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Overview of Land Surface Processes and Modelling

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Programme

- The Earth's Radiation Balance
- Example 1: Stomata
- Example 2: Albedo

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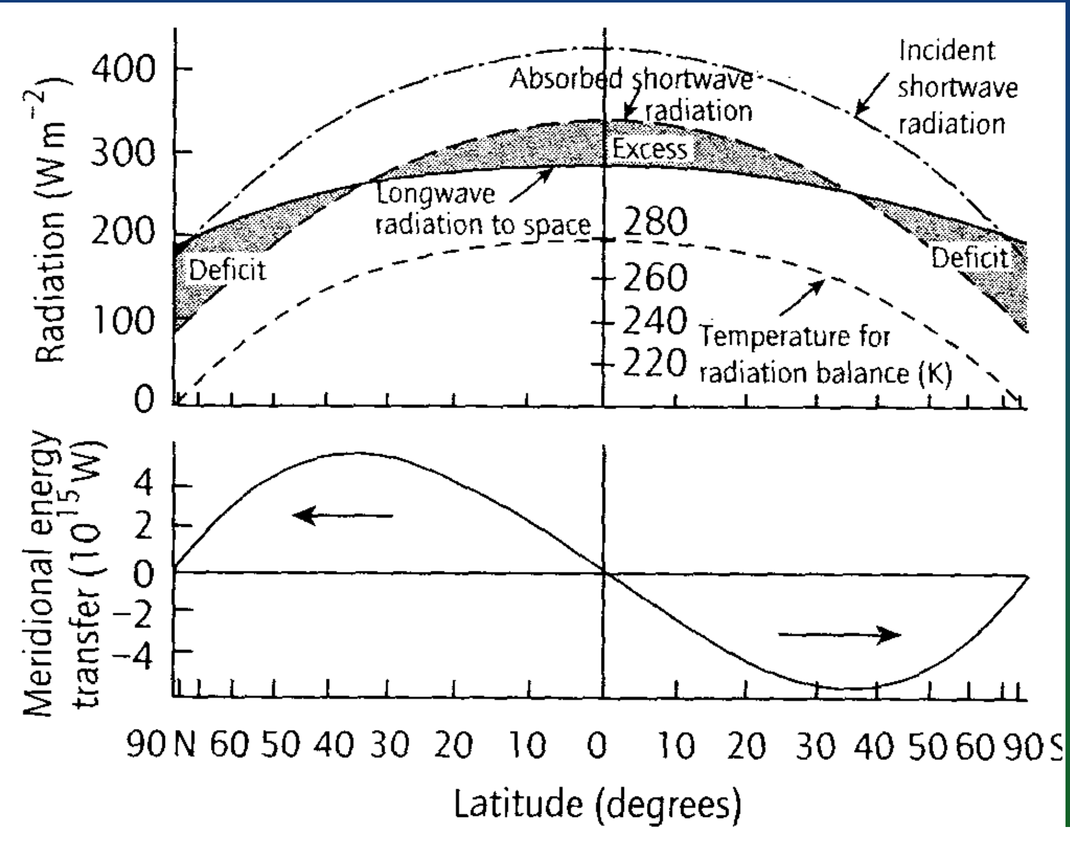
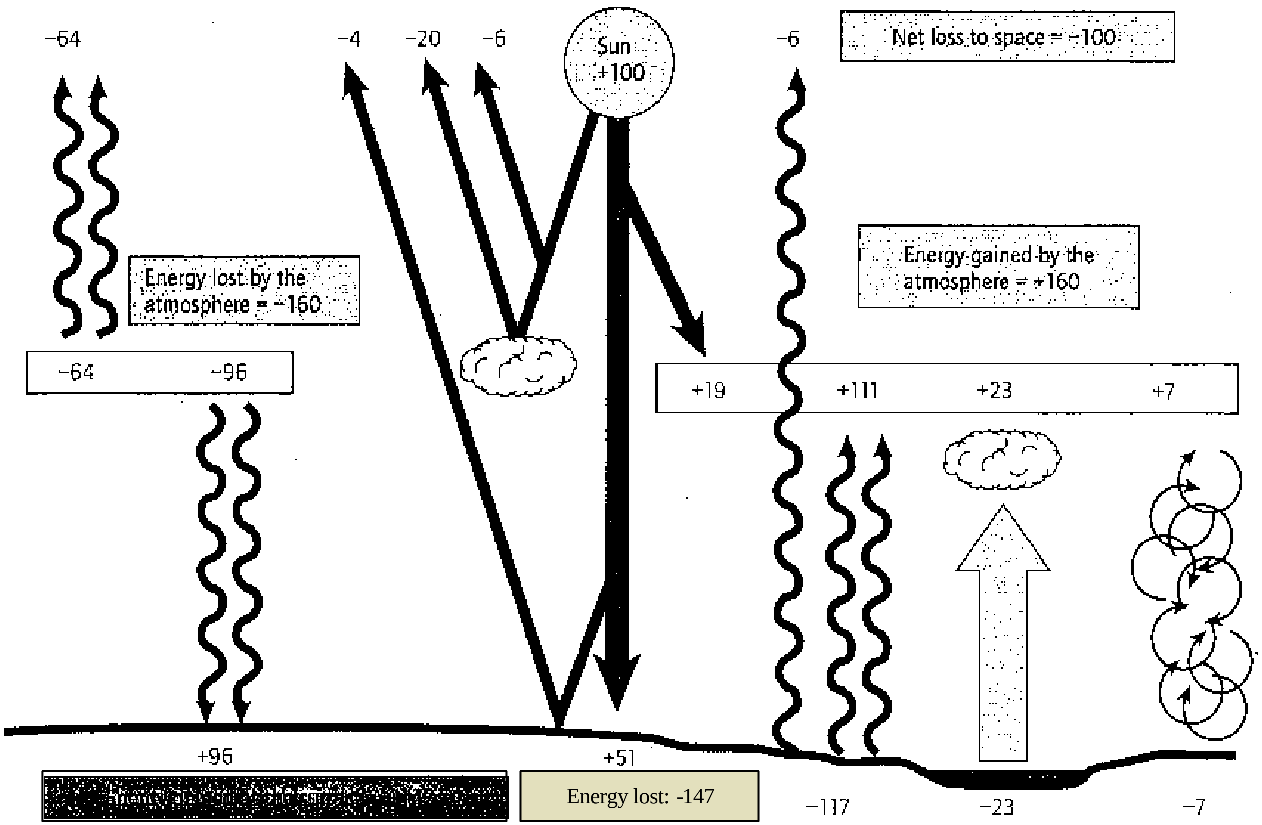
Earth Radiation Budget



taken from: Hewitt & Jackson (eds.), Handbook of Atmospheric Sciences

Earth Radiation Budget



Programme

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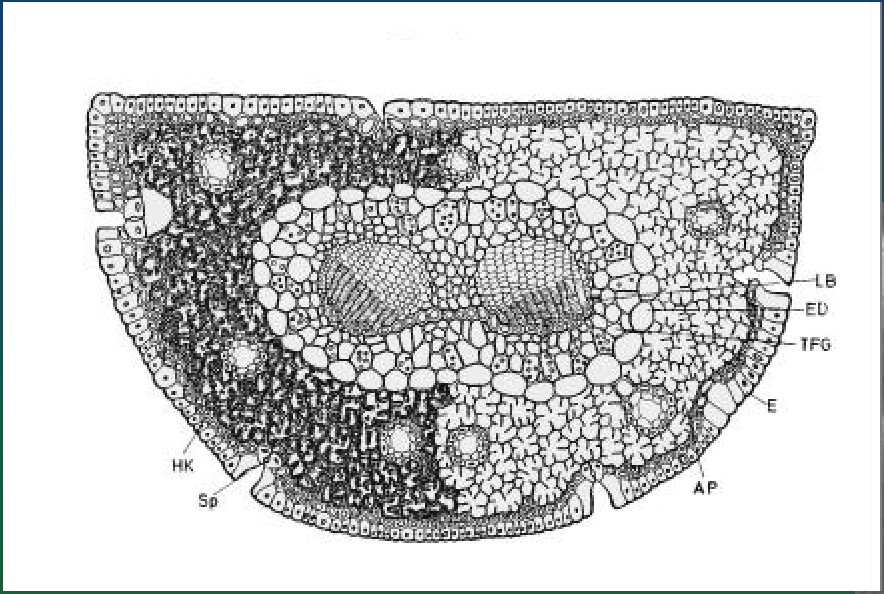
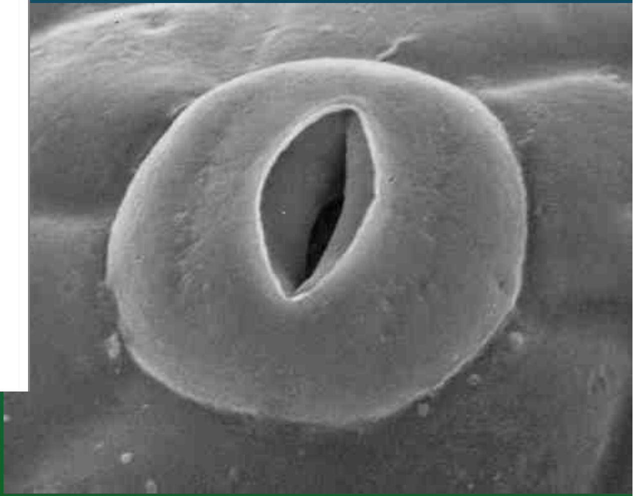
Stomata





