# 2022 DRAGON 5 SYMPOSIUM

## MID-TERM RESULTS REPORTING

17-21 OCTOBER 2022

## 59199

# CRYOSPHERE-HYDROSPHERE INTERACTIONS OF THE ASIAN WATER TOWERS: USING REMOTE SENSING TO DRIVE HYPER-RESOLUTION ECOHYDROLOGICAL MODELLING

# Dragon 5 Mid-term Results Project

**THURSDAY, OCTOBER 20TH 2022**

**ID. 59199**

**PROJECT TITLE: CRYOSPHERE-HYDROSPHERE INTERACTIONS OF THE ASIAN WATER TOWERS: USING REMOTE SENSING TO DRIVE HYPER-RESOLUTION ECOHYDROLOGICAL MODELLING**

**PRINCIPAL INVESTIGATORS: FRANCESCA PELLICCIOTTI (WSL), MASSIMO MENENTI (CAS – AIR)**

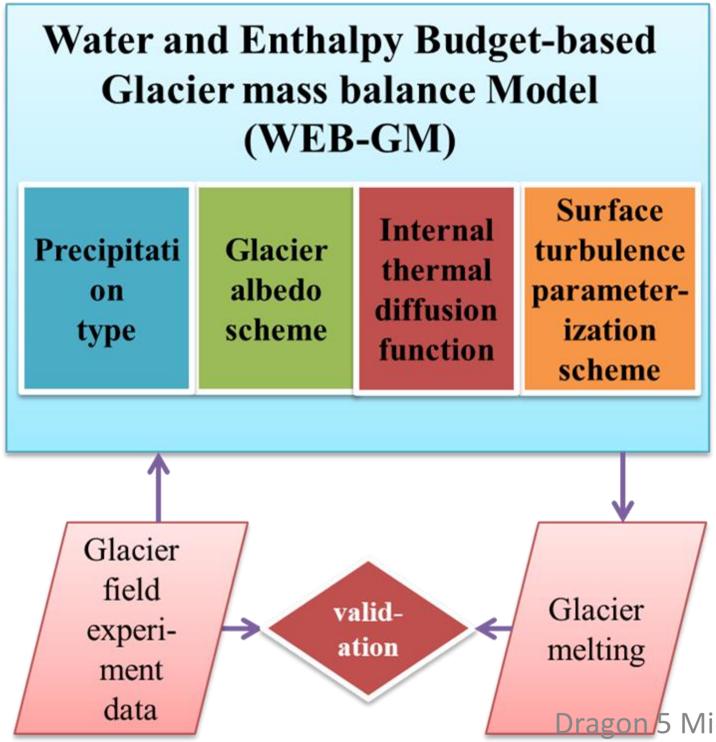
**CO-AUTHORS:EVAN MILES , SHAOTING REN, PASCAL BURI, JING ZHANG, ACHILLE JOUBERTON, JUNRU JIA, THOMAS SHAW, LIAN LIU, MIKE MCCARTHY, QIUXIA XIE, STEFAN FUGGER, CATRIONA FYFFE, YUBAO QIU AND LI JIA**

**PRESENTED BY: MASSIMO MENENTI**

# Objectives

**Document and understand the drivers of blue and green water flows at high elevation:**

- ➢ **Understand cryospheric, vegetation and land surface changes**
- ➢ **Generate glacier-specific altitudinal surface mass balance profiles**
- ➢ **Model land-surface interactions across the cryosphere, hydrosphere and biosphere**



**Water and Enthalpy Budget-based Glacier mass balance Model (WEB-GM)**

**Precipitation type**

**Glacier albedo scheme**

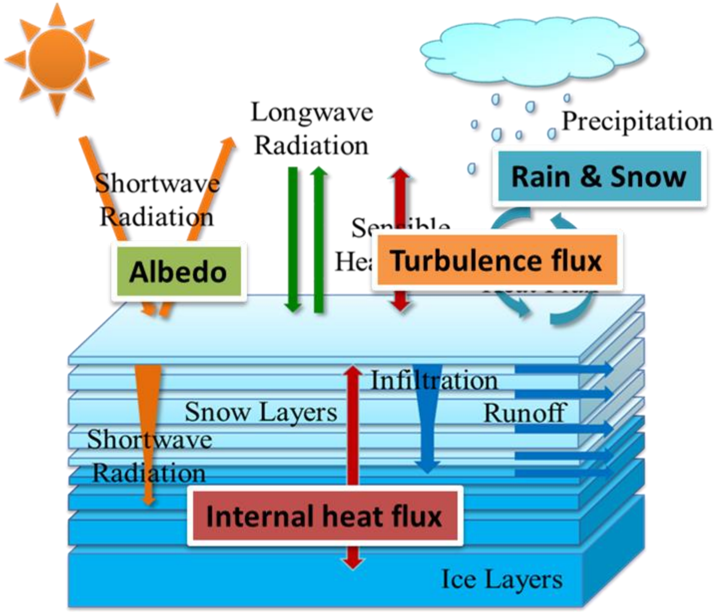
**Internal thermal diffusion function**

**Surface turbulence parameterization scheme**

Glacier field experiment data

validation

Glacier melting

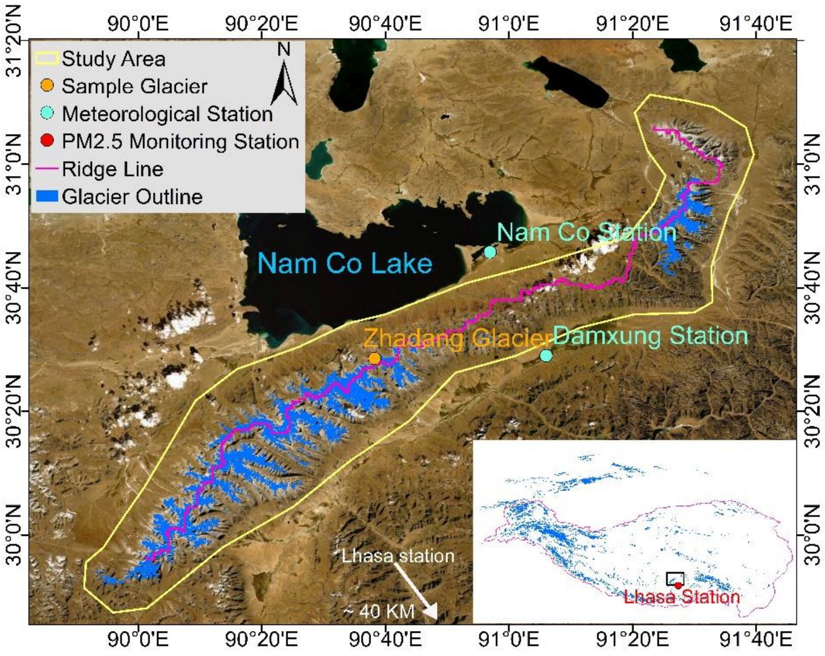


(Ding et al., 2020)

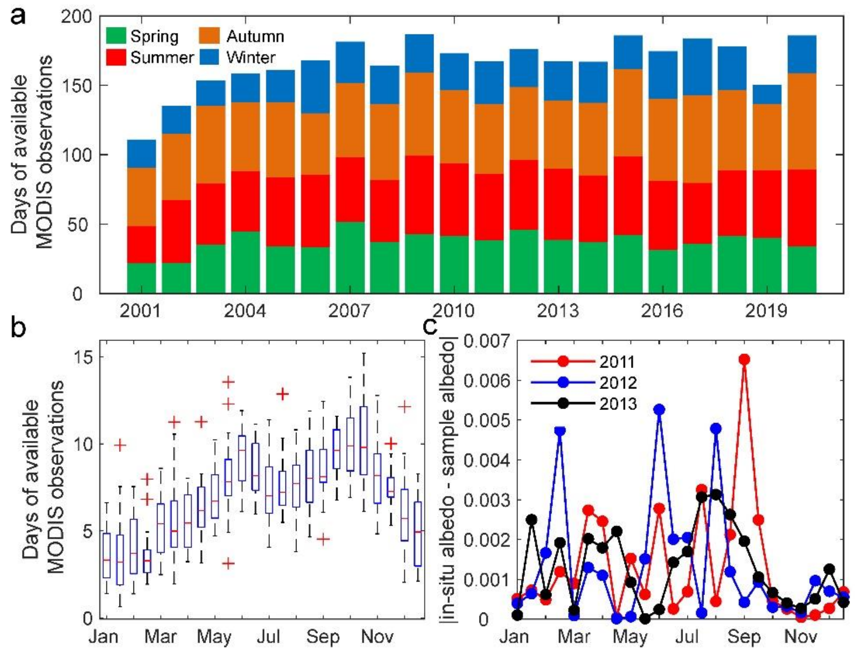
# Cryospheric, vegetation and land surface changes

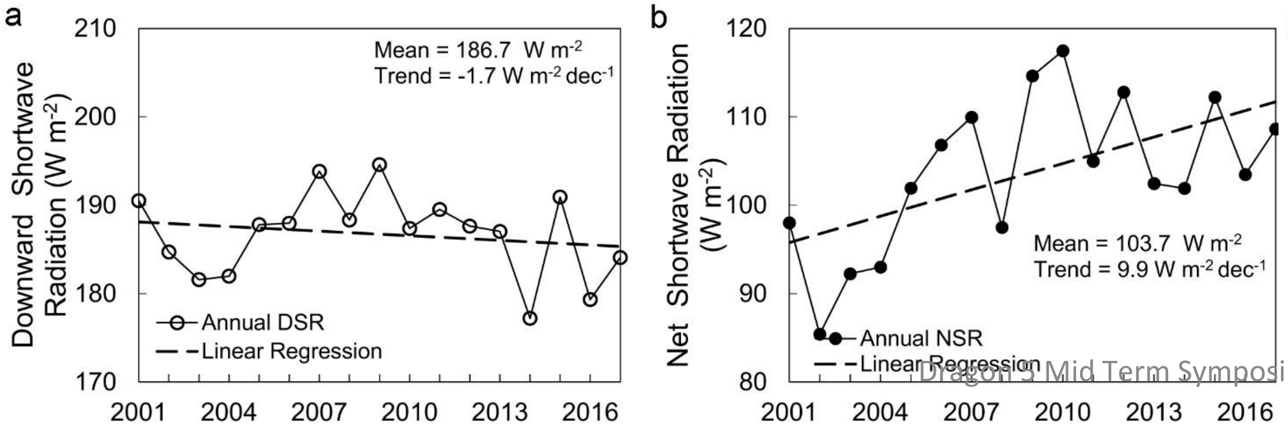
## Albedo and mass loss in the Western Nyainqentanglha

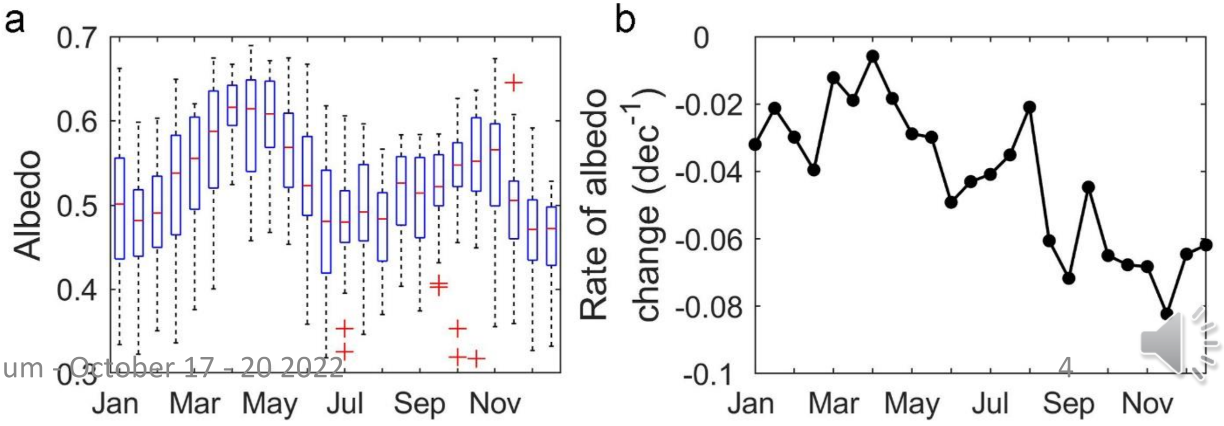
(**Ren et al., 2021**)



