

# Land-surface modelling: understanding evaporation

Emma Robinson, CEH

Cardiff, 12<sup>th</sup> June 2015

# Centre for Ecology & Hydrology

## NERC Research Centre

4 UK sites, 600 staff

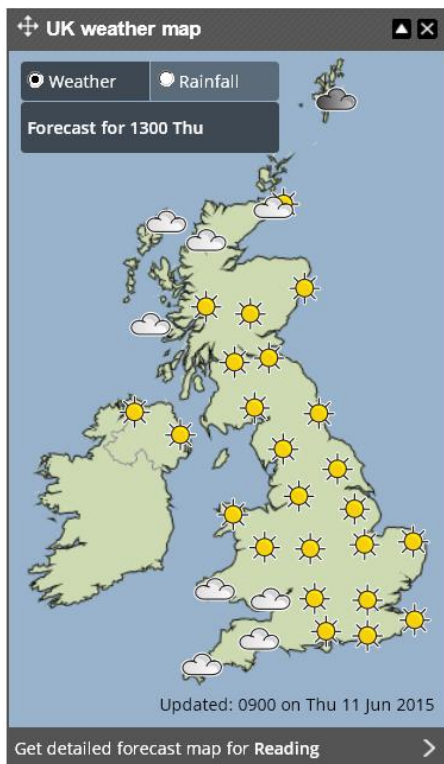
### Science areas:

- Natural capital
- Natural hazards
- Soil
- Water resources
- Biosphere-atmosphere interactions
- Ecological processes and resilience
- Monitoring and observation systems
- Pollution and environmental risk
- Sustainability and land management
- Environmental informatics



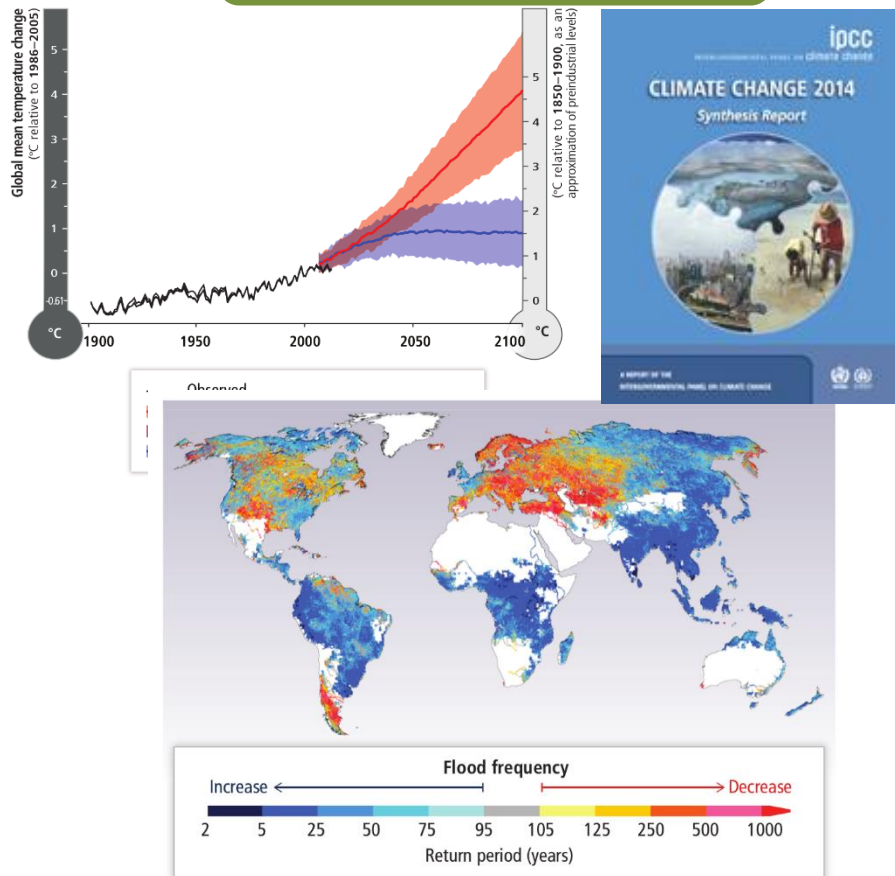
# Earth system modelling

## Weather forecasting



Met Office

## Climate



IPCC Fifth assessment report

## MetO Unified Model

# Earth system modelling



Atmospheric circulation

Atmospheric chemistry



Ocean circulation

Land physics and hydrology

Ocean biogeochemistry

Plant and soil biogeochemistry

Sea ice

# Land surface modelling

## Processes:

Energy

Water

Carbon

Other chemistry



## Impacts:

Feedbacks

Water resources

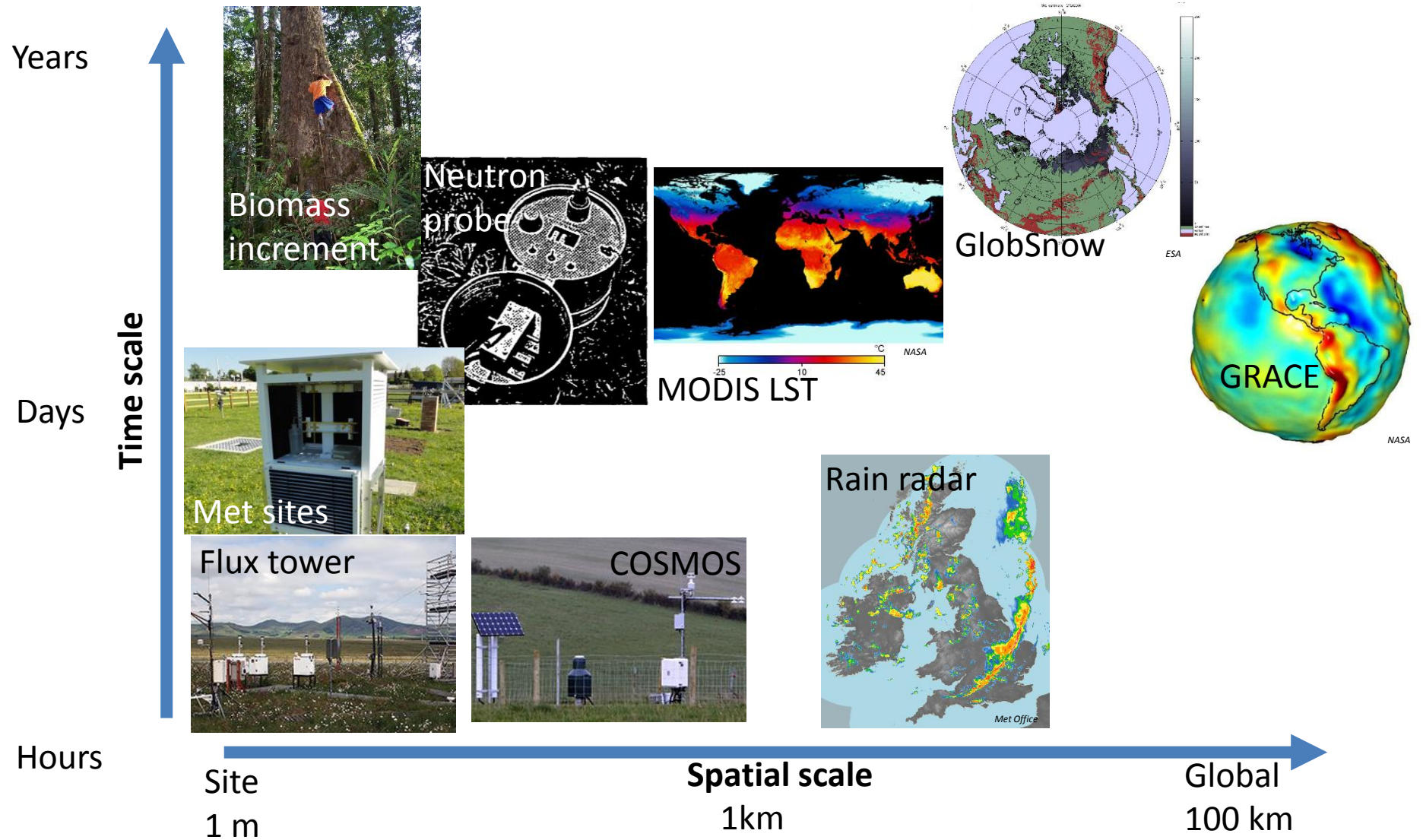
Agriculture

Ecosystems

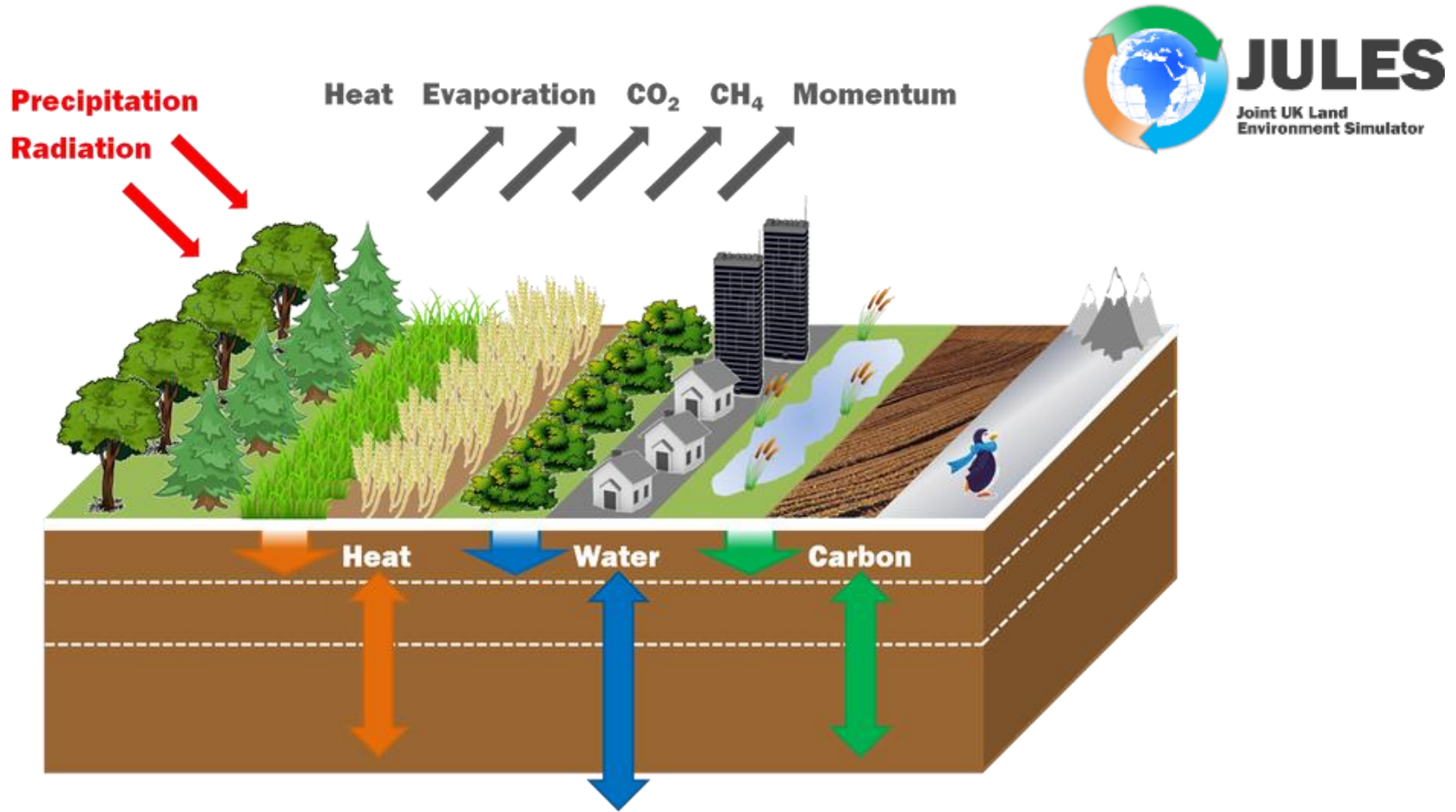
Hazards

Policy

# Observations



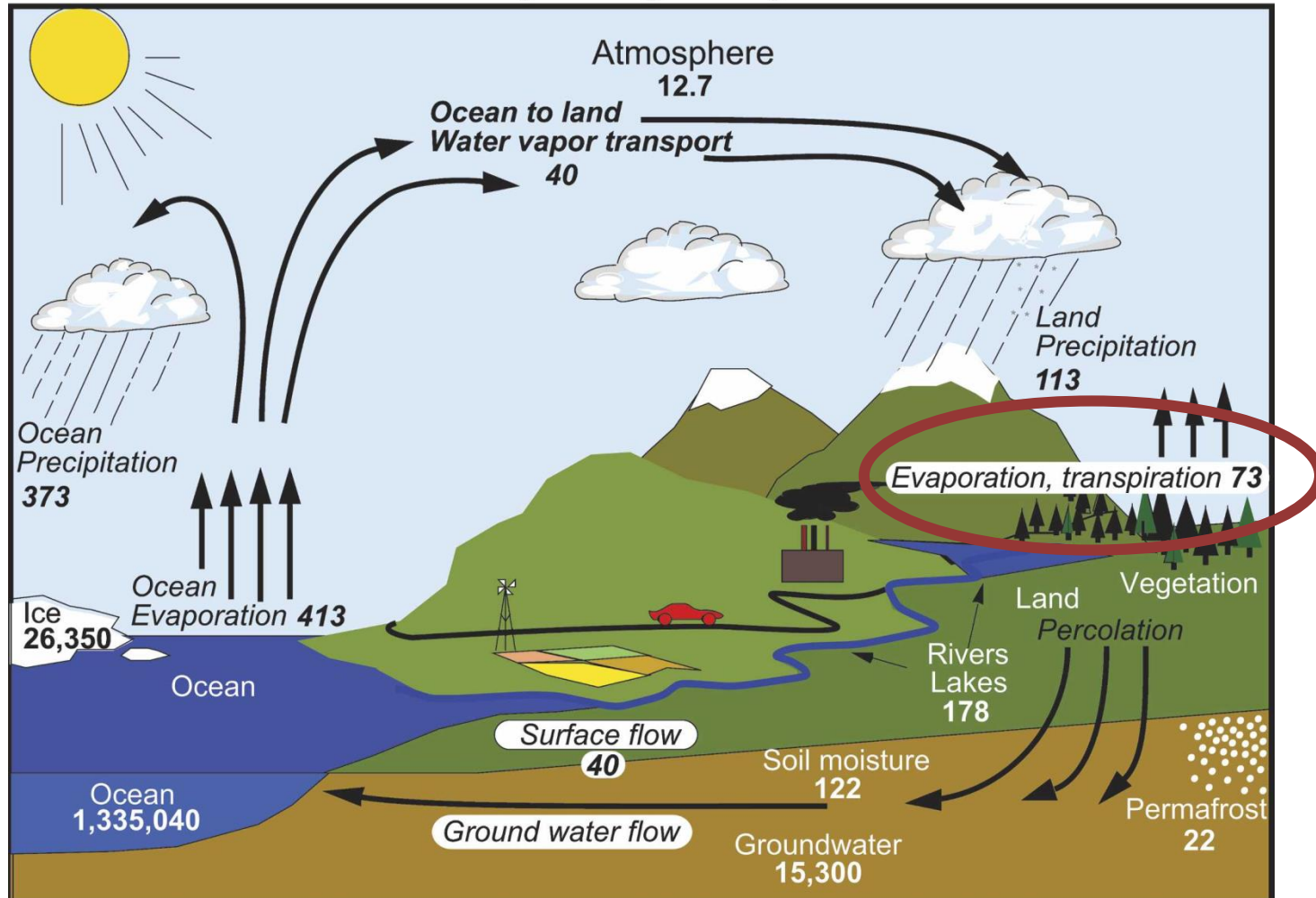
# JULES



Other land surface models are available:  
ISMA, CLASS, TESSEL, NOAH, CLM...