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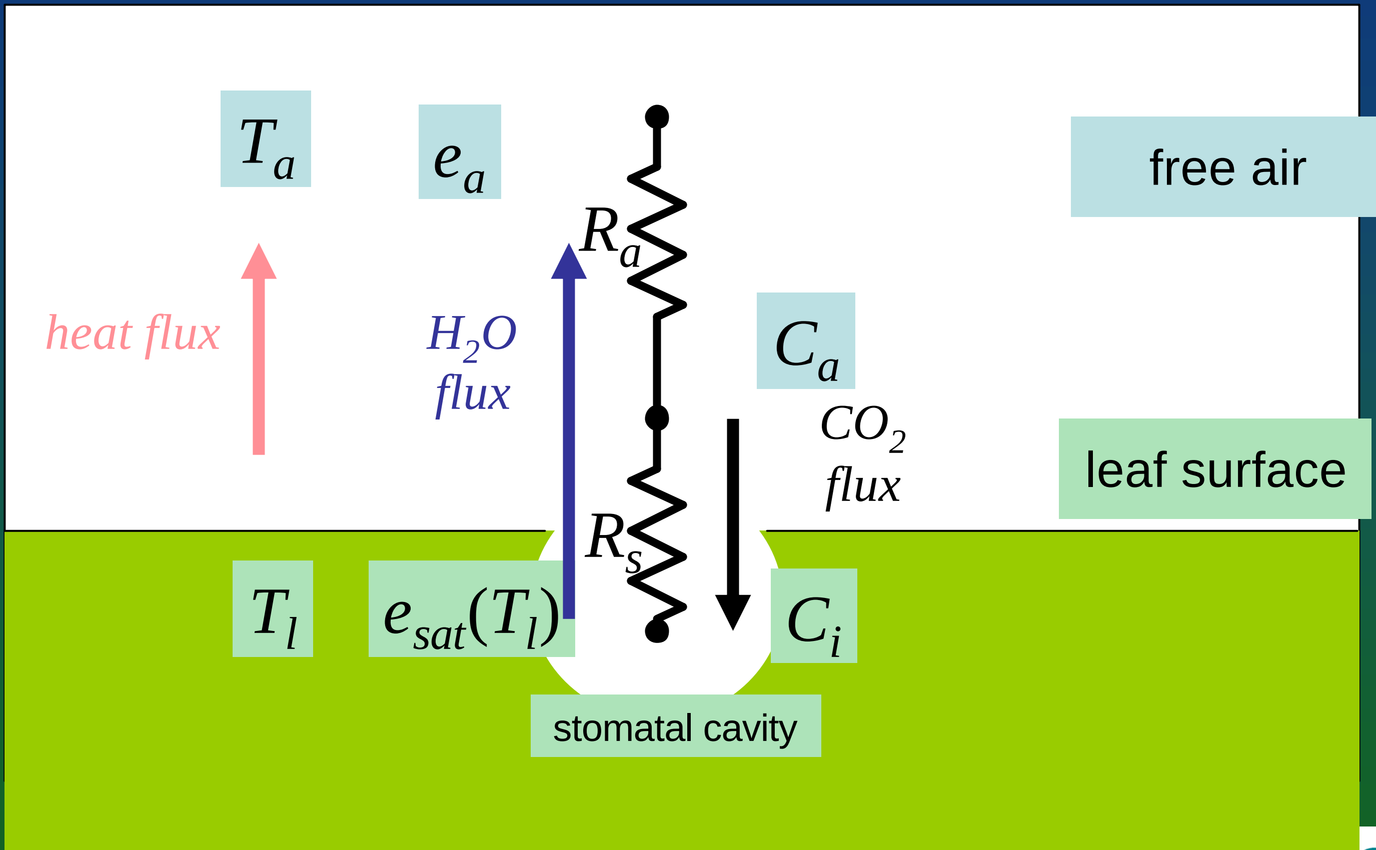
Stomata


T_a
e_a
R_a
free air
heat flux
H_2O flux
C_a
CO_2 flux
leaf surface
R_s
T_l
$e_{sat}(T_l)$
C_i
stomatal cavity

Fluxes & Resistances

sensible heat flux:

$$H = r c_p \frac{T_l - T_a}{R_a}$$

aerodynamic resistance

problem: you don't normally know T_l!

latent heat flux:

$$l E = \frac{r c_p}{g} \frac{e_{sat}(T_l) - e_a}{R_a + R_s}$$

stomatal resistance

CO_2 flux:

$$A_n = \frac{C_a - C_i}{1.6 R_s}$$

Fluxes & Resistances

enter: the radiation balance

problem: you don't normally know T_l!

$$\underbrace{R_s^{\downarrow} + R_s^{\uparrow} + R_J^{\downarrow} + R_J^{\uparrow}}_{R_n} + H + lE = 0$$

and a linear approximation,

$$e_{sat}(T_l) \cong e_{sat}(T_a) + s(T_a)\left(T_l - T_a\right)$$

slope of saturated vapour pressure curve

yields:

$$g\,\left(R_a + R_s\right) l\,E = r\,c_p \left(e_{sat}(T_a) + s(T_a)(T_l - T_a) - e_a\right)$$

Penman-Monteith Formula

$$g\,(R_a + R_s)\,lE = rc_p\left(e_{sat}(T_a) + \frac{sR_a H}{rc_p} - e_a\right)$$

latent heat formula

$$= rc_p\left(e_{sat}(T_a) - sR_a\frac{R_n + lE}{rc_p} - e_a\right)$$

net radiation formula

$$= rc_p\Delta e - sR_aR_n - sR_a\,lE$$

$$\left[g\left(1+\frac{R_s}{R_a}\right)+s\right]lE = rc_p\Delta e/R_a - sR_n$$

$$lE = \frac{rc_p\Delta e/R_a - sR_n}{s + g\left(1+\frac{R_s}{R_a}\right)}$$

opposite sign convention to conventional form

Fluxes & Resistances

sensible heat flux:

$$H = lE - R_n$$

latent heat flux:

$$lE = \frac{rc_p \Delta e / R_a - sR_n}{s + g\left(1 + \frac{R_s}{R_a}\right)}$$

stomatal resistance

problem: need model of stomatal control

Fluxes & Resistances

CO_2 flux:

$$A_n = \frac{C_a - C_i}{1.6 R_s}$$

diffusion

$$C_i = 0.7 C_a$$

reasonable approximation (no water stress)

$$A_n = \min\begin{cases} V_m \dfrac{C_i - \Gamma_*}{C_i + K_C(1 + O/K_O)} \\ \dfrac{a_q J_m I}{\sqrt{J_m^2 + a_q^2 I^2}} \dfrac{C_i - \Gamma_*}{4(C_i + \Gamma_*)} \end{cases} - R_d$$

Farquhar model

Fluxes & Resistances

CO_2 flux:

$$A_n = \frac{C_a - C_i}{1.6 R_s}$$

$$C_i = 0.7 C_a$$

$$A_n = \min \begin{cases} V_m \dfrac{C_i - \Gamma_*}{C_i + K_C (1 + O/K_O)} \\ \dfrac{a_q I J_m}{\sqrt{J_m^2 + a_q^2 I^2}} \dfrac{C_i - \Gamma_*}{4(C_i + \Gamma_*)} \end{cases} - R_d$$

Γ_*: ca. 60ppm

O: Oxygen concentration

K_C, K_O: constants

α_q: photon use efficiency

V_m, J_m: related to leaf N

$$I = \frac{\text{fAPAR} \bullet \text{PAR}}{E_q}$$

E_q: average photon energy

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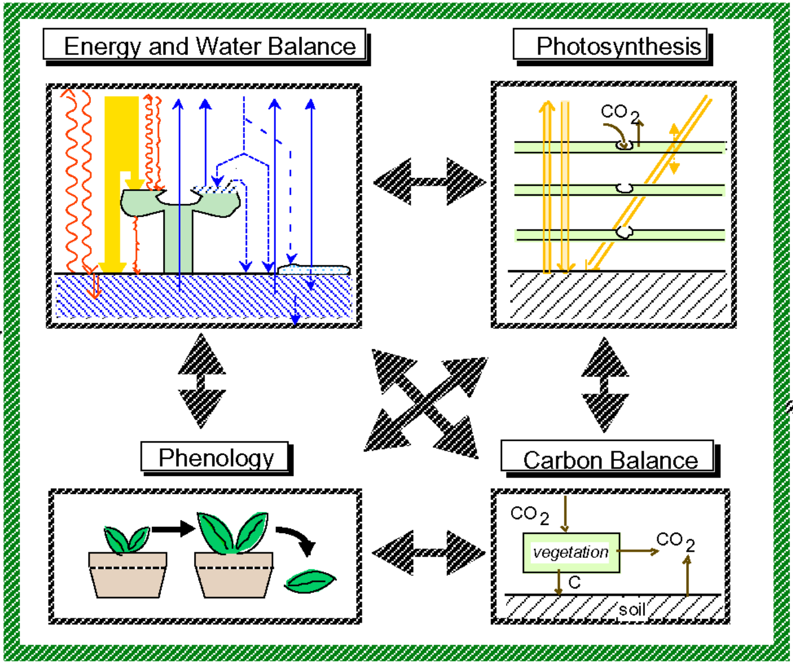
BETHY
(Biosphere Energy-Transfer-Hydrology Scheme)

