The Influence of Aerosols on Crop Production

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Introduction

- **The absorption and scattering of light by atmospheric aerosols changes the amount of radiation available to plants**
- **Aerosol light attenuation also changes the fraction of radiation which is diffuse.**

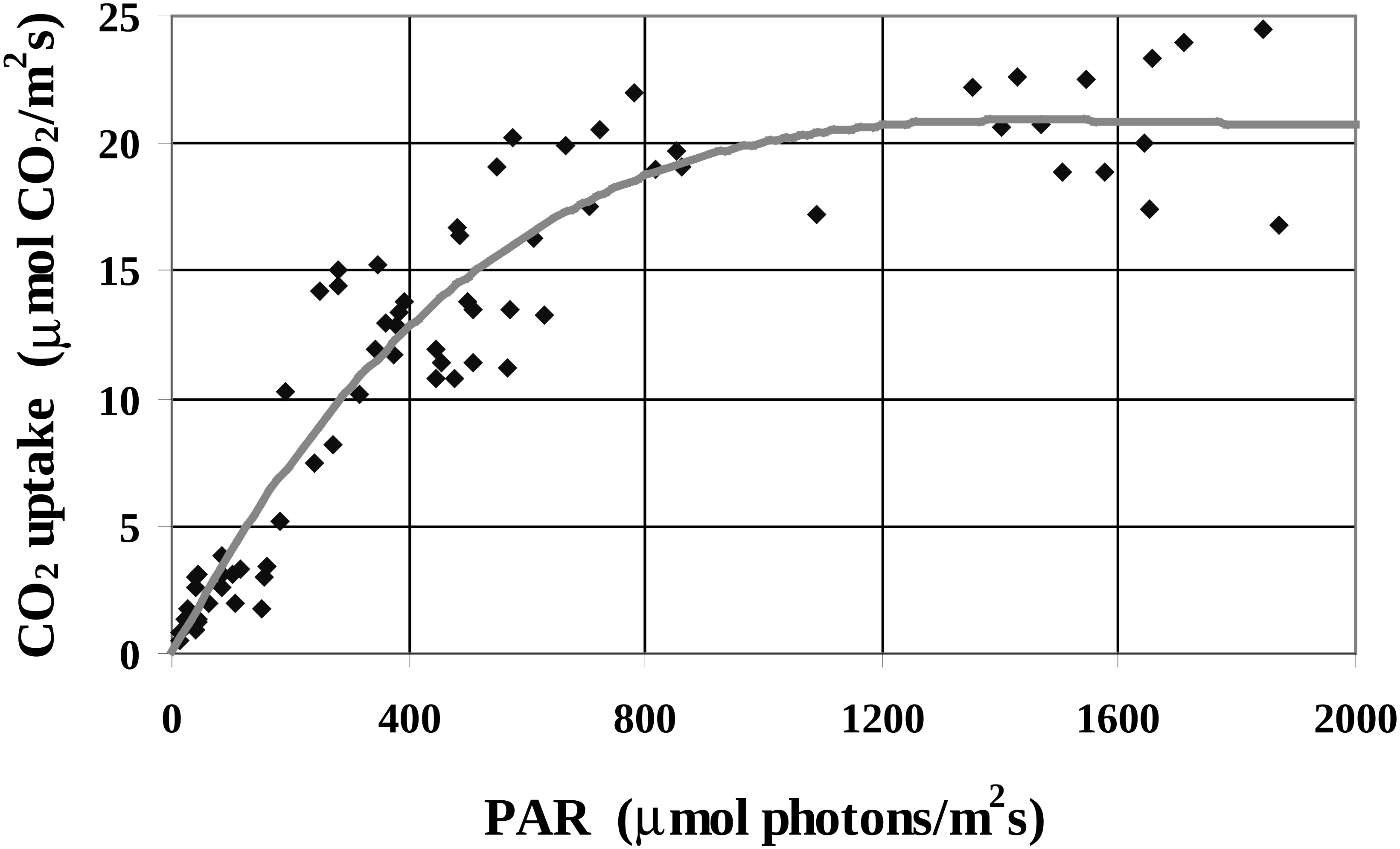
Importance

- **Many of the world's most important agricultural regions (such as the Yangtze delta region of China) are located in areas with extremely high aerosol loadings.**
- **The radiative effects of these aerosols may be influencing agricultural production.**

