# Regional Water Balance Analysis with an Atmosphere-to-Groundwater Coupled Model for the Pre-Alpine TERENO Region

Benjamin Fersch, Thomas Rummler, David Gochis, Sven Wagner, Harald Kunstmann

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Regional Climate Systems / Regional Climate and Hydrology

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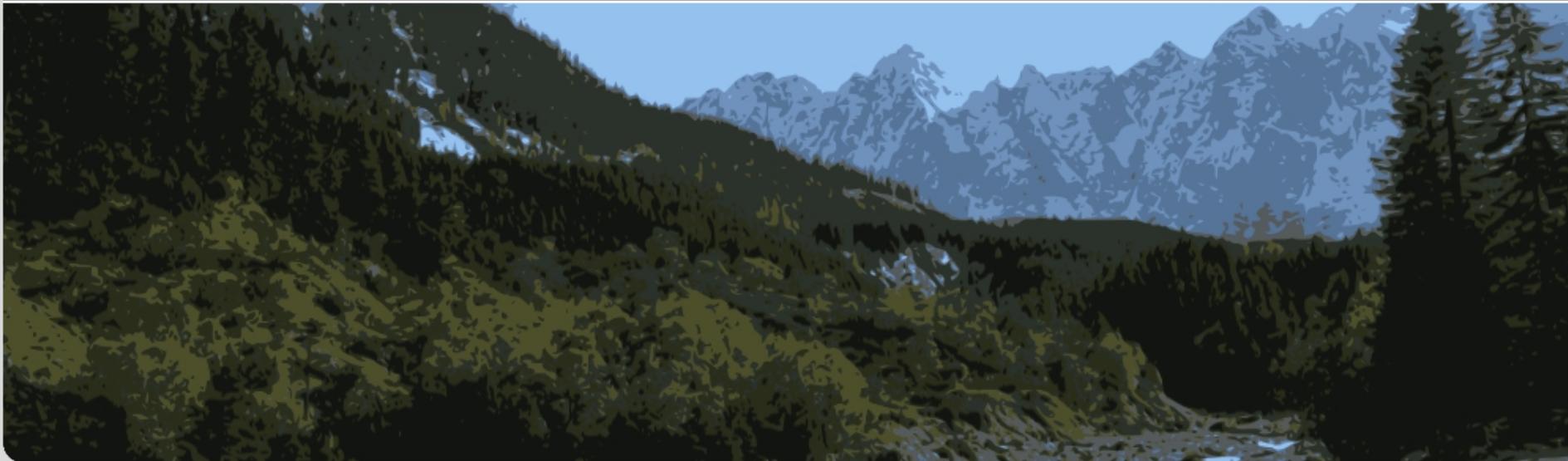
Introduction

- Regional atmospheric models
  - Short term forecasting
  - Medium term hind-casting
  - Long term climate projections

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- **Regional atmospheric models**
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  - Medium term hind-casting
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- **Poor representation of hydrological processes**
  - Lateral (spatial) redistribution of surface & subsurface water usually neglected
 - No prediction of river channel flow

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- How does the model's reality (water budgets) change if the physical detail of hydrological processes is increased

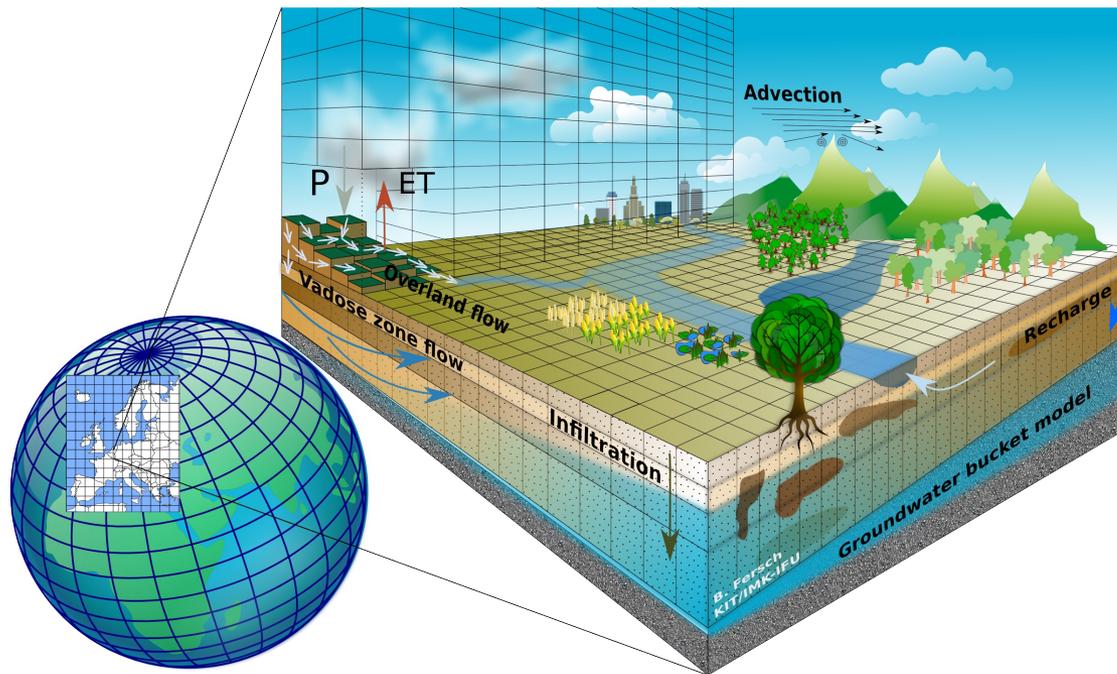# The Noah-LSM in the Weather Research and Forecasting Model WRF
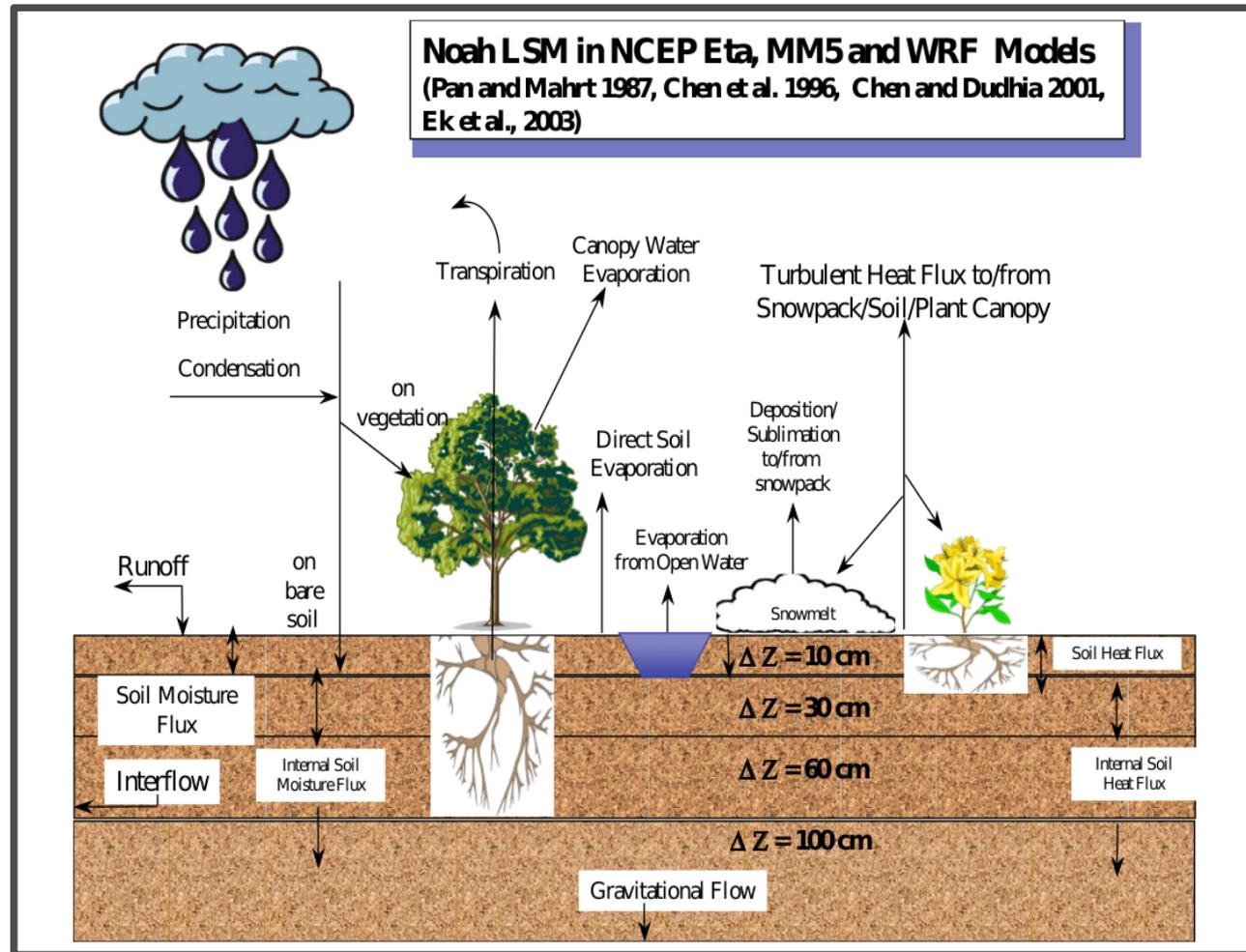
The Noah-LSM in the Weather Research and Forecasting Model WRF
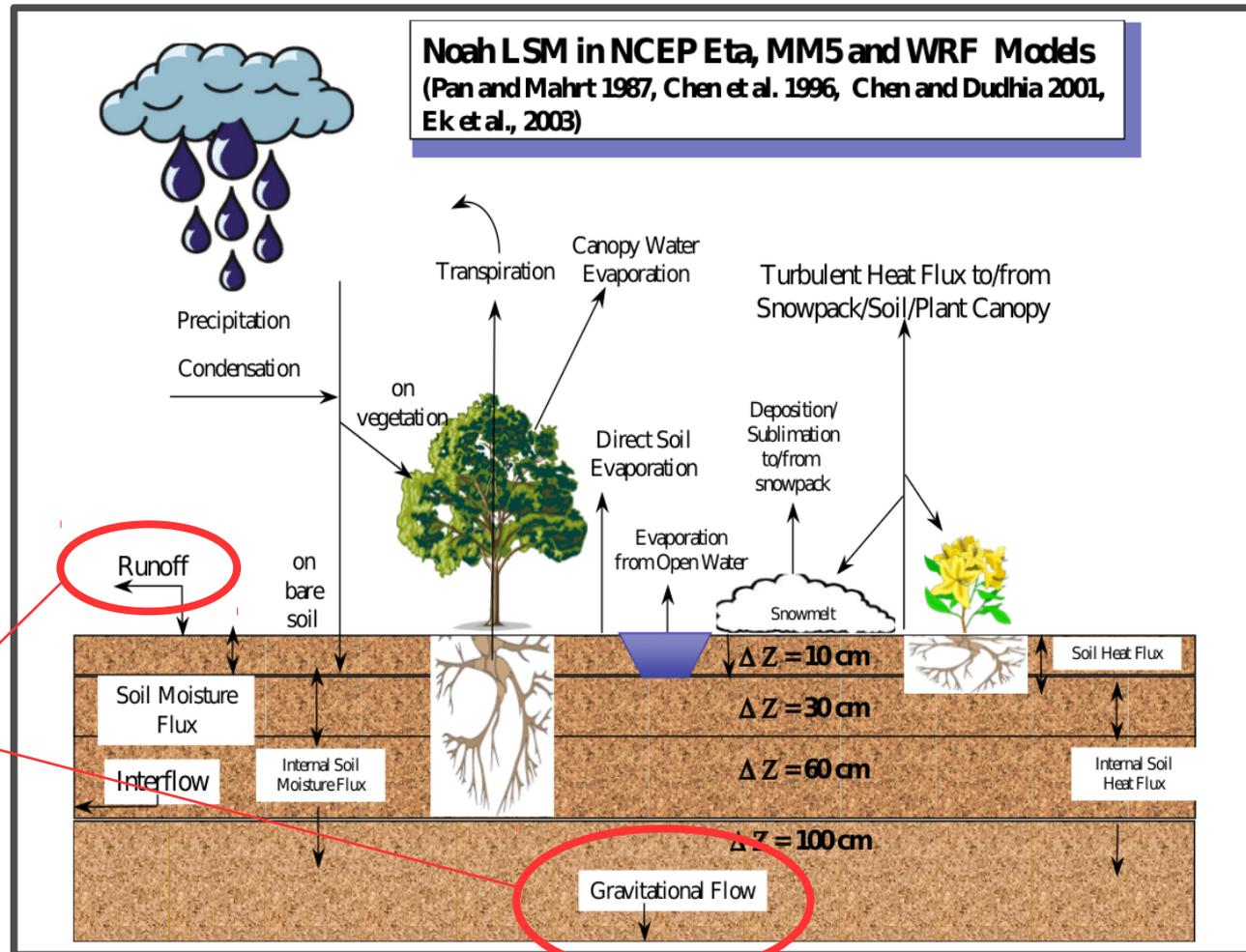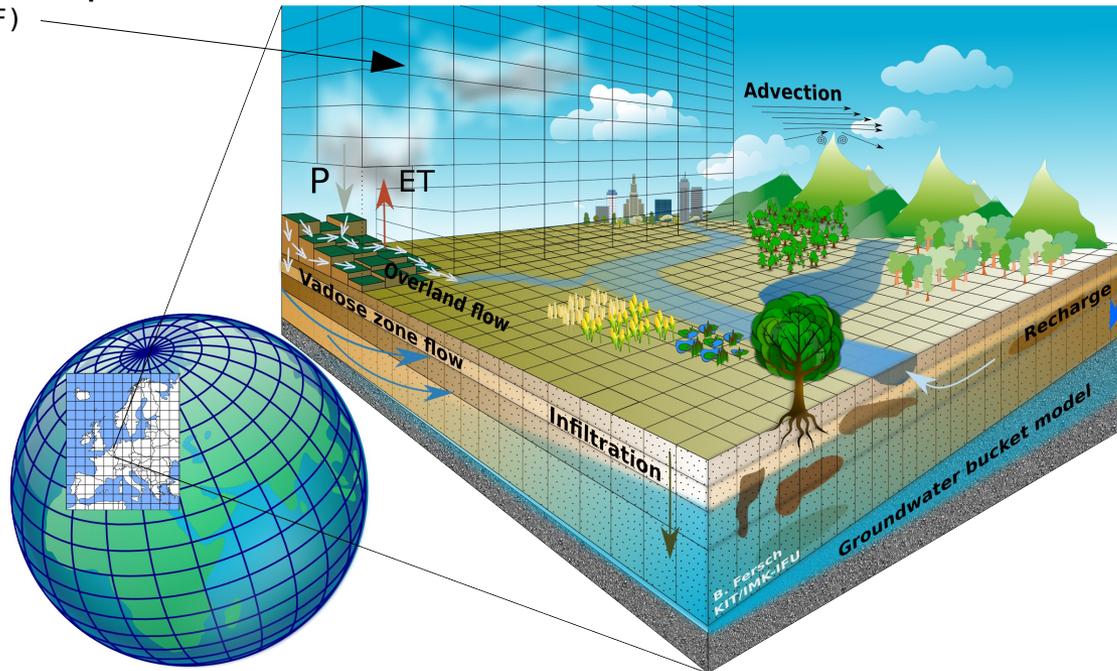
WRF-Hydro Modeling System

