Land surface contribution to *seasonal* climate predictability: Growing evidence but unfulfilled expectations

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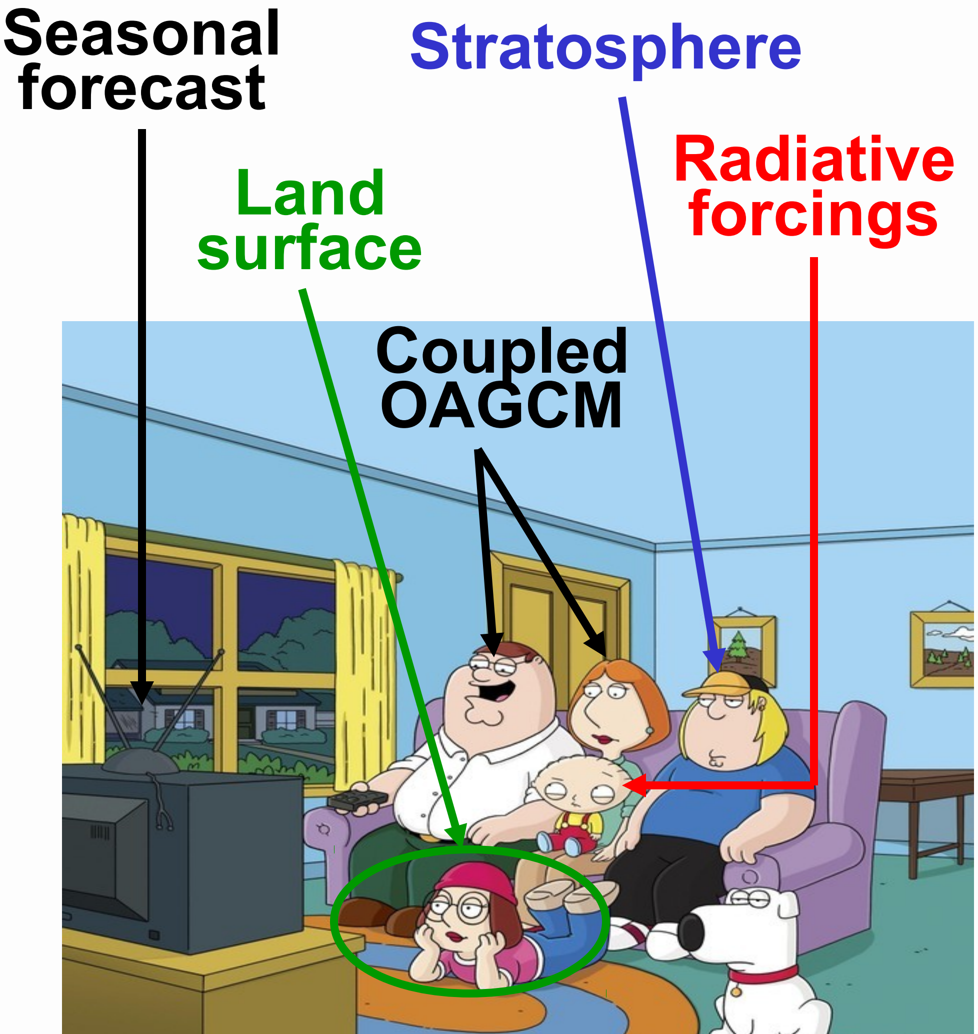
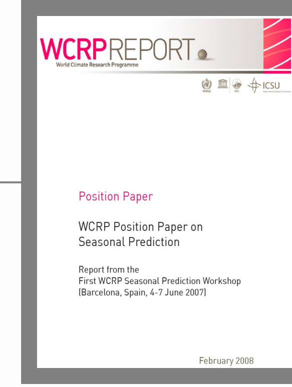
Motivation and outline



« Need to improve the representation of climate system interactions and their potential to improve forecast quality. » (WCRP position paper, Barcelona 2007)


WCRP REPORT
World Climate Research Programme

Position Paper

WCRP Position Paper on Seasonal Prediction

Report from the First WCRP Seasonal Prediction Workshop (Barcelona, Spain, 4-7 June 2007)

February 2008

1. Observational studies (and their limitations)
2. Numerical studies (and their limitations)
3. Some reasons not to despair…

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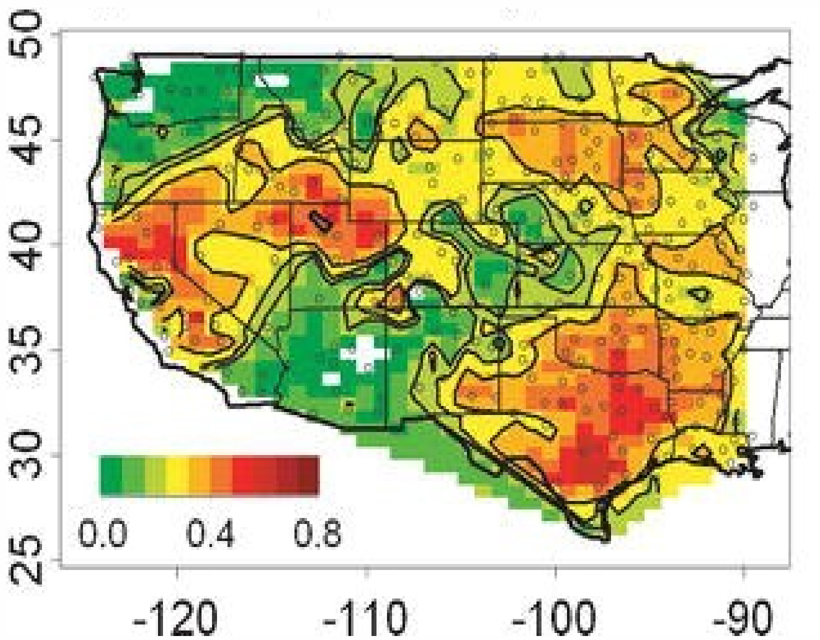
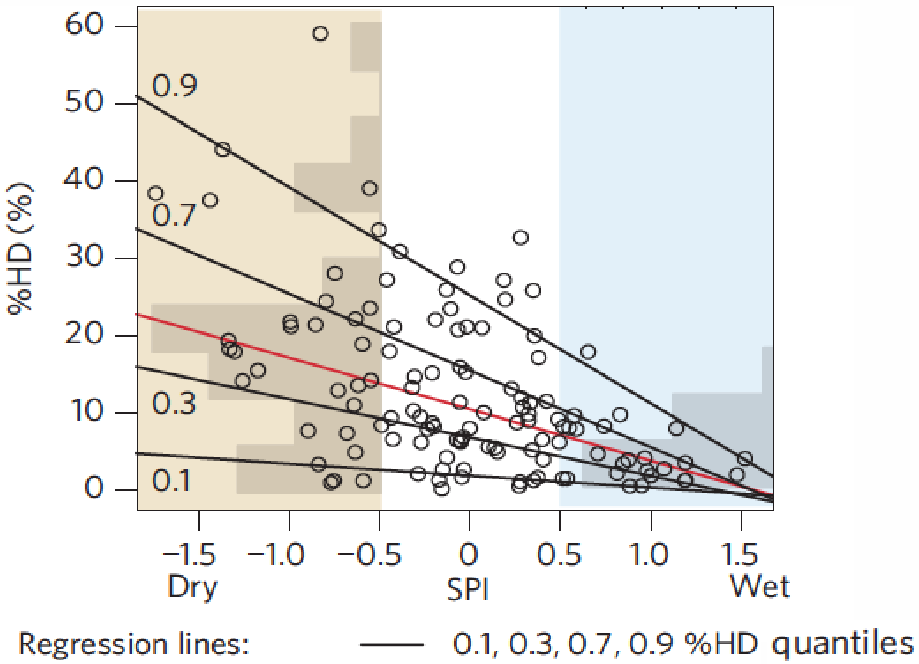
Local impact of spring soil moisture on summer surface air temperature

