Storylines of the 2018 Northern Hemisphere heat wave at pre-industrial and higher global warming levels

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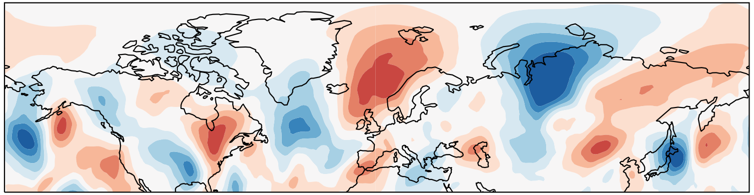

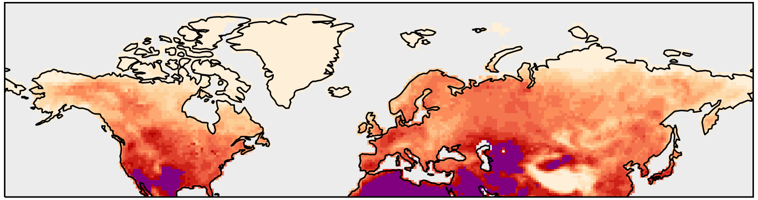

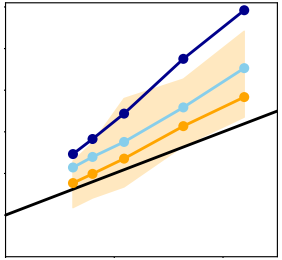

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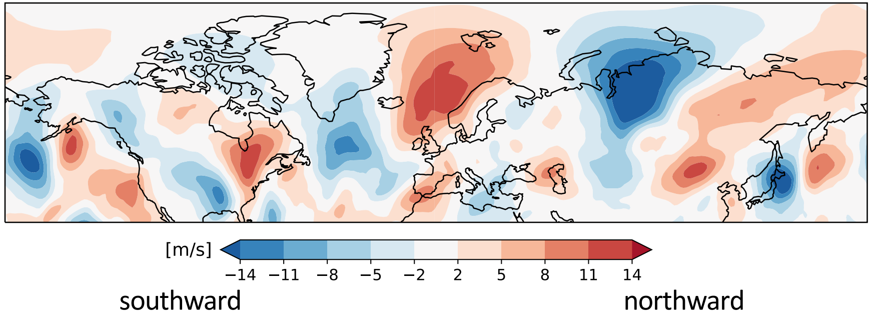
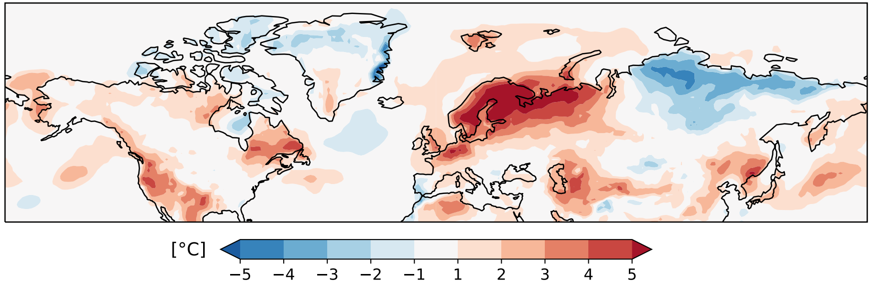
The 2018 Summer Heatwave – Event and Synoptic Situation

Meridional Wind Anomaly @ 250hPa July 13-27 2018



Near-Surface Temperature Anomaly July 13-27 2018



Rossby wavenumber 7 circulation pattern and a positive mode of NAO characterize the 2018 Northern Hemisphere summer heat wave (“NH2018 event”)

See Kornhuber et al., 2019, ERL and Kornhuber et al., 2019, Nat. Clim. Change for the role of stationary Rossby waves on summer heat waves.

See Drouard et al., 2019, GRL for the NAO during summer 2018.

Positive temperature anomalies below and downstream of upper-level positive meridional wind anomalies.

