An effective hyper-resolution pseudo-3D implementation of small scale hydrological features to improve regional and global climate studies

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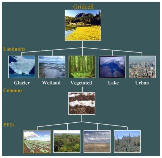
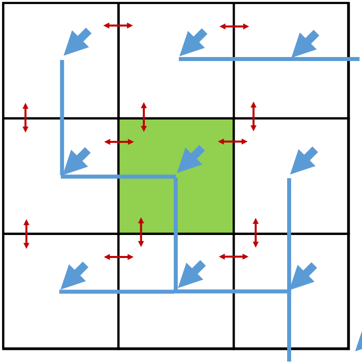
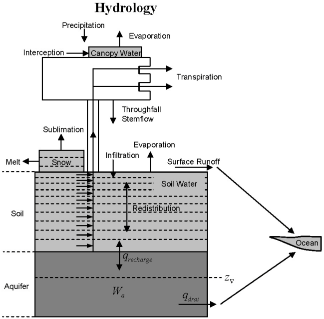
Introduction: Current hydrology in CLM







Lateral subsurface flow

Subsurface-river network flow

No lateral subsurface flow taken into account!

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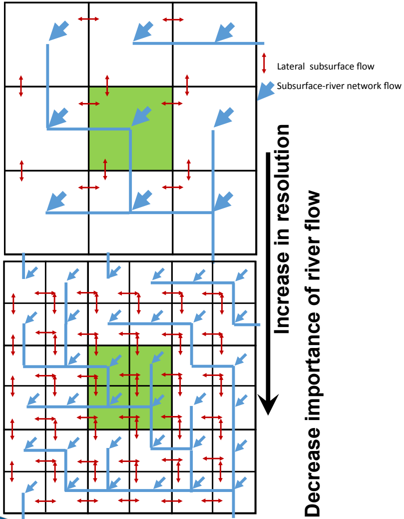
Model resolution increases due to computational developments



Importance of:

- river network decreases,
- lateral subsurface flow increases,
- elevation differences increase.

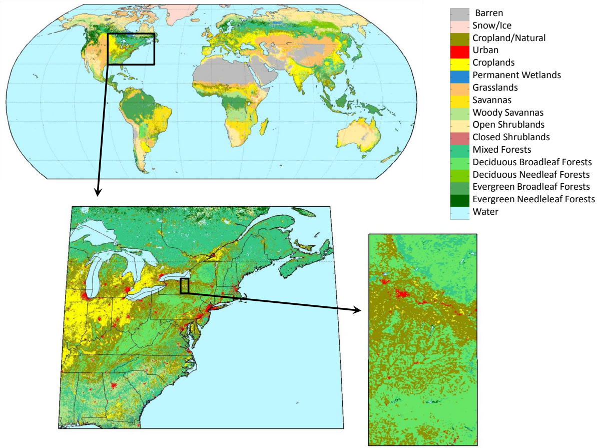
Question: How to improve the CLM's hydrology while still making use of vertical column information and focus?

Develop a new hybrid 3-D hydrological model

Separating the vertical and lateral hydrological response (pseudo 3-D):

- Vertical response:
  - Use CLM soil column,
  - Extend depth of column to bedrock,
- Lateral response:
  - Design a new model (no linear reservoir),
  - Defining a generic approach resolution independent,
  - Differentiating different hydrological response units,
  - Here: 1 km pixel resolution (hyperresolution),
- Using different resolutions for vertical and lateral hydrological response,
- Making use of high resolution datasets.

Make use of high resolution datasets



Broxton et al., 2014

- Vegetation data
- Digital elevation model (DEM)
- Soil databases

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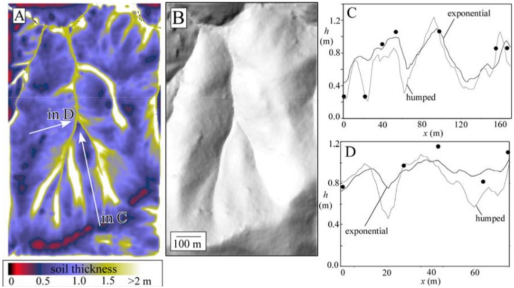
Make use of high resolution datasets



