We need to talk about runoff projections

- Itsy bitsy background
- Challenges (obstacles?)
- Future pathways

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15 December 2016

What purpose does multi-decadal runoff projections serve?

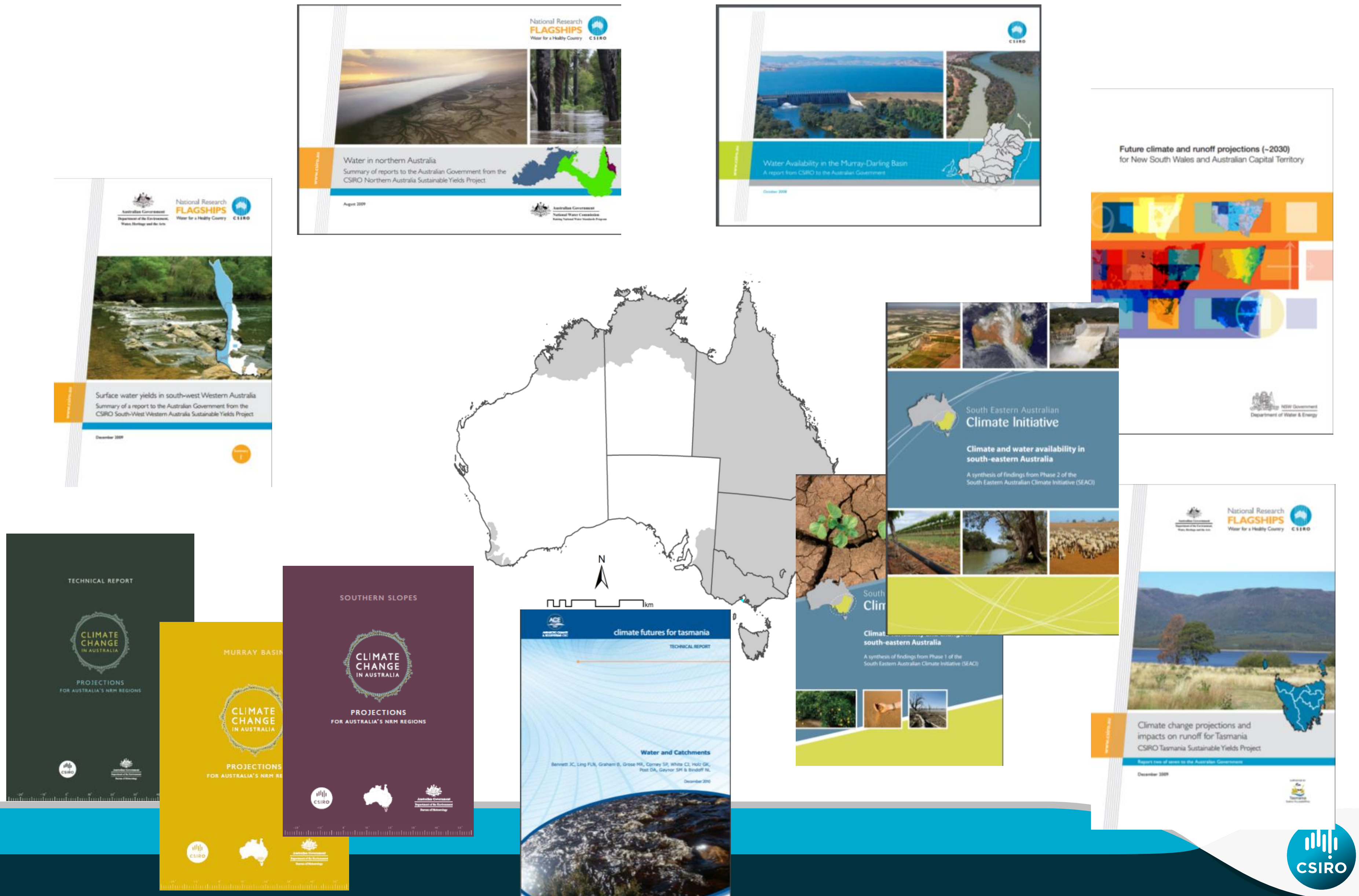
There are two reasons for conducting projections about future change to runoff:

Build understanding about the range of physically plausible impacts on water resources as a response to climate change. Such knowledge can support long-term planning of water resources and increase 'societal' adaptive capacity.

The modelling experience should lead to improved skills and capabilities in system understanding, the very least provide insights into physical model behaviour under transient (abrupt?) climate change.

Has projection work in Australia focused too long on the former?

10 years of regional runoff projections in Australia



CSIRO

Previous projection research suggest that in this geographical region, uncertainty from choice of GCMs is much greater than uncertainty from rainfall-runoff models. Hence, empirical scaling:

1. Sample one of the greatest source of uncertainty in future projections.

2. Because baseline is observed data, hydrological rainfall-runoff models can easily 'ingest' the data. No need for bias correction.

