Surface Energy Budget Changes During the Early 21st Century Australian Drought

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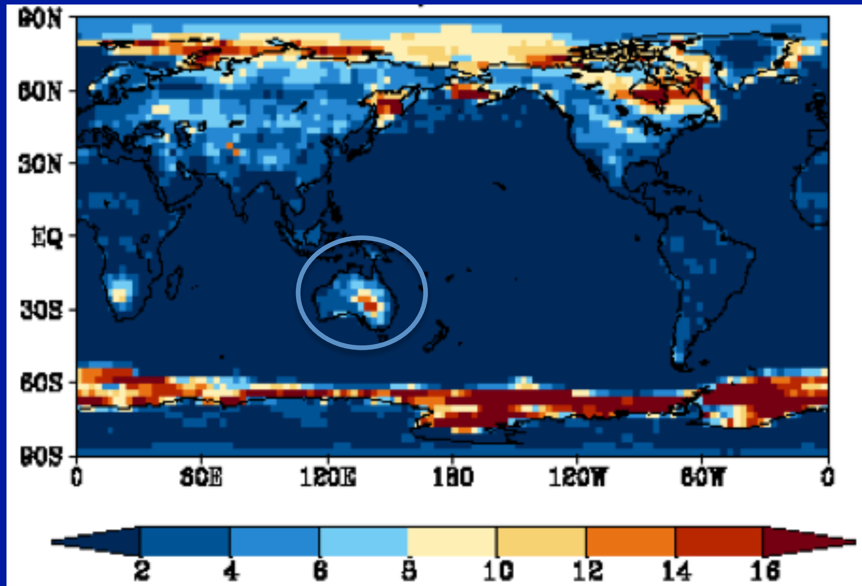
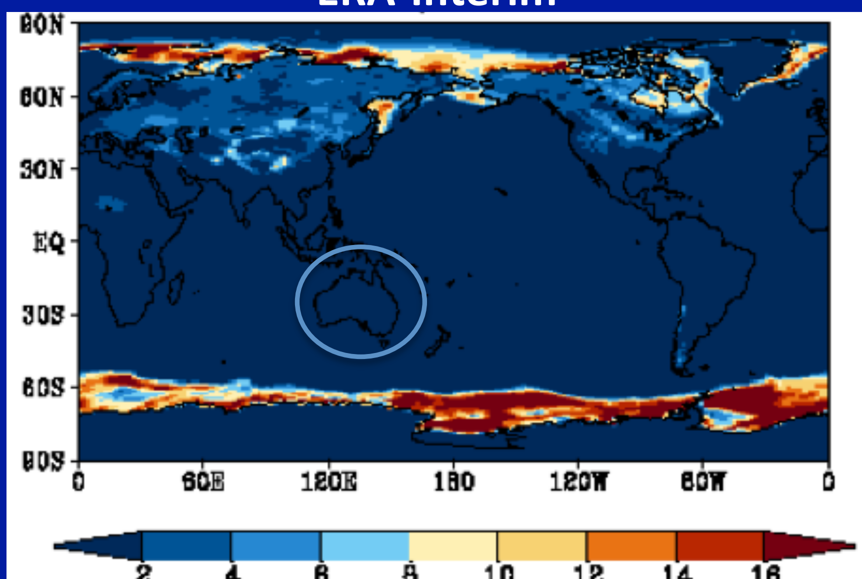
Standard Deviation in Clear-Sky SW TOA Flux Anomalies (March 2000-February 2013)

CERES EBAF Ed2.8



ERA-Interim



- Significant variability over Australia in CERES is not apparent in ERA-Interim.
- Is this an artifact or real feature?

Tak Wong CERES presentation

The Millenium Drought over Australia

- A large portion of Australia experienced one of the worst droughts in its climate record of the last 120 years.

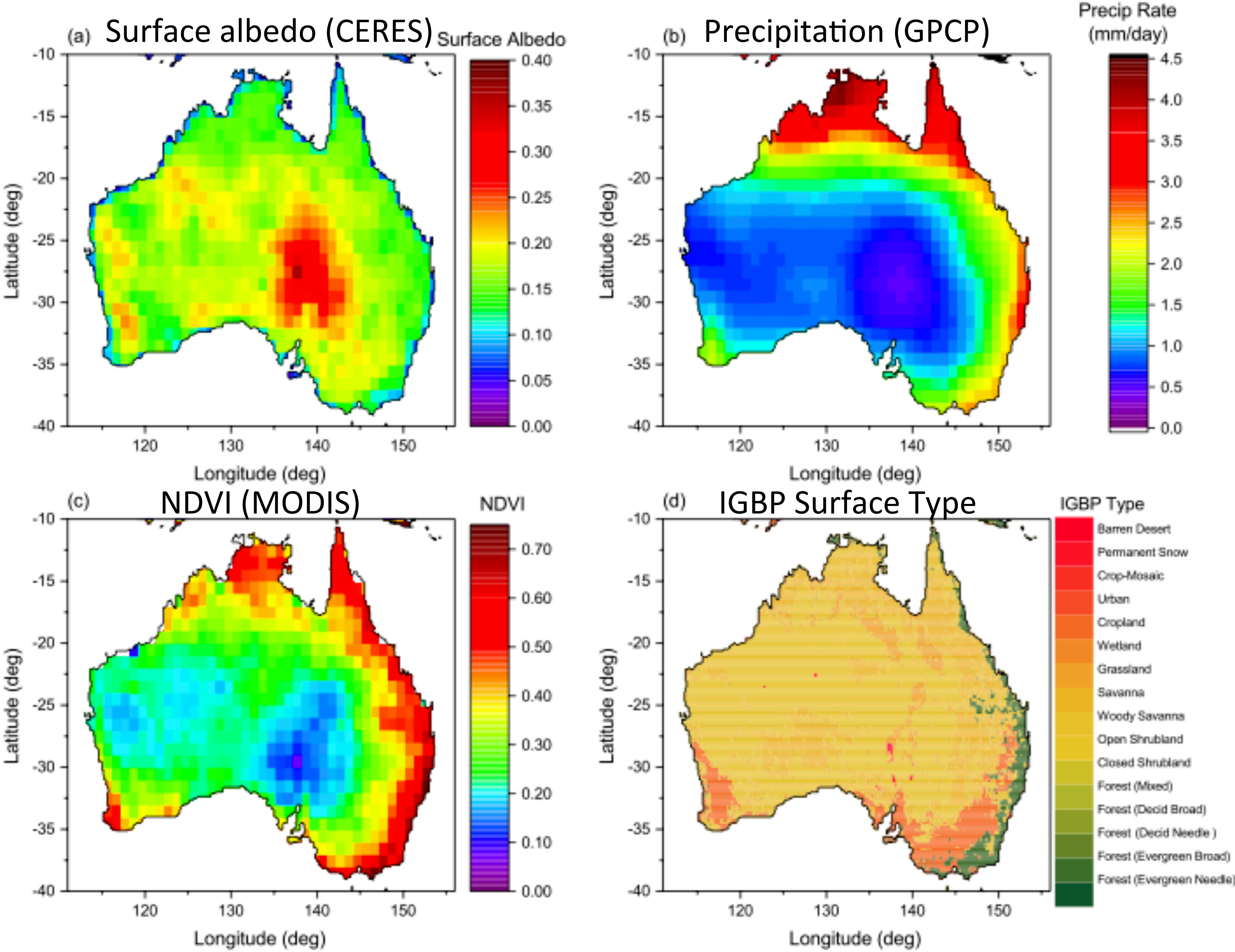
- Began in 1997 in southern areas such as Victoria during the El Niño event of that year and in late 2001 over a large portion of New South Wales and parts of Queensland and South Australia.