Background Information

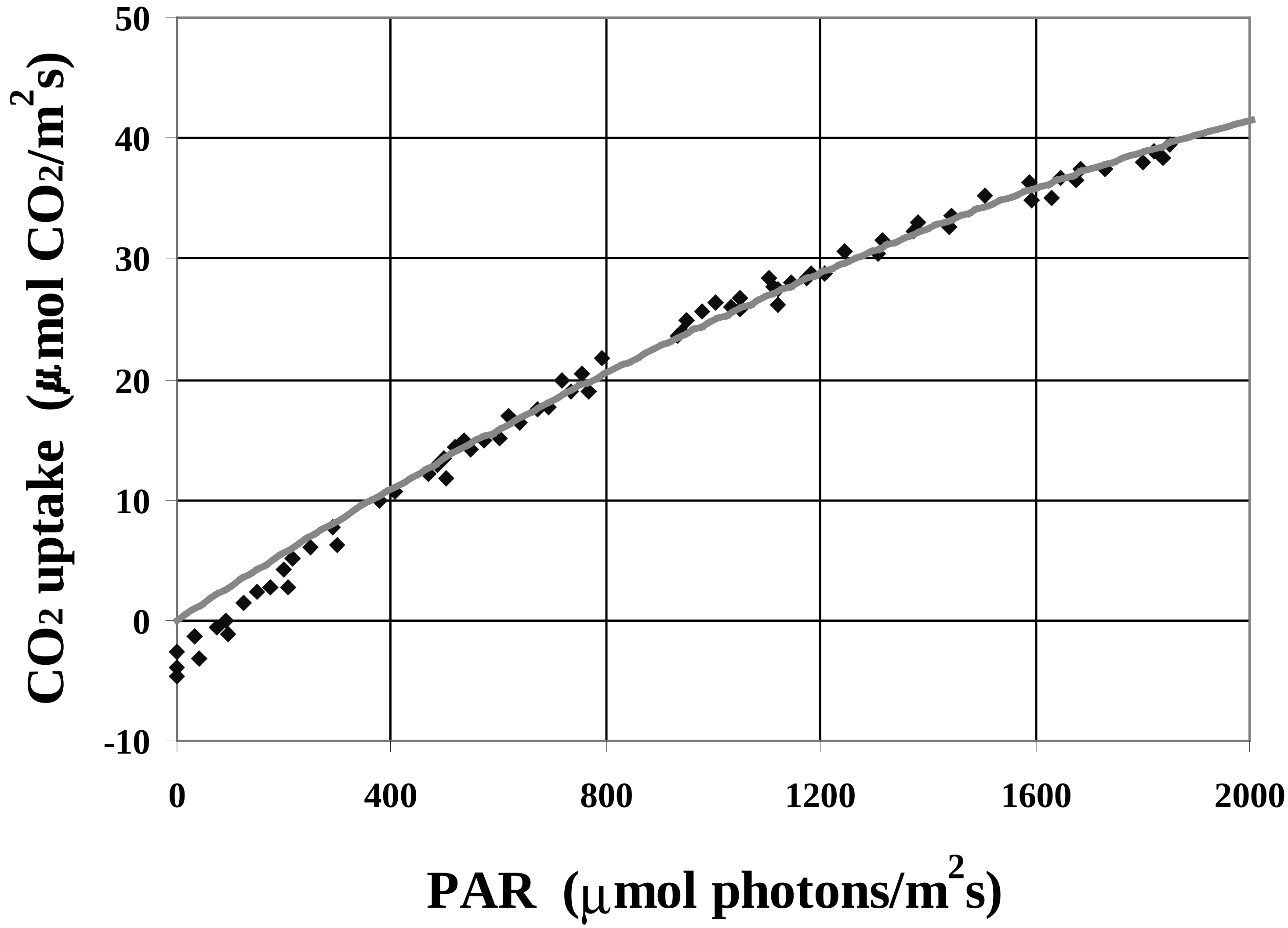
- **Plants utilize the wavelength band of 400-700 nm.**
- **This range is known as PAR or photosynthetically active radiation.**
- **Plants can be divided into two main categories based on metabolic pathway:**
- **C_3 plants (such as wheat and rice) become light saturated at about 1/3 to 1/2 full sunlight.**
- **C_4 plants (such as corn) are not light saturated even at full sunlight.**

