Past land-use induced surface albedo and shortwave radiation changes inferred from global simulations and observations

J. P. Boisier, N. de Noblet, P. Ciais
+ LUCID participants

LUCID model intercomparison project

Land-use and climate: Identification of robust impacts (LUCID) is an initiative under the auspices of IGBP-iLEAPS and GEWEX-GLASS to identify and quantify those impacts in climate of LULCC that are robust (shared by models and above their natural variability).

Past land-use modeling experiment:

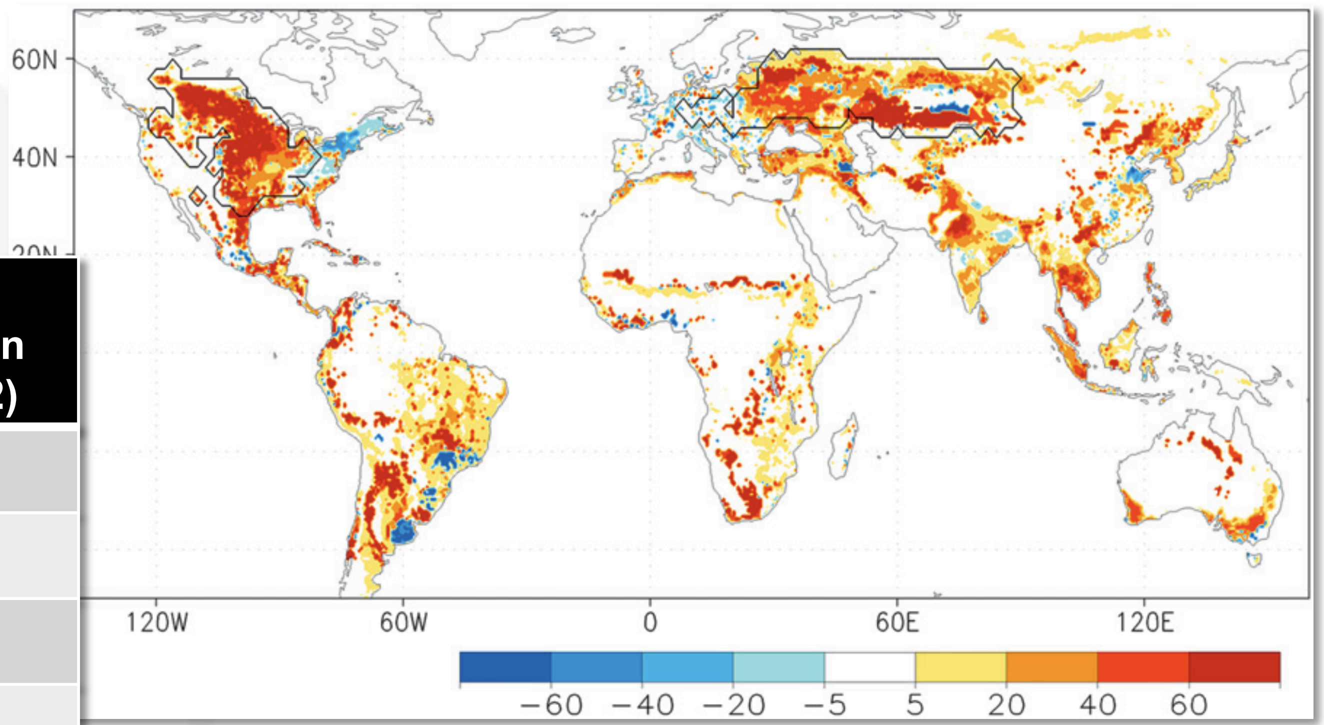
7 GCMs carried out ensemble simulations with preindustrial (1870) and present-day (1992) land cover, based on a merged dataset of crop (SAGE) and pasture (HYDE).

All of them used prescribed SSTs (HadISST) and fixed atmospheric CO2 concentrations.

> Only the biogeophysical impacts of LULCC are assessed.

LUCID

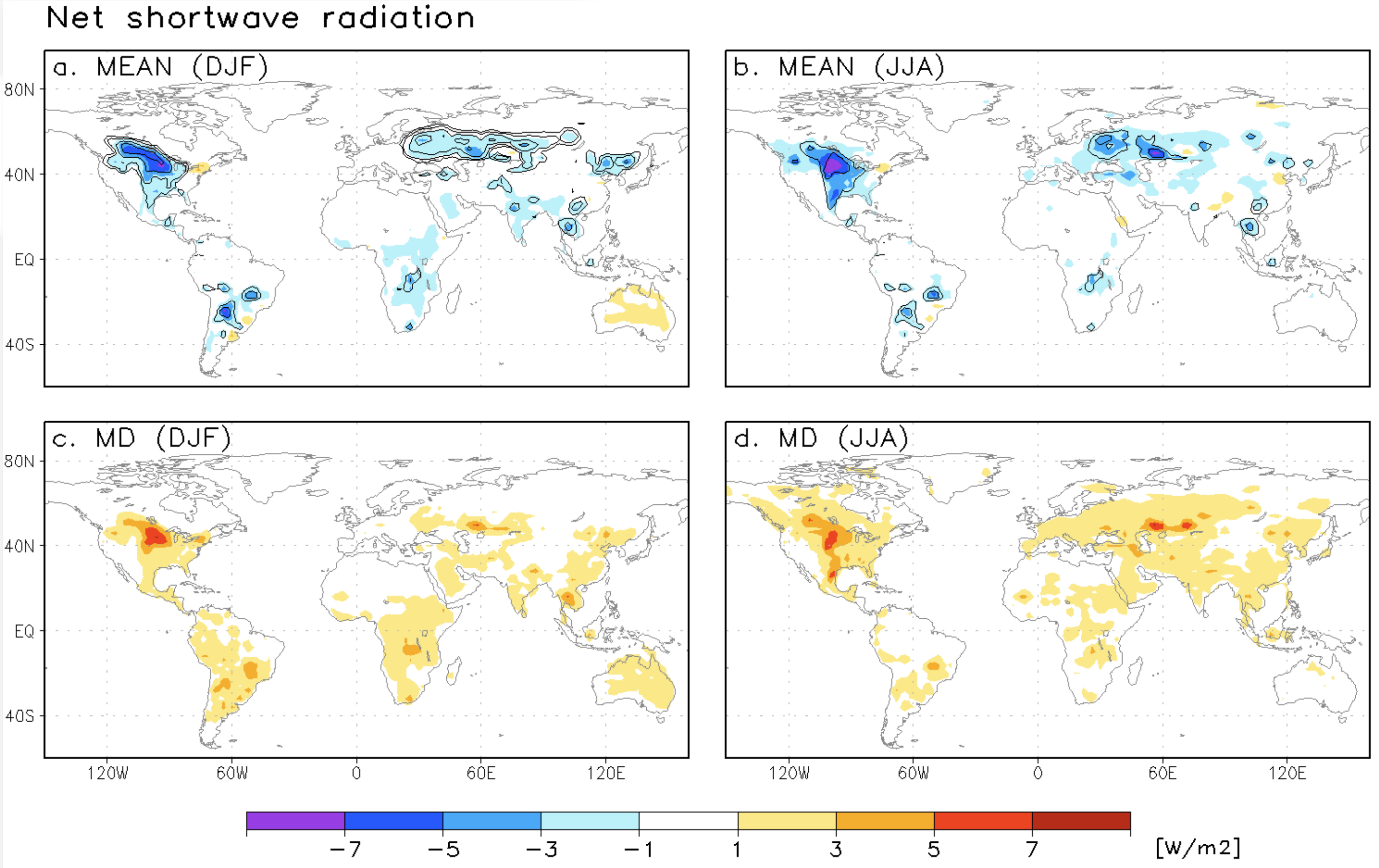
Difference (1992-1870) in areal fraction of crop+pasture



GCM/LSMs	Global deforestation (million km2)
ARPEGE/ISBA	- 5.1
CCAM/CABLE	- 4.4
CCSM/CLM	- 5.0
ECEARTH/TESSEL	- 10.0
ECHAM5/JSBACH	- 4.0
IPSL/ORCHIDEE	- 9.5
SPEEDY/LPJmL	- 7.2

The final forcing (LULCC) highly dependent on the background (natural) land-cover map and the strategy used to incorporate the agricultural data in LSMs.

