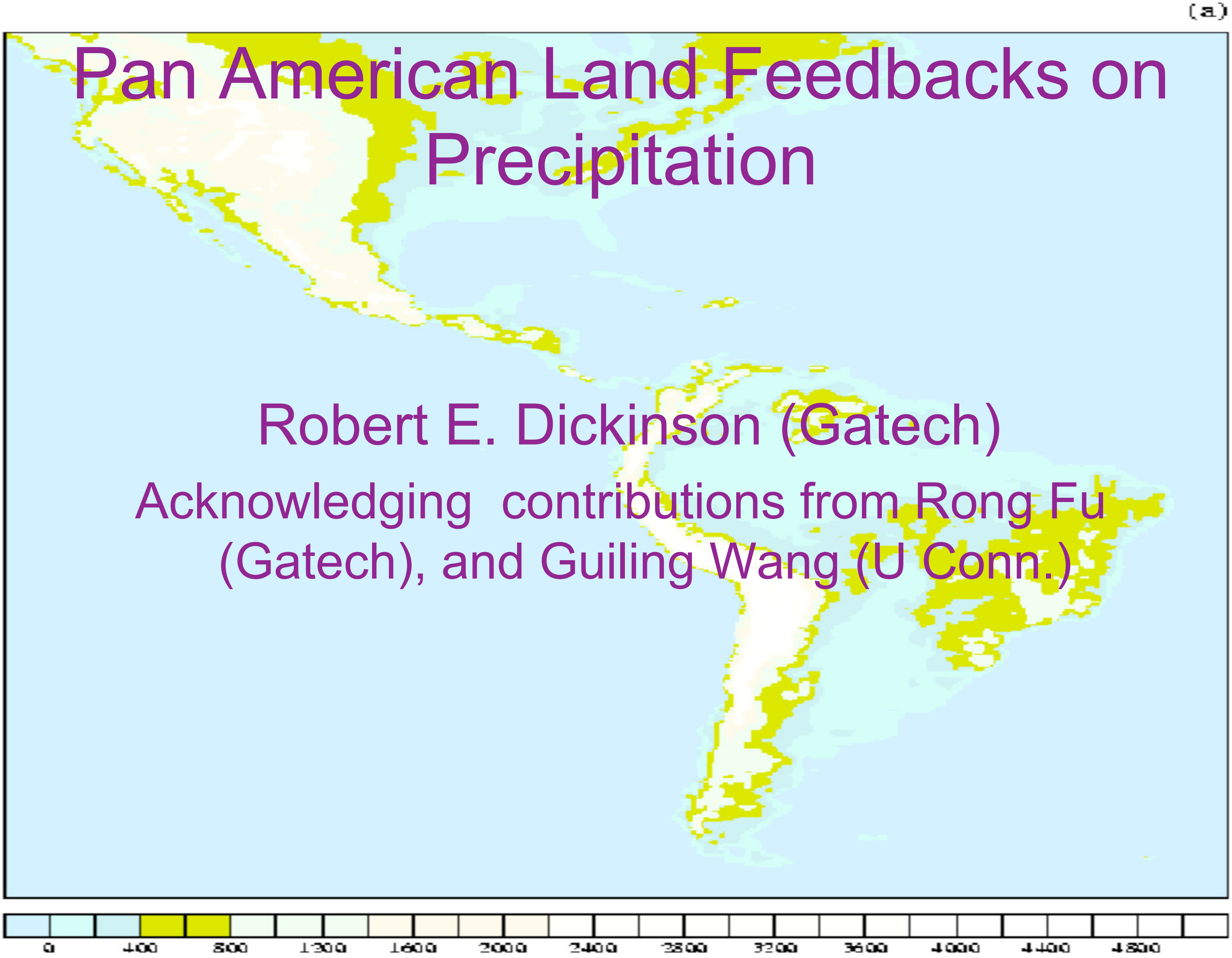
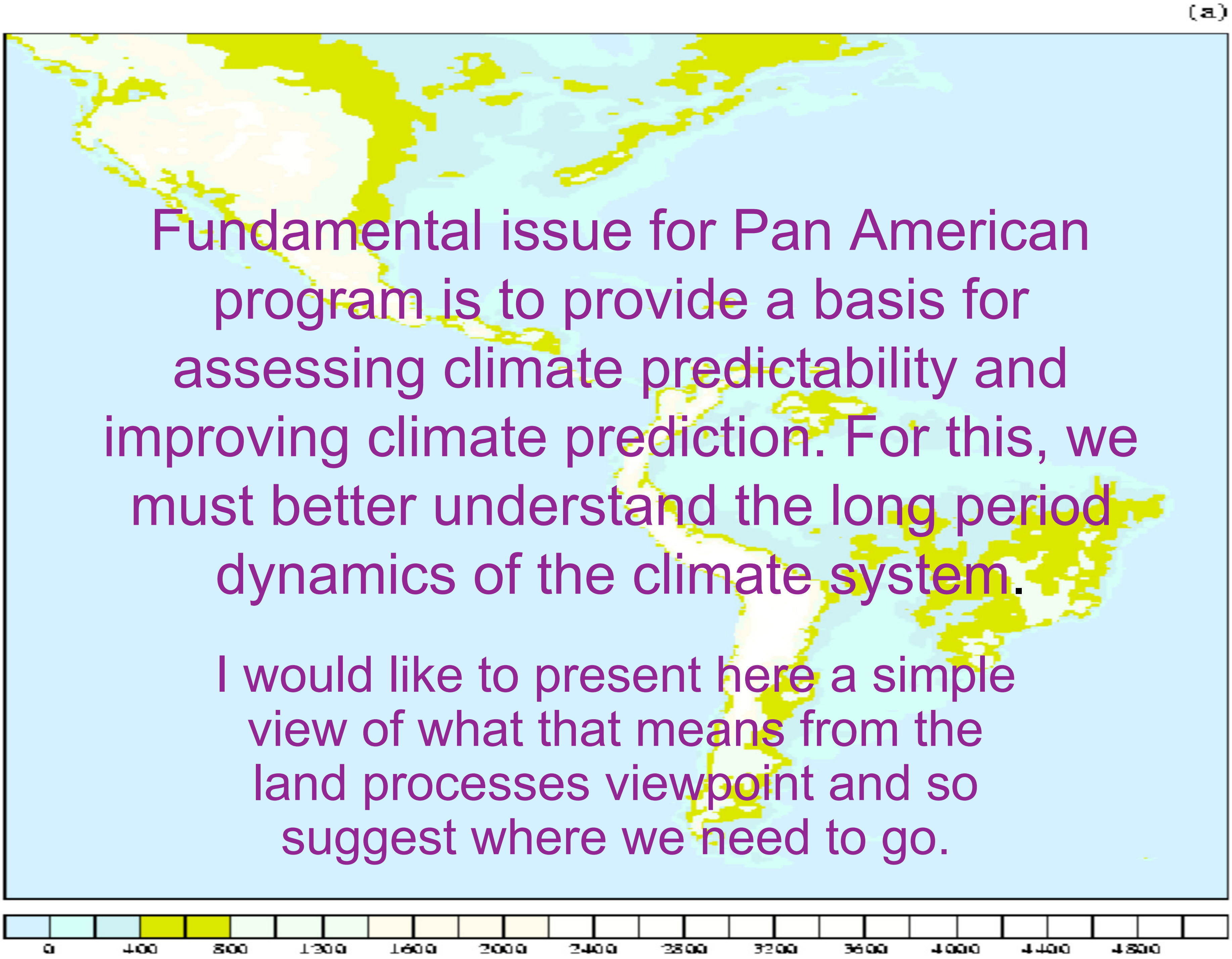
Pan American Land Feedbacks on Precipitation

Robert E. Dickinson (Gatech)

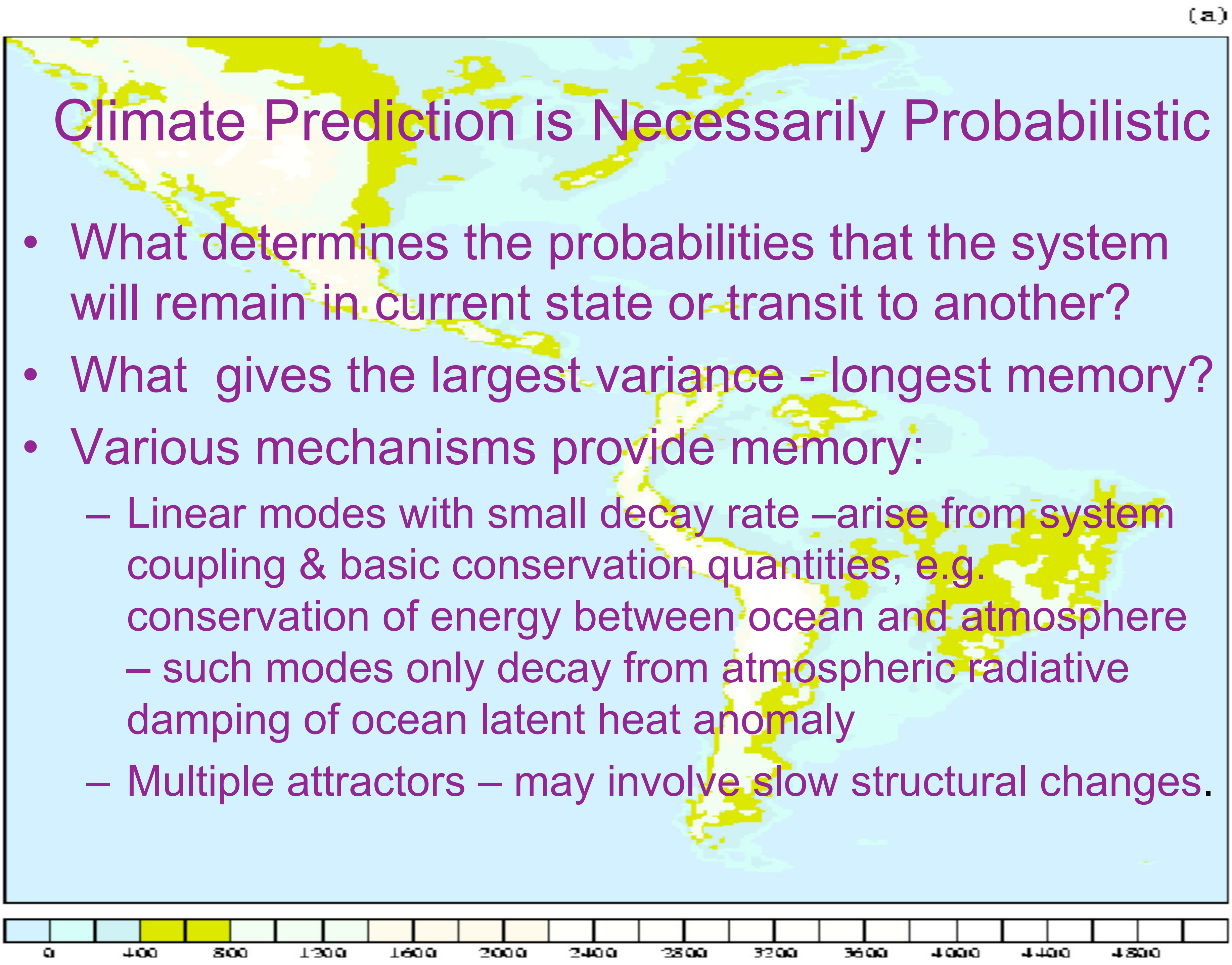
Acknowledging contributions from Rong Fu (Gatech), and Guiling Wang (U Conn.)