Measured Instantaneous CO_2 Uptake vs. PAR for a C_3 Species



- **Soegaard et al.(1998)**

Measured Instantaneous CO_2 Uptake vs. PAR for a C_4 Species

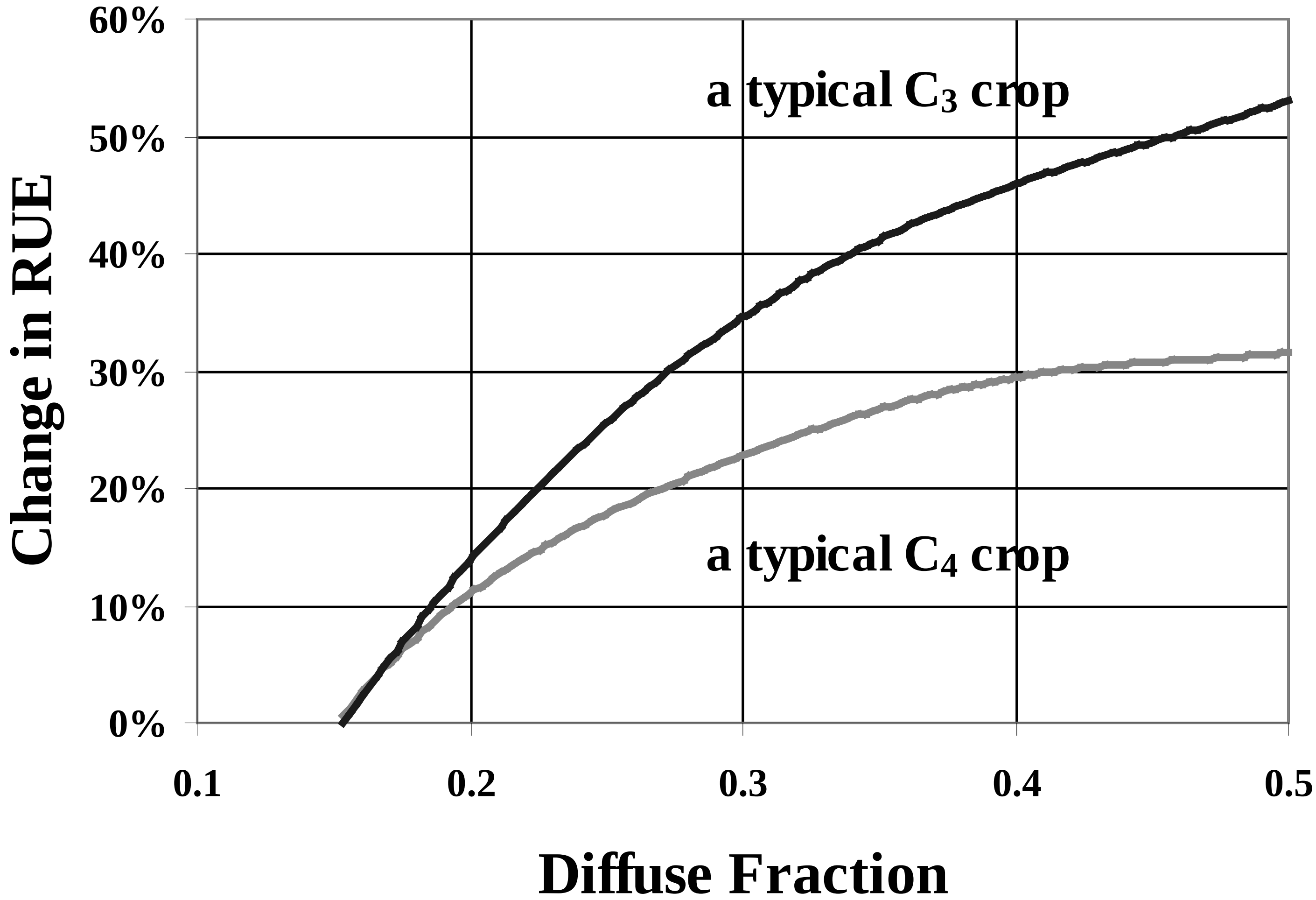


- Levy et al.(1997)

Effect of Diffuse Radiation

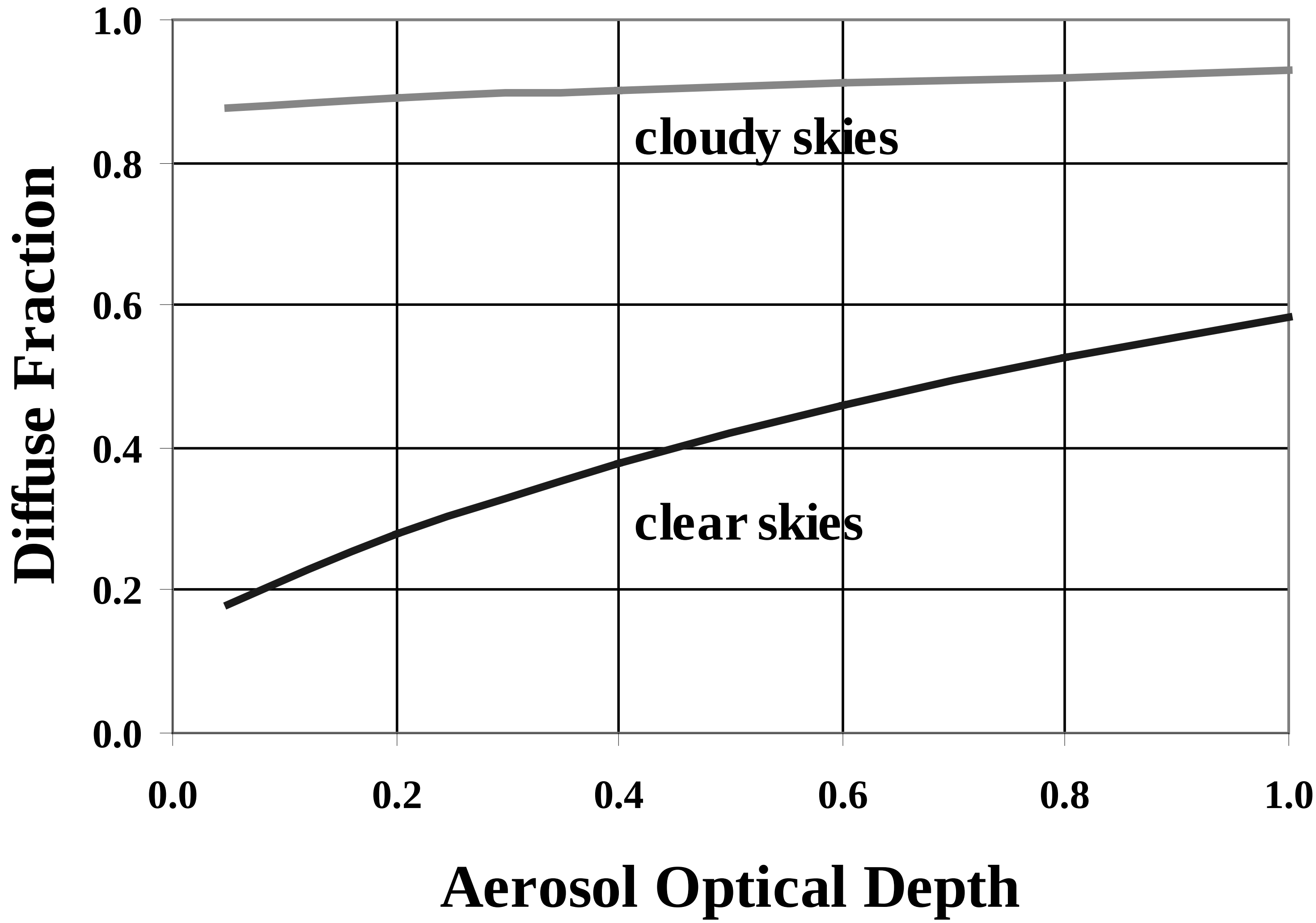
- Direct radiation is absorbed by leaves on the top of the canopy.
- Diffuse radiation is more able to penetrate into the canopy and expose shaded leaves underneath.
- This has the effect of increasing Radiation Use Efficiency or RUE.