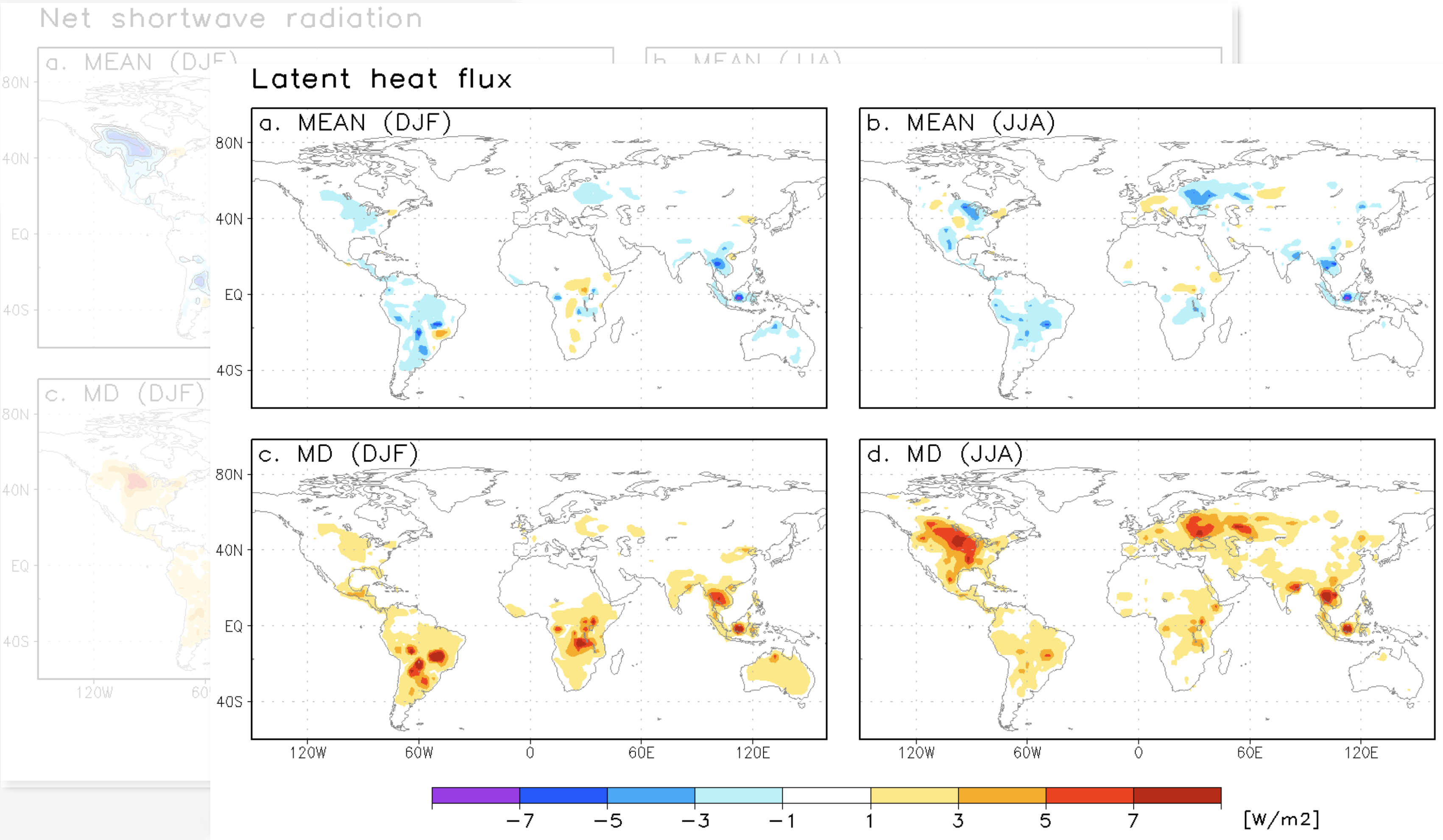
Seasonal responses to past LULCC: model mean and inter-model variation (MD)



Net SW radiation decreases in most regions and seasons

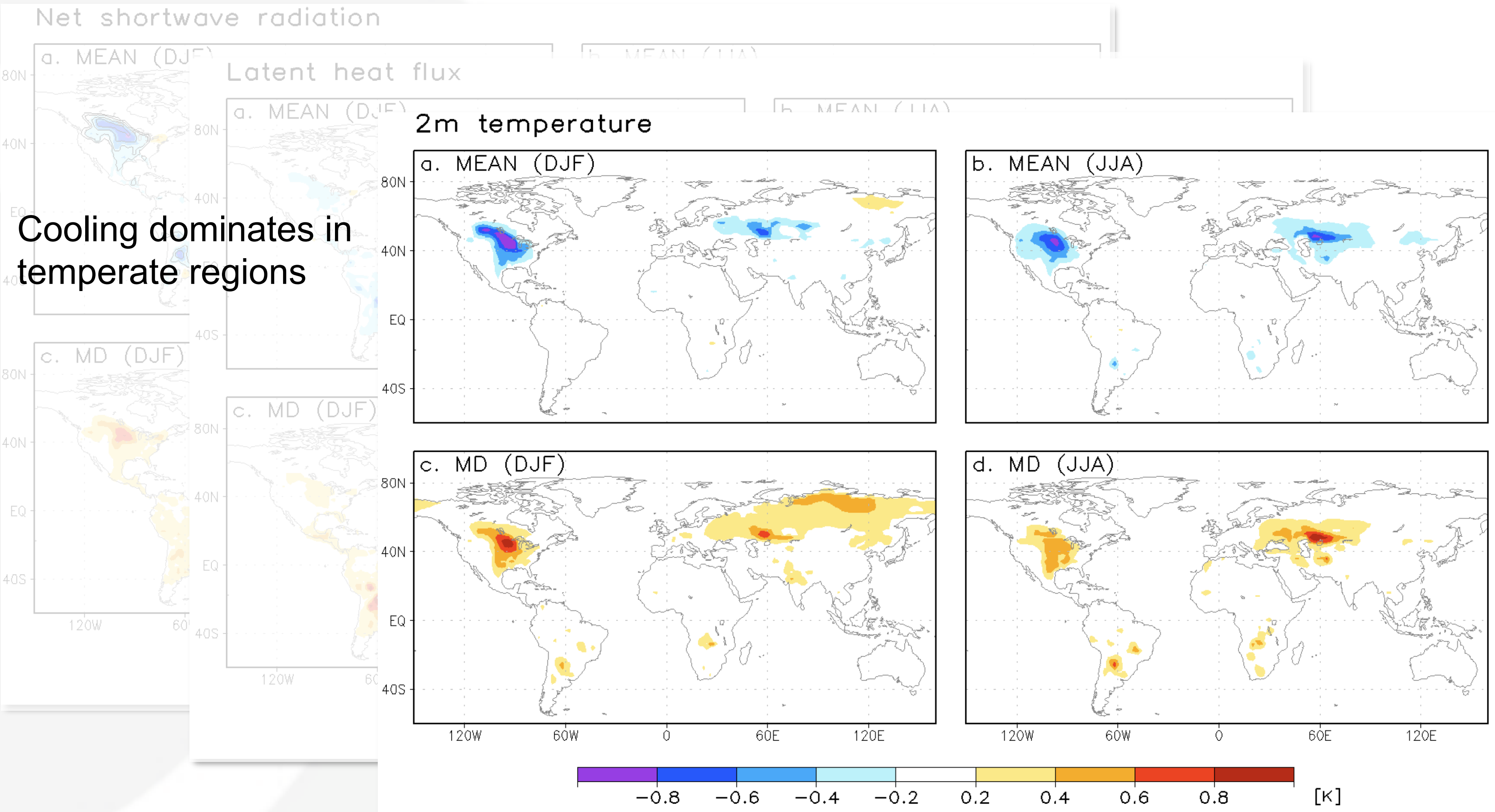
Large differences between the various model outputs

Seasonal responses to past LULCC: model mean and inter-model variation (MD)



LUCID

Seasonal responses to past LULCC: model mean and inter-model variation (MD)



Cooling dominates in temperate regions

LUCID

> In accordance with previous studies, LUCID models simulate systematic increases in surface albedo as response to LULCC (deforestation), leading to reductions in available energy at the surface (net SW rad.) and cooling in temperate regions.

> They show however large differences in the amplitude of those impacts and, in the case of turbulent fluxes, differences in amplitude and sign.

> Small global impacts and constrained to the region where LULCC is prescribed (Pitman et al. GRL2009)

How large are the impacts of LULCC at the regional scale compared to those induced by other historical climate forcings ?

