Three types of monsoons?

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

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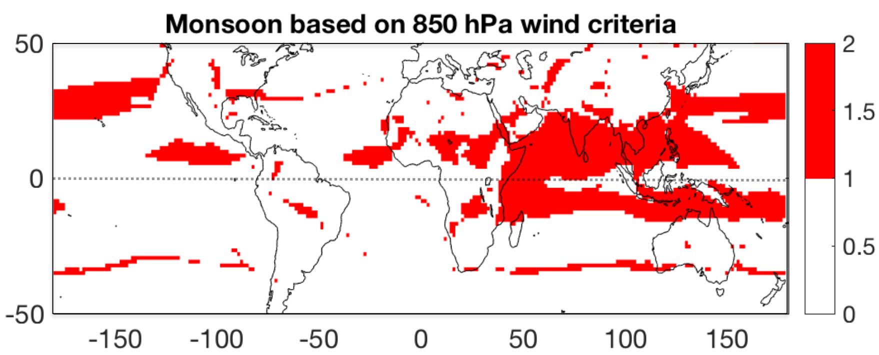
- What is a monsoon?
  - Seasonal change in winds
  - Seasonal change in precipitation

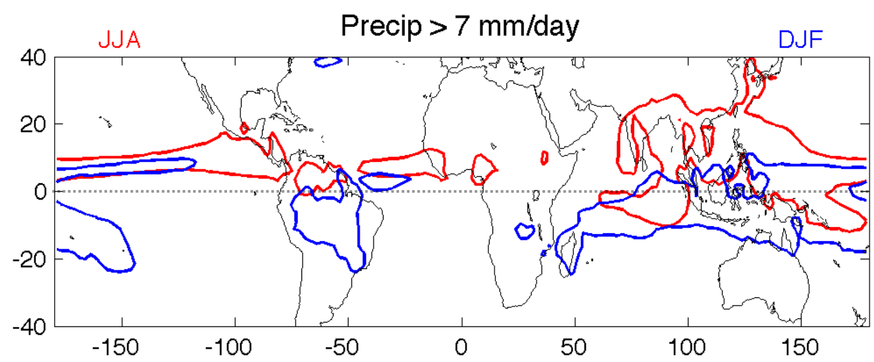
Seasonal changes in wind



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

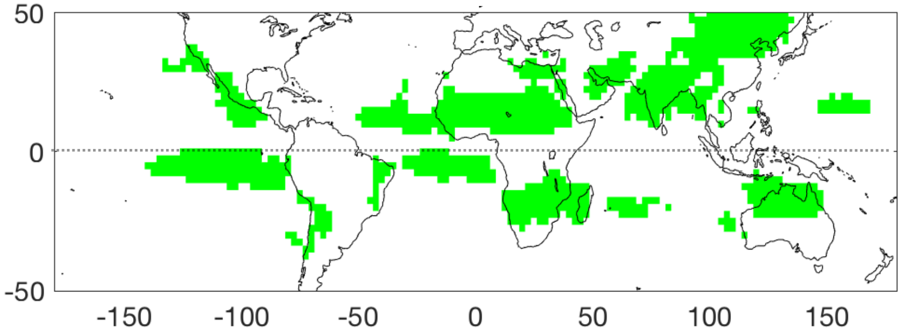


Austral-Asian
South America
N-S Africa

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

Three types of monsoons?

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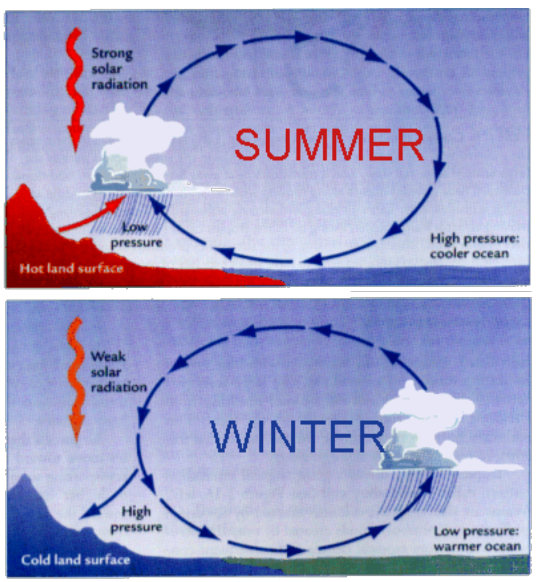
- Three types of monsoons
  - Classic monsoon: land-ocean interaction
  - Marine Monsoon: atmosphere-ocean interaction
  - ITCZs

