Investigating Climate Impacts of Land Cover Change in the Community Land Model (CLM)

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Talk Outline

1. Background on the Climate Impacts of Land Cover Change
2. Reconstructing Potential Vegetation from Bio-climatically modeled vegetation and current day MODIS in CLM Parameters
3. Global Land Cover Change Experiments with CCSM
4. Asian Land Cover Change compared to average El Nino SST anomalies in CCSM (compare surface flux forcing on CAM 3.0)
5. Conclusions, Outstanding Issues, and Future Work

1. Land Cover Change Overview

Land Cover Change Impacts on Climate System are divided into:

Biogeophysical Processes:

- **Albedo**
- **Surface Hydrology – Transpiration, Canopy Evap, Soil Evap**
- **Surface Roughness**
- **Atmospheric Response in Temperature, Precipitation and Circulation**

Biogeochemical Processes:

- **Carbon**
- **Methane**
- **Volatile Organics (Isoprene) -> Photochemistry with NOX resulting in Tropospheric Ozone**

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1. Land Cover Change Investigations

1. **There have been a wide range of investigations into the Climate Impacts of Land Cover Change focussing on changes in Biogeophysical Land Surface Processes**

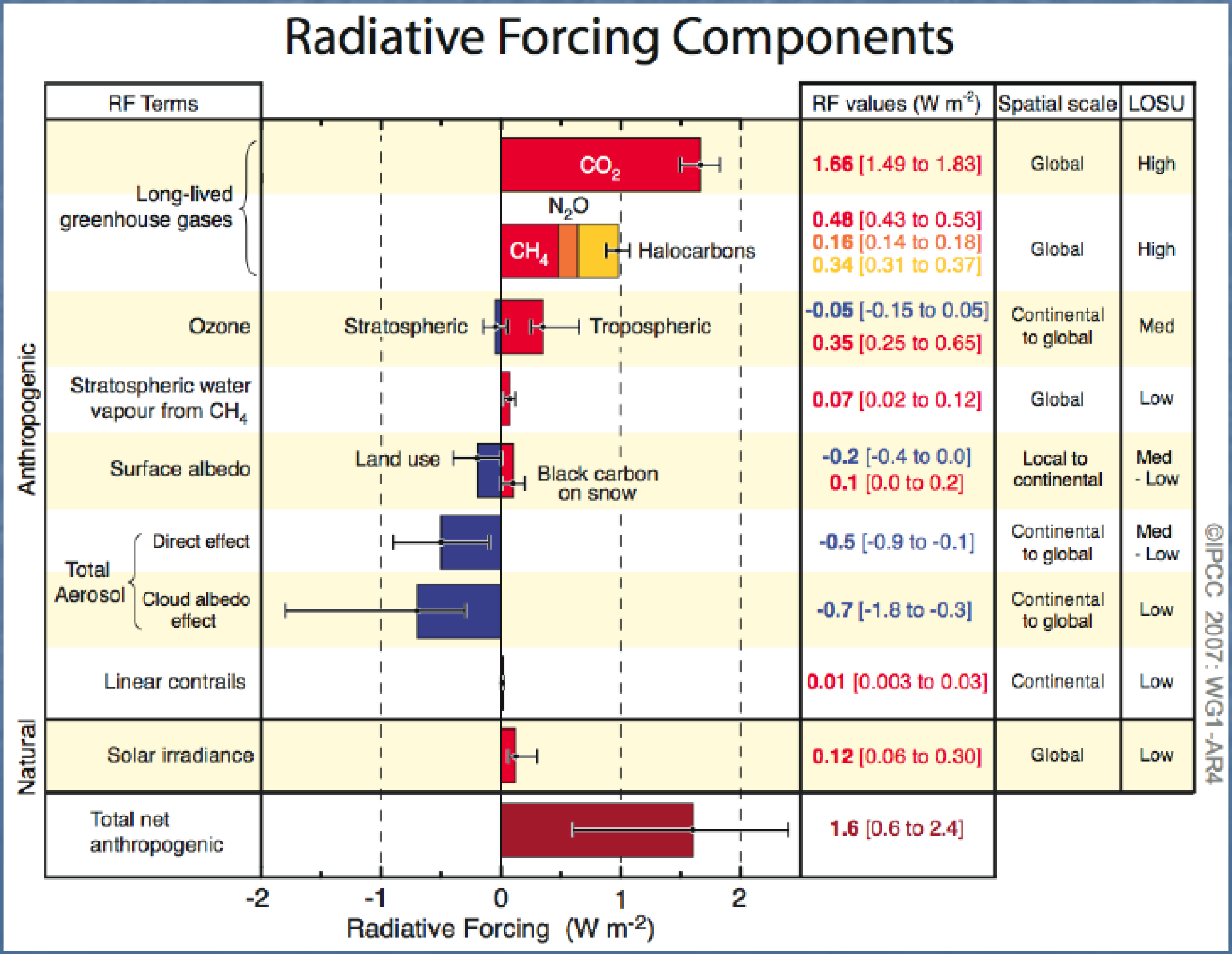
2. **Studies by *Oleson et al.*, (2004), *Findell et al.*, (2007), *Brovkin et al.*, (1999), *Betts*, (1999), and others have found replacing Needleleaf and Broadleaf forests with Agriculture in mid-latitudes results in cooling of mean surface temps by 1-2 C regionally through increased albedo**

3. **Studies by *Feddema et al.*, (2005), *Chase et al.*, (1996), *Pielke*, (2001), and others have found Tropical Deforestation results in warming of mean surface temps by 1-2 C regionally through reduced evapo-transpiration and increased sensible heat flux**

4. **The latter studies also found the reduced evapo-transpiration impacts tropical convection and precipitation, with impacts on monsoon systems, as well as impacts on extra-tropical circulation through tele-connected changes in tropical divergence**

1. IPCC 4th Assessment Report:

In AR4 the Climate Impacts of Land Cover Change are limited to radiative cooling of -0.2 W/m^2 through increased albedo



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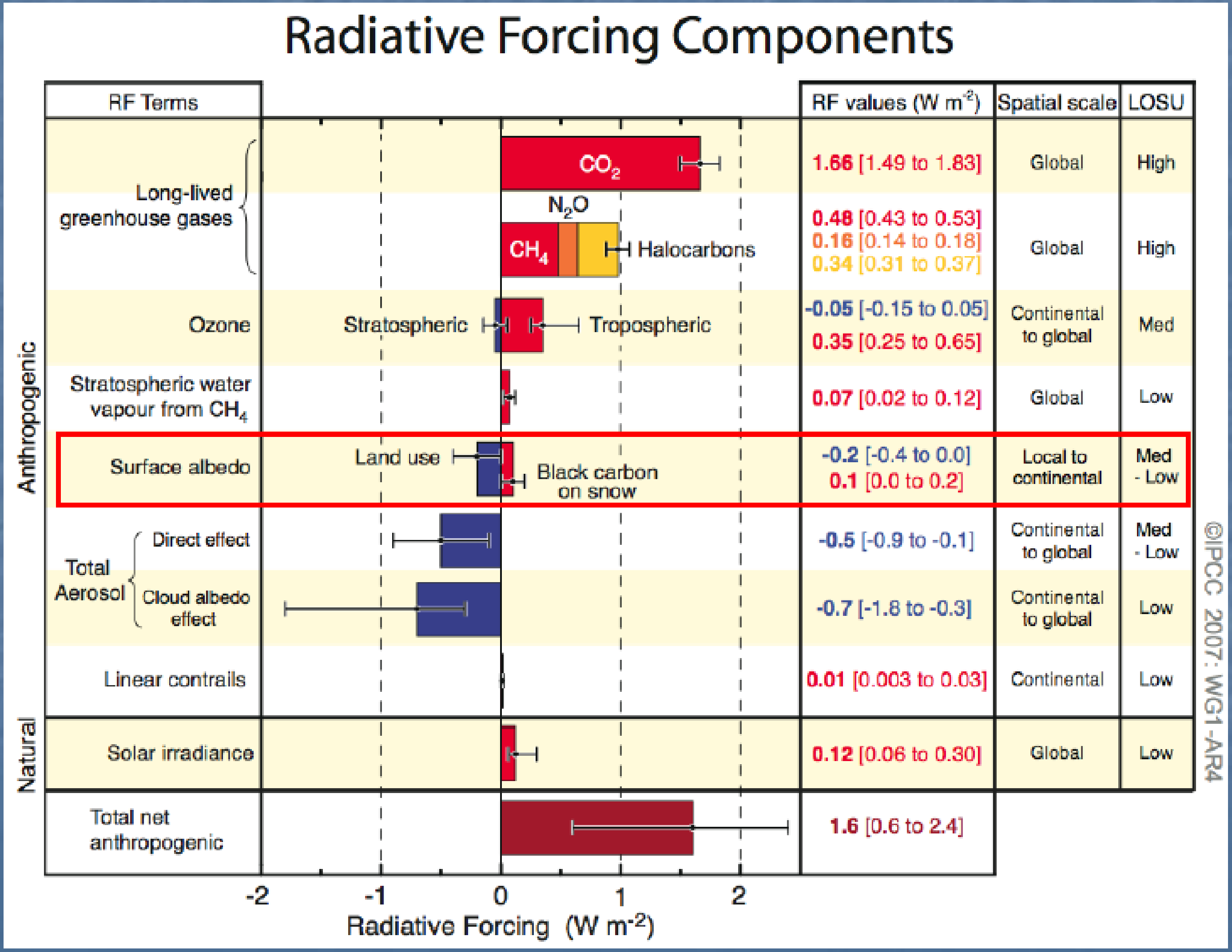


