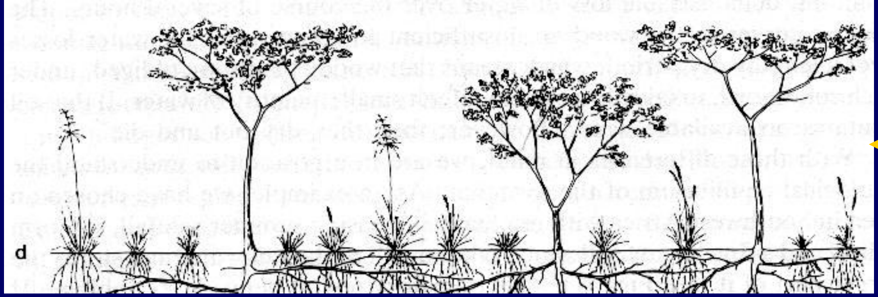
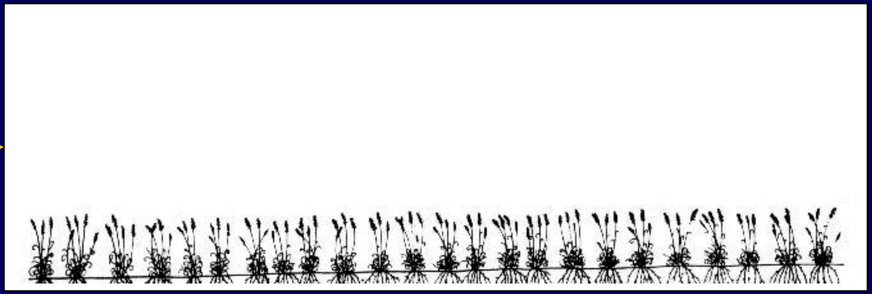
FUTURE VEGETATION CHANGE

RESPONSE OF ECOSYSTEM STRUCTURE AND DISTRIBUTION TO ALTERED FORCING

- Importance of ecosystem/vegetation structure
- How model future sensitivity – and results
- Implications for science and policy



SAVANNA



GRASSLAND

WHAT FACTORS CONTROL VEGETATION DISTRIBUTION? – I

FIVE KEY FACTORS:

☞ REGIONAL CLIMATE – Broad patterns of:

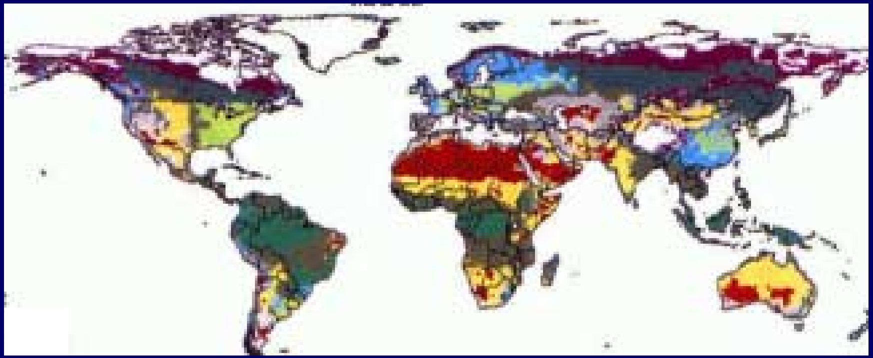
- Physical Climate
  - Seasonal thermal, moisture, and light regime
  - Climate variability and directional change
- Chemical Climate
  - Atmospheric CO_2 concentration – fertilization effect
  - Acid rain
  - N deposition – fertilization effect

WHAT FACTORS CONTROL VEGETATION DISTRIBUTION? – II

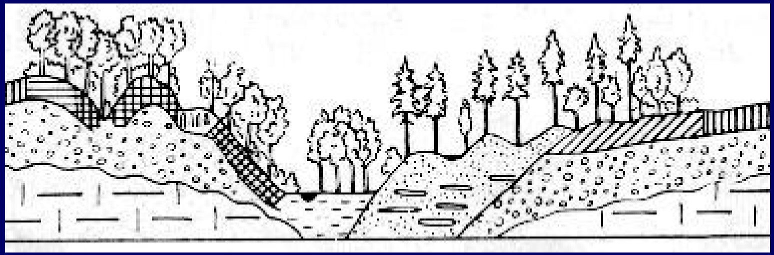
Scale determines relative importance of controls:

- GLOBAL/CONTINENTAL – Broad patterns of climate determines biome to ecoregional vegetation
- LANDSCAPE/LOCAL – Microclimate, geomorphology, soils, time, grazers, human activity

e.g., Conifer forests, Southern Arizona



(Neilson et al. 1998)

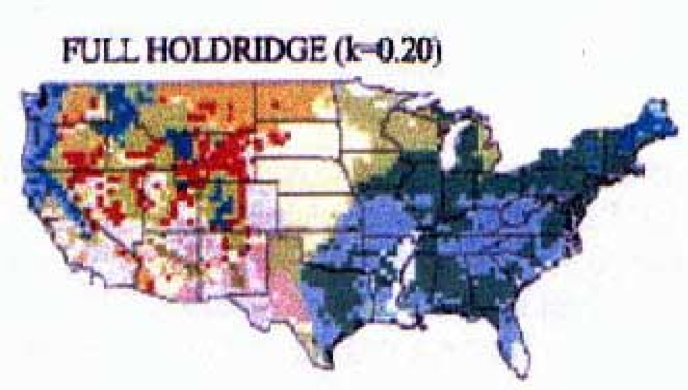


(Walter 1985)

METHODS TO EVALUATE FUTURE VEGETATION CHANGE – I

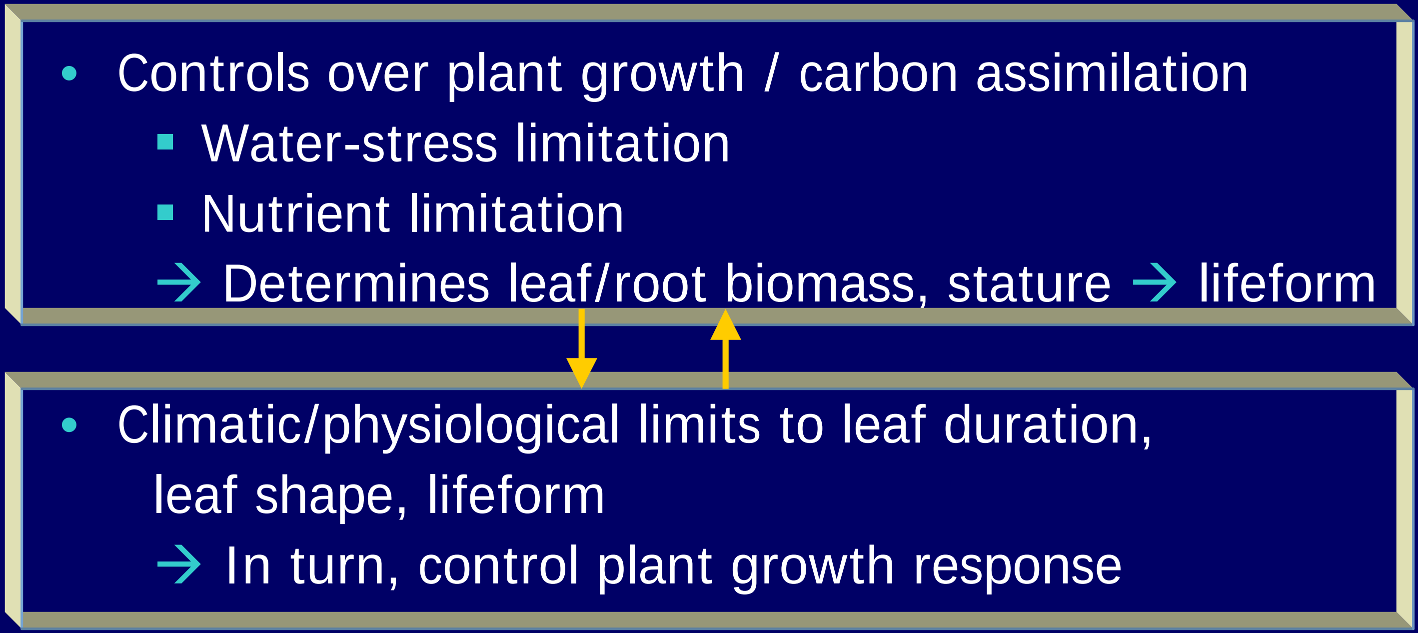
☞ EMPIRICAL MODELS – Correlation, analog approach

- Vegetation limits tied to set isotherms, precipitation limits
- Problems – Don’t consider:
  - Climatic changes outside of current climate space
  - Effects of non-climatic drivers – CO2 changes
  - Interacting, compensating processes
  - Role of time, disturbance



