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Comprehensive Expansion: Advancements in Downscaling Algorithms Beyond Temperature and Precipitation for the CHELSA Dataset

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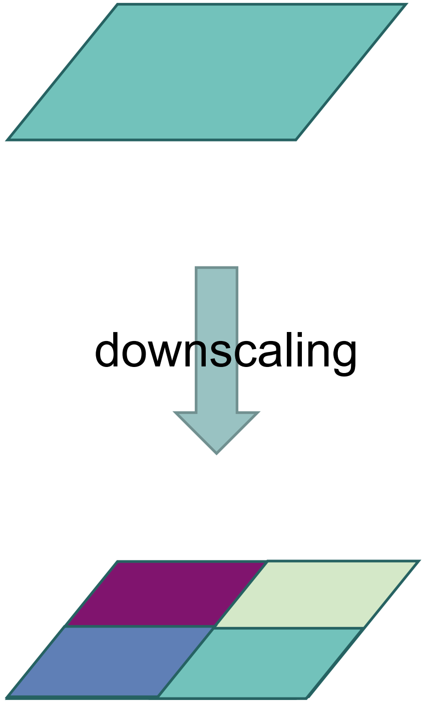
Swiss Federal Institute for Forest, Snow
and Landscape Research WSL

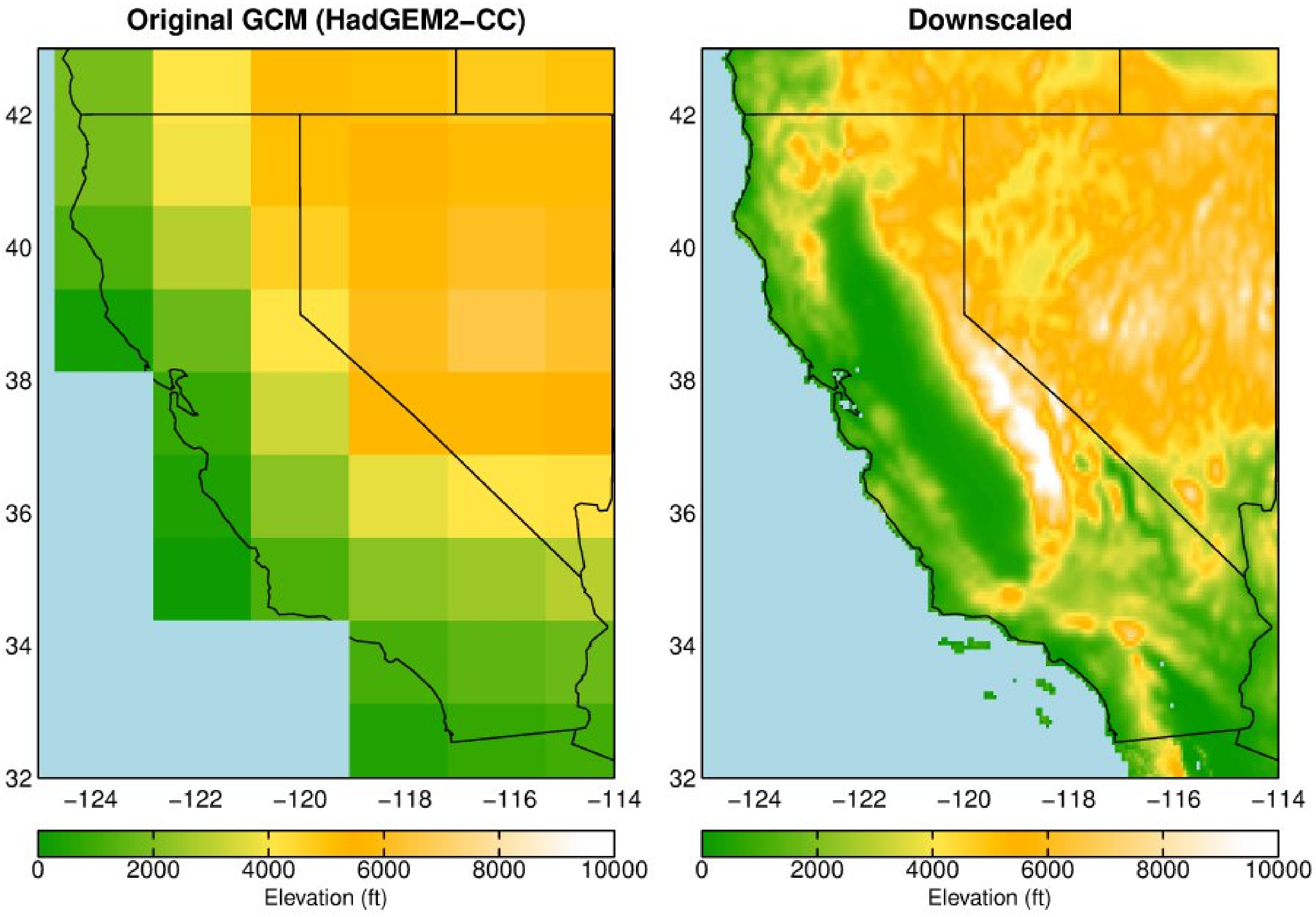
CHELSA – W5E5 variables in ISIMIP

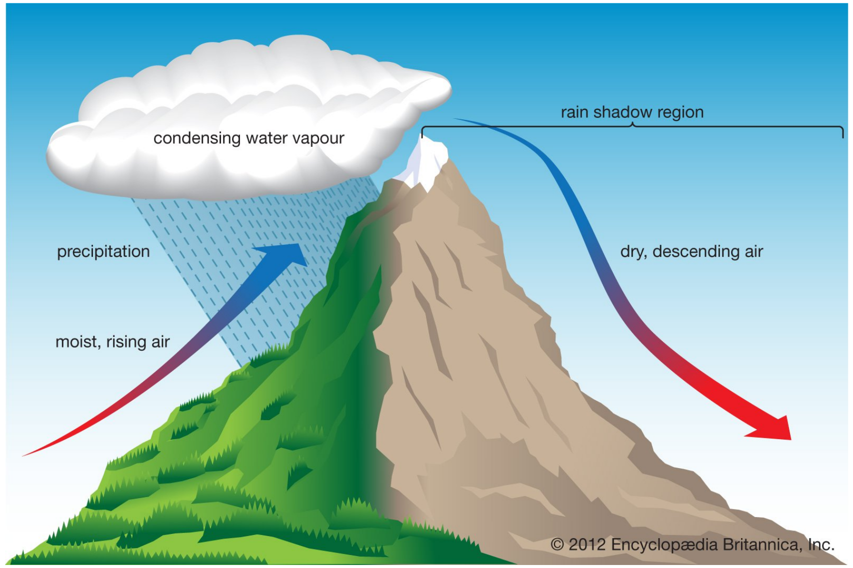
shortname	description	CF Standard Name	levels	frequency
tas	daily-mean near-surface (2 meter) air temperature	air temperature	surface	day
tasmax	daily-maximum near-surface (2 meter) air temperature	air temperature	surface	day
tasmin	daily-minimum near-surface (2 meter) air temperature	air temperature	surface	day
rsds	total downwelling shortwave solar radiation	surface downwelling shortwave flux in air	surface	day
pr	daily precipitation flux (liquid and solid)	precipitation flux	surface	day

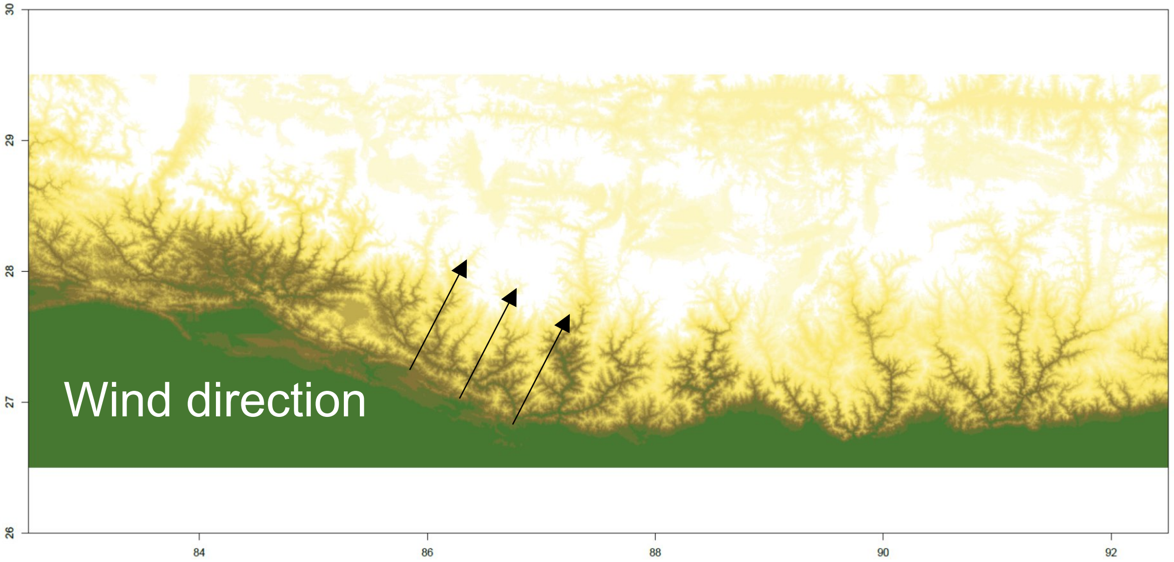
CHELSA uses gridded coarse resolution data as input

Coarse resolution







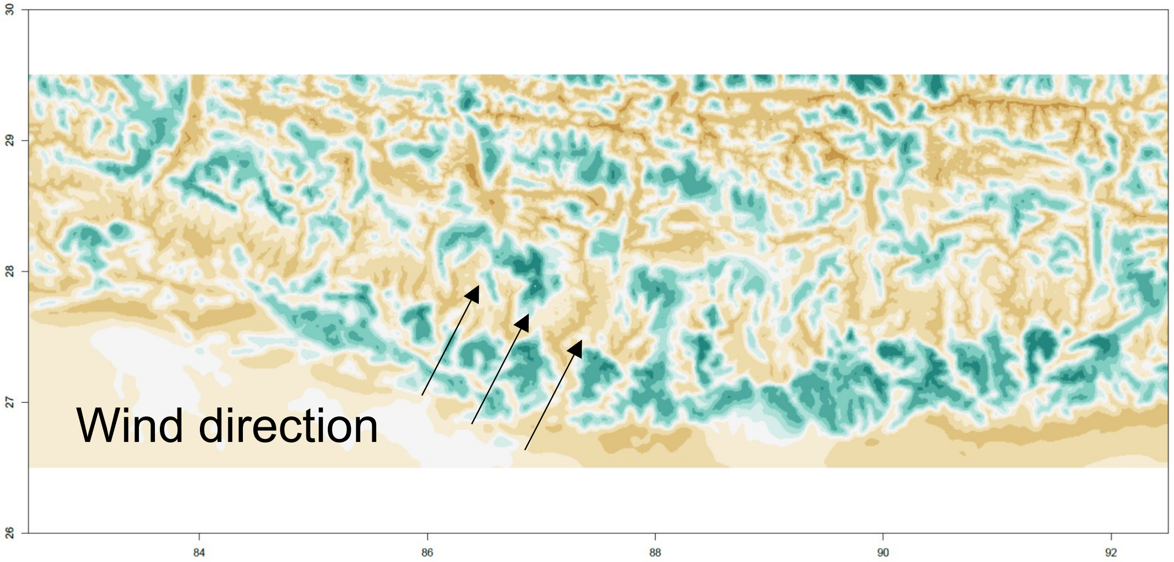


Wind direction and condensation levels are taken into account

$$H_{\mathrm{W}} = \frac{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{WH}i}} \tan^{-1}\left(\frac{d_{\mathrm{WZ}i}}{d_{\mathrm{WH}i}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}}} + \frac{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}} \tan^{-1}\left(\frac{d_{\mathrm{LZ}i}}{d_{\mathrm{LH}i}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}}}$$

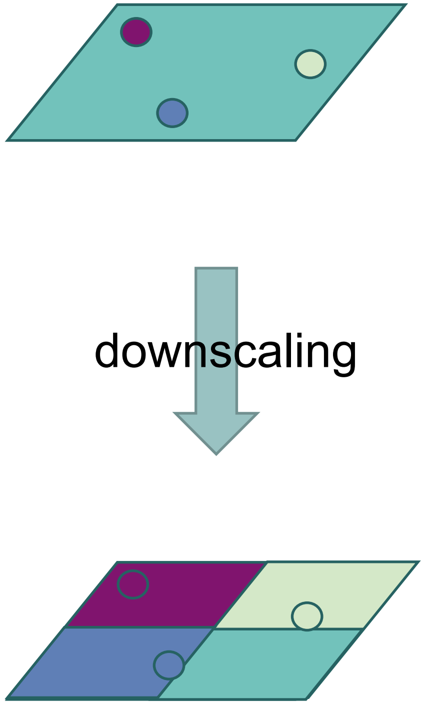
$$H_{\mathrm{L}} = \frac{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{WH}i}} \tan^{-1}\left(\frac{d_{\mathrm{LZ}i}}{d_{\mathrm{WH}i}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}}}$$

$$pr_h = S(pr_c) * \frac{\frac{1}{n}\sum_{i=1}^{n} H_n}{\frac{1}{n}\sum_{i=1}^{n} \sum_{i=1}^{n} H_n}$$



Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., and Kessler, M.: Climatologies at high resolution for the earth's land surface areas, ***Scientific Data***, 4, 170122, 2017. https://doi.org/10.1038/sdata.2017.122

Principle of the precipitation downscaling in CHELSA



orography

$S(pr_c)$

B-spline

$$H_{\mathrm{W}} = \frac{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{WH}i}} tan^{-1}\left(\frac{d_{\mathrm{WZ}i}}{d_{\mathrm{WH}i}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}}} + \frac{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}} tan^{-1}\left(\frac{d_{\mathrm{LZ}i}}{d_{\mathrm{LH}i}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{\mathrm{LH}i}}}$$