What is behind the large inter-model dispersion ?

LUCID

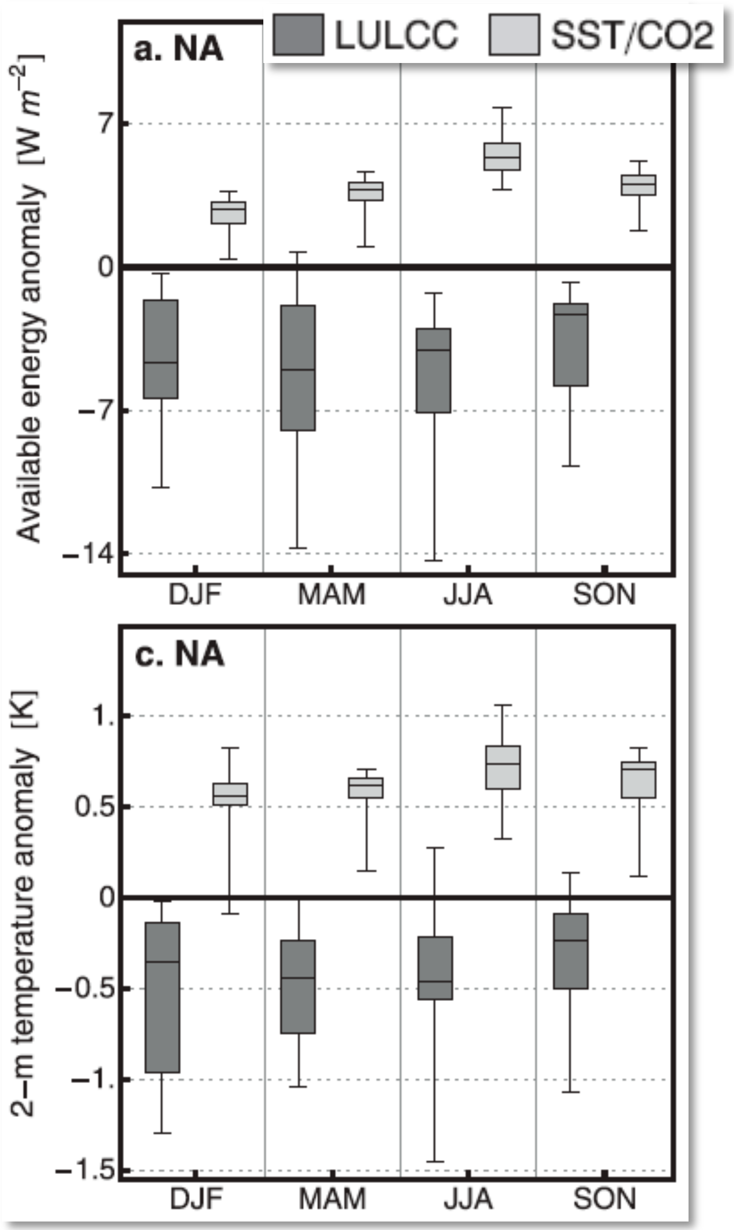
LUCID simulations

	PD	PDv	PI	PIv
SST/SIC	1970-99	1970-99	1870-99	1870-99
CO_2 [ppm]	375	375	280	280
Land cover	1992	1870	1870	1992

- Land-use induced changes: PD-PDv and PIv-PI
- SST/CO2 induced changes: PD-PIv and PDv-PI

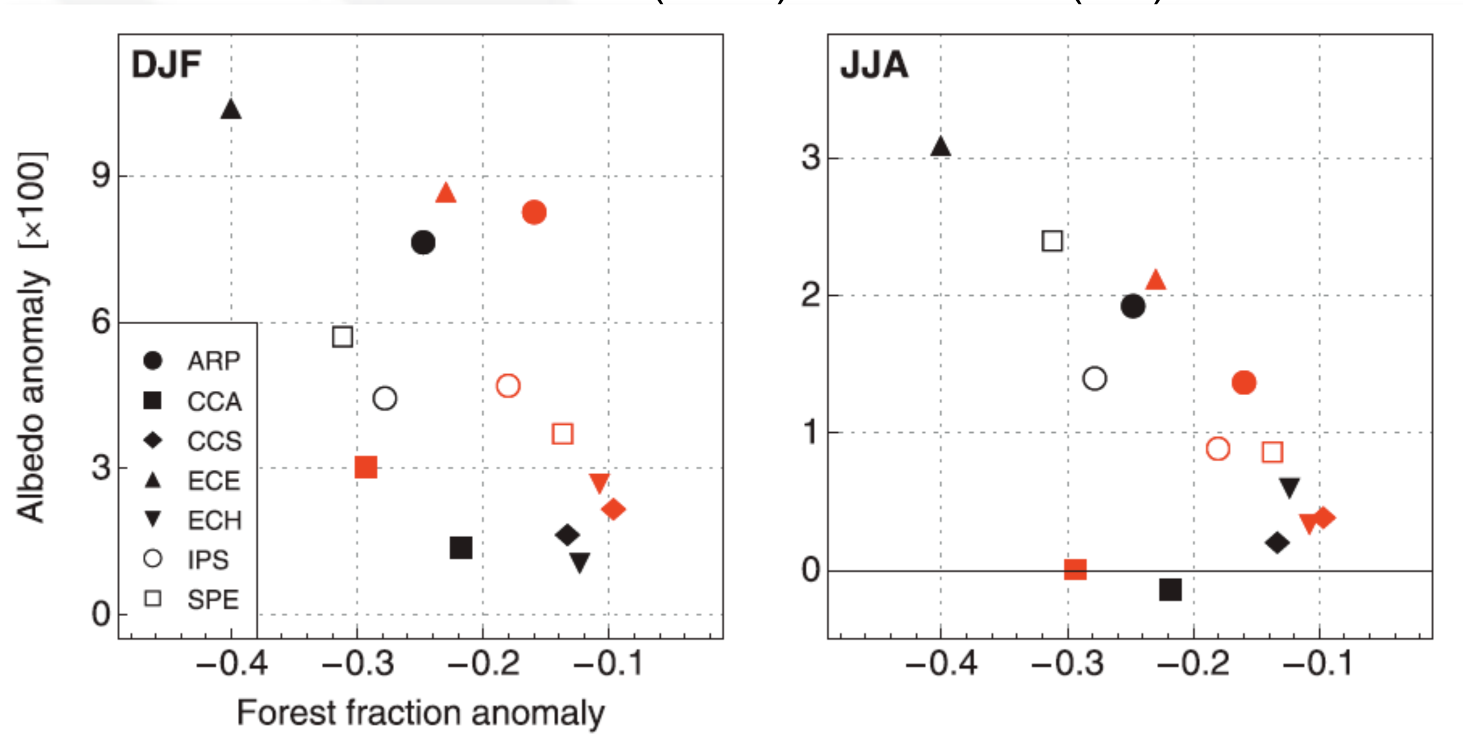
> Regionally, the rad. effects and temperature responses to LULCC are as large as (opposite in sign) the ones induced by CO_2 increases.
LULCC must be taken into account in climate D/A studies!

> Quite larger inter-model dispersion in the case of LULCC.
(see more in de Noblet et al. JClimate 2012)



