Using MODIS Data to Characterize Climate Model Land Surface Processes- Impacts of Land Cover/Use Change on Surface Hydrological Processes

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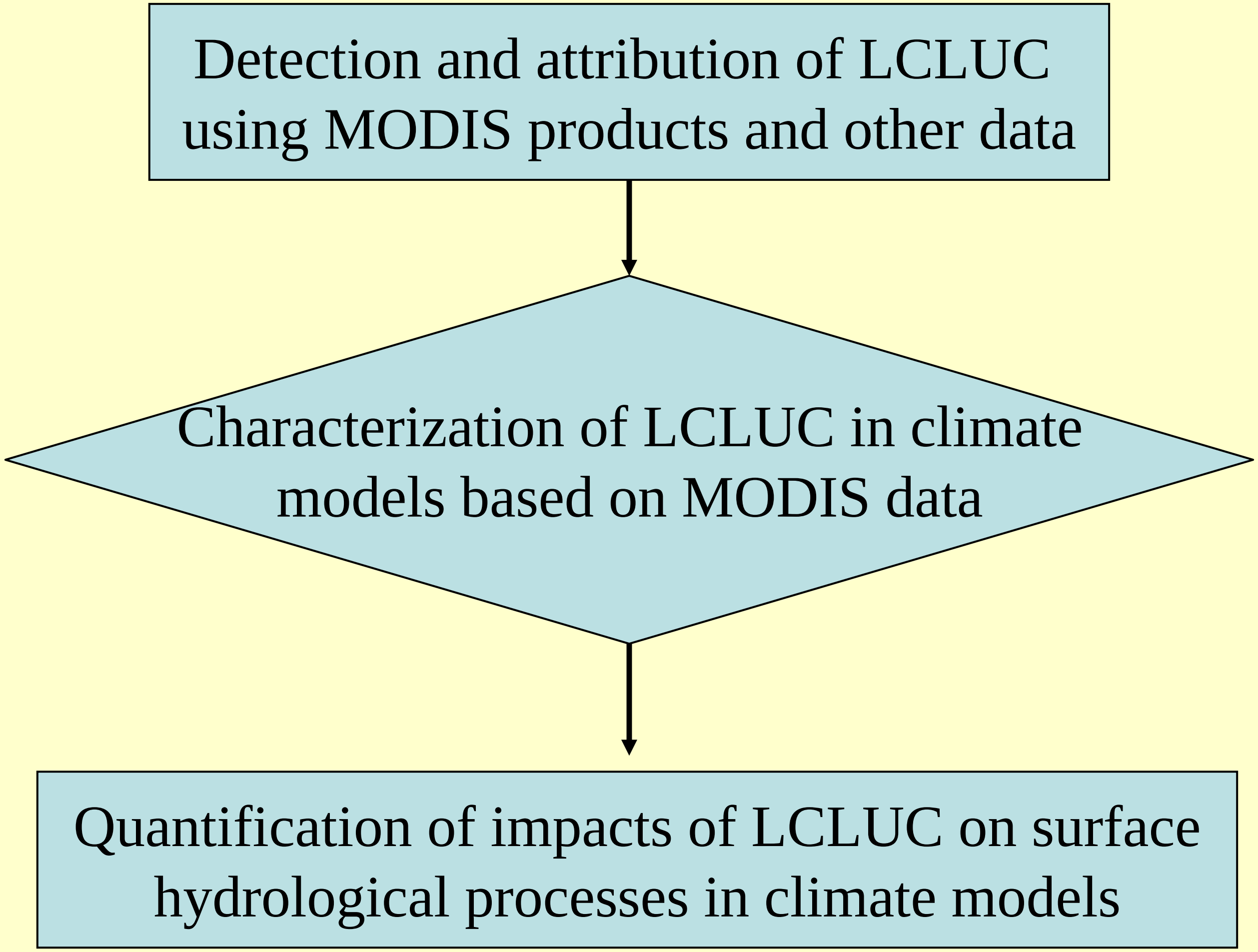
Personnel

- **PI: R.E. Dickinson,** Georgia Tech
- **Coinvestigators**:
  - **Climate modelers**: Georgia Tech, NCAR, U. Arizona, U. Texas at Austin
  - **MODIS land teams**: albedo/BRDF, fractional vegetation cover, LAI/FPAR, and land cover/land cover change
  - **Others**: Institute for Environment and Sustainability, Potsdam Institute of Climate Impact Research, U. Maryland
- **Collaborators**: some major groups working on related fields

Outline of Proposal



Work Done or Doing

- Assessing effects of desertification on diurnal temperature range over the Sahel
- Developing more realistic radiation models for climate models
- Deriving a bare soil albedo dataset from MODIS (not discussed here)
- Improving climate model land surface parameterizations using MODIS products (not discussed here)

