

Community Land Model 5 (CLM5) Workshop

08.12.2021

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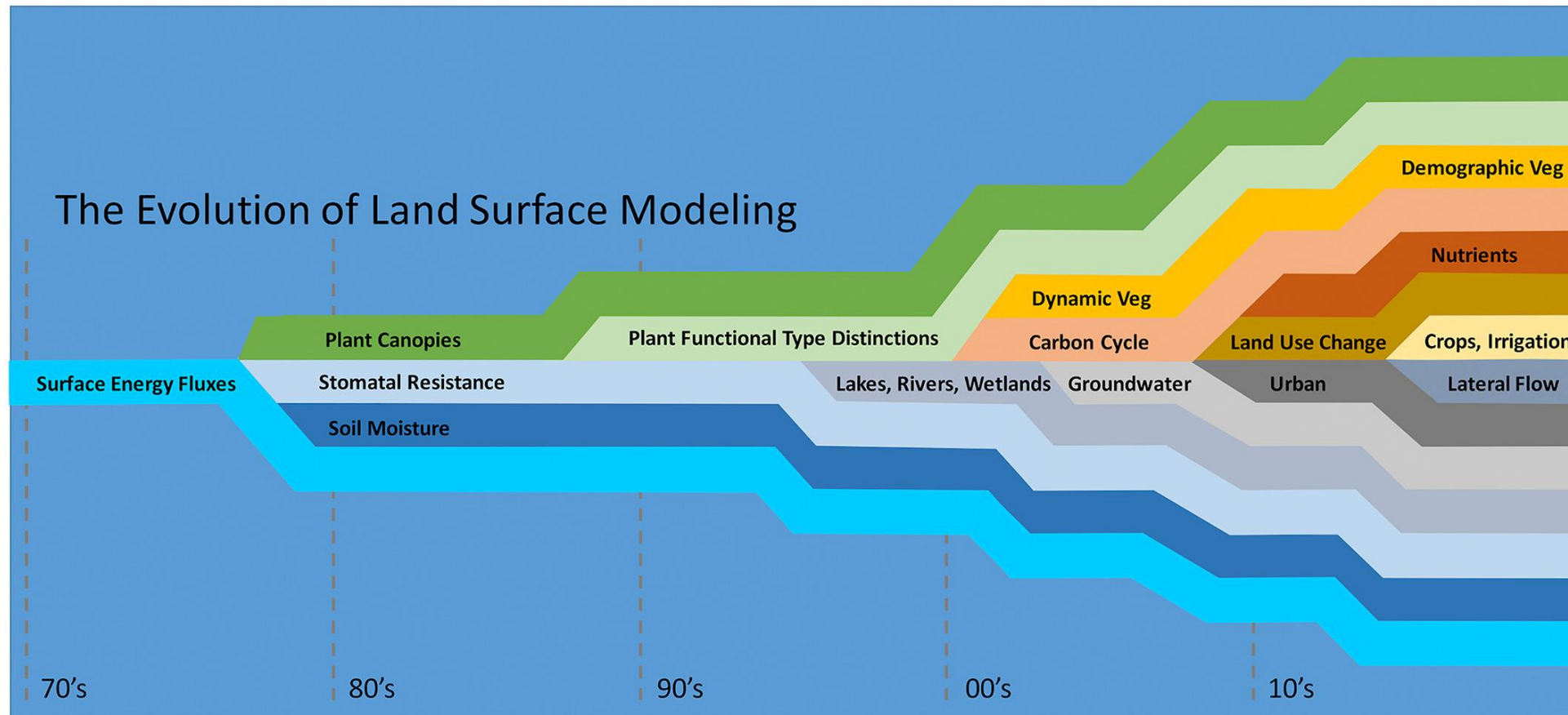
Overarching goal: Bridge the gap between **WSL's site scale research** on land surface **processes** and the representation of these processes within **global scale land surface models**



Outline

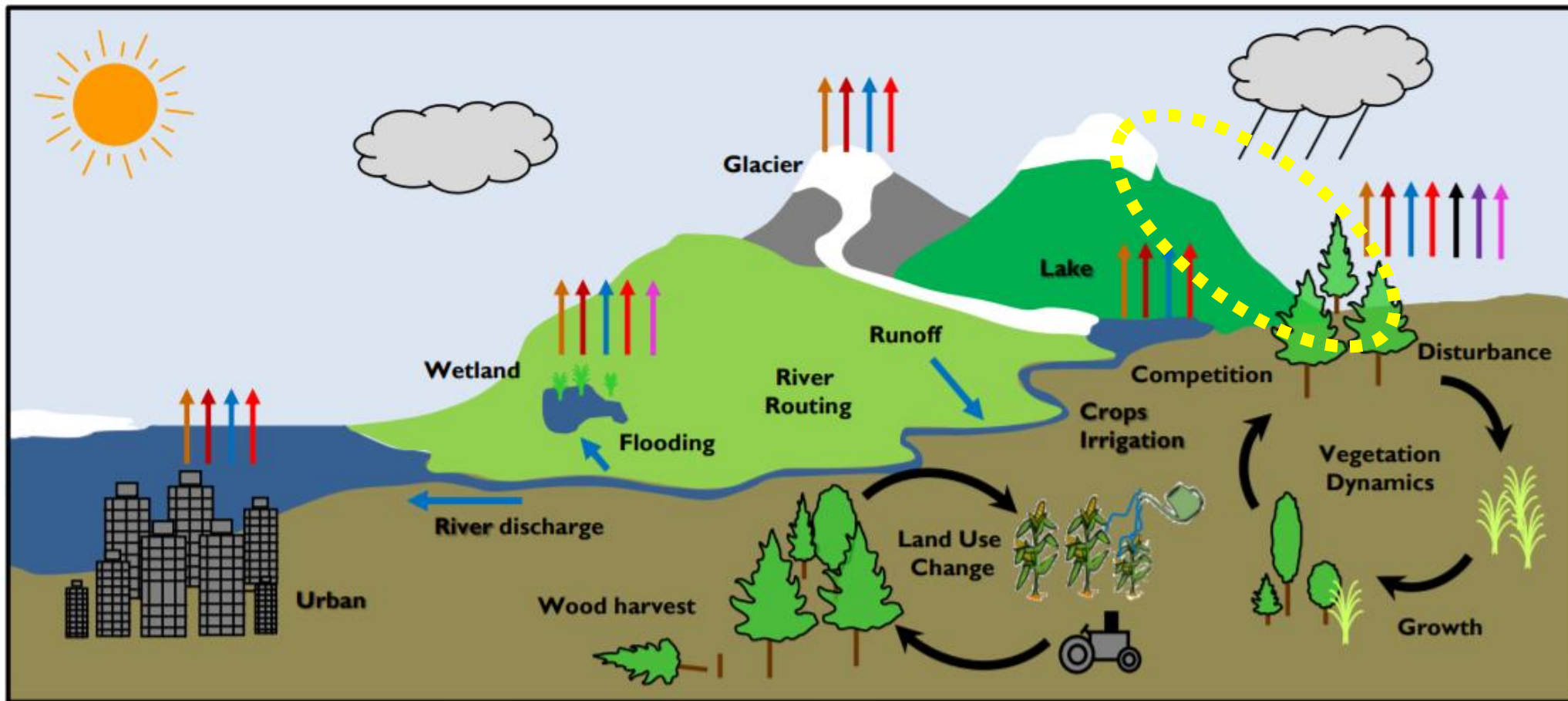
- 1a) Land surface modelling – yesterday and today
- 1b) Introduction to the Community Land Model 5.0
- 1c) What's special about the CLM5 instance @ WSL
 - Meteorological forcing datasets
 - OSHD data
 - CRUIRA data
 - Surface datasets
- 1d) Current use-case examples
- 2) How to set-up and run CLM5 on Hyperion
- 3) Potential future use-cases at WSL?

The evolution of land surface modelling



Fisher & Koven (2020, DOI: 10.1029/2018MS001453)

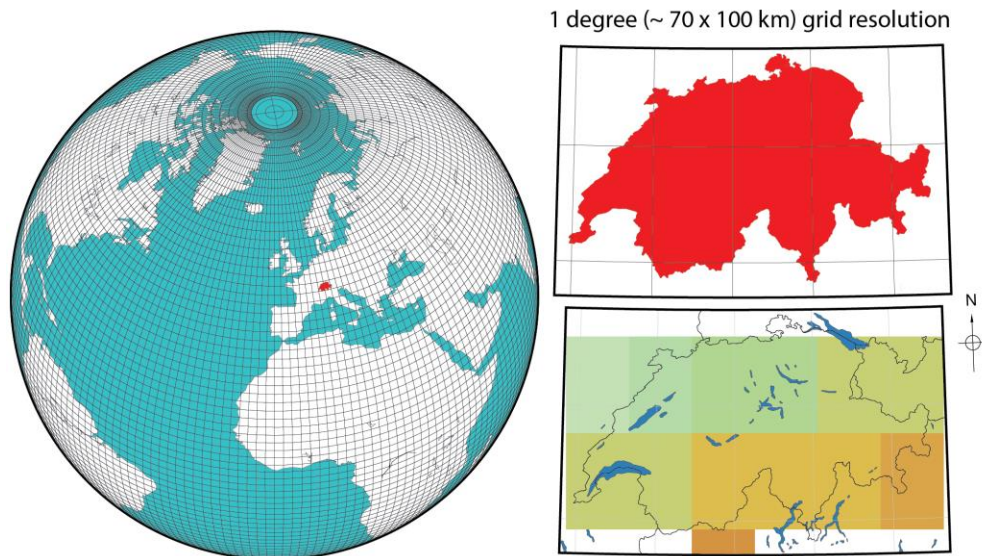
Land surface processes



Lawrence et al. (2019, DOI: 10.1029/2018MS001583)

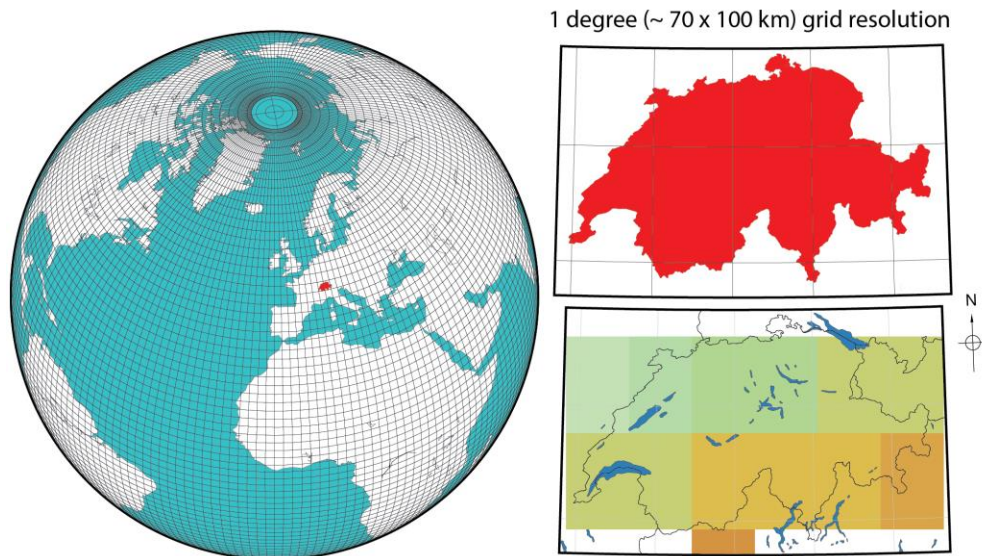
Land surface models

- Key component of earth system models
- Resolve surface energy, water and carbon balance
- Due to computational constraints, large scale (e.g. global) simulations are usually run at coarse spatial resolutions (e.g. 1 degree)



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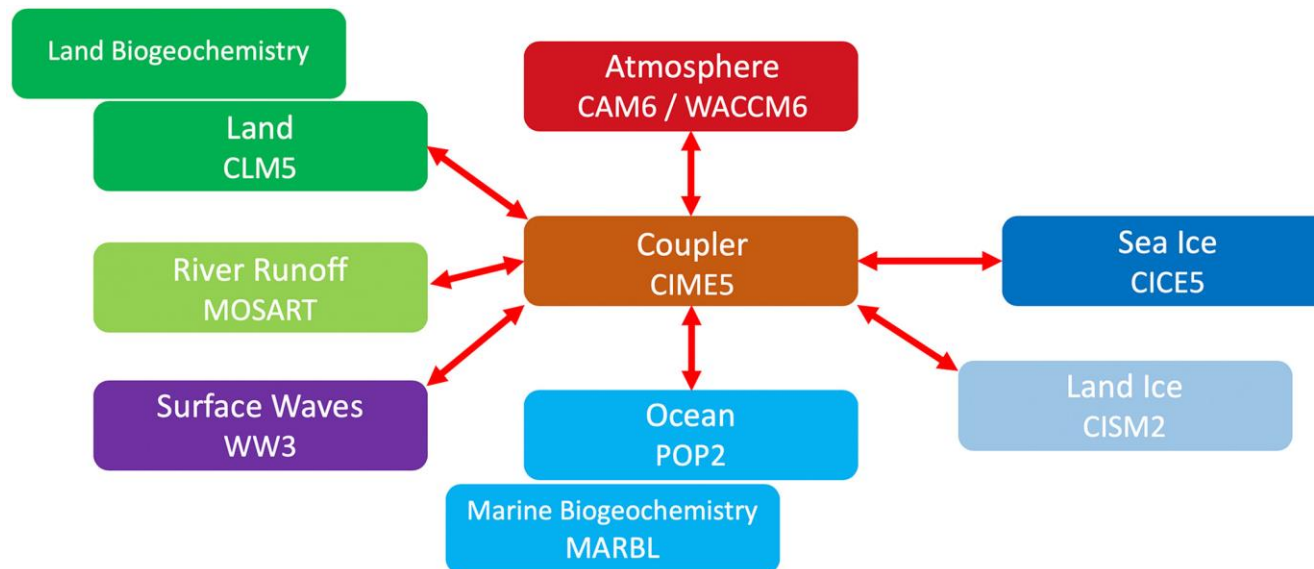


⇒ **Uncertainties** arise due to **unresolved sub-grid variability** of major land surface processes involved in water/energy/carbon cycles

⇒ Forcing, structural, and parametric uncertainties

The Community Land Model 5.0

- Land component of Community Earth System Model (CESM2)
=> open-source community fully coupled model, developed at NCAR
- Fun fact: CESM has about 1.5 million line of code, CLM5 about 0.2 million



Danabasoglu et al. (2020). The Community Earth System Model Version 2 (CESM2). *Journal of Advances in Modeling Earth Systems.*, 12(2). <https://doi.org/10.1029/2019MS001916>

The Community Land Model 5.0

- Widely used, process-based land surface model
- Resolves surface energy, water (and carbon balance) at each time step
- Complex, **multidisciplinary** model
- Like most land models, CLM5 is parameter heavy

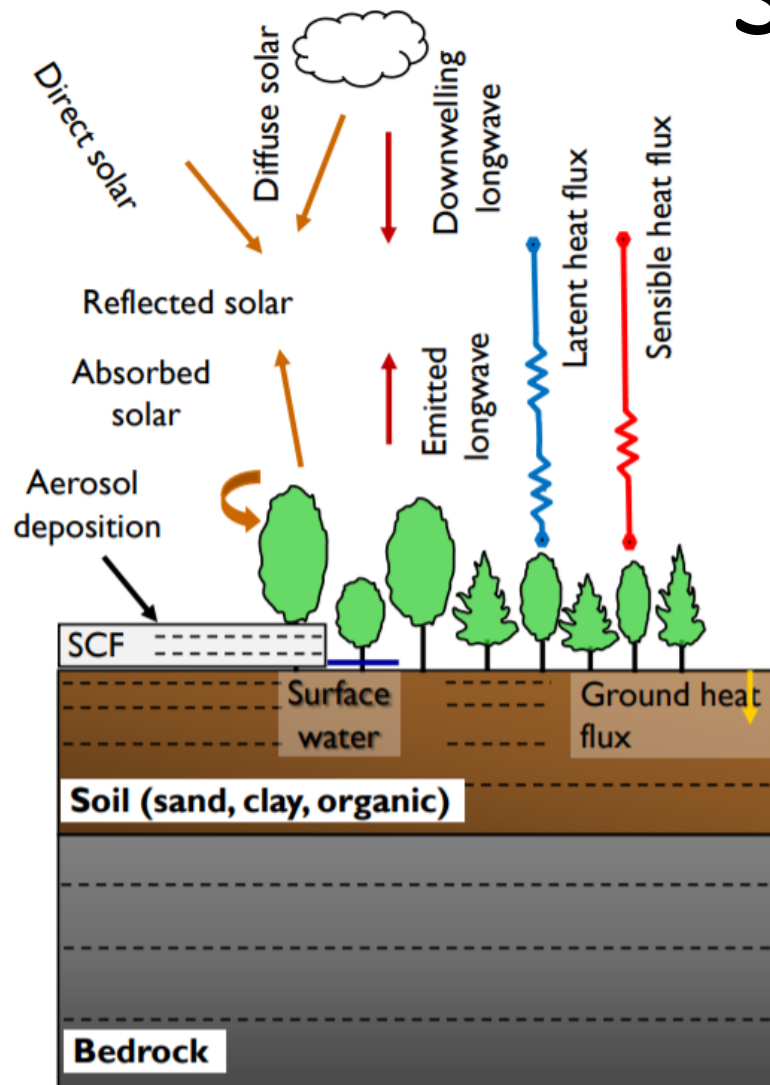


NCAR



UCAR

Surface energy balance



$$SWR \uparrow - SWR \downarrow + LWR \uparrow - LWR \downarrow = \lambda E + H + G$$

