Observations and Radiative Transfer Model Calculations of Shortwave Irradiance Reduction during 2017 Solar Eclipse

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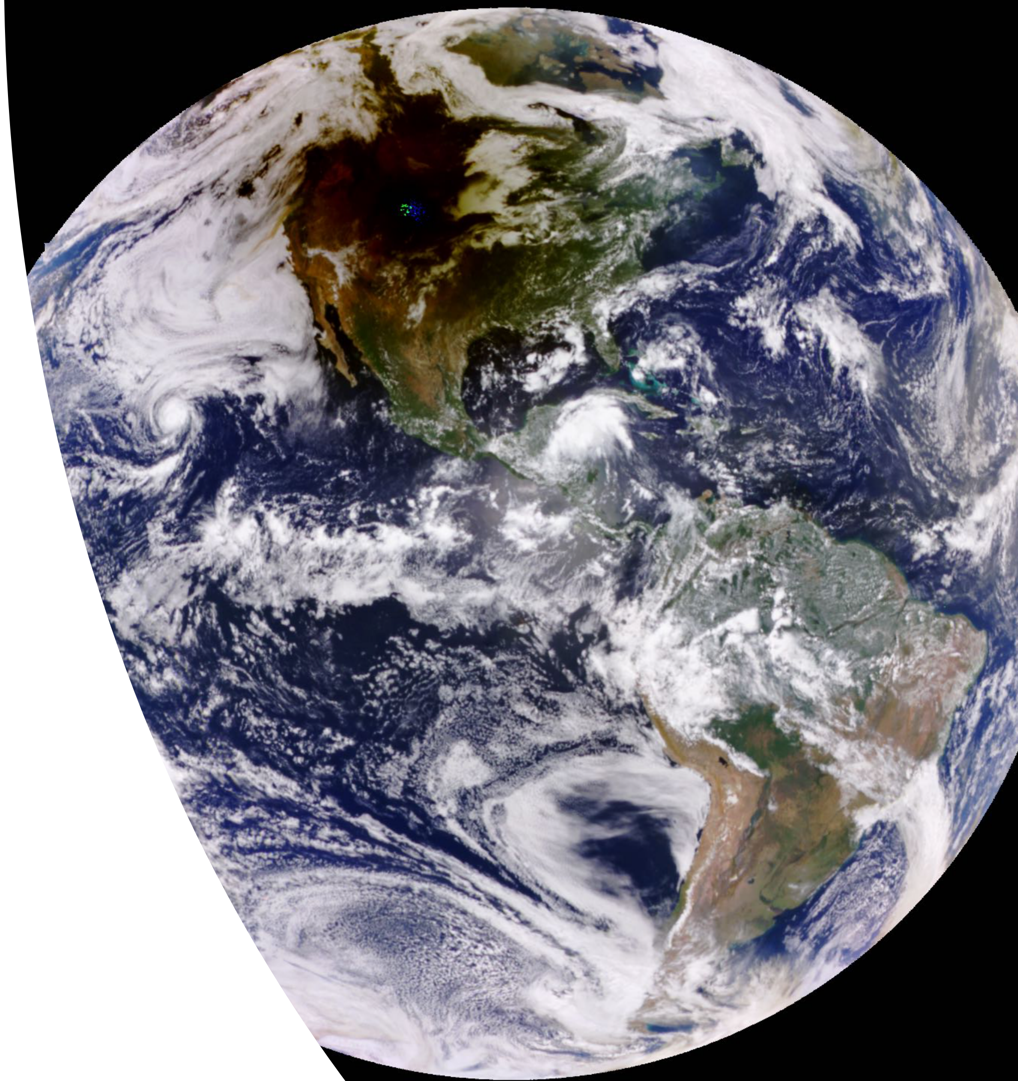
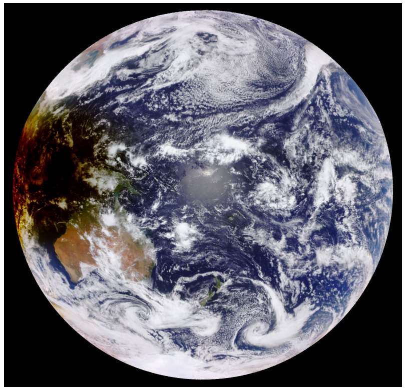


Objectives

- It is fun and a natural experiment
- Quantify global energy disturbance under eclipse conditions (never done before)
- Test radiative transfer model with known TOA solar irradiance change

Example

March 9, 2016 over Indian Ocean and Pacific Ocean



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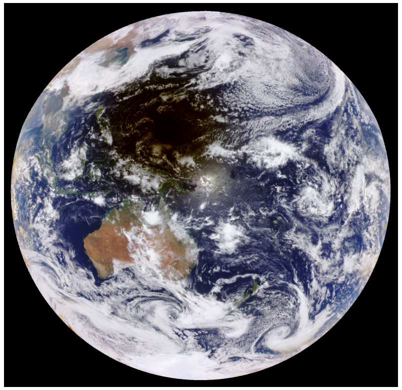

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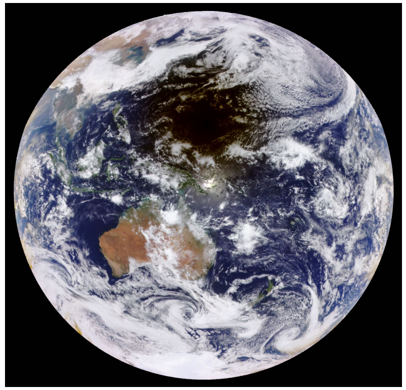

