observed impacts listed in Table SM2.11.

IPCC Report on the Ocean and Cryosphere in a Changing Climate (2019), Chapter 2, High Mountains
Hock, R., et. Al (2019)

Peak Water from Glaciers

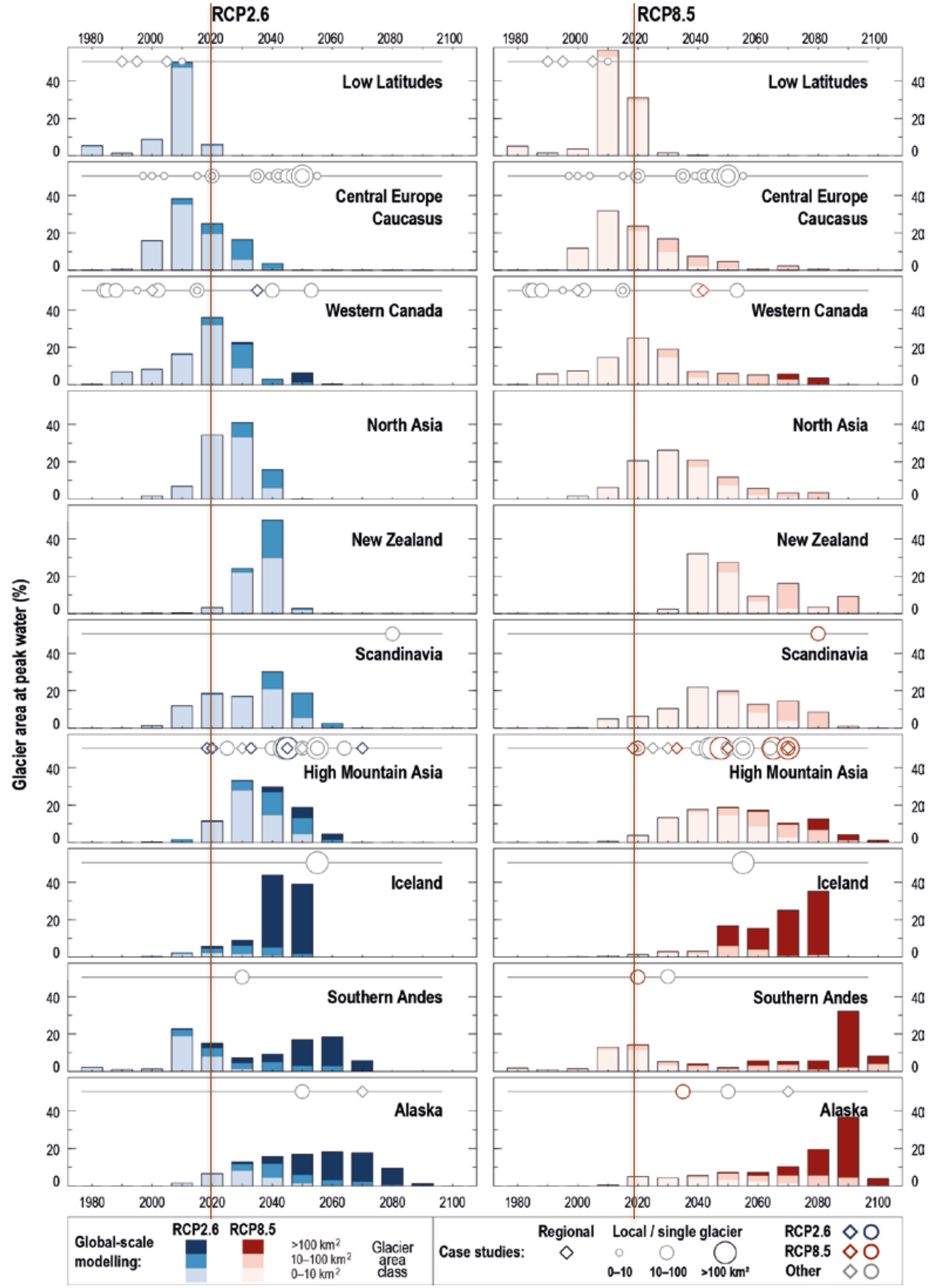
Glaciers: water reservoirs

Peak water refers to **the year when annual runoff** from the initially glacier-covered area **will start to decrease** due to glacier shrinkage after a period of melt induced increase.

Figure 2.6 | Timing of peak water from glaciers in different regions under **two emission scenarios** for Representative Concentration Pathways RCP2.6 and RCP8.5.

Circles/diamonds mark timing of peak water from individual case studies based on observations or modelling (Table SM2.10).

IPCC Report on the Ocean and Cryosphere in a Changing Climate (2019), Chapter 2, High Mountains
Hock, R., et. Al (2019)



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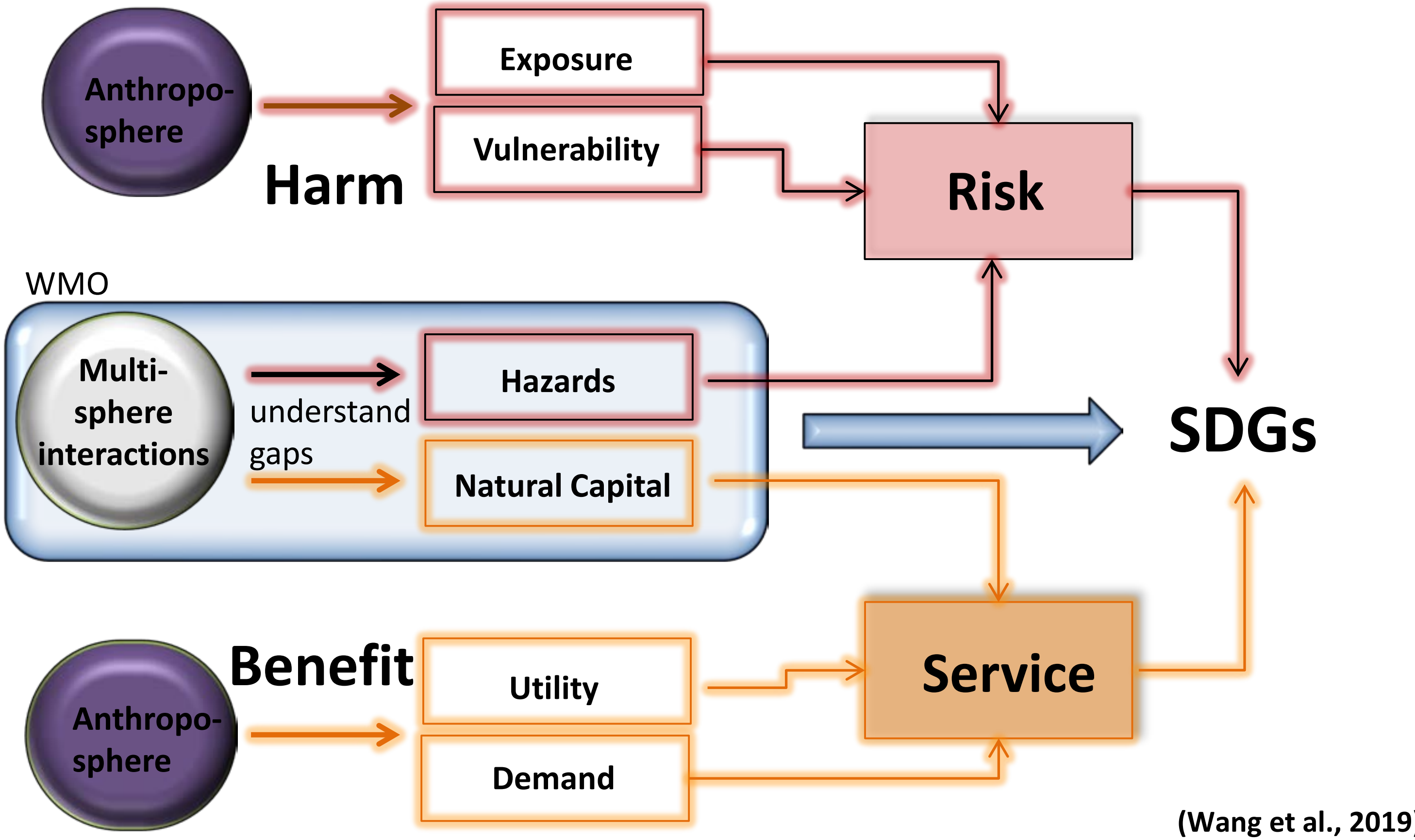
Changing environments:

Risks vs Services

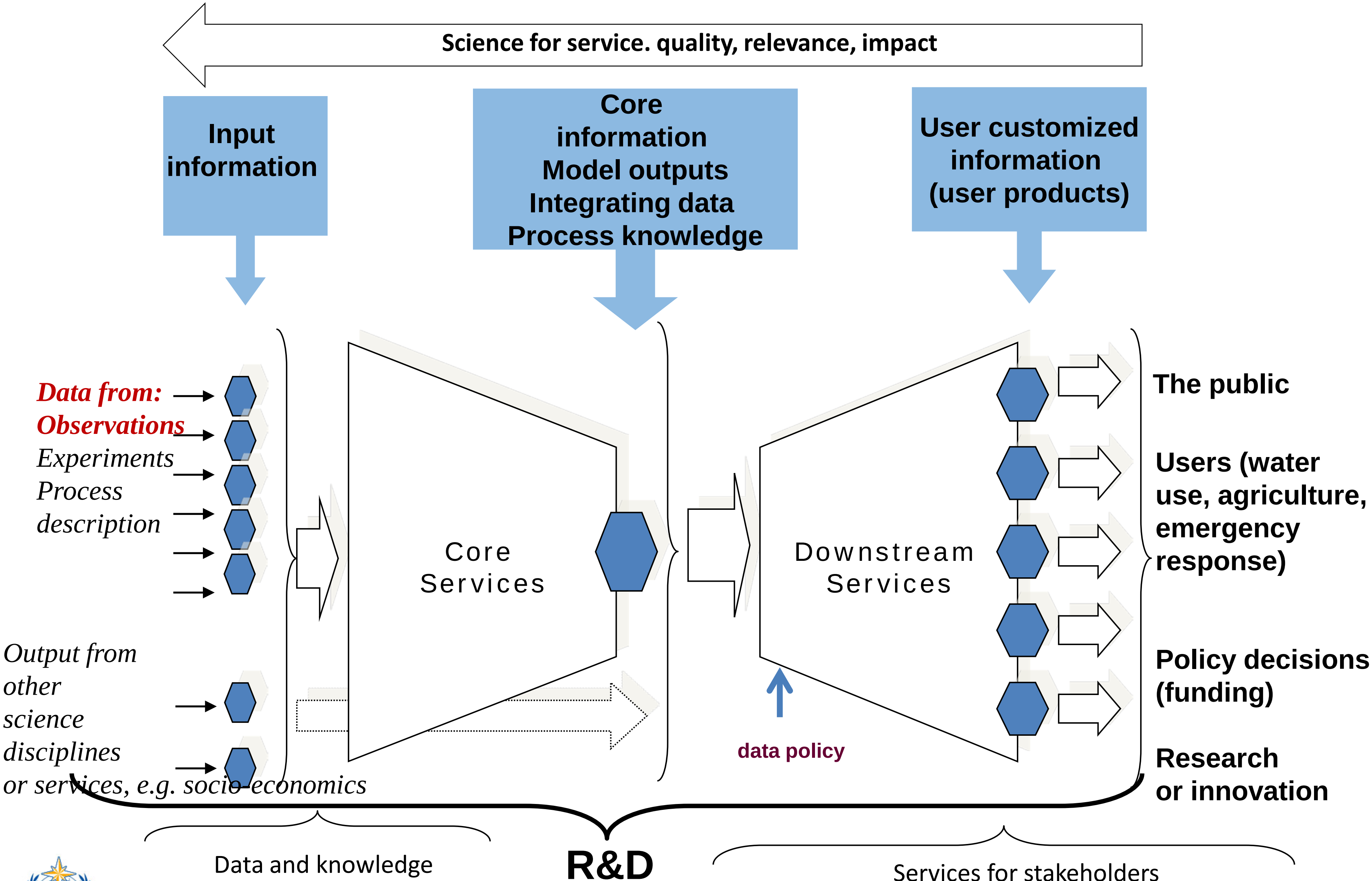
Both harm and benefits need to be emphasized