1. Climate Impacts of Land Cover Change Experiments

1. Turns out the Climate Impacts of Land Cover Change are highly dependent on the nature of the vegetation changes and the climate regime of the region in which the change occurs

2. The experiments are also very sensitive to:

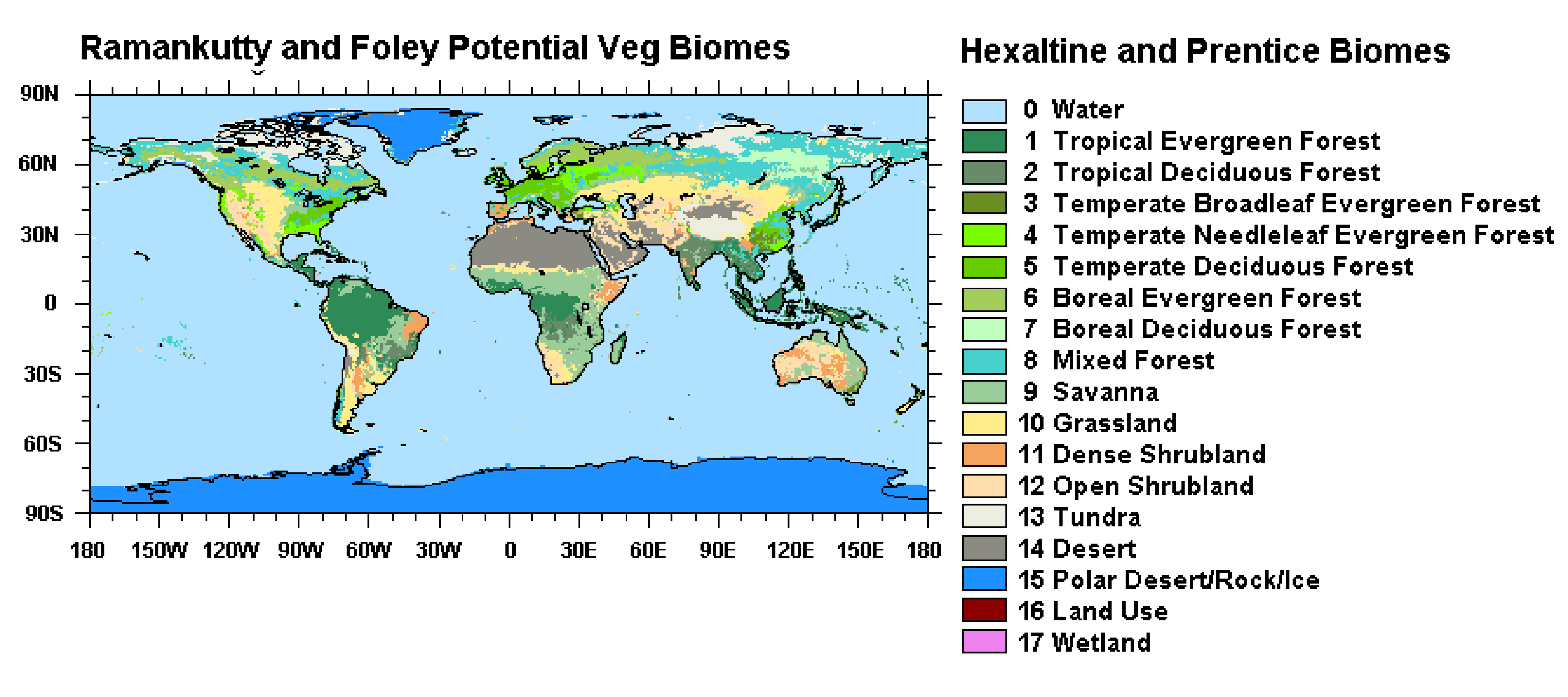
3. How the Land Cover Changes are represented in the parameters of the Land Surface Model;

4. How the Land Surface Model simulates the changes in albedo, surface hydrology, and roughness described in the changed land surface parameters;

5. And how the Atmospheric Model responds to the changes in surface fluxes that result from the changed Land Surface

2. Reconstructing Potential Vegetation – R&F Biomes

Describe potential vegetation from *Ramankutty and Foley*, (1999)

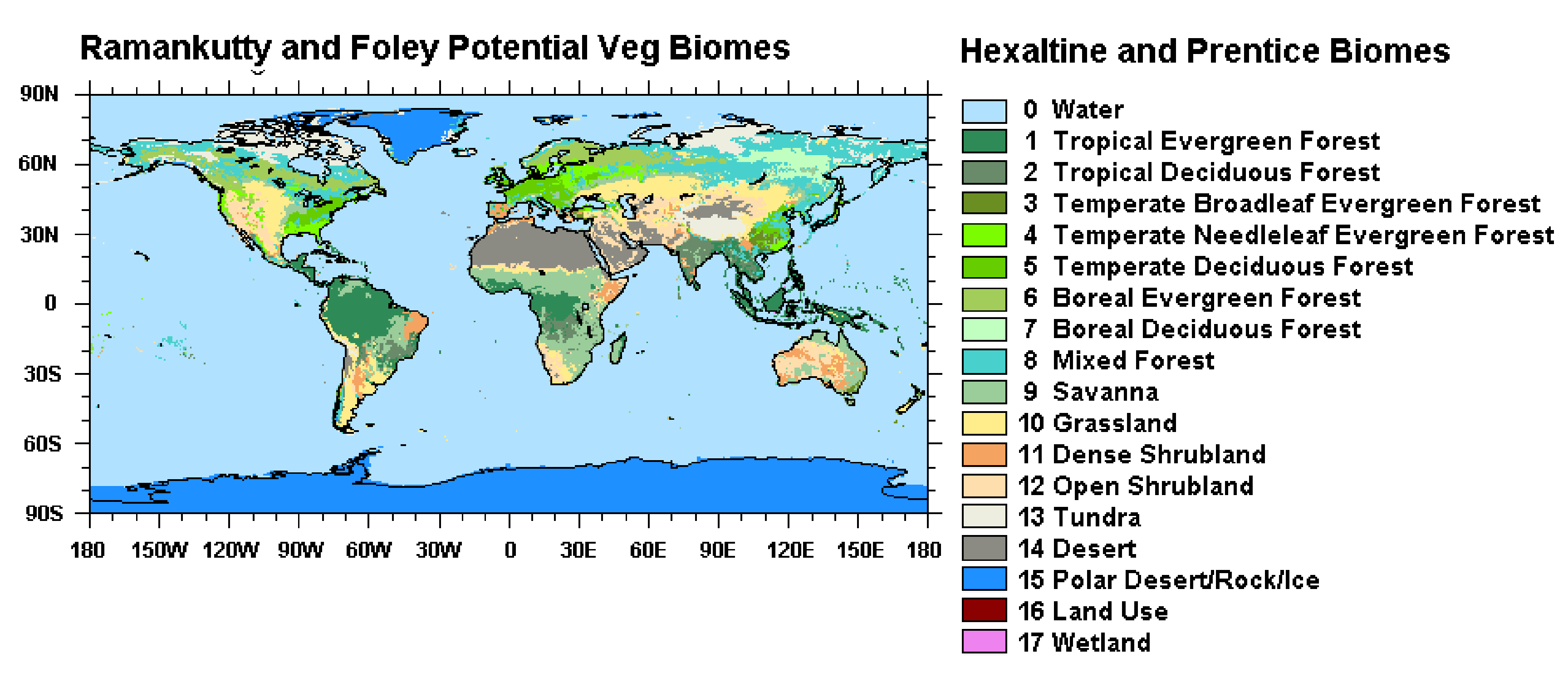


Current Day Remnant Natural Vegetation mapped from the 1992 AVHRR Global Land Cover Classification of *Loveland et al.*, (2000)

