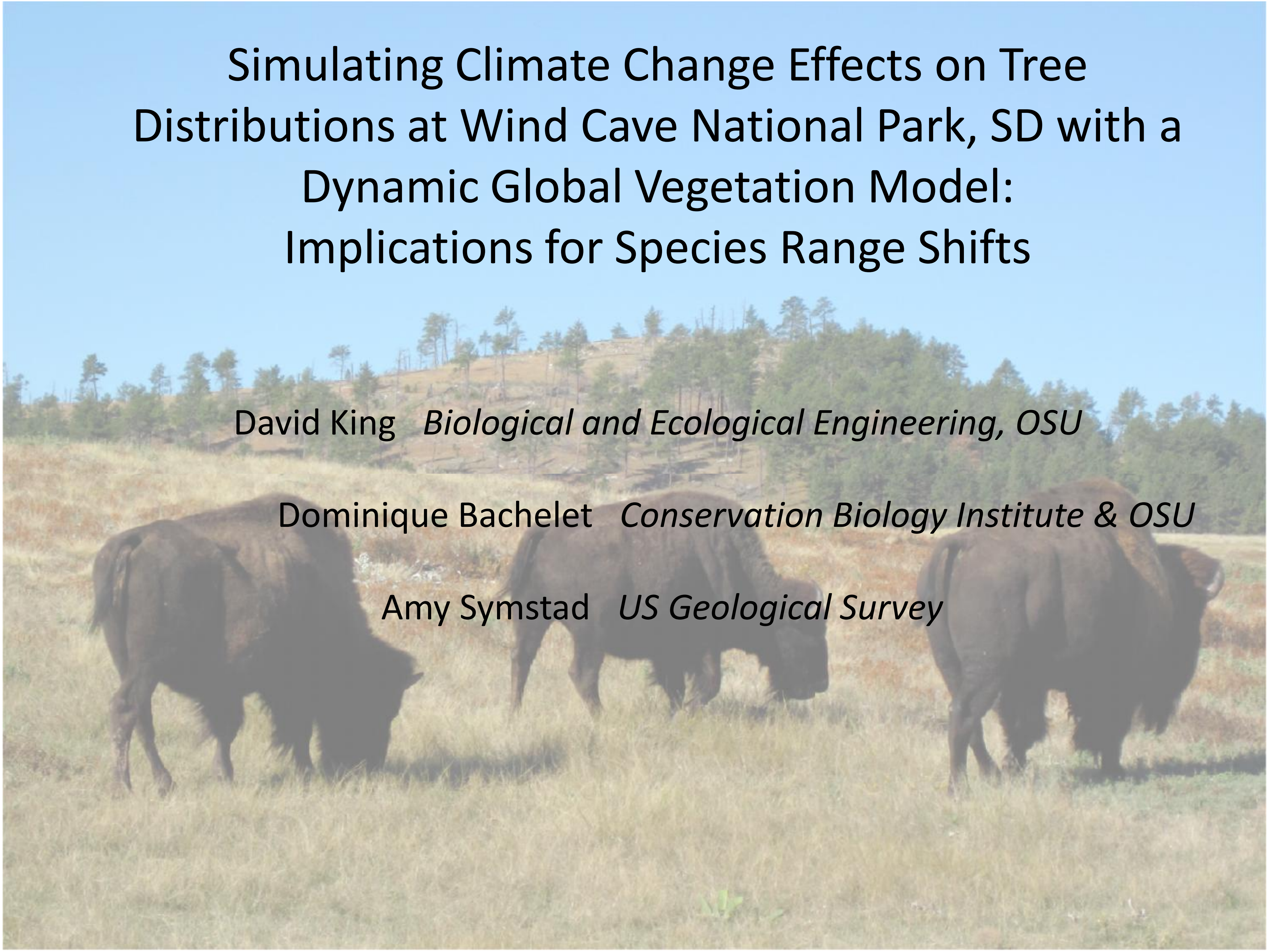
Simulating Climate Change Effects on Tree Distributions at Wind Cave National Park, SD with a Dynamic Global Vegetation Model: Implications for Species Range Shifts

David King *Biological and Ecological Engineering, OSU*

Dominique Bachelet *Conservation Biology Institute & OSU*

Amy Symstad *US Geological Survey*



Scientists Predict Big Biotic Effects of Climate Change, but Large Uncertainties Remain

- Empirical species distribution models predict that much of the current habitat for many species may become unsuitable over this century.
- But many plants survive when planted outside their natural range and current species ranges may reflect past biotic interactions.
- Fire can have big effects on species abundances, so species relations to climate may also reflect climatic controls of fire.
- Process based models predict substantial changes in the future distributions of tree species, albeit with long lag times, but seldom include fire.