JJA Tmax prediction skill
(cross-validated over 1950-2001)
using the PDSI in May
as a predictor
Alfaro et al. 2006



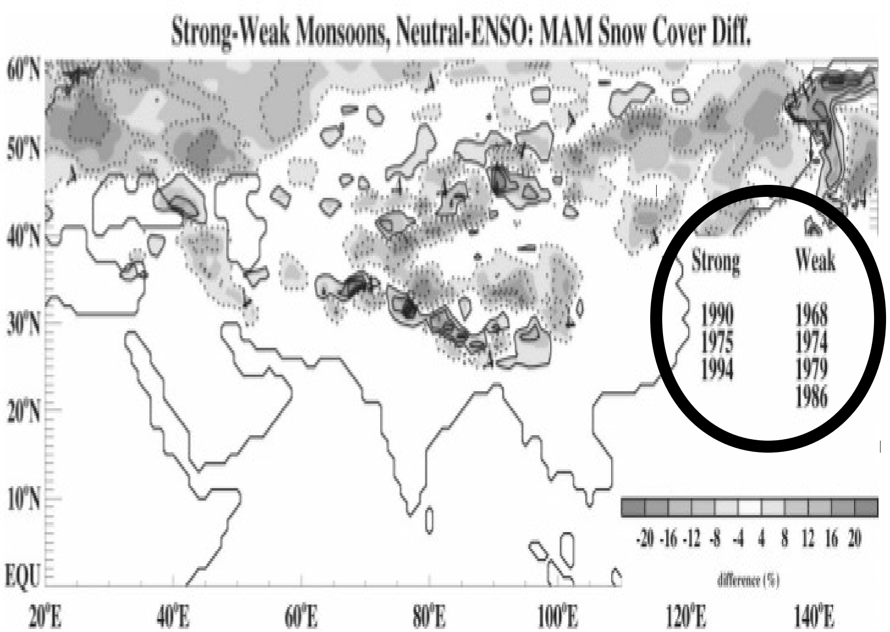
Quantile regression of
% of JJA hot days with
6-month SPI over
Southeastern Europe
Hirschi et al. 2011



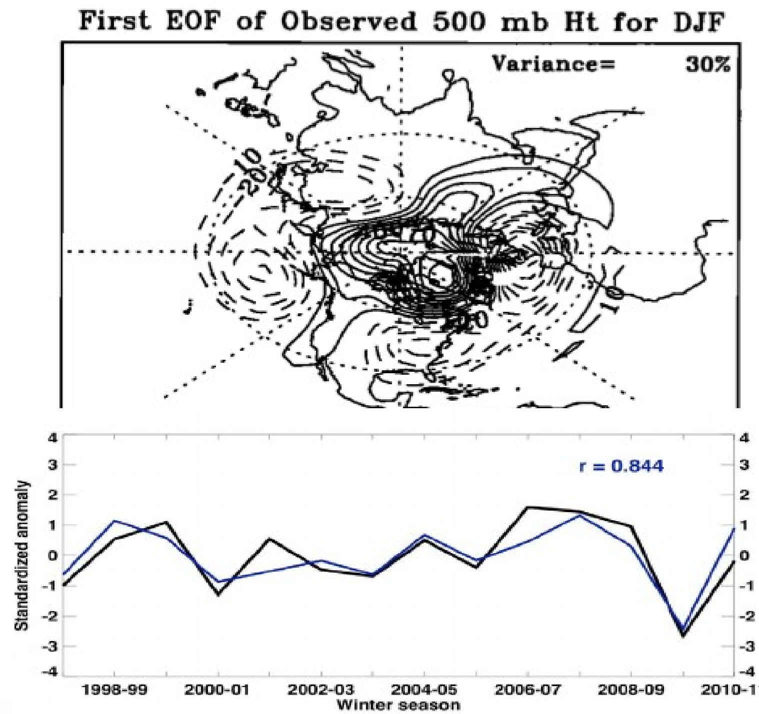
Significant but asymmetric impact of spring « soil moisture » on summer mid-latitude temperatures and their extremes

Remote impact of fall / spring snow cover on the subsequent AO / Indian monsoon

Strong-Weak Indian summer monsoon rainfall composite of spring Eurasian snow cover for neutral ENSO years (1967-2001) Fasullo 2004



Correlation between fall Eurasian snow cover and winter Arctic Oscillation (1973-1996) Cohen & Entekhabi 1999 (1998-2010) Cohen & Jones 2011



Statistical studies also suggest remote land surface impacts e.g. related to the variability of the Eurasian snow cover

Limitation of statistical studies

- Lack of reliable global land surface datasets
  - Proxy rather than direct observations
  - Model-dependent & non-homogeneous land surface reanalyses
  - Short satellite records
- Lack of statistical significance
  - No test at all or test hypotheses not fully satisfied
  - Non-stationarity of the suggested relationship
  - Overconfidence in the prediction skill (e.g. cross-validation)
- Statistical relationship does not mean causality
  - Physical mechanism remains uncertain
  - Apparent relationship due to a common SST forcing

=> Need of numerical sensitivity experiments

Impact of soil moisture initialization on multi-model "consensus" predictability

Impact on pot. predictability (r^2_{ideal})