NCAR developed community model for the simulation of **coupled atmospheric and hydrological** processes (Gochis et al. 2013)

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Available land surface models:

Noah-LSM

Noah-MP

CLM (Community Land Model)

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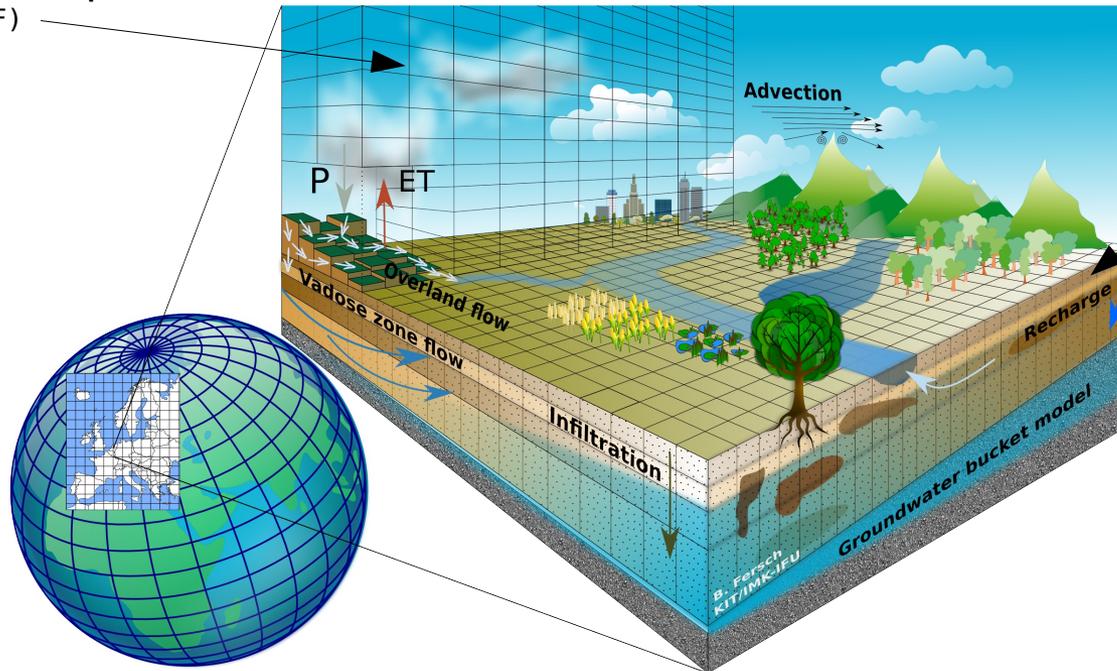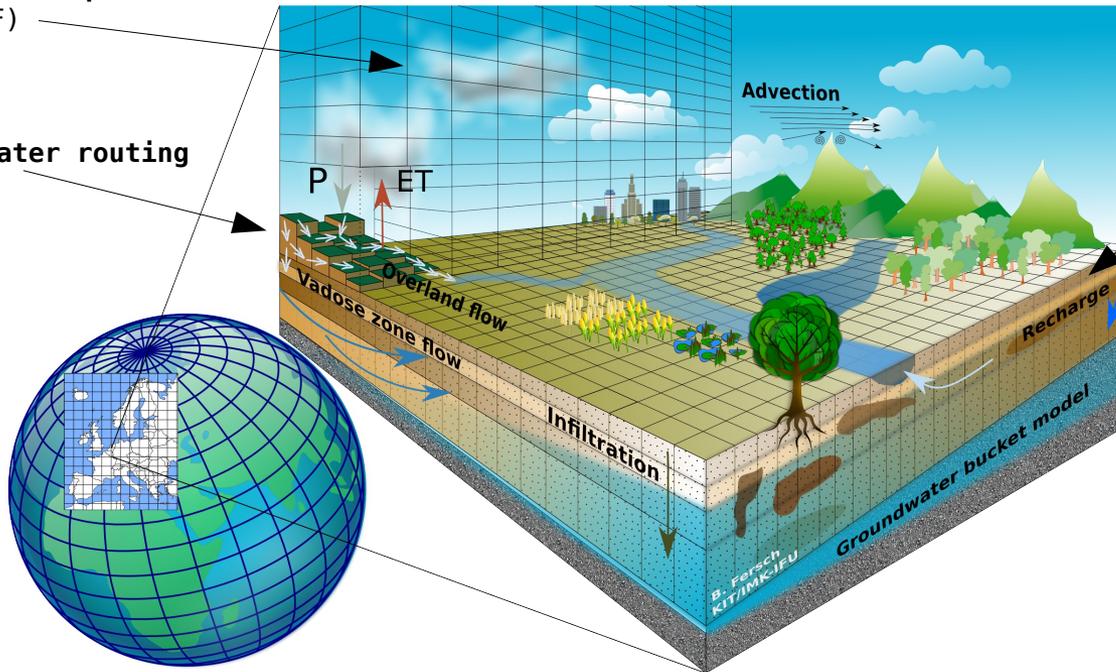
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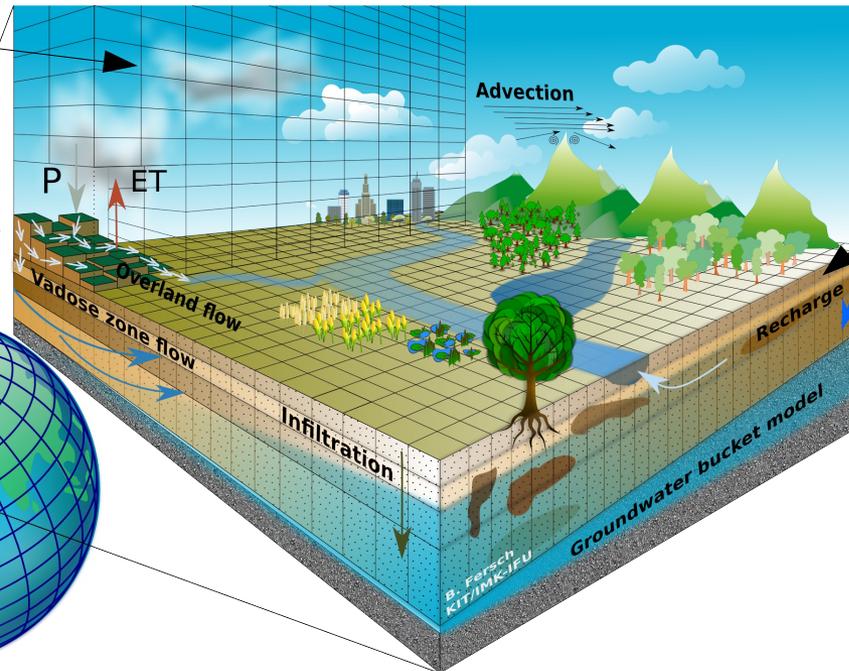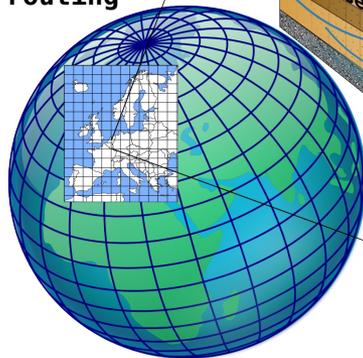
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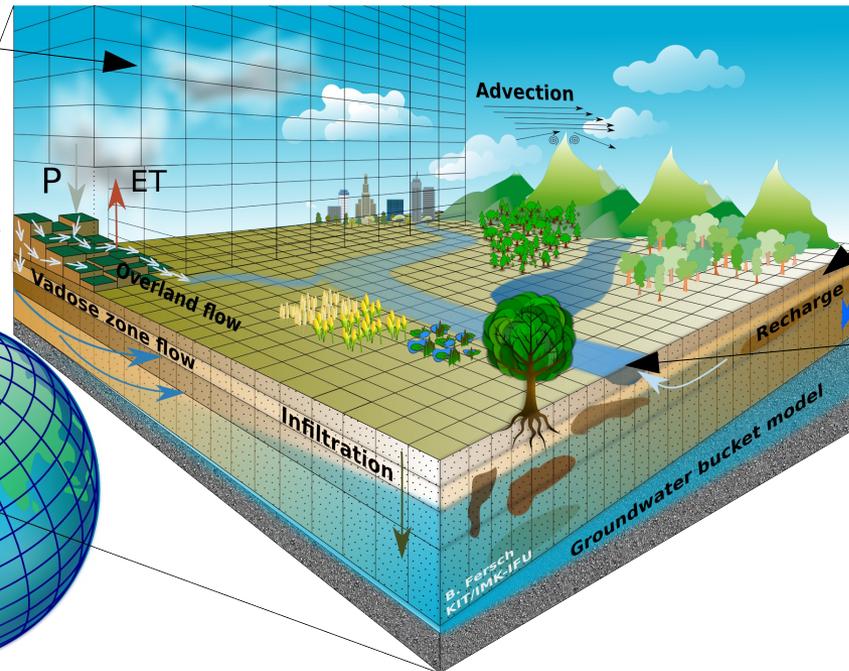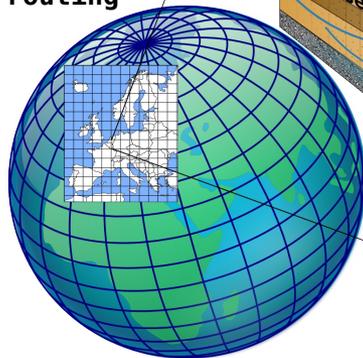Available land surface models:

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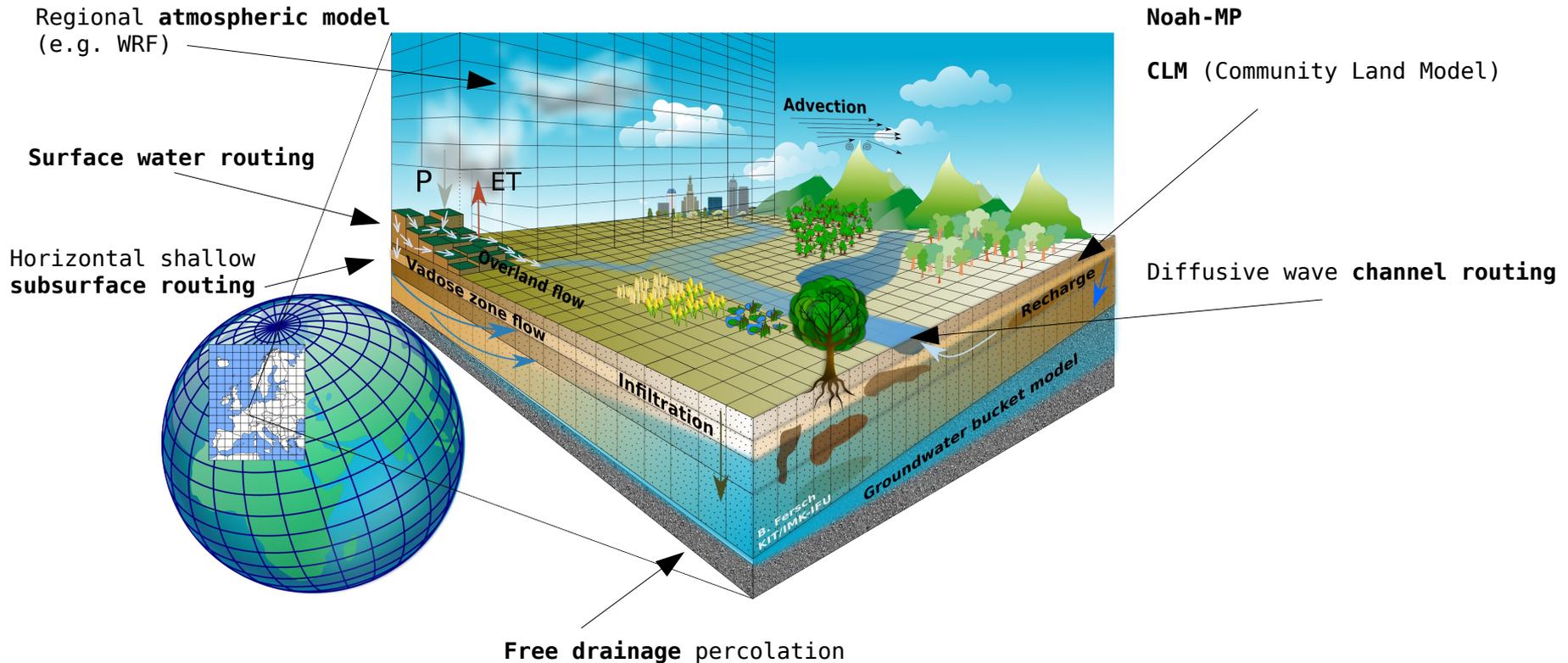**Free drainage** percolation
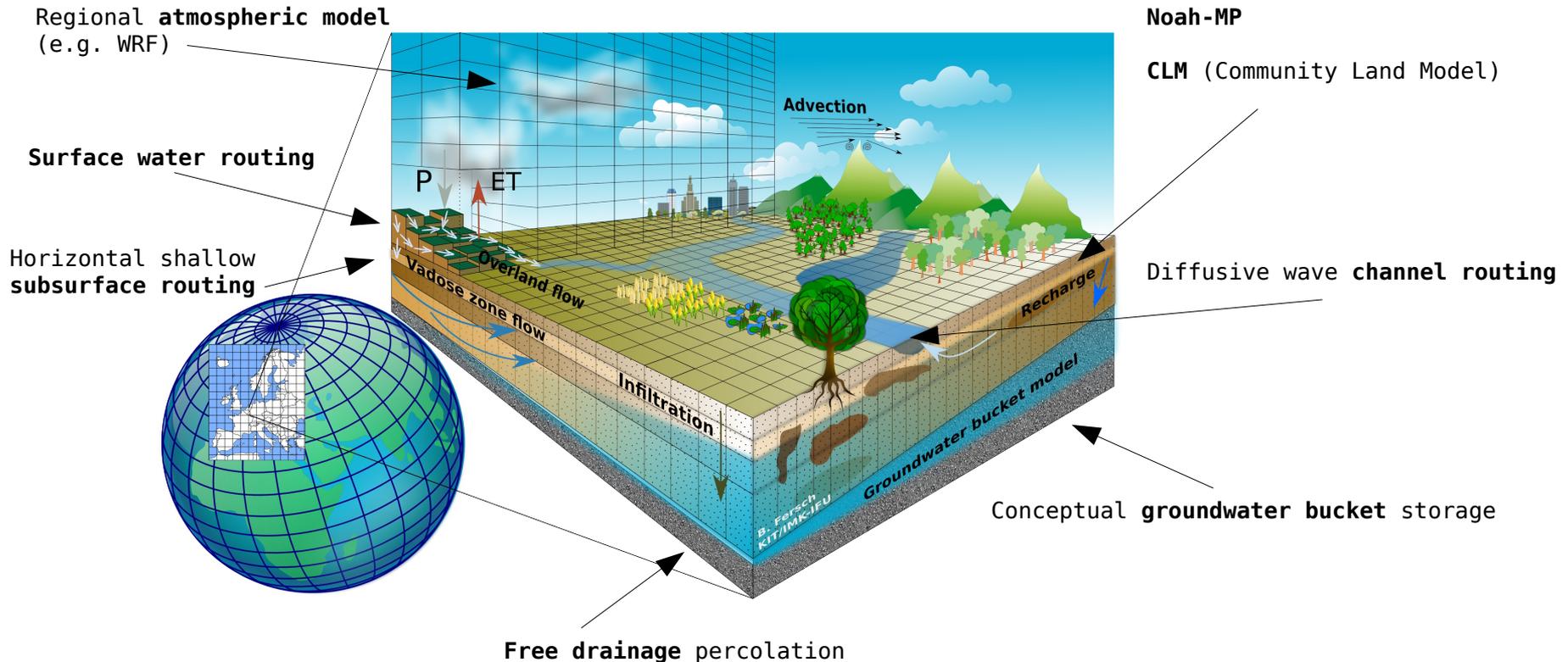
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Conceptual **groundwater bucket** storage

