Disturbance, albedo, and radiative forcing

Thomas L. O'Halloran[1*], Beverly E. Law[1], Zhuosen Wang[2], Jordan G. Barr[3], Crystal Schaaf[2], Mathew Brown[4], Michael L. Goulden[5], José D. Fuentes[6], Mathias Göckede[1], Andrew Black[4], Vic Engel[3]

[1]Dept. of Forest Ecosystems and Society, Oregon State University, Corvallis, OR, USA

[2]Dept. of Geography and Environment, Boston University, Boston, MA, USA

[3]South Florida Natural Resource Center, Everglades National Park, Homestead, Florida, USA

[4]Faculty of Land and Food Systems, University of British Columbia, Vancouver, Canada

[5]Dept. of Earth System Science, University of California, Irvine, CA, USA

[6]Dept. of Meteorology, Penn State University, University Park, PA, USA

[*]To whom correspondence should be addressed. E-mail: tom.ohalloran@oregonstate.edu

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Photo: Mara Spencer

Motivation/background

Biogeochemical vs biogeophysical climate influences of vegetation

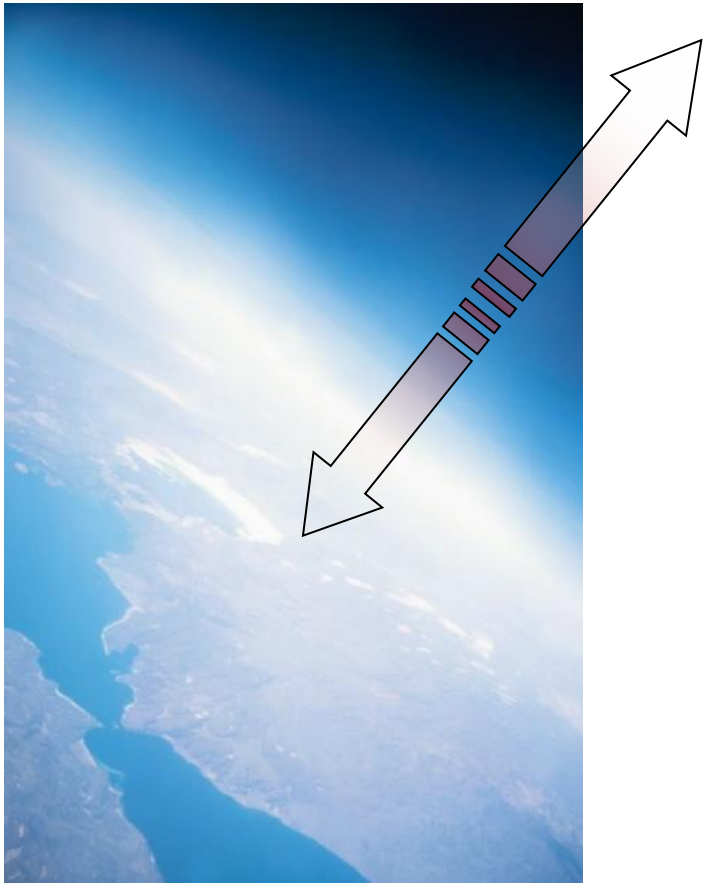
- Albedo important relative to carbon in boreal forests
- Important in global deforestation studies
- Mostly hypothetical modeling studies

- Conventional wisdom:
  - Disturbance effect on albedo only important for fire and in boreal forests

The case for albedo

albedo CO_2

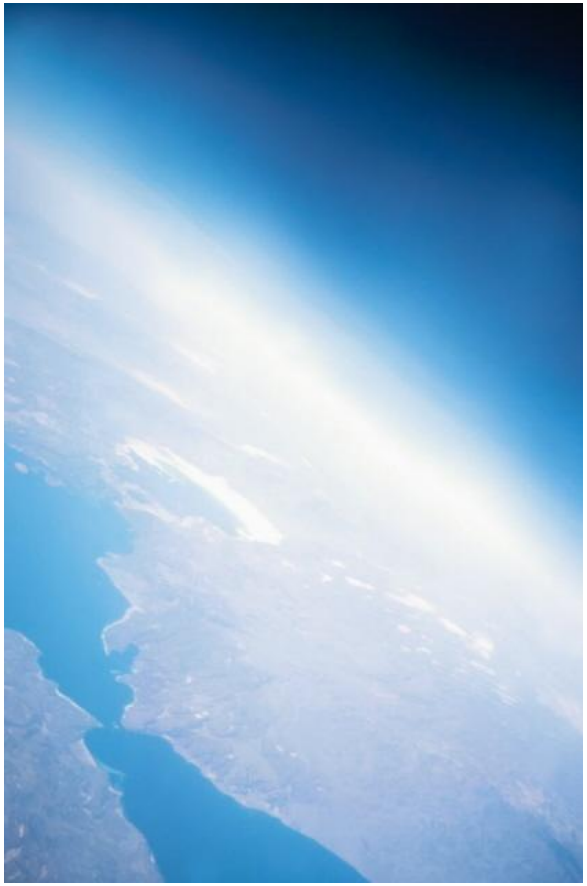
$$Kin\,(1-\alpha) + \varepsilon \mathbf{Lin} - \sigma\varepsilon T^4 = \mathbf{Rnet} = H + LE + G$$



The case for albedo

Quantity | **Quality**

$$\text{Kin}\,(1-\boldsymbol{\alpha}) + \varepsilon\mathbf{Lin} - \sigma\varepsilon T^4 = \mathbf{Rnet} = H + LE + G$$



Greenhouse gases and surface albedo change the net amount of energy in the climate system

LE, roughness etc., only move energy around (at the first order)

Outline

Part 1

Compare the ***per-unit area*** CO_2 and albedo radiative forcings caused by 3 forest disturbances:

1. Hurricane defoliation of mangroves
2. Mountain pine beetle mortality
3. Wildfire

Part 2 (preliminary)

Global CO_2 and albedo radiative forcings of gross deforestation

Part 1. Case studies
Methods

Albedo and carbon fluxes:

Albedo: AmeriFlux towers and MODIS broadband albedo

CO_2 fluxes: AmeriFlux towers, biometric NEP measurements, fire emission factors, models

∂NBP – accounts for NEP of undisturbed stand

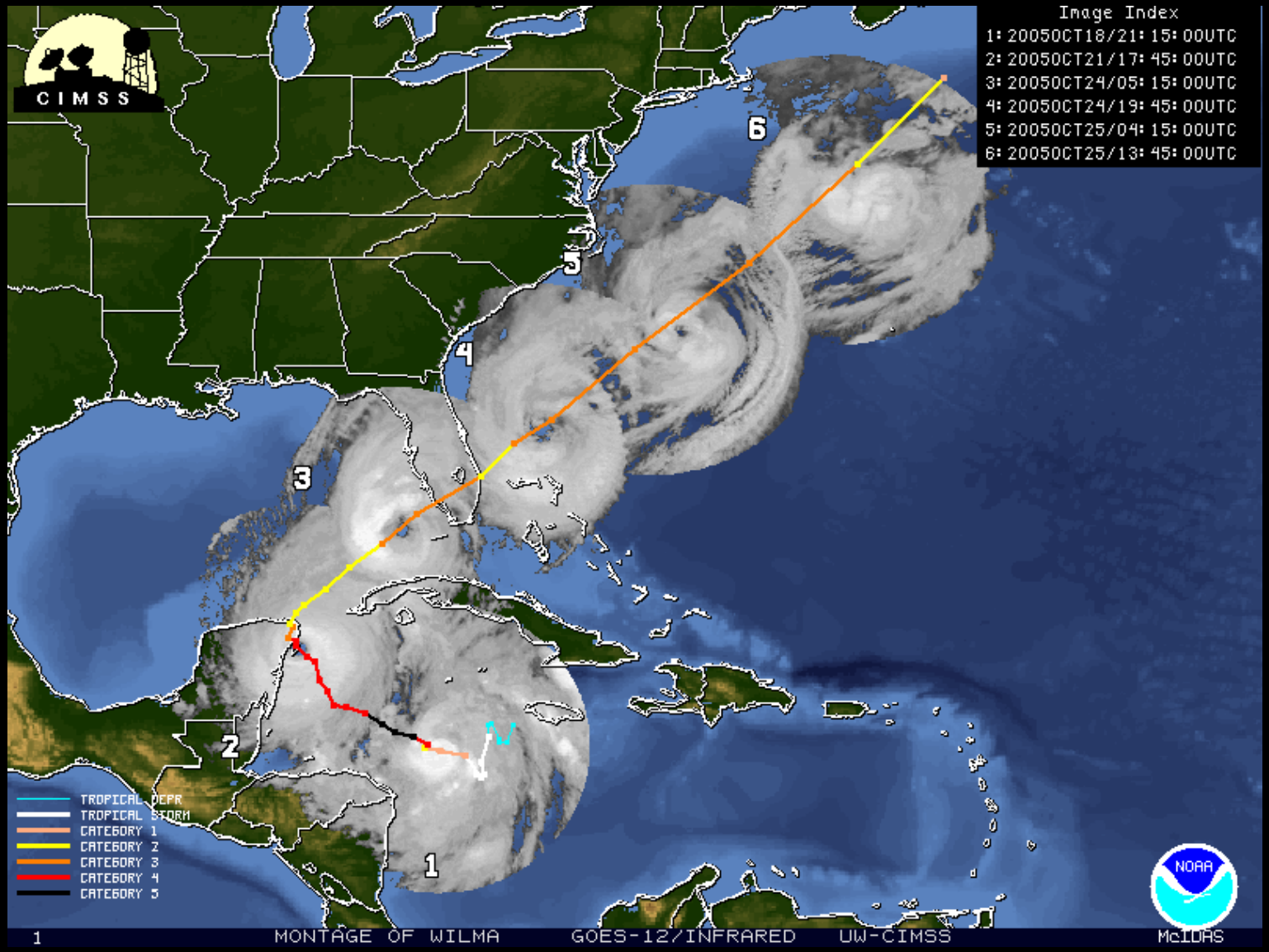
Radiative forcing:

Albedo: change in reflected outgoing shortwave at surface, scaled to TOA using offline radiative transfer calculations (Shell et al., 2008)

CO_2: RF calculation from Myhre et al., (1998): $RF = 5.35 \times \ln \frac{C}{C_0} \quad [W\,m^{-2}]$

where C is CO_2 perturbation to atmosphere after uptake by land and ocean are accounted for (HILDA model)