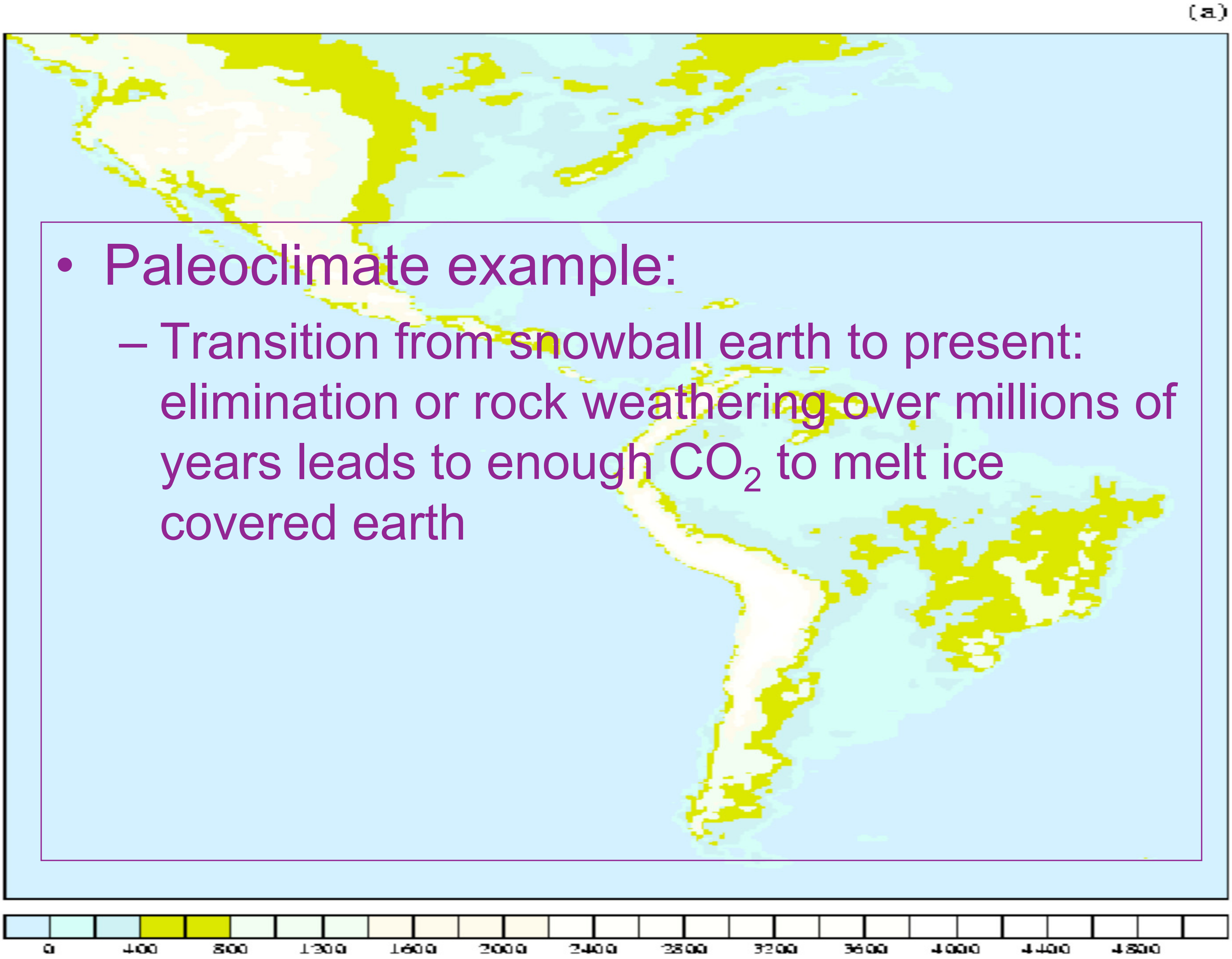
Fundamental issue for Pan American program is to provide a basis for assessing climate predictability and improving climate prediction. For this, we must better understand the long period dynamics of the climate system.

I would like to present here a simple view of what that means from the land processes viewpoint and so suggest where we need to go.



Climate Prediction is Necessarily Probabilistic

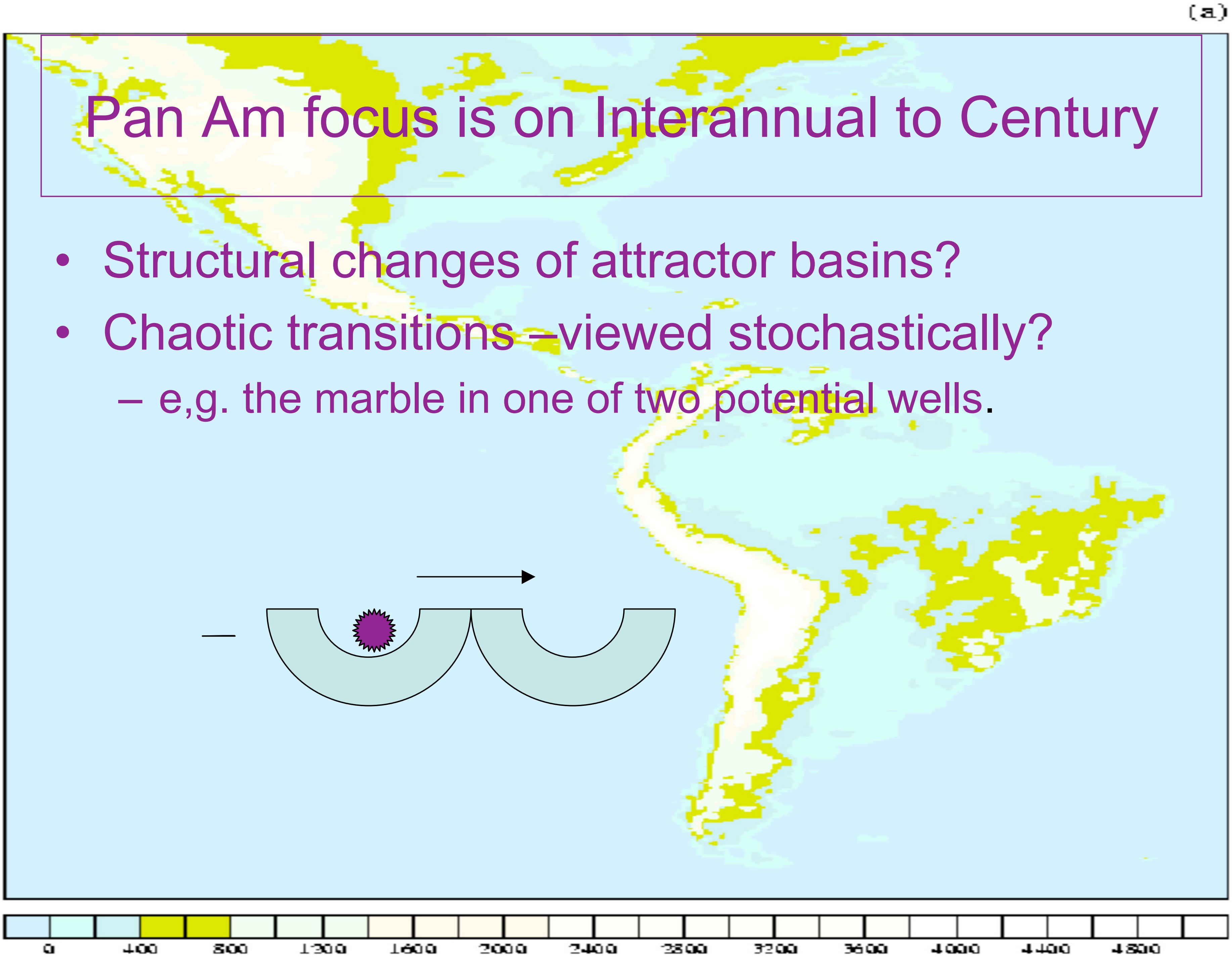
- What determines the probabilities that the system will remain in current state or transit to another?
- What gives the largest variance - longest memory?
- Various mechanisms provide memory:
  - Linear modes with small decay rate –arise from system coupling & basic conservation quantities, e.g. conservation of energy between ocean and atmosphere – such modes only decay from atmospheric radiative damping of ocean latent heat anomaly
  - Multiple attractors – may involve slow structural changes.



