Impact of ozone on future land- atmosphere carbon exchange

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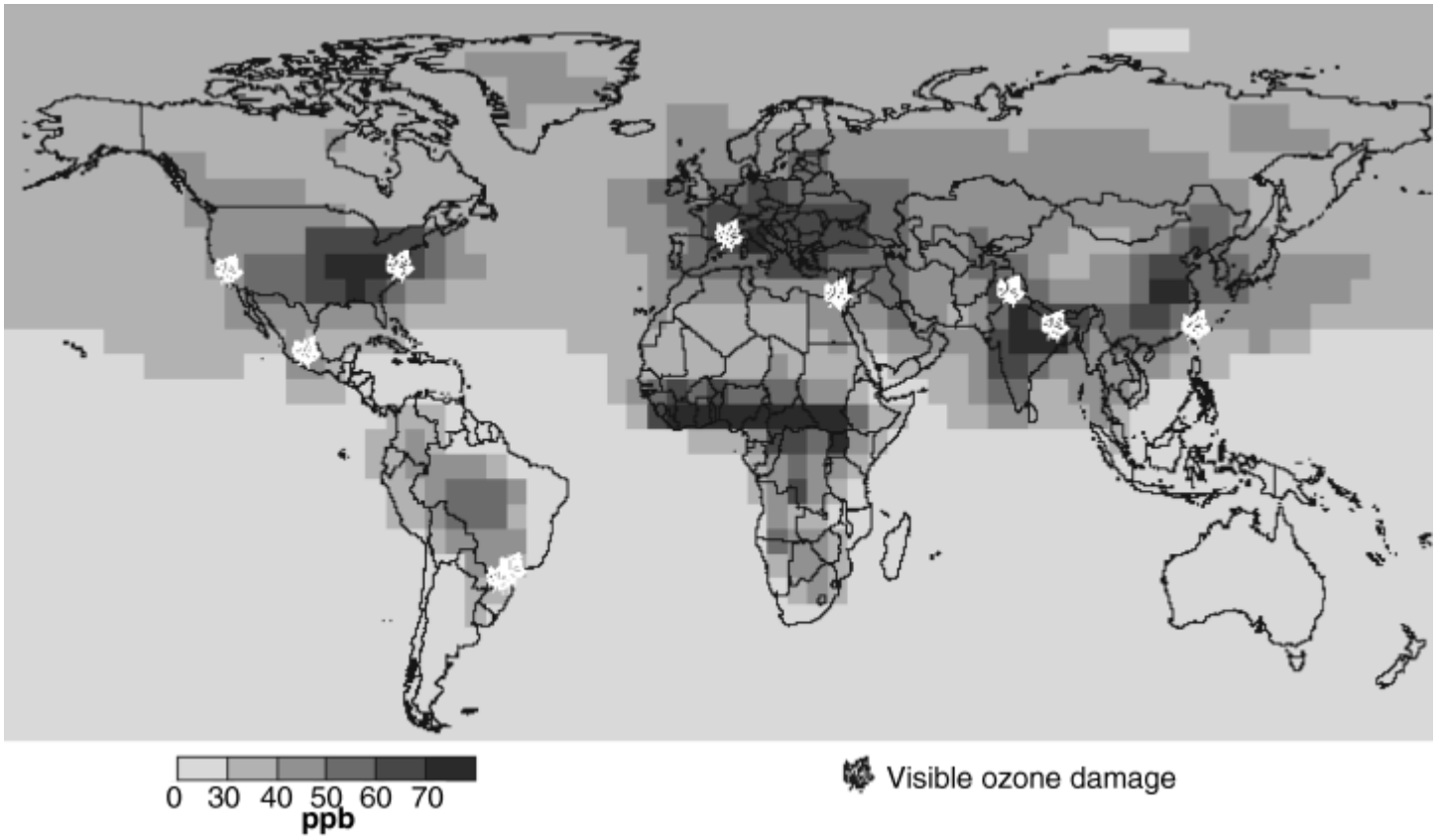
Royal Society, London, 24 May 2007

OUTLINE

- Introduction
  - Effects of Ozone Exposure on Plants
- Modelling Ozone effects on plants in MOSES
- Evaluation Against FACE experimental data
- Global Future Simulations 1901-2100
  - Ozone Effects on Global Plant Productivity
  - Plant protection against ozone damage at high CO_2
  - Ozone Effect on Land Carbon Sink and Climate
- Conclusions

