Dynamical versus Land-Surface Factors in the African Monsoon

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- **Dynamical and land-surface factors in summer monsoon climatology**
- **Contrast of N. Amer. and Asian cases with African case**
  - ❖ **Experiments in an intermediate complexity model**
- **The question of land-surface feedbacks in teleconnected SST impacts in interannual-interdecadal variability**

Climate Systems Interactions Group

http://www.atmos.ucla.edu/~csi

Factors in summer monsoon extent

- **Thermodynamic:**
  - positive net flux (Rad + SH + Latent) into atmospheric column = TOA over land
- **Land-Surface processes:**
  - Albedo
  - Soil wetness/ evapotranspiration
- **Ocean heat storage and transport**

- **Dynamic:**
  - "ventilation mechanism"
    - $v \cdot \nabla(q + T)$ importing low moist static energy air
  - wave dynamics
    - Kelvinoid
    - Rossby-related "interactive Rodwell-Hoskins" mechanism

Temperature *T* and Moisture *q* equations

dry static energy $s = T + \phi$

$$(\partial_t + \mathbf{v} \bullet \nabla)T + \omega\partial_p s - \partial_p R + \partial_p S - \partial_p F_{SH} = Q_c$$

convective heating

vertical velocity

Fluxes: longwave radiation(R), solar(S) sensible(SH), latent heat(L)

$$(\partial_t + \mathbf{v} \bullet \nabla)q + \omega\partial_p q - \partial_p F_L = Q_q$$

moisture source/sink

Energy constraint in vertical integral ⟨ ⟩

$$\langle Q_c \rangle = -\langle Q_q \rangle$$

⟨Moist static energy equation⟩

$$\langle(\partial_t + \mathbf{v} \bullet \nabla)(T + q)\rangle + \langle\omega\partial_p h\rangle - F_{net} = 0$$

Transport of moist static energy by divergent flow
≈ (measure of divergence)
x gross moist stability

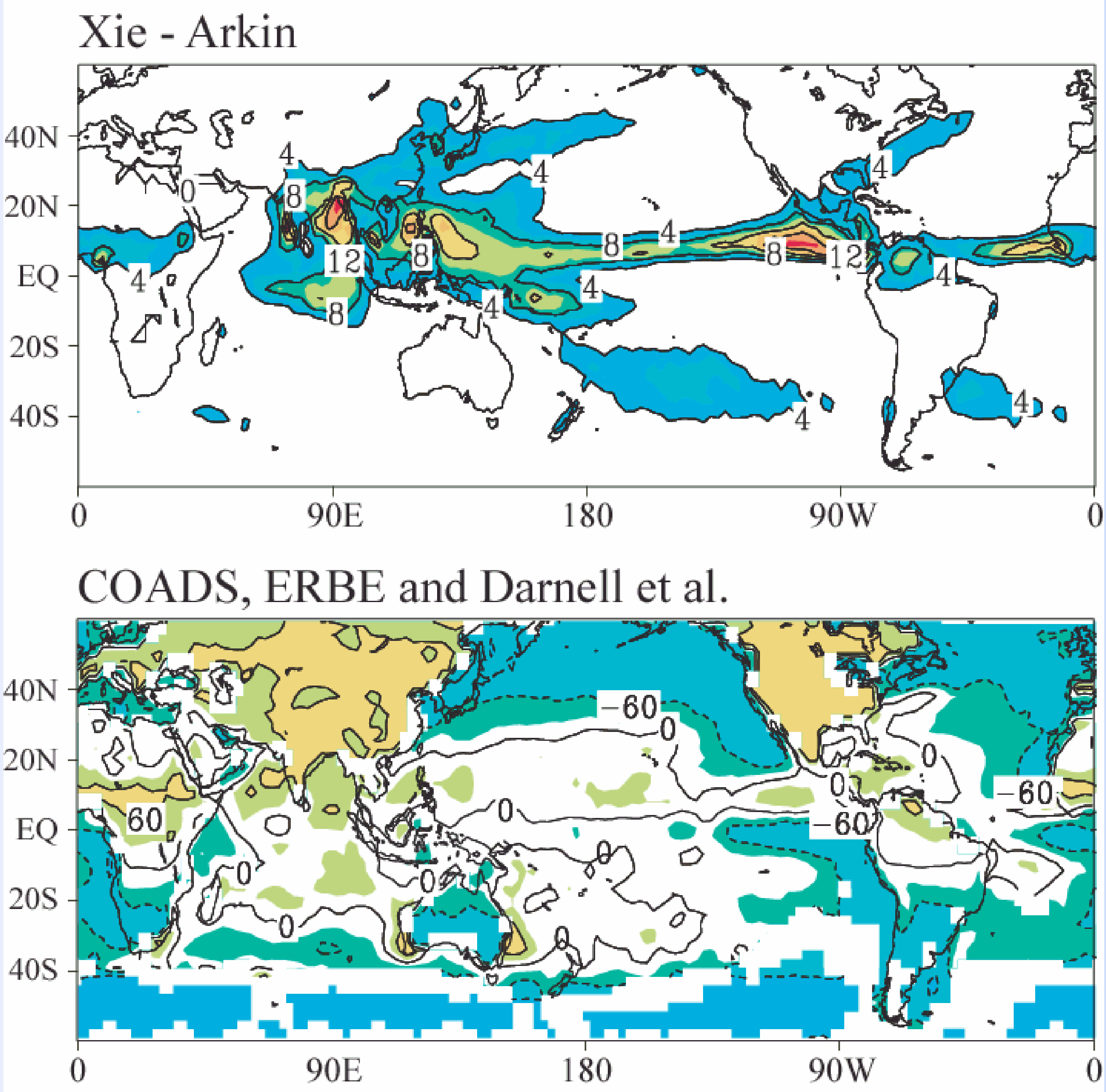
Net energy flux into column

Moist static energy $h = s + q$

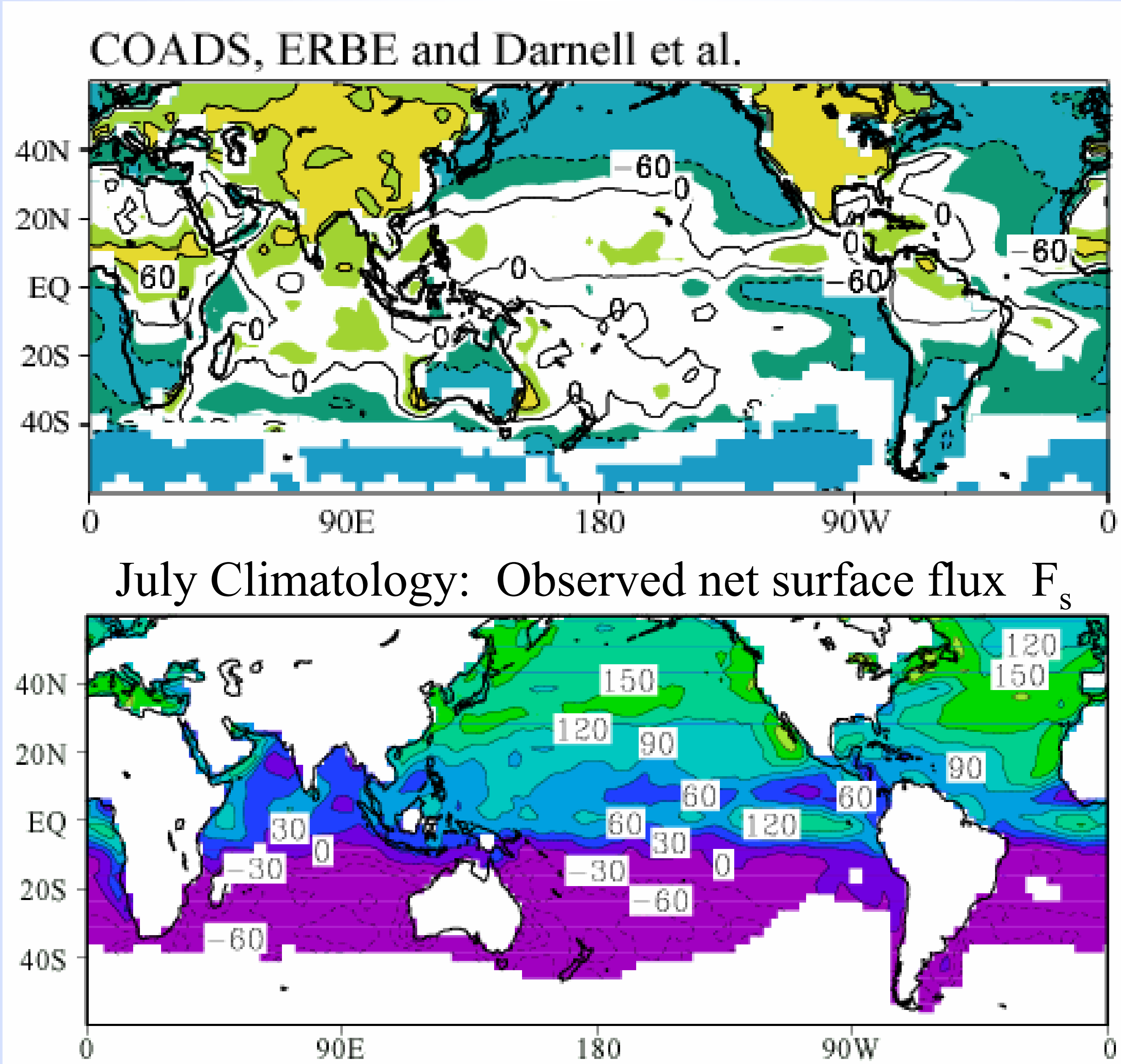
Observed climatology July

Precipitation

Net Flux into the atmosphere



Observed net flux into atmosphere and net surface flux



The "ventilation mechanism"