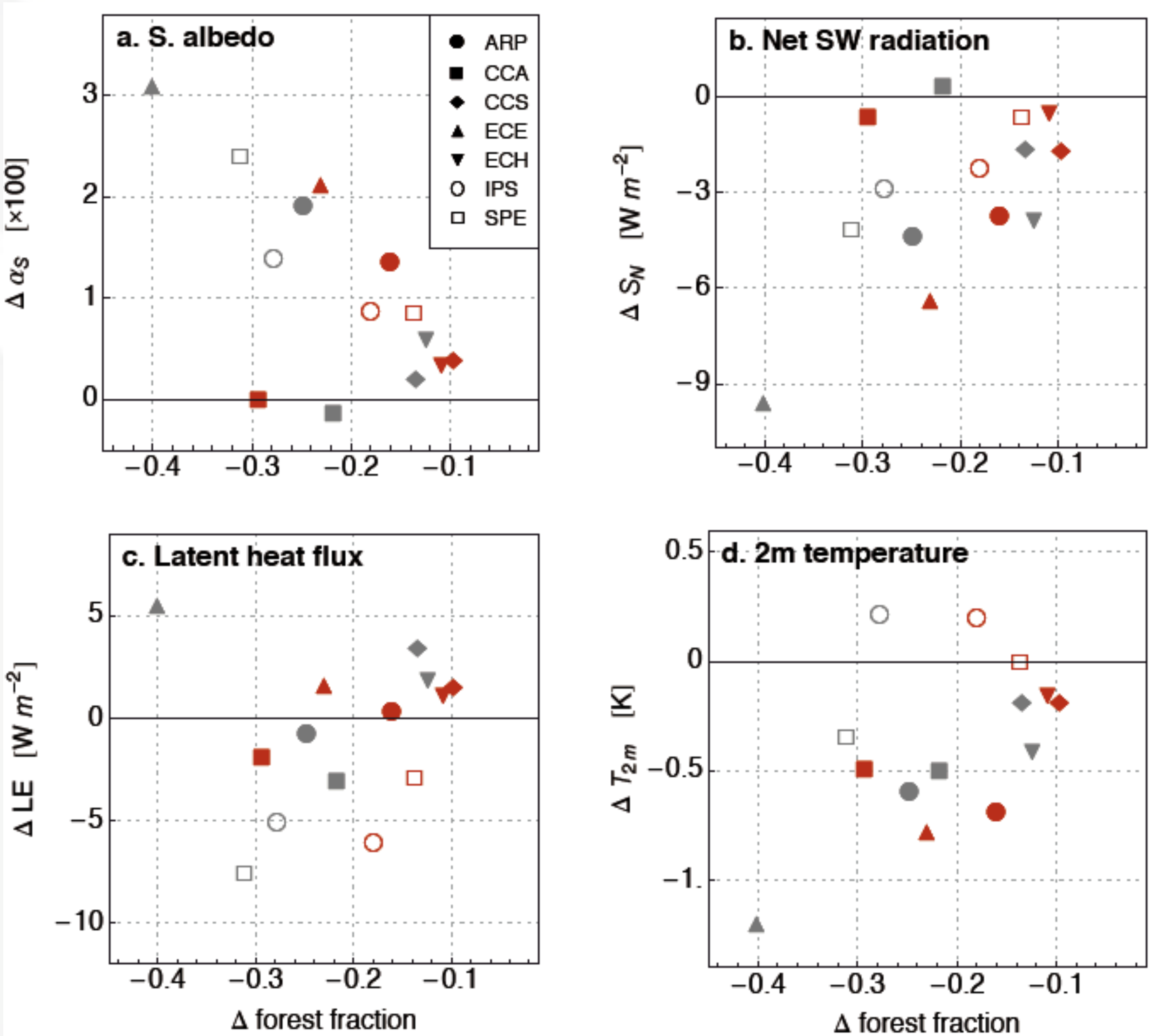
Inter-model dispersion: LULCC strength vs. models' intrinsic sensitivities to LULCC

North America (black) and Eurasia (red)



Inter-model dispersion: LULCC strength vs. models' intrinsic sensitivities to LULCC

JJA

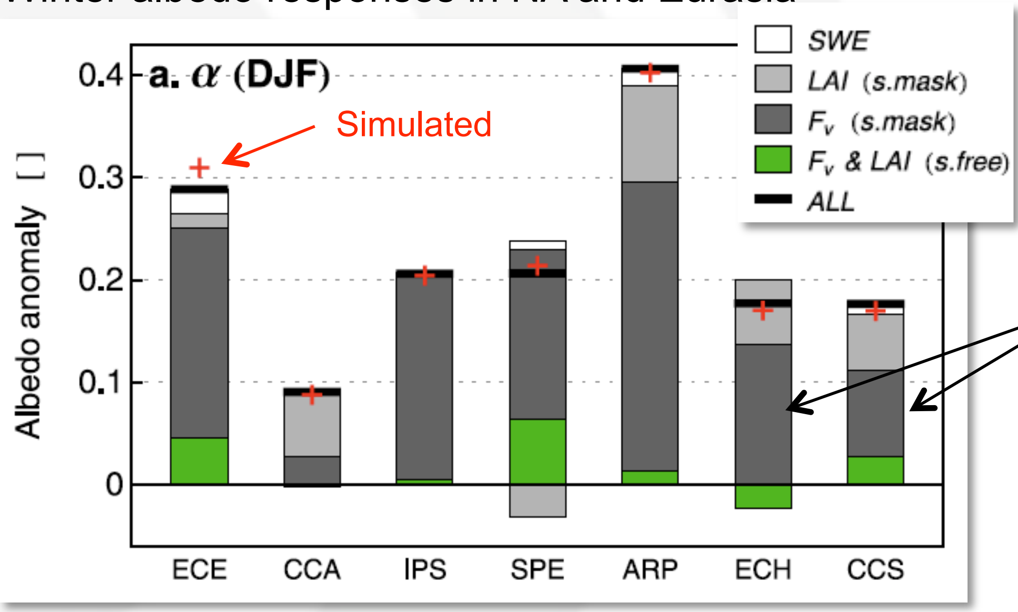


Inter-model dispersion: LULCC strength vs. models' intrinsic sensitivities to LULCC

The attribution of the simulated responses to LULCC to a number of drivers were more thoroughly explored based on multivariate analyses.

Statistical models of surface albedo, latent heat and total turbulent flux were computed in order to mimic the LUCID model outputs.

Winter albedo responses in NA and Eurasia



> LULCC-induced changes in winter albedo depend principally on snow-covered parameterizations of the different land-cover types (dark grey).

> LAI is also an important driver for the simulated changes in albedo, and quite uneven between the models (light grey).

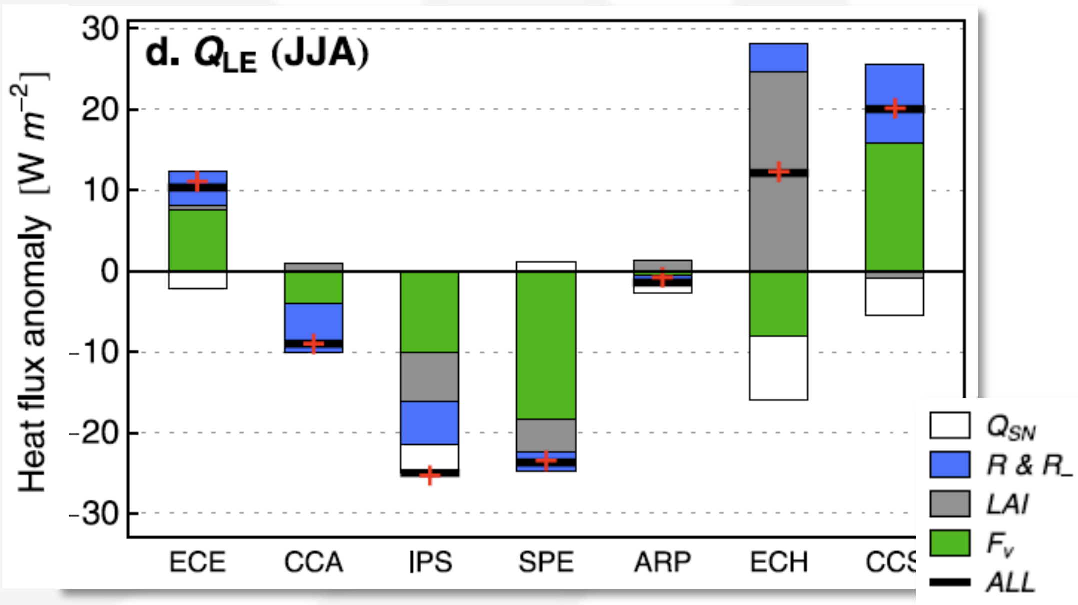
Boisier et al. JGR 2012

Inter-model dispersion: LULCC strength vs. models' intrinsic sensitivities to LULCC

The attribution of the simulated responses to LULCC to a number of drivers were more thoroughly explored based on multivariate analyses.

Statistical models of surface albedo, latent heat and total turbulent flux were computed in order to mimic the LUCID model outputs.

Summer LE responses in NA and Eurasia



> In the case of LE, all the drivers assessed contribute to model responses, including radiation (white) and precip. (blue).

> LAI (gray) and the specific parameterization of vegetation (green) (e.g., canopy conductance) control the sign and amplitude of the changes in LE.