Ozone and Plants

Mean Maximum growing season ozone concentrations, 1990 emissions



Emberson *et al.* 2003

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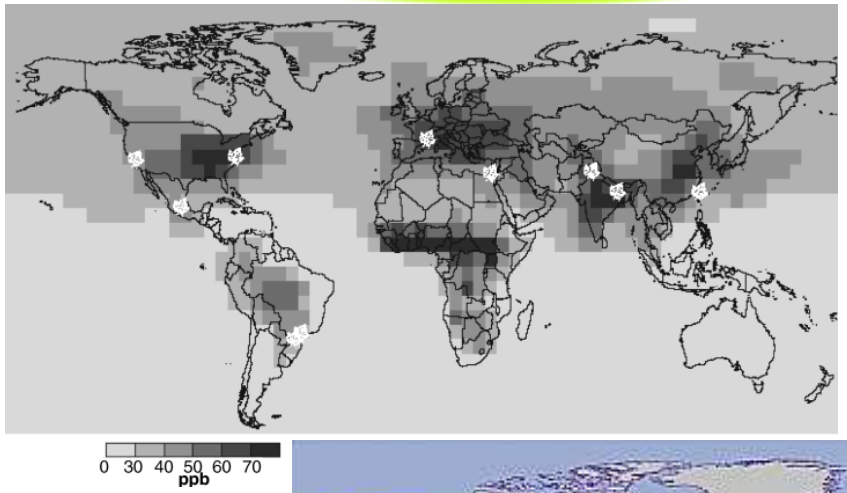
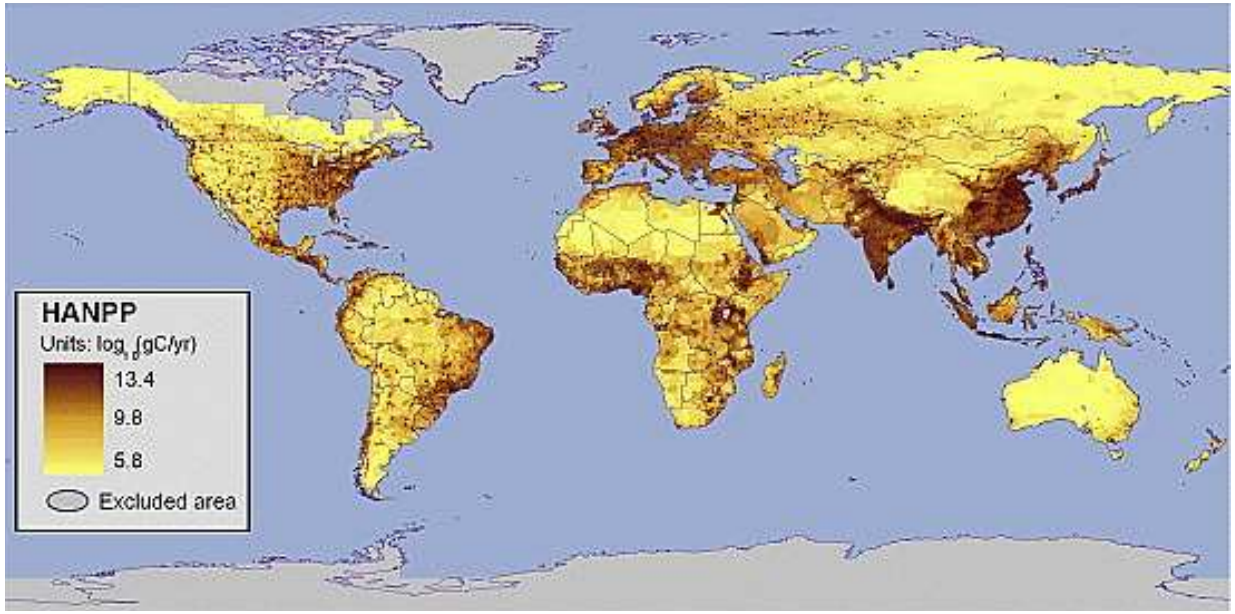
Human appropriation of NPP



Costs associated with reduction in crop yields:

USA = US$2-4 billion (Murphy et al. 1999)

Europe = 4 billion EU (Holland et al. 2002)



Imhoff et al., 2004

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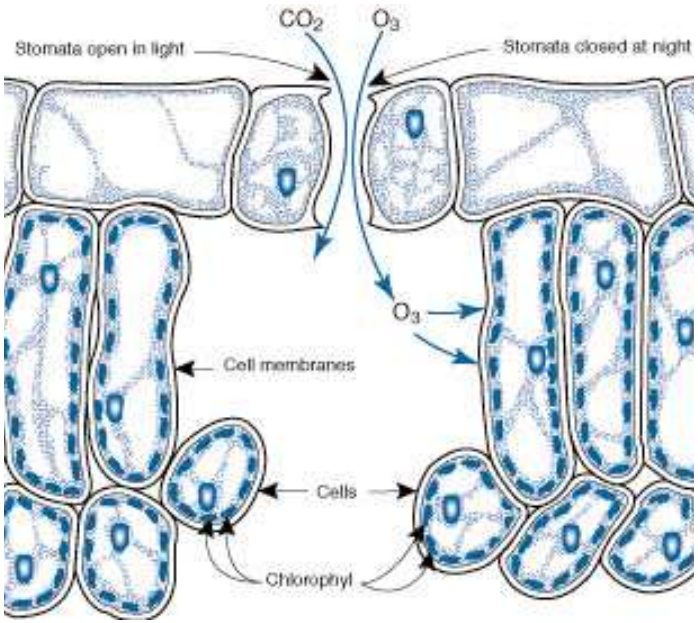
Effects of Ozone Exposure on Plants

- O_3 reduces plant production
  - causes cellular damage inside leaves
  - reduced photosynthetic rates
  - Increased C-allocate to detoxify and repair leaves



- O_3 reduces stomatal conductance
  - lowers internal leaf [CO_2] reducing rates of photosynthesis
  - reduces O_3 uptake.

- Investigate interactions at elevated [CO_2] &[O_3]

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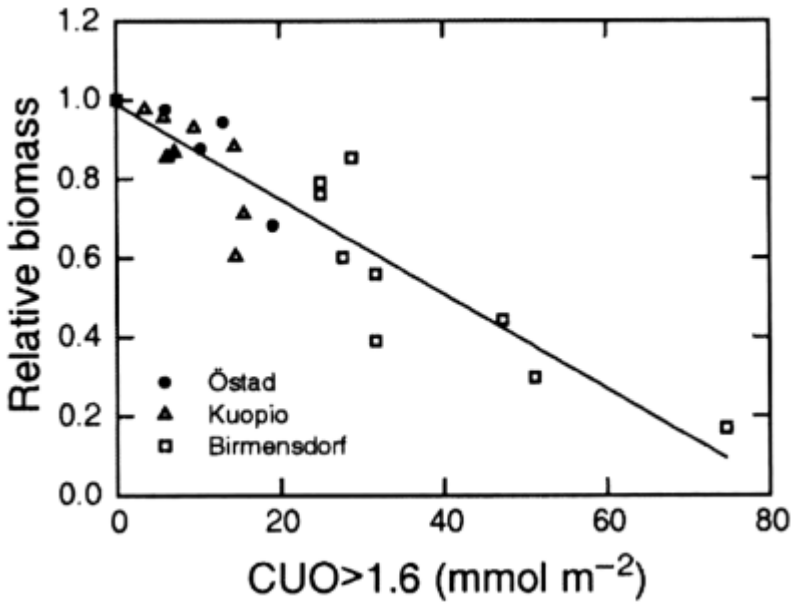
MOSES-Ozone Model Calibration

