The relevance of coupled climate model WRF-CTSM for land-atmosphere interactions analysis

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1. MOTIVATION

The uncertainty of:
- the water and energy budget at high latitudes in a changing climate
- the climate model representation of spatial variability in land-atmosphere fluxes

2. KEY OBJECTIVES

- **To provide a systematic evaluation of the performance of a recently developed WRF-CTSM coupled climate model** (Weather Research and Forecasting model, WRF, and Community Terrestrial Systems Model, CTSM) in simulating the interannual variability and spatial patterns of hydroclimatic variables in a high-latitude region
- **To investigate the added value of using the state-of-the-art WRF-CTSM Hillslope Hydrology model configuration** for the assessment of the combined effect of topography and hydrological fluxes in modulating the land surface conditions

3. MODEL SETUP

Selected WRF-specific options / schemes	
Initial and boundary conditions	ERA5
Radiation	RRTMG (4)
Planetary boundary layer (PBL)	MYNN2 (5)
Cumulus	GF (3)
Microphysics	WSM6 (6)
Spectral nudging	not applied at the PBL

The 2 model configurations

- Domain extent
- 10.5 km resolution

Default WRF-CTSM run
2010 – 2022
8 years long spin-up period (2002 – 2009)

WRF-CTSM Hillslope Hydrology run
2018
16 years long spin-up period (2002 – 2015 from the default WRF-CTSM run and 2016 – 2017 from the WRF-CTSM Hillslope Hydrology run

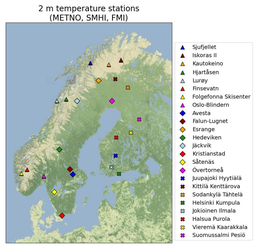
4. EVALUATION DATASETS

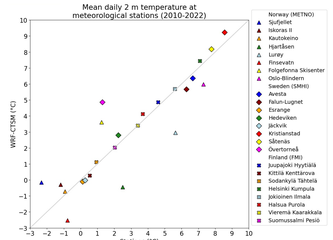
- The openly available **station-based datasets** from the Norwegian, Swedish and Finnish meteorological and hydrological institutes and **gridded observational datasets** on different spatial resolutions
- Daily aggregates (2010 – 2022)

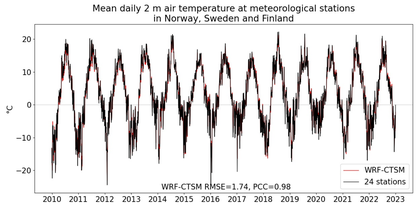
Overview of the observational datasets			
2 m air temperature	Meteorological stations (METNO, SMHI, FMI)	E-OBS (0.1°)	NGCD (1 km)
Soil moisture	Hydrological stations (NVE, FMI, GTK) Soil depth 10 cm	ESA CCI SM (0.25°) Soil depth layer approx. 0-5 cm	GLEAM (0.25°) Soil depth layer 0-10 cm
Snow depth	Meteorological stations (METNO, SMHI, FMI)		
Snow water equivalent	Hydrological stations (NVE, SMHI, SYKE)		