(Wang et al., 2019)

Sustained access to data and information to support:
- Understanding risks (floods, draught, avalanches, landslides, etc);
- Harvesting benefits (when/what to plant and harvest, water resources, transportation, infrastructure, etc)

Observation-Prediction-Service Chain



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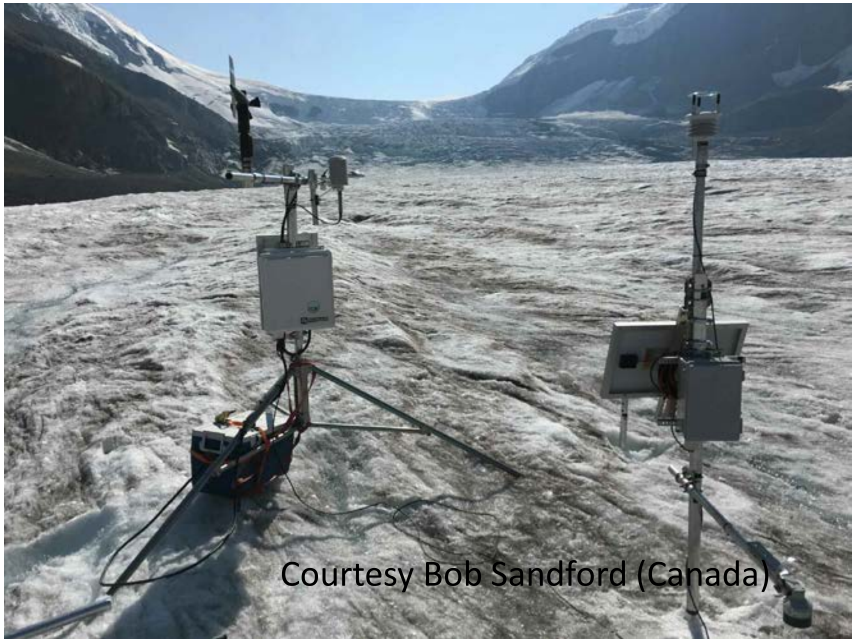
Courtesy C Xiao, China

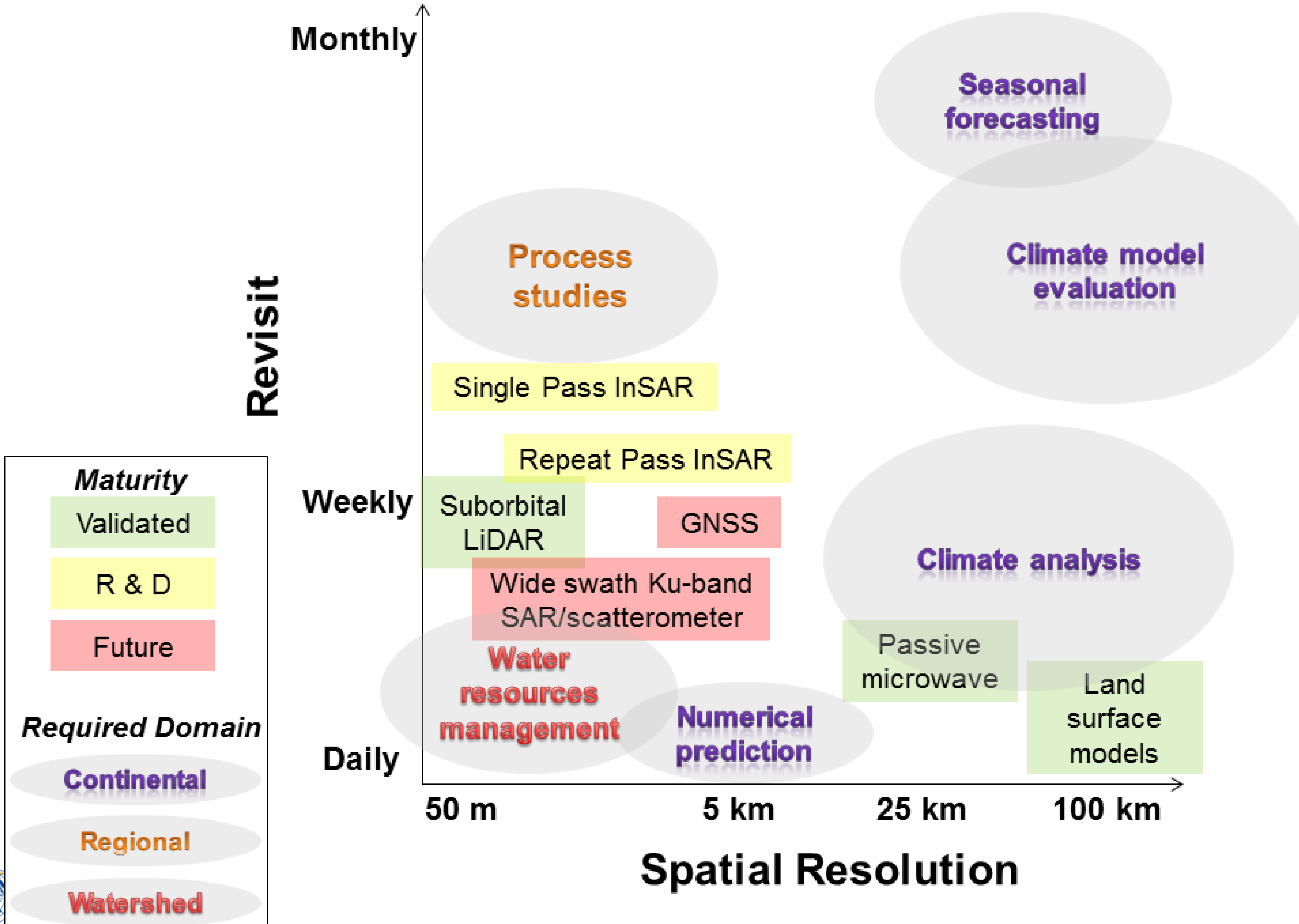
Weather, climate, water, cryosphere observations

- Foundation for understanding;
- **Continuity** of observations;
- Fit for purpose;
- Availability of data, long-term.
- **Interoperability** of data systems;
- **Sustainability** of observing and data systems.



Courtesy WB -GFDRR – Daniel Kull

Use of snow observations

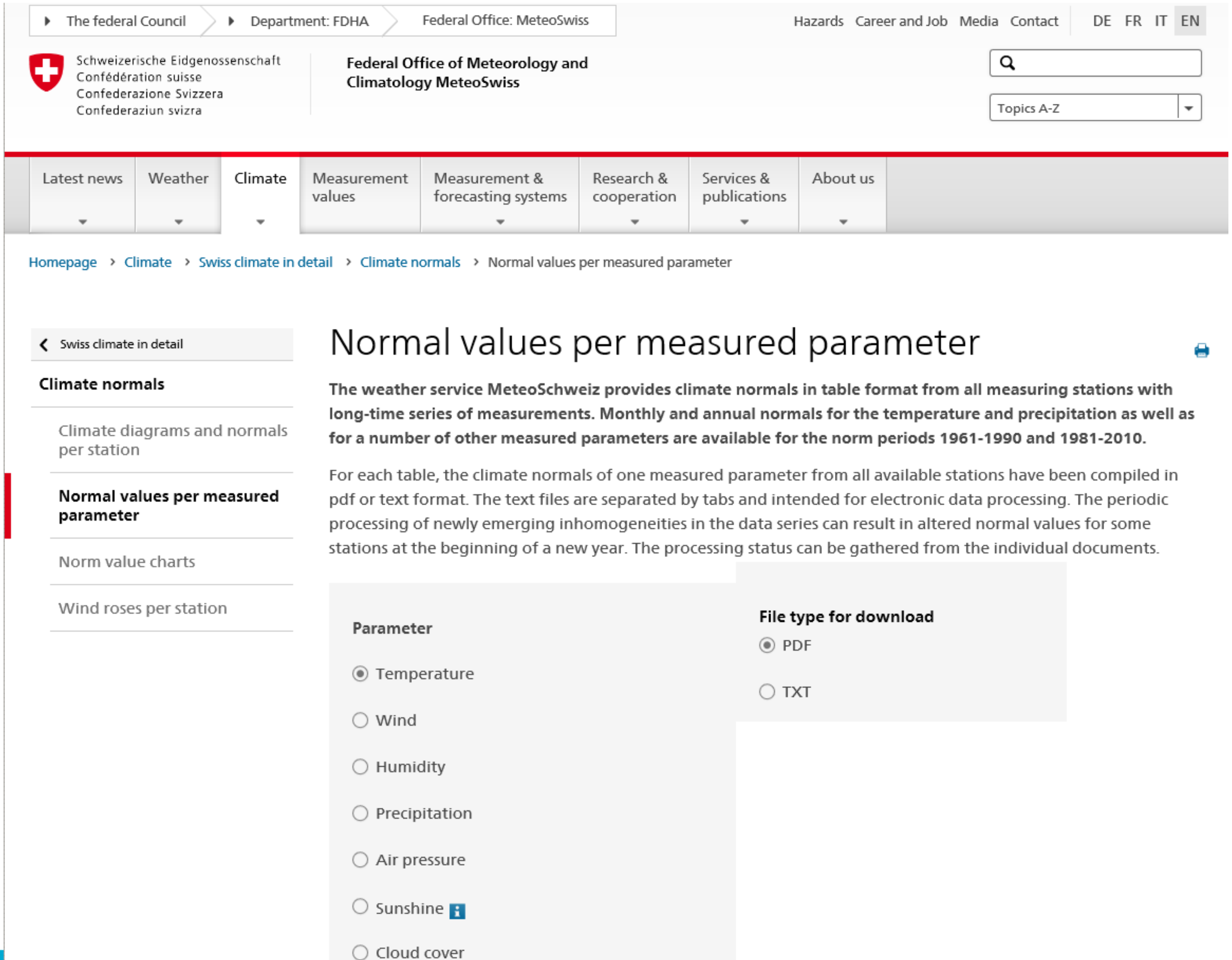


Courtesy, C Derksen, Canada

Climate is what we expect, Weather is what we get

- **Climatological Normals:**
  - **reference** against which conditions (current or recent) can be assessed,
  - widely used (implicitly or explicitly) as **an indicator** of the conditions likely to be experienced in a given location.