Experimental Analysis

$$RelativeYield = 1 - b \cdot CUO_{>FO3crit} \quad (4)$$

$CUO_{>FO3crit}$ is the Cumulative leaf Uptake of O_3, over the experimental period. *b* is a plant type specific parameter.



Uddling *et al.* 2004, Ashmore 2005

MOSES-Ozone Model (2)

$$F = 1 - a \cdot UO_{>FO3crit}$$

$UO_{>FO3crit}$ is the instantaneous leaf uptake of O_3, and *a* is a plant type specific parameter.

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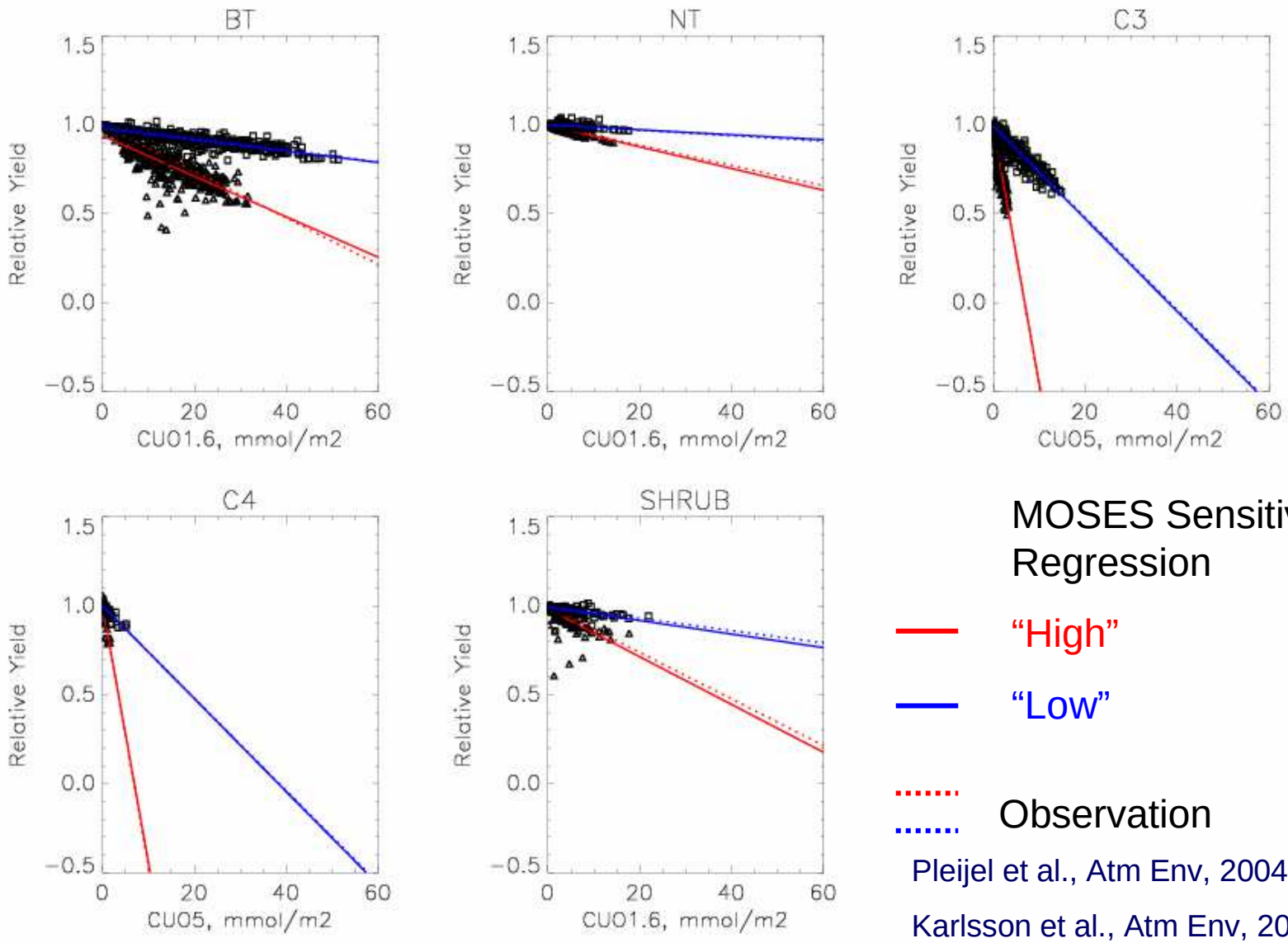
“High” and “Low” Plant Ozone Sensitivities



MOSES Sensitivity Regression

“High”