1. Hurricane wind throw: Wilma in Everglades



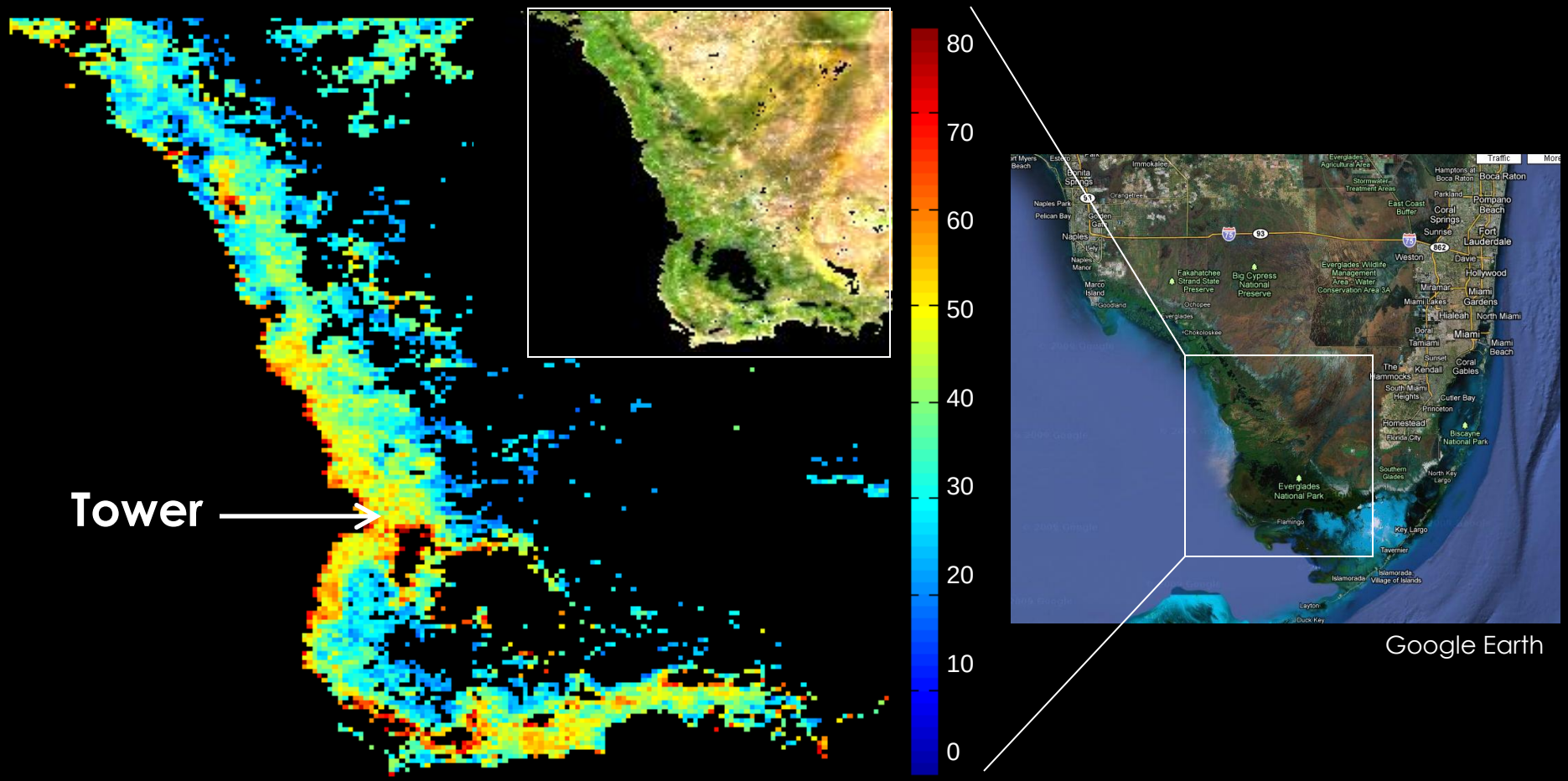
Cat. 3

Winds >190 km hr^{-1}

Before hurricane Wilma

After hurricane Wilma

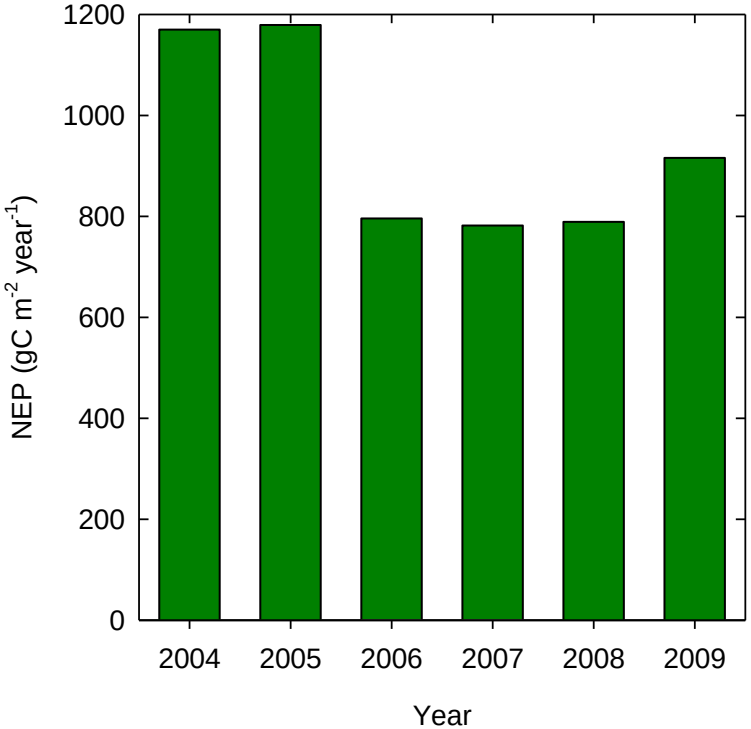
Δ MODIS EVI (%)

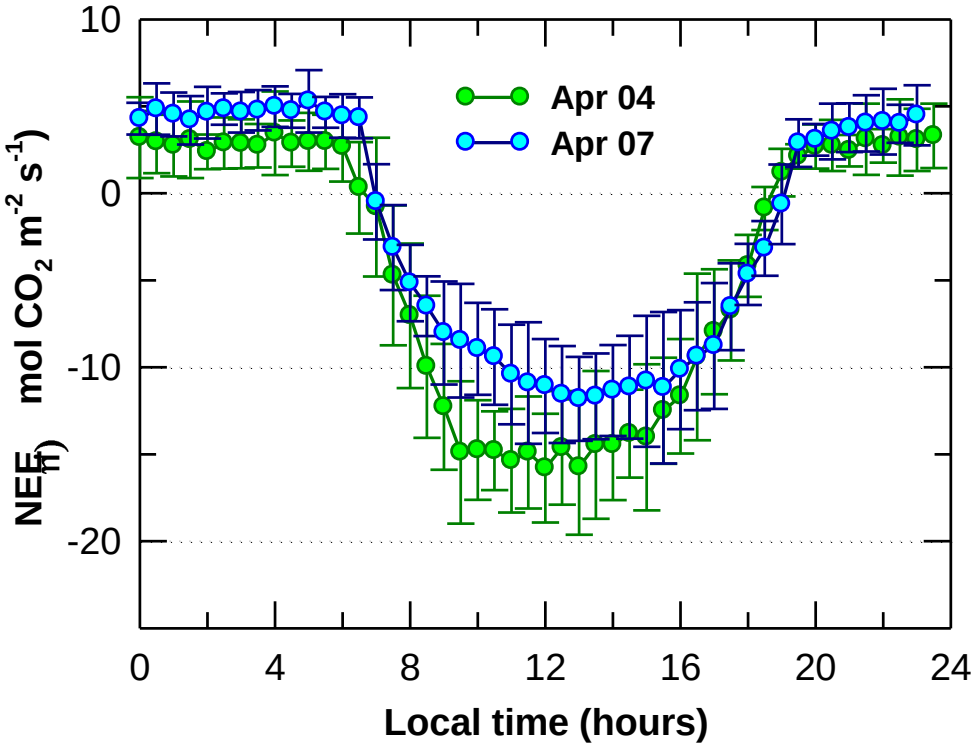


% change MODIS EVI

> 2,700 km^2 affected

Hurricane

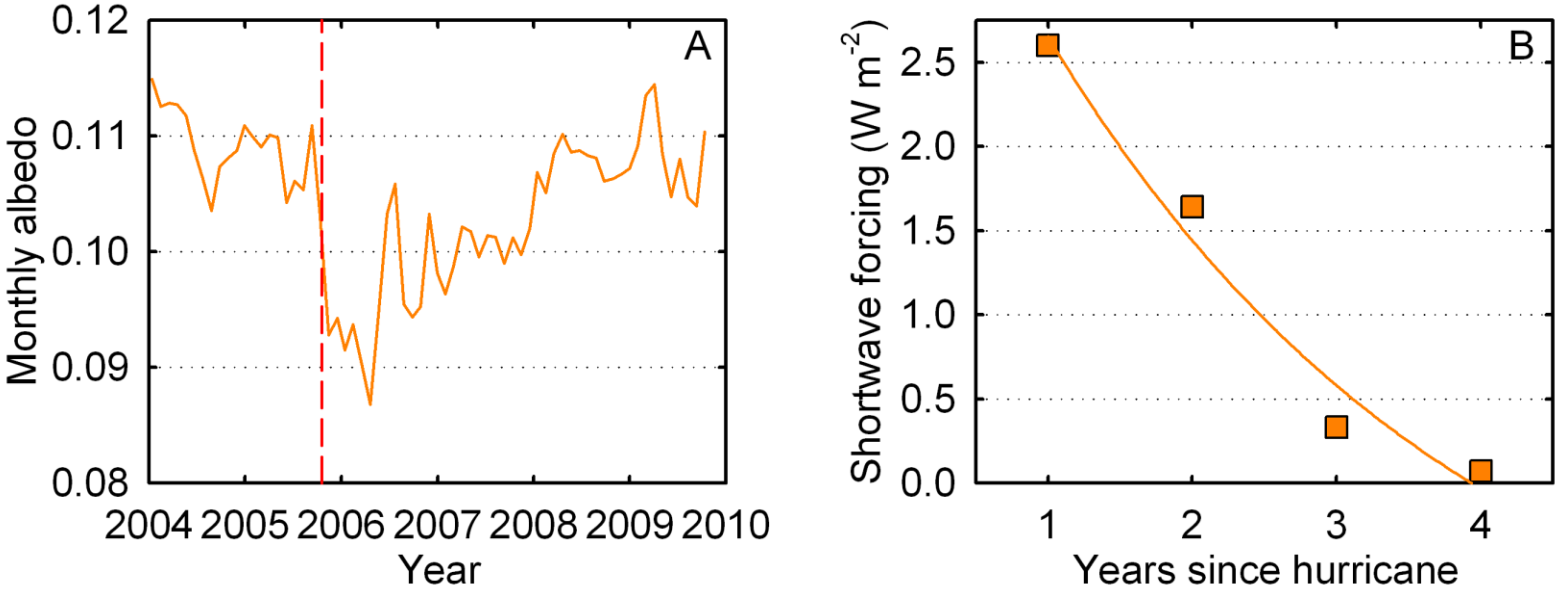




NEP reduced by 33% in first year

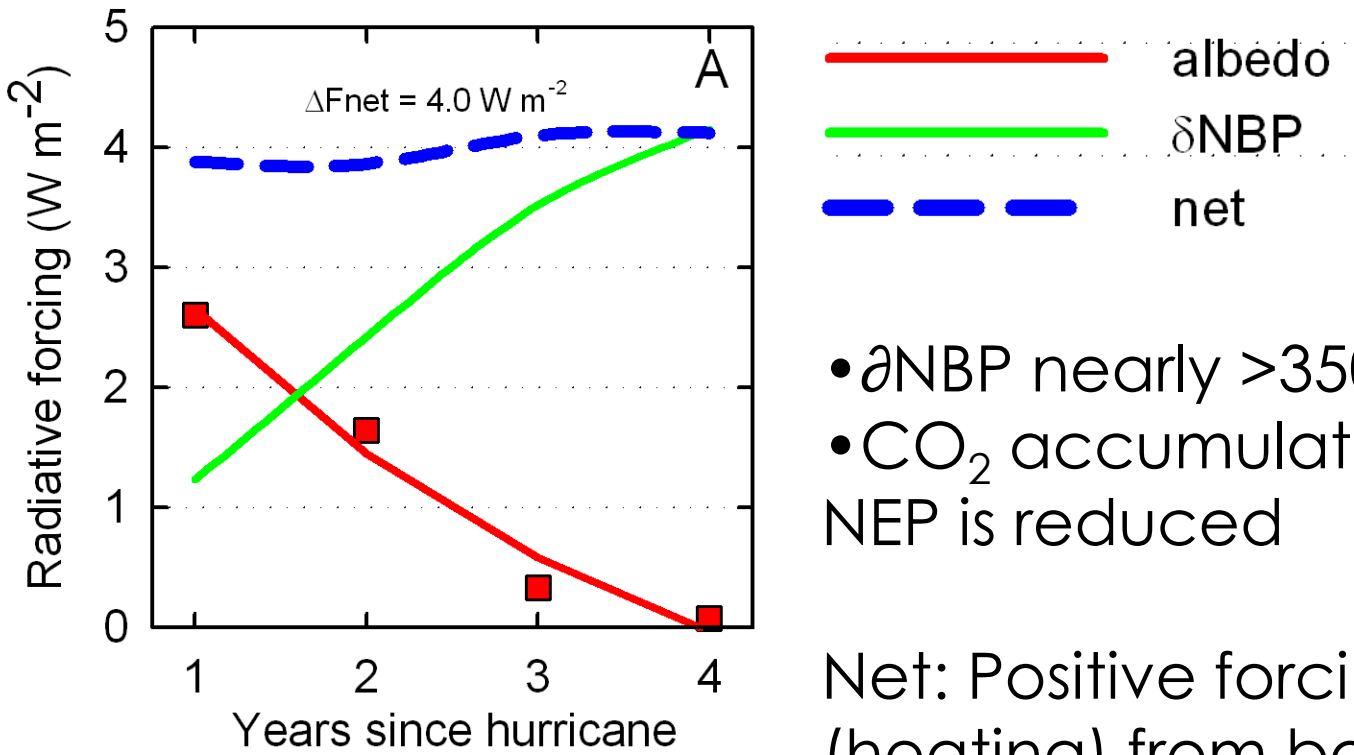
Barr, J.G., T.J. Smith III, J.D. Fuentes, and V. Engel, Hurricane disturbance and recovery of energy balance, CO_2 fluxes and canopy structure in a mangrove forest of the Florida Everglades. *Submitted*.