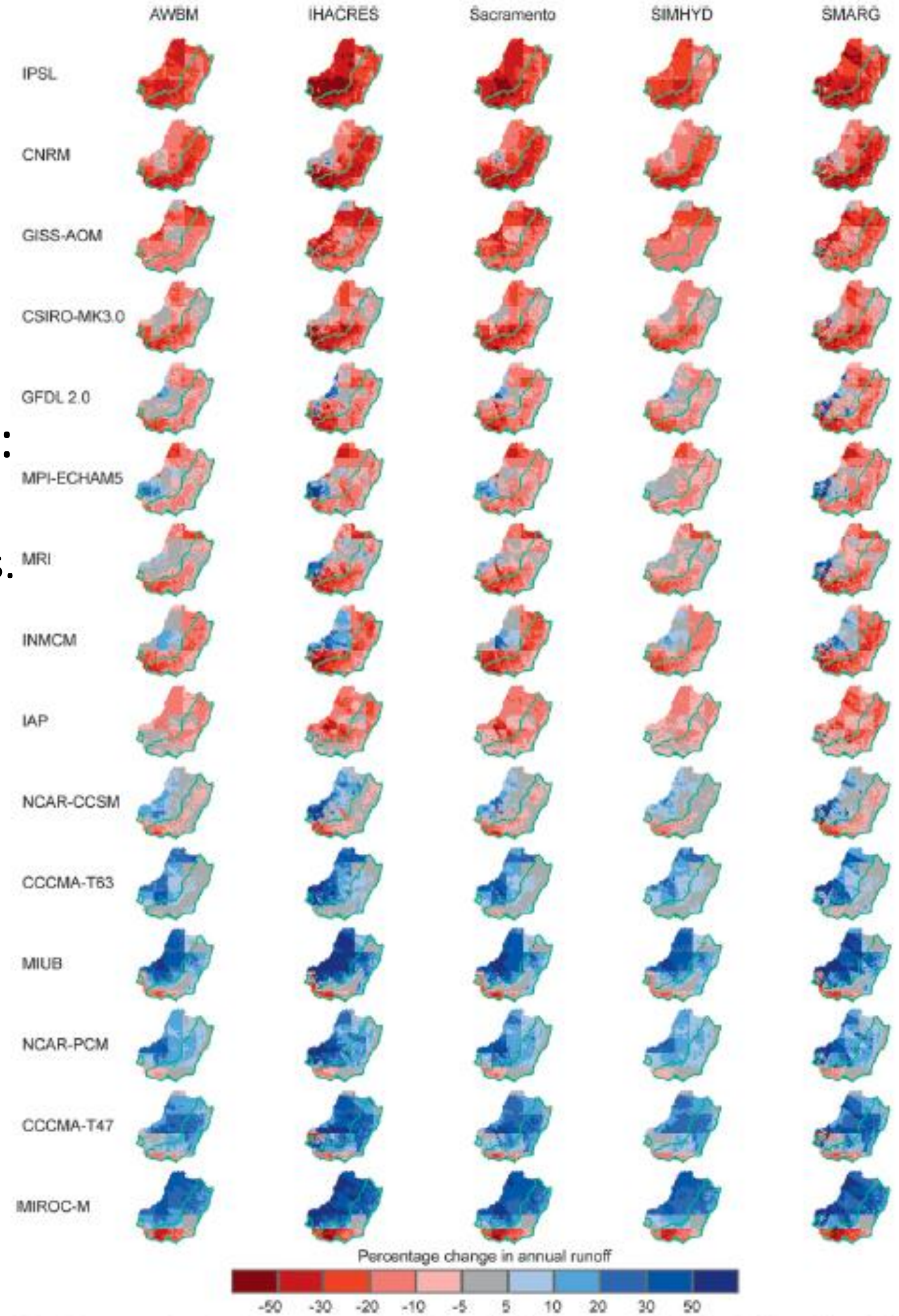


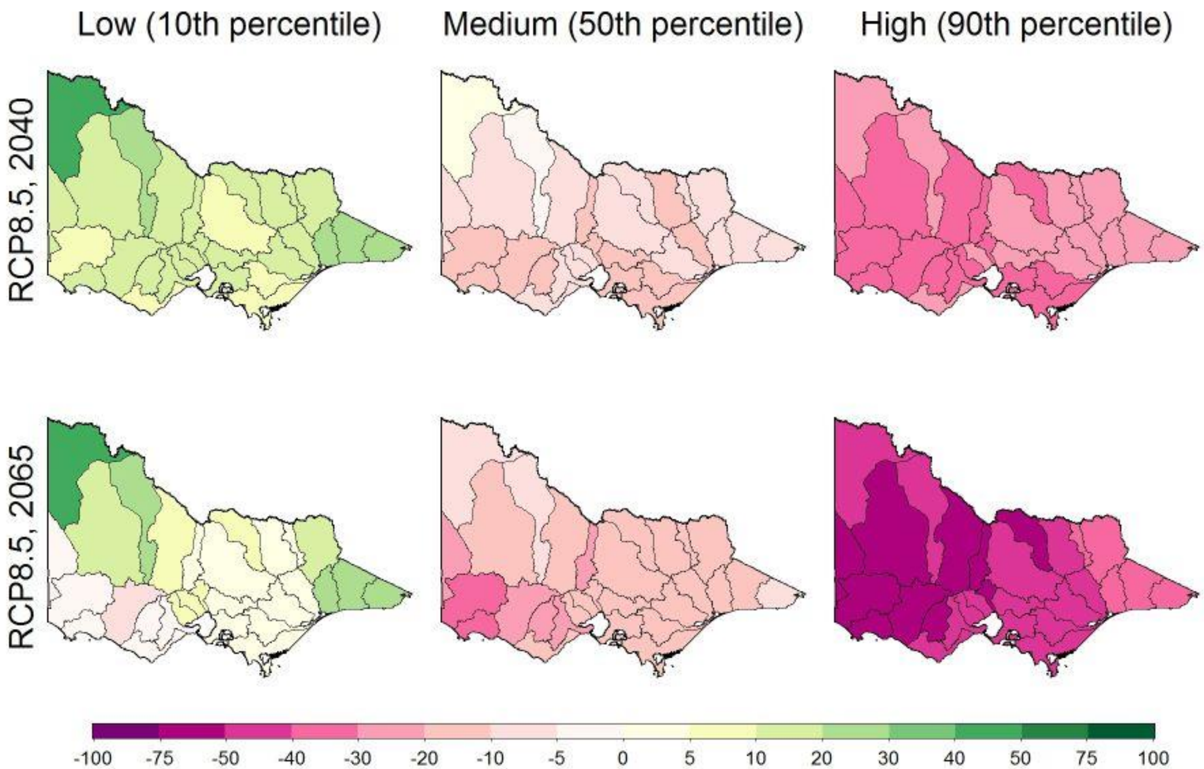
FIG. 4. Percentage change in future mean annual runoff (for a 1°C global warming) modeled by 5 hydrological models informed by projections from 15 GCMs.

Teng et al., J. Hydromet., 2012, Estimating the Relative Uncertainties…

Victorian Climate Initiative (VicCI) 2013-2016

Partnership between the Victorian government and the Australian Bureau of Meteorology and the CSIRO.

Four scenarios of future-runoff were produced for VicCI. Three of these were model based and chosen to span the range of CMIP5 GCM ensemble range.



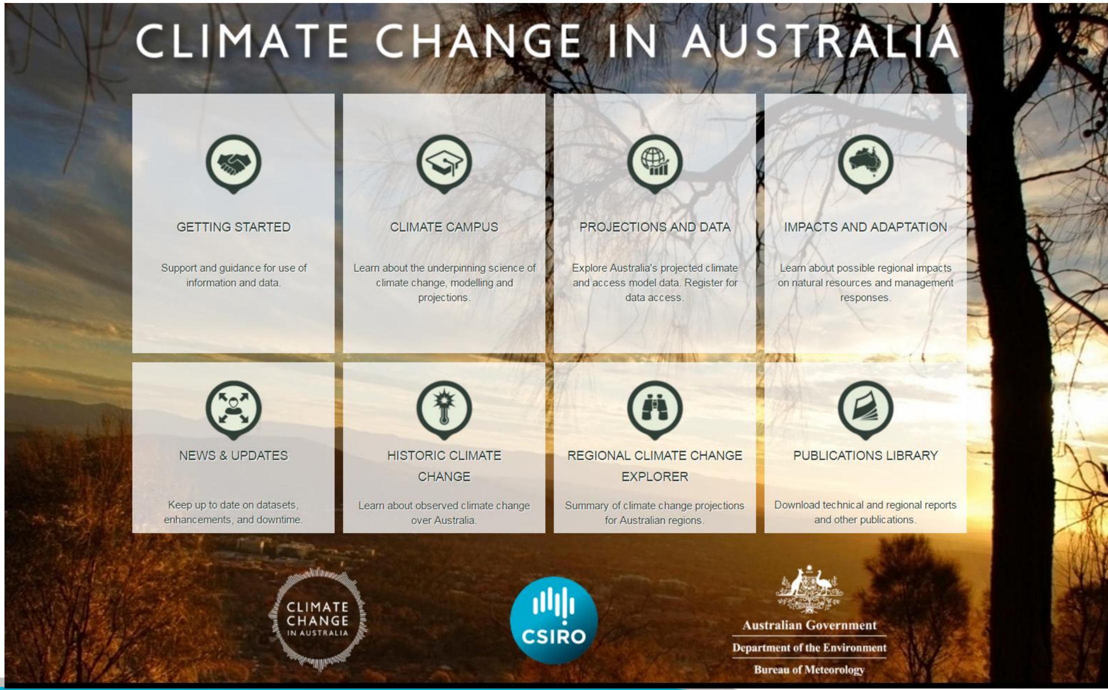
Low, Median and High model changes to basin runoff by 2031-2050 or 2056-2076 relative to 1986-2005 following RCP8.5.

‘Refining Australia’s water futures’ Project 2.7 of the Earth Systems and Climate Change (ESCC) Hub of the National Environmental Science Programme (NESP)

Information about, and analyses of, future water availability are critical for water resources planning and investment decisions; however, credible and consistent projections for a range of hydroclimate variables are not currently available.

Improving our national ability to simulate how changes in climate and land use in the future will affect Australia’s hydroclimates and water resources.

Ensuring that the projections are both relevant and useful to sectors that are significantly affected by climate and water, such as (but not limited to) agriculture.



http://nespclimate.com.au/about-the-escc-hub/

http://nespclimate.com.au/australias-water-futures/

Arising challenges

Much information of interest to stakeholders cannot be captured through empirical scaling