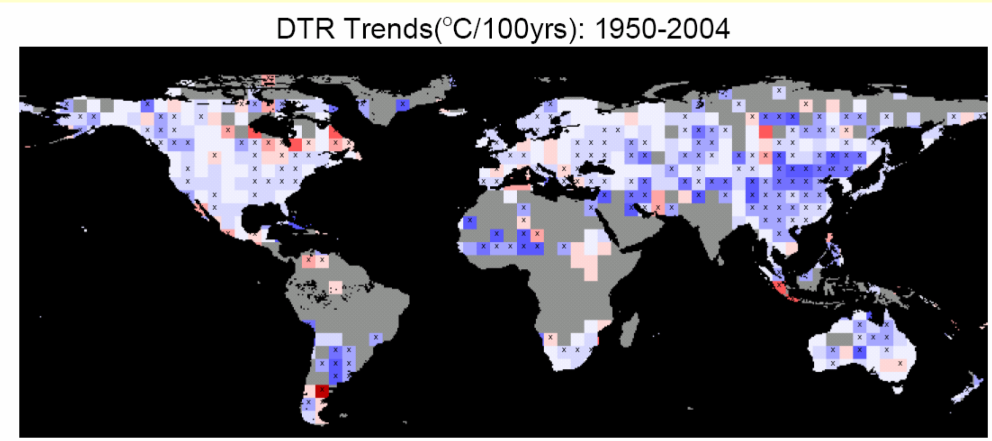
Part I

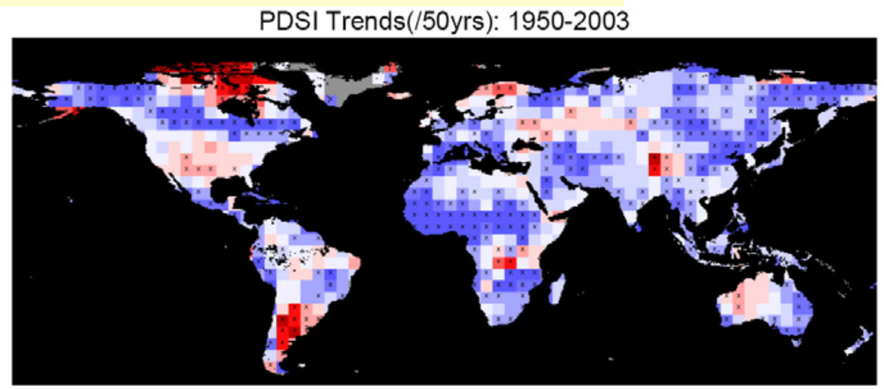
Assessing effects of desertification on diurnal temperature range over the Sahel

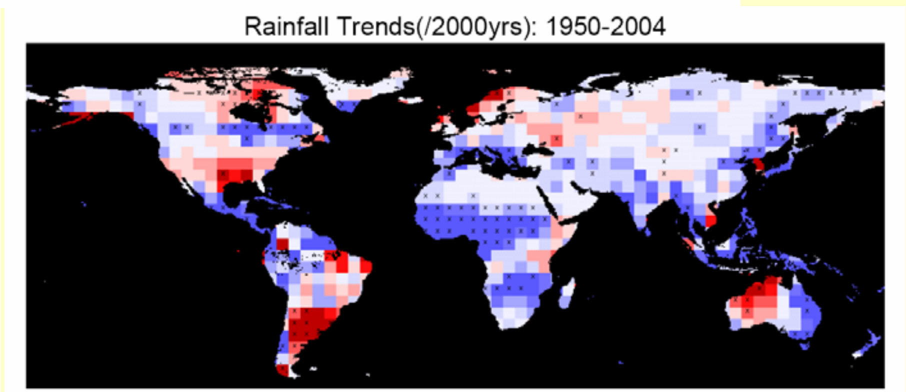
Observed DTR Trends: Global View

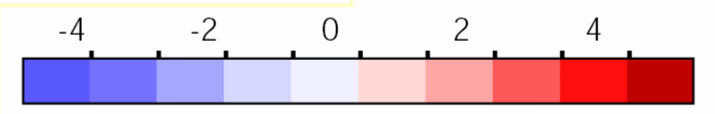
- DTR declines most over semi-arid regions such as the Sahel

	T_{max}	T_{min}	DTR
dry:	1.96,	2.84,	-0.48
mid:	1.68,	2.48,	-0.39
wet:	1.00,	1.54,	-0.28