Areas of landuse are replaced with the BIOME 3.0 bio-climatically modeled natural vegetation of *Haxeltine and Prentice*, (1996)

2. Reconstructing Potential Vegetation – R&F Biomes

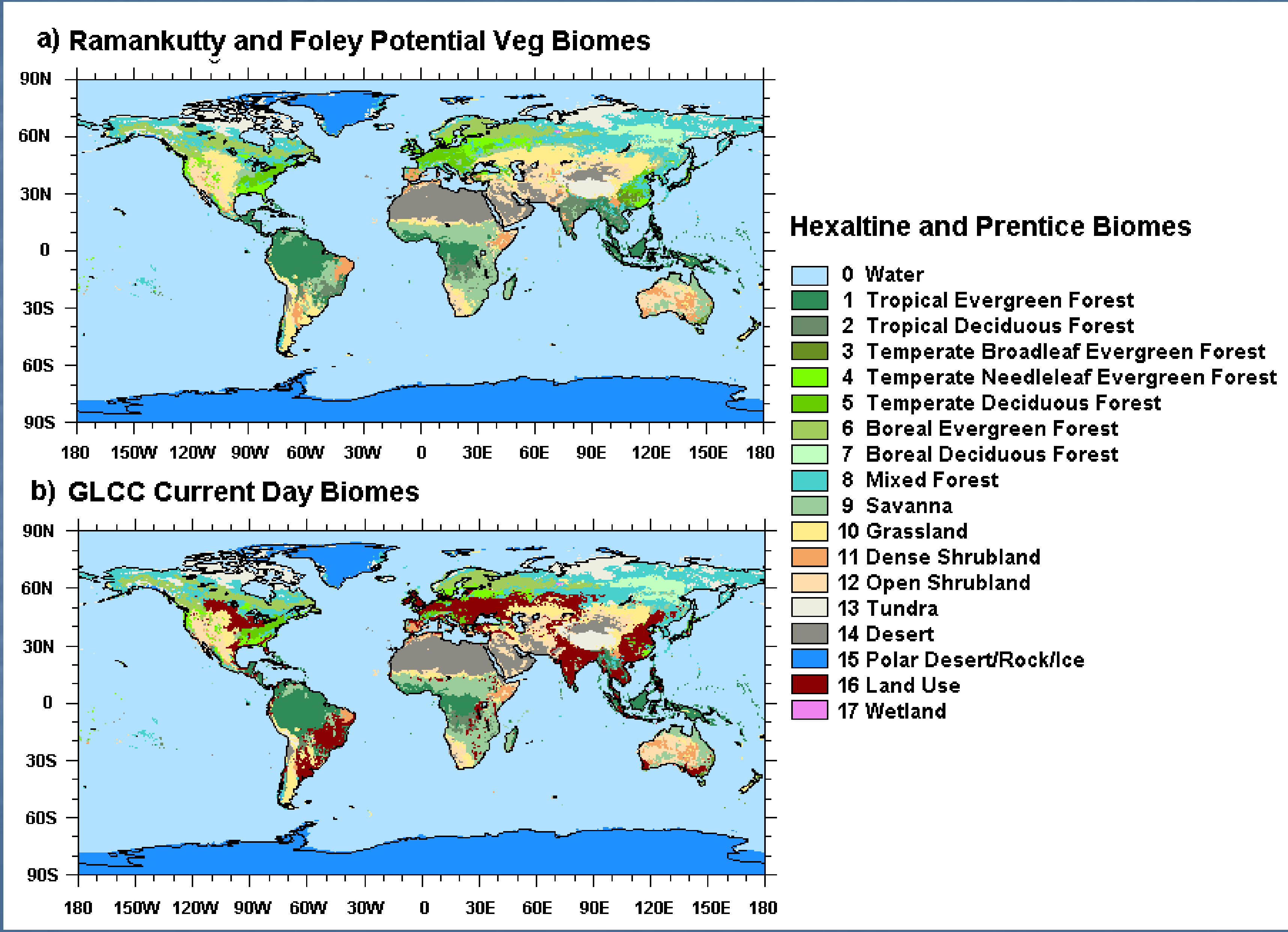
Describe potential vegetation from *Ramankutty and Foley*, (1999)



Problem: We have a Potential Vegetation biome map that doesn't match any current day vegetation map

Solution: Create an equivalent Current Day Biome Map using the GLCC current day data, and the methods described in *Ramankutty and Foley*, (1999) but keep Land Use

2. Reconstructing Potential Veg – Current Day Biomes



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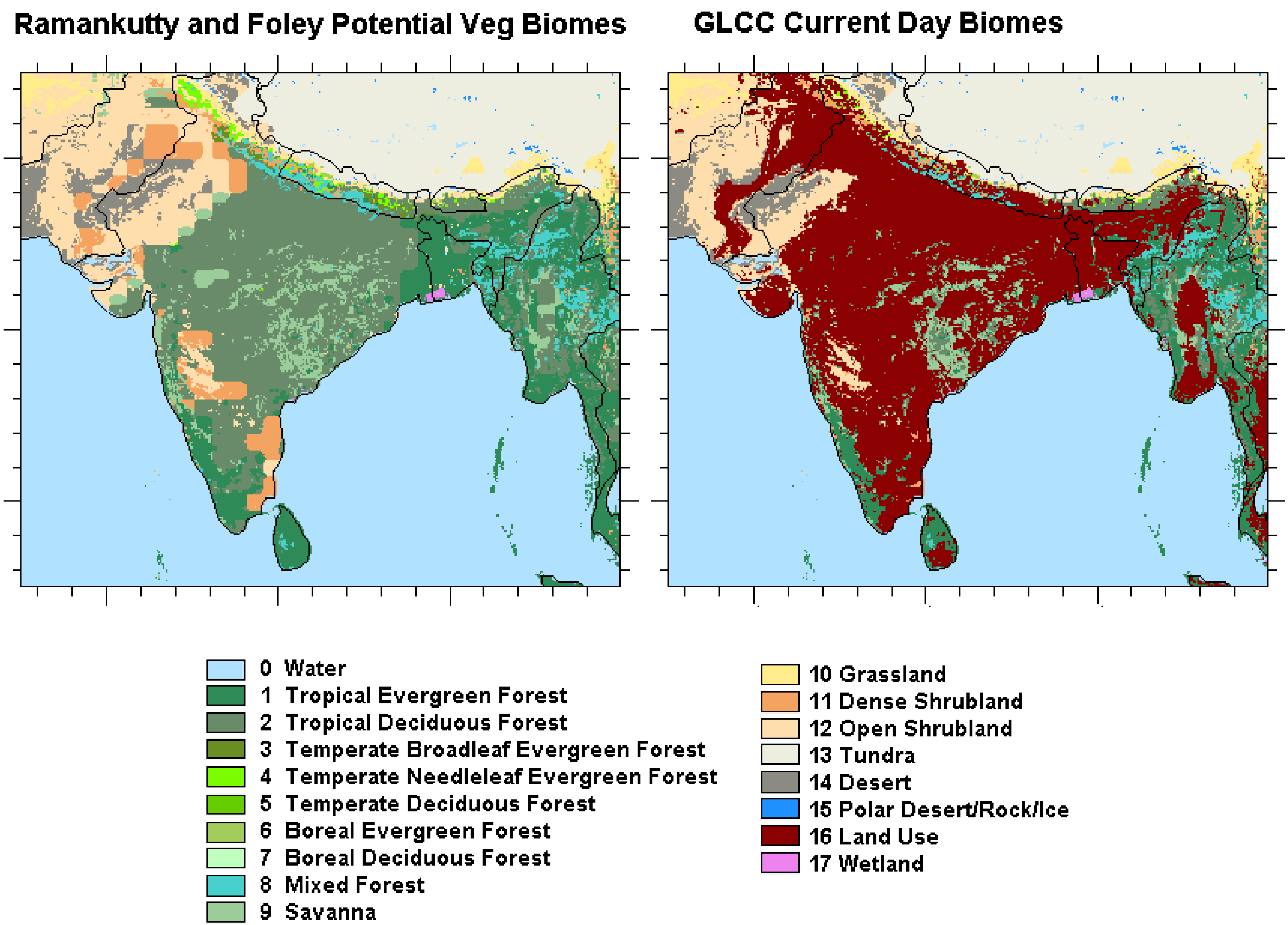