Input data

monthly:
- temperature
  Cramer & Leemans
- precipitation
  Cramer & Leemans
- solar radiation
  ISCCP

fixed:
- soil type
- atmosph. CO2
- vegetation type
  (unless potential)

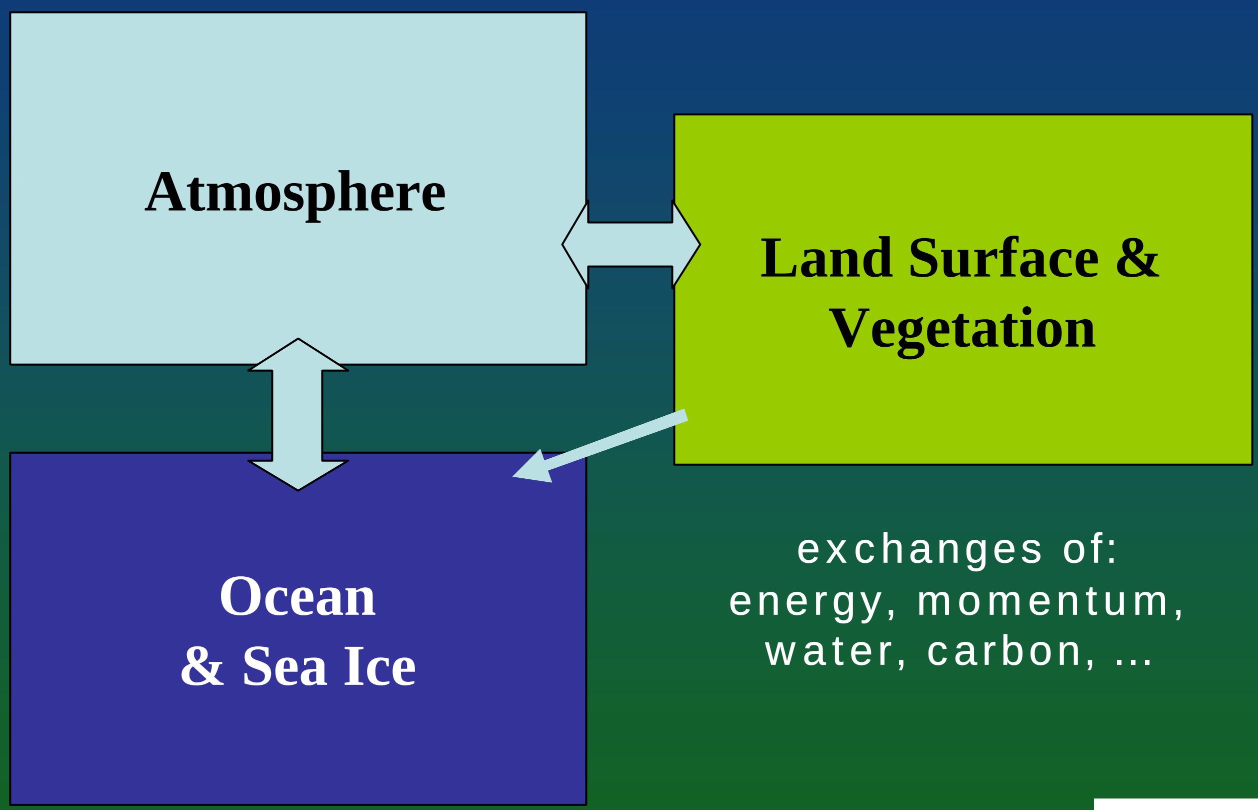


Output data

monthly:
- gross primary productivity
- net primary productivity
- soil respiration
- transpiration
- evaporation
- rainwater runoff
- soil water content
- leaf area index (LAI)

fixed:
- fractional vegetation cover
- vegetation type
  (if potential)

Earth System



exchanges of:
energy, momentum,
water, carbon, ...

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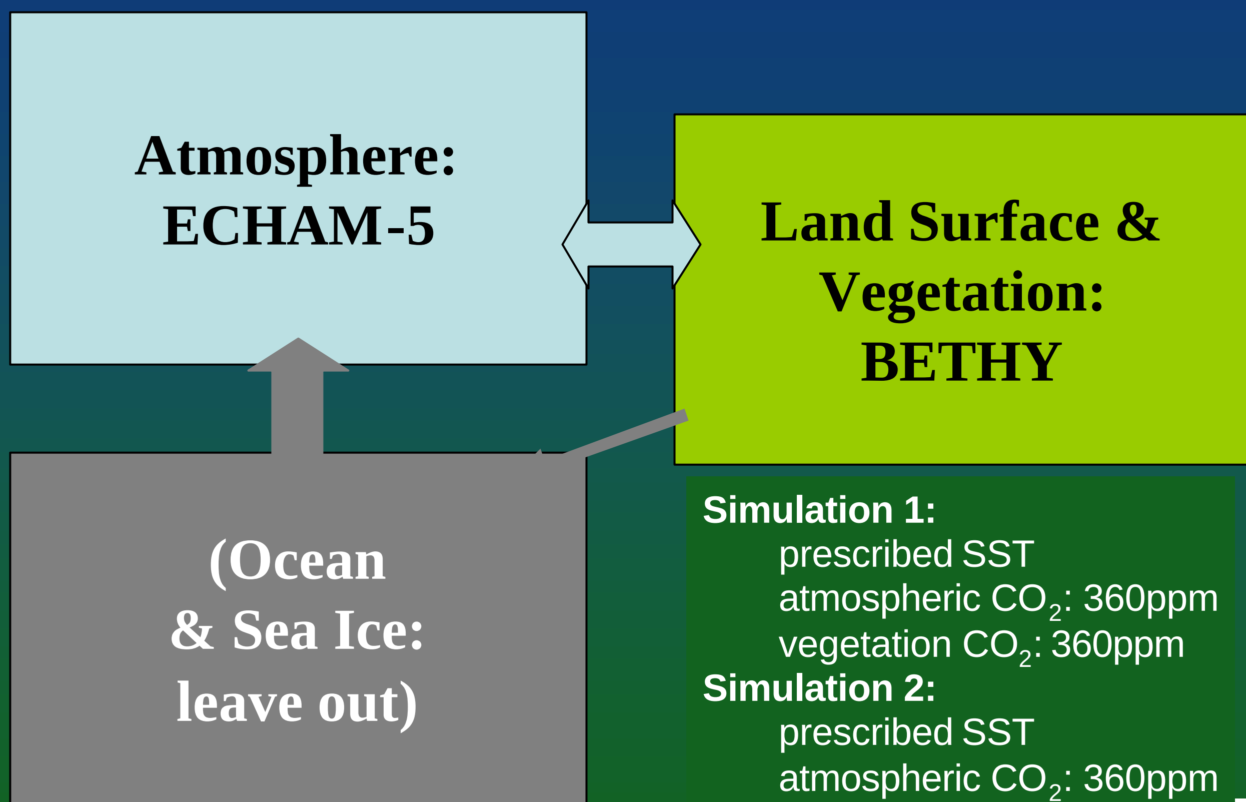
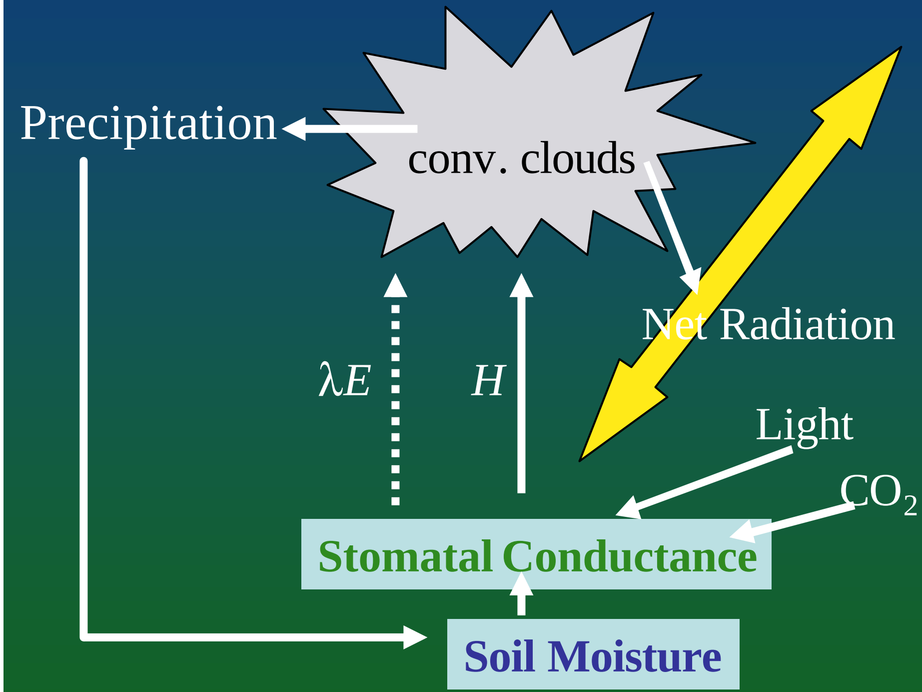
Climate Model "Experiment"