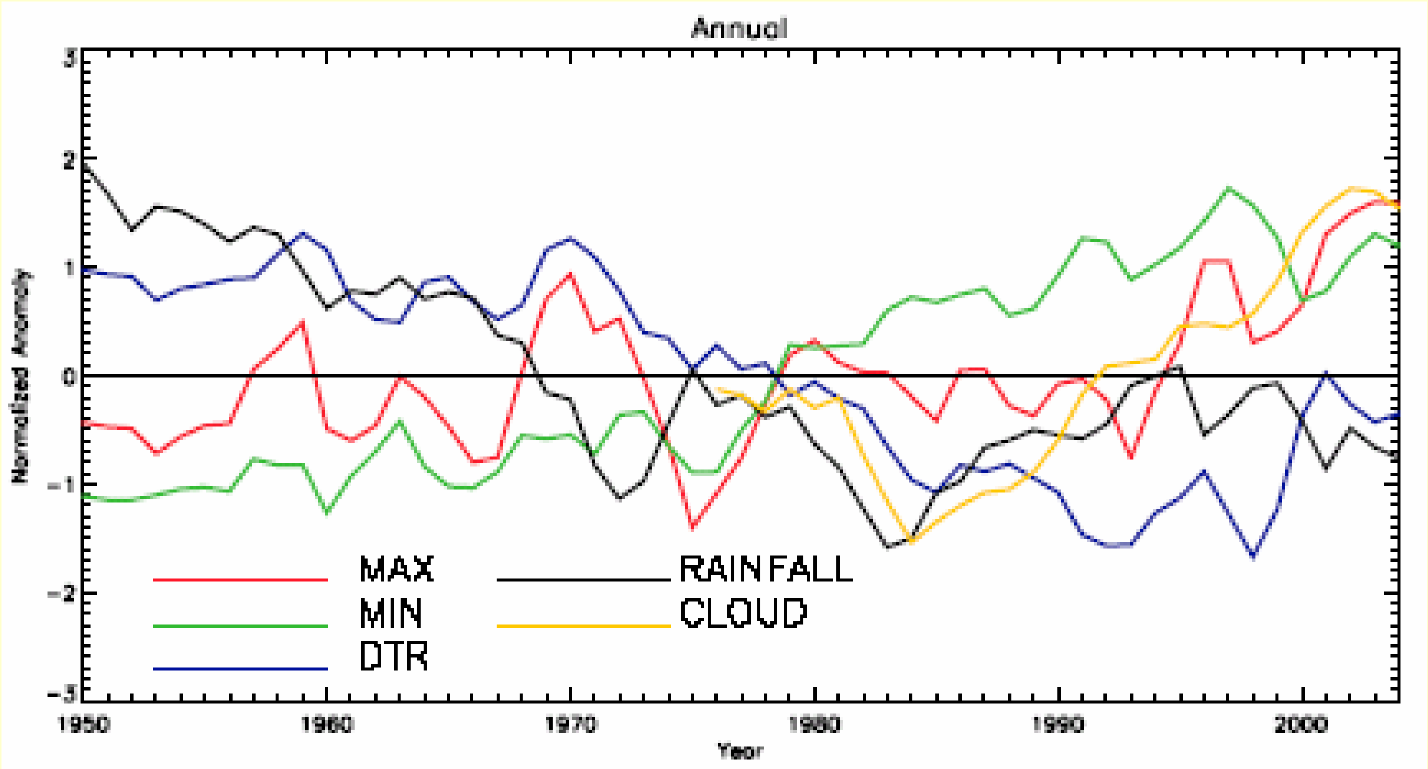




(Data sources: Vose et al., 2005; Chen et al., 2001)

Observed DTR Trends: The Sahel

- T_{min} has a strong/significant warming trend while T_{max} shows a small/insignificant trend, and thus the DTR declines.



Normalized time series anomalies of annual mean T_{max},T_{min}, DTR, cloud cover and rainfall for the period of 1950-2004.

Clouds/Rainfall Decreased the DTR?

- Increased clouds, rainfall, and soil moisture have been used to explain the worldwide reduction of DTR, but cannot explain the DTR trends over the Sahel

Relationship between DTR and Rainfall/Clouds

		$Y = \beta_0 + \beta_1 X + \beta_2\,\text{time}$			$\Delta Y = \beta_0 + \beta_1 \Delta X$	
Y	X	R^2	β_1	β_2	R^2	β_1
DTR	rainfall	0.60	**-0.57**	**-0.030**	0.42	**-1.21**
DTR	clouds	0.15	0.06	**-0.025**	0.15	**-0.11**

Other Factors Reducing the Sahelian DTR?

- **New hypothesis:**

Desertification-induced reduction in vegetation cover and soil emissivity

- Desertification, due to drought, deforestation, land degradation, soil erosion and population growth, increases albedo and decreases emissivity.
- Higher albedo reduces the absorption of solar radiation but such effect is compensated by more incoming radiation due to less cloud cover.
- Lower emissivity reduces thermal emission and less vegetation increases soil heat storage, both warming the surface during nighttime over semiarid regions when and where evapotransporation is very limited.

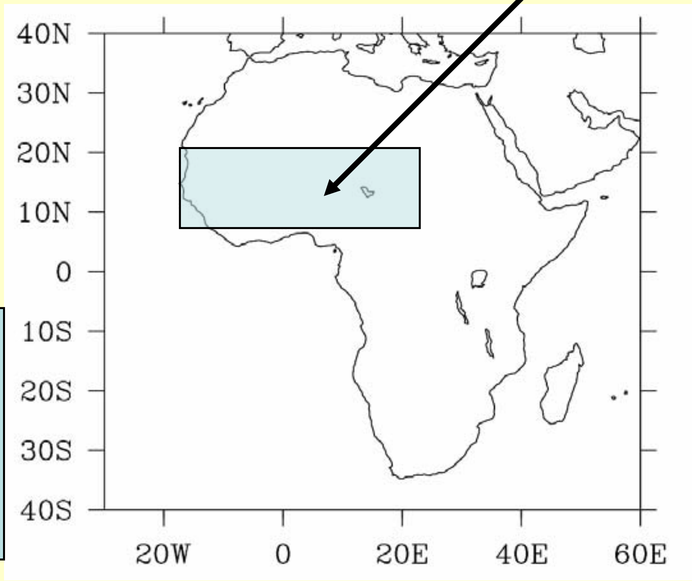
Climate Model Sensitivity Tests

- Three 20yrs simulations using NCAR CAM3/CLM3:
  - Control run (CTL): no changes in vegetation and ε_g =0.96
  - Exp A: remove all vegetation and ε_g =0.89
  - Exp B: remove all vegetation and ε_g =0.96