- ➢ New method to retrieve glacier daily albedo using MODIS data;
- ➢ Terrain slope and aspect; snow and ice BRDF anisotropy correction.
- ➢ Evaluation of response to rainfall, temperature and PM 2.5: trends,seasonality, spatial variability and elevation



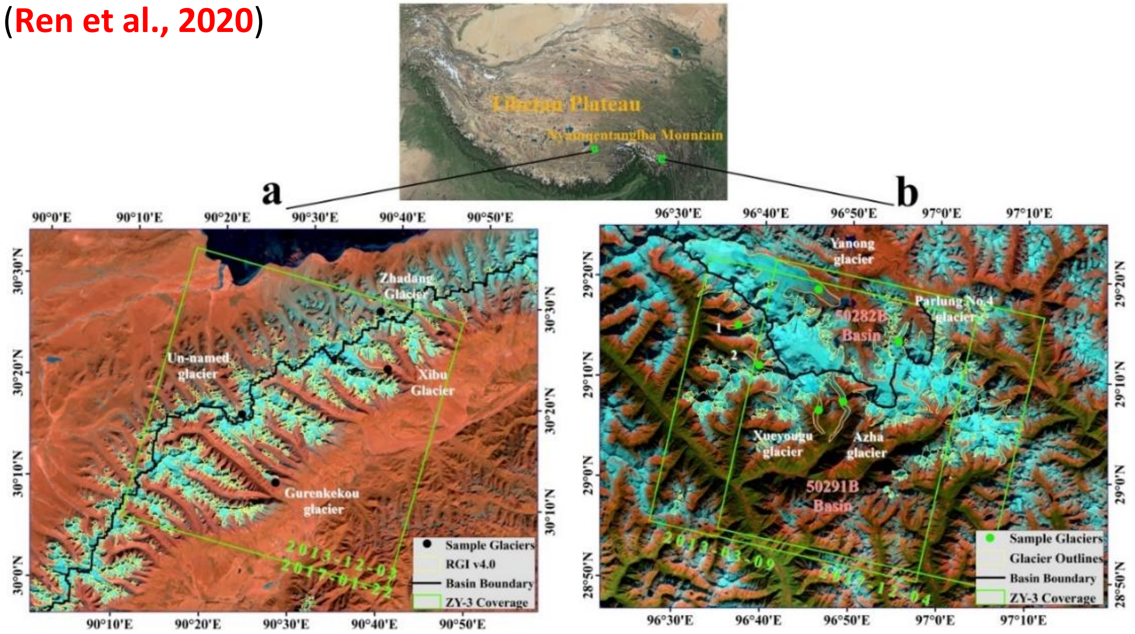




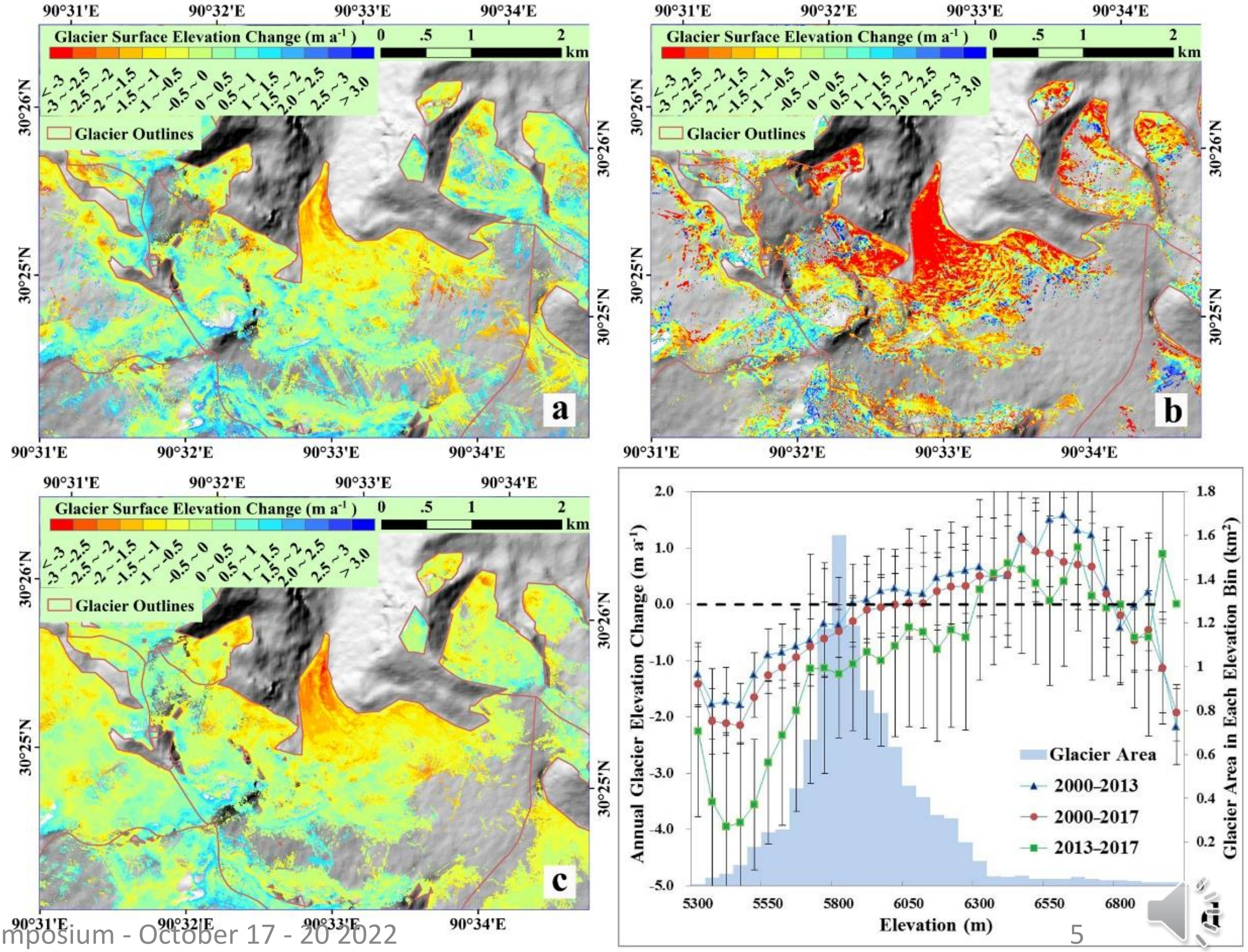
# Cryospheric, vegetation and land surface changes

(Ren et al., 2020)

## Albedo and mass loss in the Western Nyainqentanglha

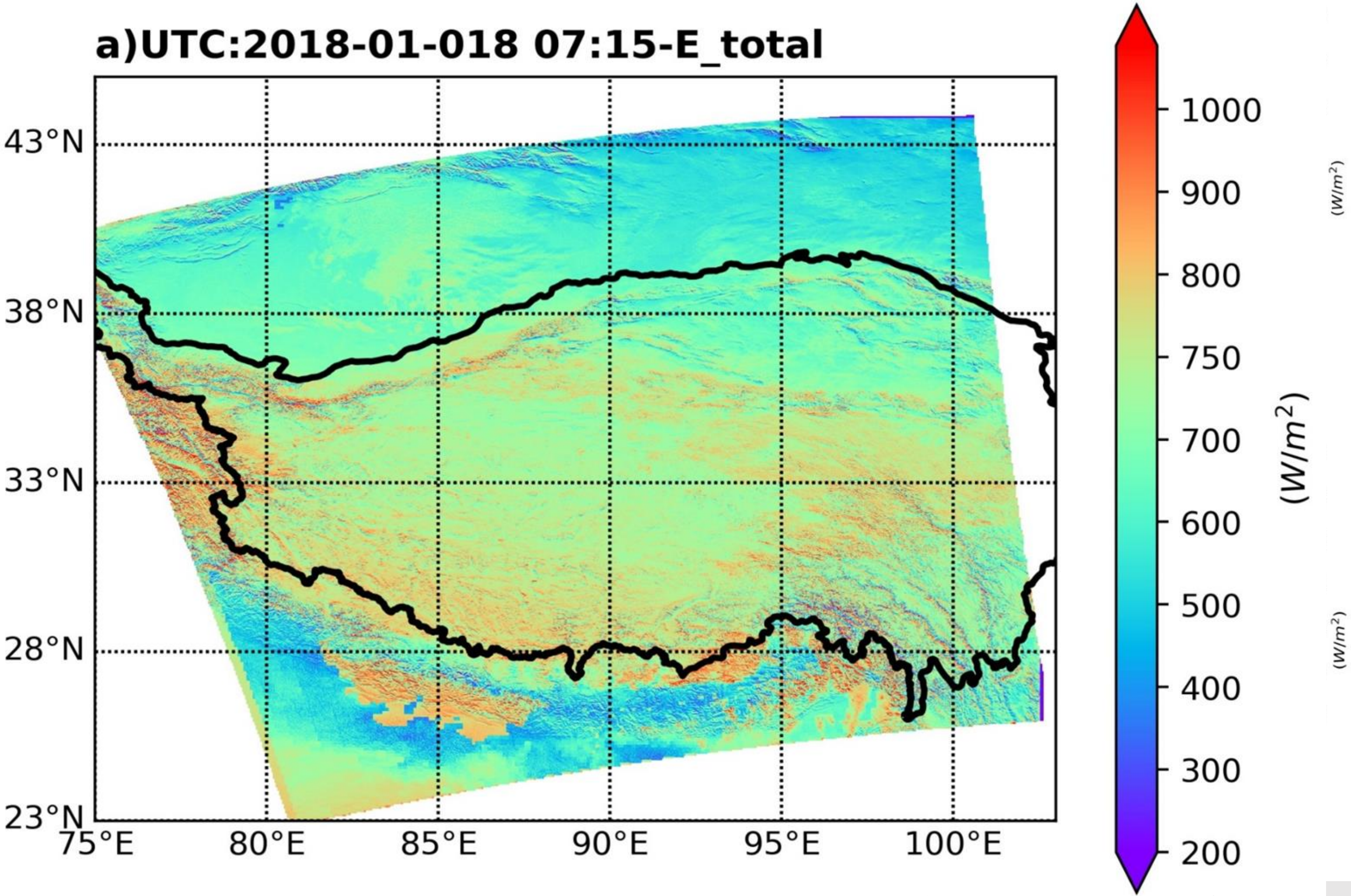


- High spatial resolution ZiYuan-3 (ZY-3) Three-Line-Array (TLA) stereo images to retrieve glacier mass balance;
- ZY-3 TLA: higher point cloud density and less invalid data;
- High resolution (5 m) glacier mass balance map;
- Geodetic mass balance of representative glaciers in WNM and ENM
- 2000–2013, 2013–2017 and 2000–2017

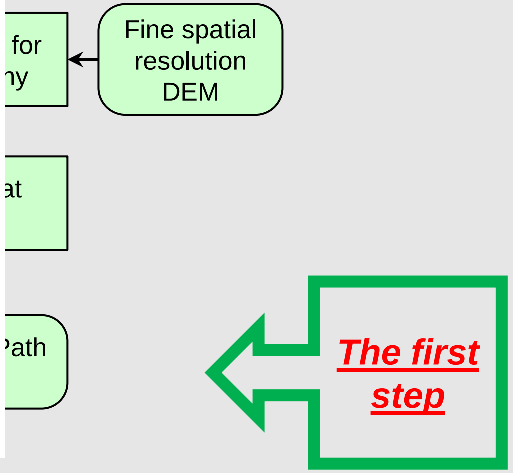


# Cryospheric, vegetation and land surface changes

## Simultaneous retrieval of AOD and surface BRDF: components of at-surface irradiance



- ➢ **Accurate knowledge of the magnitude and angular dependence of downwelling radiance necessary to retrieve both surface reflectance and AOD**
- ➢ **Increasing scattering increases path-radiance and modifies the angular dependence**
- ➢ **Terrain irradiance at a facet increases with increasing scattering**