- Caused water shortages for rural and urban areas, drying of major river systems, and unprecedented agricultural losses.

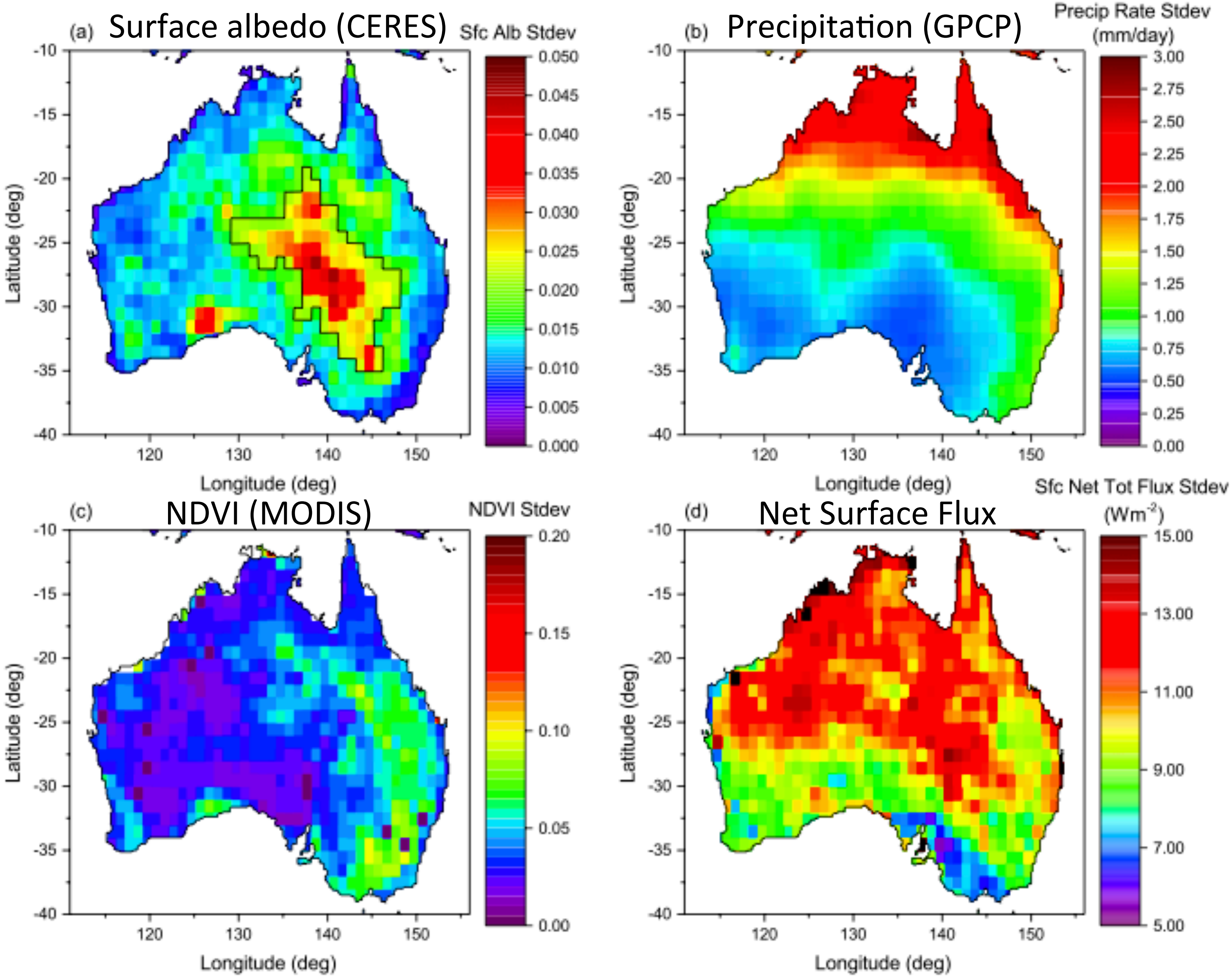
- The drought finally ended in 2010 with the arrival of record-high rainfall across much of Australia.

- Drought conditions in southeastern Australia are attributed to the contraction of westerly rainfall during the cool season.