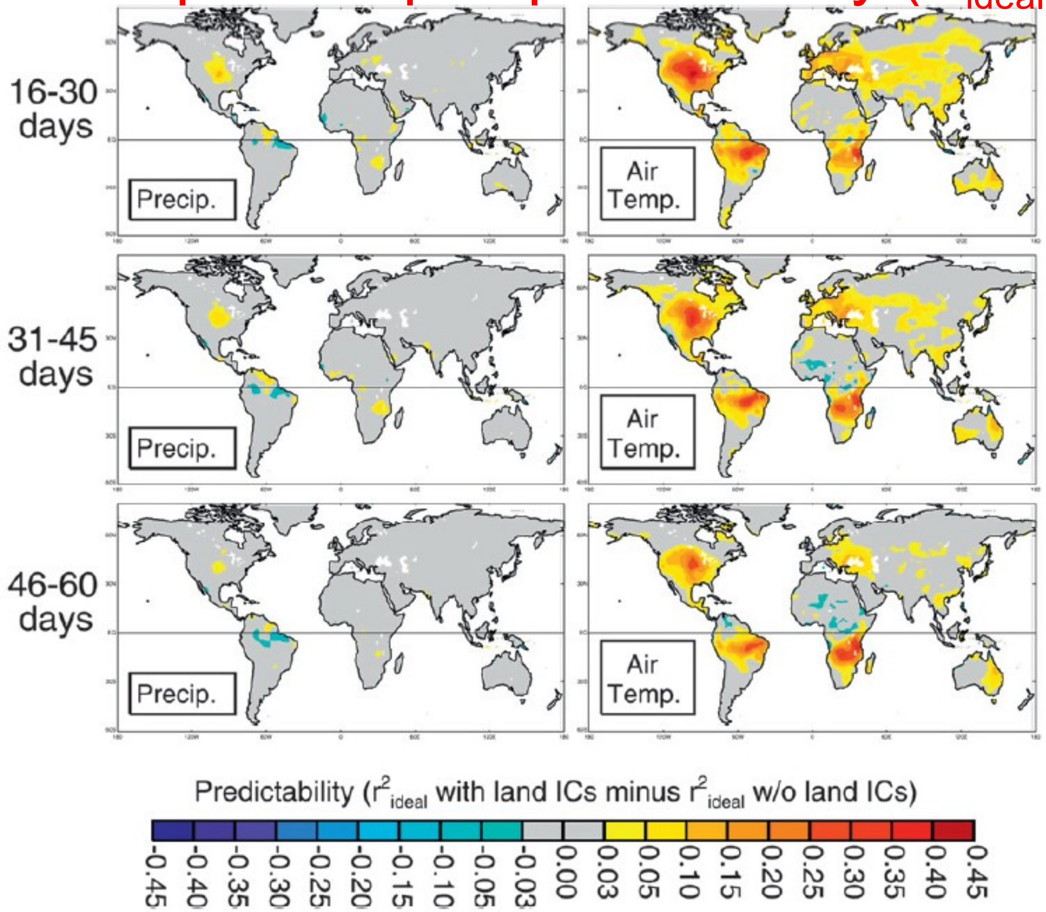


FIG. 3. Multimodel-consensus estimate of (left) precipitation and (right) air temperature

GLACE-2

Koster et al. 2011

- ✓ 2-month hindcasts x 10 years (1986-1995) x 10 members
- ✓ 11 AGCMs driven by prescribed observed SST
- ✓ 2 series: GSWP-2 vs random initialization
- ✓ Focus on **JJA**

Significant impact on potential predictability for temperature (much weaker for precipitation) at subseasonal timescale

Impact of soil moisture initialization on multi-model "consensus" predictability

Impact on effective predictability (r²)

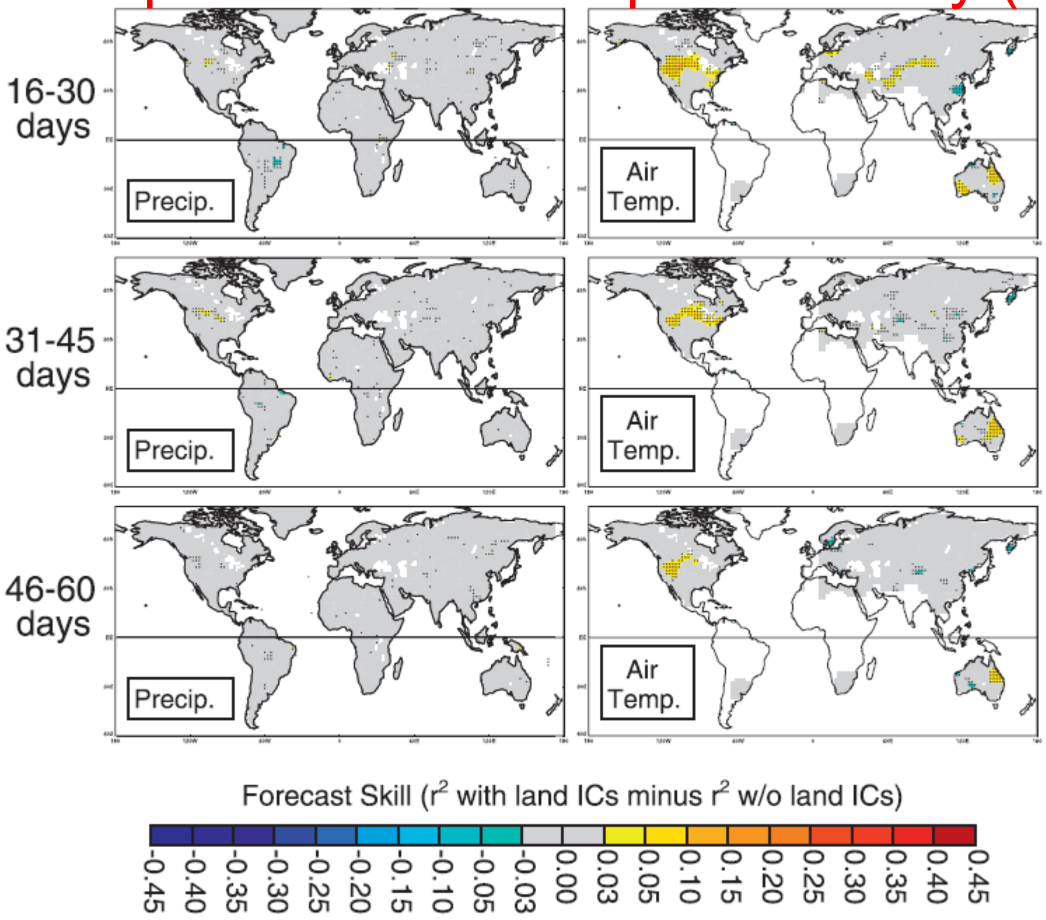


FIG. 2. Consensus (left) precipitation and (right) air temperature forecast skill (r^2 against observations for Series 1 minus that for Series 2) as a function of lead, considering (top to bottom) all 15-day forecast periods during JJA. (See text for details.) Dots are shown where the plotted results are statistically different from 0 at the 99% confidence level; white areas lack available validation data.