Change in RUE as a Function of the Diffuse Fraction



- **based on both observations and theoretical calculations from Norman et al.(2000), Rochette et al.(1996), Sinclair et al.(1992)**

- **The diffuse fraction (diffuse/total irradiance) increases with aerosol optical depth under both clear sky and cloudy conditions.**



Estimating Crop Yields

- A modified version of the CERES v. 3.5 (Singh, et al., 1998) crop model was used to estimate yields.
- Model runs were configured so that the crops never experienced water or nutrient stress.
- Twenty years of daily temperature and precipitation data from Ames, Iowa were used and yield results were averaged.

Crop Model Information

- **Biomass production is calculated as a function of light, temperature, RUE, leaf area index (LAI), and water or nutrient stress according to the equation:**

  biomass production = PAR · RUE · Stress · (1-exp(-LAI)

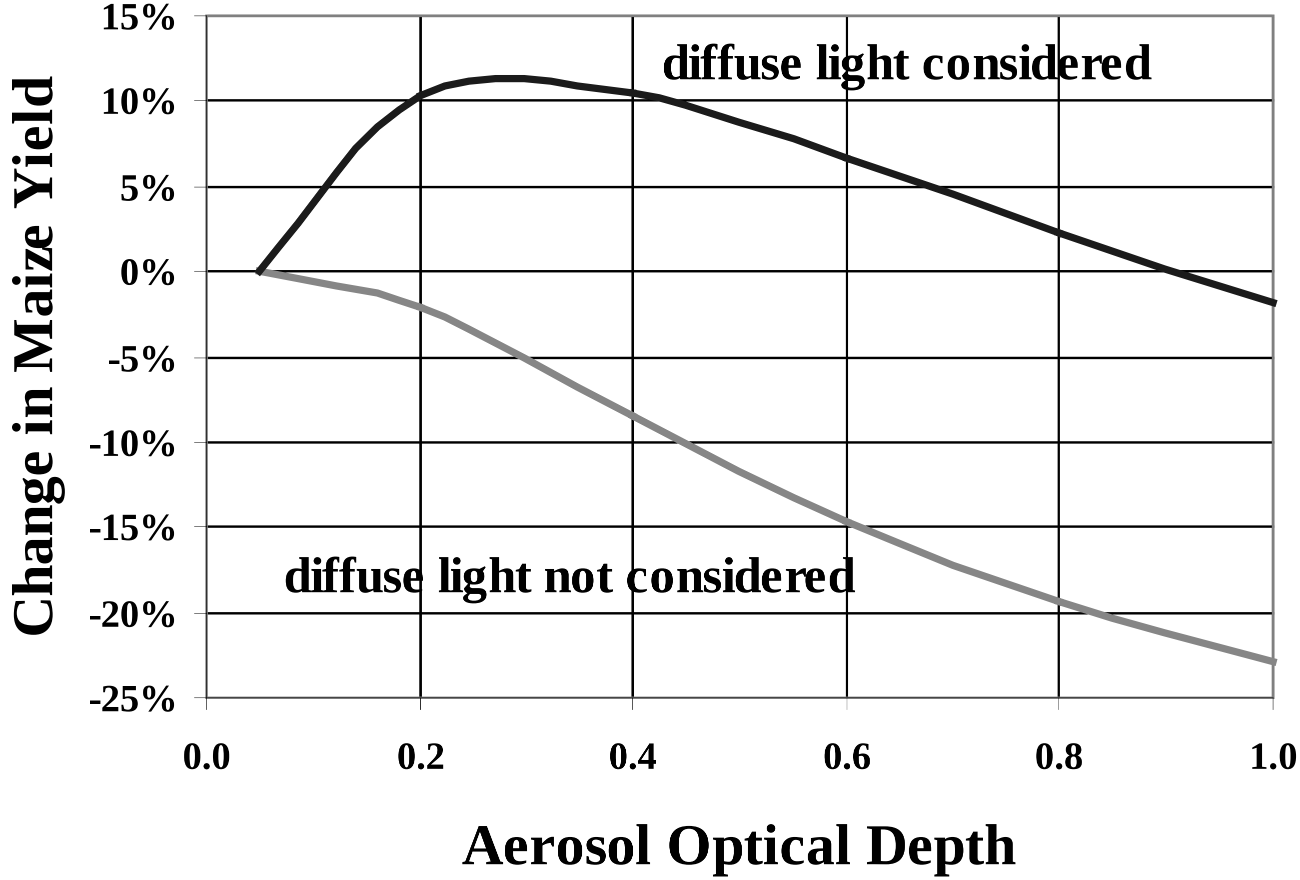
- **The time step is one day (i.e. the radiation input value is cumulative PAR over one day).**
- **Biomass is apportioned to different parts of the plant based on stage of phenological development.**