Free drainage percolation

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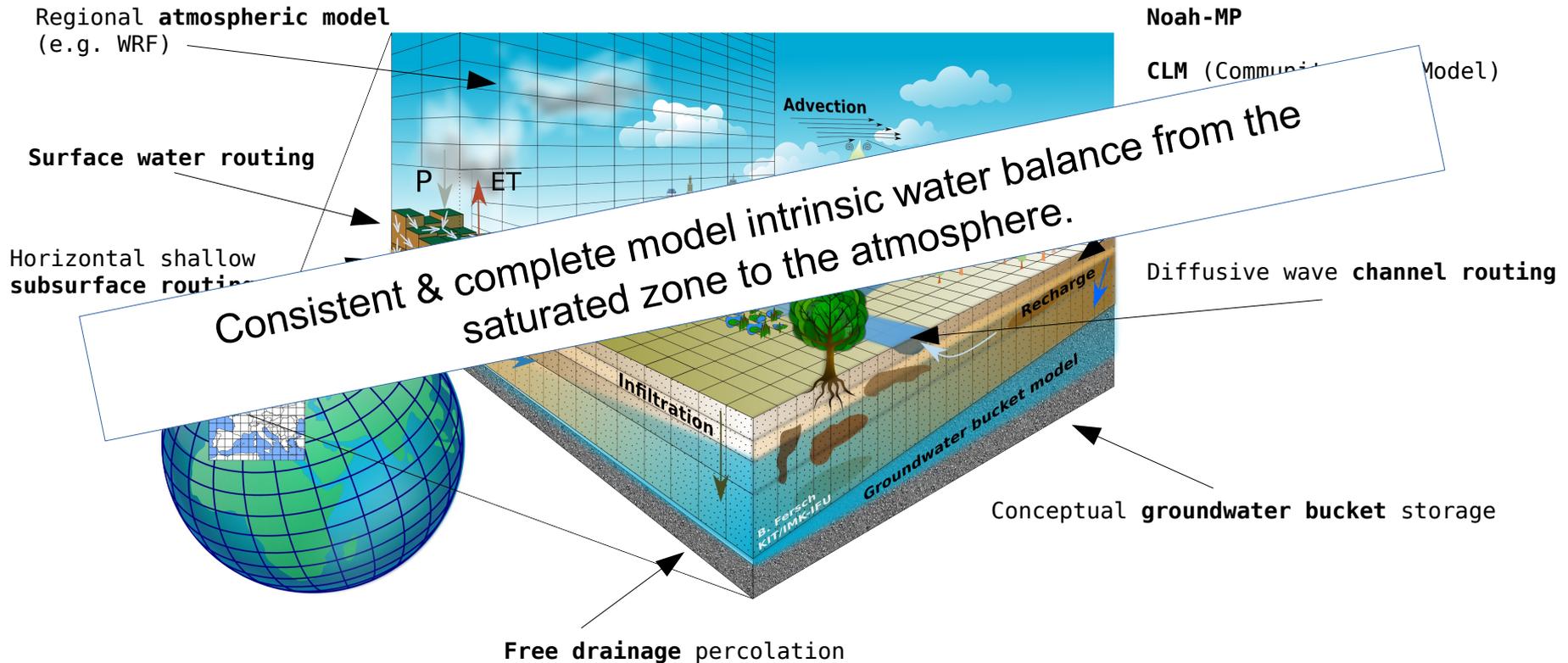
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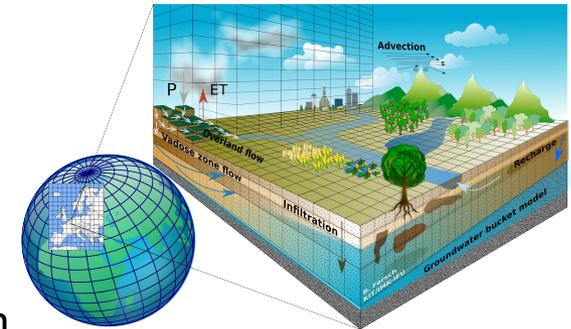
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Conceptual **groundwater bucket** storage

Free drainage percolation

Consistent & complete model intrinsic water balance from the saturated zone to the atmosphere.

Advection

P   ET

Recharge

Infiltration

Groundwater bucket model

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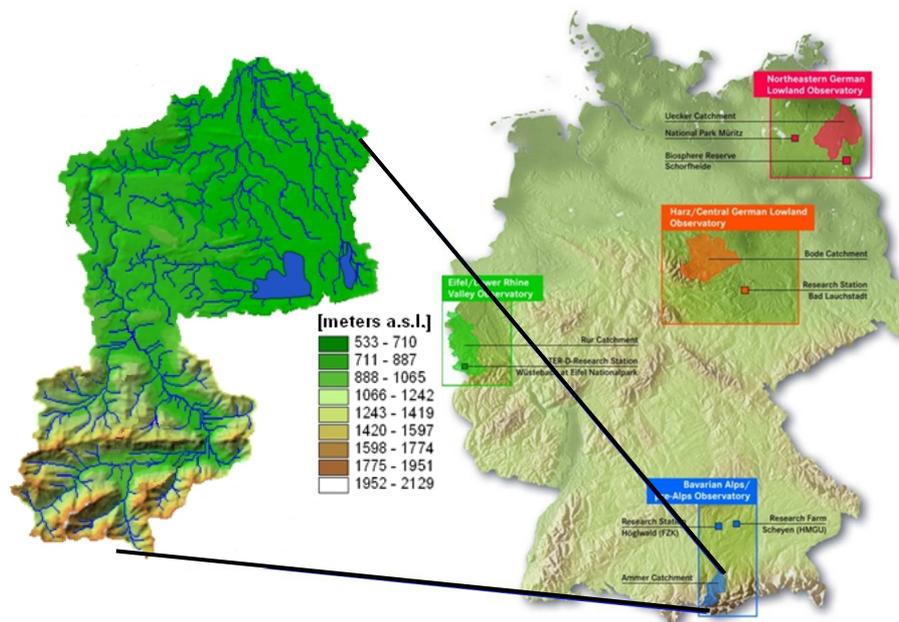
WRF-Hydro Benefits & Potential

- Hydrological extensions
  - Distributed river discharge information
  - Regionally closed water balance
  - Surface and subsurface routing → water remains in the system
  - Lateral redistribution of surface and subsurface water

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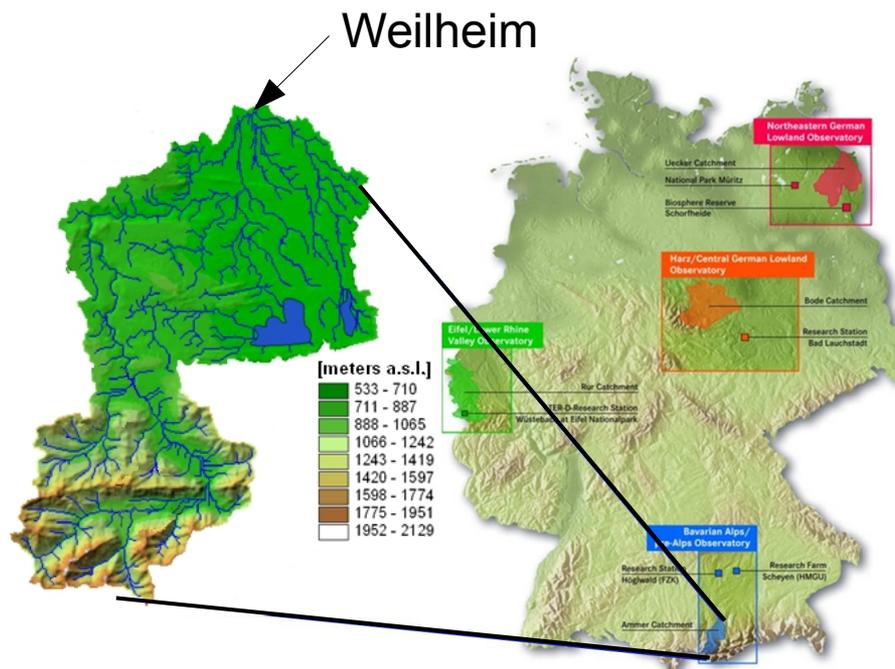 - Lateral redistribution of surface and subsurface water

- Fully two-way atmosphere to groundwater coupling
  - Lateral water redistribution → improved soil moisture patterns
  - Improved simulation of land-surface – PBL moisture and energy exchange
  - Impact on local precipitation generation
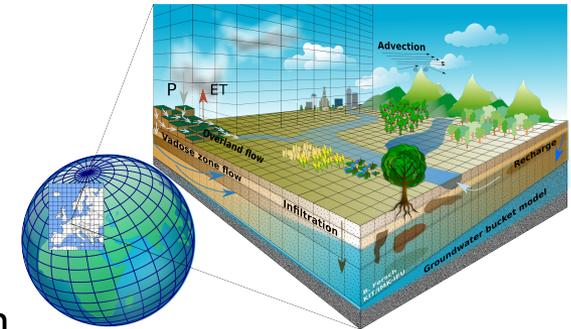
WRF-Hydro Application for the Pre-Alpine Ammer Catchment of Southern Bavaria

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Weilheim

[meters a.s.l.]
- 533 - 710
- 711 - 887
- 888 - 1065
- 1066 - 1242
- 1243 - 1419
- 1420 - 1597
- 1598 - 1774
- 1775 - 1951
- 1952 - 2129

Ammer catchment characteristics

~800 km² up to gauge Weilheim

~550-2000 m a.s.l

TERENO Alpine/pre-Alpine

Landuse: forest, grassland, cropland

~700-1800 mm/a precipitation
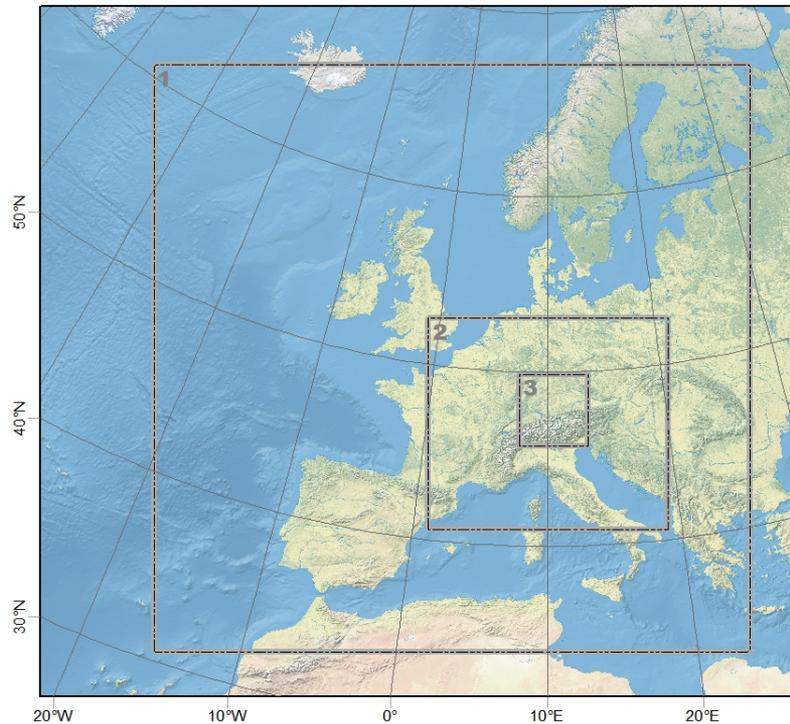
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Standard WRF & WRF-Hydro Setup