METHODS TO EVALUATE FUTURE VEGETATION CHANGE – II

☞ MECHANISTIC (or SIMULATION) MODELS – Process oriented

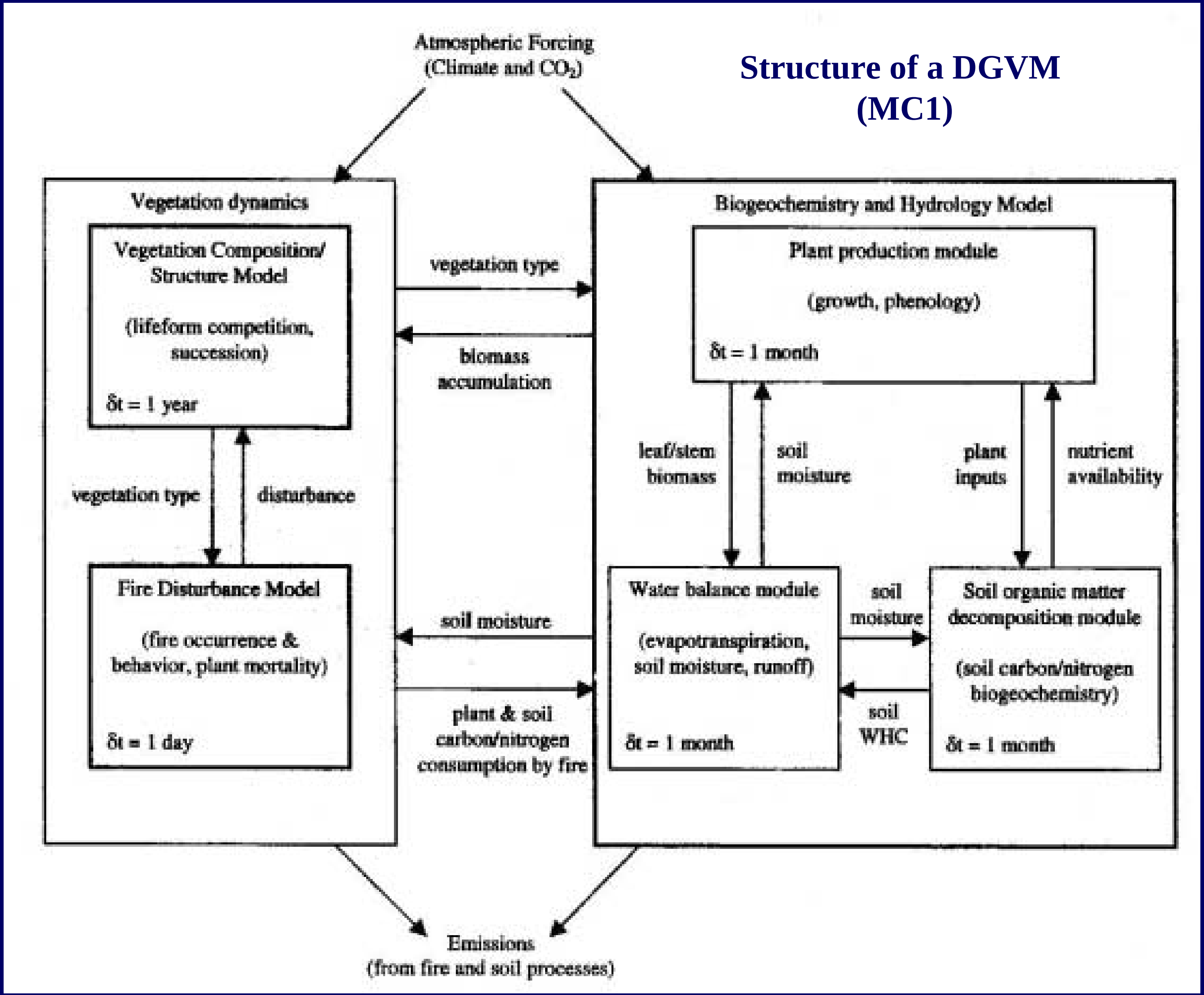


- Controls over plant growth / carbon assimilation
    - Water-stress limitation
    - Nutrient limitation
    - → Determines leaf/root biomass, stature → lifeform

- Climatic/physiological limits to leaf duration, leaf shape, lifeform
    - → In turn, control plant growth response

- Iterative numerical solution, *or*
- Dynamic interactions: time dependence
    - With establishment, succession, competition, disturbance

METHODS TO EVALUATE FUTURE VEGETATION CHANGE



Structure of a DGVM (MC1)

Dynamic Global Vegetation Models (DGVMs)

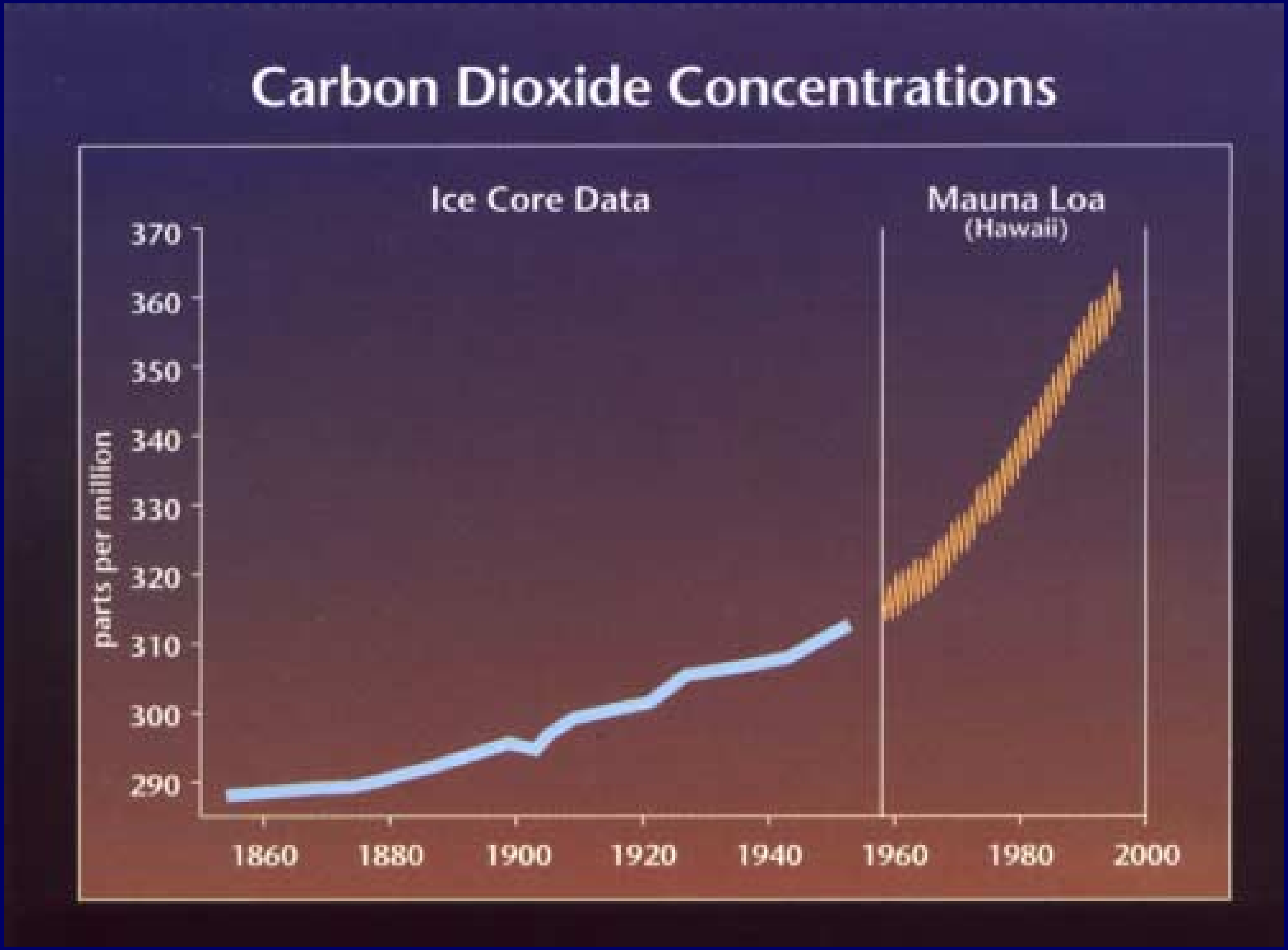
- Complex, sophisticated
- Incorporate key processes
- Responses to multiple factors – Climate, CO_2, disturbance
- Time-dependent simulation

(Kittel et al. 2000)

DRIVERS OF FUTURE ECOLOGICAL CHANGE: MULTIPLE FACTORS

- ☞ Climate change – Anthropogenic forcings:
  - Greenhouse gas emissions (GHG): CO_2, CH_4, etc
  - Sulfate aerosols (SUL), Cloud condensation nuclei, ..
  - Landuse change → Surface biophysical properties
- ☞ Disturbance – Landuse change:
  - Deforestation, cropland conversion
  - Overgrazing, desertification
  - Species invasions
- ☞ Fertilization effects:
  - CO_2
  - N deposition

