Coupled land-atmosphere variability: does land contribute to predictability?

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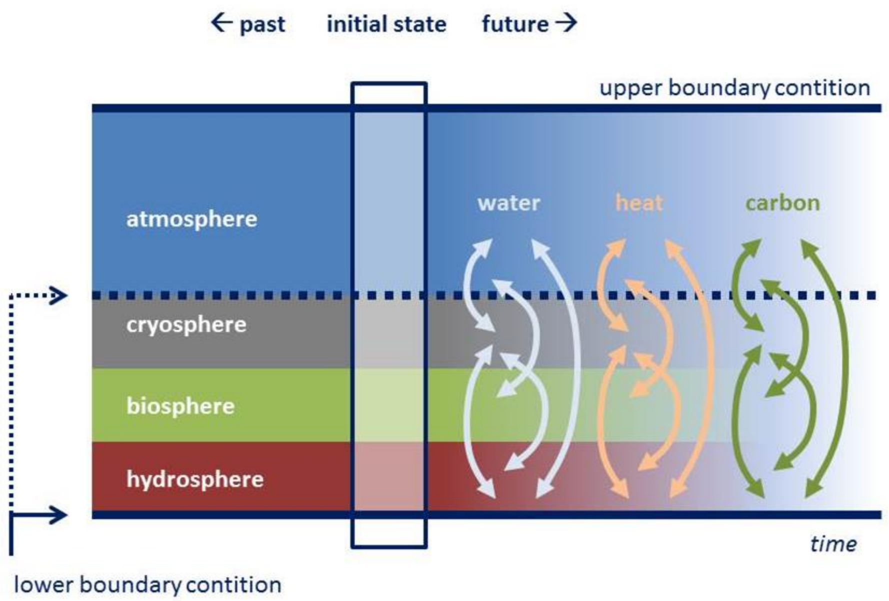

Why do we care about land processes?

- Energy-budget
  - Albedo

Surface	Albedo
Dark forest	9-12%
Grassland	15-20%
Bare soil	20-30%
Snow in forest	15-25%
Open snow	50-85%


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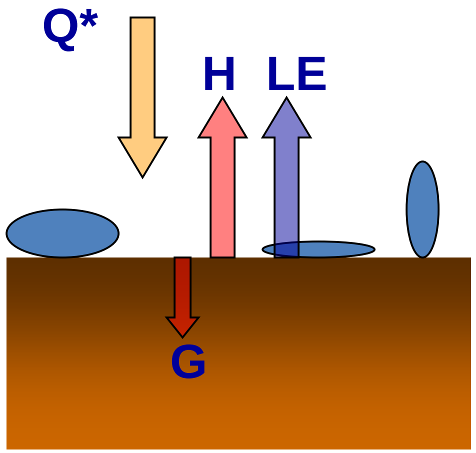
Why do we care about land processes?

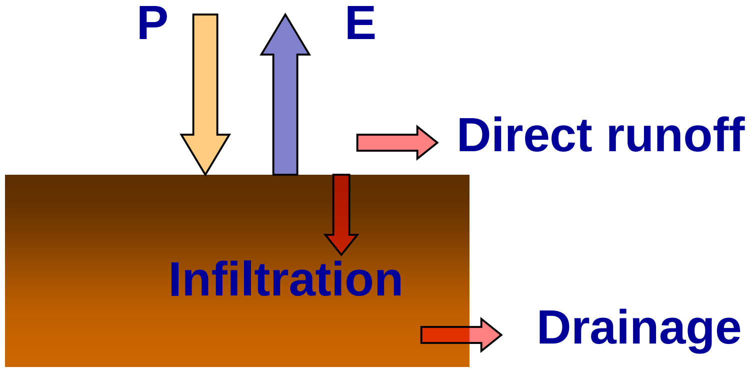
- Energy-budget
  - Albedo
  - Evaporative fraction



Surface	LE/Q*
Boreal forest	25%
Forest in temperate climate	65%
Dry vineyard	20%
Irrigated field in dry area	100%

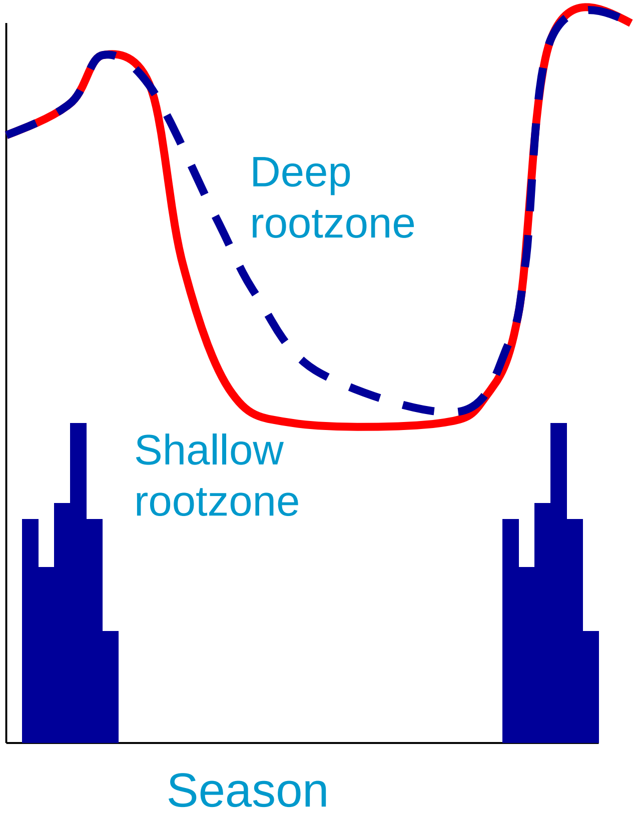
Why do we care about land processes?

- Energy-budget
  - Albedo
  - Evaporative fraction
- Water budget
  - Runoff-fraction



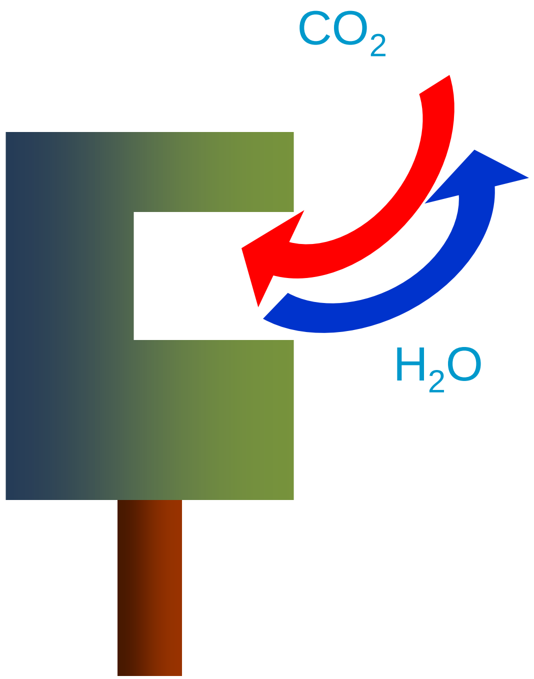
Land processes in atmospheric models

- Energy-budget
  - Albedo
  - Evaporative fraction
- Water budget
  - Runoff-fraction
  - Soil water reservoir



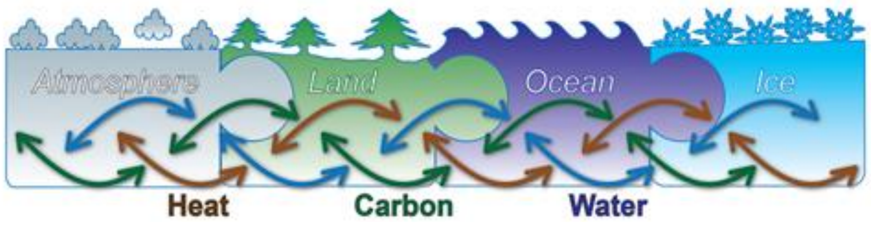
Land processes in atmospheric models

- Energy-budget
  - Albedo
  - Evaporative fraction
- Water budget
  - Runoff-fraction
  - Soil water reservoir
- Carbon budget

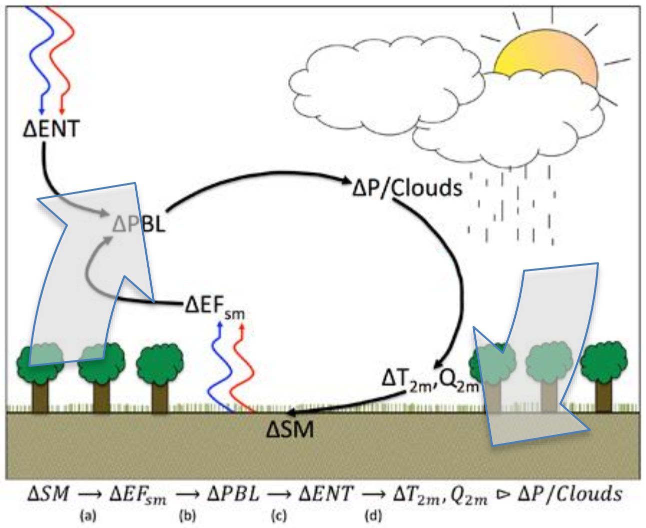


What is needed to contribute to predictability?