Estimating Radiation and Diffuse Fraction

- **Radiation levels and diffuse fractions were estimated for each day of the year using the TUV model (Madronich, et al. 1998) with aerosol inputs of aerosol optical depth, τ, single scattering albebo, $\omega = 0.9$, and asymmetry parameter, $g = 0.61$ (for aerosols) and $g = 0.85$ (for clouds).**
- **The radiation files were altered for each run by assuming that the aerosol optical depth was constant at a new value for the entire growing season.**

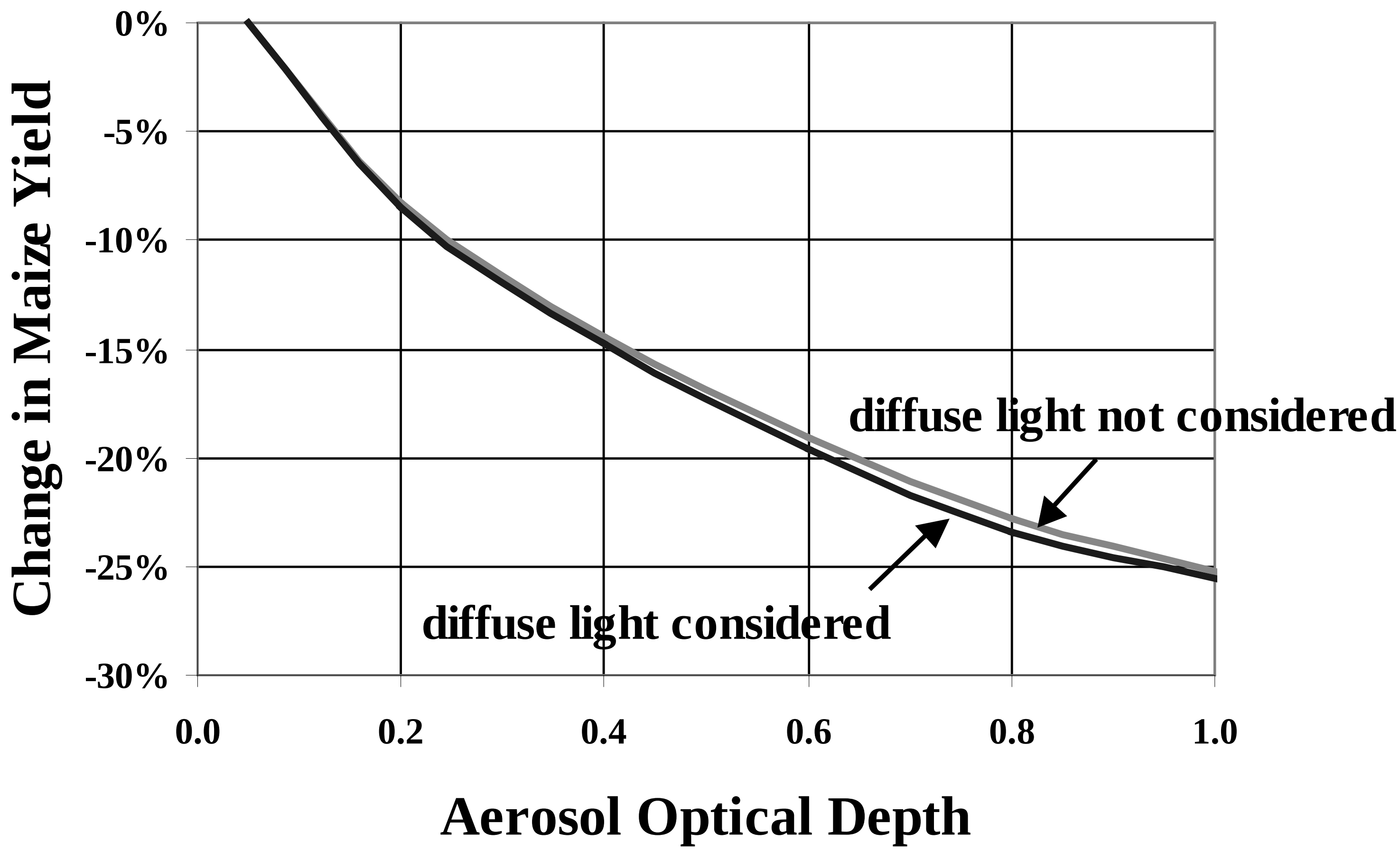
- **For both corn and wheat, three cases were examined: clear skies, cloudy skies, and variable cloud conditions.**
- **The background aerosol optical depth was assumed to be 0.05.**
- **For cloudy conditions, τ_{cloud} was assumed to be 5.0 (moderately cloudy).**
- **For the variable case, skies were assumed to be clear except on days with and on days preceding days with precipitation.**
- **The change in yield compared to the base case of $\tau = 0.05$ was calculated for each cloud condition.**