ATMOSPHERIC CO2 CHANGE: CLIMATIC AND BIOLOGICAL FORCING

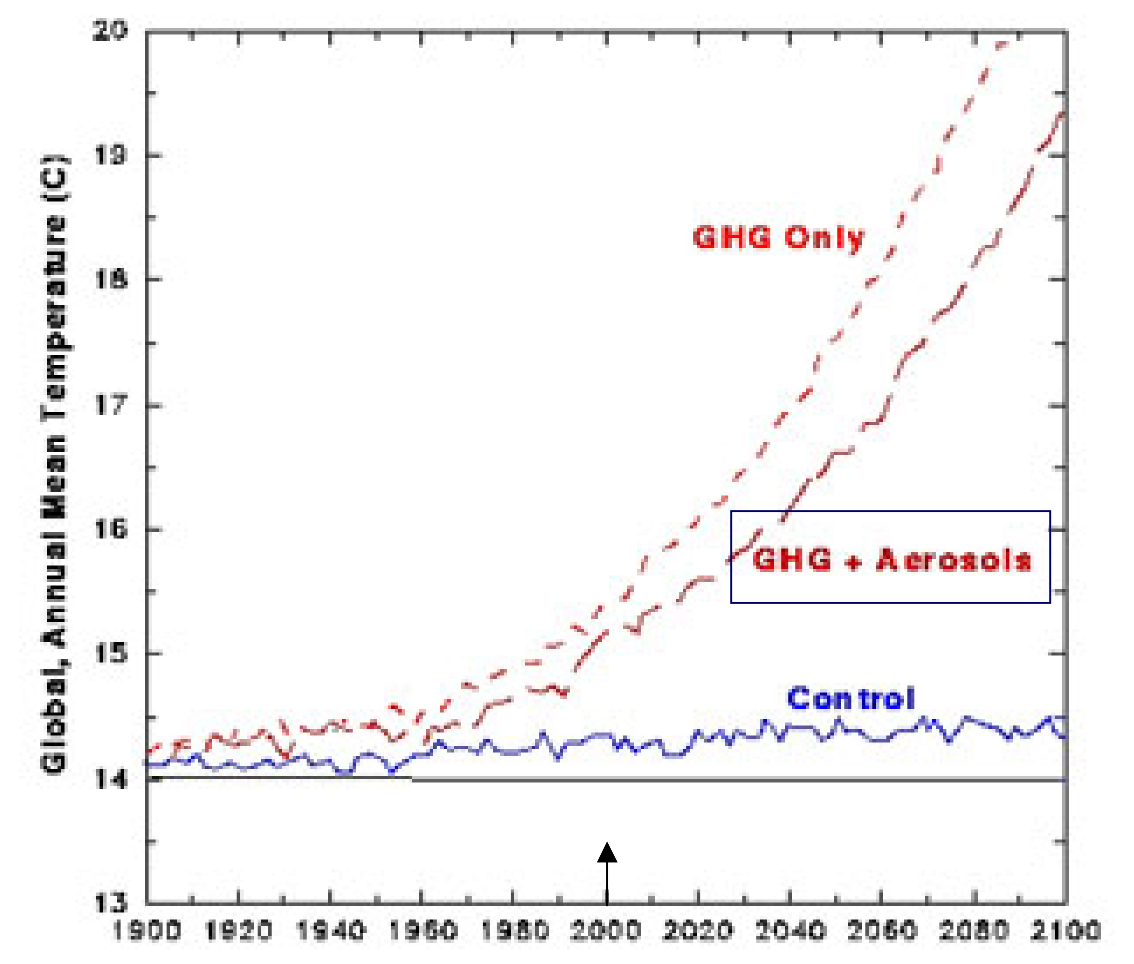


Increasing CO2 from fossil fuels, biomass burning, etc.

- Radiatively-active → Climate effect
- Biologically-active: Increased water and nutrient use efficiency → Fertilization

(Backlund et al./OSTP, 1997)

GLOBAL CLIMATE RESPONSE TO INCREASING GHG AND SUL EMISSIONS

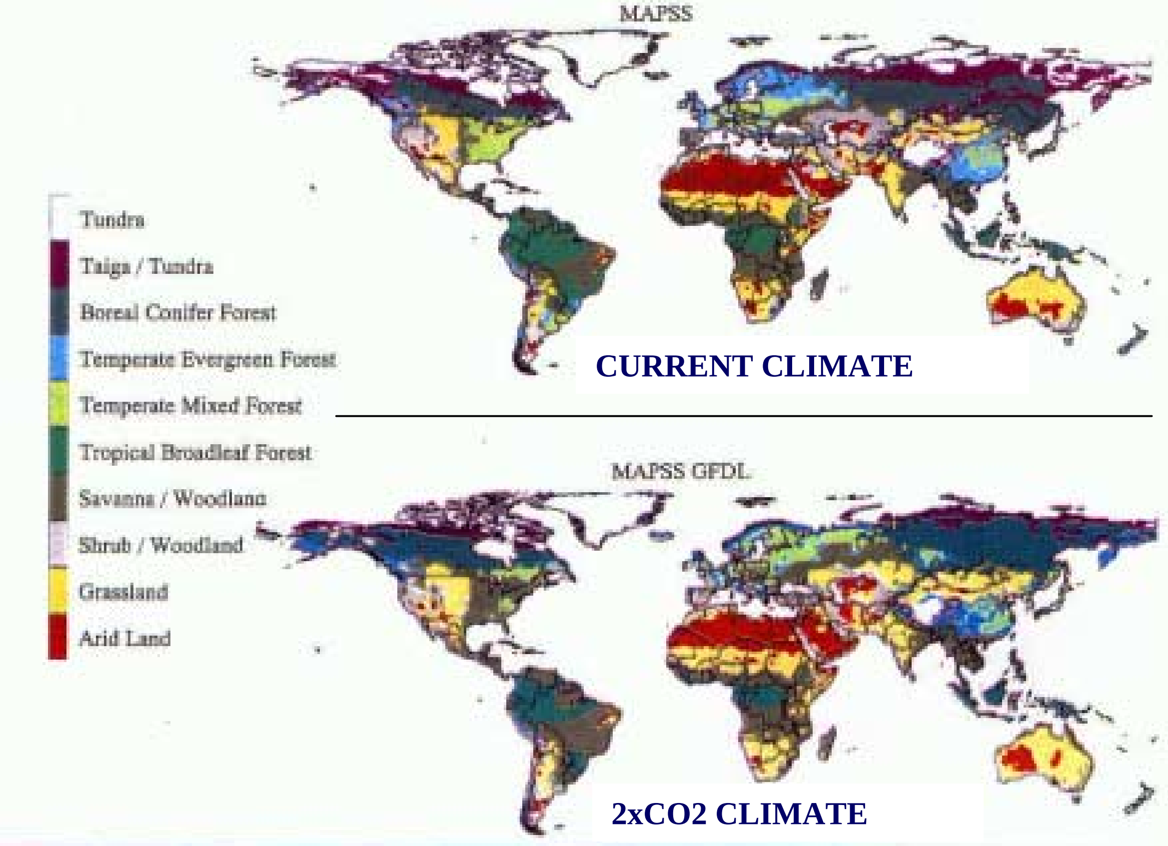


Canadian Coupled Model: CCCma/CGCM1 (Boer et al., Flato et al.)

Global Surface Air Temperature Response

- Coupled GCM
- Greenhouse gases
  + Sulfate aerosols
- Transient response:
  → Trend
  → Annual variability

GLOBAL VEGETATION RESPONSE TO CLIMATE & CO2 CHANGE - I



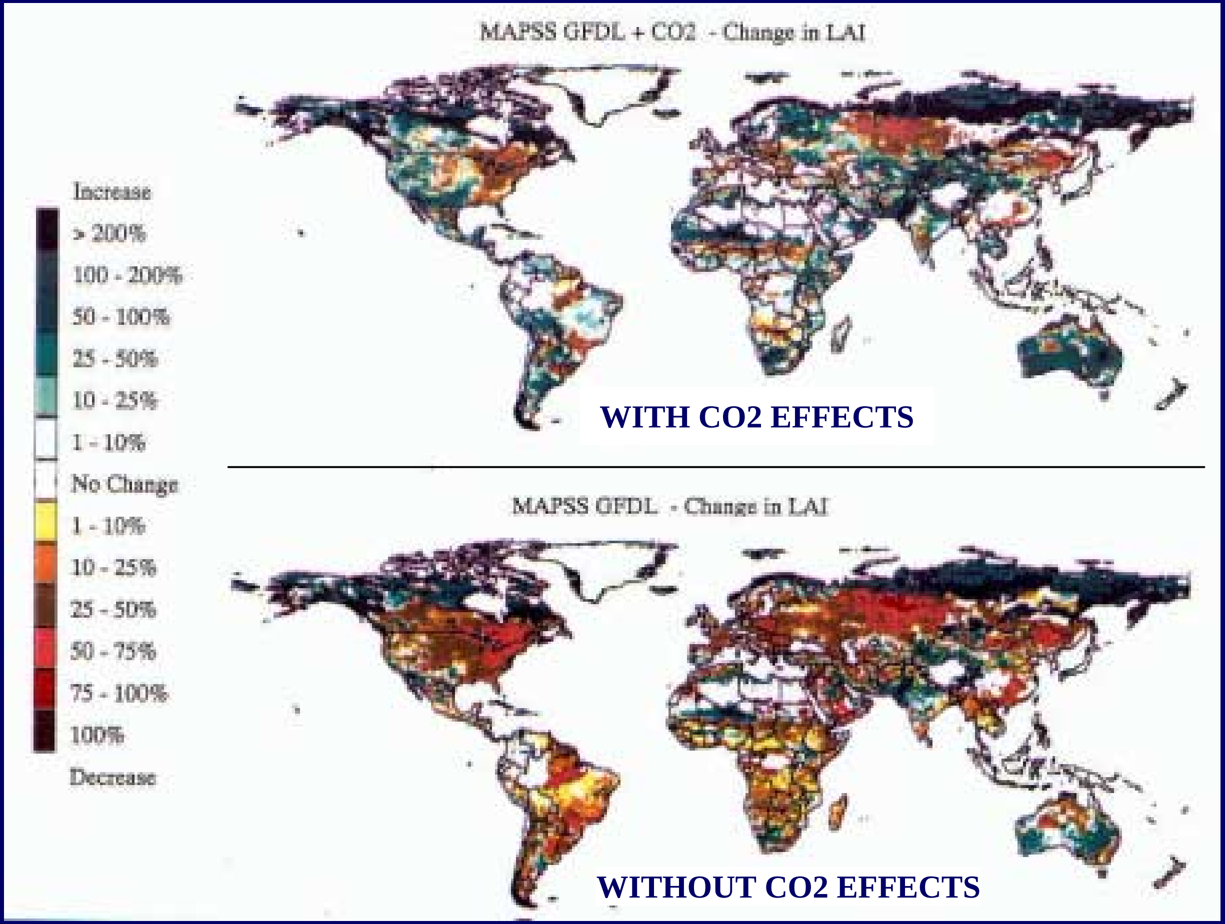
(Neilson et al. 1998)