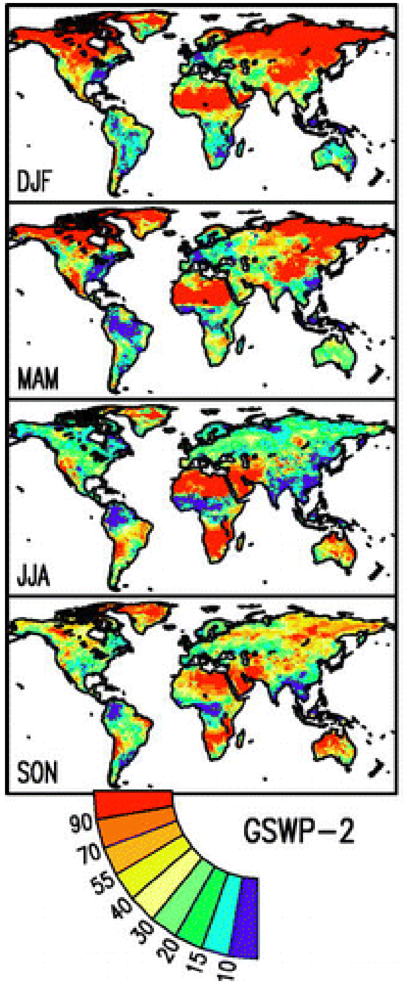
- In the climate system all processes are connected



- A systematic influence of land surface on atmosphere requires:
  - **Variability**
  - **Memory**
  - **Coupling to the atmosphere**



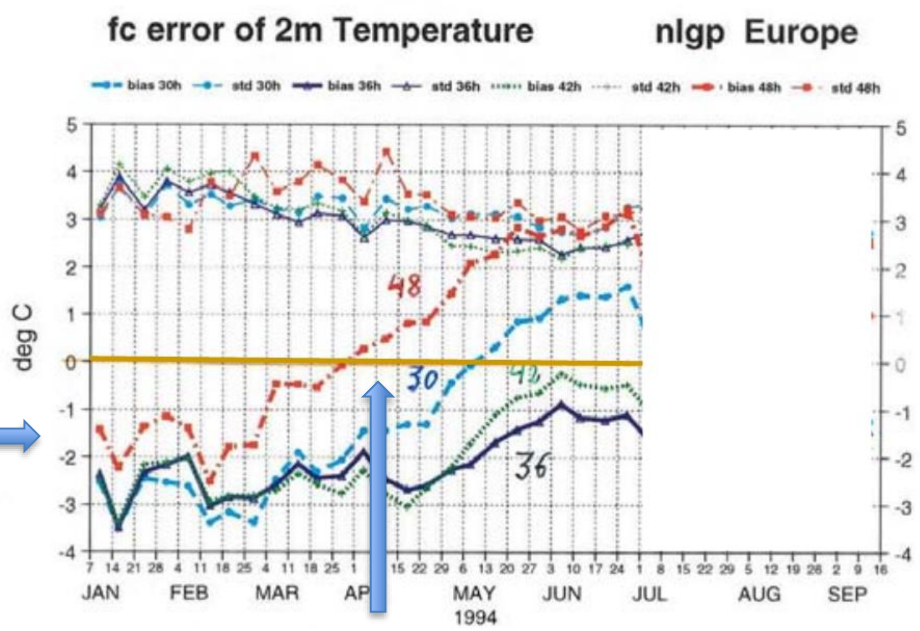
Dirmeyer et al, 2009



An anecdote demonstrating impact of soil moisture

- Mid ’90’s: introduction of **prognostic soil moisture** scheme

Model normally too cold



Suddenly extreme warm dry drift

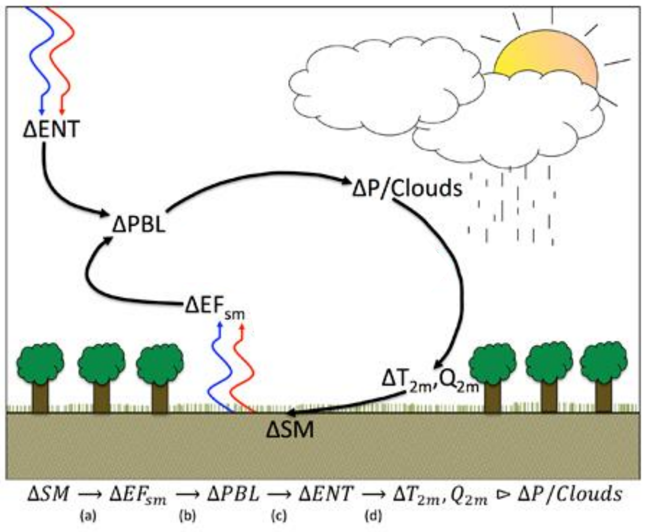
START HERE

Positive radiation bias

Soil drying due to overestimated evaporation

Evaporation stops, Less land cooling

Dry atmosphere, too little clouds



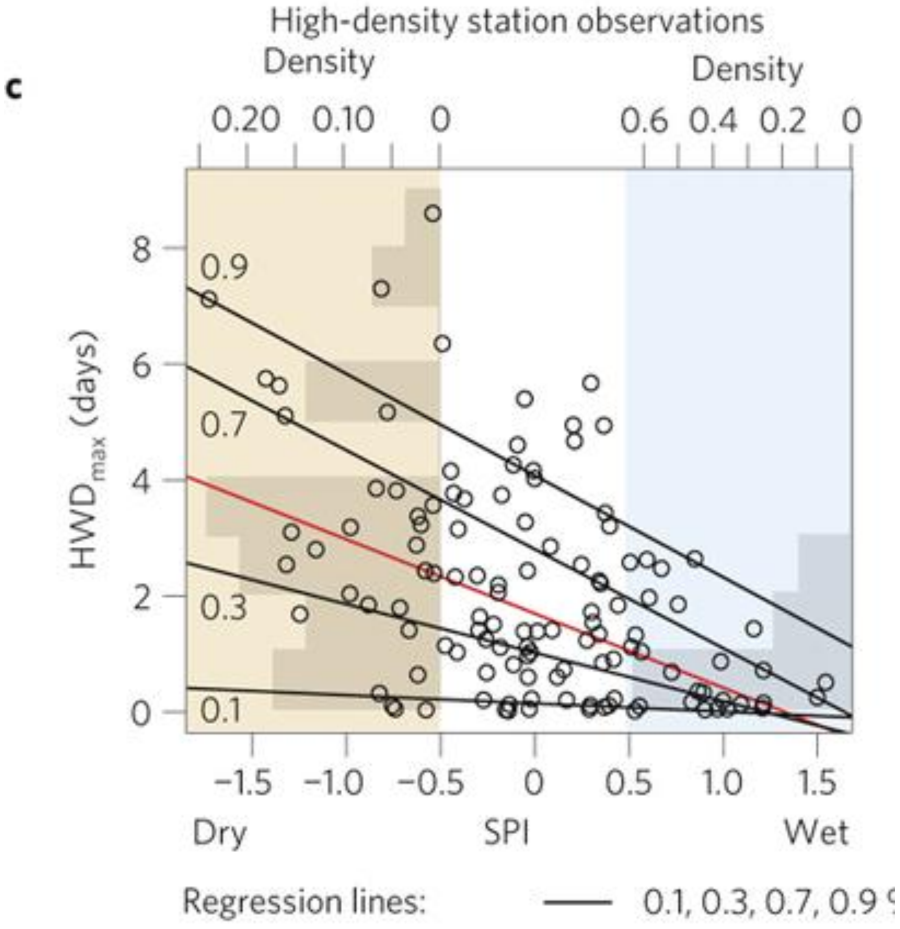
- Soil moisture **data assimilation** needed to control drift

(Root cause of drift was model bias, but once unphysical constraint was removed, model bias led to errors that grew over time)

Measures to quantify land-atmosphere coupling

- From observations:
  - relation between (soil) wetness and extreme temperatures