Concurrent heat waves occur on three continents. Most affected are western United States, eastern Canada, eastern Asia and large areas in Europe. The area of agriculturally used and highly populated areas (AgPop) experiencing simultaneous heat waves peaked at the end of July.

See Vogel et al., 2019, Earth’s Future for extent of agricultural and inhabited areas affected by the 2018 heat wave.

Research Question and Approach

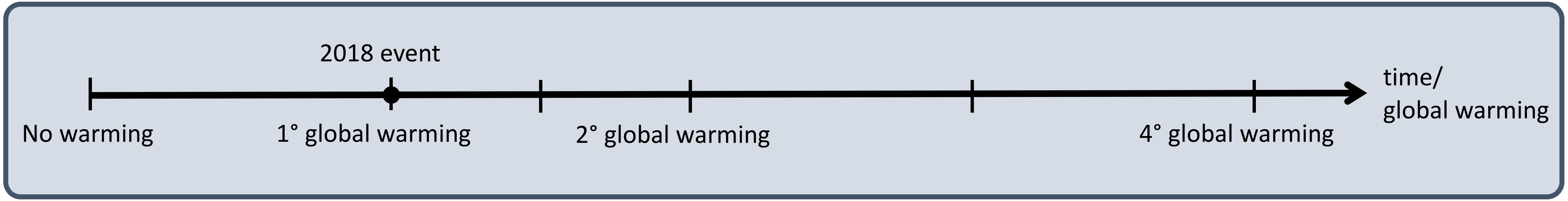
How much has global warming contributed to the 2018 Northern Hemisphere heat wave?

How severe are future equivalents of this event in a warmer climate?

➢ Storyline method

Take the atmospheric circulation leading to the event and quantify the impact of global warming conditional on that flow configuration.

While it cannot provide information on probability, the storyline approach allows to explore the consequences of a specific event in a future climate in order to improve understanding of the driving factors involved.



See Trenberth et al., 2015, Nat. Clim. Change, Shepherd et al., 2016, Curr. Clim. Change Rep. and Hazeleger et al., 2015, Nat. Clim. Change for literature on the storyline method.

Method

Storylines: Here the storyline approach is applied to a multi-week heat wave by nudging the horizontal atmospheric circulation in CESM to reanalysis.

Four warming scenarios and one natural scenario are considered. The warming scenarios are designed to match 1.5°C, 2°C, 3°C and 4°C global warming levels from CMIP5. The natural scenario follows 1860-1881 conditions.

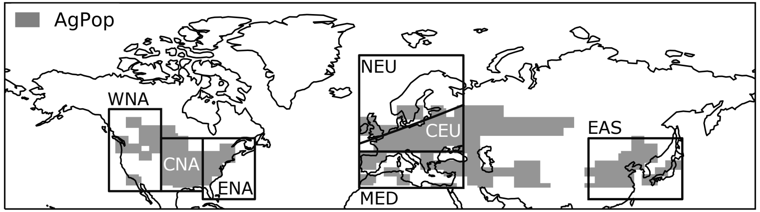
Ocean: Delta SSTs are computed from CMIP5 and added to the observed SSTs to create the SSTs prescribed in the warming and natural scenarios.

Sea ice fields are derived using a relationship between sea ice fraction anomalies and SST anomalies.