CLIMATE RESPONSE

- Poleward shifts in temperate and boreal forests and arctic tundra with overall warming
- Shifts in subtropical and temperate deserts and grasslands dependent on regional precipitation changes

GLOBAL VEGETATION RESPONSE TO CLIMATE & CO_2 CHANGE - II

CHANGE IN LEAF AREA

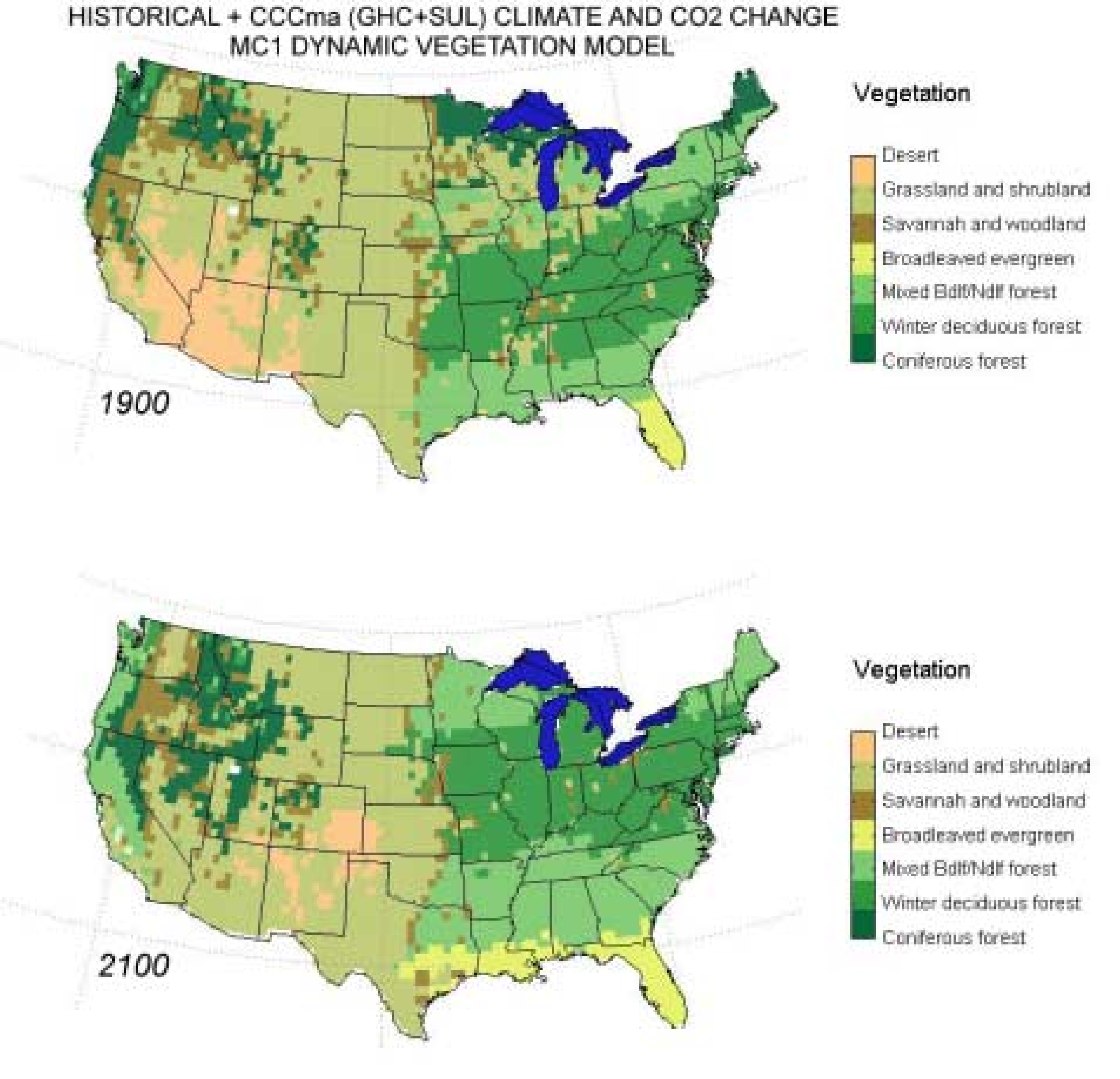


(Neilson et al. 1998)

CO_2 RESPONSE

- “Greening” response to CO2 due to increased water use efficiency
  - countering drying effect of increasing temperatures, etc
- Response is model dependent
  - reflects uncertainties in our knowledge of long-term, ecosystem-level responses to elevated CO2

REGIONAL VEGETATION RESPONSE



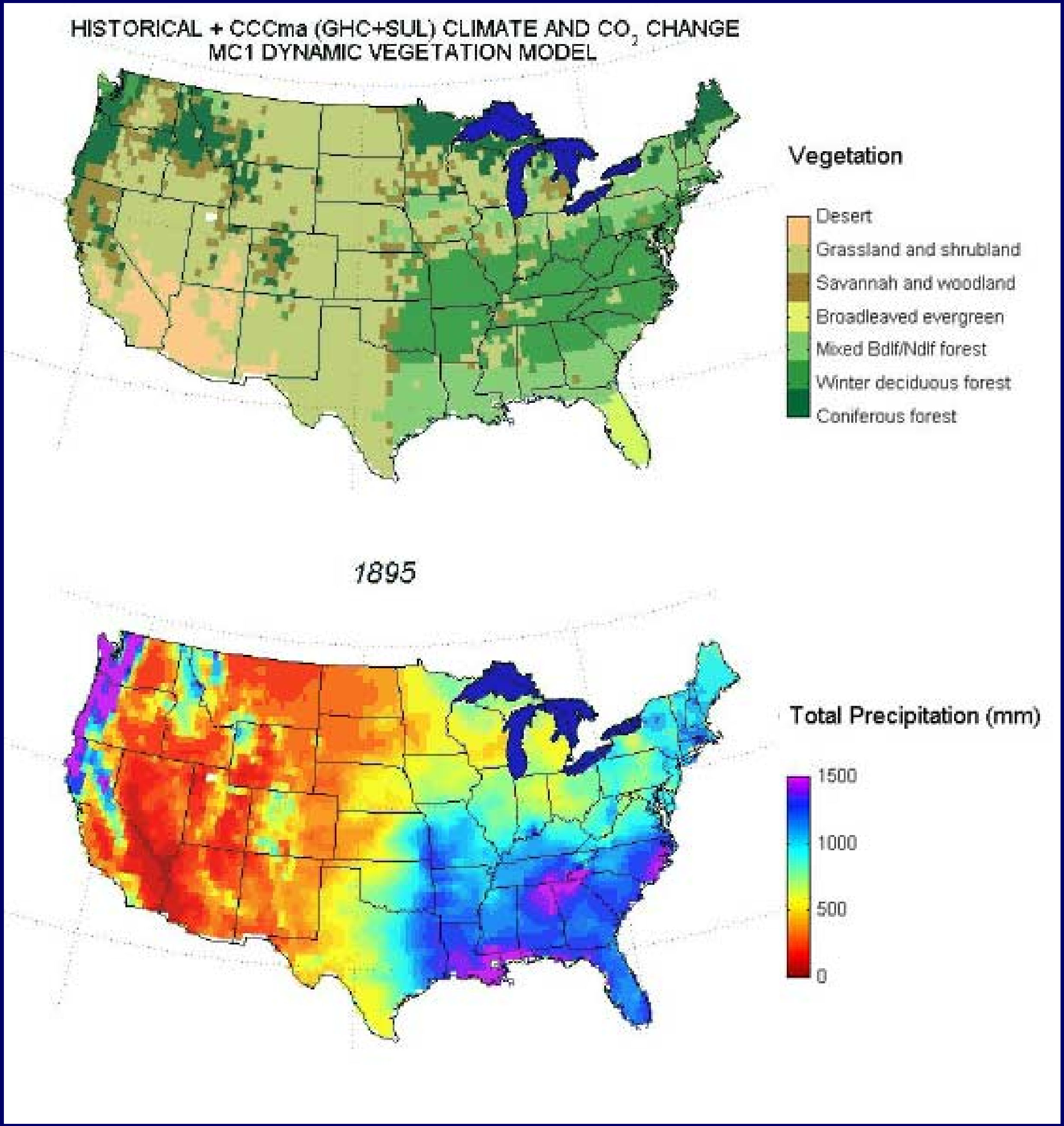
HISTORICAL + CCCma (GHC+SUL) CLIMATE AND CO2 CHANGE
MC1 DYNAMIC VEGETATION MODEL