Hirschi et al, 2011

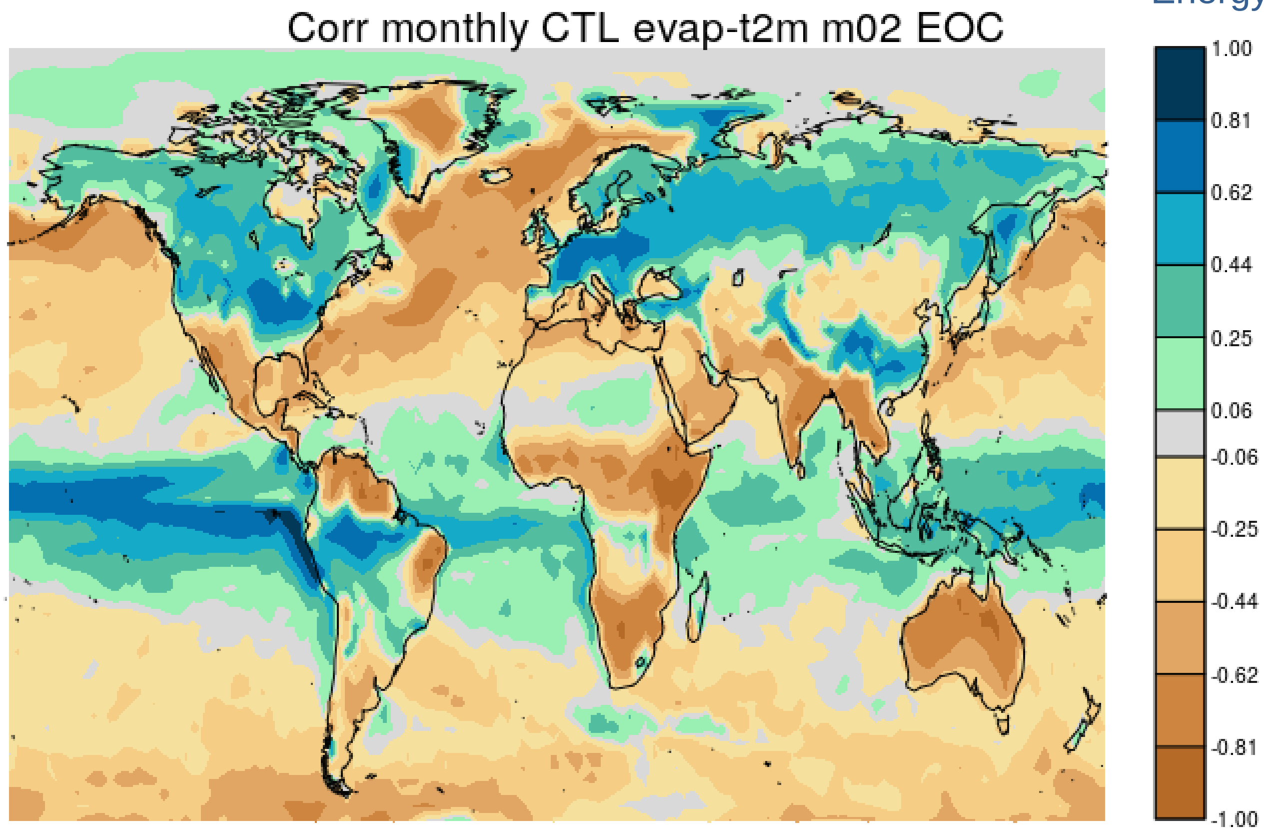


Predictability over wet conditions better than over dry conditions

Measures to quantify land-atmosphere coupling

- From (pseudo)observations:
  - Correlation between evaporation and temperature

Feb-Apr

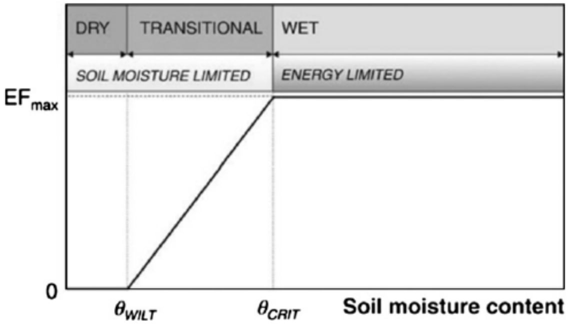


Corr monthly CTL evap-t2m m02 EOC

Energy limited

Soil water limited

Seneviratne et al, 2010

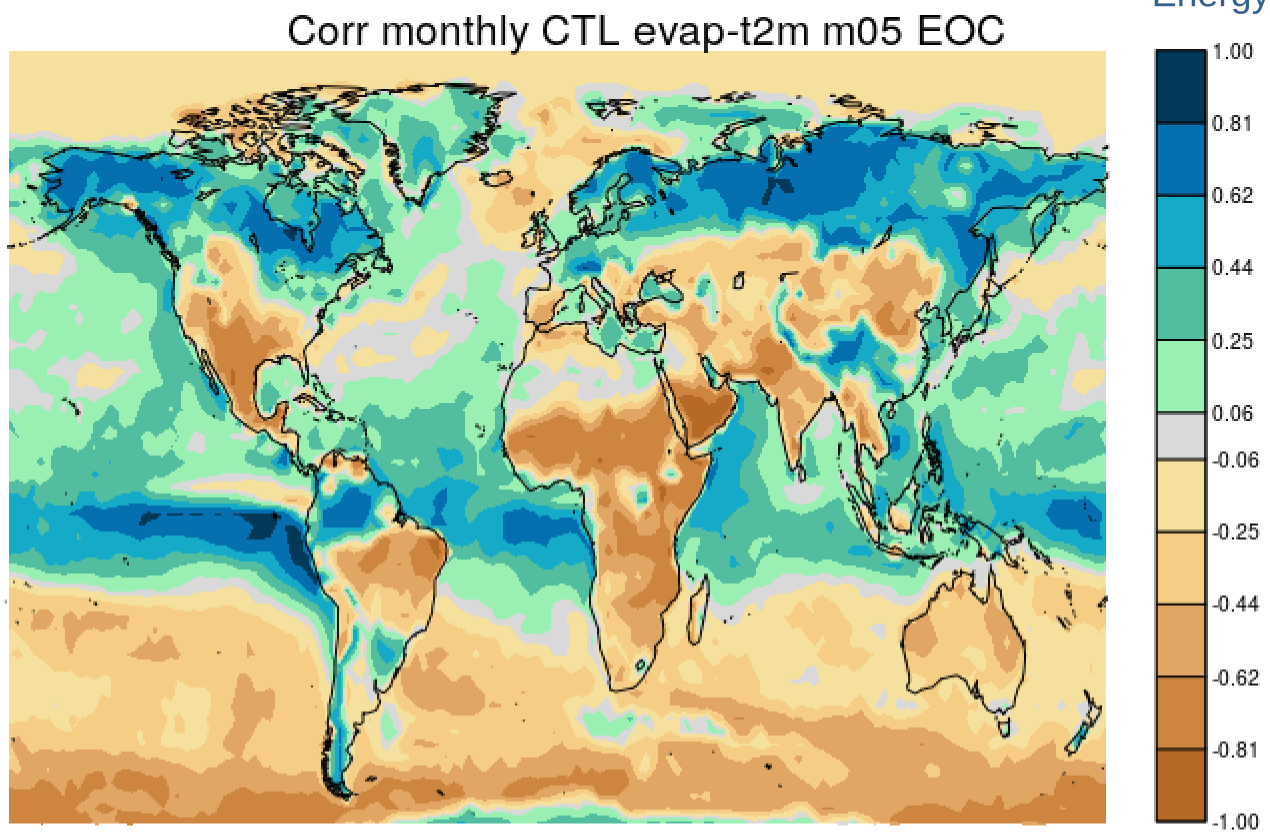


Measures to quantify land-atmosphere coupling

- From (pseudo)observations:
  - Correlation between evaporation and temperature

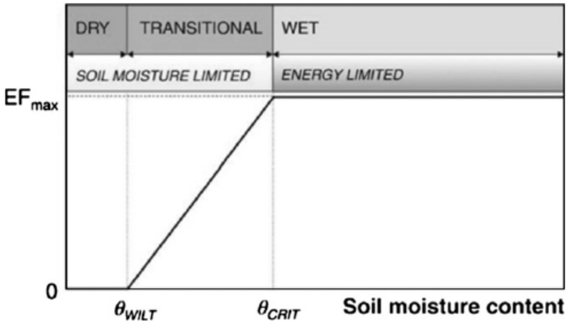
May-Jul

Energy limited


Corr monthly CTL evap-t2m m05 EOC

Soil water limited

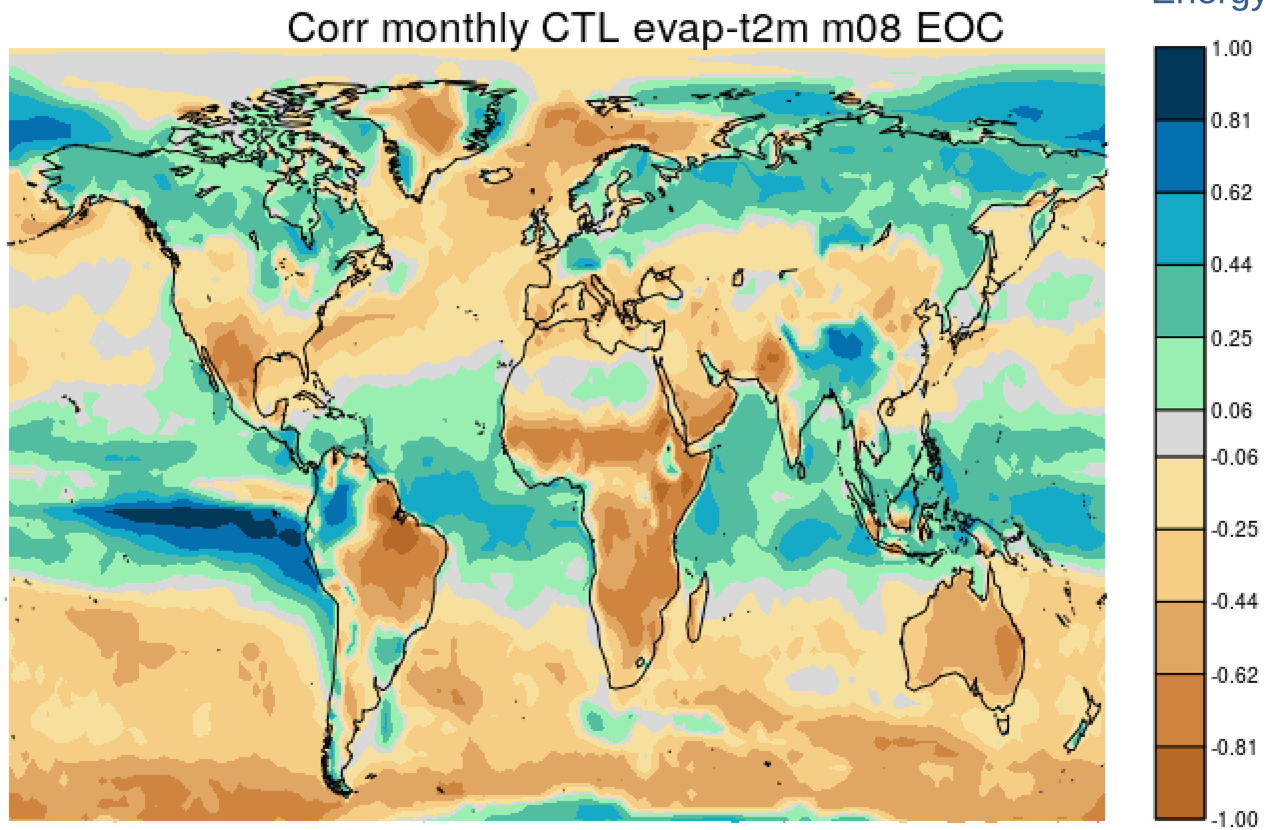