- import of low moist static energy air from ocean where heat storage opposes summer warming
- oceanic air: cooler and moisture is lower than convection threshold over warm continent
- import to continents by wind (including upper level jets) via advection terms in temperature and moisture equations

Chou, Neelin and Su 2001

The "interactive Rodwell-Hoskins mechanism"

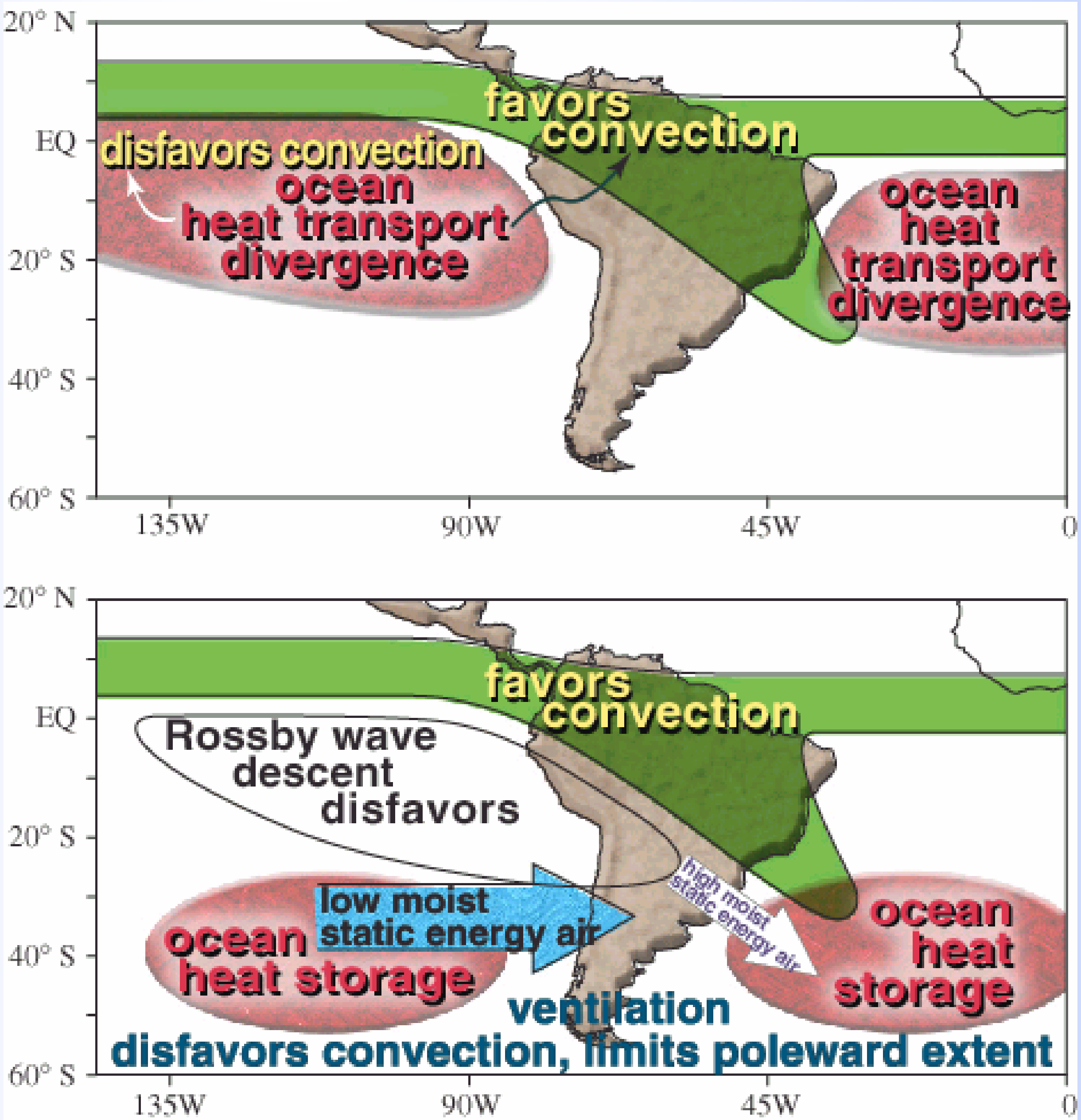
- Rodwell and Hoskins (1996): imposed convective heating in Asia gives Rossby wave descent pattern to west, enhancing deserts.
- when convection is interactive: associated flow feeds back on heating, creating characteristic convection/dry region pattern
  - » we emphasize feedback (convection ⇔ baroclinic Rossby wave dynamics), hence:
  - » "interactive Rodwell-Hoskins" (IRH) mechanism

Chou, Neelin and Su 2001

Mechanisms affecting convective zones (S. American case)

Ocean heat transport out of the tropics

Ventilation and the interactive Rodwell-Hoskins mechanism



After Chou and Neelin 2001

Quasi-equilibrium Tropical circulation model:

- Primitive equations projected onto vertical basis functions from convective quasi-equilibrium analytical solutions
- for Betts-Miller (1986) convective scheme, accurate vertical structure in deep convective regions for low vertical resolution
- GCM-like parameters but easier to analyze

Radiation/cloud parameterization:

- Longwave and shortwave schemes simplified from GCM schemes (Harshvardhan et al. 1987, Fu and Liou 1993)
- deep convective cloud, CsCc fraction param. on precip

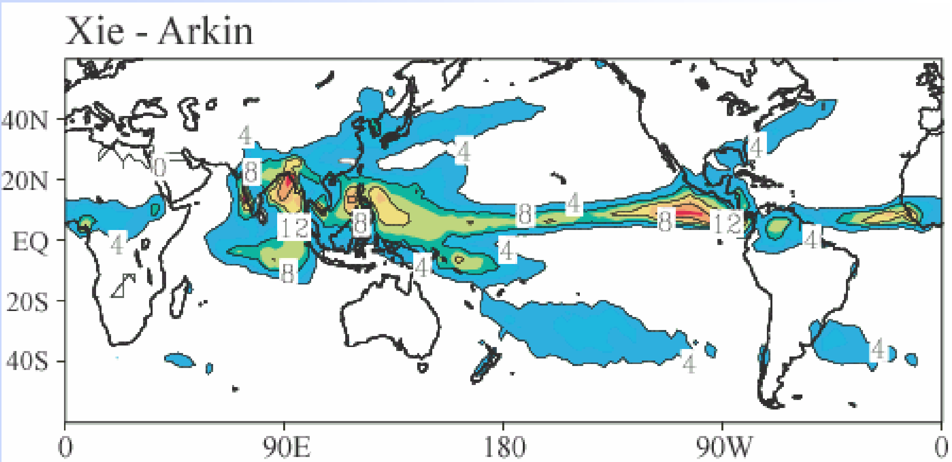
Simple land model:

- 1 soil moisture layer; evapotranspiration with stomatal/root resistance dep. on surface type (e.g., forest, desert, grassland)
- low heat capacity; Darnell et al 1992 albedo