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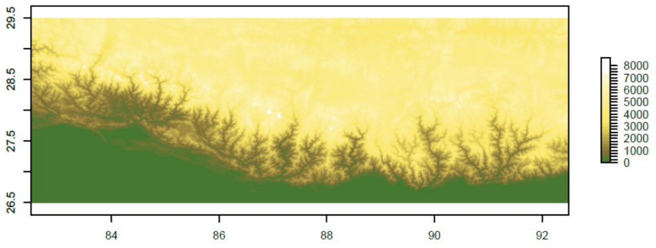
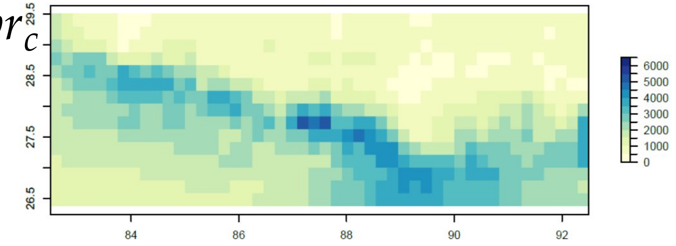
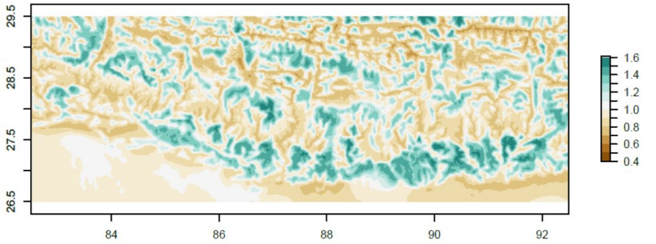


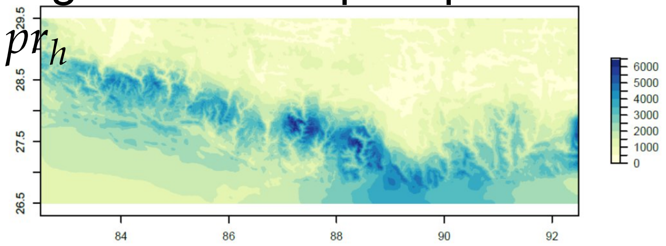
Coarse resolution precipitation pr_c



Windward leeward index H



High resolution precipitation pr_h



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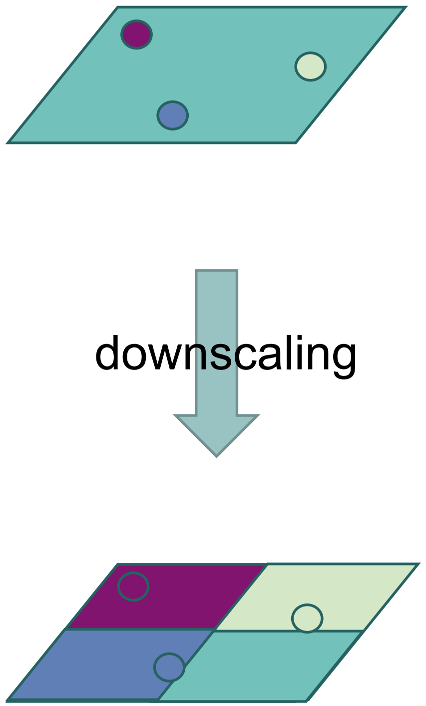


orography

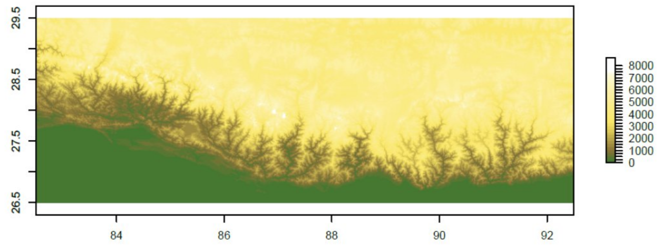
$S(pr_c)$

B-spline

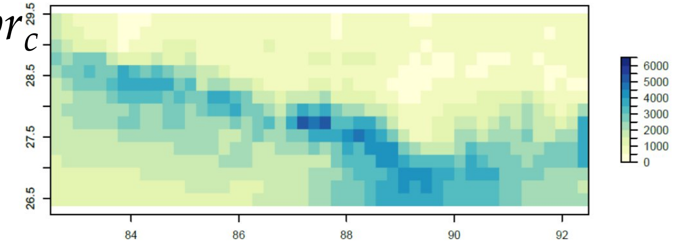
$$H_W = \frac{\sum_{i=1}^{n} \frac{1}{d_{WHi}} tan^{-1}\left(\frac{d_{WZi}}{d_{WHi}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{LHi}}} + \frac{\sum_{i=1}^{n} \frac{1}{d_{LHi}} tan^{-1}\left(\frac{d_{LZi}}{d_{LHi}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{LHi}}}$$

$$H_L = \frac{\sum_{i=1}^{n} \frac{1}{d_{WHi}} tan^{-1}\left(\frac{d_{LZi}}{d_{WHi}}\right)}{\sum_{i=1}^{n} \frac{1}{d_{LHi}}}$$

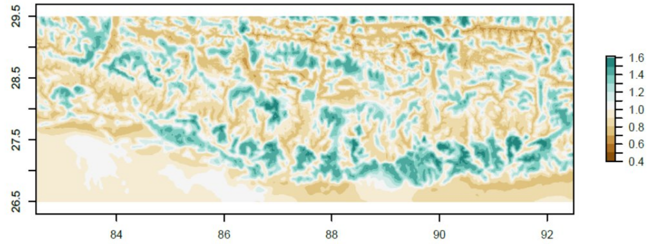
Physical constrain (mass preservation)



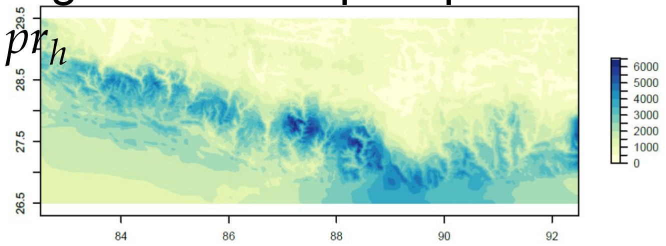
Coarse resolution precipitation pr_c



Windward leeward index H



High resolution precipitation pr_h



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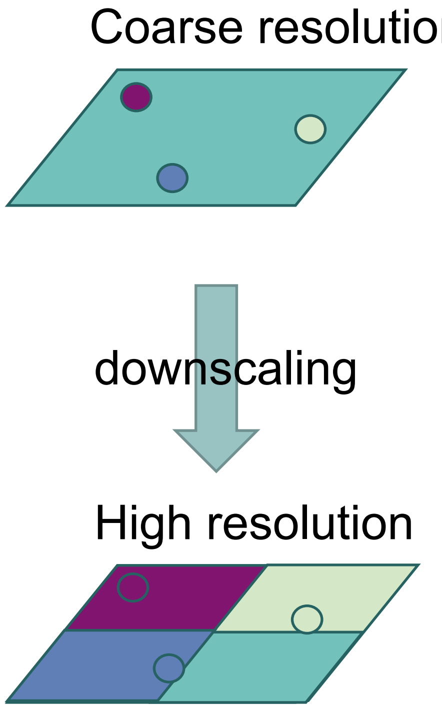
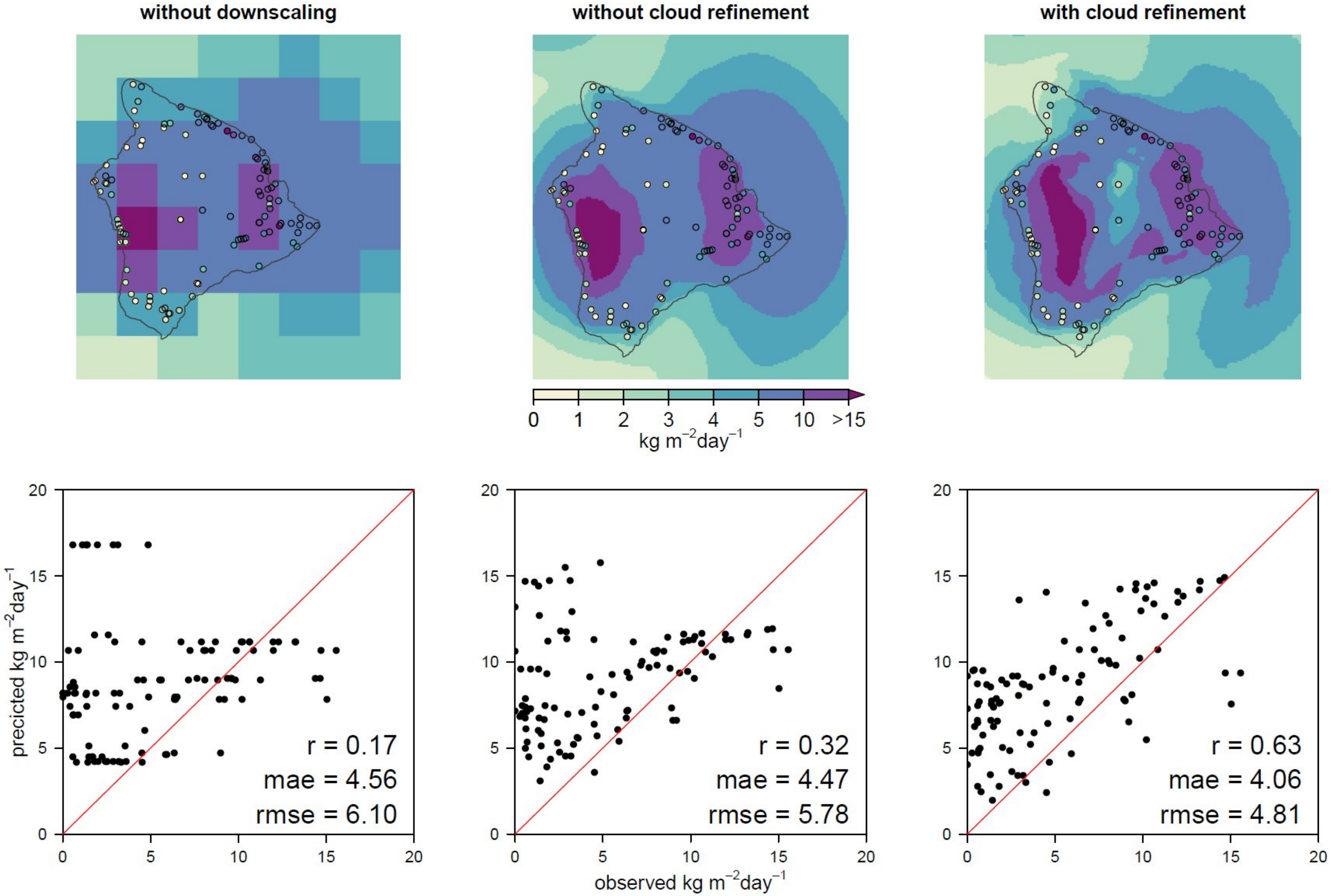
Absolute Bias reduction from coarse to high resolution