Seneviratne et al, 2010



Measures to quantify land-atmosphere coupling

- From (pseudo)observations:
  - Correlation between evaporation and temperature

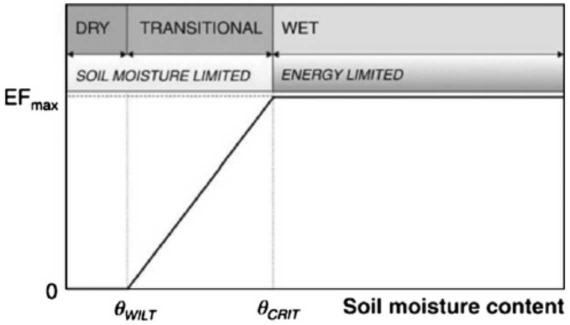
Aug-Oct


Corr monthly CTL evap-t2m m08 EOC

Energy limited

Soil water limited

Seneviratne et al, 2010

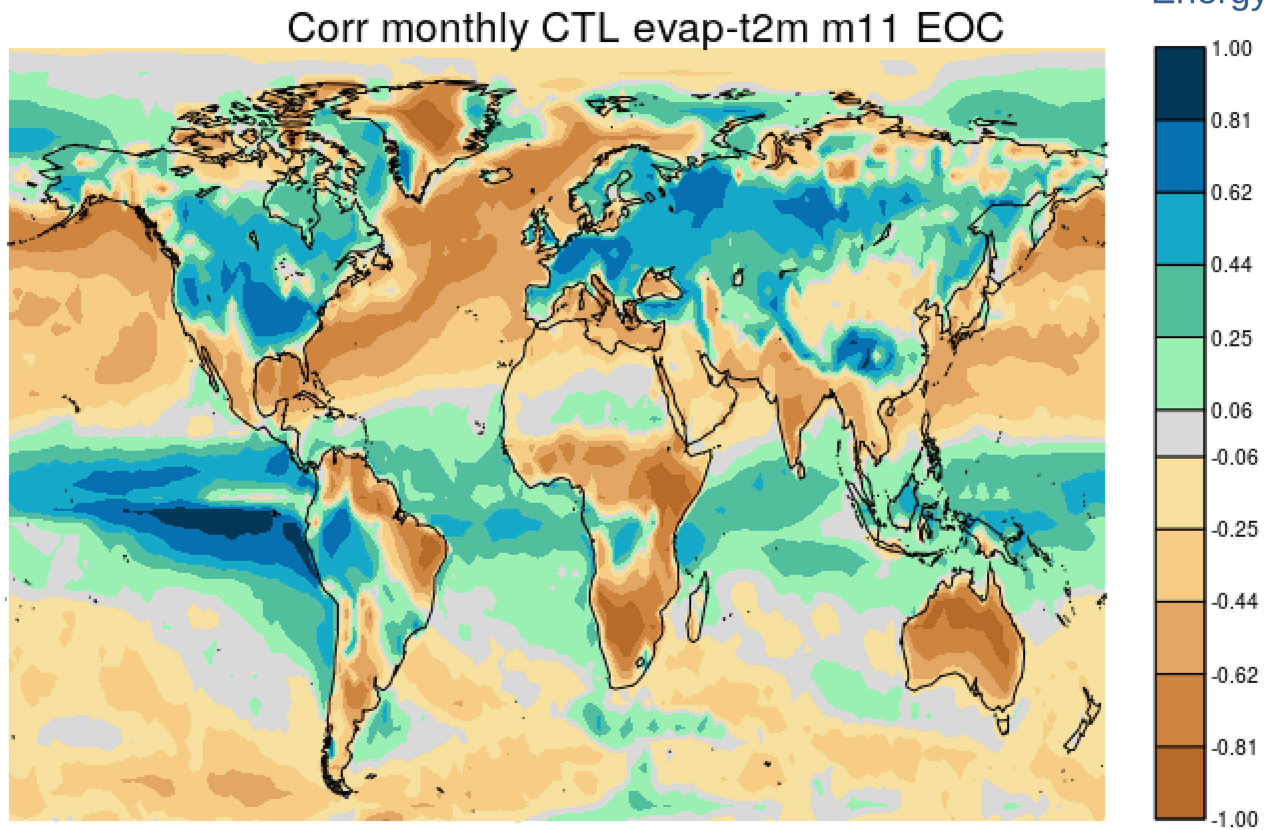


Measures to quantify land-atmosphere coupling

- From (pseudo)observations:
  - Correlation between evaporation and temperature

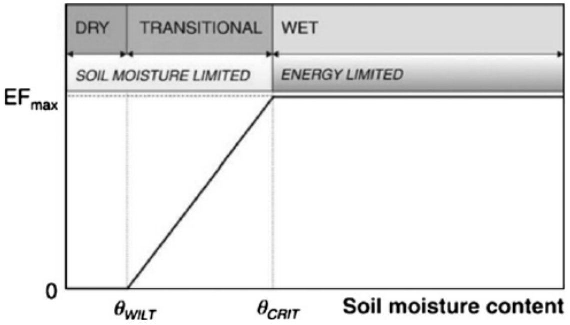
Nov-Jan

Energy limited



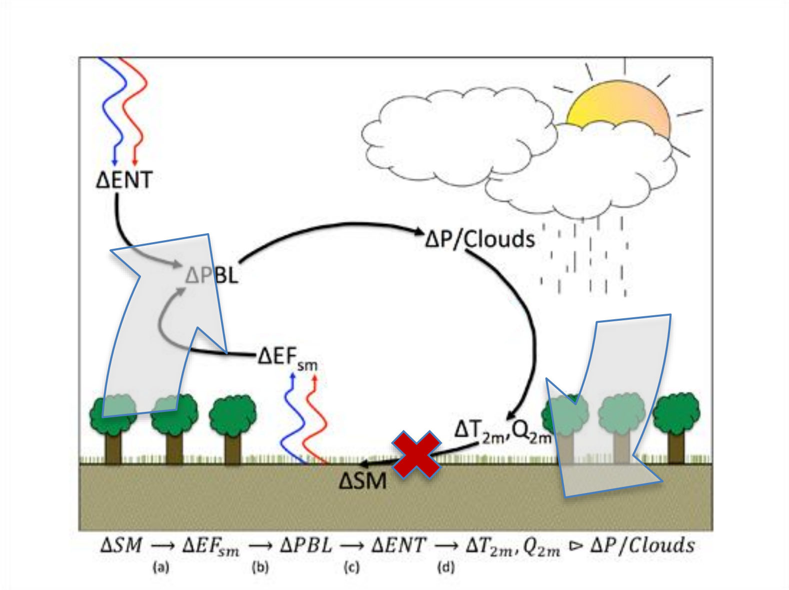
Soil water limited

Seneviratne et al, 2010



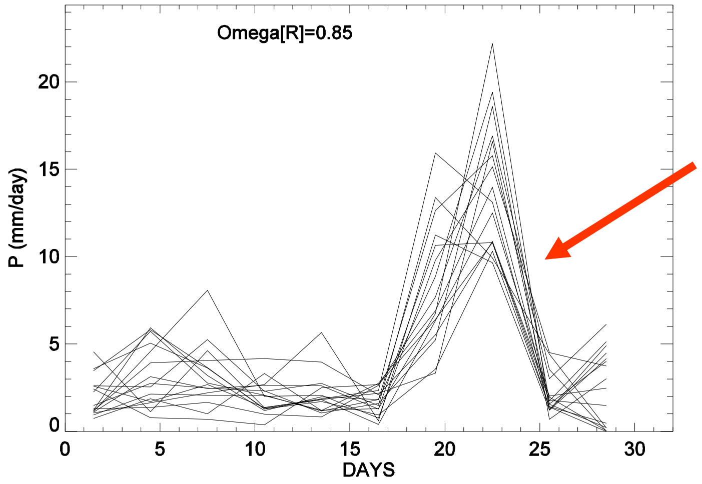
Measures to quantify land-atmosphere coupling