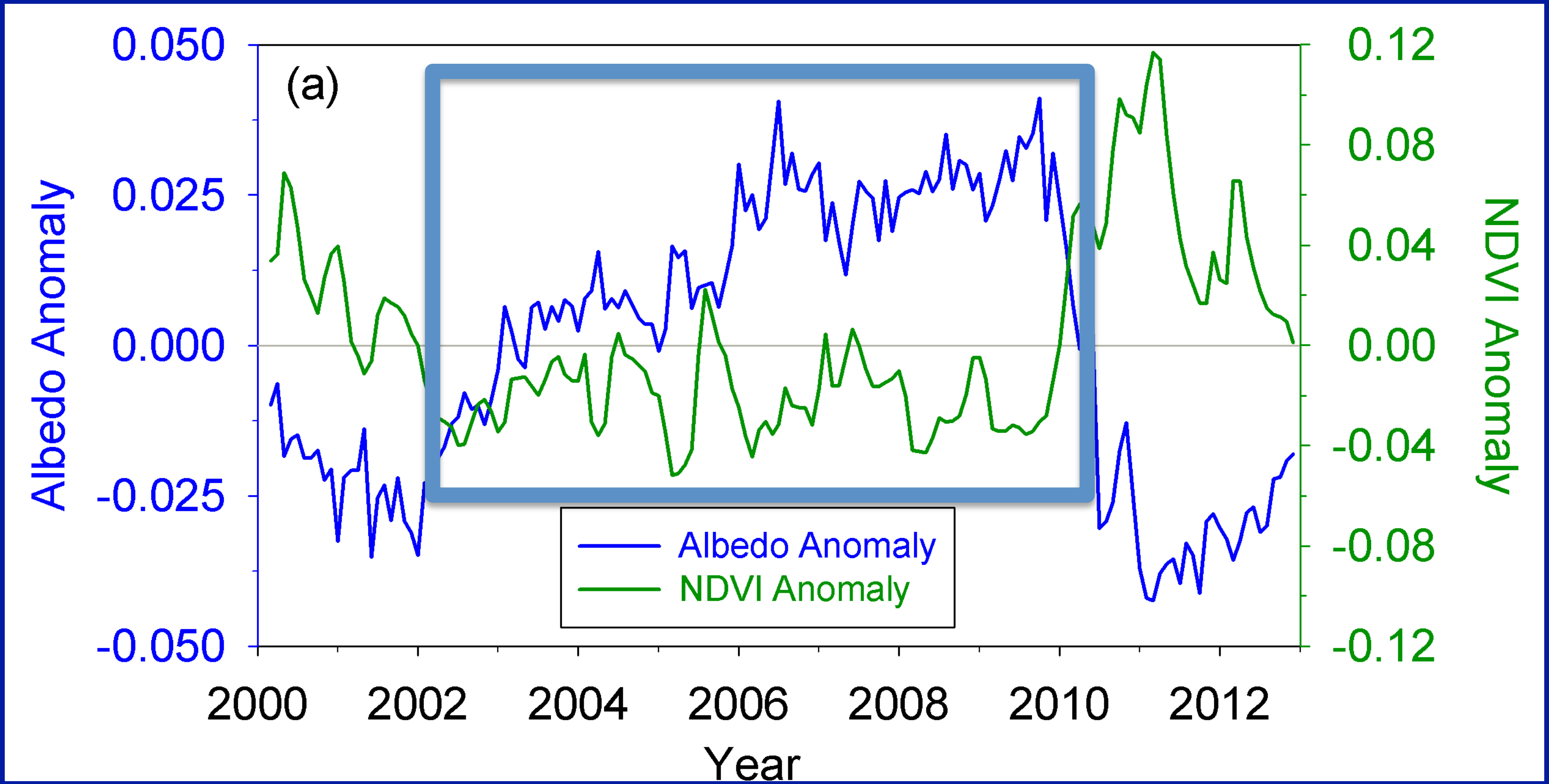
Mean Surface Properties for January 2001-December 2012



Anomaly Standard Deviations for January 2001-December 2012



Deseasonalized Monthly Anomalies in CERES Surface Broadband Albedo and MODIS NDVI (March 2000-December 2012; For Regions with Albedo STD > 0.02)

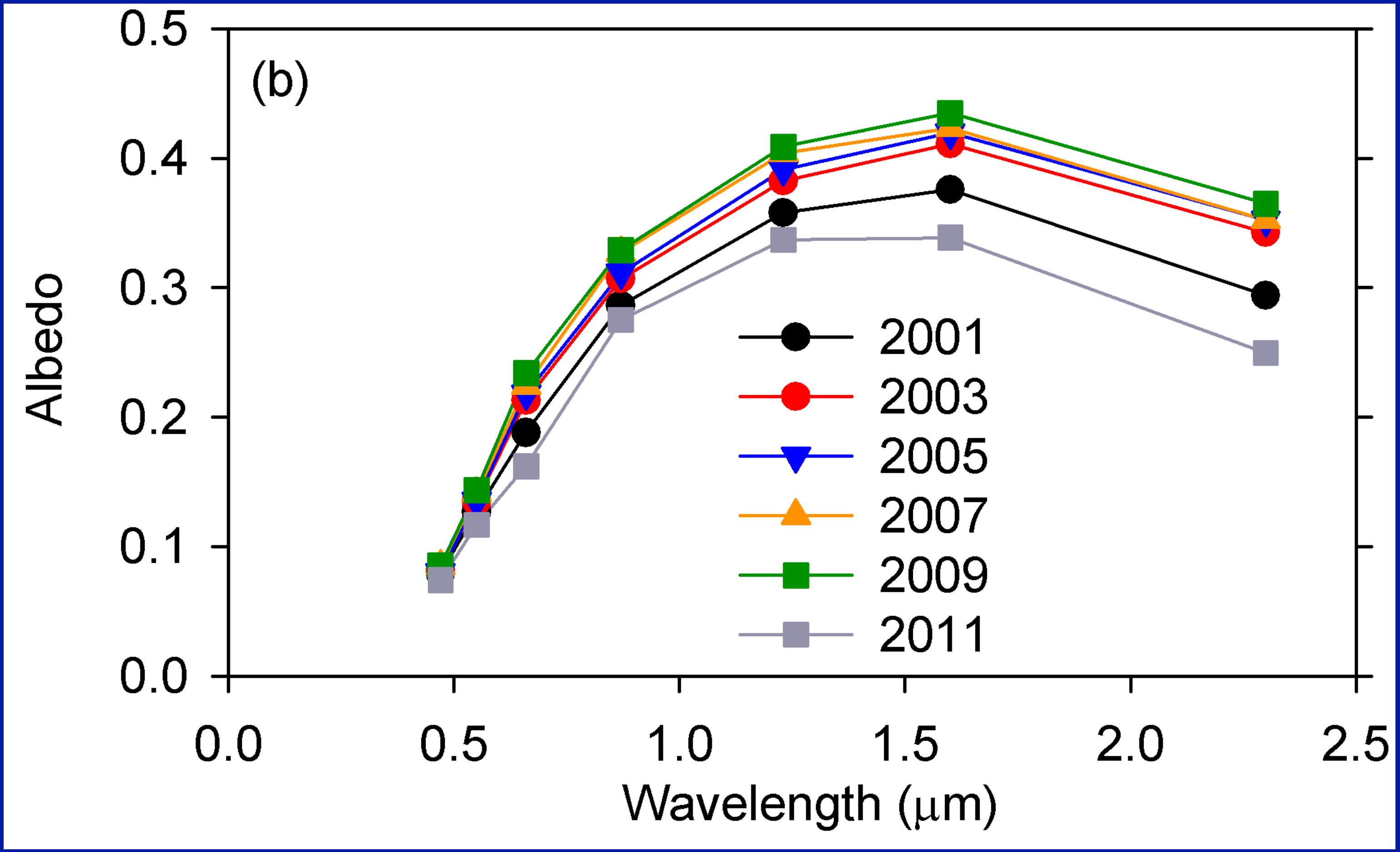


- Surface albedo increases 0.06 during the drought and decreases 0.08 after the drought.
- Surface albedo variations are associated with increased NDVI during wet years and decreased NDVI during drought years.

- During the worst drought years (2002 and 2009), surface albedo increases while NDVI shows no trend.
- What drives the multiyear surface albedo increase during the worst drought years?