# Evaporation

## Hydrological Cycle

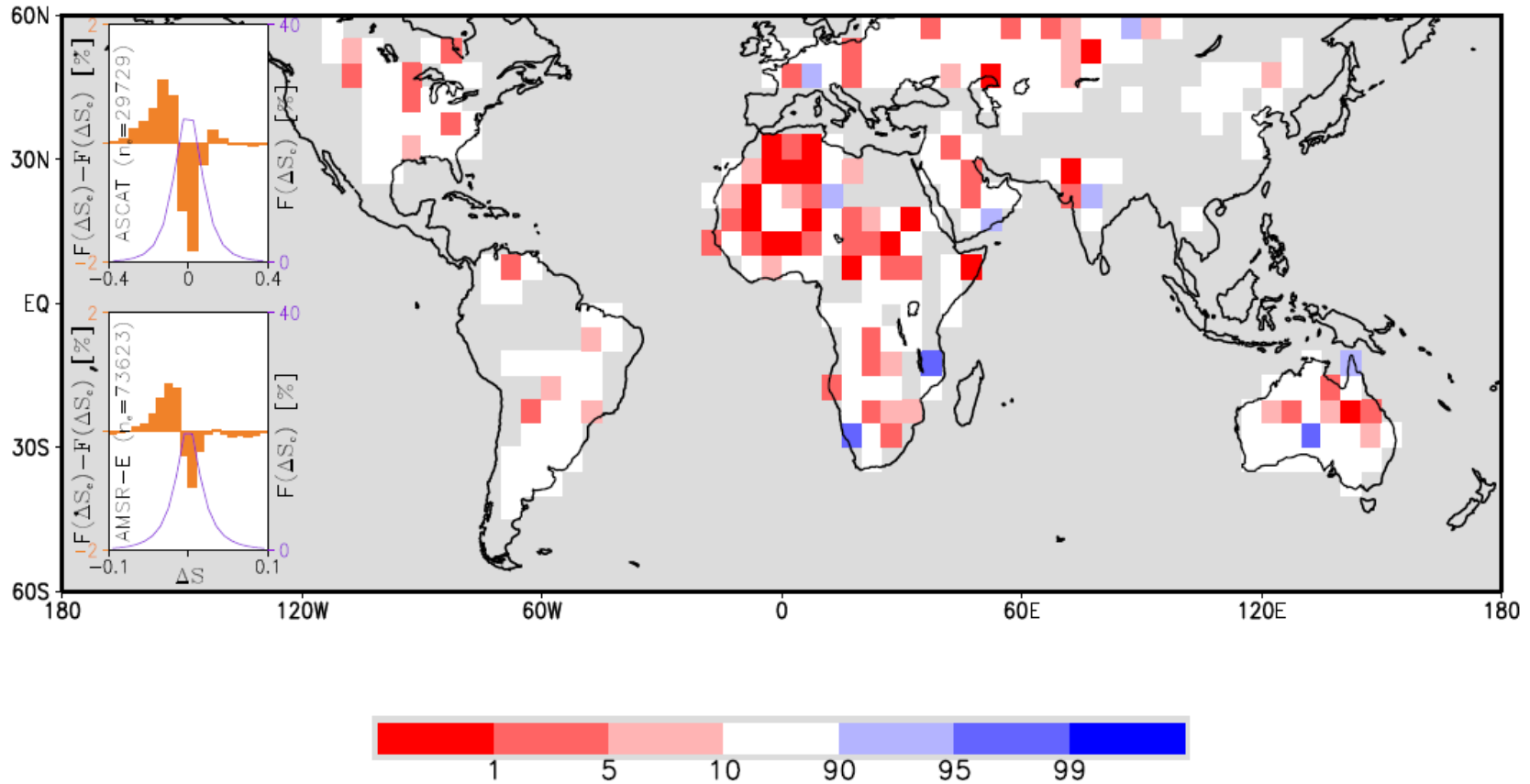


Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

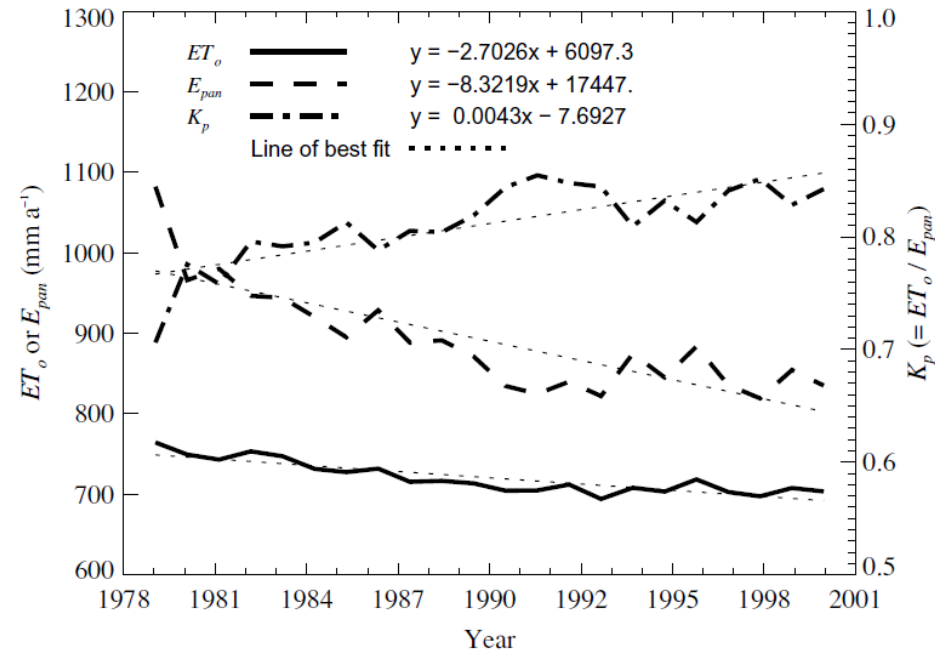
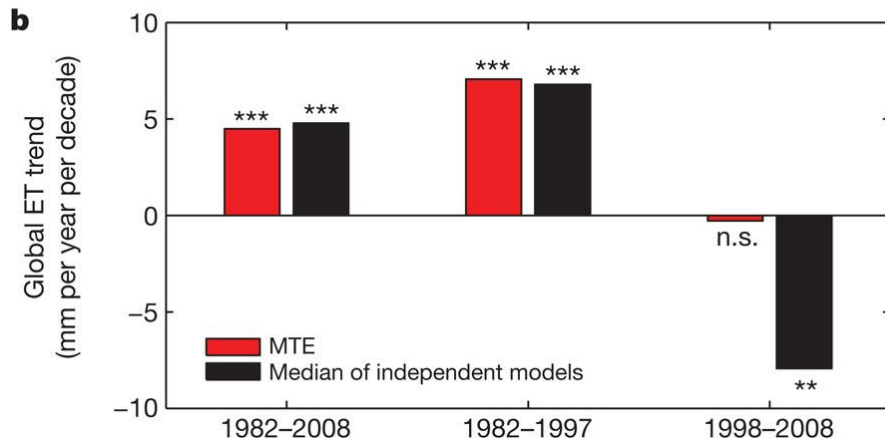
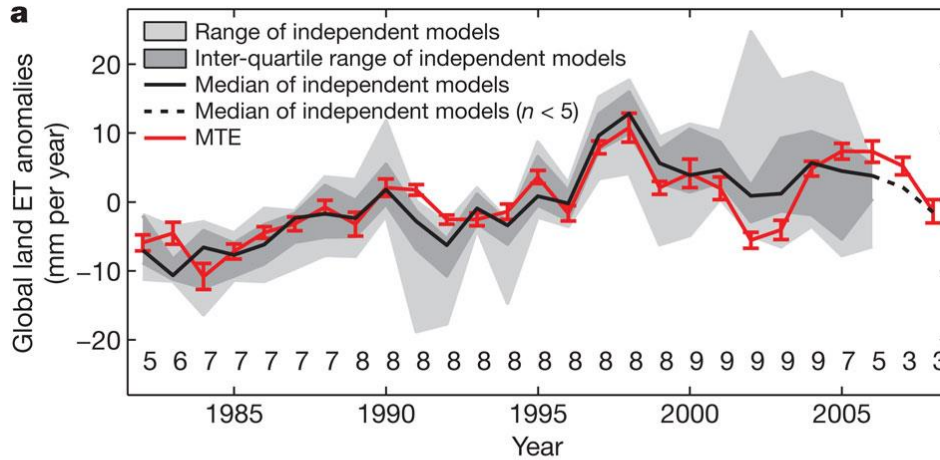
Trenberth et al (2007)



# Evaporation: feedback on rainfall



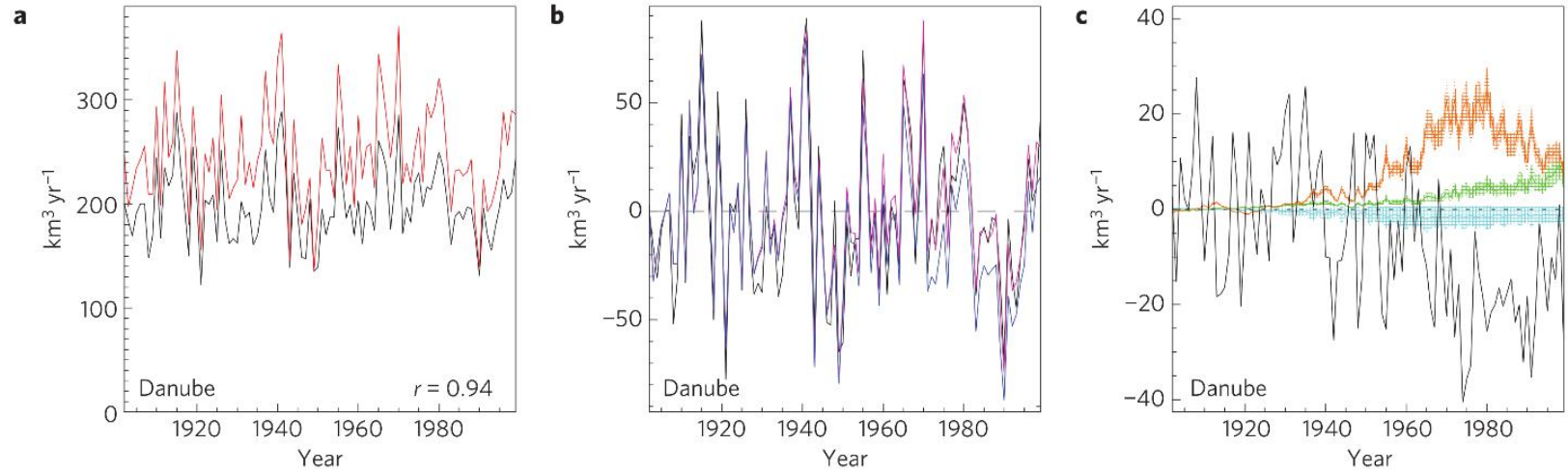
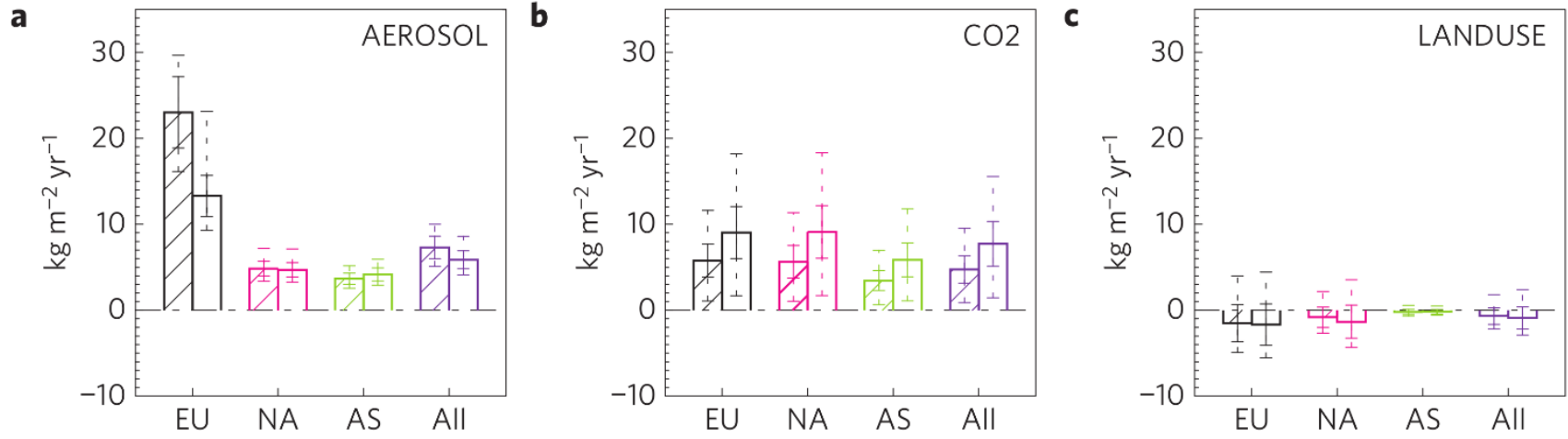
# Evaporation changes