Change in Maize Yield under Clear Skies



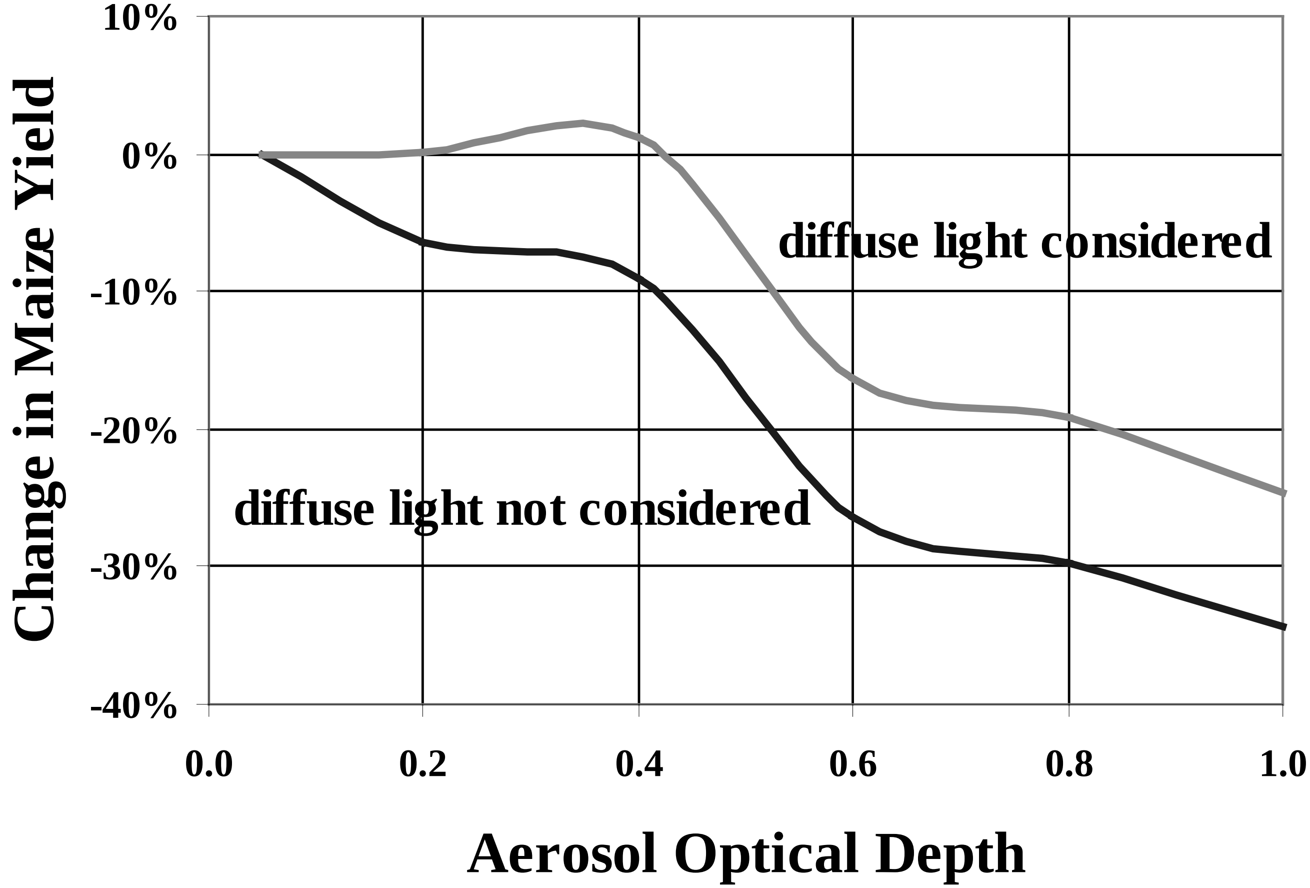
- **skies are assumed to be free of clouds for the entire growing season**

Change in Maize Yield under Cloudy Skies



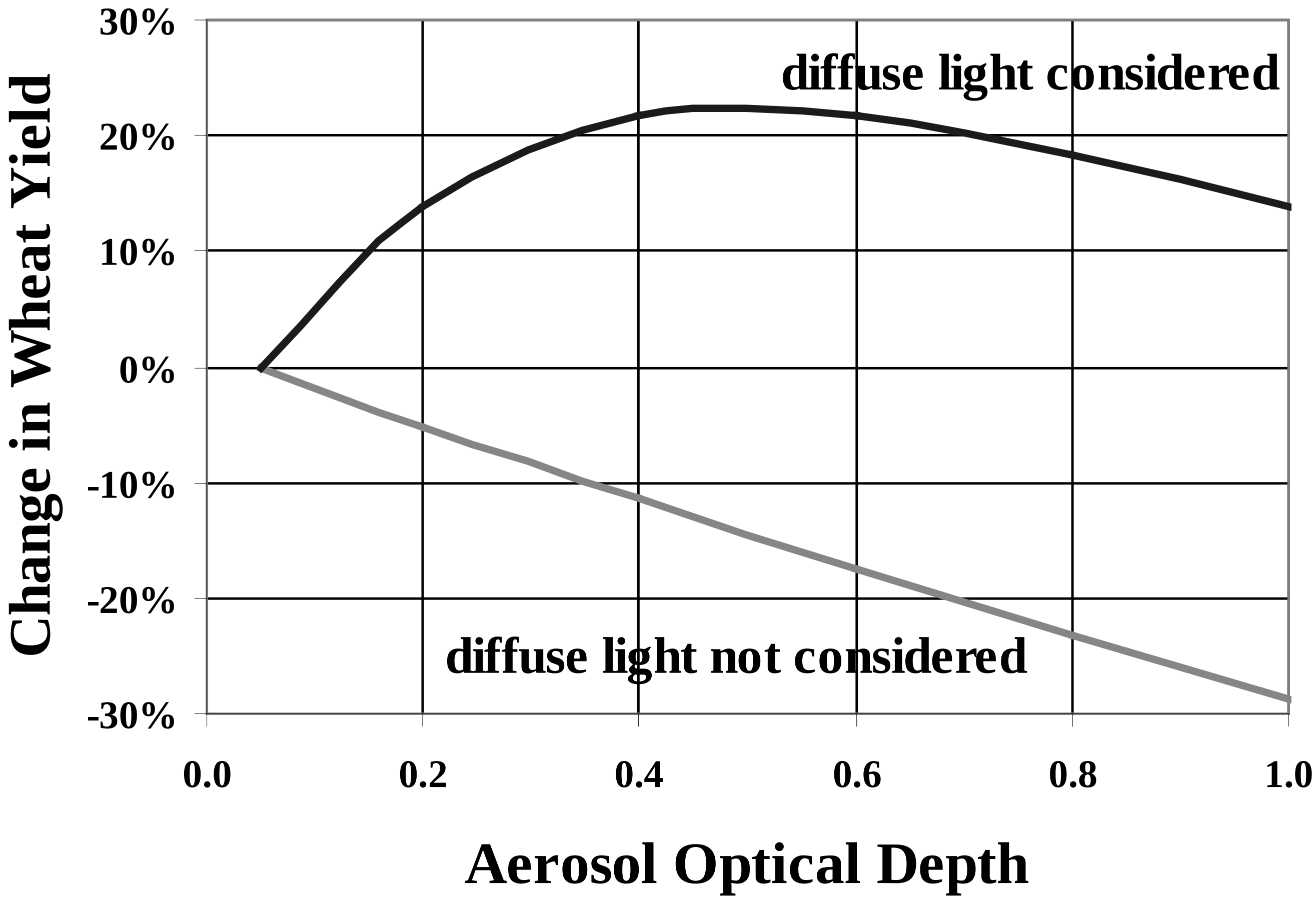
- **skies are assumed to be continuously cloudy (τ_{cloud} = 5.0) for the entire growing season**