- **Temporal issues**

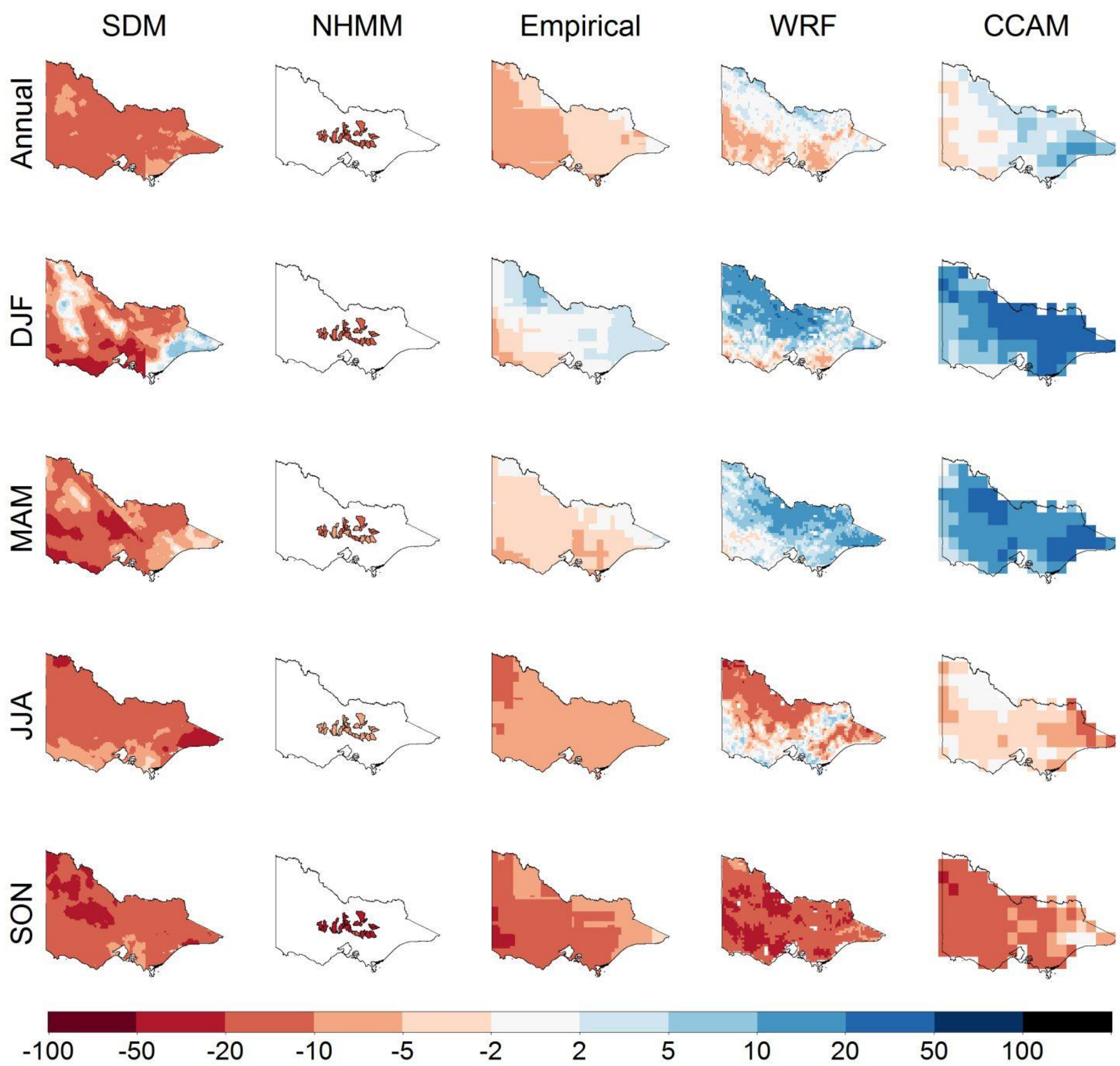
Can't capture change in sequencing (or duration of events – e.g. low flow events). Can only capture broad 'climate' style change (seasonal or monthly depending on resolution of scaling factor).

- **Spatial issues**

Can only capture change in processes/systems resolved by GCMs – hence no extremes associated with convective forced rainfall, poorly resolved orographic enhancement and influence of topography on spatial characteristics of rainfall climatology (matters if you're interested in catchment rainfall).

- **Mounting evidence of presence of regional change signal beyond the range of empirical GCM scaling.**

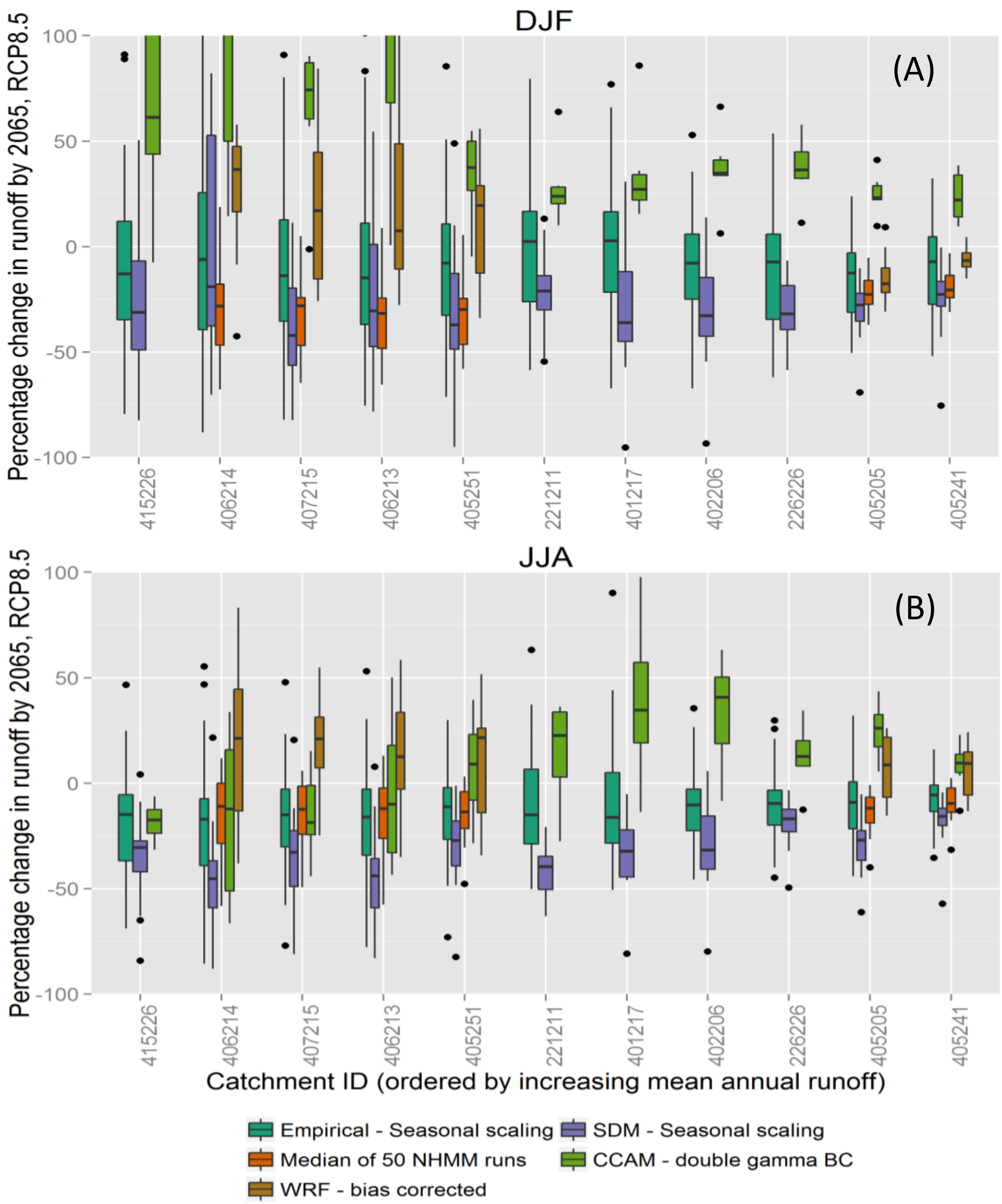
Results from VicCI indicate that downscaling expands the range of uncertainty

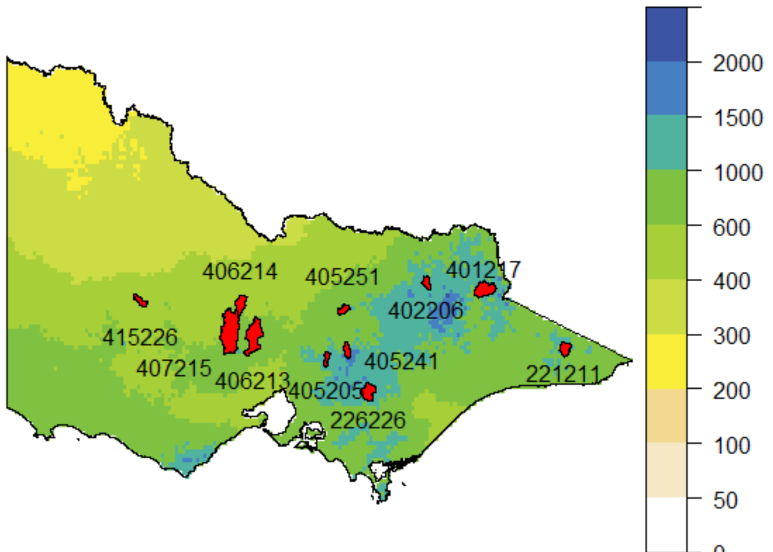


Median rainfall change [%] in mid-late 20th century following a high-emission scenario