Typical soil emissivity:
ε_g = 0.96
Desert soil emissivity:
ε_g =0.89

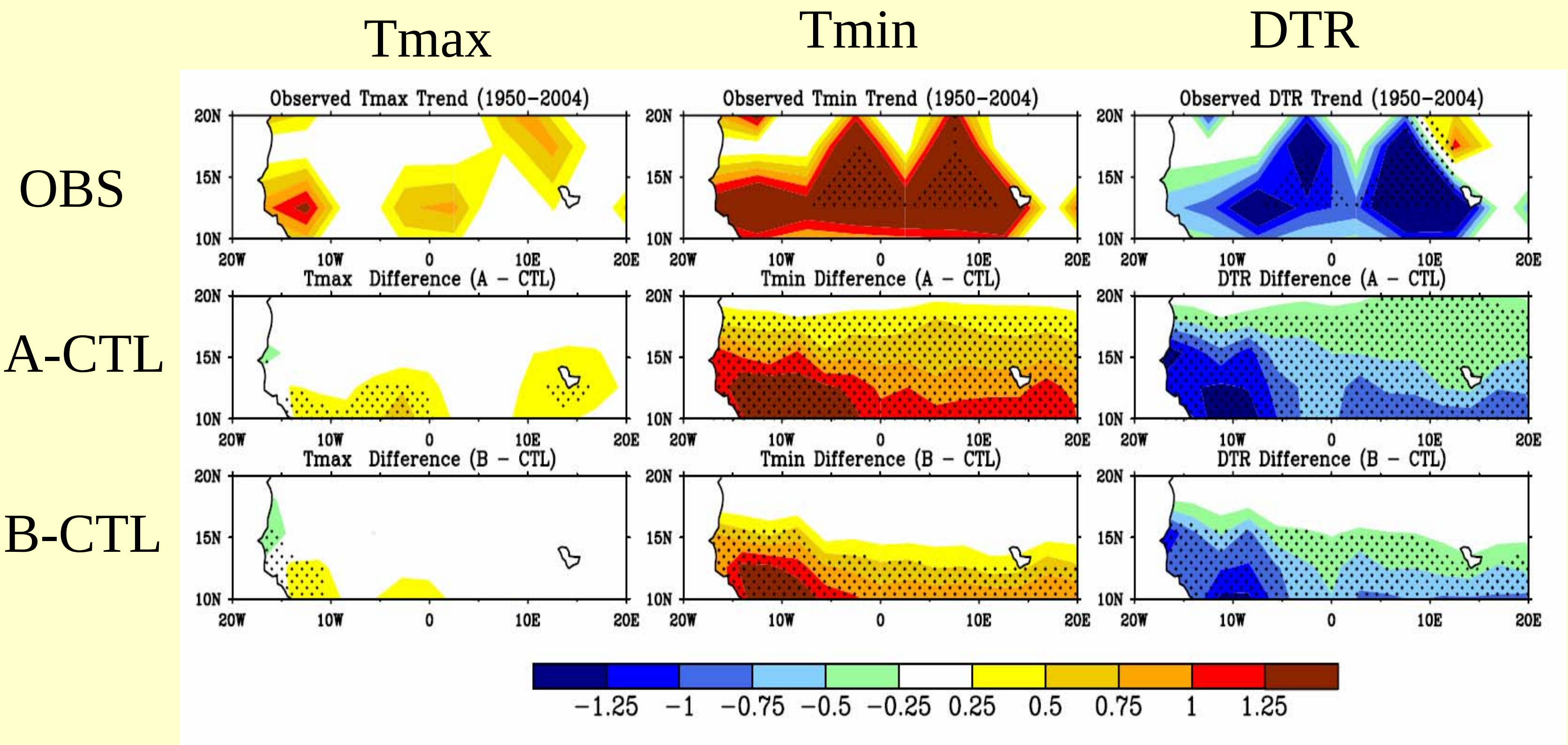
A-CTL: effects of vegetation + emissivity
B-CTL: effects of vegetation only

Test region: Sahel



Observed vs Simulated Temp: Spatial Pattern

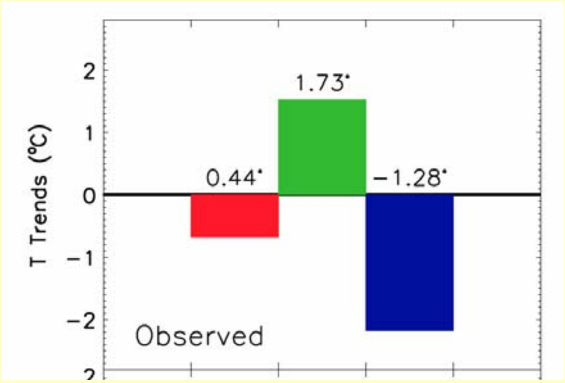
- Stronger warming for T_{min} than T_{max} over the Sahel



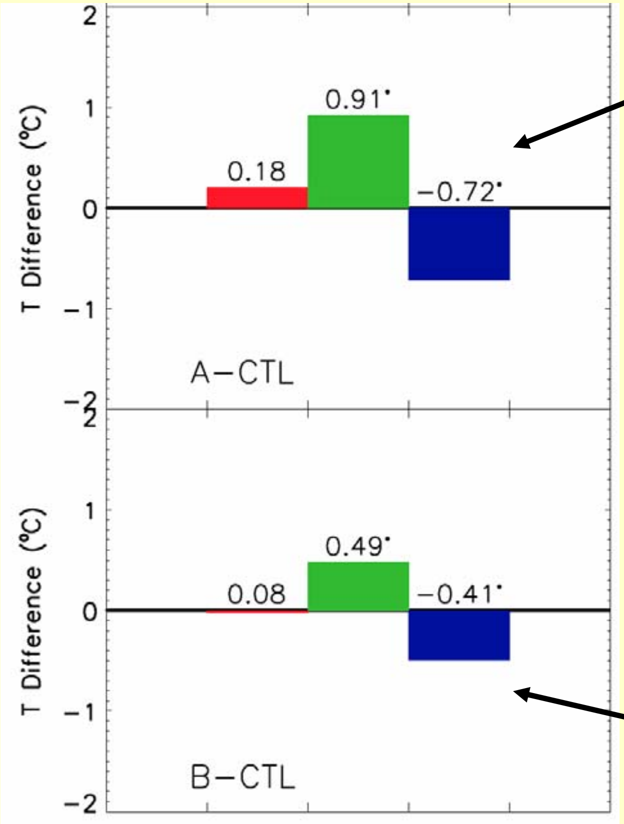
Observed and simulated annual mean T_{max},T_{min}, and DTR