Domain setup

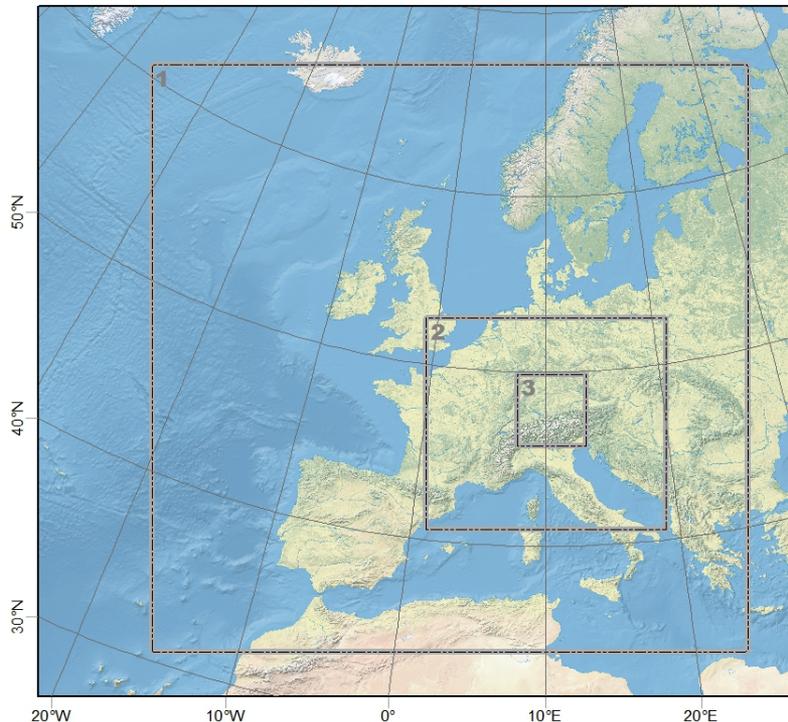3 nested WRF domains

Domain 1 → 140 x 140 @ 27 km

Domain 2 → 169 x 151 @ 9 km

Domain 3 → 145 x 154 @ 3 km

51 vertical layers

Standard WRF & WRF-Hydro Setup

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3 nested WRF domains

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Hydro

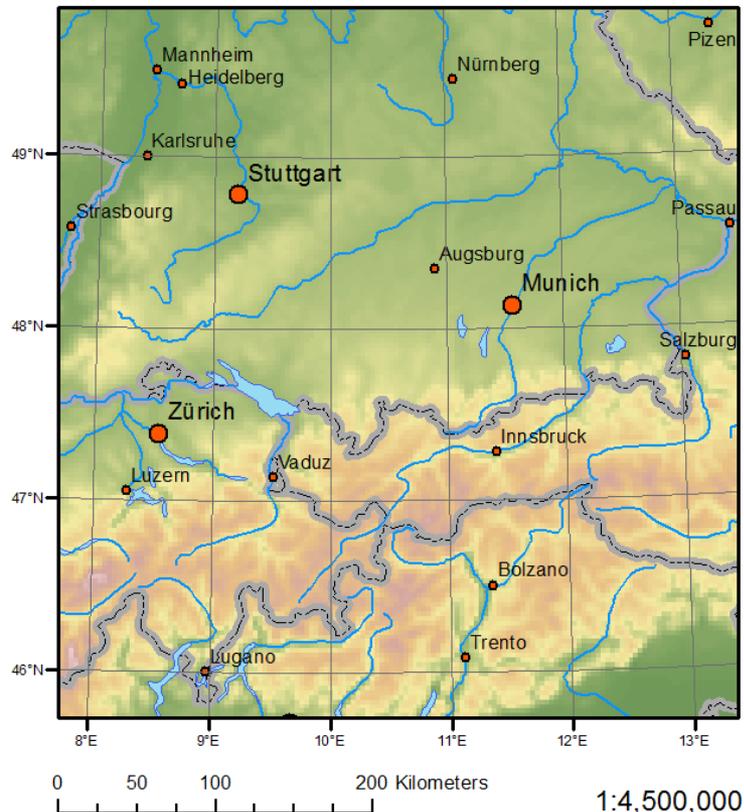Coupled with Domain 3

4320 x 4590 @ 100 m

99% of horizontal grid cells

4 soil layers

82,755,099 grid cells in total

Standard WRF & WRF-Hydro Setup

Domain 3

ECMWF ERA-INTERIM forcing

```
  6 hourly input

  37 pressure levels, 4 soil levels

  ~ 0.75° x 0.75° resolution
```

Physics setup

```
  Microphysics:     Goddard scheme

  SW/LW Radiation: CAM scheme

  PBL:             YSU scheme

  Convection:      Kain Fritsch scheme

  LSM:             Noah-LSM (Hydro Version)
```

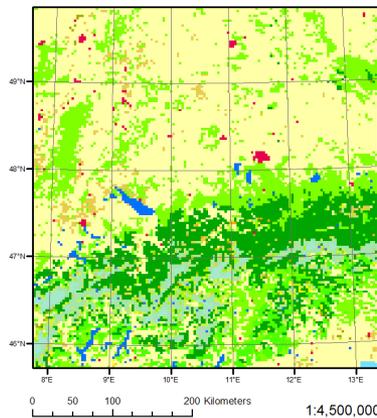# Offline HRLDAS WRF-Hydro

- HRLDAS (High Resolution Land Data Assimilation System) driver
    - Forcing from uncoupled standard WRF simulation at hourly resolution
    - WRF precipitation exchanged with German Weather Service product
    - Noah – land surface model

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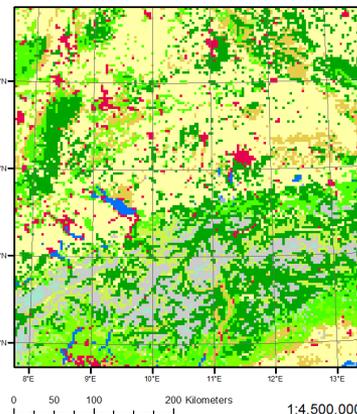IMK-IFU: Atmospheric Environmental Research

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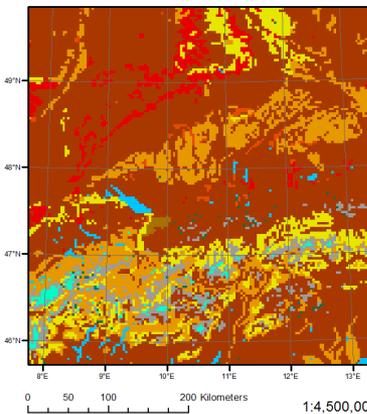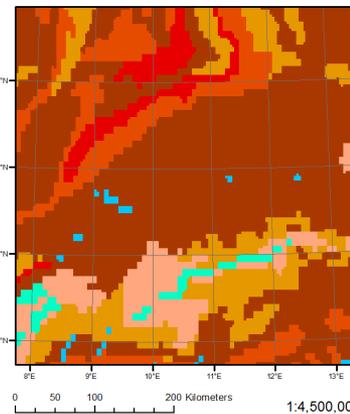   - Noah – land surface model

- WRF-Hydro configuration
    - 2-d surface & subsurface routing
    - Diffusive wave channel routing
    - Pass-through groundwater bucket model

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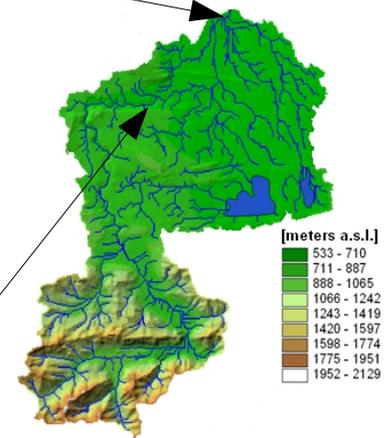 - Pass-through groundwater bucket model