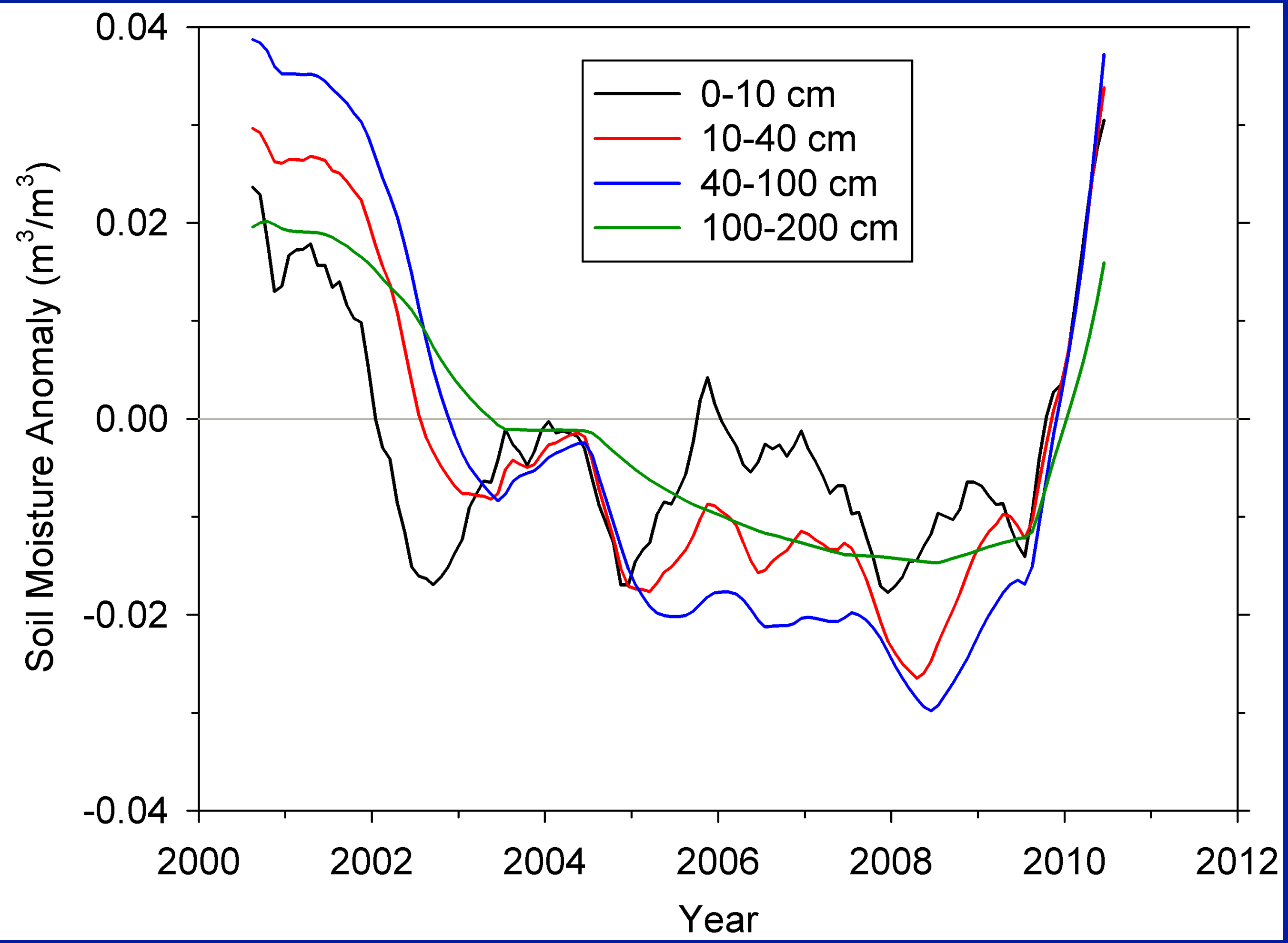
Annual Mean MODIS Surface Albedo Spectra

(For Regions with Albedo STD > 0.02)

