Evolution of the Indian monsoon since the last glacial maximum: forcing vs feedbacks

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OBJECTIVE

Identify the feedbacks. (TraCE-21k)

Quantify the role of forcings and feedbacks.
ENERGETICS FRAMEWORK

(Neelin & Held 1987; Raymond 2009)

\[ P - E = \frac{Q_{\text{div}}}{GMS} \]

- Net energy flux into atmosphere
- Gross Moist Stability

\[ GMS = \frac{\int_{P_B}^{P_T} \vec{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} \, dp}{L_v \int_{P_B}^{P_T} \vec{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} \, dp} \]

METHOD
ENERGETICS FRAMEWORK
(Neelin & Held 1987; Raymond 2009)

\[ P - E = \frac{Q_{\text{div}}}{GMS} \]

\[ GMS = - \frac{\int_{P_B}^{P_T} \mathbf{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} \, dp}{L_v \int_{P_B}^{P_T} \mathbf{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} \, dp} \]

Includes effect of insolation & cloud radiative feedbacks

Over land
ENERGETICS FRAMEWORK

(Neelin & Held 1987; Raymond 2009)

\[ P - E = \frac{Q_{\text{div}}}{\text{GMS}} \]

\[ \text{GMS} = - \frac{\int_{P_B}^{P_T} \vec{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} \, dp}{L_v \int_{P_B}^{P_T} \vec{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} \, dp} \]
GMS IS A UNIQUE FUNCTION OF WATER VAPOR

\[ P - E = \frac{Q_{\text{div}}}{GMS} \]

\[ P - E = \frac{Q_{\text{div}}}{80.4/CWV} - 1.3 \]

(P-E) OVER THE LAST 22,000 YRS

\[ P - E = \frac{Q_{\text{div}}}{80.4/CWV} - 1.3 \]

$Q_{\text{div}}$ DRIVES (P-E) DURING HOLOCENE

$P - E = \frac{Q_{\text{div}}}{80.4/CWV} - 1.3$

CWV fixed at pre-industrial values.

WATER VAPOR PLAYS CRUCIAL ROLE DURING DEGLACIAL

\[ P - E = \frac{Q_{\text{div}}}{80.4 \frac{\text{mm day}^{-1}}{\text{CWV}}} - 1.3 \]

\( Q_{\text{div}} \) fixed at pre-industrial values.

Energy available

Total column water vapor

Surface temperature

Precipitation

1 - Dominant during the Deglacial
2 - Dominant during the Holocene

Insolation

Energy available

Energy available

GHG & Ice sheets

Insolation

Surface temperature

Total column water vapor

Precipitation

1 - Dominant during the Deglacial

2 - Dominant during the Holocene

GHG & Ice sheets

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Thank you