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WRF-HMS: a fully-coupled regional atmospheric-hydrological modeling system for long-term scale applications

Sven Wagner[1,2] (sven.wagner@kit.edu), Benjamin Fersch[1], Fei Yuan[3], Zhongbo Yu[3], Harald Kunstmann[1,2]

[1] Institute of Meteorology and Climate Research (IMK-IFU), KIT, Garmisch-Partenkirchen, Germany; [2] Institute of Geography, Chair for Regional Climate and Hydrology, University, Augsburg, Augsburg, Germany; [3] State Key Laboratory of Hydrology- Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China

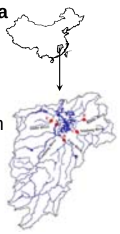
Motivation

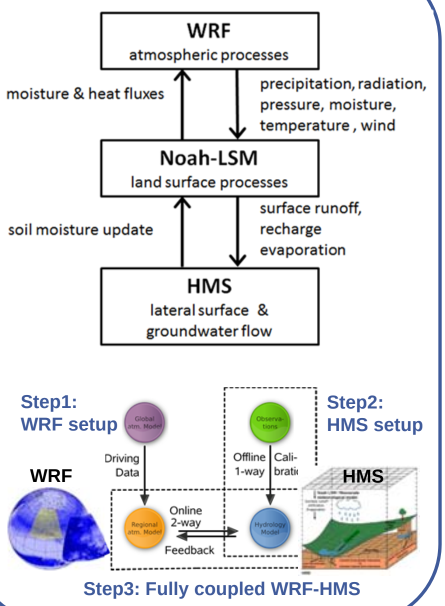
- Studying the water and energy fluxes among the atmosphere, land surface and subsurface is important to understand the role of non-linear feedback within the hydrological cycle.
- Investigations of climate and land-use change impact on the regional water balance require **fully-coupled atmospheric-hydrological modeling systems**, which describe such feedback mechanisms and allow long-term simulations at climate-relevant scales.

Research Area

Poyang Lake catchment, China

- size: ~160,000 km²
- Tributary of Yangtze River
- Humid subtropical climate:
  - mean temperature: 17.5°C
  - annual precipitation: 1600 mm
- 5 main tributaries:





Coupling Approach

- The regional atmospheric model **WRF-ARW** is coupled with the hydrological model **HMS.** Both models use the **Noah-LSM** and therefore share compatible water and energy flux formulations and communicate at the same spatial scale.
- **2-way interaction between groundwater and the Noah-LSM** is implemented by a Fixed-head or Darcy-flux method.
- The integration of the hydrological model HMS into WRF-ARW required primarily
  - a **hydrology driver routine** for the implementation of HMS into the WRF code structure,
  - **MPI-parallelization of HMS** to run the coupled modelling system on HPC clusters,
  - changes to the pre-processing system, e.g. additional static surface and sub-surface hydrological parameters.

➡ In comparison to standard WRF simulations, the **fully coupled WRF-HMS model system** enables

- lateral water flows at the surface and subsurface,
- 2-way interaction between groundwater, the unsaturated zone, the land surface, and the atmosphere.

➡ The reasonable computational demand allows regional, long-term simulations for climate-relevant scales of multiyears, and longer time periods.

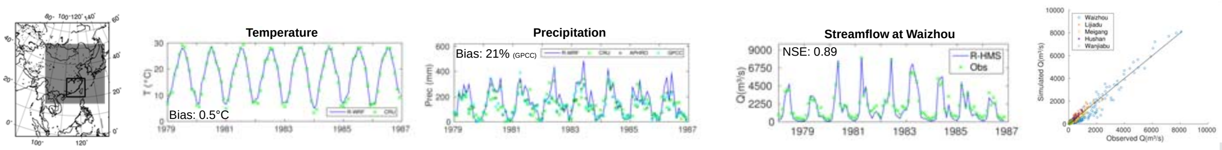
Step1&2: Stand-alone WRF & HMS simulations

WRF:

- Double nesting approach: D01 (30km), D02(10km)
- Reanalysis simulations using ERA interim:

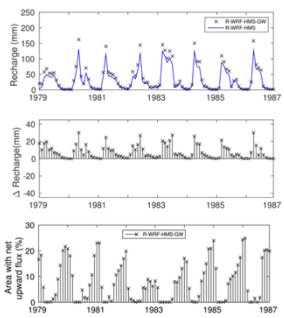
HMS:

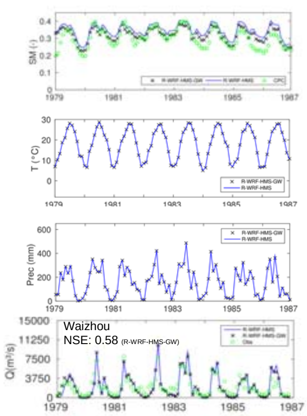
- Met. Forcing: station data



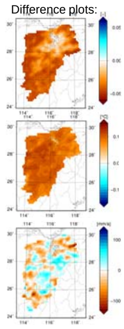
Step3: Fully coupled WRF-HMS simulations

- Results of fully coupled simulations and impact analysis of groundwater coupling on recharge (flux out of bottom layer of LSM) and further hydrometeorological and streamflow variables:





Difference plots:



Legend:
R-WRF-HMS-GW: with groundwater coupling
R-WRF-HMS: without groundwater coupling
CPC: Reanalysis from CPC, NOAA

	Runoff [mm]	Recharge [mm]	SM top [-]	SM bottom [-]	ET [mm]	T [°C]	P [mm]
R-WRF-HMS	442	371	0.315	0.364	1141	18.0	1942
R-WRF-HMS-GW	381	467	0.304	0.330	1112	18.1	1941
Absolute Differences	-61	95	-0.01	-0.03	-29	0.1	-1
Relative Differences	-14%	26%	-3.5%	-9.5%	-3%	0.5%	-0.03%

Conclusions

- **WRF-HMS enables a closed description of the water cycle at regional and long-term scale.**
- A **significant impact** on the regional water balance was found **if groundwater-unsaturated zone interaction is considered**. But the differences between the two groundwater coupling approaches are minor.
- For the fully coupled model system, **streamflow results strongly depend on the simulation quality for precipitation**.
- Two-way interaction results in net upward water fluxes in up to 25% of the basin area after the rainy season.
- In total, two-way interaction increases basin averaged recharge amounts.
- The evaluation with CPC and GLEAM indicates a **better performance of the fully coupled simulation**.
- The impact of groundwater coupling on LSM and atmospheric variables differs. Largest differences occur for the variable recharge (26%), whereas for atmospheric variables, the basin-averaged impact is minor (<1%).
- But locally, a **spatial redistribution up to 5% occurs for precipitation**.

- **The WRF-HMS model system is suitable for** many further applications, including **joint climate and land use change impact studies**, to investigate hydro-meteorological flux responses at basin scale for different climate regions worldwide.

Reference: *Wagner, S., B. Fersch, F. Yuan, Z. Yu, and H. Kunstmann (2016), Fully coupled atmospheric-hydrological modeling at regional and long-term scales: Development, application, and analysis of WRF-HMS, Water Resour.Res., 52, doi:10.1002/2015WR018185.*

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