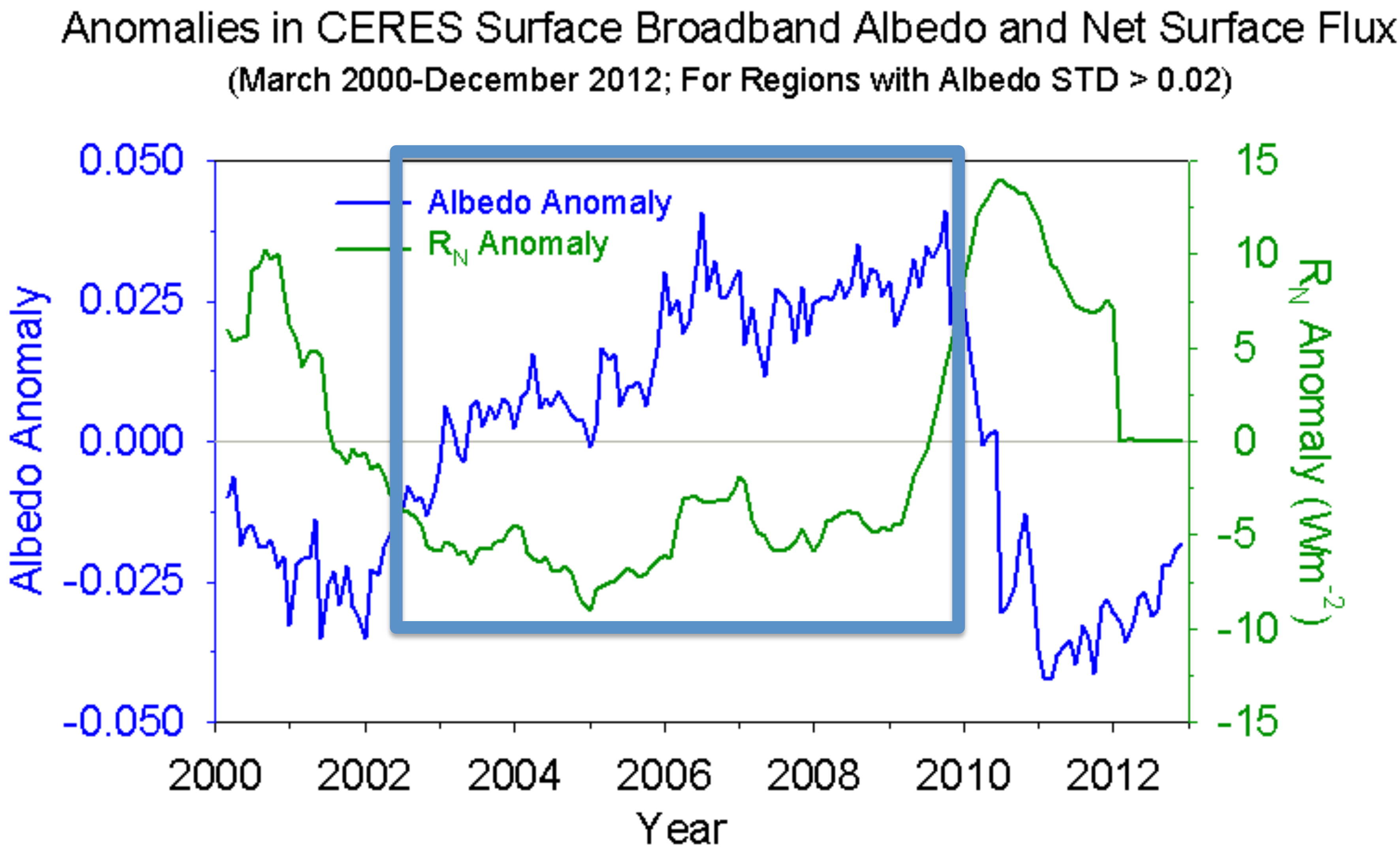


- Albedo changes are most pronounced in shortwave infrared region (1 to 3 μm).
- The changes are characteristic of those due to soil moisture content changes associated with water absorption features centered at 1.45 μm, 1.9 μm and 2.8 μm.

Anomalies in Layer-Average Soil Moisture Content Against Depth Beneath the Surface (March 2000 - December 2010; from the GLDAS-2 NOAH model)



- Marked multiyear decrease between 2000 and 2009 and recovery after 2010.
- Year-to-year variations more pronounced for the topmost layers associated with short-term fluctuations in precipitation.
- Deeper layers reflect the longer-term decline in rainfall.



- Despite marked increase in surface albedo, net surface flux (R_N) remains fairly flat during worst drought years (2002-2009).

Surface Energy & Moisture Budgets

$$R_N - H_G = H_L + H_S$$

R_N = Net downward radiative flux at the surface (CERES EBAF-SFC Ed2.8)
H_G = Ground heat flux into surface (negligible at interannual timescales)
H_L = Latent heat flux (determine from moisture budget)
H_S = Sensible heat flux

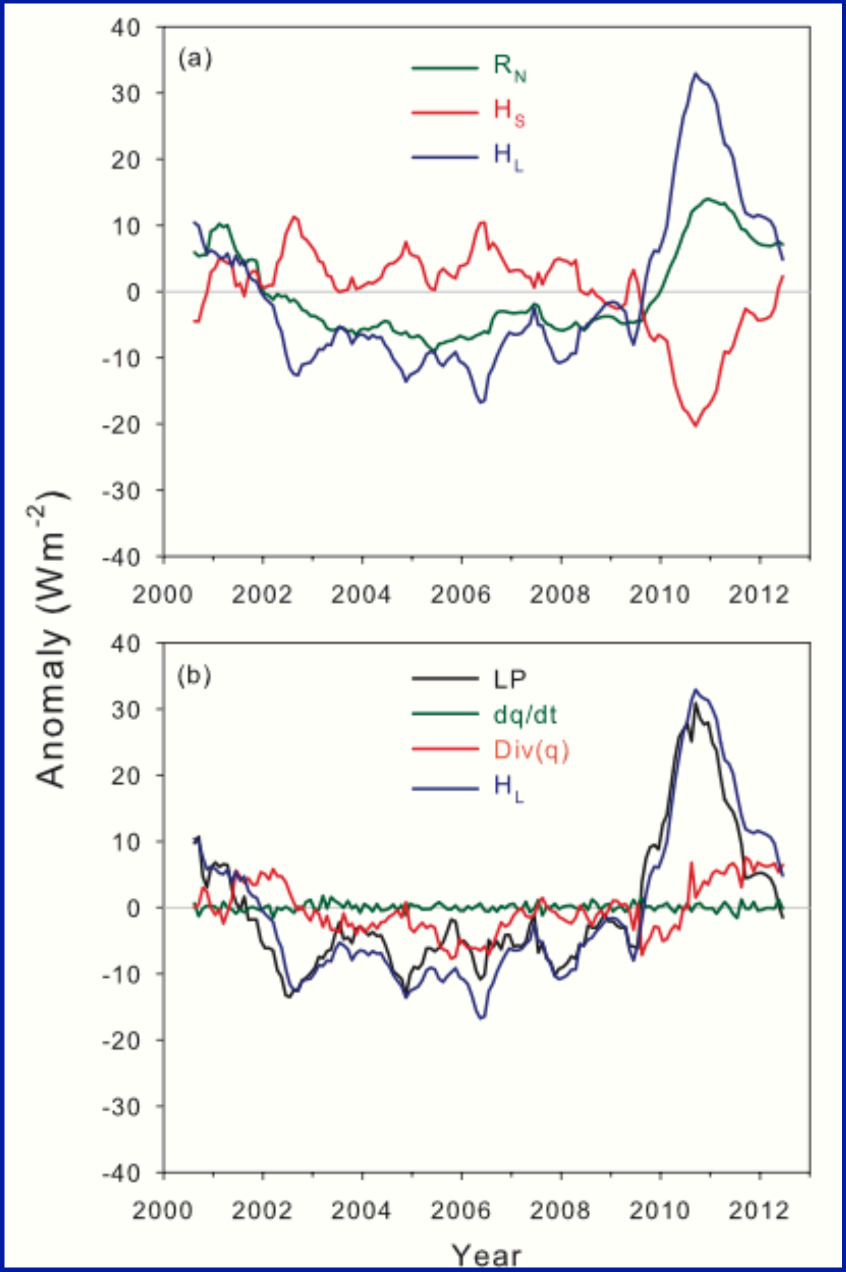
$$H_L = LP + \left(\frac{\partial q}{\partial t} + \nabla.\frac{1}{g}\int_0^{p_s} Lqvdp\right)$$

P = Precipitation (GPCP v2.2)
q = Specific humidity
ν = Specific velocity

- Moisture tendency and divergence are from mass corrected vertically integrated energy and moisture budget terms for ERA-Interim (NCAR Climate Data Guide, 2014).