Simulation 1:
- prescribed SST
- atmospheric CO_2: 360ppm
- vegetation CO_2: 360ppm

Simulation 2:
- prescribed SST
- atmospheric CO_2: 360ppm
- vegetation CO_2: 560ppm

Stomatal Response in a Climate Model



- **CO_2** directly acts on canopy resistance
- **Net radiation** ultimately supplies energy for evapotranspiration
- **Soil moisture** storage and **precipitation** feedbacks

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Fluxes & Resistances

CO_2 flux:

$$A_n = \frac{C_a - C_i}{1.6 R_s}$$

decrease

$$C_i = 0.7 C_a$$

$$A_n = \min\begin{cases} V_m \dfrac{C_i - \Gamma_*}{C_i + K_C(1 + O/K_O)} \\ \dfrac{a_q J_m I}{\sqrt{J_m^2 + a_q^2 I^2}} \dfrac{C_i - \Gamma_*}{4(C_i + \Gamma_*)} \end{cases} - R_d$$

Γ_*: ca. 60ppm

O: Oxygen concentration

K_C, K_O: constants

α_q: photon use efficiency

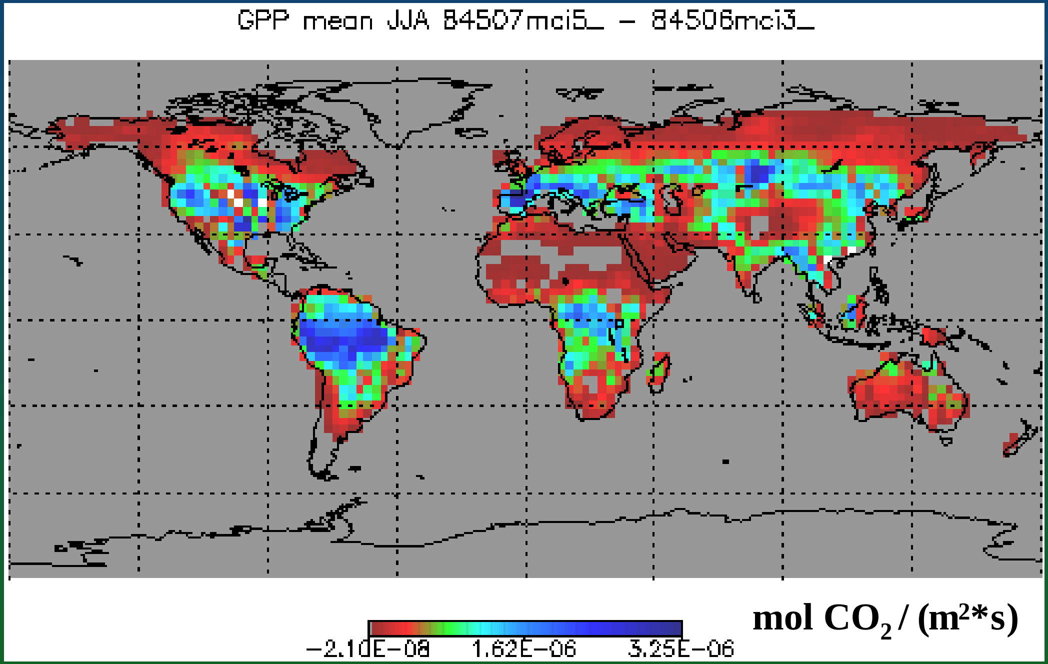
V_m, J_m: related to leaf N

$$I = \frac{\text{fAPAR} \bullet \text{PAR}}{E_q}$$

E_q: average photon energy

ECHAM-5 coupled to BETHY

CO_2-assimilation (GPP): Difference between 360 ppm and 560 ppm (vegetation only)



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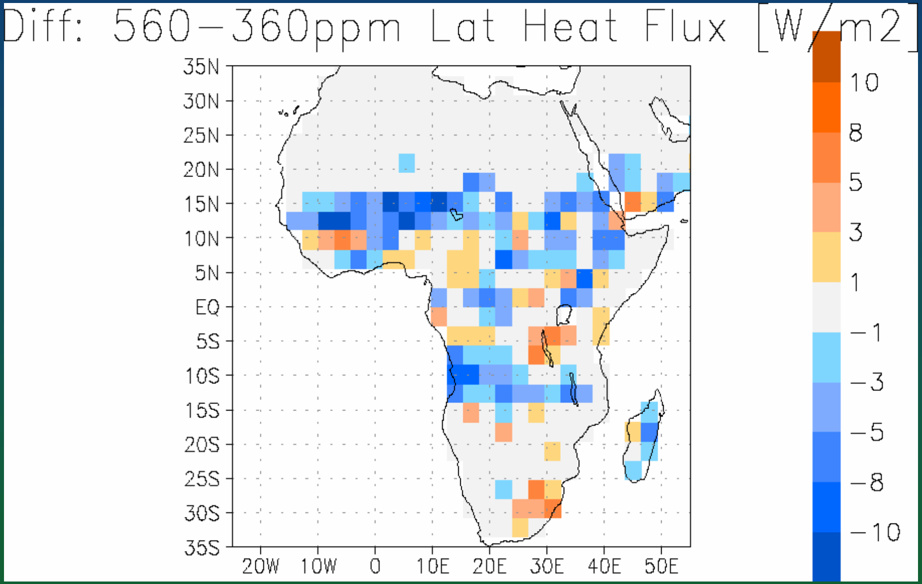
Latent Heat Effect



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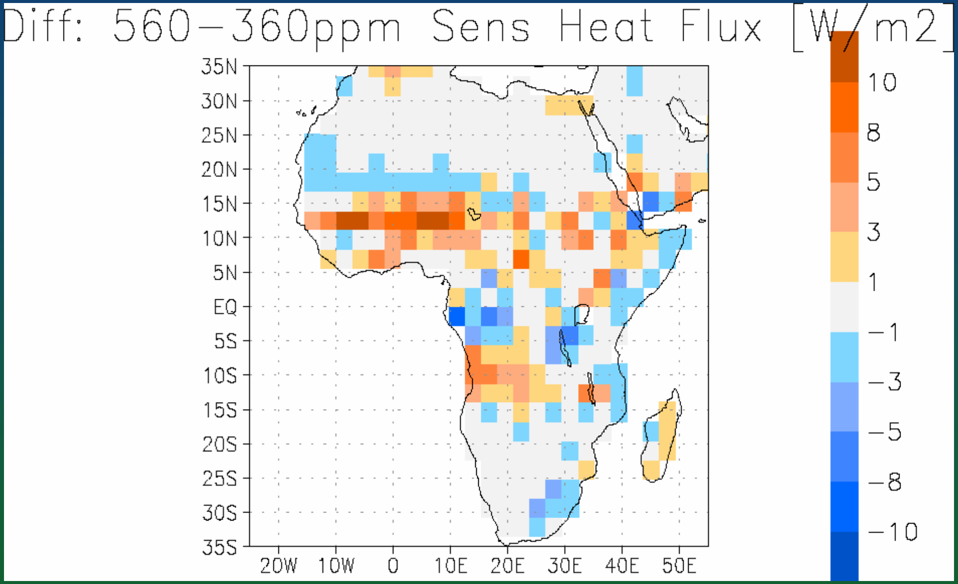
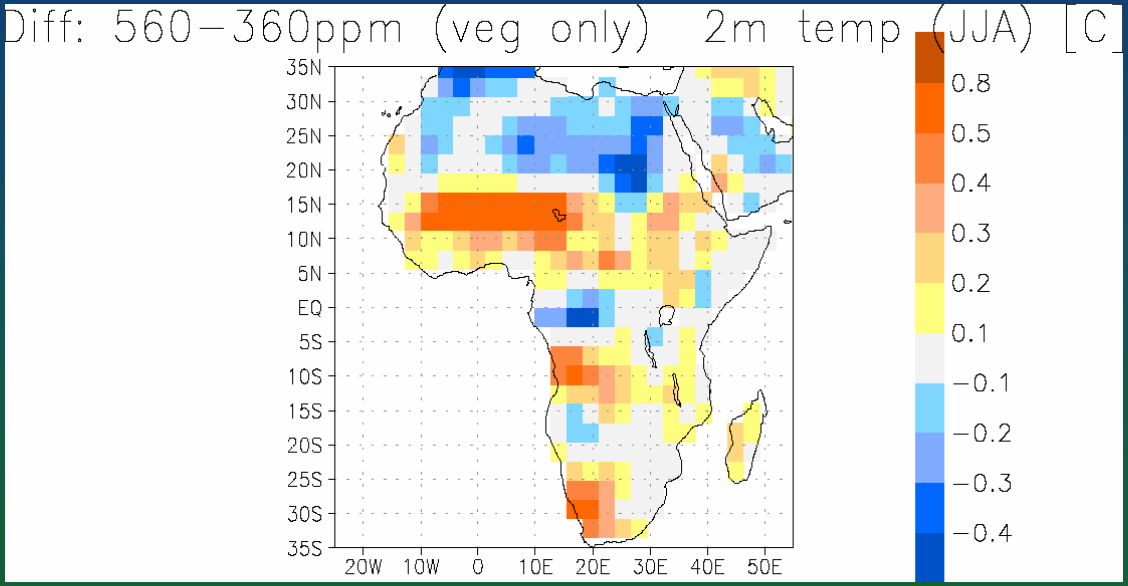
Sensible Heat Effect