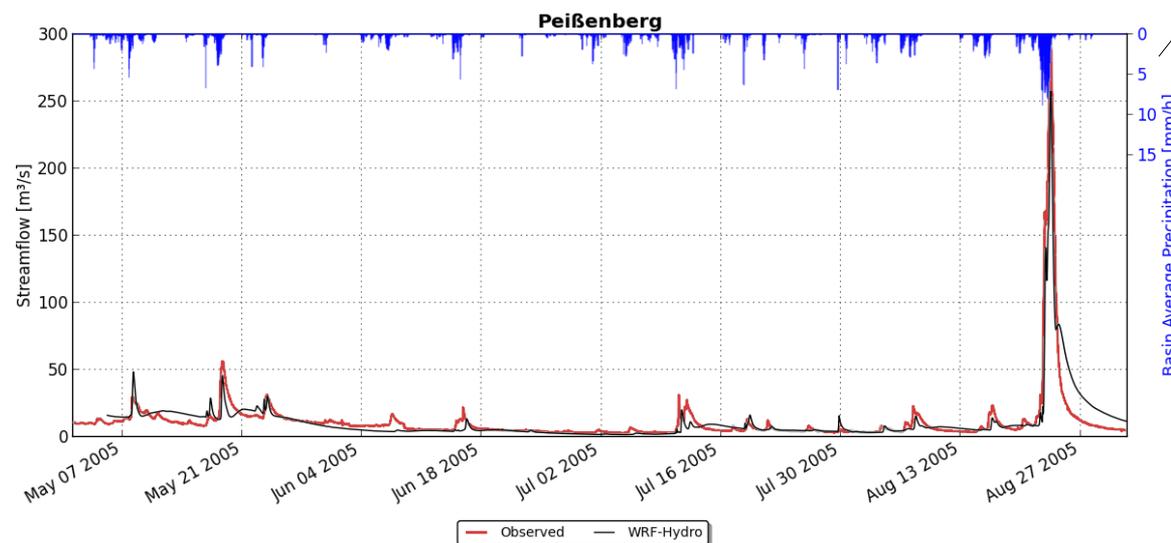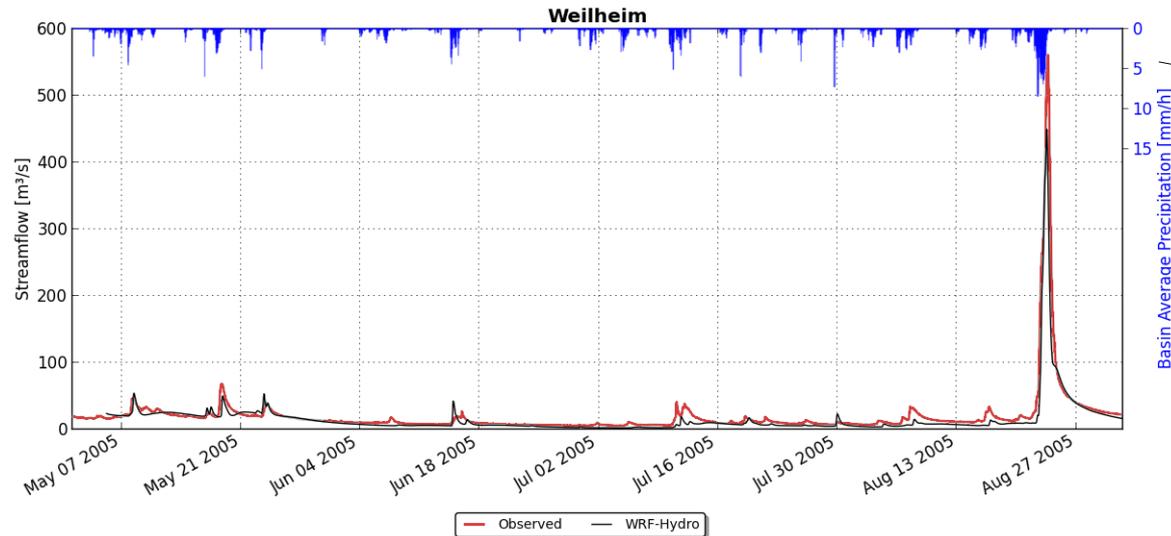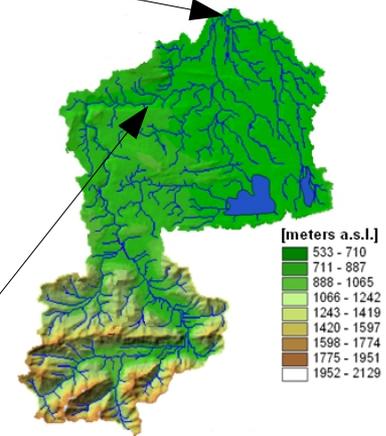Land-use (NOAA AVHRR)   Soil (European Soil Data Base)
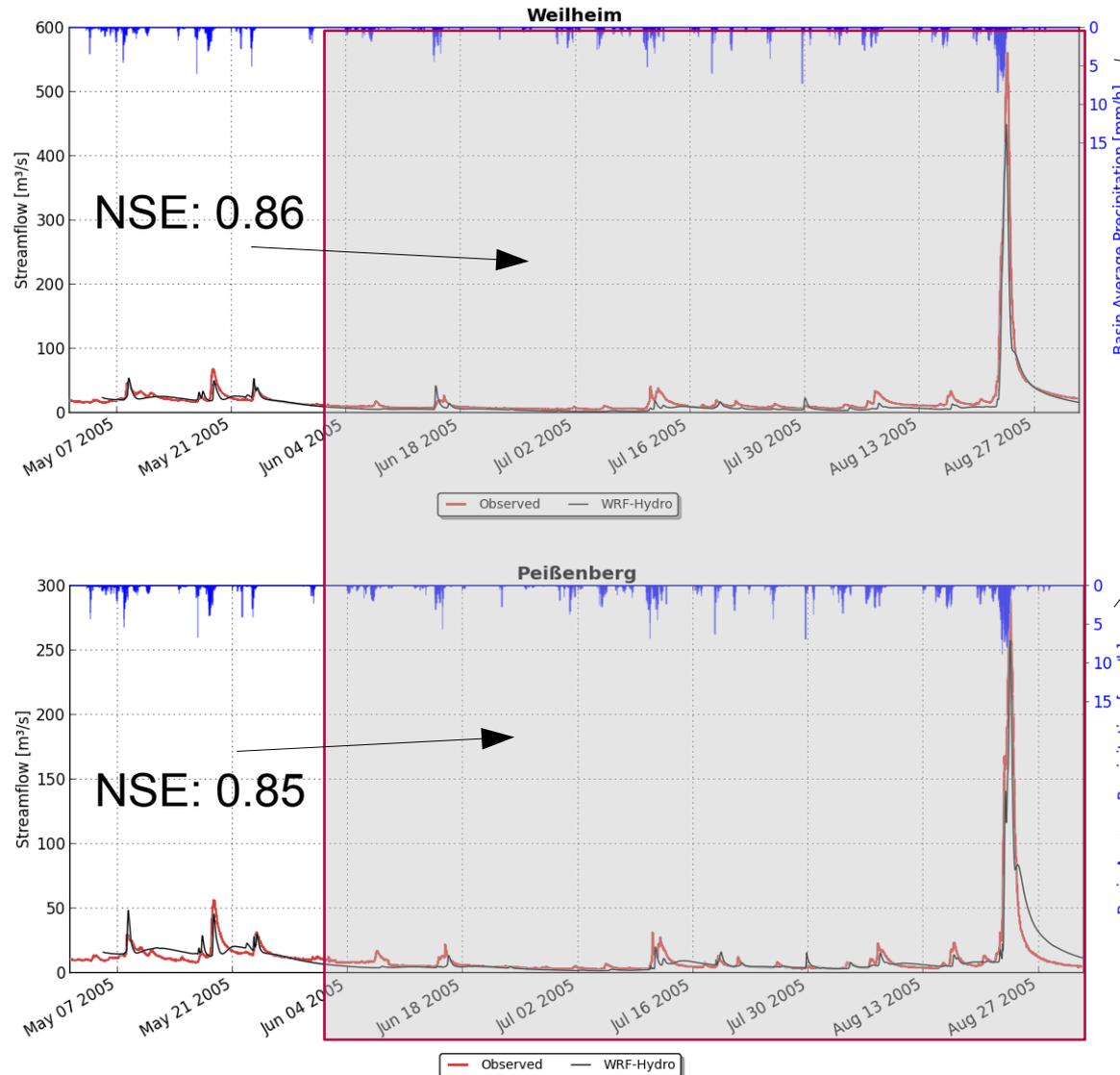
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Offline HRLDAS WRF-Hydro Calibration
Summer 2005 Flood

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Summer 2005 Flood

NSE: 0.86

NSE: 0.85

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WRF vs. Two-Way Coupled WRF-Hydro
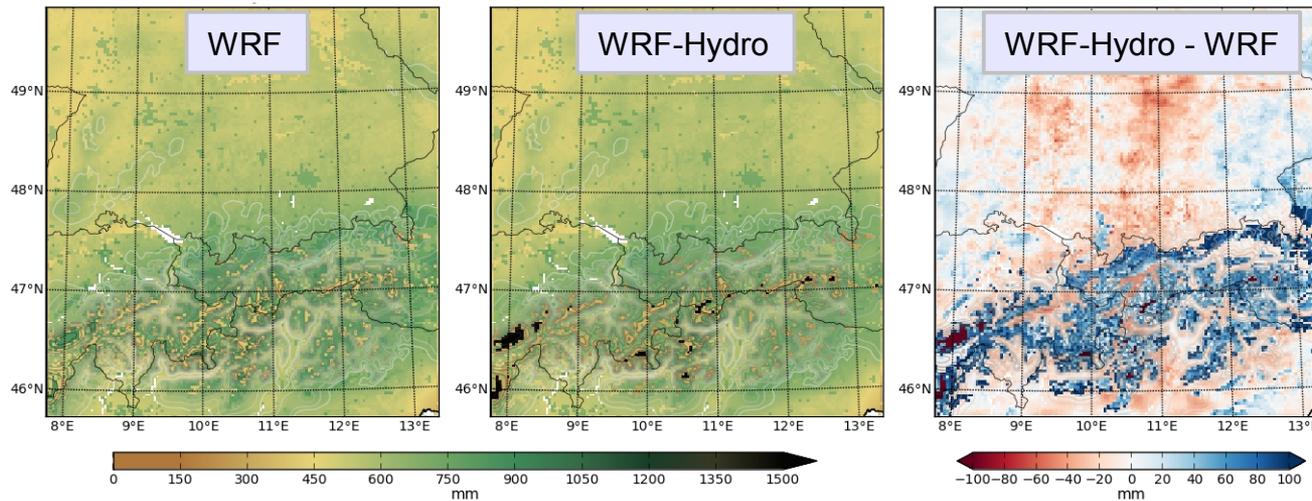
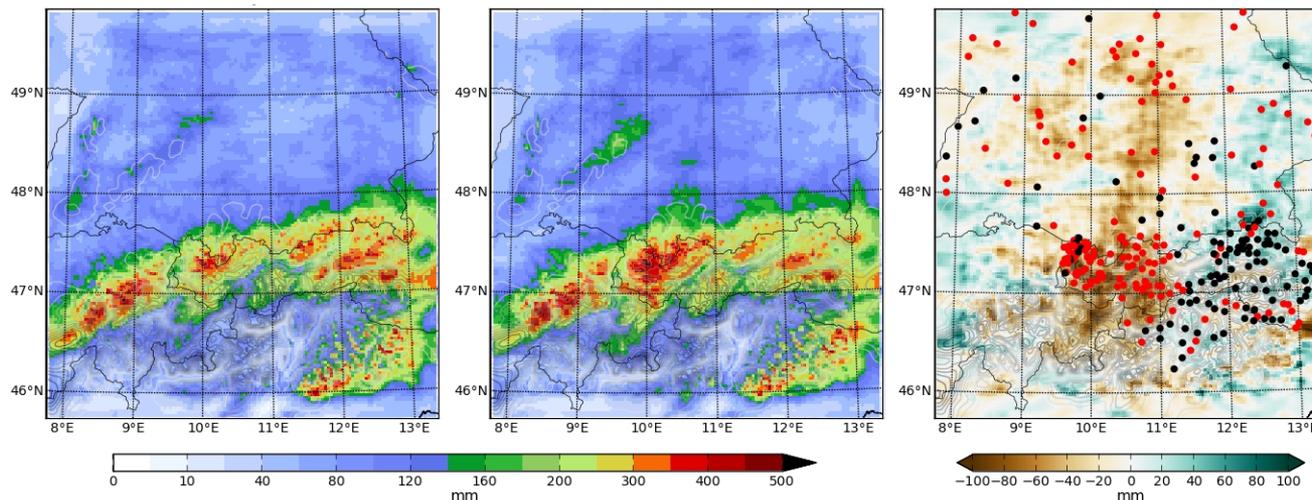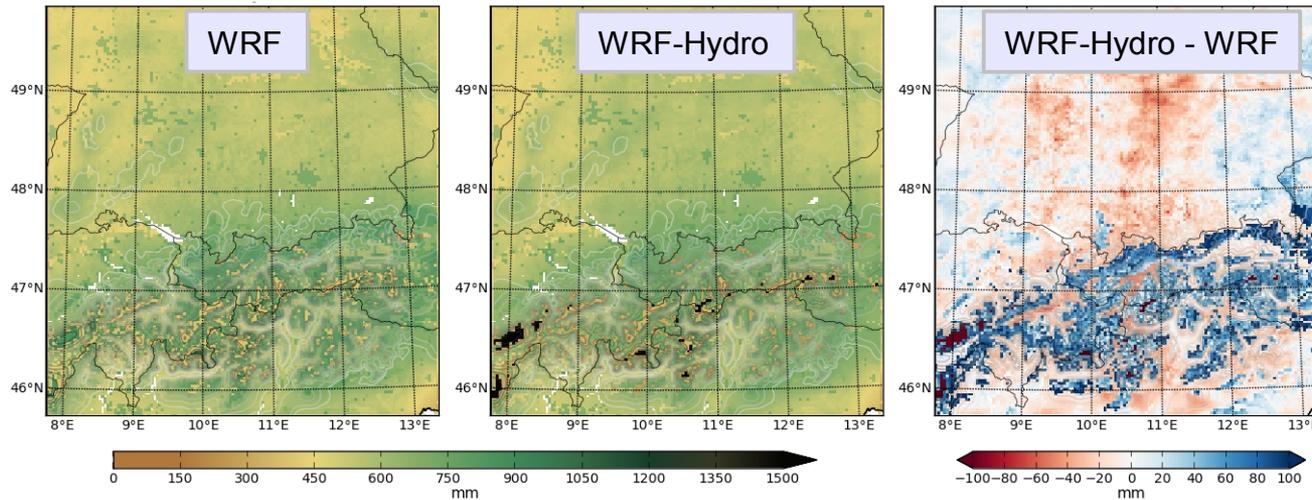Column
Soil Water
June 2004