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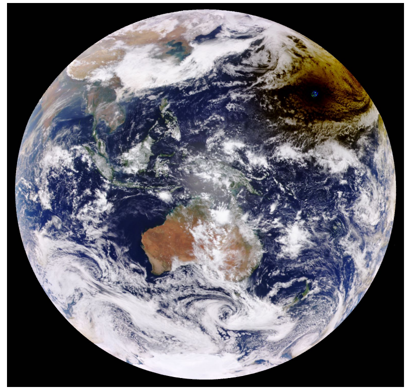

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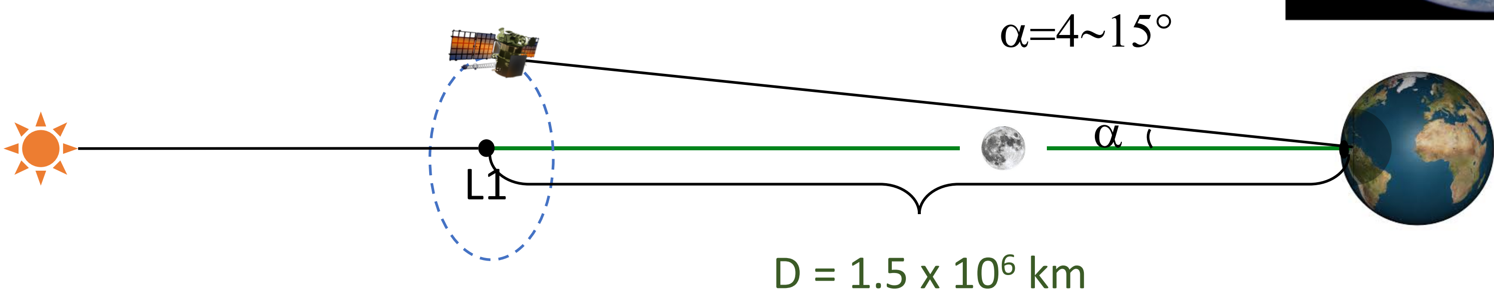
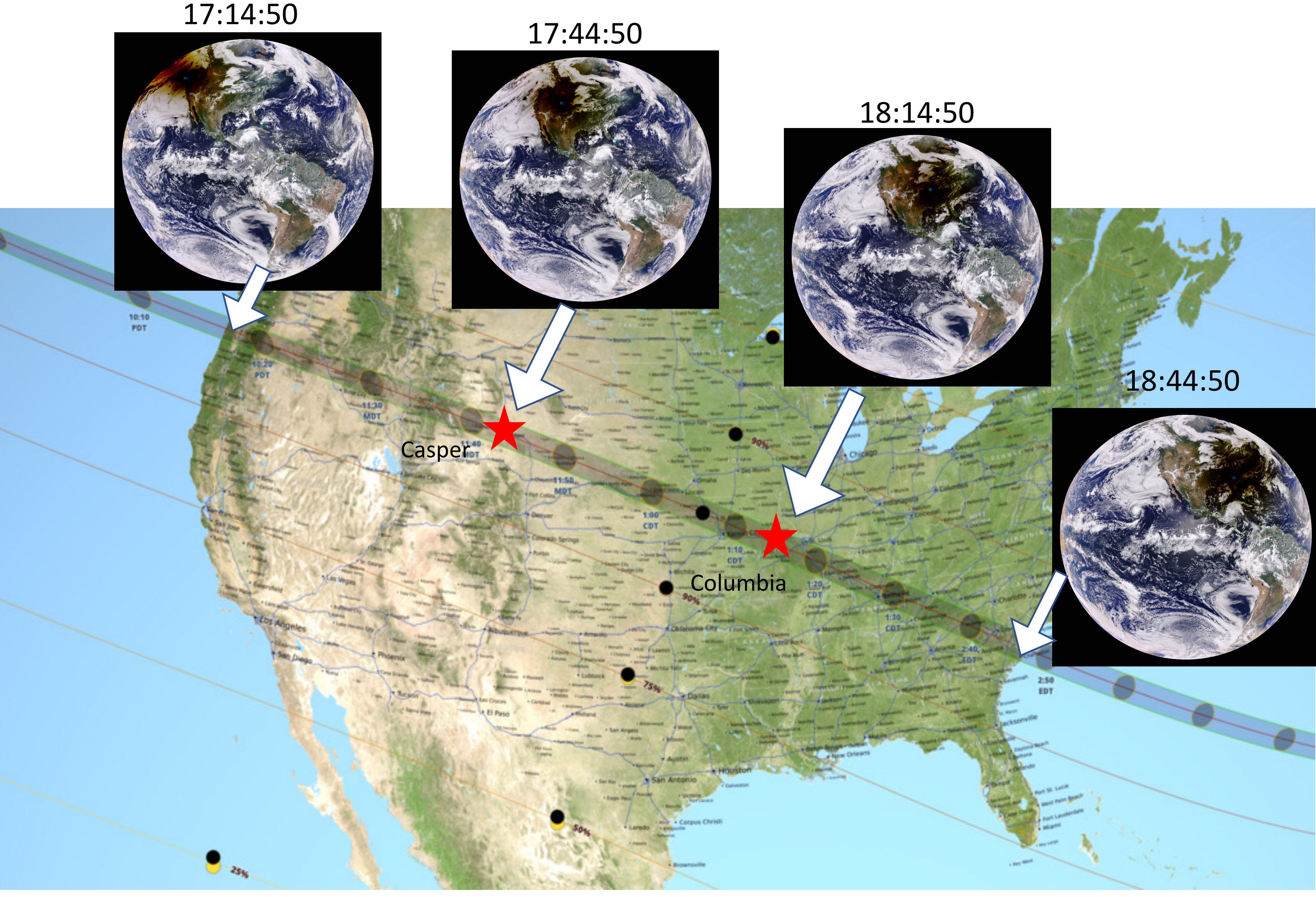
Not a solar eclipse



Solar Eclipse of August 21, 2017
“The Great American Eclipse”