- Paleoclimate example:
  - Transition from snowball earth to present: elimination or rock weathering over millions of years leads to enough CO_2 to melt ice covered earth

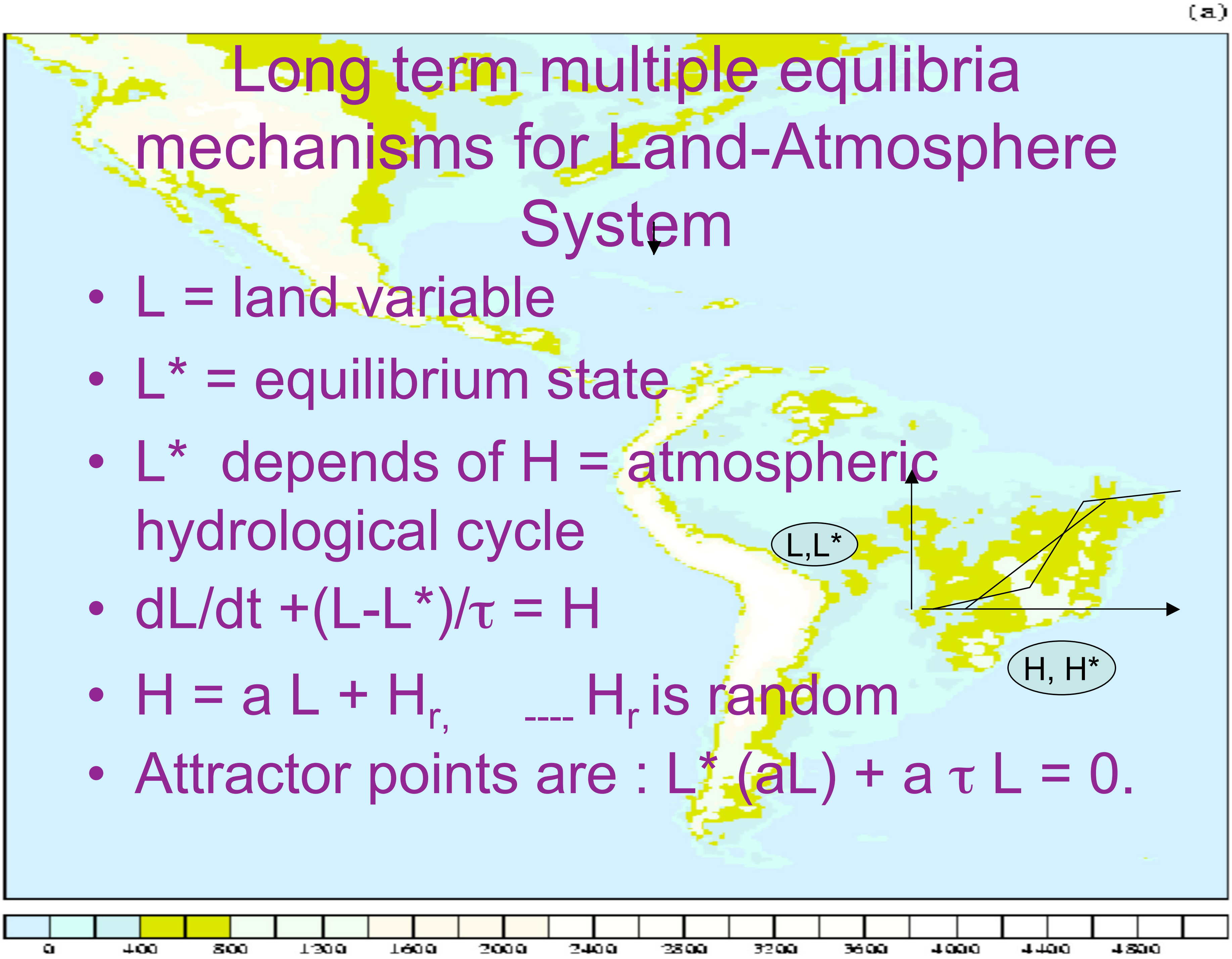
Pan Am focus is on Interannual to Century

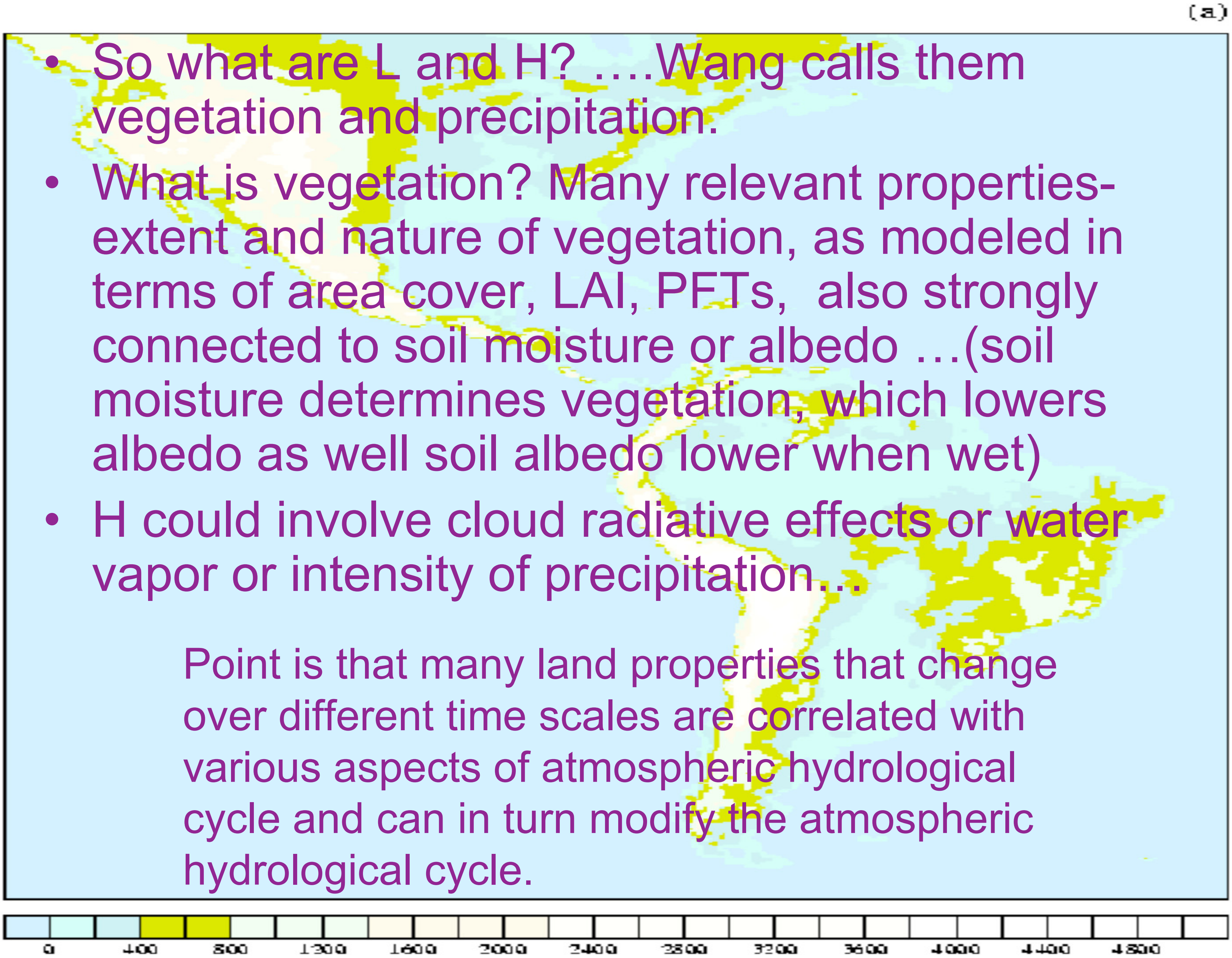
- Structural changes of attractor basins?
- Chaotic transitions –viewed stochastically?
  - e,g. the marble in one of two potential wells.



Long term multiple equlibria mechanisms for Land-Atmosphere System

- L = land variable
- L* = equilibrium state
- L* depends of H = atmospheric hydrological cycle
- $dL/dt + (L-L^*)/\tau = H$
- $H = a L + H_{r,}$ ---- H_r is random
- Attractor points are : $L^* (aL) + a \tau L = 0.$