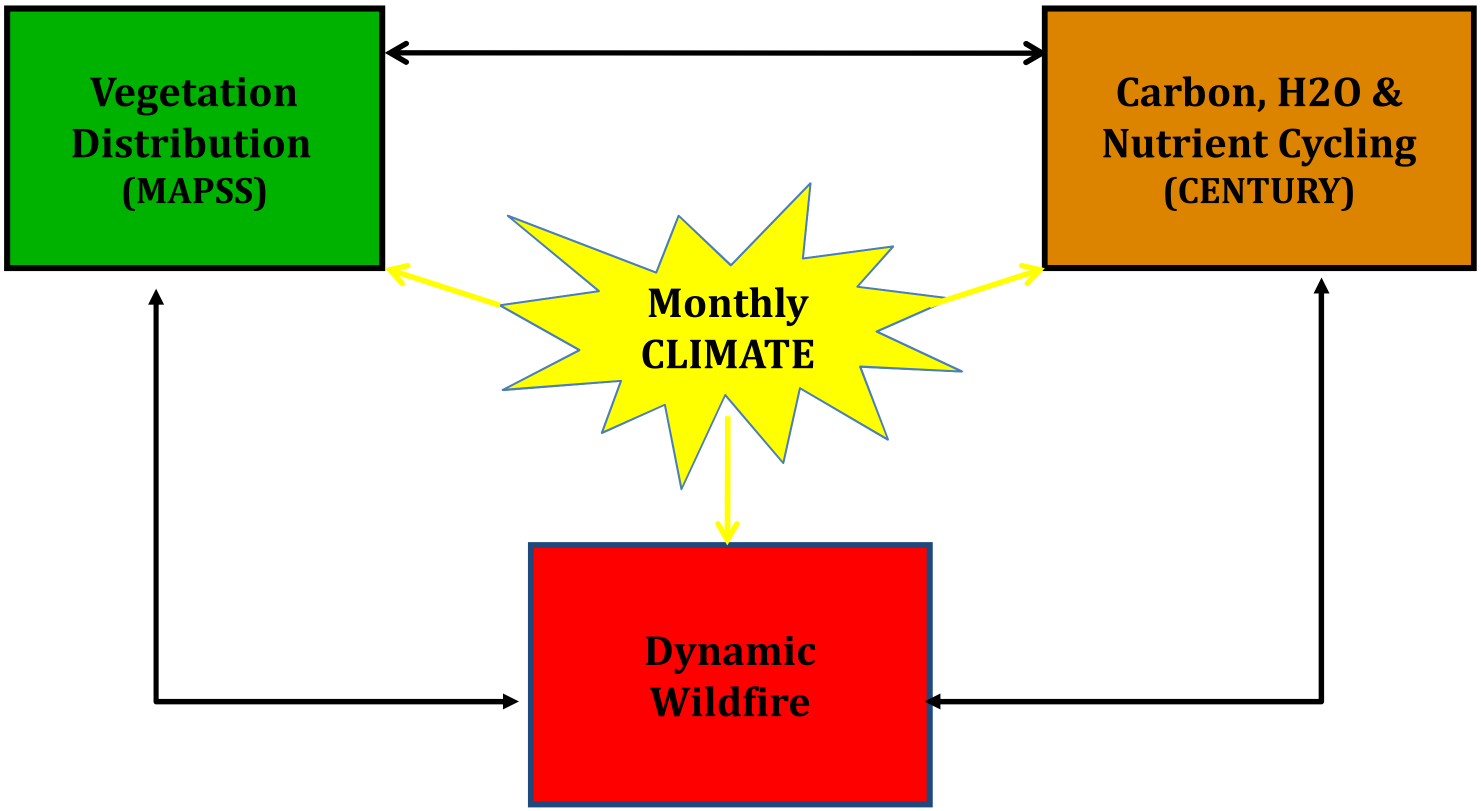
Wind Cave Project

- The results presented here are part of a larger project to forecast above and belowground climate change impacts at Wind Cave National Park.
- The Park is best known for its Cave system, but also encompasses 11,450 ha of mixed grass prairie and ponderosa pine woodlands on the southeastern edge of the Black Hills of South Dakota.
- For future planning, park managers need information on how climate change may affect the natural resources of the park, including grasslands and the grazers dependent on them (bison, elk, pronghorn and deer).
- We have therefore used a dynamic vegetation model to simulate future vegetation for three future climate scenarios.

Approach

1. Adjust a dynamic global vegetation model (MC1) to project observed proportions of grasslands and ponderosa pine woodlands at Wind Cave
2. Project future vegetation for three future climate projections derived from downscaled global climate models.
3. Compare results to those of an empirical species distribution model for ponderosa pine

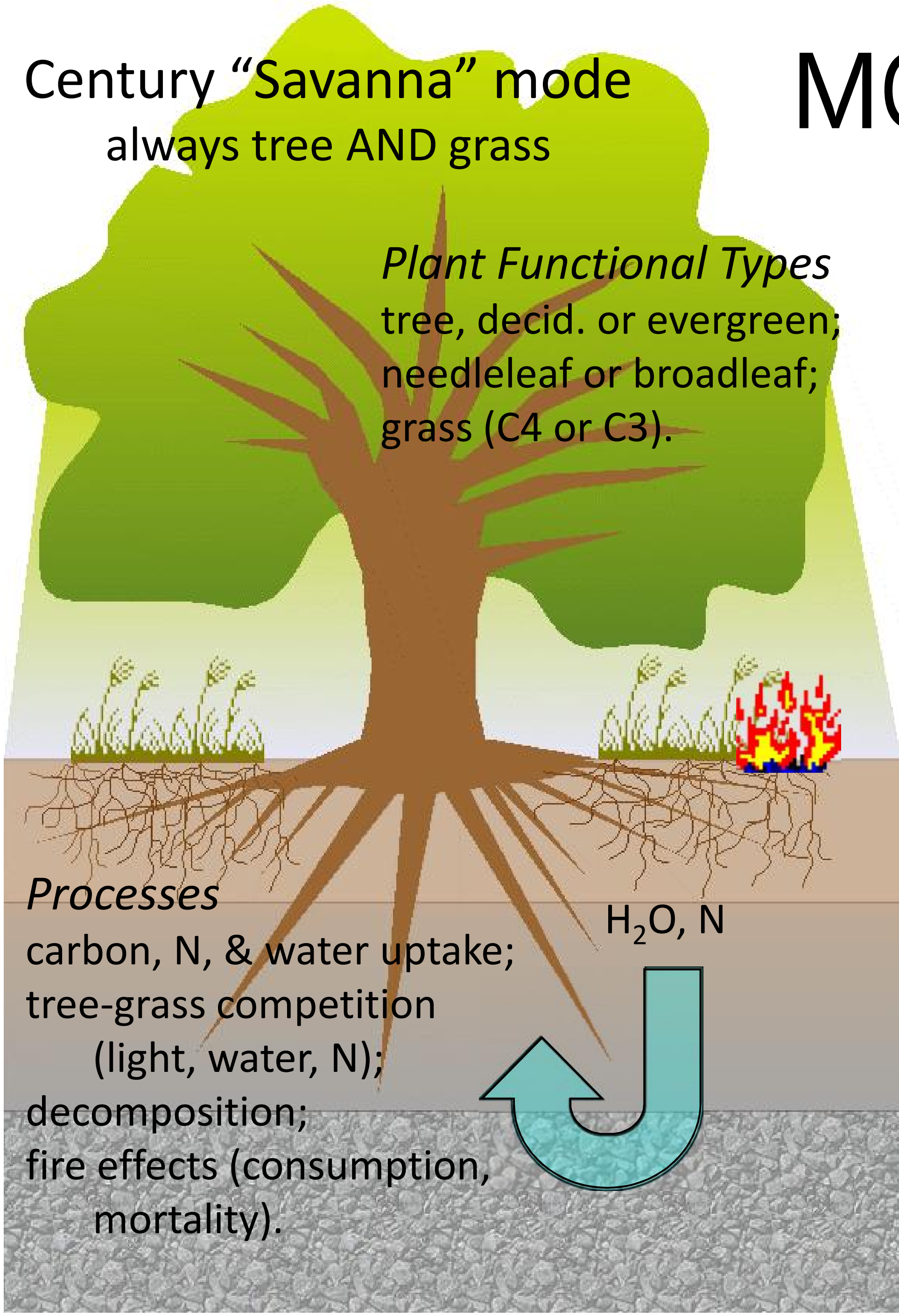
MC1 Dynamic Global Vegetation Model



MC1 is designed to simulate natural vegetation and is hence appropriate for a national park