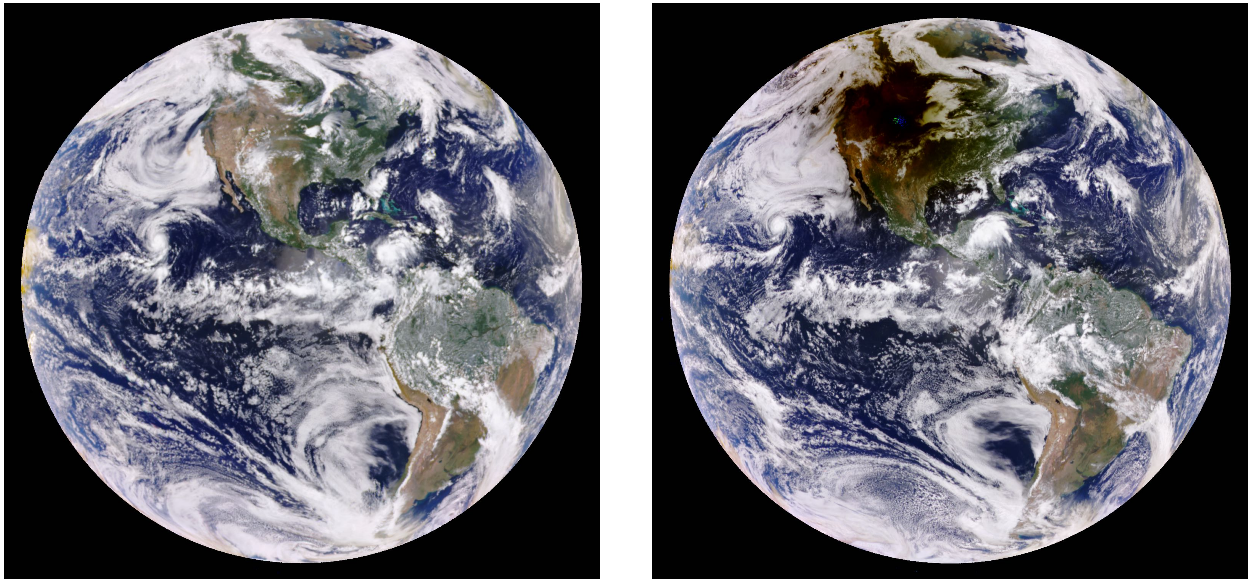


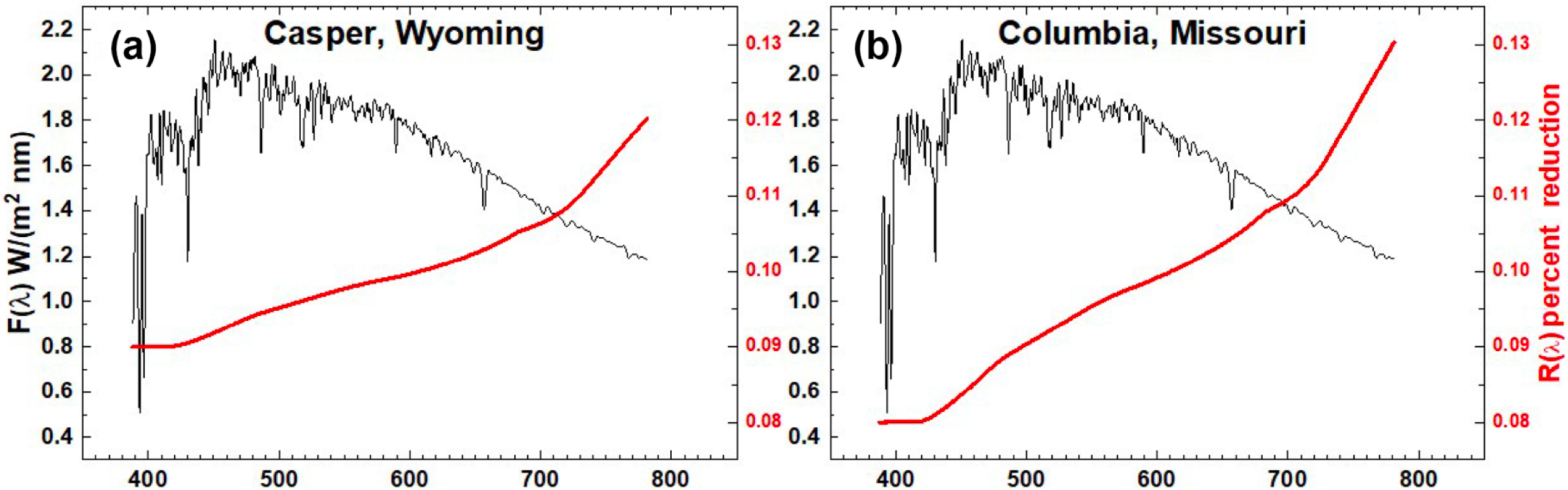
Estimate Reduction in Global Average SW Radiation Budget

- **Well prepared. Coordinated EPIC observations every 30 min. Deployed radiometers to two ground sites.**
- **From space, compare EPIC images on eclipse date with those from nearest date.**
- **From ground-based observations**
  - **pyranometer for surface irradiance**
  - **Pandora Spectrometer System for trace gas, aerosol, cloud**