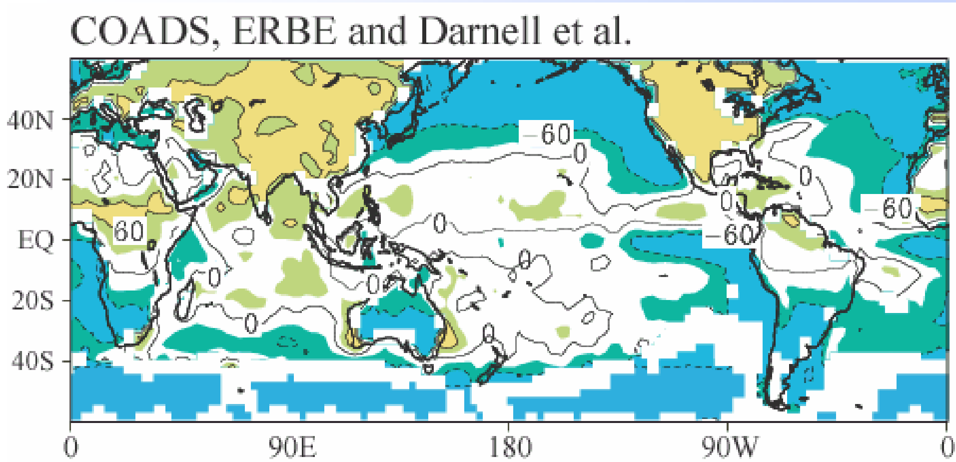
- http://www.atmos.ucla.edu/~csi/QTCM

Observed climatology July

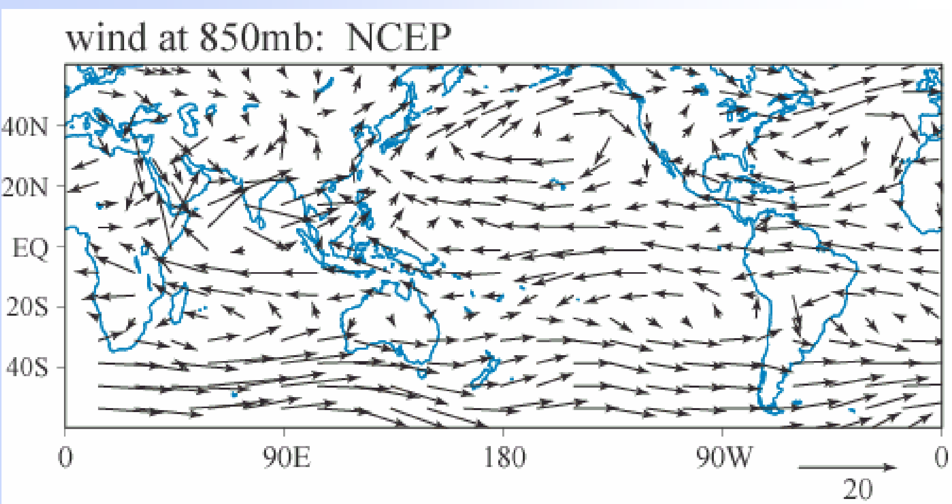
Precipitation



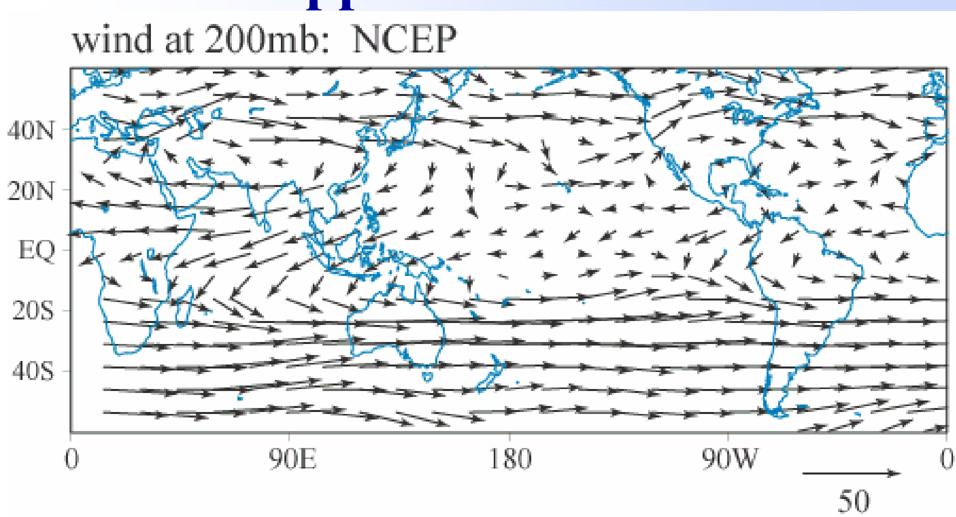
Net flux into atmosphere



Low-level wind

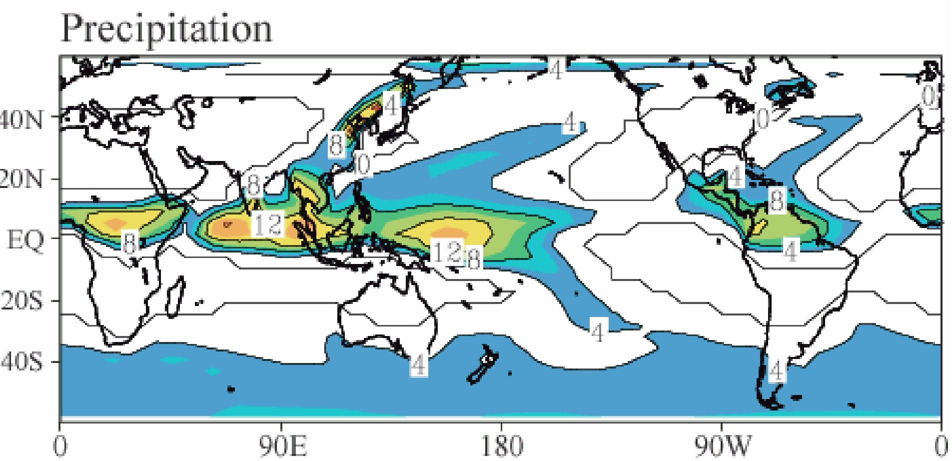


Upper-level wind

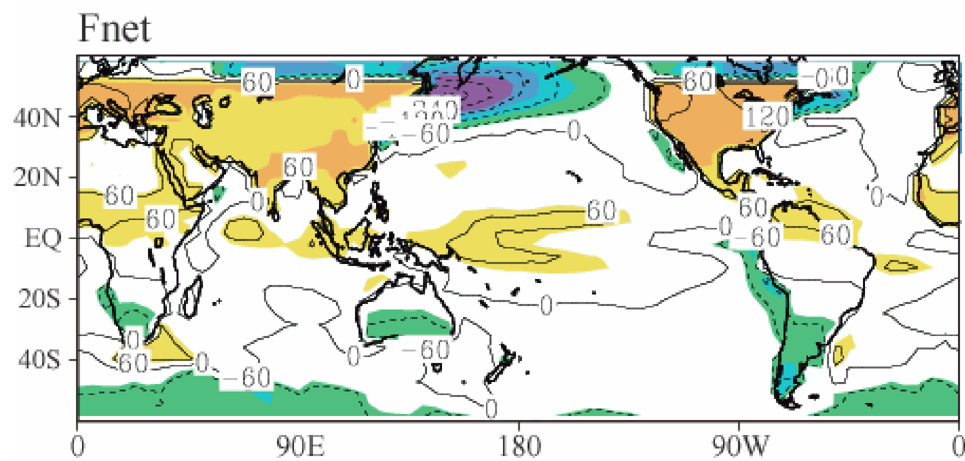


QTCM climatology July
(coupled to a mixed-layer ocean)