***Original modeling team**: Chris Daly, James Lenihan, Dominique Bachelet, and Ron Neilson*

MC1



SOME MODEL ASSUMPTIONS

Trees shade grasses (light competition)

Saturated water flow between soil layers (bucket model)

Different rooting depths between trees and grasses determine competition for water and nutrients

Plant parts have fixed min and max C/N, depending on lifeform

Fire consumes aboveground biomass; 20% of the N is returned to the system


Ponderosa pine is the dominant tree at Wind Cave

Modifications to MC1 for Wind Cave

1. Adjusted tree production algorithms to be appropriate for ponderosa pine, a drought tolerant species, with relatively low LAI.
2. Adjusted fire parameters to better simulate frequent low-severity surface fires, as were once common in the Black Hills.
3. Reduced the minimum LAI assumed in the calculation of tree productivity, thereby retarding the simulated invasion of unburned grasslands by trees.
4. Somewhat lowered high CO_2 enhancement of growth, based on recent long-term experimental results.

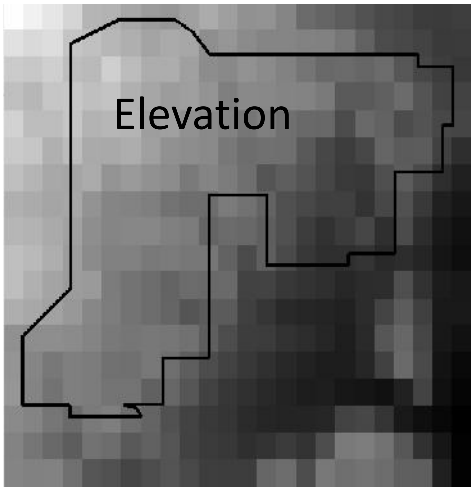
Simulation Details

- Input data:
  Elevation, soil properties and depth.
  Monthly climate inputs of precipitation, Tmax, Tmin and either dewpoint temperature or vapor pressure.
  Annual atmospheric CO_2 concentrations.

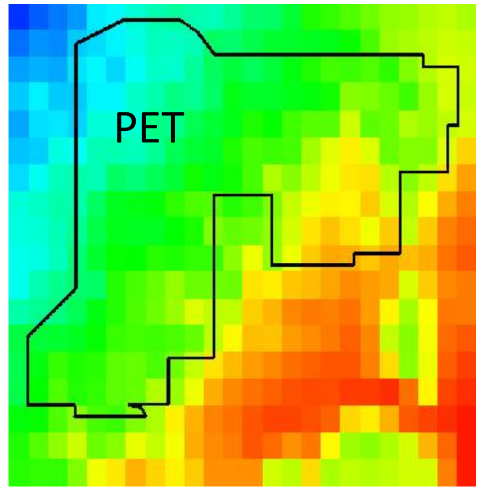
- Scale of simulation: In this case, 30-arc second grid cells (670m E-W x 930m N-S at latitude of Wind Cave).

- Four simulation stages:
  Equilibrium run initializes veg and carbon pools;
  Spinup run includes dynamic fire effects, based on detrended and looped historical climate;
  1895-2000 historical run uses PRISM climate data;
  2001-2100 future runs based on downscaled climate inputs from general circulation models (GCMs)

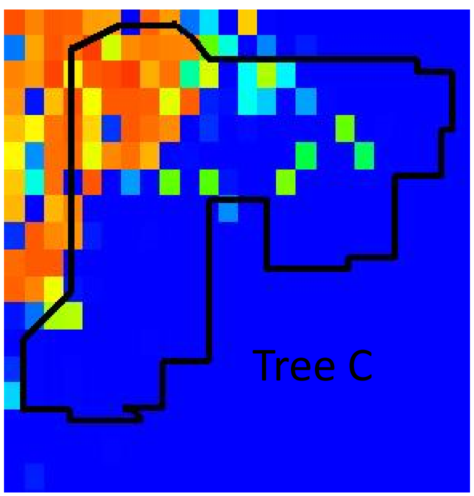
Projected live tree carbon vs. observed tree distribution



Elevation Range: **1020 (black)**
– 1560 (white) m



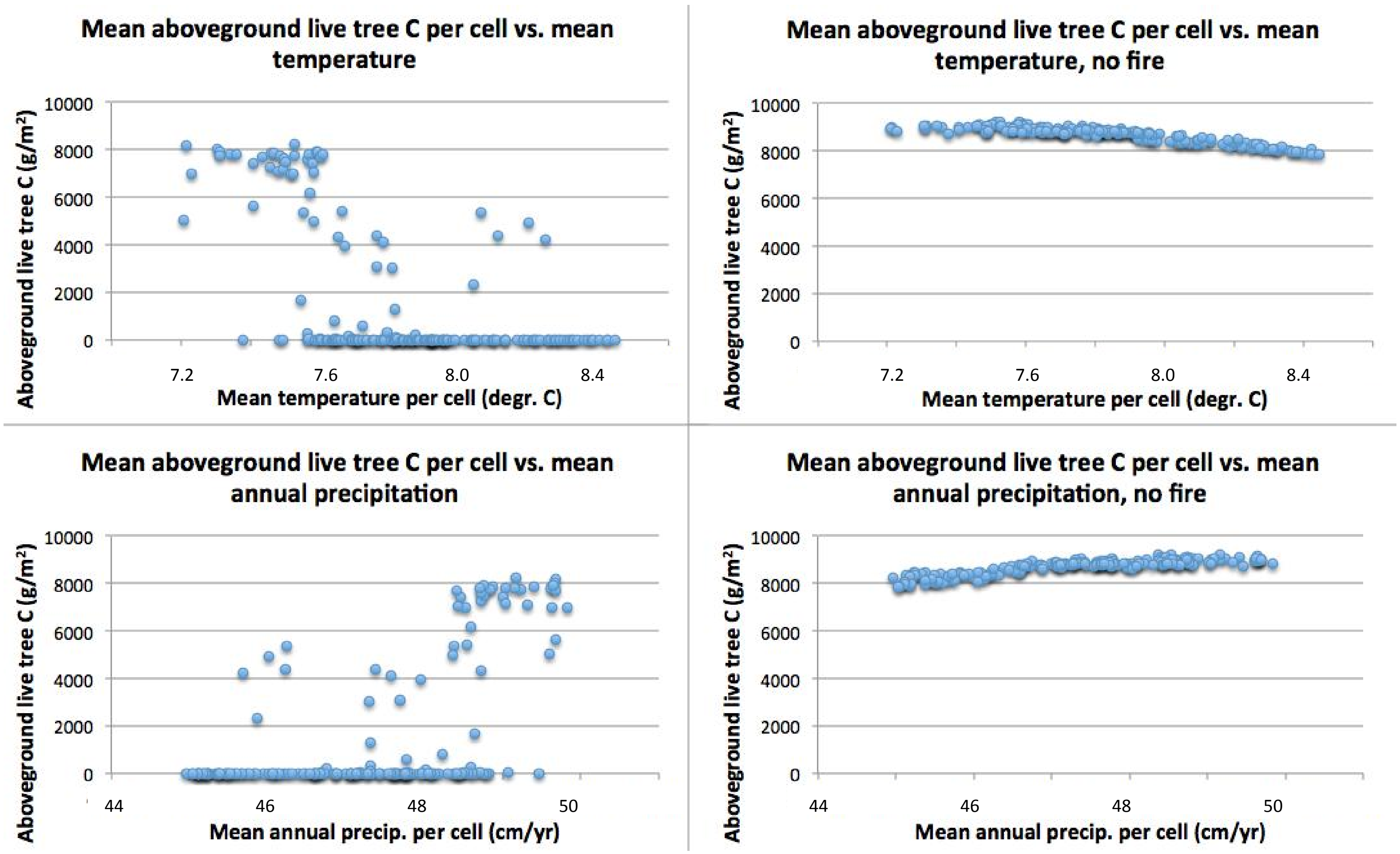
Mean annual potential evapotranspiration (PET)
Range: **106 (blue) – 140 (red) cm/yr**