Courtesy Nick Potter, CLW

Differences amongst datasets increase for runoff due to rainfall elasticity





Regional projections of runoff for 11 catchments in Victoria for summer (A) and winter (B). Projections follow high emission scenario RCP8.5 and represent the change between the 20-year periods 1986-2005 and 2056-2075

Courtesy Nick Potter, CLW

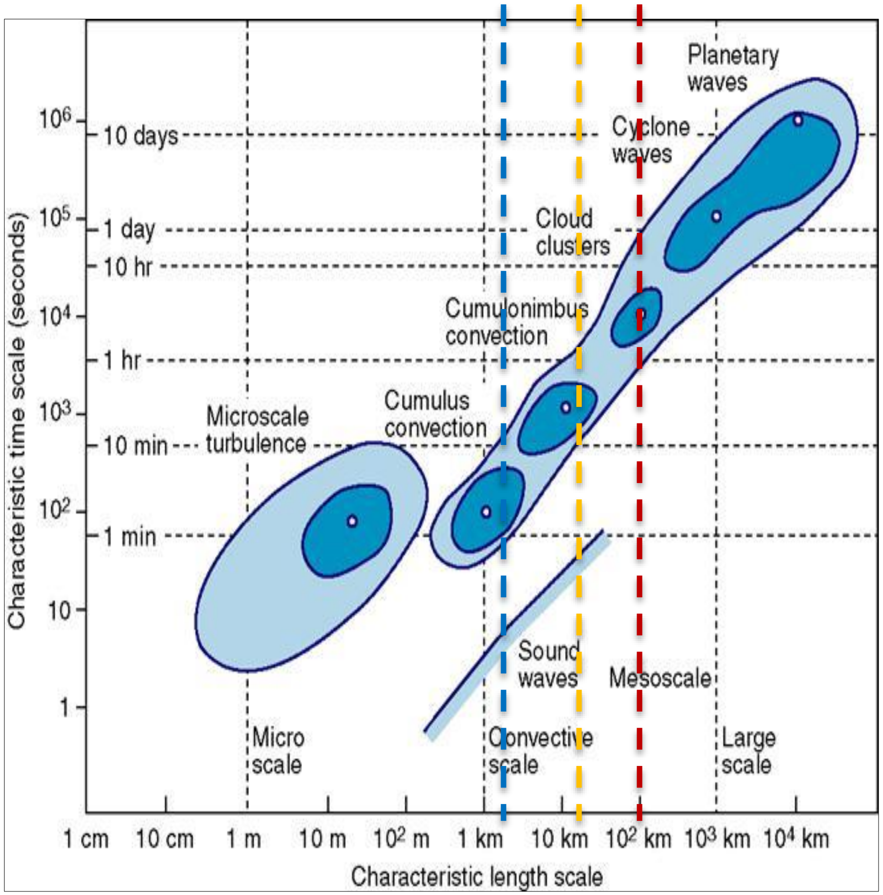
Where to next?

- Fine-resolution regional climate modelling?
- Fine-resolution intermediate complexity regional climate modelling?
- Improved modelling of surface and sub-surface (eco-)hydrology?

Fine resolution regional climate modelling

Finer resolution regional climate models ->

- Finer discretization of continuous equations describing physical processes in the atmosphere, particularly important around boundaries (e.g. coasts and marked topography).
- Avoid the use of parameterisation schemes for processes that can be explicitly resolved, e.g. cumulus convection schemes giving surface precipitation by cumuli.
- Enables the use of finer resolved land surface models, implying improved representation of ground cover, water bodies and urban settlements.



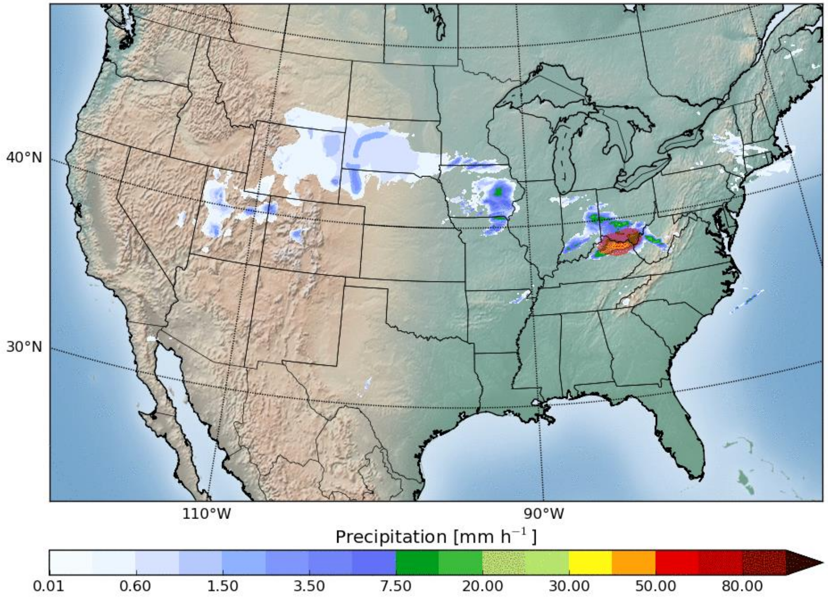
ECMWF

CPM (<4 km) RCM (>12 km) GCM (>100km)