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WRF vs. Two-Way Coupled WRF-Hydro
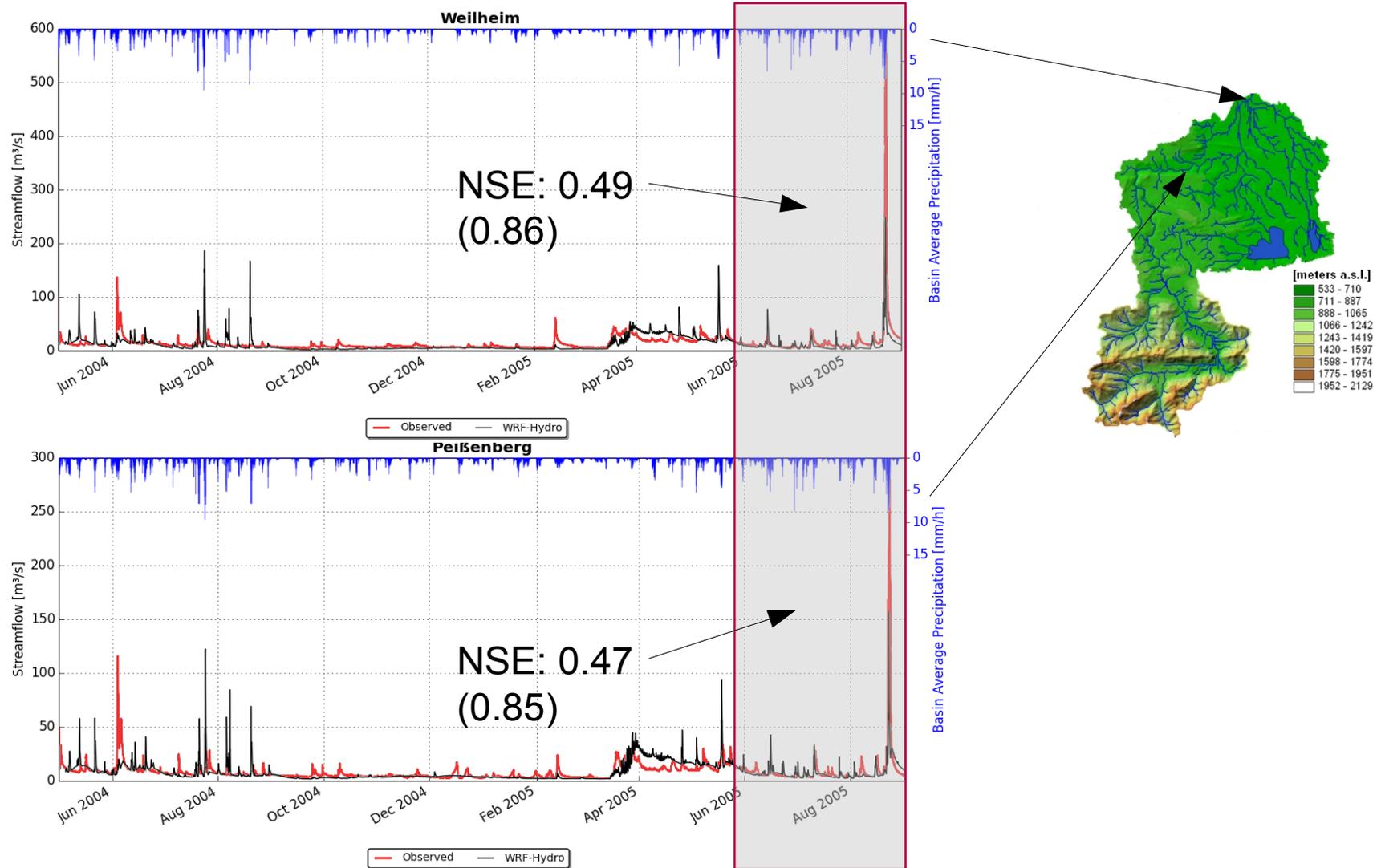

Column Soil Water June 2004

Accumulated Precipitation June 2004

WRF vs. Two-Way Coupled WRF-Hydro

Column Soil Water June 2004

Accumulated Precipitation June 2004

Min. Bias

● WRF-Hydro

● WRF
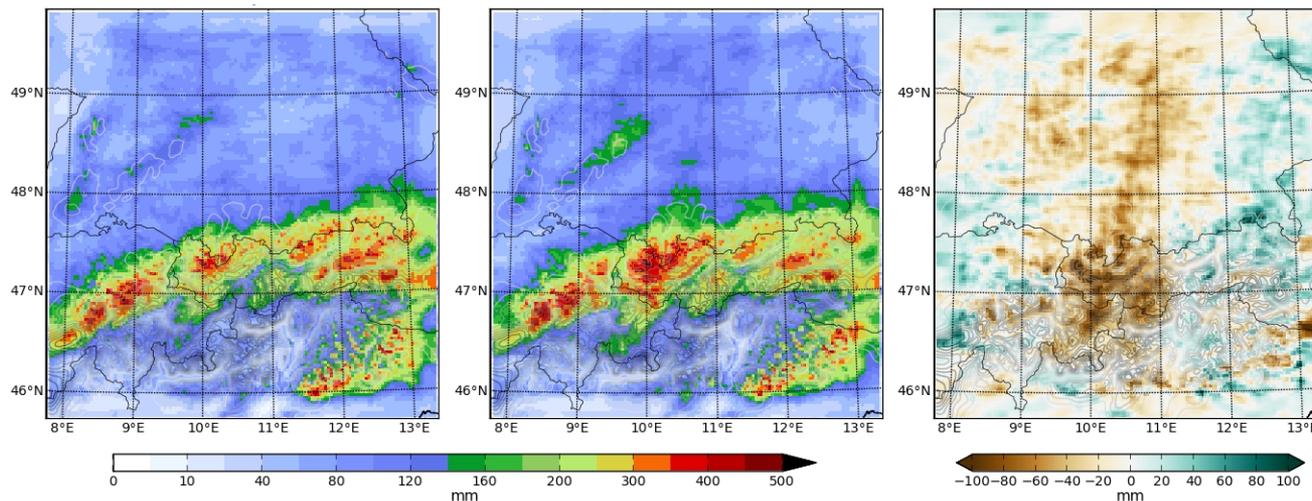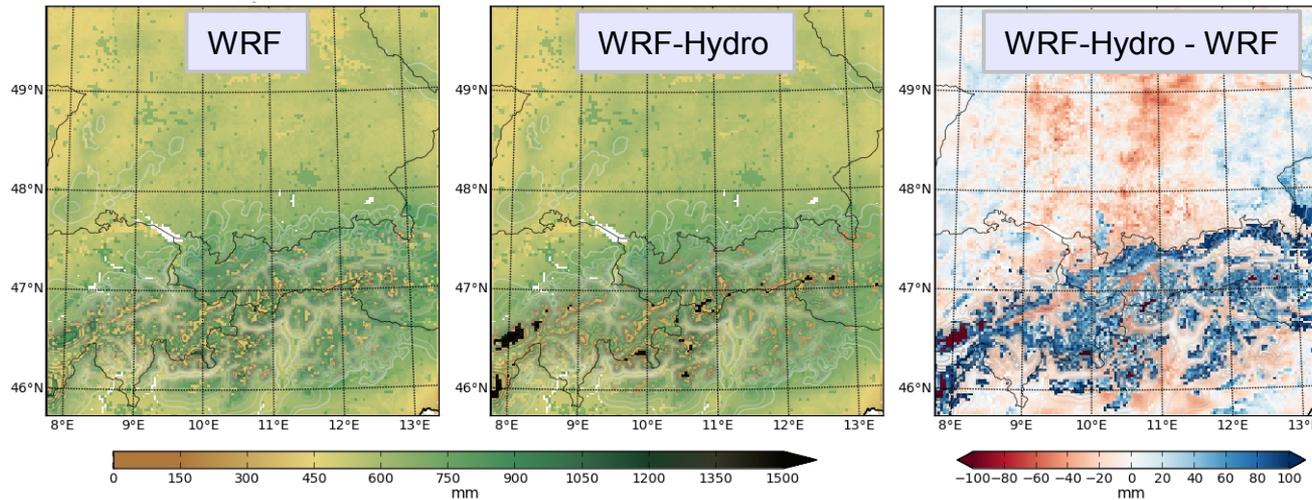
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Budget Comparison (WRF vs. WRF-Hydro)
Ammer Catchment upstream of Weilheim
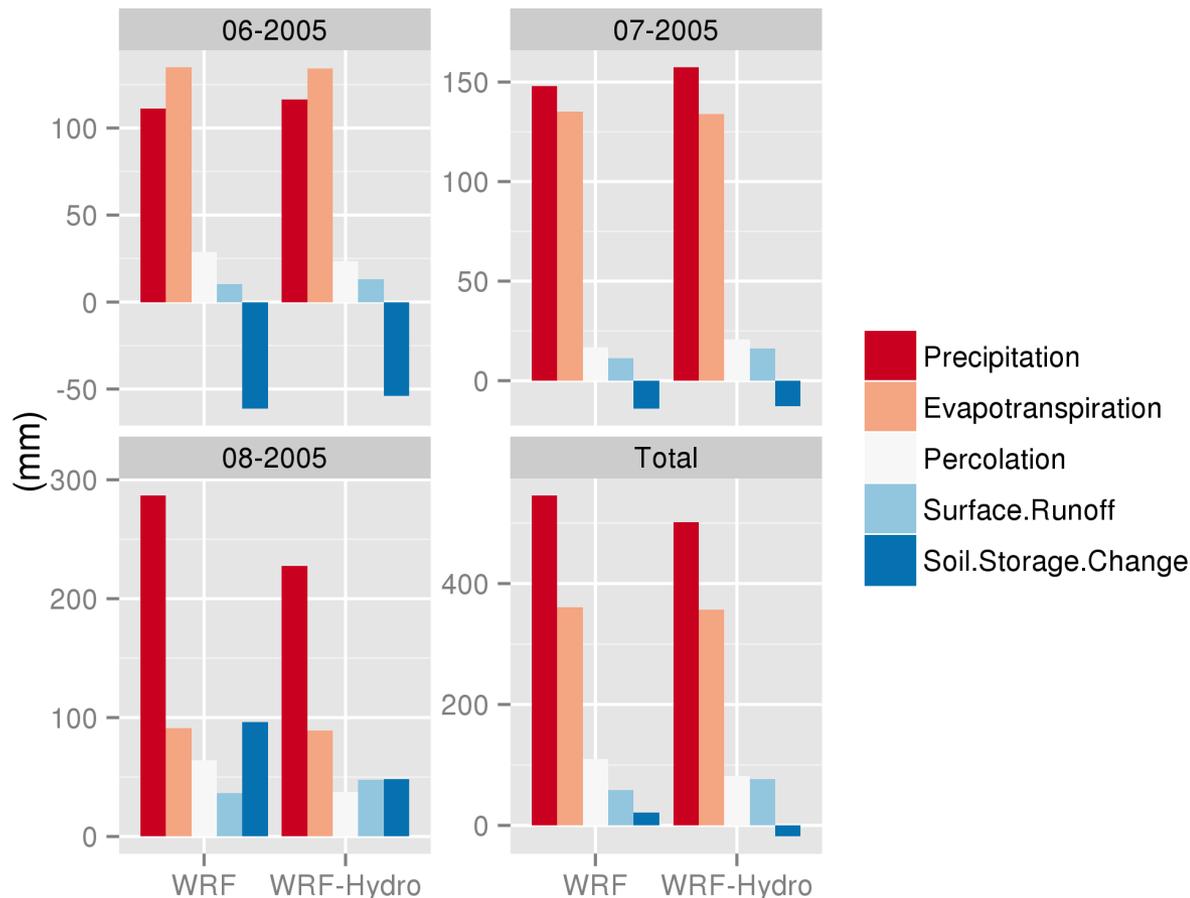
Monthly deviations
(WRF-Hydro - WRF)