Live aboveground wood C
Range: **0 (blue) – 9000 (red) g /m²**

Google Earth image of Wind Cave N P

Simulated mean historical live tree C per grid cell vs. mean climate with fire (left side) and without fire (right side)



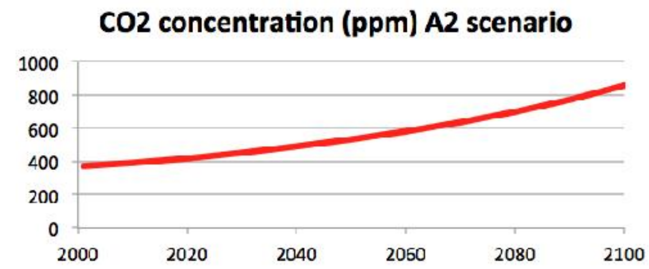
Climate change scenarios

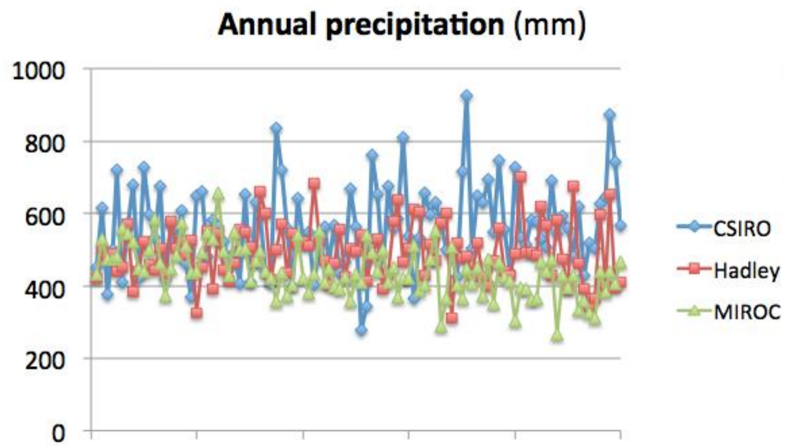
1. Climate projections from the **CSIRO Mk3, Hadley CM3 and MIROC 3.2. Medres** GCMs, run with the A2 emission scenario.

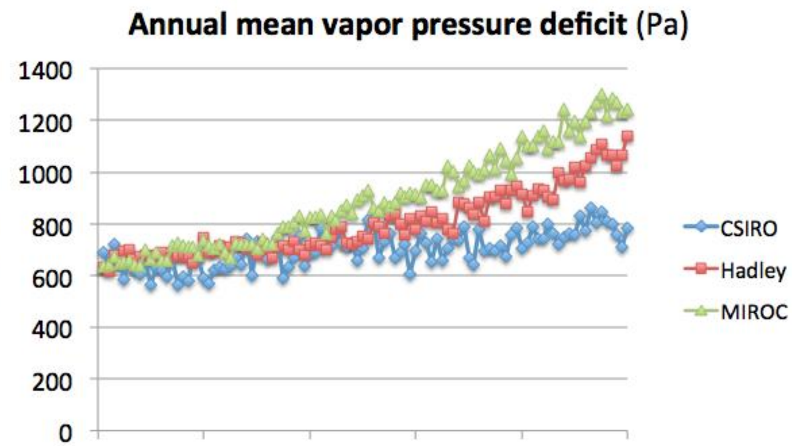
2. Representative range of temperature scenarios.

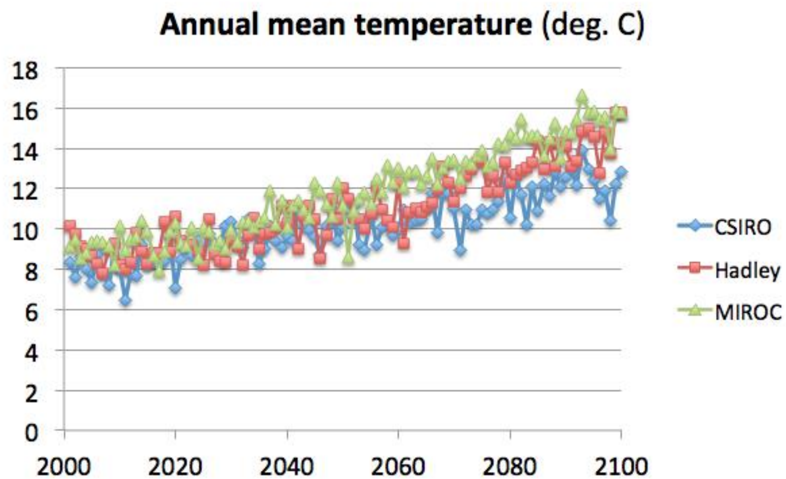
3. GCM values for monthly precipitation and mean monthly Tmax, Tmin and dewpoint temperature **downscaled** to ~800m with anomaly/delta method using PRISM 800m baseline (1971-2000).