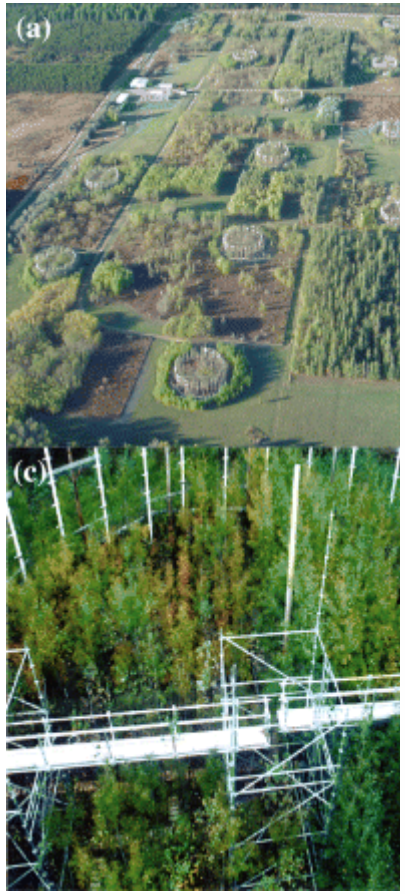
“Low”

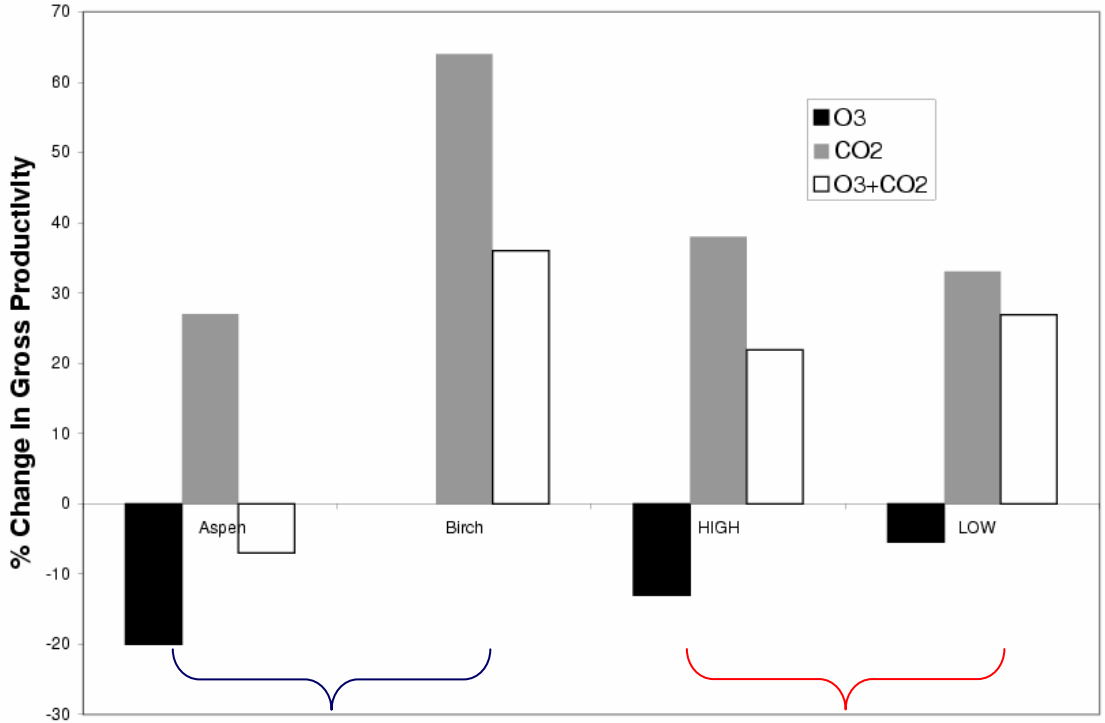
Observation

Pleijel et al., Atm Env, 2004

Karlsson et al., Atm Env, 2004

Evaluation Against FACE experimental data





Measurements (Amax)

Model (GPP)