2. Reconstructing Potential Vegetation - Extrapolation

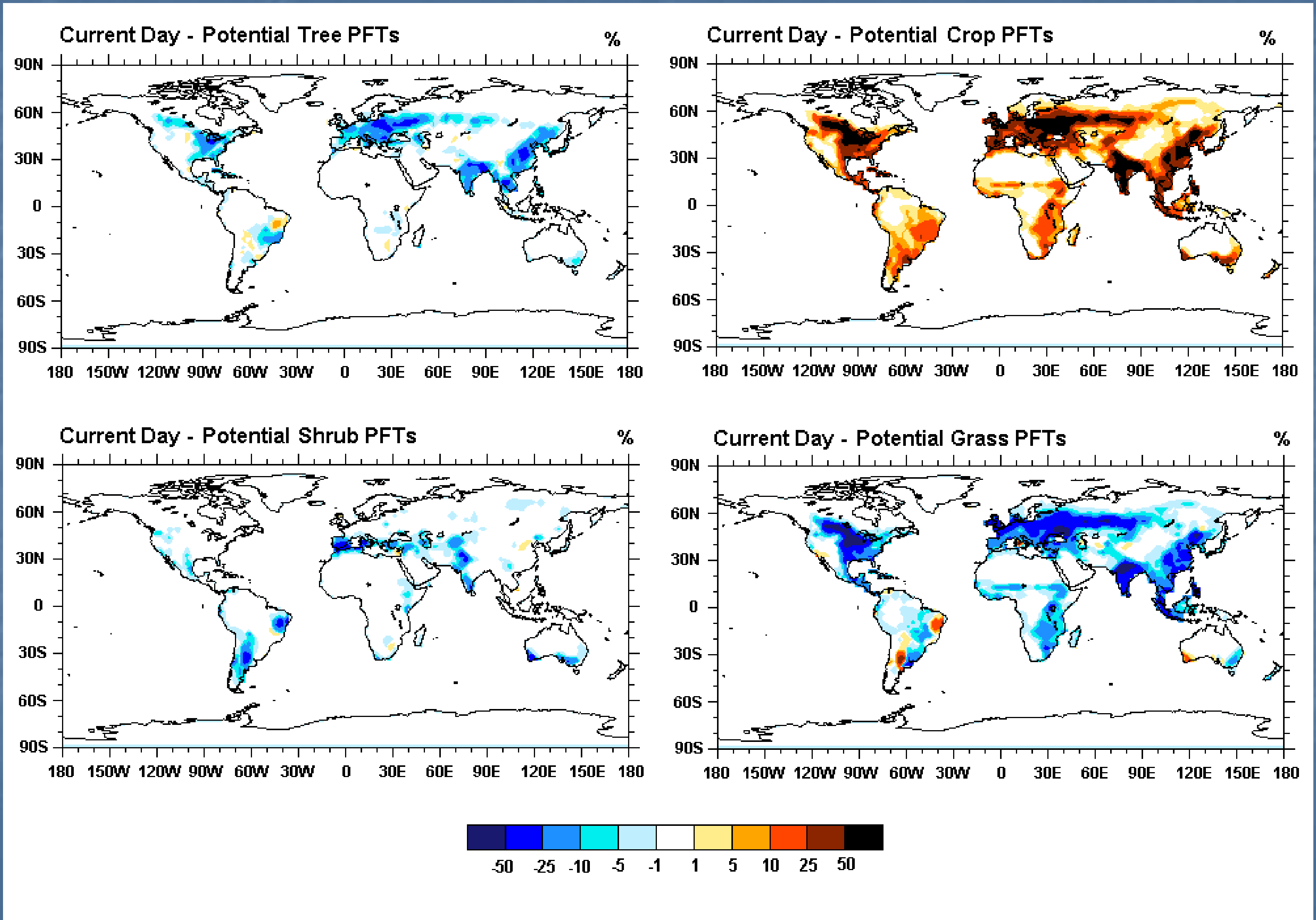
Problem: We now have consistent biome maps, but how do we generate Potential Vegetation PFTs, LAI, SAI and Soil Color consistently with current day MODIS parameters?

Solution: Spatially extrapolate the MODIS CLM parameters of *Lawrence and Chase*, (2007) from current day remnant natural biomes to the potential vegetation biome distributions

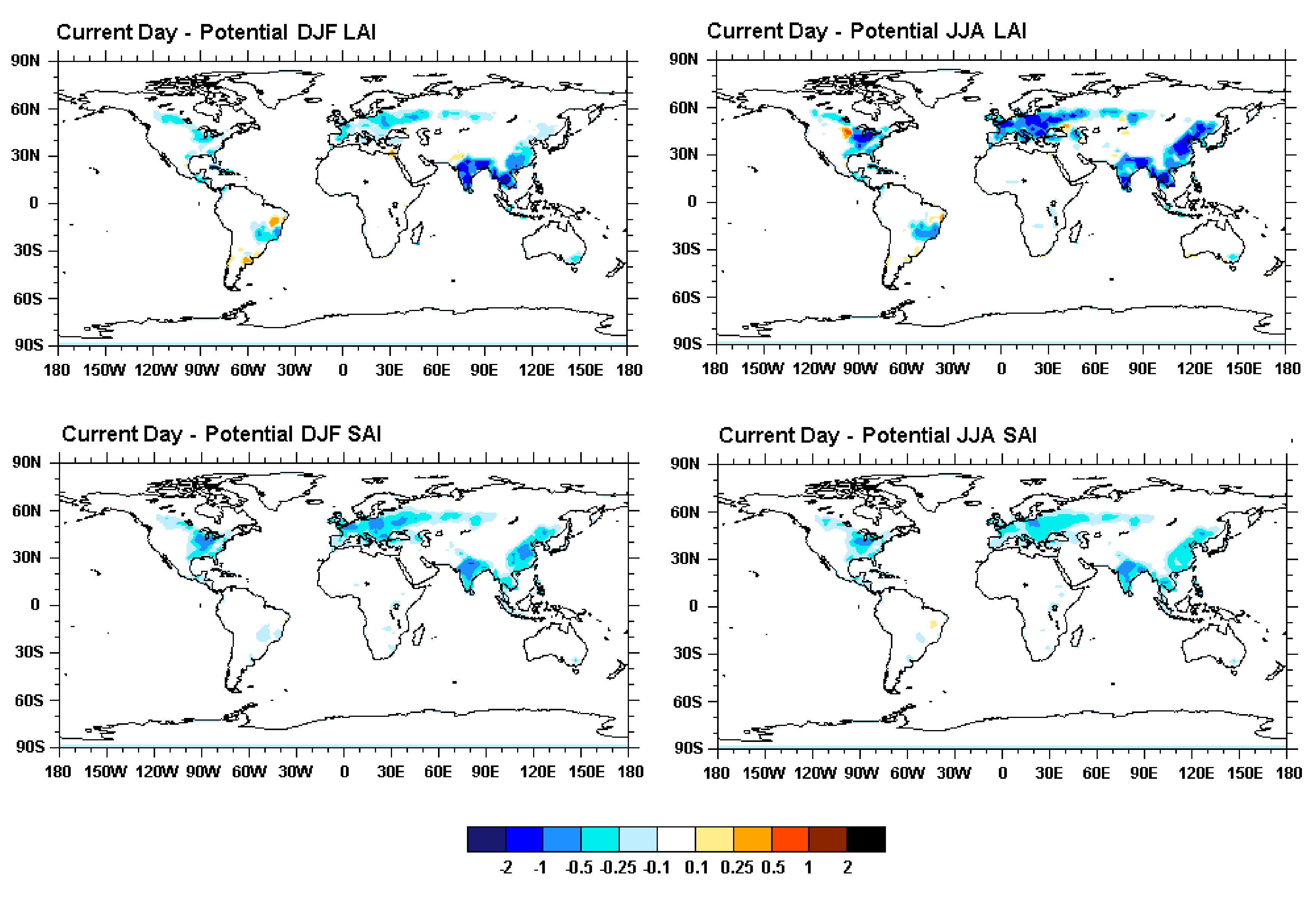
Caveat: The MODIS Land Cover map is used as a secondary filter so current day biomes are not used if they have been degraded between the 1992 GLCC Mapping and the MODIS data (2001 – 2004)

We also apply MODIS VCF tree cover thresholds to remnant natural biomes as a further filter to remove degraded biomes not filtered by MODIS Land Cover

2. Reconstructing Potential Veg – CLM PFT Differences



2. Reconstructing Potential Veg – LAI & SAI Differences



3. Land Cover Change Experiments

So now we have:

- Current Day CLM parameters described from MODIS

- Potential Vegetation CLM parameters consistent with *Ramankutty and Foley*, (1999) biome mapping and the PFTs, LAI, SAI and Soil Color are consistent with MODIS params

- We found that coupled to CAM 3.0, CLM 3.0 is too dry, CLM 3.5 is too wet, and both are dominated by soil evaporation. This has big impacts on climate response to land cover change.