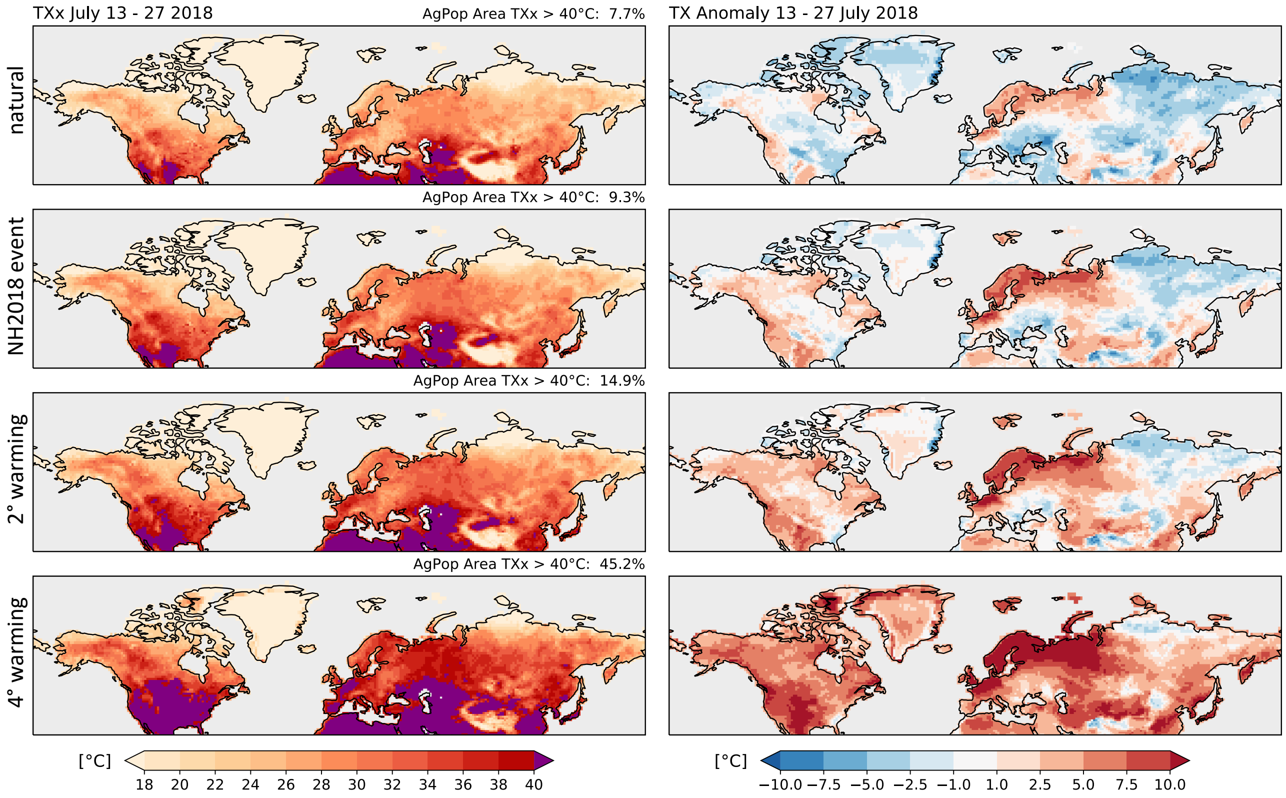
Bias correction: Absolute daily maximum temperatures (TX) are bias-corrected using quantile-mapping.

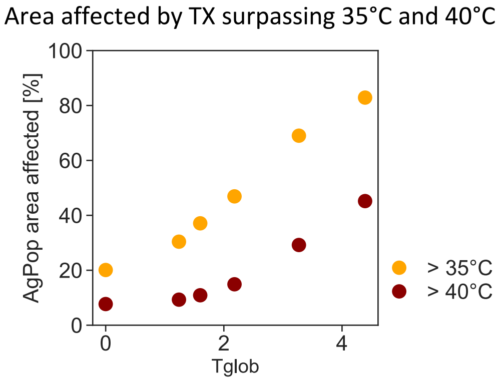
Study period and region: The analysis focuses on a 15-day period in the second half of July.

Considered are seven SREX regions (black outlines) and a region north of 30°N that is especially vulnerable to extreme conditions because it is either densely populated and/or an important area for agriculture (AgPop).