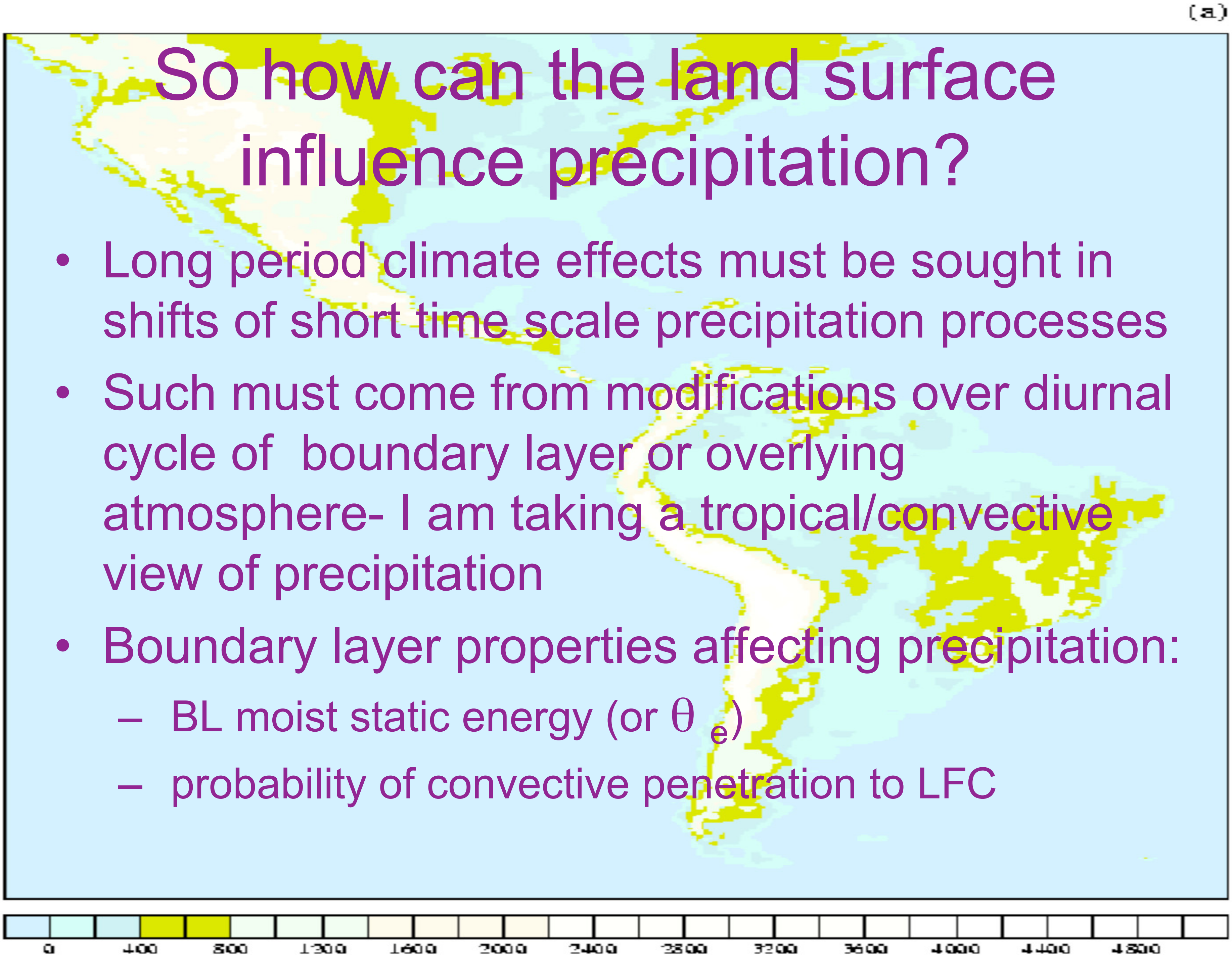


- So what are L and H? ….Wang calls them vegetation and precipitation.
- What is vegetation? Many relevant properties- extent and nature of vegetation, as modeled in terms of area cover, LAI, PFTs, also strongly connected to soil moisture or albedo …(soil moisture determines vegetation, which lowers albedo as well soil albedo lower when wet)
- H could involve cloud radiative effects or water vapor or intensity of precipitation…

Point is that many land properties that change over different time scales are correlated with various aspects of atmospheric hydrological cycle and can in turn modify the atmospheric hydrological cycle.

So how can the land surface influence precipitation?

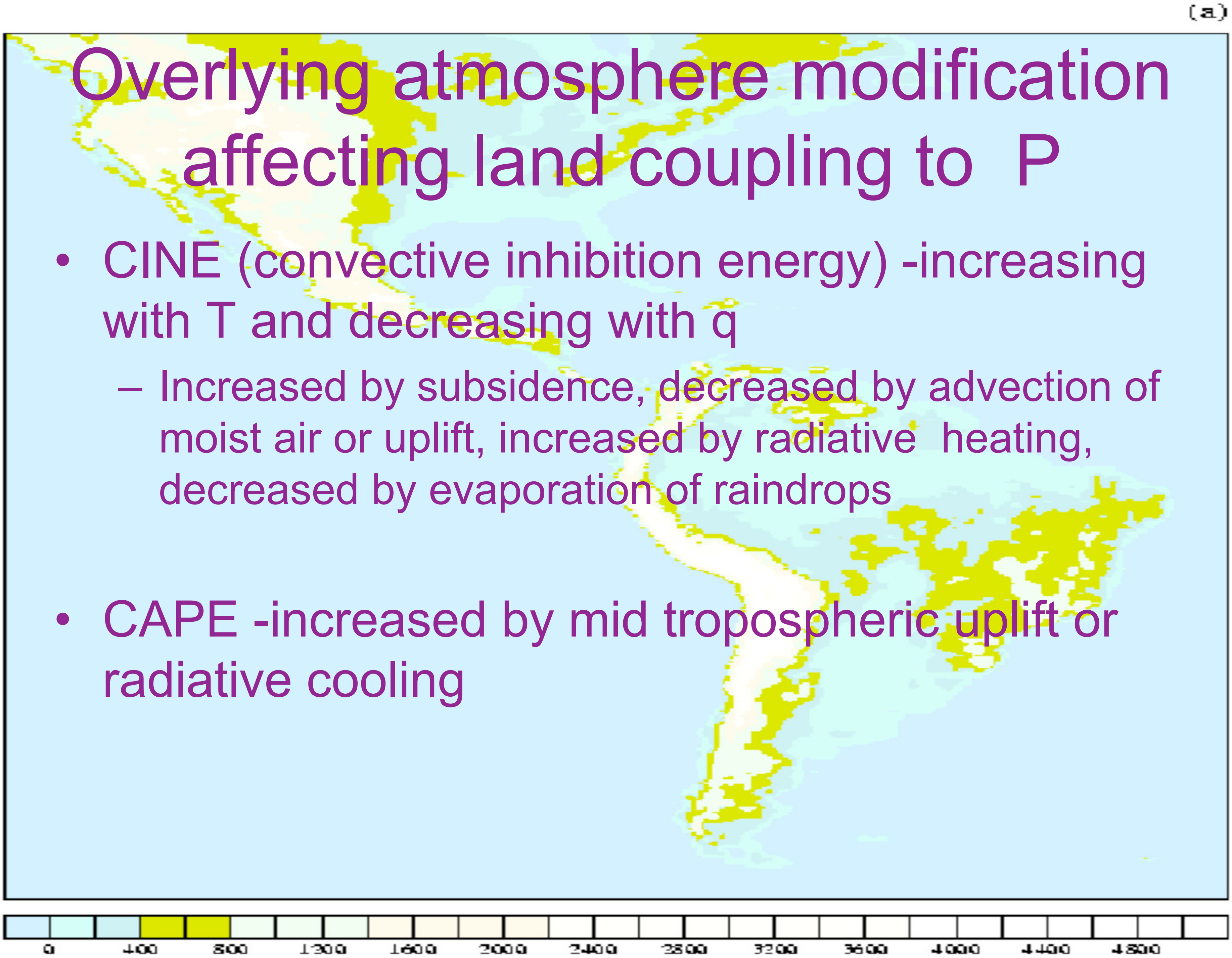
- Long period climate effects must be sought in shifts of short time scale precipitation processes
- Such must come from modifications over diurnal cycle of boundary layer or overlying atmosphere- I am taking a tropical/convective view of precipitation
- Boundary layer properties affecting precipitation:
  - BL moist static energy (or θ_e)
  - probability of convective penetration to LFC



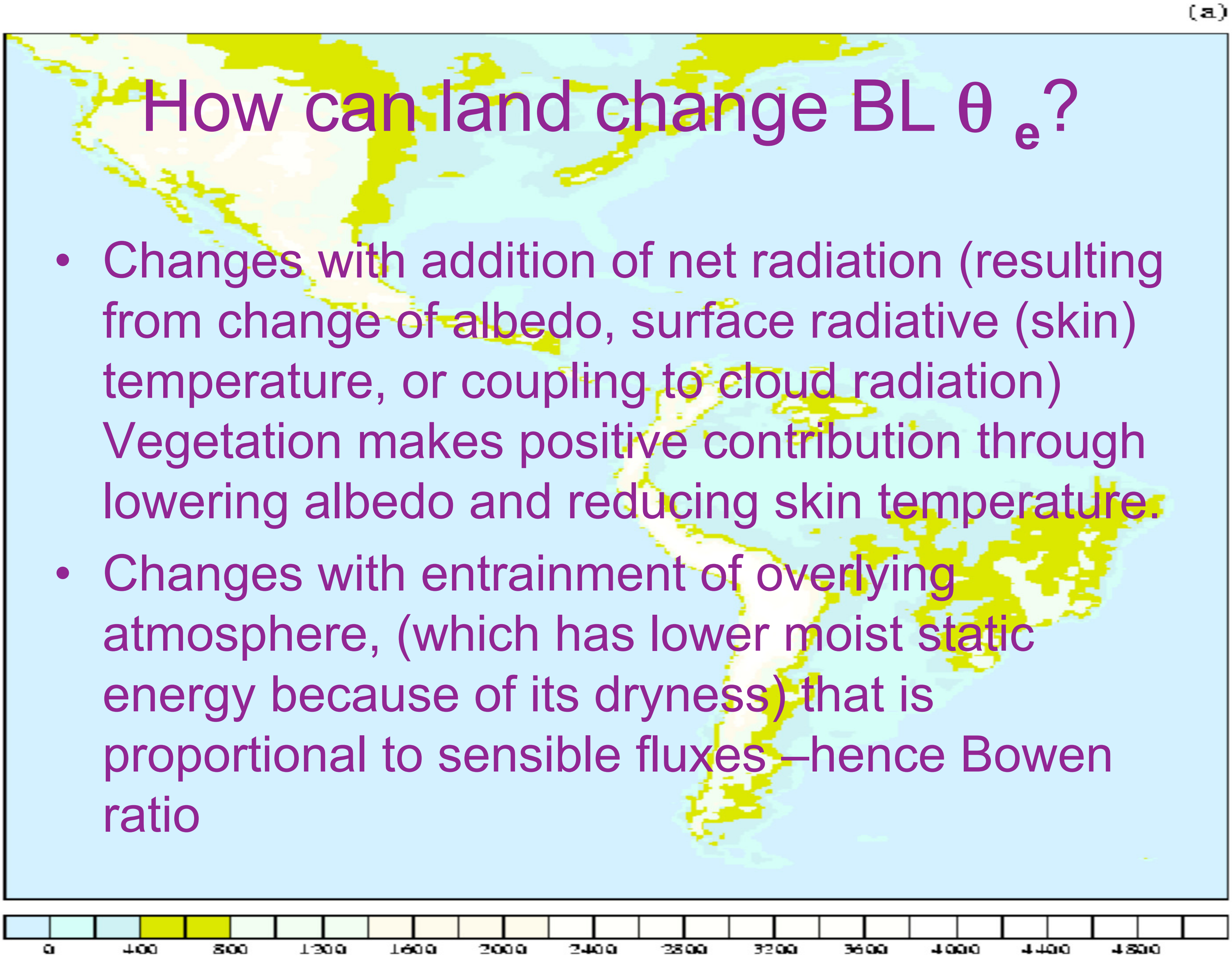
Overlying atmosphere modification affecting land coupling to P