Hurricane



Defoliation by Hurricane Wilma in October 2005 (red dashed line) reduced albedo from 0.11 to 0.09, resulting in a positive radiative forcing of 2.5 W m^{-2} (heating) in the first year, which quickly recovered in only 4 years.

Hurricane: Net Forcing

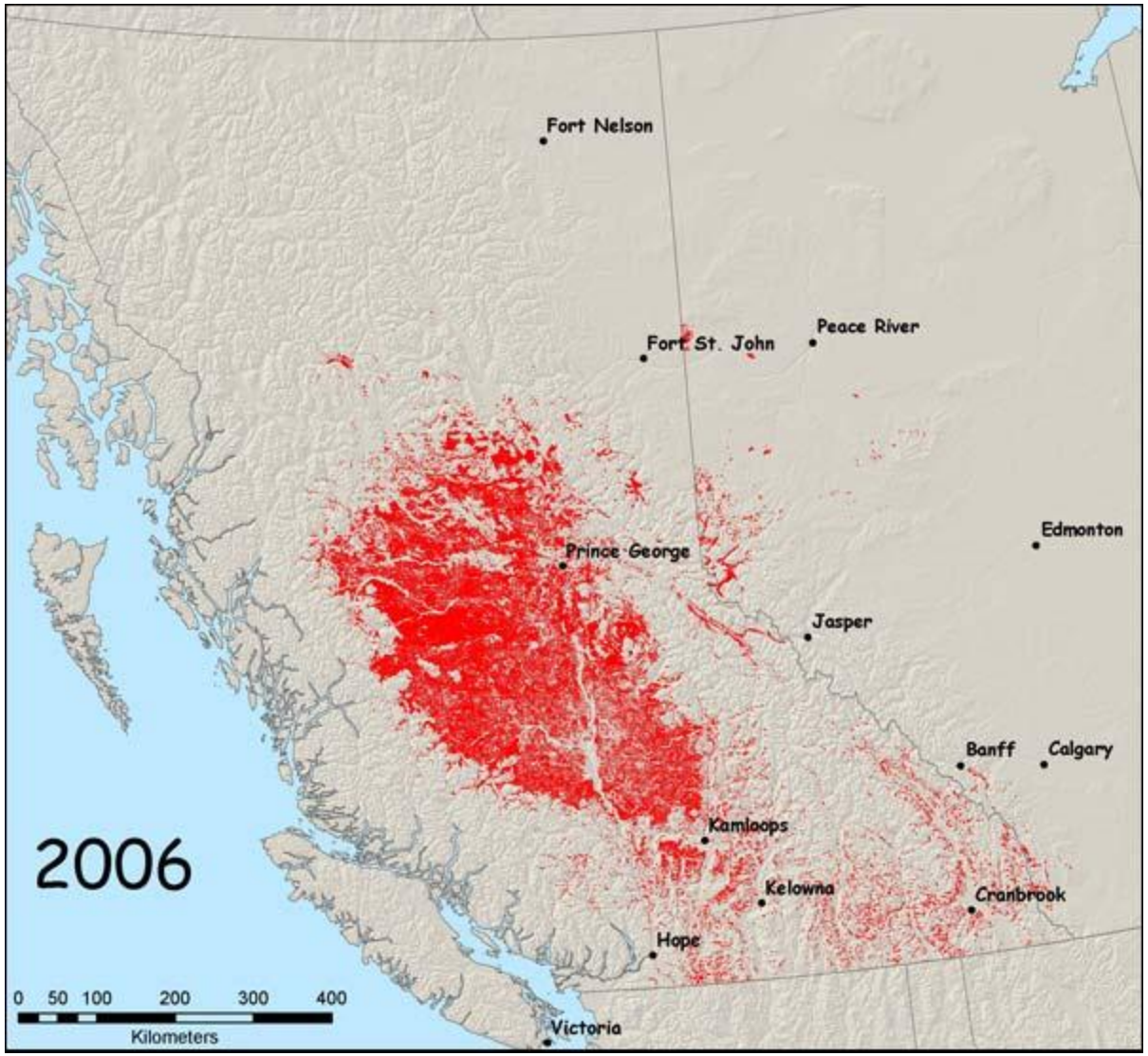


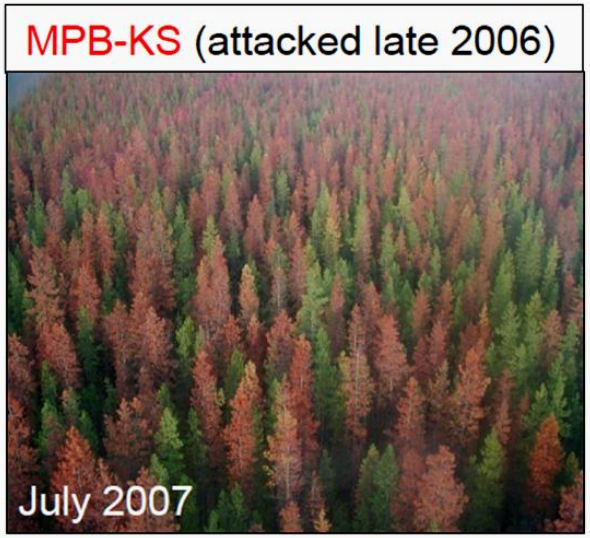
- ∂NBP nearly >350 gC m^{-2}
- CO_2 accumulating while NEP is reduced

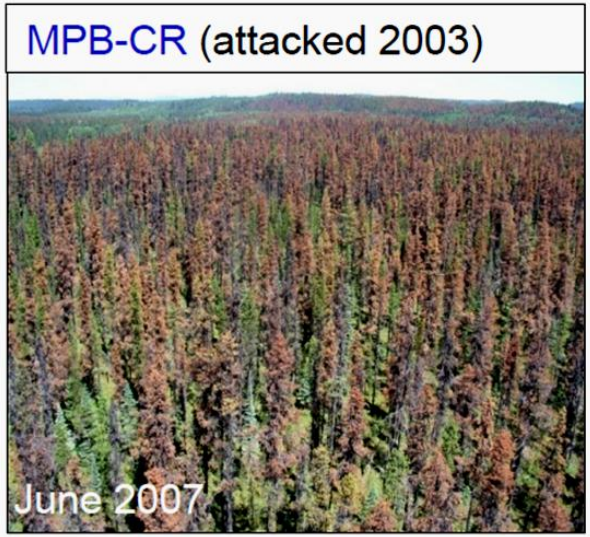
Net: Positive forcing (heating) from both CO_2 and albedo