Historical and GHG+SUL Simulated Climate with CO2 Biological Effects

USFS/ Oregon State Univ/VEMAP2 Members (2000)

REGIONAL VEGETATION RESPONSE

THIS SLIDE IS AN ANIMATION
To run - move cursor over maps, left click
To exit - press Esc

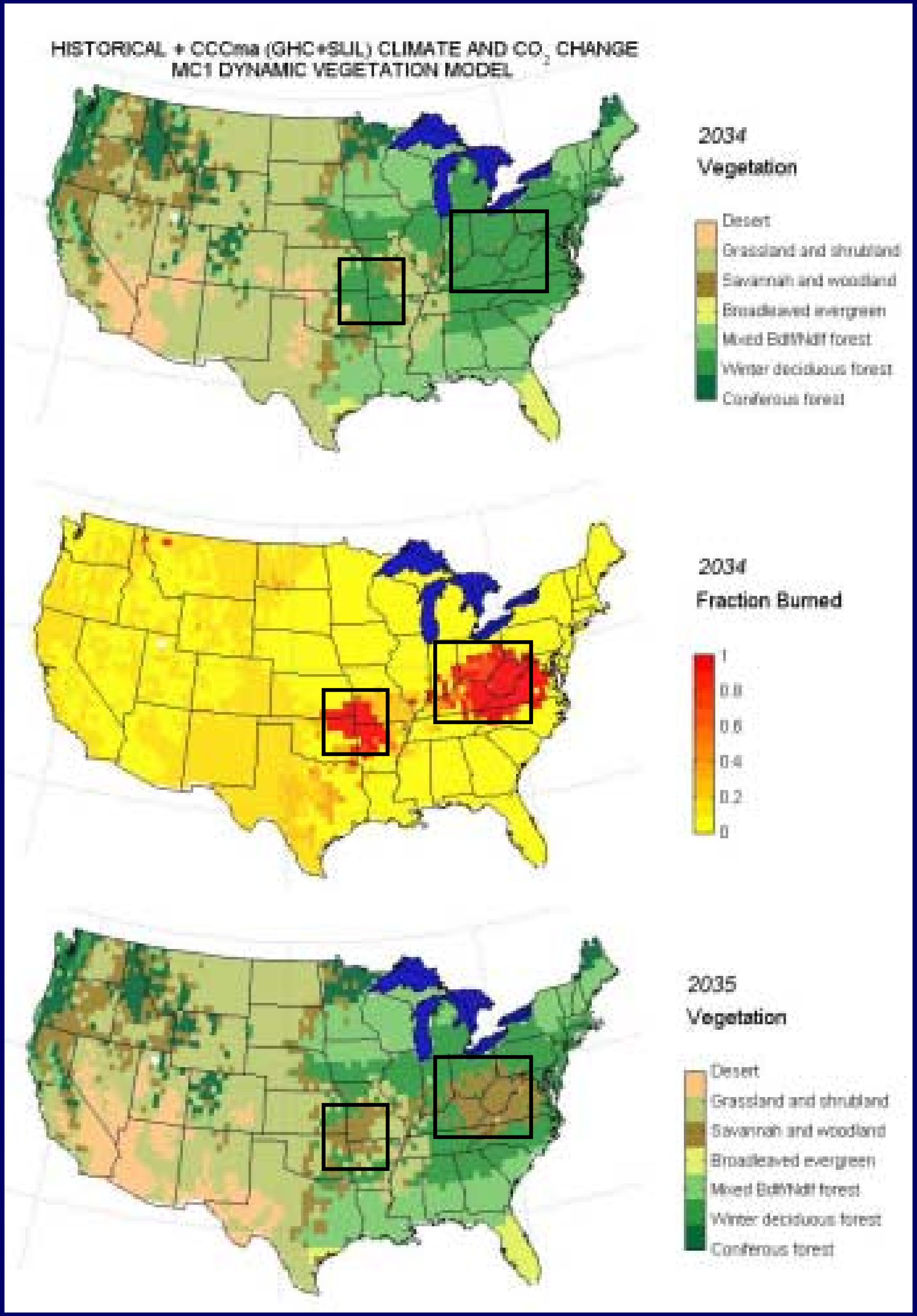


VEMAP2

Animation

DYNAMIC VEGETATION RESPONSE:

ROLE OF FIRE



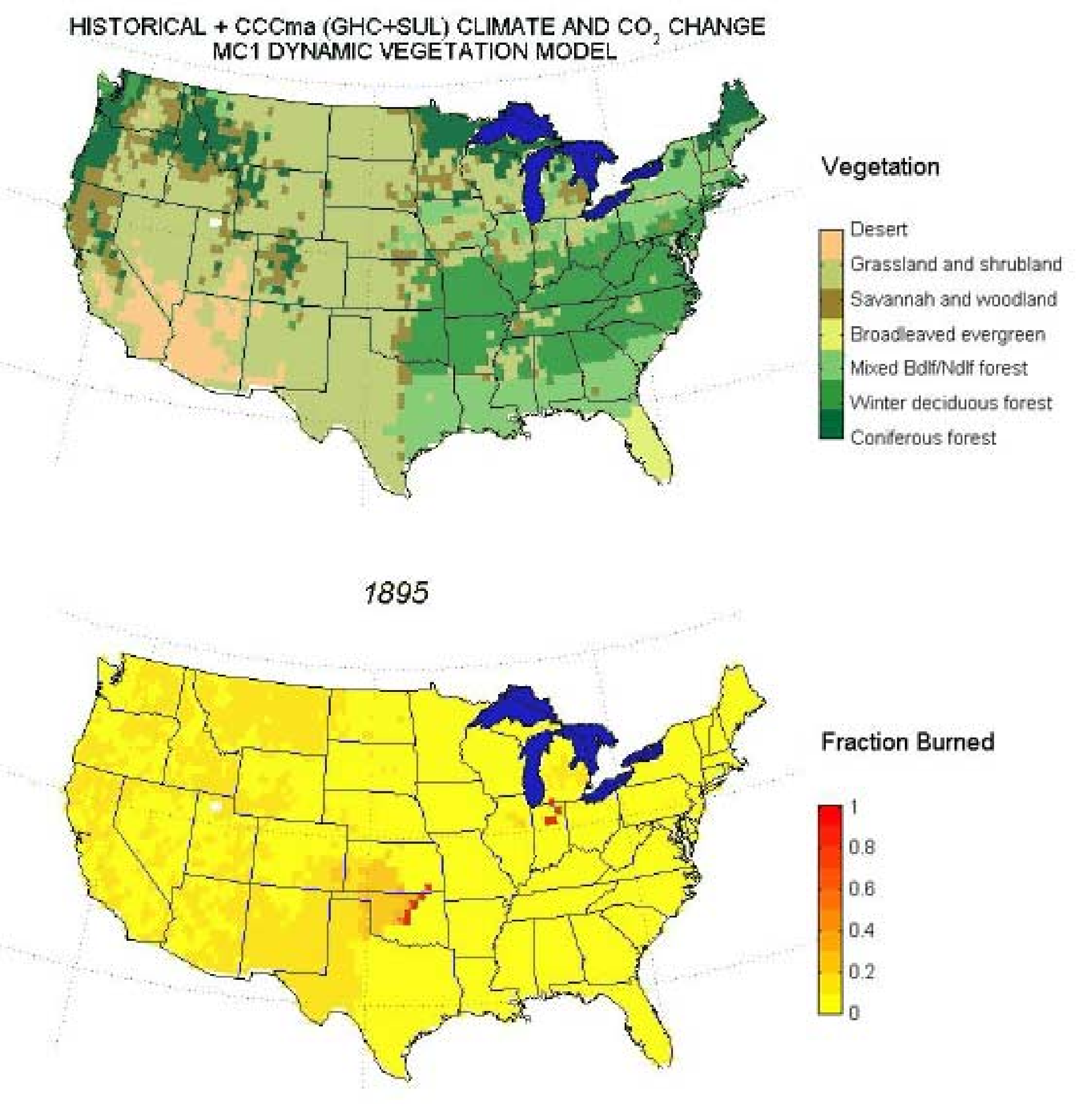
VEMAP2

- Maintenance of grasslands and savannas over shrublands and forests

- Disturbance as agent of change against tendency of forests to persist.