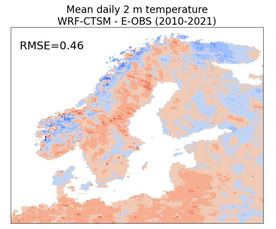
5. WRF-CTSM EVALUATION

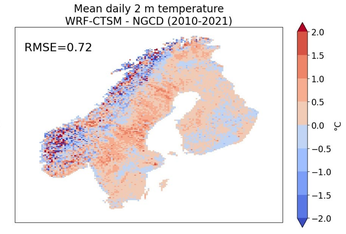
2 m air temperature



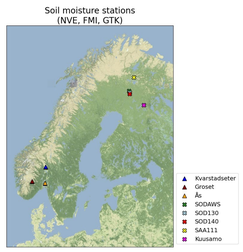


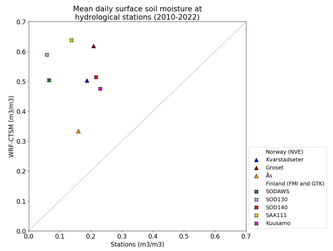


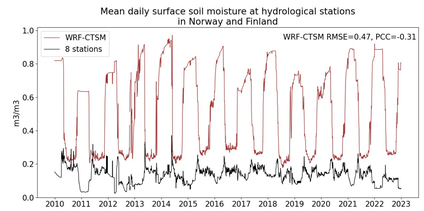


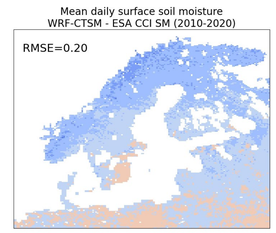


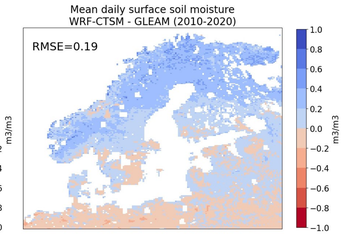
Soil moisture



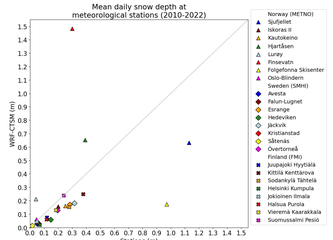


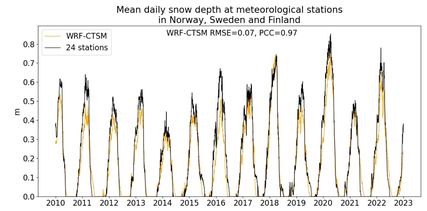




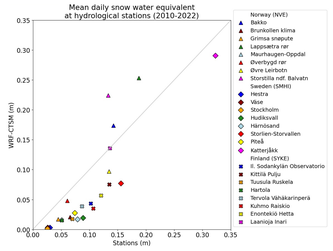


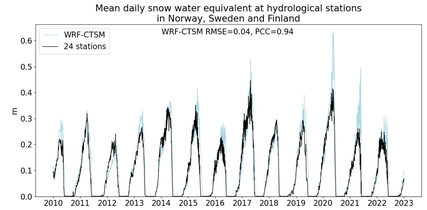
Snow depth





Snow water equivalent





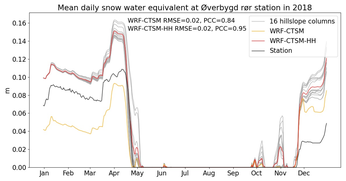
Discussion

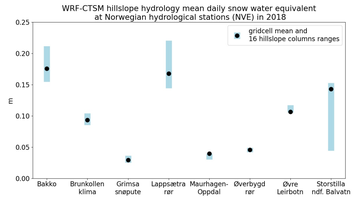
- Station-based 2 m temperature results indicate a good alignment with the observations across all 3 countries
- Regional-based comparisons illustrate some underestimation predominantly in the mountainous areas in the domain which is also visible in some Norwegian stations' results

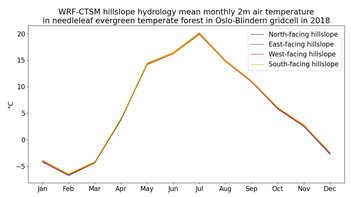
- A very sparse availability of the continuous soil moisture point measurements across the domain constraints the model evaluation
- Generally, there is an overestimation that may be partly attributed to the comparison of measurements at slightly different soil depths (model data used is on 10 cm soil depth)

- Seasonal cycle variability of the snow variables is well represented in the station-level comparisons, predominantly in the transition seasons of autumn and spring
- Mean daily model snow depth in winter is slightly underestimated while the snow water equivalent is slightly overestimated
- The difference in the sign of the bias in snow variables could be attributed to different snow densities across stations or to different elevations between the stations in the model and in the observations that can for the Norwegian stations be up to 527 m

6. WRF-CTSM HILLSLOPE HYDROLOGY CAPABILITIES







- WRF-CTSM Hillslope Hydrology includes lateral flow and differentiates between slopes and aspects on the subgrid-scale level
- Here, each gridcell contains 4 hillslopes (4 different aspects) that each consists of 4 columns (4 different elevations) → the setup includes **16 hillslope columns**
- Hillslope columns in a gridcell also exhibit different vegetation types, and water and energy budget
- This capability facilitates the analysis of the spatial variability in land-atmosphere fluxes primarily in the areas with heterogeneous topography

7. TAKE-HOME MESSAGES

- This study is the first to systematically evaluate WRF-CTSM and utilise it in the European context
- WRF-CTSM is a viable tool for land-atmosphere interactions analysis
- In general, it exhibits good alignment with the observations
- The key rationale for the differences between the observational and model results is the disparity between their elevations
- In this study, CTSM Hillslope Hydrology configuration was coupled with WRF for the first time
- WRF-CTSM Hillslope Hydrology enables analysis of the land surface conditions on the hillslope-scale level

Link to abstract:

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