$SWR \uparrow, SWR \downarrow$ = up & down-welling solar radiation

$LWR \uparrow, LWR \downarrow$ = up & down-welling longwave radiation

λ = latent heat of vaporization

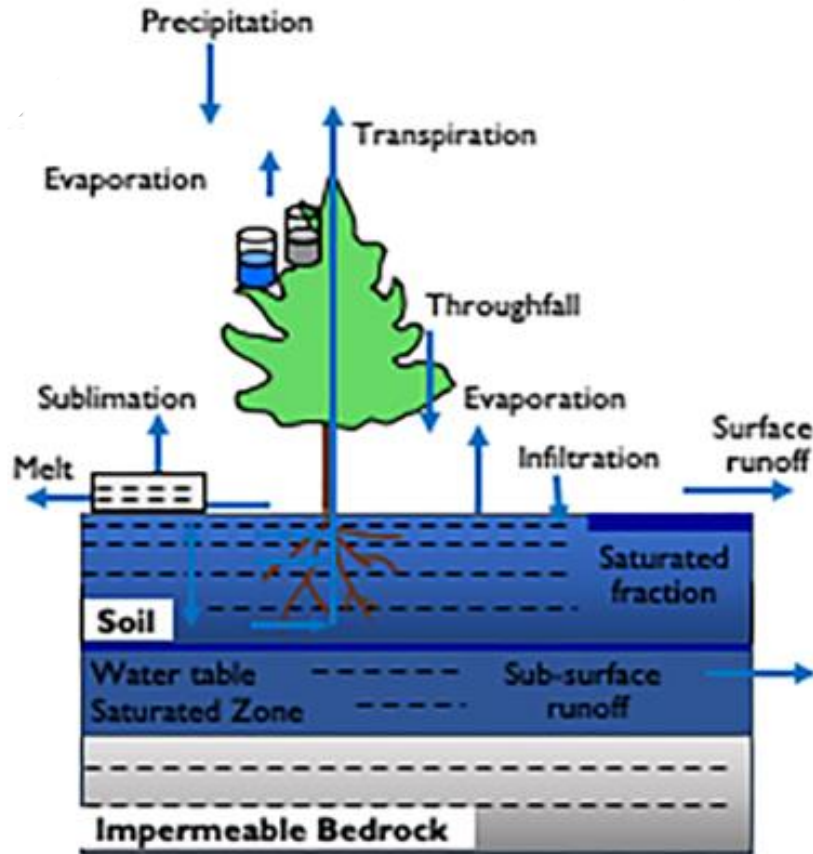
E = Evaporation

H = Sensible heat flux

G = Ground heat flux

Lawrence et al. (2019, DOI: 10.1029/2018MS001583)

Surface water balance



Lawrence et al. (2019, DOI: 10.1029/2018MS001583)

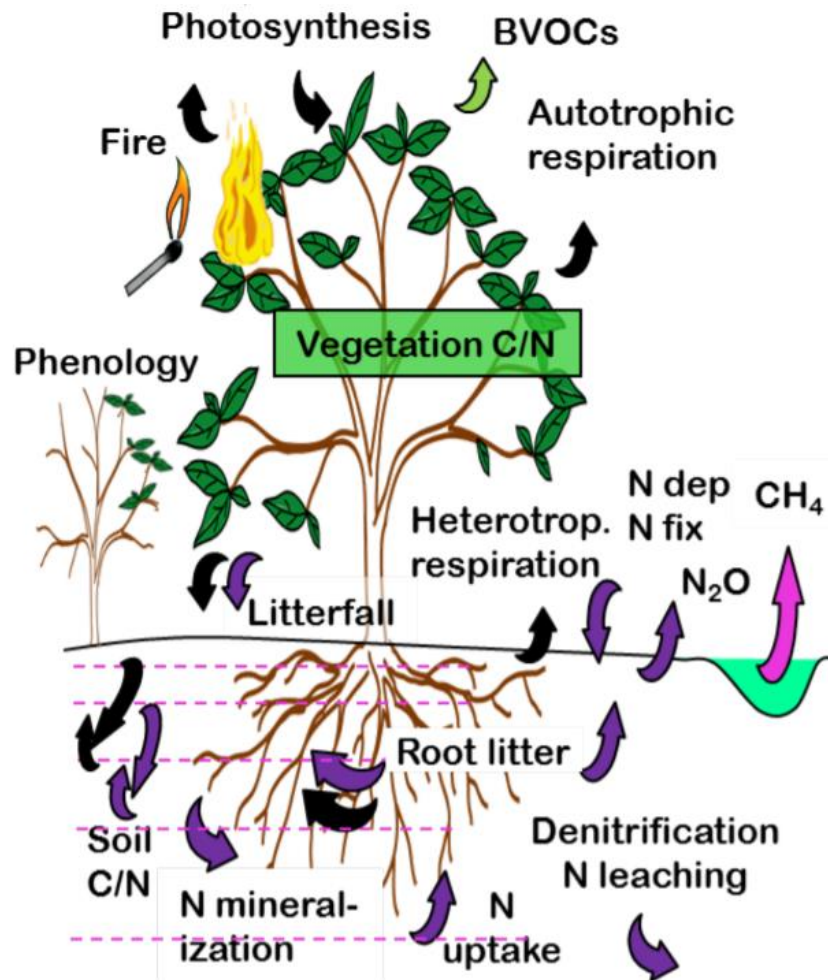
P = rainfall/snowfall
 E_S = soil evaporation
 E_T = transpiration
 E_C = canopy evaporation
 R = runoff (surface + sub-surface)

$\frac{(\Delta W_{soi} + \Delta W_{snw} + \Delta W_{sfc} + \Delta W_{can})}{\Delta t}$ = change in soil moisture, surface water, snow, canopy water over a time step (respectively)

$$P = E_S + E_T + E_C + R + \frac{(\Delta W_{soi} + \Delta W_{snw} + \Delta W_{sfc} + \Delta W_{can})}{\Delta t}$$

Surface carbon balance

...optional (biogeochemical mode)



$$NEE = GPP - HR - AR - Fire - LUC$$

NEE = Net ecosystem exchange

GPP = Gross primary productivity

HR = Heterotrophic respiration

AR = Autotrophic respiration

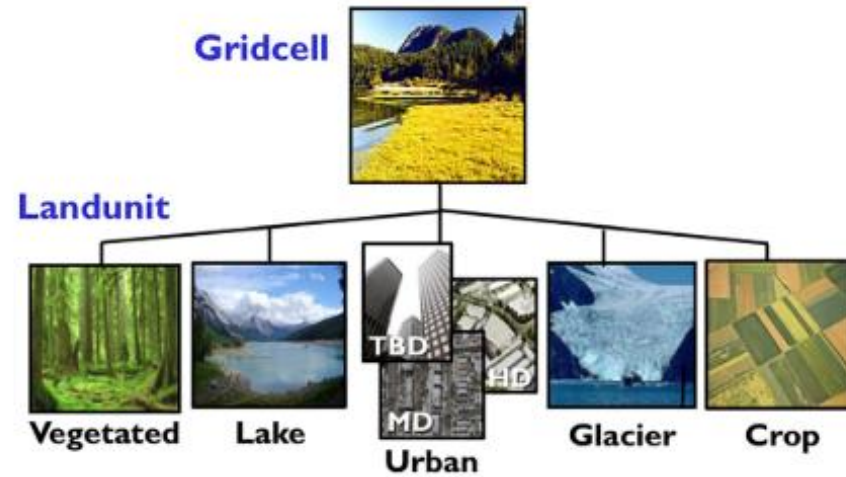
Fire = carbon flux due to fire

LUC = carbon flux due to land use change

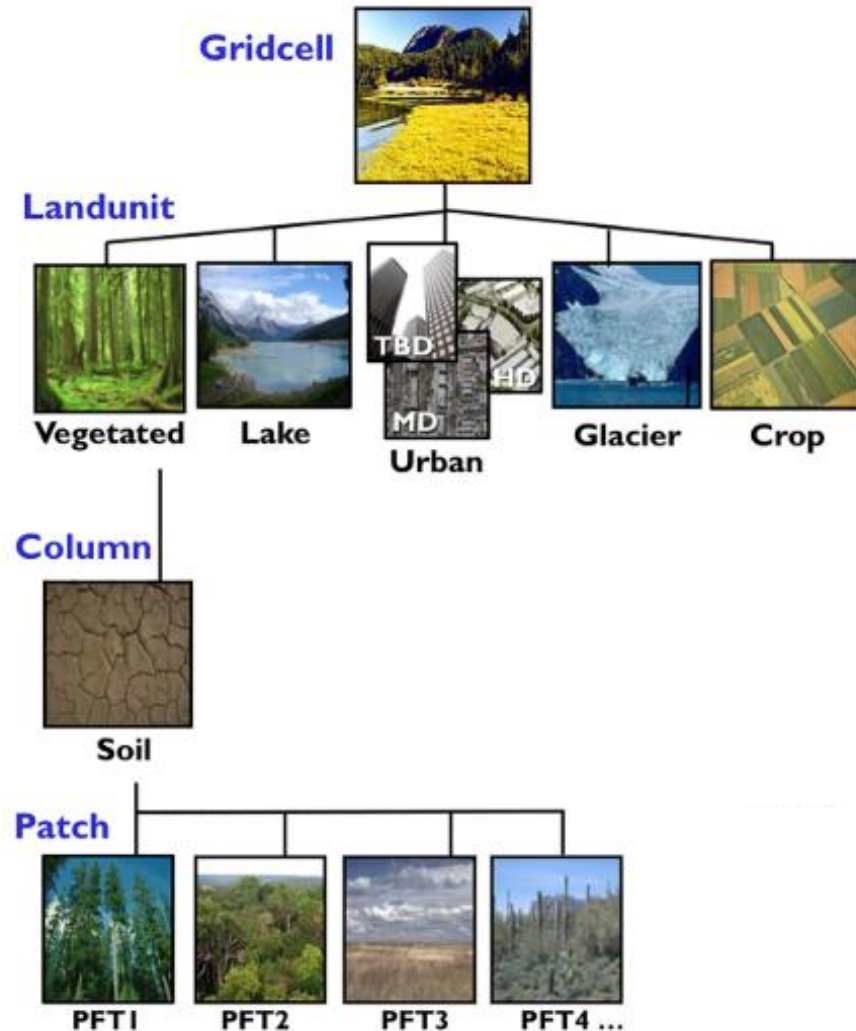
Representing land surface heterogeneity = one of the key challenges in land surface modelling



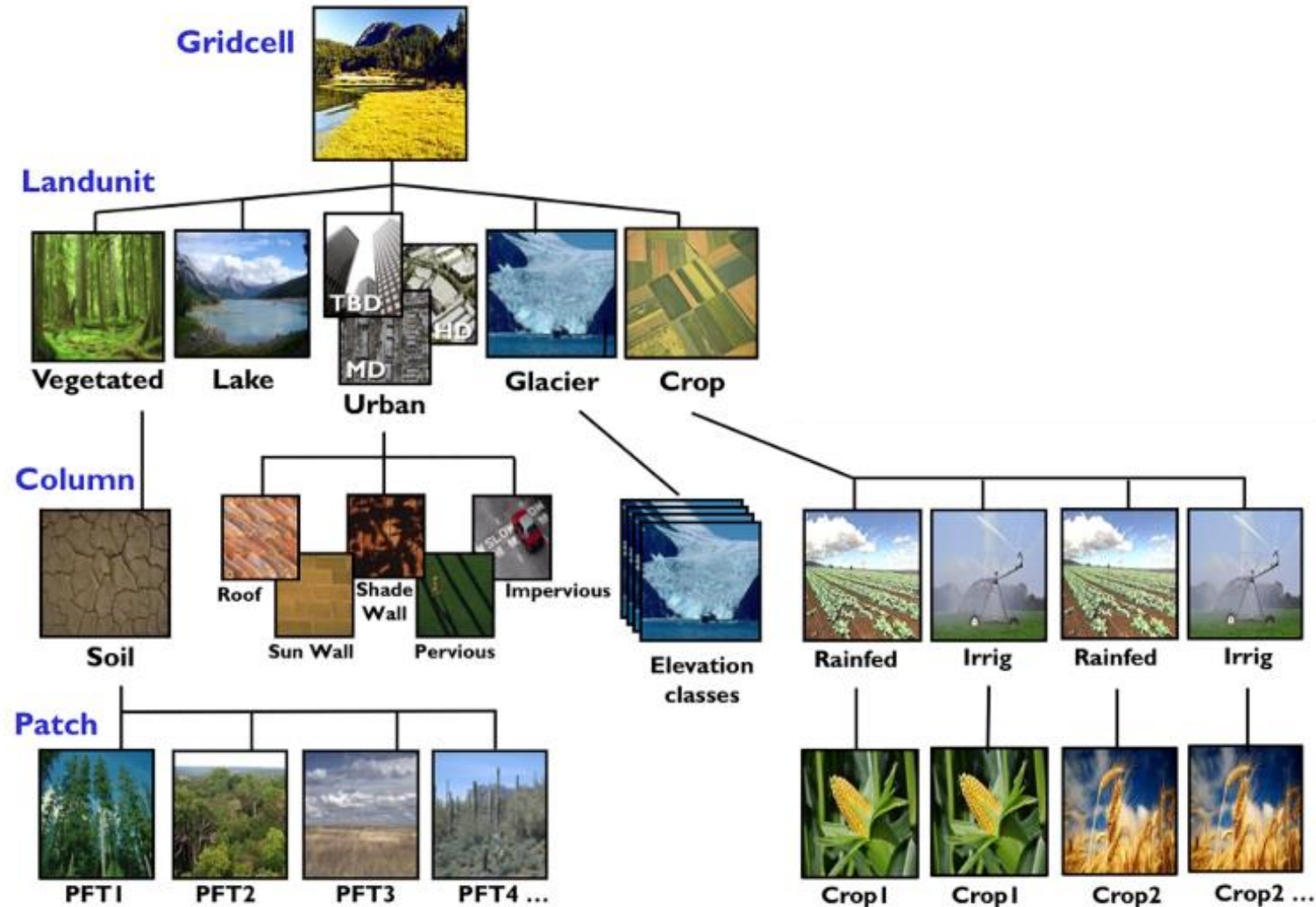
How does CLM5 deal with land surface heterogeneity?



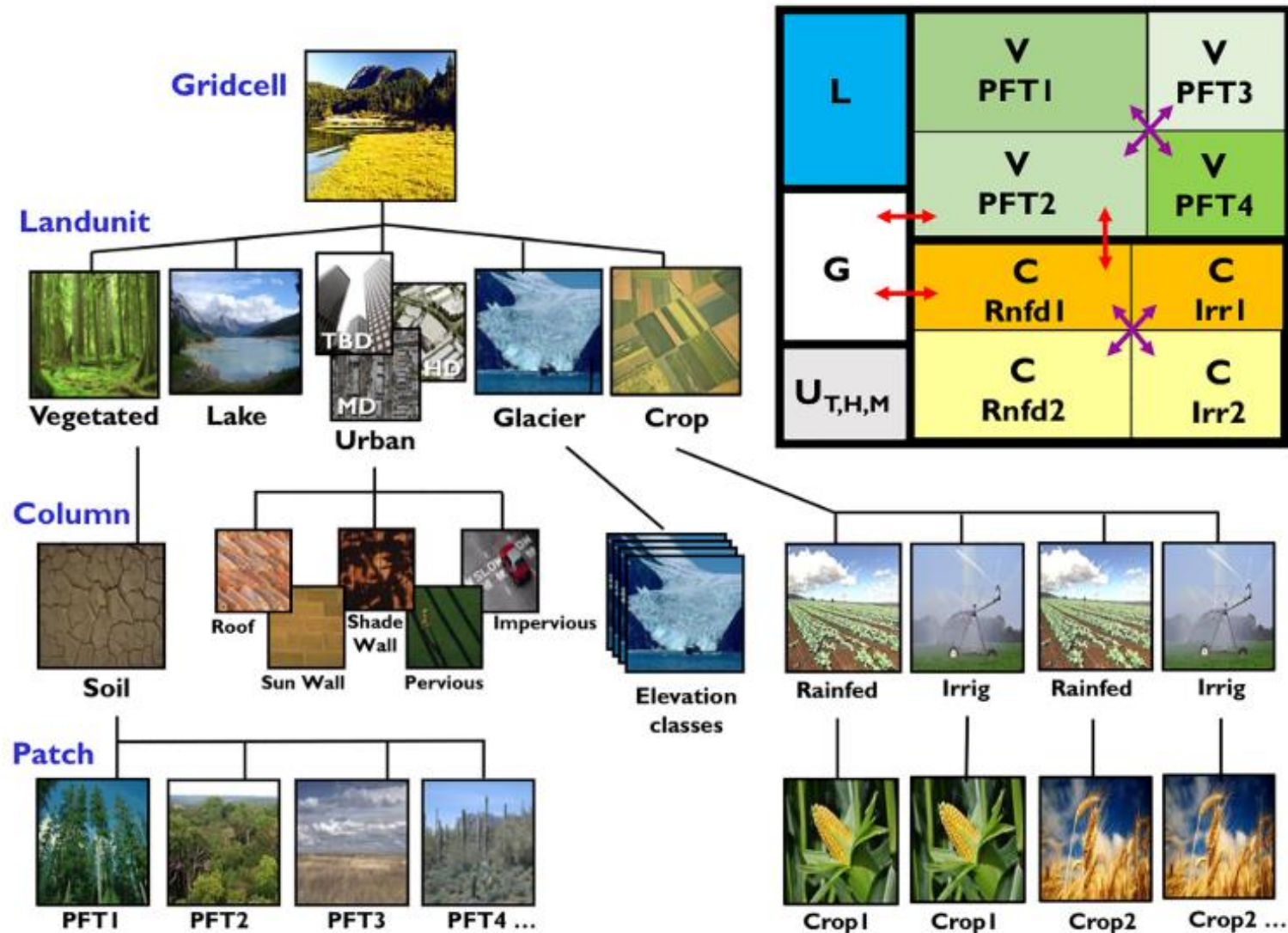
How does CLM5 deal with land surface heterogeneity?



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How does CLM5 deal with land surface heterogeneity?