- ***Climatological standard normals:***
  - Averages of climatological data computed for the following consecutive periods of 30 years: 1 January 1981 to 31 December 2010, 1 January 1991 to 31 December 2020, etc.
  - The period 1961 to 1990 - standard reference period for long-term climate change assessments;



- Reported by parameter and station:
  - E.g. monthly mean values of maximum, minimum and daily mean temperatures, etc)

- **Published by National Meteorological Services**
- **Require a minimum of 30 years of continuous and reliable observations at the same location;**

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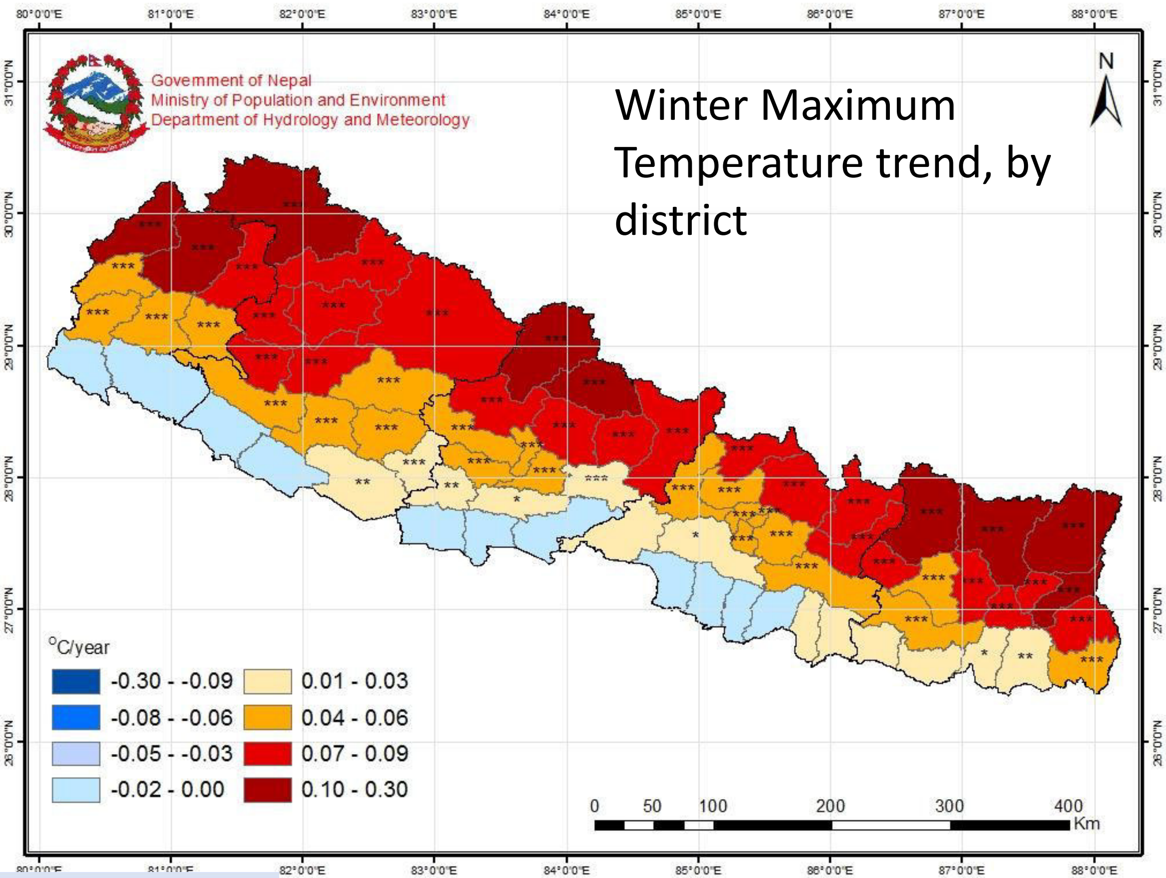
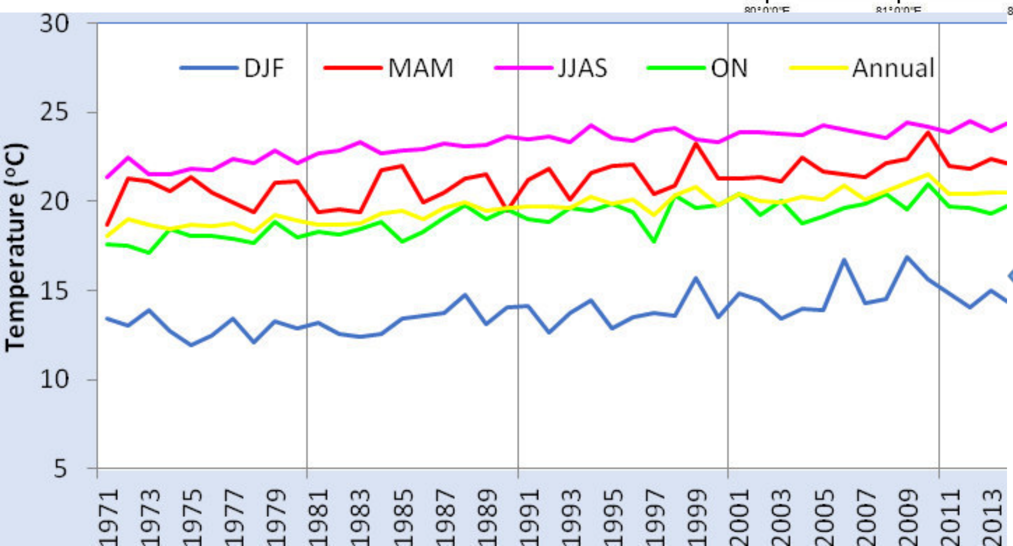
Climatological Normals

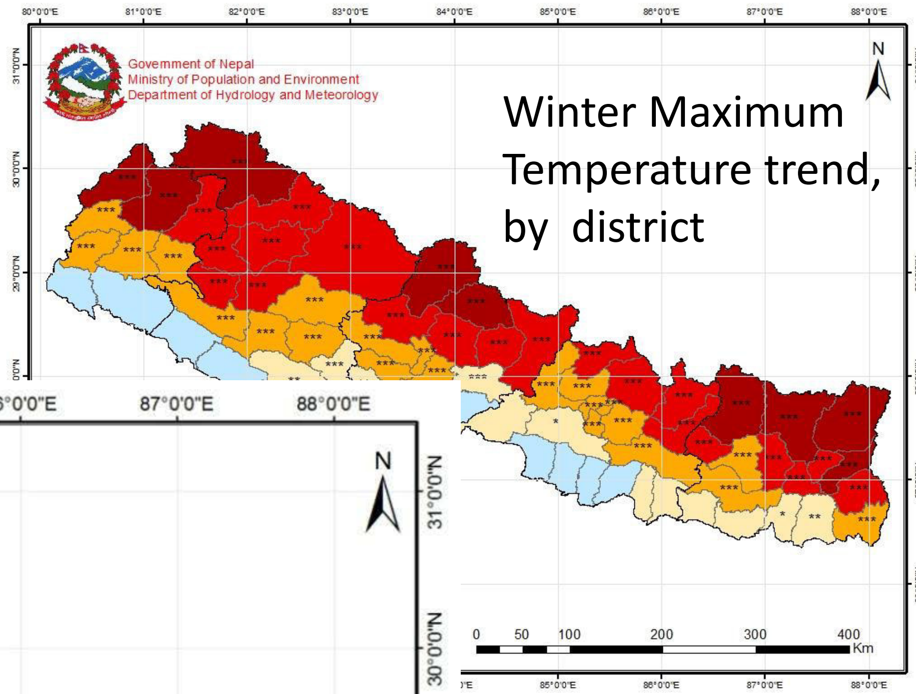
Observed Climate Trend Analysis of Nepal (1971-2014)



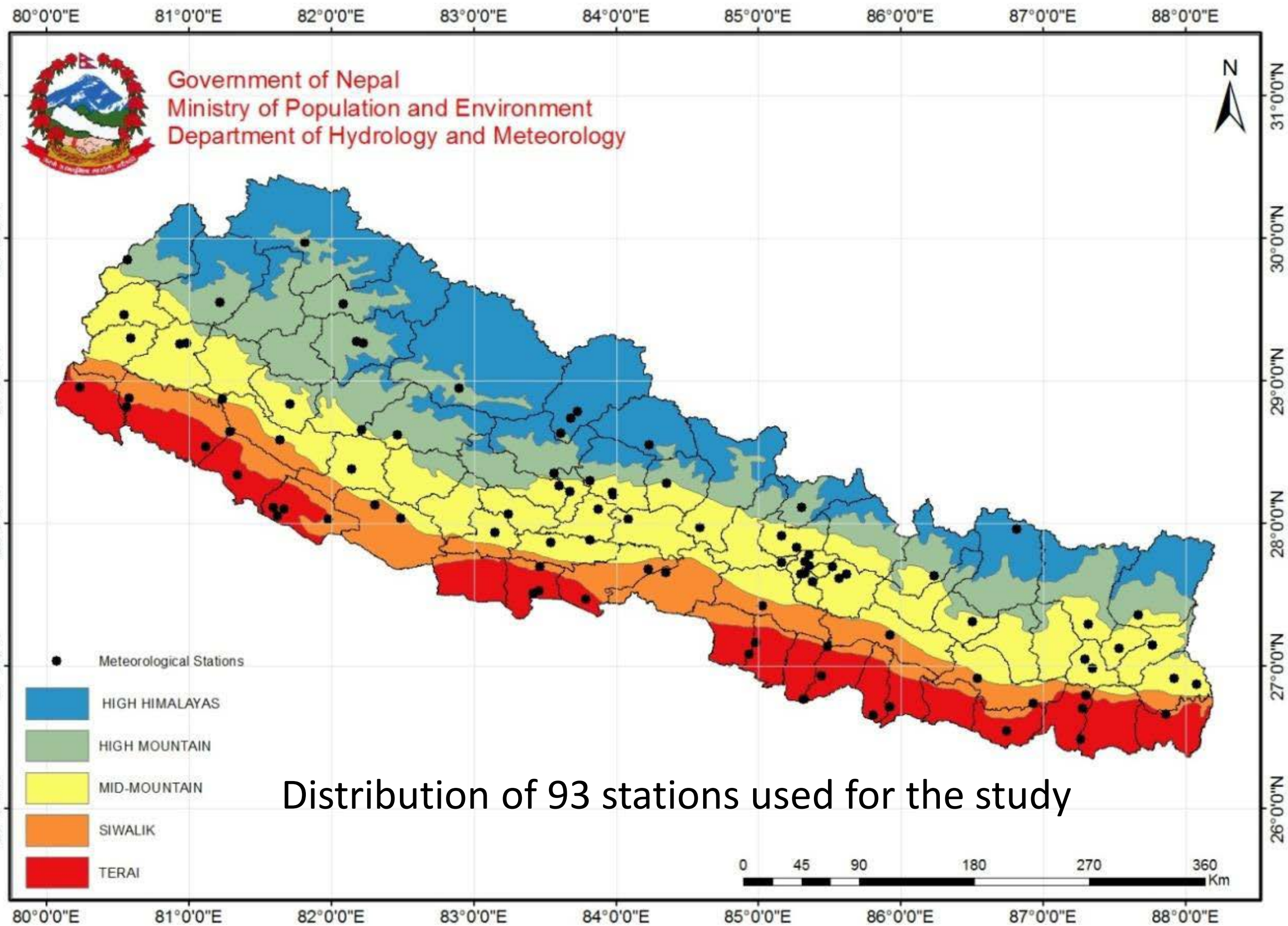


Seasonal and annual maximum temperature time series of Nepal

Observed Climate Trend Analysis of Nepal (1971-2014)