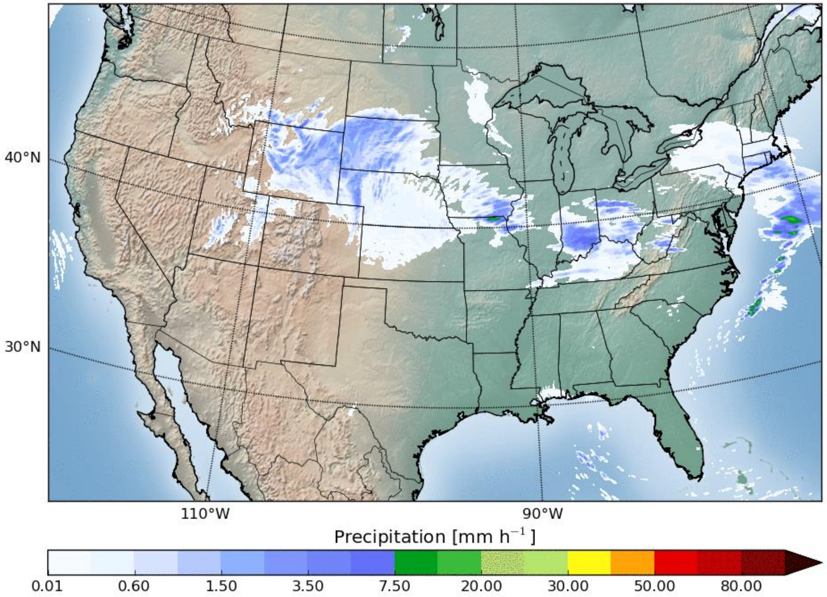
Simulating on the Storm-scale

Convective outbreak in May 2010

Observation

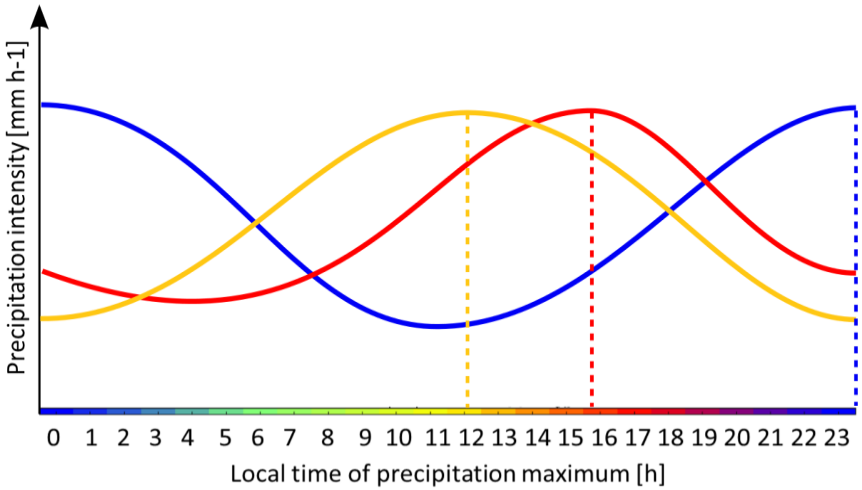


WRF 4 km

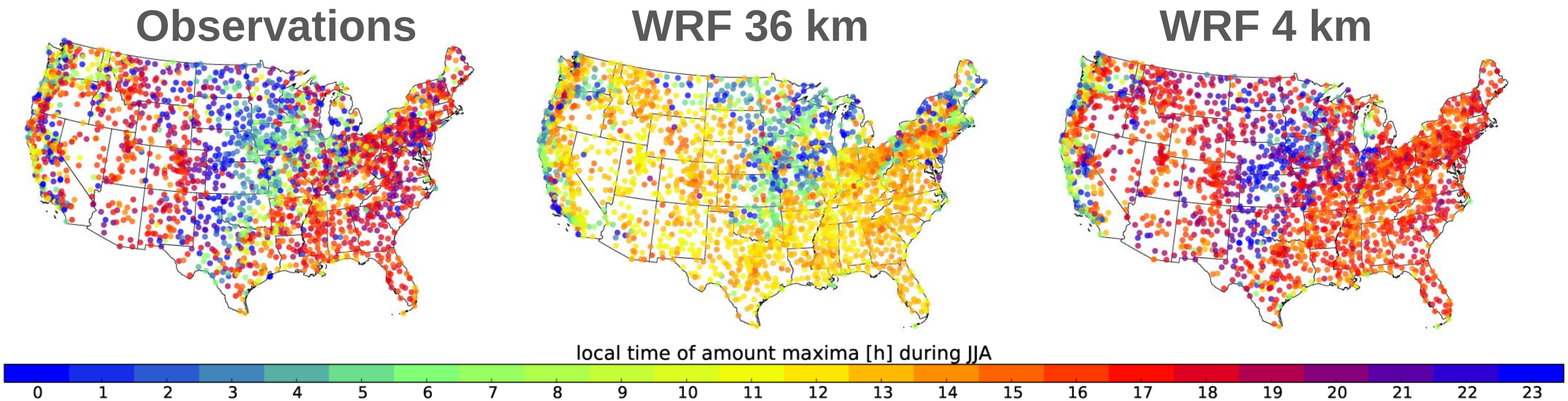


Courtesy Andreas Prein, NCAR

Diurnal Cycle in JJA



Afternoon Peak
Noon Peak
Nighttime Peak



[Mooney et al. 2016]

CPM improve diurnal cycle of of the amount, intensity, and frequency of precipitation

[Ban et al. 2014, Kendon et al. 2012, Langhans et al. 2013, Prein et al. 2013; Fosser et al. 2014]

Very high resolution climate modelling

Met Office
Hadley Centre

- 1.5km model simulates realistic hourly rainfall characteristics including extremes, unlike coarser resolution climate models (Fig 1).
- We find evidence of a future intensification of hourly rainfall in summer in the 1.5km model, which is not seen in a coarser 12km resolution model (Fig 2).
- The benefits of the 1.5km model are largely confined to summer, with the 1.5km and 12km models showing similar future changes in hourly rainfall in winter.

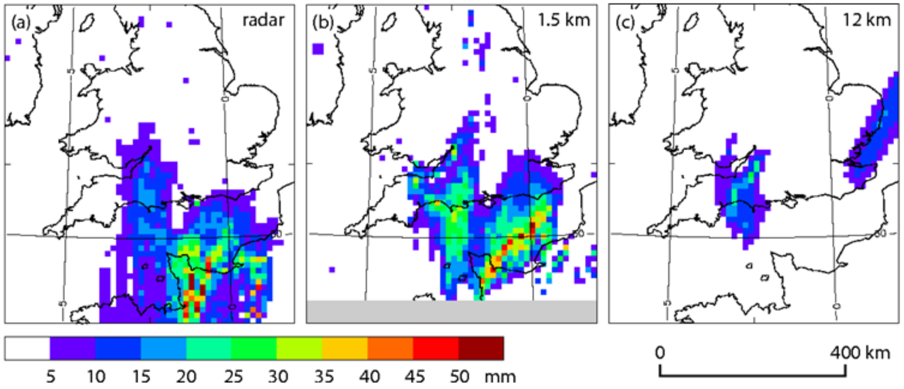


Fig 1. Rainfall accumulations for 5h period 13-18 UTC on 27th July 2013 for (a) radar, (b) 1.5km forecast model, (c) 12km forecast model. The improvement at 1.5km is typical for convective storms.

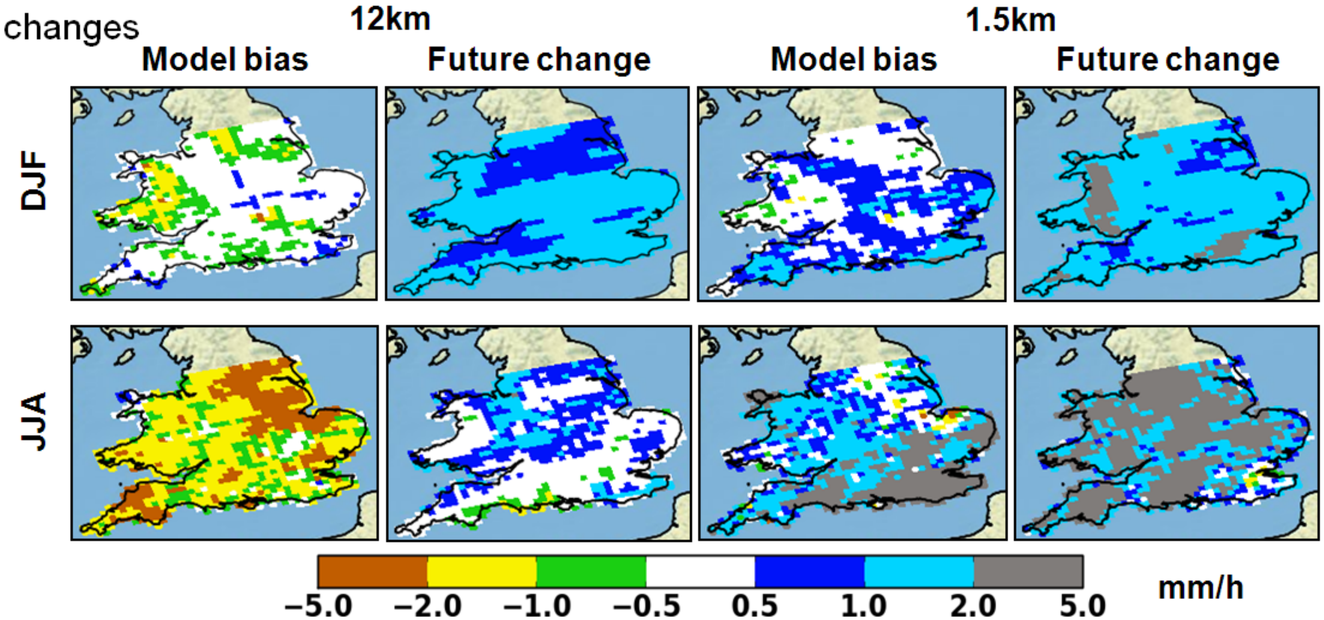


Fig 2. Model biases and future changes in heavy rainfall at the hourly timescale in the 12km (left) and 1.5km (right) models, for winter (top) and summer (bottom).

Courtesy Lizzie Kendon, UK Met Office

Does improved representation of storm dynamics and fine resolution orography also lead to improved climate change information for water resource management planning?