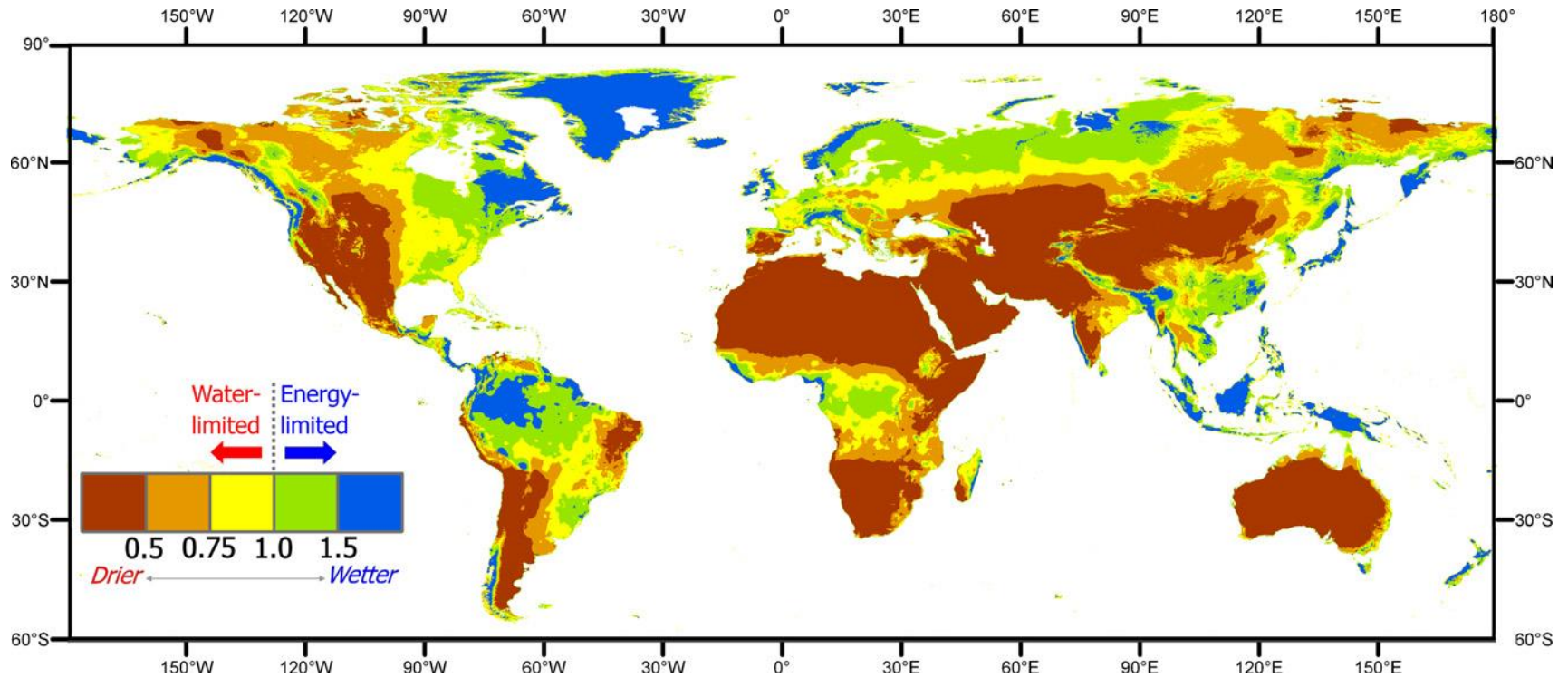
Jung et al (2010), Nature

McVicar et al (2012) J Hydrol

# Changing PET

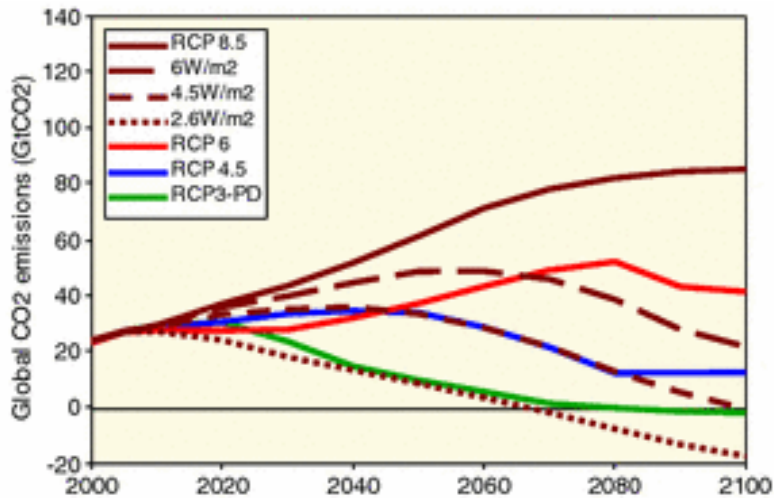


# Evaporation limitation

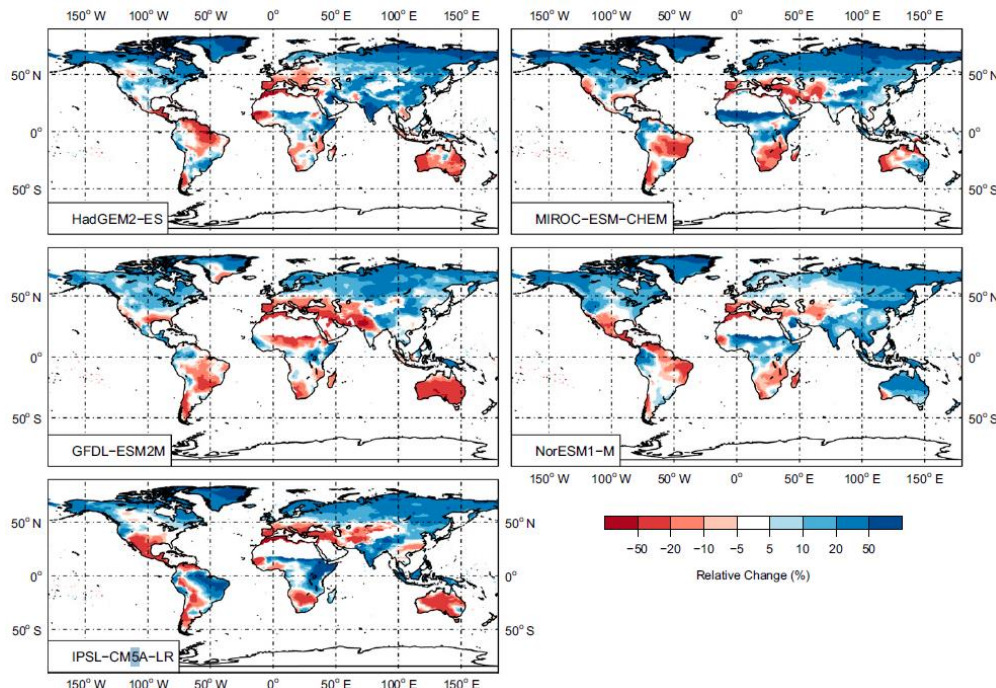
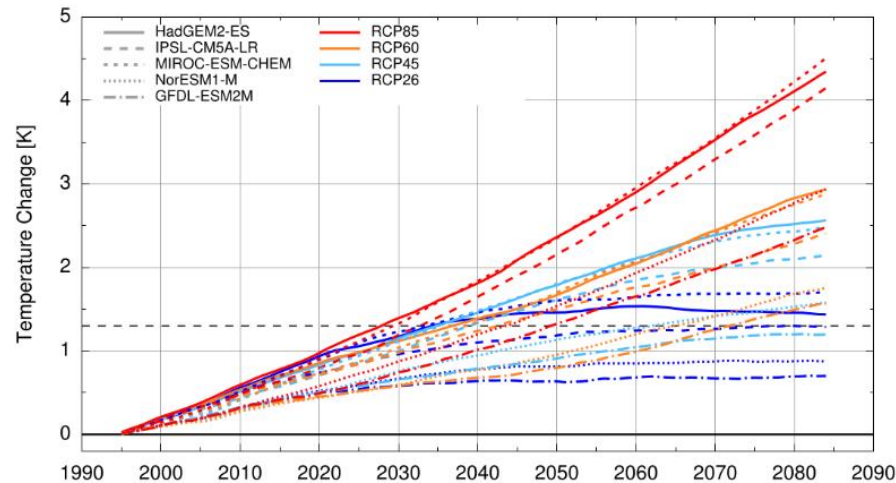


McVicar et al (2012) *J Hydrol*

# Model uncertainty (ISI-MIP)



Riahi et al (2011) Climatic Change



Warszawski et al (2014) PNAS

HadGEM2-ES

GFDL-ESM-2M

IPSL-CM5A-LR

NORES1-M

MIROC-ESM-CHEM

# Model uncertainty (ISI-MIP)

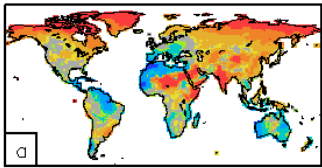
## GCMs

## Impact models

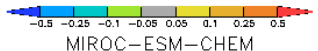
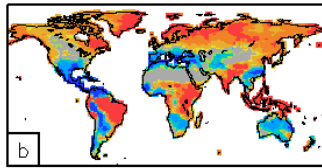
## Drought metric