Impact on temperature



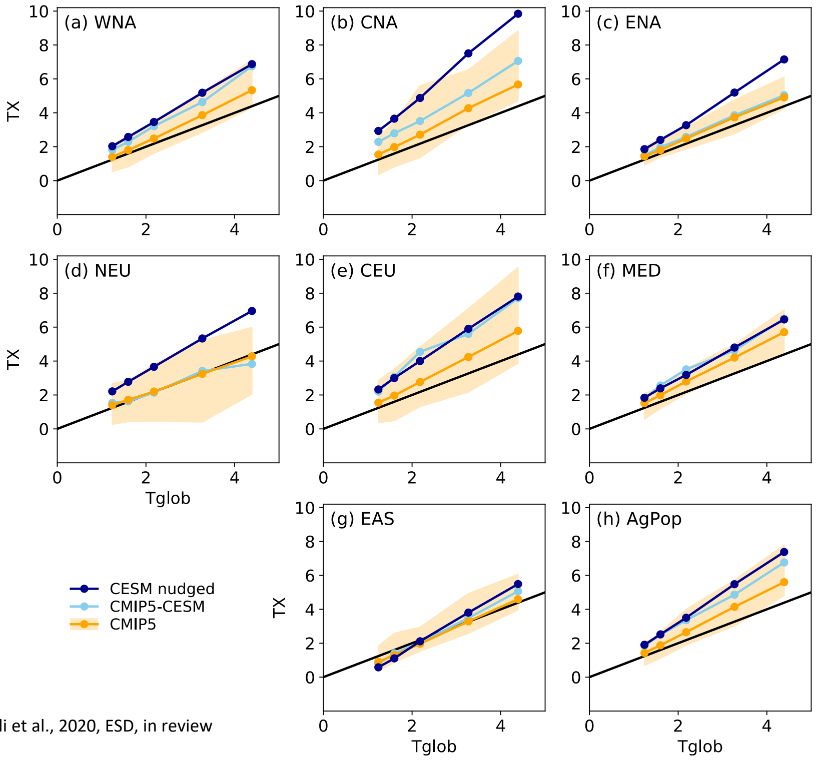


The fraction of densely populated and agriculturally used areas experiencing maximum daytime temperatures > 40°C increases dramatically at higher global warming levels

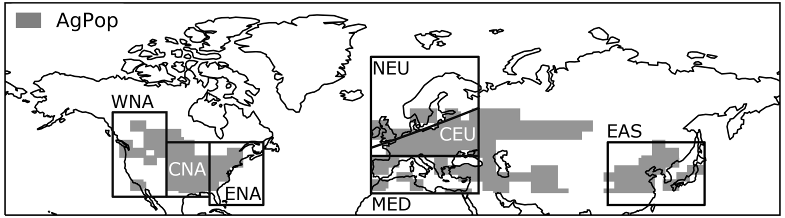
TXx values are bias corrected with respect to Berkeley-Earth using quantile mapping