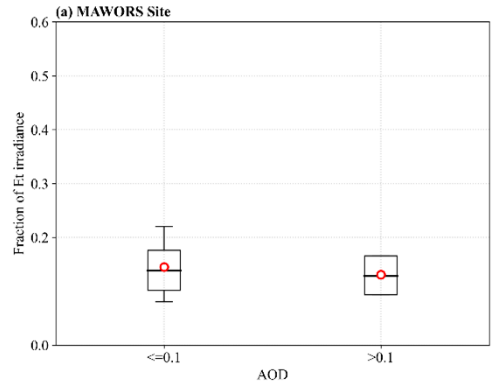


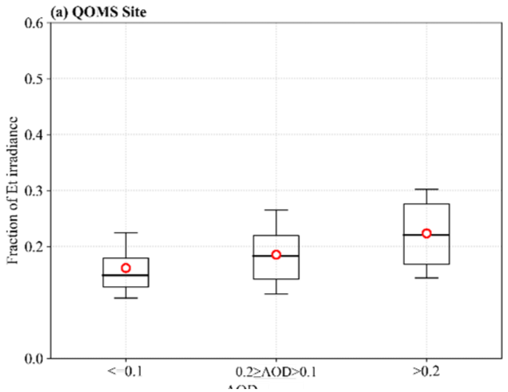
***The first step***

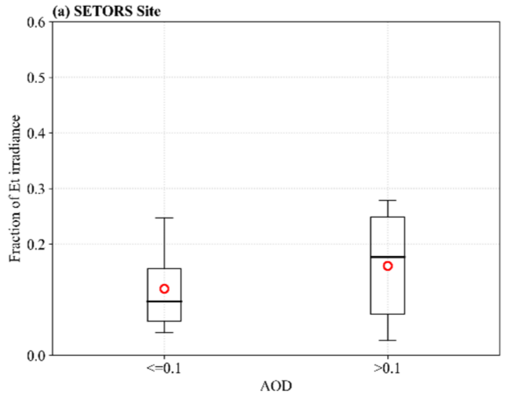
(Jia et al., 2021)

# Cryospheric, vegetation and land surface changes

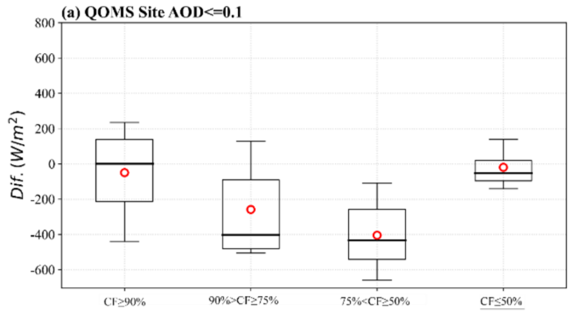
## Simultaneous retrieval of AOD and surface BRDF

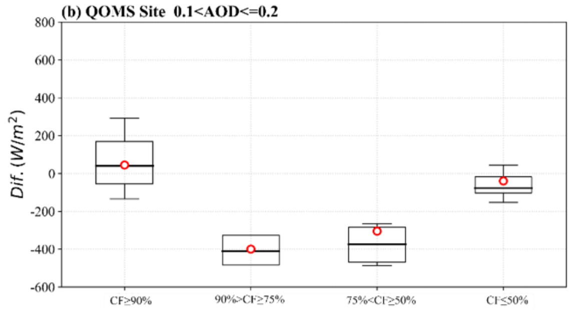


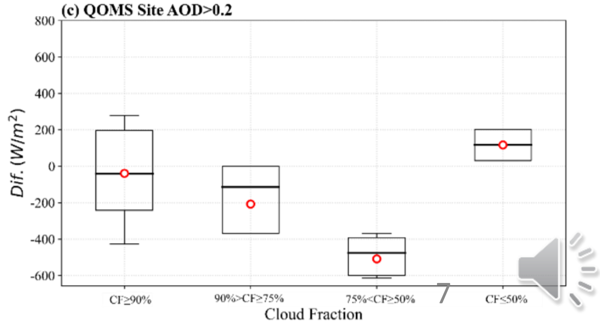




- Scattering increases with increasing AOD
- Diffuse irradiance increases
- Et increases → larger fraction of total irradiance.
- Impact of AOD depends on adjacent terrain







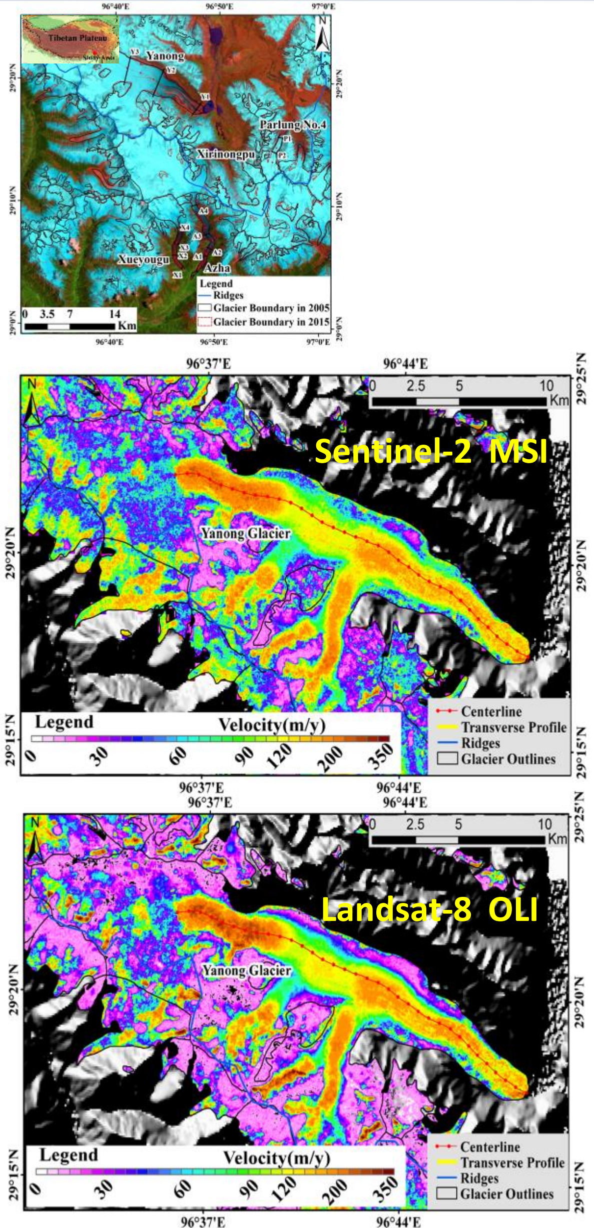
- Accuracy lower at intermediate cloud fraction
- Impact of fragmented clouds difficult to parameterize
- Larger fraction of direct and circum-solar irradiance

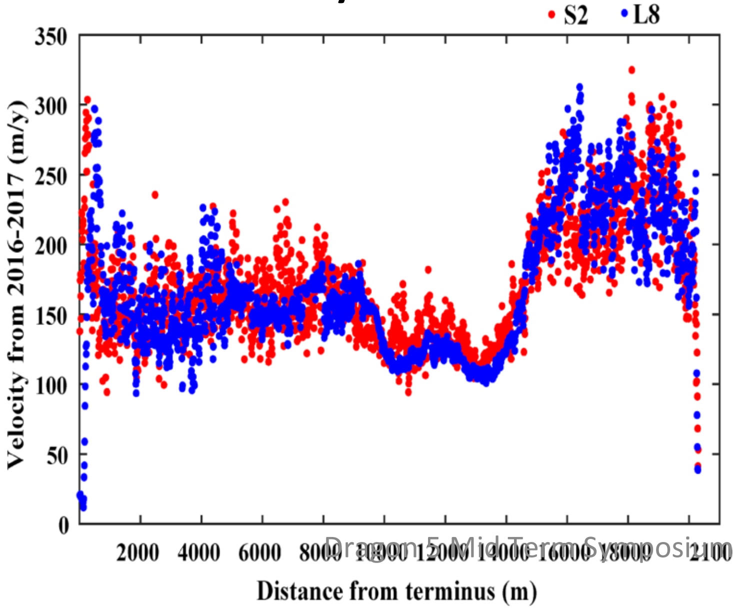
# Cryospheric, vegetation and land surface changes

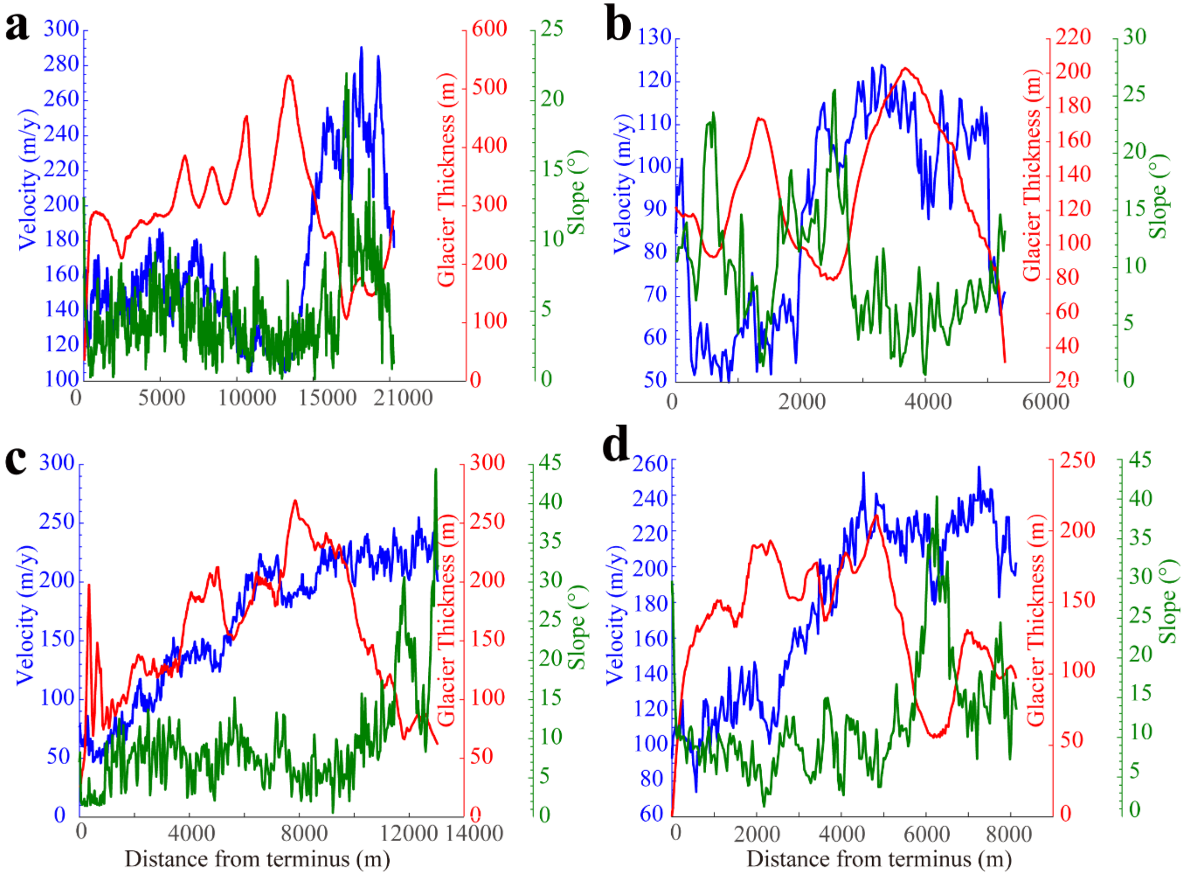
## Glacier flow velocity

(**Zhang et al., 2021 a**)

- **Updated maps of glacier surface velocity in the Parlung Zangbo Basin;**
- **Glacier motion mechanisms using central flowline and transversal velocity profiles of four typical glaciers**
- **glacier velocity patterns vs. topographic profiling and glacier thickness analyses**