### Precipitation change

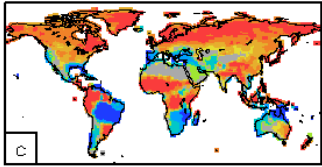
HadGEM2-ES



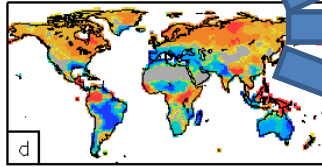
IPSL-CM5A-LR



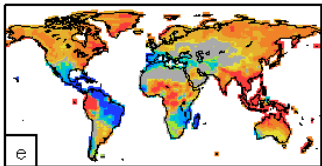
MIROC-ESM-CHEM



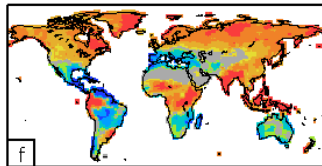
GFDL-ESM2M



NorESM1-M



All GCMs



JULES

H08

MPIHM

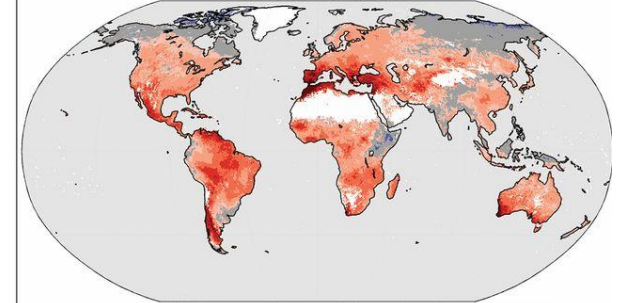
MACPDM

VIC

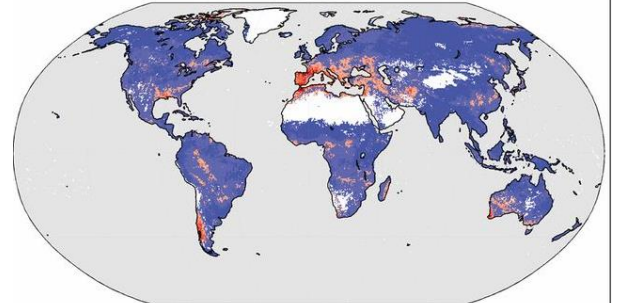
WBM

PCRGL

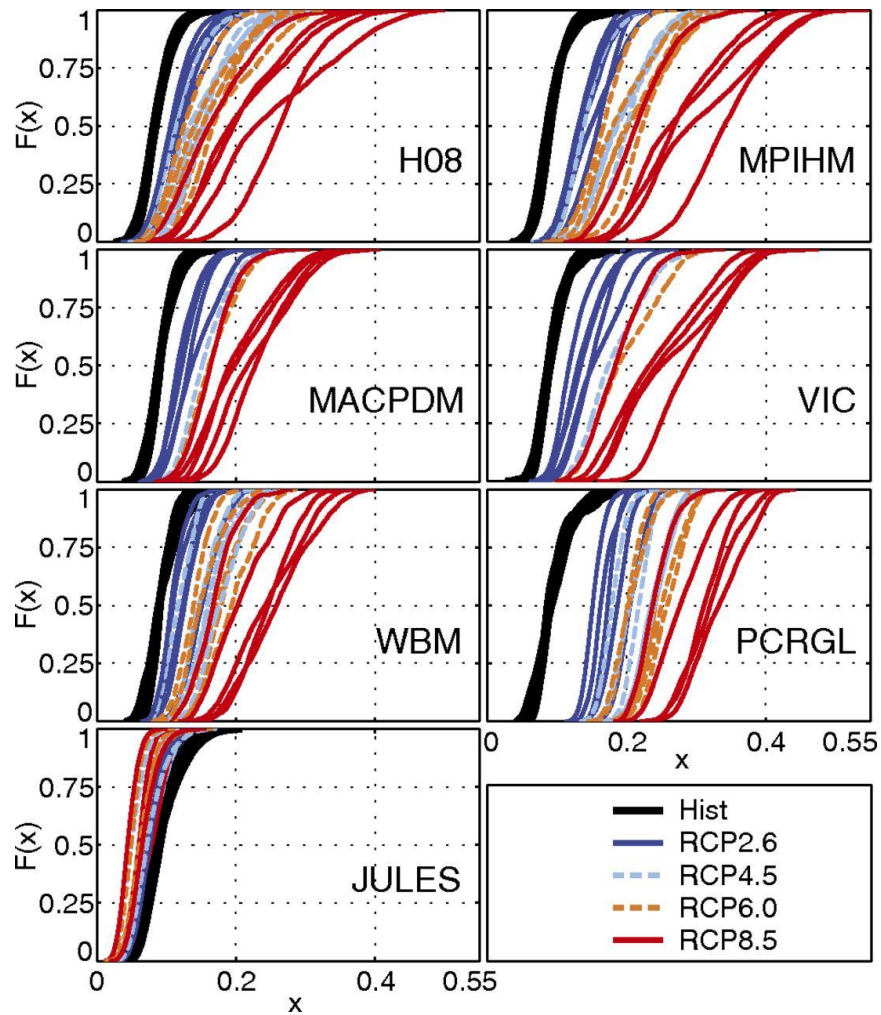
YEAR Mean change



YEAR S2N

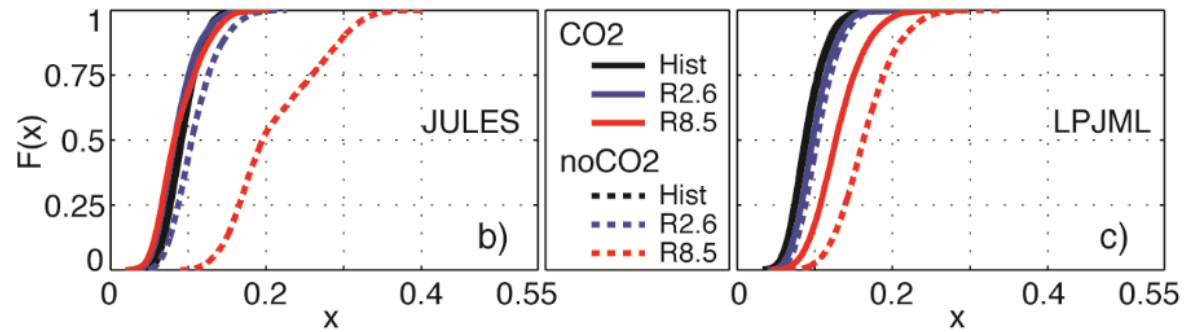
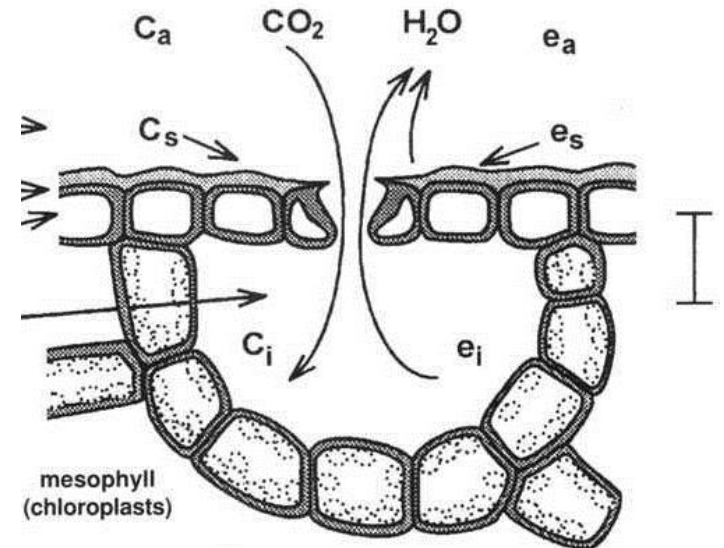
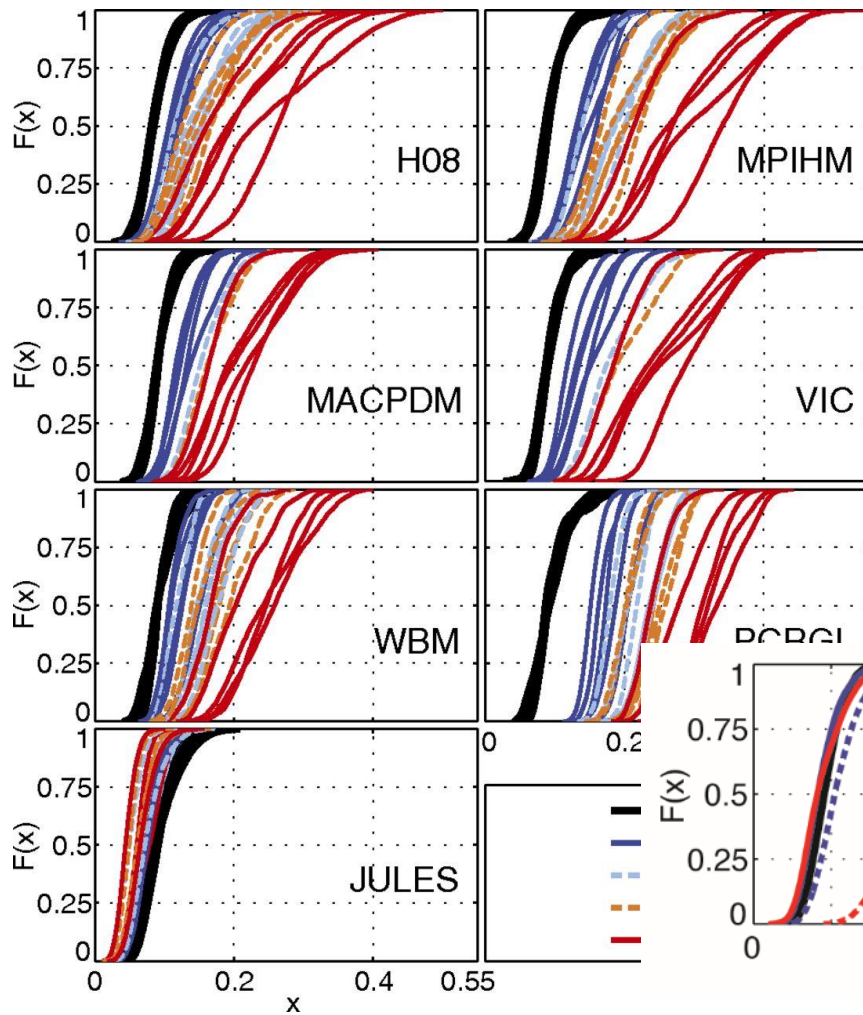


# Model uncertainty (ISI-MIP)



Prudhomme et al (2014), PNAS

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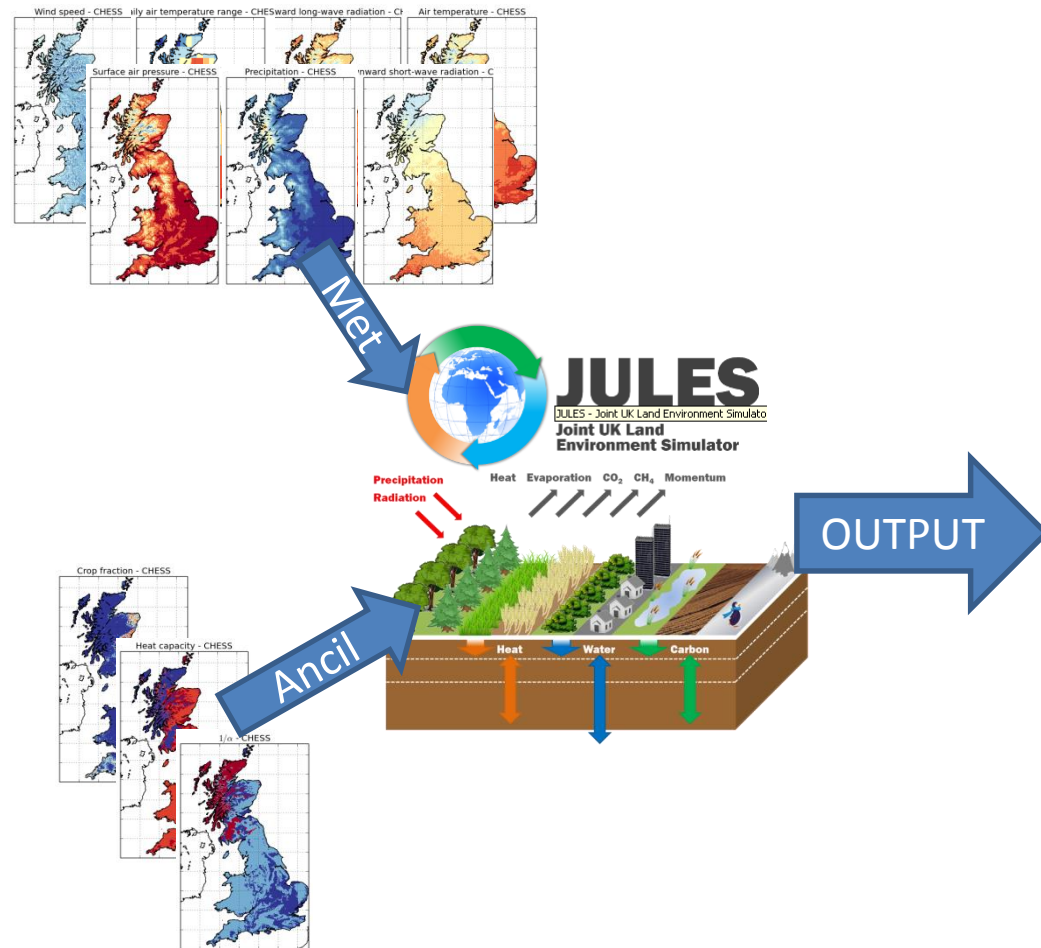


Prudhomme et al (2013), PNAS



# Driving data (CHESS)

- 1km resolution UK driving data set
- 230k land points
- 1961-2012 daily data
- 8 meteorological variables (netCDF)
- + ancillary files
- Daily disaggregation in JULES



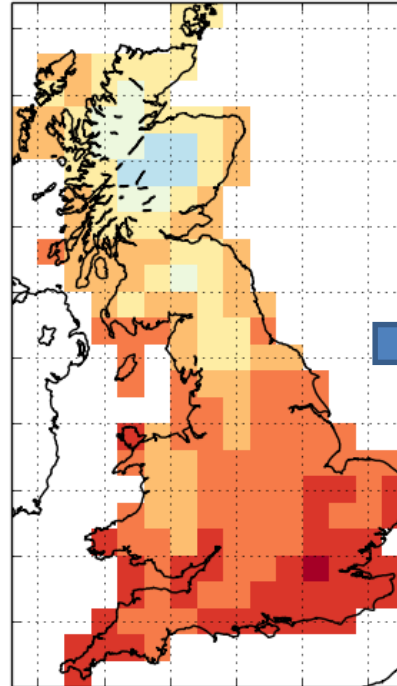
# Driving data (CHESS)

Interpolate coarse resolution data (40km) to higher resolution (1km) using topographic information

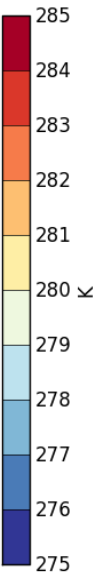
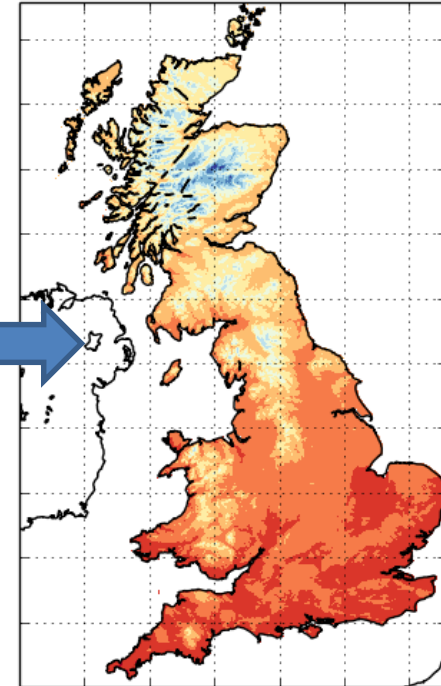
MORECS: Daily meteorological synoptic station data interpolated to 40km grid (Met Office)  
1961-Present

Temperature, humidity, wind speed, sunshine hours

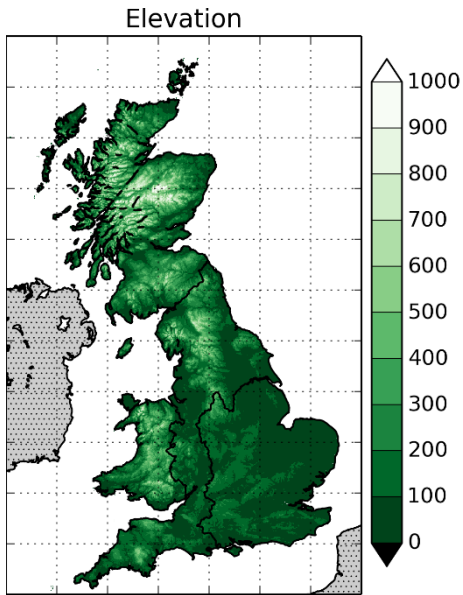
Air temperature - MORECS



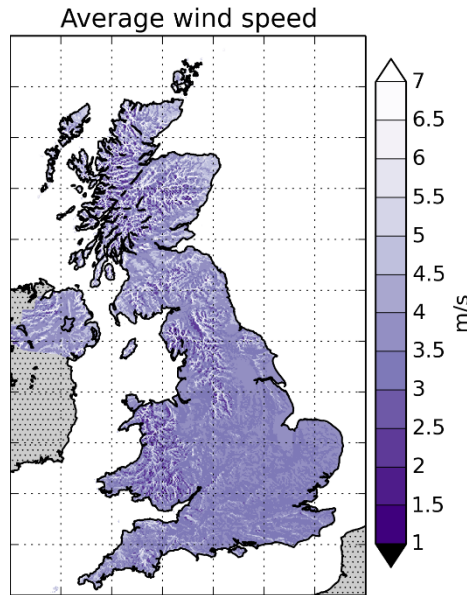
Air temperature - CHESS



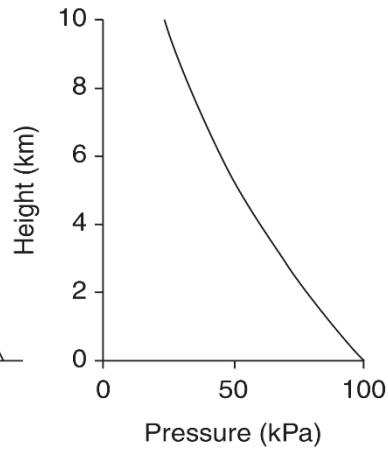
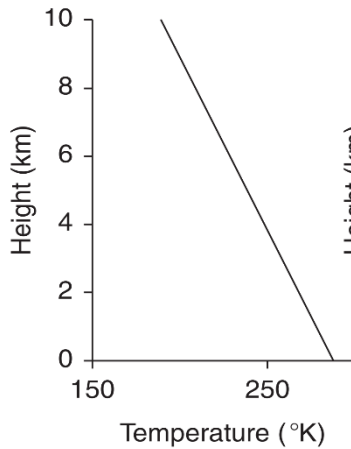
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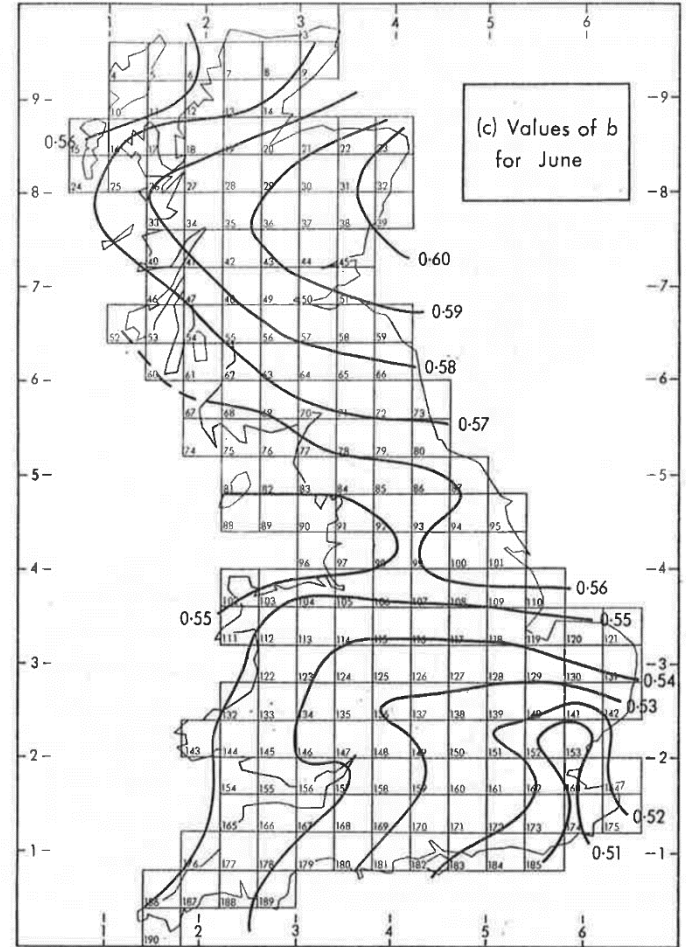
Morris & Flavin (1990)



Burch & Ravenscroft (1992)



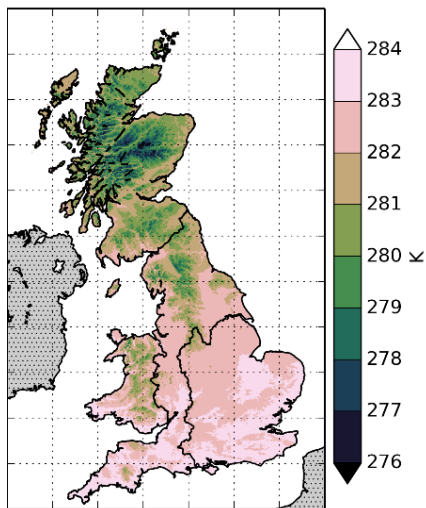
Shuttleworth, Terrestrial Hydrometeorology