Reduction of Reflectance from EPIC

ΔR ≈ 10%



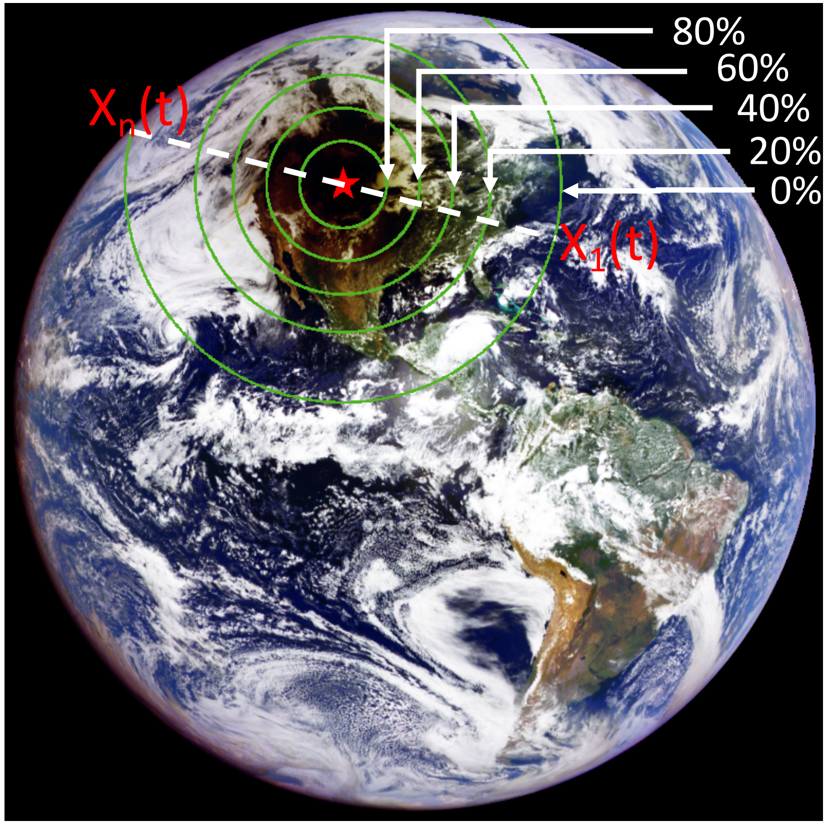


Spectral irradiance and percentage reduction of reflectance (Herman et al, 2018)

How to Estimate Global Average Irradiance Reduction from Local Observations?

1. Temporal to Spatial for Estimating Average Irradiance ($F_{eclipse}$)

- Assume N pyranometers uniformly placed along the totality path at $X_1, X_2, \ldots, X_n$.
- For Casper site, the pyranometer observed downward flux at times $t_1, t_2, \ldots, t_n$.
- The spatial average from n pyranometers at time t is equivalent to temporal average of observations from Casper site if the atmospheric condition and surface properties do not change with time and space.



$$F_{eclipse} = \frac{\sum_{i=1}^{N} F(X_i)}{N} = \frac{\sum_{i=1}^{N} F_{Casper}(t_i)}{N}$$

How to Estimate Global Average Irradiance Reduction from Local Surface Observations?

2. How to estimate global average?

Global averages

- Global average for Eclipse:

  $F_1 = (\pi R_e^2 - \pi r^2)F' + \pi r^2 F_{eclipse}$

  B + A

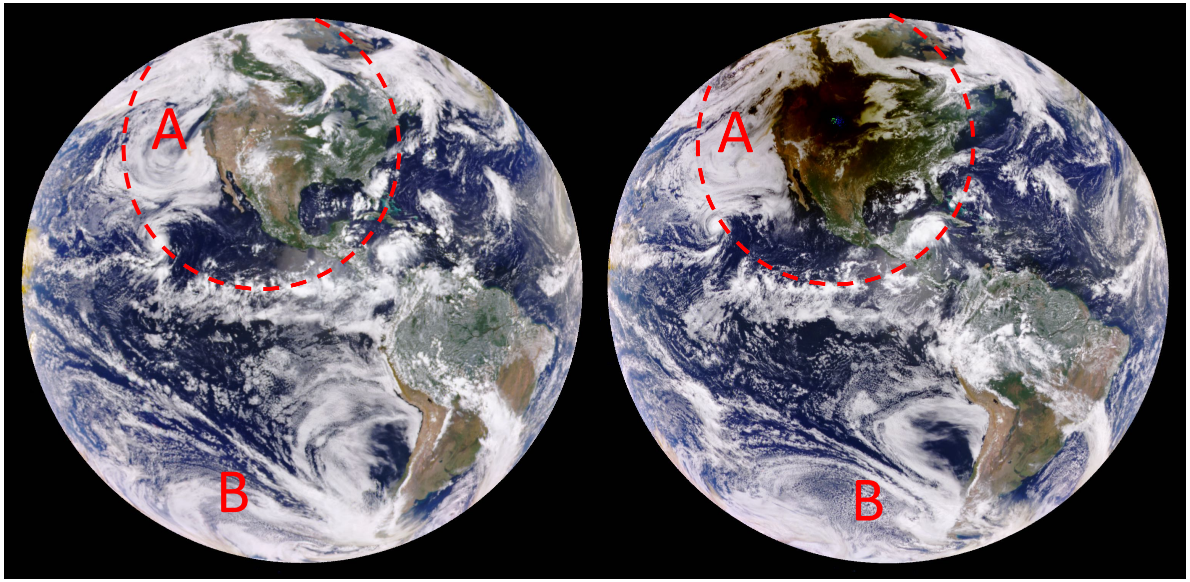
  F'=avr outside penumbra

  $F_{eclipse}$ =avr in penumbra

- Global average for Non-Eclipse:

  $F_2 = (\pi R_e^2 - \pi r^2)F' + \pi r^2 F_{non\text{-}eclipse}$

  B + A



$F_{non\text{-}eclipse}$ =avr would be without eclipse

- Eclipse induced diff in global average:

$$\Delta F = \frac{\pi r^2 (F_{eclipse} - F_{non-eclipse})}{\pi R_e^2 F}$$

- Estimated from temporal average
- Need to be computed from RT models
- Global average (A and B) for non-eclipse estimated using Tr=0.55 (trans) α=0.3 for reflected, TSI = 1360.8 W/m2, r = 3430 km, R_e = 6370km