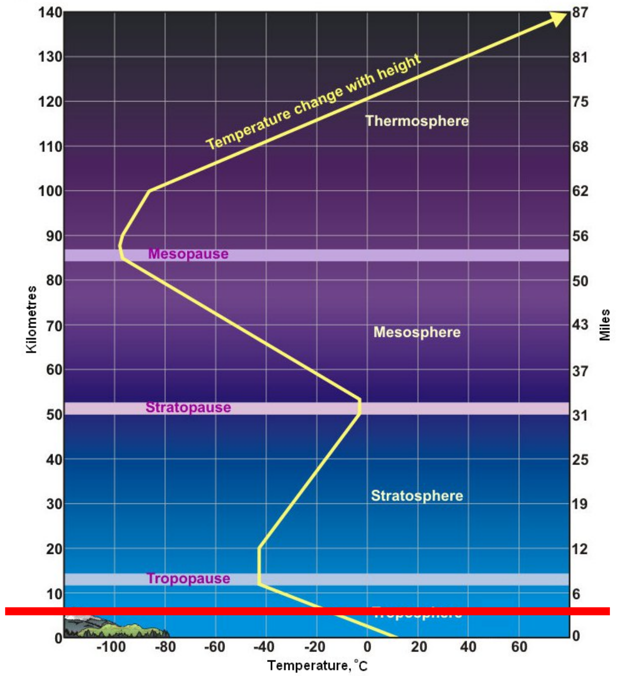


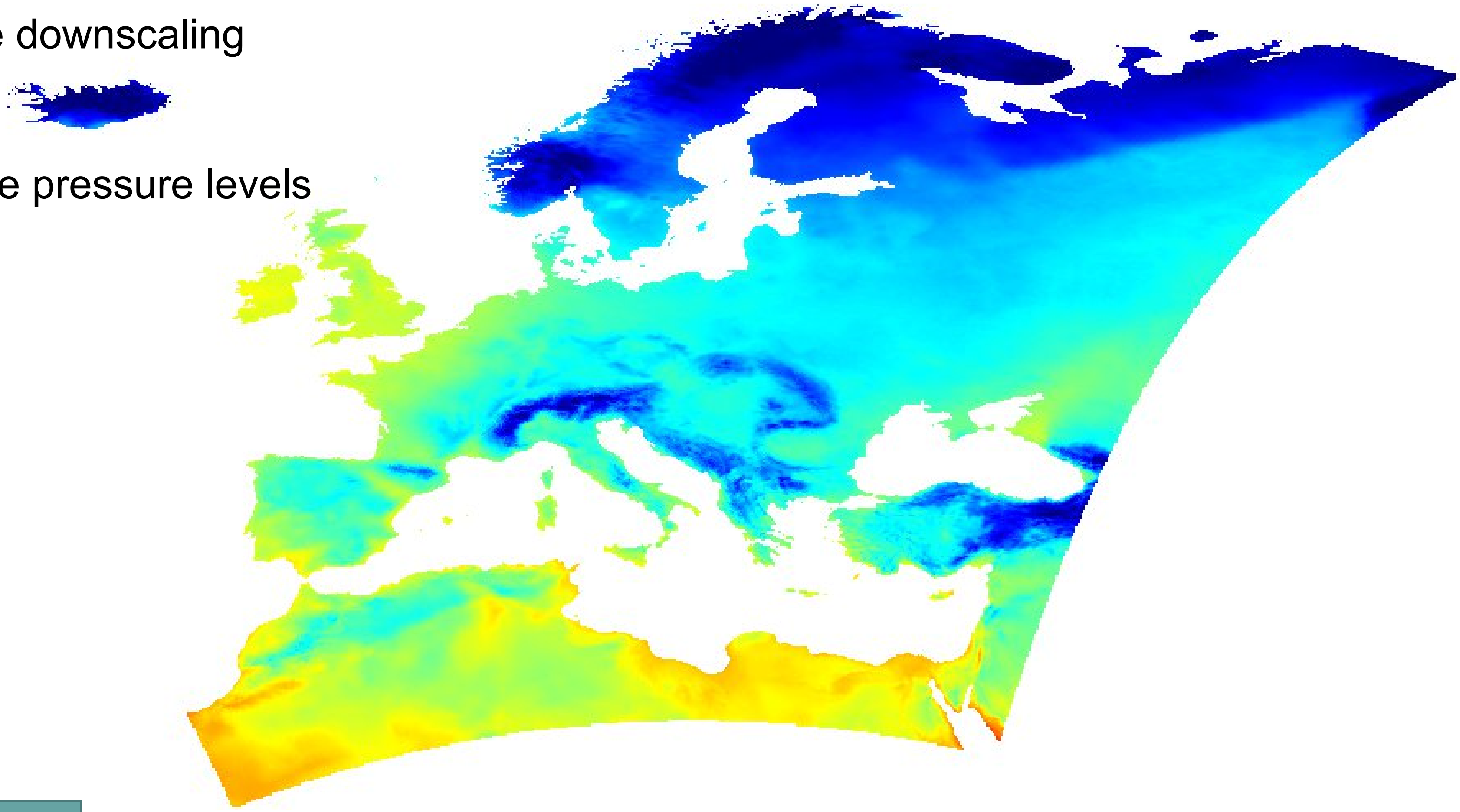
Karger, D.N., Wilson, A.M., Mahony, C., Zimmermann, N.E., Jetz, W. (2021) Global daily 1km land surface precipitation based on cloud cover-informed downscaling. ***Scientific Data.***
doi.org/10.1038/s41597-021-01084-6

Temperature

Lapse rate based temperature downscaling

Using two surface near surface pressure levels





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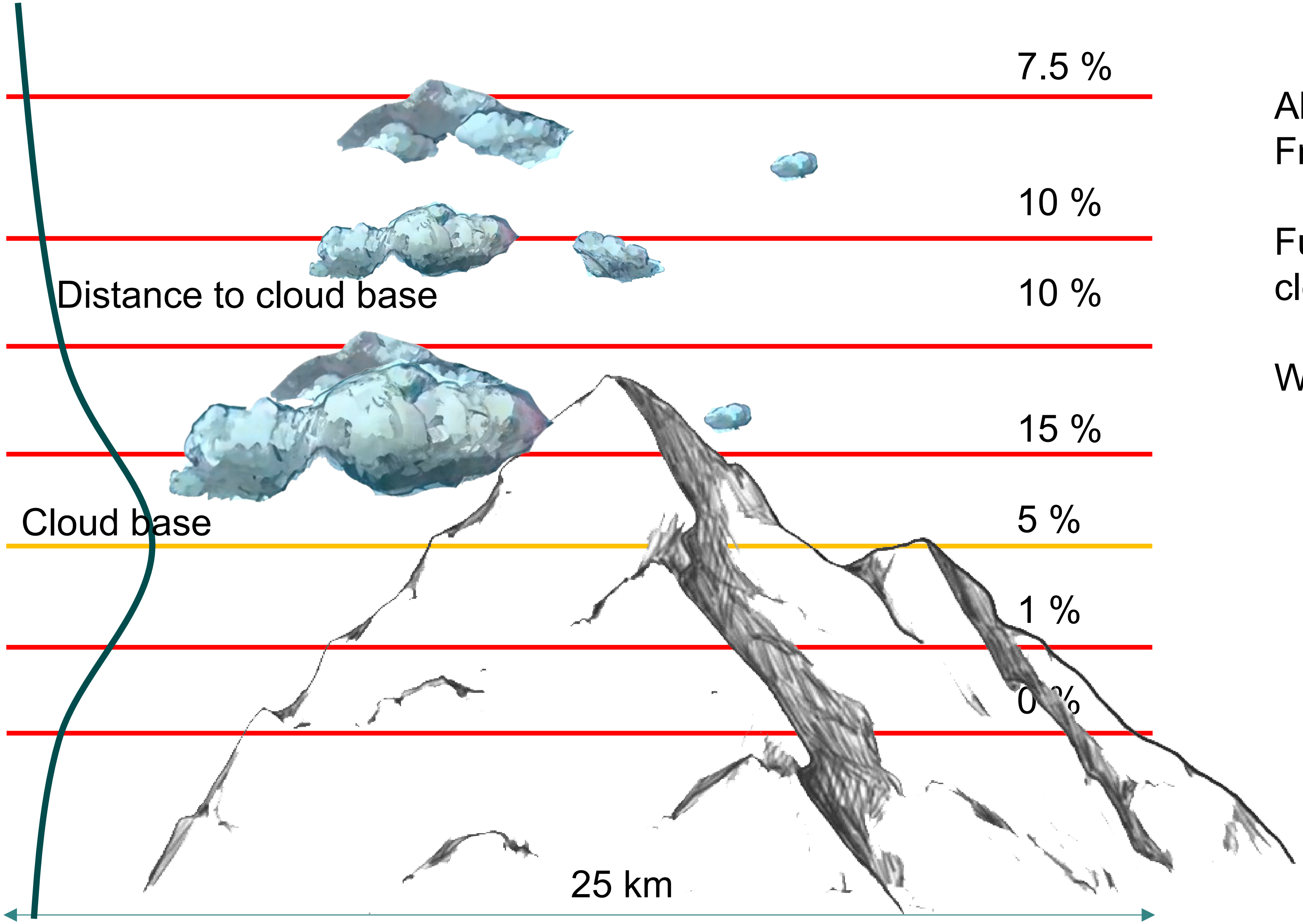
Solar radiation


Orographic clouds

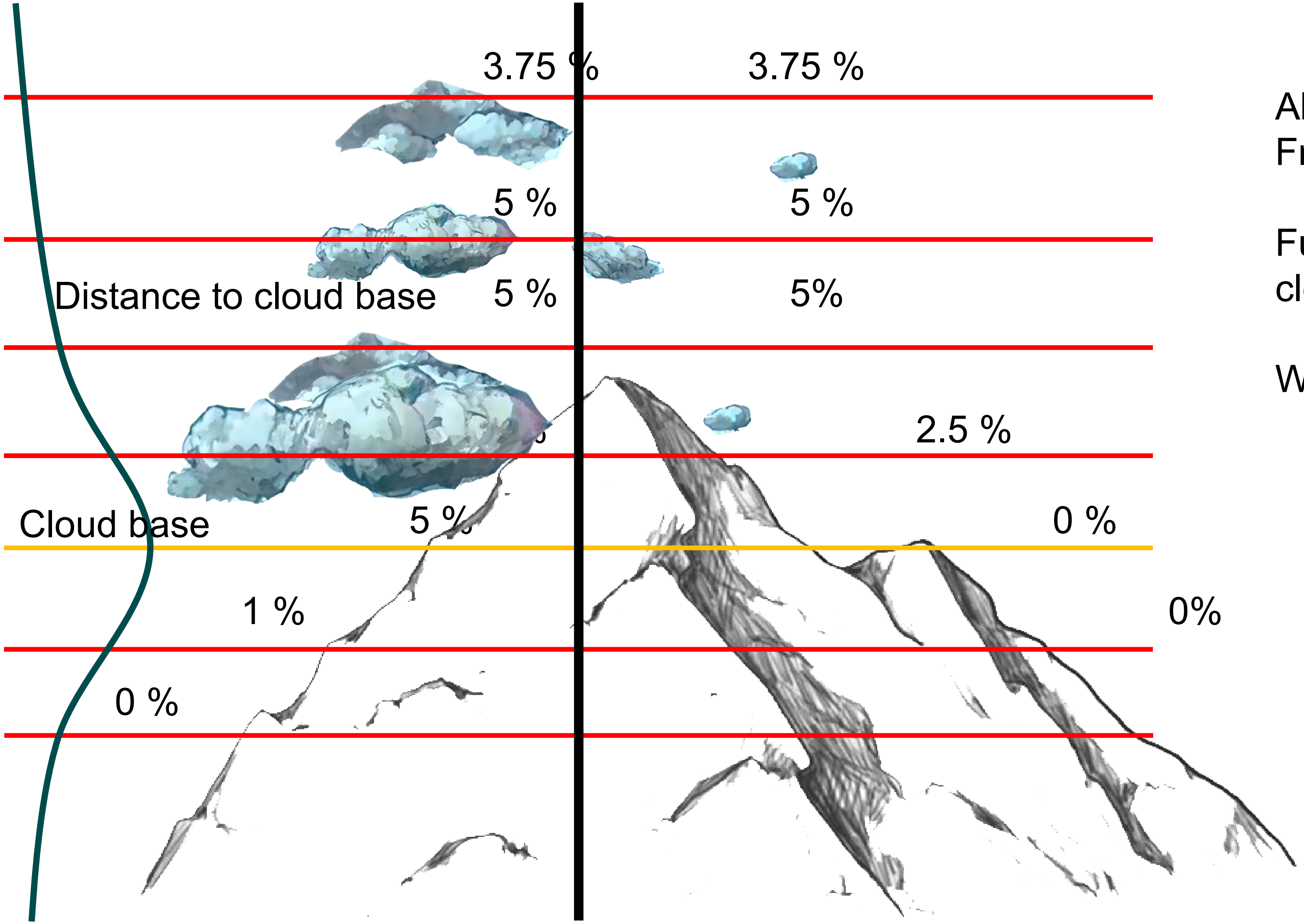


Algorithm to downscale cloud cover
From atmospheric cloud cover fractions

Function describing distance from cloud base

Windward leeward index

Karger, D.N., Lange, S., Hari, C., Reyer, C.O.P., Conrad, O., Zimmermann, N.E., Frieler, K. (2023) CHELSA-W5E5: Daily 1 km meteorological forcing data for climate impact studies. ***Earth System Science Data***



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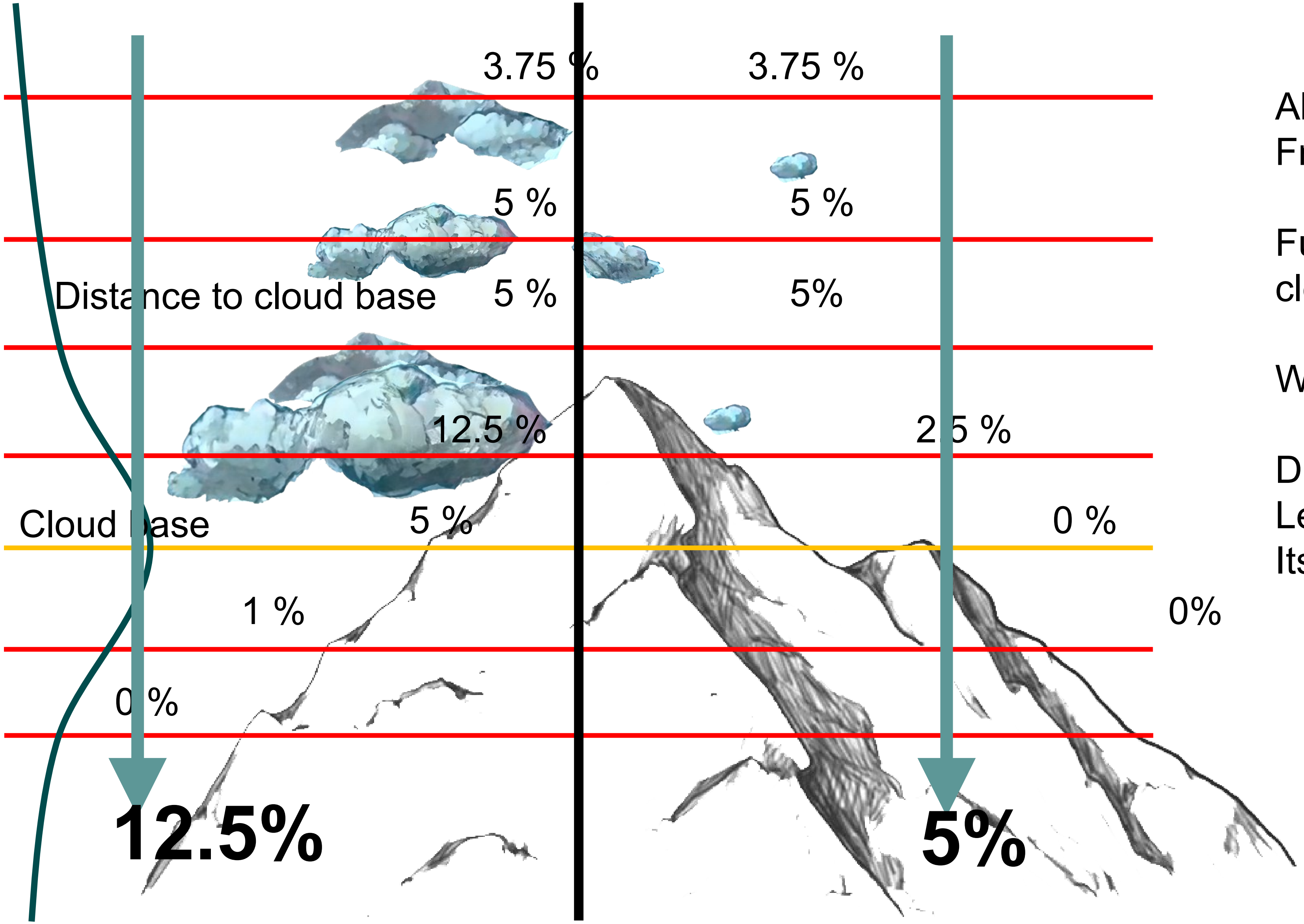