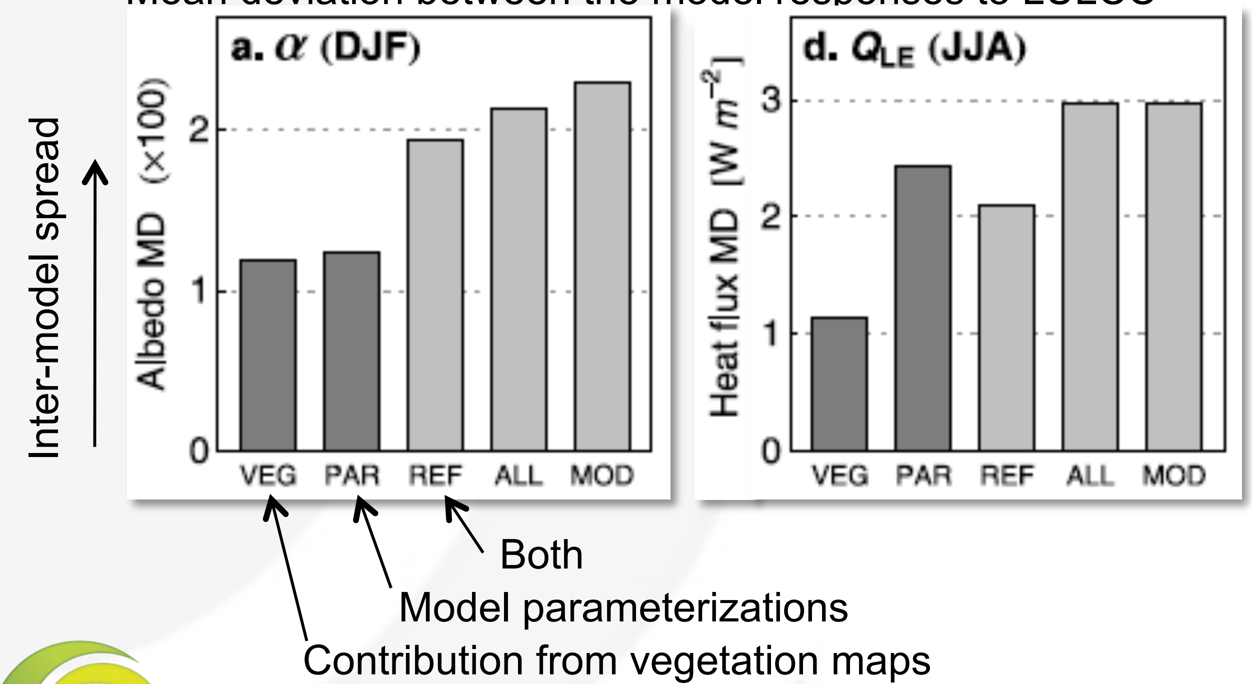
Boisier et al. JGR 2012

Inter-model dispersion: LULCC strength vs. models' intrinsic sensitivities to LULCC

The statistical model constructed for each LUCID GCM/LSM were evaluated with all the seven LC maps of the other LUCID LSMs, in order to quantify the relative contribution to the resulting inter-model spread of

(1) differences in the imposed land-cover changes and
(2) differences in the models' parameterizations and resulting sensitivities to land conversions.

Mean deviation between the model responses to LULCC



Differences in parameterizations explain ~50 to 75 % of the model spread.

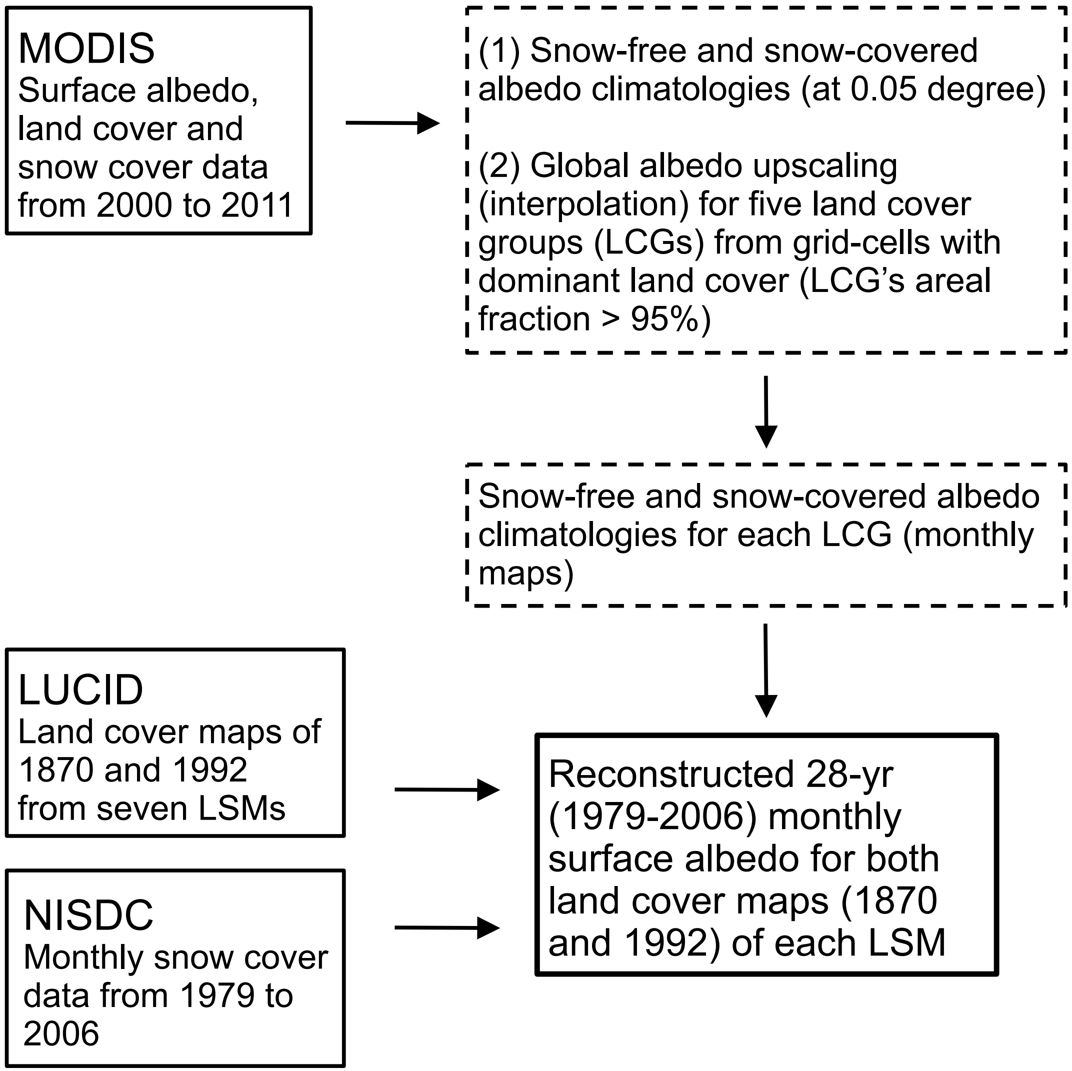
Boisier et al. JGR 2012

MODIS-based albedo reconstructions

Objectives:

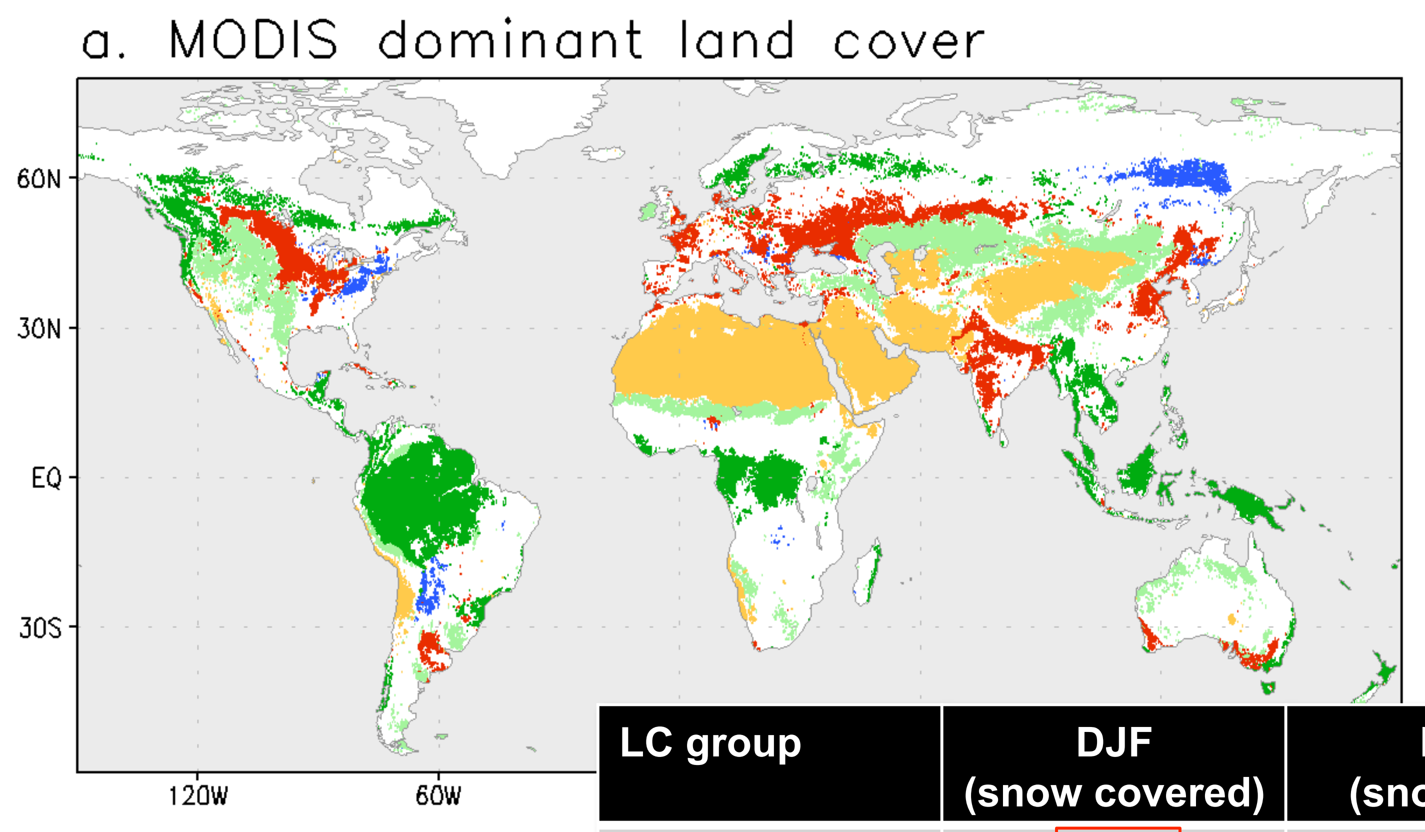
1) Bring realistic estimates of the past surface albedo changes due to LULCC, based on present-day observations.

2) Use these reconstructions as benchmark for model results and evaluate them.



Boisier et al.
(discussion in Biogeosciences)

MODIS-based albedo reconstructions

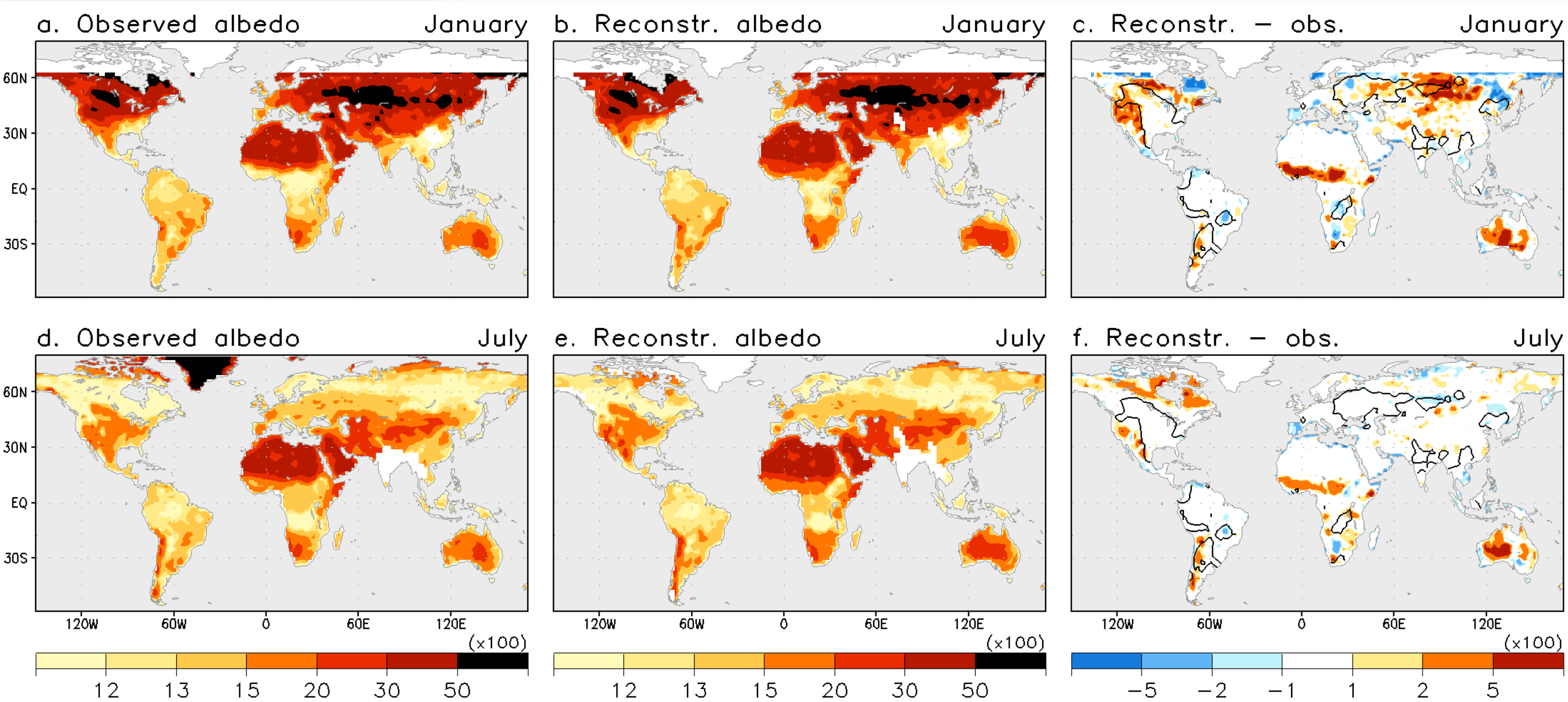


LC group	DJF (snow covered)	DJF (snow free)	JJA (snow free)
Evergreen trees	0.22	0.10	0.09
Deciduous trees	0.29	0.12	0.12
Grasses	0.61	0.19	0.16
Crops	0.59	0.15	0.15
Bare	0.59	0.26	0.26