Winter Maximum Temperature trend, by district

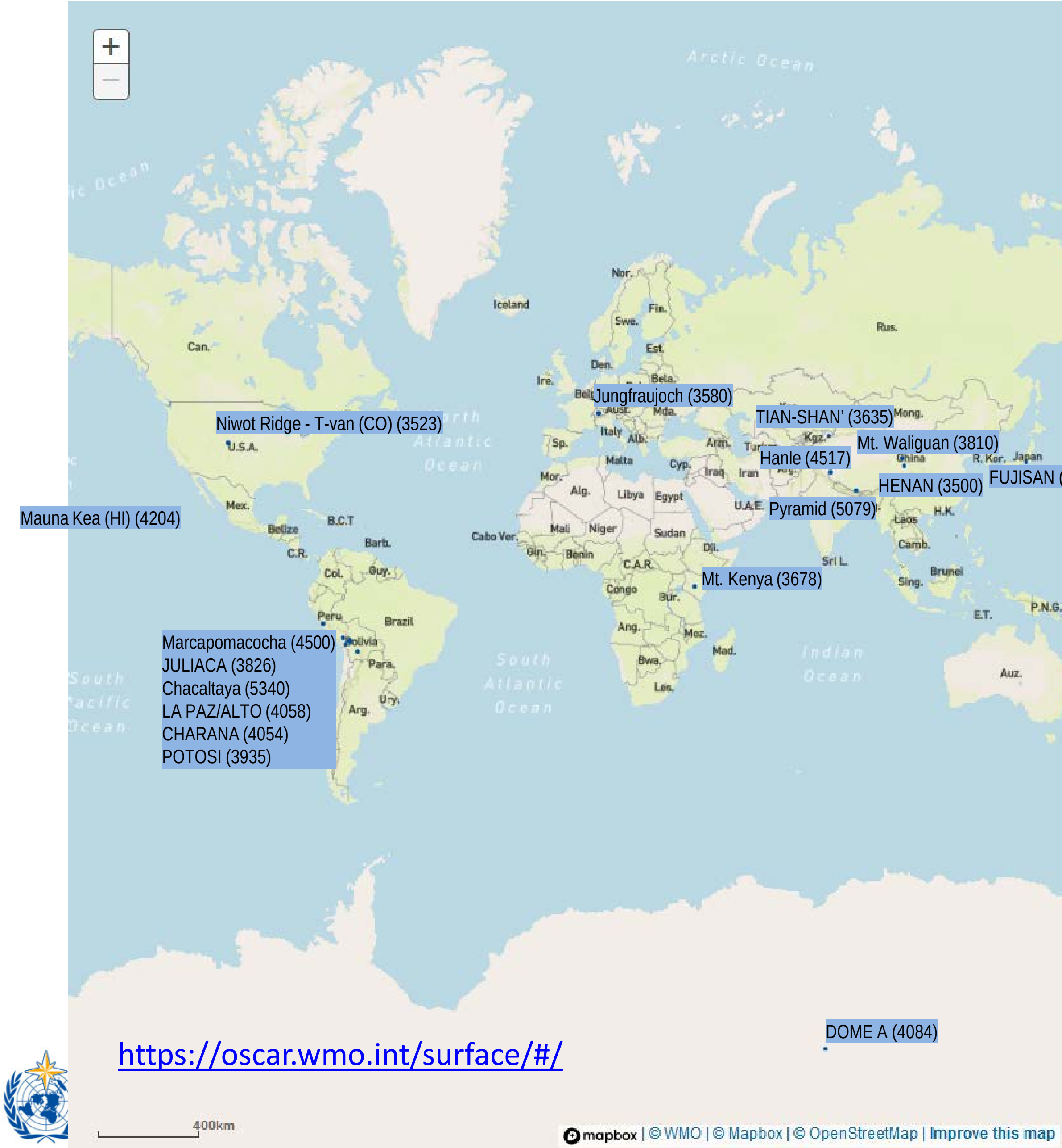


Distribution of 93 stations used for the study

Continuity of observations at the same location over the study period is essential for understanding climate trends

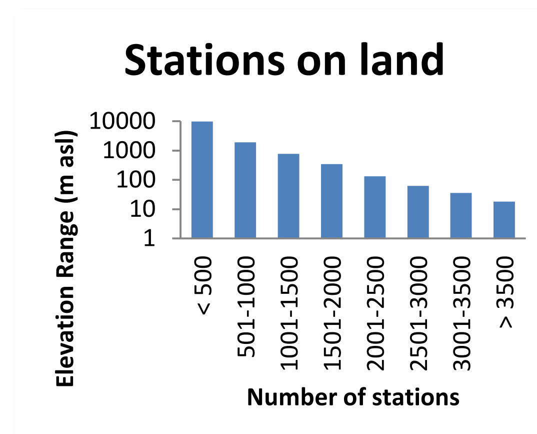
Tracking what is measured

OSCAR Observing Systems Capability Analysis and Review Tool

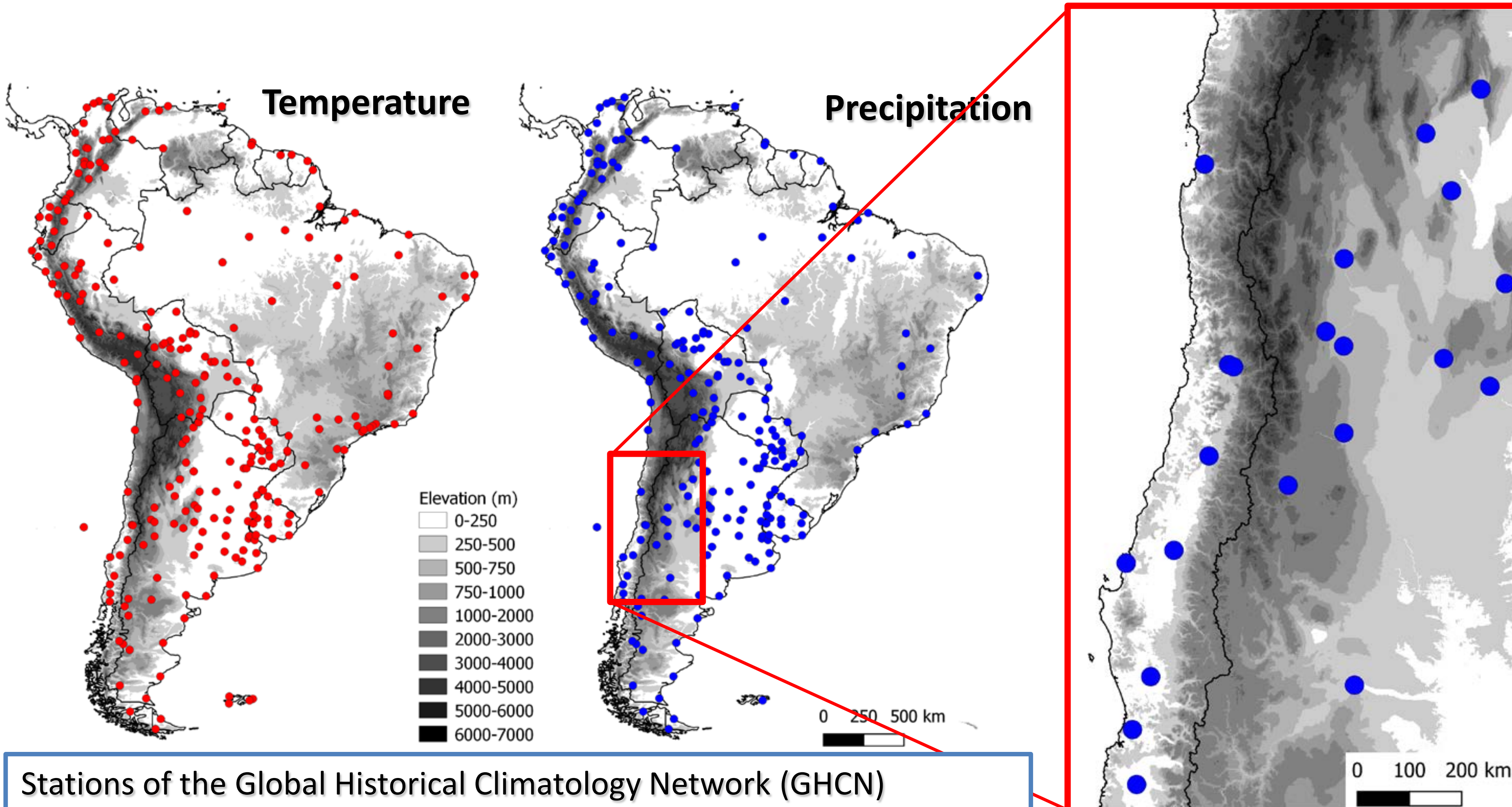


https://oscar.wmo.int/surface/#/

< 500 m a.s.l.	9929 stations
501 – 1000 m a.s.l.	1938 stations
1001 – 1500 m a.s.l.	769 stations
1501 – 2000 m a.s.l.	350 stations
2001 – 2500 m a.s.l.	132 stations
2501 – 3000 m a.s.l.	62 stations
3001 - 3500 m a.s.l.	36 stations
> 3500 m a.s.l.	17 stations



The most complete hydro-climatic records in the southern Andes are only available for low elevation sites and/or away from the mountains: **limited understanding of** many glaciological and hydro-meteorological processses and interactions –



Stations of the Global Historical Climatology Network (GHCN) reporting data in 2019

Courtesy M Masiokas, Argentina

From measurements to data:

- configuration;
- sound observing practices;
- fit for purpose.

Meteorological and Climatological Observations

In-situ observations:

- **Temperature;**
- **Precipitation** (mostly rainfall), intensity and amount;
- Wind speed and direction;
- Atmospheric pressure;
- Humidity;
- Solar radiation;
- Snow depth.

Space-based observations.