Algorithm to downscale cloud cover
From atmospheric cloud cover fractions

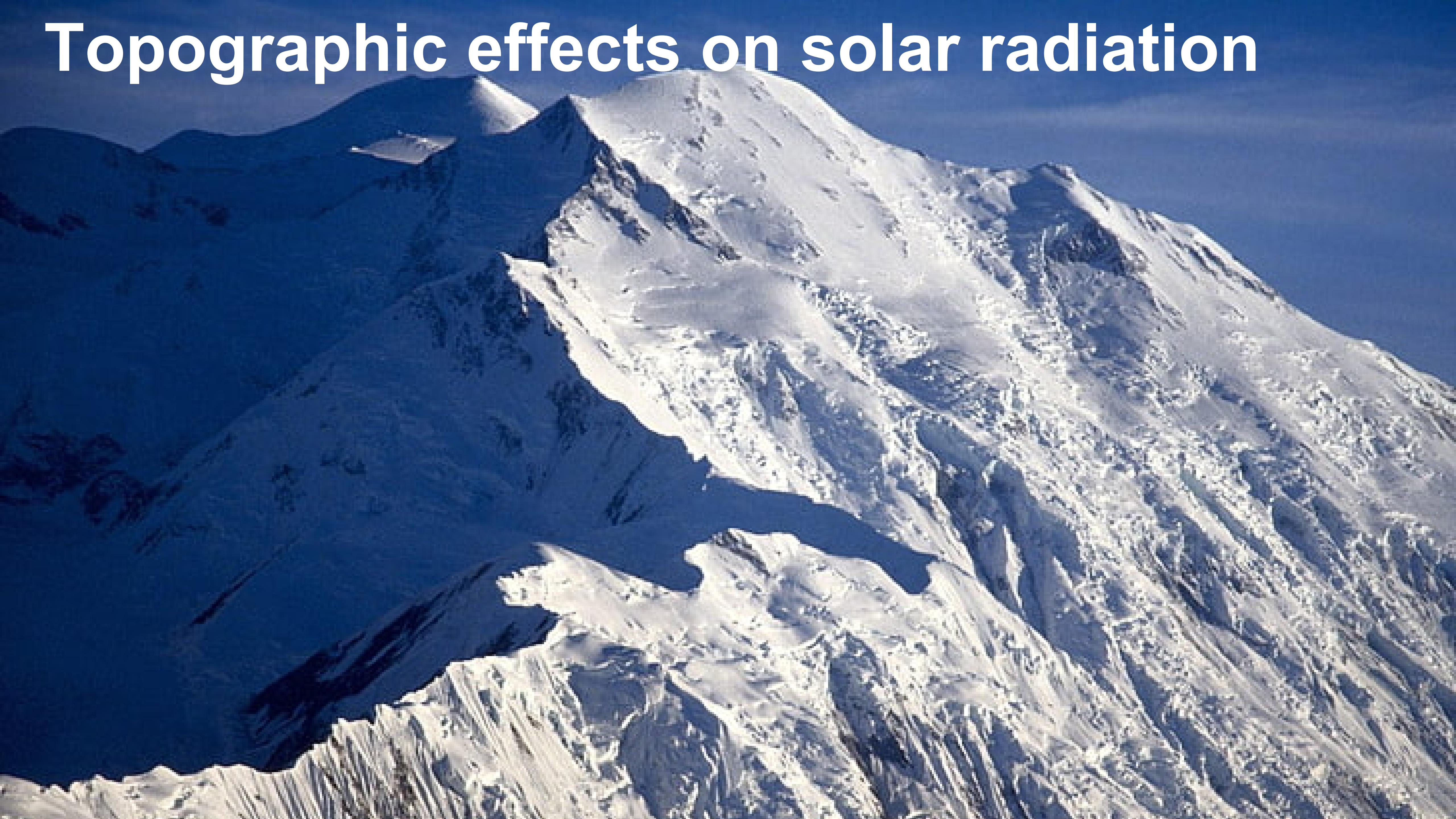
Function describing distance from cloud base

Windward leeward index

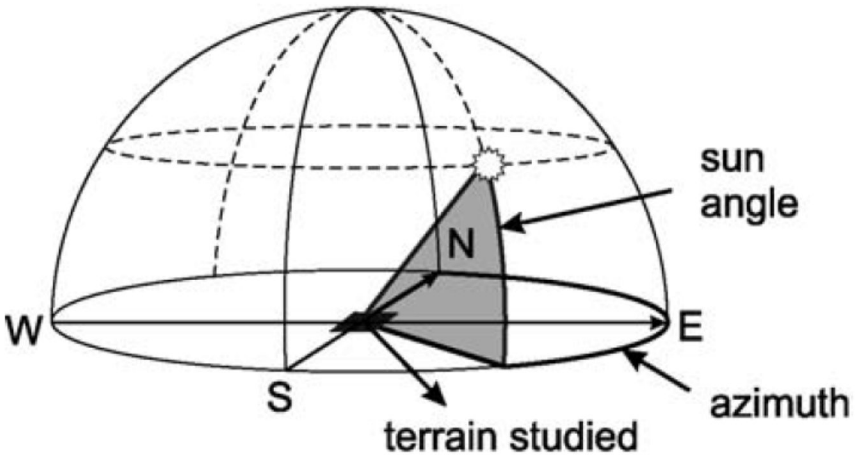
Distribute cloud cover based on windwar
Leeward position of a pressure level and
Its distance to cloud base height

Karger, D.N., Lange, S., Hari, C., Reyer, C.O.P., Conrad, O., Zimmermann, N.E., Frieler, K. (2023) CHELSA-W5E5: Daily 1 km meteorological forcing data for climate impact studies. ***Earth System Science Data***

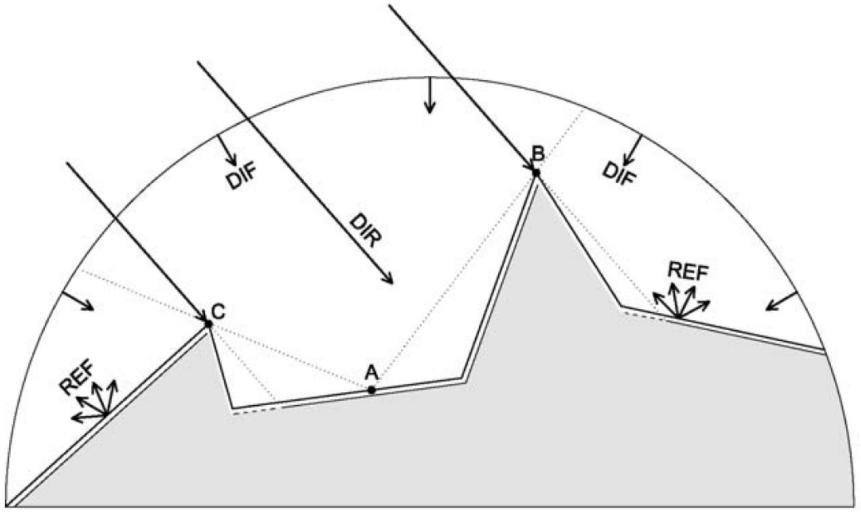
Topographic effects on solar radiation



Solar radiation based on terrain exposition and sun angle



Böhner, J., & Antonic, O. (2009). Land-Surface Parameters Specific to Topo-Climatology. In T. Hengl, & H. I. Reuter (Eds.), GEOMORPHOMETRY: CONCEPTS, SOFTWARE, APPLICATIONS (pp. 195-226). Elsevier Science., in: in T. Hengl, & H. I. Reuter (eds.) Geomorphometry: Concepts, Software, Applications, Elsevier Science, 195–226, 2009.



- Clear sky conditions
- Direct and diffuse radiation

Karger, D.N., Lange, S., Hari, C., Reyer, C.O.P., Conrad, O., Zimmermann, N.E., Frieler, K. (2023) CHELSA-W5E5: Daily 1 km meteorological forcing data for climate impact studies. ***Earth System Science Data***

Solar radiation based on Terrain exposition and sun angle

First approximation

Combine with cloud cover
To get total incoming
solar radiation at surface

$R = R_0(1 - 0.75n^{3.4})$

where:

R= solar radiation

n= cloud cover (0.0 - 1.0)

and

$R_0 = 990 \sin\phi - 30$

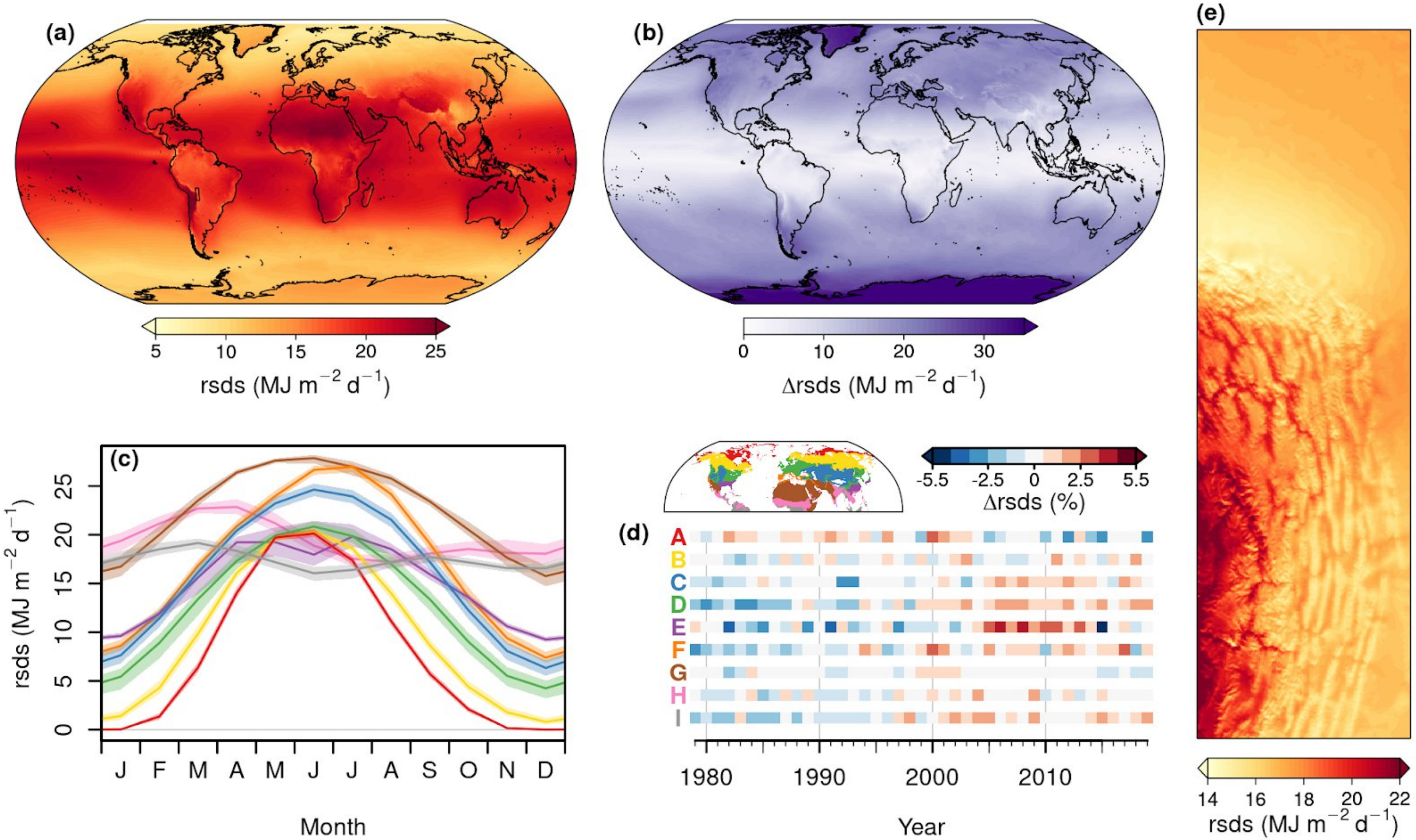
where:

$\phi = \frac{\phi_{tp} + \phi_p}{2}$

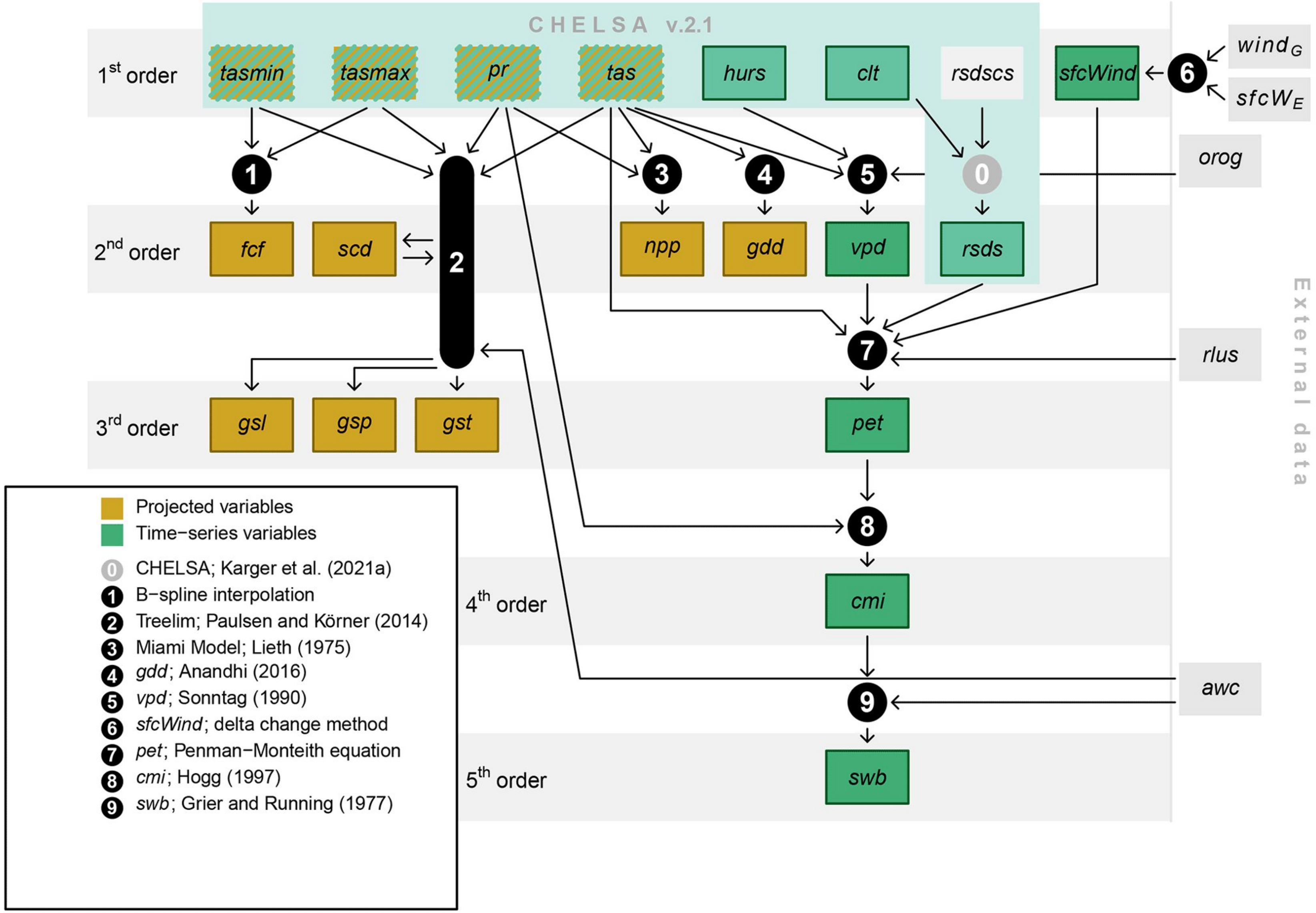
ϕ_{tp} = previous hour solar elevation angle

ϕ_p = current hour solar elevation angle

R_0 = clear sky insolation ($W \cdot m^2$)



Brun, P., Zimmermann, N.E., Hari, C., Pellisier, L., Karger, D.N. (2022) Global climate-related predictors at kilometer resolution for the past and future, Earth System Science Data 14, 5573–5603
https://doi.org/10.5194/essd-14-5573-2022



Philipp Brun

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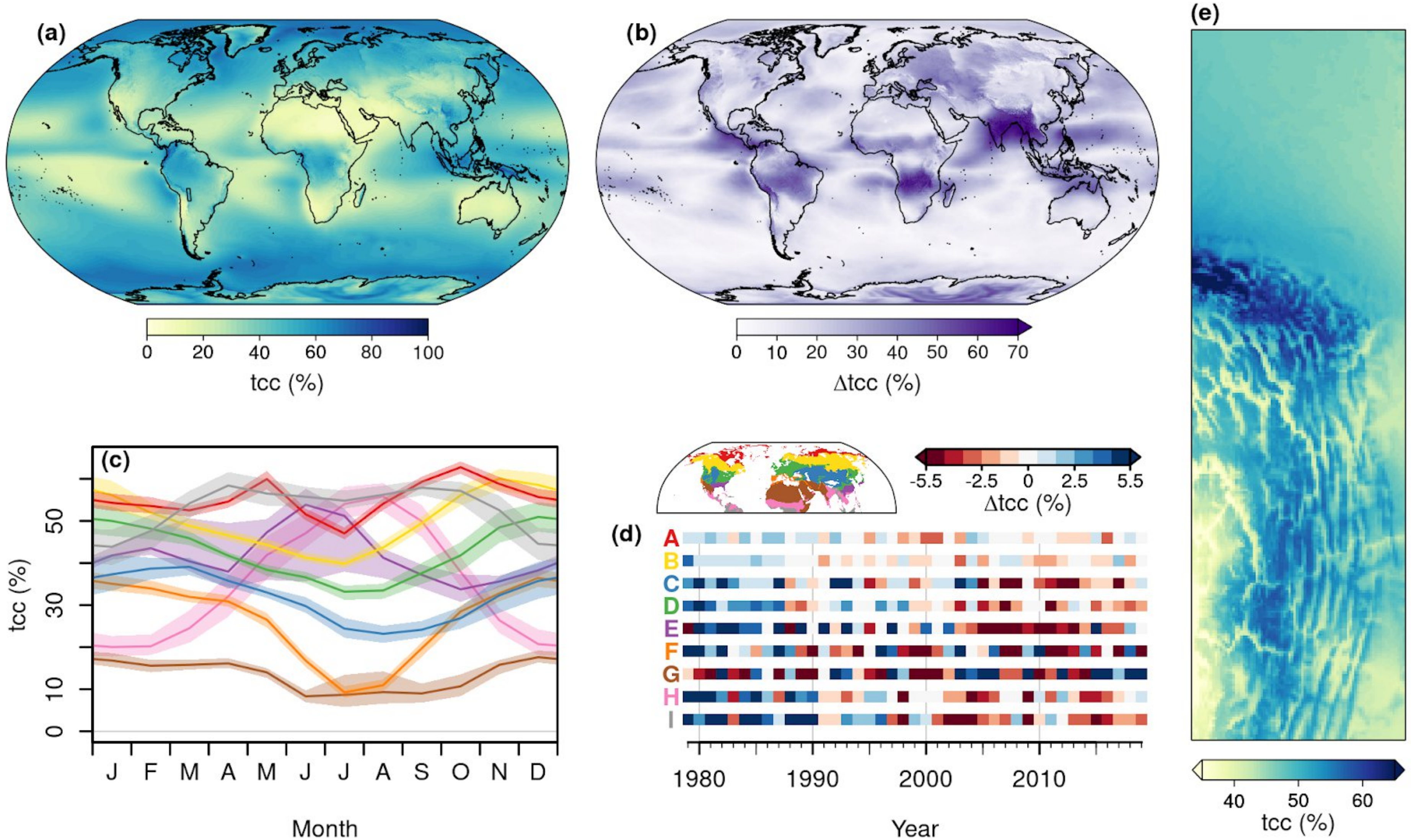
Cloud cover based on maximal overlap assumption



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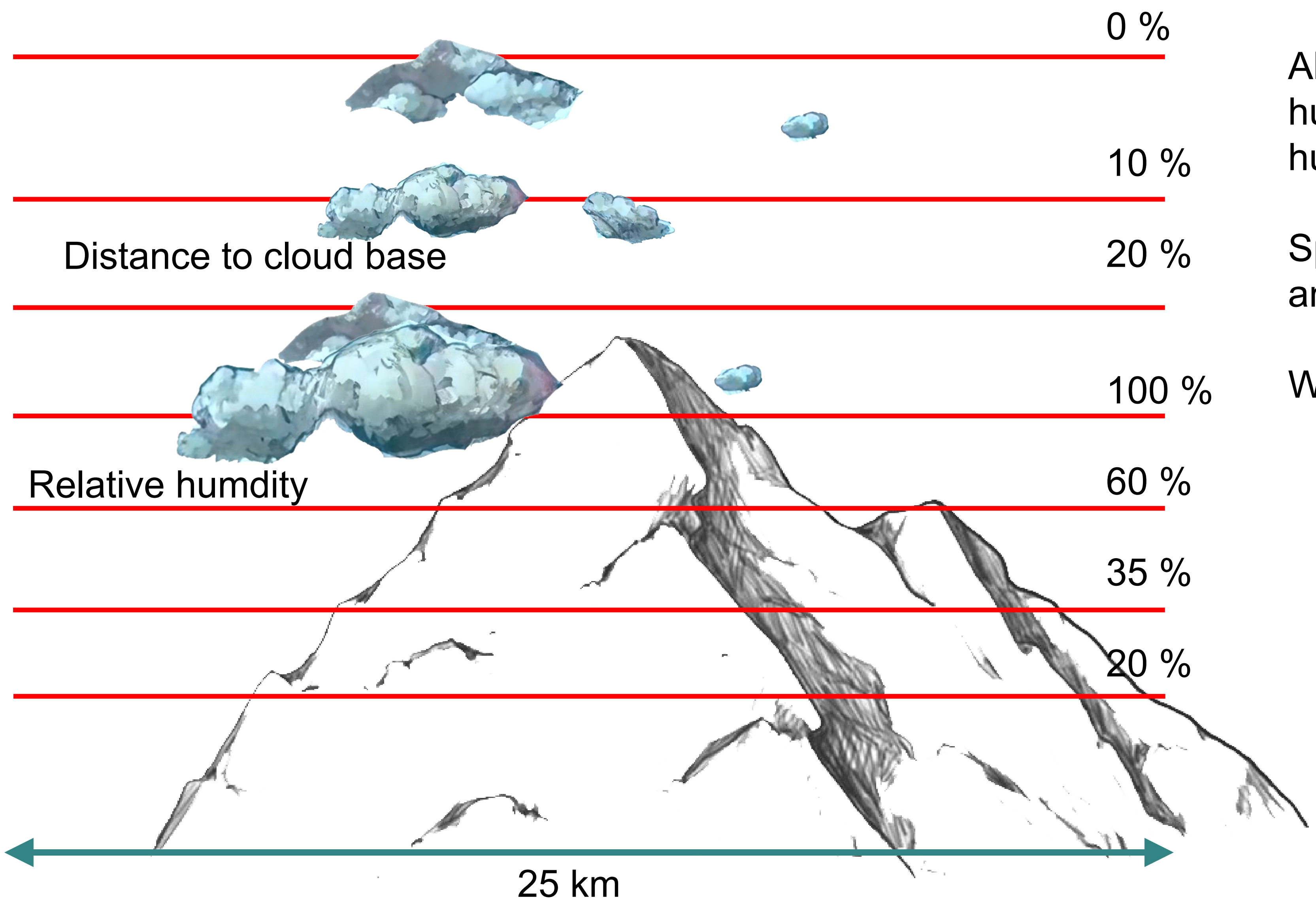
Problems with cloud cover

- No convection included
- Still huge biases in the forcing data (e.g. ERA5) compared to observations -> maybe a bias correction of the ERA5 data is needed



Algorithm to downscale relative humity (*hurs*) from atmospheric humidity (*hur*) on pressure levels

Spline interpolation between *hur* and altitude

Windward leeward index

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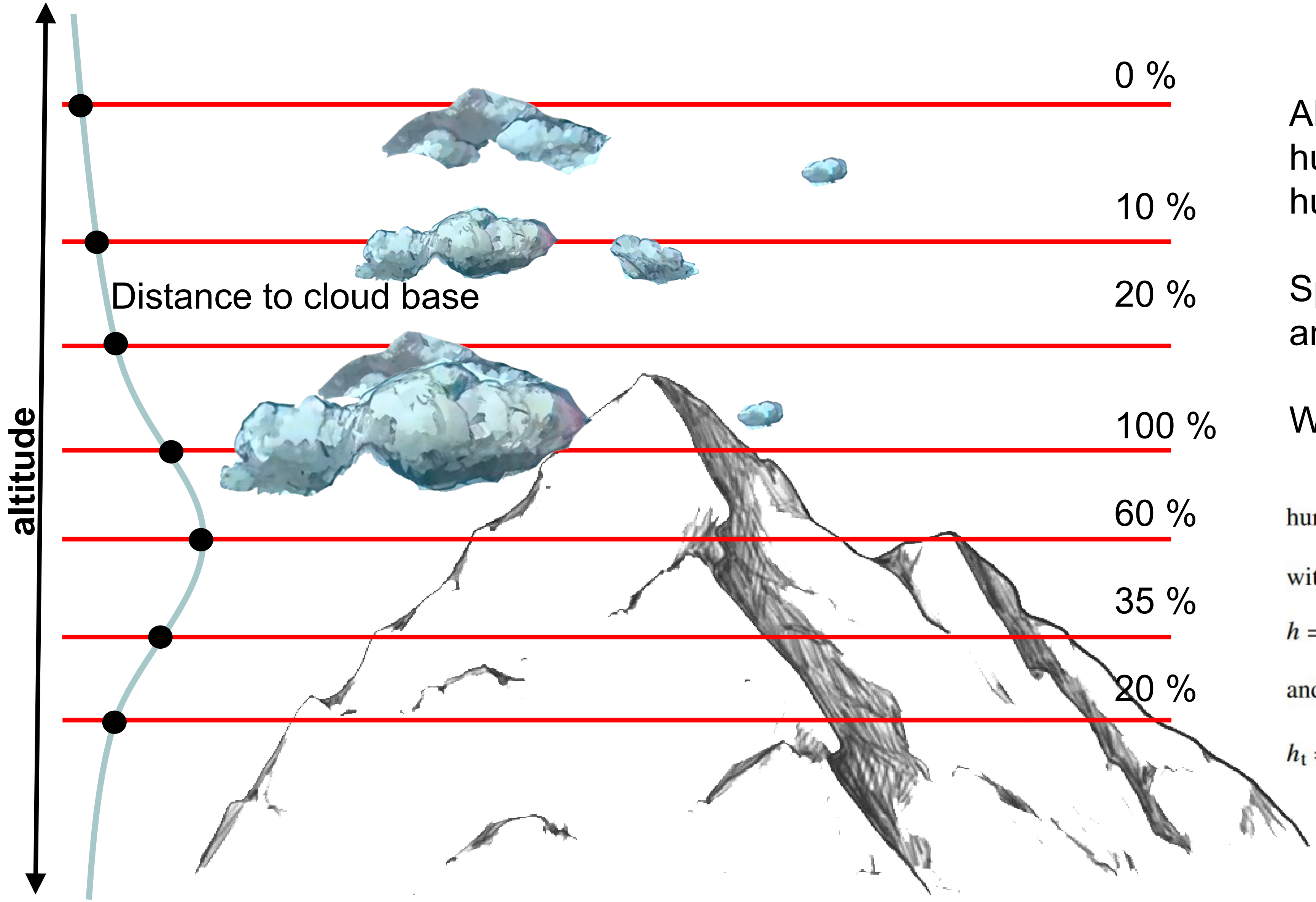