- CINE (convective inhibition energy) -increasing with T and decreasing with q
  - Increased by subsidence, decreased by advection of moist air or uplift, increased by radiative heating, decreased by evaporation of raindrops

- CAPE -increased by mid tropospheric uplift or radiative cooling



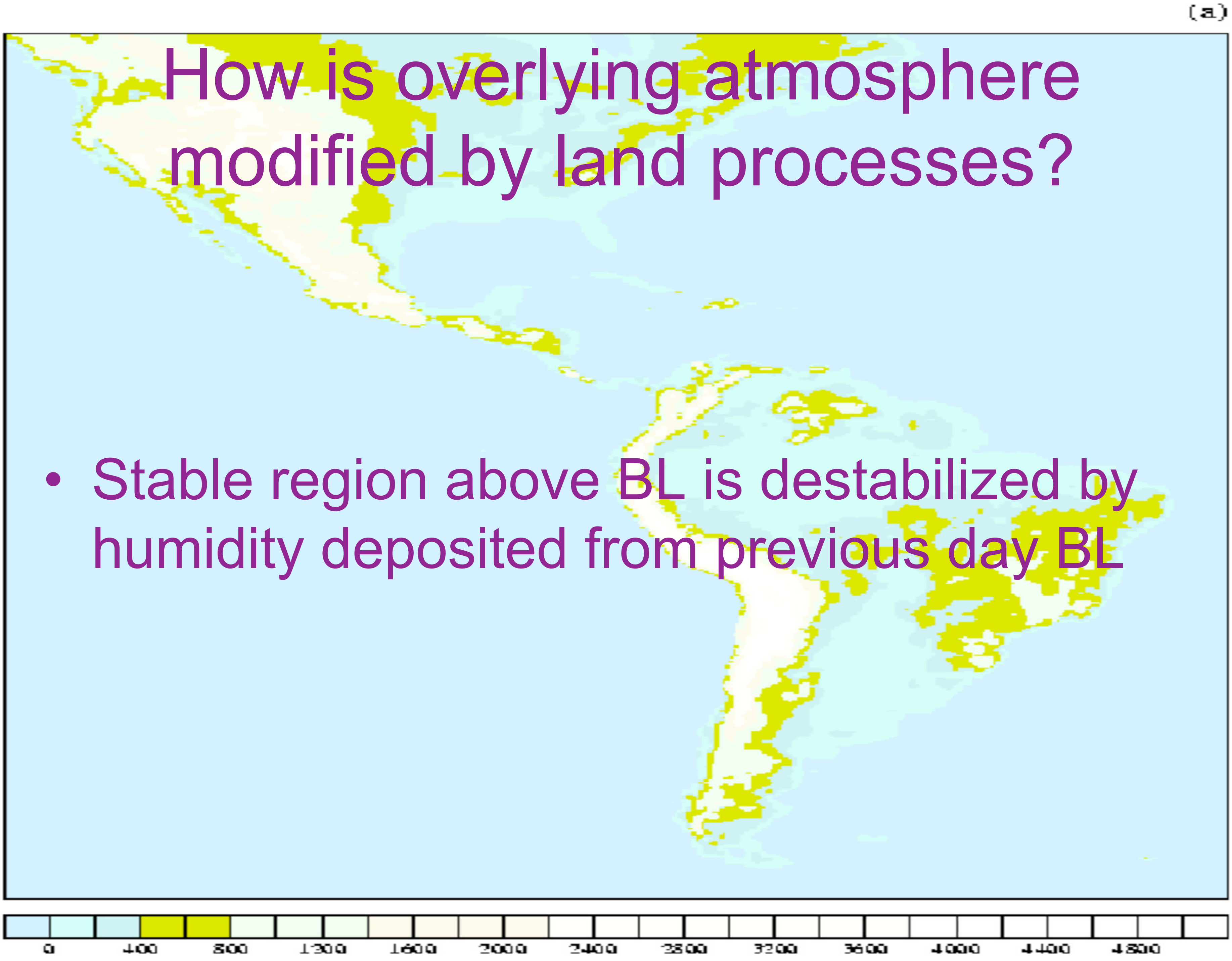
How can land change BL θ_e?



- Changes with addition of net radiation (resulting from change of albedo, surface radiative (skin) temperature, or coupling to cloud radiation) Vegetation makes positive contribution through lowering albedo and reducing skin temperature.
- Changes with entrainment of overlying atmosphere, (which has lower moist static energy because of its dryness) that is proportional to sensible fluxes –hence Bowen ratio

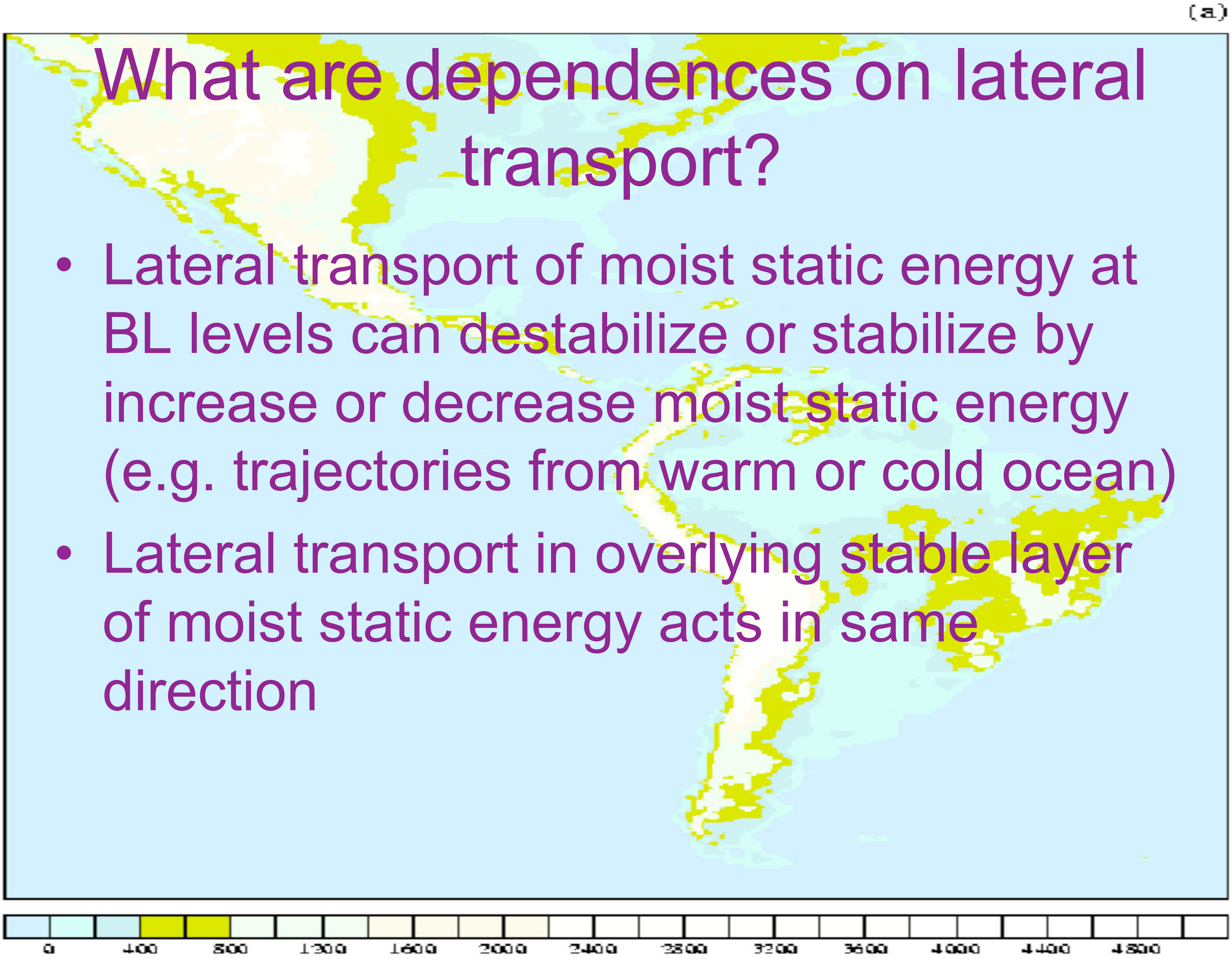
How is overlying atmosphere modified by land processes?