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High elevation observations challenges

- High costs to install and operate;
- Difficult access;
- Lack of power and communication;
- Remoteness;
- Special observing techniques for cryosphere;
- Capacity

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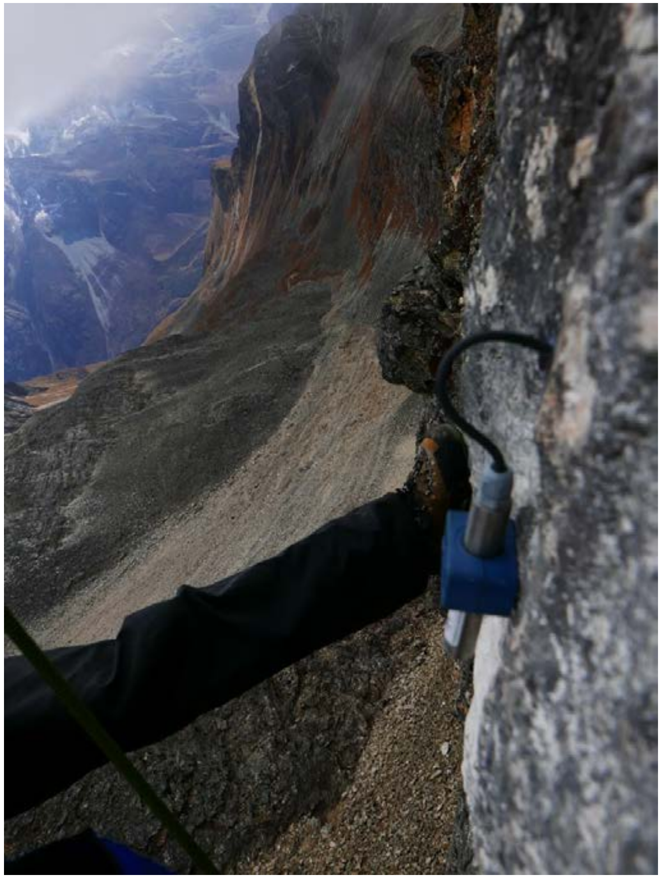
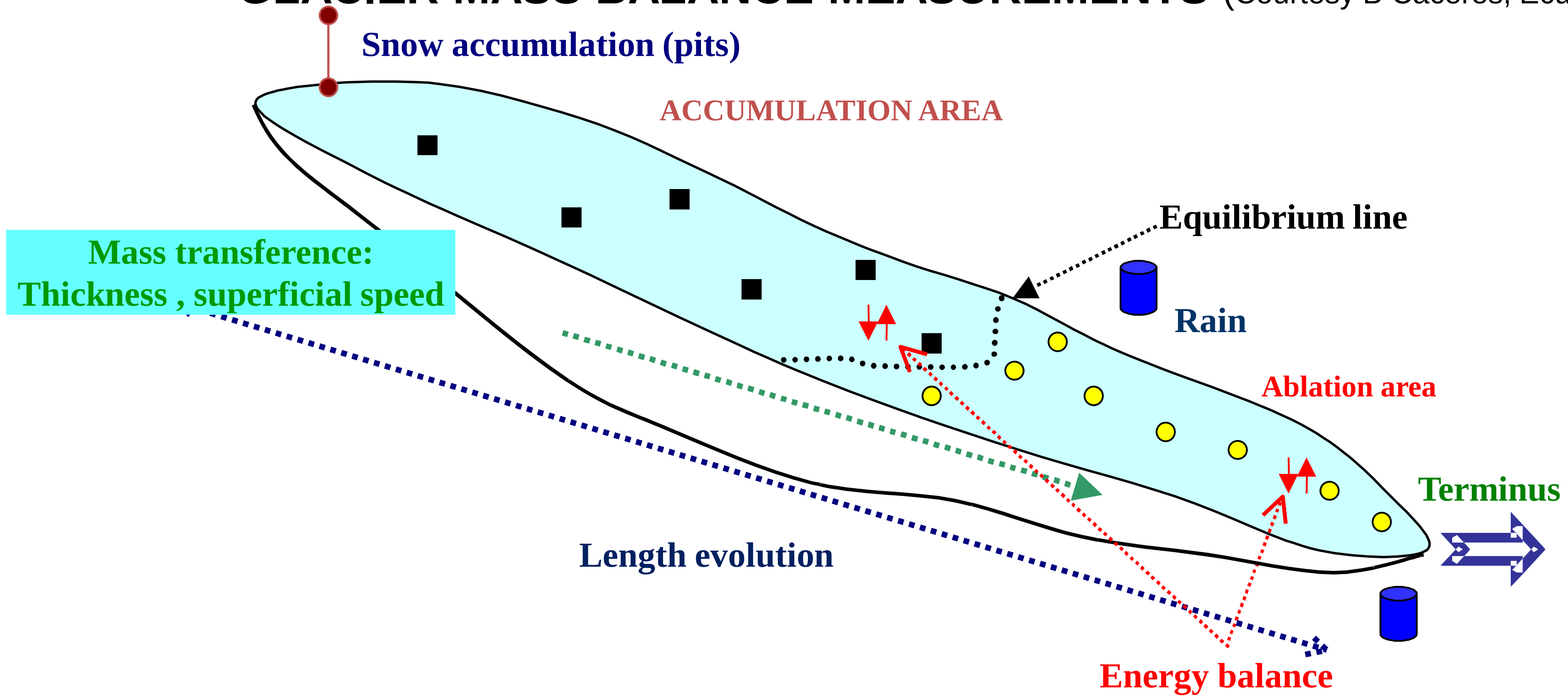
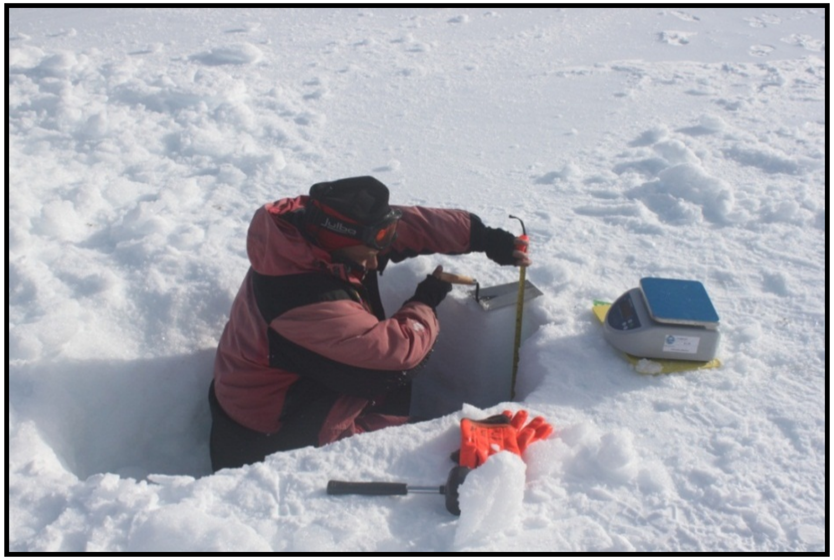
Snow Measurements and Permafrost Monitoring (Tajikistan)



GLACIER MASS BALANCE MEASUREMENTS (Courtesy B Caceres, Ecuador)



Pits (density snow /ice , thickness)
Stakes (ablation, speed)
Hydrological station
Total rain gauge (snow/rain)
Automatic wheather station (AWS)



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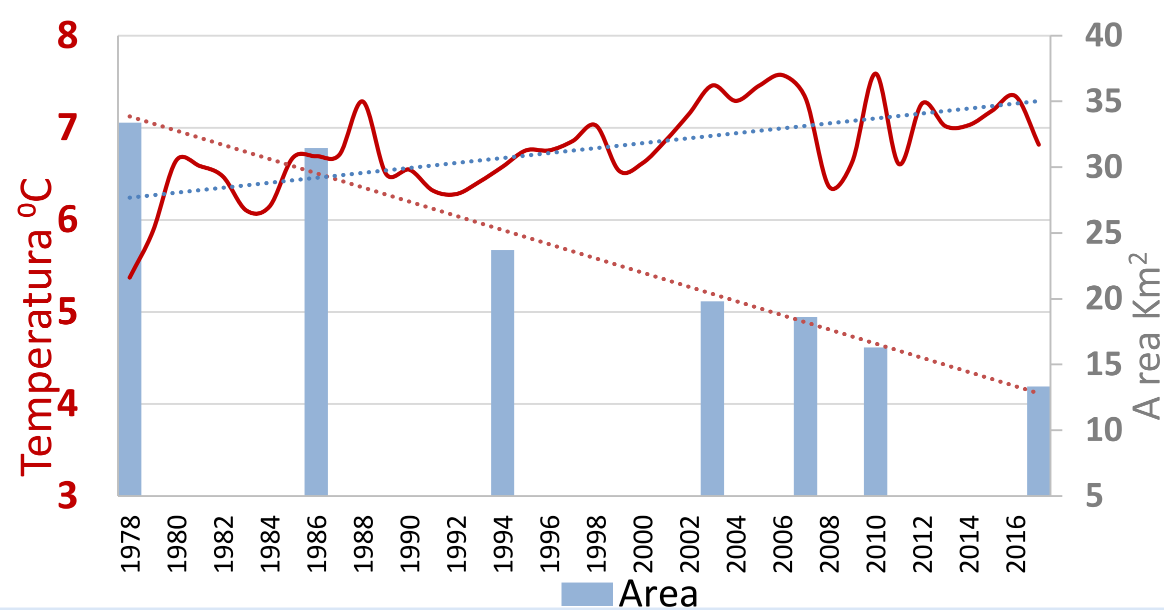
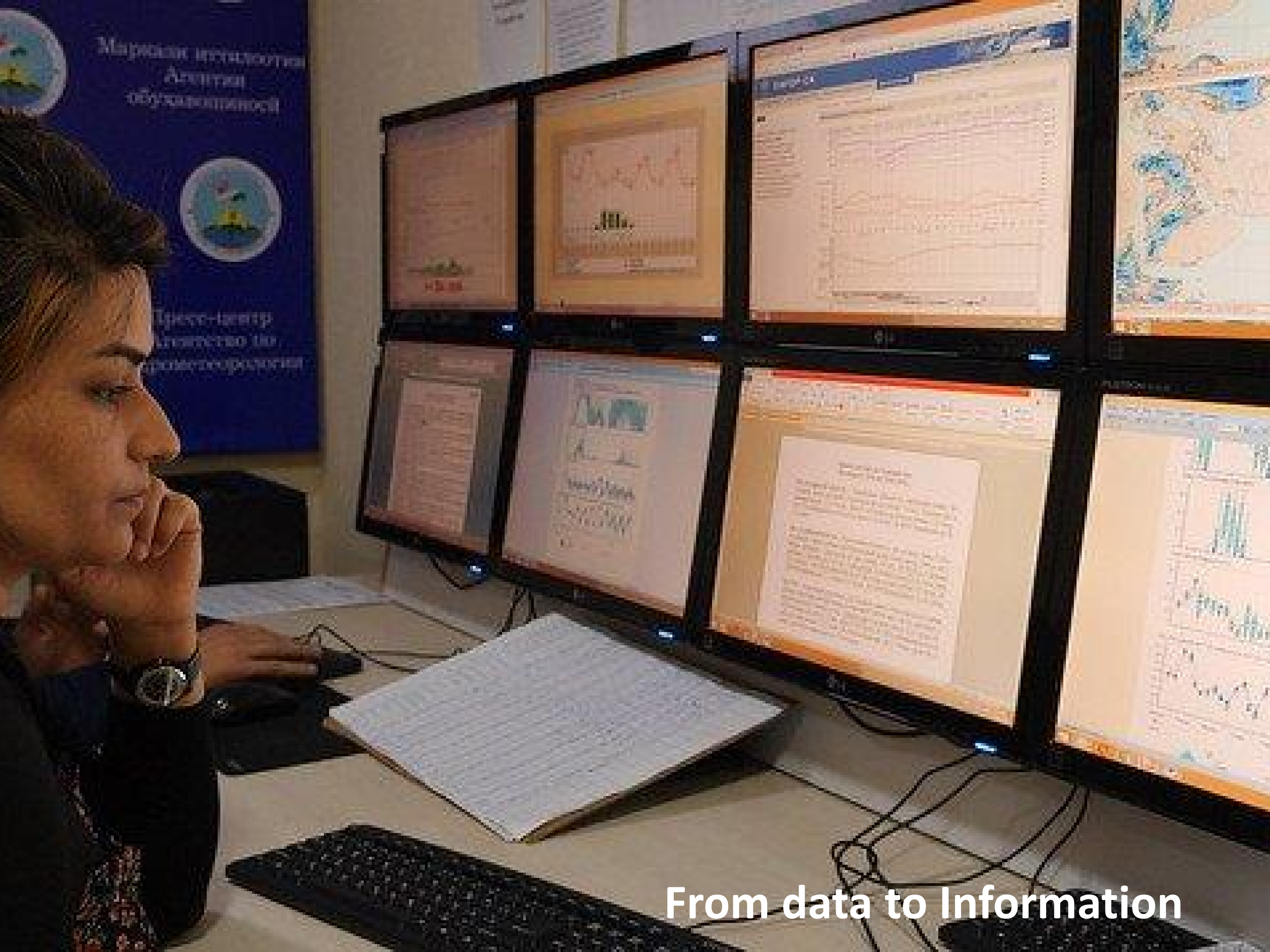
El ambiente es de todos
Minambiente

