Three types of monsoons?

- What is a monsoon?
- Three types of monsoons
- Examples of monsoon types
- A closer look at the Indian Monsson
- Summary

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Seasonal changes in wind

Monsoon based on 850 hPa wind criteria

Austral-Asian-E Africa
N-S Africa

Major component of wind must reverse; annual ave wind speed must average > 4 m/s

Seasonal changes in precipitation

Austral-Asian
South America
N-S Africa

SE US & E. Africa could be included (wind), as could SW US
Seasonal changes in precipitation

Places where 2/3 of annual precipitation is accumulated in ≤ 4 months

Austral-Asian
N - S Africa
Atlantic ITCZs
Western C. America

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- What is a monsoon?
  - Seasonal change in winds
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- Three types of monsoons
  - Classic monsoon: land-ocean interaction
  - Marine Monsoon: atmosphere-ocean interaction
  - ITCZs

Classic monsoon: land-ocean interaction

Summer Monsoon
- Land heats faster than ocean
- Draws air with moisture from ocean to land
- Condensational heating drives circulation (positive feedback)

Winter Monsoon
- Opposite happens

Monsoons as atmosphere-ocean interaction

- Aquaplanet: atmosphere coupled to motionless ocean w/o land

Dynamics ~ follow Privé & Plumb 2005a,b, Bordoni and Schneider 2008
- Abrupt transitions
ITCZs

- 2D view: symmetric instability due to hemispherically asymmetric PBL pressure gradients (Stevens 1983, Emanuel 1995)
- 3D view: precipitation mainly a time average of westward propagating easterly waves (ATL) and mixed Rossby-gravity waves (PAC) (Privé and Plumb 2007; Holton et al 1971; Wallace and Hobbs 1977; Liebmann and Hendon 1990)

Monsoon vs. Marine ITCZ

<table>
<thead>
<tr>
<th>Where found</th>
<th>Monsoon</th>
<th>Marine ITCZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-equatorial (&gt;15° lat)</td>
<td></td>
<td>Within ~15° of equator</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position set by</th>
<th>Monsoon</th>
<th>Marine ITCZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of max PBL MSE</td>
<td>2D: Symmetric instability ($\nabla^2 \Theta_e$)</td>
<td>3D: synoptic waves</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Precip intensity primarily set by</th>
<th>Monsoon</th>
<th>Marine ITCZ</th>
</tr>
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<tbody>
<tr>
<td>max PBL MSE</td>
<td>max PBL MSE &amp; eddy momentum transports (aloft)</td>
<td></td>
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<th>Strength of Hadley circulation controlled by</th>
<th>Monsoon</th>
<th>Marine ITCZ</th>
</tr>
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<td>diabatic heating (condensation; radiative cooling equatorward of precip maximum) &amp; by eddy momentum transports (aloft)</td>
<td>eddy momentum transports (aloft)</td>
<td></td>
</tr>
</tbody>
</table>

Examples:
- Indian summer monsoon
- Central & Eastern Pacific and Atlantic

An explanation for abrupt monsoon onsets?
It takes a large off-equatorial heating to convert an ITCZ to a monsoon (ie, to overcome the stabilization of the (symmetric) mean state by synoptic eddies)

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- Examples of monsoon types
  - Marine monsoon (with some land assist): Australian, Indian
  - ITCZ: Pacific, Atlantic, Indian Ocean in NH Winter (?)

Near surface $\Theta_e$ and Precipitation maximum

Near surface $\Theta_e$ and Precipitation maximum

- Jan
- July

Max Precip

* MSE and $\Theta_e$ are functionally equivalent
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Near surface $\theta_e$ and Precipitation maximum

Near surface Moist State Energy

Precessional Forcing

- Experiments with ECHAM4.6 AGCM
  - T42 horizontal resolution (2.8°), coupled to a slab ocean with SST adjusted to ~ modern day values when forced by modern day insolation, greenhouse gases and boundary conditions
  - Isotope module included

- Two core Experiments
  - 218K insolation (High)
  - 207K insolation (Low)
  - Modern day geometry, orography & greenhouse gas concentration
The change in forcing
High minus Low NH summer insolation

Not surprisingly, the simulated NH climate in the “Low Forcing” at 207 kyr BP is similar to the modern climate.

For “high” summer insolation
- Heavy rainfall from the Sahel to Arabia to Northern India
- 50% less over SE Asia
- More over China (~40%)
- Green Sahara?
- Collapse of Atlantic ITCZ/Trades

Simulated changes in δ18O of precipitation show a remarkable agree with speleothem records throughout the global tropics

Top of the Atmosphere Net Radiation

With sufficiently high summer insolation, there is a fundamental transition to entirely different climate state.

Why is the Eastern Mediterranean a desert today?
- Not due to sinking branch of the Hadley Cell (max in DJF)
- Today – in low phase of precessional cycle – monsoon precipitation is maximum in the northern Bay of Bengal (not over land)
- Condensational heating in the Bay of Bengal forces a westward Rossby wave and cold air advection over the eastern Med and Central Asia that is balanced by subsidence

JJA Observed Omega (477 hPA)
(1983-1988)

JJA Observed Omega (477 hPA)
(1983-1988)

Rodwell and Hoskins 1996
Regional Heating during High Precession

• How do you break the desertification mechanism?

  – Hypothesis: More intense summer insolation heats land (fast) enough to create a sufficiently large land-ocean temperature contrast to shift the maximum in MSE – and hence convection – to be over land. A classic monsoon.

Mid-Holocene (PMIP3) minus today
Zonal mean or zonally asymmetric?

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• The east Asian (Meiyu): a faux monsoon
  – See Molnar et al 2009; Chiang et al (in review)
Three types of monsoons?

- With strong enough asymmetric hemispheric heating, a monsoon ...
  - Due mainly to ocean-atmosphere (e.g., Indian monsoon today) or classic land-atmosphere (e.g., S. Africa, S. America) interaction
  - Thermodynamics (max MSE) important

- With modest asymmetric hemispheric heating, an ITCZ
  - Due to flow instability that sheds equatorial waves (e.g., easterly waves in Atlantic and far eastern Pacific)
  - Due to convection organized by mixed Rossby gravity waves (e.g., central Pacific); Indian Ocean in DJF (?)
  - Thermodynamics (max MSE) and dynamics (symmetric instability, PBL pressure gradients, eddy momentum fluxes aloft) important