Classic monsoon: land-ocean interaction



Ruddiman 2007

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

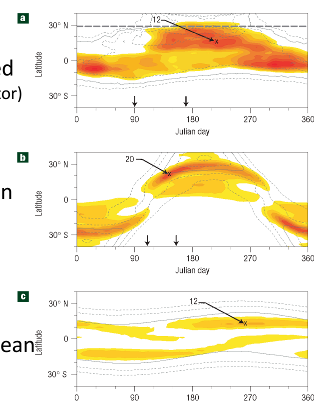
- Aquaplanet: atmosphere coupled to motionless ocean w/ no land

Precipitation

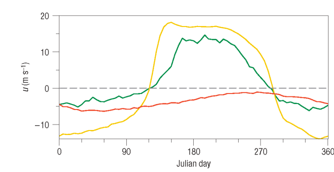
Observed (Indian Sector)

1m ocean

100m ocean



Zonal wind at 15N



West'ly

East'ly

Day of Year

Observed; 100m and 1m ocean

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

Bordoni and Schneider 2008

ITCZs

BRANT LIEBMANN AND HARRY H. HENDON

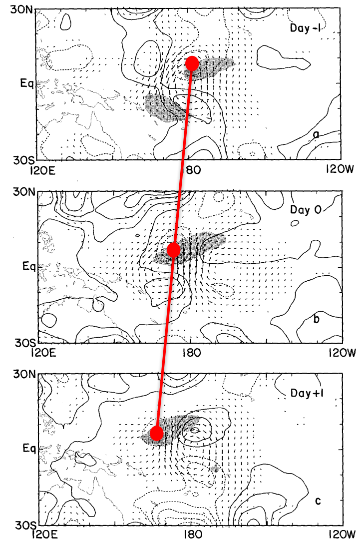


FIG. 12. Linear regression between 850 mb meridional wind at (Equator, 180°) and vector wind (arrows), heights (c … anomalies (shading) for (a) fields leading base grid point by one da … h base grid point; (c) fields lagging behind base grid point by one da… …ies associated with an anomaly at the base grid point of 1 m s^{-1}. Tl … meridional wind at the base grid point is 1.57 m s^{-1}. Vector anomalies greater than 0.1 m s^{-1} are plotted. Contour interval is 0.2 m, with negative anomalies dashed. Shading includes OLR anomalies less than −2.0 W m^{-2}.

~ - 7 m/s

- 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

	Monsoon	Marine ITCZ
Where found	Off-equatorial (>15° lat)	Within ~15° of equator
Position set by	Location of max PBL MSE	2D: Symmetric instability ($\nabla^2 \theta_e$) 3D: synoptic waves
Precip intensity primarily set by	max PBL MSE	max PBL MSE & eddy momentum transports (aloft)
Strength of Hadley circulation controlled by	diabatic heating (condensation; radiative cooling equatorward of precip maximum) & by eddy momentum transports (aloft)	eddy momentum transports (aloft)
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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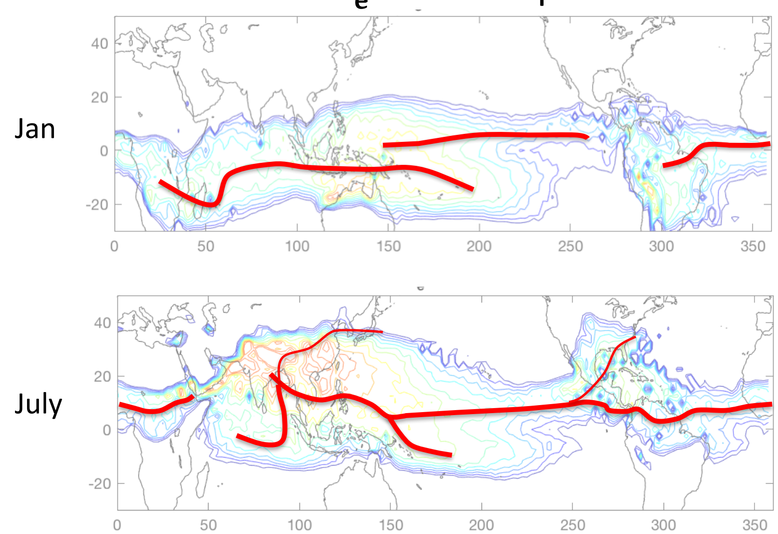
  - ITCZs
- Examples of monsoon types
  - Classic land-ocean: S. African monsoon, S. American Monsoon, Eastern North American monsoon
  - Marine monsoon (with some land assist): Australian, Indian
  - ITCZ: Pacific, Atlantic, Indian Ocean in NH Winter (?)