Mean albedo values for the northern hemisphere extratropics

MODIS-based albedo reconstructions

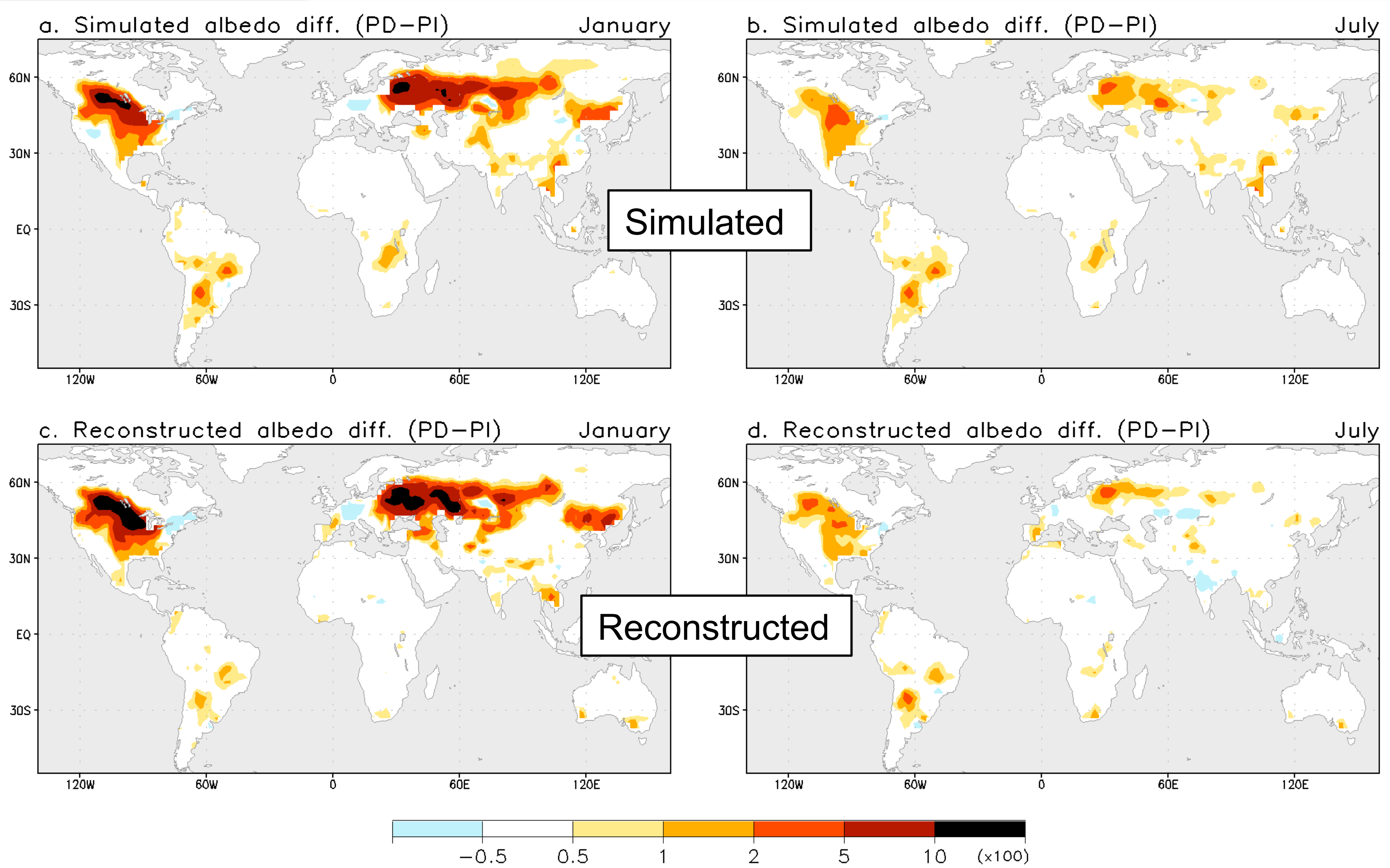
Method evaluation



> In general, reconstructions do a good job, with errors lower than 1% in most regions.
> Important biases in some areas (e.g., sub-Sahel), where few pixels have a dominant vegetation associated.

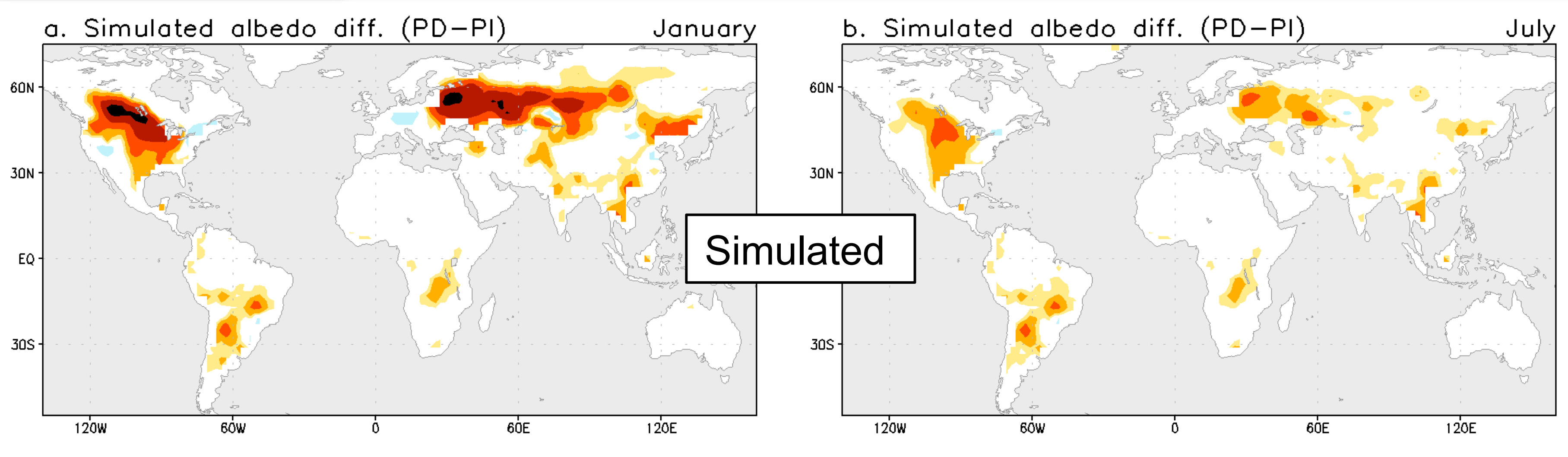
MODIS-based albedo reconstructions

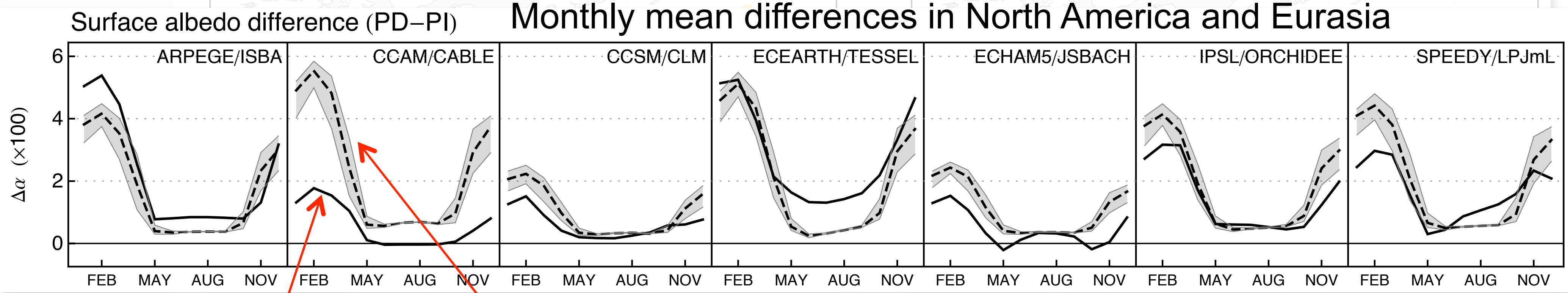
Surface albedo differences between 1870 and 1992 (model mean).



MODIS-based albedo reconstructions

Surface albedo differences between 1870 and 1992 (model mean).