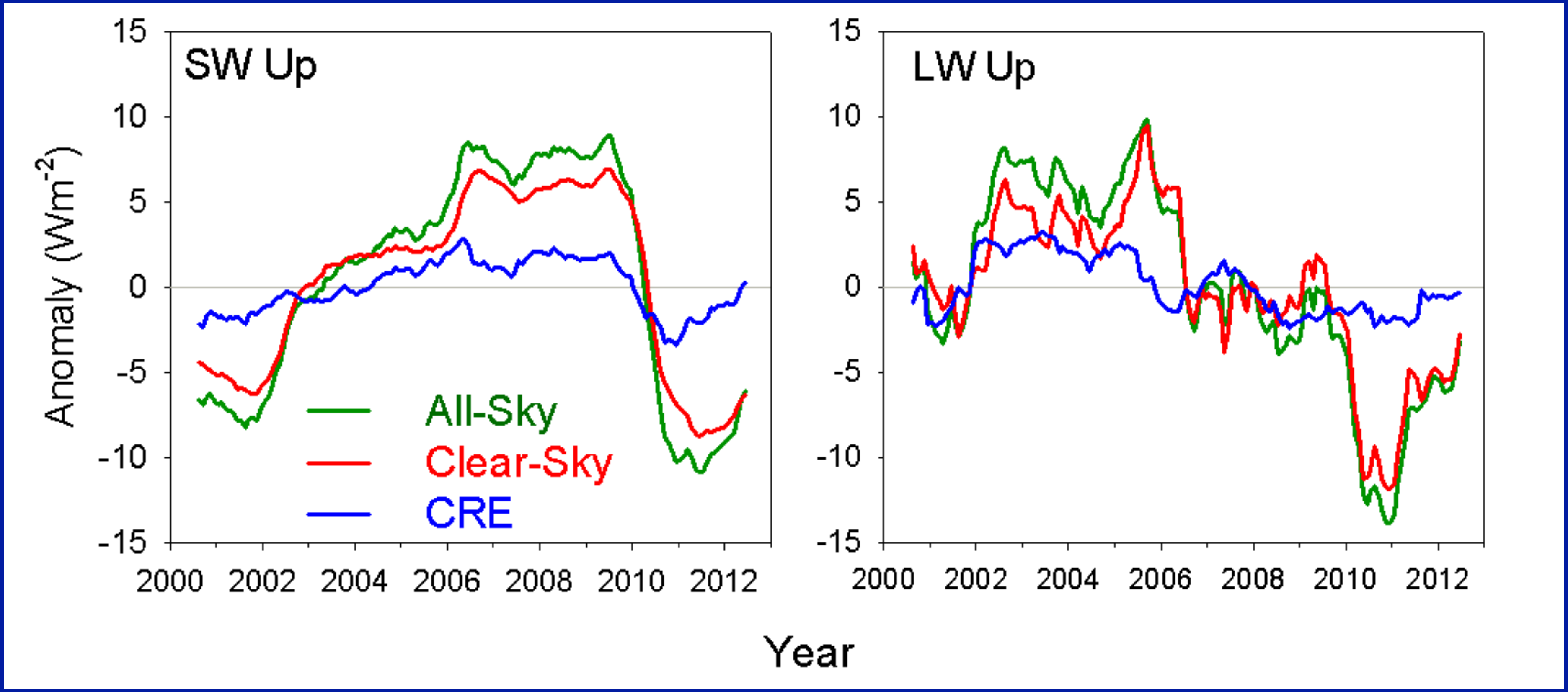
$$H_S = R_N - H_L$$

Anomalies in Surface Energy and Moisture Budget Terms
(For Regions with Albedo STD > 0.02)



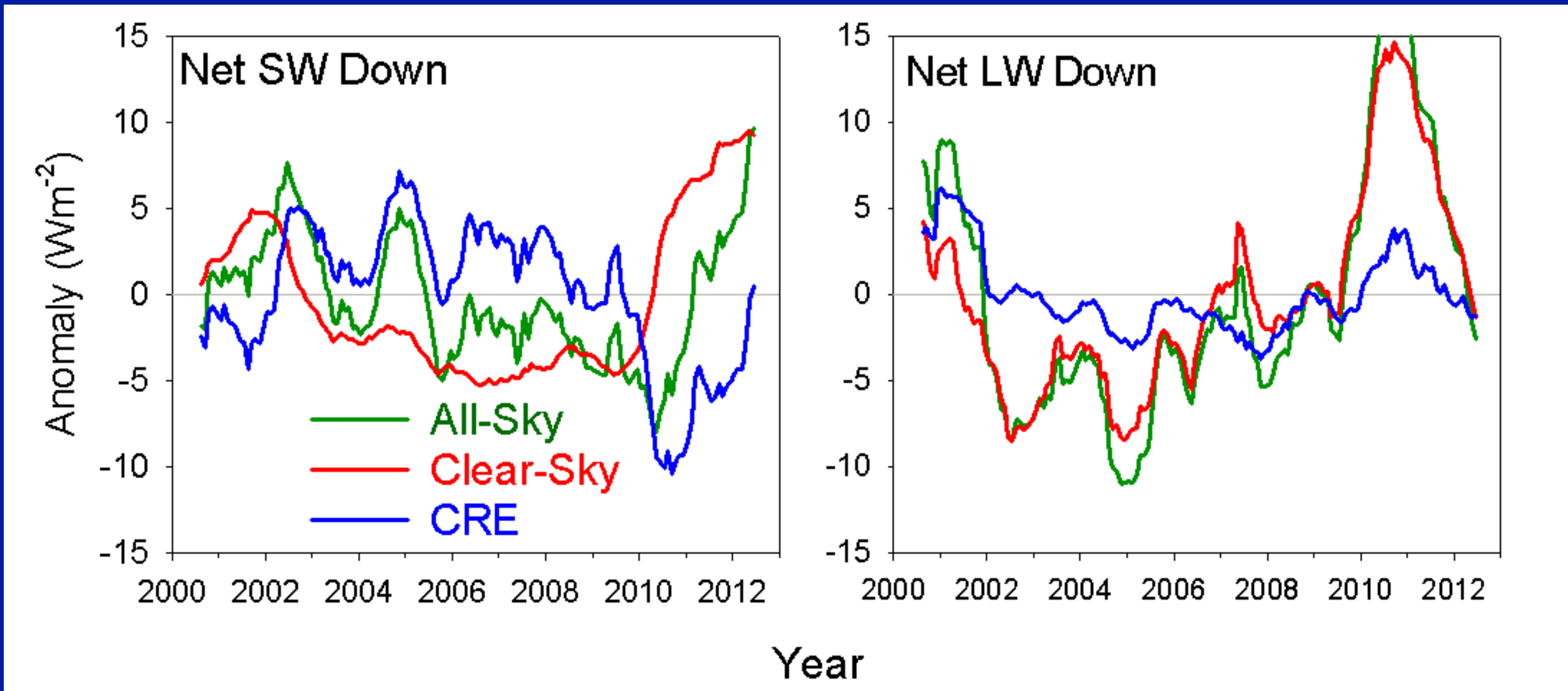
- Negative anomalies in H_L & R_N and positive anomalies in H_S during worst drought years (2002 and 2009).
- Evaporative fraction ($EF=H_L/(H_L+H_S)$) as low as 0.068 during drought.
- Following drought, anomalies in H_L reach 30 Wm^{-2} and the EF reaches 0.53.
- Precipitation variations dominate the moisture budget.