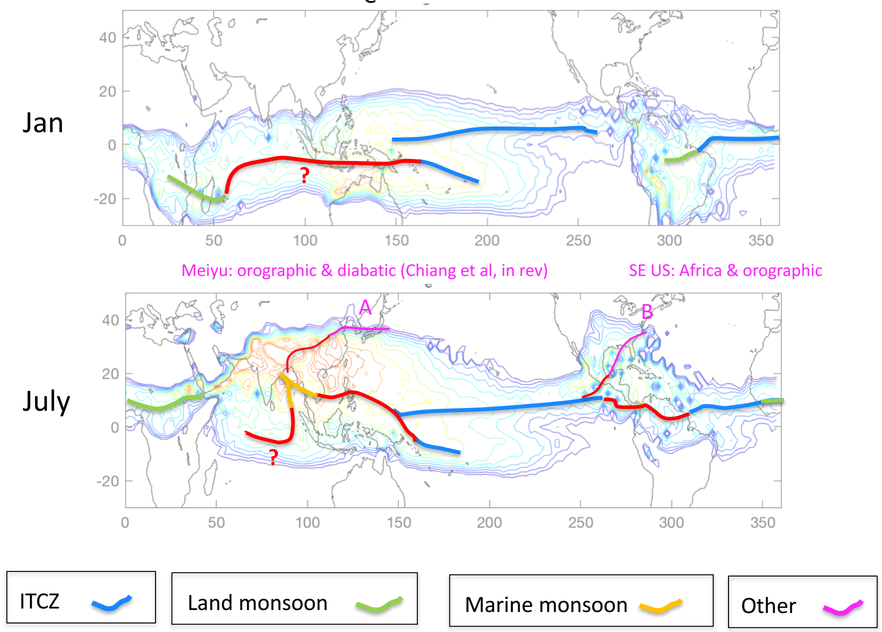
Near surface θ_e and Precipitation maximum



Max Precip

* MSE and Θ_e are functionally equivalent

Near surface θ_e and Precipitation maximum



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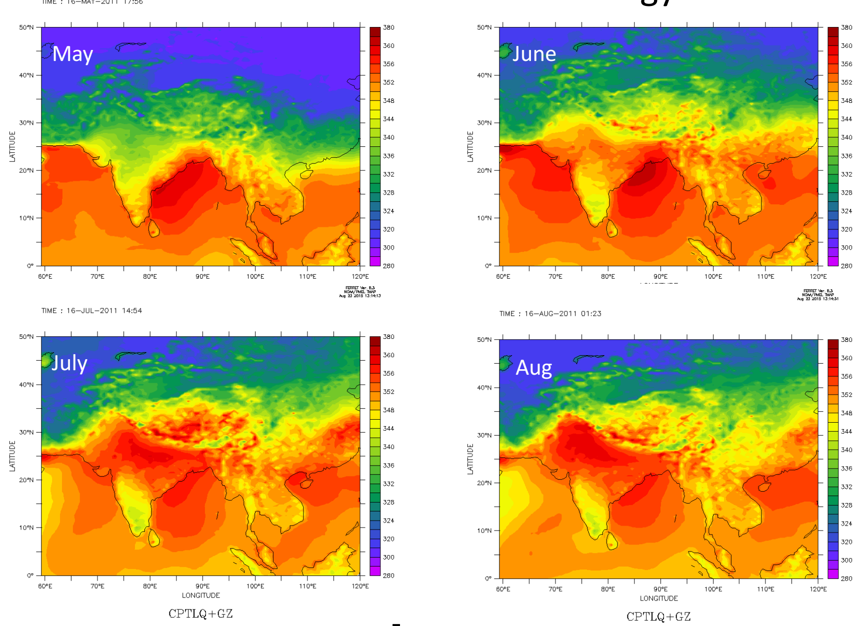
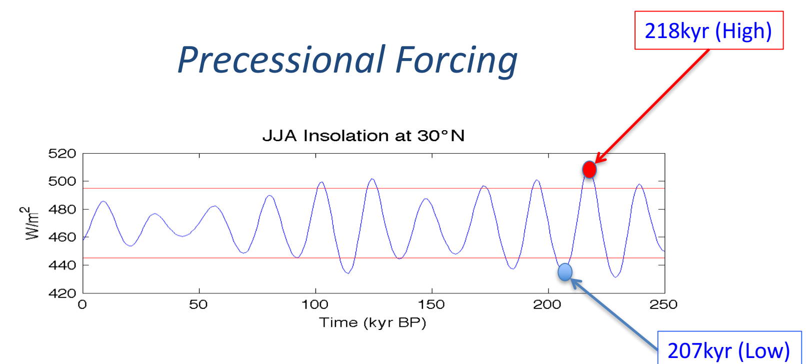
Near surface Moist State Energy