Koster et al. 2011

- ✓ Overall, limited impacts on skill (r²)
- ✓ Impacts increase dramatically when conditioned on the size of the initial soil moisture anomaly
- ✓ Impacts stronger in areas with dense rain gauge networks
- ✓ Impacts vary across the models

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Impact of snow mass on T2m predictability in CNRM AGCM

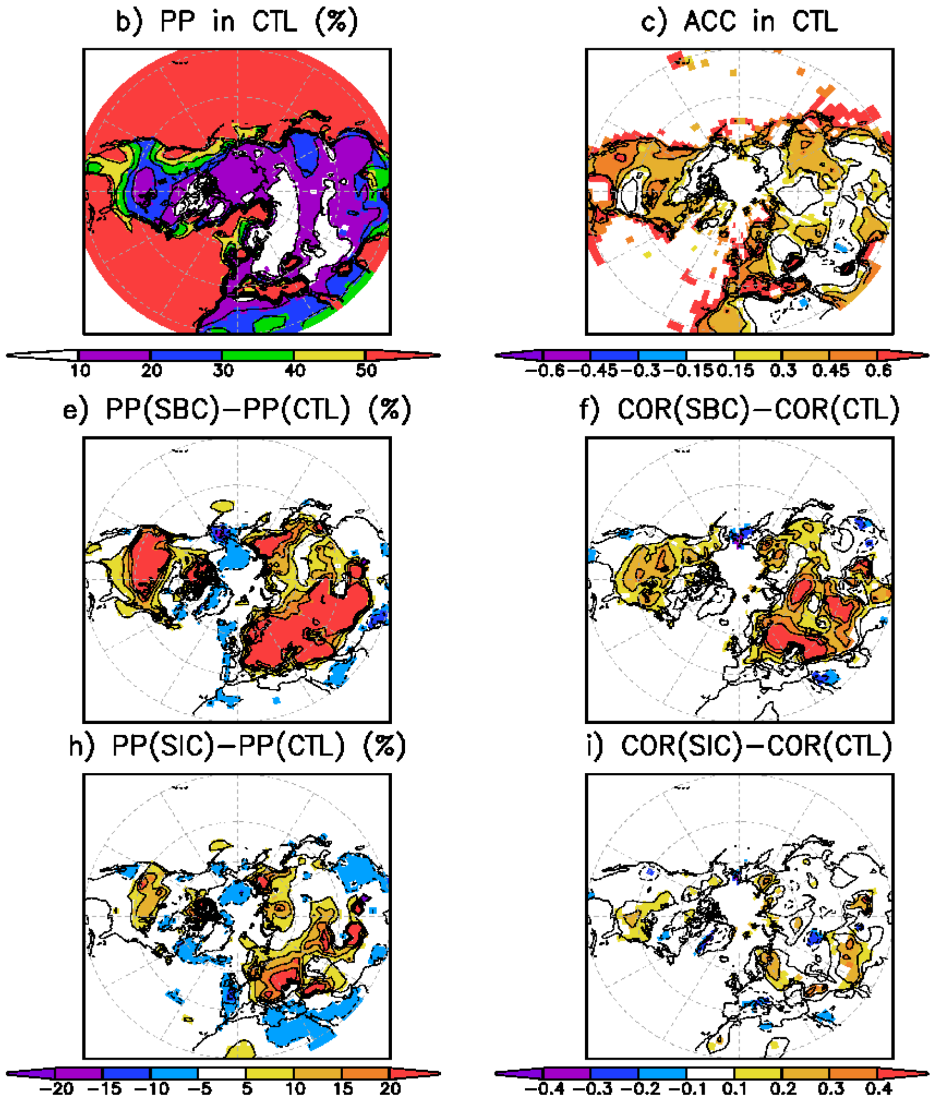
MAM T2m
1950-2000

Control (CTL)
Free snow without initialization

SBC – CTL
Impact of « realistic » boundary conditions

SIC – CTL
Impact of « realistic » initial conditions

r^2_{ideal} r^2



Peings et al. (2011)

- ✓ CNRM AGCM
- ✓ Observed SST
- ✓ 3 10-member ensembles

- ✓ Strong impact on r^2_{ideal}
- ✓ Weaker impact on r^2
- ✓ Limited snow predictability