Upward SW and LW Surface Flux
(For Regions with Albedo STD > 0.02)



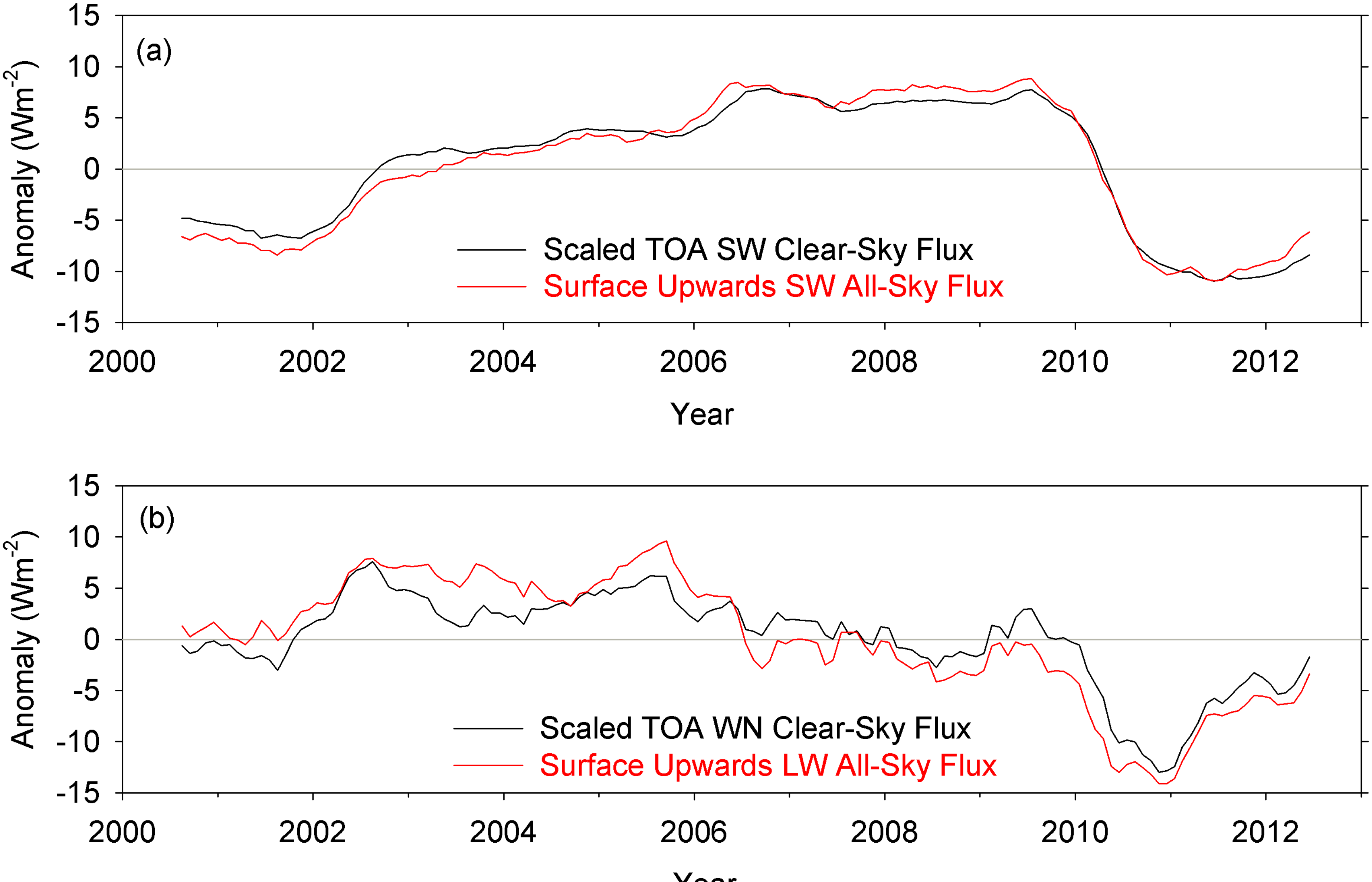
- The changes in R_N are largely determined by opposing trends in surface albedo and upward thermal radiation.
- As a result, R_N remains negative during the worst drought years but does not show a noticeable trend.

Net Downward SW and LW Surface Flux (For Regions with Albedo STD > 0.02)



- Positive SW CRE anomalies (due to reduced cloud cover) are largely offset by negative anomalies in clear-sky net downward LW fluxes.
- Extreme reductions in cloud cover=> warmer surface temperatures & drier atmosphere => stronger LW radiative cooling of the surface.

Anomalies in TOA Clear-Sky (Scaled) and Surface Upward Radiative Fluxes



Conclusions

- During the Millenium drought over Central Australia, surface albedo increased approximately 0.06 (20%) during a 10-year period, followed by a sudden drop of 0.08 after heavy rainfall associated with a strong La Niña.

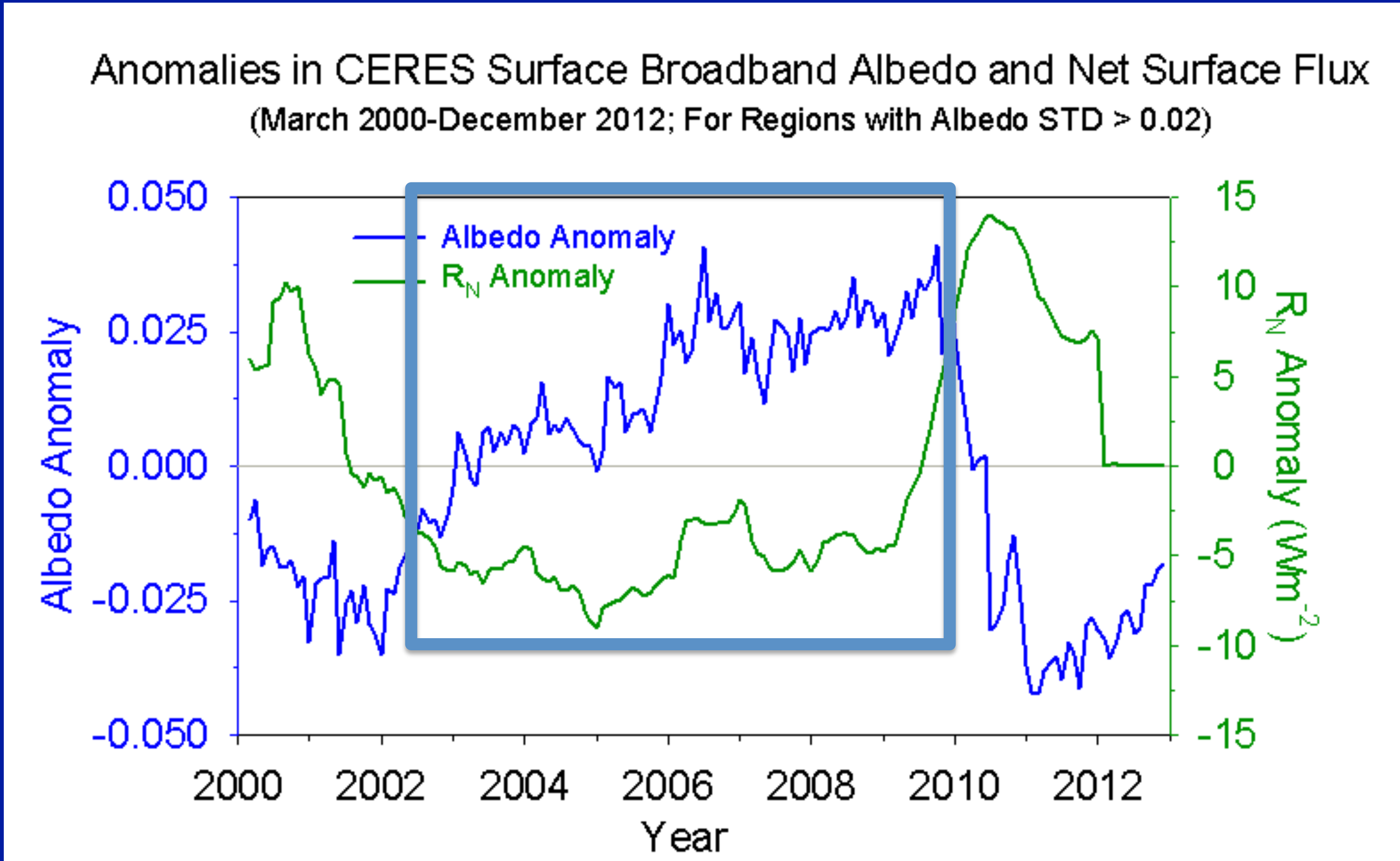
- Albedo changes are most pronounced in shortwave infrared region (1 to 3 μm).