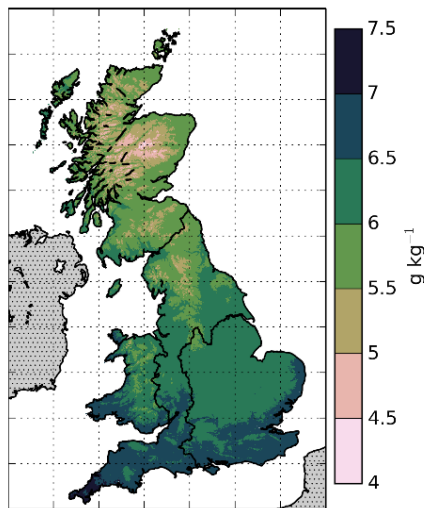
Cowley (1978)

# Driving data (CHESS)

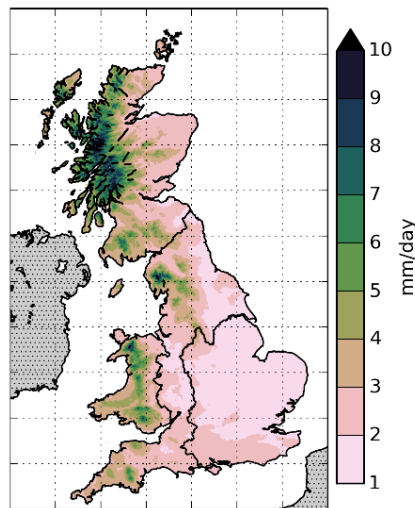
Air temperature



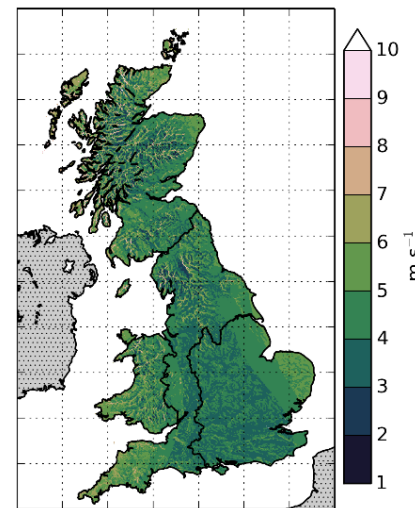
Specific humidity



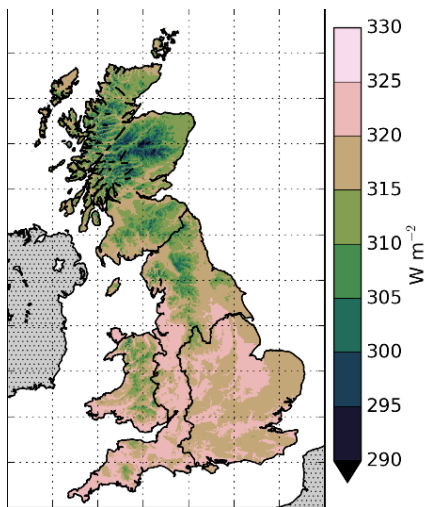
Precipitation



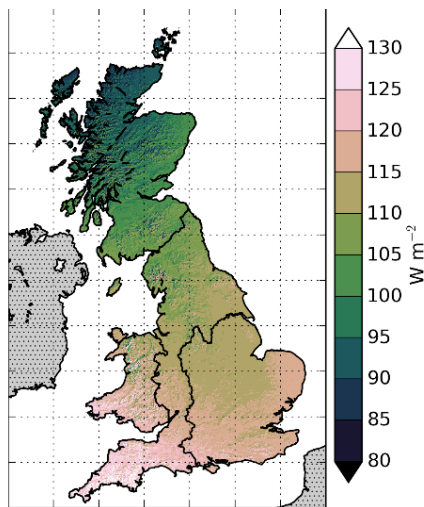
Wind speed



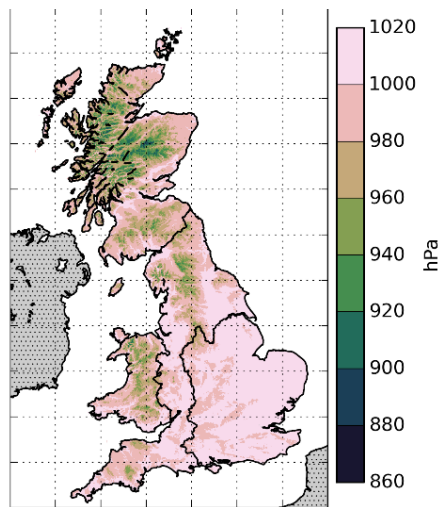
Downward LW



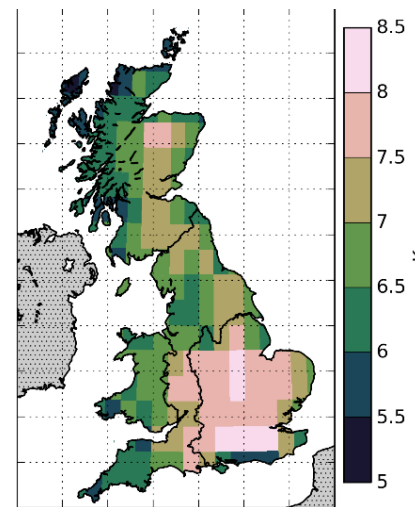
Downward SW



Air pressure



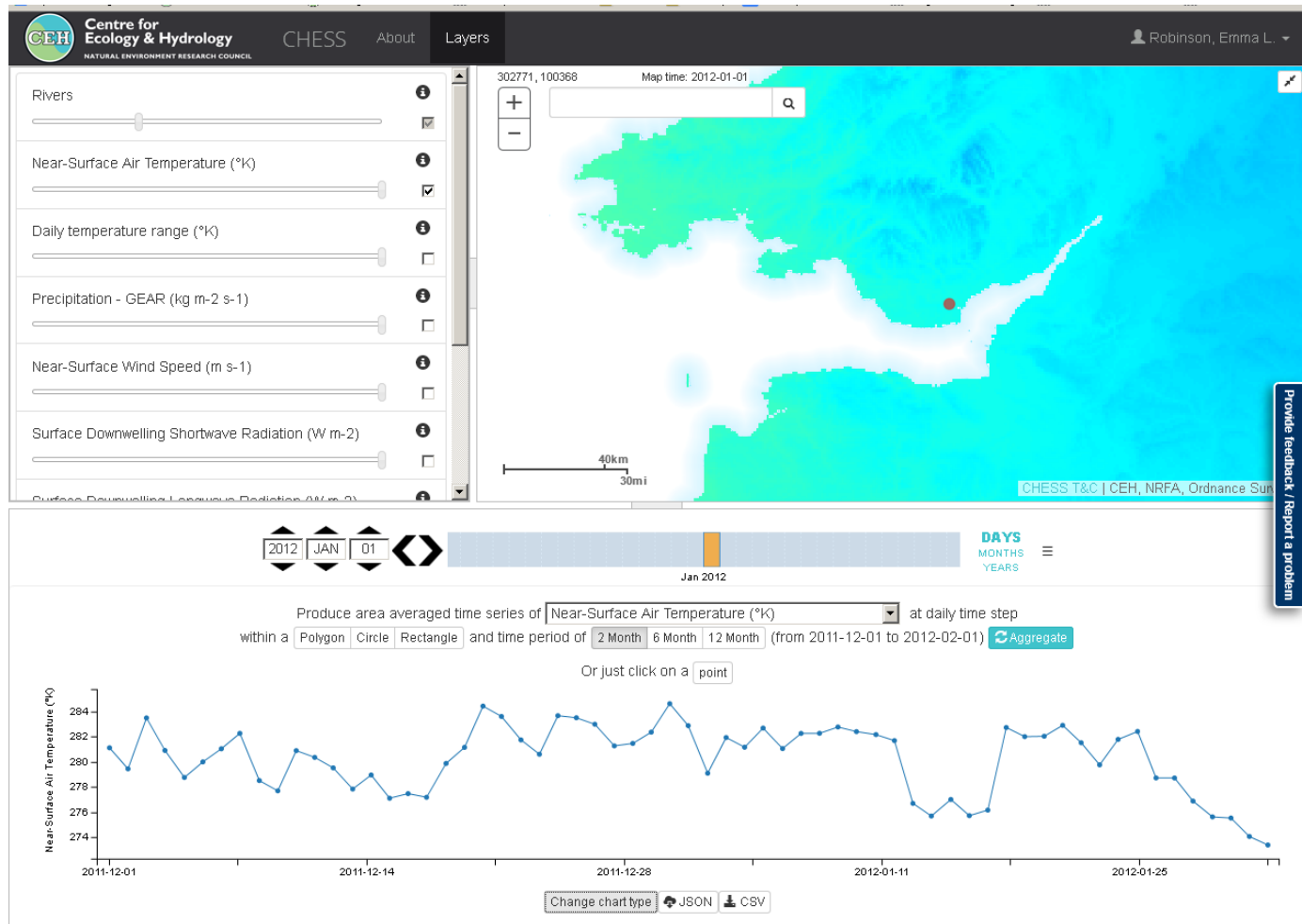
Daily temp range



# Uses of CHES data

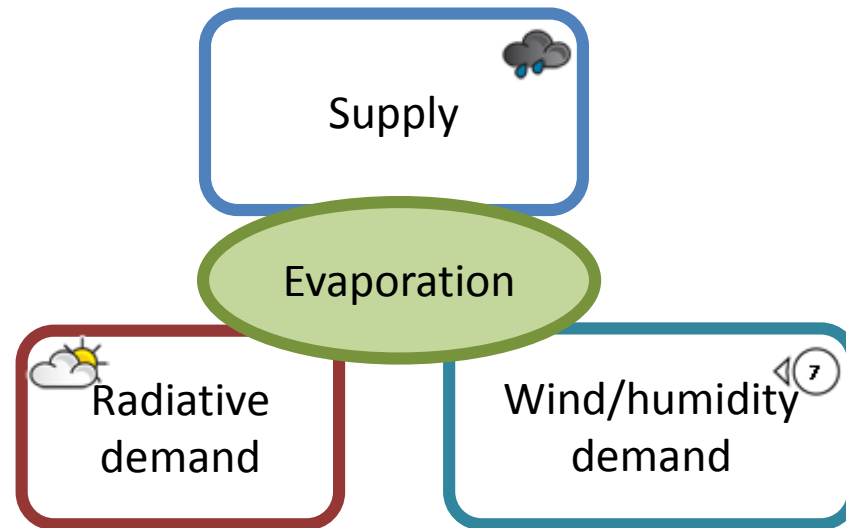
- JULES (and other LSMs)
- Rainfall-runoff models (CLASSIC, Grid To Grid)
- Soil moisture regulation of heatwaves (ESTRESS)
- Macronutrient cycles in Wales (Turf2Surf)
- River water quality
- Bird populations
- Mosquito-borne disease
- ...

# Environmental Information Platform



<https://eip.ceh.ac.uk/>

# Potential evapotranspiration



## Penman-Monteith equation

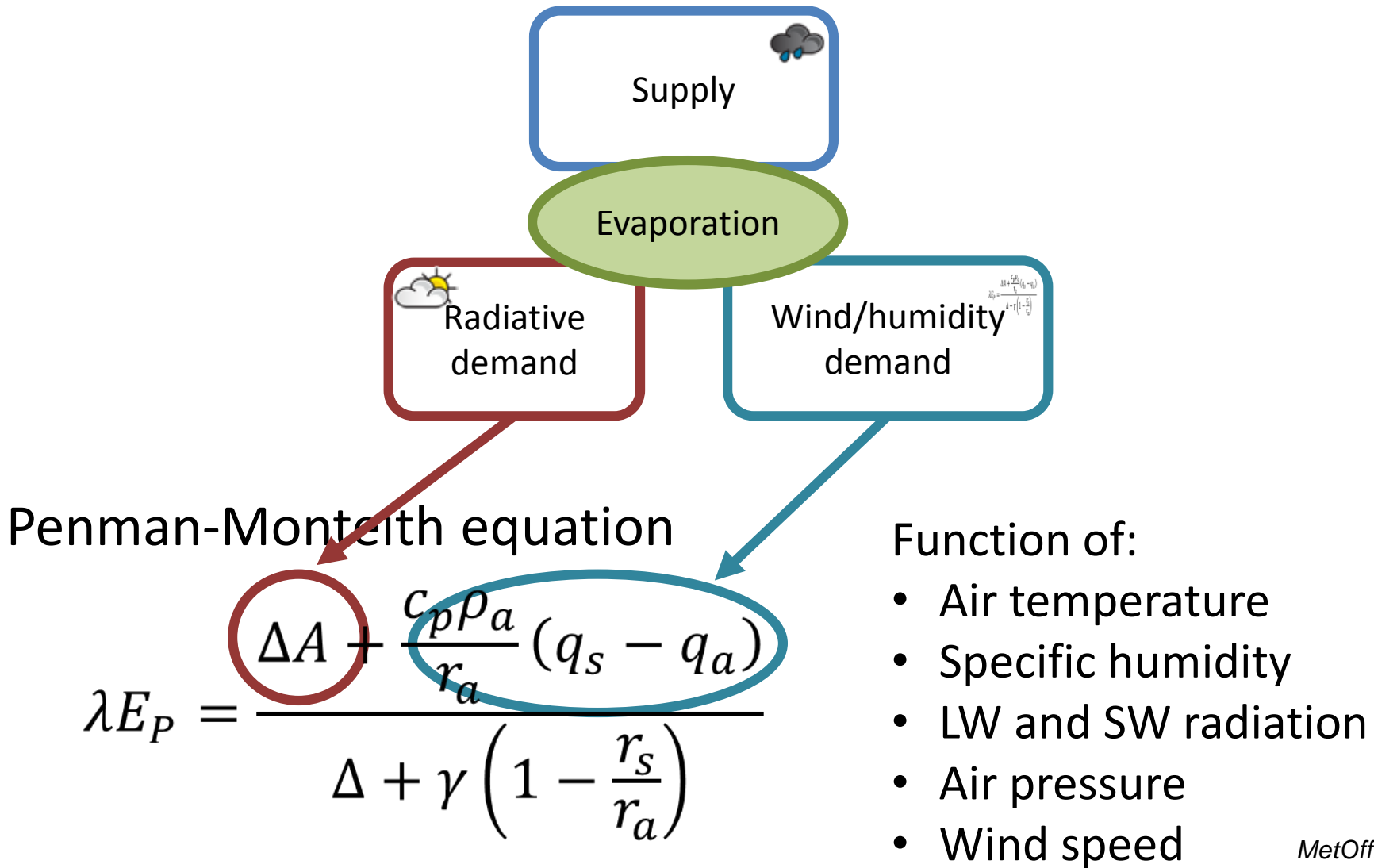
$$\lambda E_p = \frac{\Delta A + \frac{c_p \rho_a}{r_a} (q_s - q_a)}{\Delta + \gamma \left(1 - \frac{r_s}{r_a}\right)}$$