2. Insects: Mountain pine beetle in lodgepole pine

British Columbia

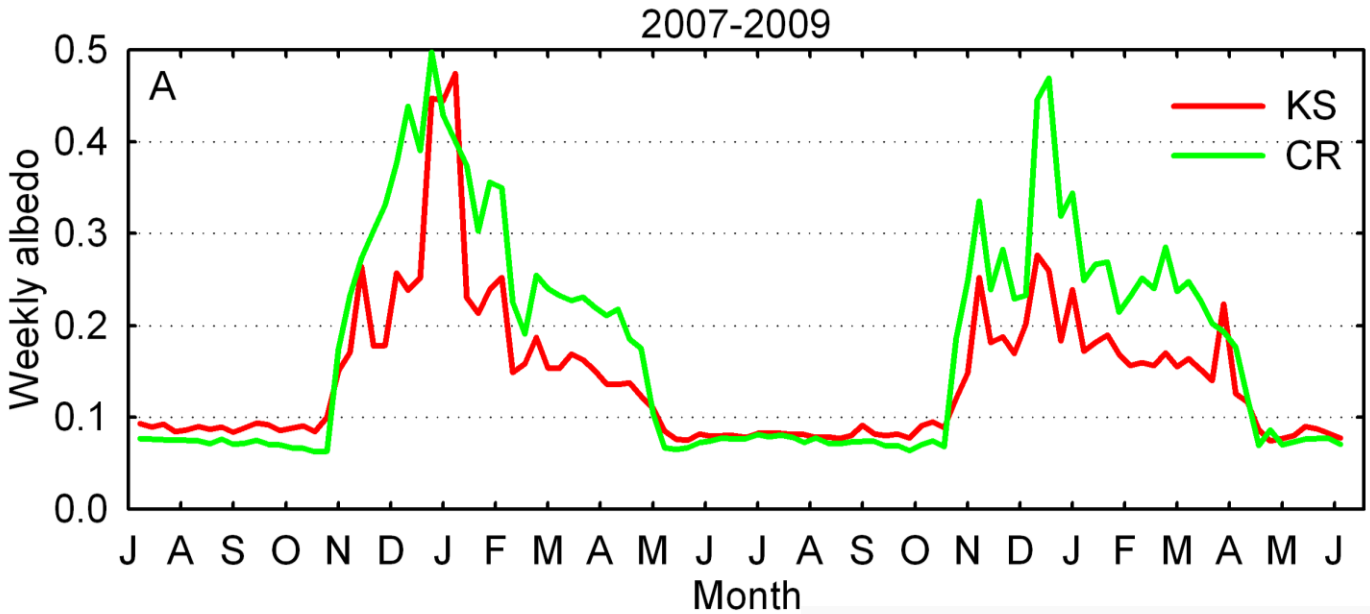


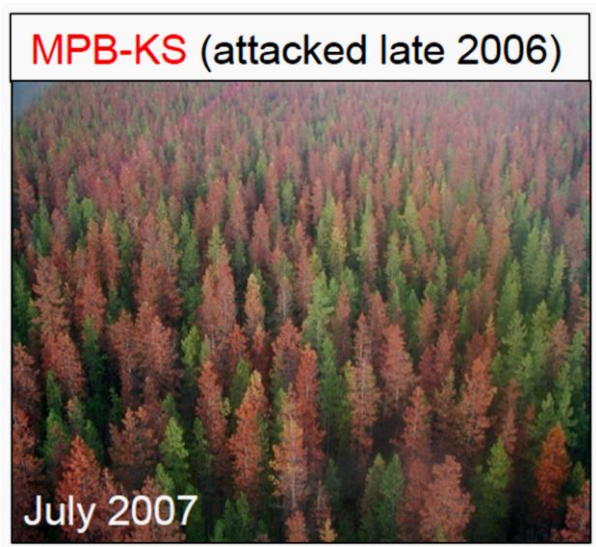


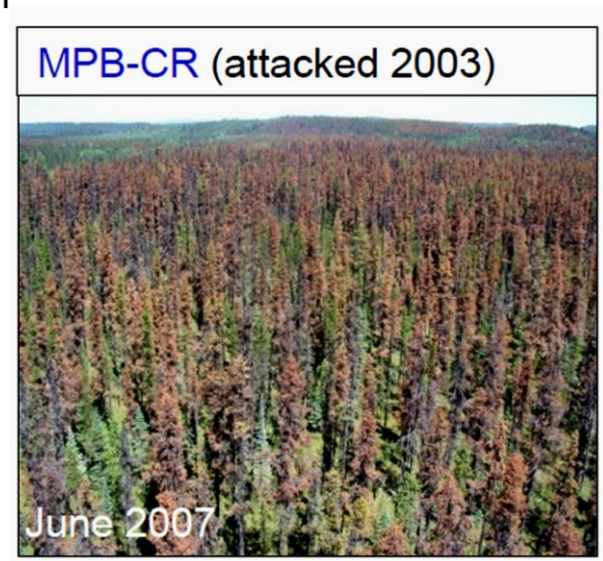


Natural Resources Canada

Insects

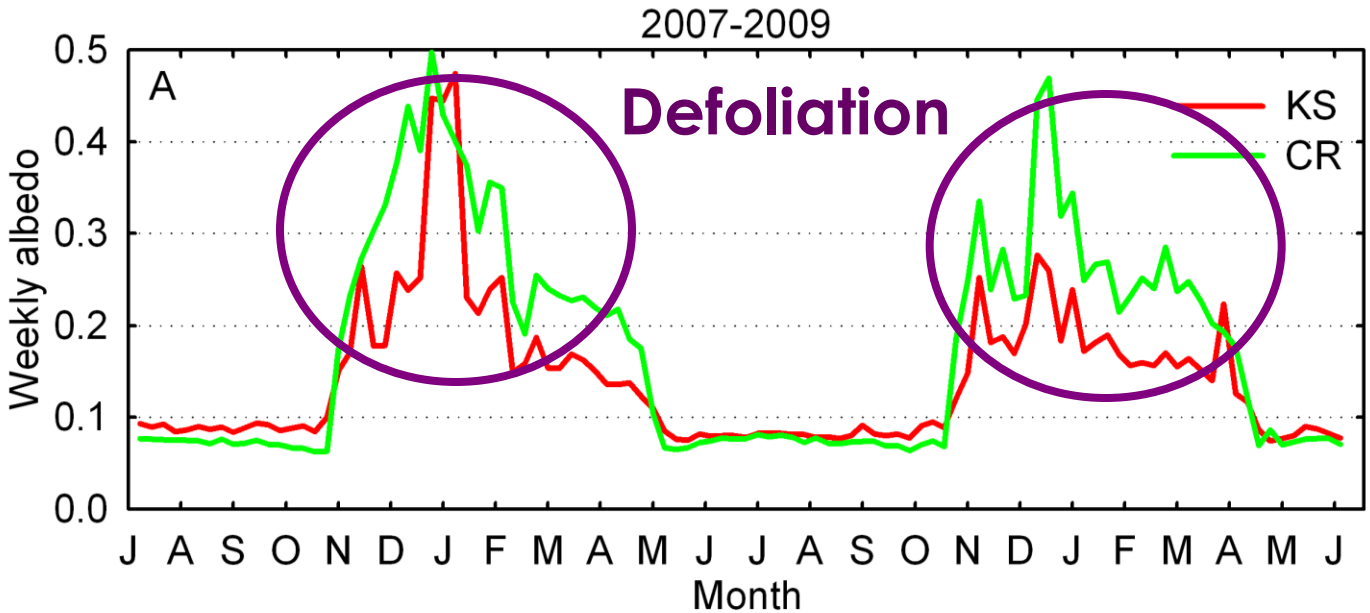


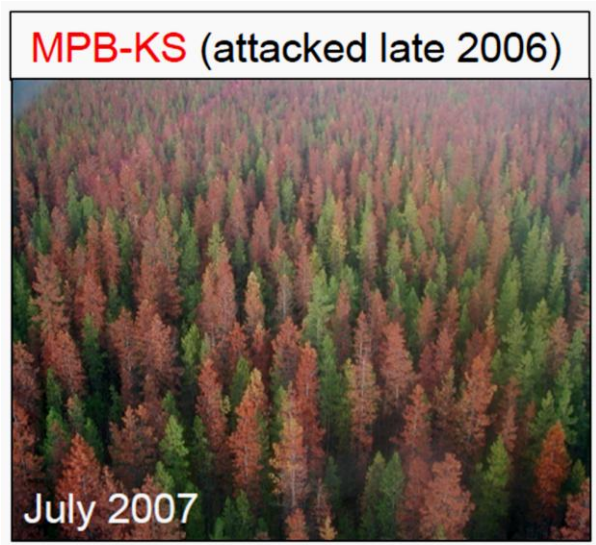


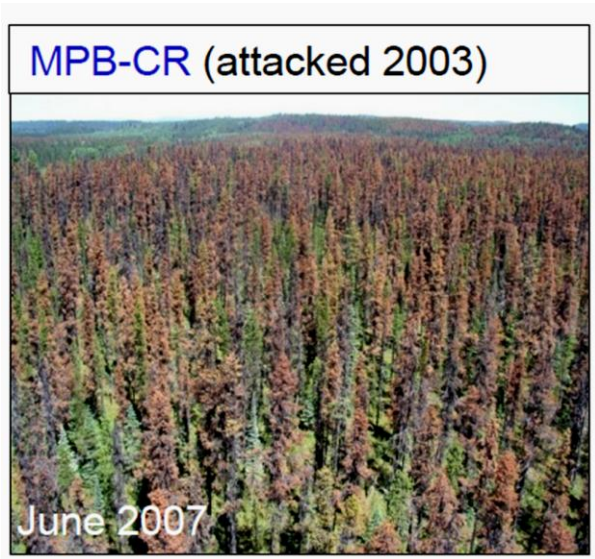


Data source: Andy Black's towers, British Columbia

Insects







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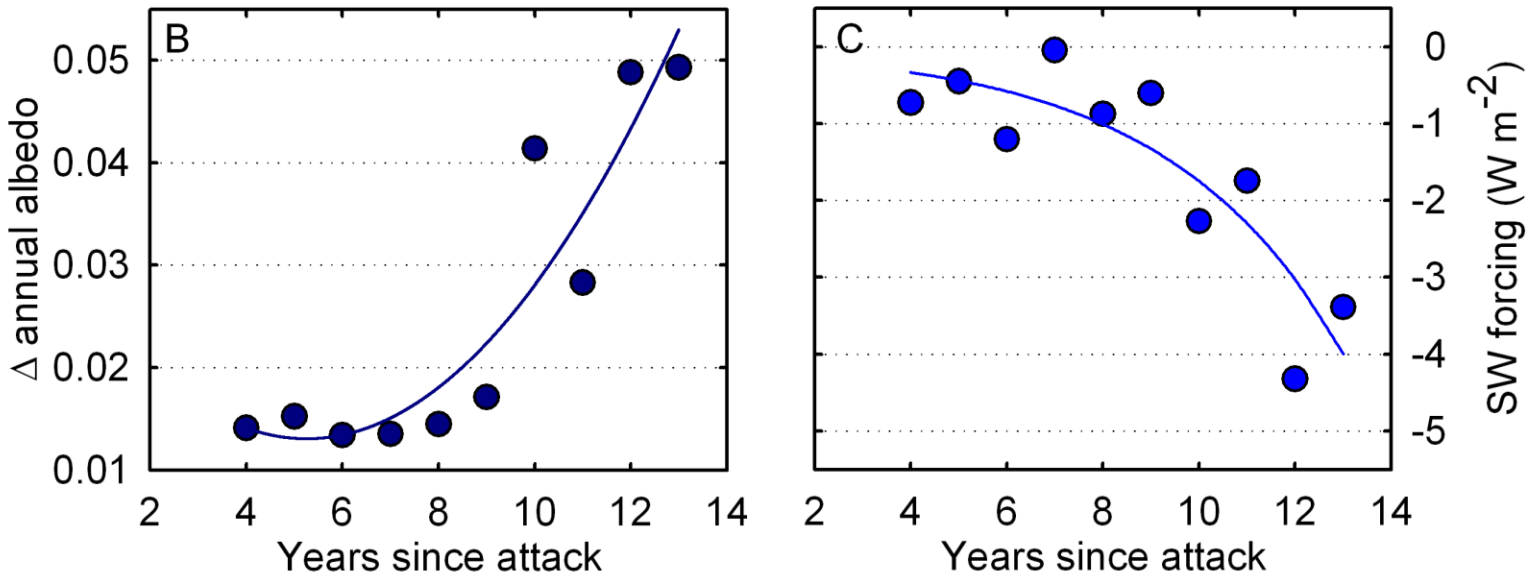
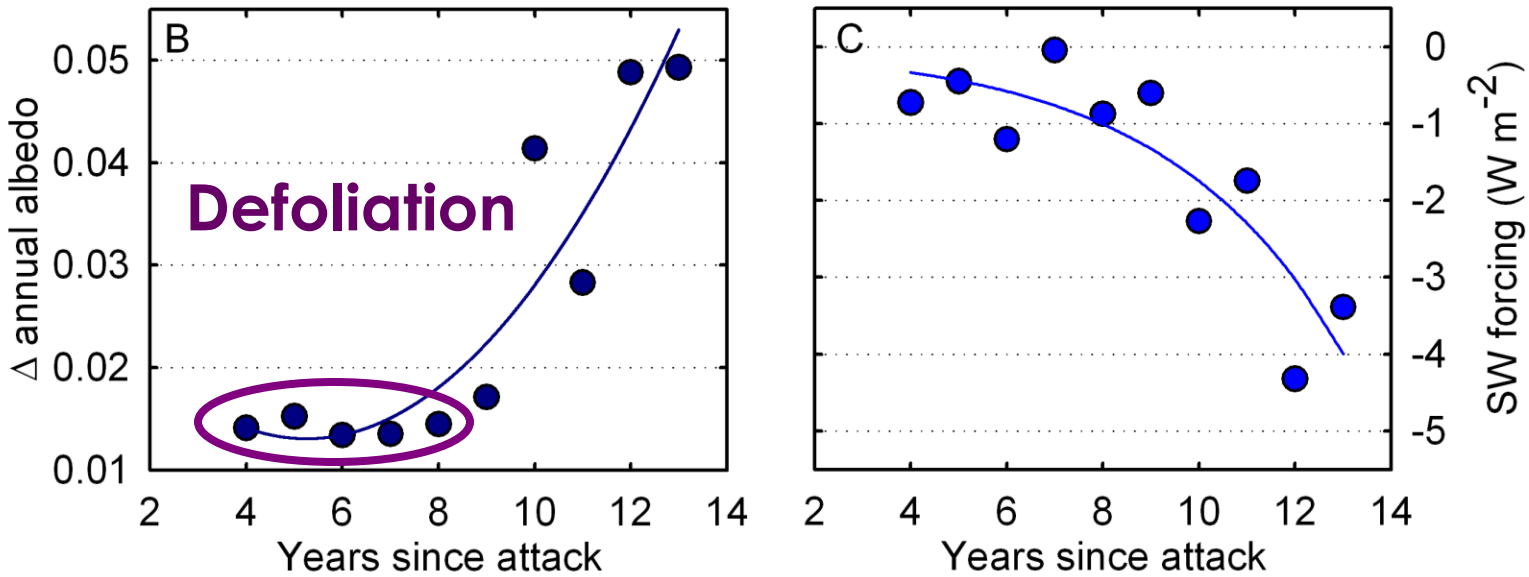