Karnosky *et al.* 2005, PCE 28, 965-981

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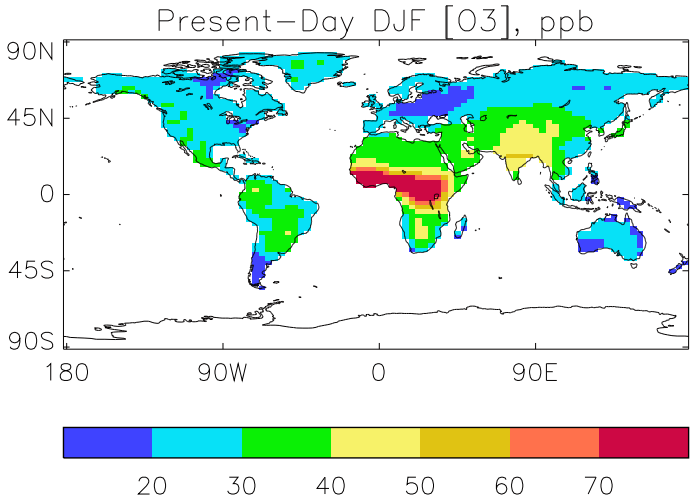
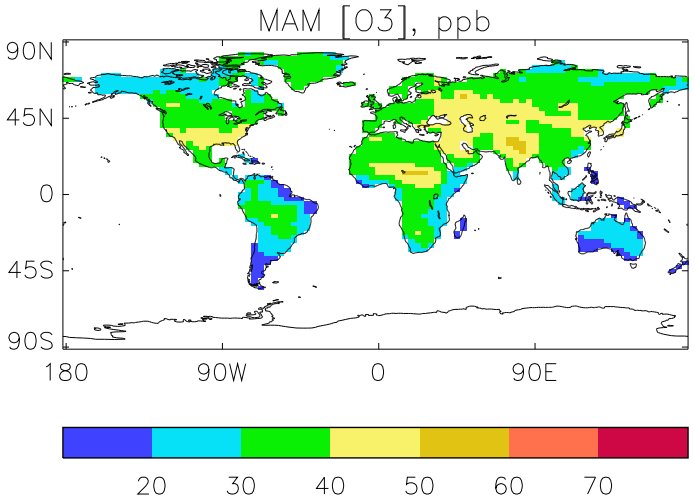
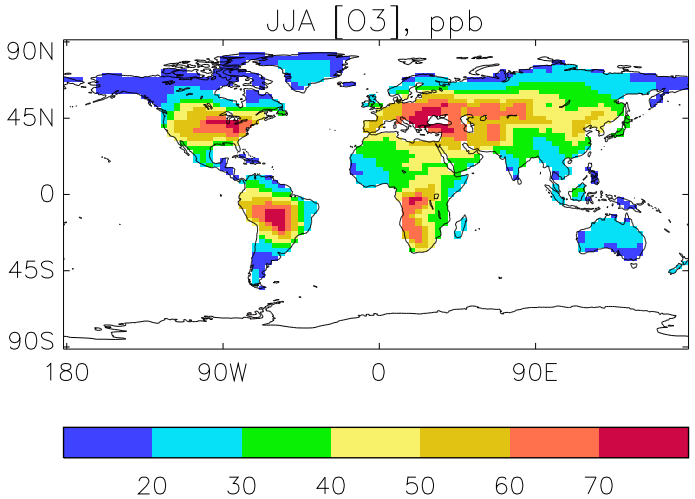
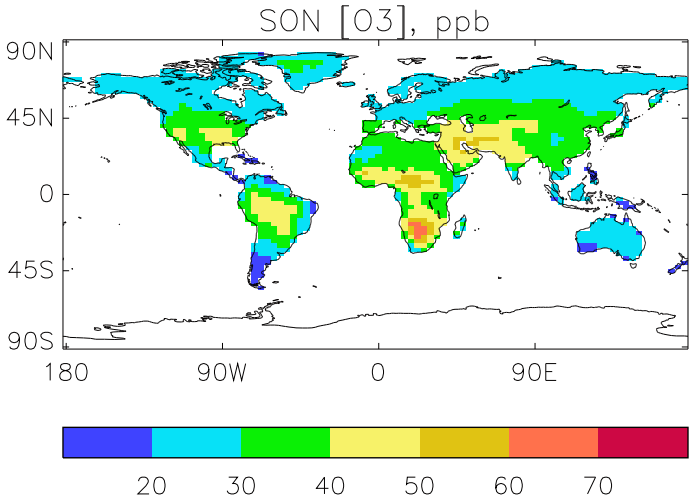
Present Ozone Concentrations (1990)









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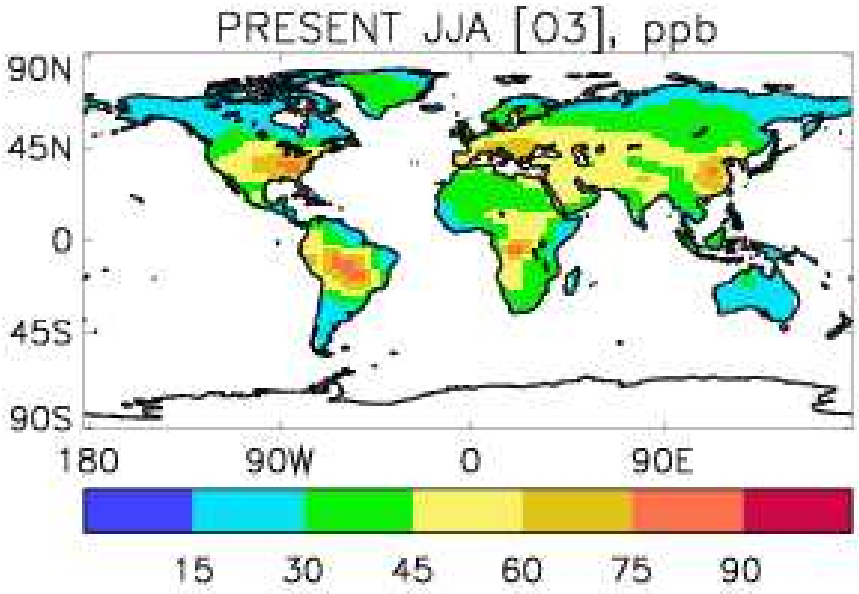
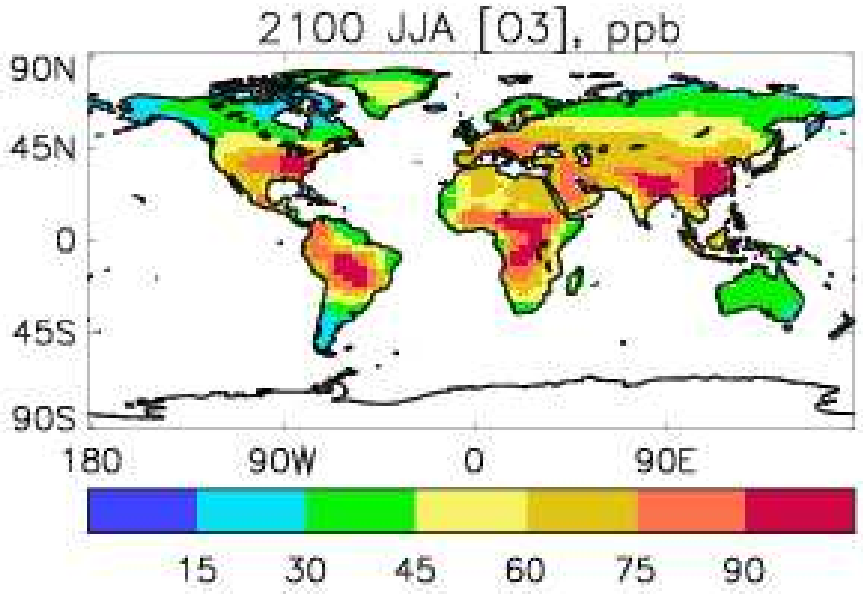
Future O_3 Concentrations (SRES A2)