Temperature Effect



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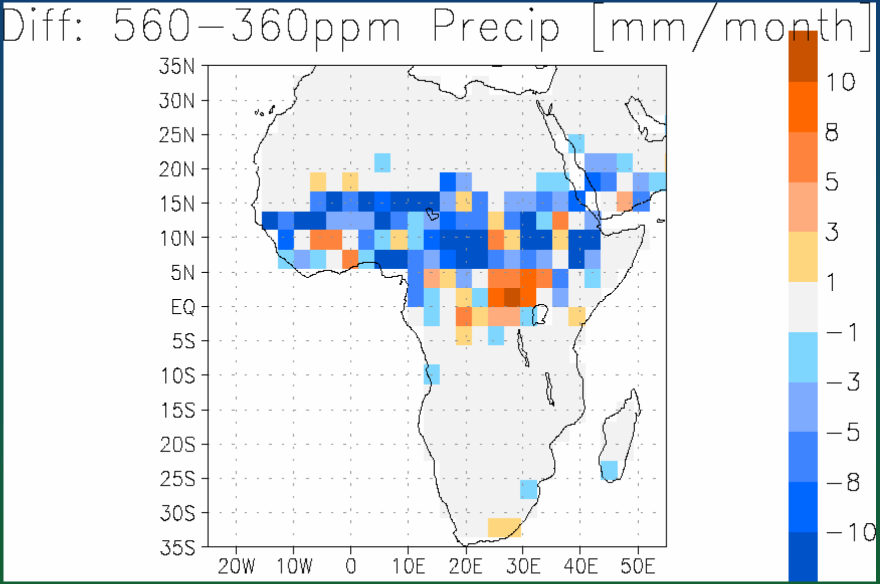
Precipitation Effect



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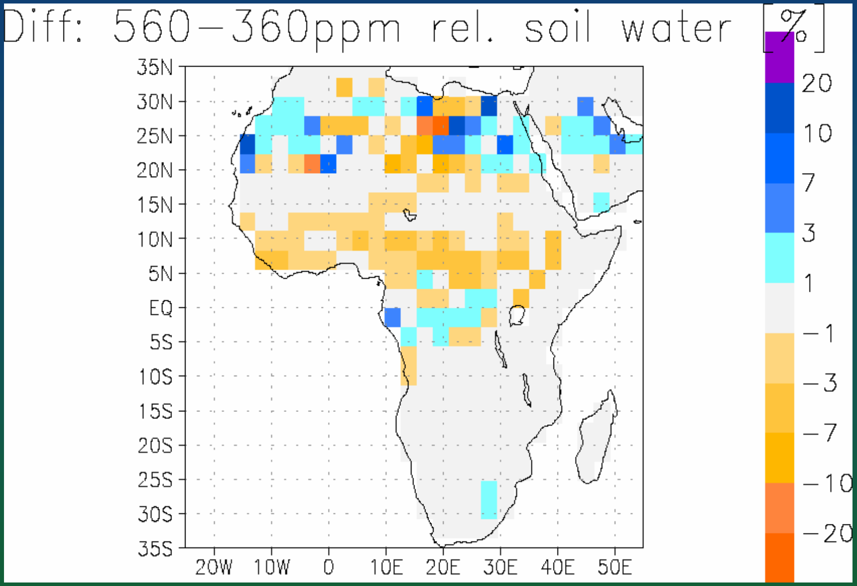
Soil Moisture Effect



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Programme

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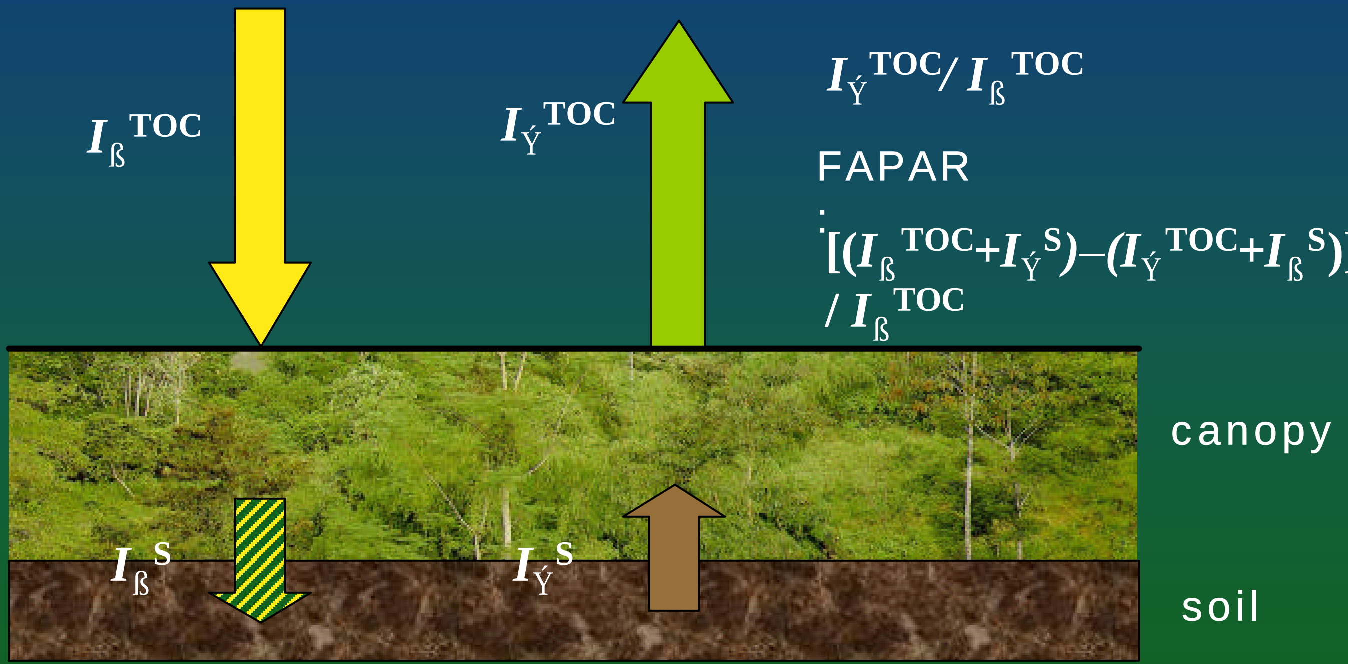
- Example 2: Albedo

Key Remotely Sensed Variables



albedo:

$I_{Ý}^{TOC} / I_{ß}^{TOC}$

FAPAR:

$[(I_{ß}^{TOC}+I_{Ý}^{S})-(I_{Ý}^{TOC}+I_{ß}^{S})] / I_{ß}^{TOC}$

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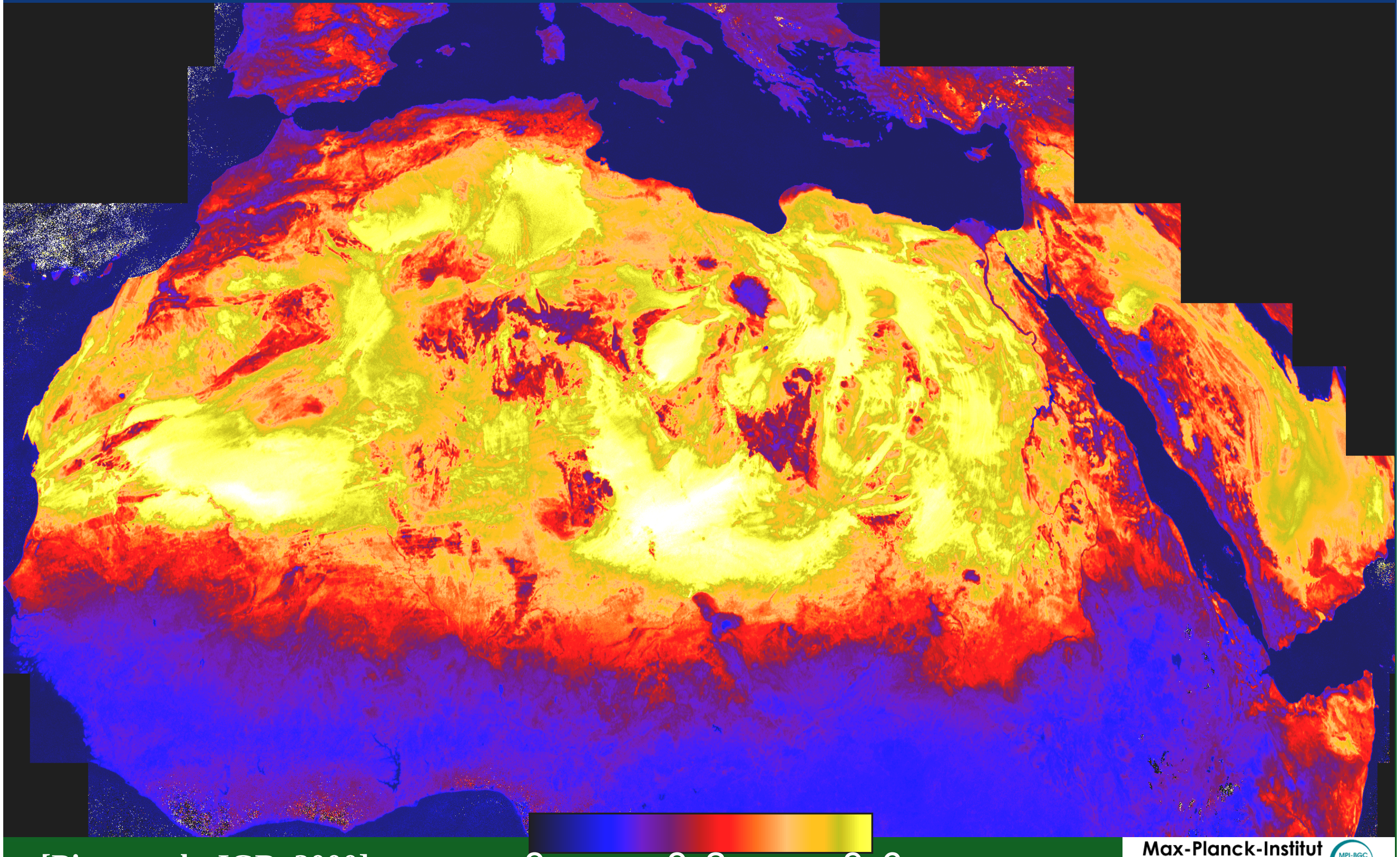
Meteosat Surface Albedo



[Pinty et al., JGR, 2000]

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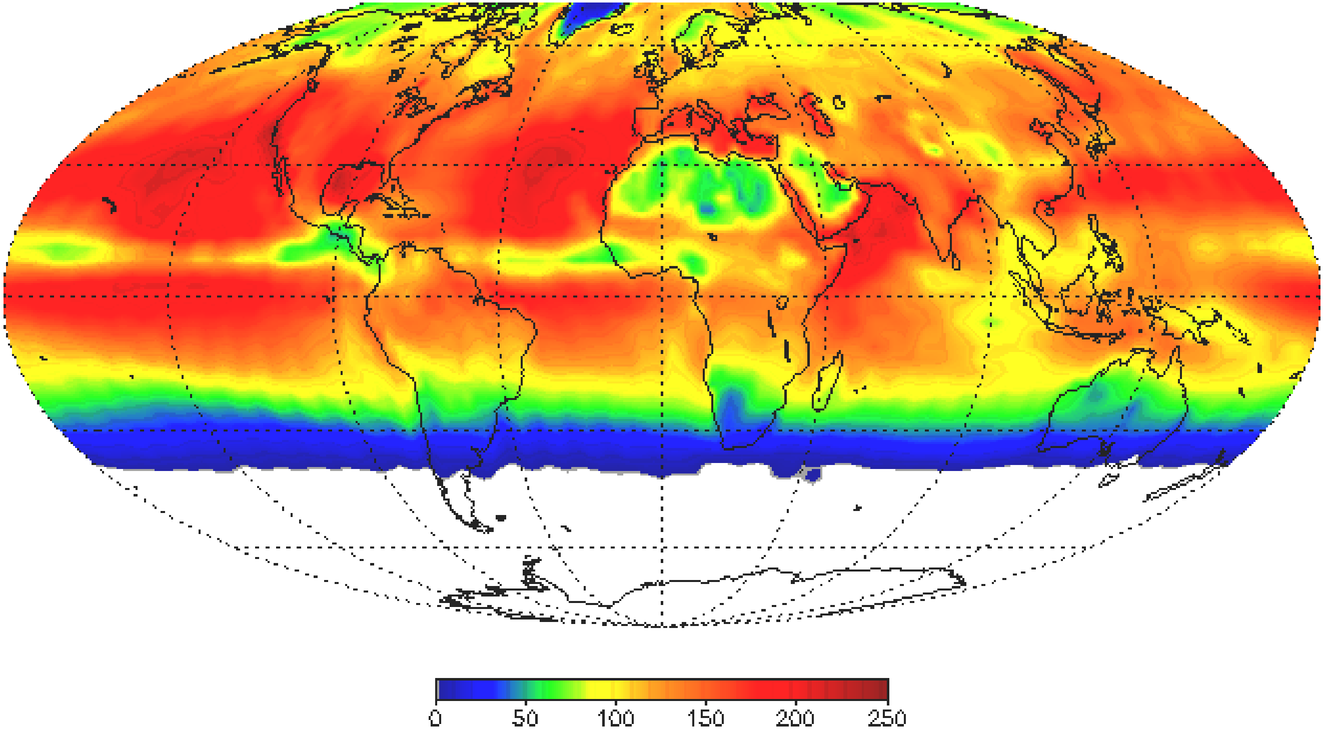
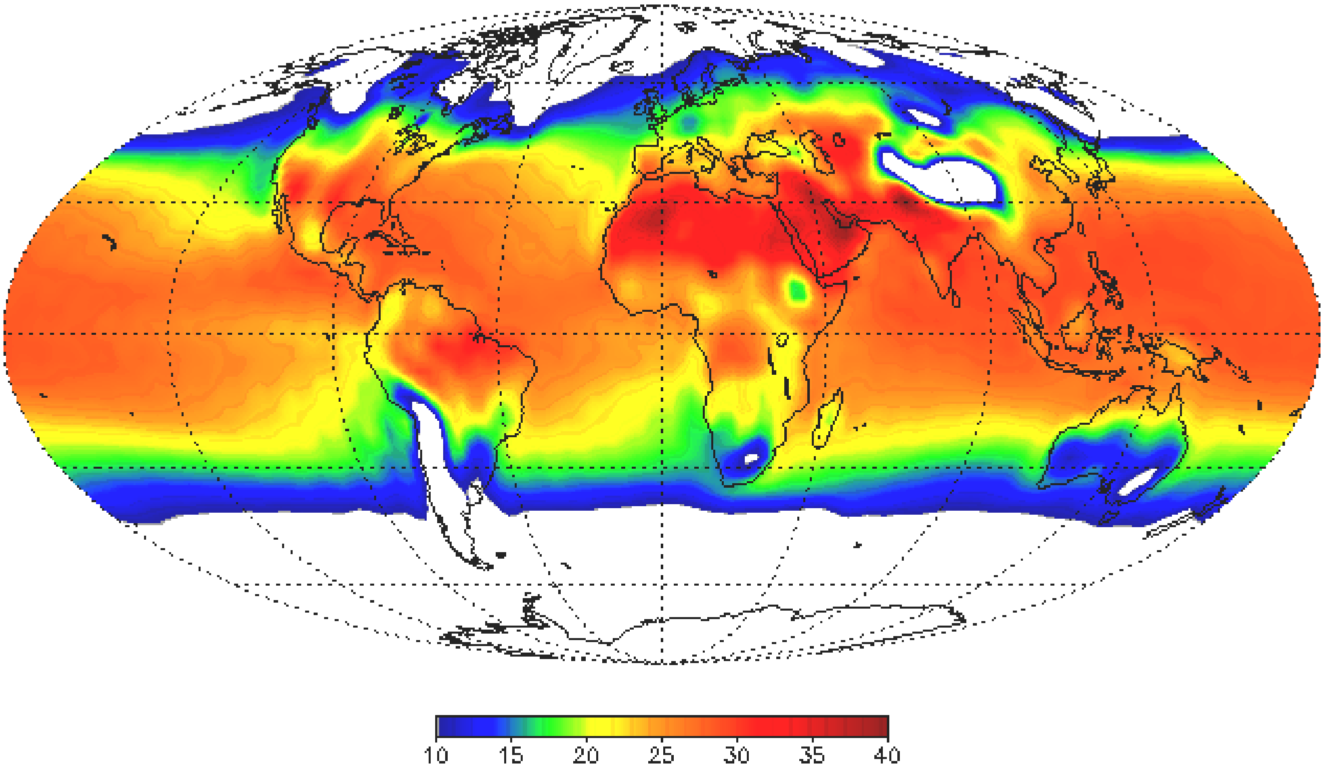
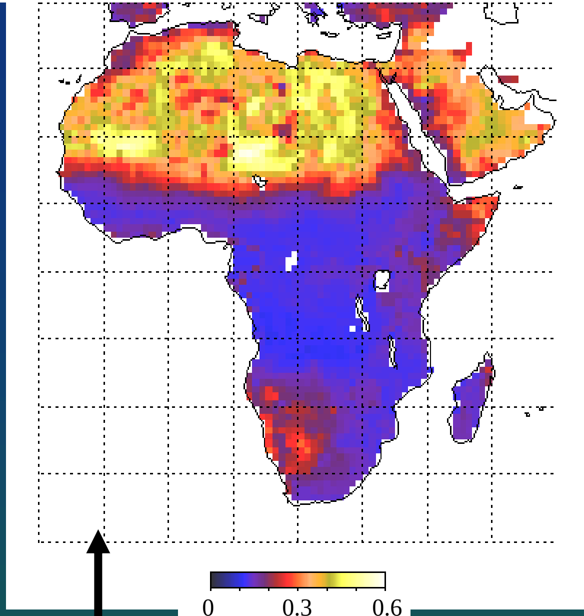
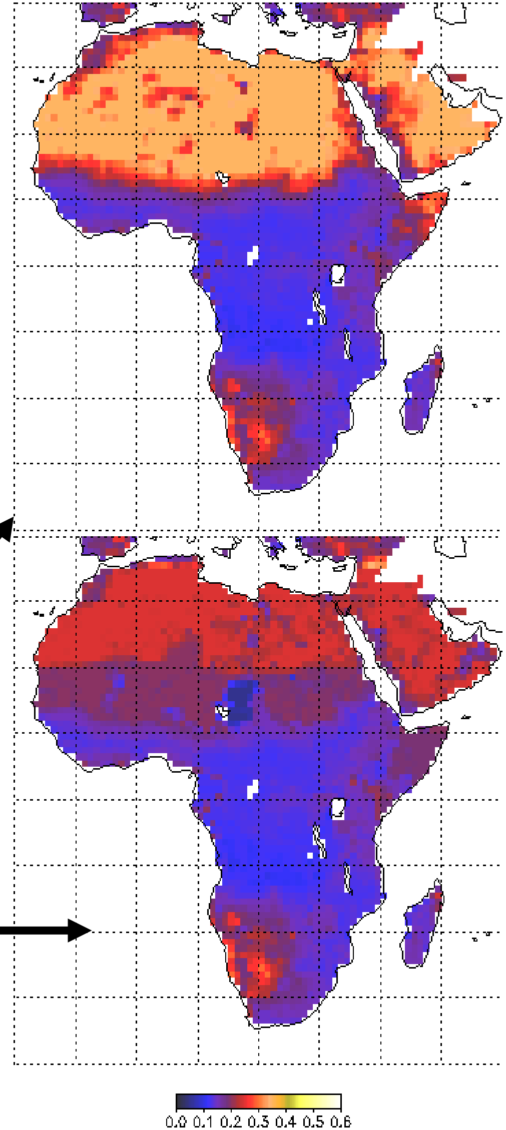
June-August Surface Net Radiation Balance [W/m^2]