- We now need to change CLM Surface Hydrology so that global ET is dominated by transpiration following *Dirmeyer et al.*, (2005) and *Lawrence (D. M.) et al.,* (2007)

3. Surface Hydrology

1. **When coupled to CAM 3.0 the modified CLM model (CLM SiB) has ET dominated by transpiration, with evapo-transpiration partition consistent with the multi-model average of *Dirmeyer et al.*, (2005)**

Av Global Hydrology	Precip mm/day	Total ET mm/day	Transp (%ET)	Can Evap (%ET)	Soil Evap (%ET)	Runoff mm/day	Drain mm/day
CLM 3.0	2.46	1.52	0.23 (15%)	0.58 (38%)	0.70 (46%)	0.47	0.41
CLM SiB	2.44	1.55	0.65 (42%)	0.34 (22%)	0.56 (36%)	0.32	0.51
Dirmeyer	2.29	1.34	0.64 (47%)	0.22 (17%)	0.48 (36%)	0.32	0.63

CLM SiB is fully described in *Lawrence and Chase*, (2008) *Journal of Hydrometeorology* accepted with revisions

3. Land Cover Change Experiments

So now we have:

- **Current Day CLM parameters described from MODIS**

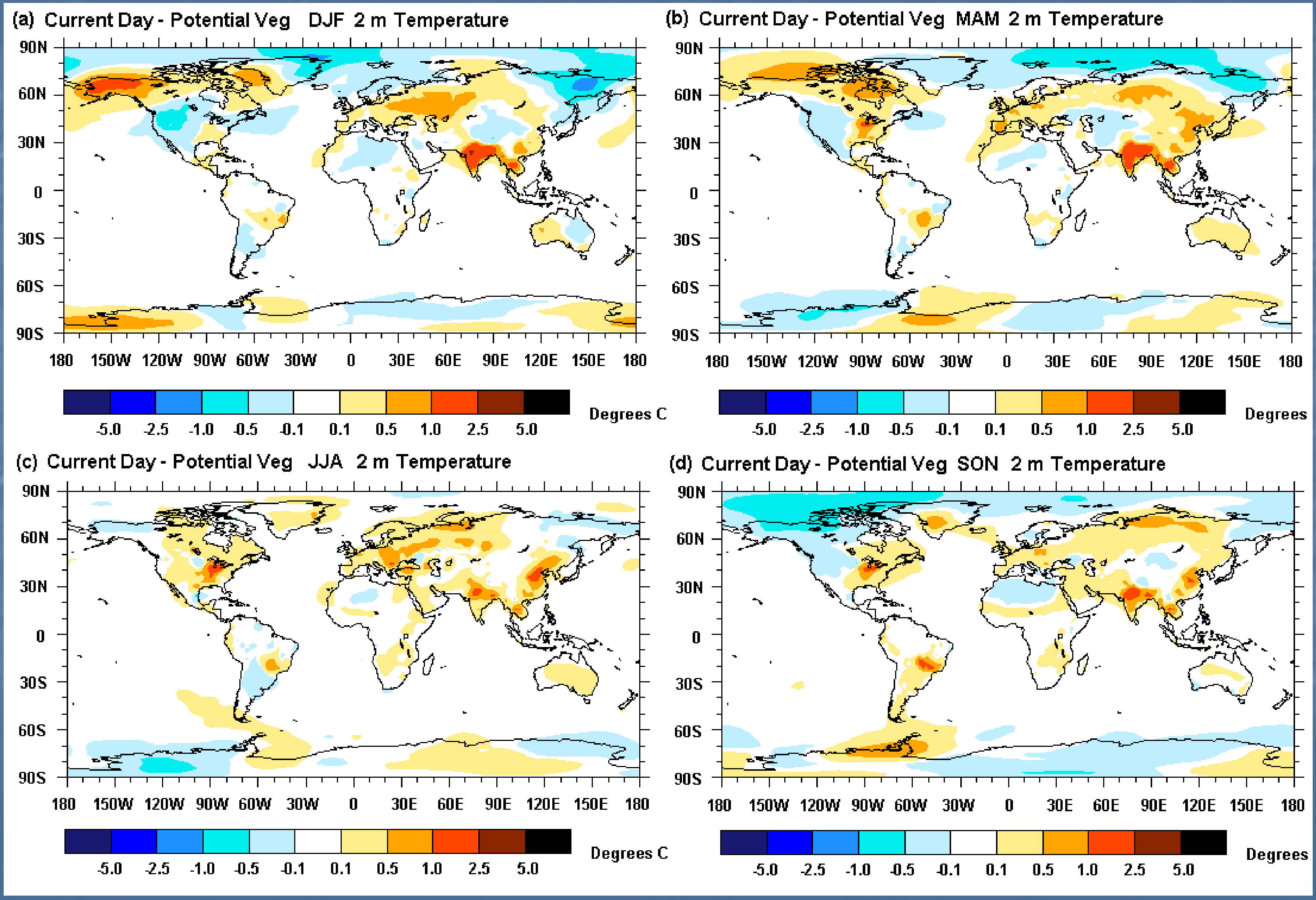
- **Potential Vegetation CLM parameters consistent with *Ramankutty and Foley*, (1999) biome mapping and the PFTs, LAI, SAI and Soil Color are consistent with MODIS params**

- **CLM SiB Surface Hydrology with global ET is dominated by transpiration following *Dirmeyer et al.*, (2005) and *Lawrence (D. M.) et al.*, (2007)**

3. Land Cover Change Experimental Design

CCSM Experiments with CAM 3.0 Atmosphere	**1949 – 2001 Climatology SSTs and Sea Ice**
Current Day MODIS Land Cover	**3 x 30 years**
Potential Vegetation Land Cover	**3 x 30 years**