Observed vs Simulated Temp: Regional Mean

- Reduced soil emissivity and vegetation both decrease DTR



Observed



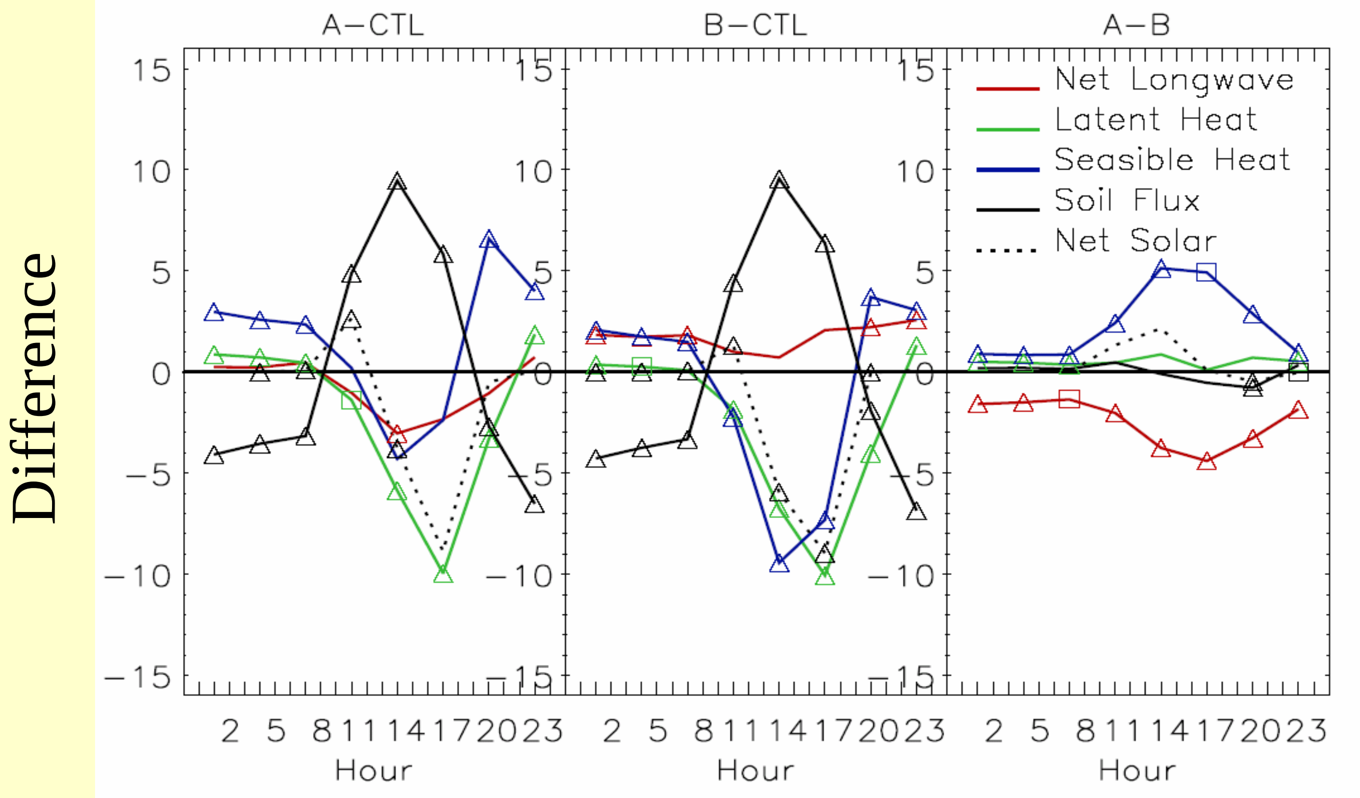
vegetation + emissivity

vegetation only

Observed and simulated annual mean T_{max},T_{min}, and DTR

Explanations: Radiation and Energy Budget?

- emissivity ↓ ⇨ thermal emission ↓ ⇨ sensible heat ↑ ⇨ Tmin ↑
- vegetation ↓ ⇨ soil heat storage ↑

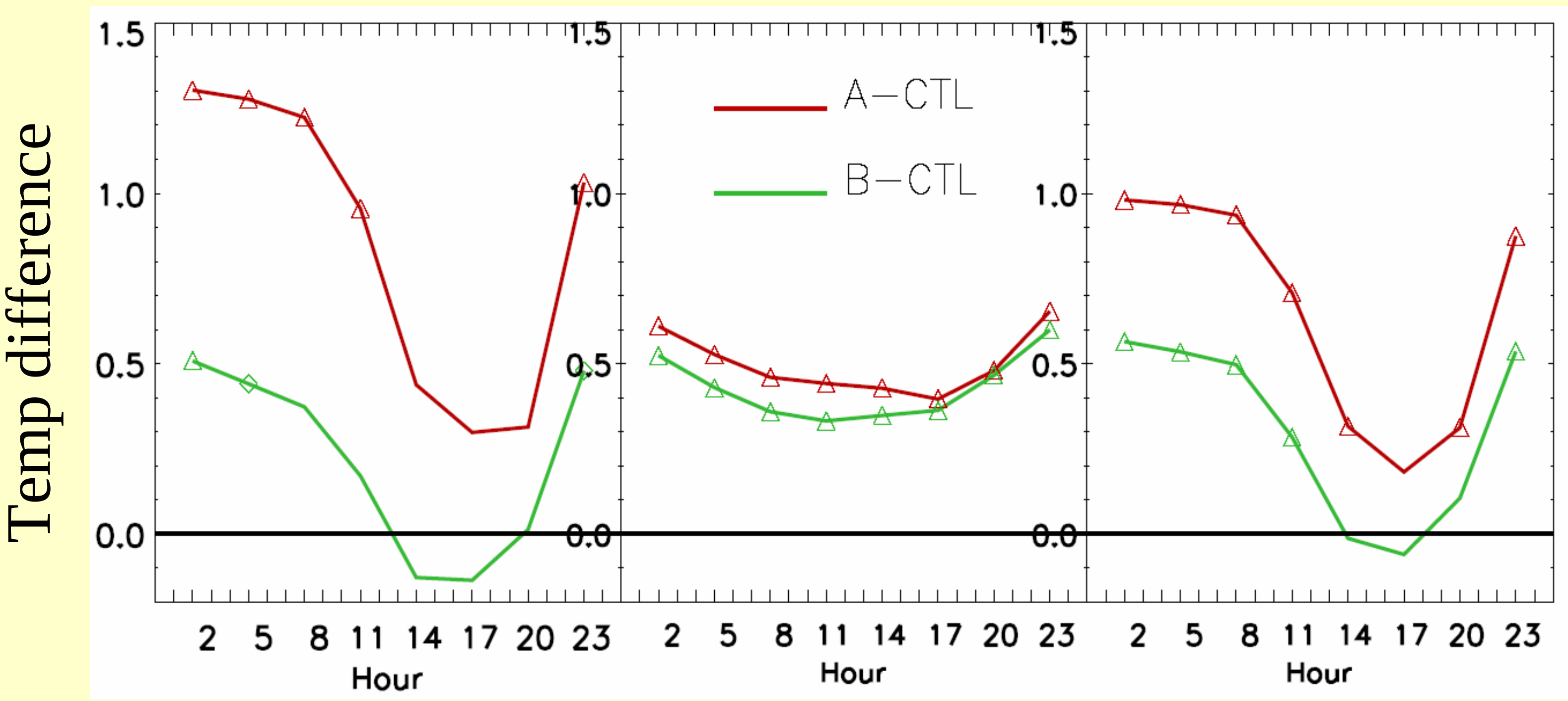


Differences in the diurnal cycle of radiation and energy budget

Simulated Temp Diurnal and Seasonal Cycle

- Largest warming during nighttime and dry seasons
- Smallest warming during daytime and wet seasons
- Larger warming in A-CTL than B-CTL