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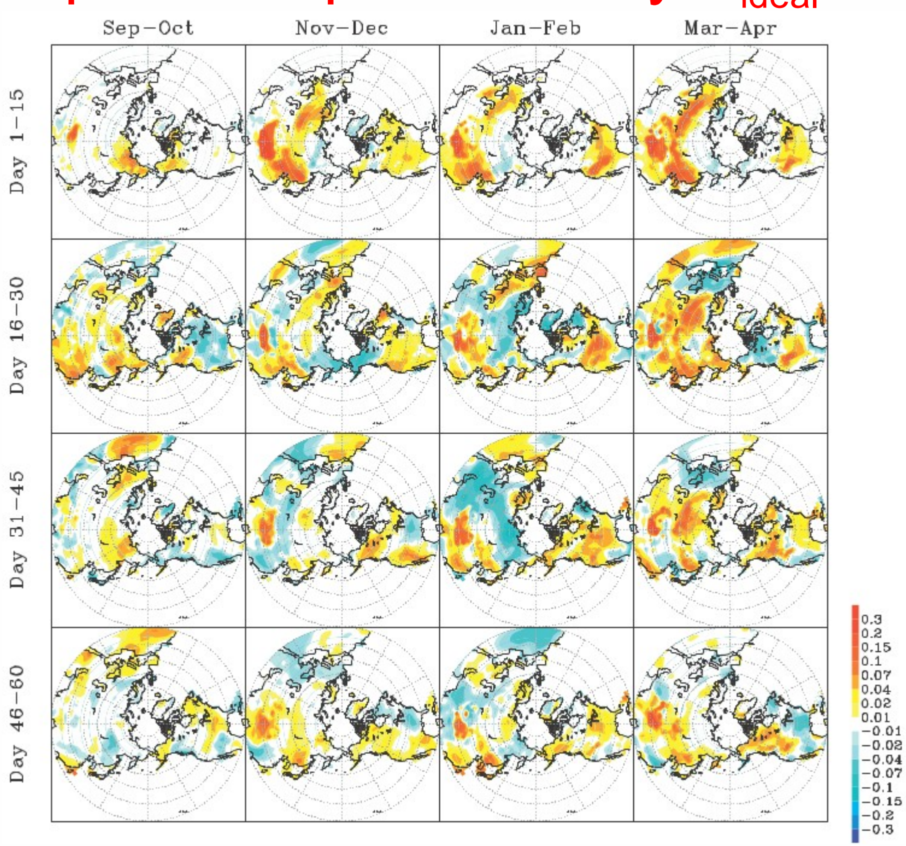
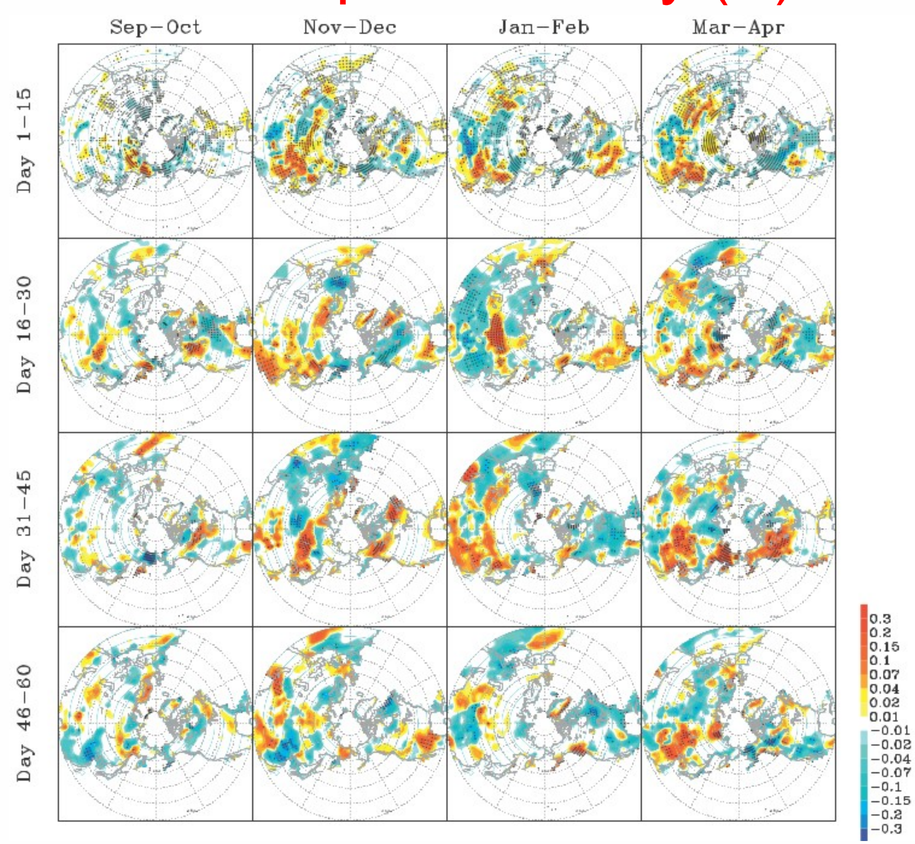
Impact of snow mass initialization on T2M predictability in NCAR AGCM

Impact of snow initialization (1999-2010) on

potential predictability r^2_{ideal} effective predictability (r^2)





Jeong et al. (2013)

✓ Positive impact on r^2_{ideal} but not so clear on r^2

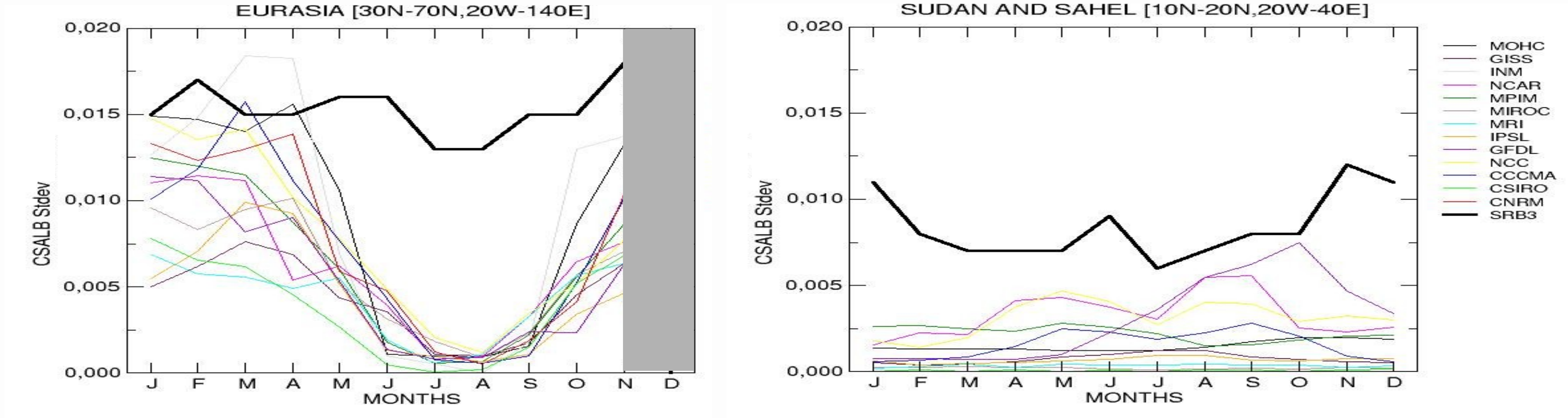
✓ 12 years are not enough for an accurate assessment

Limitation of numerical studies

- LS impacts can be overestimated if the focus is on:
  - Potential rather than effective predictability (e.g. Jeong et al. 2008)
  - Extreme case studies (e.g. Ferranti and Viterbo 2006)
  - Hindcasts rather than real-time forecasts (e.g. Koster et al. 2011)

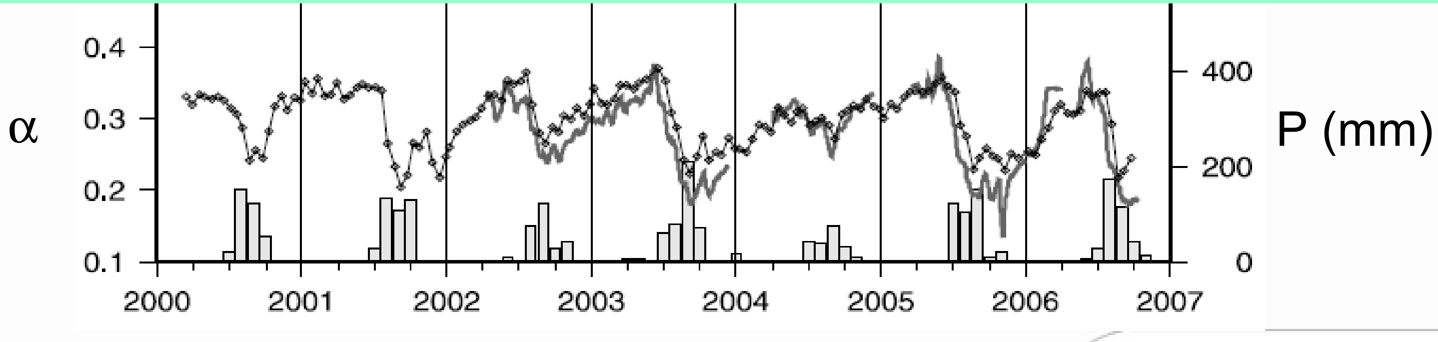
- LS impacts can be underestimated due to:
  - Lack of LS variability (e.g. Hardimann et al. 2008)
  - Missing LS processes such as groundwater (e.g. Bierkens and van den Hurk 2008) or vegetation (e.g. Gao et al. 2008) dynamics
  - Lack of ocean coupling (e.g. Henderson et al. 2013)
  - Large atmospheric biases (e.g. Peings et al. 2012)