3. CCSM Land Cover Change – Temperature Change



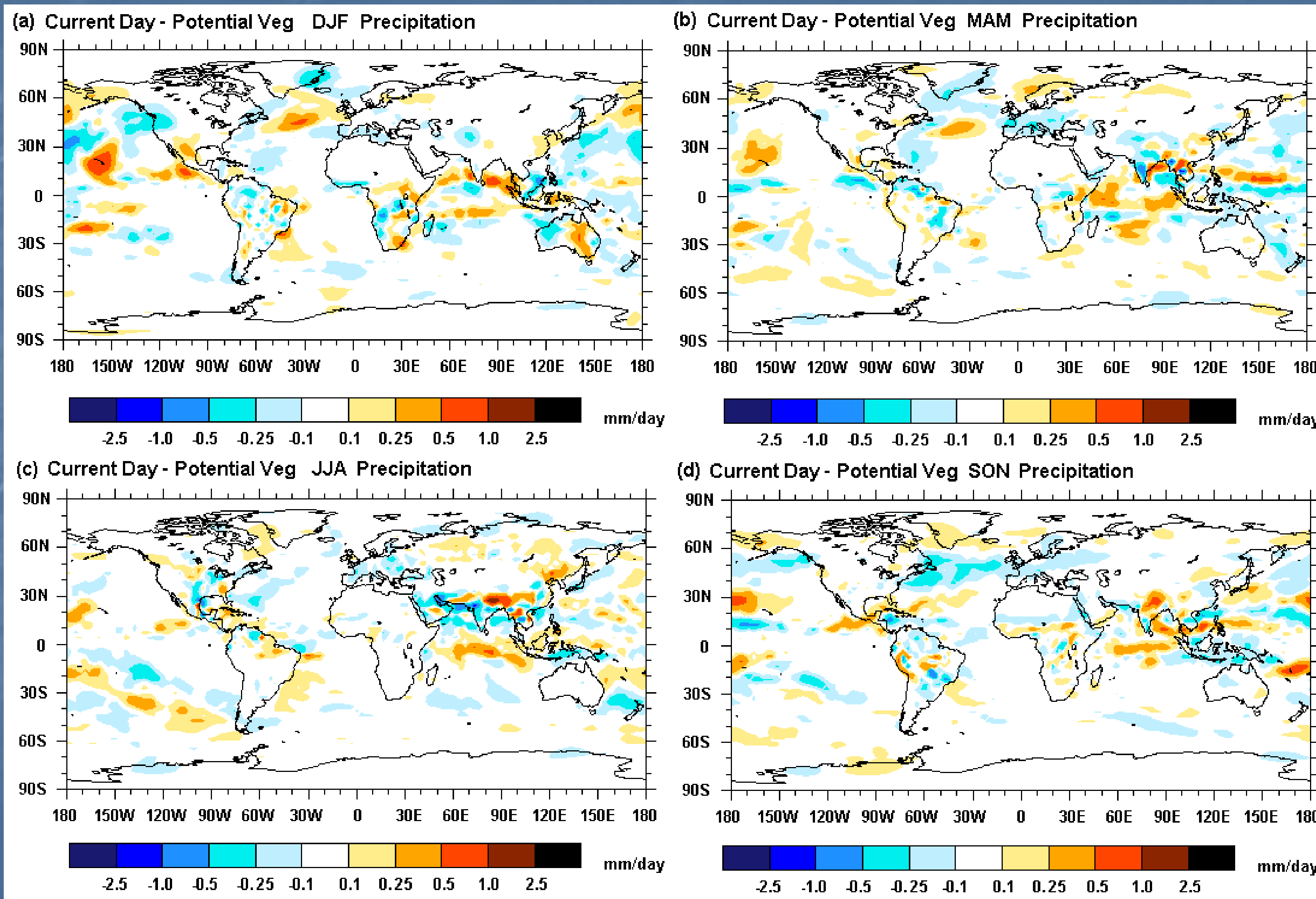
3. Surface Hydrology

1. 2m Air Temperature Changes with Land Cover Change

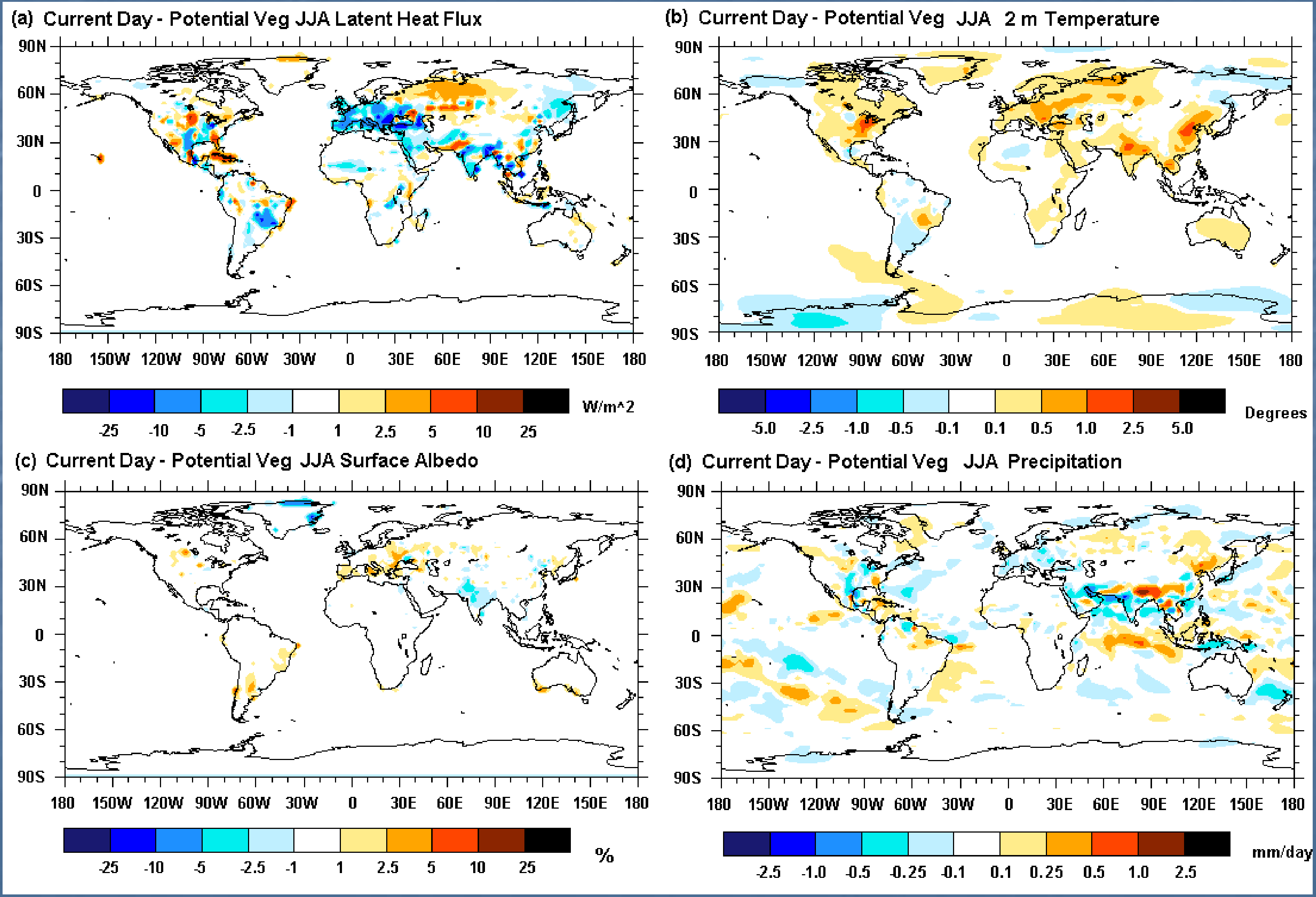
	All Land		Asia		North America		Europe	
	Pot V	Curr (Diff)	Pot V	Curr (Diff)	Pot V	Curr (Diff)	Pot V	Curr (Diff)
DJF	5.8	5.9 (+0.1)	6.9	7.2 (+0.3)	-2.3	-2.5 (-0.2)	3.2	3.4 (+0.2)
MAM	9.8	9.9 (+0.1)	15.9	16.4 (+0.4)	8.5	8.6 (+0.1)	9.3	9.6 (+0.3)
JJA	14.5	14.6 (+0.1)	22.2	22.5 (+0.3)	20.6	20.9 (+0.3)	17.9	18.2 (+0.3)
SON	10.6	10.7 (+0.1)	15.0	15.3 (+0.3)	10.5	10.7 (+0.2)	10.9	11.1 (+0.2)
ANN	10.2	10.3 (+0.1)	15.0	15.4 (+0.3)	9.4	9.4 (+0.1)	10.3	10.5 (+0.2)

Climate Impacts of Global Land Cover Change is fully described in *Lawrence and Chase*, (2008b) *Journal of Geophysical Research* in review