Data: MERRA

I. Fung, pers. Comm.

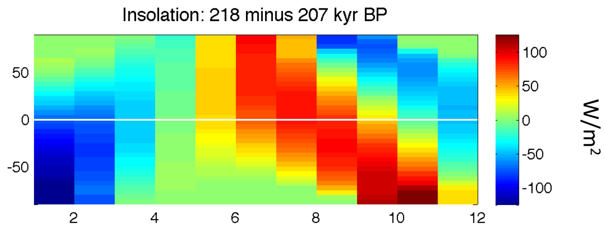
Precessional Forcing

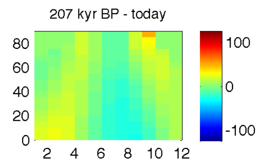


- Experiments with ECHAM4.6 AGCM
  - T42 horizontal resolution (2.8°), coupled to a slab ocean with SST adjusted to ~ modern day values when forced by modern day insolation, greenhouse gases and boundary conditions
  - Isotope module included
- Two core Experiments
  - 218K insolation (High)
  - 207K insolation (Low)
  - Modern day geometry, orography & greenhouse gas concentration

The change in forcing

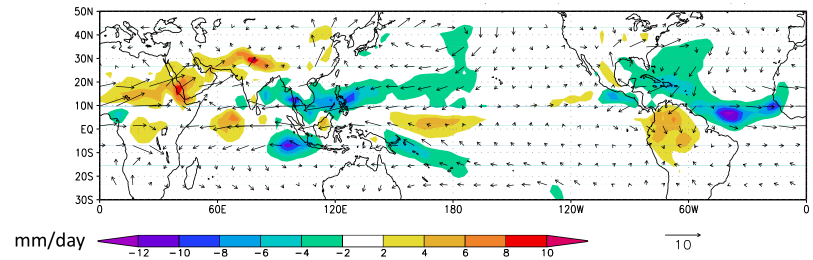
High minus Low NH summer insolation





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

Change in Precipitation and 850 hPa Winds JJA (218 minus 207 kyr)



For “high” summer insolation

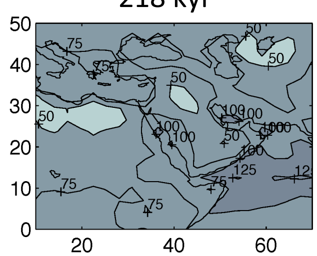
- Heavy rainfall from the Sahel to Arabia to Northern India
- 50% less over SE Asia
- More over China (~40%)
- Green Sahara?
- Collapse of Atlantic ITCZ/Trades

Simulated changes in *$\delta^{18}O$* of precipitation show a remarkable agree with speleothem records throughout the global tropics

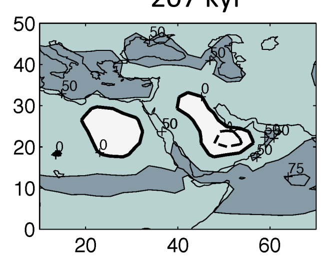
Battisti et al 2014

Top of the Atmosphere Net Radiation

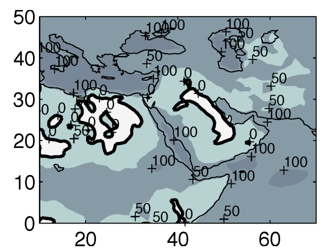
218 kyr



207 kyr



Observed 2001-2012



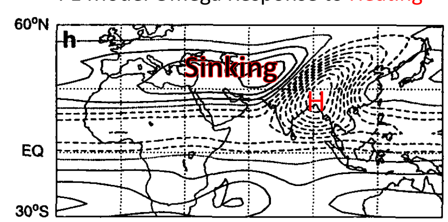
- With sufficiently high summer insolation, there is a fundamental transition to entirely different climate state.