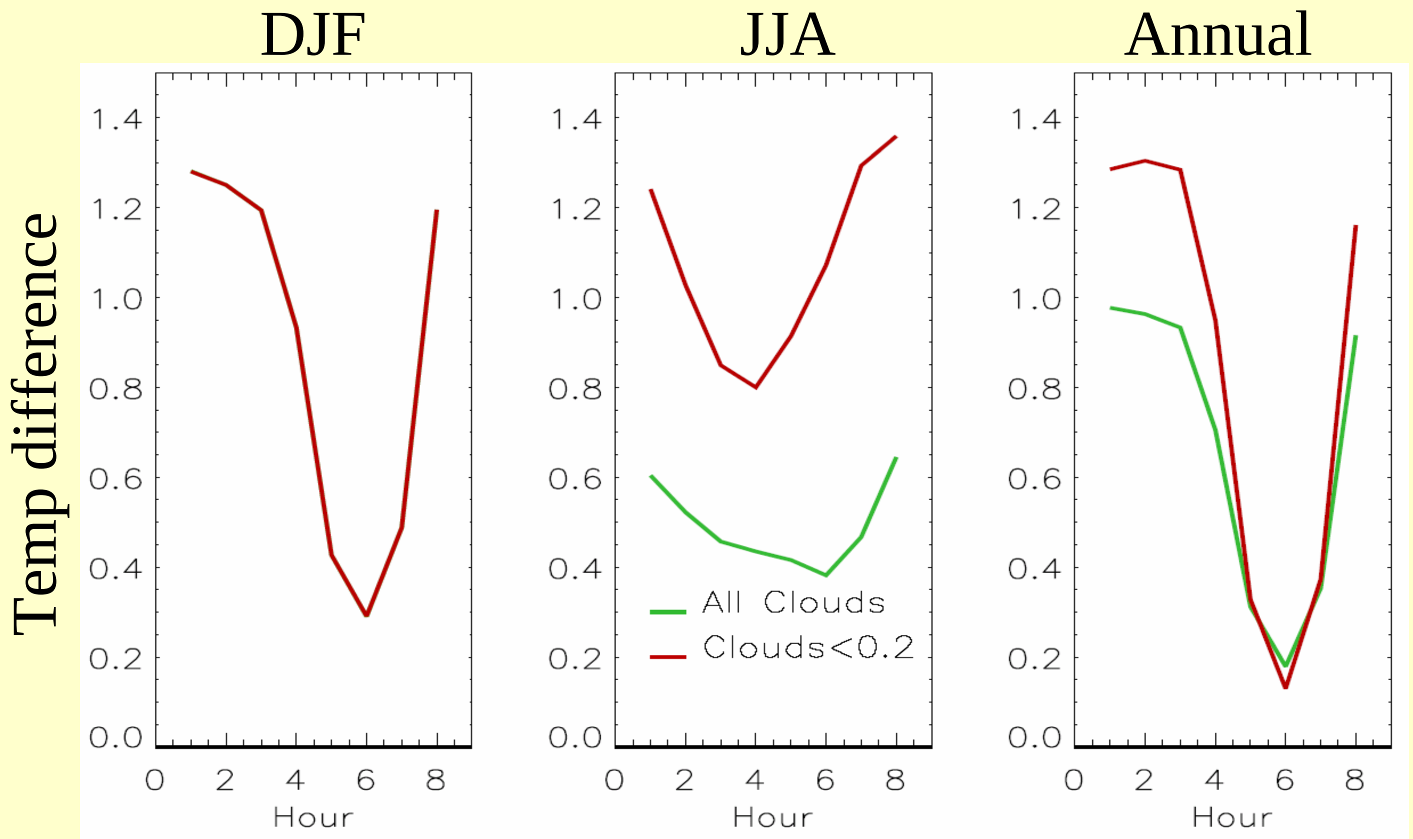
DJF JJA Annual



Differences in the diurnal cycle of temperature

Explanations: Seasonal Differences?

- Stronger cloud effects in wet seasons than in dry seasons



Differences in the diurnal cycle of temperature (A-CTL)

Conclusions

- Our simulations show that the desertification-induced reduction in soil emissivity and vegetation cover warms T_{min} much faster than T_{max} and thus substantially declines the DTR.

- Drought and deforestation over semiarid regions like the Sahel could initiate an important land-atmosphere positive feedback on warming land surface air temperature and decreasing the DTR.

Part II

Developing more realistic radiation models

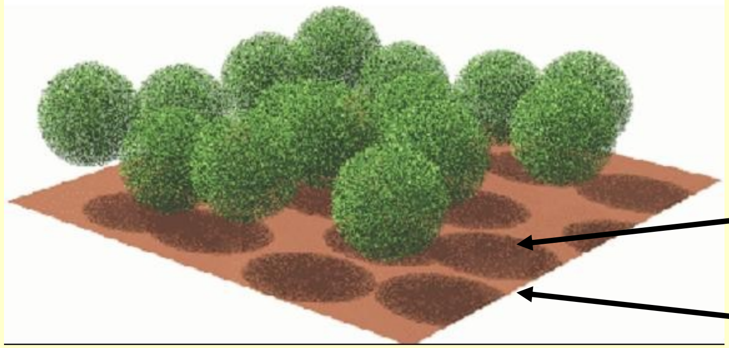
Essential Problem in Radiation Modeling?