Pelletier & Rasmussen, 2009

- Vegetation data
- Digital elevation model (DEM)
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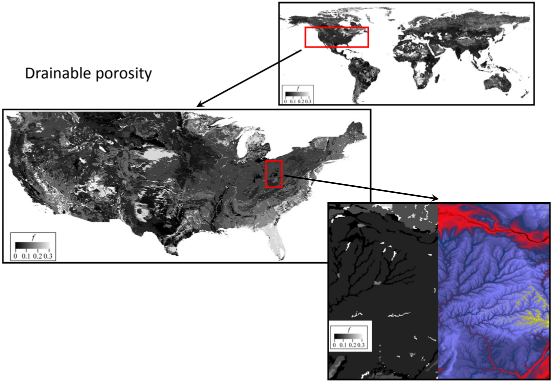
Make use of high resolution datasets

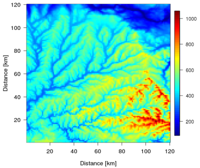
Drainable porosity

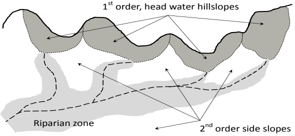


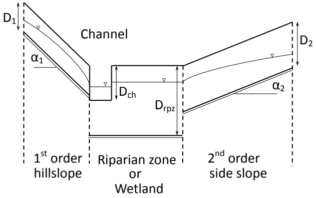
30 m DEM

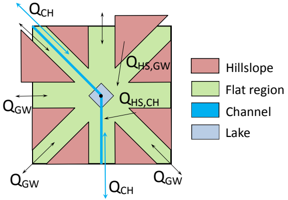
- Vegetation data
- Digital elevation model (DEM)
- Soil databases

Differentiation between different hydrological units

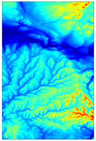




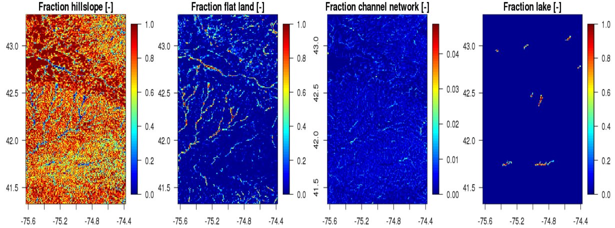




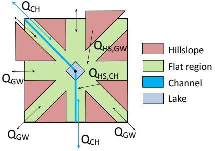
Make use of high resolution DEM to differentiate between hydrological units



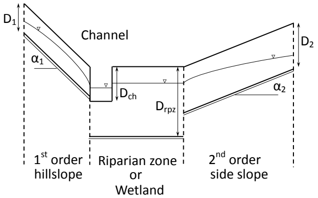
30 m DEM

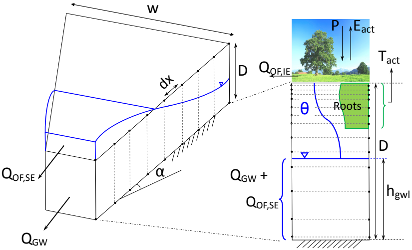


Fraction of the different lateral hydrological components for each 1 km pixel.



A hybrid 3-D approach for the hillslope type





The 1-D Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K_v(\Psi)\left(\frac{\partial \Psi}{\partial z} + 1\right)\right] - G(h)$$

The 1-D hillslope storage Boussinesq equation (Troch et al., 2003)

$$\frac{\partial}{\partial t}(f(h)\,h) = \frac{1}{w}\frac{\partial}{\partial x}\left(w\,K_l\,h\left(\sin\alpha + \frac{\partial h}{\partial x}\cos\alpha\right)\right) + \cos\alpha\,R_{gw}$$