June-August 2m Temperature [°C]







3 Climate Model Simulations

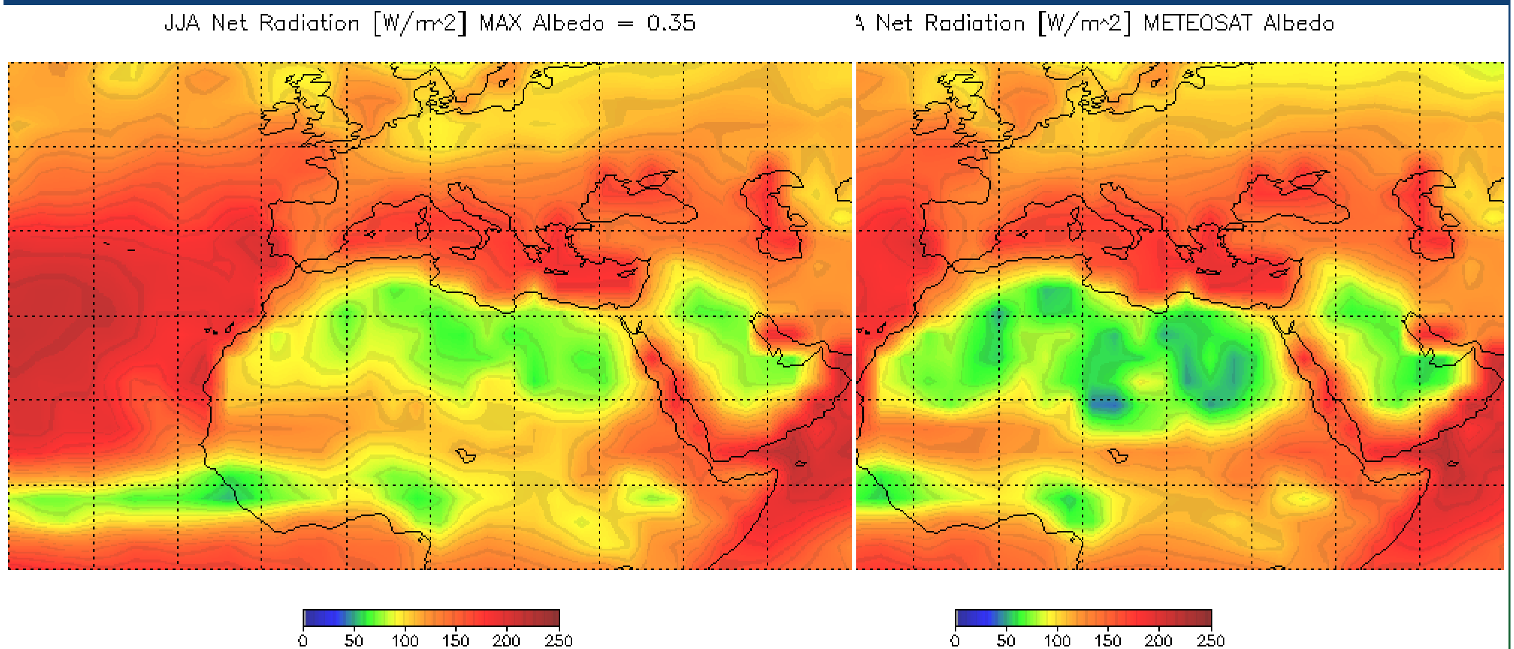
(1) Meteosat Albedo

(2) Albedo = 0.35

(3) Albedo 6000 yr BP

+ climat. SST, modern insolation

June-July-August Net Surface Radiation [W/m²]