Data source:
MODIS, Oregon

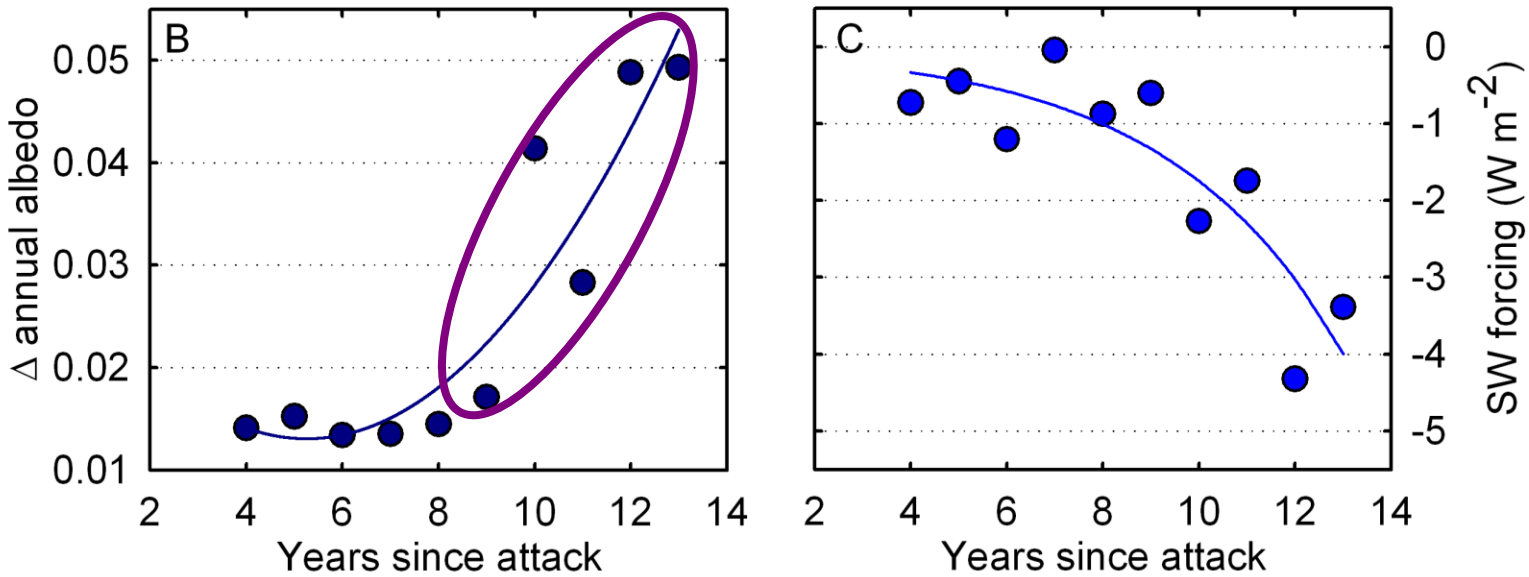
Insects



Data source:
MODIS, Oregon

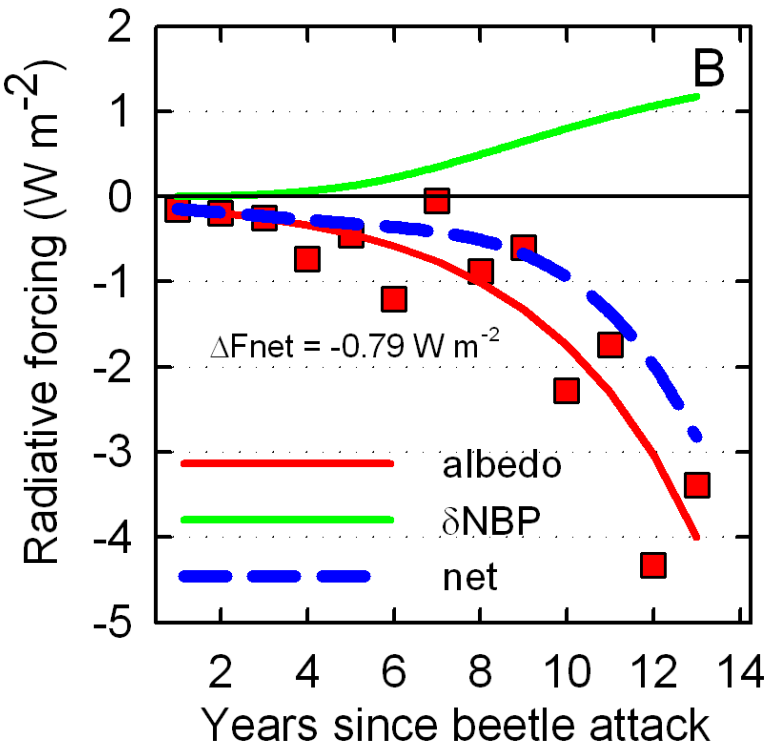
Insects

Snag fall



Data source:
MODIS, Oregon

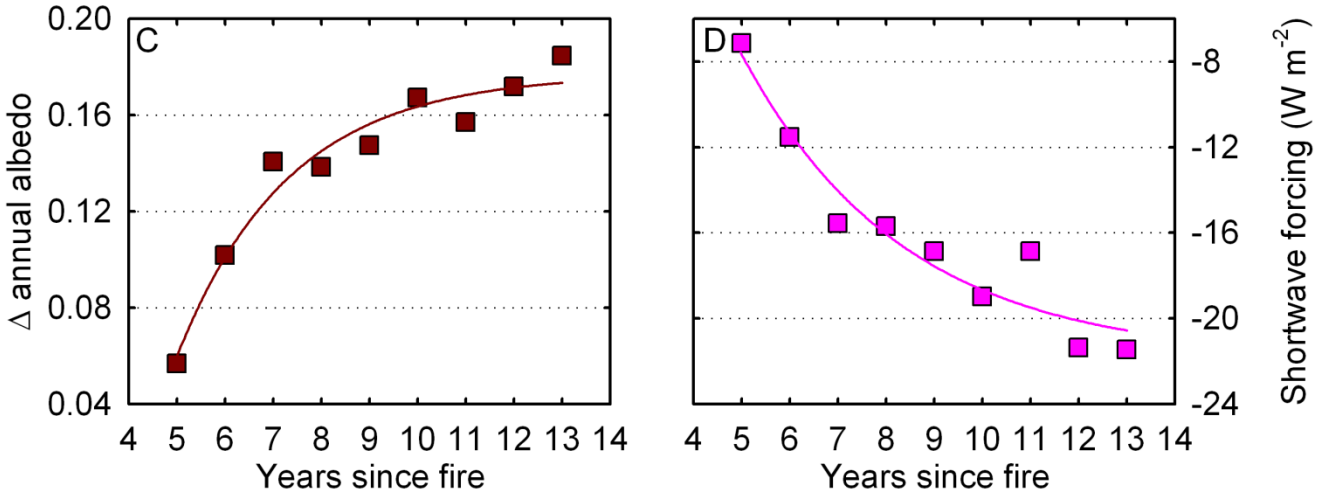
Insects: Net Forcing



- ∂NBP from Kurz et al., 2008
- Mild in early years
- ~55 gC m^{-2} by year 13

Net: Positive forcing (heating) from CO_2 and negative (cooling) from albedo

3. Wildfire (short term)

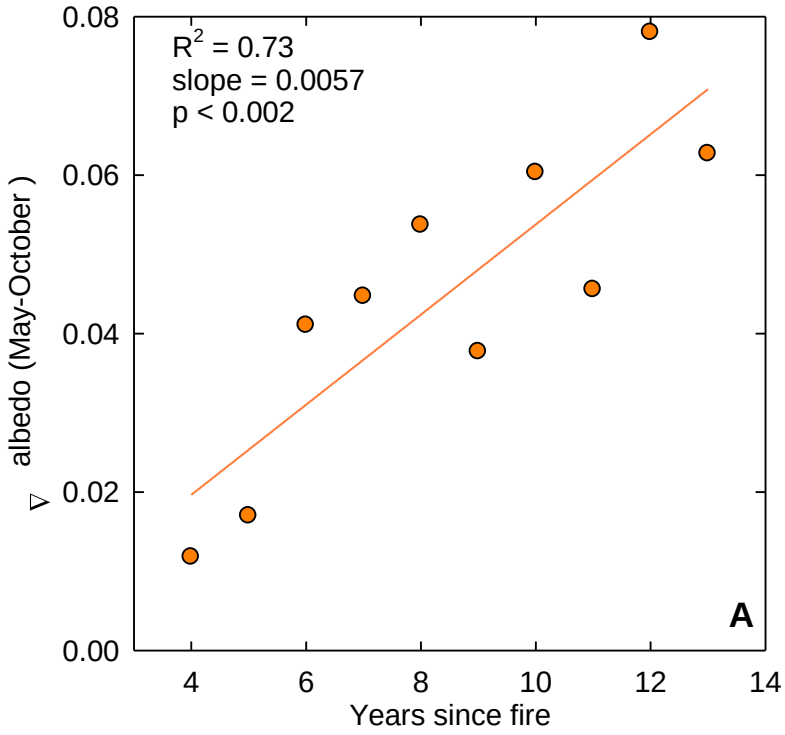


The Charlton (Waldo Lake) fire burned ~3,800 ha of ~300 year old mountain hemlock stand in the Cascades of central Oregon in 1996. Photos from 2007 (Mara Spencer).