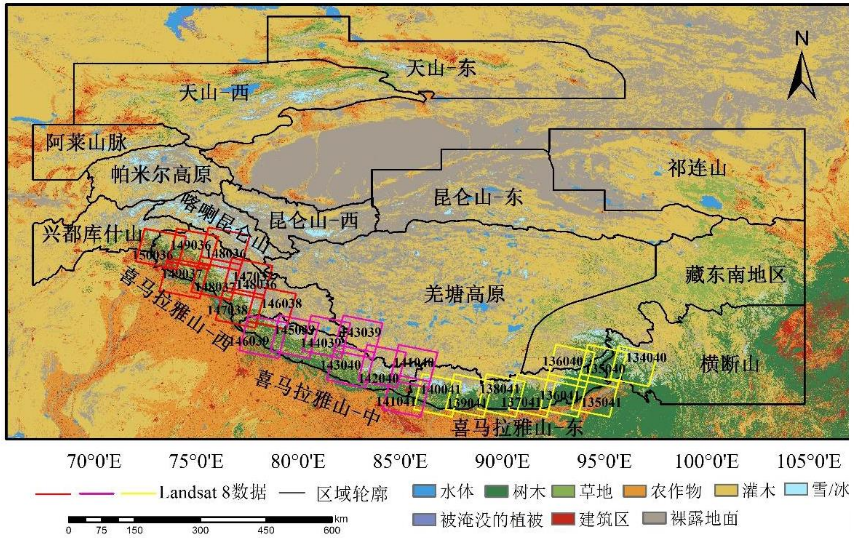


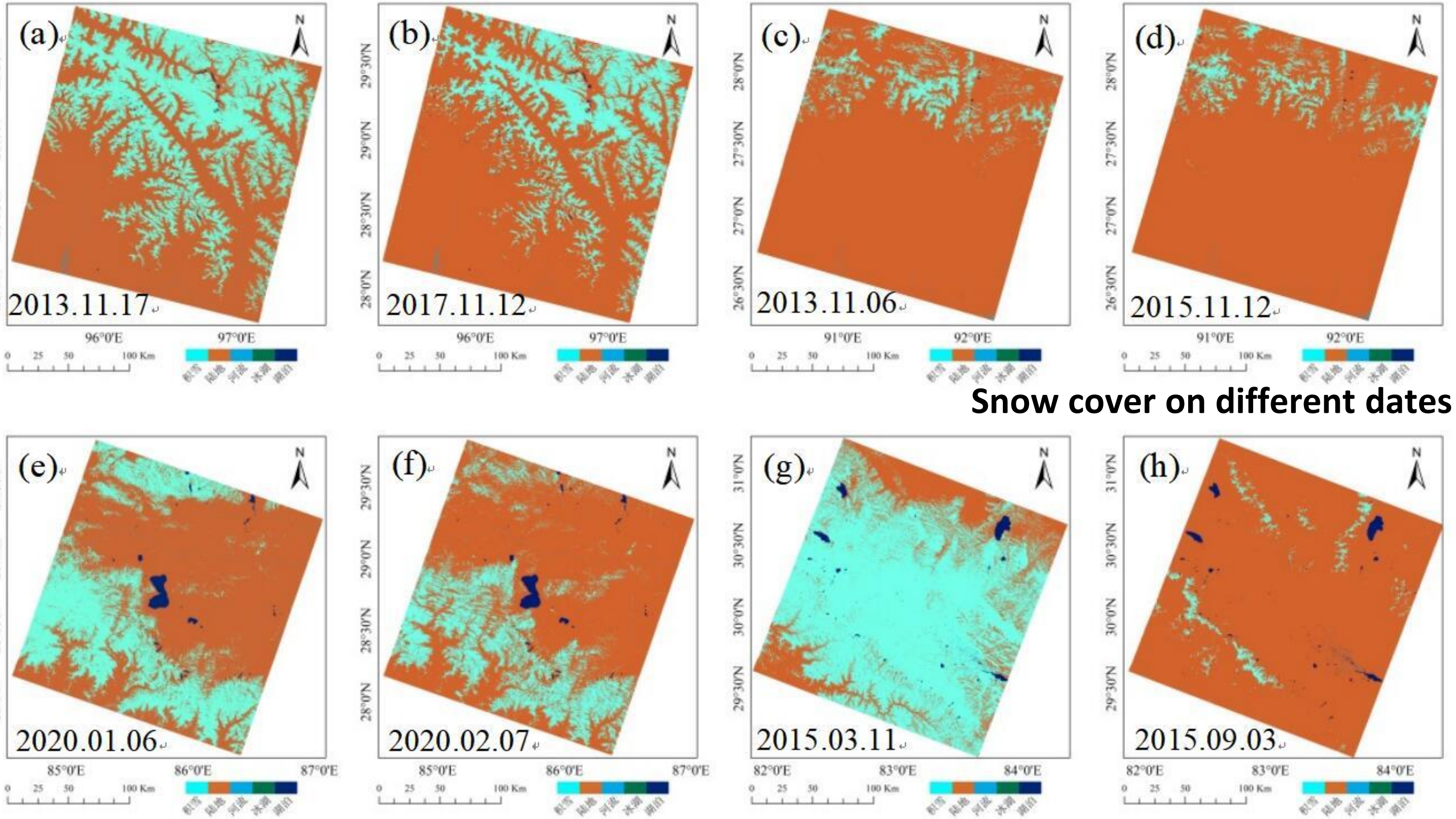


**Annual mean centerline glacier velocity (blue line) versus glacier thickness (red line) versus slope (green line): (a) Yanong Glacier (b) Parlung No.4 Glacier (c) Azha and (d) Xueyougu Glacier**

# Cryospheric, vegetation and land surface changes

## A dataset of Landsat 8 snow coverage in the Himalayas from 2013 to 2020





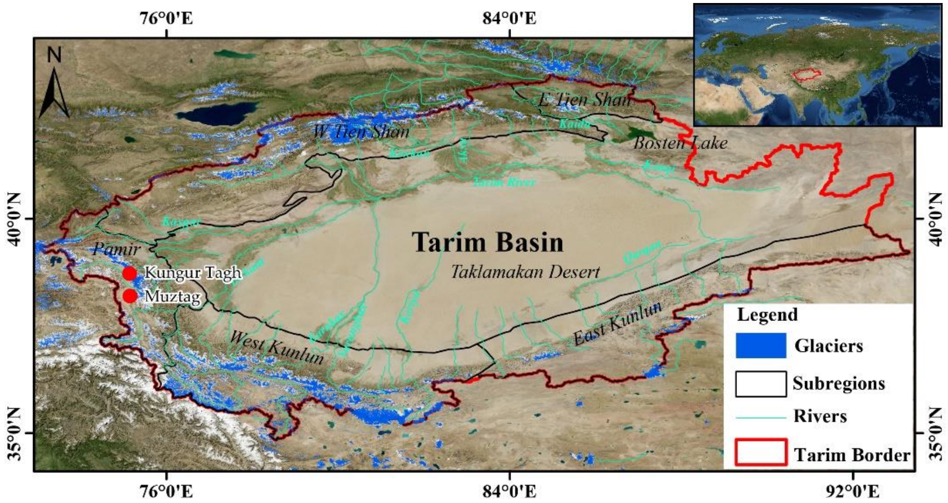
Snow cover on different dates

- **Landsat 8 OLI clear sky conditions**
- **Support Vector Machine (SVM) to select the snow cover training samples and correct for terrain and shadows**

**Evaluation against snow cover classification of Sentinel-2 MSI within a grid of 900×900m: correlation coefficient > 0.95, RMSE = 0.1%**

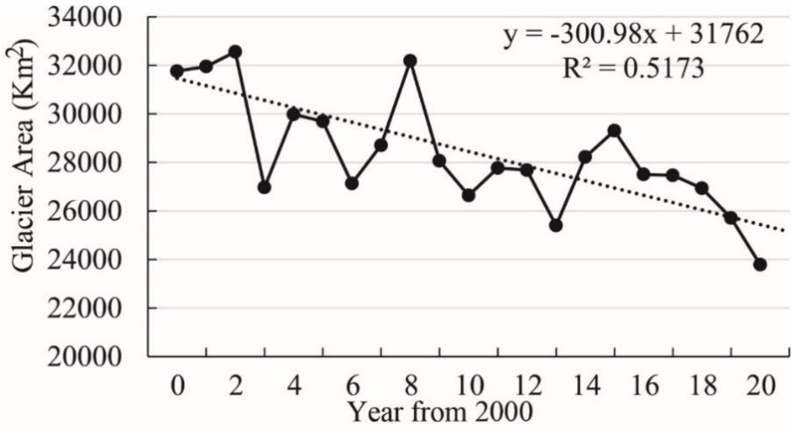
# Cryospheric, vegetation and land surface changes

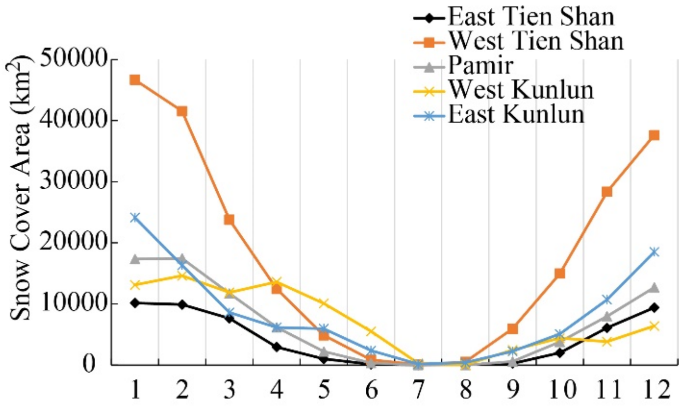
## Glacier Area and Seasonal Snow Cover Changes in the Tarim basin - 2013 to 2020

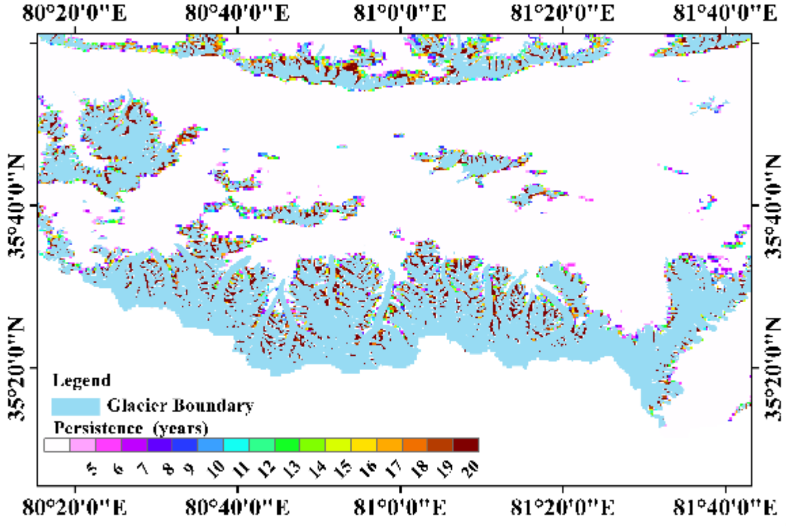


- Thresholding the NDSI to extract annual glacier area and snow cover
- MODIS Surface Reflectance 8-Day product (MOD09A1)
- Multiple snowfall and snowmelt events → intermittent snow cover → discriminate snow and glacier.
- Glacier outlines 2000, 2005, 2010, 2015 and 2020)
- Glacier area decreased 7975.71 km2 from 2001 to 2020; annual rate of change – 0.94 %

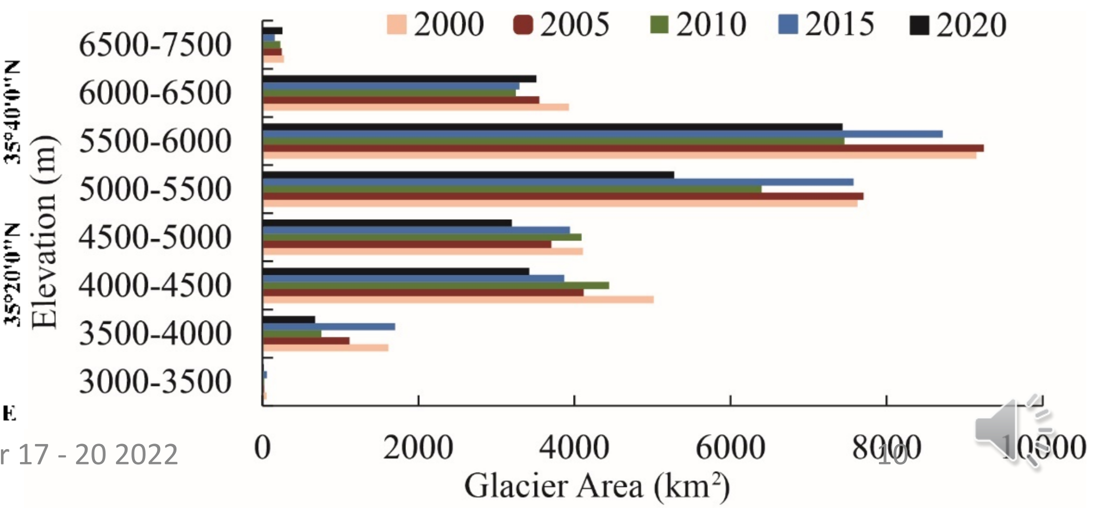
(Zhang et al., 2021 b)