- From a model experiment (GLACE = Global Land Atmosphere Coupling Experiment)
- How?
  - Simulate the hydrological cycle **with** and **without** interactive land-atmosphere coupling and compare.
- How to remove coupling?
  - In second ensemble, replace soil moisture by values from one of the integrations in the first (interactive) ensemble.
- How to measure the effect?
  - Ensemble simulations
  - Compare within-ensemble spread



GLACE

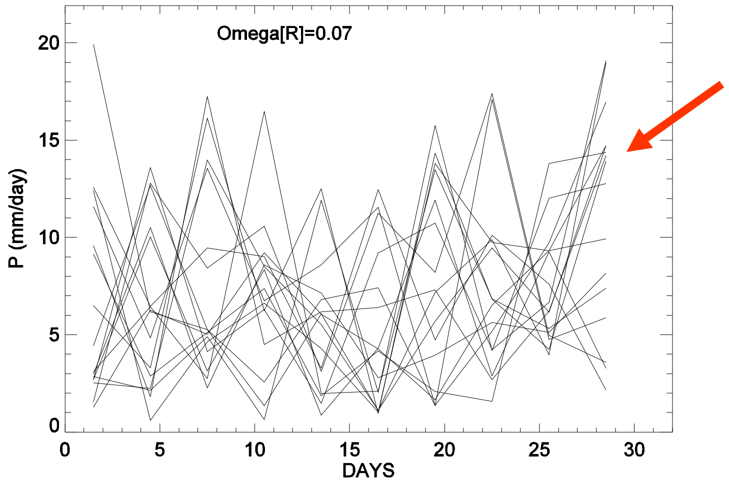
Comparison between ensembles



All simulations in ensemble respond to the land surface boundary condition in the same way

→ strong coupling

$$\Omega = \frac{\sigma_P^2(W) - \sigma_P^2(S)}{\sigma_P^2(W)}$$



Simulations in ensemble have no coherent response to the land surface boundary condition