- Stable region above BL is destabilized by humidity deposited from previous day BL



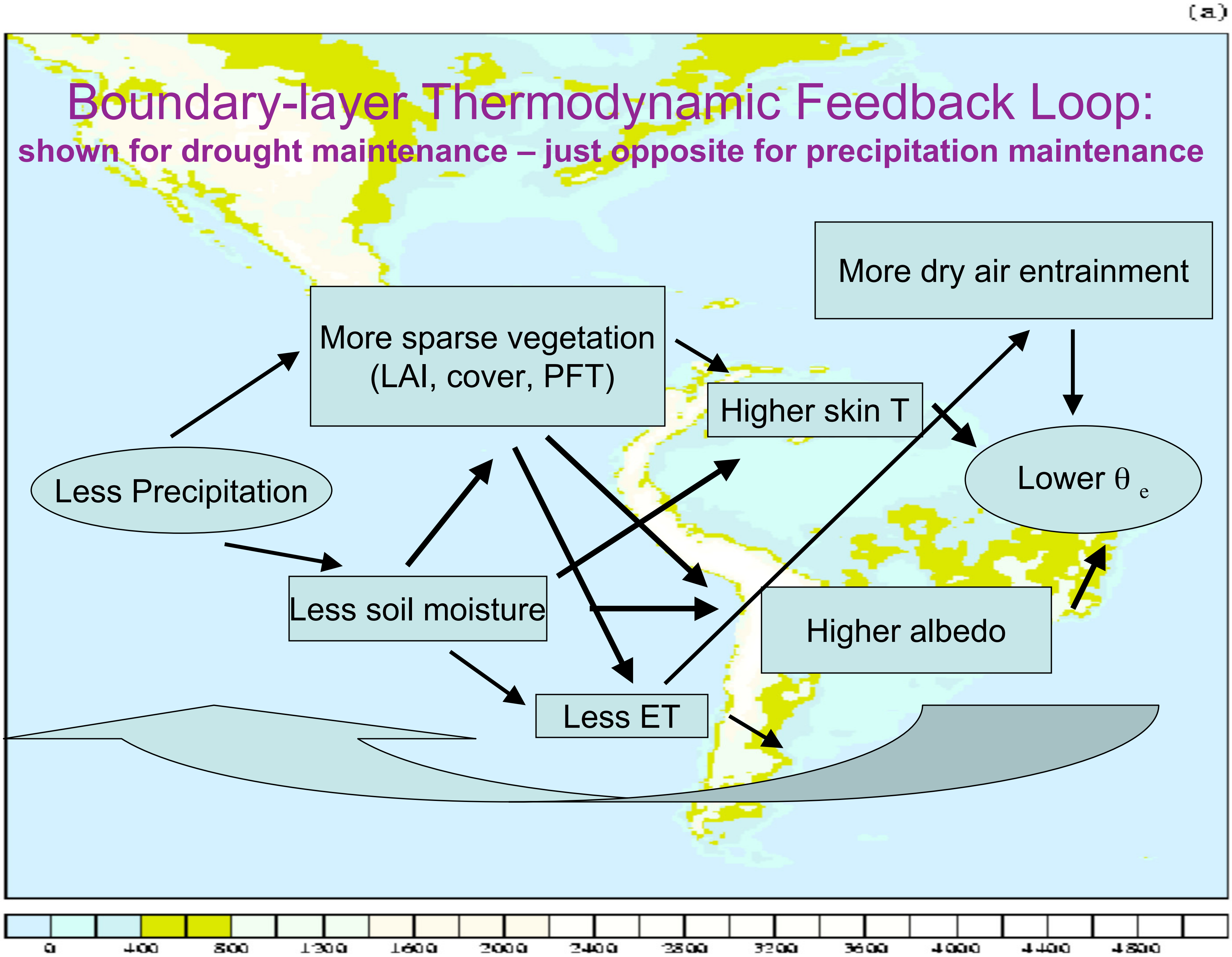
What are dependences on lateral transport?

- Lateral transport of moist static energy at BL levels can destabilize or stabilize by increase or decrease moist static energy (e.g. trajectories from warm or cold ocean)
- Lateral transport in overlying stable layer of moist static energy acts in same direction



Boundary-layer Thermodynamic Feedback Loop:

shown for drought maintenance – just opposite for precipitation maintenance



Less Precipitation

More sparse vegetation (LAI, cover, PFT)