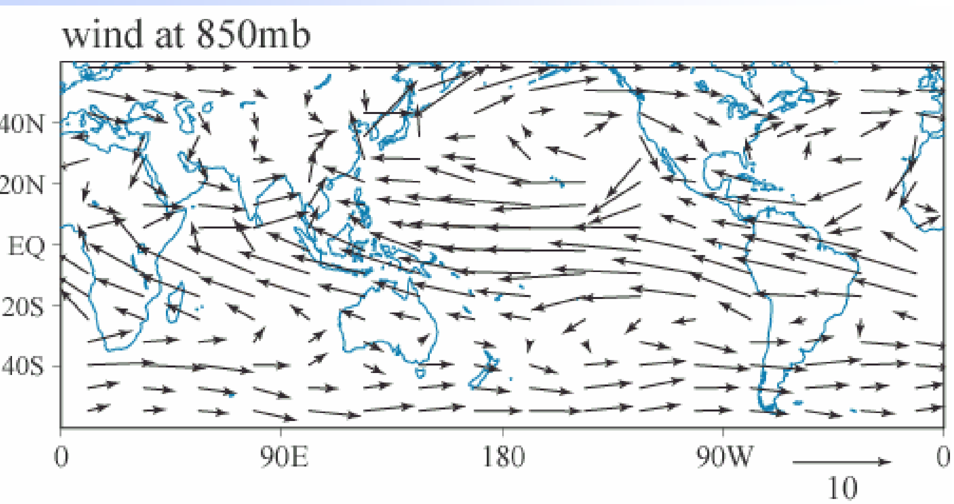
Precipitation



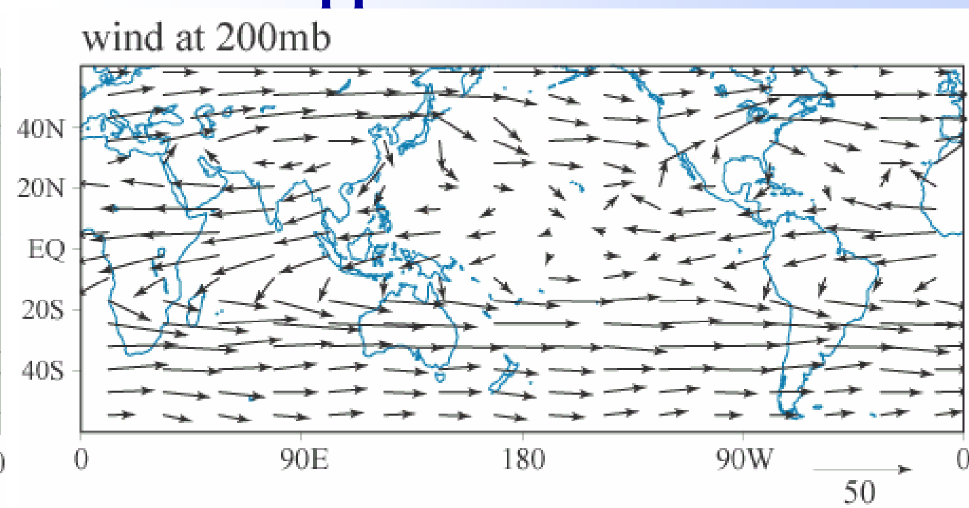
Net flux into atmosphere



Low-level wind



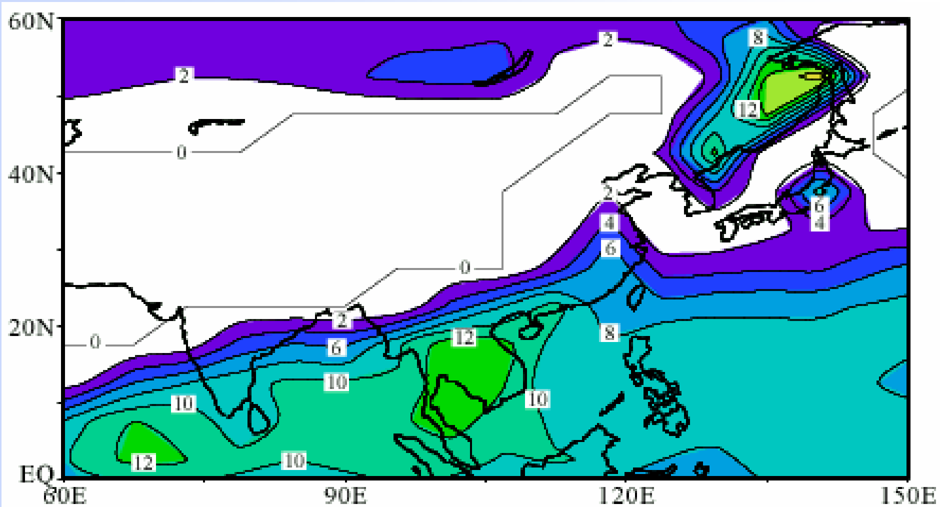
Upper-level wind



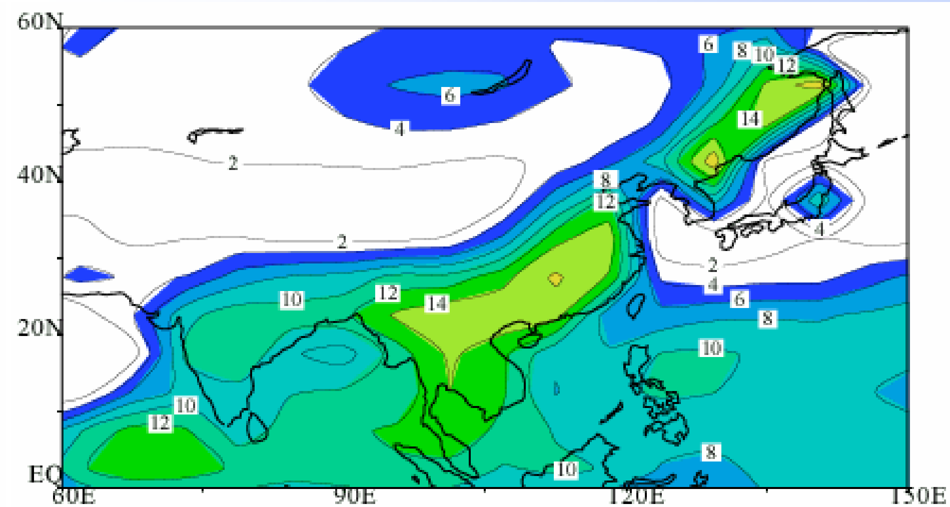
Asian region case – July

Precipitation

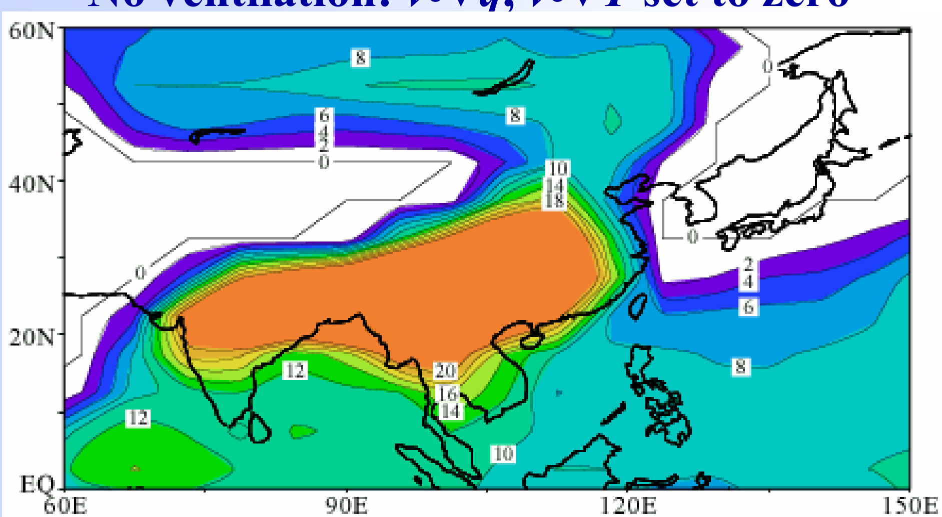
Control



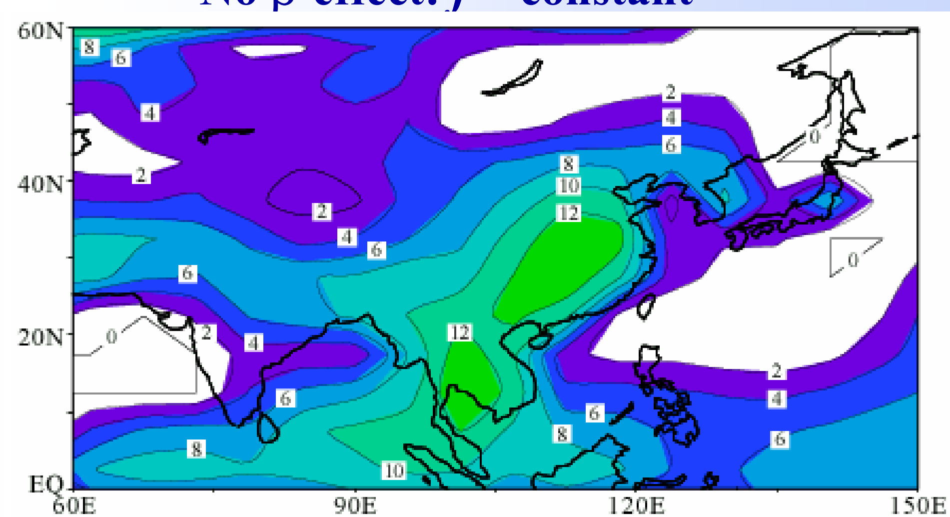
Saturated soil moisture



No ventilation: $v \bullet \nabla q$, $v \bullet \nabla T$ set to zero



No β-effect: f = constant

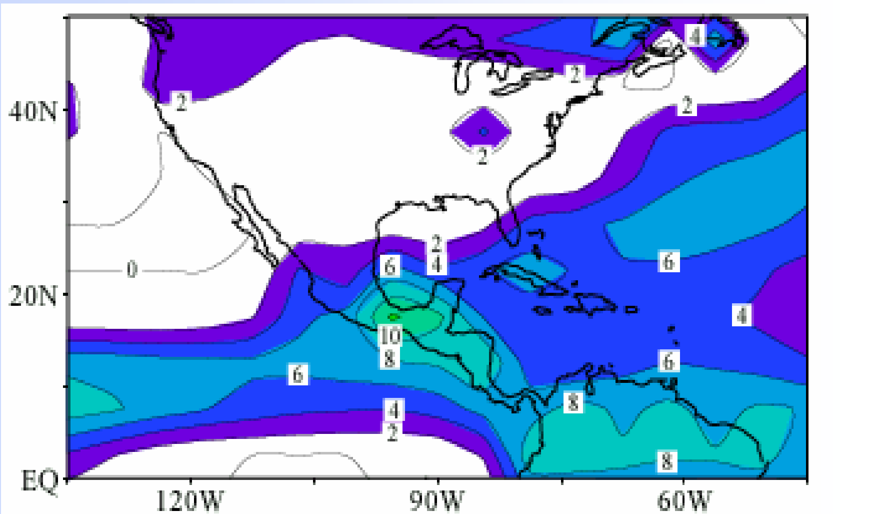


Chou and Neelin 2003

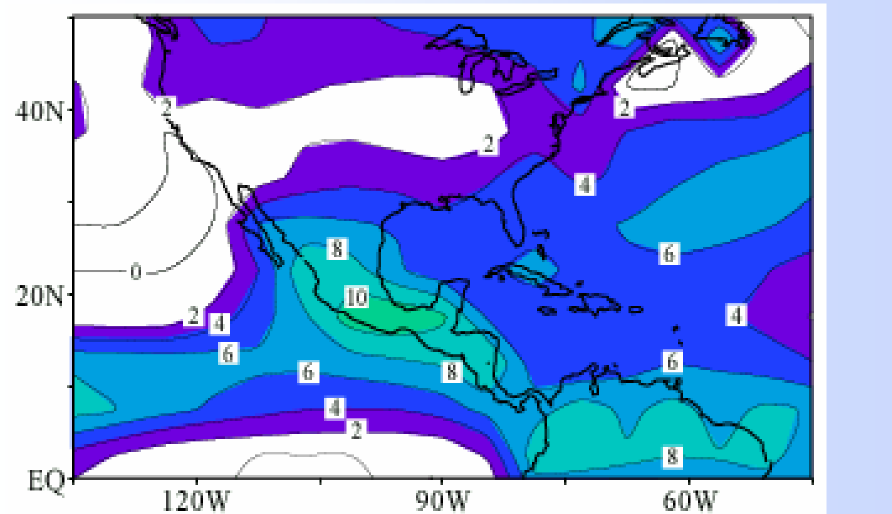
North American region case