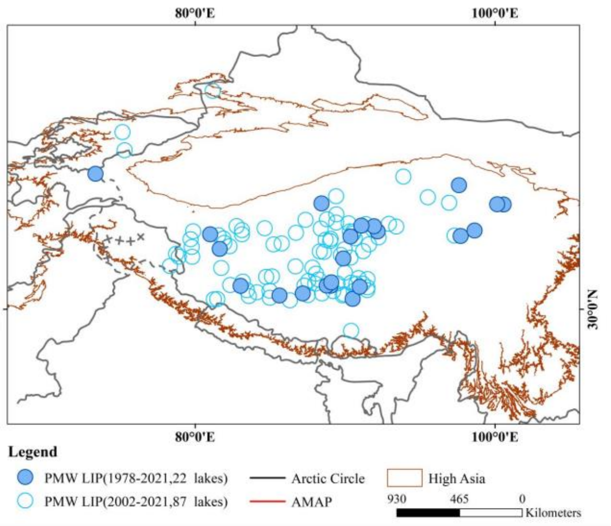


Long lasting snow

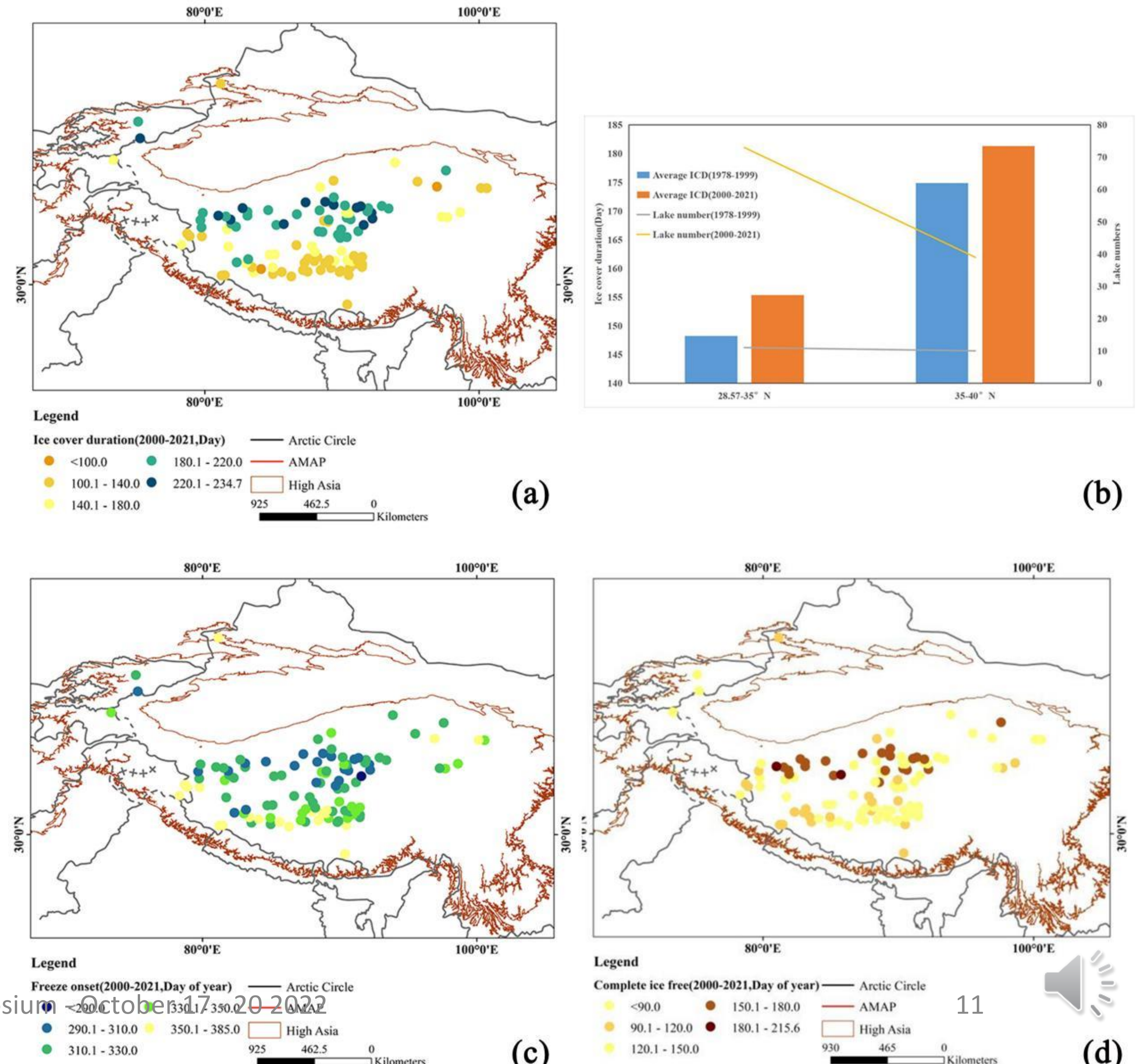


# Cryospheric, vegetation and land surface changes

## Lake ice monitoring in HMA

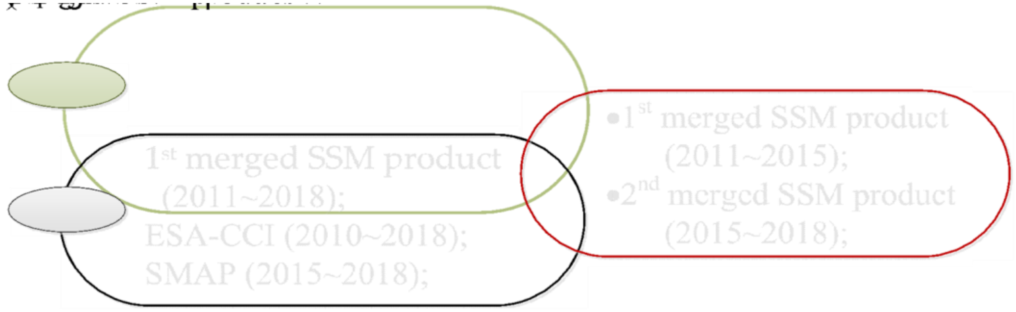


- PMW: Passive MicroWave
- LIP: Lake Ice Phenology
- 22 Lakes 1978 to 2021
- 87 Lakes 2002 to 2021
- Freeze Onset (FO), Complete Ice Cover (CIC), Melt Onset (MO), and Complete Ice Free (CIF) dates



# Cryospheric, vegetation and land surface changes

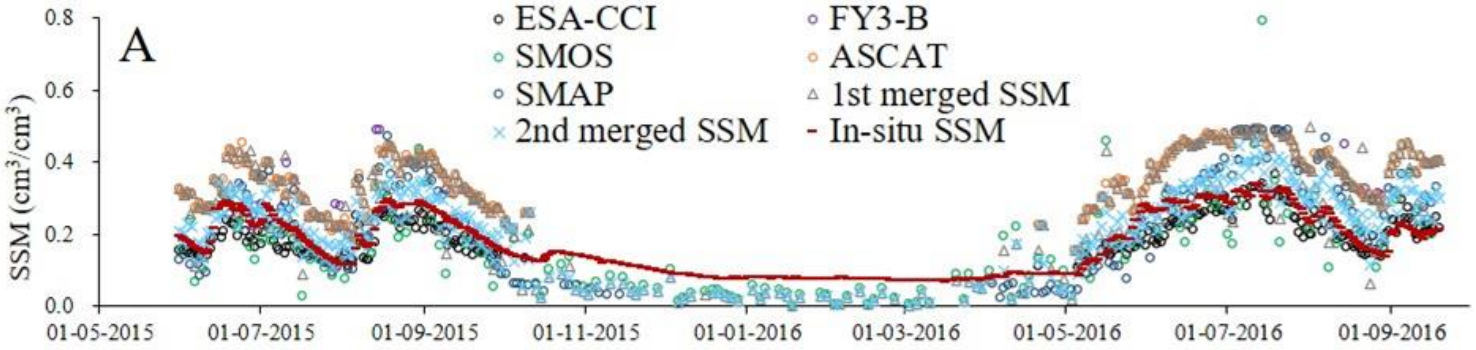
## Soil Moisture Data Fusion by Triple Collocation Analysis - 2011 to 2018

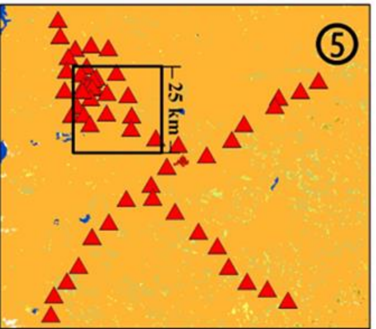


1st merged SSM product (2011~2018);
ESA-CCI (2010~2018);
SMAP (2015~2018);

- 1st merged SSM product (2011~2015);
- 2nd merged SSM product (2015~2018);

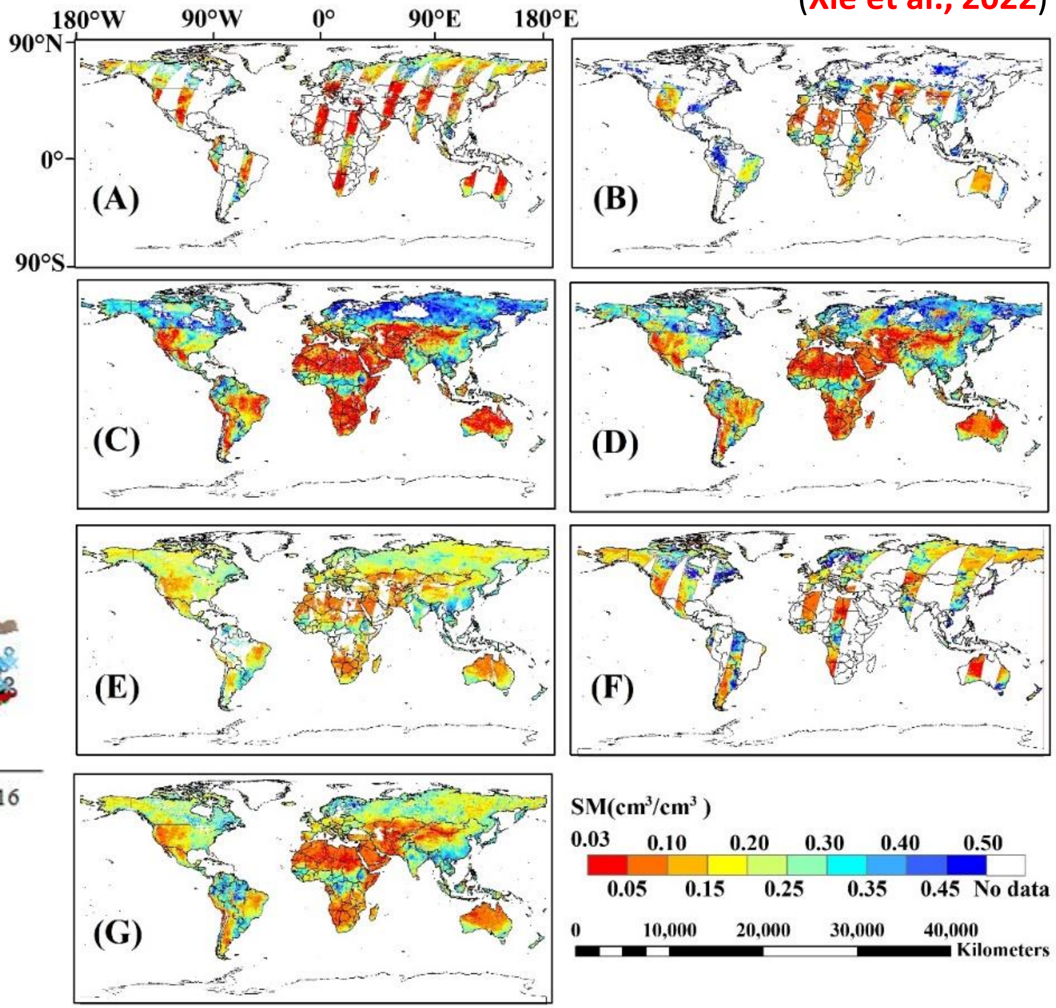
**Evaluation against in situ measurements Tibetan Plateau**