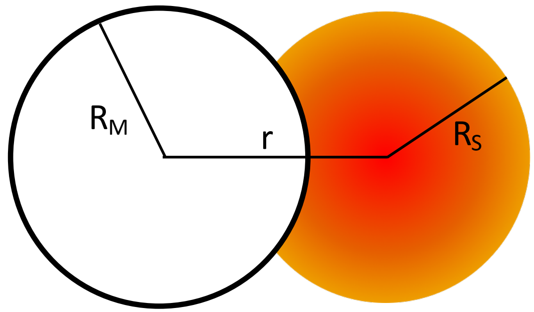
Radiative Transfer Model and Inputs

Radiative Transfer Model

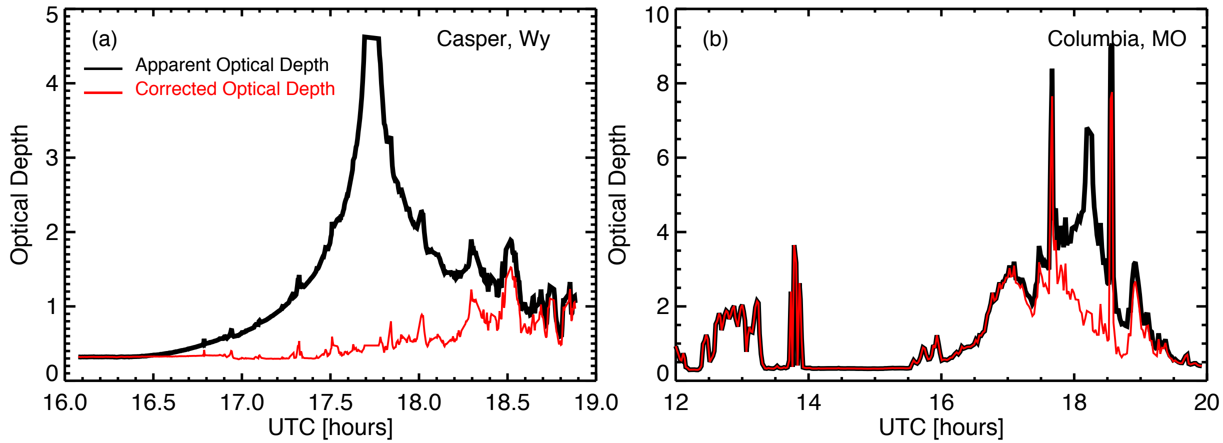
- ✓ Fu&Liou Broadband Radiation Code

Model Inputs

- ✓ Aerosol optical depth
- ✓ Precipitable water
- ✓ Total column O_3
- ✓ Altitude
- ✓ MODIS/IGBP Surface albedo
- ✓ TOA Spectral Solar Irradiance
- ✓ Cloud optical depth
- ❖ Cloud fraction (inferred)



Compute reduced TOA brightness



Pandora Observed Cloud Optical Depth

Cloud fraction is needed for

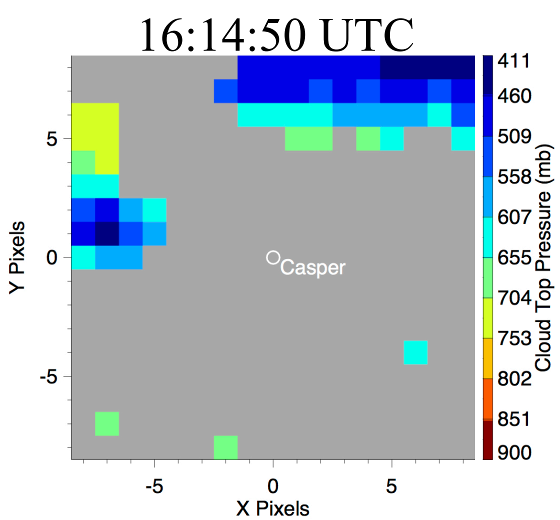
- Downward irradiance for non-eclipse
- TOA upward irradiances for both eclipse and non-eclipse

Observations vs RT Model Computations

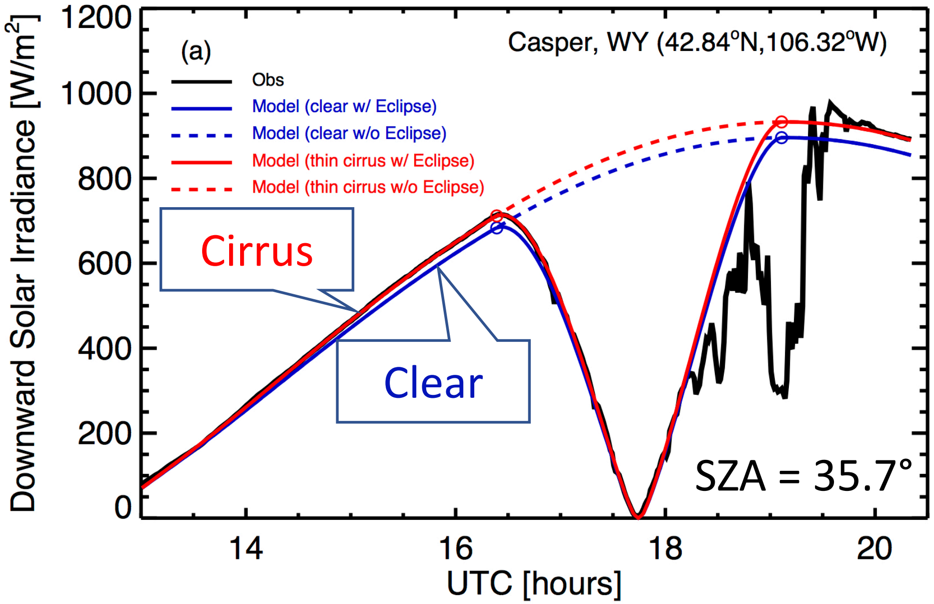
Casper, WY

Clear sky conditions

- Model captures the main feature of irradiance variations
- Thin cirrus cloud not blocking the Sun makes a difference