July Precipitation

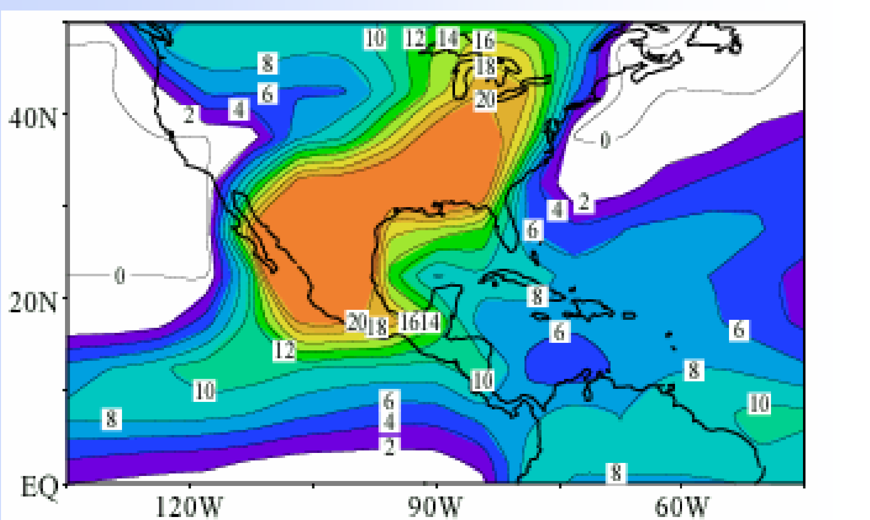
Control



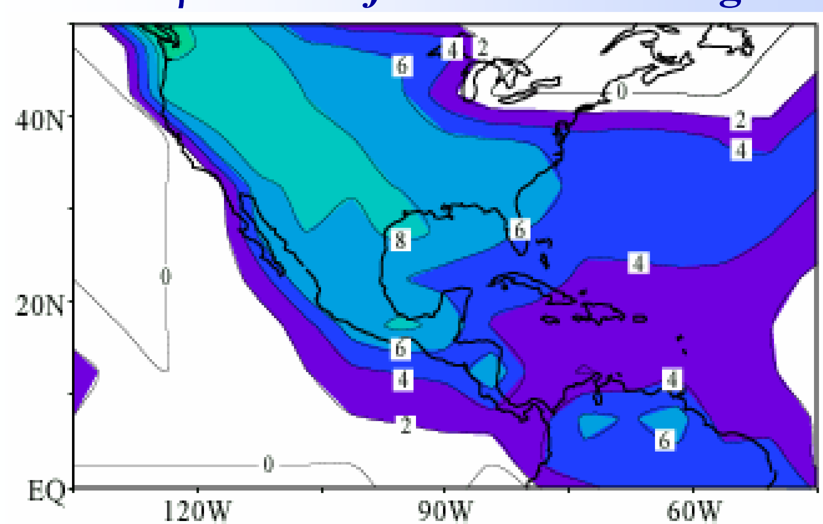
Saturated soil moisture



No ventilation: $v \bullet \nabla q$, $v \bullet \nabla T$ set to zero



No β-effect: f = constant in region

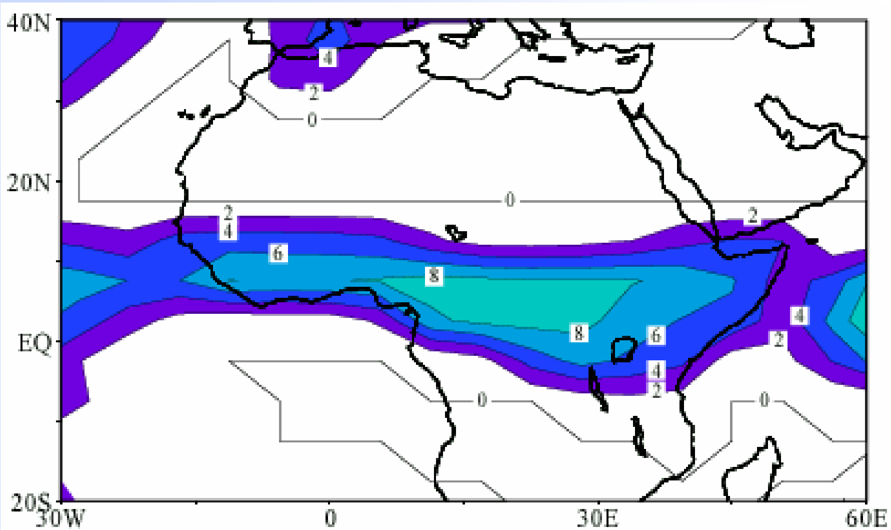


Chou and Neelin 2003

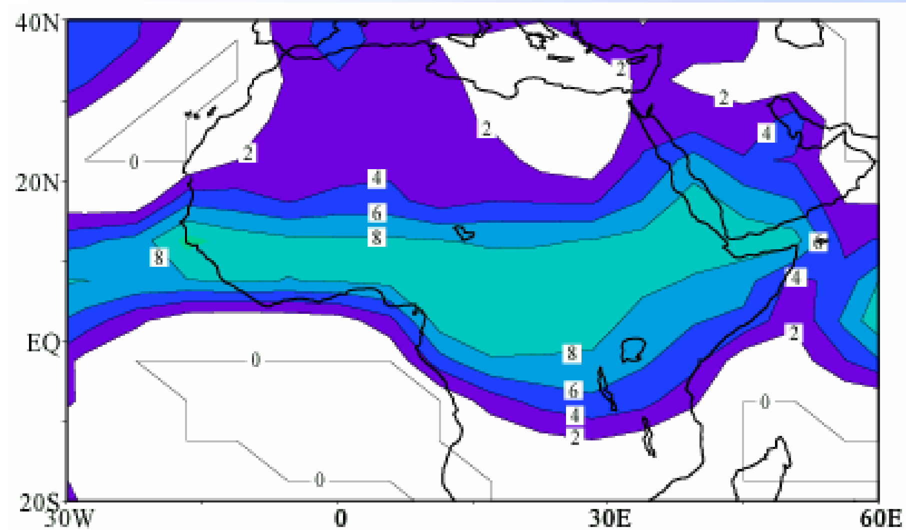
African region case (observed albedo) July

Precipitation

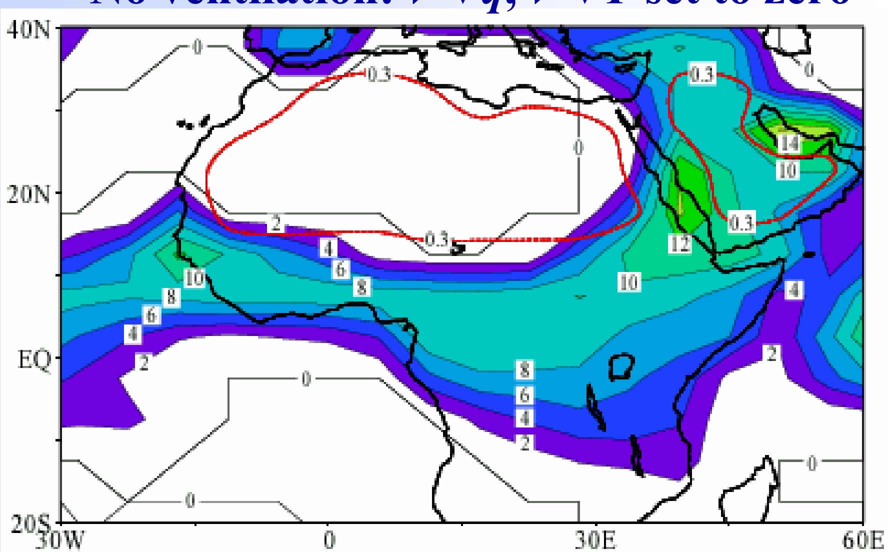
Control



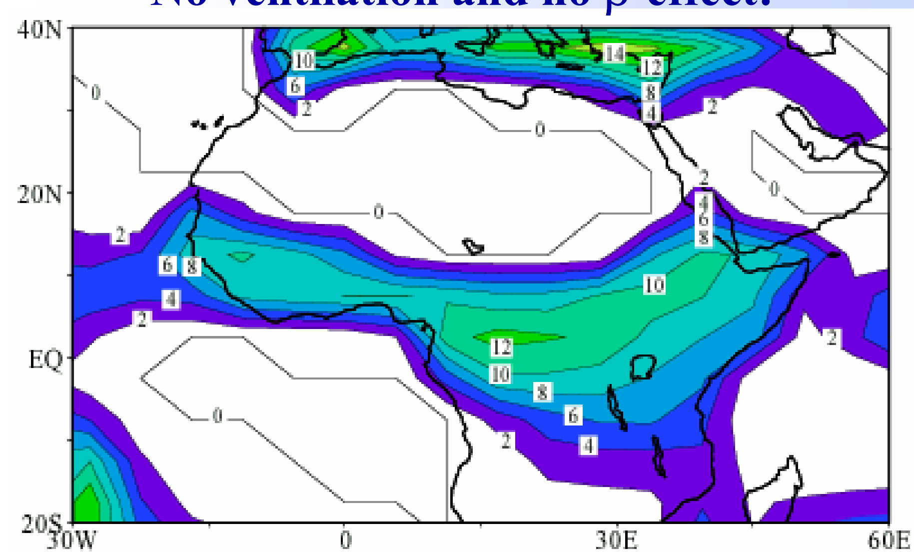
Saturated soil moisture



No ventilation: $v \bullet \nabla q$, $v \bullet \nabla T$ set to zero



No ventilation and no β-effect:

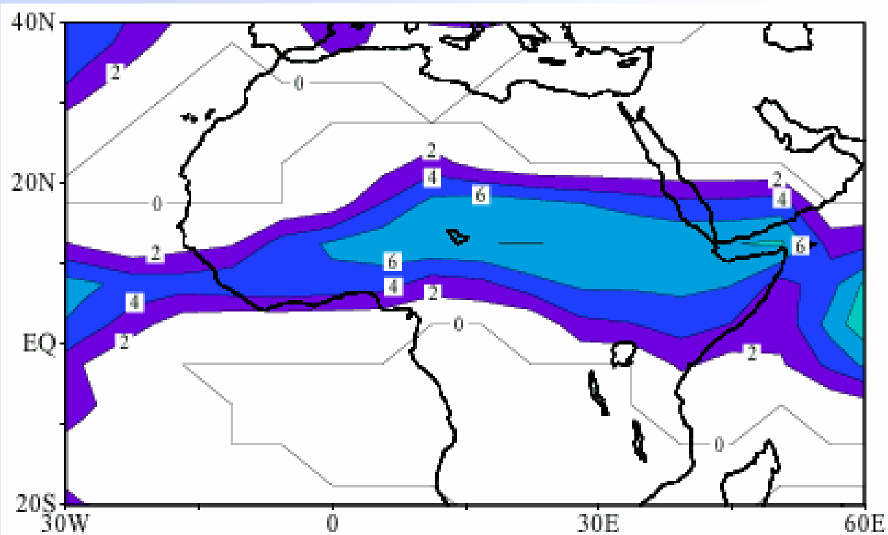


Chou and Neelin 2003

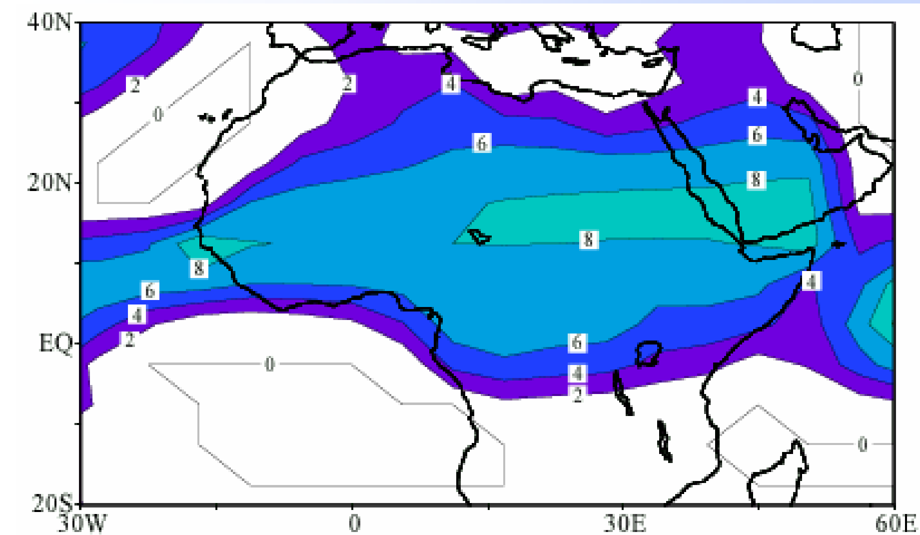
African region constant albedo case (0.26 over Africa) July

Precipitation

Control



Saturated soil moisture



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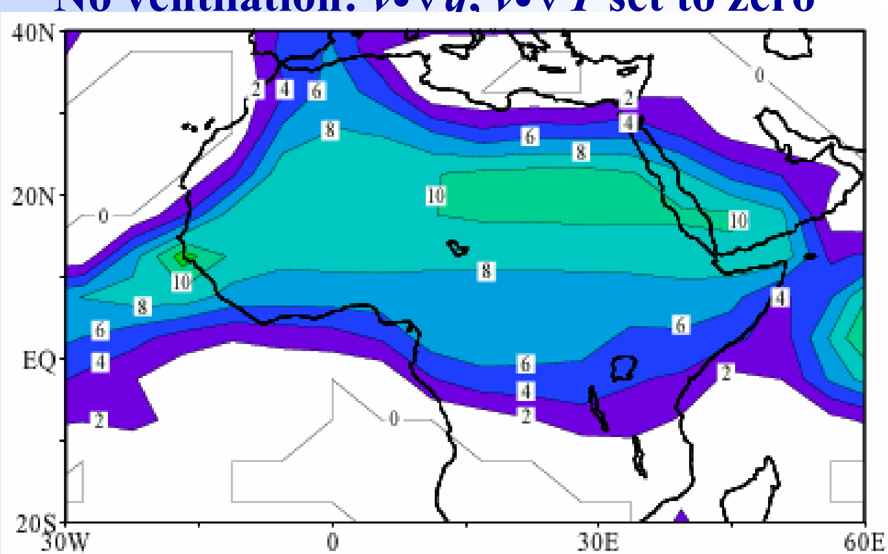
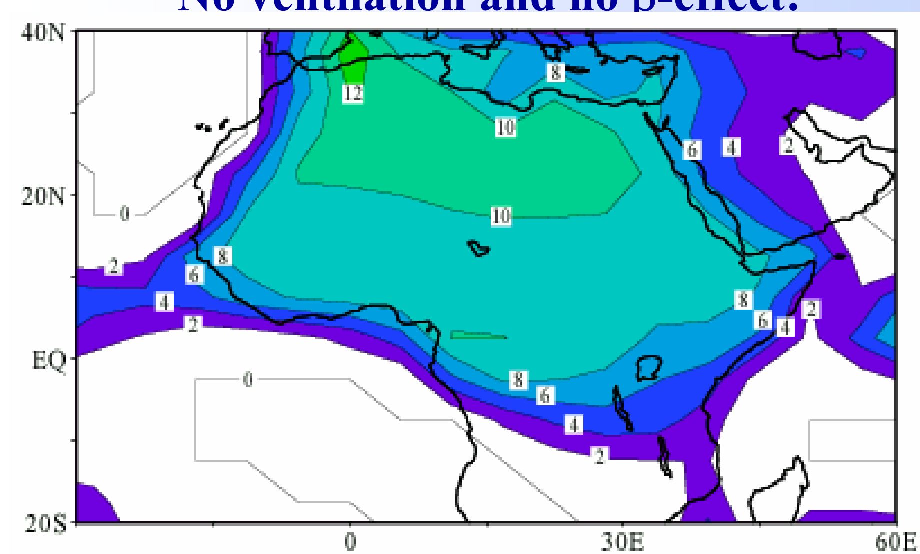