DISTURBANCE: ROLE OF FIRE

THIS SLIDE IS AN ANIMATION
To run - move cursor over maps, left click
To exit - press Esc



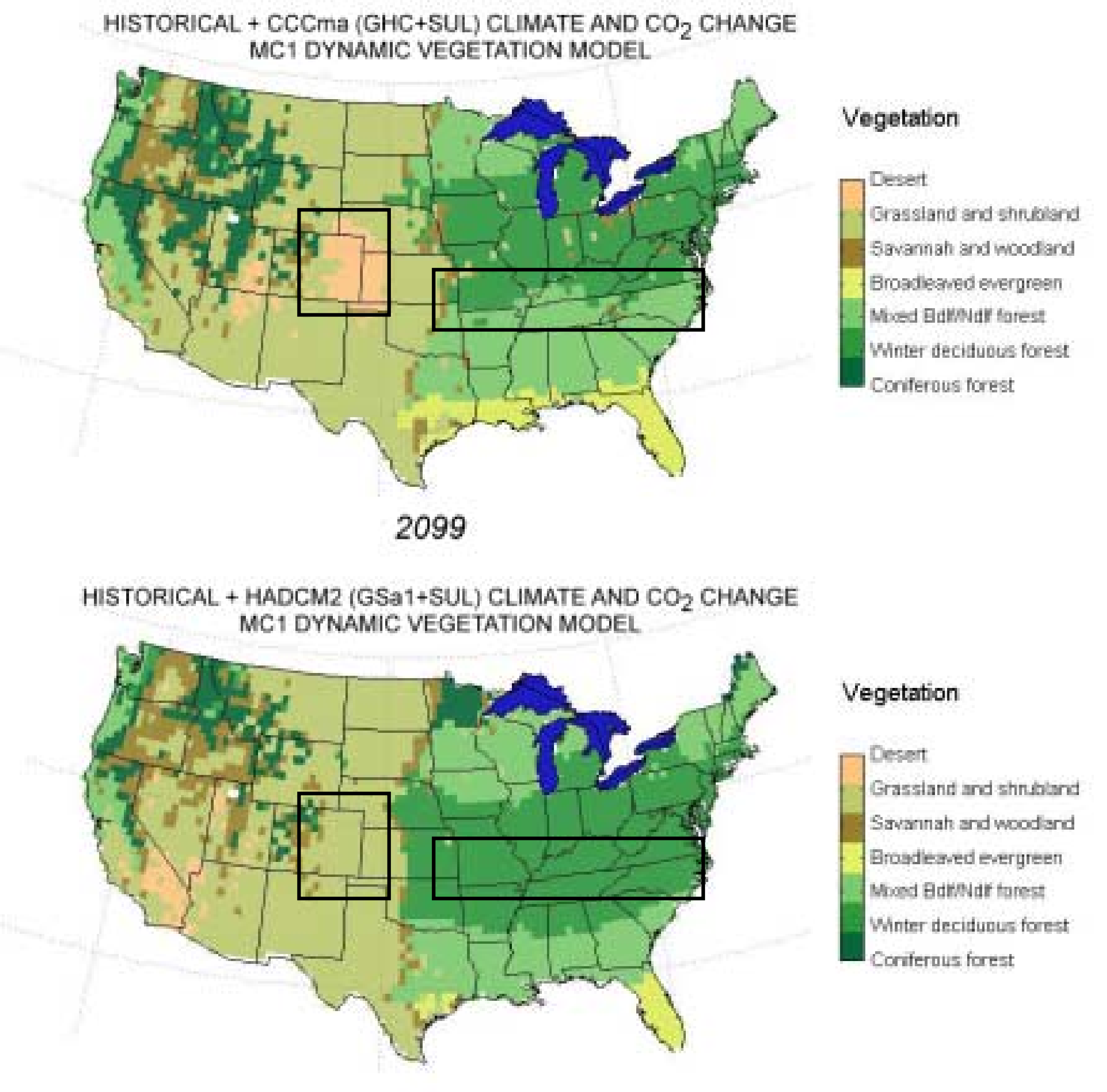
HISTORICAL + CCCma (GHC+SUL) CLIMATE AND CO$_2$ CHANGE
MC1 DYNAMIC VEGETATION MODEL

1895

VEMAP2

Animation

SOURCES OF UNCERTAINTY:
DIFFERENT DRIVING CLIMATE SCENARIOS



CANADIAN COUPLED MODEL

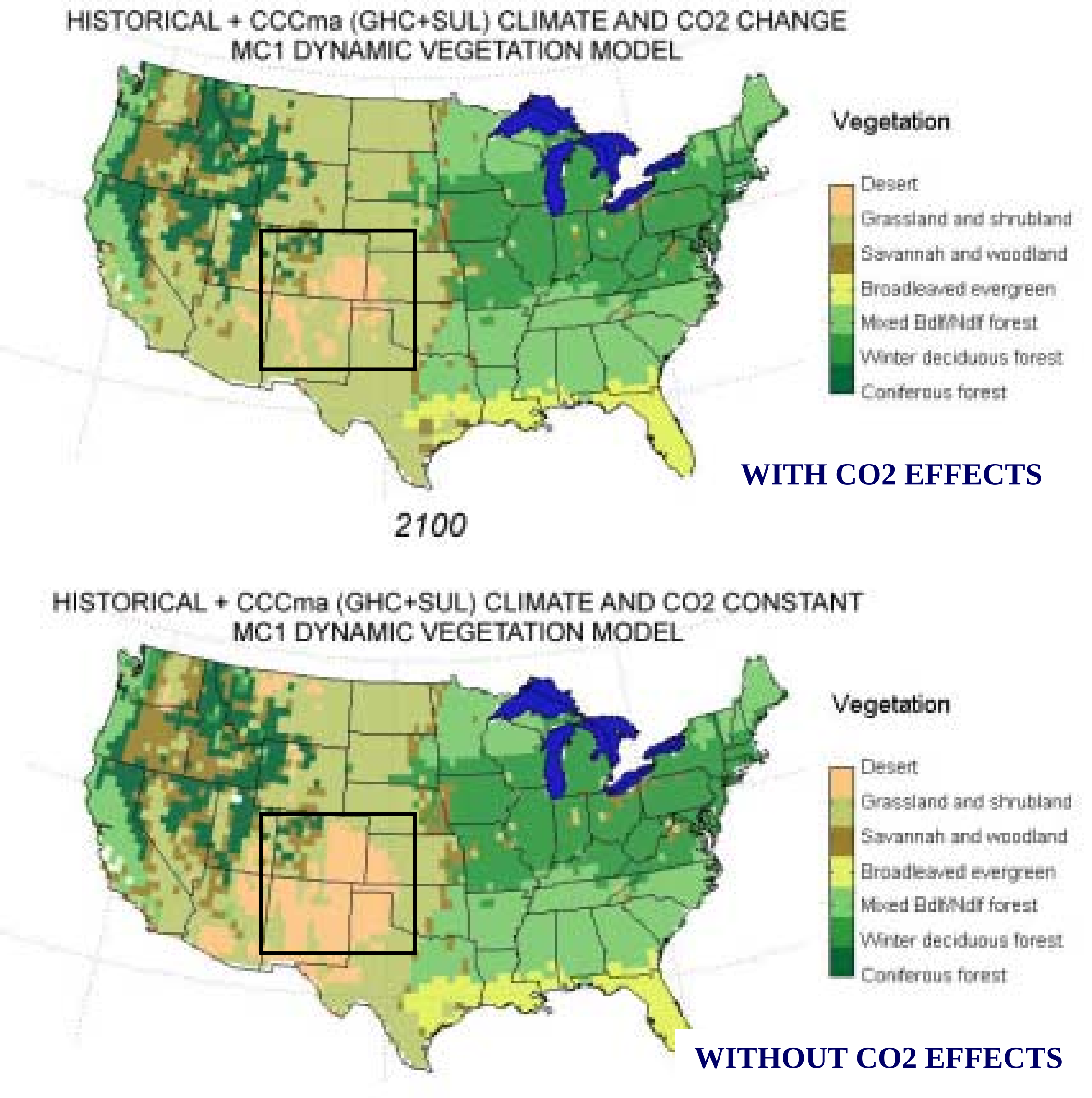
VS

HADLEY CENTRE (UK) COUPLED MODEL

- Differences in GCM warming trend and distribution of PPT change
- Driven by different model representations of physics, etc.