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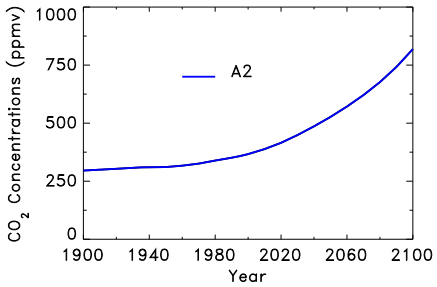
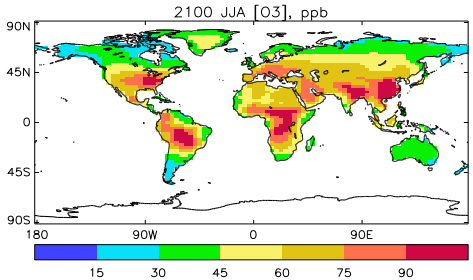
Future Simulations:1901-2100

- f1=CO_2



- f2= O_3 ["Low" & "High" O_3 Sensitivity]



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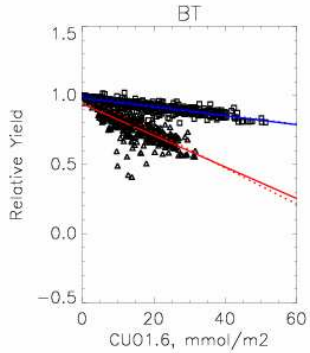
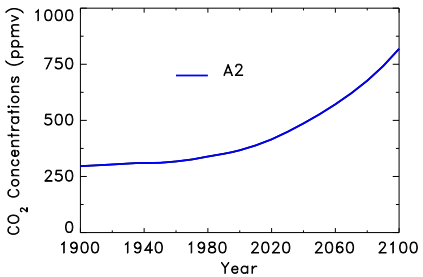


- f3= CO_2 + O_3 ["Low" & "High" O_3 Sensitivity]



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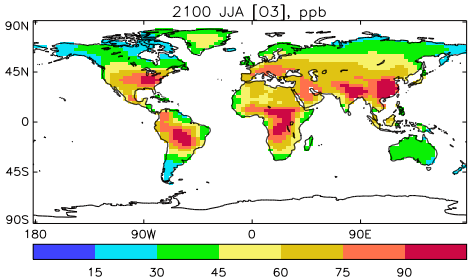

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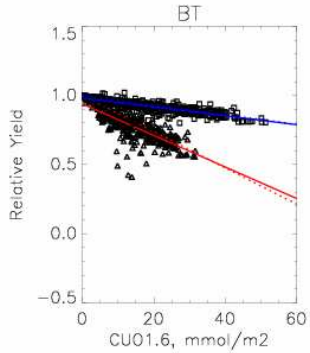

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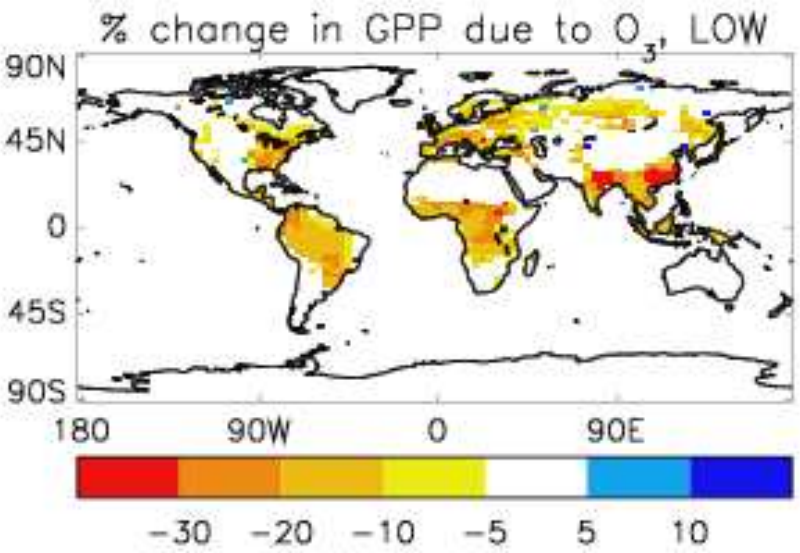
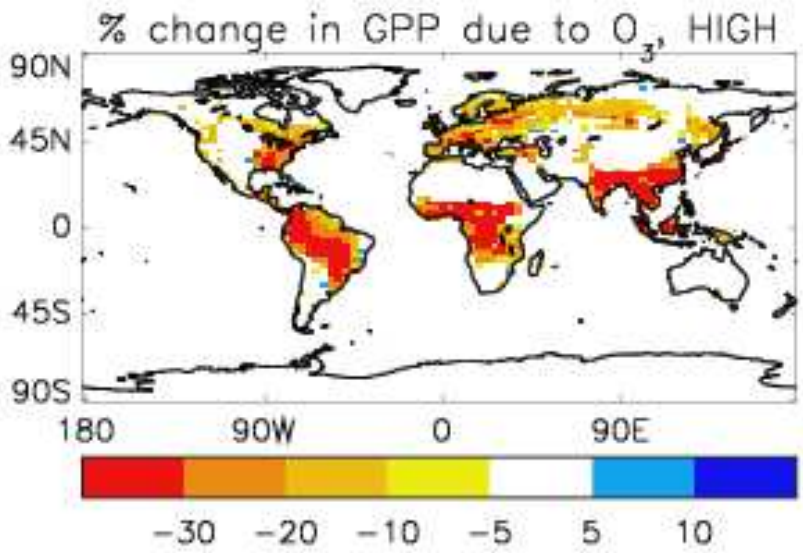
Ozone Effects on Global Plant Productivity, 1901-2100