Temperature *vs.* Glaciar area
Sierra nevada El Cocuy (Colombia)
3716 msnm

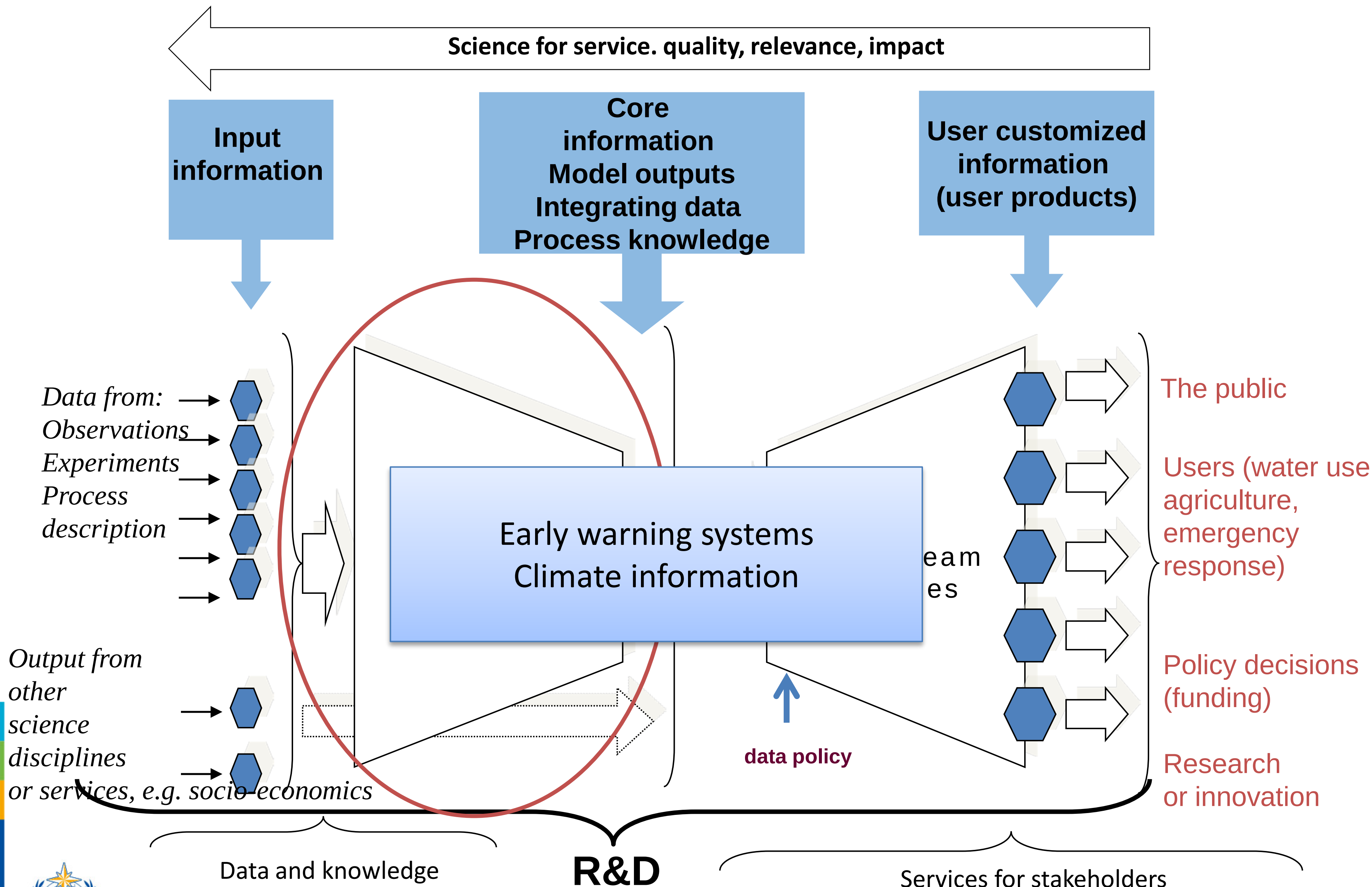


Courtesy, Yolanda Gonzales Hernandez, Colombia

IDEAM


From data to Information

Observation-Prediction-Service Chain



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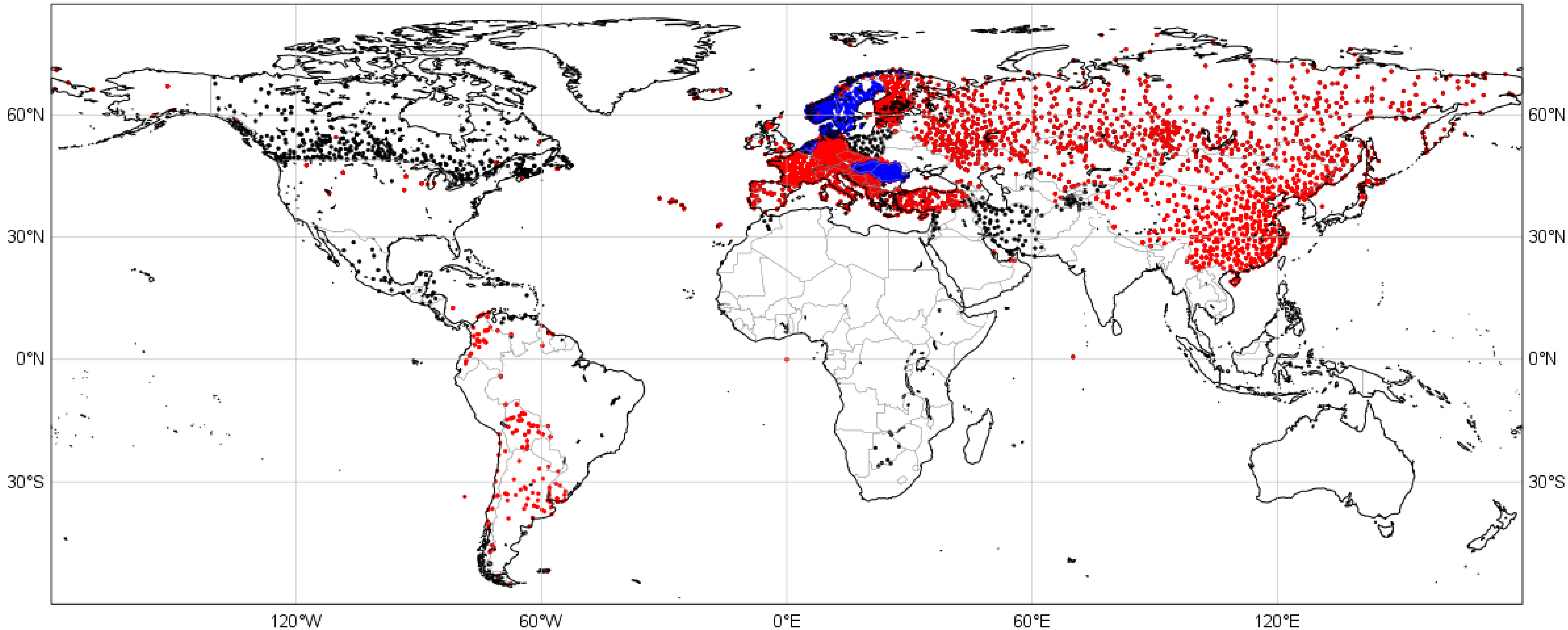
Courtesy C Xiao, China

In situ snow depth observations

GTS Snow depth availability

SYNOP TAC **SYNOP BUFR** **national BUFR data**

15 January 2020



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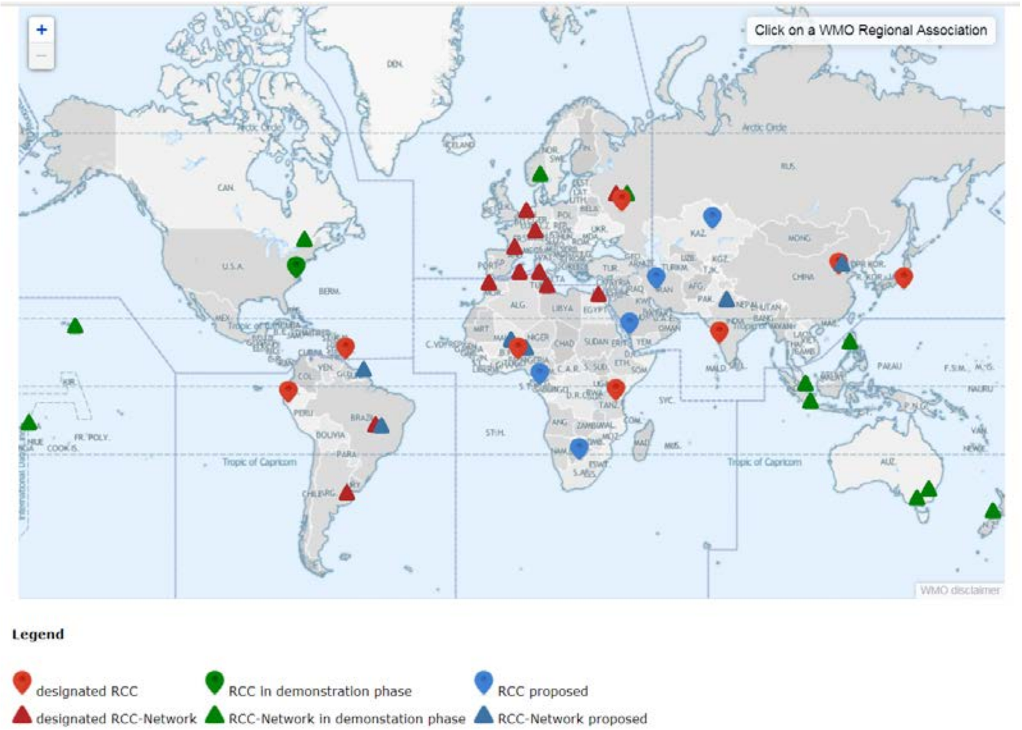
Regional Climate Centres functions