- During worst drought years, the increase in albedo is accompanied by a slow decline in soil moisture in deeper layers beneath surface.

- Mechanisms coupling multiyear surface albedo increase and decline in deep-layer soil moisture are unclear.

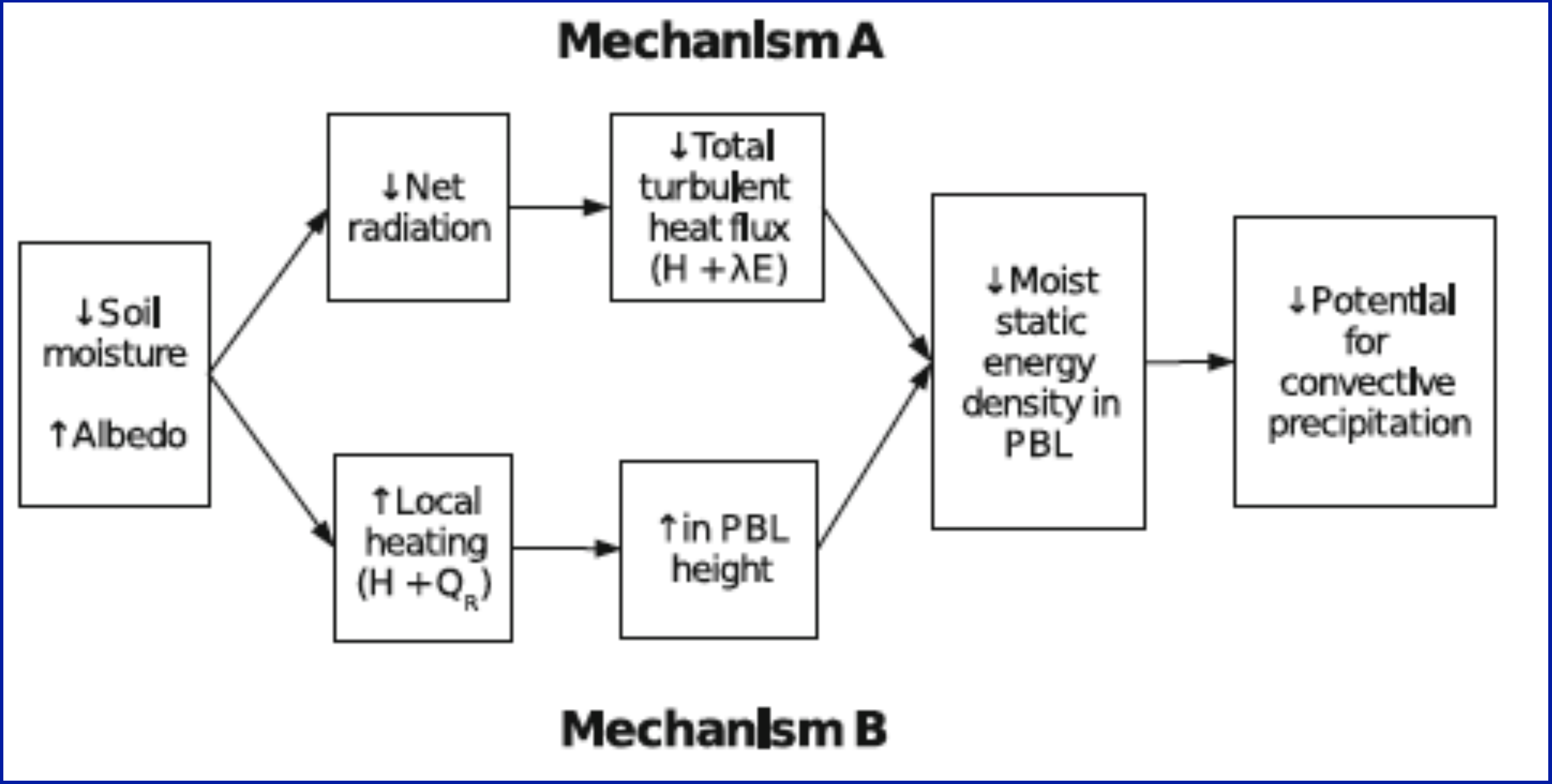
Conclusions

- Energy budget analysis shows the following changes relative to average conditions:
  - ⇒ Higher surface albedo, increased upward emission of thermal radiation, lower downwelling LW radiation, reduced net total downward radiation, less evaporation, and more sensible heating.
- During extreme drought (EF=0.068), net surface radiation stays constant despite continued increase in surface albedo (decrease in LW up compensates).
- Most land surface models do not dynamically account for these surface energy budget changes.
  - Rather, surface albedo is often prescribed using its monthly climatology and held constant in time.



- Despite marked increase in surface albedo, net surface flux (R_N) remains fairly flat during worst drought years (2002-2009).

Land–Atmosphere Drought Feedback Mechanisms
(Transition from Wet-to-Dry Period)



Meng et al., Clim. Dyn., 2014