A: Site Tibetan Plateau (CTP_SMTMN)

(Xie et al., 2022)

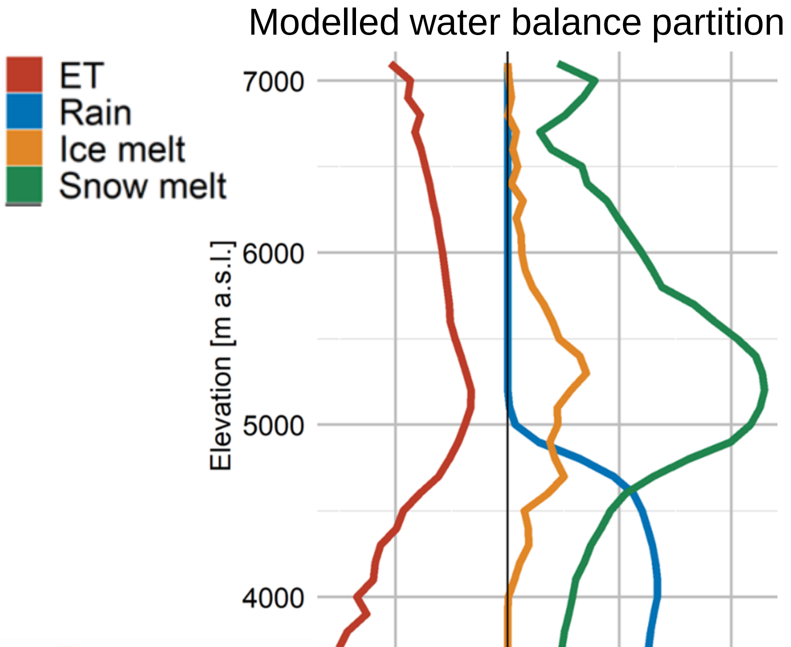


# Glacier-specific altitudinal surface mass balance

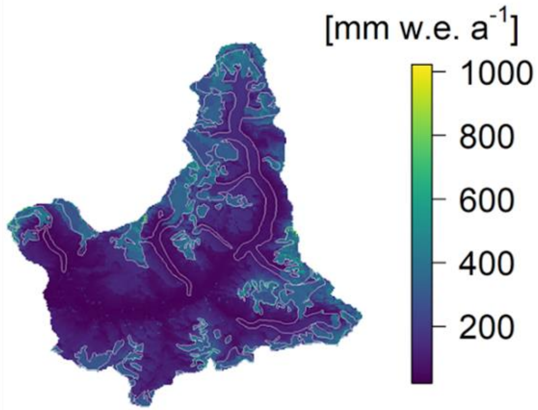
## Importance of latent heat fluxes for the water balance of a high elevation catchment

- Land surface modeling reveals high altitudinal/subseasonal variability in water balance partitioning in a glacierized Himalayan catchment
- Water loss through snow sublimation, evaporation and transpiration exceeds water production from glacier melt by 54% at the catchment scale
- LE fluxes are particularly important for the catchment water balance above 6500 m (snow sublimation) and below 4500 m (transpiration)

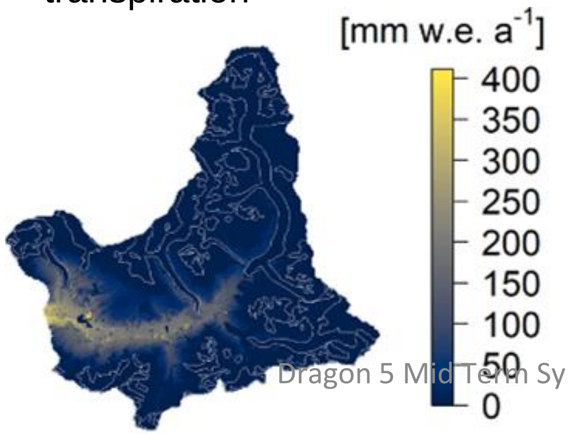
Modelled water balance partition



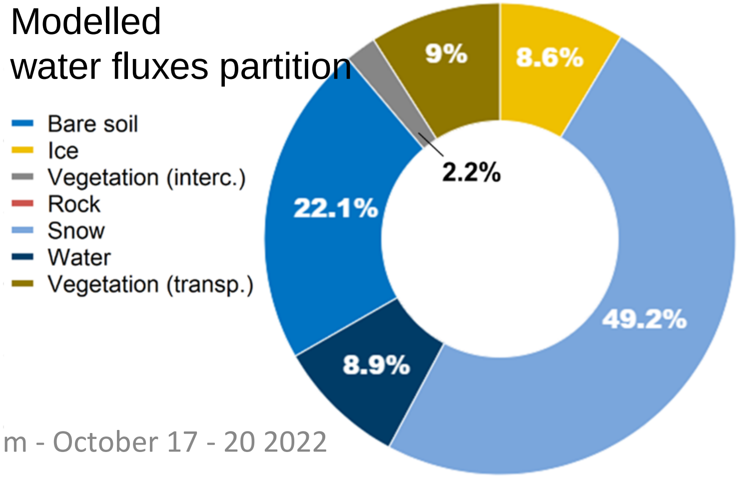
Modelled sublimation from snow



Modelled transpiration



Modelled water fluxes partition

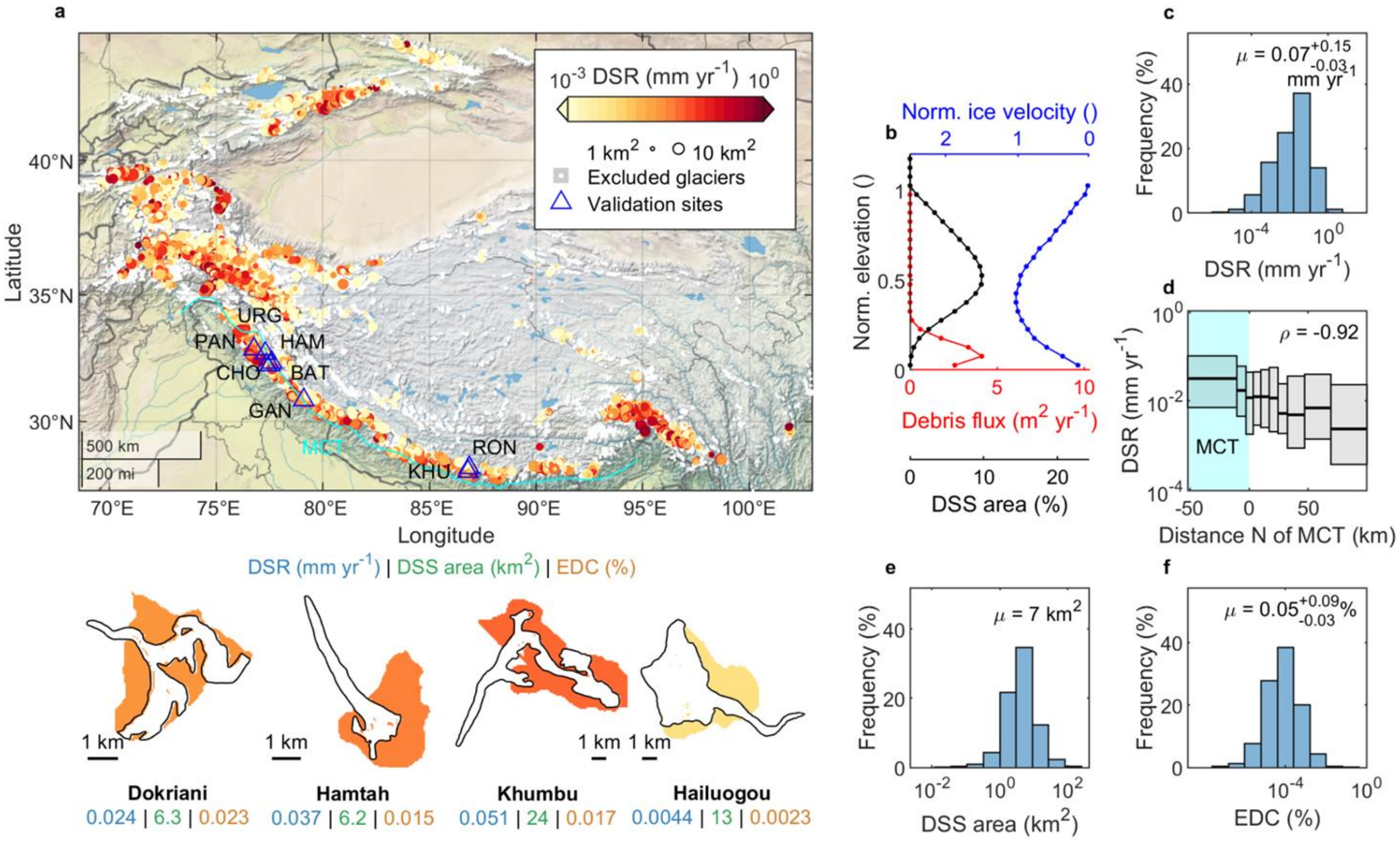


(**Buri et al., under review**)

# Glacier-specific altitudinal surface mass balance

## Supraglacial debris thickness and supply rate in High-Mountain Asia

- Also estimated the rate of supply of debris to glaciers in the region from glacier headwalls
- This is highly spatially variable
- Debris-supply rates are interestingly an order of magnitude or more lower than erosion rates measured using 10-Beryllium isotopes, likely because debris supply is highly episodic

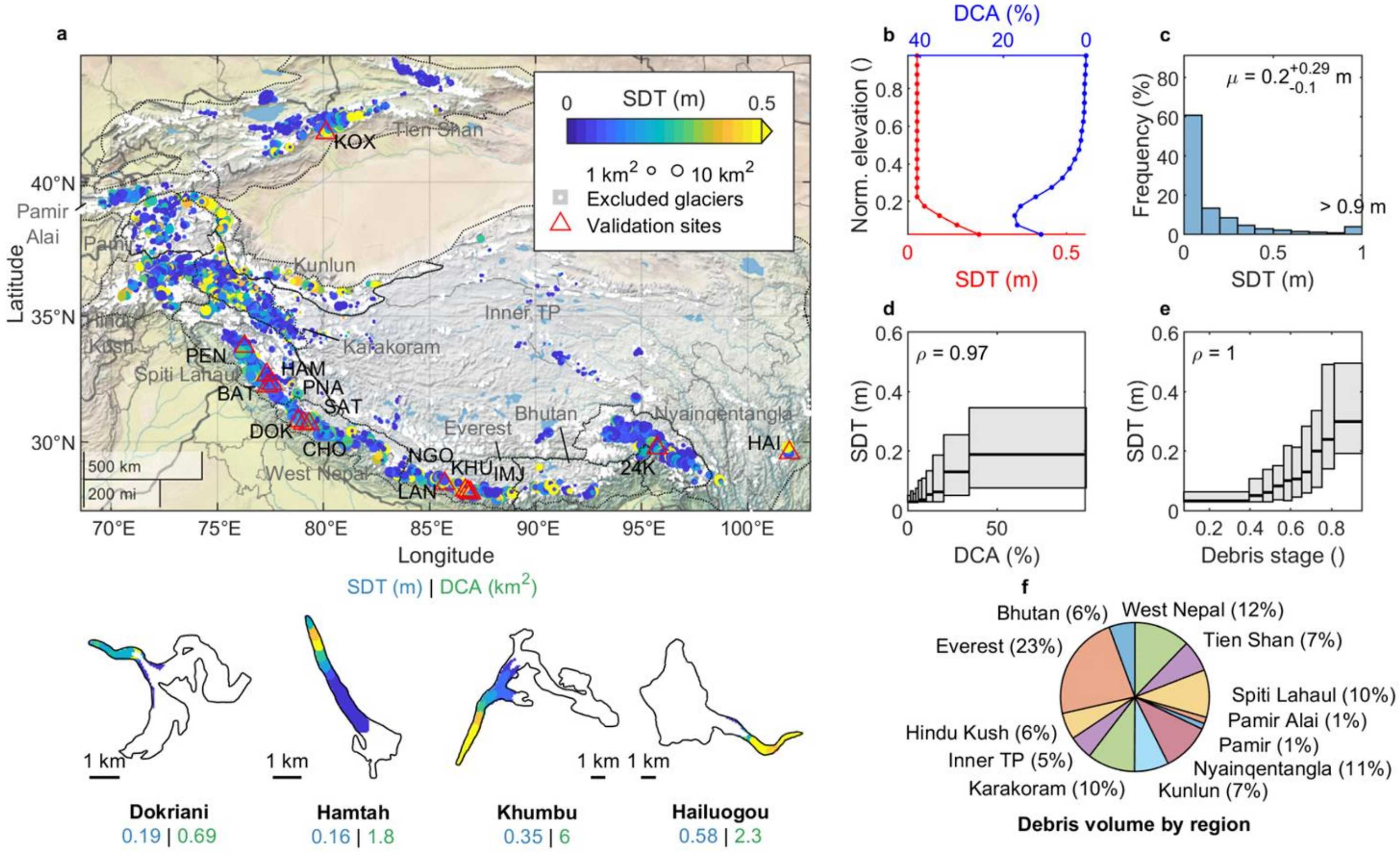


(McCarthy et al., accepted)