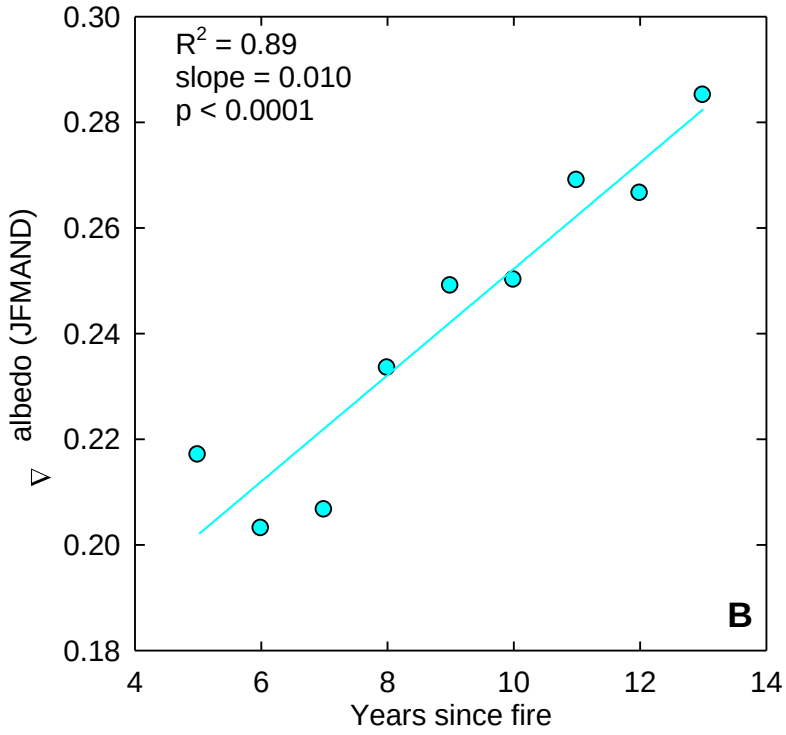
Wildfire

Albedo increases in summer and winter via two different mechanisms

Summer



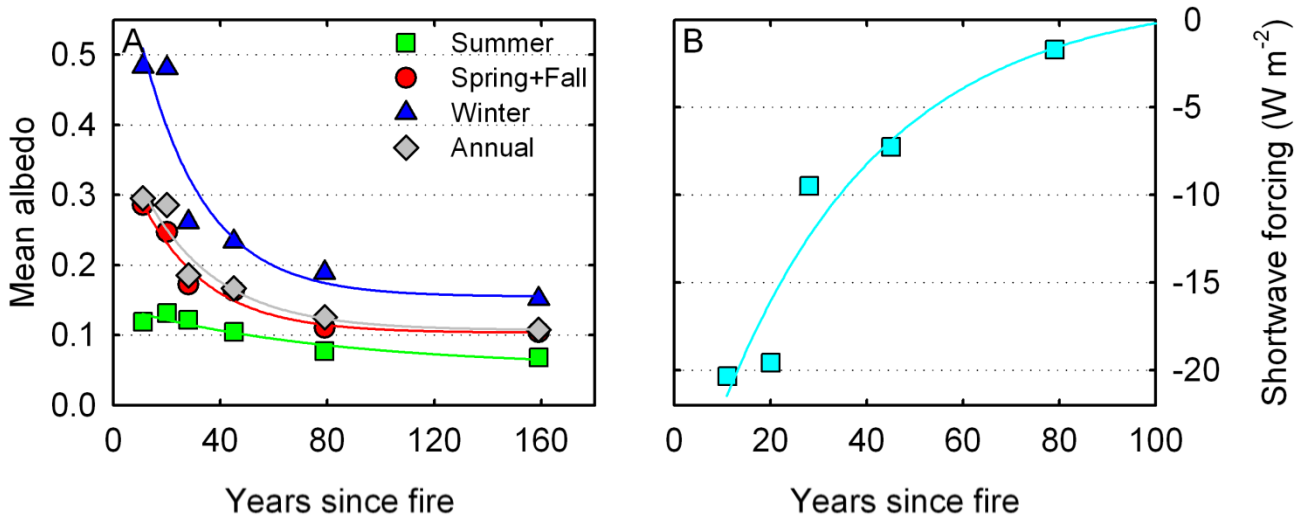
Winter



Summer green-up

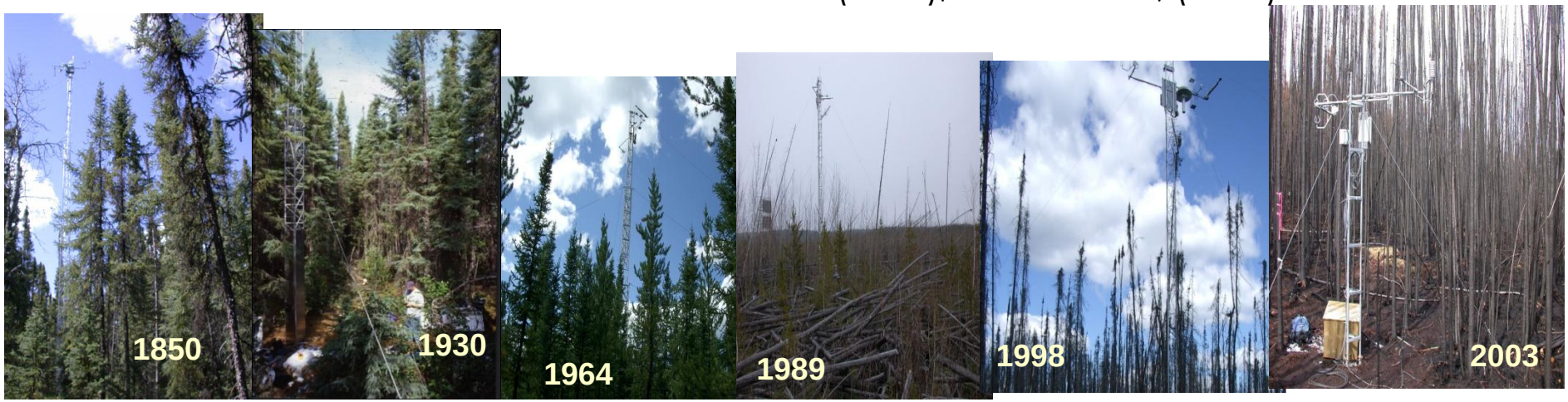
Snag fall

Wildfire (long term)

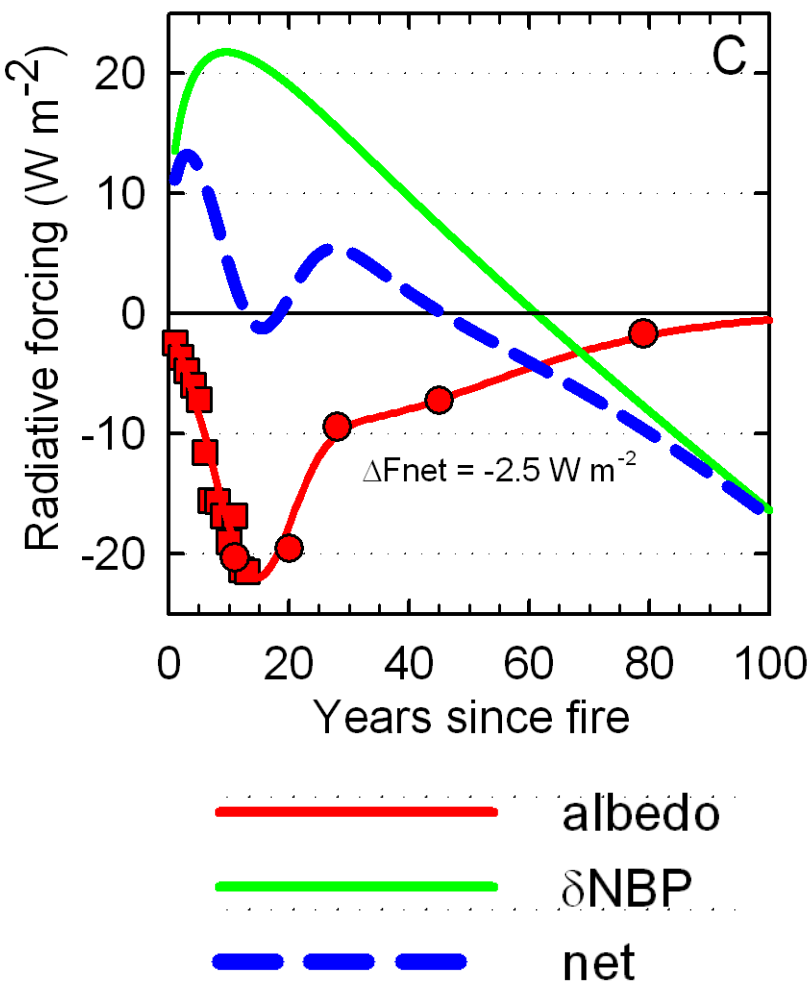


UC Irvine boreal fire chronosequence (Manitoba)

See also McMillan and Goulden (2008), Amiro et al., (2006)



Wildfire: Net Forcing



- Pyrogenic flux of 2160 280 gC m^{-2}
- Local NEP curves (e.g. Goulden et al., 2010)

Net: Large positive forcings from CO_2 (heating) and albedo (cooling) largely offset for a net cooling of only -2.5 W m^{-2} over 100 years.

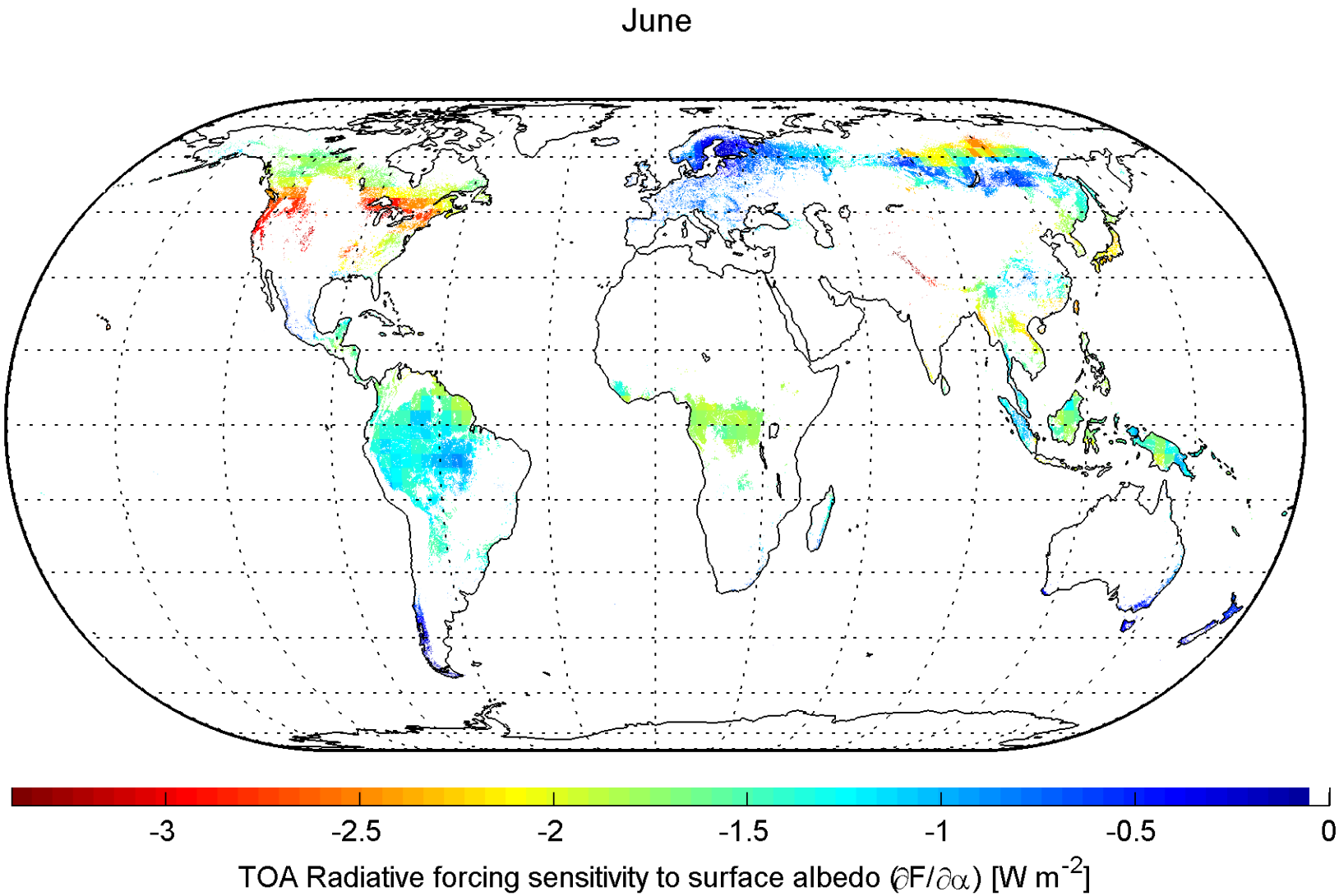
Part 2. Globally significant?