EPIC observed cloud top height



Clear Sky: $\Delta F = F_{eclipse} - F_{non\text{-}eclipse} = -368.5 W/m^2$

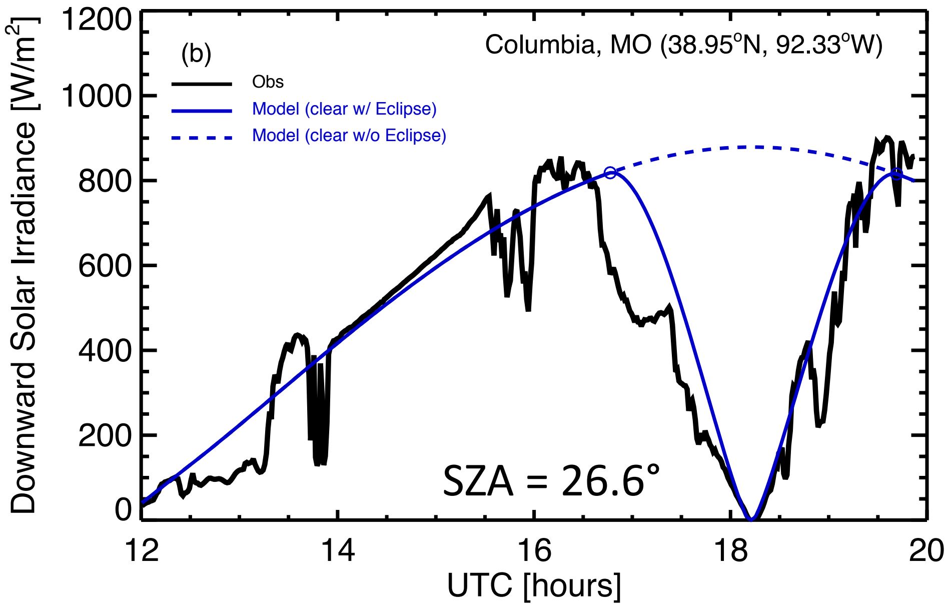
- ➢ about -14.6% reduction in global transmitted SW irradiance
- ➢ Additional thin cirrus ➔ -15.2%

Observations vs RT Model Computations

Columbia, MO

Clear sky conditions

- Model captures the main feature of irradiance variations
- Cloud plays important role



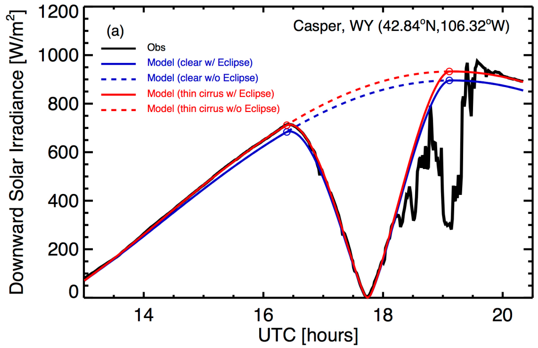
Clear Sky: ΔF = -385.0W/m^2 (5% larger than Casper)
about -15.3% reduction in global transmitted SW irradiance compared to ΔF = -368.0W/m^2 or -14.6% for Casper due to SZA and precipitable water.

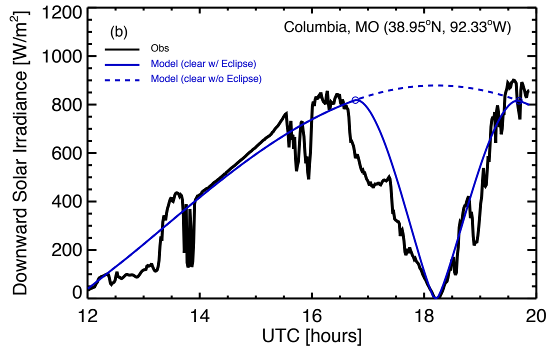
Need to Infer Radiative Effective Cloud Properties