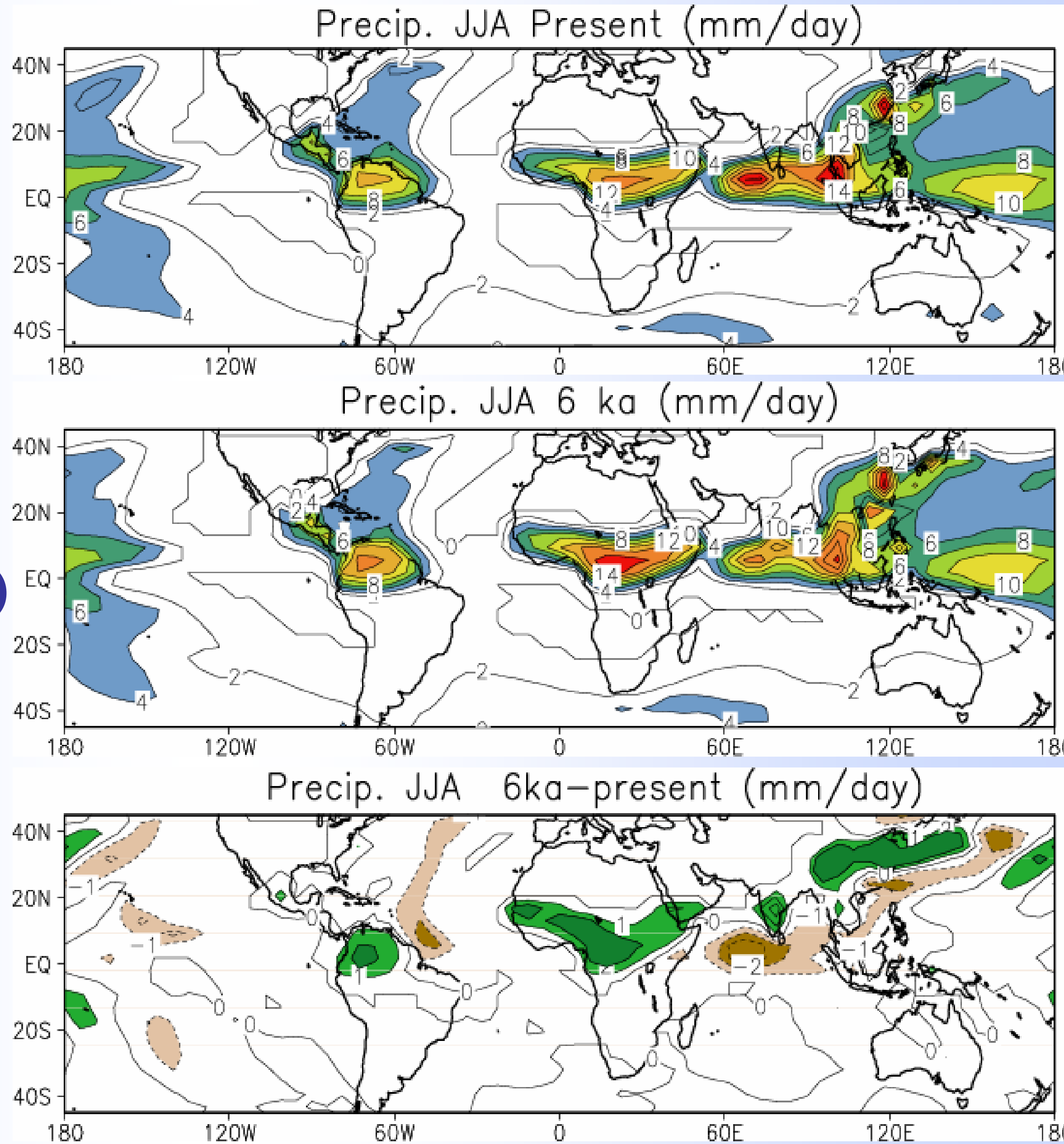
No ventilation and no β-effect:



Chou and Neelin 2003

QTCM PMIP - type 6ka BP simulation

- For comparison to Paleo Model Intercomparison Project (PMIP) mid-Holocene experiment Joussaume et al (1999)
  - Present day SST, albedo
  - 6kaBP orbital params., CO_2

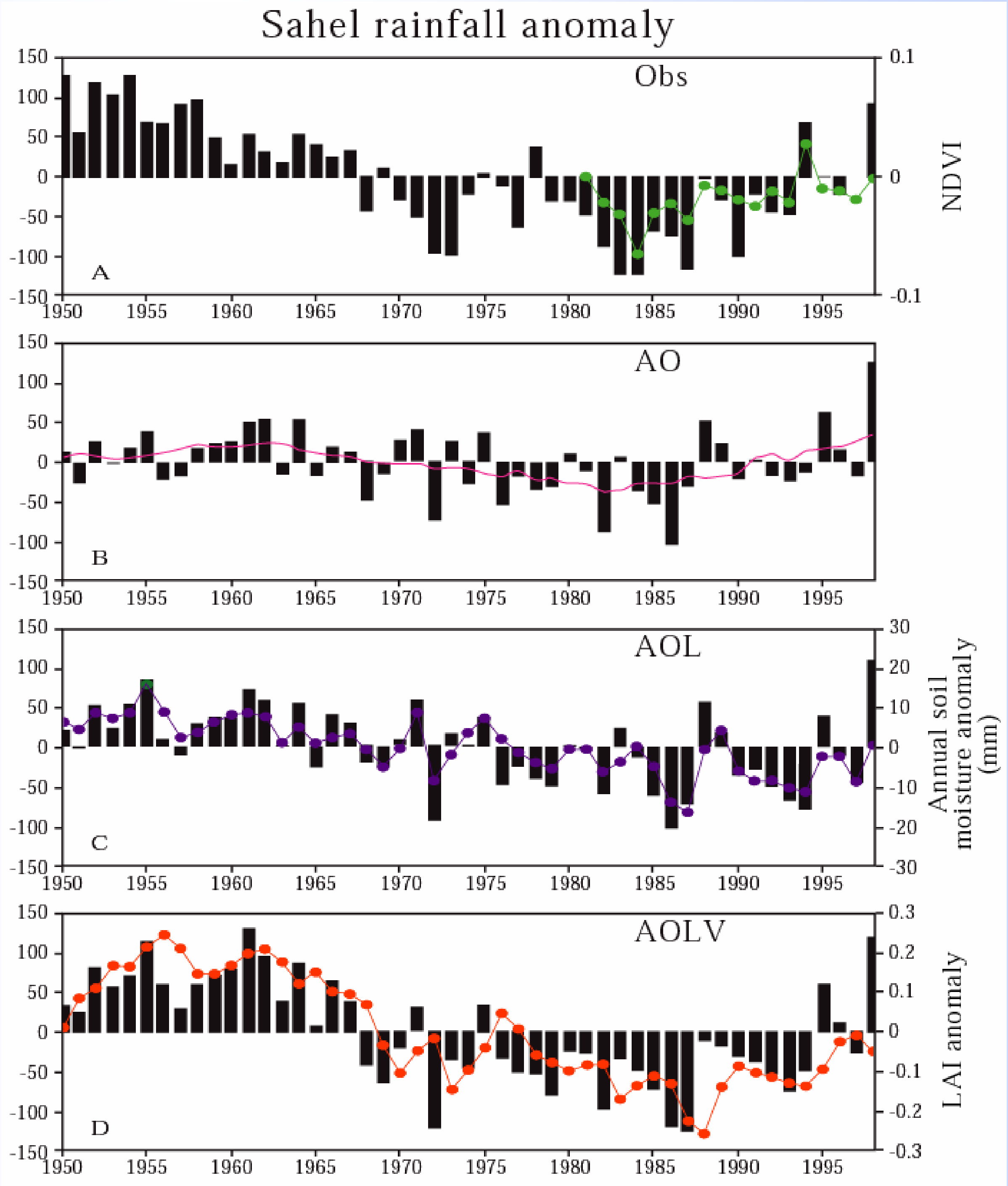


Drying trend in the Sahel 1950s -1980s

(A) Observed
(B) Forced by SST
(C) Amplified by soil moisture and
(D) vegetation

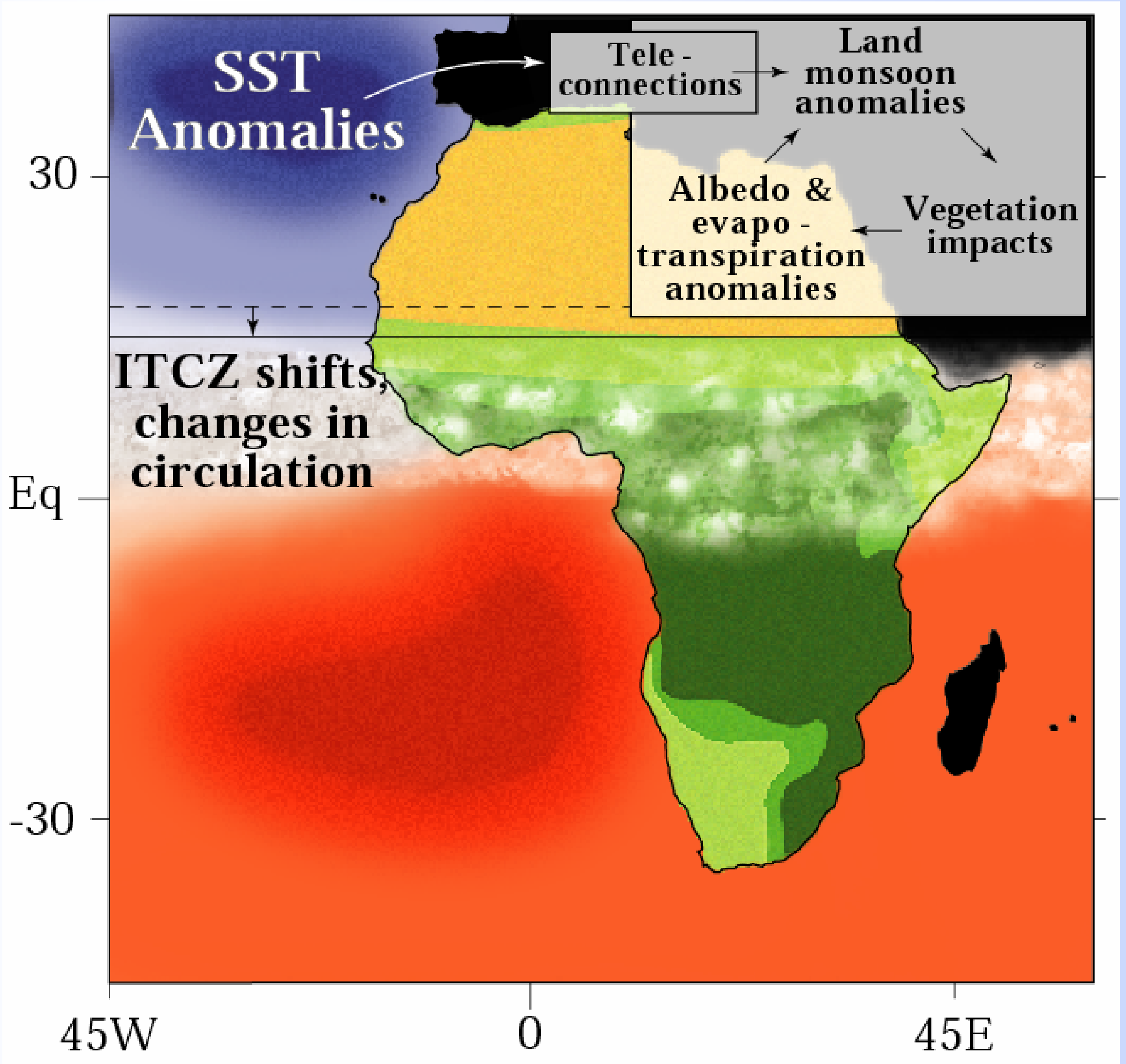
Zeng et al 1999

- Land-Surface
  e.g., Charney 1975
  Xue and Shukla 1993
  Nicholson 2000
- SST impact
  e.g., Folland et al 1986