Function of:

- Air temperature
- Specific humidity
- LW and SW radiation
- Air pressure
- Wind speed

*MetOffice*

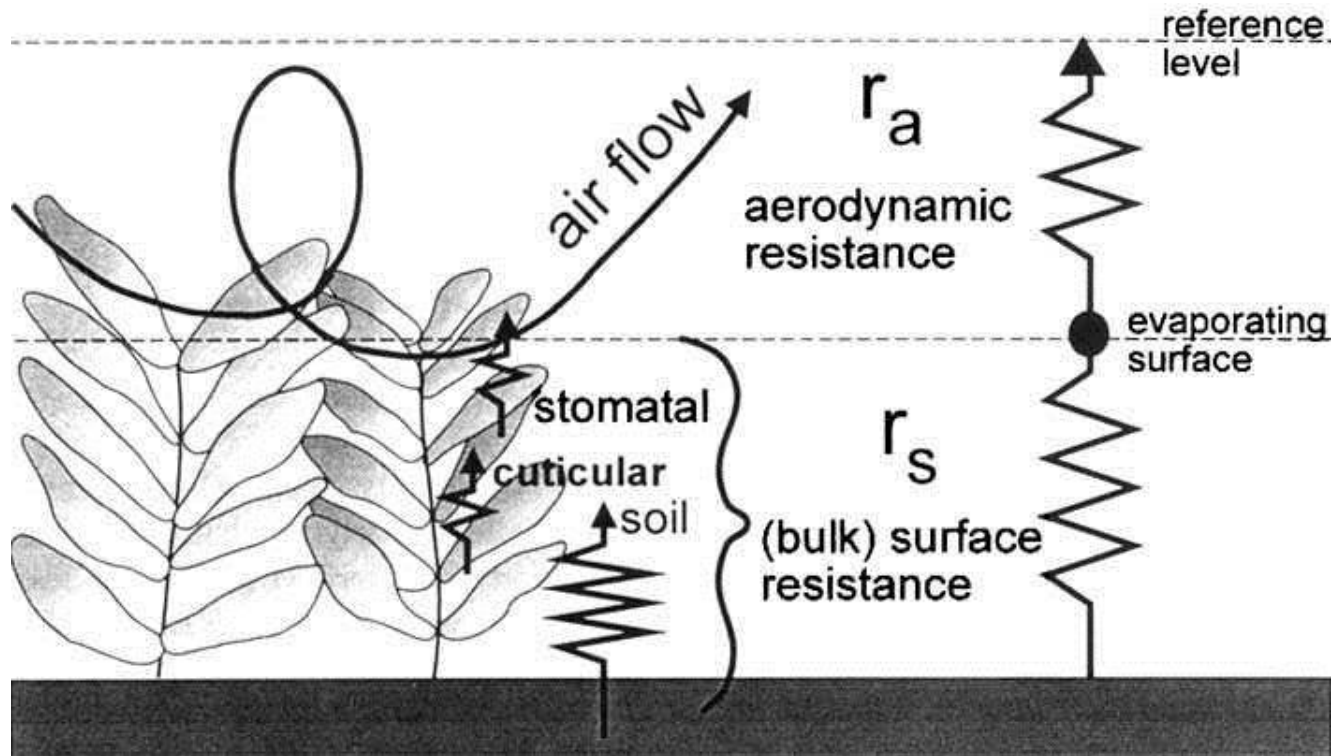
# Potential evapotranspiration



MetOffice

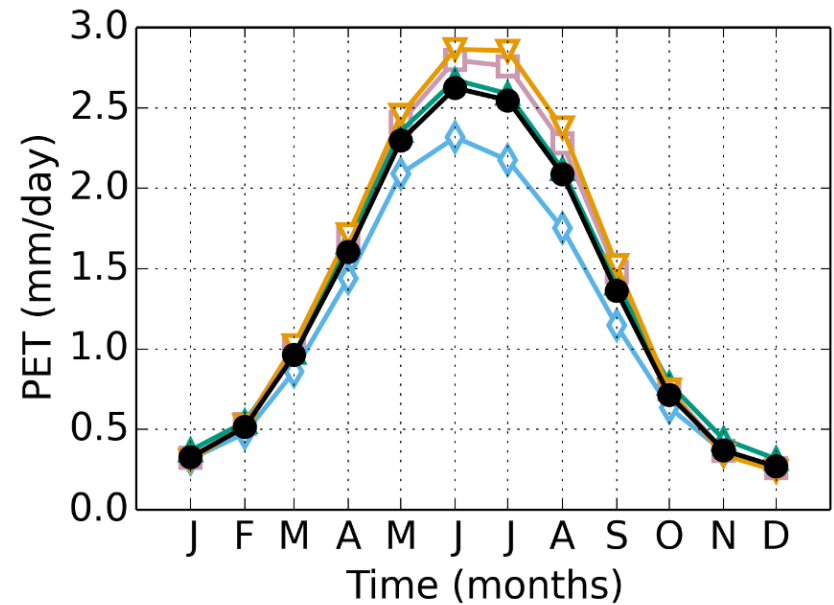
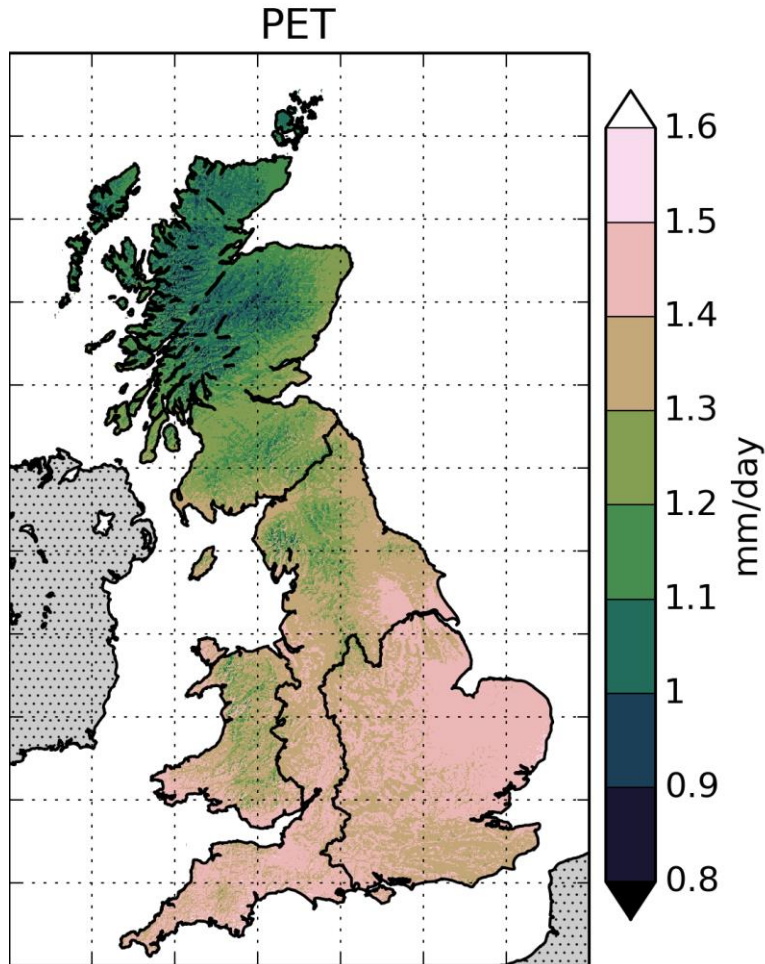