- Mandatory Functions:
  - Operational Activities for LRF
  - Operational Activities for Climate Monitoring
  - Operational Data Services,
  - Training - use of operational RCC products and services

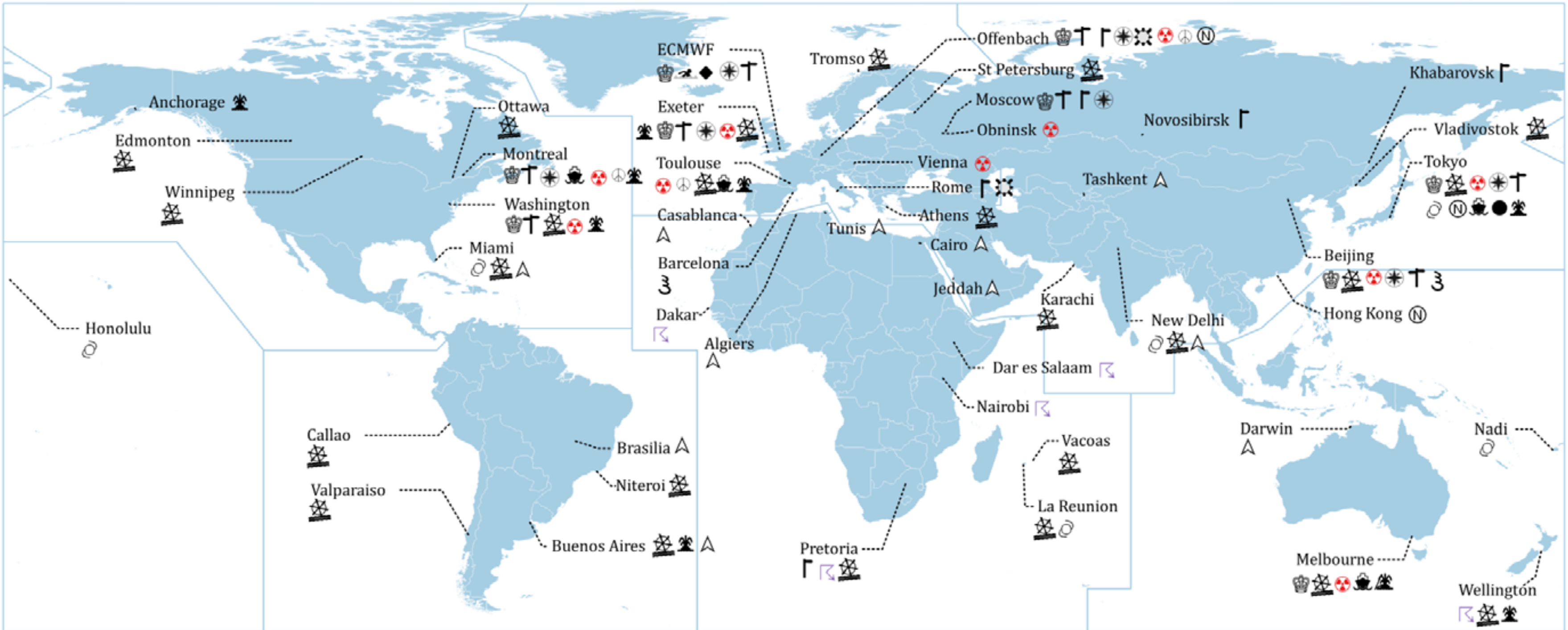
- Highly Recommended Functions:
  - Climate prediction and projection
  - Non-operational data services
  - Coordination
  - Training and capacity building
  - Research and development



WMO Designated Global Data-processing and Forecasting System Centres

- Nowcasting and Weather Forecasting (upto 30 days)

Updated on 30 July 2019



Legend

- World Meteorological Centres (WMCs)* (9)
- RSMCs Geographic (12)
- RSMCs(NRT***) Lead Centre for Coordination of Wave Forecast (1)
- RSMCs(NRT***) Lead Centre for Coordination of EPS Verification (1)
- RSMCs(NRT***) Lead Centre for Coordination of DNV (1)
- RSMCs Numerical Ocean Wave Prediction (4)
- RSMCs TC (6)
- RSMCs Severe Weather Forecasting (5)
- RSMCs Marine Meteorological Services (24)
- RSMCs Nuclear Emergency Response** (10)
- RSMCs Non-Nuclear Emergency Response** (3)
- RSMCs Sand Dust (2)
- RSMCs Nowcasting (3)
- RSMCs Limited Area Ensemble NWP (2)
- RSMCs Global Ensemble NWP (7)
- RSMCs Limited Area Deterministic NWP (6)
- RSMCs Global Deterministic NWP (8)
- ICAO designated Volcanic Ash Advisory Centres (9)

* World Meteorological Centres are also Global Producing Centres for a) Deterministic Numerical Weather Prediction, b) Ensemble Numerical Weather Prediction, and c) Long-Range Forecasts.
** RSMC for nuclear and non-nuclear emergency response have Atmospheric Transport and Dispersion Modelling (ATDM) capabilities.
*** NRT stands for Non-Real-Time

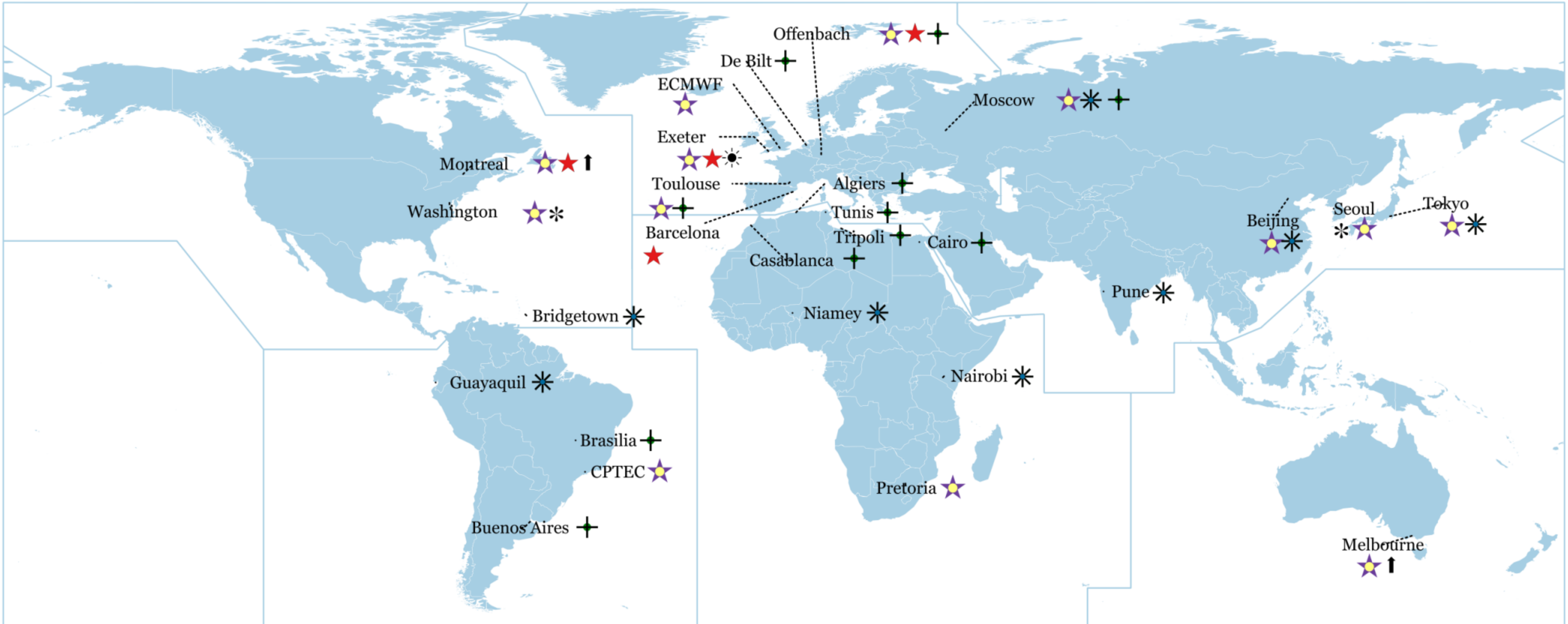
DESIGNATIONS USED

The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on this web site are not warranted to be error free nor do they necessarily imply official endorsement or acceptance by the WMO.

WMO Designated Global Data-processing and Forecasting System Centres

- Long-range and Climate Forecasting (over 30 days)

Updated on 14 February 2019



Legend

- World Meteorological Centres (WMCs)* (9)
- RSMCs(NRT**) Lead Centre for coordination of ADCP*** (1)
- RSMCs(NRT**) Lead Centre for coordination of LRFMME**** (2)
- RSMCs(NRT**) Lead Centre for coordination of LRF verification (2)
- RCC - Networks Regional Climate Prediction and Monitoring NODEs (11)
- RCCs Regional Climate Prediction and Monitoring (8)
- GPC for ADCP*** (4)
- GPC for Long-Range Forecasting (13)

* World Meteorological Centres are also Global Producing Centres for a) Deterministic Numerical Weather Prediction, b) Ensemble Numerical Weather Prediction, and c) Long-Range Forecasts.
**NRT stands for Non-Real-Time
***ADCP stands for Annual to Decadal Climate Prediction
****LRFMME stands for Long-Range Forecast Multi-Model Ensemble

DESIGNATIONS USED
The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on this web site are not warranted to be error free nor do they necessarily imply official endorsement or acceptance by the WMO.

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High Mountain Summit (29-31 October 2019)

Mountain regions and mountain people deserve **adequate and reliable hydro-meteorological and climate services**, equally so as in the lowlands, accounting for **their specific needs and the specificities of the mountain environment** (including cryosphere elements).