F2 (O_3)





Large reductions in Production across

Temperate (Agricultural) and Tropical Ecosystems

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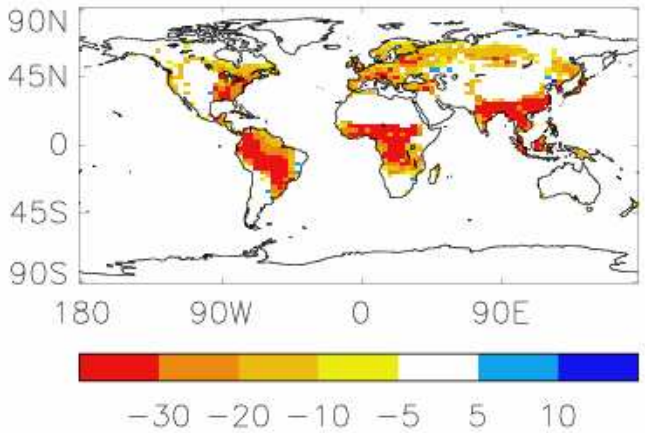
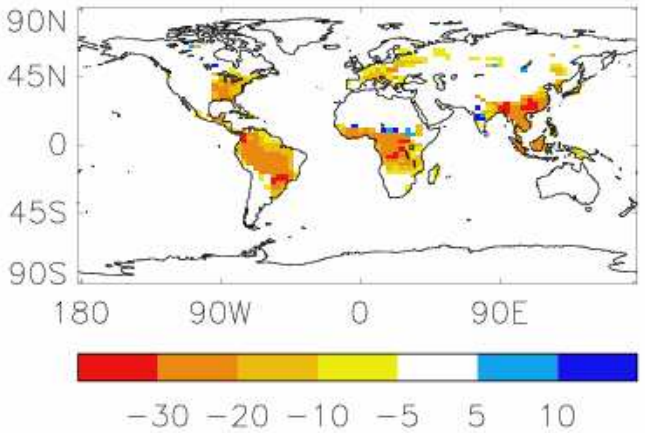
Plant protection against ozone damage at high CO_2

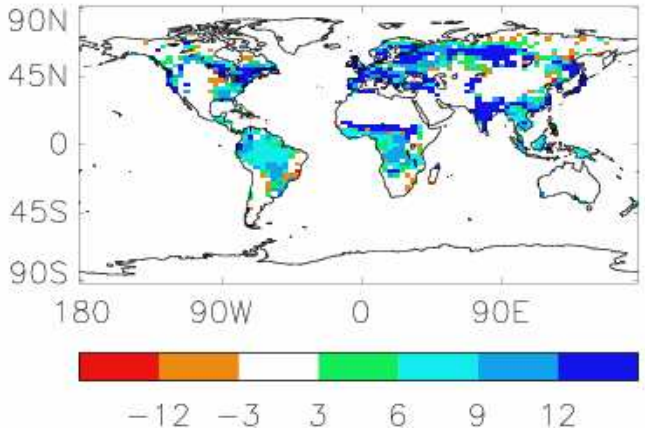
% Δ GPP O_3-effect at 1901 CO_2 (A)



O_3-effect at 2100 CO_2 (B)



Alleviation O_3-effect by CO_2 increases (B-A)



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Ozone and CO_2 effects on Land Carbon Sink

	ΔLandC (PgC)	
	"Low"	"High"
f1(CO_2)	835.8	856.7
f2(O_3)	-143.2	-262.5
f3(CO_2+O_3)	715.6	617.5

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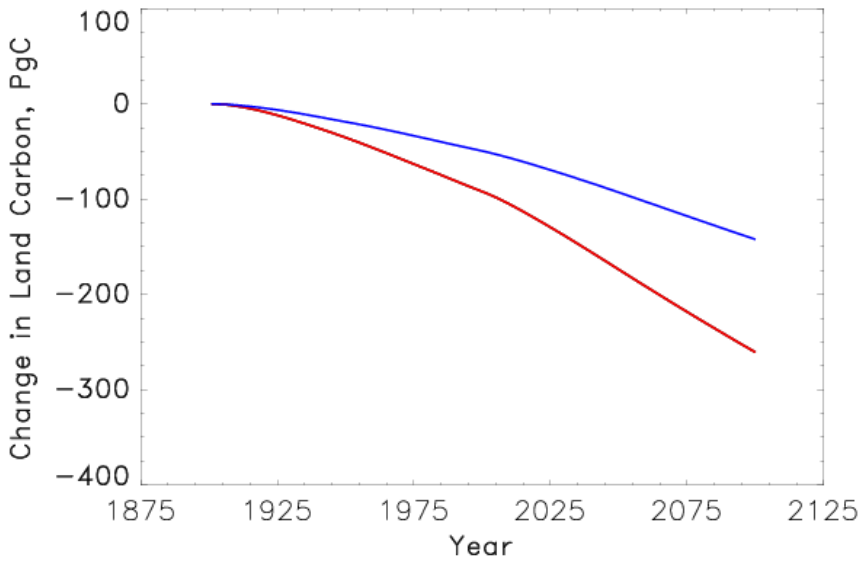
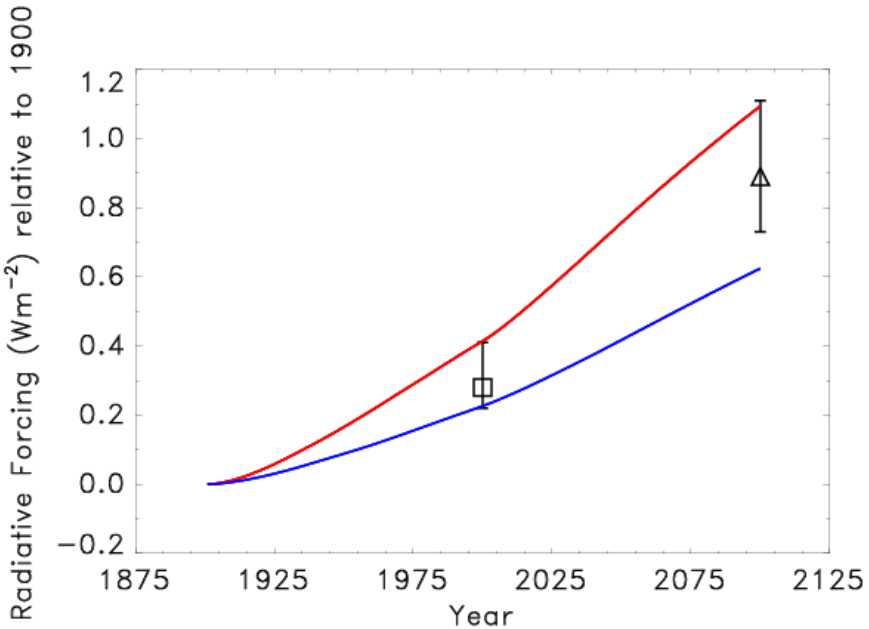
Ozone Effects on Land Carbon Sink and Climate