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Spline interpolation between *hur* and altitude

Windward leeward index

$$\text{hurs} = \frac{1}{(1 + \exp(-1 \cdot h))},$$

with

$$h = \frac{h_t \cdot (H + (H_c - H)(1 - H_c))}{H_c}$$

and h_t being the logit-transformed version of $\text{hurs}_{\text{orog}}$:

$$h_t = \log\left(\frac{\text{hurs}_{\text{orog}}}{1 - \text{hurs}_{\text{orog}}}\right),$$

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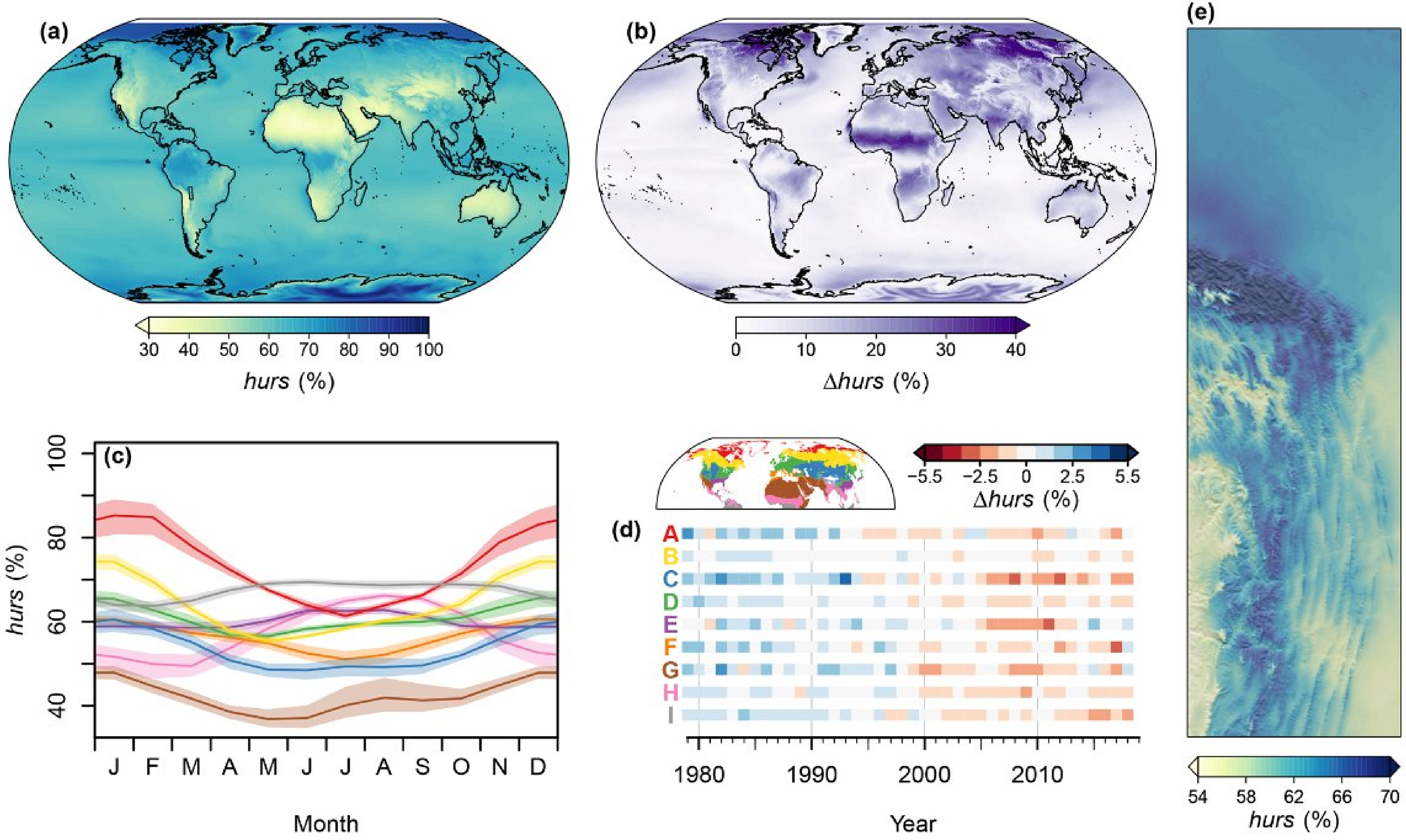

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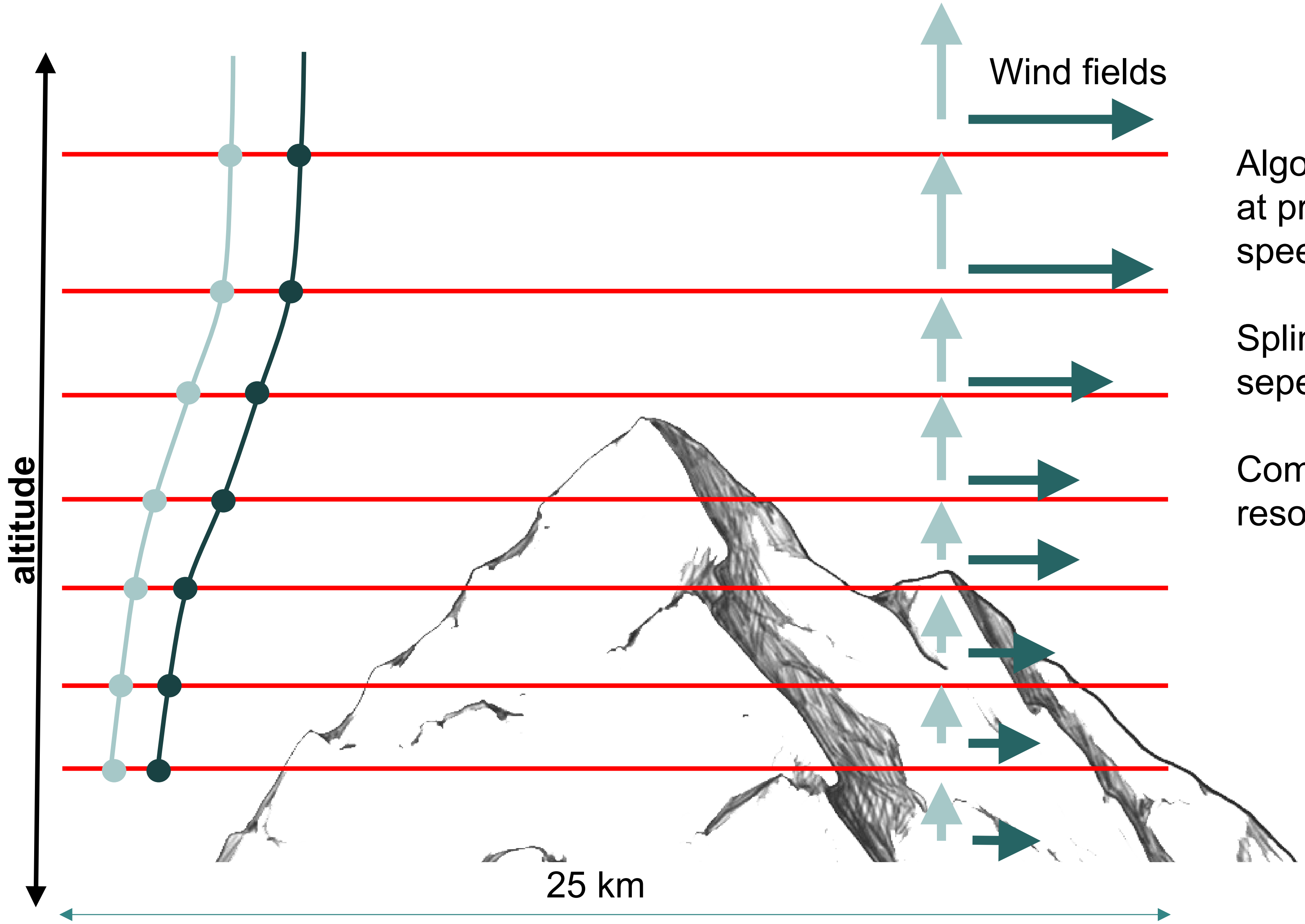
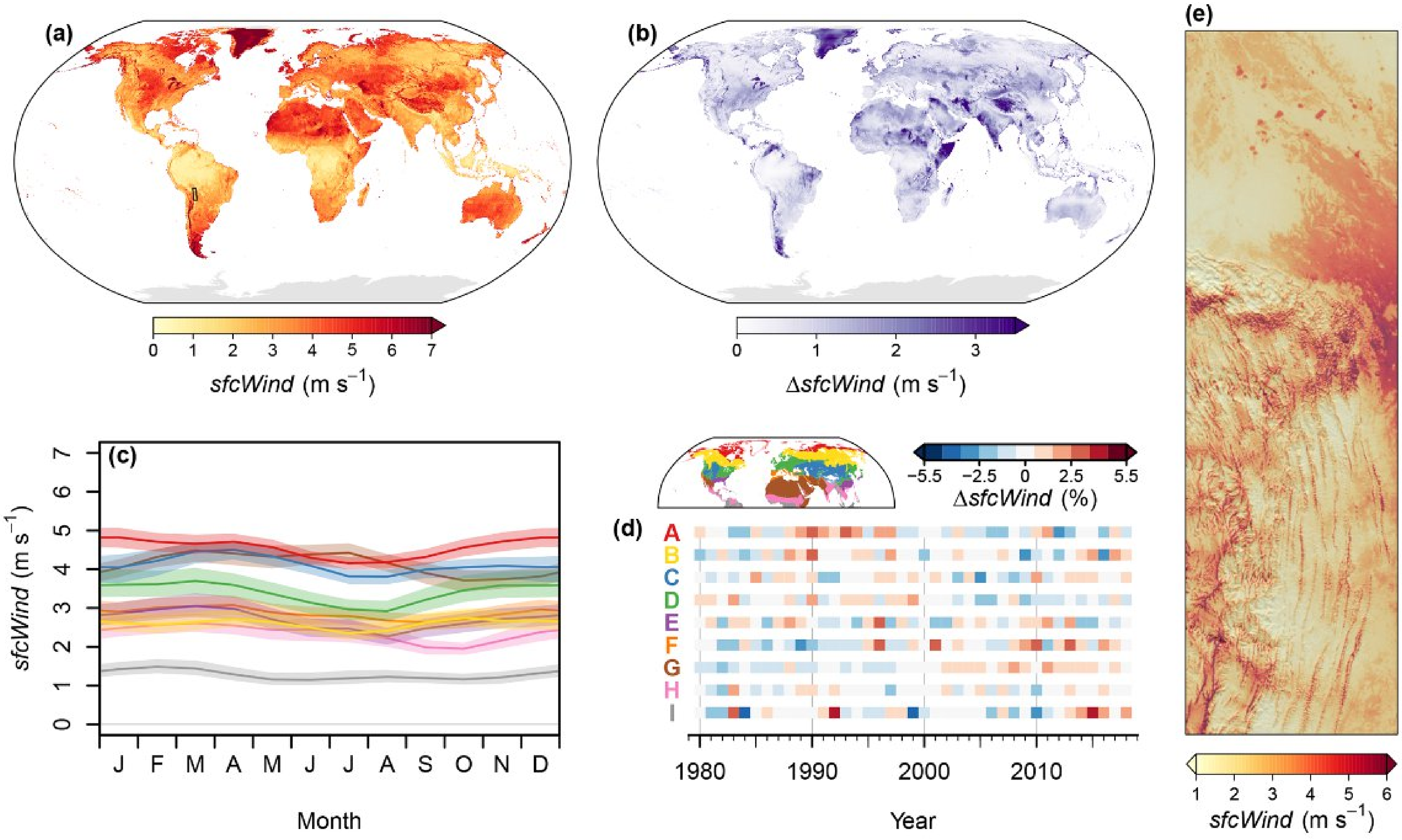


Algorithm to downscale wind speed at pressure levels to surface wind speed (*sfcWind*)

Spline interpolation between seperatly for wind components (*u*, *v*)