Lawrence et al. (2019, DOI: 10.1029/2018MS001583)

CLM5 model configurations

- Satellite phenology (SP) mode – prescribed vegetation
- Biogeochemical (BGC) mode – prognostic carbon and vegetation
- BGC-crop – same as BGC+ crops
- BGC FATES – Ecosystem dynamics

Spin-up of CLM5 to steady-state

- Start from arbitrary initial conditions
- Run until $<3\%$ of the land surface is in total ecosystem carbon disequilibrium
 - **SP-mode:** ~20 years “accelerated decomposition” spin-up + ~20 years “normal” spin-up
 - **BGC-mode:** few hundred years “accelerated decomposition” spin-up + few hundred years “normal” spin-up

CLM5 is parameter-heavy:

Example of plant functional type parameters, related to:

- Optical parameters (visible/NIR)
- Morphological properties
- Photosynthetic parameters
- Fire



CLM5 meteorological driving data

- Downwelling short-wave radiation
- Downwelling long-wave radiation
- Air temperature
- Specific or relative humidity
- Wind speed
- Air pressure
- Precipitation

What is special about CLM5 @ WSL

- **Multi-resolution modelling infrastructure**

Multi-resolution modelling infrastructure

Focus on spatial extent of **Switzerland+** (44 050 km²):

- ⇒ Point scale @ 60 locations across Switzerland
- ⇒ 1 km grid scale (365 x 272 grid cells)
- ⇒ 0.25 degree grid scale
(19 x 10 grid cells => 1152 x 768 grid cells if run globally)
- ⇒ 1 degree grid scale
(6 x 3 grid cells => 288 x 192 grid cells if run globally)

⇒ **Advantage:** identical model architecture across scales

Overarching goal: Bridge the gap between **WSL's site scale research** on land surface **processes** and the representation of these processes within **global scale land surface models**

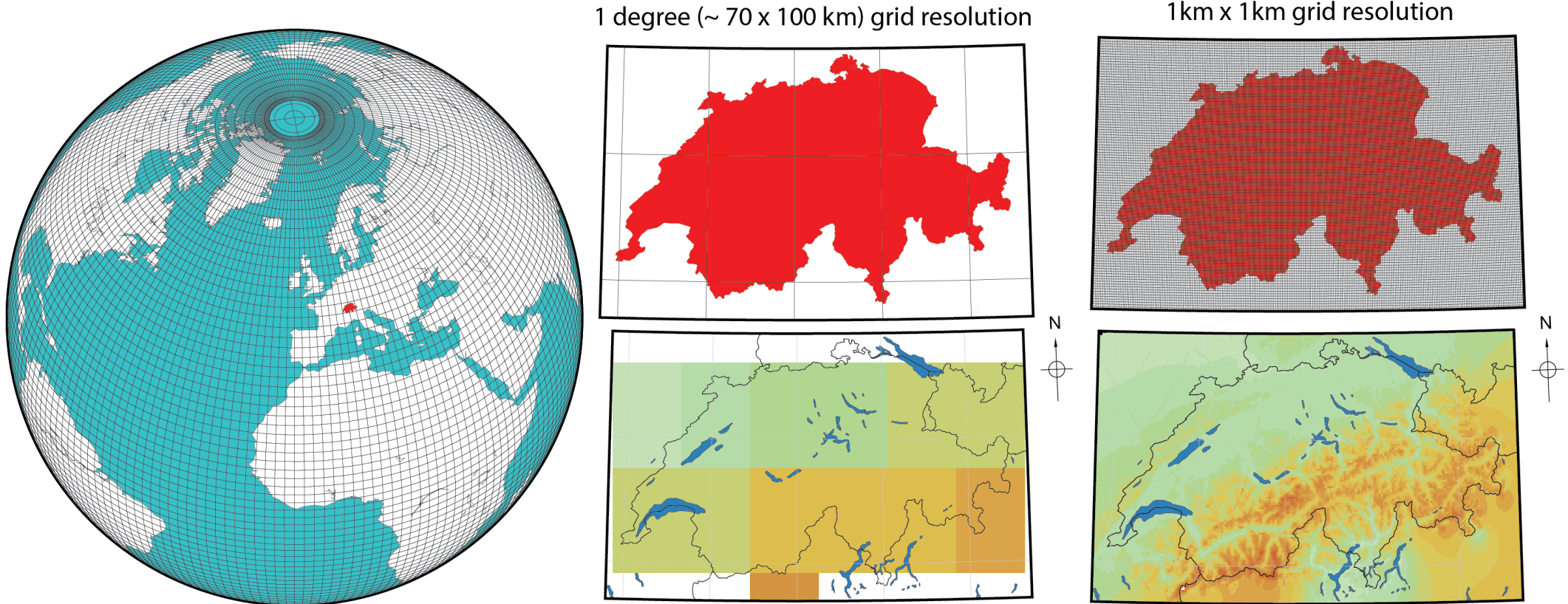


⇒CLM5 as a research tool!

⇒CLM5 development

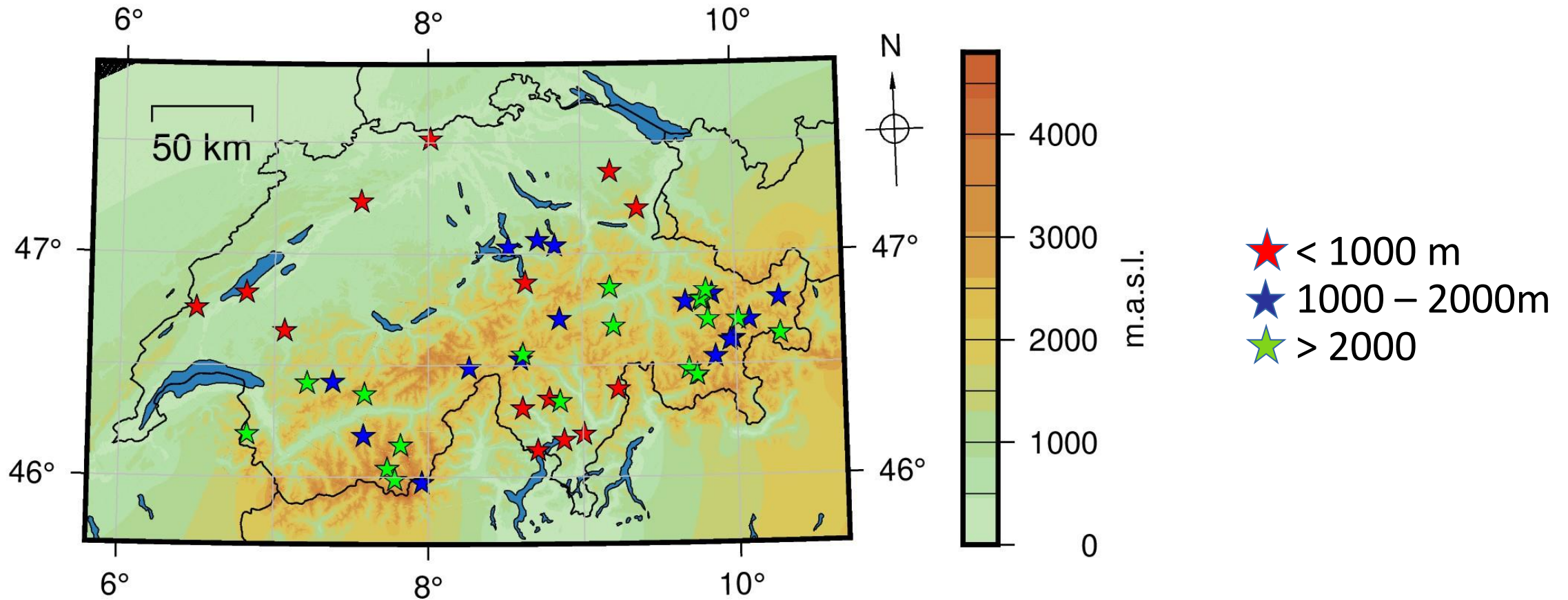
⇒Use our point/site-scale process-level knowledge/data to assess/improve model representation across scales








⇒ Assess and mitigate the degradation in process representation arising from unresolved sub-grid variability as model resolution is coarsened

Point scale locations



'ValdIlliezLesCollines (IMIS)'	'ILI2'	2022
'ValsAlpCalasa (IMIS)'	'VLS2'	2064
'OberMeielGrossStand (IMIS)'	'OBM2'	2097
'FrascoEfra (IMIS)'	'FRA2'	2100
'VallasciaSchneestation (IMIS)'	'VAL2'	2268
'DavosGrueniberg (IMIS)'	'DAV5'	2315
'DavosFrauentobel (IMIS)'	'DAV4'	2330
'CrapMasegnSchneestation (ENET)'	'CMA2'	2330
'OfenpassMurtaroel (IMIS)'	'OFE2'	2359
'JulierVairana (IMIS)'	'JUL2'	2426
'DavosHanengretji (IMIS)'	'DAV3'	2455
'TrubelbodenSchneestation (IMIS)'	'TRU2'	2459
'Weissfluhjoch (BEOB)'	'5WJ'	2540
'DavosBaerentaelli (IMIS)'	'DAV2'	2558
'ZernezPuelschezza (IMIS)'	'ZNZ2'	2677
'PizLagrevSchneestation (IMIS)'	'LAG2'	2730
'Gugla (IMIS)'	'GUG2'	2832
'ZermattWisshorn (IMIS)'	'ZER3'	2930
'GornergratSchneestation (ENET)'	'GOR2'	2950

 < 1000 m
 1000 – 2000m
 > 2000

'Magadino (NIME)'	'*MAG'	197
'Bellinzona (NIME)'	'*BLZ'	225
'Brissago (NIME)'	'*BSG'	280
'Frick (NIME)'	'*FRI'	345
'Cevio (NIME)'	'*CEO'	418
'Altdorf (NIME)'	'*ALT'	449
'Landquart (BEOB)'	'5LQ'	520
'Chaebles (NIME)'	'*CBS'	589
'LAbergement (NIME)'	'*ABG'	645
'Marsens (NIME)'	'*MAS'	718
'Brusio (BEOB)'	'7BR'	800
'Degersheim (NIME)'	'*DEH'	830
'Sonogno (NIME)'	'*SON'	925
'Wildhaus (NIME)'	'*WHA'	1000

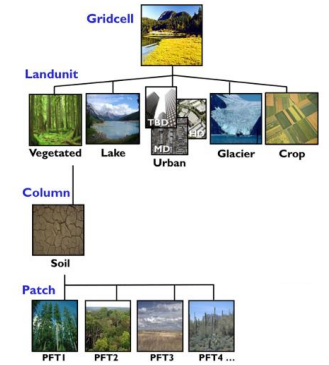
'Alpthal (NIME)'	'*APT'	1031
'Airolo (NIME)'	'*AIR'	1139
'DisentisSedrun (ANETZ)'	'#DIS'	1197
'Scuol (BEOB)'	'7SU'	1285
'LaCombballaz (BEOB)'	'1LC'	1360
'Muenster (BEOB)'	'4MS'	1410
'Zernez (BEOB)'	'7ZN'	1475
'DavosFluelastr (BEOB)'	'5DF'	1560
'SLFFluelastrasse (IMIS)'	'SLF2'	1563
'SanBernardino (BEOB)'	'6SB'	1640
'Schanf (BEOB)'	'7SC'	1660
'Ybrig (IMIS)'	'YBR2'	1701
'Zuoz (BEOB)'	'7ZU'	1710
'Samedan (BEOB)'	'7SD'	1750
'Arosa (NIME)'	'*ARO'	1840
'LauenenTruettlisbergpass (IMIS)'	'LAU2'	1970

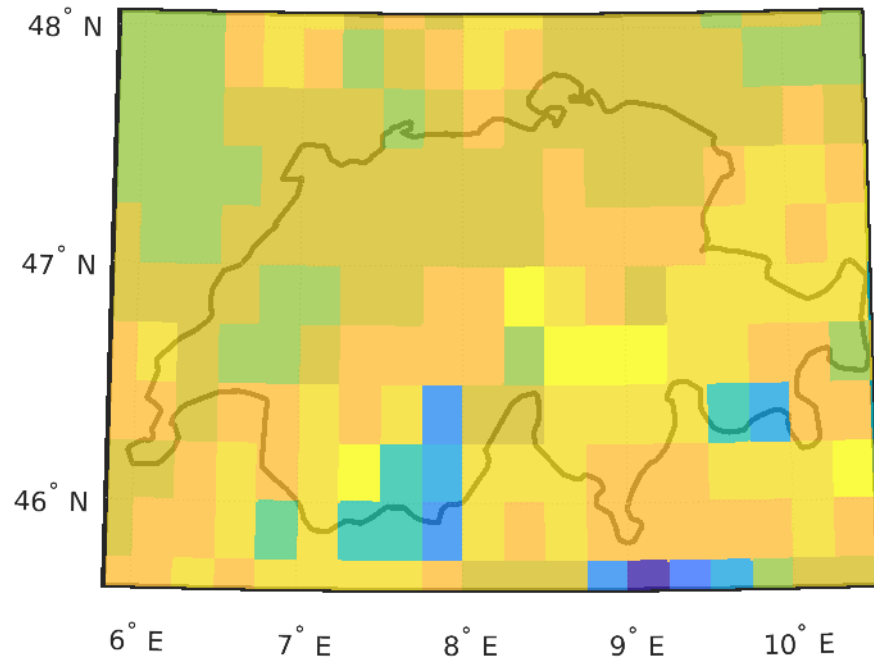
What is special about CLM5 @ WSL

- Multi-resolution modelling infrastructure
- High resolution **land surface datasets** based on areal-statistics, forest mixing ratios and satellite products

Land surface datasets

1. Regrid global surface dataset to match our domain
(use ESMF regridding tools) => coarse grid





VS.

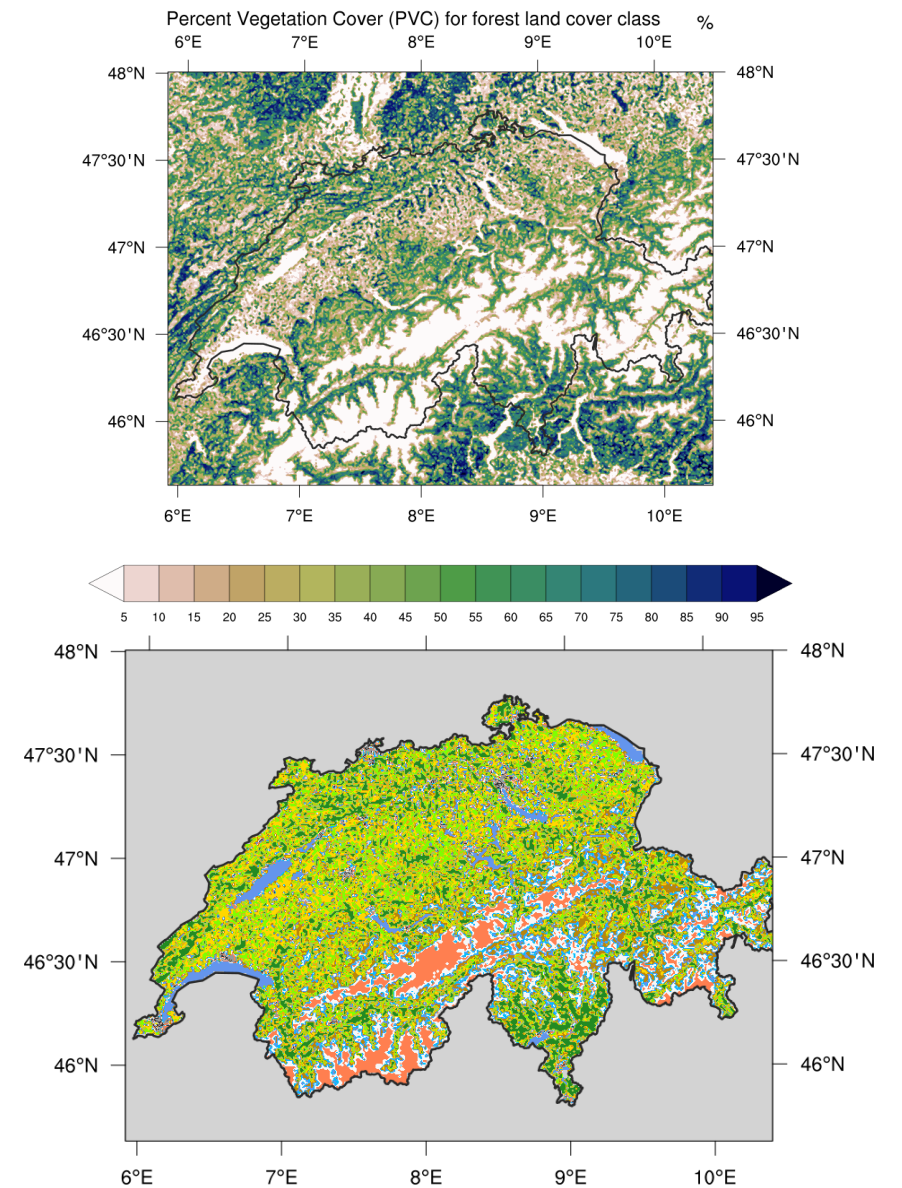


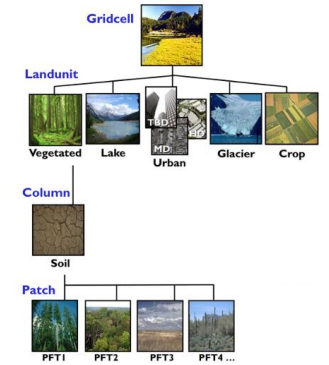
Table 2.2: Canopy top and bottom heights for PFTs in snow-covered regions, as used by CLM5.

Plant functional Type	Canopy top height (m)	Canopy bottom height (m)
Needleleaf evergreen tree - boreal & temperate	17	8.5
Needleleaf deciduous tree - boreal	14	7
Broadleaf deciduous tree - boreal & temperate	20	11.5

⇒ Incorporate additional info!