VEMAP2

SOURCES OF UNCERTAINTY:
MAGNITUDE OF CO2 FERTILIZATION EFFECT


HISTORICAL + CCCma (GHC+SUL) CLIMATE AND CO2 CHANGE
MC1 DYNAMIC VEGETATION MODEL

WITH CO2 EFFECTS

2100

HISTORICAL + CCCma (GHC+SUL) CLIMATE AND CO2 CONSTANT
MC1 DYNAMIC VEGETATION MODEL

WITHOUT CO2 EFFECTS

WITH vs WITHOUT CO2

- Long-term and ecosystem CO2 effects smaller than estimated from greenhouse and plot experiments

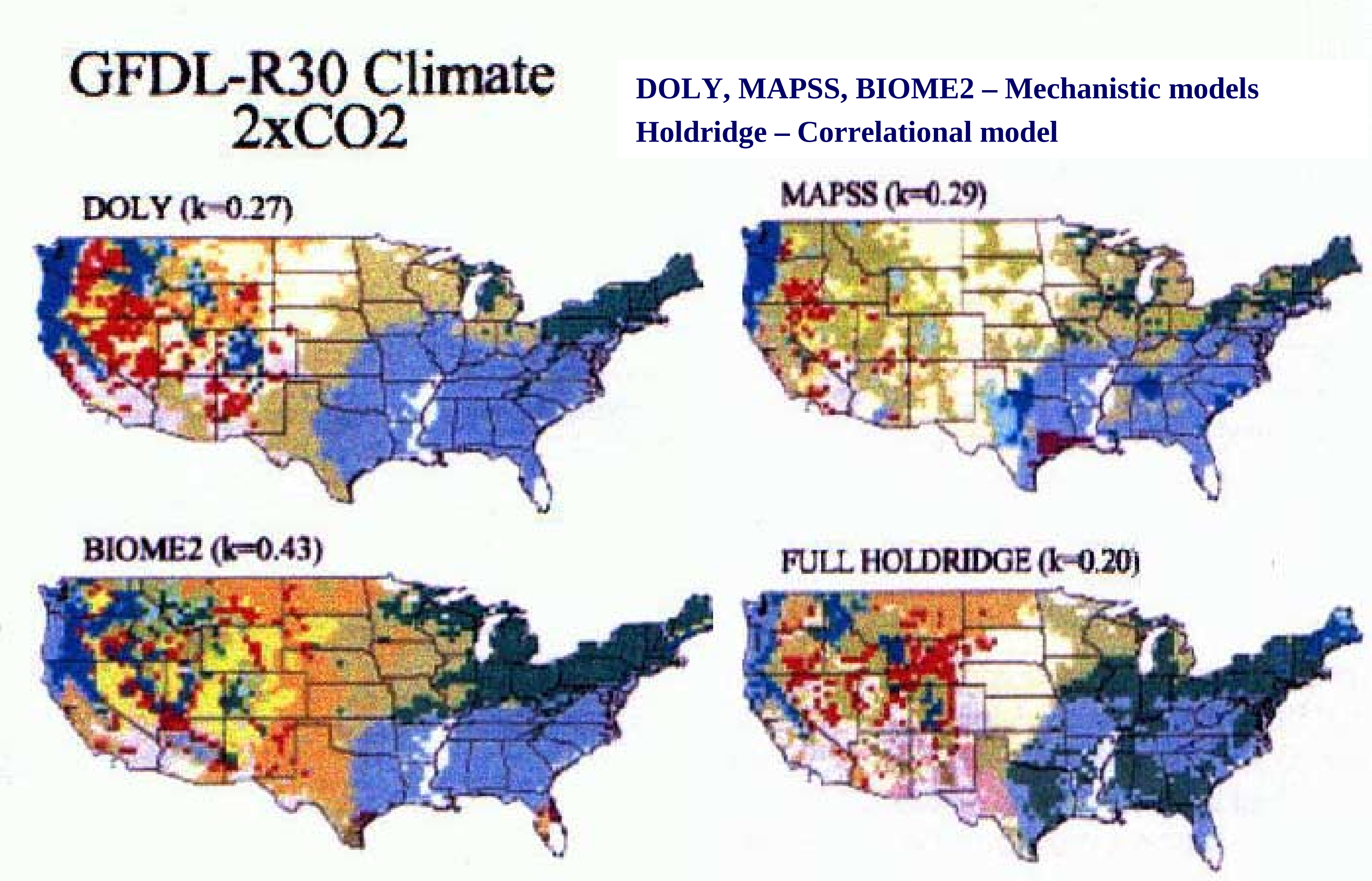
  →Physiological acclimation
  →Ecosystem compensating feedbacks

- Models implement range of CO2 mechanisms

- Actual responses probably somewhere in between

VEMAP2

SOURCES OF UNCERTAINTY: ECOLOGICAL MODEL DIFFERENCES



DOLY, MAPSS, BIOME2 – Mechanistic models
Holdridge – Correlational model

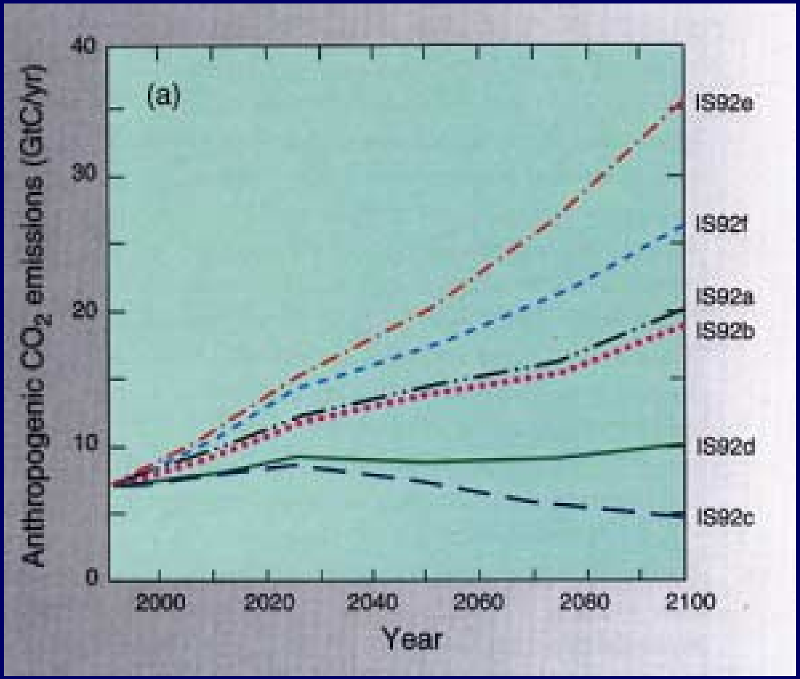
(Yates et al. 2000)

- Mechanistic models similar conceptually, but have noticeably different vegetation responses to climate and CO_2 change
- Driven by different model representations of ecological processes

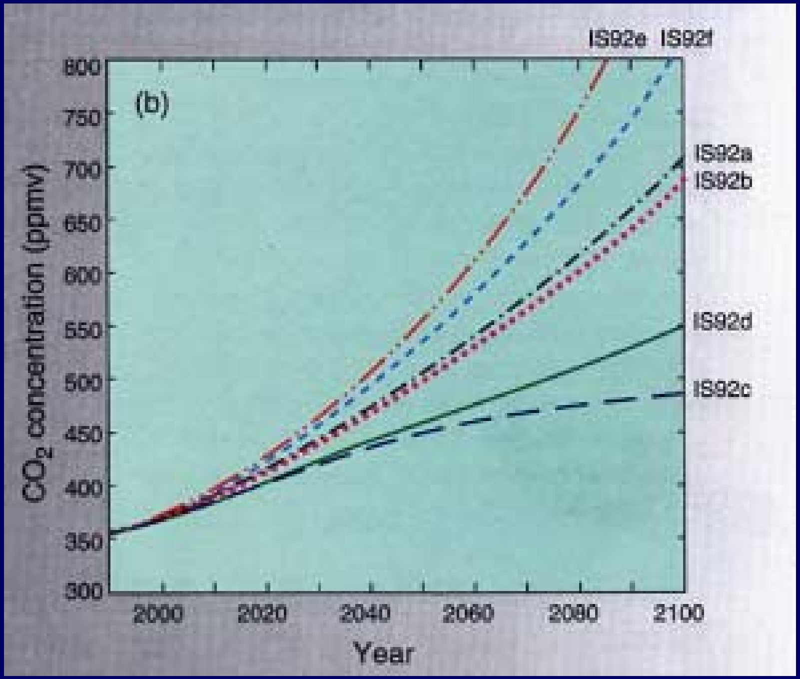
SCIENTIFIC UNCERTAINTIES - I

- Many sources of uncertainty in assessments of ecological change:
  - Multiple forcings – climate, CO2, landuse change, N-deposition ...
  - Emission scenarios – dependent on future economies, future policy

CO2 EMISSIONS



CO2 CONCENTRATION



(IPCC 1995)

SCIENTIFIC UNCERTAINTIES – I (con’t)

☞ Many sources of uncertainty in assessments of ecological change:

  - ✓ Multiple forcings
  - ✓ Emission scenarios
  - Modeled climate sensitivity – especially at regional level
  - Modeled ecological sensitivity – e.g., CO_2 effect

SCIENTIFIC UNCERTAINTIES - II

Why is system sensitivity to altered forcing difficult to model?

☞ Earth system and components are complex systems

- Multiple factors at play and interactions are complex
  → difficult to understand, difficult to model
- Some changes in forcing operate at fine scales
  → difficult to scale up
- Responses of societal interest at regional and local scales
  → difficult to scale down

☞ Bottom line:

- Uncertainty in forcings + models
  → Modeling not a “crystal ball”

SCIENTIFIC CERTAINTIES - I

What are the "certainties"?