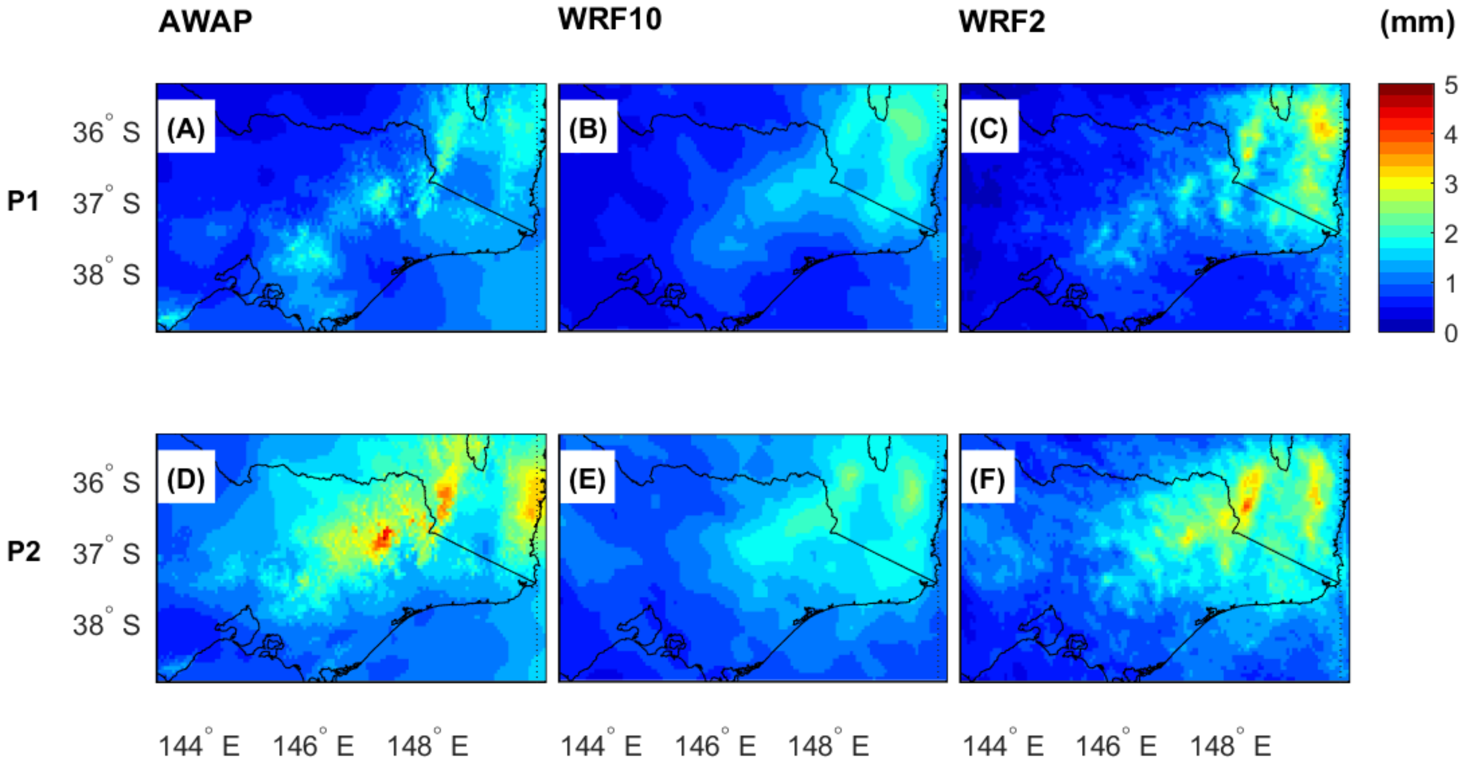
- Projections often delivered for river basins, so is the very fine resolution necessary?
- Critical rainfall characteristics are sequences of dry years (or low rainfall years), a question more related to the host GCM than the RCM.
- Running at 10-12km resolution would allow us to:
  - sample more GCMs (relevant here given he very wide range of results for this region)
  - Longer runs, relevant from hydrology perspective - noting that GCMs don't capture decadal variability that well, so larger ensemble may be more relevant.

No significant difference in AE loss for WRF output on 10 and 2 km resolution

Summer rainfall mean (DJF)

Low intensity days

High intensity days



SPC test
P-value
all 0.78
>90 0.82

SPC test
P-value
all 0.88
>90 0.99

Ekstrom and Gilleland, WRR in revision

Fine resolution regional modelling is a key tool for insights into process understanding, but output is not necessarily that meaningful (yet) for water resource management where spatial precision on output scale is important. No clear evidence that CPM is superior to coarser resolution on daily scales.

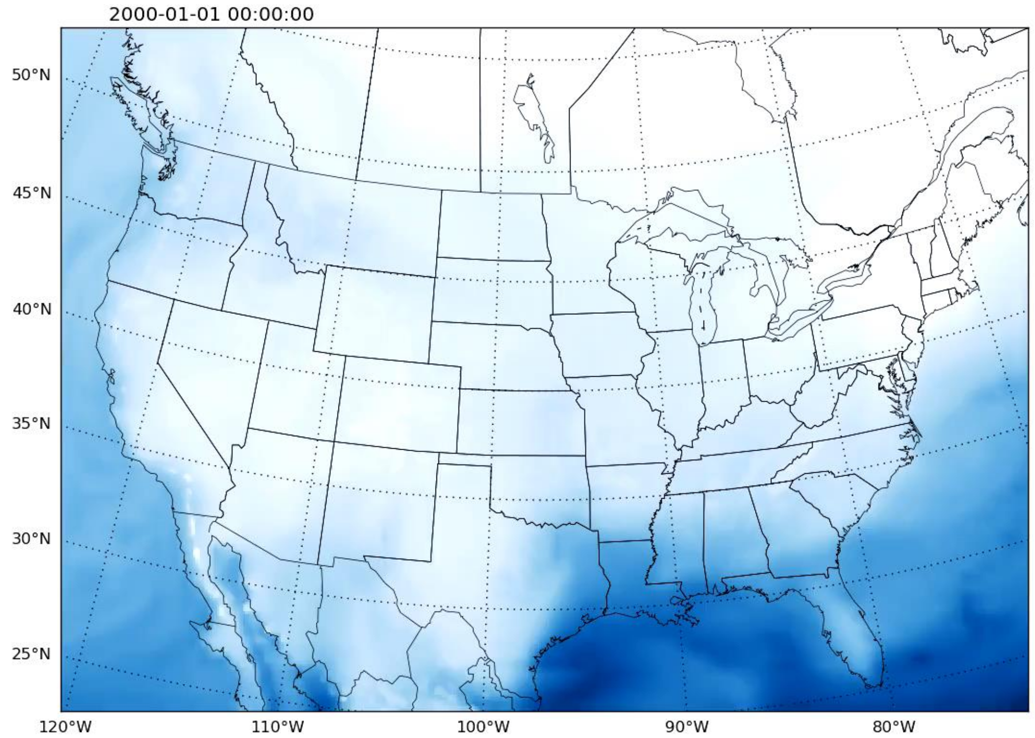
see e.g.

Kundzewicz, Z. W., and E. Z. Stakhiv (2010), Are climate models "ready for prime time" in water resources management applications, or is more research needed?, *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, *55*(7), 1085-1089

Chan, S.C. et al., Clim Dyn (2013), Does increasing the spatial resolution of a regional climate model improve the simulated daily precipitation? 41: 1475. doi:10.1007/s00382-012-1568-9

Kay, A. et al. (2015), Use of very high resolution climate model data for hydrological modelling: baseline performance and future flood changes, *Climatic Change*, *133*(2), 193-208

Fine resolution intermediate complexity models could provide similar skill projections, but allow a much greater sampling of GCM uncertainty