Change in Maize Yield under Variable Cloud Conditions



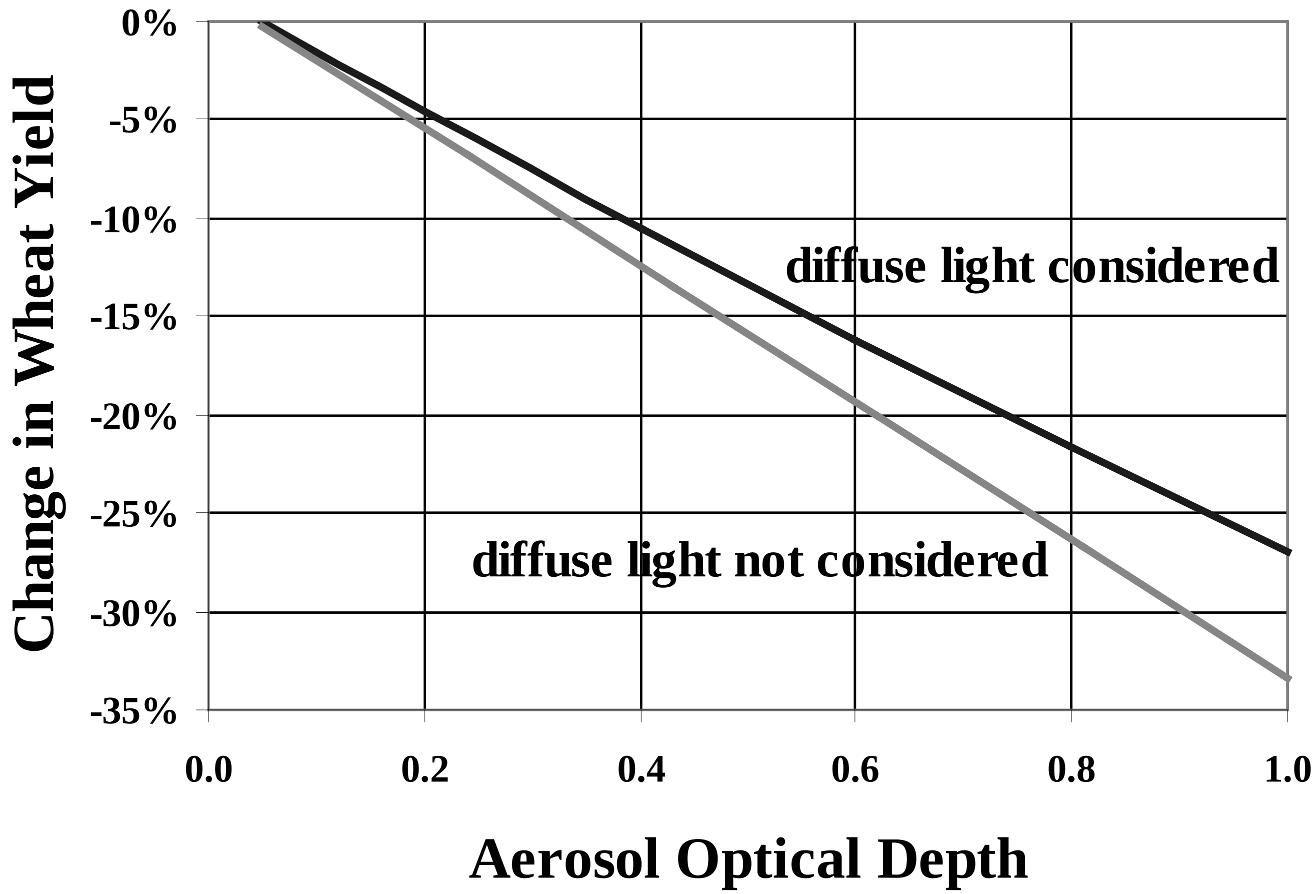
- **cloudy skies only on days with and days preceding days with precipitation**