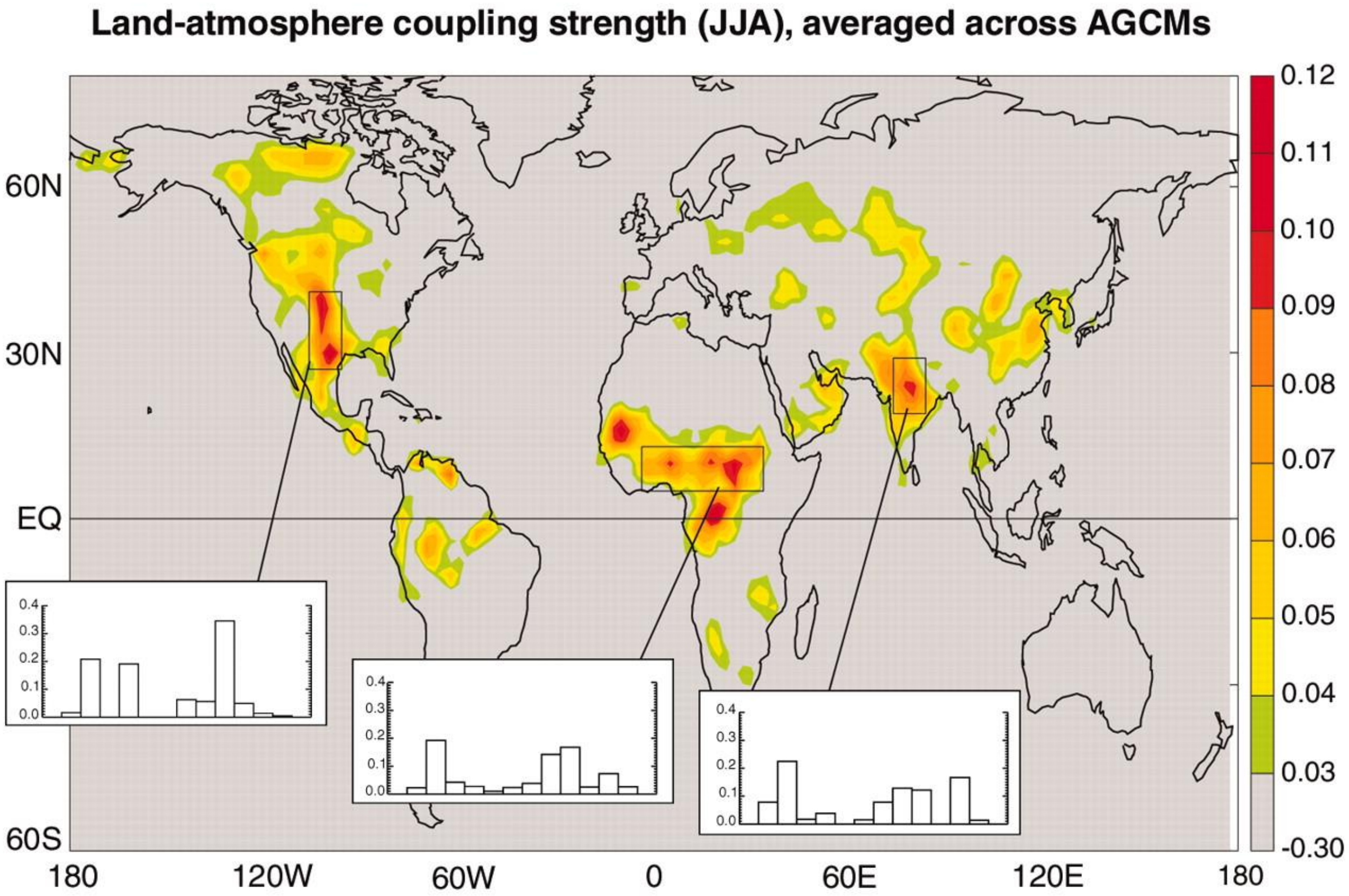
→ weak coupling

ECMWF

Koster et al, 2004, Science

GLACE

Areas with strong feedback



$$\Omega = \frac{\sigma_P^2(W) - \sigma_P^2(S)}{\sigma_P^2(W)}$$

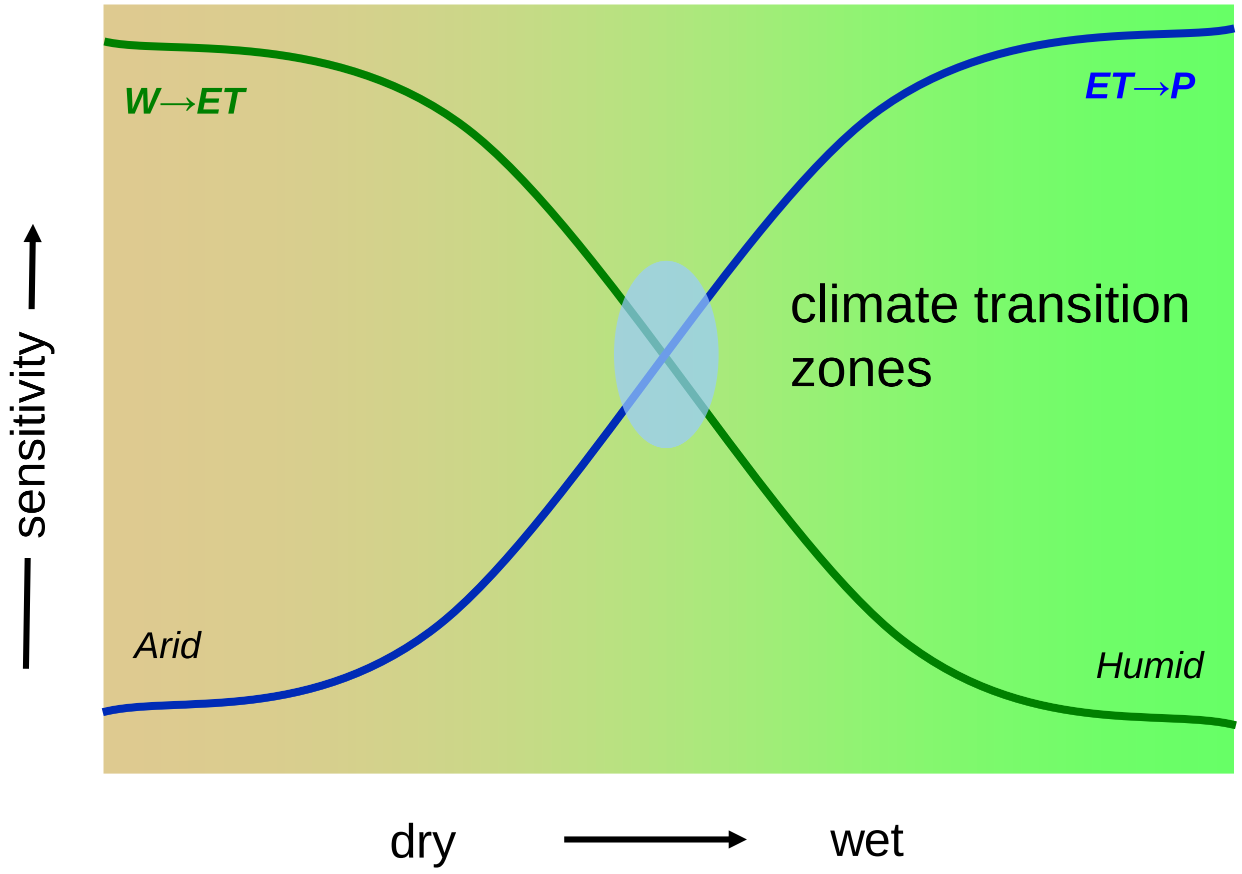
This is a famous figure, and looks very nice. But note that different models gave substantially different results. Model representation of land surface processes is improving, but still has some way to go.

Koster et al, 2004, Science

ECMWF

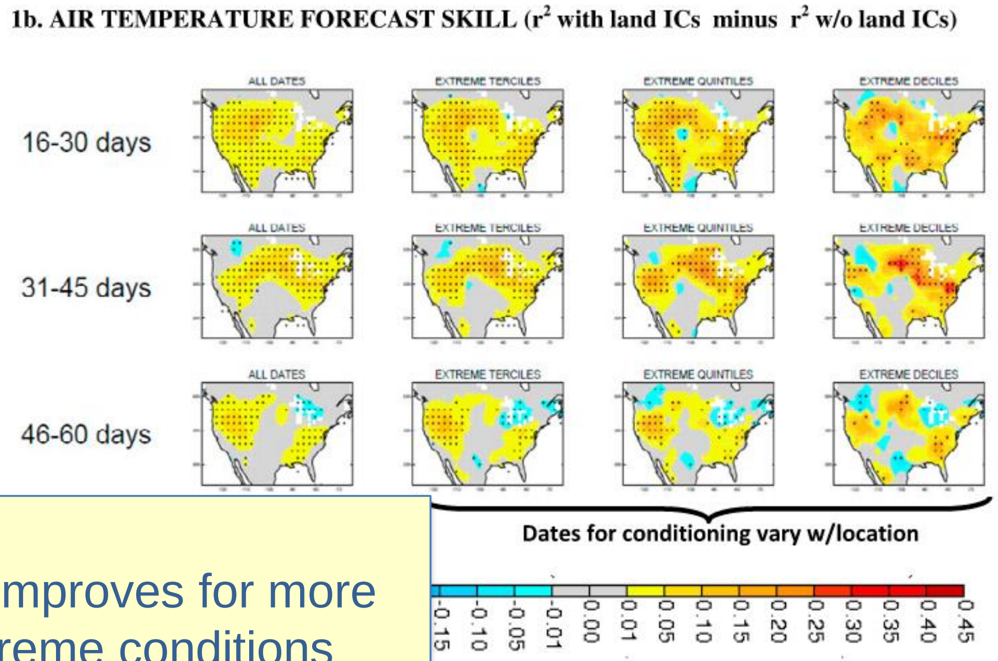
GLACE

Strong coupling needs combination of sensitivities



Some “real” land-surface predictability experiments

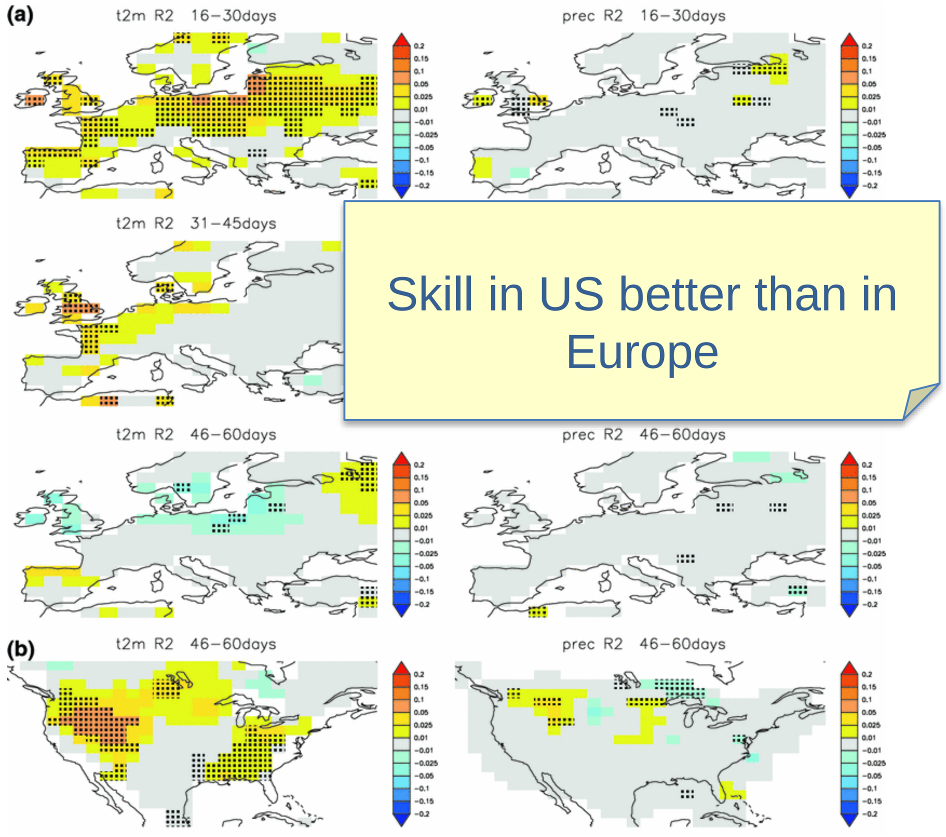
- Global Land Atmosphere Coupling Experiment – 2
  - Compare 2 ensembles of seasonal forecasts (8 weeks ahead)
    - Ensemble 1: all members use the same realistic initial conditions
    - Ensemble 2: every member gets a randomly selected initial condition
  - Measure R^2 difference using real observations