- Goals:

- Model albedo perturbation of recently published gross deforestation rates from 2000-2005 (Matthew Hansen et al., 2010, PNAS)

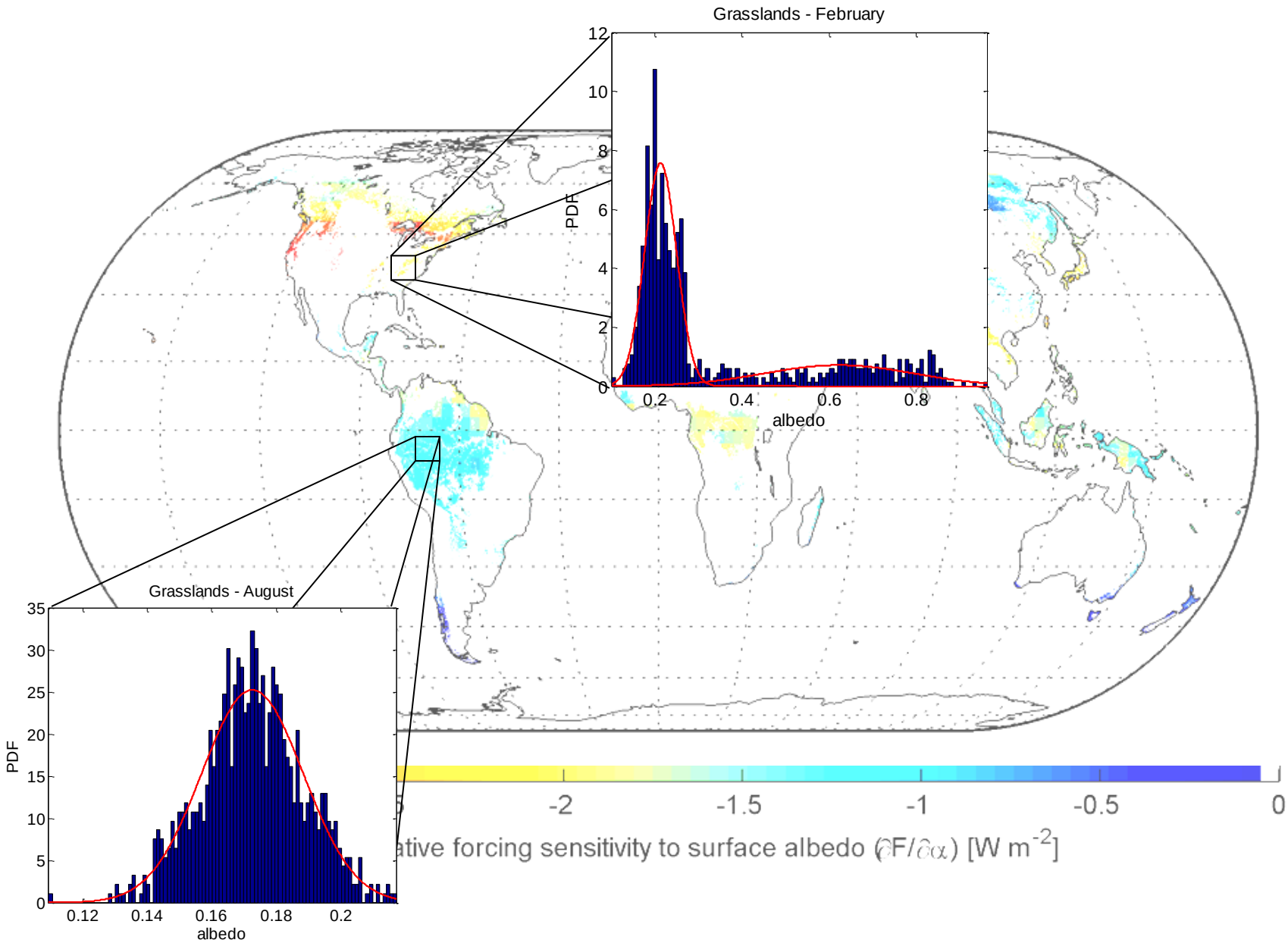
- Estimate CO_2 forcing from the concomitant emissions

Global albedo radiative forcing model

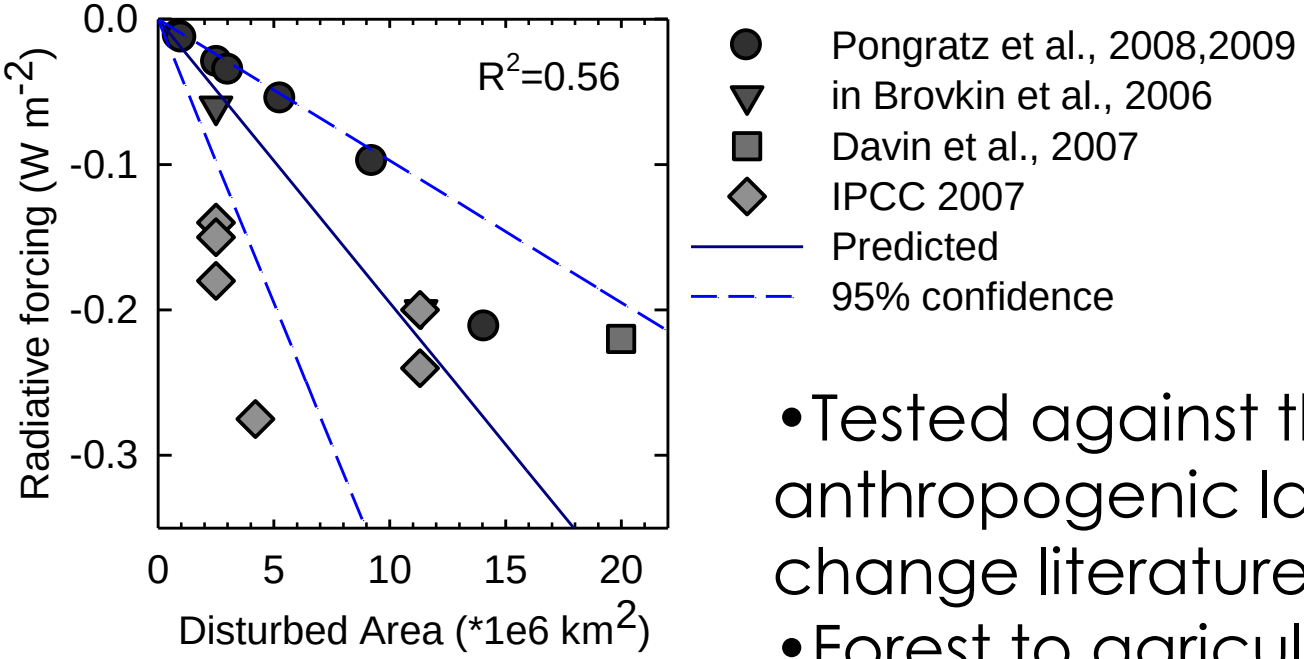


Shell et al., 2008, J.Clim.

Albedo statistics



Global results: albedo (preliminary)

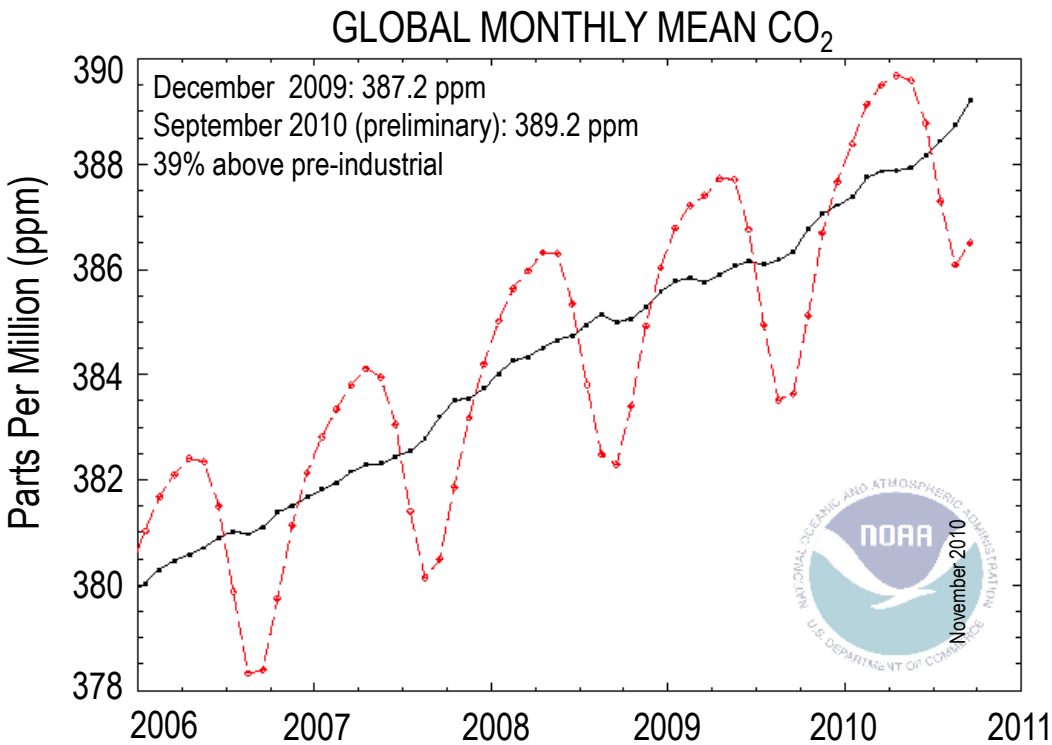


- Tested against the historical anthropogenic land use change literature
- Forest to agriculture conversion, mostly

5 year albedo RF = -0.018 0.003 W m^{-2} (forest to grass)

5 year albedo RF = -0.015 0.003 W m^{-2} (forest to crops)

Atmospheric CO_2 Concentration

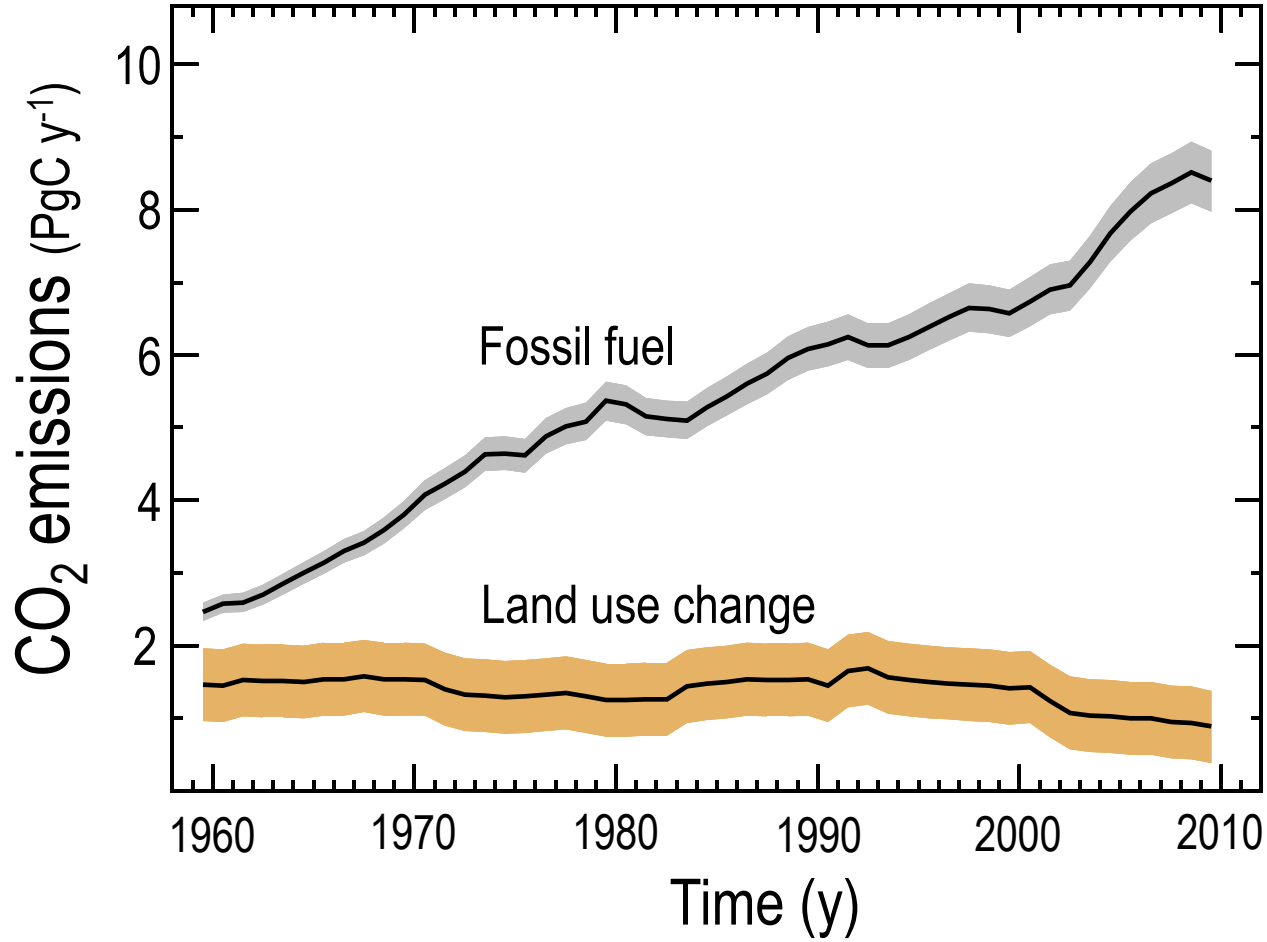


Annual Mea	Growth Rate (ppm y^{-1})
2009	1.62
2008	1.80
2007	2.14
2006	1.84
2005	2.39
2004	1.60
2003	2.19
2002	2.40
2001	1.89
2000	1.22