P → +5 to -30% (9 to -60 mm)

E → -1 to   -3% (-1 to -4 mm)

Rs → +27 to +40% (3 to 19 mm)

Rp → +23 to -40% (4 to -30 mm)

S → -10 to -50% (7 to -50 mm)

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Towards a Physically Based, Distributed Groundwater Representation

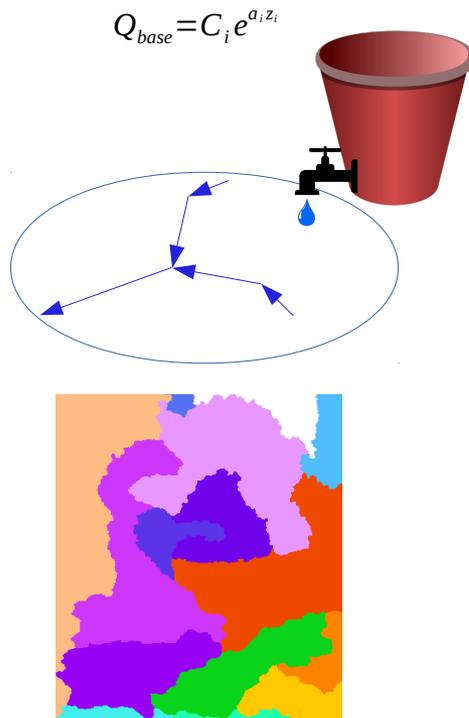# Towards a Physically Based, Distributed Groundwater Representation

Bucket groundwater model

$$Q_{base} = C_i e^{a_i z_i}$$

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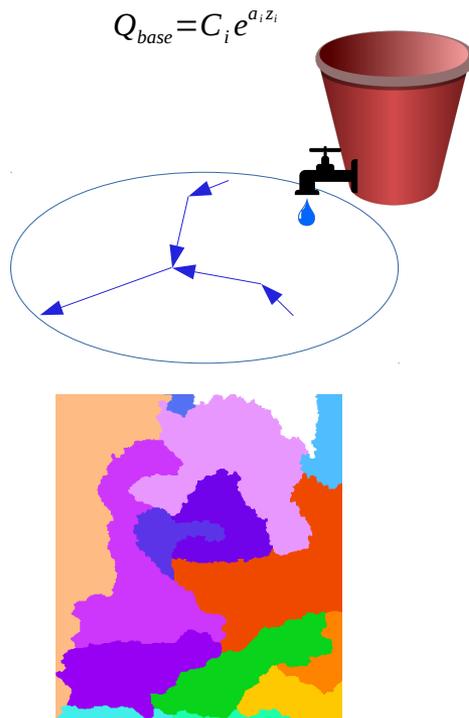
2-d coupled groundwater model

$$\frac{\partial}{\partial x}(T\frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(T\frac{\partial h}{\partial y}) = S\frac{\partial h}{\partial t} + Q$$
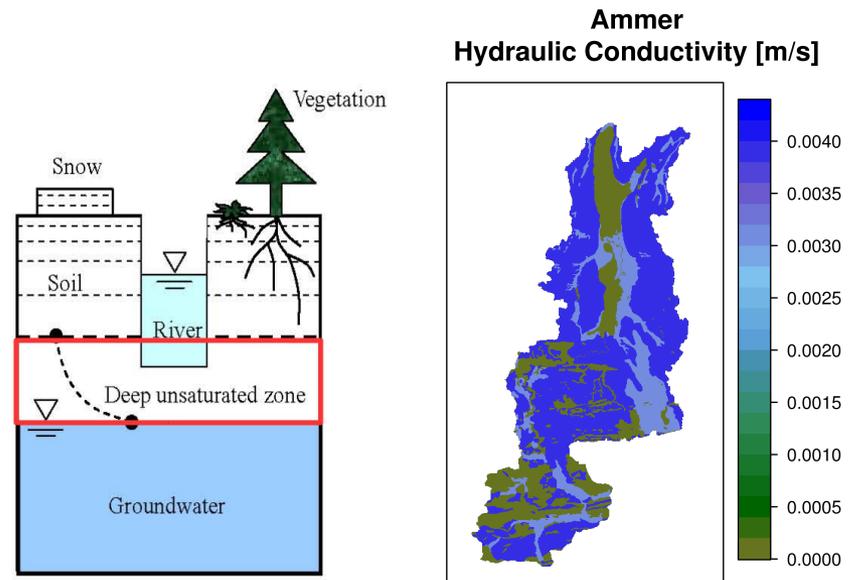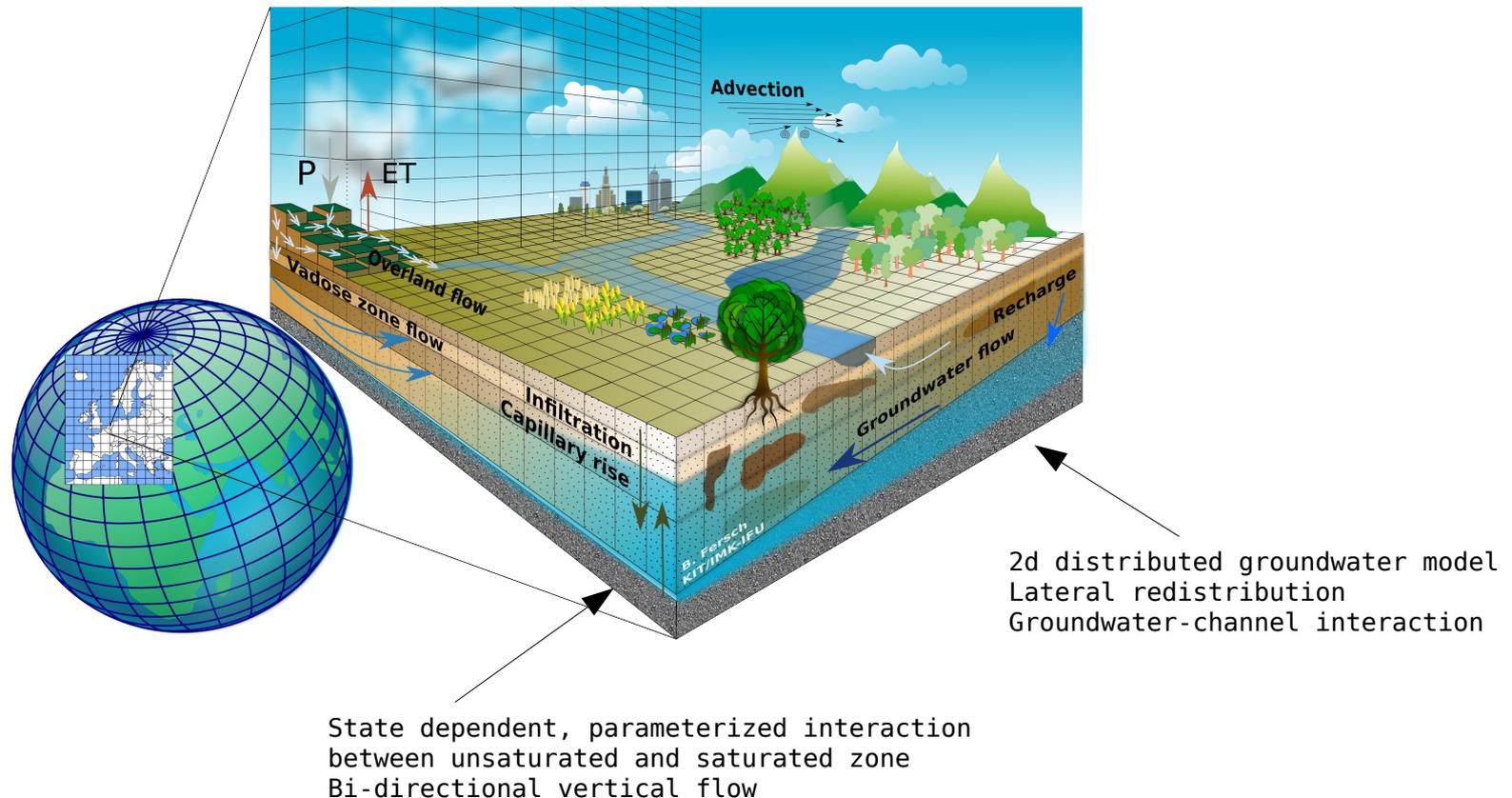
Ammer Hydraulic Conductivity [m/s]

Towards a Physically Based, Distributed Groundwater Representation

2d distributed groundwater model
Lateral redistribution
Groundwater-channel interaction

State dependent, parameterized interaction
between unsaturated and saturated zone
Bi-directional vertical flow

Summary & Conclusions

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  - Good results for standalone model to simulate 2005 summer flood
  - Considerable variations in spatial patterns of precipitation and soil moisture
  - Coupled discharge simulations possible with fully coupled WRF-Hydro
  - Coupling leads to changes in precipitation amounts and runoff partition but no changes in evapotranspiration (no shallow groundwater in conceptual bucket model)
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- Next step: simulation of 2010-2014 period and validation with data from the pre-alpine Tereno sites

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Calibration