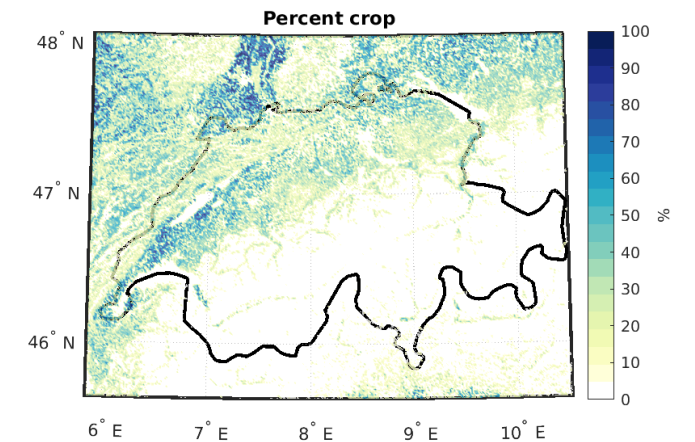
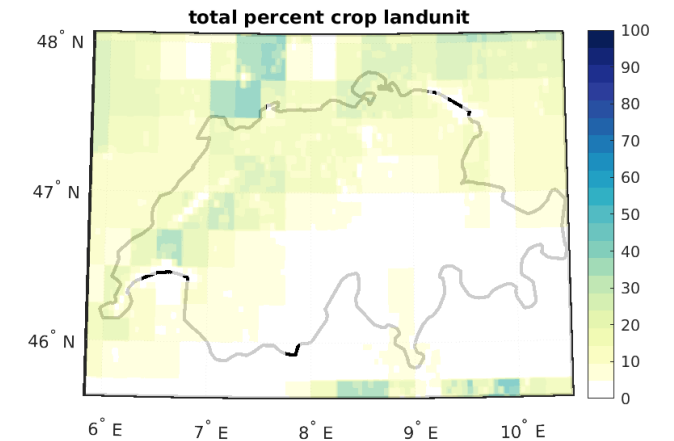
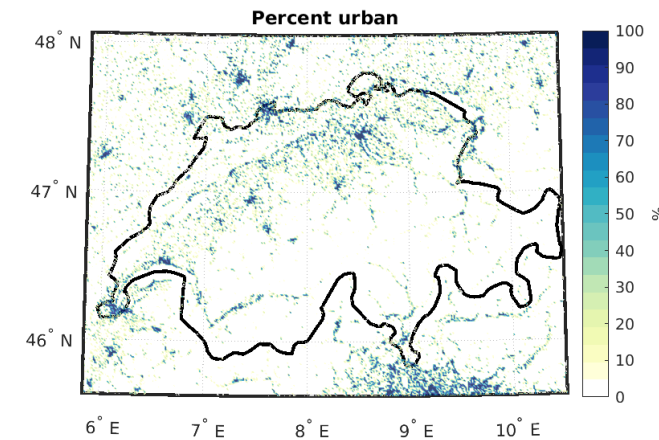
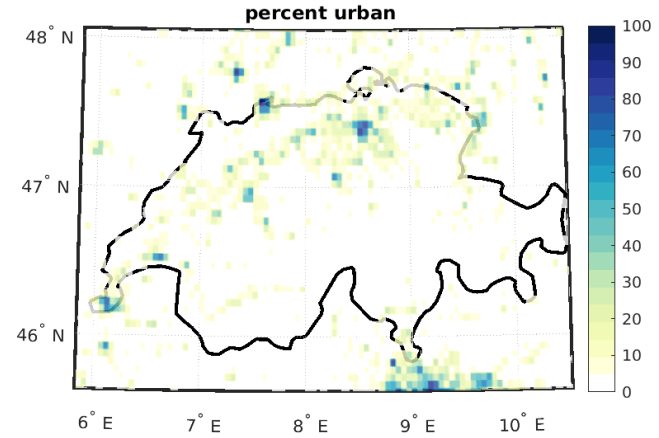
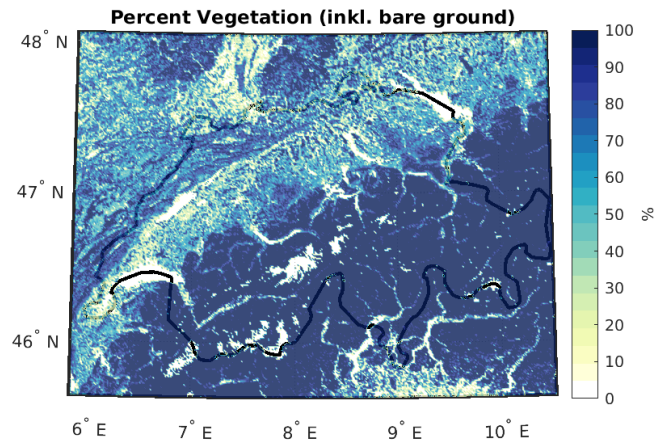
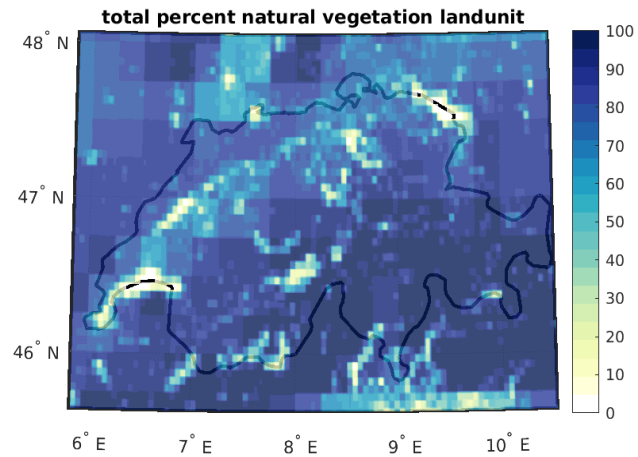


Land surface datasets

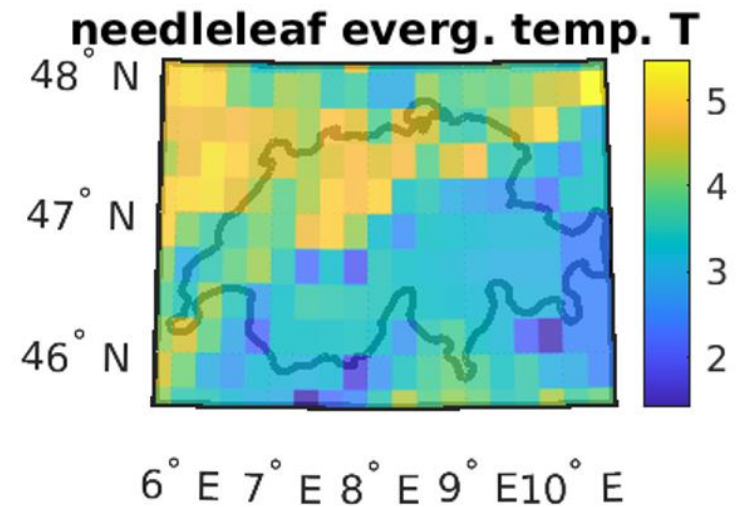
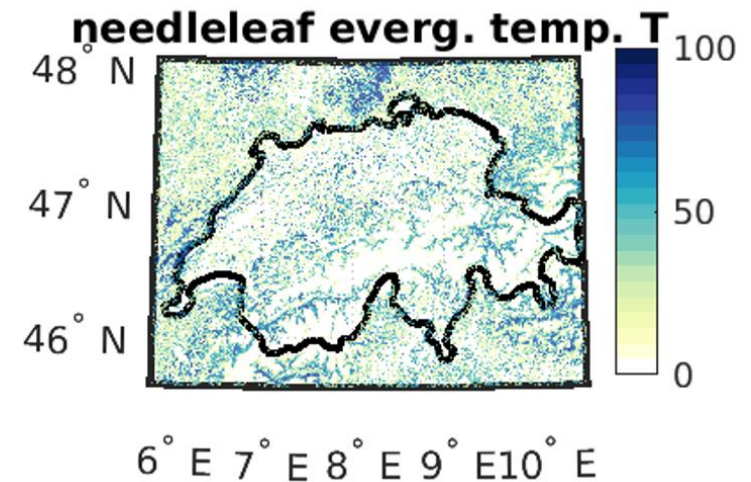
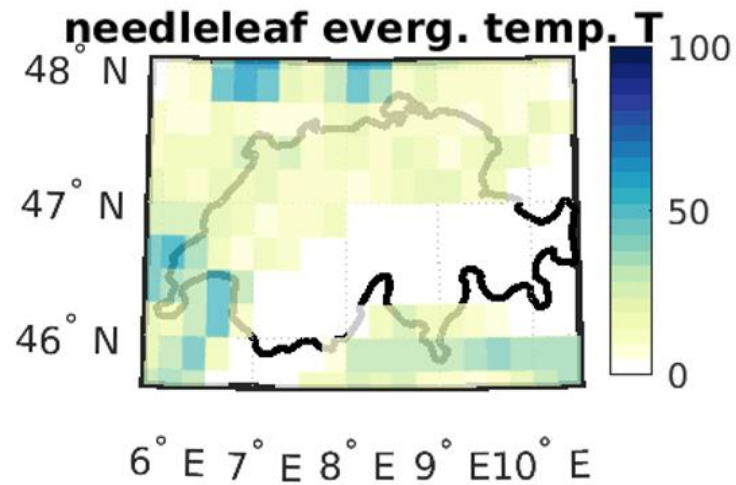


1. Regrid global surface dataset to match our domain (use ESMF regridding tools) => coarse grid
2. **Landunit-level:** Merge arealstatistics Switzerland & Copernicus Sentinel-3/OLCI, PROBA-V @333m
=> vegetation, lake, urban, glacier, crop-fraction
3. **Column level:** Forest mixing ratios, Copernicus Sentinel-3/OLCI, PROBA-V @333m
=> monthly LAI, SAI, fraction per PFT (incl. bare ground)

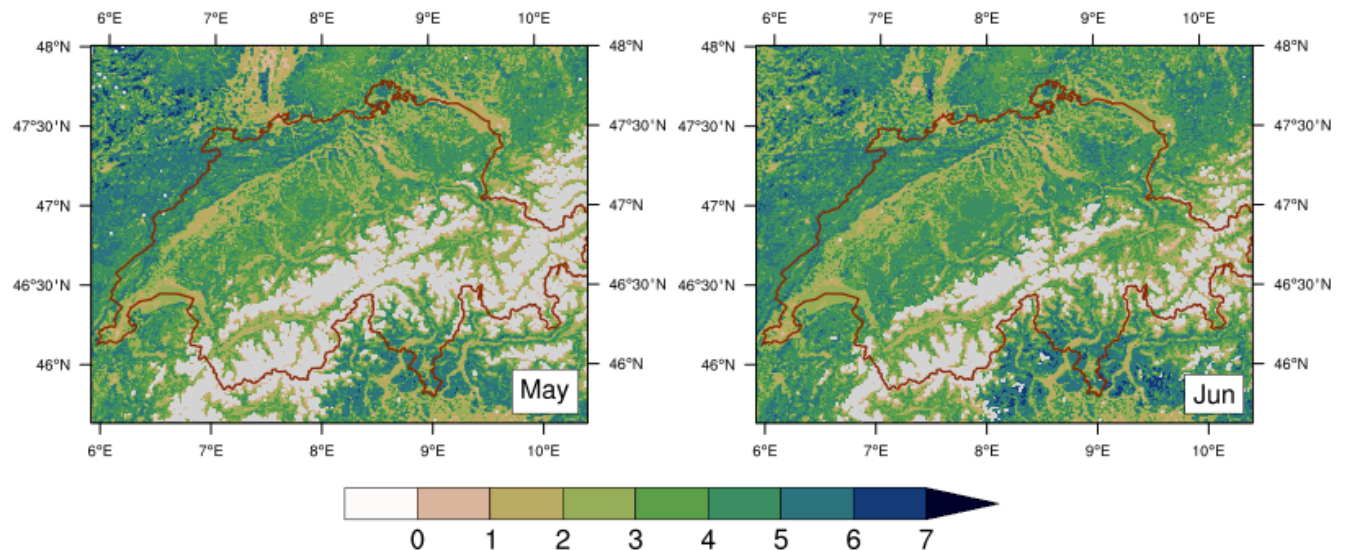
Example land-unit level



Example column level



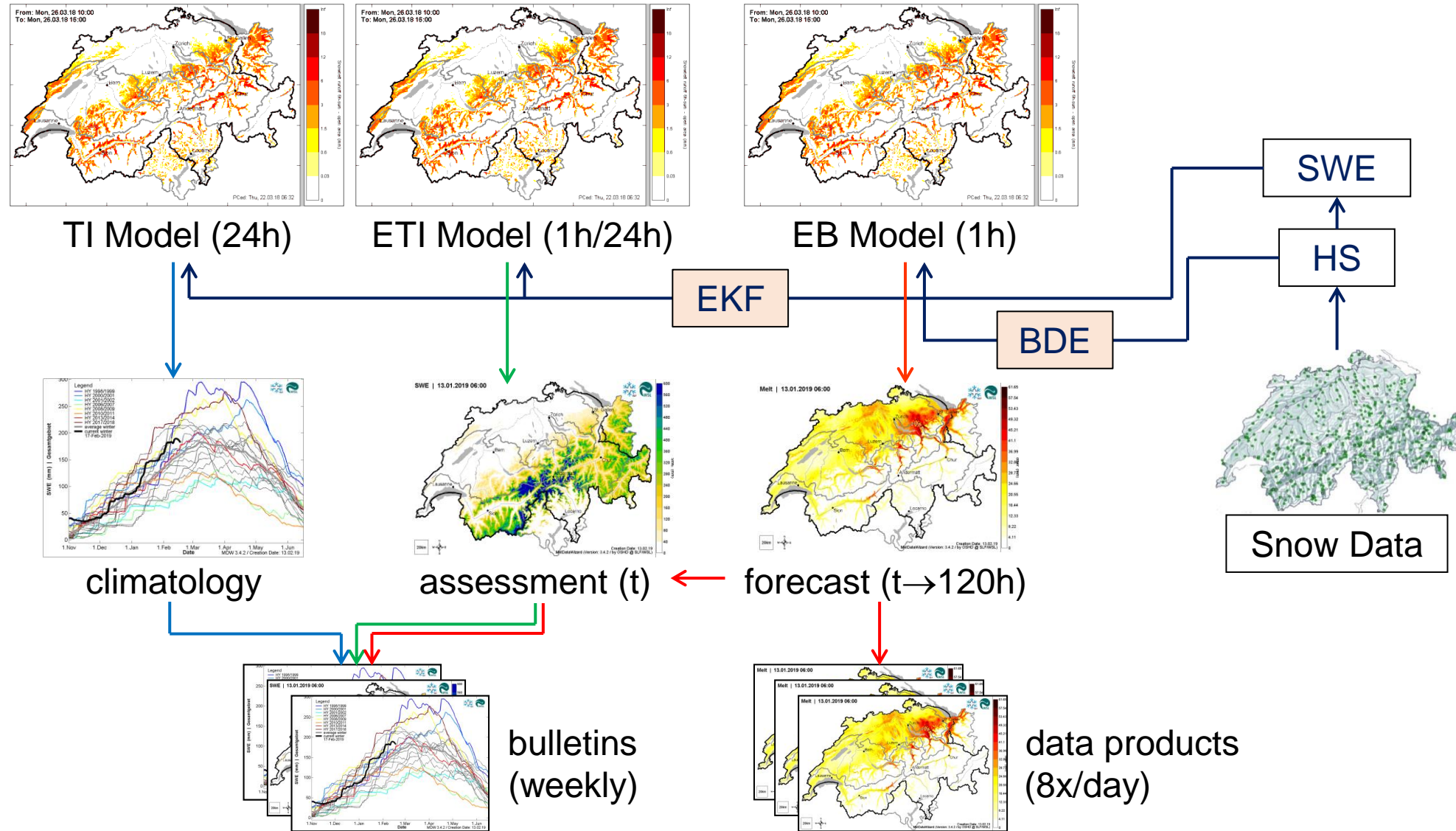
Monthly LAIs (333m OLCI/PROBA-V @ OSHD 1km grid)



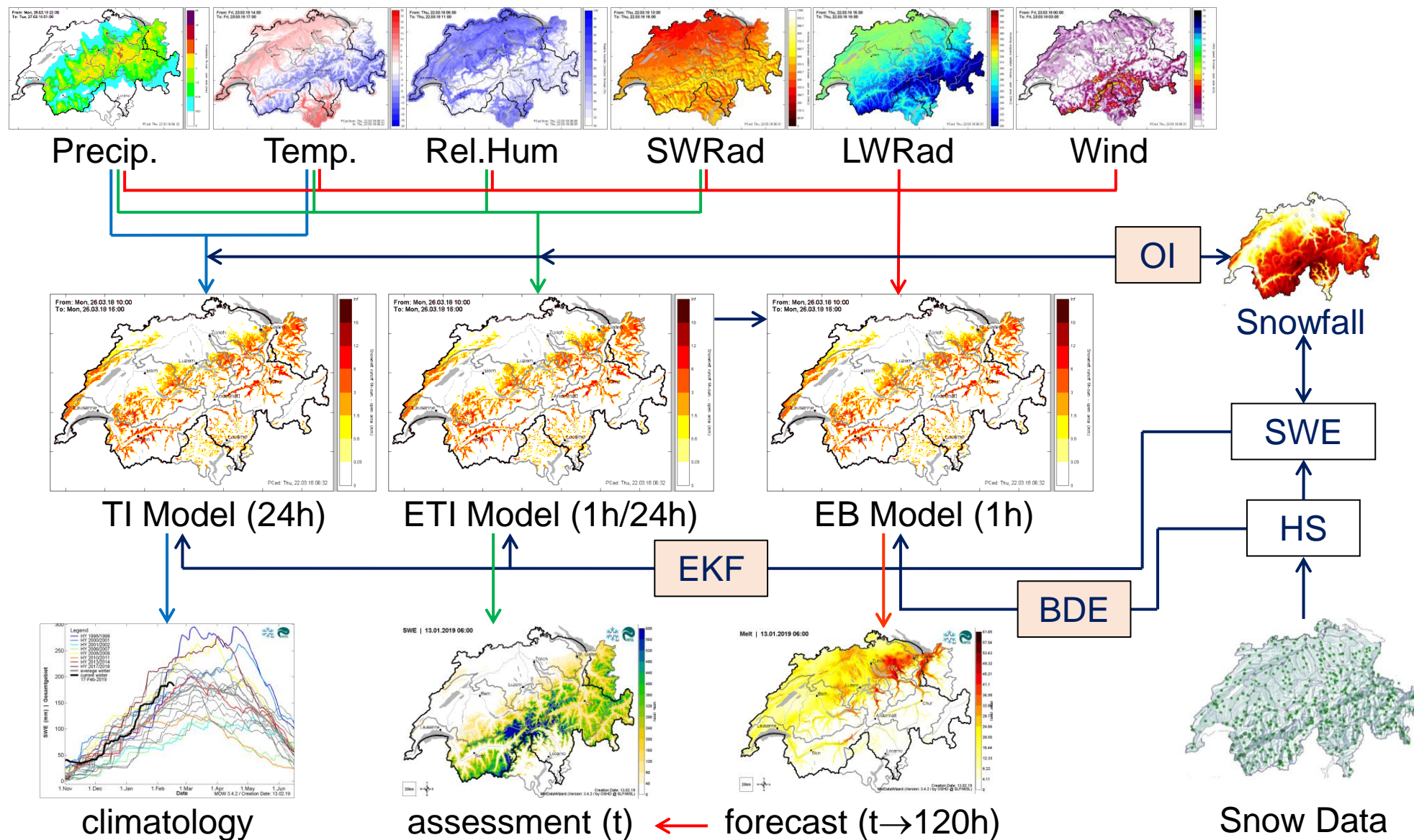
What is special about CLM5 @ WSL

- Multi-resolution modelling infrastructure
- High resolution land surface datasets based on areal-statistics, forest mixing ratios and satellite products
- Detailed meteorological forcing datasets
 - ⇒ Generated according to methods developed by the Operational Snow Hydrological Service (OSHD)
 - ⇒ OSHD-output = unique way to assess model performance