Over 2000-2005, atmospheric CO_2 concentration rose **+10.4 0.1 ppm** (small uncertainty)

Slide courtesy Pep Canadell, Global Carbon Project. Data Source: Pieter Tans and Thomas Conway, 2010, NOAA/ESRL

CO_2 Emissions from Land Use Change (1960-2009)



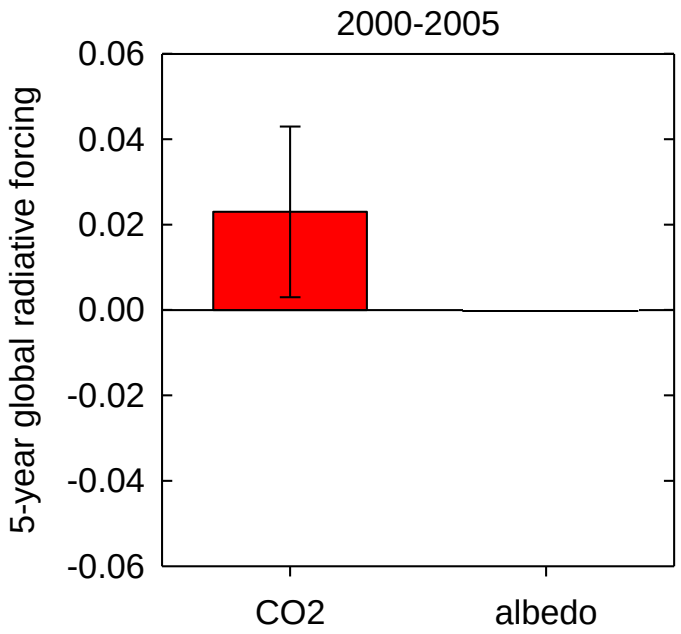
Over 2000-2005, ALUC accounted for **15 10%** of the increase in atmospheric CO_2 concentration (large uncertainty)

Slide courtesy Pep Canadell, Global Carbon Project. Updated from Le Quéré et al. 2009, Nature Geosciences

Global results

2000-2005, due to global gross forest cover loss:

CO_2 radiative forcing: **+0.023±0.02 W m^{-2}**

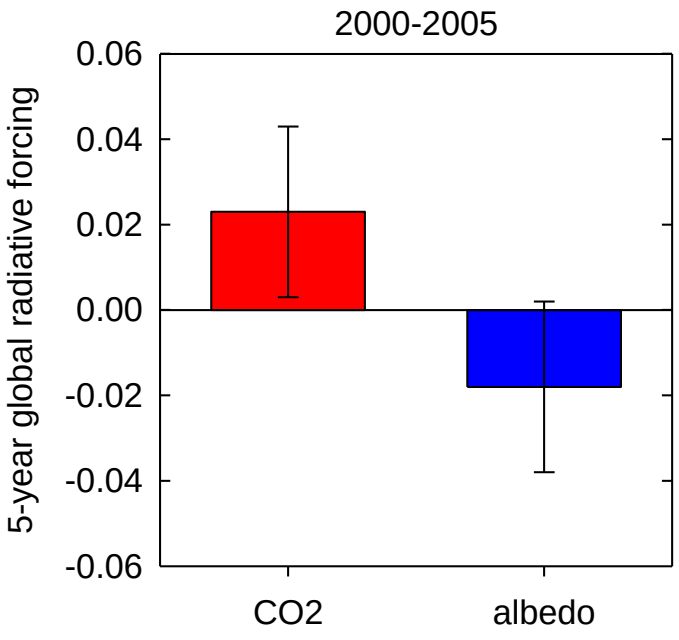


Global results

2000-2005, due to global gross forest cover loss:

CO_2 radiative forcing: **+0.023±0.02 W m^{-2}**

Albedo radiative forcing **-0.018±0.02 W m^{-2}**



Conclusions

1. Over the timescales investigated, the albedo radiative forcing is on the same order of magnitude as the CO_2 forcing. This is true for both:
   - Natural disturbances, calculated bottom-up and per-area
   - Global gross deforestation from 2000-2005

Conclusions

2. Recovery times vary for albedo and CO_2, complicating the net climate effect in time.

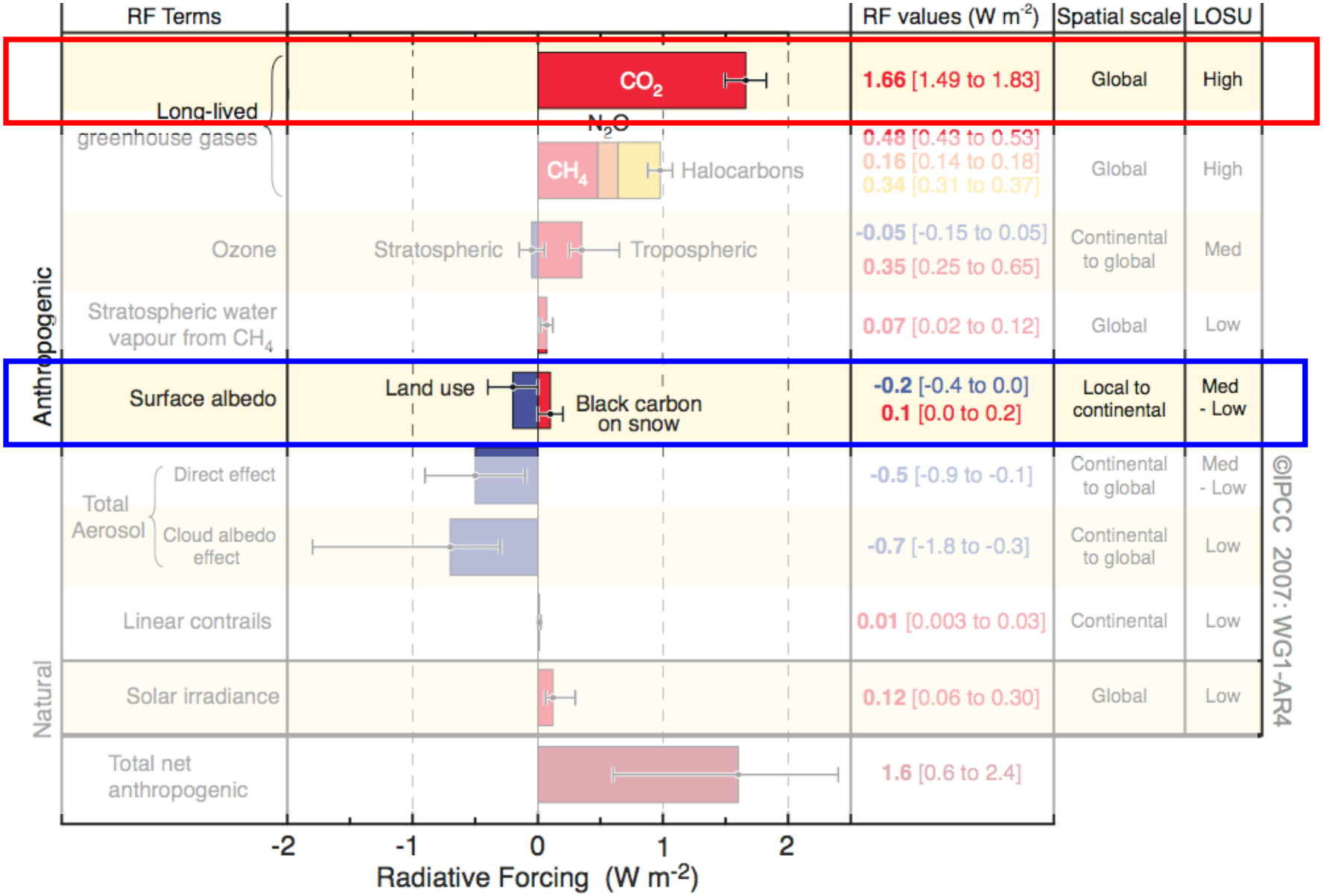
- Recovery of carbon stocks is a complex ecological process (succession), with lots of controls (seed dispersal, nutrient limitation, competition etc.)
- Albedo recovery is that plus optical effects.

Conclusions

3. Should we manage forests for albedo?

- Probably not. (see IPCC chart)

Radiative Forcing Since 1750



Source: IPCC (2007)

Conclusions

3. Should we manage forests for albedo?

- Probably not. (see IPCC chart)
- However, if we wanted to, radiative forcing provides a quantitative framework to compare albedo and CO_2.
- REDD+ forestry activities will be more beneficial to global climate if they consider albedo
  - e.g. deciduous vs. evergreen
- Evapotranspiration should be a local to regional management decision
  - Important not to deplete groundwater

THE END

Climate models corroborate

<u>Climate sensitivities</u>

Albedo = 1.07 K/W/m^2

CO_2 = 1.2 K/W/m^2

LE = 12 K/W/m^2

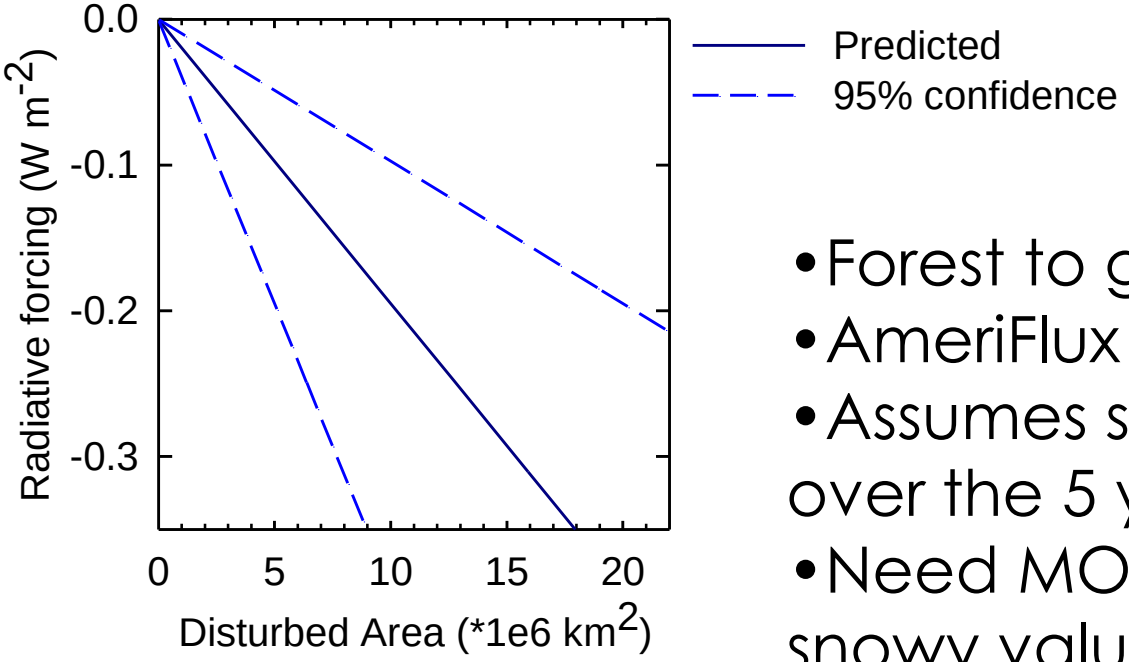
Roughness = 7.25 K/W/m^2

"These results demonstrate that the nature of the forcing owing to change in **evapotranspiration efficiency or surface roughness** is different from a classical radiative forcing perturbation. Instead, the climatic influence of these factors involves **internal redistribution of energy** in the climate system."
(Davin and Noblet-Ducoudré, J.Clim. 2010.)

Insects

Photo: Pat Teti

Global results: albedo (preliminary)



- Forest to grass conversion
- AmeriFlux data
- Assumes static replacement over the 5 years
- Need MODIS albedo with snowy values