# Surface type



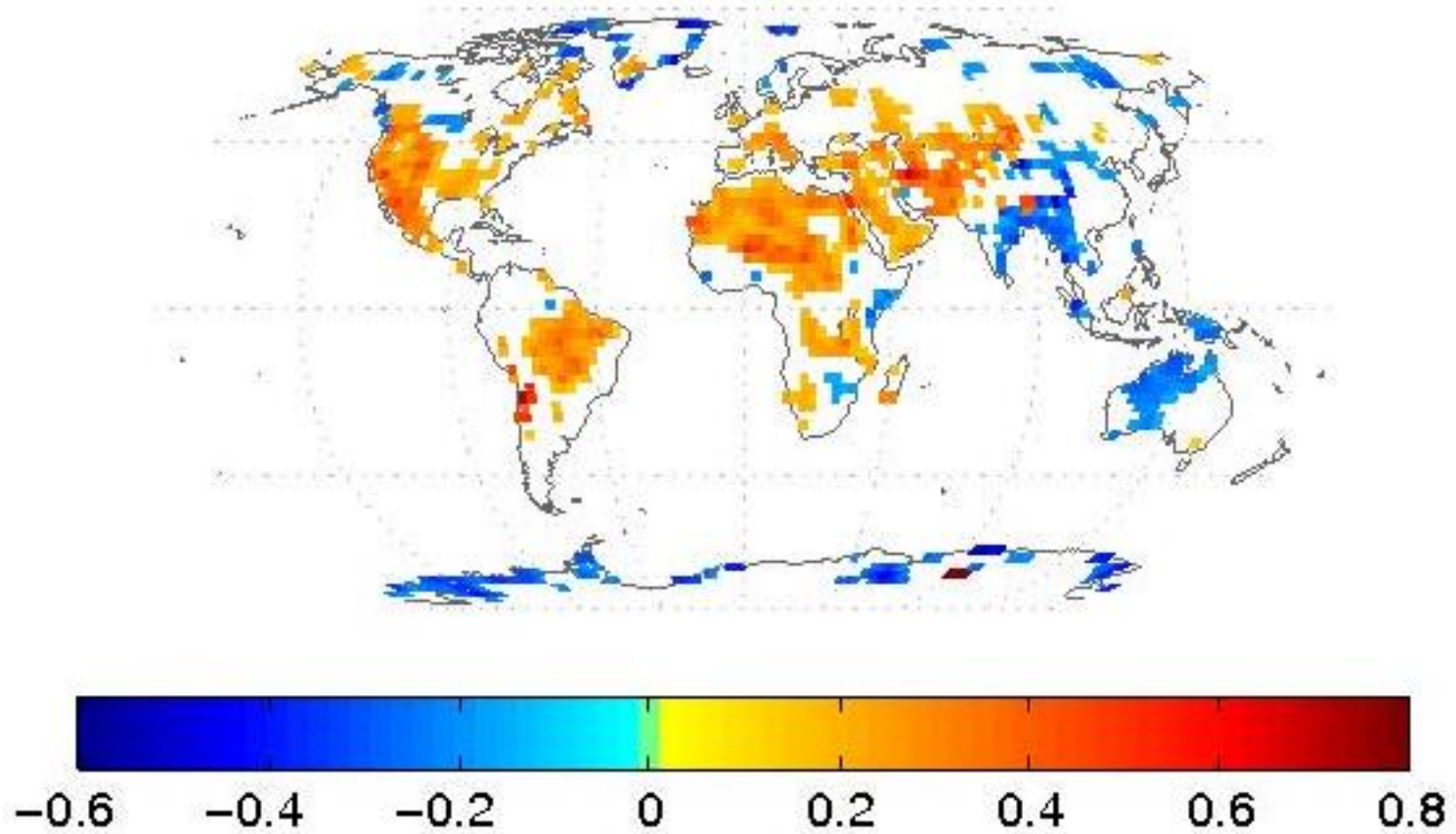
FAO Irrigation and drainage paper 56

# Potential evapotranspiration



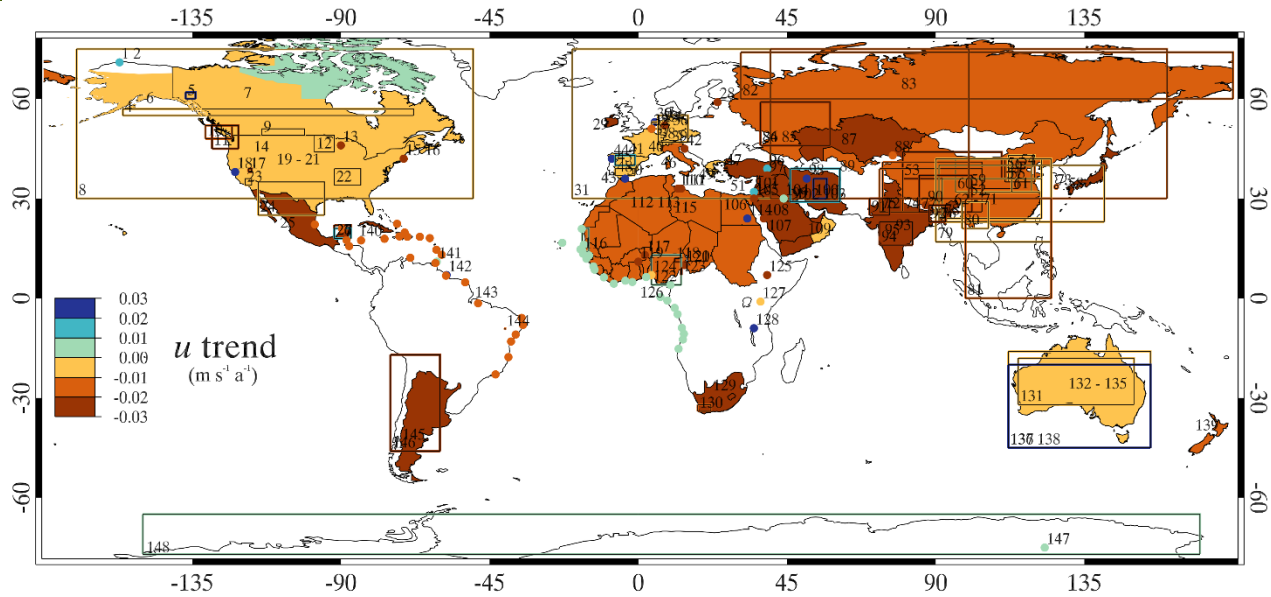
*Robinson et al (in prep)*

# Changing PET

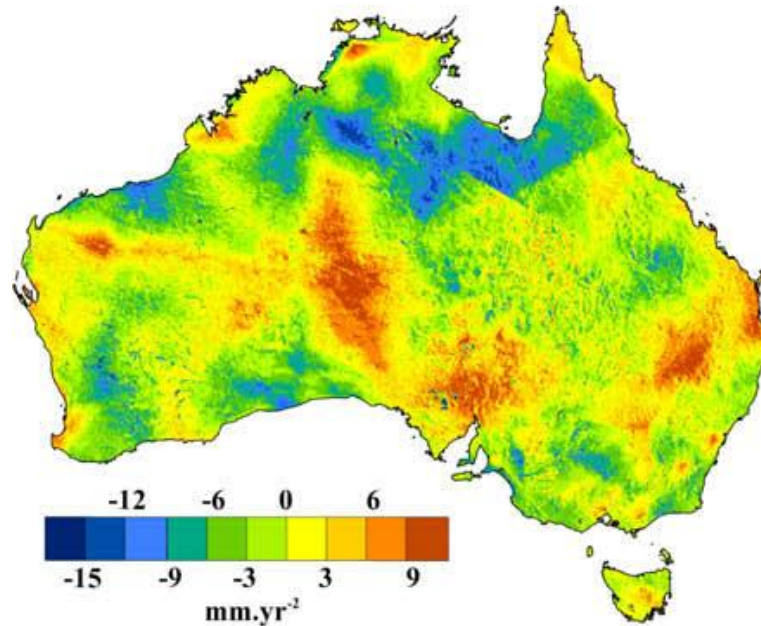


*Matsoukas et al (2011) Atmos Chem Phys*

# Changing PET

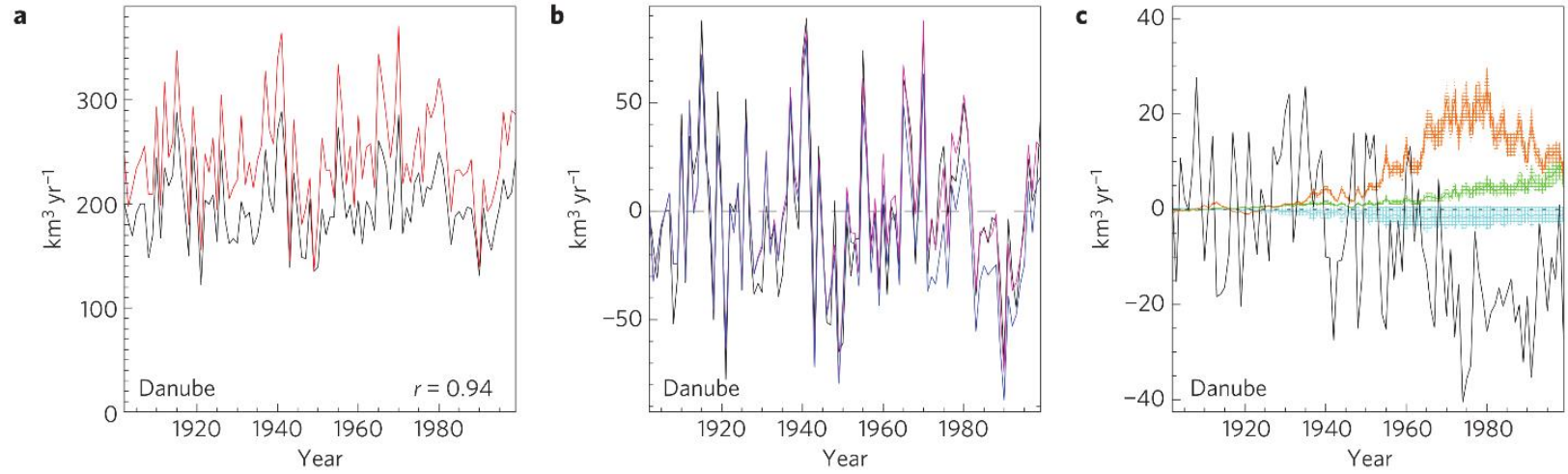
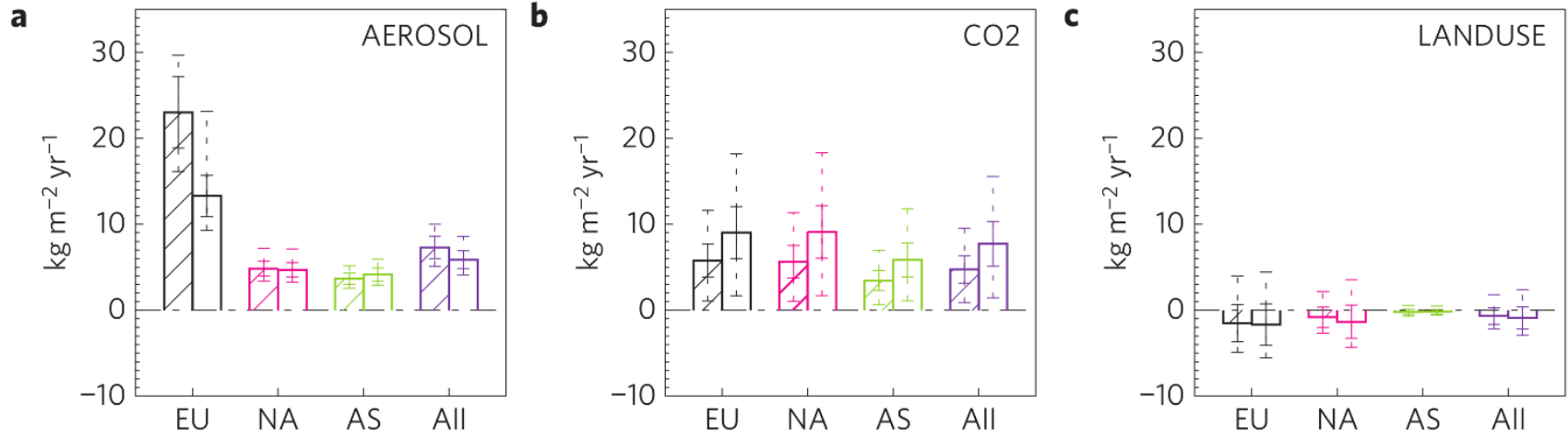


*McVicar et al (2012) J Hydrol*

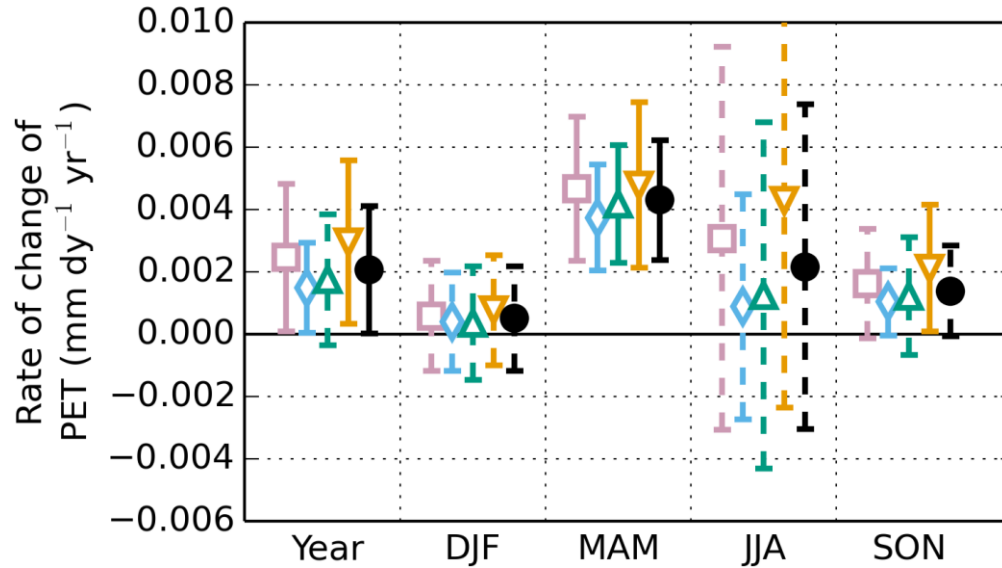
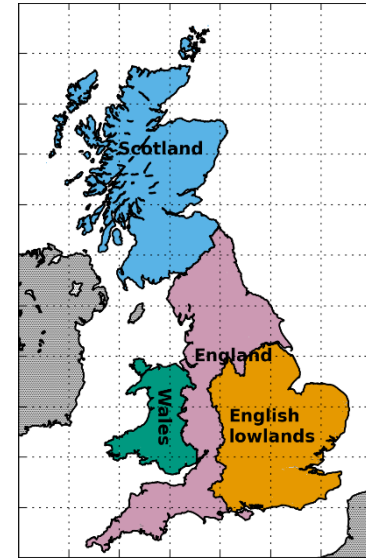
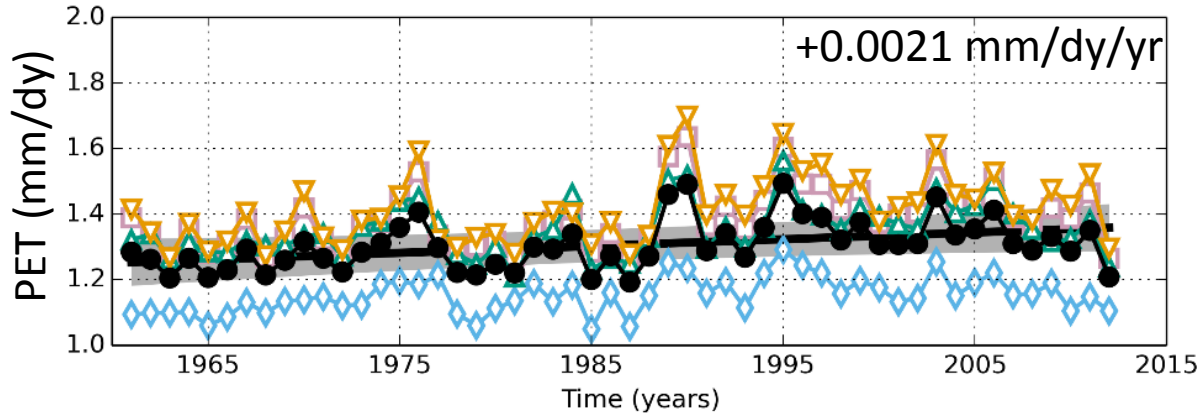


*Donohue et al (2010) J Hydrol*

# Changing PET

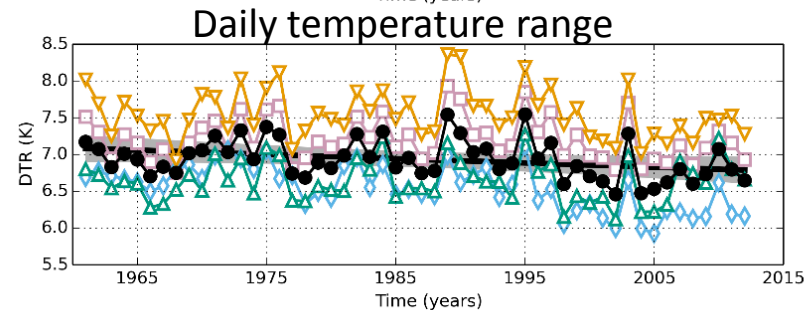
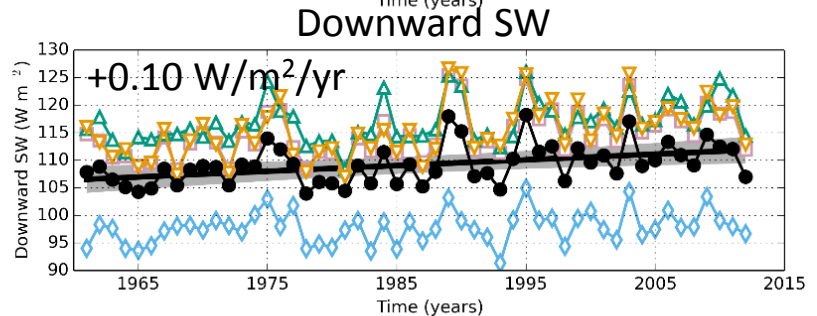
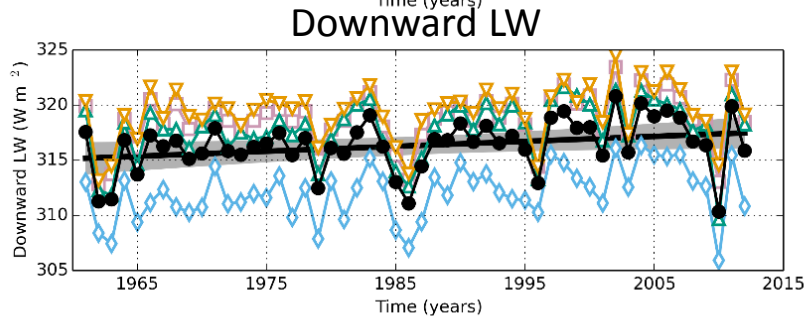
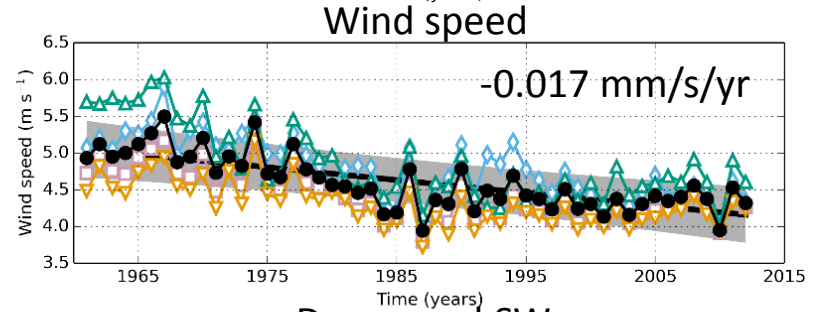
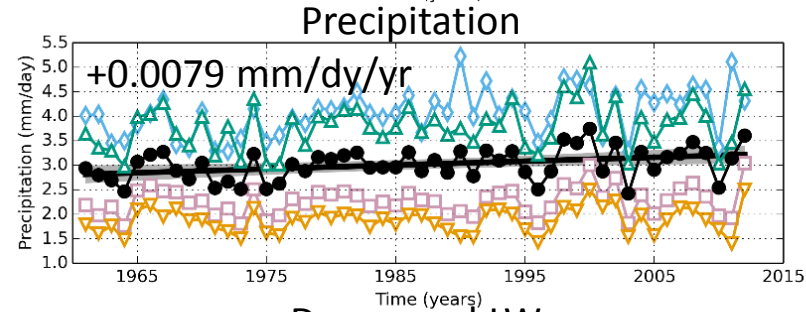
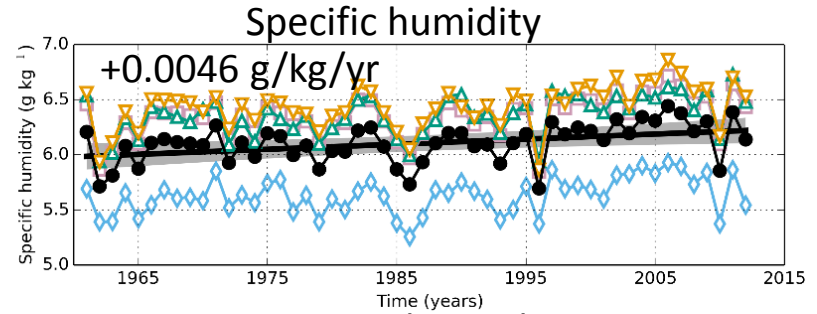
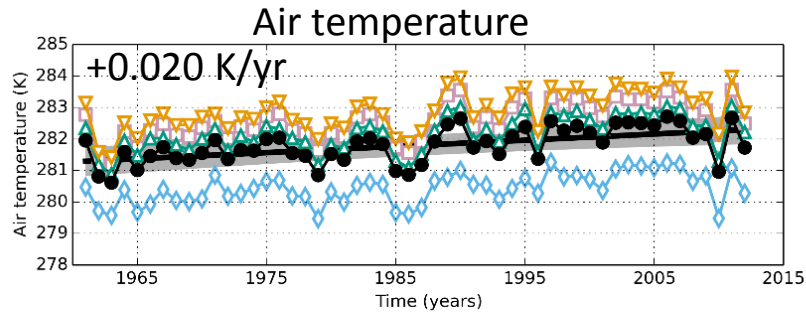