Combine wind vectors at high resolution to wind speed



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CHELSA – variables

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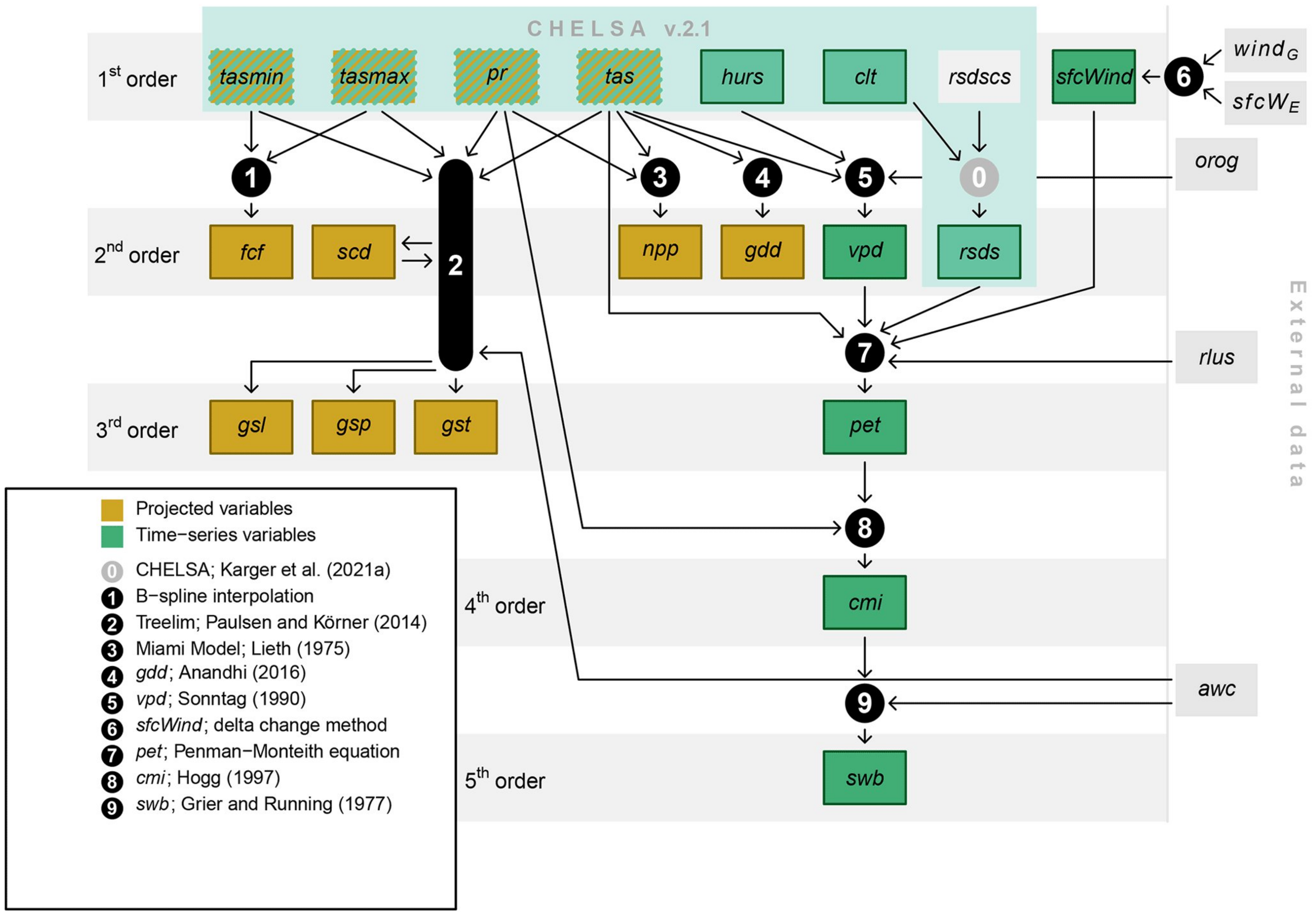
tasmax	daily-maximum near-surface (2 meter) air temperature	air temperature	surface	day
tasmin	daily-minimum near-surface (2 meter) air temperature	air temperature	surface	day
rsds	total downwelling shortwave solar radiation	surface downwelling shortwave flux in air	surface	day
rlds	total downwelling longwave solar radiation	surface downwelling longwave flux in air	surface	day
hurs	daily-mean near-surface (2 meter) relative humidity	relative humidity	surface	day
pr	daily precipitation flux (liquid and solid)	precipitation flux	surface	day
ps	daily mean near-surface (2 meter) air pressure	surface air pressure	surface	day
clt	surface total cloud area fraction	cloud area fraction	surface	day
tz	near surface temperature lapse rate	-	surface	day
sfcWind	daily-mean 10m wind speed	wind speed	surface	day



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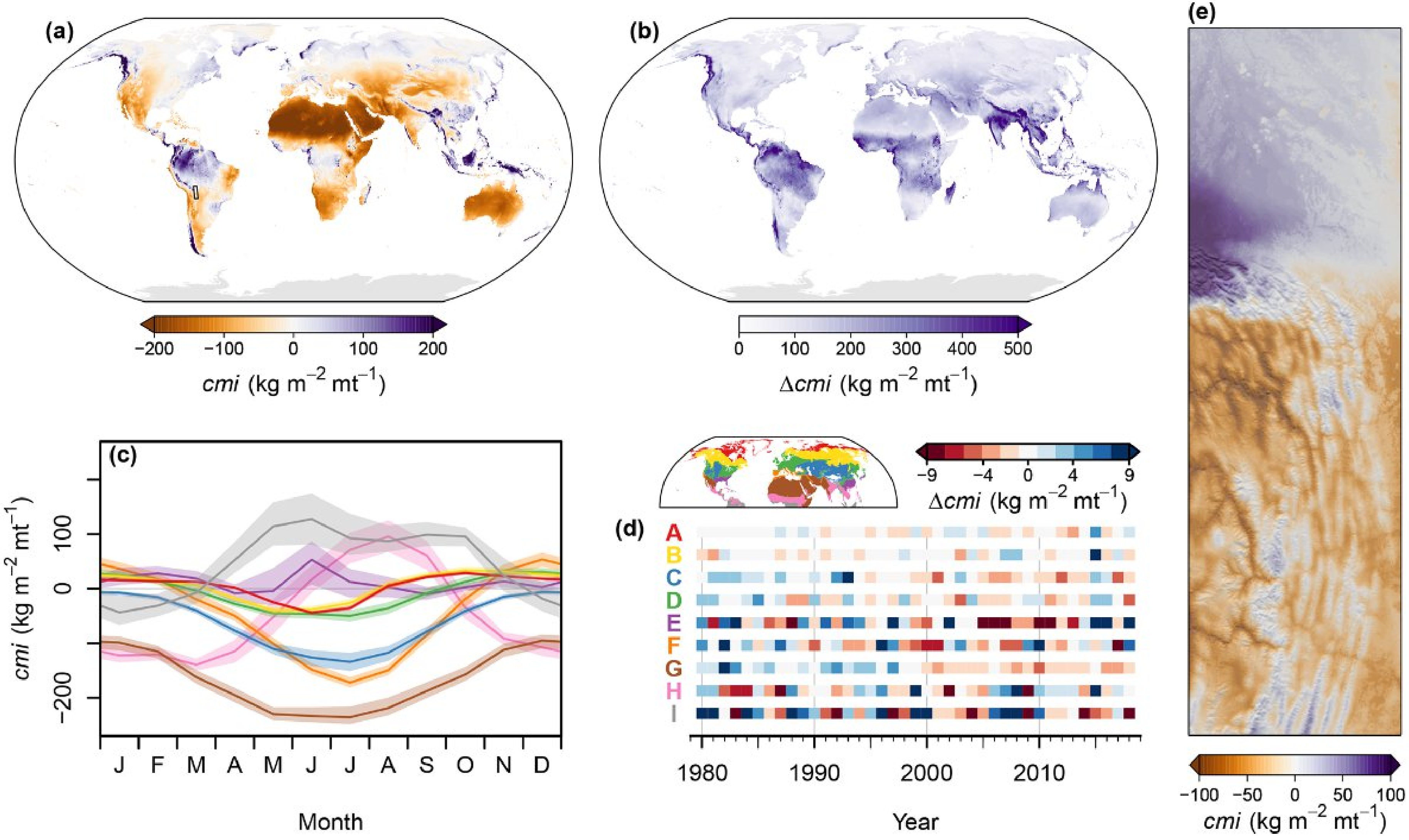

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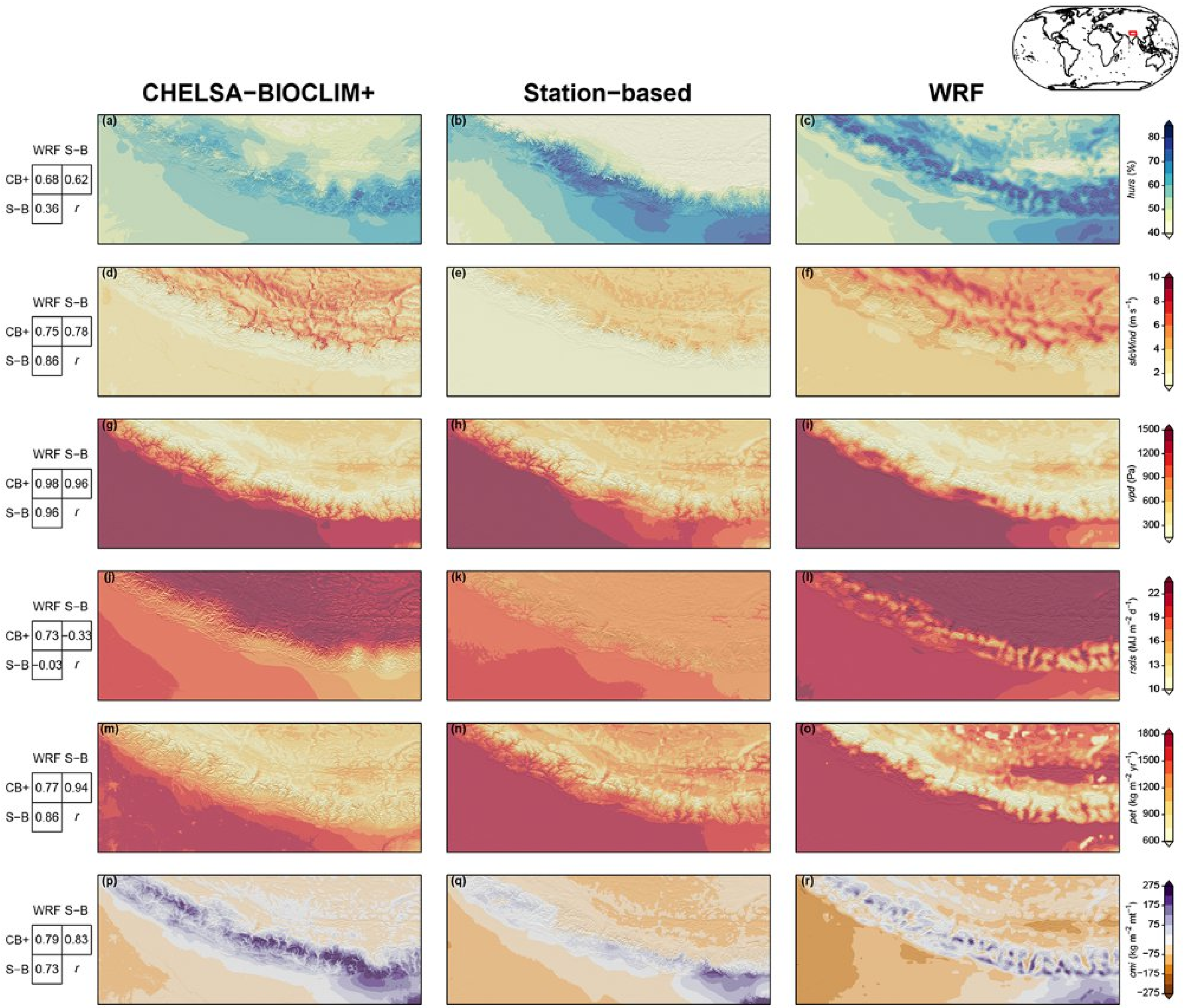

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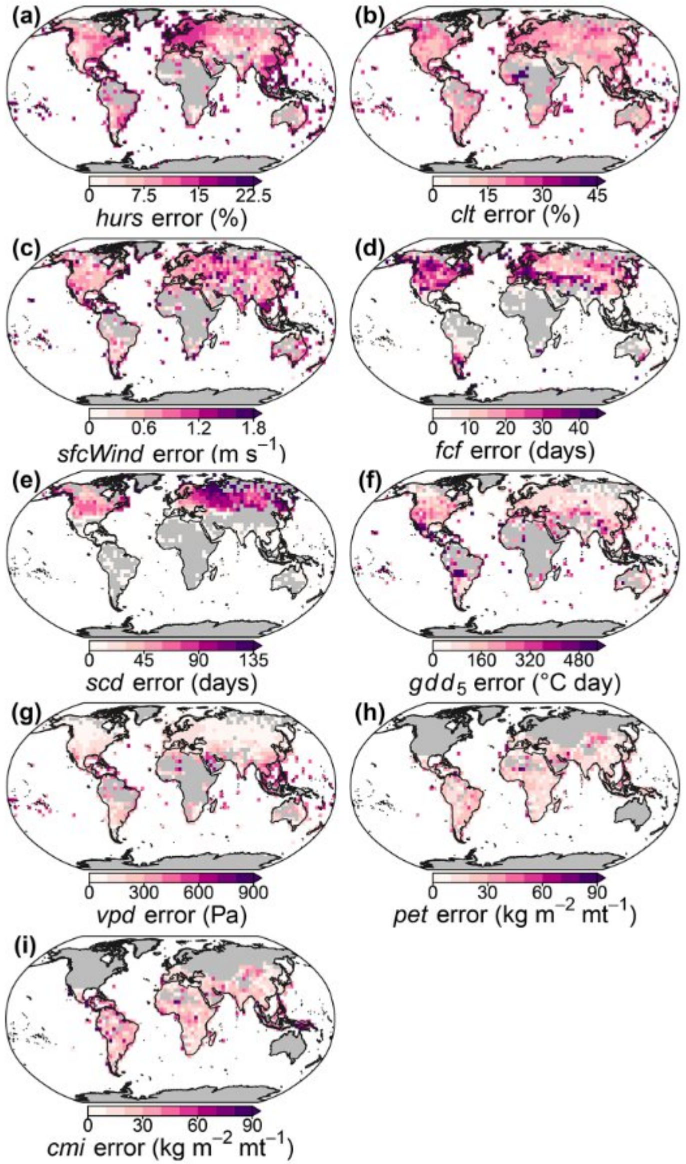

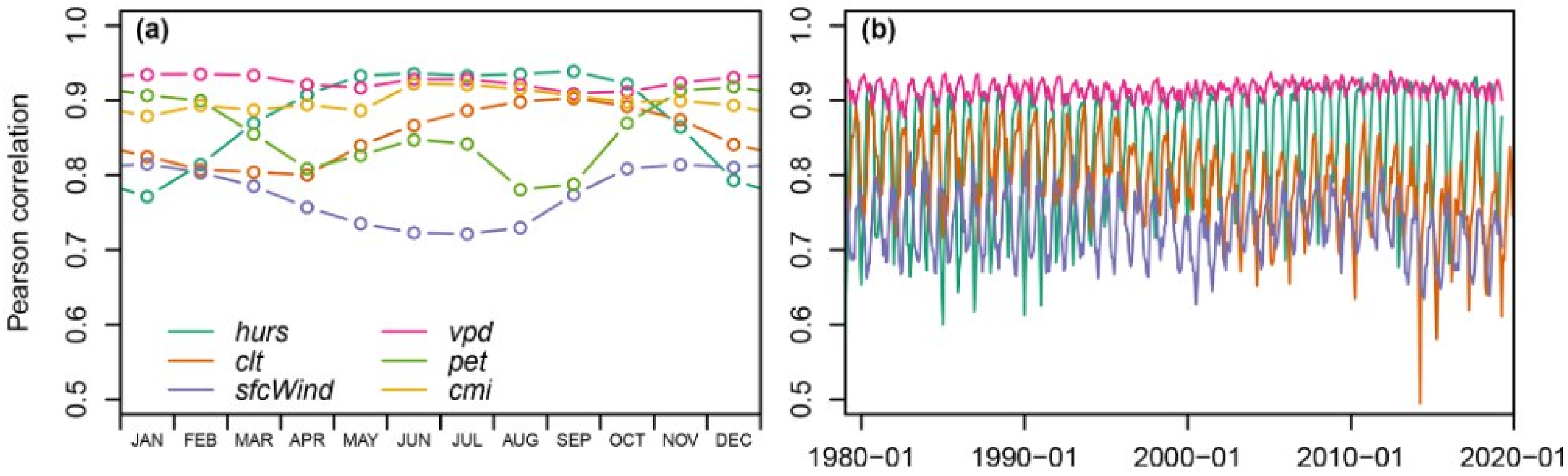

Correlations with observations high for:

vpd
pet
cmi

lower for:
clt
sfcWind
hurs

Good news: Low error propagation !