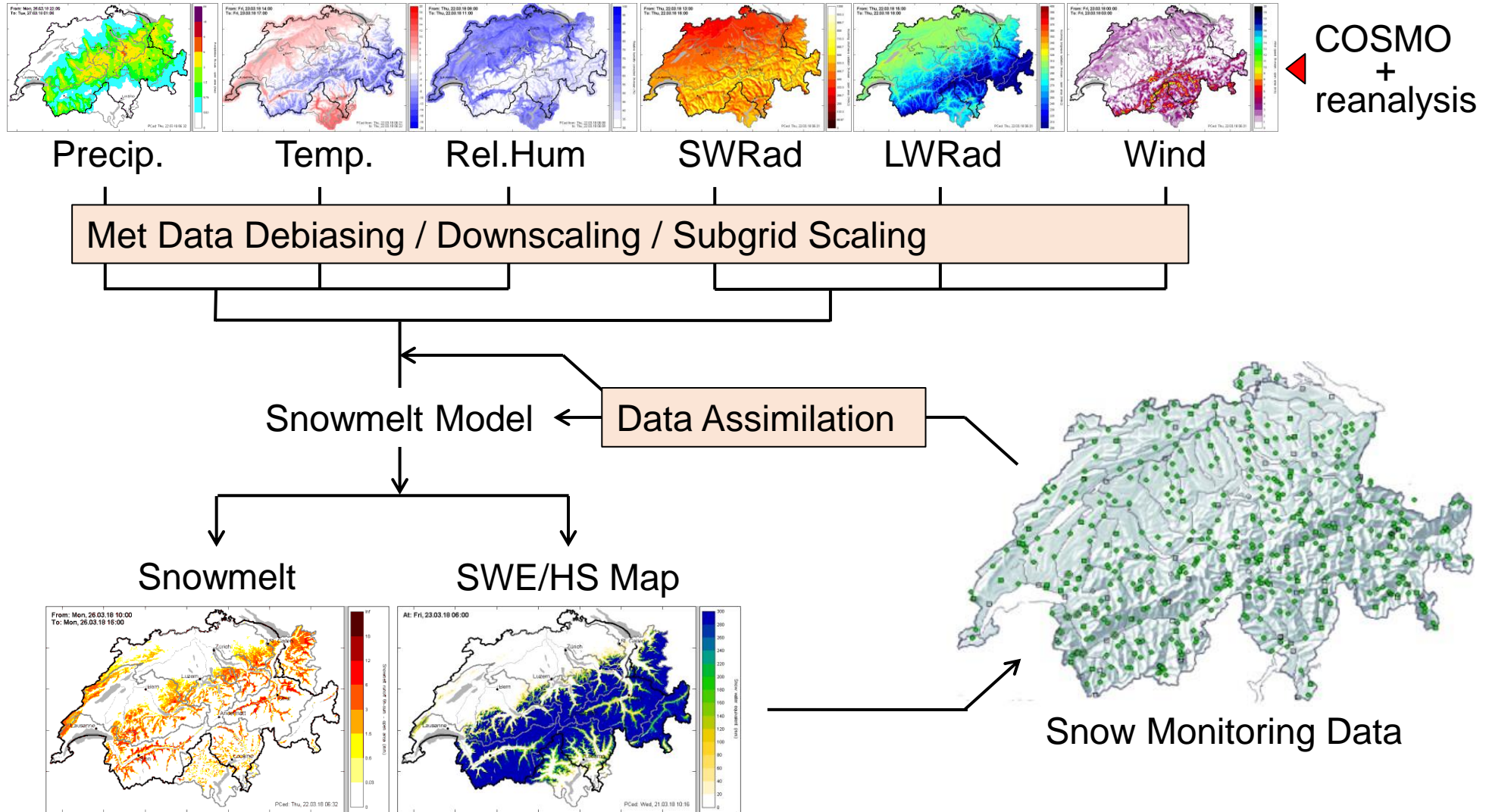
OSHD multi-model framework



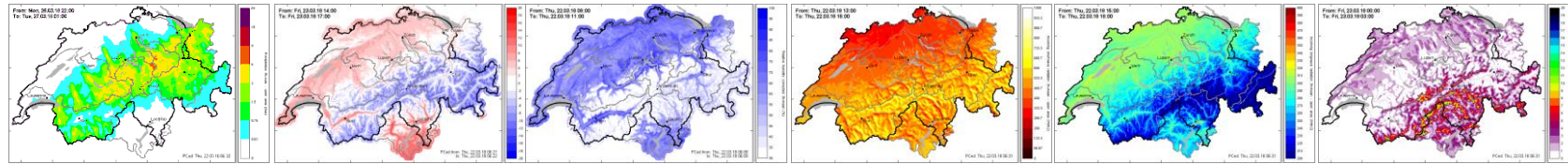
OSHD framework – driving data and data assimilation



OSHD framework – meteo data preprocessing



OSHD framework – wind data preprocessing



Precip.

Temp.

Rel.Hum

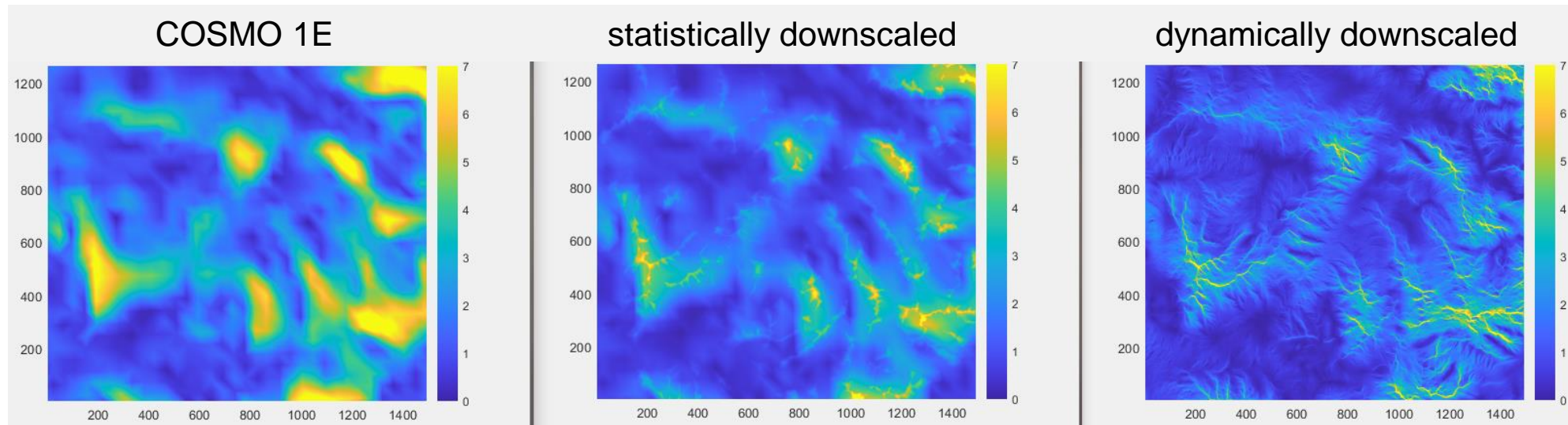
SWRad

LWRad

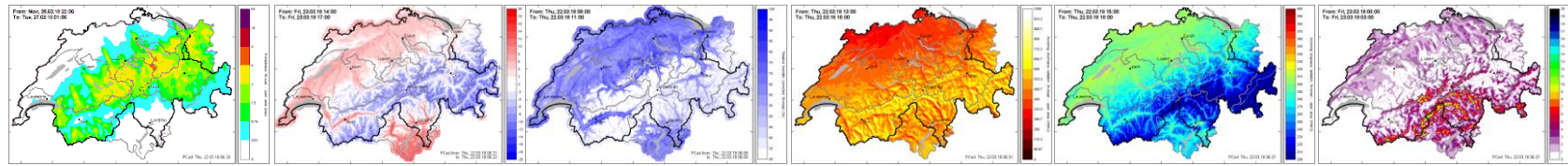
Wind

Met Data Debiasing / Downscaling / Subgrid Scaling

Downscaling and debiasing of wind
→ correcting overall bias and biased distribution



OSHD framework – radiation data preprocessing

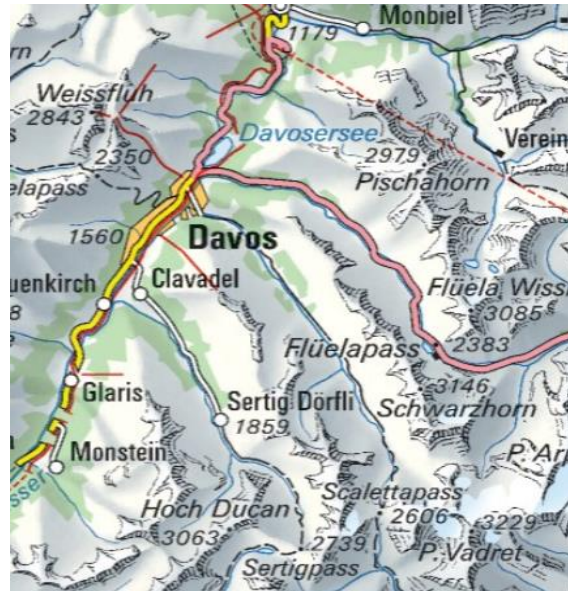
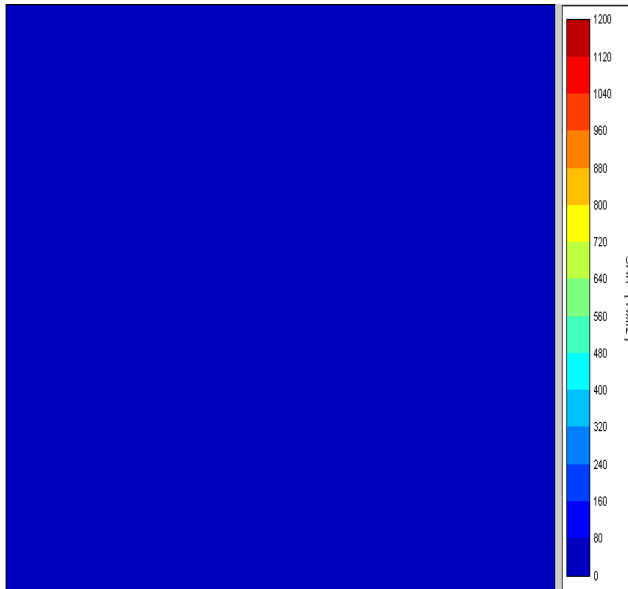


◀ COSMO
+
reanalysis

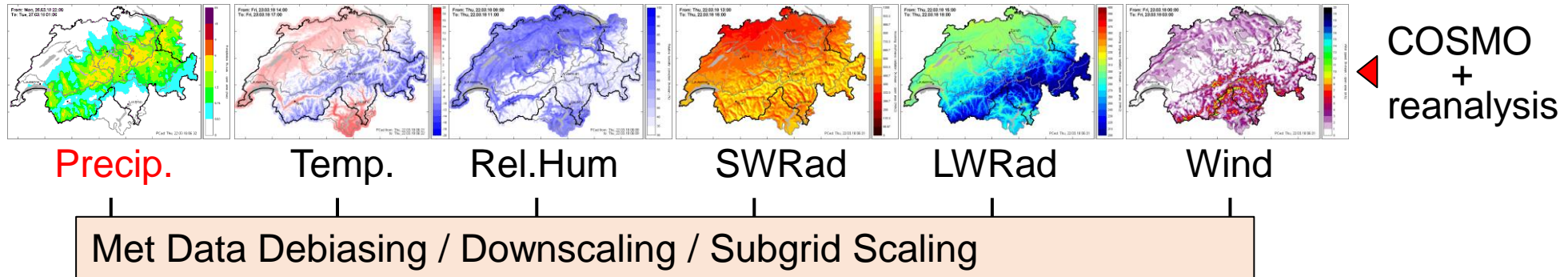
Precip. Temp. Rel.Hum **SWRad** **LWRad** Wind

Met Data Debiasing / Downscaling / Subgrid Scaling

Dynamical downscaling of shortwave radiation
→ to include high-resolution terrain shading

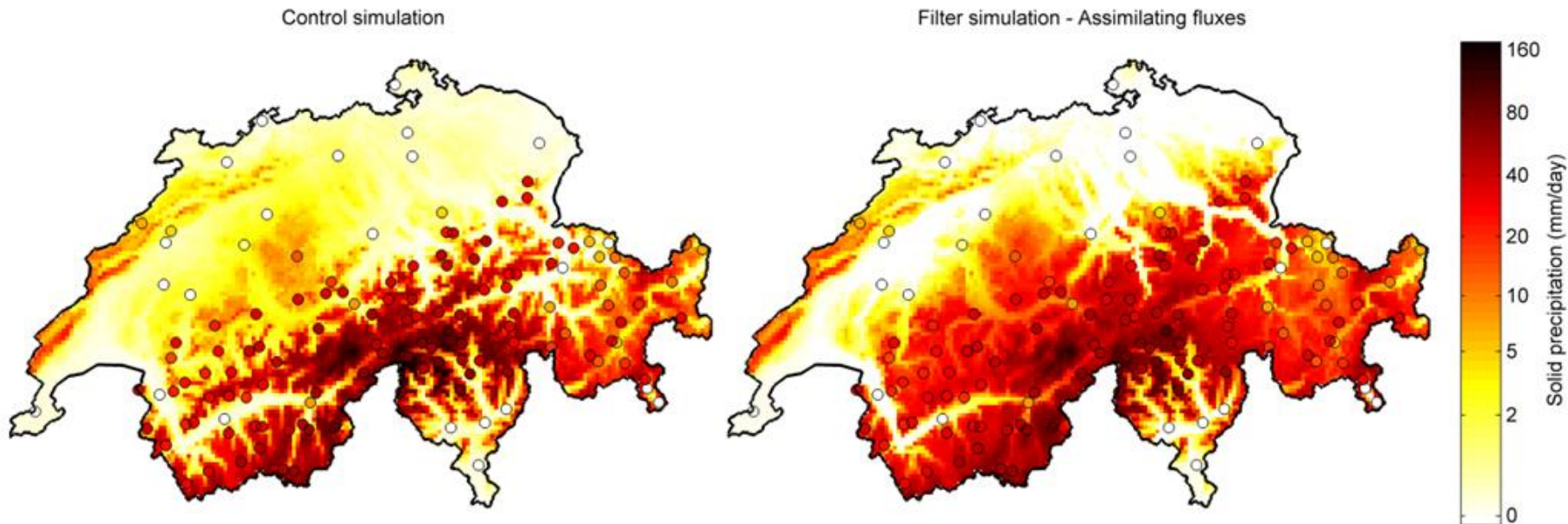


OSHD framework – precipitation data preprocessing

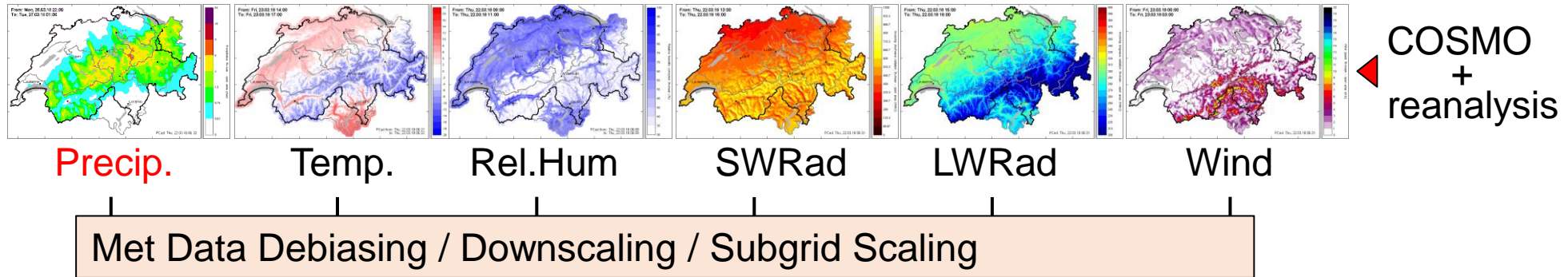


Assimilation of snow data

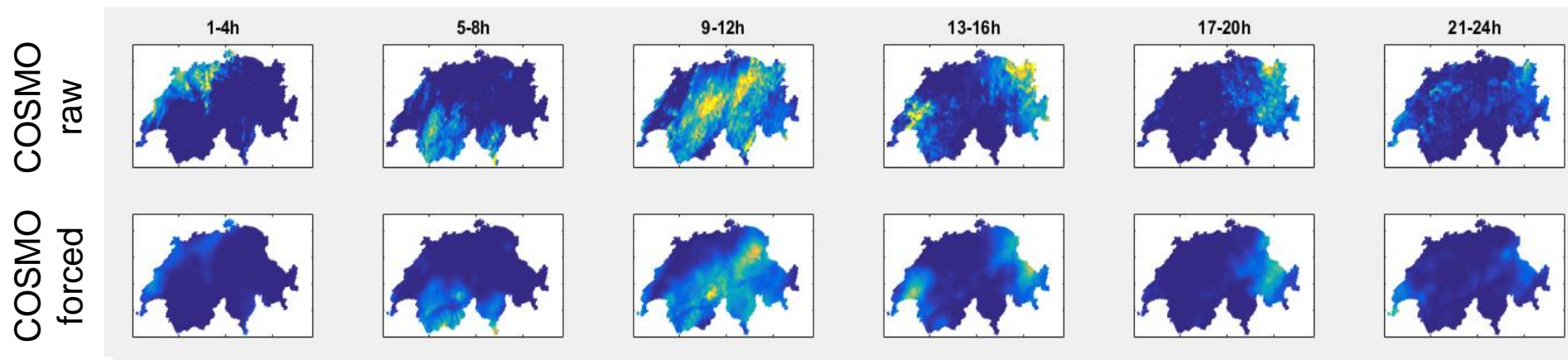
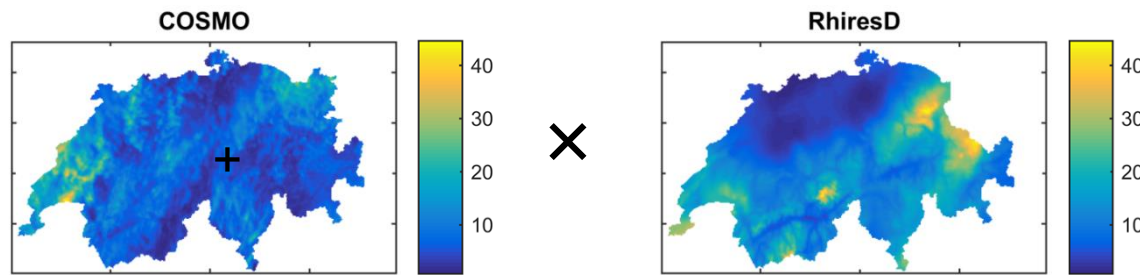
→ to improve solid precipitation estimates (using optimal interpolation)



