Groundwater flow in the JULES LSM – an update

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An equation: 2D unconfined groundwater

\[ K \frac{\partial}{\partial x} \left( h \frac{\partial h}{\partial x} \right) + K \frac{\partial}{\partial y} \left( h \frac{\partial h}{\partial y} \right) = S_y \frac{\partial h}{\partial t} \]

Challenges:

- \( K \) – Hydraulic conductivity (L/T)
- \( S_y \) – Specific yield (-)
- \( q \) – Boundary flux (L/T)
Global groundwater modelling – challenges

Compared to Land Surface and Climate models: physics of groundwater flow is a (mostly) lot simpler, but...

...Challenges do exist:

Complexity, lack of data and resulting uncertainty

- Complexity: 3D nature of the sub-surface - aquifers are not laterally connected necessarily
- Data availability: low density of boreholes, particularly globally
- Uncertainty wrt parametrisation: driven by lack of confidence in geological structure and rock mass properties
JULES-DGW – saturated–unsaturated zone coupling

Water table below soil layers

Water table within soil layers

From Niu et al. (2007), analogous to Batelis et al. (2020)

As in Batelis et al. (2020)
Water table below soil layers

\[ R = -K \frac{Z_{wt} - (\psi_{bot} - Z_{bot})}{Z_{wt} - Z_{bot}} \]

From Niu et al. (2007), analogous to Batelis et al. (2020)
Lateral flow and interaction with rivers is the same as in LeafHydro.

Lateral flow between neighbours occurs on an octagonal grid.

Head-dependent flux to/from rivers (as in Fan et al 2007, Miguez-Macho et al 2007)

Gaining stream

Losing stream
Aquifer hydraulic conductivity can either decrease exponentially with depth (as in LeafHydro) or remain constant with depth (as in most groundwater models).
... and abstraction, which was not included in other models, is introduced as prescribed data (i.e. time dependent)

Depth to groundwater (m)

Drawdown from extraction well
Code changes – new (and edited) modules

src/science/soil/…

- **lat_flow_mod.F90**
  - Calculates cell neighbours, transmissivity
  - Returns lateral flows between cells

- **soil_hyd_jls_mod.F90**
  - Determines position of water table
  - Adds/removes abstraction, lateral flow, baseflow

- **dgw_baseflow_mod.F90**
  - Returns baseflow (+) or leakage (-) from river into aquifer

- **calc_smveq_mod.F90**
  - Called only at initialisation
  - Calculates the ‘equilibrium’ soil moisture in each soil layer (i.e. moisture content below which water starts to rise from saturated layer below)
# Code changes – new inputs and outputs

## Input variables

- **ancillaries.nml**
  - JULES_dgw
  - 11 variables:
    - Parameterise hydraulic conductivity, river-aquifer interaction
    - Grid box elevation, cell area, groundwater grid in x and y (if lat long conversion inappropriate)

- **prescribed_data.nml**
  - 1 variable:
    - Temporally and spatially variable abstraction

- **jules_hydrology.nml**
  - 3 flags:
    - Turn on groundwater, pumping, constant K with depth
  - 1 variable:
    - Time step for groundwater model

## Output variables

- 3 variables:
  - Lateral flow
  - Groundwater baseflow
  - Water table depth
Example 1: Infiltration test

Infiltration test – sandy loam soil moisture profiles (fractional saturation)
Example 2: V-shaped valley test

V-shaped valley test: sandy soil outlet discharge

(Benchmarks all use van Genuchten, JULES-DGW Brooks Corey)
Finish validation and combine code with data.

Kal to back-calculate the anisotropy ratio

e-folding depth
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