METR 5223: Atmospheric Radiation

Global Dimming

Lecture for Spring 2009, v0.2

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From the Wikipedia: Global dimming is the gradual reduction in the amount of global *direct* irradiance at the Earth's surface, observed since the beginning of systematic measurements in 1950s.

More commonly it is defined as a reduction both *direct* and *indirect* downward solar irradiance at the Earth's surface.

Worldwide it is of the order of a 4% reduction over the three decades from 1960 - 1990.

TOA of changes in upward or downward solar irradiance are much smaller.

Much of the reduction has been inferred from the rate of evaporation from standardized evaporation pans:

Typical reduction in E is 0.1 m yr^{-1}.

Relating changes in E to changes in R_s

Recall our symbols for energy balance at the surface:

$$R = H + LE + G$$

The evaporation mass flux E is controlled by the difference in specific humidity q across the surface layer:

$$E = \rho C U (q_s - q)$$

For a saturated surface, or $q_s = q^*(T_s)$, Penman (1948) has derived:

$$LE = \frac{s}{s+\gamma}(R-G) + \frac{\gamma}{s+\gamma}L\rho CU(q^* - q)$$

$q^* - q$, or Δq, is the saturation deficit above the surface layer.

$\gamma = c_p/L$ (the pyschrometric constant) and $s = \frac{\partial q*}{\partial T}$.

The derivation follows...

$$q_s - q = q^*(T_s) - q = q^*(T_s) - [q^*(T) - \Delta q]$$

$$= q^*(T_s) - q^*(T) + \Delta q$$

$$= \frac{\partial q^*(T)}{\partial T}(T_s - T) + \Delta q$$

$$= s(T_s - T) + \Delta q$$

So

$$E = \rho C U (q_s - q)$$

$$E = \rho C U s(T_s - T) + \rho C U \Delta q$$

$$LE = L\rho C U s(T_s - T) + L\rho C U \Delta q$$

but

$$H = c_p \rho C U (T_s - T)$$

$$LE = \frac{L}{c_p} s H + L \rho C U \Delta q$$

$$LE = \frac{1}{\gamma} s H + L \rho C U \Delta q$$

$$LE = \frac{s}{\gamma} (R - LE - G) + L \rho C U \Delta q$$

$$\left(1 + \frac{s}{\gamma}\right) LE = \frac{s}{\gamma} (R - G) + L \rho C U \Delta q$$

$$LE = \frac{s}{s + \gamma} (R - G) + \frac{\gamma}{s + \gamma} L \rho C U \Delta q$$

Roderick and Farquhar (2002) make the following modifications for application to the annual pan evaporation:

- G is dropped in the time-average.
- They adopt the Priestley and Taylor (1972) approximation that the second term simply boosts the first by 26%. RF claim that Δq had not changed in recent decades so there is no harm in not explicitly retaining the second term when investigating *changes* in LE.

$$LE = 1.26 \frac{s}{s+\gamma} R$$

From an evaporation pan, E is enhanced compared to a flat surface (pond, lake) because the sides of the pan are warmed but the *flux* is constrained to come out of the water surface. The *flux density* is enhanced by 40%:

$$LE_{\text{pan}} = 1.4 \times 1.26 \frac{s}{s+\gamma}\ R$$

RF state that

$$0.48 < \frac{s}{s+\gamma} < 0.82$$

We take a value of 0.65:

$$LE_{\text{pan}} = 1.4 \times 1.26 \times 0.65\ R$$

The net radiation R is the sum of inward solar radiation R_s, inward IR, minus outward IR, minus outward solar. Changes in the latter two terms tend to cancel as the surface and air temperature change up and down together. RF assume changes in R are dominated by changes in R_s: $\delta R = 0.8\ \delta R_s$.