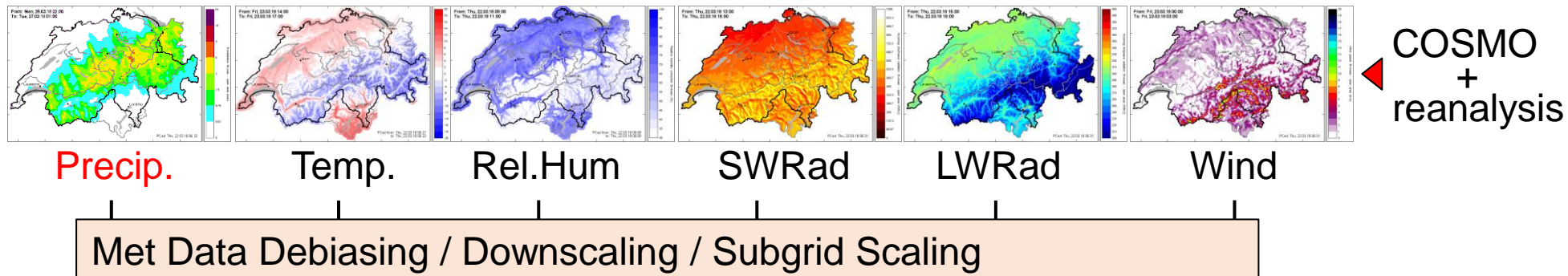
OSHD framework – precipitation data preprocessing



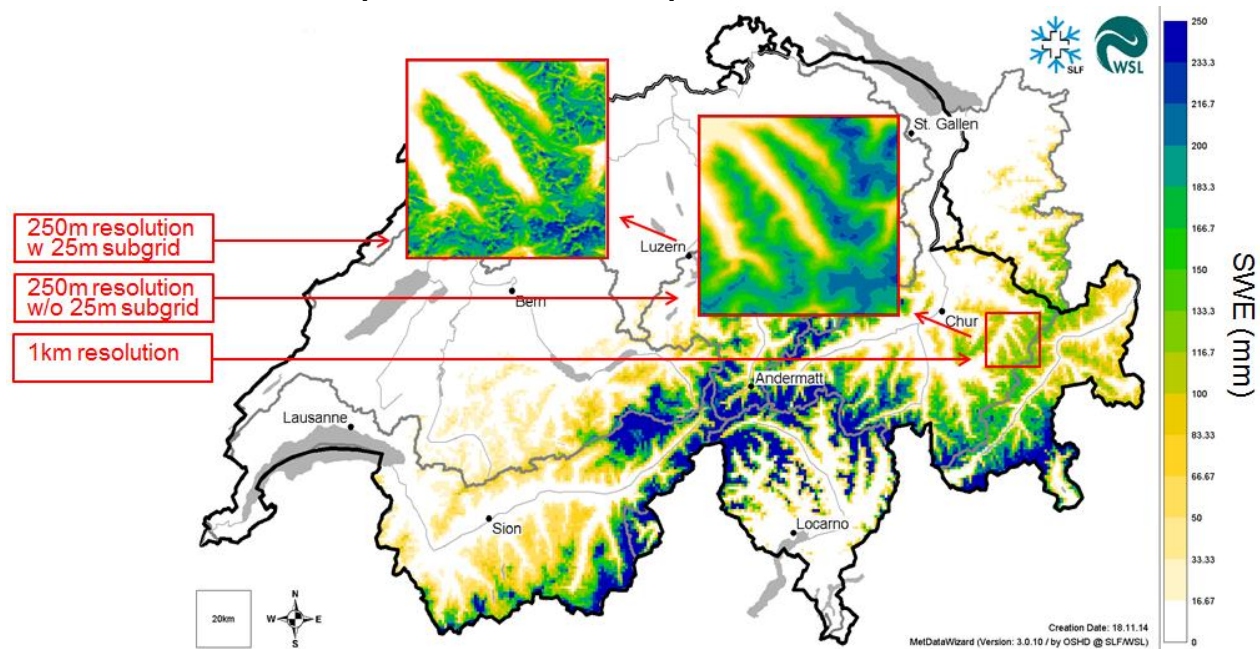
Fusion of COSMO
and RhiresD



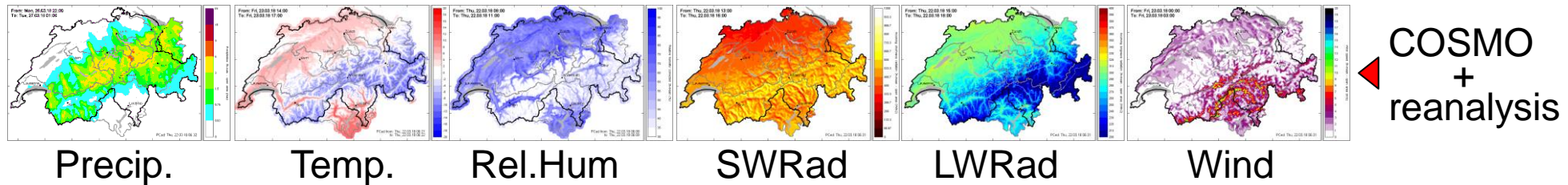
OSHD framework – precipitation data preprocessing



Subgrid scaling of solid precipitation
→ to account for preferential deposition



OSHD framework – precipitation data preprocessing

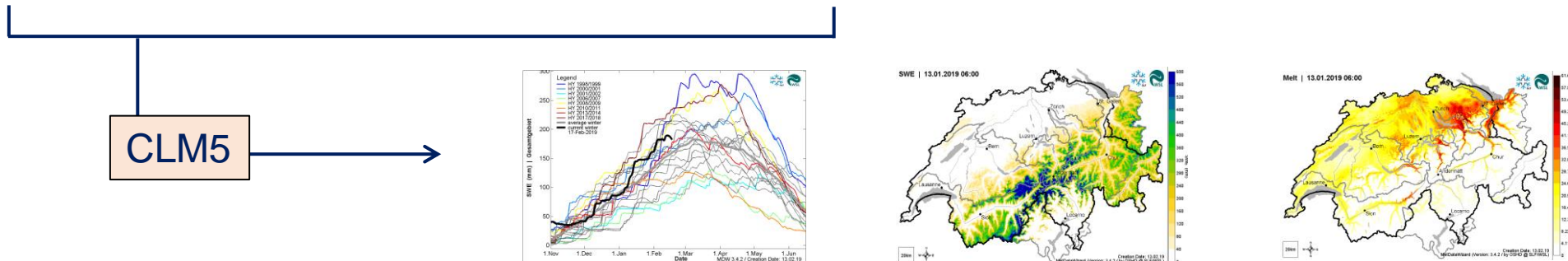


Coverage:

- Aug 2015 – Jul 2019: COSMO1
- Aug 2019 – Jul 2021: COSMO1E
- upscaled to temporal resolution of 6h and spatial resolution of 1km

Preprocessing:

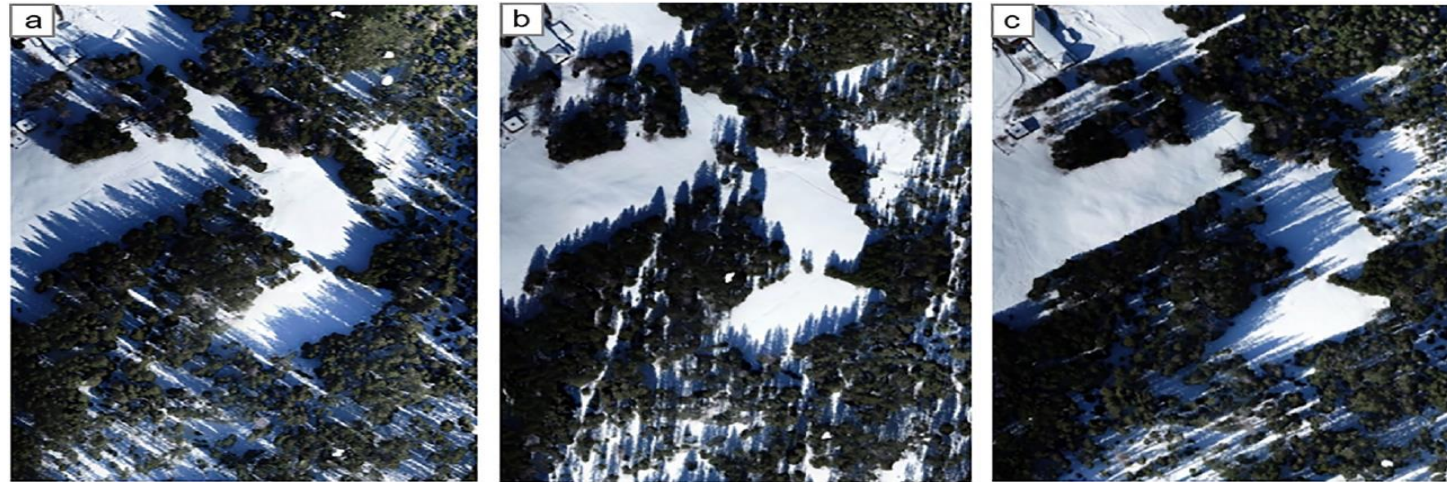
- Downscaled and debiased: wind speed, air temperature
- Downscaled and assimilated: precipitation
- Downscaled: shortwave and longwave radiation



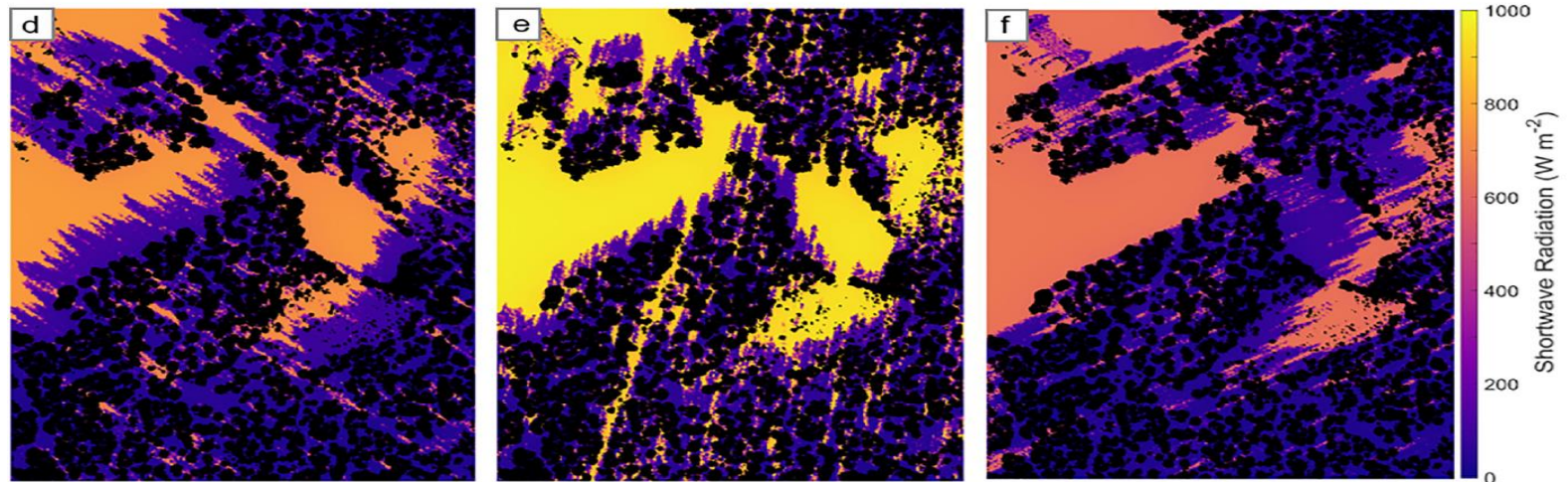
OSHD model framework – representing forests