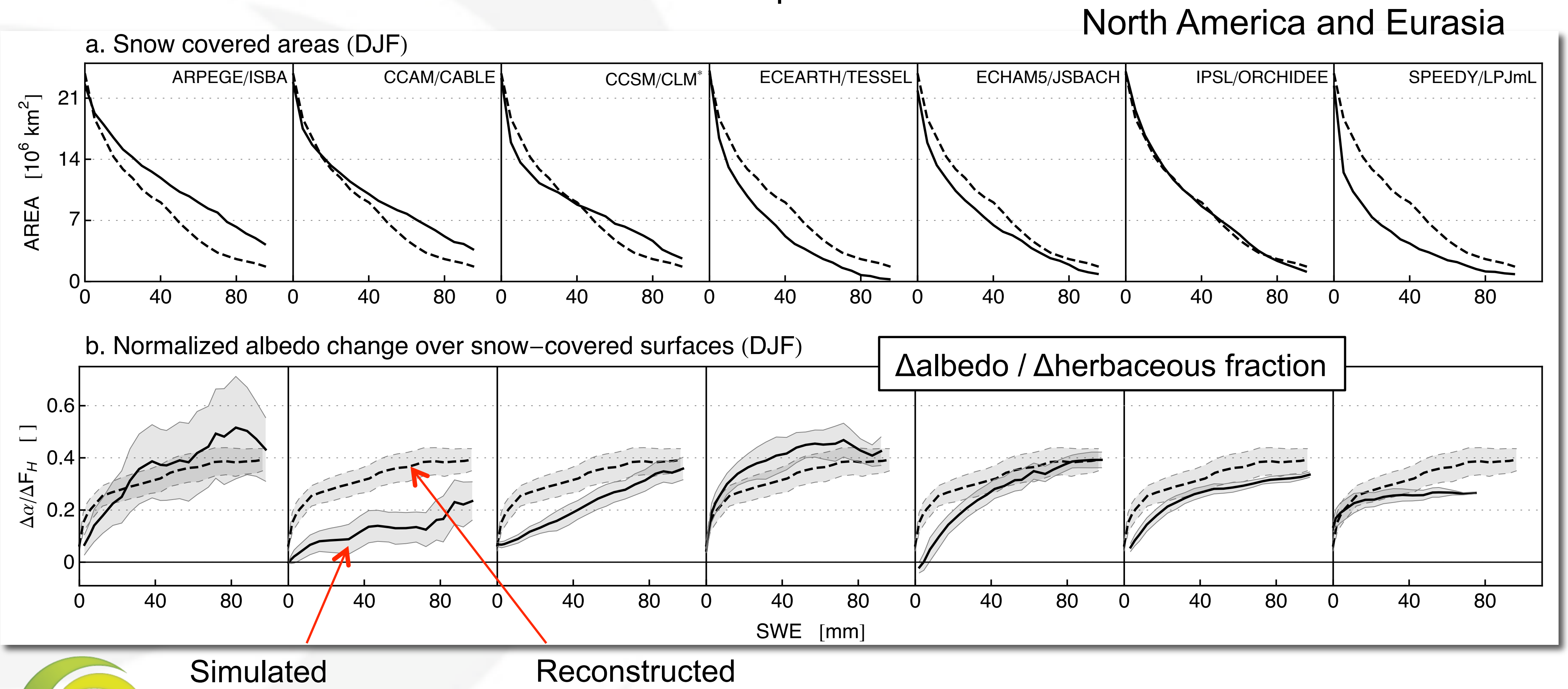
Simulated

Reconstructed

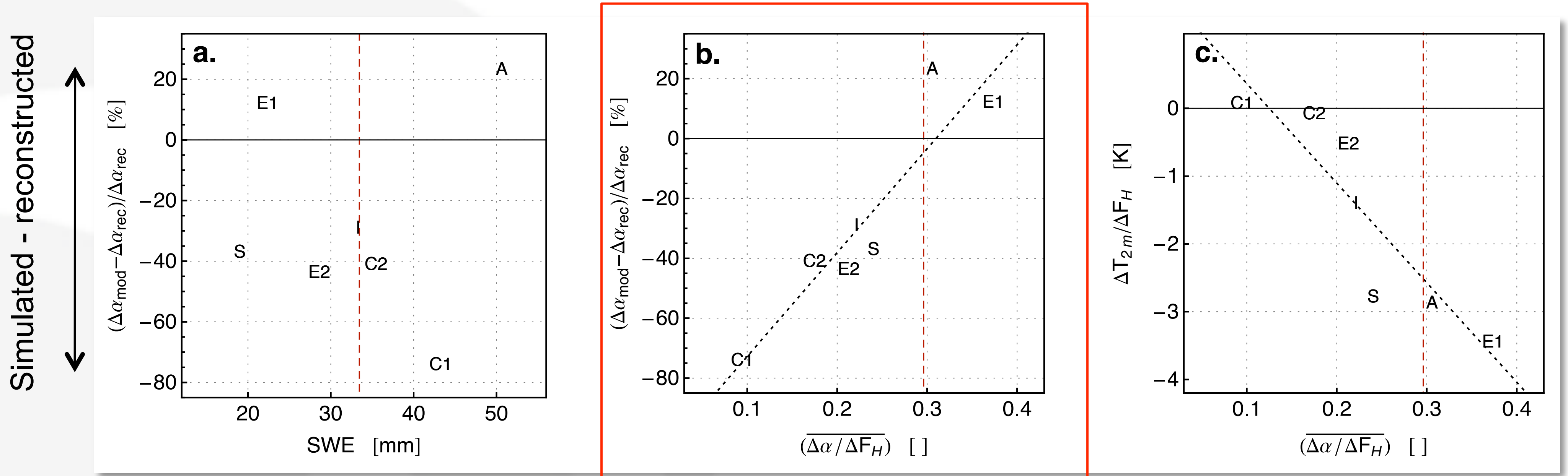
MODIS-based albedo reconstructions

The various LUCID GCM/LSMs show quite different albedo responses to LULCC in regard to their respective MODIS-based reconstructions.

Assessing the model albedo sensitivity to deforestation:
> Snow cover and content vs. surface albedo parameterization



MODIS-based albedo reconstructions



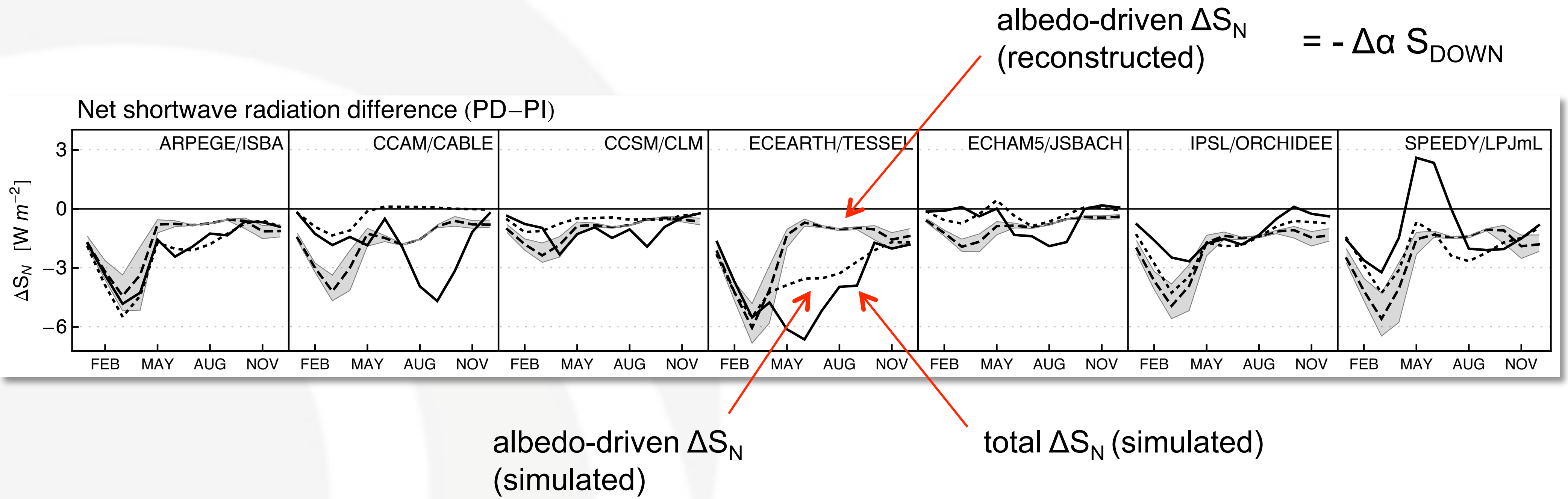
snow content

mean sensitivity

The LSMs' albedo parameterizations and resulting sensitivities to land conversions are the principal factor explaining the differences between the simulated albedo responses to LULCC.

MODIS-based albedo reconstructions

Changes in net shortwave radiation at the surface.



> In temperate regions, the direct (albedo) radiative impact of LULCC is maximized during the earlier spring (snowy conditions and relatively high solar radiation).

> The indirect effects of LULCC and atmospheric feedbacks (changes in downwelling SW rad.) play a very important role, adding more uncertainty to the model result.

Summary

Land-use induced surface albedo changes in temperate regions have very likely led to local cooling during the winter and spring.

The uncertainties of the radiative effect of LULCC, and of the impacts on the surface climate in general are still very large.

These uncertainties could be widely narrowed with

a) improved historical scenarios of LULCC (including specific LU transitions) and more rigid protocols to implement them in LSMs, and
b) a thoroughly LSMs validation (from site to large-scale), revisiting some basic parameterizations (e.g. leaf/steam albedo).

Calculating RF from LULCC

Two issues:

1) The RF metric does not characterize well the climate signatures of LULCC.
Non-radiative effects are very important, even at high latitudes.

2) How to calculate it ?
Depend on what is considered as direct impacts, indirect impacts and feedbacks.

e.g. Δ surf. albedo + Δ ET + Δ cloud coverage + …

rad. trans. scheme + adj. moist. content + ??

↓ ↓ ↓

RF (IPCC-like) + RF (Davin et al.)

Table 1. RF, Temperature Response, and Climate Sensitivity Relative to

Simulations	ΔF_{alb}, W/m^2	ΔF_{vap}, W/m^2	ΔF_{ALCC}, W/m^2
PRES – PAST	−0.22	−0.07	−0.29
FUTU – PRES	−0.55	−0.15	−0.7