Lack of land surface variability
Ex: Interannual variability of surface albedo



Annual cycle of interannual standard deviation of clear-sky surface albedo simulated by a subset of CMIP5 ESMs (against satellite observations)

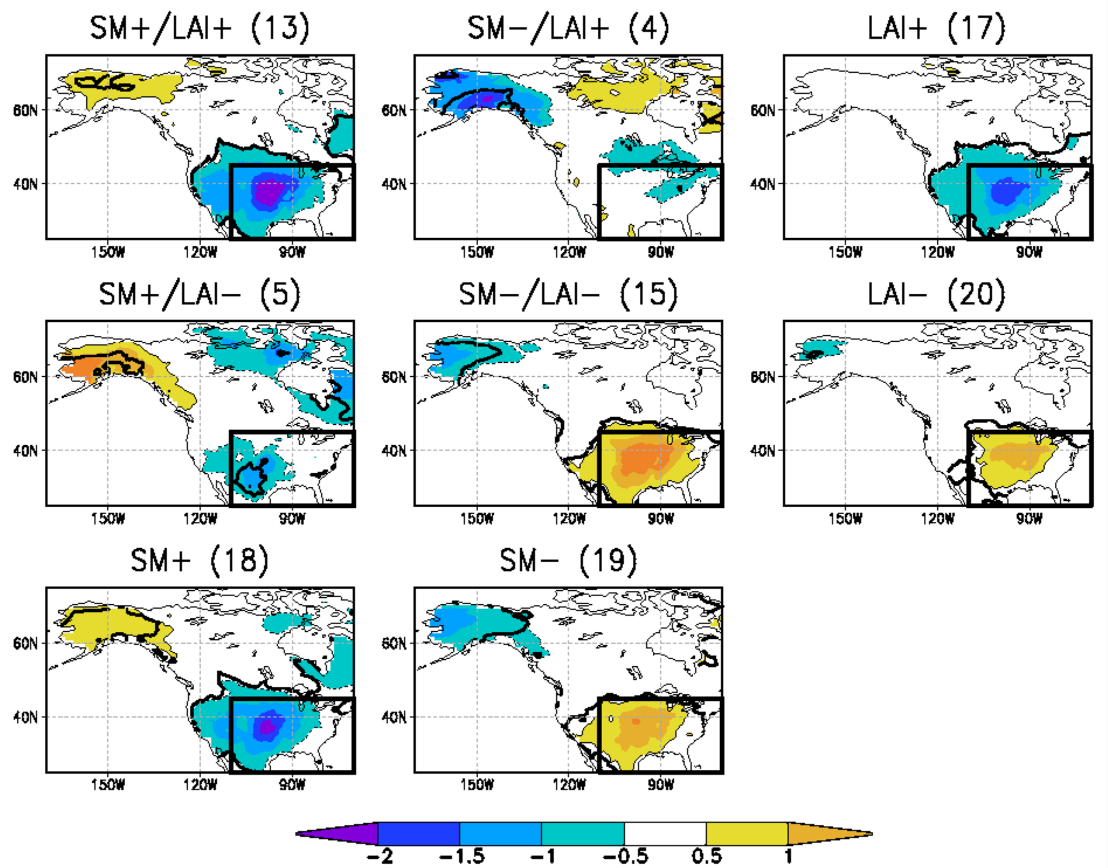
Poor simulation of snow, vegetation and soil moisture impacts on land surface albedo



Albedo from MODIS and field station data and monthly precipitation at Agoufou in West Africa (Samain et al. 2008)

Lack of multi-variate studies
Ex: soil moisture & LAI

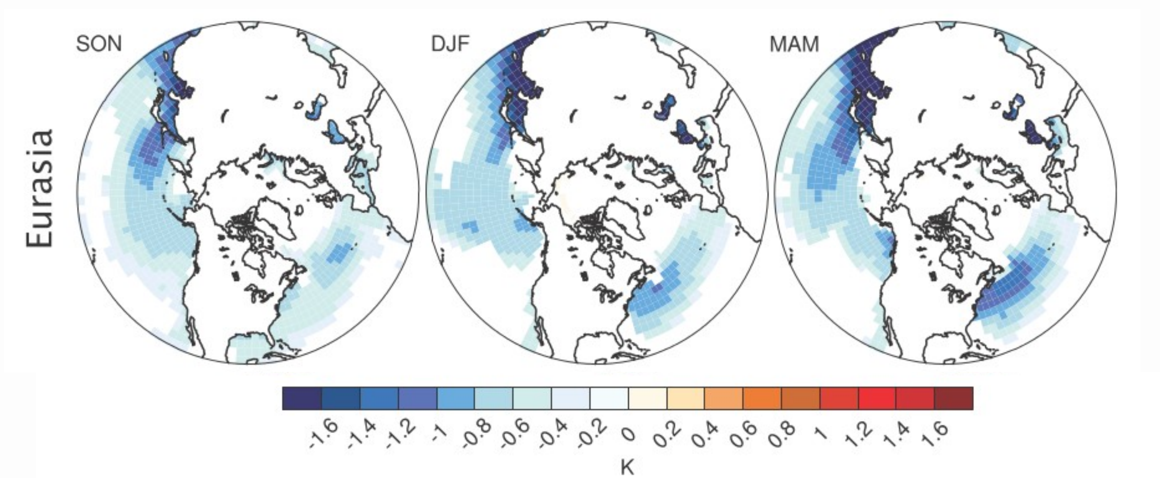
South West US JJA soil moisture & LAI composites of JJA T2M (°C) over North America in a CMIP5 historical simulation based on CCSM4



Most studies on summertime land-atmosphere interactions focus either on soil moisture (e.g. Koster et al. 2011) or on vegetation (e.g. Weiss et al. 2012) while both contribute to the interannual variability of evapotranspiration