Modelling sub-canopy shortwave radiation

Observed

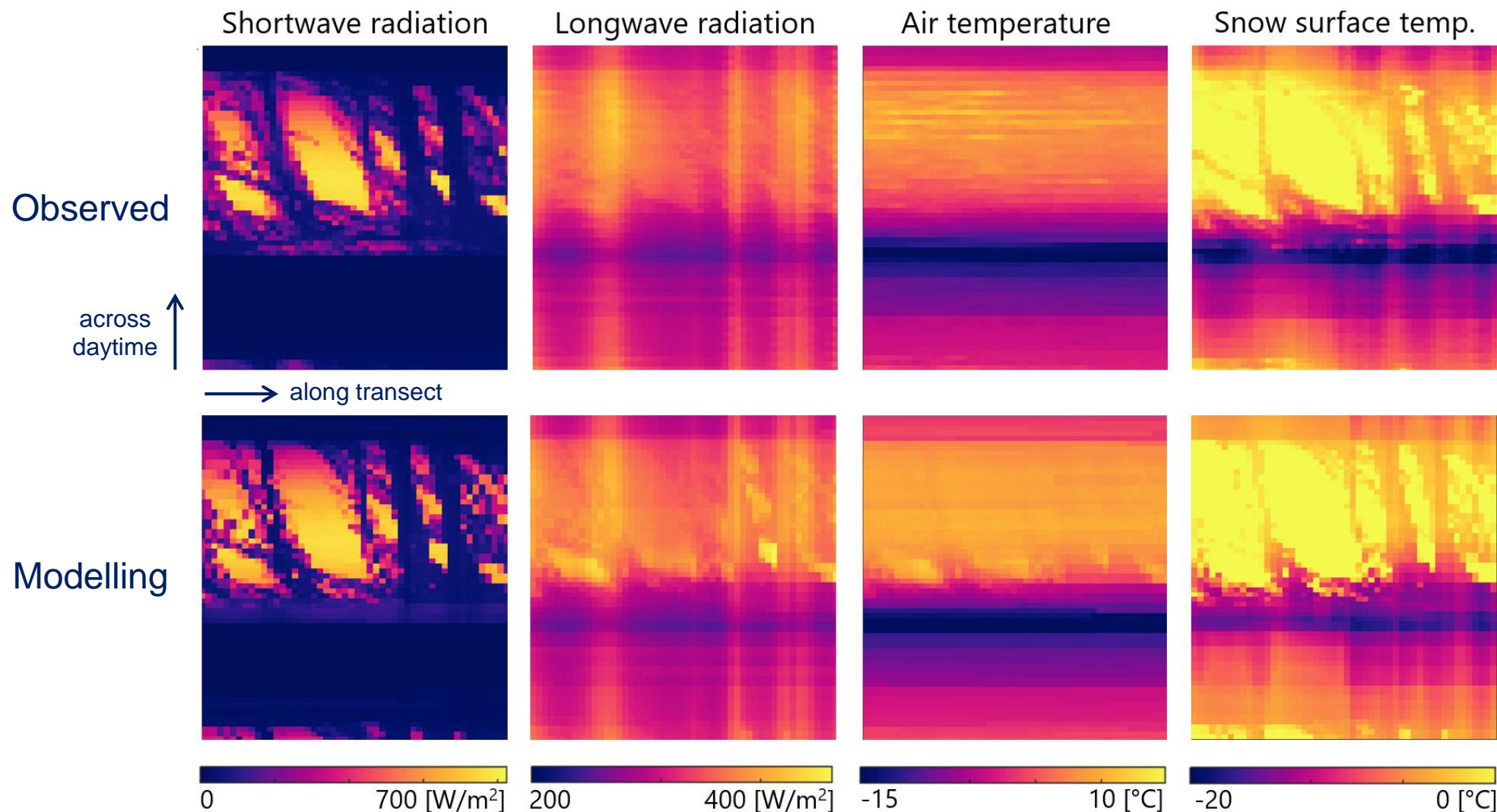


Modelling



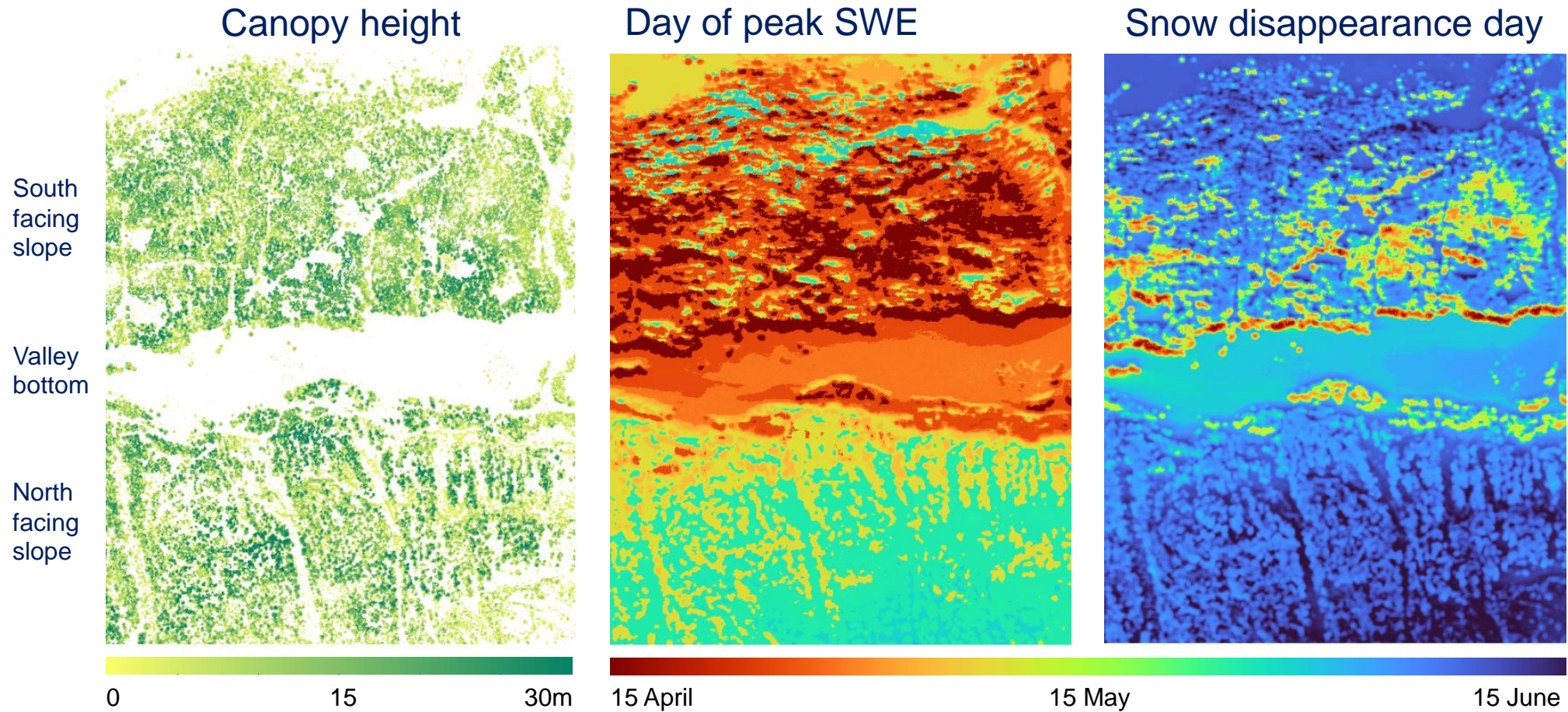
OSHD model framework – representing forests

Spatio temporal patterns of energy fluxes + states

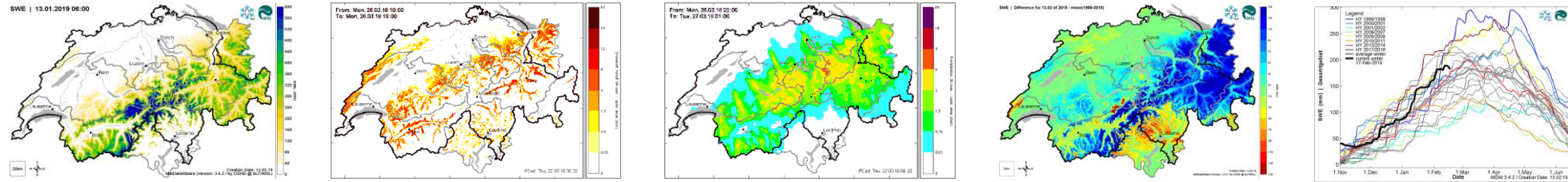


OSHD model framework – representing forests

Spatial patterns of snow distribution dynamics in Flüela Valley, Davos



OSHD model framework – representing forests



→ Our nation-wide operational snow models represent these forest snow processes down to 10m spatial resolution, and upscale them to 250m output



Meteorological forcing data

- HighRes case: OSHD-based high resolution data @ 1km & point locations
- “Global” case: CRUIRA-based, re-gridded using linear interpolation @ 1km & point locations
- “Global” case +: ^ incl. downscaled temperature based on 1km DEM and under the assumption of a constant temperature lapse rate (6.5K/1000m)

Global meteo input – CRUJRA

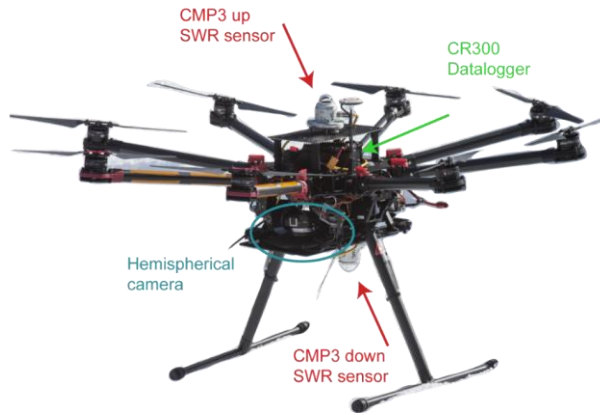
- Gridded land surface blend of UEA Climatic Research Unit (CRU) and Japanese reanalysis (JRA) data (JRA-55 reanalysis dataset)
- Used by LS3MIP & TRENDY projects
- 6 hourly, 0.5deg x 0.5deg, near global grid (excluding Antarctica)
- Available from 1.1.1901 – 31.12.2020 => good overlap with OSHD-based input data

University of East Anglia Climatic Research Unit; Harris, I.C. (2019): CRU JRA: Collection of CRU JRA forcing datasets of gridded land surface blend of Climatic Research Unit (CRU) and Japanese reanalysis (JRA) data. Centre for Environmental Data Analysis.

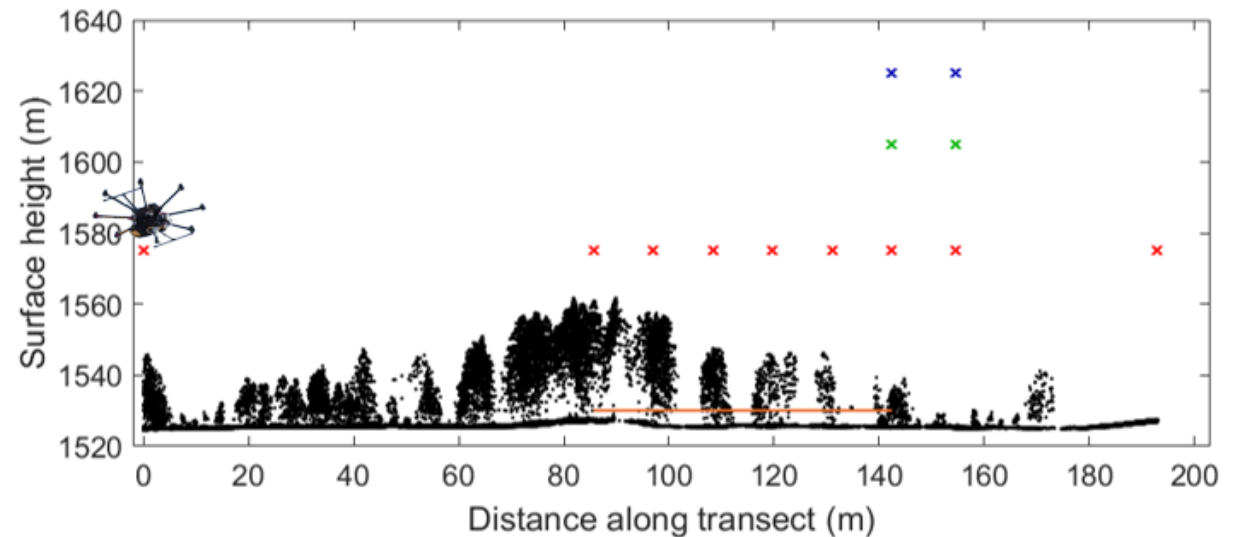
<http://catalogue.ceda.ac.uk/uuid/863a47a6d8414b6982e1396c69a9efe8>

Use-case example 1:

UAV-based measurements of land surface albedo & point-scale CLM5 runs

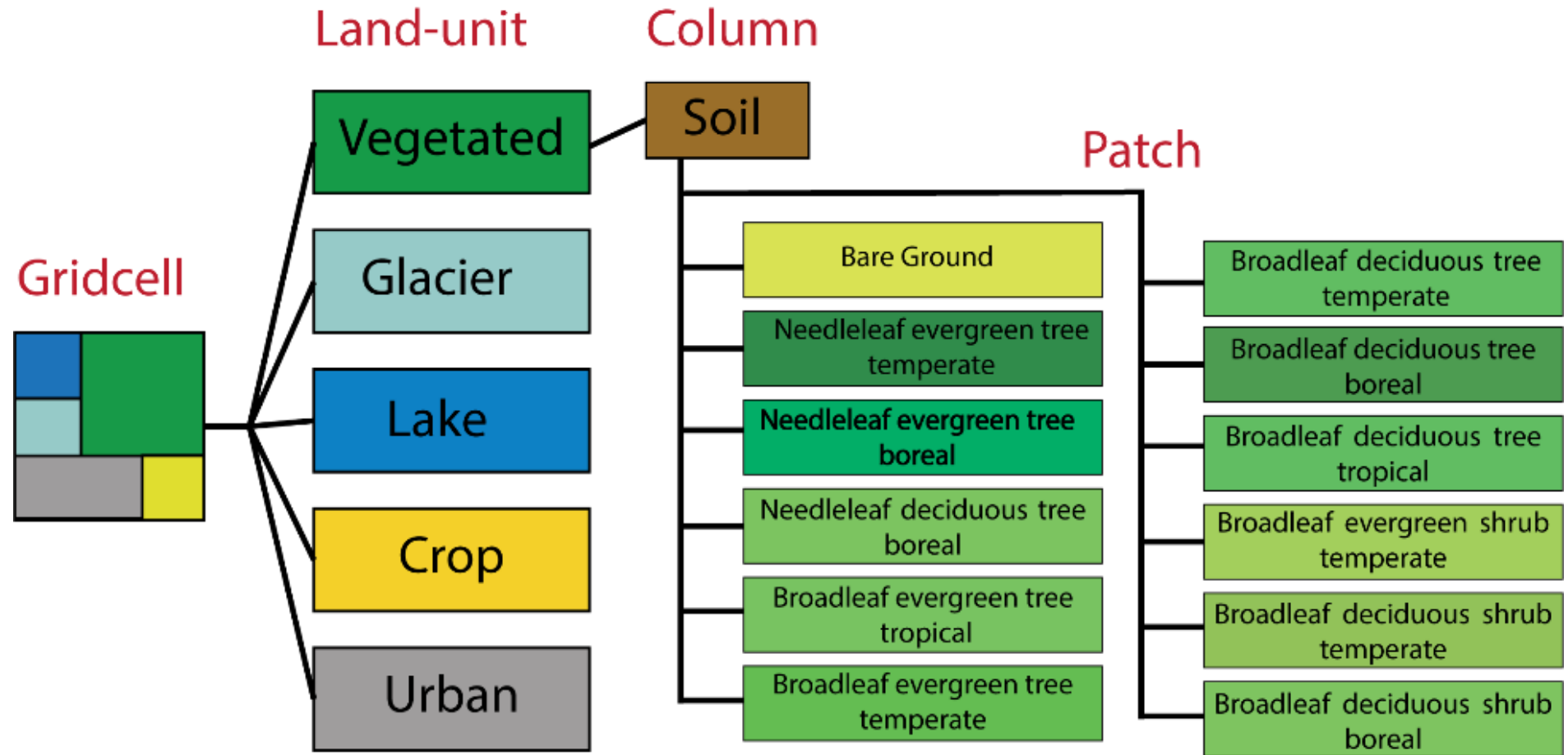


UAV-System to measure land surface albedo above the trees

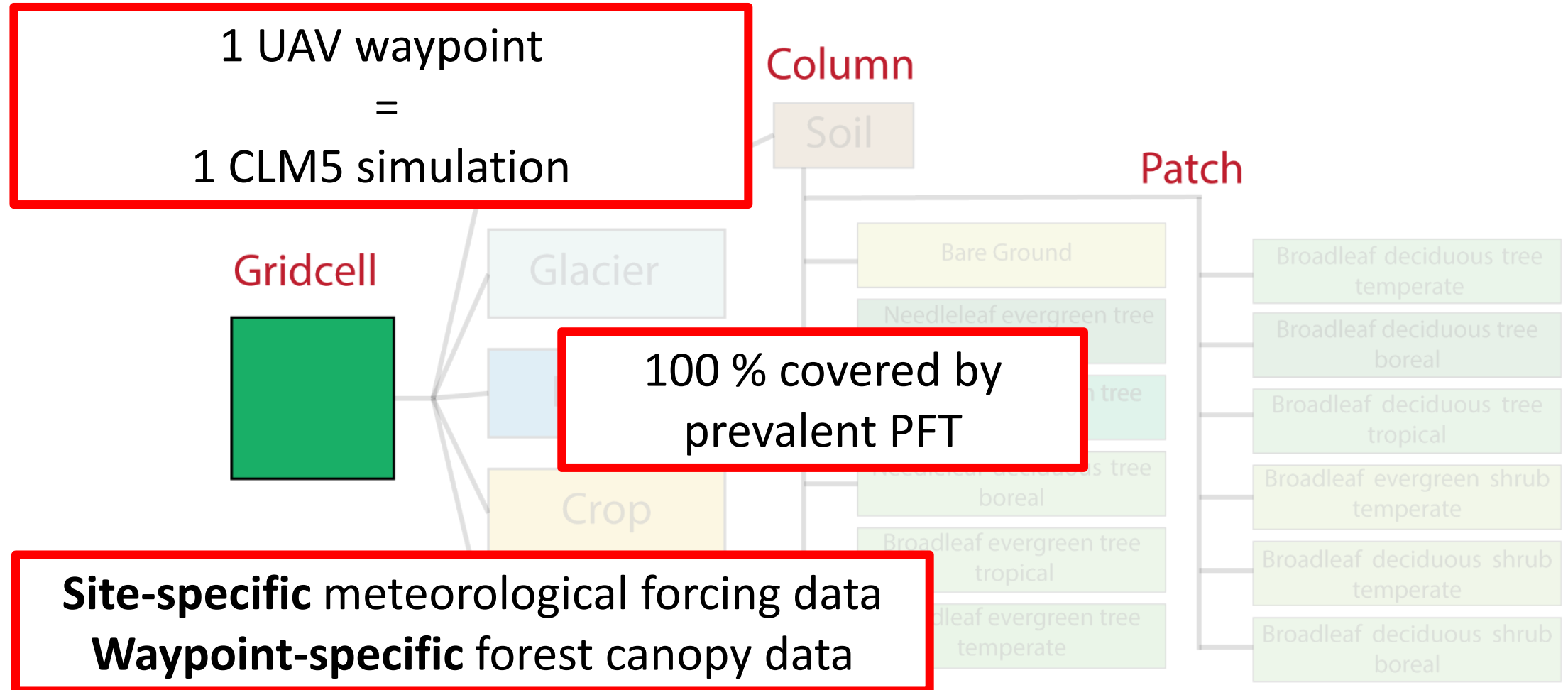


How well do radiative regimes implemented in CLM5 represent measured land surface albedo?

Global-scale modelling algorithms of CLM5 applied to the point-scale

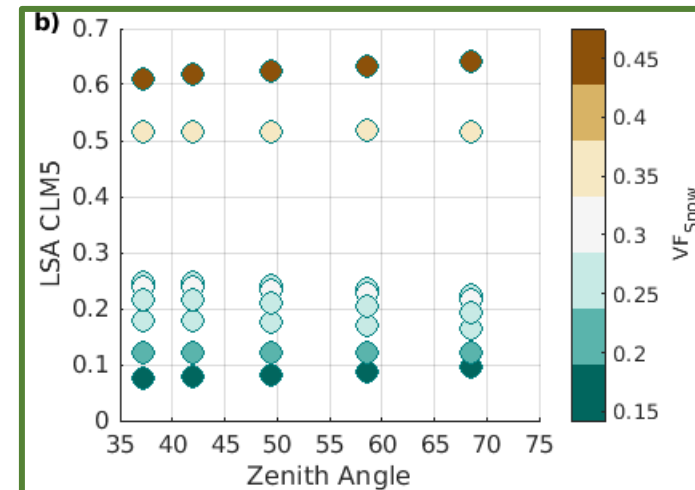
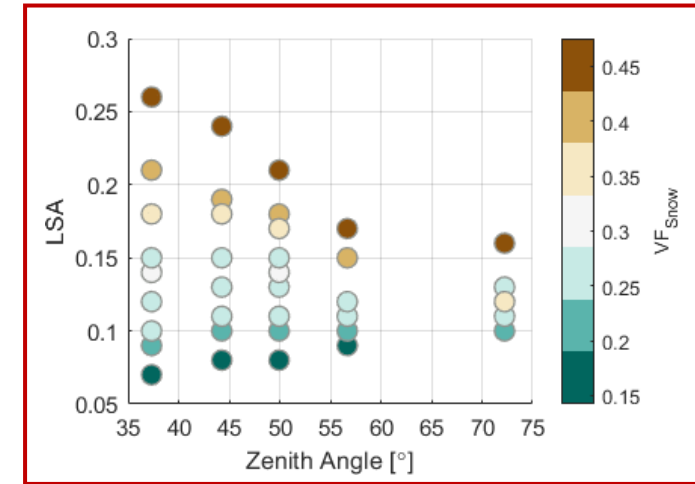


Global-scale modelling algorithms of CLM5 applied to the point-scale



Diurnal patterns of measured LSA revealed strong effects of zenith angle, which were not represented in CLM5 simulations

- **Measurements:** LSA can decrease (sparse sites) or increase (dense sites) as zenith angle increases
- **CLM5:** minimal response of LSA to diurnal changes of the zenith angle
- **CLM5:** large positive bias of up to 40% in LSA estimates for sparse canopy