Less soil moisture

Less ET

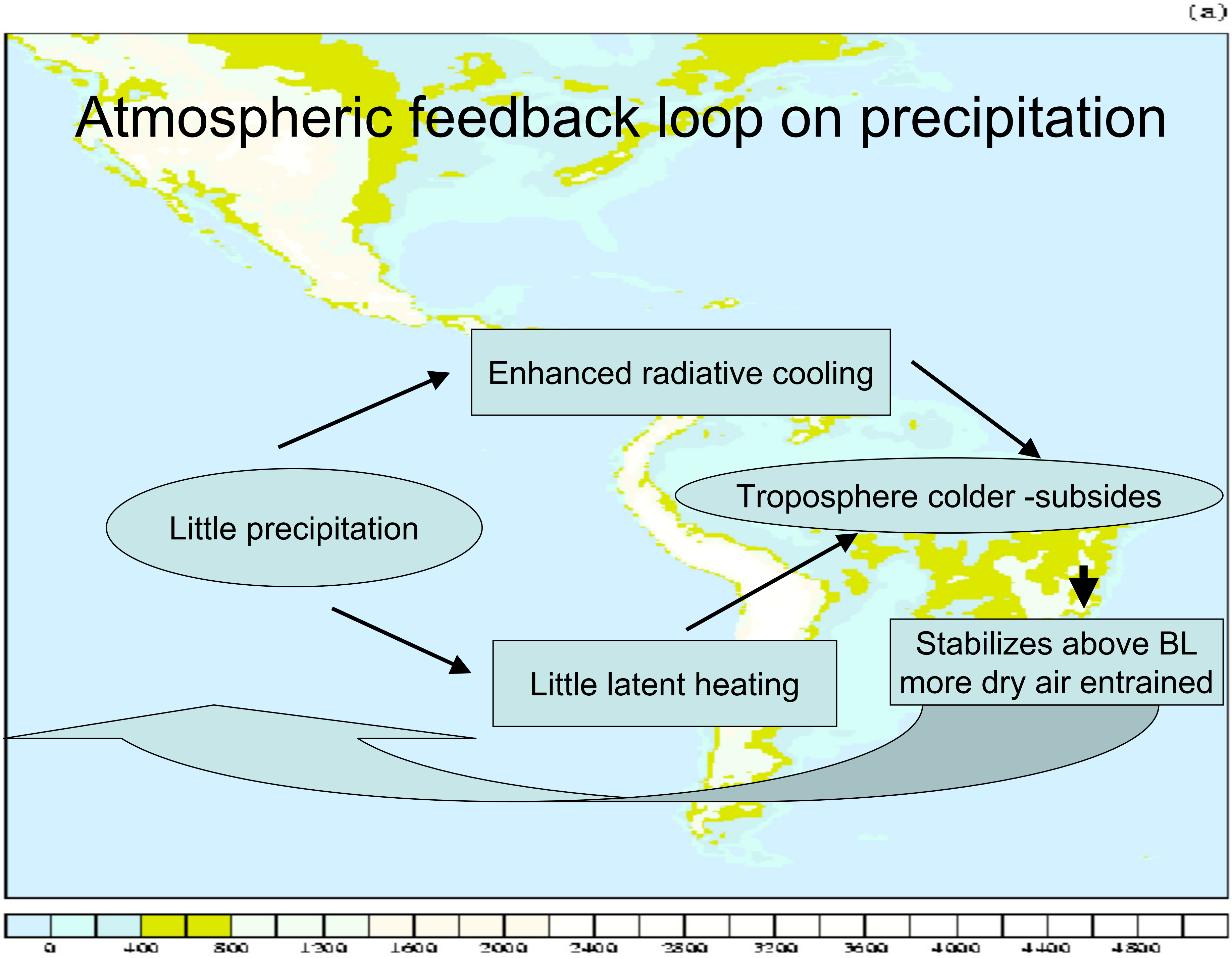
Higher skin T

Higher albedo

More dry air entrainment

Lower θ_e

Atmospheric feedback loop on precipitation



Little precipitation

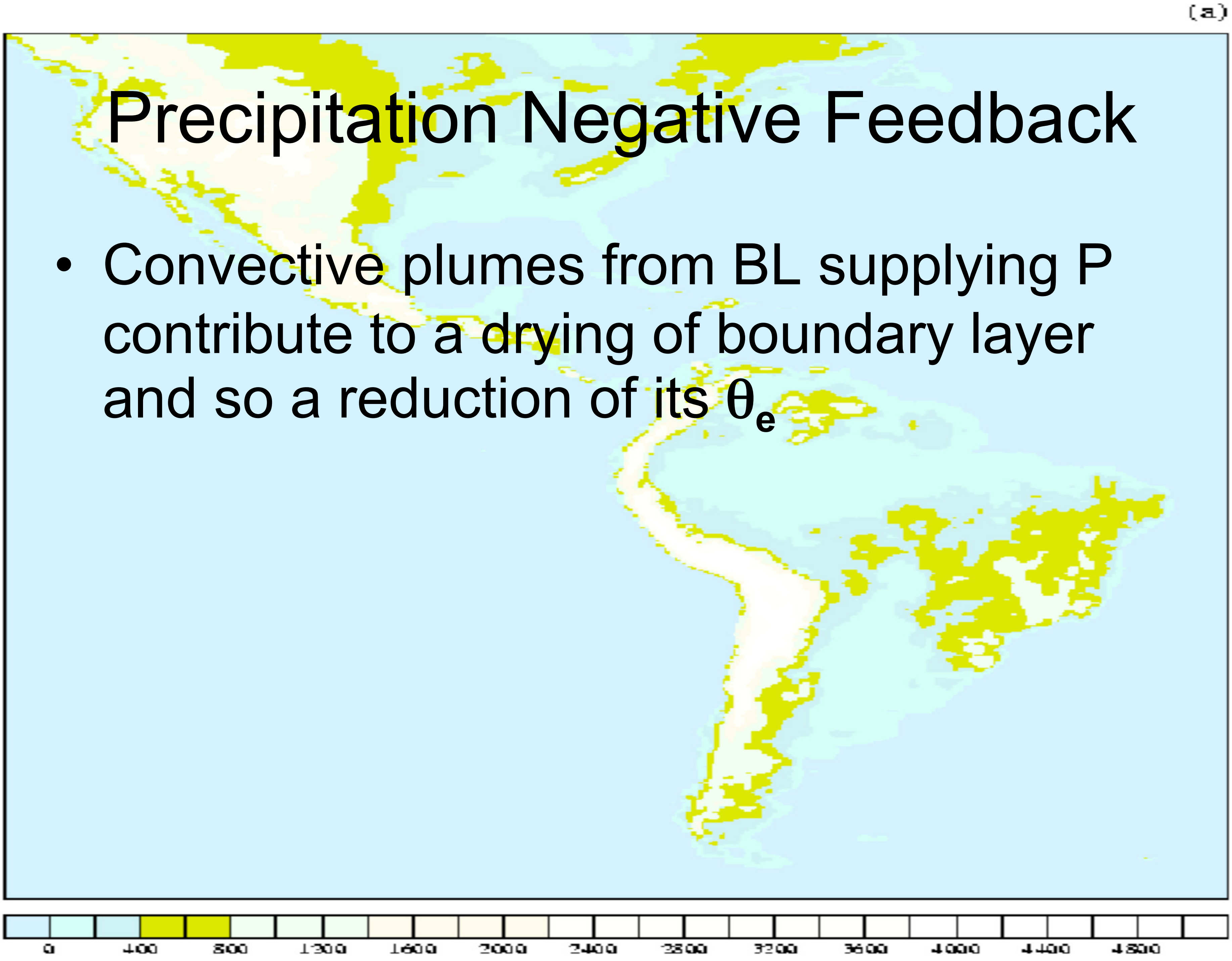
Enhanced radiative cooling

Troposphere colder -subsides

Stabilizes above BL
more dry air entrained

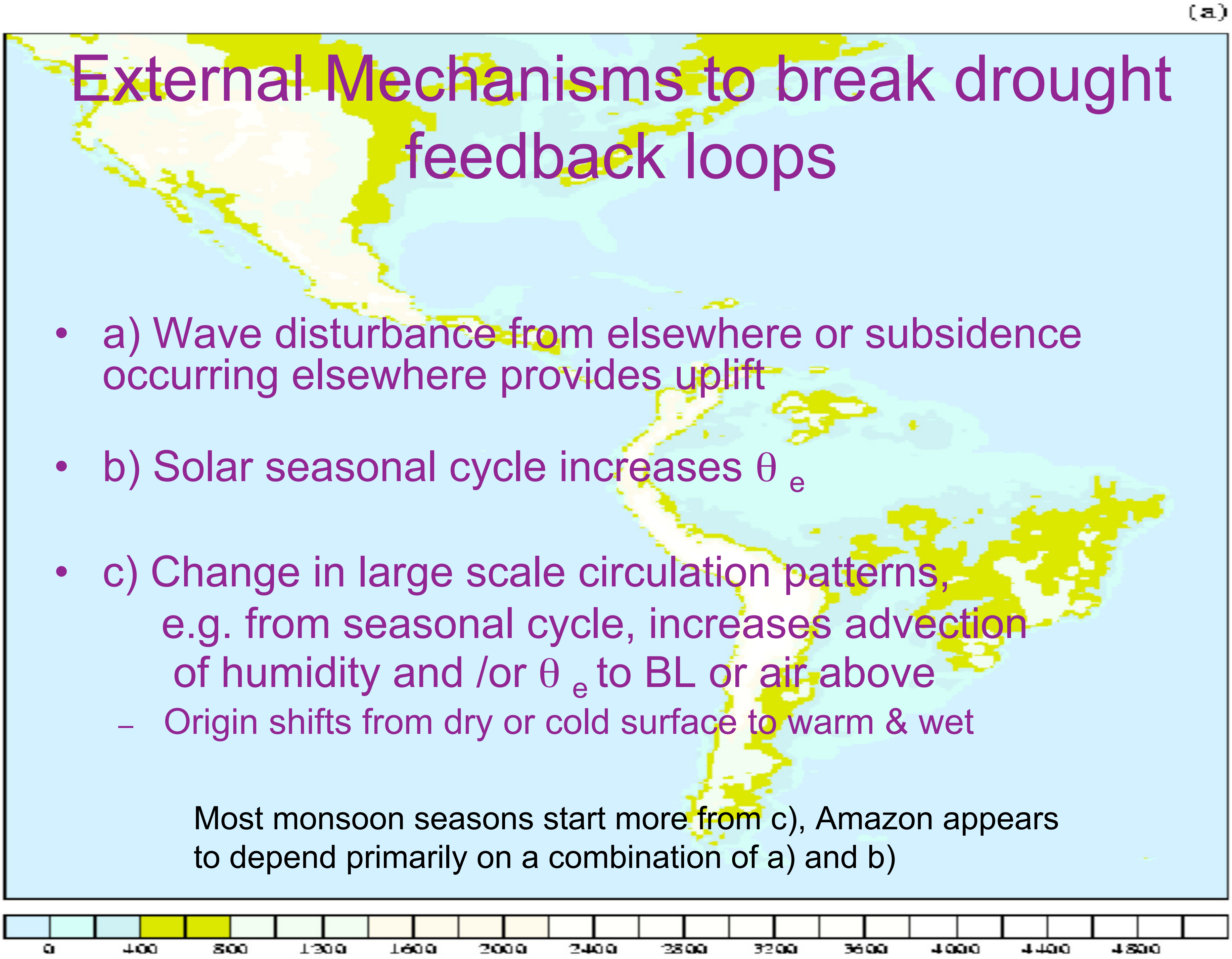
Little latent heating

Precipitation Negative Feedback



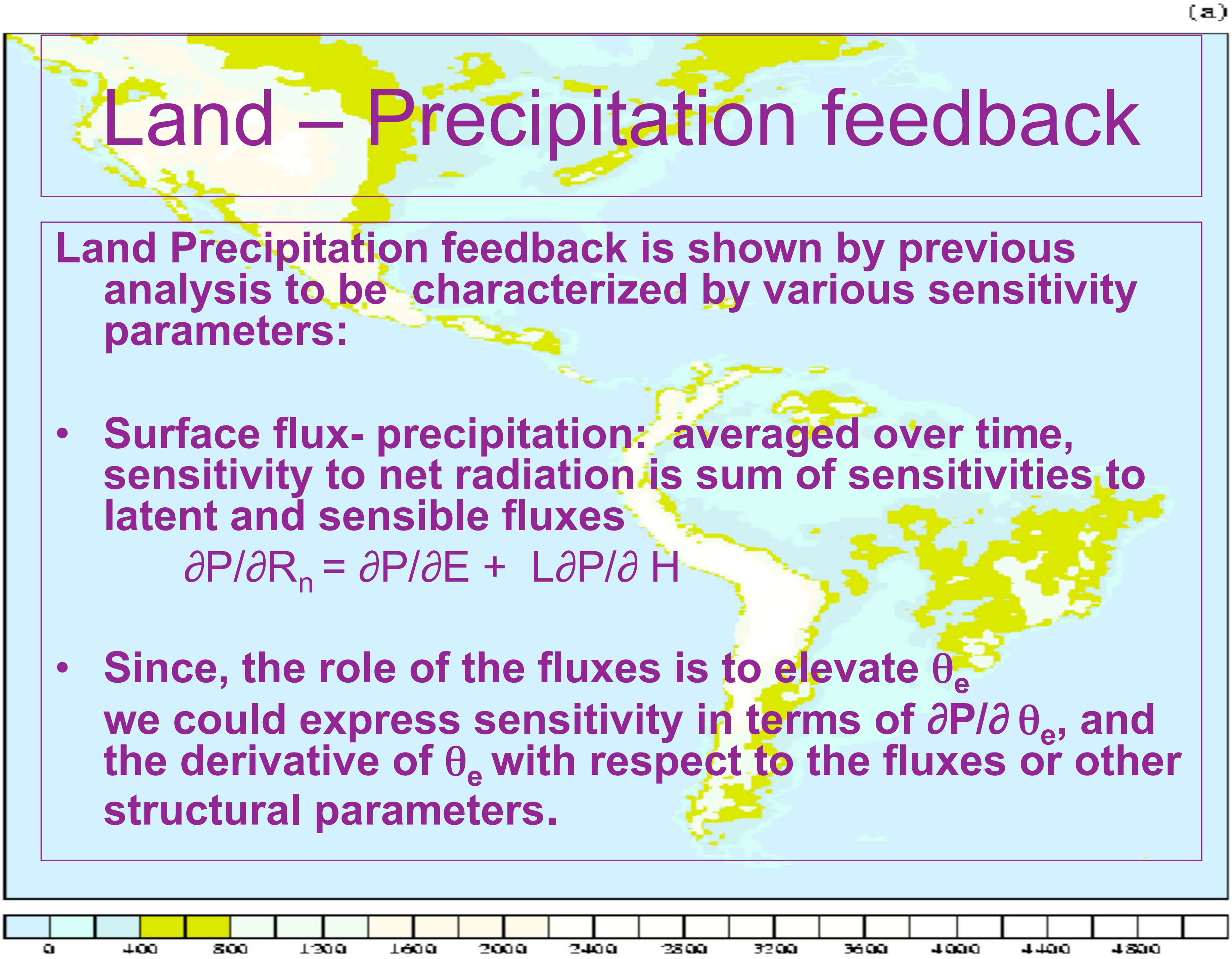
- Convective plumes from BL supplying P contribute to a drying of boundary layer and so a reduction of its θ_e

External Mechanisms to break drought feedback loops



- a) Wave disturbance from elsewhere or subsidence occurring elsewhere provides uplift
- b) Solar seasonal cycle increases θ_e
- c) Change in large scale circulation patterns, e.g. from seasonal cycle, increases advection of humidity and /or θ_e to BL or air above
  - Origin shifts from dry or cold surface to warm & wet