Wehrli et al., 2020, ESD, in review

Scaling with global warming



Wehrli et al., 2020, ESD, in review



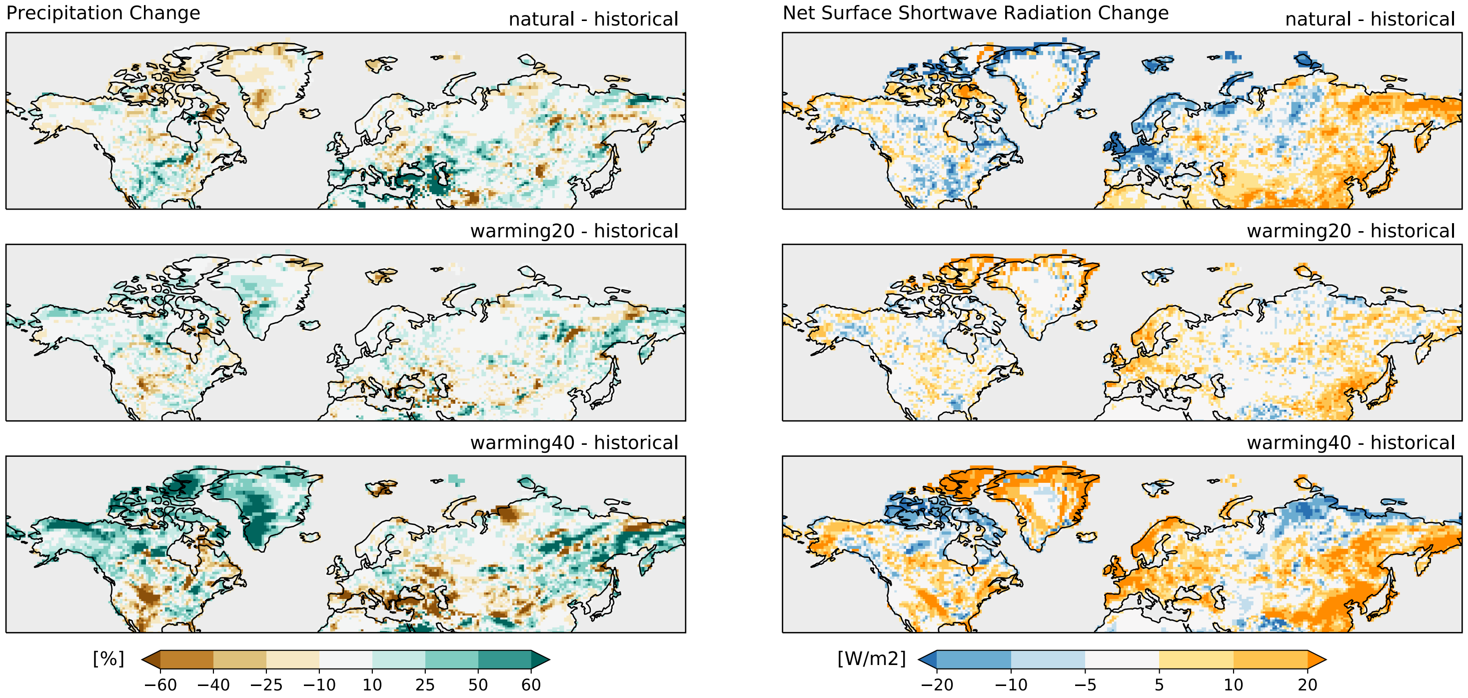
Where CESM nudged and CMIP5-CESM lie close, there is no change in the relationship induced by the atmospheric circulation of 2018. Hence, the increase in TX is driven by the background global warming (MED, CEU, WNA).

There is an effect of the circulation pattern in regions where CESM nudged and CMIP5-CESM diverge (CNA, ENA, NEU, EAS, AgPop).

The increase in July TX with global mean warming between 1°C and 4°C follows a linear relationship

Shown are anomalies of July TX against global mean temperature for the CESM simulations with circulation forced to the NH2018 event (dark blue line). The CMIP5 multi-model-mean TX corresponding to the same warming level is shown by the orange line. The shading shows the range of CMIP5 models. CESM from the CMIP5 ensemble is highlighted in light blue.
Note that CMIP5-CESM and CMIP5 have random atmospheric circulation!

Changes in precipitation and shortwave radiation

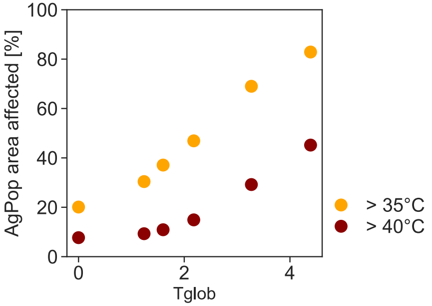


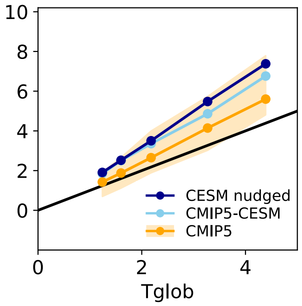
Wehrli et al., 2020, ESD, in review

Decrease in precipitation and cloud cover (resulting in higher net surface shortwave radiation) may exacerbate a NH2018-like event in the future

The 2018 heat wave was strongly amplified by global warming

Potential similar events in the future will put an even larger fraction of populated area at risk





Earth System Dynamics Discussion Paper:
https://doi.org/10.5194/esd-2019-91

Credits: Sea ice reconstruction: Adapted from HAPPI (Half a degree additional warming, prognosis and projected impacts), made available by Eunice Lo.