We need to derive radiative effective cloud fraction

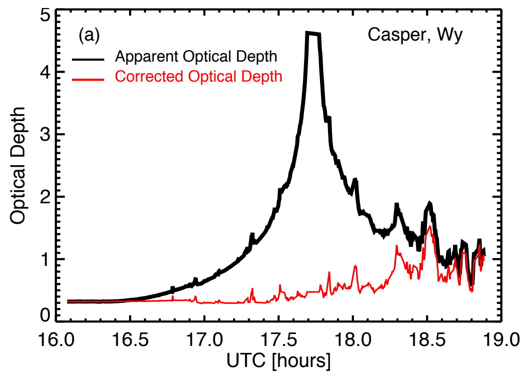
Casper

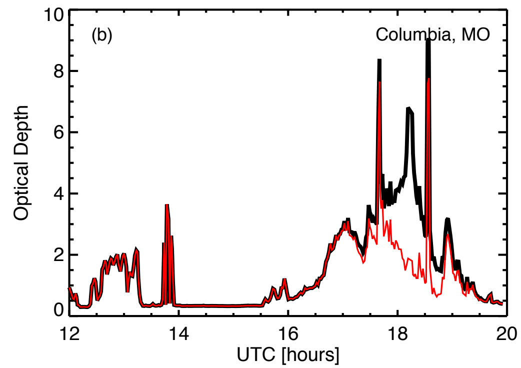
Columbia



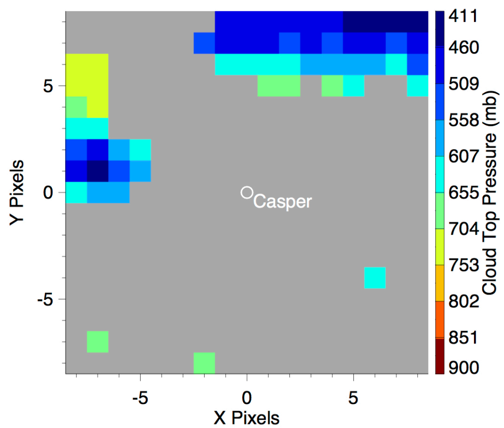


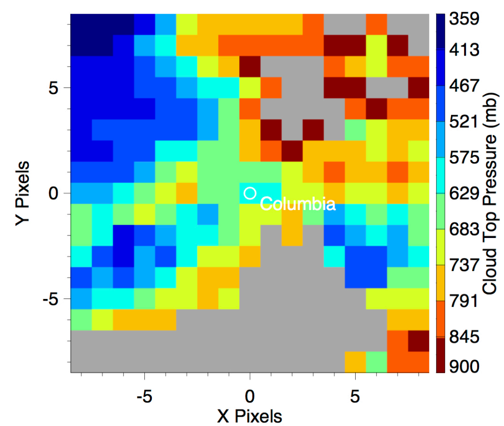
Cloud optical depth





EPIC Cloud Top Height





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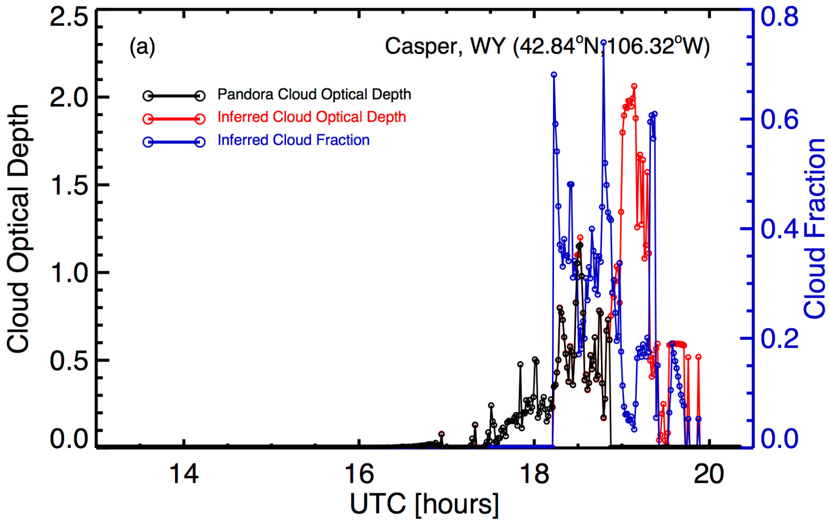
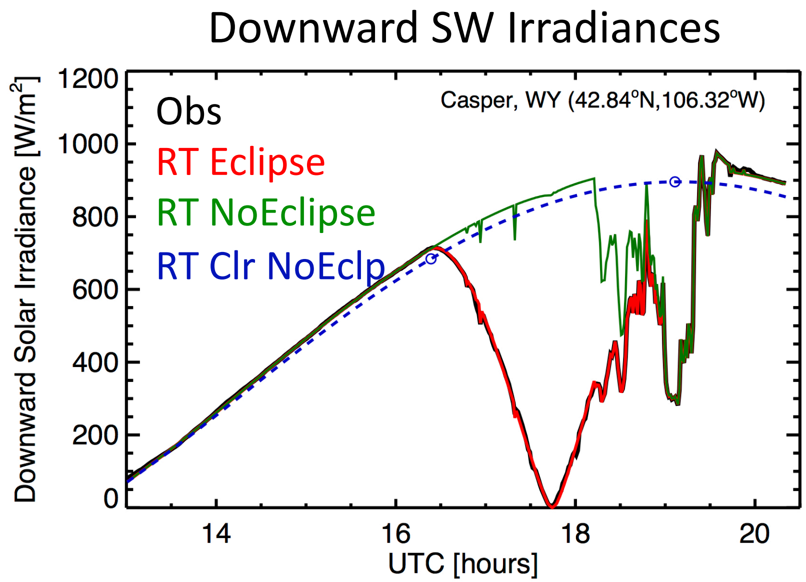
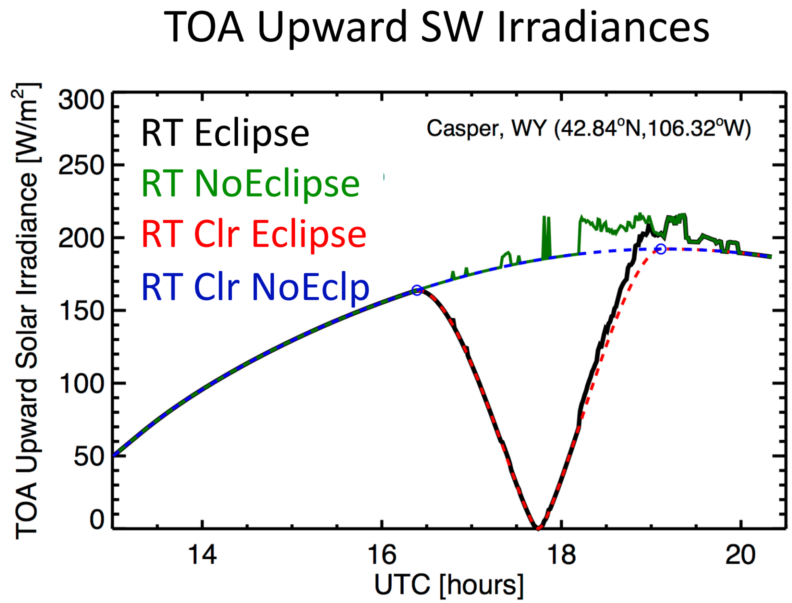
Estimate of Global Average SW Irradiance Change