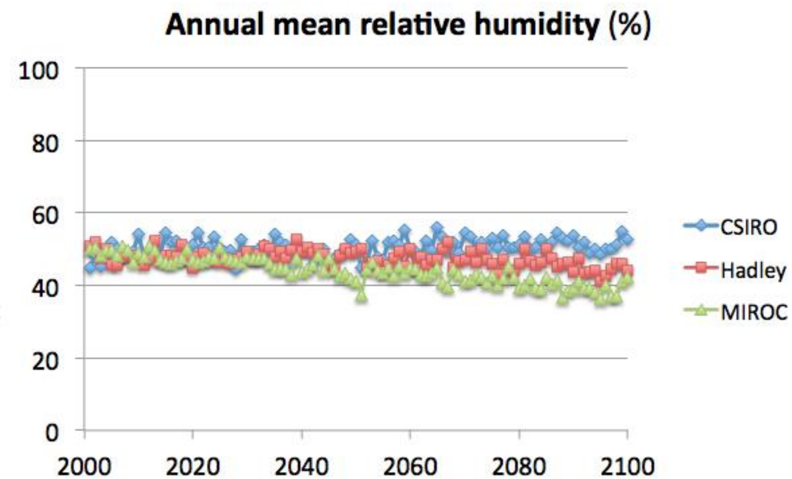
Climate change scenarios:
3 downscaled GCM projections
for Wind Cave