3. CCSM Land Cover Change – Precip Change



3. CCSM Land Cover Change – Forcing Changes JJA



3. Impacts of Global Land Cover Change Summary

1. Overall Warming and Drying Globally

2. Largest impacts are in Asia and Europe with smaller impacts in North America, South America, Africa and Australia

3. Climate impact are predominantly driven by changes in hydrology with albedo playing a secondary role

4. Asian Land Cover Change vs El Nino Experiments

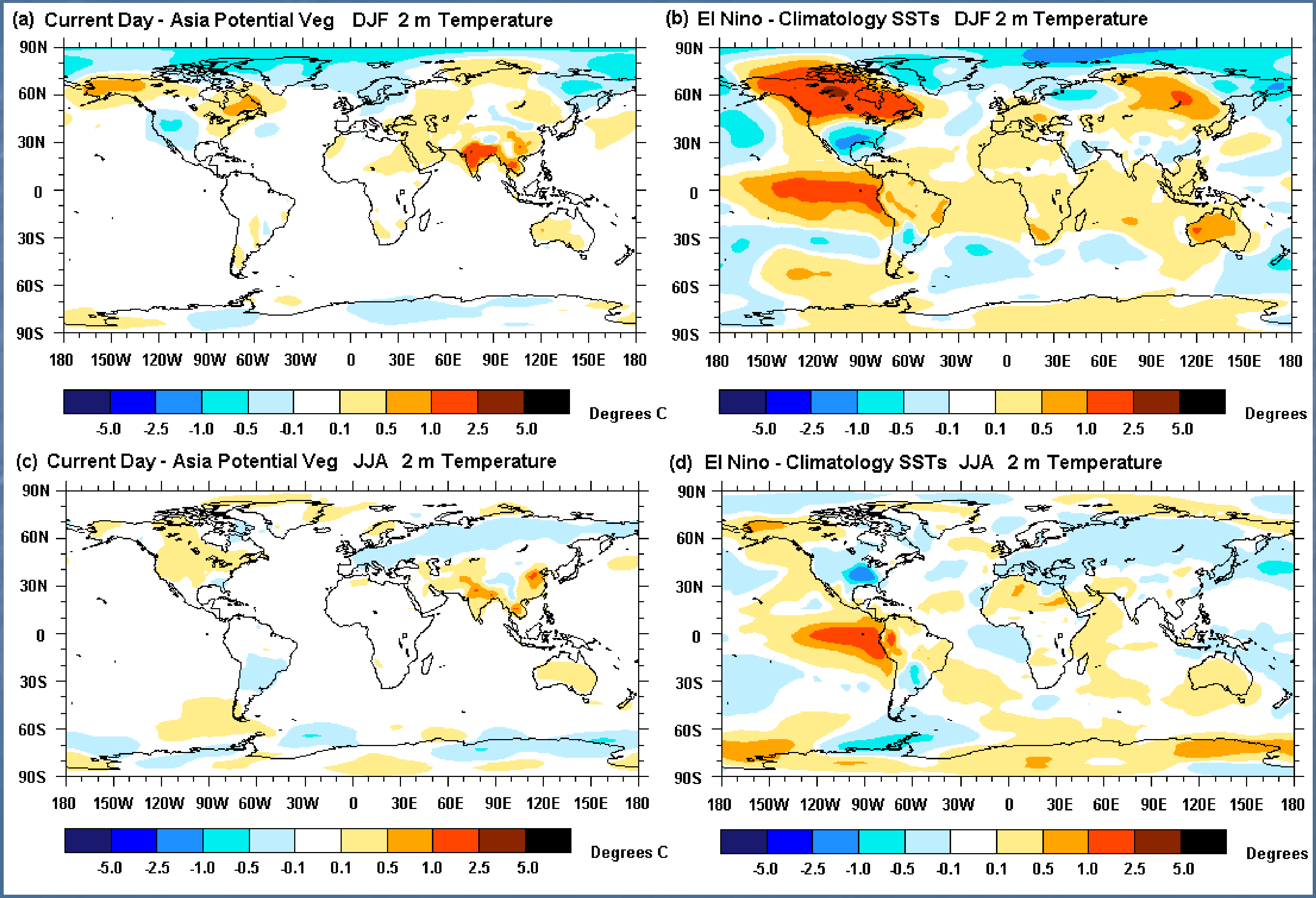
Given the strong influence of Land Cover Change in Asia we have further investigated the land cover change surface forcing compared to the relatively well understood surface forcing from an El Nino:

- Average El Nino monthly SSTs prescribed from in DOCN compared to 1949 – 2001 climatology monthly SSTs.
- El Nino SST anomalies taken from Hadley Center monthly SSTs where Nino 1, 2 and 3 regions are warmer than climatology by 1^{O}C for the season (1870 – 2003).
- Asia Potential Vegetation CLM parameters from new Global Potential Vegetation parameters subset to

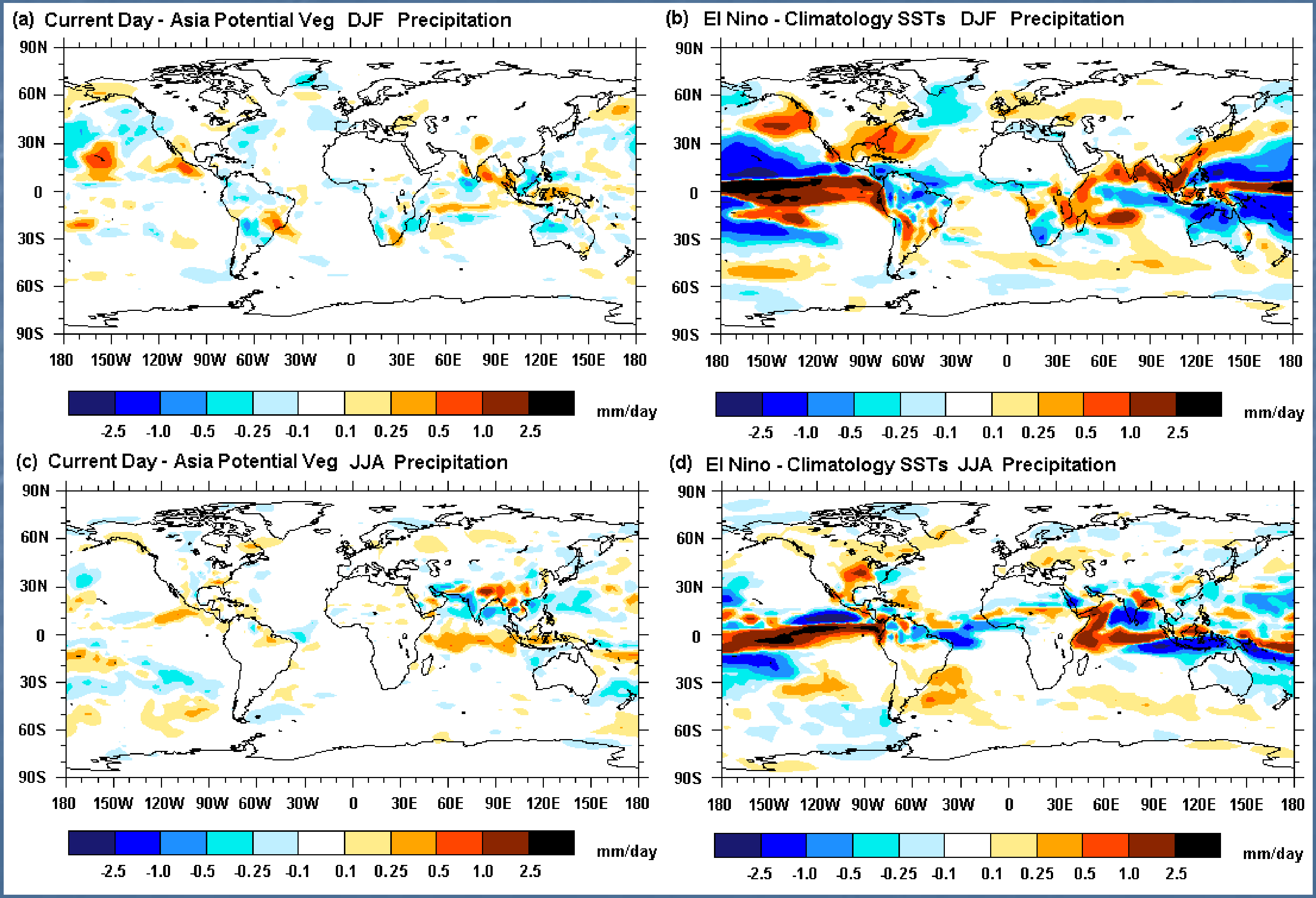
4. Land Cover Change Experimental Design

CCSM Experiments with CAM 3.0 Atmosphere	1949 - 2001 Climatology SSTs and Sea Ice	Average 1870 – 2003 El Nino SSTs
Current Day MODIS Land Cover	3 x 30 years	3 x 30 years
Asian Potential Vegetation Land Cover	3 x 30 years	