- Climate models generally use 2-stream radiation schemes to calculate albedos for vegetated surfaces.

Problem: accuracy for horizontally homogeneous canopies but largest errors for semiarid and snow-covered vegetated surfaces

Solution: a more realistic radiation model plus a more accurate boundary condition

climate model view of vegetation



shading effects

soil albedo

what it looks like for semi-arid system

Step 1:

Developing a 4-stream approximation scheme for use in climate models

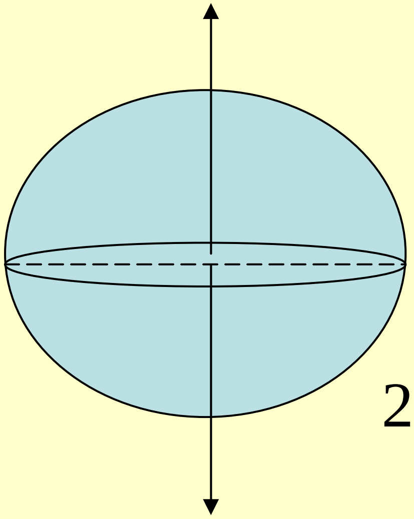
Canopy Radiative Transfer

- Solving differential integral equations to get canopy albedo, transmittance, and absorptance
- Remote Sensing: radiative transfer models (RT)

multiple layers: 10 layers multiple angles: 20 angles in zenith and azimuth speed: 10 hours (to get 200 values)

- Climate models: 2-stream schemes

1 layer two angles speed: 1second (to get 200 values)



2-stream

Objective of 4-stream Scheme

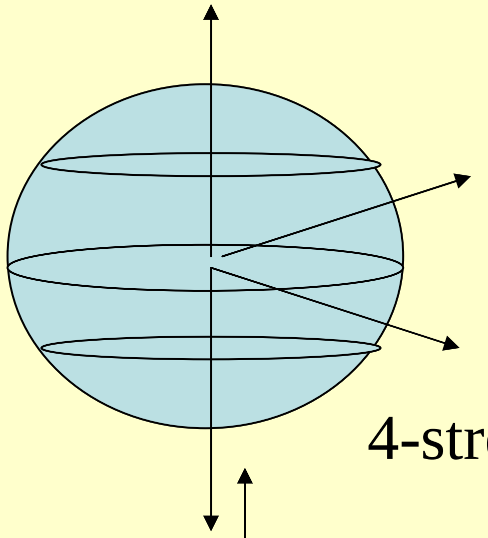
- To improve the accuracy of 2-stream but maintain its simplicity and computational efficiency

- 4-stream schemes

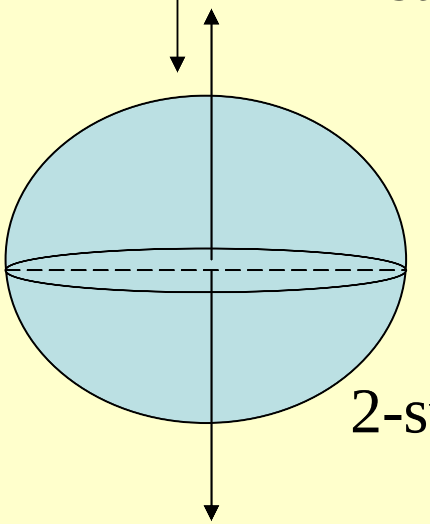
1 layer four angles speed: 1 second (to get 200 values)

- 2-stream schemes

1 layer two angles speed: 1 second (to get 200 values)



4-stream



2-stream

Analytical Solutions

- Solving equations symbolically using the software "Mathematica"

$$\frac{dI_2^{\downarrow}}{dL} = \frac{1}{\mu_2}[(\alpha^+ - \kappa_{-2})I_2^{\downarrow} + \beta^+ I_1^{\downarrow} + \beta^- I_1^{\uparrow} + \alpha^- I_2^{\uparrow}] + [\frac{G(\mu_0)}{\mu_2}\varepsilon_{-2}e^{-G(\mu_0)L/\mu_0}],$$

$$\frac{dI_1^{\downarrow}}{dL} = \frac{1}{\mu_1}[\beta^+ I_2^{\downarrow} + (\gamma^+ - \kappa_{-1})I_1^{\downarrow} + \gamma^- I_1^{\uparrow} + \beta^- I_2^{\uparrow}] + [\frac{G(\mu_0)}{\mu_1}\varepsilon_{-1}e^{-G(\mu_0)L/\mu_0}],$$