Battisti et al 2014

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

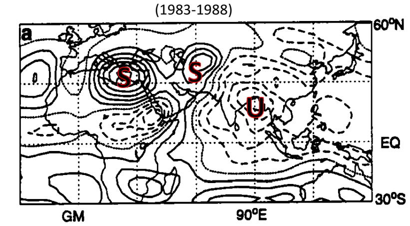
PE Model Omega Response to Heating



(c.i. 0.014 Pa/s)

JJA Observed Omega (477 hPA)

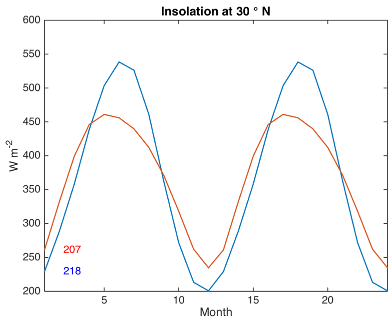
(1983-1988)



Rodwell and Hoskins 1996

Regional Heating during High Precession

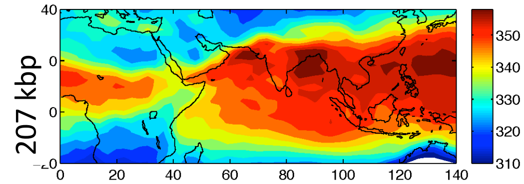
- How do you break the desertification mechanism?



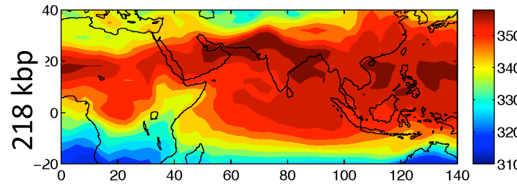
  – Hypothesis: More intense summer insolation heats land (fast) enough to create a sufficiently large land-ocean temperature contrast to shift the maximum in MSE – and hence convection – to be over land. A classic monsoon.

Battisti et al 2014

Equivalent potential temperature, Θ_e *

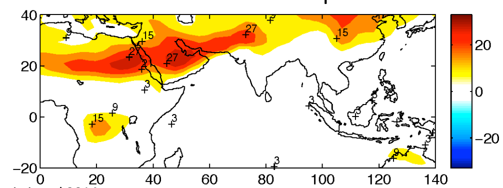


Convection is centered over maximum Θ_e → over oceans in low NH summer insolation (e.g., today)



Convection is centered over land in high insolation (a textbook monsoon)

218 minus 207 kbp

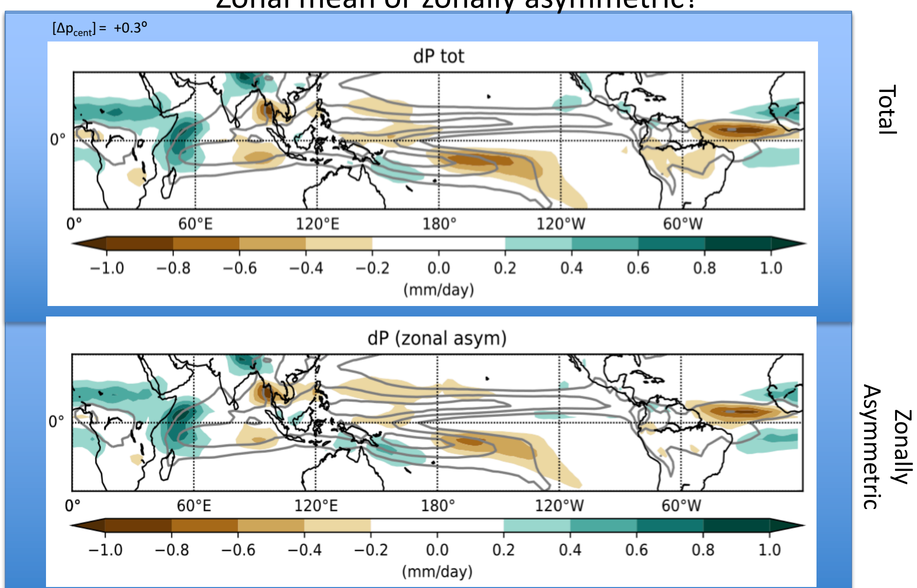


Battisti et al 2014

* MSE and Θ_e are functionally equivalent

Mid-Holocene (PMIP3) minus today

Zonal mean or zonally asymmetric?



Atwood et al in prep

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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