Skill improves for more extreme conditions

Koster et al, 2010

Van den Hurk et al, 2012



Skill in US better than in Europe

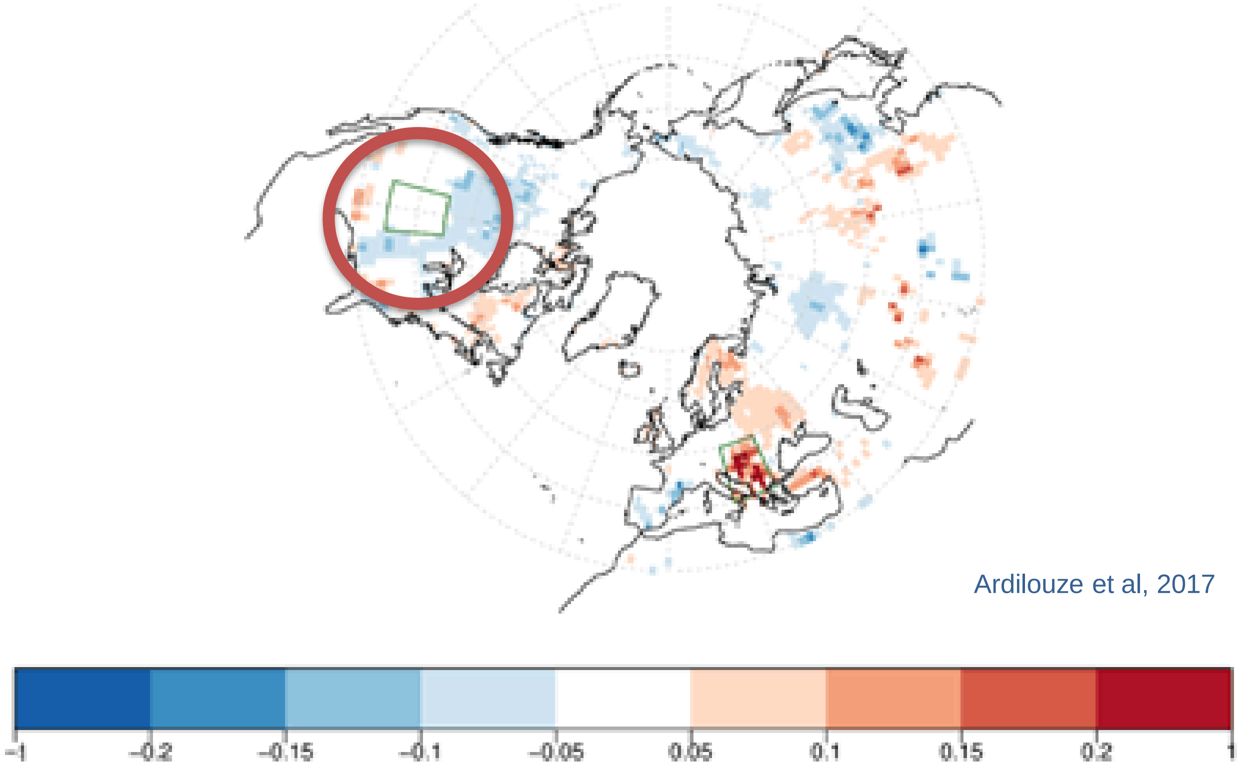
Another experiment, similar set-up, different results!

- Similar to GLACE-2, multi-model study (5 models), but
  - comparing realistic versus climatological initial conditions
  - coupled ocean model instead of prescribed SSTs
  - Longer period (19 yrs instead of 10 yrs)

Model bias in correlation between soil moisture and temperature gives poor results in US

(Models have dry bias, which results in a too-strong sensitivity of T2m to initial soil moisture).

RMS skill INIT – CLIM



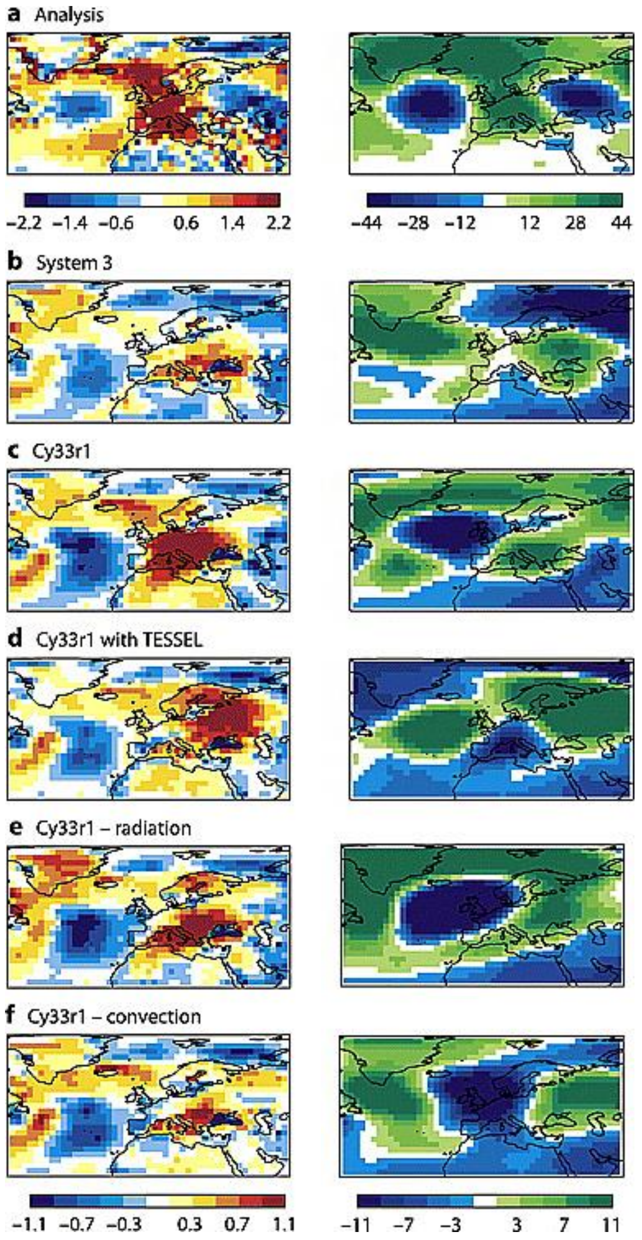
Ardilouze et al, 2017

Prediction of an individual event

- European heat wave 2003
- Different set-ups of ECMWF forecasting system

Temperature anomaly

Z500 anomaly



OBS

Old model

New model

New model
(old land surface)

New model
(old radiation)

New model
(old convection)

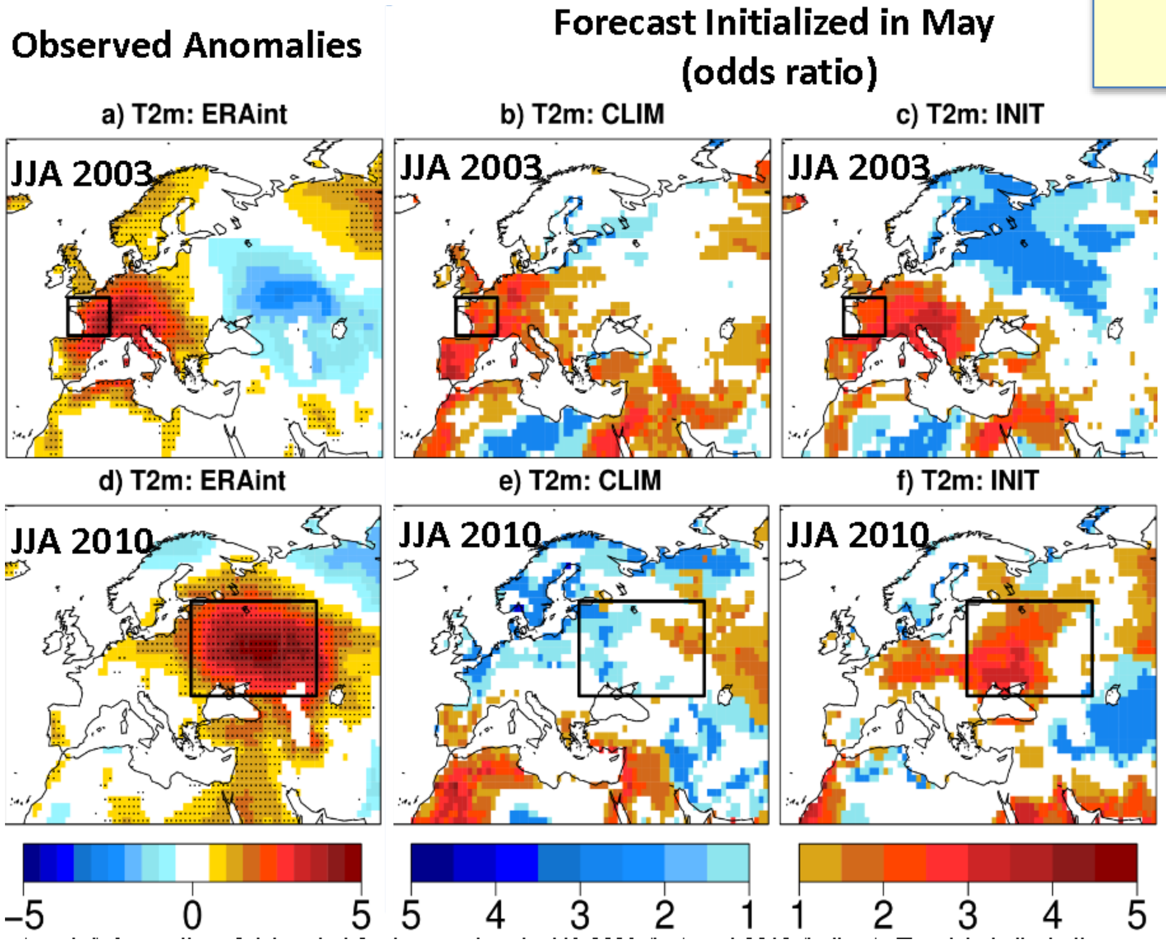
Combination of land surface and atmosphere is needed to improve forecasts