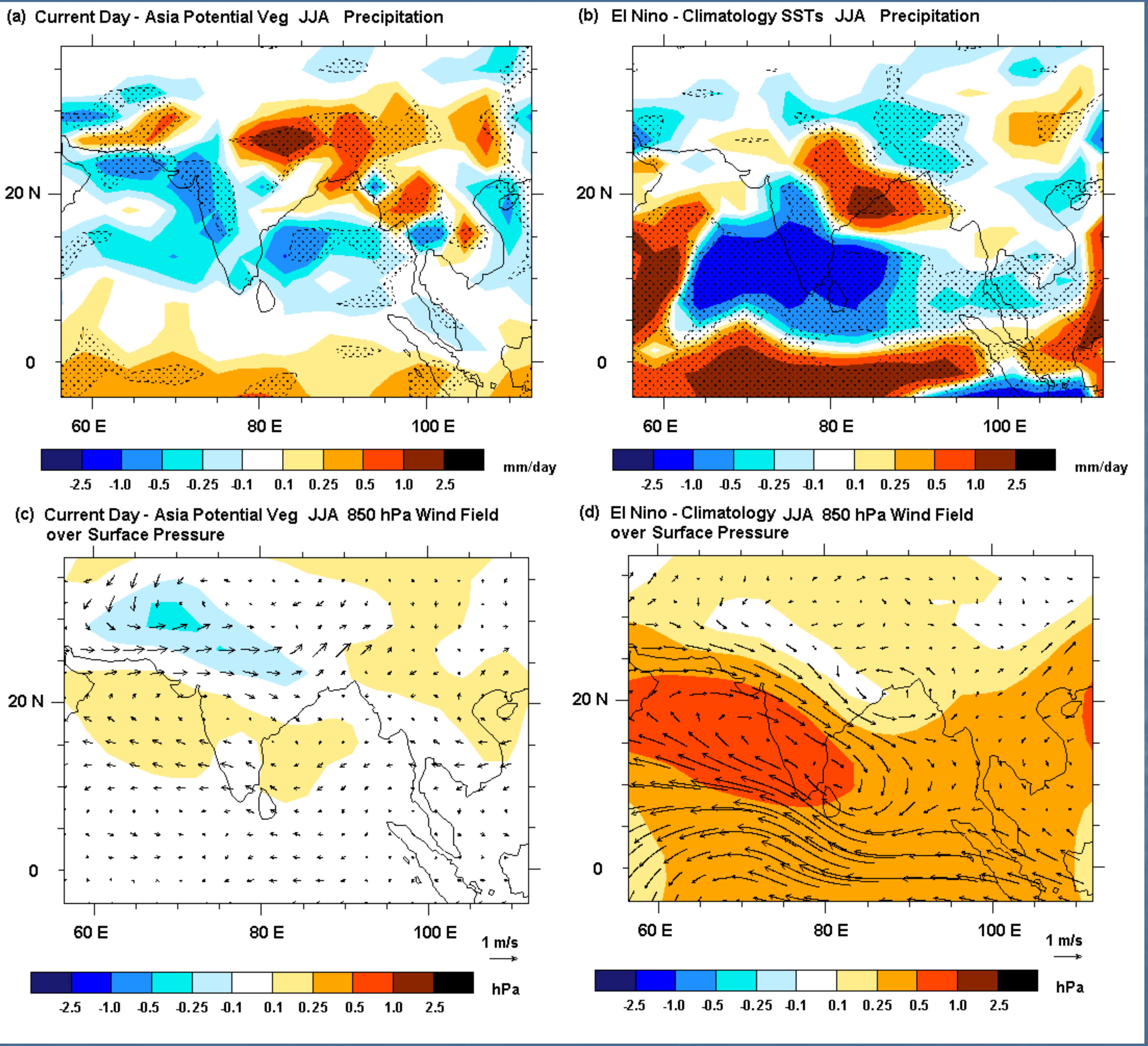
4. CCSM Asia Land Cover Change vs El Nino 2 m Temp



4. CCSM Asia Land Cover Change vs El Nino Precip



4. CCSM Asia LCC vs El Nino Precip and Circulation



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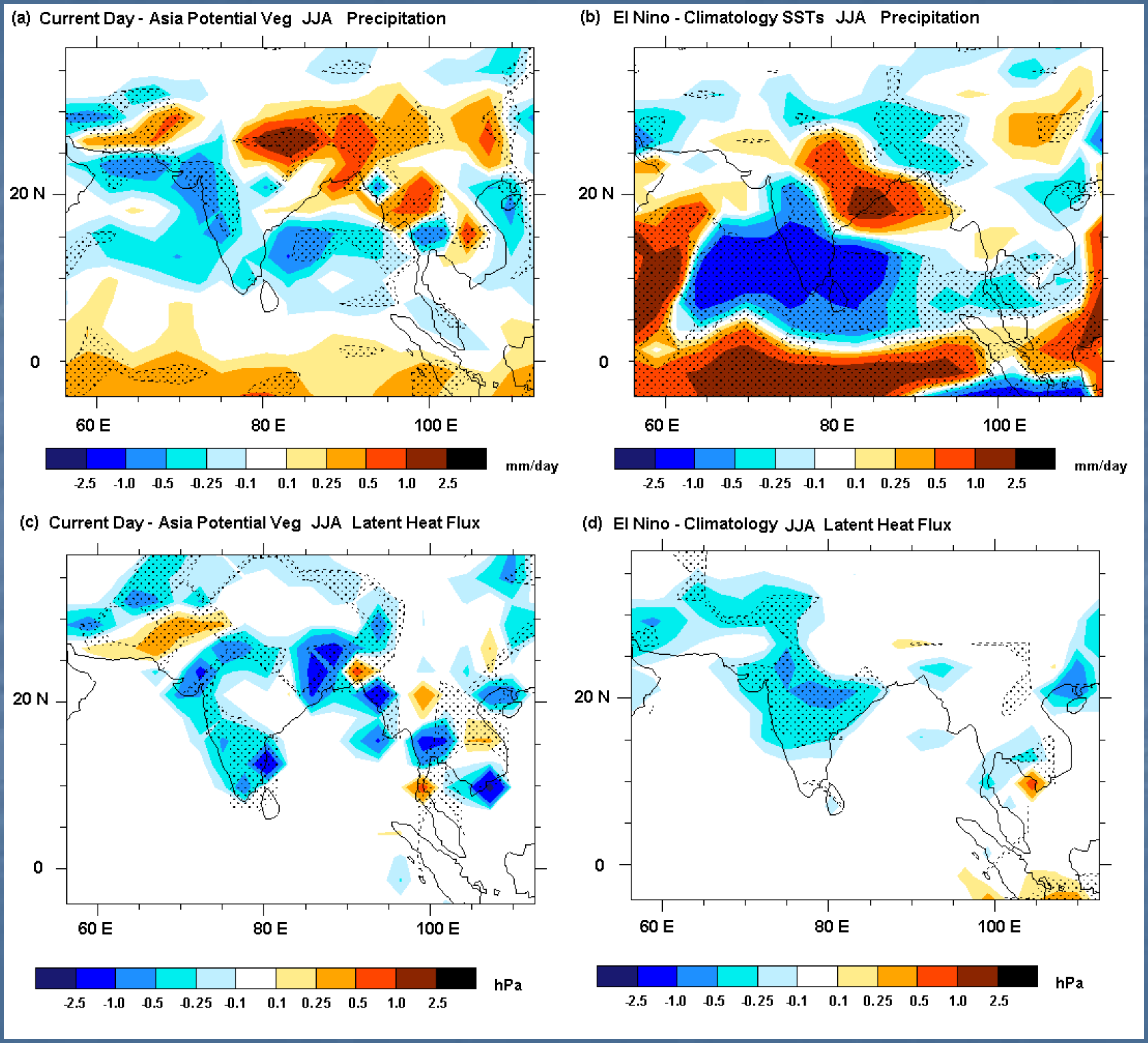

4. Asian Land Cover Change vs El Nino Summary

1. Asian LCC has smaller surface forcing in terms of area but similar in temperature change
2. Monsoon circulation changes are substantially weaker than El Nino forcing but still present
3. There are weak tele-connections to higher latitudes in DJF with reduced magnitude and significance but still present
4. Localized surface hydrology changes are bigger than El Nino feedbacks and are the major driver of Asian climate changes

5. Outstanding Issues

1. **Ramankutty and Foley Potential Vegetation is highly conservative as Current Day "natural vegetation" is poor guide in many areas with other human disturbance**

2. **Large amounts of grass in potential vegetation**
   - This can be traced to 100% grassy understorey in current PFT calculation (currently under investigation)

3. **No Irrigation currently formulated in CLM**
   - Important if hydrology is dominant forcing in LCC

4. **No Urban – soon to be addressed**

5. **It is difficult to construct realistic Land Cover Change parameters, with arbitrary decisions having big impacts on climate response**