$$L\delta E_{\text{pan}} = 1.4 \times 1.26 \times 0.65 \times 0.8\ \delta R_s$$

$$\boxed{L\delta E_{\text{pan}} = 0.91\ \delta R_s \approx 1.0\ \delta R_s}$$

$$\delta R_s = -2.5\times10^6\ \text{J kg}^{-1}\times 100\ \text{kg m}^{-2}\ \text{yr}^{-1} \div 3.16\times10^7\ \text{s yr}^{-1}$$

$$\delta R_s = -7.9\ \text{W m}^{-2}$$

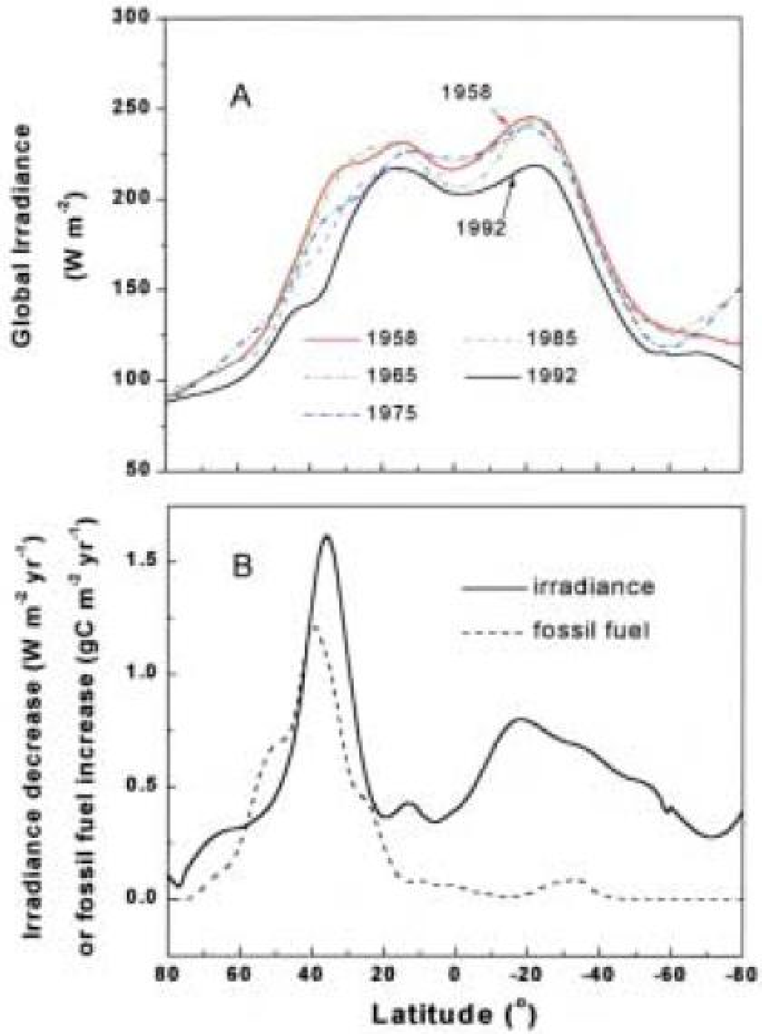

Fig. 1 Latitudinal variation of global dimming, 1958–92 (from Stanhill and Cohen 2001). ($gC\ m^{-2} yr^{-1}$ is grams of carbon per square metre per year.)

In the absence of changes in surface air temperature or relative humidity, the fundamental cause of reduced evaporation is reduced temperature of the water.

(Or, with “global warming” of surface air, the water cools relative to the air.)

By how much does the water cool with $\delta R_s = -7.9$ W m^{-2} ?

With

$$LE = 1.26 \frac{s}{s + \gamma} R$$

and

$$\delta R = 0.8 \ \delta R_s$$

we have

$$\delta LE = 1.0 \frac{s}{s + \gamma} \delta R_s$$

Recall the Δ in Δq signified a specific humidity deficit:

$$\Delta q = q^*(T) - q$$

Otherwise, δ is been used to signify the state in the presence of global dimming minus the state without global dimming.

It is thus meaningful to write $\delta\Delta q$, and, consistent with RF, to discount it in

$$L\delta E = \frac{s}{\gamma}\delta H + L\rho C U \delta\Delta q$$

$$\delta H = \frac{\gamma}{s+\gamma}\delta R_s$$

We used $\frac{s}{s+\gamma} = .65$ so $\frac{\gamma}{s+\gamma} = .35$ and $\delta H = -2.8$ W m^{-2}
But $\delta H = c_p \rho C U \delta(T_s - T)$, and with $C = .001$ (for a water surface) and $U = 5$ m s^{-1},

$$\frac{\delta T_s}{\delta H} = \frac{1}{c_p \rho C U} = .17 \text{ K W}^{-1} \text{ m}^2$$

This gives $\delta(T_s - T) = -0.48$ K
for $\delta R_s = -7.9$ W m^{-2} .