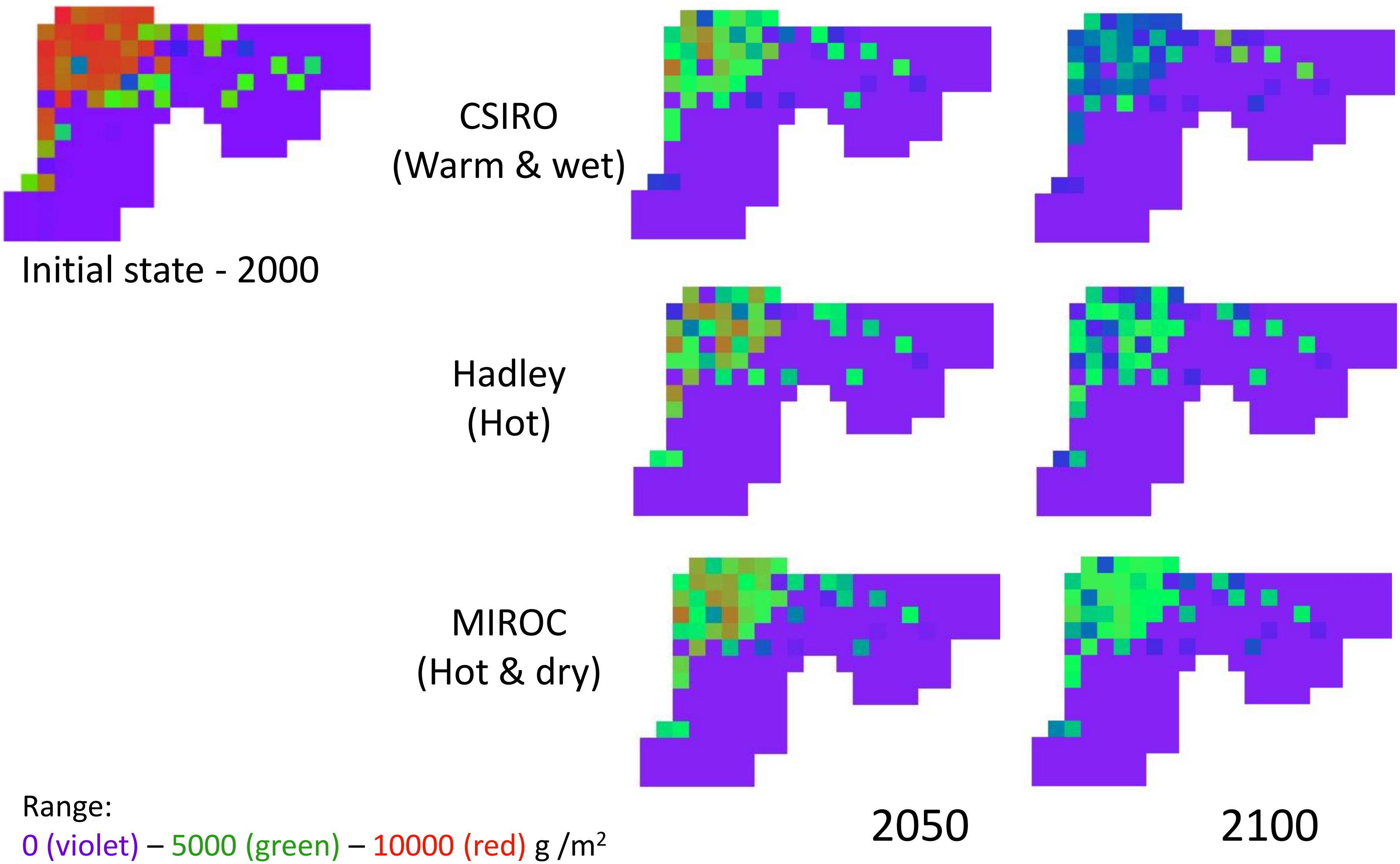




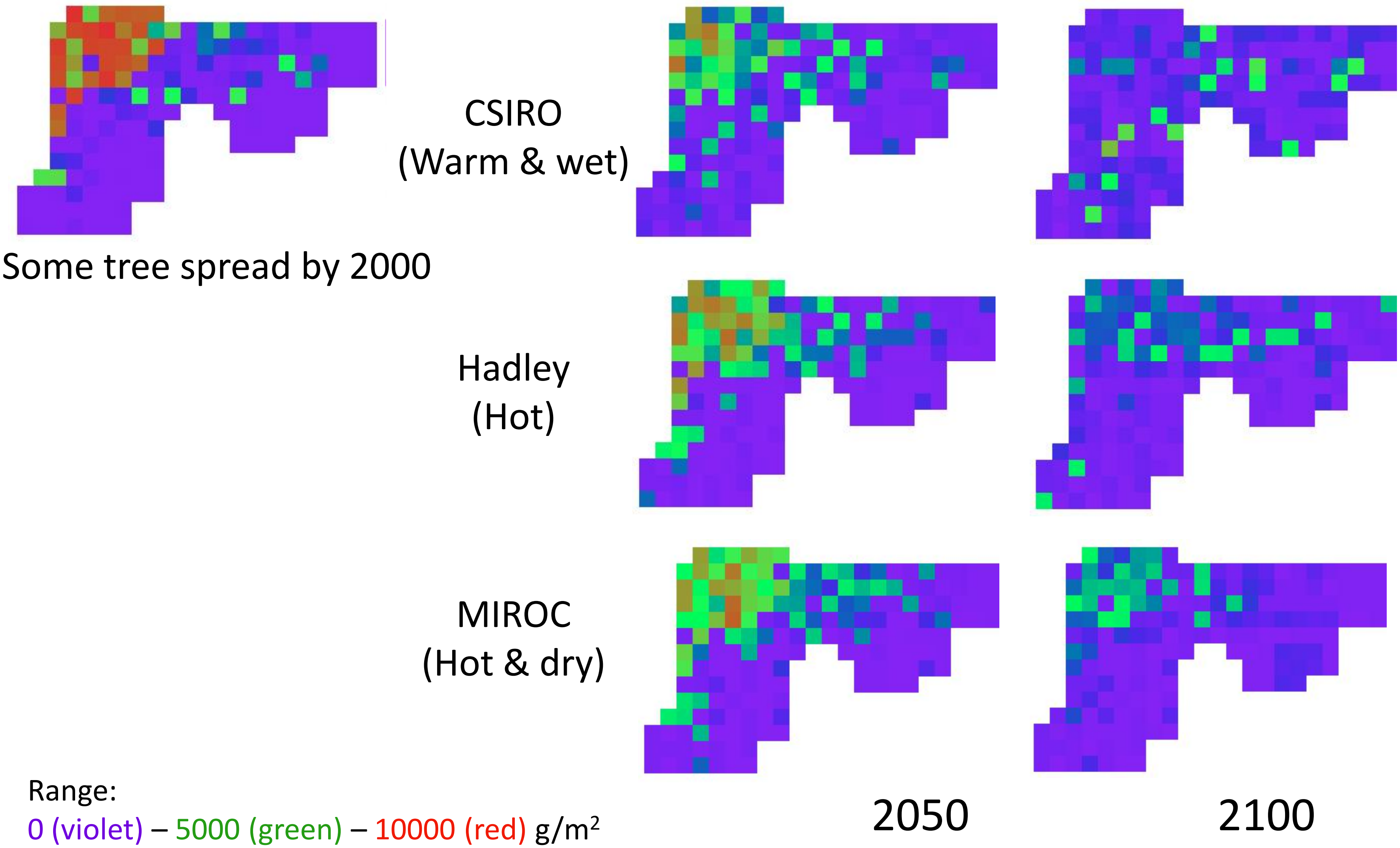




Aboveground live tree carbon simulated with natural fire

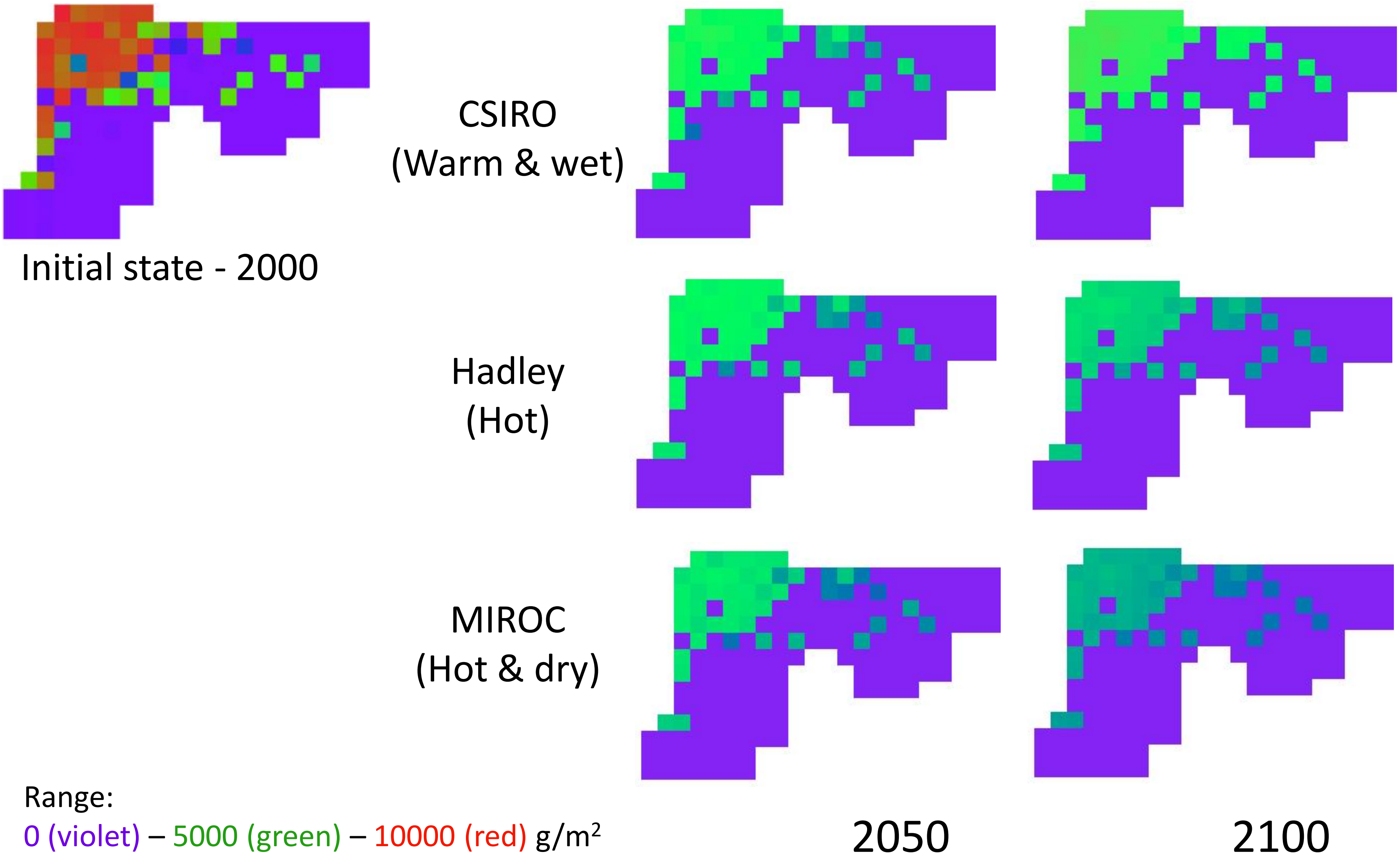


Aboveground live tree carbon simulated with fire suppression beginning in 1941



Range:
0 (violet) – 5000 (green) – 10000 (red) g/m^2

Prescribed fire effects on aboveground live tree carbon: 10 year interval, 20% tree mortality



