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

Norman G. Loeb¹, Hailan Wang², Lusheng Liang², Seiji Kato¹, Fred G. Rose²

¹NASA Langley Research Center, Hampton, VA, USA
²Science Systems and Applications, Inc., Hampton, VA, USA
- 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

(a) Surface albedo (CERES)

(b) Precipitation (GPCP)

(c) NDVI (MODIS)

(d) IGBP Surface Type
Anomaly Standard Deviations for January 2001-December 2012

(a) Surface albedo (CERES)

(b) Precipitation (GPCP)

(c) NDVI (MODIS)

(d) Net Surface Flux
- 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?
- 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.
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

\[ H_L = LP + \left( \frac{\partial q}{\partial t} + \nabla \cdot \left( \frac{1}{g} \int_0^P Lqv \, dp \right) \right) \]

\( P \) = Precipitation (GPCP v2.2)
\( q \) = Specific humidity
\( v \) = 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.
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

(a) Scaled TOA SW Clear-Sky Flux
(b) Scaled TOA WN Clear-Sky Flux

Year

Anomaly (Wm$^{-2}$)

Surface Upwards SW All-Sky Flux
Surface Upwards LW All-Sky Flux

Conclusions

- During the Millennium 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