Albedo = 0.35

ECHAM4
obs. SST

Meteosat Albedo

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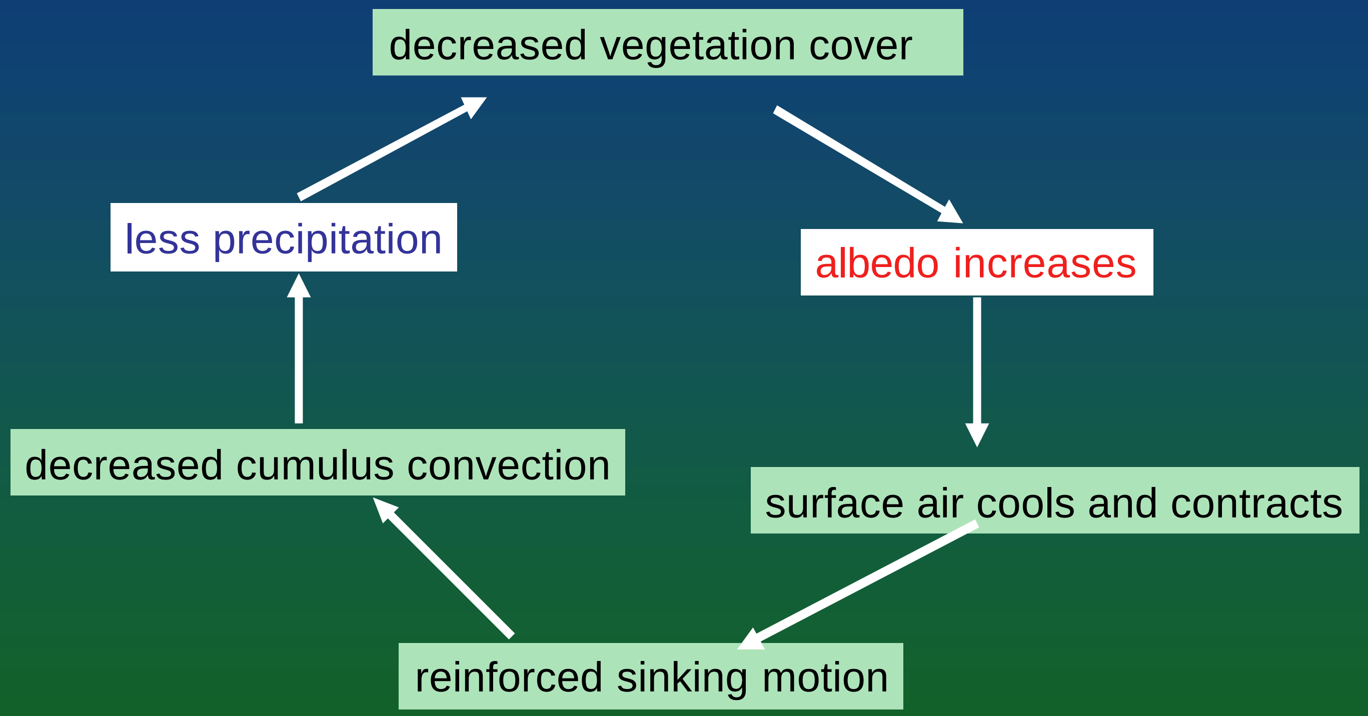
Charney's Feedback Loop



Charney et al. 1975, Drought in the Sahara: A biogeophysical feedback mechanism. *Science*, 187, 434-435.

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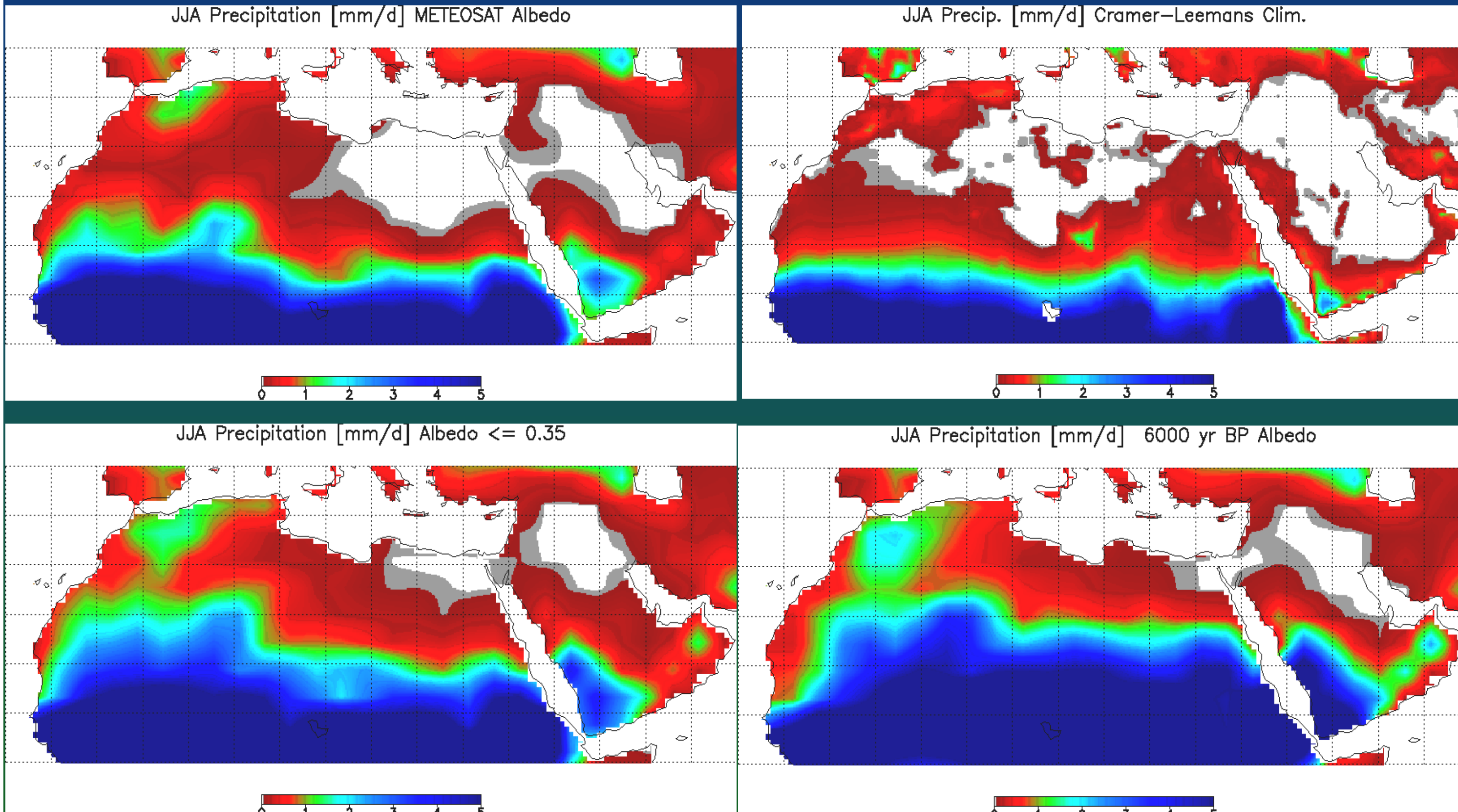
Energy and Water Balance of Sahara

Longitidude from to:	9.8°W	35.2°E	
Latidude from to:	14.1°N	30.9°N	
Sahara	ECHAM4 with Albedo from:		
June to August	METEOSAT	conventional	6000 yr BP
Albedo:	0.38	0.33	0.22
Incident shortwave radiation:	293	273	252
Outgoing shortwave radiation:	-112	-91	-55
Net shortwave radiation:	180	182	196
Atmospheric radiation:	398	404	412
Outgoing thermal radiation:	-501	-497	-499
Net thermal radiation:	-103	-92	-86
Net radiation:	76	90	109
Sensible heat flux:	-44	-45	-51
Latent heat flux:	-18	-33	-50
Evapotranspiration:	20	36	54
Precipitation:	25	47	78
Observed precipitation:	22		
Energy fluxes in W/m ^{2}, water balance in mm/month.			
"Conventional" means maximum desert albedo of 0.35.			

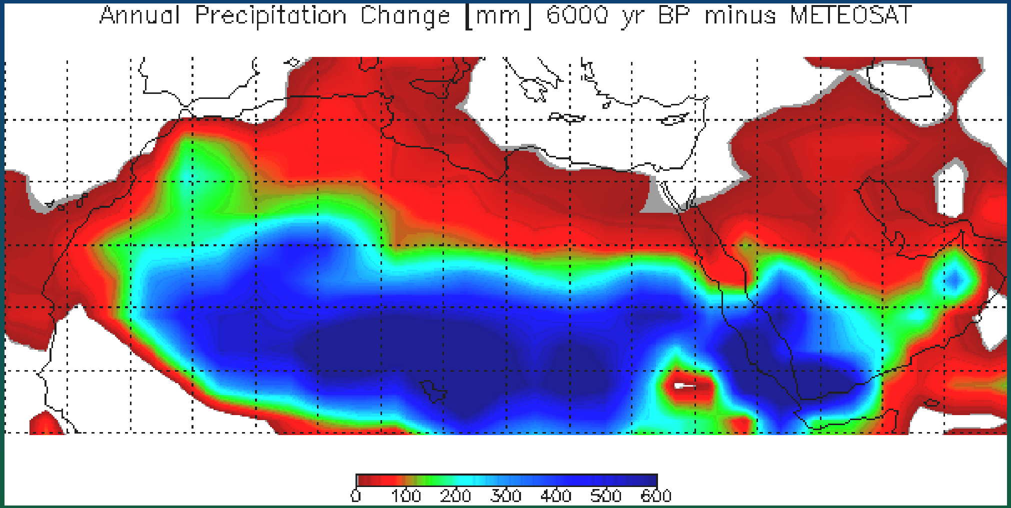
June-August Precipitation

METEOSAT albedo | **Observed precipitation**



Conventional Albedo | **Reconstructed Albedo 6000 yr BP**

Annual Precipitation Change
6000 yr BP minus today [mm]



Next Lecture:

- Assimilation of satellite data into a land surface model

... see you there!

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