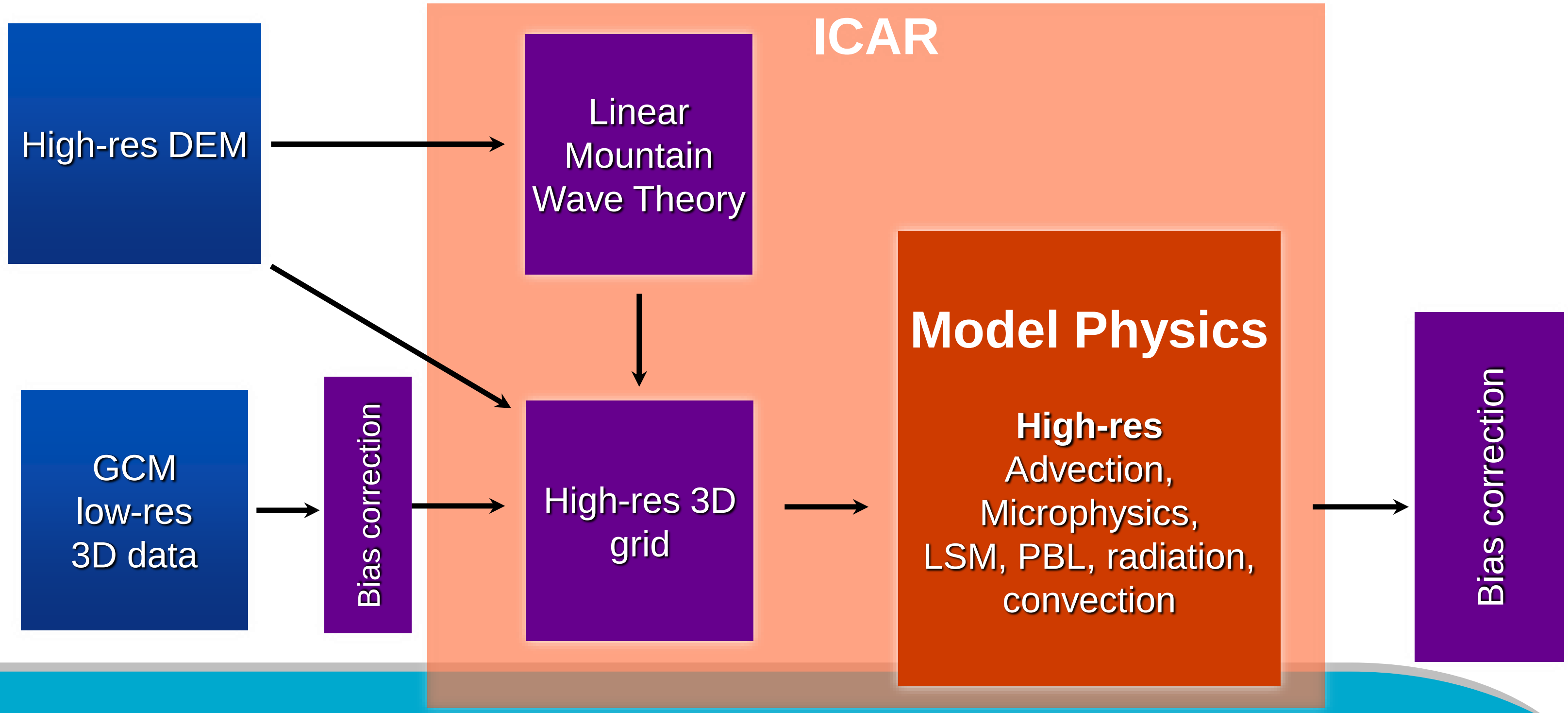


Courtesy Ethan Gutmann, NCAR

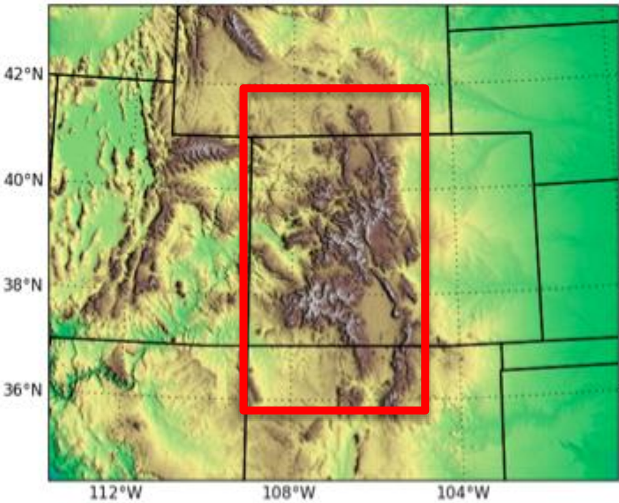
Intermediate Complexity Atmospheric Research model (ICAR)

Gutmann et al 2016: The Intermediate Complexity Atmospheric Research Model (ICAR). J.Hydrometeor., 17, 957–973, doi: 10.1175/JHM-D-15-0155.1.

Identify the key physics and develop a simple model
GOAL: >90% of the information for <1% of the cost



ICAR Precipitation Real Simulation



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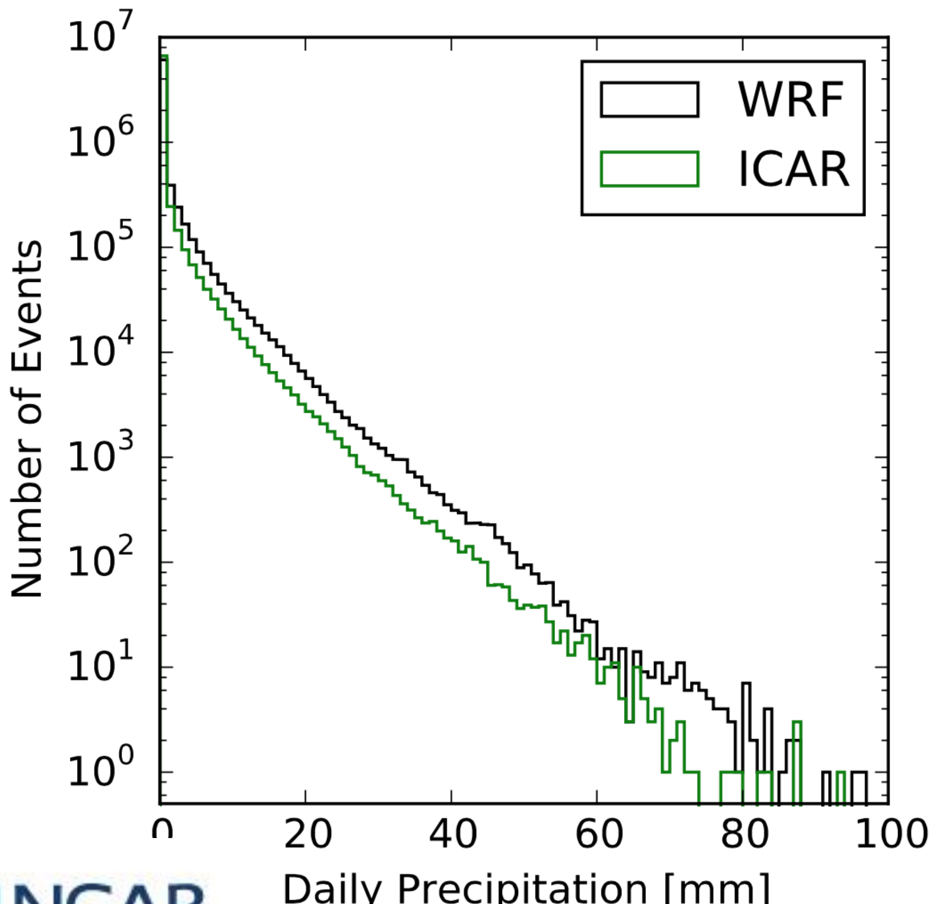
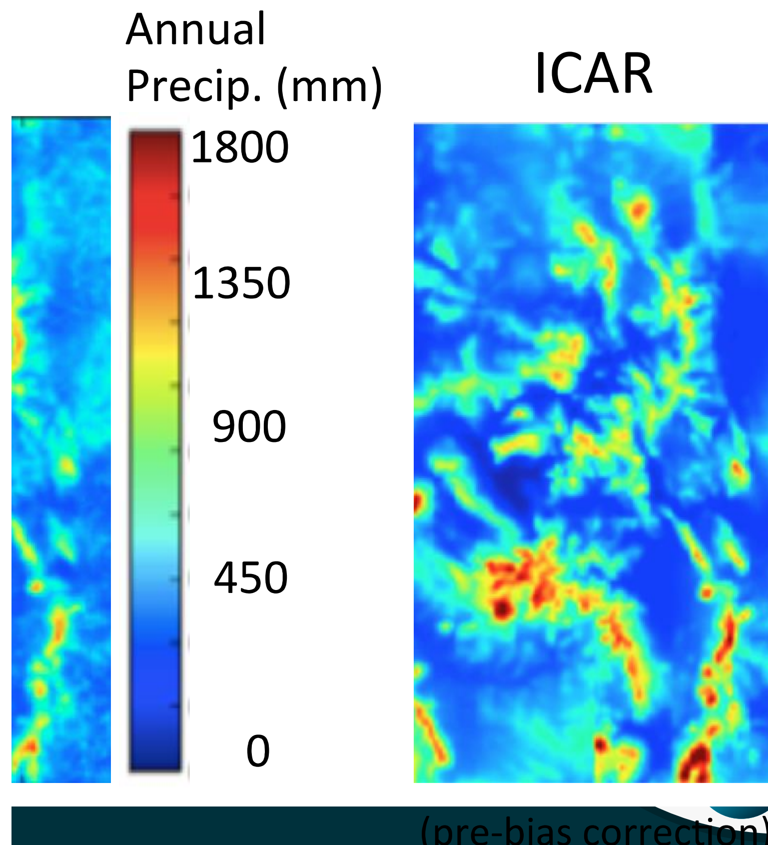




Simulating the hydrologic response to climate change

We know about issues around rainfall-runoff model sensitivity to non-stationarity in the climate (and catchment characteristics?).