# Glacier-specific altitudinal surface mass balance

## Supraglacial debris thickness and supply rate in High-Mountain Asia

- Supraglacial debris thickness was estimated across High-Mountain Asia using a combination of remote sensing and energy-balance modelling techniques
- High spatial variability in supraglacial debris thickness
- Majority of the region's debris is relatively thin (>50% < 0.1 m)
- Debris thickness increases with fractional debris-covered area and 'stage' of debris evolution



(McCarthy et al., accepted)

# Improved Noah Snow Albedo Scheme in the Simulation of Snow Processes

- Ingestion of MODIS albedo improved performance WRF + Noah
- **NEW scheme** MODIS albedo vs. model snow depth, age, fresh snow albedo, snow free albedo (background abedo)
- MODIS albedo: **is it good enough?**

Noah default

$$\alpha_{\text{snow}} = \alpha_{max} \times A^{t^B}$$

$$\alpha = \alpha_{bg} + sc \times \left(\alpha_{\text{snow}} - \alpha_{bg}\right)$$

New parameterization

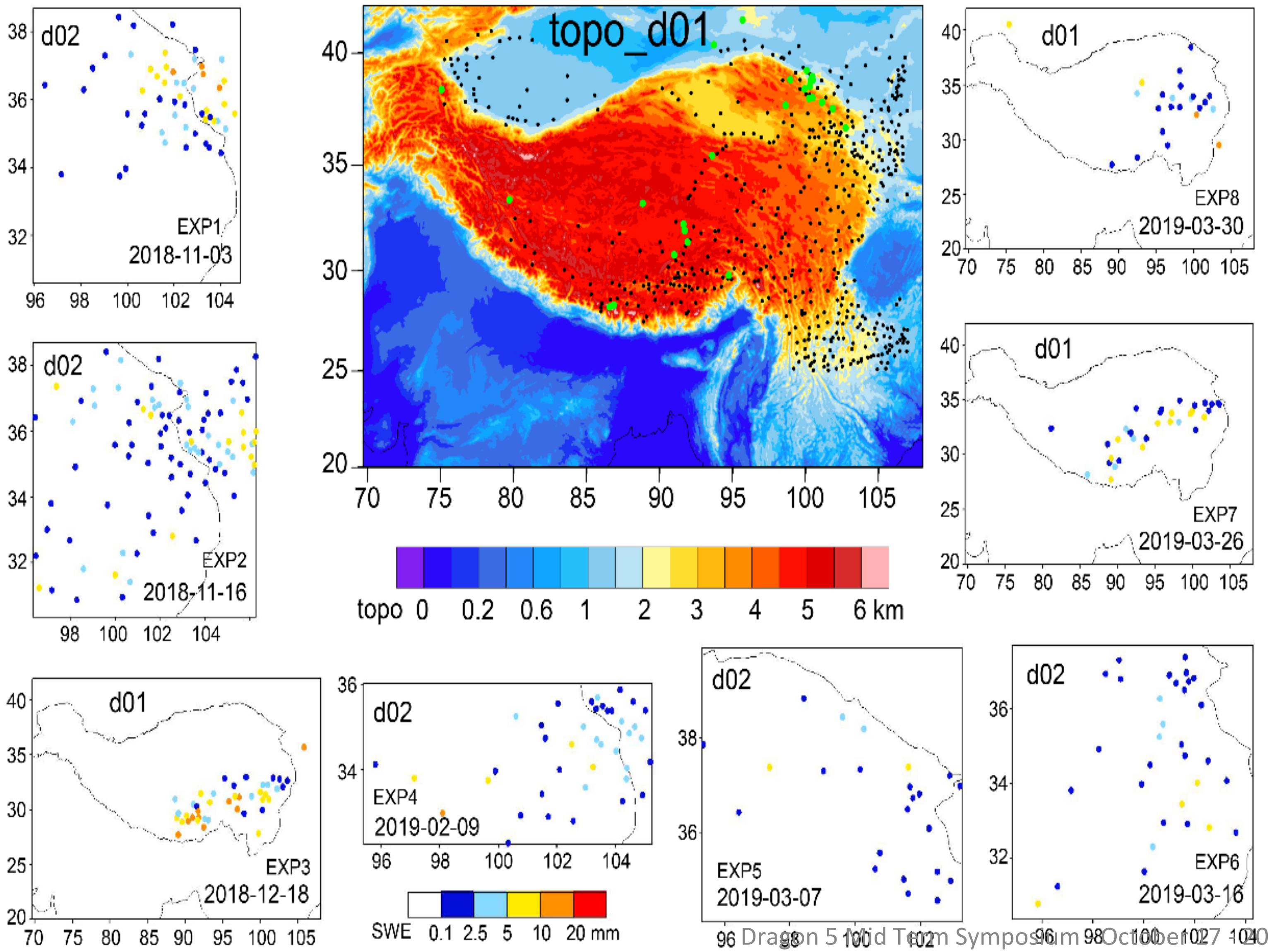
$$\alpha_{\text{snow}} = 0.13 + 0.66e^{\left(\frac{t}{1.38}\right)}$$

$$\alpha = \alpha_{\text{snow}} + (0.19 - \alpha_{\text{snow}})e^{\left(\frac{-d}{0.11}\right)}$$

**$\alpha_{\text{snow}}$ = snow albedo**
**$\alpha_{\text{max}}$ = fresh snow albedo**
**t = snow age (days)**
**$\alpha_{\text{bg}}$ = background albedo**
**α= albedo (MODIS; WRF+Noah)**
**d = snow depth (m)**

(**Liu et al., 2021**)

# Land-surface interactions: cryosphere, hydrosphere and biosphere



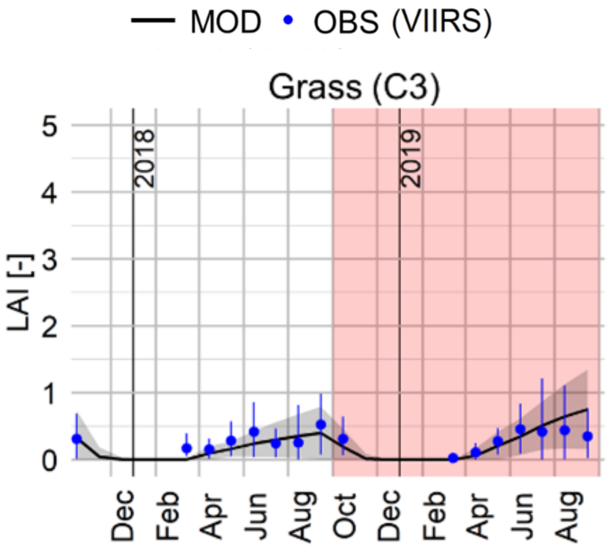
**Improved Noah Snow Albedo Scheme in the Simulation of Snow Processes**

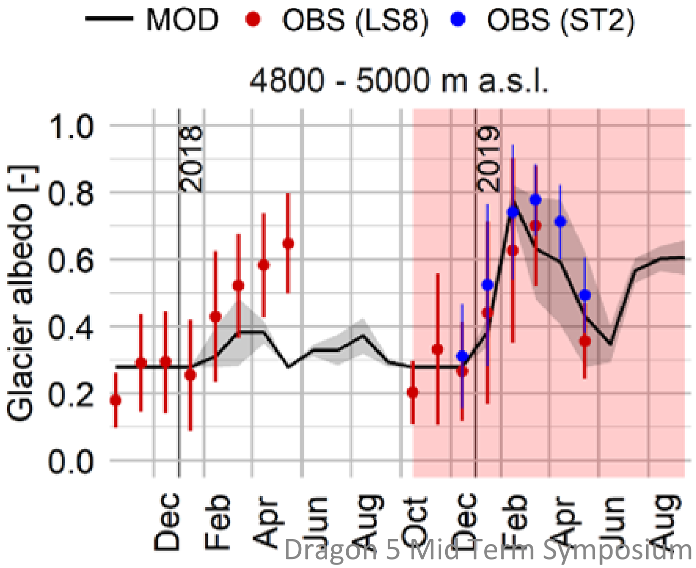
(**Liu et al., 2021**)

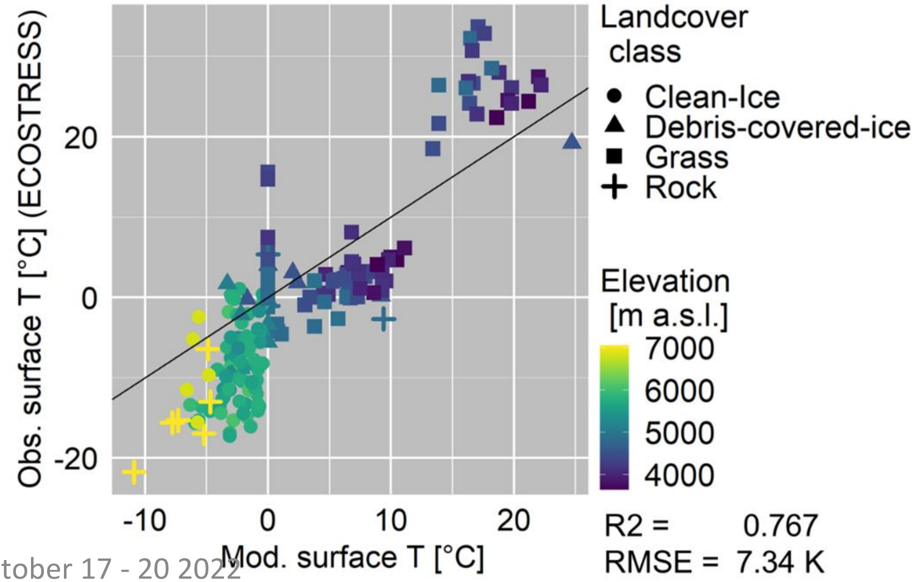
# Land-surface interactions: cryosphere, hydrosphere and biosphere

## Importance of vapour fluxes for the water balance of a high elevation catchment

- Application of Land Surface Model of very high spatial, temporal and physical detail to simulate the glacierized Langtang catchment (Nepal)
- Model evaluation against various EO datasets:
  snow covered area (MODIS), leaf area index (VIIRS), land surface temperature (ECOSTRESS), glacier albedo (Sentinel2/Landsat8), glacier mass balance (Pléiades)