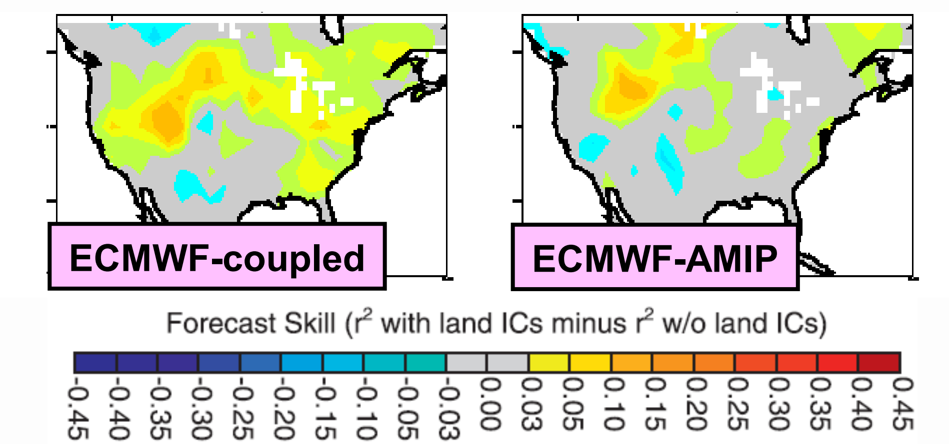
Lack of ocean coupling: Land surface impacts can be SST-mediated

Impact of Max minus Min snow depth over Eurasia on seasonal mean SST (K)



Henderson et al. (2013) showed a significant and persistent SST cooling, both downstream and upstream of the snow forcing

Impact of soil moisture initialization on JJA T2m predictability at 16-30 days



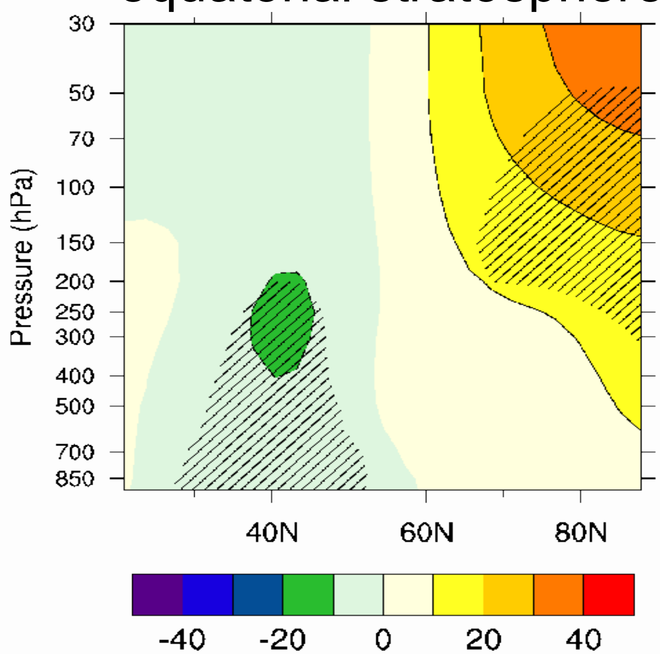
Van den Hurk et al. (2012) showed a stronger impact with coupled than with AMIP SST => land surface impacts on SST predictability?

AO response to deep snow over Siberia
Sensitivity to CNRM AGCM biases

Impact of a deep snow anomaly prescribed over Siberia
on DJF mean zonal mean geopotential height (m)
in 50-member ensembles of AGCM winter simulations

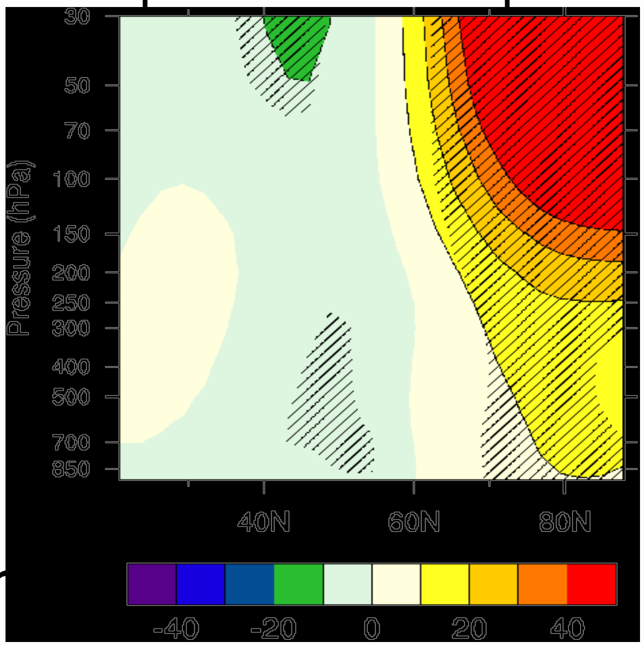
Peings et al. (2012)