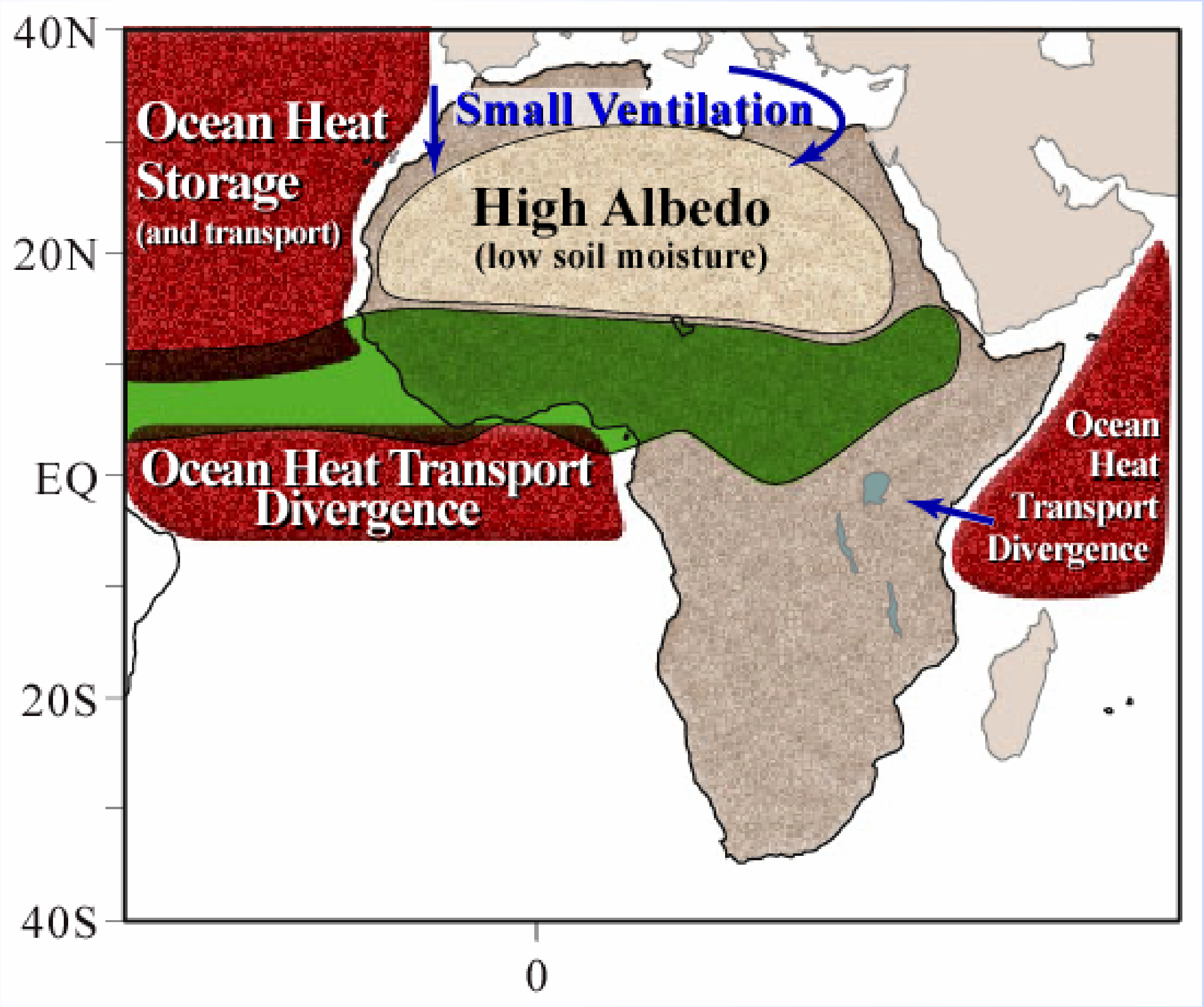
Interdecadal - interannual variability

- Teleconnected SST impacts, possibly enhanced by land-surface feedbacks
- Dynamical factors apparently dominate (exact mechanisms TBD)
- Variability tends to smooth gradient in precipitation climatology



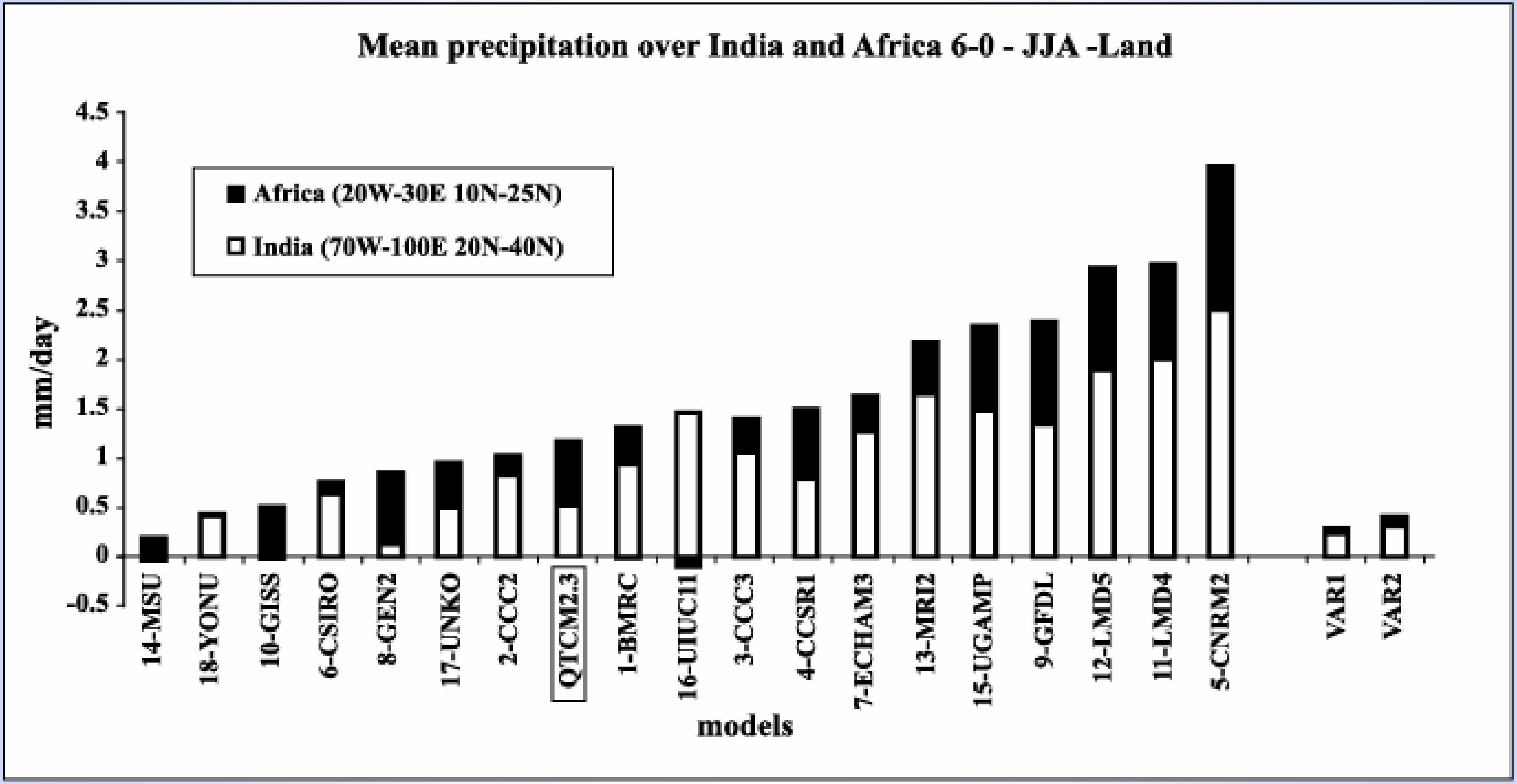
African northern summer monsoon climatology

- Albedo is leading effect on poleward extent of convection
- Dynamical mechanisms:
  - ❖ affect margin of convective zone
  - ❖ take over if albedo gradient is flattened



PMIP 6kaBP precipitation change over India & Africa

After Joussaume et al 1999



PMIP 6kaBP precipitation change over Africa

After Joussaume et al 1999