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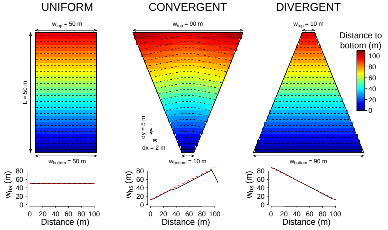
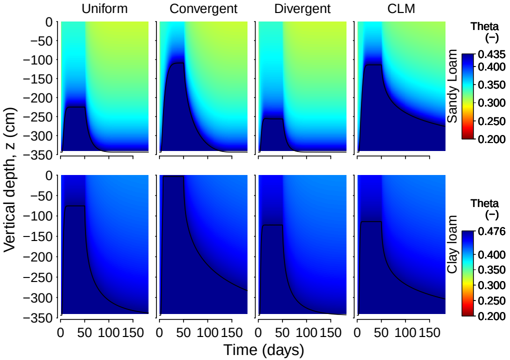
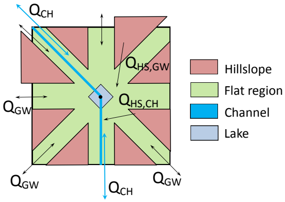
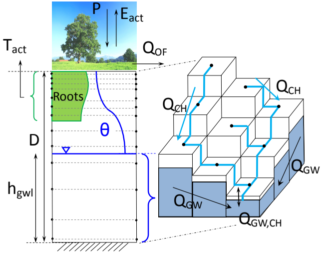
Comparison of hsB and CLM at the hillslope scale





A hybrid 3-D approach for lateral interaction between pixels





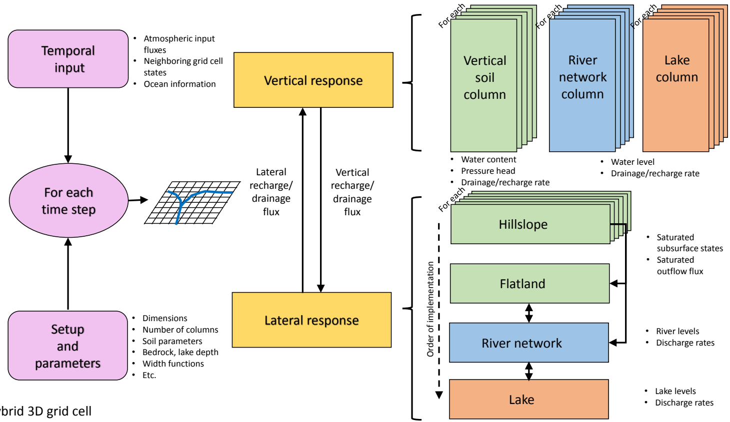
The 1-D Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K_v(\Psi)\left(\frac{\partial \Psi}{\partial z} + 1\right)\right] - G(h)$$

The 2-D subsurface Boussinesq equations (Darcy)

$$A\frac{\partial (h\,f)}{\partial t} = -\partial\left\{w_x\,h\,k_L\left(\frac{\partial h}{\partial x} + \frac{\partial E}{\partial x}\right)\right\}_x - \partial\left\{w_y\,h\,k_L\left(\frac{\partial h}{\partial y} + \frac{\partial E}{\partial y}\right)\right\}_y + R_{gw}\,A$$

Computational scheme for hybrid 3-D hydrological model



Hybrid 3D grid cell

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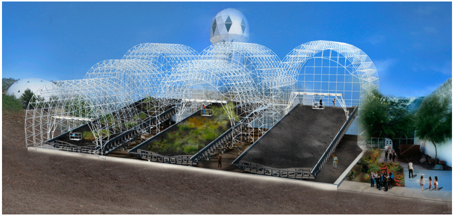
Testing the hybrid 3-D hillslope response in LEO



- Landscape Evolution Observatory (LEO) in Biosphere 2
- Convergent hillslope (11x30 m)
- Recharge and drainage experiment
- Compare to 3D Richards model CATHY (Niu et al., 2013)

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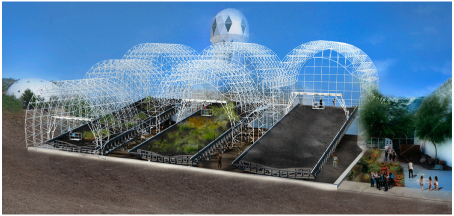