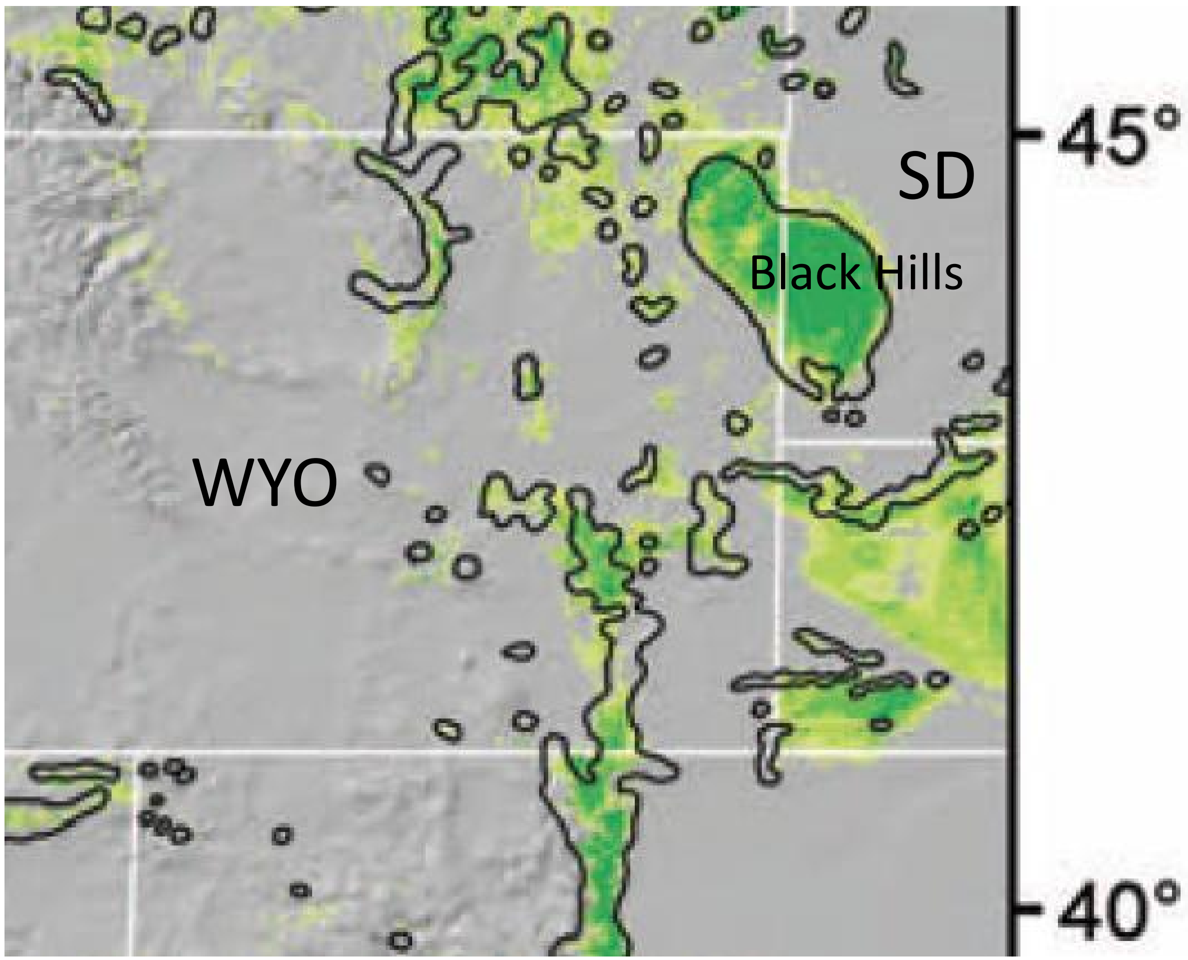
Range:
0 (violet) – 5000 (green) – 10000 (red) g/m^2

Summary

1. For 3 GCM climate projections x 3 example fire regimes MC1 predicts the persistence of ponderosa pine woodlands, but with reduced biomass due to more frequent fires.

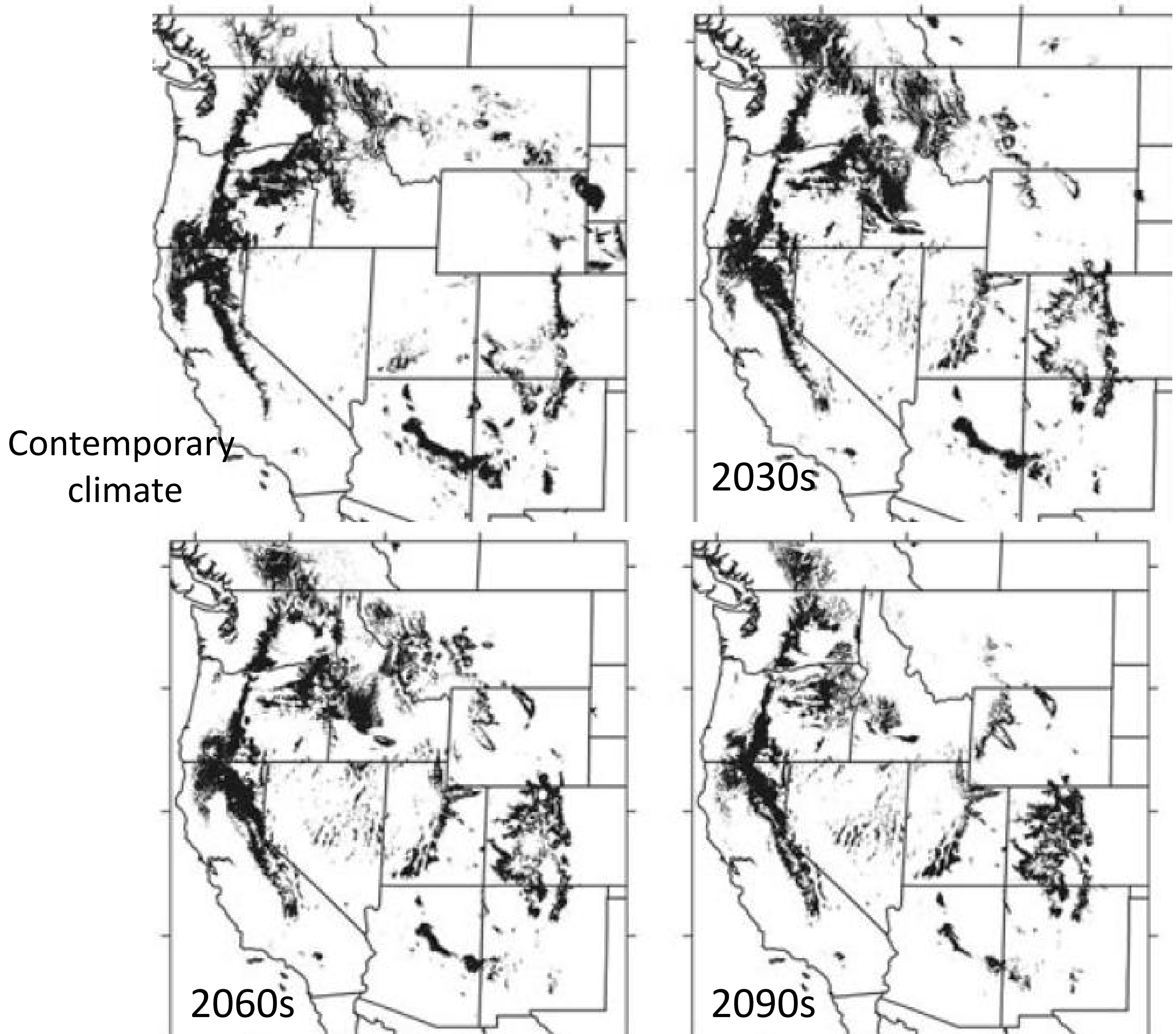
2. But these projections are based on the assumption of average wind speeds. The chances of high severity crown fires may increase with higher fire frequencies, depending on management of fire fuel loads and tree densities.