Change in Wheat Yield under Clear Skies



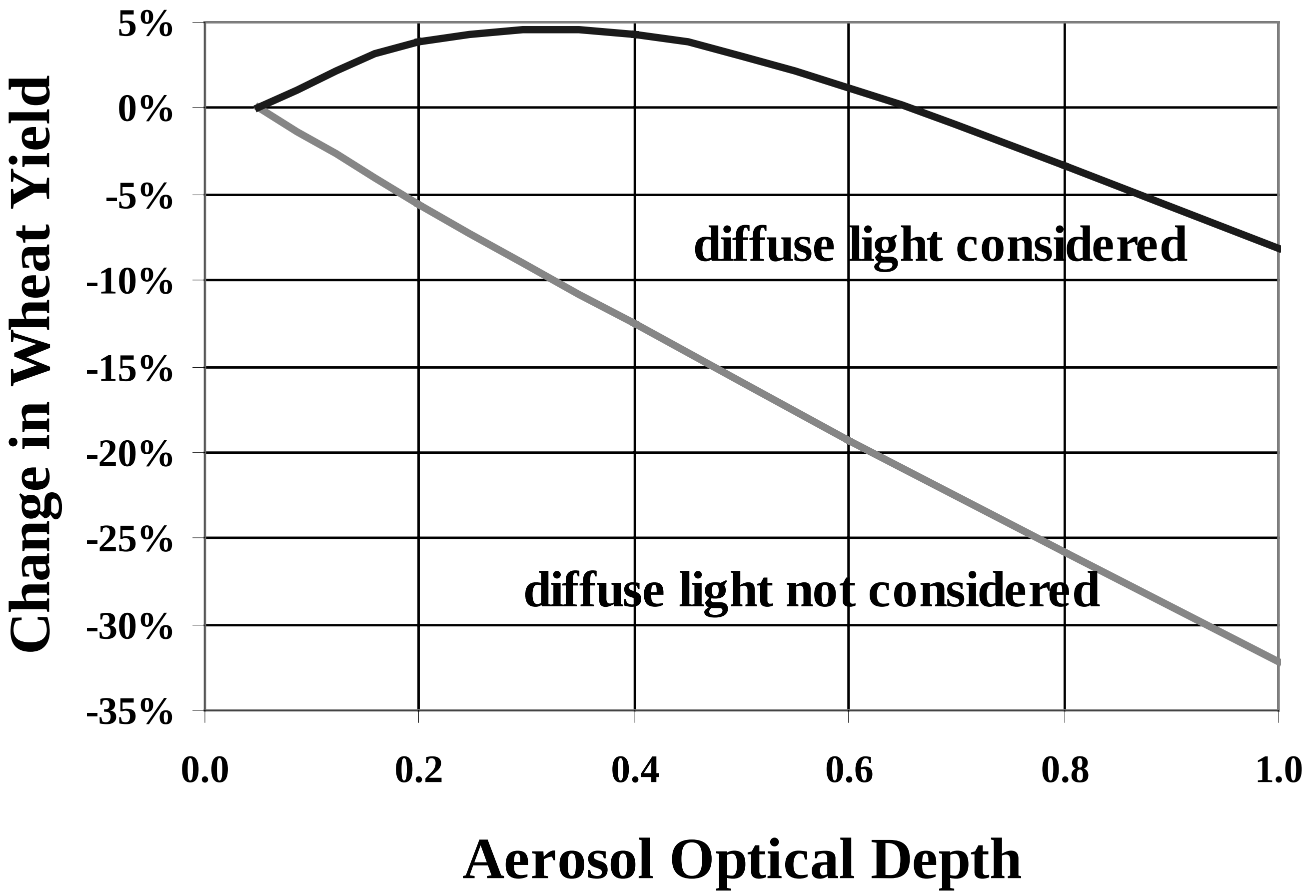
- **skies are assumed to be free of clouds for the entire growing season**

Change in Wheat Yield under Cloudy Skies



- **skies are assumed to be continuously cloudy (τ_{cloud} = 5.0) for the entire growing season**

Change in Wheat Yield under Variable Cloud Conditions



- **cloudy skies only on days with and days preceding days with precipitation**

Conclusions

- **The inclusion of diffuse radiation effects in the CERES model significantly changes the predicted yields under medium to high aerosol loadings.**
- **When the effect of diffuse radiation is not considered, crop yields are always predicted to be reduced.**
- **Under cloudy skies, even when diffuse light is considered, yields are always predicted to diminish.**
- **Under clear skies, biomass production is increased under moderate aerosol loadings.**

- **When both clear and cloudy skies are examined, yields increase slightly under moderate loadings and then decrease under heavy loadings.**
- **It should be noted that we are probably under-predicting the number of days in a season which are cloudy. The more cloudy days there are in a year, the more likely aerosols are to reduce the yield.**
- **The crops as modeled are assumed to be fully irrigated; if there is water stress, decreasing radiation has the effect of decreasing soil evaporation. This tends to increase yields.**

Future Work

- This same process will be used to estimate rice yields.
- Other locations including California, China, Florida, Georgia, India, and Thailand will be examined.
- The time step will be reduced to one hour from one day.
- The effect of aerosol deposition to leaves will be included in future model runs.

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