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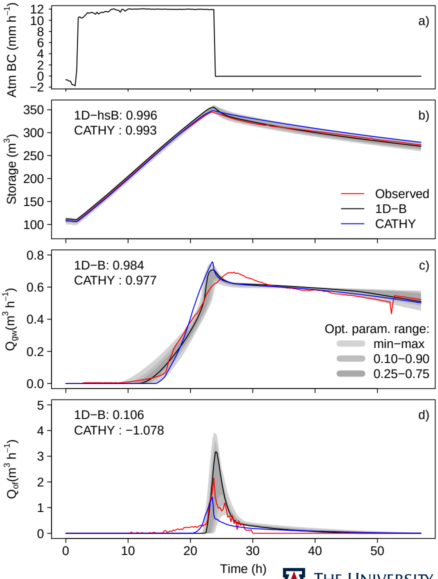

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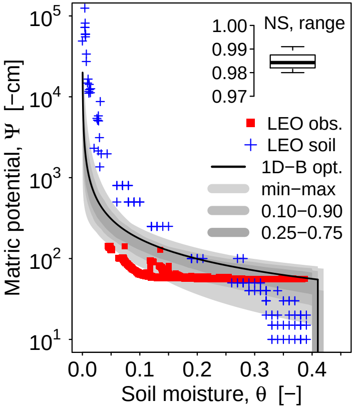
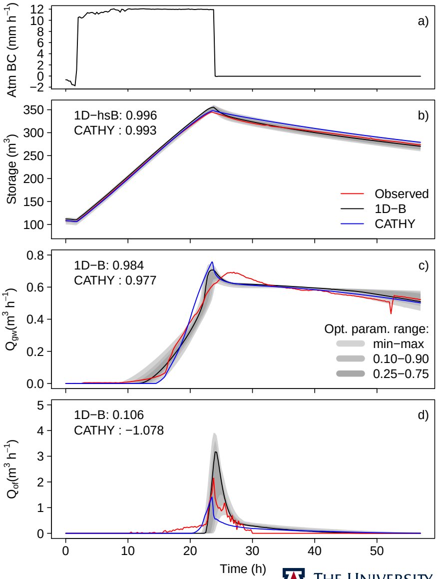
Testing the hybrid 3-D hillslope response in LEO



Good correspondence with observations!



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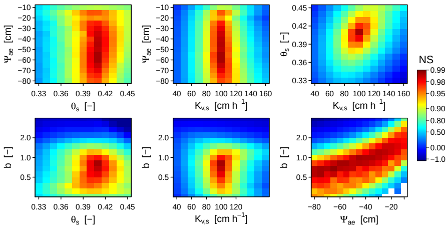
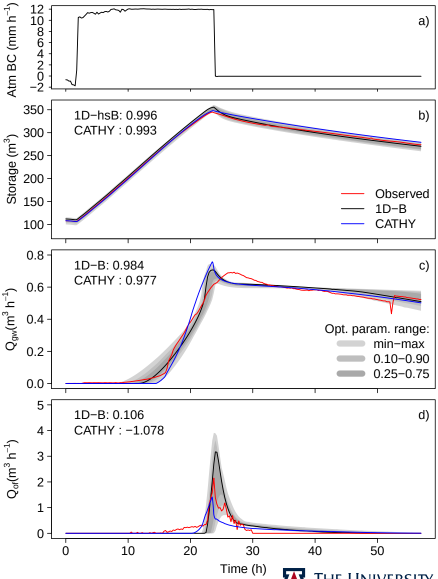


Improved understanding on parameter sensitivity!



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Conclusions

We are developing a new hybrid 3-D hydrological scheme for CLM:

- Keep the current vertical column framework of CLM,
- Differentiate between lateral and vertical response,
- Extending the depth of the vertical column to the bedrock,
- Identifying the response of different hydrological units (e.g. hillslope, flatland, river network and lake).

For next period:

- Finish implementation of shallow water equations for river network and lake,
- Couple to vertical column structure of CLM,
- Test the possibilities of this model at different scales (catchment, continental, global).
- For longer run: Add possibility of using multiple vertical columns.

Thanks for your attention!!!

Questions?

Email: pieter.hazenberg21@atmo.arizona.edu

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