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Where are we going with this?

– Monthly versions are online

– Daily version is in production (delayed due to CDS server switch)

– R package to access data on gitlabext.wsl.ch (beta version)

– Aim is: to produce a comprehensive dataset for 1940-today

– No CMIP planned yet (storage and compute problems)

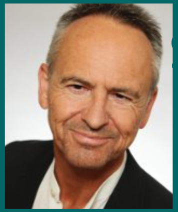
Acknowledgements



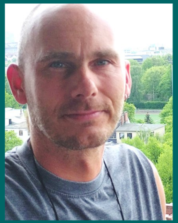












Funders & Partner institutions

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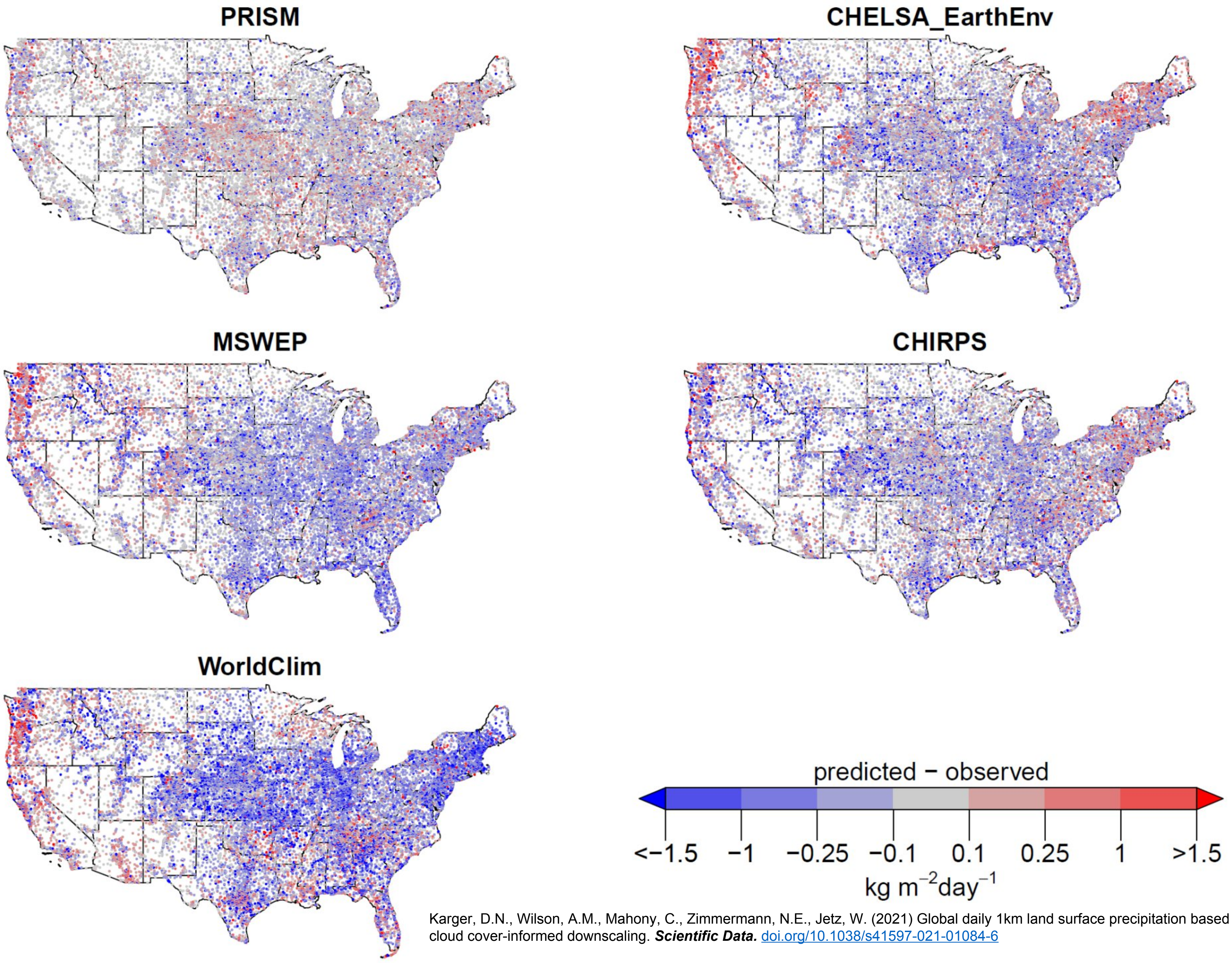
Thanks….

Bias compared to stations
In the continental United States over 2003-2016.

PRISM has lowest bias
- Only available in US
- Uses most of these stations

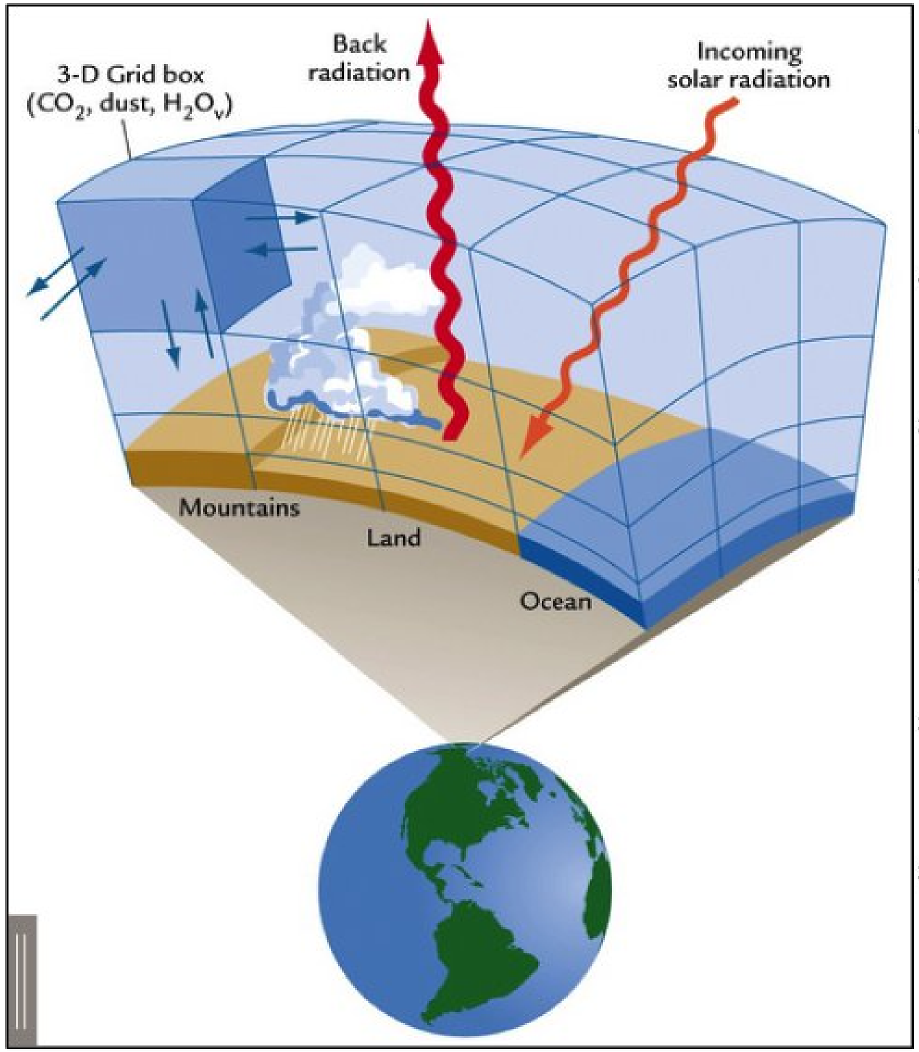
CHELSA, MSWEP, CHIRPS have moderate biases

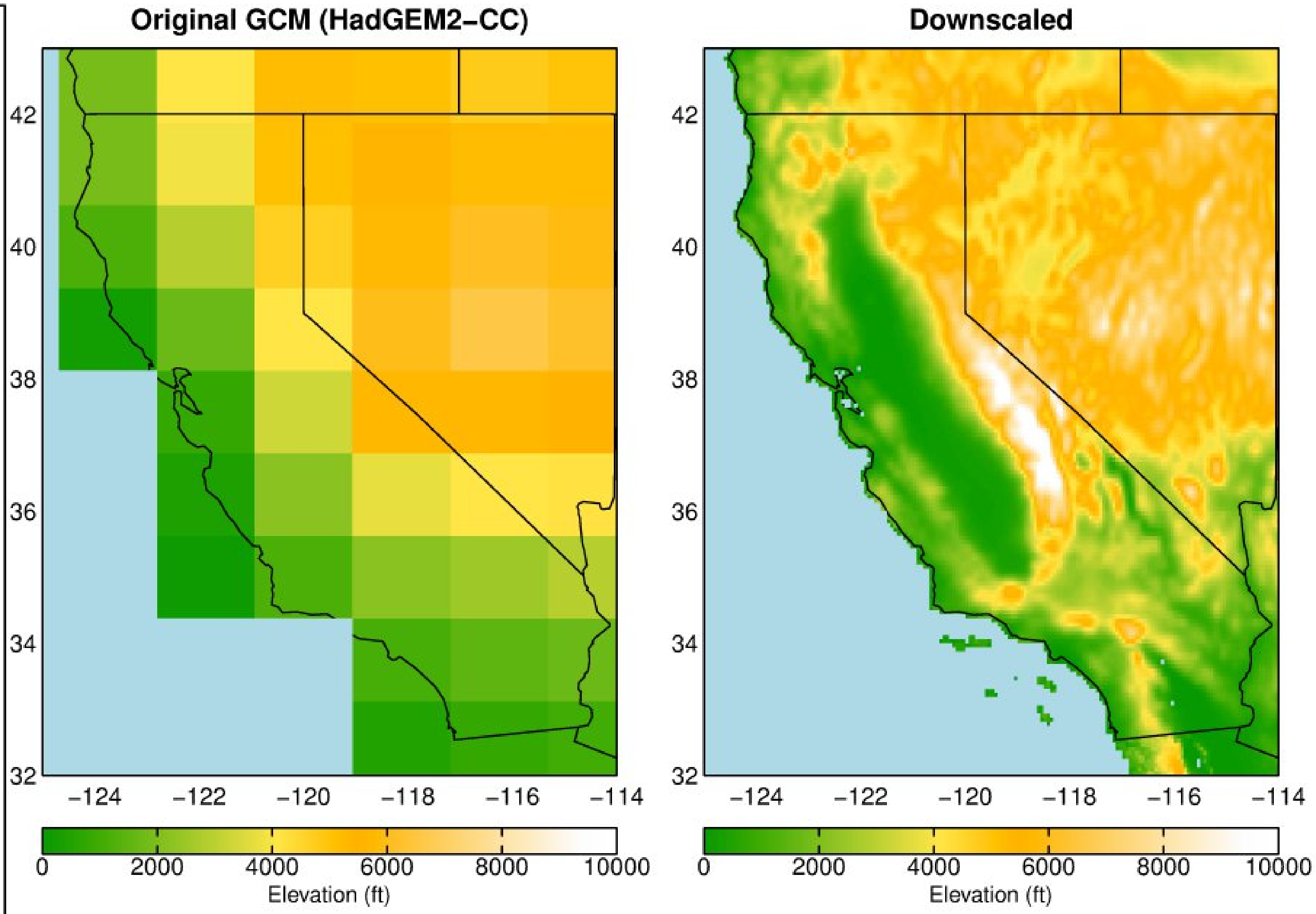
WorldClim has large bias
- Version using CRU TS stations used here



Karger, D.N., Wilson, A.M., Mahony, C., Zimmermann, N.E., Jetz, W. (2021) Global daily 1km land surface precipitation based on cloud cover-informed downscaling. ***Scientific Data.*** doi.org/10.1038/s41597-021-01084-6

Global climate model data is usually to coarse for most ecological applications





Only a few models (e.g. ICON) are currently able to run at kilometer scale globally

They are computationally extremly intensive

Run over short time periods only

Extremly large amount of data

Not available for years to come