Weisheimer et al, 2011

New study, somewhat different results

- 5 models, comparing INIT with CLIM initialization
- Start date 1 May, evaluation JJA

European heatwave 2003 is less affected by soil than Russian heatwave 2010



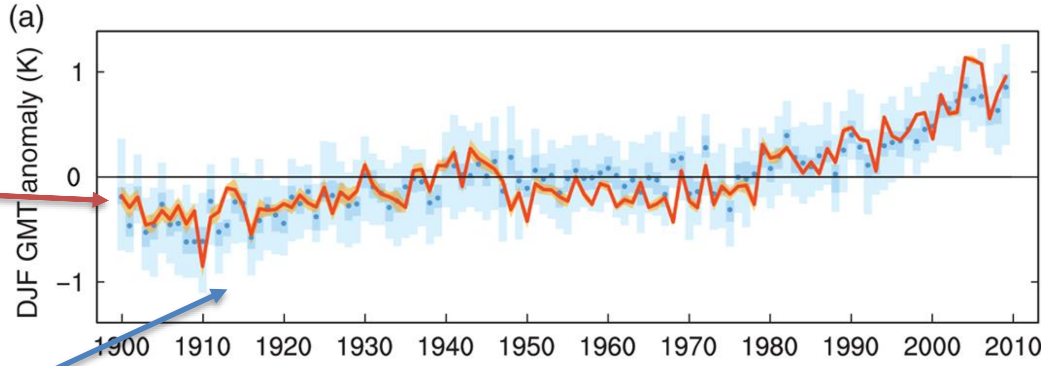
Prodhomme et al, 2015

How about trends in predictability?

- Can we see climate trends in predictability?
  - Model experiment: compare ensemble seasonal forecasts 1900-1929 to 1980-2009
- Can we see trend in land surface contribution to this predictability?
  - Model experiment: same forecasts but with random initial land conditions
- Metric: ratio between **signal** and **total** variance

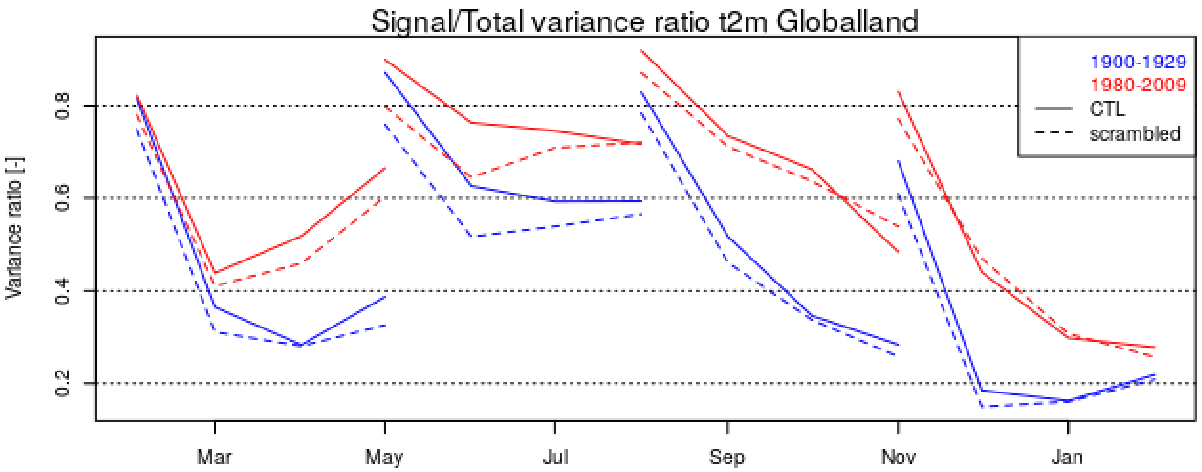
$$V_S = \frac{1}{N}\sum_{n=1}^{N}(\overline{x}_n - \overline{\overline{x}})^2$$

$$V_T = \frac{1}{NE}\sum_{n=1}^{N}\sum_{e=1}^{E}(x_{en} - \overline{\overline{x}})^2.$$

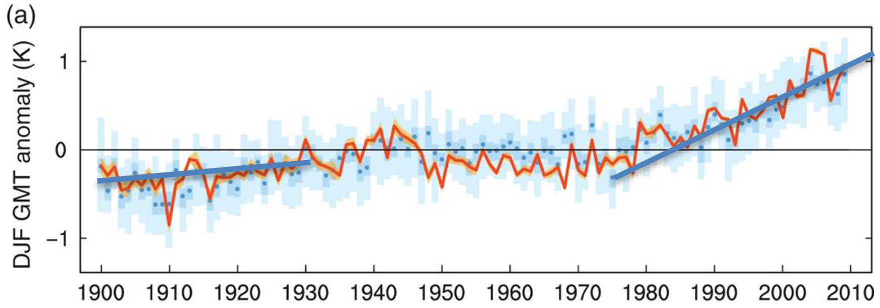


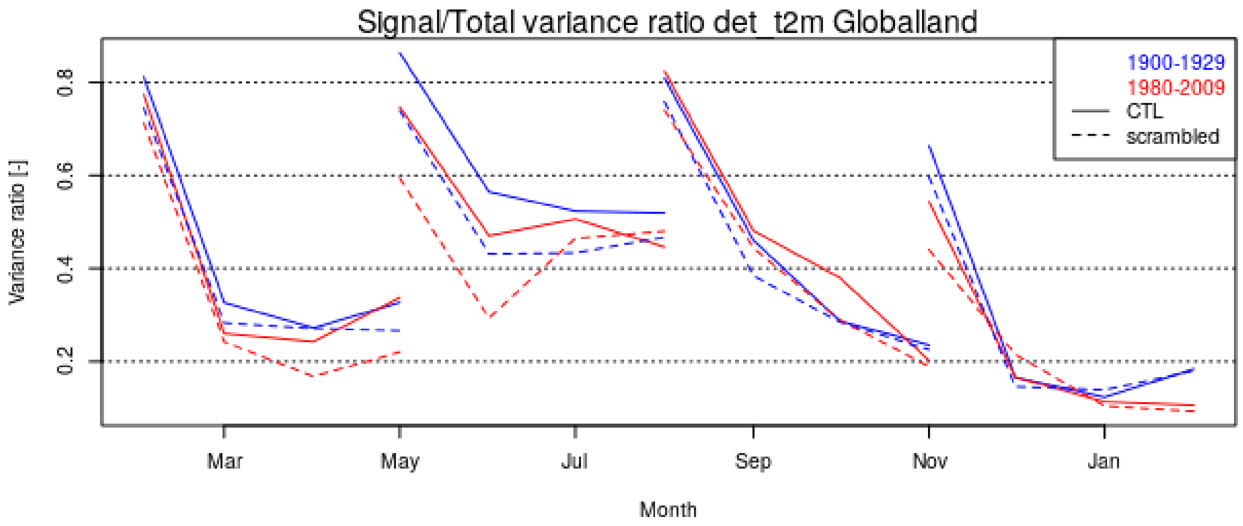
Trend contributes to predictability

Note: initialized land surface (solid line) gives additional signal in T2m, especially in early summer. Note these plots do not show skill – extra skill would require the additional signal to be correct.



Before detrending



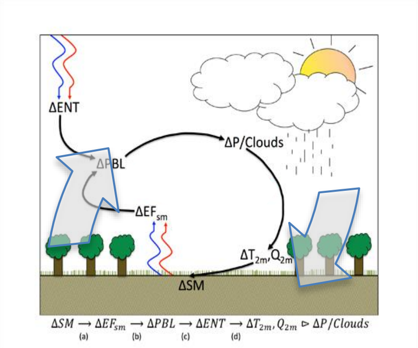


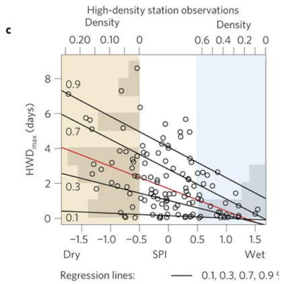
After detrending

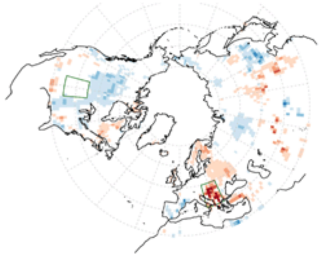
ECMWF

Conclusions

- For land-related predictability we need
  - Variability
  - Memory
  - Coupling
- Predictability affects multiple time scales which can interact
  - Predictions of heatwaves → short time scales
  - Predictions of long warm/cool spells → seasonal time scales
- Land surface signal is moderately small in a noisy climate system
  - We need unbiased model systems…
  - … and pretty large ensembles and long periods
- Land surface initialization *is* improving over time
  - Seasonal t2m skill is improving faster than other fields
  - We believe further progress is possible







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