Modeled bioclimate profile of ponderosa pine (in color) compared to the range limits mapped by Little (1971) (black lines).



from Rehfeldt et al. *[Int. J. Plant Sci. 167(6):1123–1150. 2006*]

Modeled climate profiles for ponderosa pine by Rehfeldt et al. (2006).



Based on averaged GCM projections by HadCM3 and CGCM2 with a 1%/yr increase in greenhouse gases.

MC1 results vs. Climate Suitability Model

1. Empirical model accurately predicts the range of ponderosa pine over the Black Hills region – as related to composite climate variables.
2. MC1 accurately predicts the ponderosa pine ecotone at Wind Cave – as related to climate effects on fire.
3. Predictions of the future distribution of ponderosa pine diverge, because MC1 predicts that mature ponderosa pines withstand fire, but the empirical model assumes that climate acts directly on species rather than via fire.
4. Observations suggest that ponderosa pine invades current grasslands with fire suppression, that is, it is not limited by climate.
5. But there are multiple uncertainties in MC1's projections, both of fire effects and of other mortality agents such as pest and pathogens and extreme drought effects, which are not currently modeled.

Conclusions

- Both mechanistic process models and empirical habitat suitability models have important roles to play in assessing climate change effects on the biota.
- Comparisons between these two approaches are highly instructive.
- Our simulations show that fire-climate relations can be highly important.
- These results are consistent with the growing awareness that fire suppression over the past century has had large impacts on species abundances across North America.

Acknowledgements

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and

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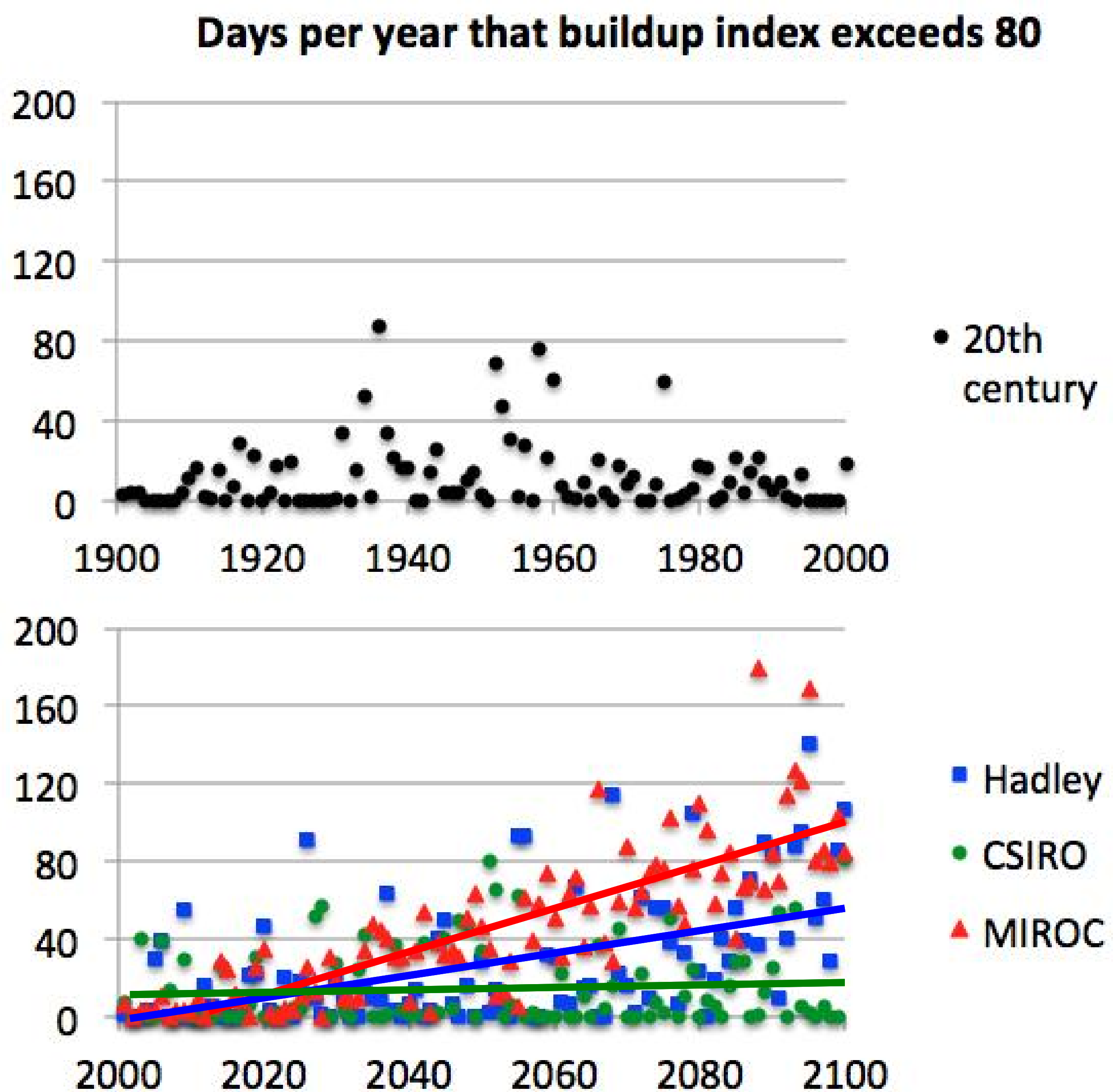

Buildup index of 80 is one of two thresholds used to simulate natural fires.