Free
equatorial stratosphere



Z (m

Bias-corrected
equatorial stratosphere

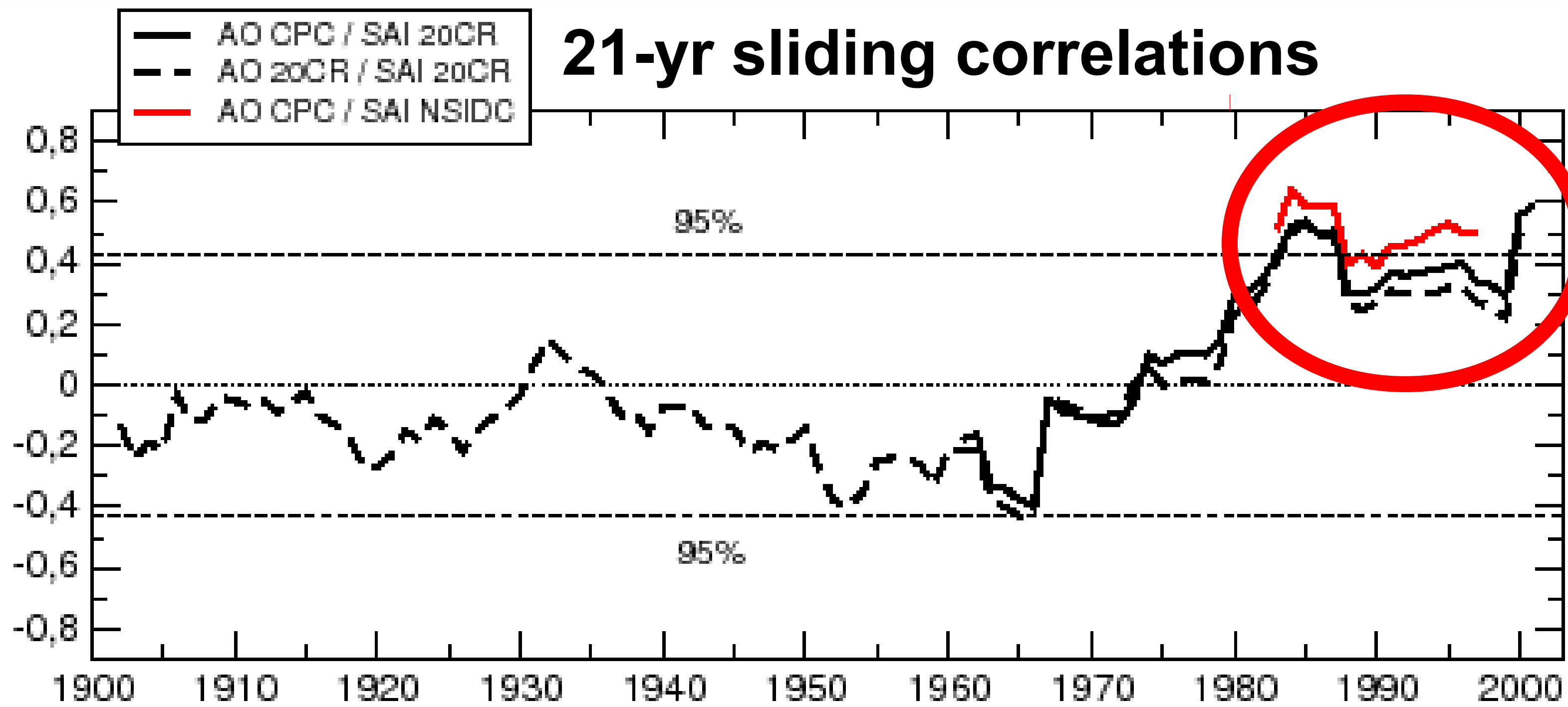


The stratospheric pathway of the snow-AO relationship is better simulated if the zonal wind model biases are reduced in the equatorial stratosphere (via a nudging technique)

CONCLUSION

- There is growing evidence of both local and remote LS impacts on climate predictability;
- Dynamical hindcasts however only show limited and short-lived impacts on prediction skill, especially for precipitation;
- We need:
  - Better GCMs with improved LS feedbacks (e.g. DICE initiative) as well as more realistic sensitivity experiments based on coupled OAGCMs (e.g. GLACE3, SPECS http://www.specs-fp7.eu) to assess the LS contribution to climate predictability;
  - Better observing and LDAS systems to improve LS initialization in operational forecasting systems;
  - Longer and more homogeneous LS and atmosphere reanalyses (e.g. 20CR) to perform longer hindcast experiments and develop more robust statistical forecasts (as benchmarks).

Snow-AO relationship:
Not stationary in the 20th century reanalysis



According to the 20th century reanalysis (20CR) (Compo et al. 2011), the snow-AO relationship is not stationary and has emerged only recently

Peings et al. (GRL 2013)

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Snow-AO relationship:
Strongly sensitive to the phase of the QBO

The AO response to the snow forcing is very sensitive to the zonal mean flow (critical latitude of zero wind between tropical easterlies and extratropical westerlies) and therefore to the phase of the QBO in the equatorial stratosphere

Contrasting two periods in NCEP reana

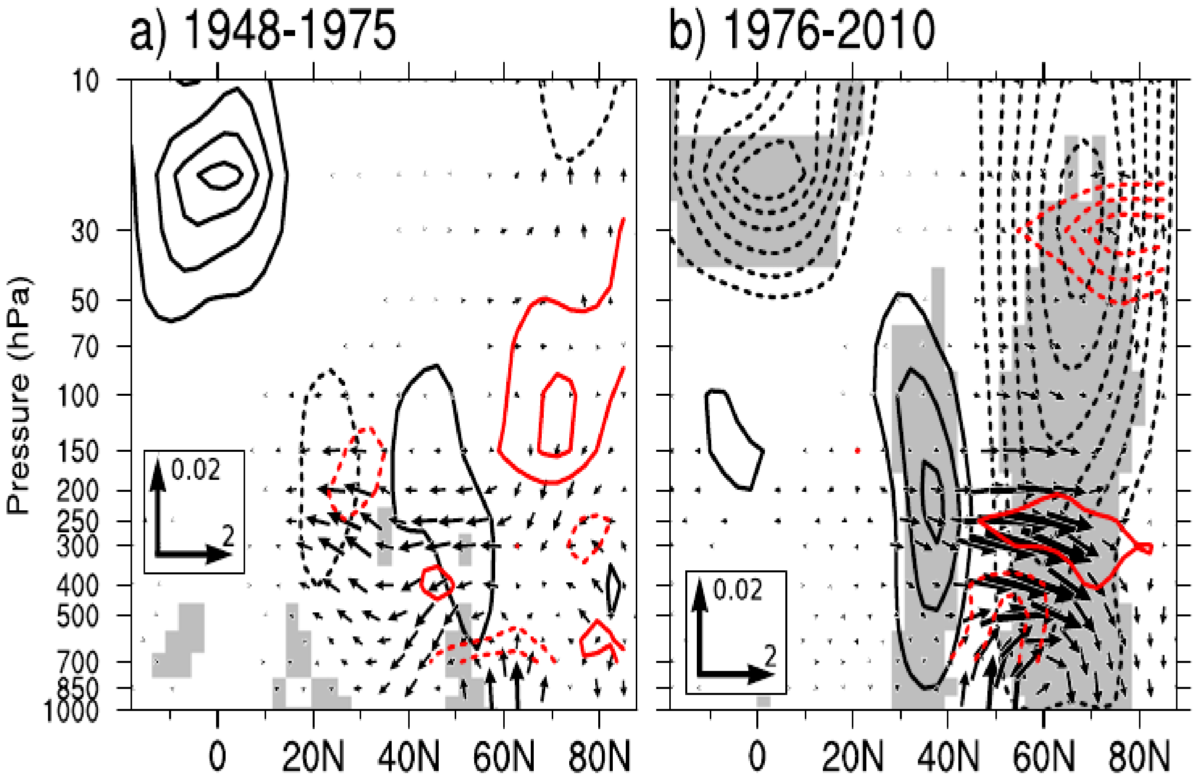

Figure 4. Regression of the DJF zonal mean zonal wind anomalies (black contours, interval is 0.5 m/s), of the WAF (arrows, scale in m^2/s^2) and of the WAF divergence (red contours, interval is 4.10^{-5} m/s^2) onto the 20CR-SAI, for (a) 1948–1975 and (b) 1976–2010. Zonal wind anomalies that are significant at the 95% confidence level are shaded. For display, the vertical component of the WAF vectors was multiplied by 100 and both WAF and divergence were multiplied by the square root of p (p = pressure/1000 hPa). The SAI is here multiplied by –1 such that these patterns are associated with a positive snow anomaly over Siberia.

Peings et al. (GRL 2013)

End

Questions ?