SREX regions: IPCC Special Report on Extremes

Quantile-mapping: qmCH2018 tool, Rajczak et al., 2016, J. Clim.

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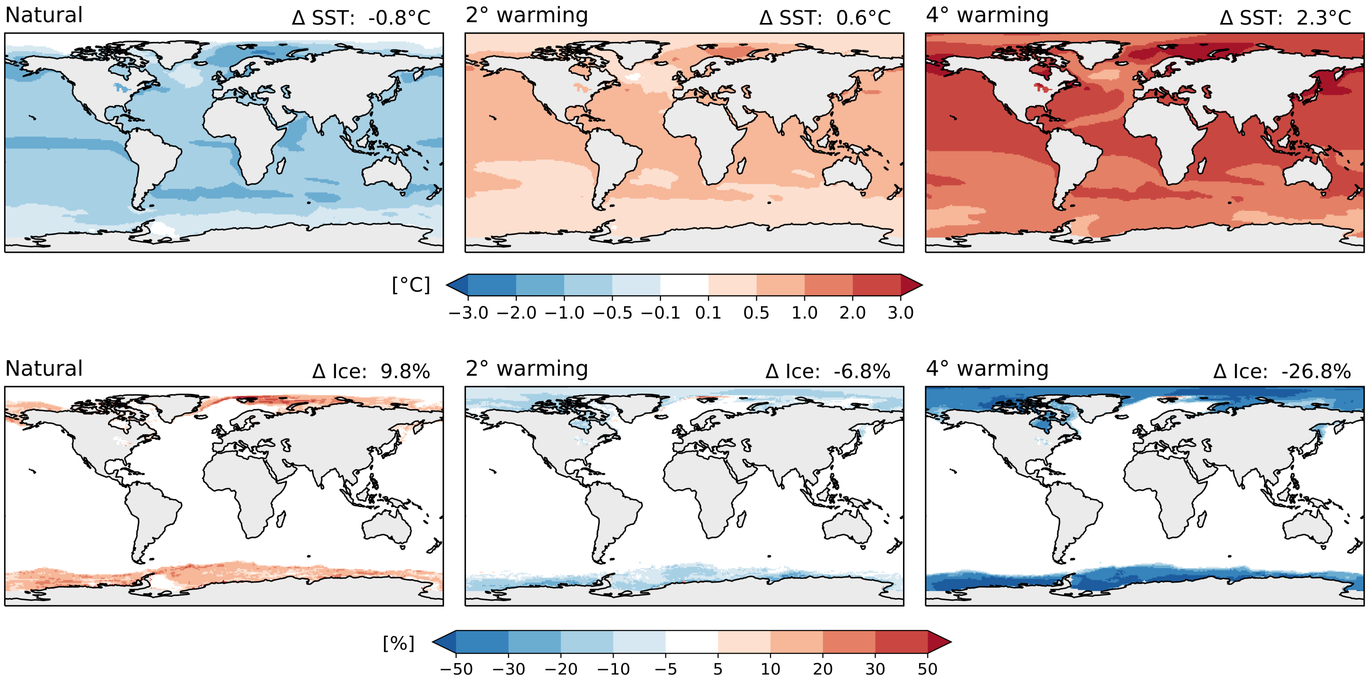
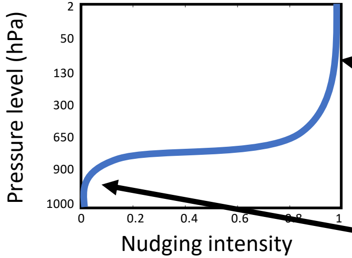
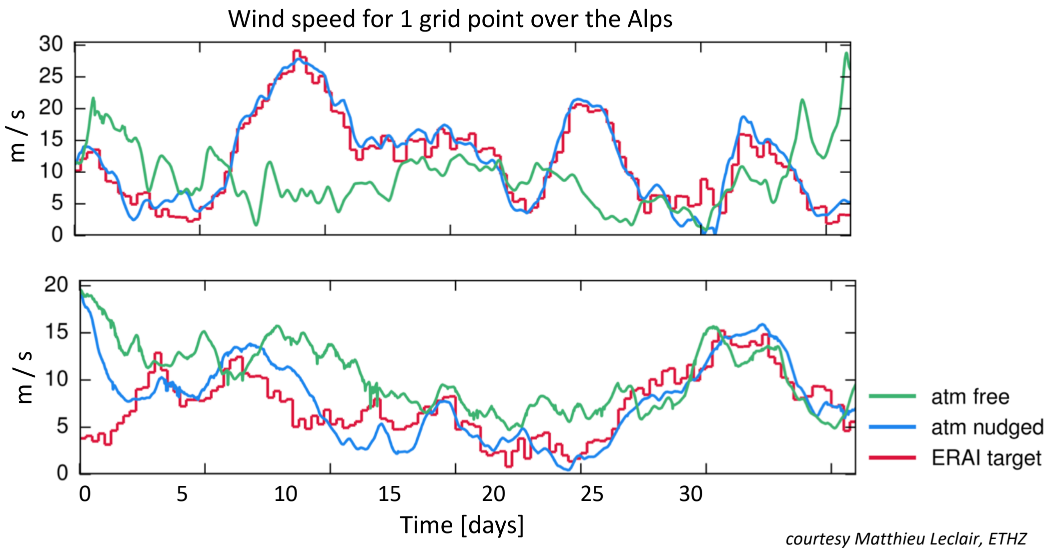
Additional Slides – deltaSST and deltaSEAICE