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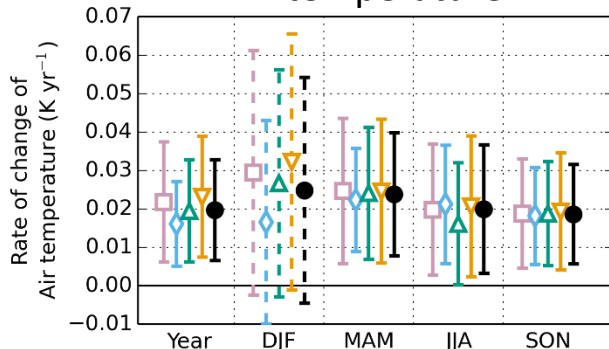
Robinson et al (in prep)

# Climate trends

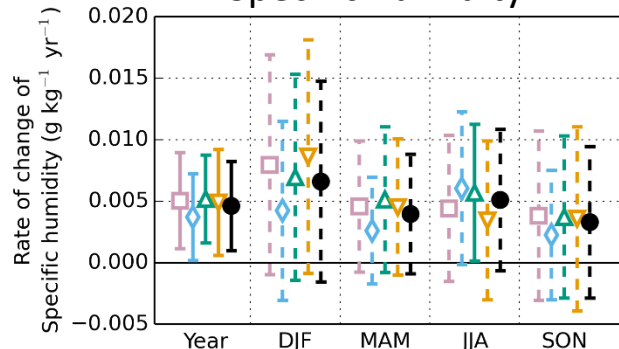


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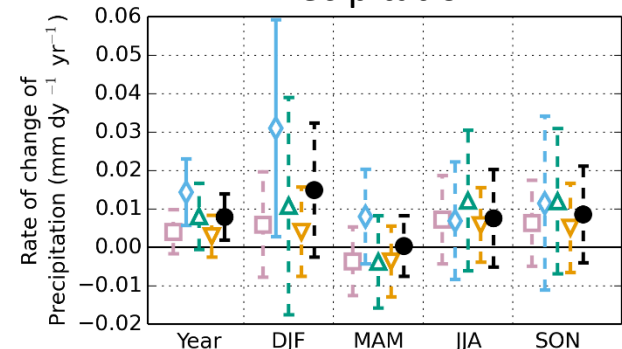
### Air temperature



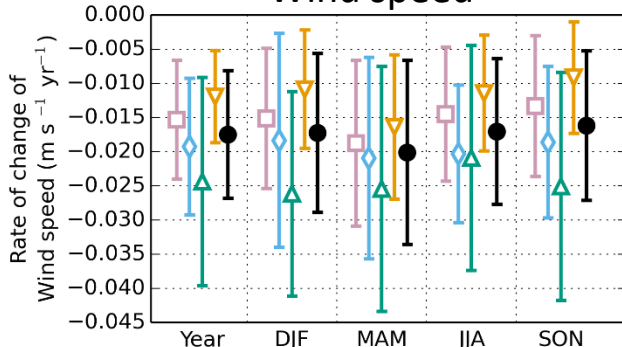
### Specific humidity



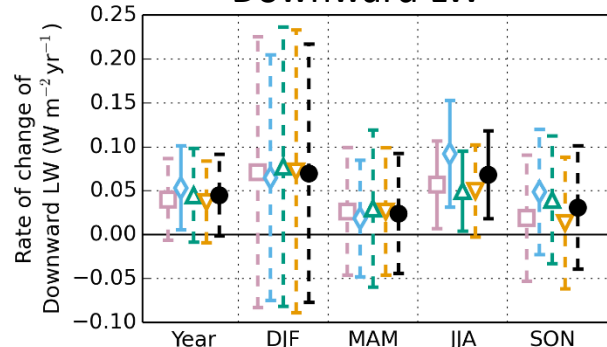
### Precipitation



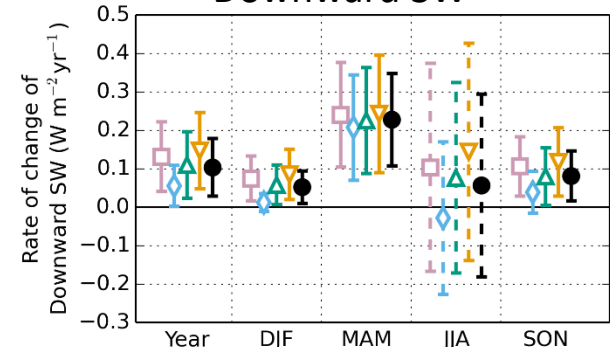
### Wind speed



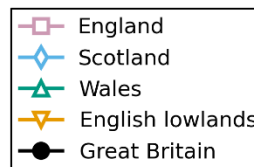
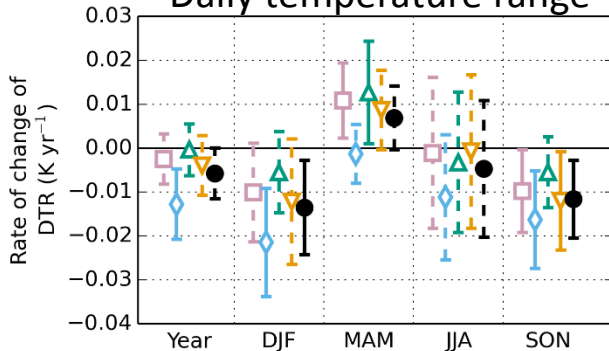
### Downward LW



### Downward SW



### Daily temperature range





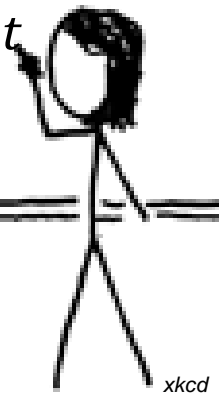
# Attributing change

- How does the change in PET depend on the changing climate?
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$$\frac{dE_P}{dt} = \frac{\partial E_P}{\partial T_a} \frac{dT_a}{dt} + \frac{\partial E_P}{\partial q_a} \frac{dq_a}{dt} + \frac{\partial E_P}{\partial u_{10}} \frac{du_{10}}{dt} + \frac{\partial E_P}{\partial L_{\downarrow}} \frac{dL_{\downarrow}}{dt} + \frac{\partial E_P}{\partial S_{\downarrow}} \frac{dS_{\downarrow}}{dt} + \frac{\partial E_P}{\partial P_*} \frac{dP_*}{dt}$$

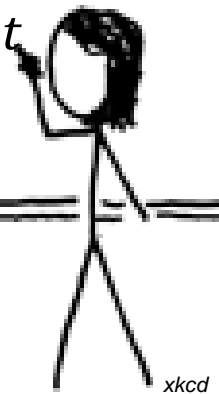


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Contribution  
of changing  
wind speed



xkcd

# Attributing change

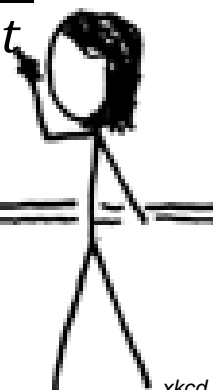
- How does the change in PET depend on the changing climate?
- PET is an analytical function of met data – we can work it out!

$$\frac{dE_P}{dt} = \frac{\partial E_P}{\partial T_a} \frac{dT_a}{dt} + \frac{\partial E_P}{\partial q_a} \frac{dq_a}{dt} + \frac{\partial E_P}{\partial u_{10}} \frac{du_{10}}{dt} + \frac{\partial E_P}{\partial L_{\downarrow}} \frac{dL_{\downarrow}}{dt} + \frac{\partial E_P}{\partial S_{\downarrow}} \frac{dS_{\downarrow}}{dt} + \frac{\partial E_P}{\partial P_*} \frac{dP_*}{dt}$$

Contribution of changing wind speed

Analytical function

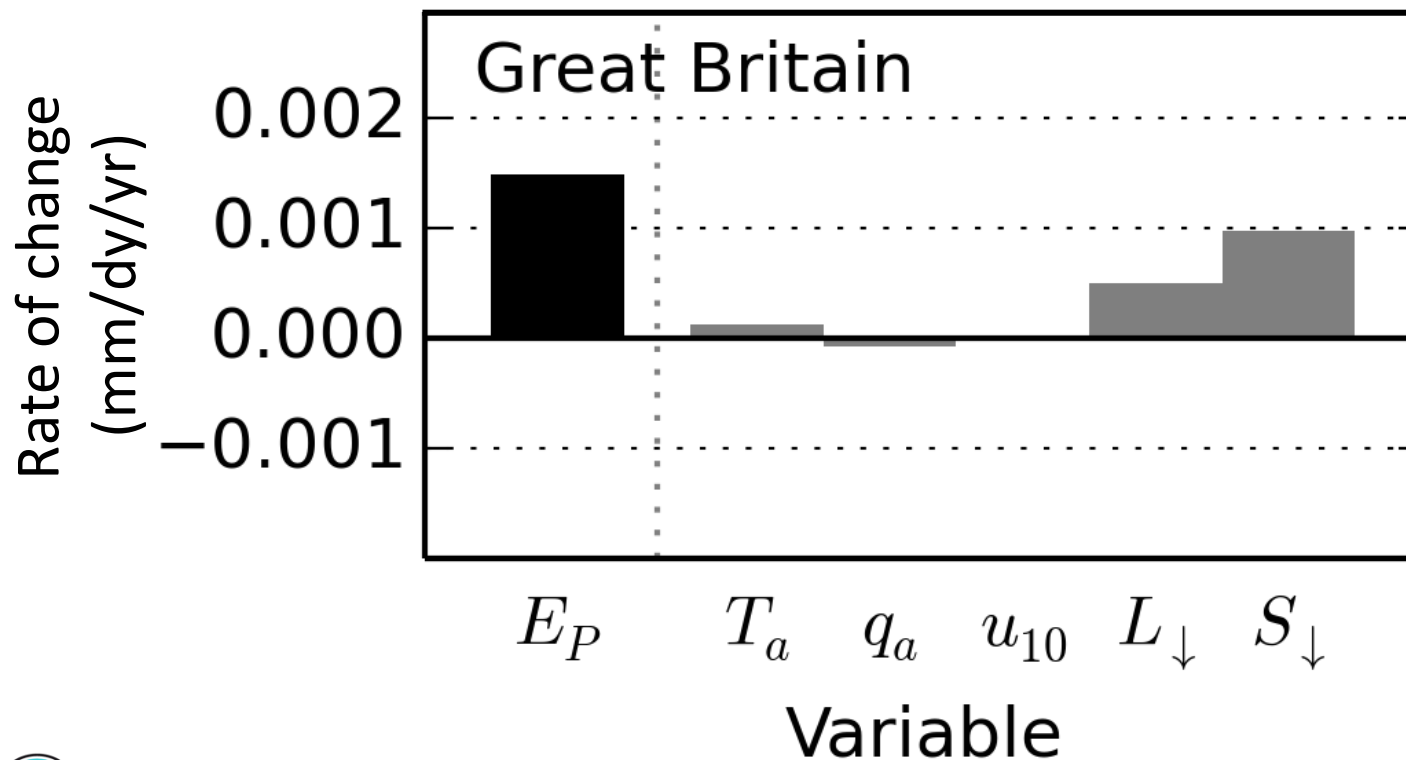
Linear regression



xkcd

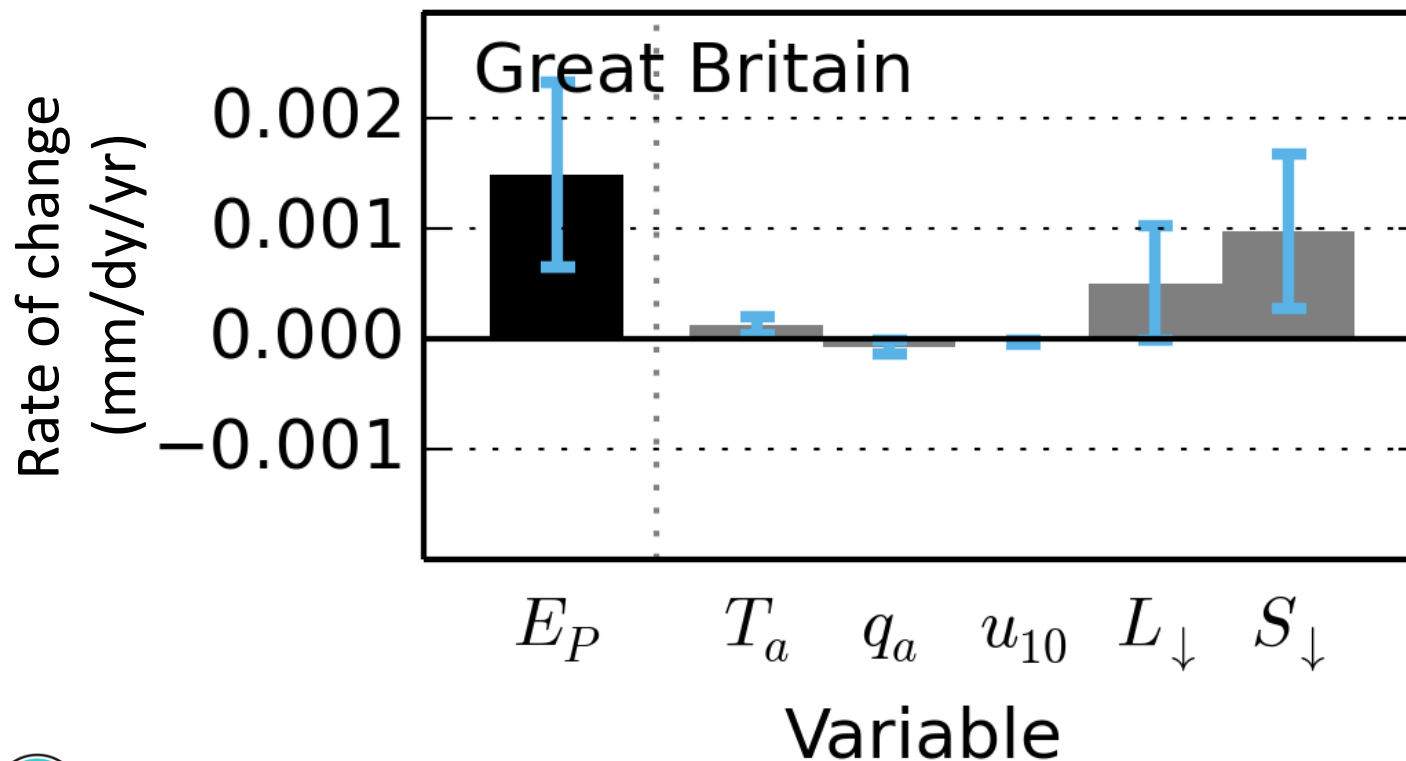
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