Improve the **governance** and interactions within and between **organizations, institutions and people** at stake ;

- Fragmented policy environments
- Insufficient budgets
- Difficulties to attract, train, and retain qualified staff
- Limited and often declining monitoring networks
- Inadequate data management systems
- Insufficient integration between meteorological, climate and hydrological services
- **Poor connection with users**
- **Inability to develop and provide products**

Need a few things…

Understand observational user requirements, capabilities and gaps

- Mix of observing technologies, incl. Space & surface-based
- New technologies
- Make use of partner & third party observations

Methods of observations and observations

- In-situ
- Space-based EO

Proper standards…

- Interoperability, structured and unstructured data
- Discoverable
- Open data

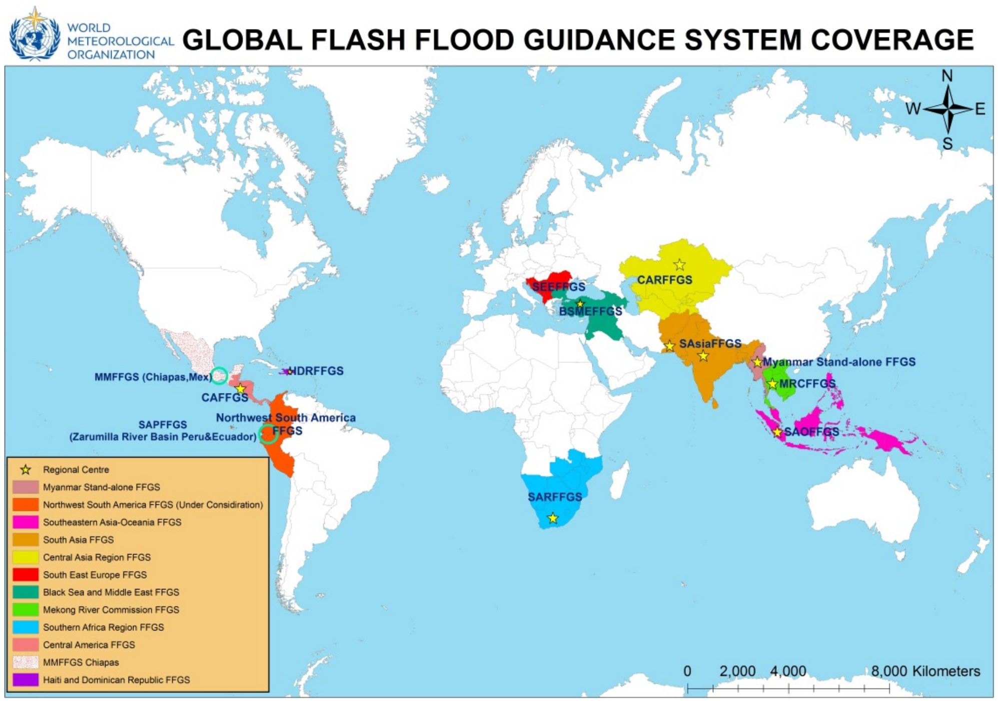
Data platform

- Data needs to be organized and close to the computing

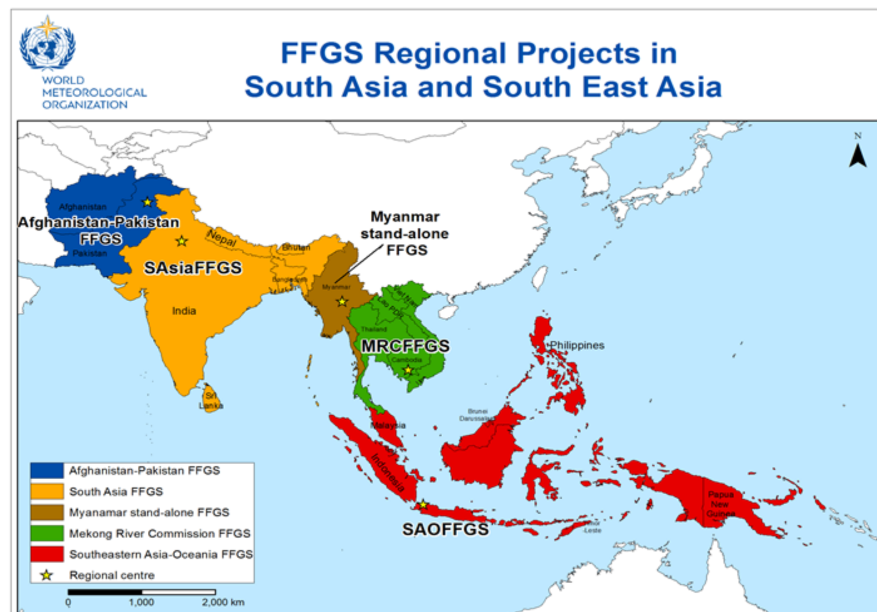
Service delivery mechanisms

- **Reaching and engaging the users in co-designing the information system required**

Development of Early Warning System capabilities



South Asia FFG (SAsiaFFG) (under implementation) includes Afghanistan, Bangladesh, Bhutan, India (RC), Nepal, Pakistan (RC), and Sri Lanka;



Flash Flood Guidance System with global coverage enhances early warning capabilities of the NMHSs, currently covers 52 countries and more than two billion people around the world saving lives and decreasing economic losses**.**

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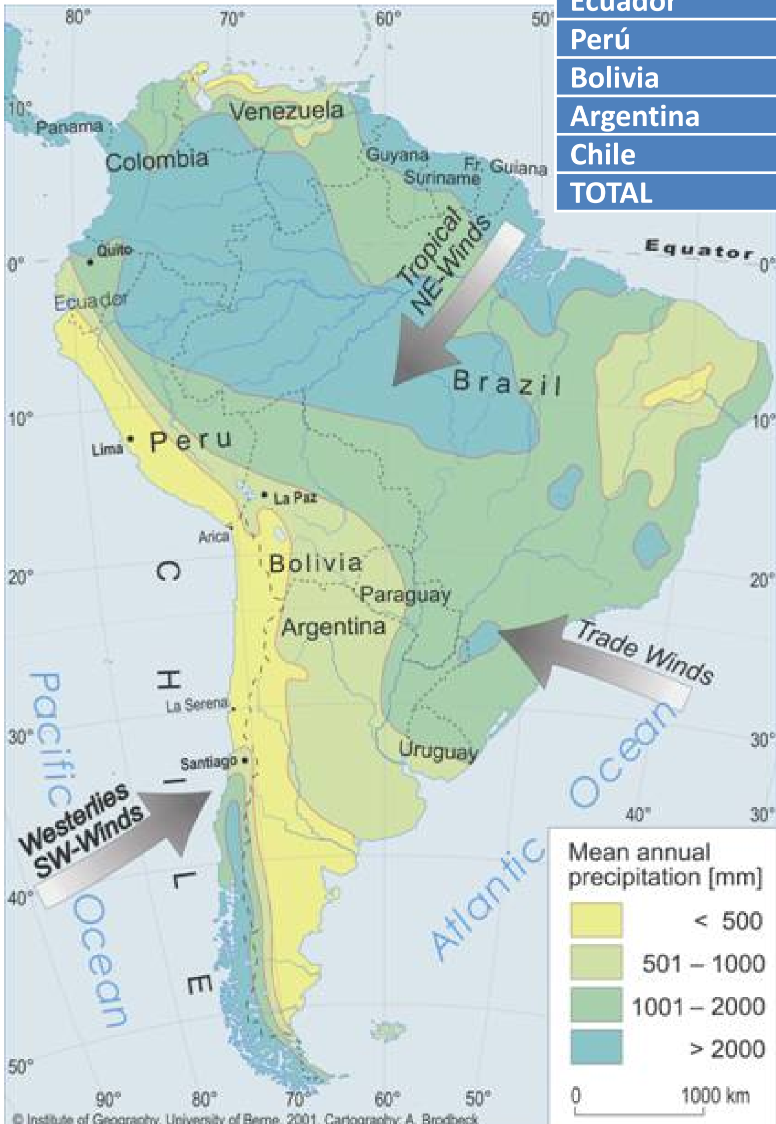
GLACIERS



Schwikowski et al., 2004

COUNTRY	AREA (km²)
Venezuela	0.1
Colombia	37
Ecuador	43.5
Perú	1,298.6
Bolivia	346.4
Argentina	4,699.7*
Chile	23,641
TOTAL	30,067

Sources
INRENA, IDEAM; INAHMI, GTNH, CECs, IANIGLA, DGA.
*Not considering glaciers located in Chilean territory of Southern Patagonia Icefield.

Pico Bolívar
Venezuela
(Vuille et al., 2011)

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Courtesy Dr. G. Casassa, Chile

Consistency of early warnings and climate information for mountain-specific threats: **example avalanche hazard**

avalanches.org

North American Public Avalanche Danger Scale

Avalanche danger is determined by the likelihood, size and distribution of avalanches.

Danger Level	Icon	Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	4 5	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	4 5	Very dangerous avalanche conditions. Travel in avalanche terrain **not** recommended.	Natural avalanches likely; human-triggered avalanches **very** likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	3	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	2	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	1	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.

No Rating		Watch for signs of unstable snow such as recent avalanches, cracking in the snow, and audible collapsing. Avoid traveling on or under similar slopes.

North America

European Avalanche Danger Scale (2018/19)

Europe

	Danger level	Icon	Snowpack stability	Likelihood of triggering
5	very high	4 5	The snowpack is poorly bonded and largely unstable in general.	Numerous very large and often extremely large natural avalanches can be expected, even in moderately steep terrain*.
4	high		The snowpack is poorly bonded on most steep slopes*.	Triggering is likely, even from low additional loads**, on many steep slopes*. In some cases, numerous large and often very large natural avalanches can be expected.
3	considerable	3	The snowpack is moderately to poorly bonded on many steep slopes*.	Triggering is possible, even from low additional loads**, particularly on the indicated steep slopes*. In certain situations some large, and in isolated cases very large natural avalanches are possible.
2	moderate	2	The snowpack is only moderately well bonded on some steep slopes*; otherwise well bonded in general.	Triggering is possible, primarily from high additional loads**, particularly on the indicated steep slopes*. Very large natural avalanches are unlikely.
1	low	1	The snowpack is well bonded and stable in general.	Triggering is generally possible only from high additional loads** in isolated areas of very steep, extreme terrain*. Only small and medium natural avalanches are possible.

India

Danger Level	Degree of Danger	Description
1	UNLIKELY	Generally safe conditions. Snowpack on slopes, if any, is generally stable with isolated instability. Movement is generally safe. Rare avalanche activity is possible with high external loading e.g. tremors, explosives or movement in formation zones.
2	LOW	Partly unsafe conditions. Small size triggering is possible on few extreme slopes. Valley movements are generally safe. Movement on slopes with care.
3	MEDIUM	Unsafe conditions. Triggering is possible from the most avalanche prone slope and may reach the valley in medium size. Avoid movement on slopes. Routes should be selected with care. Valley movement with precaution. Evacuate from unprotected settlements on/near the avalanche paths.
4	HIGH	Highly unsafe condition. Triggering is possible from all avalanche prone slopes and may reach the valley in large size. Suspend all movements. Airborne avalanches likely. Evacuate from all settlements on/near the avalanche paths.
5	ALL ROUND	Extremely unsafe condition. Numerous large avalanches are likely from all possible avalanche slopes even on moderately steep terrain. Airborne avalanche likely and may follow unexpected paths. Evacuate from avalanche prone areas.

- Different dange scales across the world, but rather homogeneous at the regional scale,
- Diversity of warning organizations (national, regional, local, within/outside/connected to NHMS).

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Summary

Sustained observations and access to data – a necessity for understanding climate changes and monitoring extreme events.

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Thank you
Merci

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