Change in SST and sea ice coverage for the natural/warming simulations compared to NH2018 conditions



Additional Slides – Nudging I





courtesy Matthieu Leclair, ETHZ

Tendency term in the prognostic equations:

$$-\frac{K(z)}{\tau}\left(U(x,t) - U_{target}(x,t)\right)$$

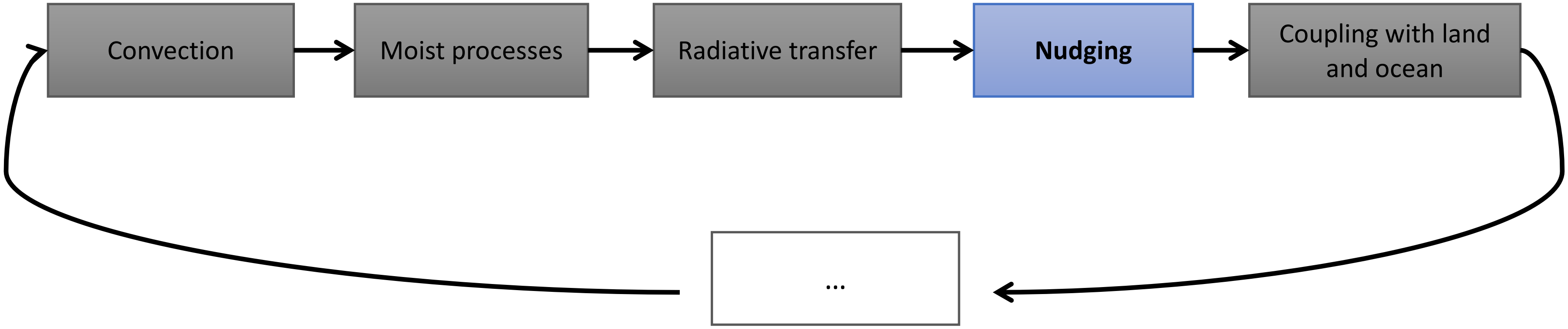
U	Model predicted value
U_{target}	Prescribed value
τ	Nudging time scale
$K(z)$	Nudging intensity profile

Nudging of horizontal winds using a height-dependent nudging function

The target are 6-hourly winds from ERA-Interim interpolated to the model grid

Additional Slides – Nudging II

- Introducing the nudging tendency in the model dynamics



$$\frac{\partial}{\partial t} U(x,t) = RHS(\dots, U(x,t), x, t) - \frac{K(z)}{\tau}\left(U(x,t) - U_{target}(x,t)\right)$$