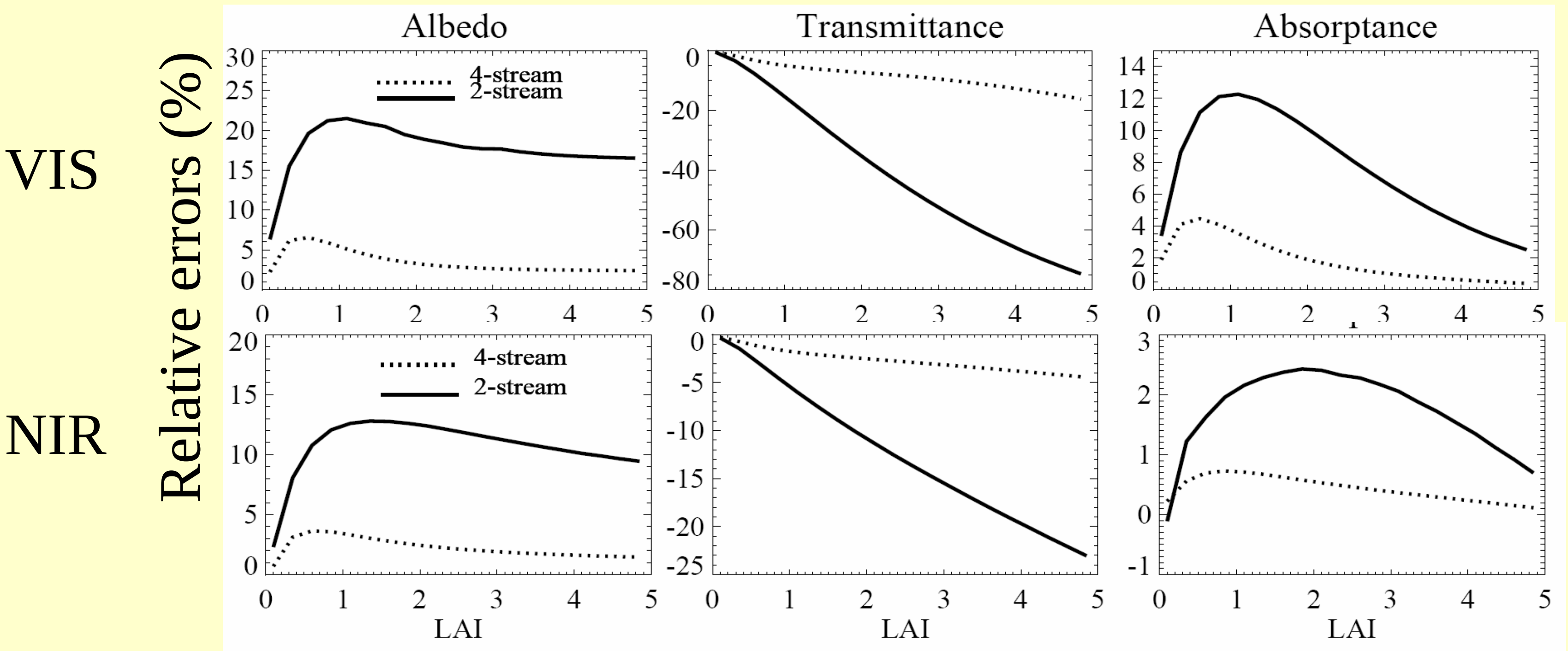
$$\frac{dI_1^{\uparrow}}{dL} = \frac{1}{\mu_1}[-\beta^- I_2^{\downarrow} - \gamma^- I_1^{\downarrow} - (\gamma^+ - \kappa_1)\gamma^- I_1^{\uparrow} - \beta^+ I_2^{\uparrow}] - [\frac{G(\mu_0)}{\mu_1}\varepsilon_1 e^{-G(\mu_0)L/\mu_0}],$$

$$\frac{dI_2^{\uparrow}}{dL} = \frac{1}{\mu_2}[-\alpha^- I_2^{\downarrow} - \beta^- I_1^{\downarrow} - \beta^+ I_1^{\uparrow} - (\alpha^+ - \kappa_2)I_2^{\uparrow}] - [\frac{G(\mu_0)}{\mu_2}\varepsilon_2 e^{-G(\mu_0)L/\mu_0}],$$

(Tian et al., JGR, 2006)

Relative Improvements in 4-stream vs 2-stream

- Higher accuracy of albedo, transmittance, and absorptance in the 4-stream relative to the 2-stream
- More improvement for visible than for NIR bands



Relative errors as a function of LAI

(Tian et al., JGR, 2006)

Step 2:

Developing a more realistic 3-D radiation model considering canopy geometric effects

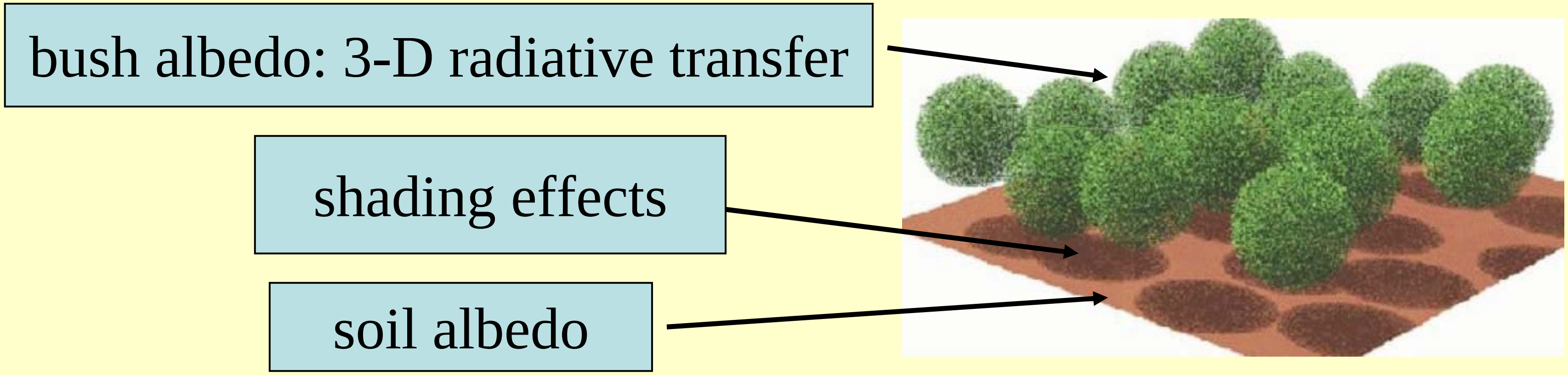
Components of New Radiation Scheme

- use of spherical bushes: describing canopy geometric (shadow) effects but remaining simple enough for economical implementation in a climate model
- albedo consists of 3 pieces:

  a) soil minus shadows: black leaves

  b) bush with underlying black soil

  c) multiple photon scatters between soil and bush – small



Conclusions

- Current climate models only consider horizontally homogeneous vegetation, which causes very serious errors in surface albedos for sparsely and snow-covered vegetated surfaces.

- The four-stream scheme substantially improves the accuracy of albedo, transmittance, and absorptance relative to the corresponding two-stream scheme.

- The four-stream scheme is an analytical model and can be easily applied as an efficient approach to a climate model.