VAZE, J., et al. 2010. Climate non-stationarity – Validity of calibrated rainfall–runoff models for use in climate change studies. *Journal of Hydrology,* 394, 447-457

MILLY, P. C. D., et al., 2015. On Critiques of "Stationarity is Dead: Whither Water Management?". *Water Resources Research,* 51, 7785-7789

We know that model structure and parameter optimisation can influence the change signal (and differently so in different geographical regions)

MENDOZA, P. A., et al. 2016. How do hydrologic modeling decisions affect the portrayal of climate change impacts? *Hydrological Processes,* 30, 1071-1095.

Explicit modelling of surface and subsurface flow

e.g. ParFlow

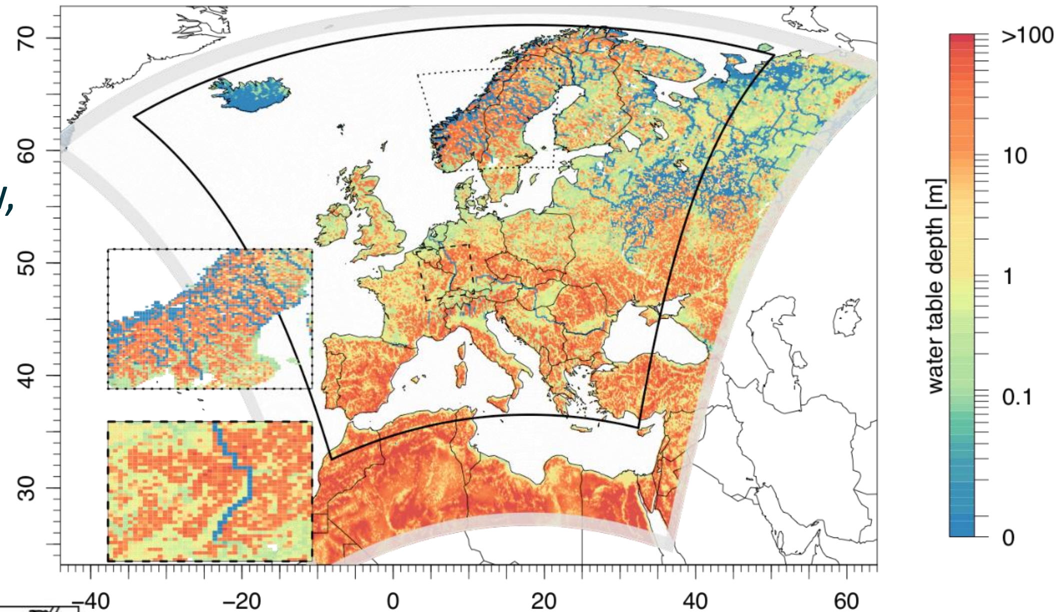
ParFlow is an open-source, object-oriented, parallel watershed flow model. It includes fully-integrated overland flow, the ability to simulate complex topography, geology and heterogeneity and coupled land-surface processes including the land-energy budget, biogeochemistry and snow. -> allows for representation of anthropogenic impacts (e.g. groundwater pumping, surface-water reservoirs, irrigation, urbanisation)

ParFlow is the result of a long, multi-institutional development history and is now a collaborative effort between CSM, F-Z Jülich, UniBonn, LLNL, WSU, LBL, and LTHE.

ParFlow has been coupled to the mesoscale, meteorological code ARPS, the NCAR code WRF and the German Weather Service model COSMO.

https://inside.mines.edu/~rmaxwell/maxwell_software.shtml

ParFlow examples: Water cycle, coupled model domains Simulated water table depth (ParFlow). European domain show, spinup runs with river networks starting to evolve, redistribution of surface and groundwater in continuum approach. Surface runoff and subsurface hydrodynamics are linked



Keune, J., et al. (2016), Studying the influence of groundwater representations on land surface-atmosphere feedbacks during the European heat wave in 2003, J. Geophys. Res. Atmos., 121, doi:10.1002/2016JD025426.

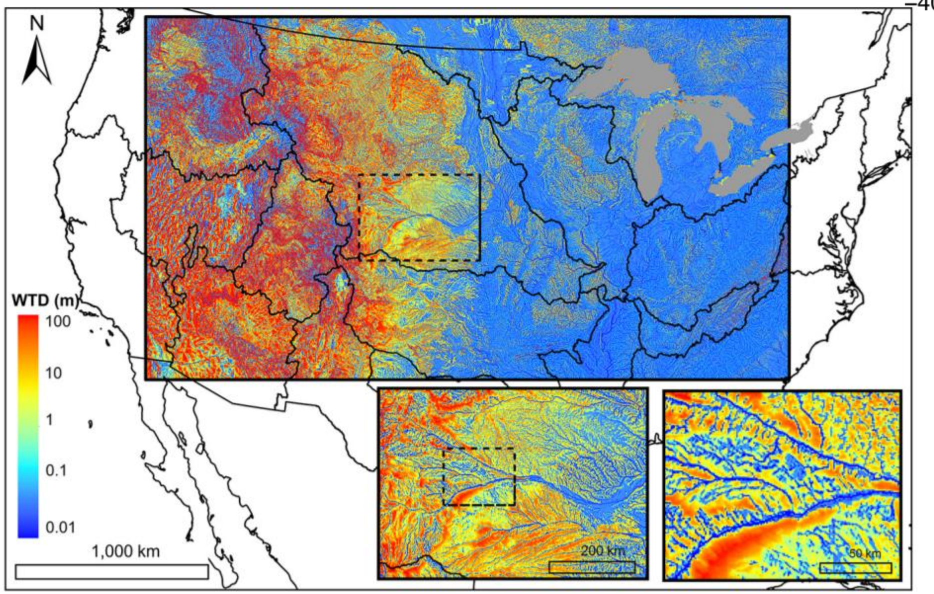


Figure 4. Map of water table depth (m) over the simulation domain with two insets zooming into the North and South Platte River basin, headwaters to the Mississippi River. Colors represent depth in log scale (from 0.01 to 100 m).

Maxwell., et al. (2015) A high-resolution simulation of groundwater and surface water over most of the continental US with the integrated hydrologic model ParFlow v3. Geosci. Model Dev., 8, 923-937, doi:10.5194/gmd-8-923-2015

Courtesy Klaus Georgen, Fz Juelich

Summary (1)

Recent and ongoing work on projecting change rely on climate change information as derived from empirically scaled gridded observed datasets. This method does a good job of sampling GCM structural uncertainty, but cannot provide some change-information sought by the water use community.

Simply providing finer resolution projections are not necessarily meaningful if we want to improve projections of streamflow.

- No clear evidence of superior skill on daily level in very fine resolution projections.
- Long simulation runs are very costly – what information is not sampled if restricted computing resources are spent on long runs with single models forced by a small selection of GCMS?

Summary-ish (2)

A suggestion of meaningful activities:

- Improve representation of key uncertainties through methods more sophisticated than empirical scaling, but less computationally demanding to RCMS.
- Idealised case studies on rainfall processes, land-surface response, etc.
- Improve confidence in the ability of hydrological models to operate in regimes not sampled in historical data.
- Knowledge based research rather than end-product focused research. This **require funding agencies to value knowledge and trust that improved knowledge leads to improved methods and higher confidence in model output**. It requires **cross discipline collaboration** of climate and hydrological community using the same model framework. Regional climate models and LSMs can be used for hydrological purposes if projects are designed to support advances in hydrological processes.

Thank you

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