Most monsoon seasons start more from c), Amazon appears to depend primarily on a combination of a) and b)



Land – Precipitation feedback

Land Precipitation feedback is shown by previous analysis to be characterized by various sensitivity parameters:

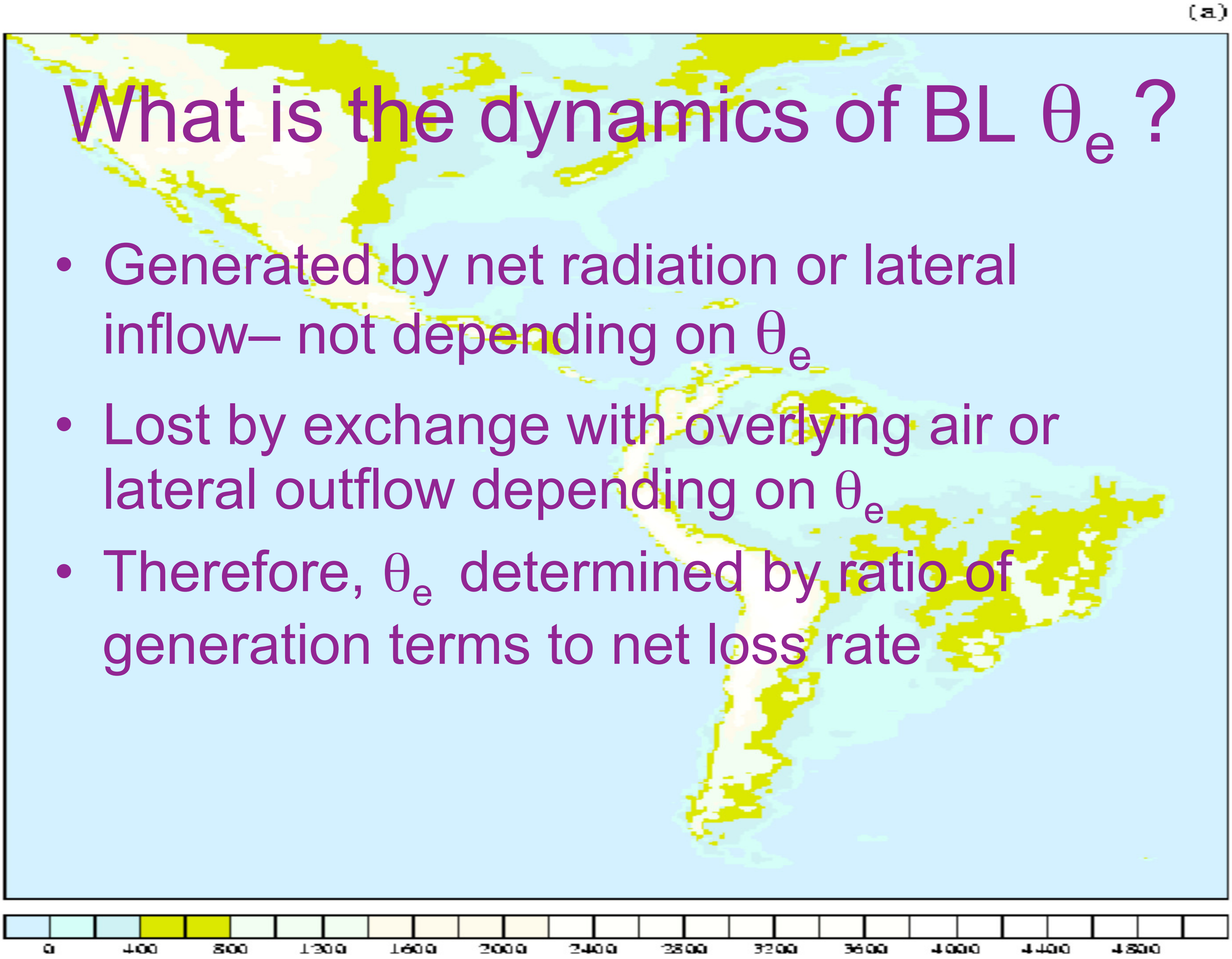
- **Surface flux- precipitation: averaged over time, sensitivity to net radiation is sum of sensitivities to latent and sensible fluxes**

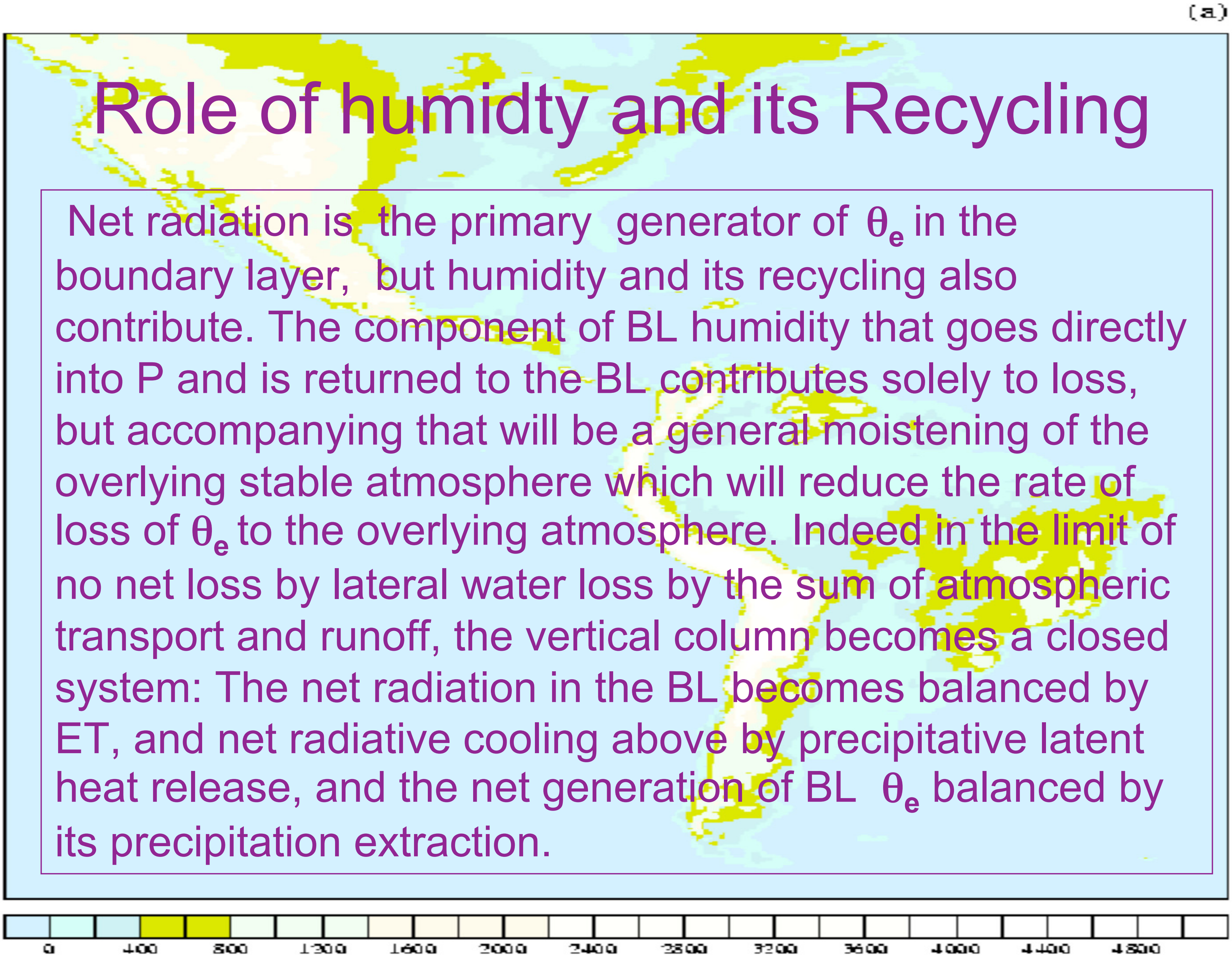
  $$\partial P/\partial R_n = \partial P/\partial E + L\partial P/\partial H$$

- **Since, the role of the fluxes is to elevate θ_e we could express sensitivity in terms of $\partial P/\partial \theta_e$, and the derivative of θ_e with respect to the fluxes or other structural parameters.**

What is the dynamics of BL θ_e ?

- Generated by net radiation or lateral inflow– not depending on θ_e
- Lost by exchange with overlying air or lateral outflow depending on θ_e
- Therefore, θ_e determined by ratio of generation terms to net loss rate





Role of humidty and its Recycling

Net radiation is the primary generator of θ_e in the boundary layer, but humidity and its recycling also contribute. The component of BL humidity that goes directly into P and is returned to the BL contributes solely to loss, but accompanying that will be a general moistening of the overlying stable atmosphere which will reduce the rate of loss of θ_e to the overlying atmosphere. Indeed in the limit of no net loss by lateral water loss by the sum of atmospheric transport and runoff, the vertical column becomes a closed system: The net radiation in the BL becomes balanced by ET, and net radiative cooling above by precipitative latent heat release, and the net generation of BL θ_e balanced by its precipitation extraction.

Example From Wenhong Li Dissertation:

- ***Increase of land surface flux begins to destabilize the atmosphere <u>prior to</u> the large-scale circulation transition, probably contribute to the <u>initial increase</u> of rainfall during the transition.***
- ***Increases rainfall probably contributes to the reversal of the cross-equatorial flow***
  - ***Weak continent-ocean temperature difference (<3°C at the surface), and in the upper troposphere (500-200 mb, Webster et al. 1998).***
  - ***The surface sensible flux and continent-ocean temperature difference decrease as the northerly cross-equatorial flow strengthens during the transition.***
- ***Can anomalous land surface fluxes during early transition cause interannual changes of wet season onset?***