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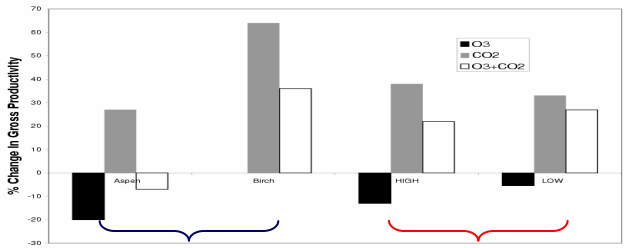
Conclusions

- Simulations broadly agree with FACE data

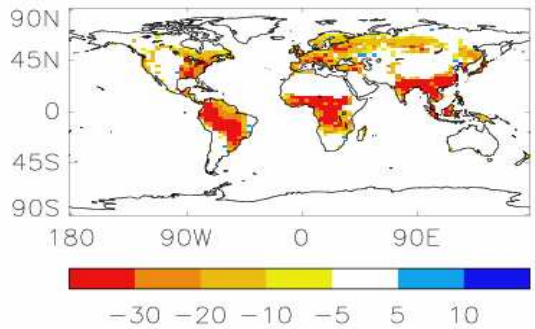


Measurements (Amax)

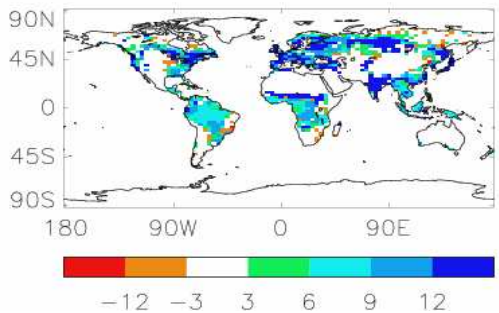
Model (GPP)

- Large reductions in productivity and land carbon storage over temperate and tropical regions
  - Implications for Ecosystem Services (Food security, Forest Productivity, Carbon Sequestration)

% Δ GPP due to O_3-effect



Alleviation O_3-effect by CO_2 increases



- Elevated CO_2 affords some protection for plants against O_3 damage (~1/3)

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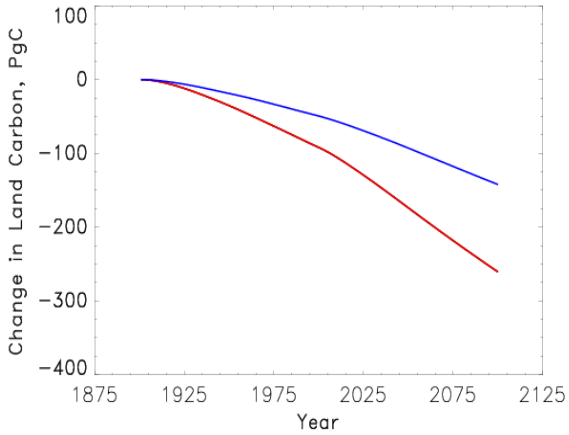
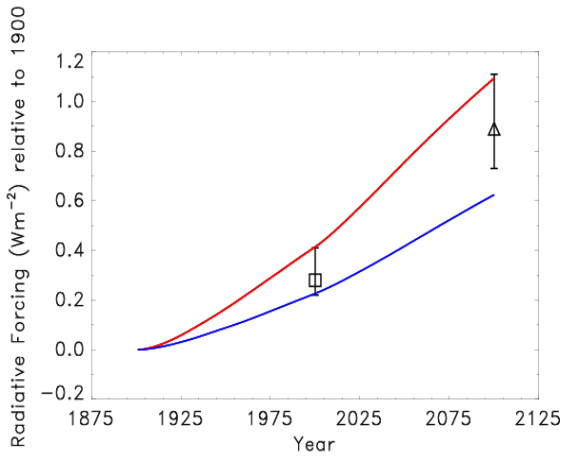
Conclusions

- Large potential threat of elevated future [O_3] on the ability of many land ecosystems to sequester carbon (loss of up to 270PgC, 1901-2100)



- The additional CO_2 in the atmosphere constitutes an indirect radiative forcing through ozone effects on plants, that could exceed global warming due to direct radiative forcing of tropospheric ozone increases.



  - Chemistry more important driver of climate change than hitherto expected

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