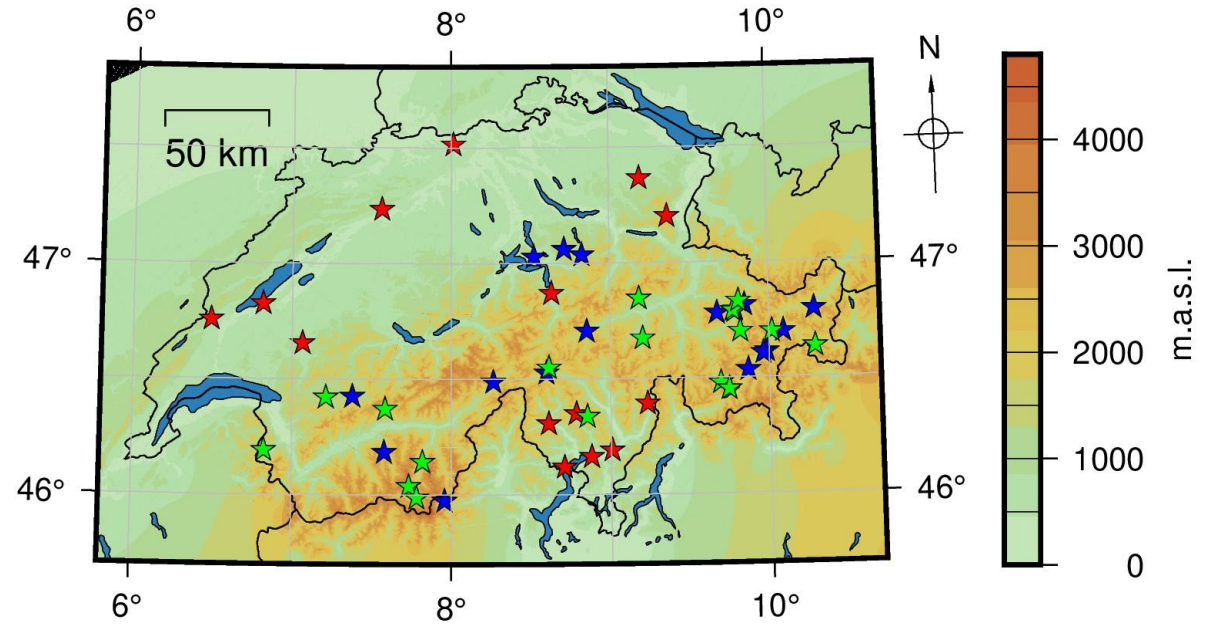


Malle, J., Rutter, N., Webster, C., Mazzotti, G., Wake, L., & Jonas, T. (2021). Effect of forest canopy structure on wintertime land surface albedo: Evaluating CLM5 simulations with in-situ measurements. *Journal of Geophysical Research: Atmospheres*, 126, e2020JD034118. <https://doi.org/10.1029/2020JD034118>

Use-case example 2:

Snow modelling with CLM5 across scales – point scale

- Set up point-simulation at 60 selected locations => elevation gradient
 1. OSHD met. forcing
 2. CRUIRA met. forcing
- Run with adjusted snow parameters (e.g. fractional snow cover parametrization had to be adjusted)
- Use HS measurements



How well does CLM5 model seasonal snow-packs?

What's the impact of using high resolution OSHD forcing on model performance?

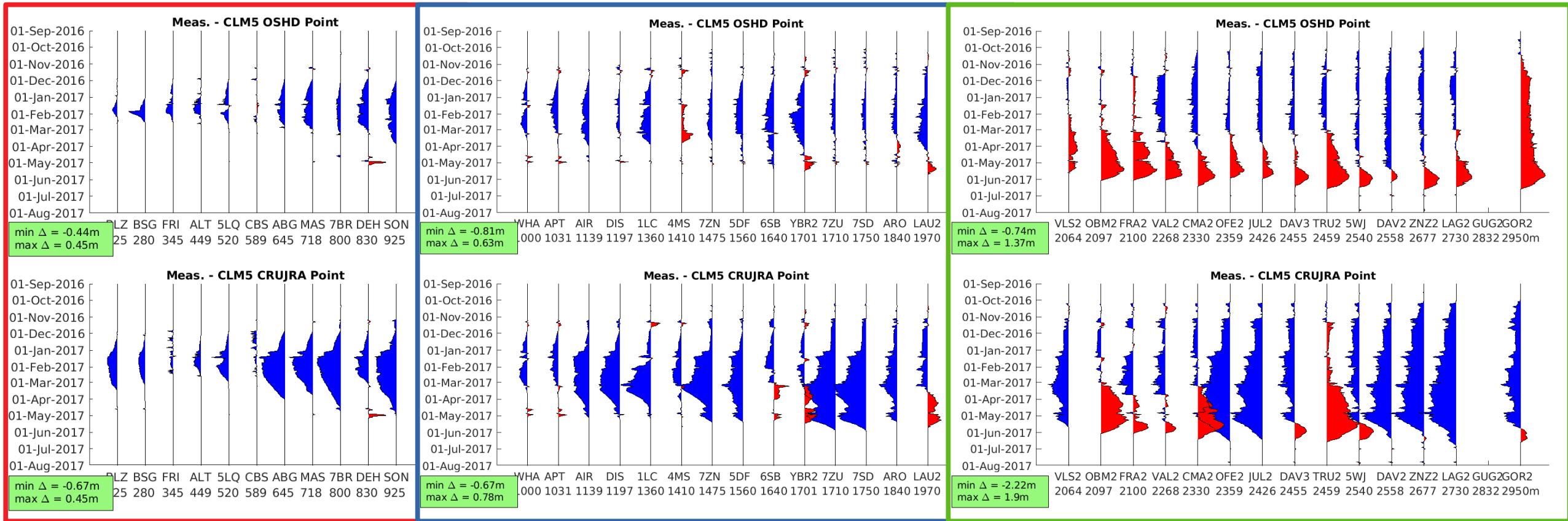
Use-case example 2:

Snow modelling with CLM5 across scales – point scale

★ < 1000 m

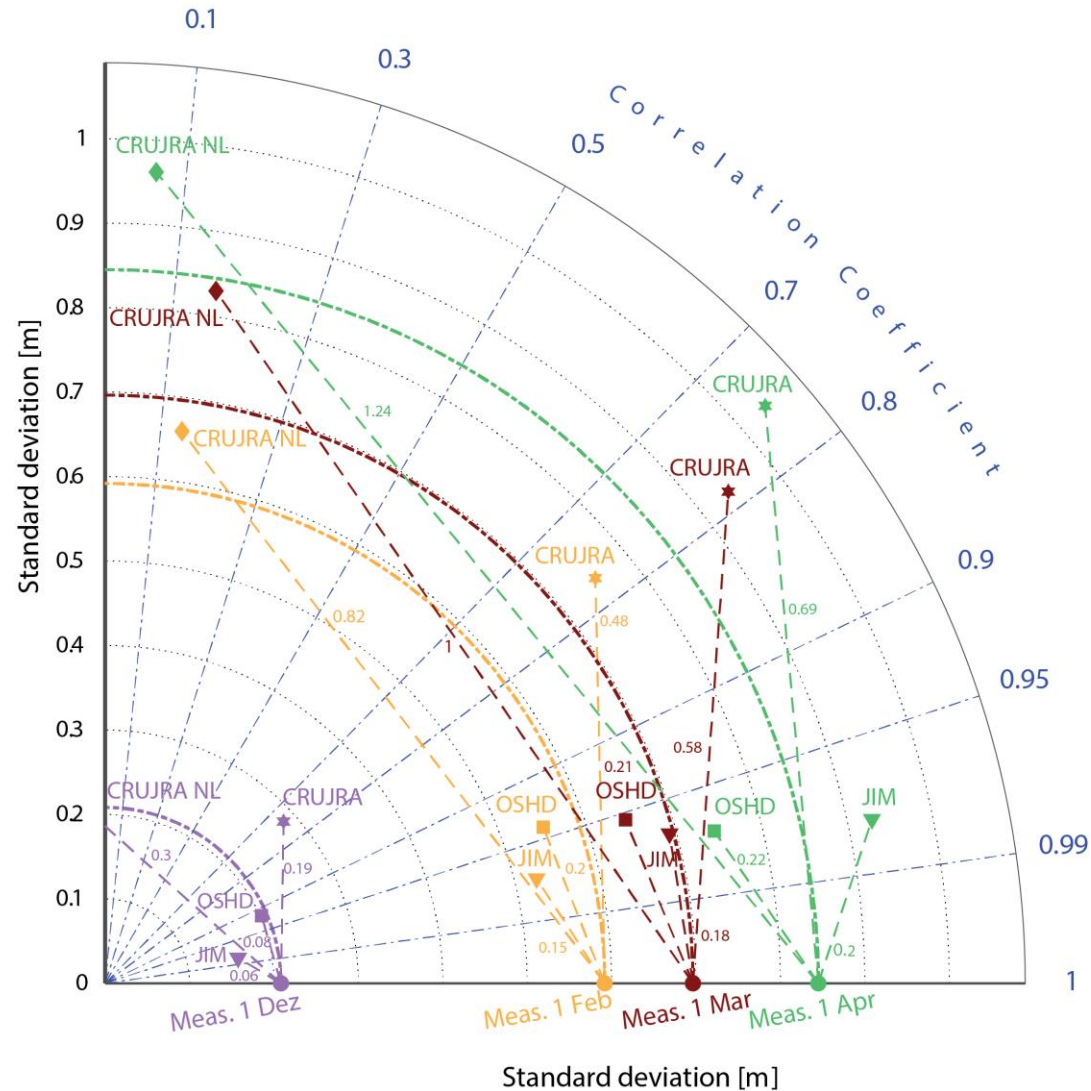
★ 1000 – 2000m

★ > 2000m



Use-case example 2:

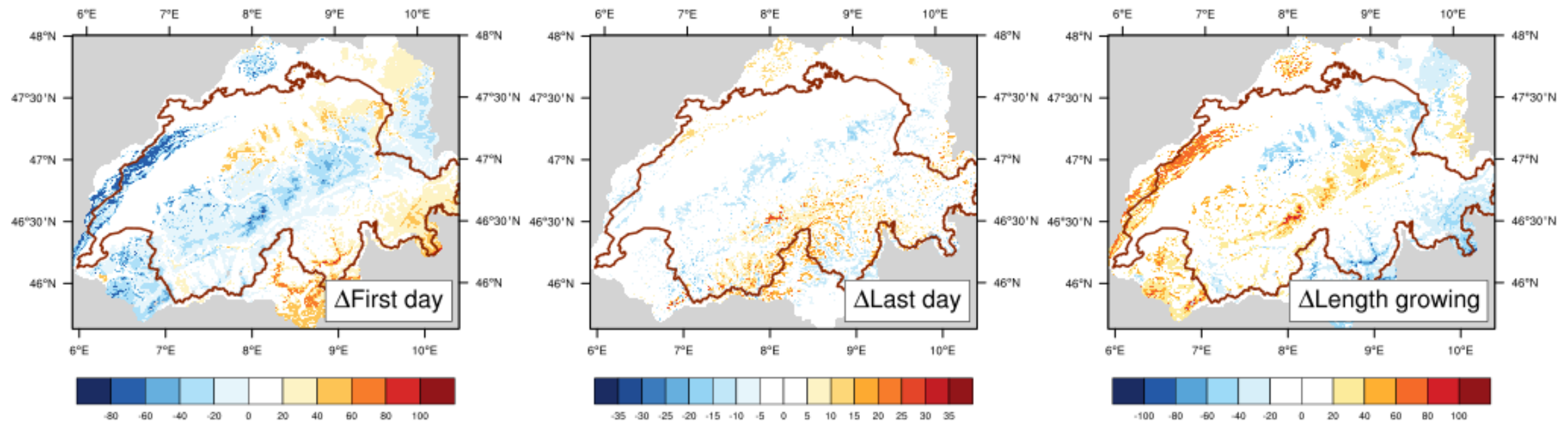
Snow modelling with CLM5 across scales – point scale



Use-case example 3:

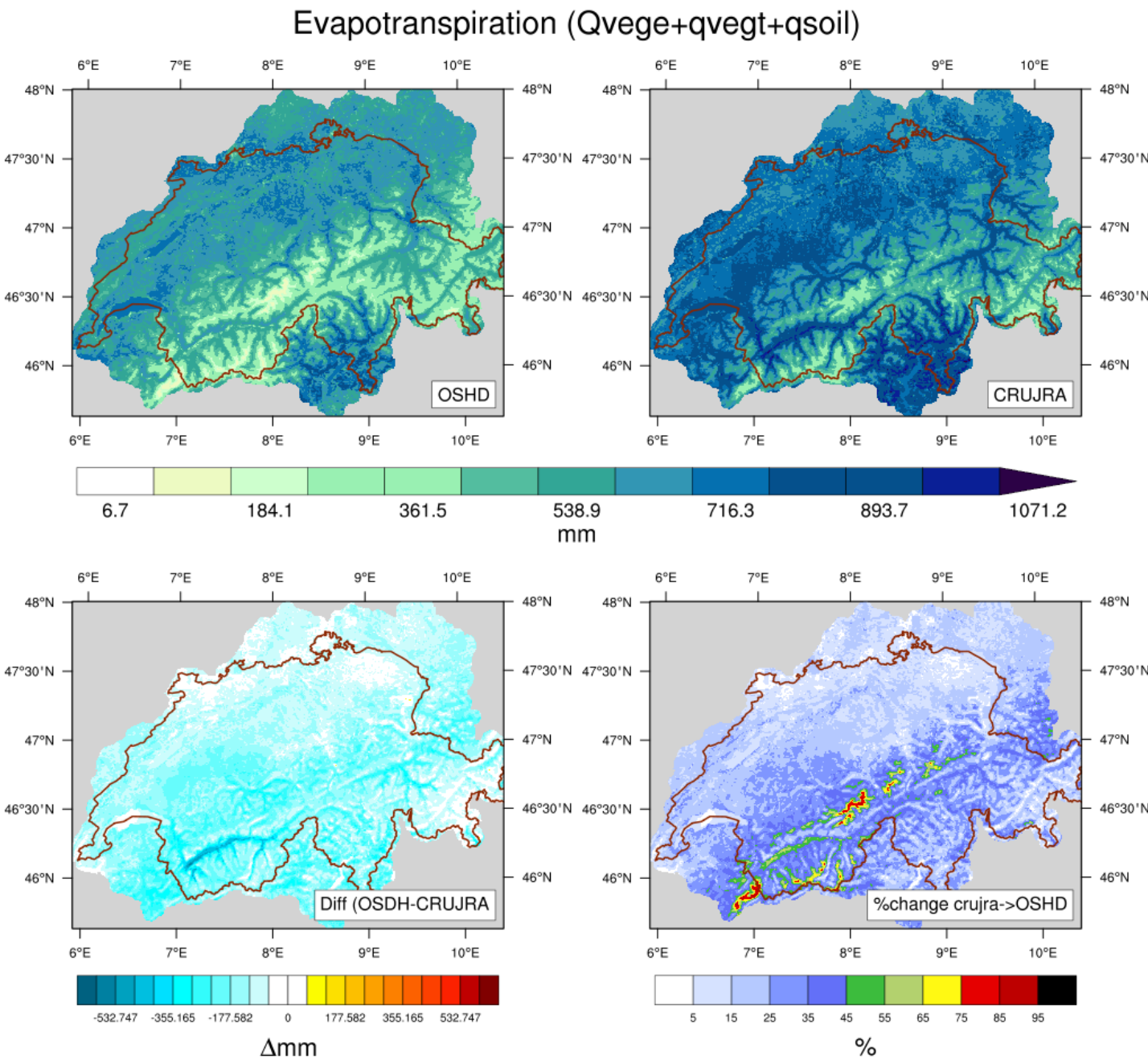
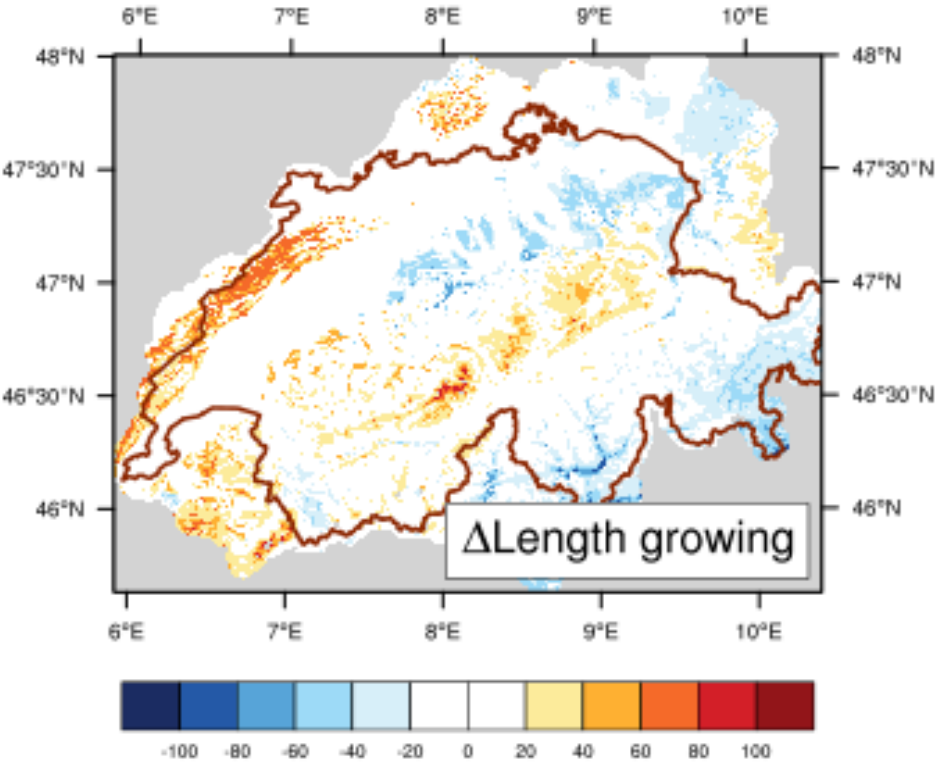
Duration of snow-cover & evapotranspiration

Growing season comparison - year 2018



Use-case example 3:

Duration of snow-cover & evapotranspiration



Thanks for your attention!

Questions?



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https://gitlabext.wsl.ch/malle/clm5_tutorial



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