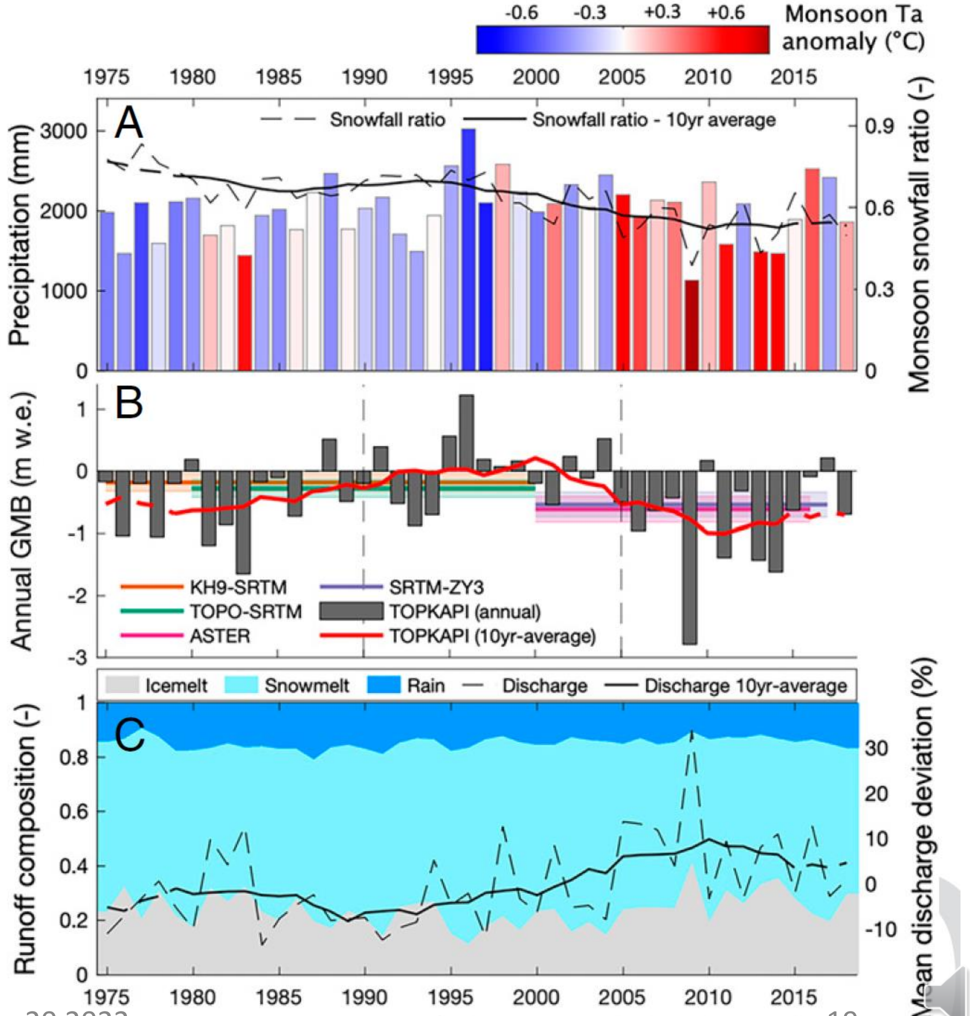


(**Buri et al., under review**)

# Land-surface interactions: cryosphere, hydrosphere and biosphere

## Understanding the causes of high glacier mass losses in the Tibetan Plateau

- Long term simulations of glacier mass balance and runoff, Parlung catchment, Eastern Tibetan Plateau
- Temperature increase (mean of 0.39 ◦C · dec−1 since 1990) has accelerated mass loss rates by altering both the ablation and accumulation regimes, in particular reducing monsoon snowfall
- Higher solid precipitation in spring (+18%) during the last two decades was increasingly important in mitigating glacier mass loss by providing mass to the glacier and protecting it from melting in the early monsoon

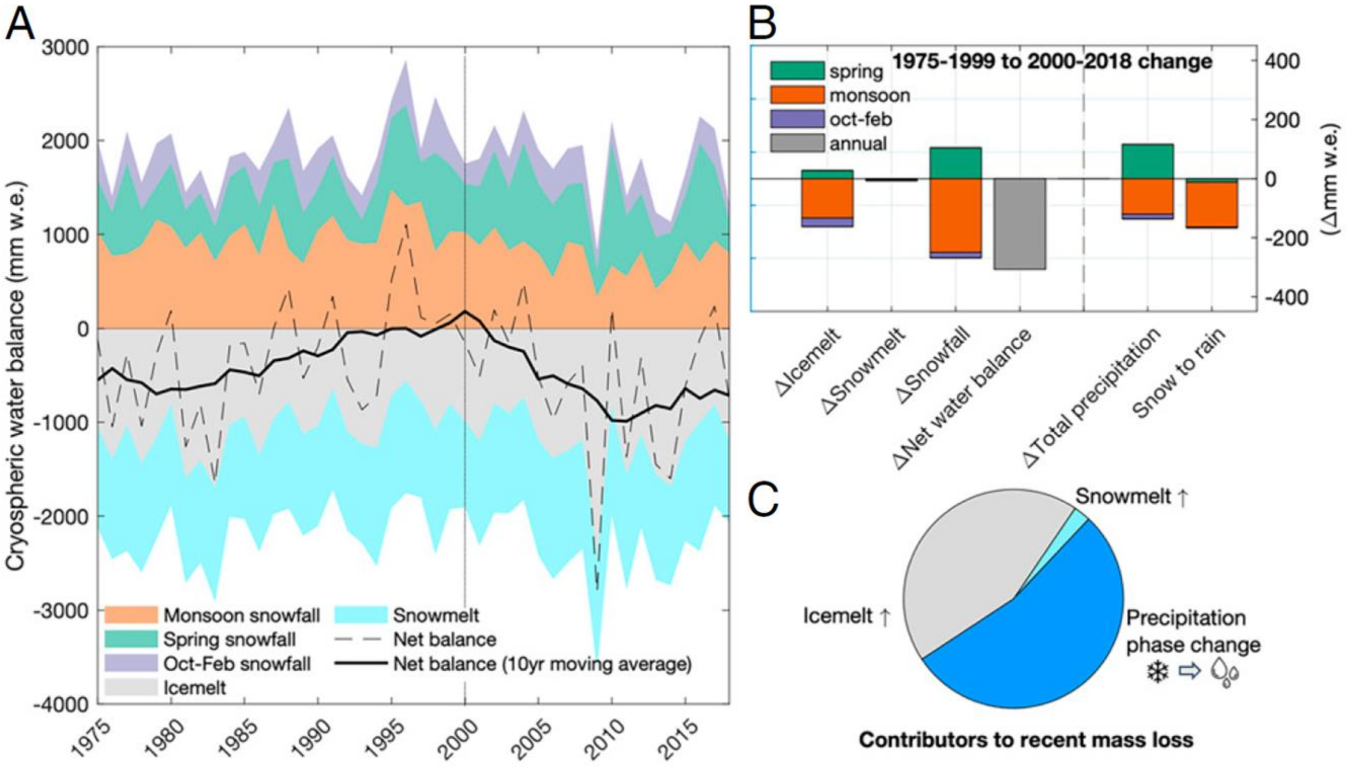


(**Jouberton et al., 2022, PNAS**)

# Land-surface interactions: cryosphere, hydrosphere and biosphere

## Understanding the causes of high glacier mass losses in the Tibetan Plateau

- Bare ice is exposed to warmer temperatures for longer periods;
- Ice melt and catchment discharge have unsustainably intensified since the start of the 21st century, raising concerns for long-term water supply and hazard occurrence in the region.
- Warming-induced monsoon precipitation phase change intensifies glacier mass loss in the southeastern Tibetan Plateau



(**Jouberton et al., 2022, PNAS**)

# EO Data Delivery

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

| **ESA** | **No. Scenes** |
|---|---|
| 1. S-1 | 30 |
| 2. S-2 | 82 |
| 3. ESA CCI/ SM | 500 |
| 4. PROBA-V | 10 |
| 5. ASCAT | 500 |
| 6. AMSR-E Enhanced data | ftp |
| 7. AMSR-2 L1 data | ftp |
| 8. | |
| 9. | |
| 10. | |
| 11. | |
| Total: | |
| Issues: | |

| **ESA Third Party Missions** | **No. Scenes** |
|---|---|
| 1. Pléiades | 16 |
| 2. SPOT | 10 |
| 3. Deimos | 2 |
| 4. L5,7,8 | 75 |
| 5. PlanetScope | 100 |
| 6. SMMR Enhanced data | ftp |
| 7. MWRI L1 data | ftp |
| 8. SSM/I Enhanced data | ftp |
| 9. MODIS | 1700 |
| 10. CALIOP | 1507 |
| 11. ASTER GDEM | 1 |
| Total: | |
| Issues: | |

| **Chinese EO data** | **No. Scenes** |
|---|---|
| 1. FY3C | 500 |
| 2. SDGSAT-1/TIS | 165 |
| 3. SDGSAT-1/GIU | 95 |
| 4. GF-3 | ftp |
| 5. GF-1/2/4/6 | ftp |
| 6. CBERS-01/03 | ftp |
| 7. ZY-3 TLA | 14 |
| 8. | |
| 9. | |
| 10. | |
| 11. | |
| Total: | |
| Issues: | |

# In-situ measurements and campaigns

| Equipment | Institution | Measurements | Application | Period |
|---|---|---|---|---|
| Camera | AIR | Colour images | Glacier surface characteristics and flow | 1/9/2019 – now |
| multiple | WSL, ETH | Debris thickness and glacier mass balance | Validation of models and data sets | 2020 – 2021 |
| Radiometers | ITP, AIR | Albedo , AOD | Validation of retrievals | 2020 – 2022 |
| | | | | |

# European Young scientists contributions in Dragon 5

| Name | Institution | Poster title | Contribution |
|---|---|---|---|
| Pascal Buri | WSL | 230 Land Surface Modelling in the Himalayas: On the Importance of Evaporative Fluxes for the Water Balance of a High Elevation Catchment | Numerical experiments on glacier response at high spatial resolution |
| Achille Jouberton | WSL, ETH | 232 Combining High Resolution Atmospheric Simulations And Land-surface Modelling To Understand High Elevation Snow Processes In An Himalayan Catchment | Numerical experiments at high spatial resolution combined with EO data analyses |
| Michael McCarthy | WSL | 233 A New Dataset of Supraglacial Debris Thickness for High-Mountain Asia | Integration of glacier flow modelling with satellite data to generate data set on debris thickness |
| Evan Stewart | WSL | 251 Applications of the Continuity Equation to Derive Targets for Glacier Models | Accurate mass balance of glaciers at high spatial resolution by integrating model and RS data |
|  |  |  |  |

# Chinese Young scientists contributions in Dragon 5

| Name | Institution | Poster title | Contribution |
|---|---|---|---|
| Shaoting REN | AIR – CAS,<br>ITP – CAS | Decreasing albedo led to mass loss in the Western Nyainqentanglha Mountains during the past 20 years | 225 Development and implementation of algorithms; data analysis |
| Junru JIA | AIR – CAS | A method of joint retrieval of AOD and surface BRDF | Development, integration, testing of algorithm; data collected in the Tibetan Plateau |
| Lian LIU | ITP – CAS | Application of an Improved Noah Snow Albedo Scheme in the Simulation of Snow Processes over the Tibetan Plateau | 136 Parameterization of the dependence of albedo on snow age and depth; implementation and experiments with Noah |
| Jing ZHANG | AIR – CAS | Annual Glacier Area and Seasonal Snow Cover Changes in the Range System Surrounding Tarim from 2000 to 2020 | 229 Development, integration, testing of algorithm; data collected in the Tibetan Plateau |
| Qiuxia XIE | AIR – CAS | Global Soil Moisture Data Fusion by Triple Collocation Analysis from 2011 to 2018 | 227 Improvement of algorithm and application to generate a global data set; evaluation with ground measurements Tibetan Plateau |

# Exchange visits 2023 - 2024

| Name | Institution | Host | Topic |
|---|---|---|---|
| Dr. Qiuxia XIE | Shandong Jianzhu University | TU Delft | Retrieval of soil moisture in the Tibetan Plateau: spatial patterns and trends |
| Dr. Chaolei Zheng | AIR – CAS | TU Delft | Multi-source retrieval of vapour fluxes in high elevation, cold regions |
| Dr. Miin Jiang | AIR – CAS | TU Delft | Time series analysis on forcing – response in land surface processes |
| | | | |


Thank you!