Casper







Local:

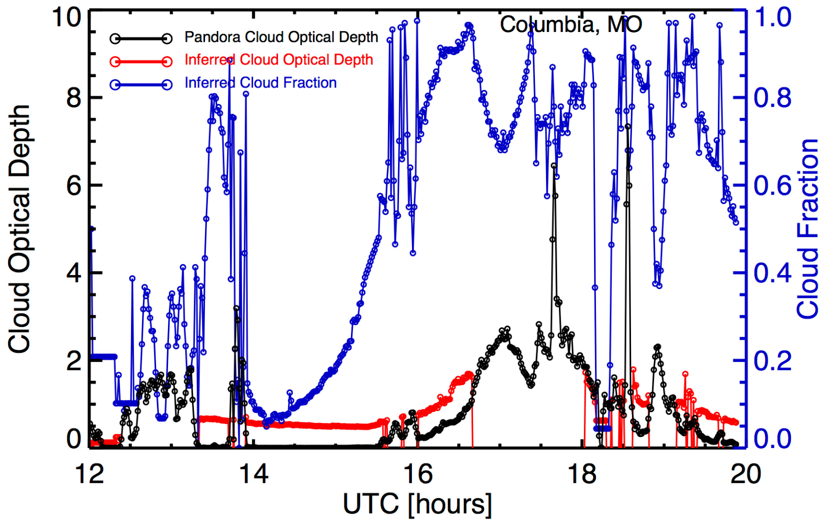
- Downward SW ΔF = - 364 W/m², -48%
- Upward SW ΔF = -84 W/m², -44%

Global:

- Downward SW ΔF = -15%
- Upward SW ΔF = -6%

Estimate of SW Irradiance Change

Columbia



Local:

- Downward SW ΔF = - 283 W/m^2, -43%
- Upward SW ΔF = -81 W/m^2, -44%

Global:

- Downward SW ΔF = -11%
- Upward SW ΔF = -8%

Casper

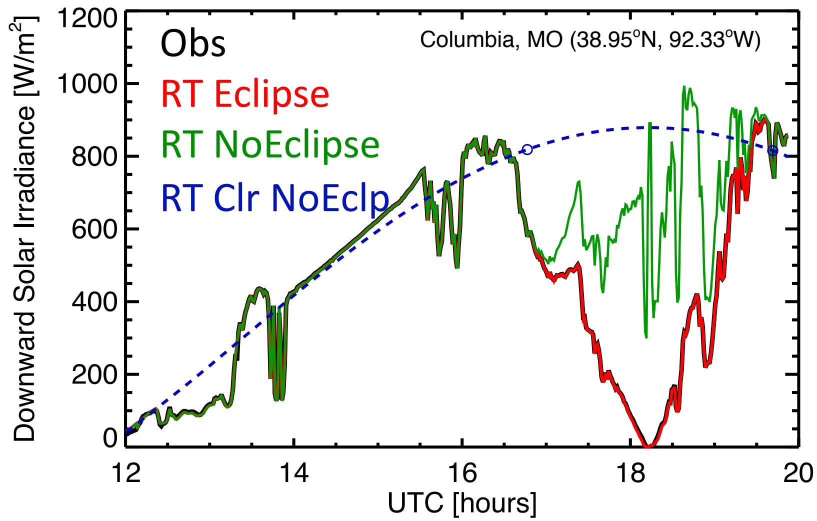
Local:

- Downward SW ΔF = - 364 W/m^2, -48%
- Upward SW ΔF = -84 W/m^2, -44%

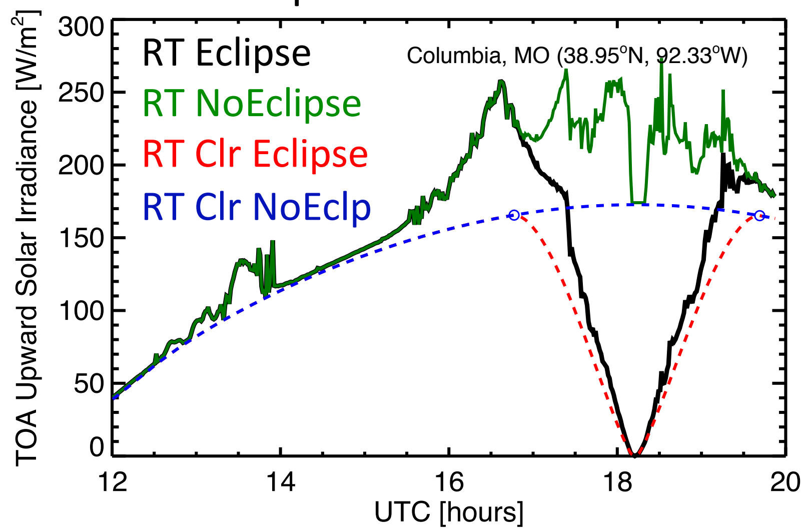
Global:

- Downward SW ΔF = -15%
- Upward SW ΔF = -6%

Downward SW Irradiances



TOA Upward SW Irradiances



Summary

- **Ability of 1D radiative transfer model**
- **Surface SW flux: larger reduction for clear atmosphere than cloudy atmosphere.**
  Local average: 48% (Casper) vs 43% (Columbia)
  Global average: 14% vs 11%.
- **TOA SW flux: larger reduction for cloudy atmosphere than clear atmosphere.**
  Global average: 6% (Casper) vs 8% (Columbia).
- **Estimated for Columbia site is close to EPIC observations of 10%.**