☞ Climate models sophisticated enough that can say:

- Global climate is sensitive to projected increases in GHGs+SUL
  - Global changes in atmospheric and ocean circulation
    - → Changes in land T and PPT
- Regional changes likely large, even if can't specify
- Climate variability changes – e.g. to El Niño cycle

SCIENTIFIC CERTAINTIES - II

☞ Ecological model results, even given uncertainties, tell us:

- Ecosystems are vulnerable to altered climate and CO_2:
  - Potential changes in structure and function significant
    - Effecting productivity, net carbon storage …
  - Changes will affect both natural and managed areas
  - Changes in rates of disturbance
    - Fire, insect outbreaks …
  - Increased vulnerability to other stressors
    - Species invasions, fragmentation, N-deposition, acid rain …

POLICY IMPLICATIONS - I

“Least regrets” policy approach –

☞ Make policy that doesn’t rely on any single scenario of future change, but which reduces overall system vulnerability

- Maintain or restore integrity of natural systems
  - Large preserves, landscape corridors, Clean Water Act ...

- Develop infrastructure enhancing resiliency of socio-economic systems to changes in forcing regardless of direction
  - e.g., Landuse policy in areas currently prone to fire, flooding, hurricanes ...

POLICY IMPLICATIONS - II

“Least regrets” policy approach (con’t) –

- ☞ Develop policy which reduces altered forcing and which give colateral benefits: “win-win”
    - e.g., Policy to increase industrial fuel efficiency that while reducing emissions also increases global competitiveness

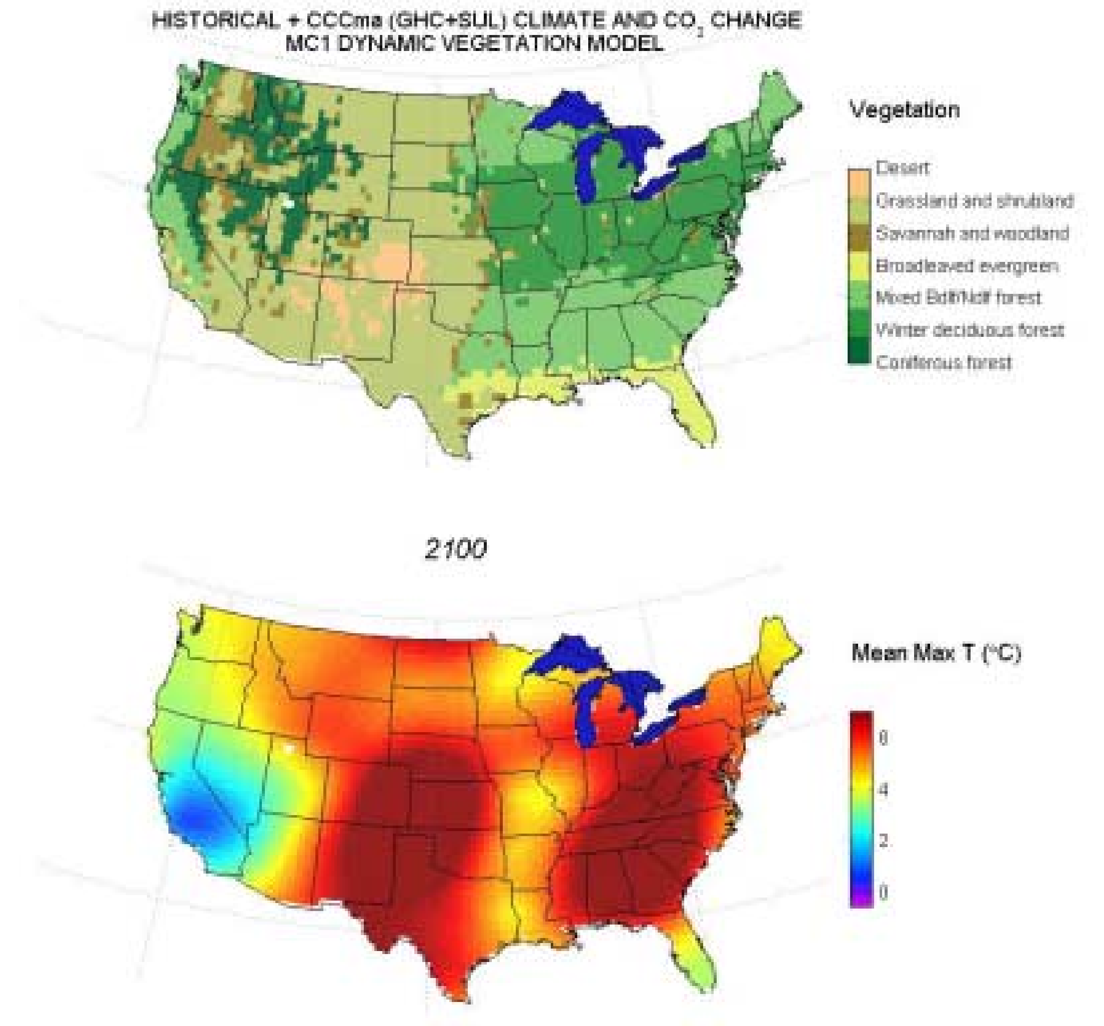
FUTURE VEGETATION CHANGE

RESPONSE OF ECOSYSTEM STRUCTURE AND DISTRIBUTION TO ALTERED FORCING

REVIEW OF TOPICS:

- Why important? – Roles in the earth system
- What factors control structure?
- Modeling change: A crystal ball?
- Drivers of future change: Multiple factors
- Vulnerability to climate and CO_2 change: Model results
- Scientific certainties and uncertainties
- Policy implications

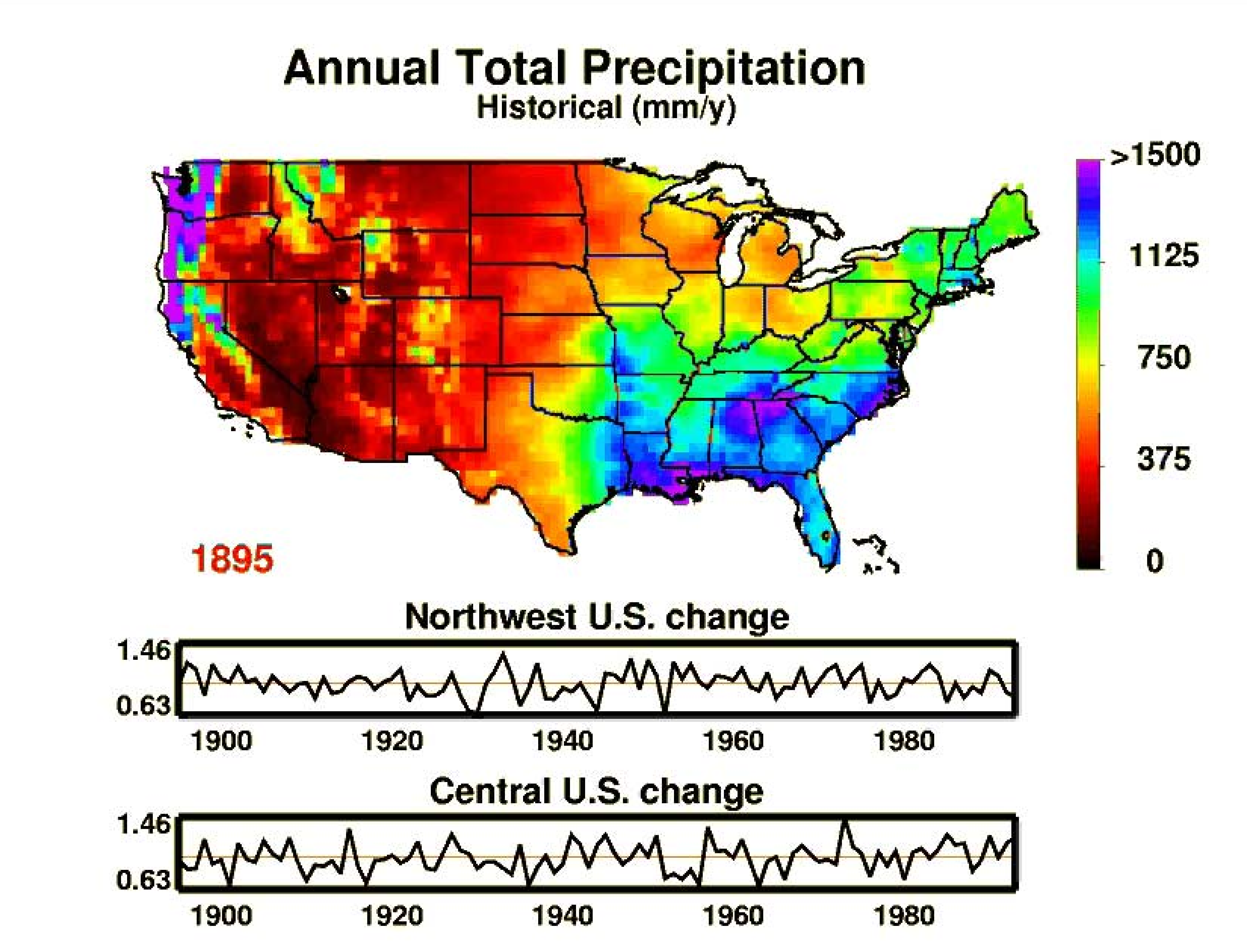
REGIONAL VEGETATION RESPONSE



HISTORICAL + CCCma (GHC+SUL) CLIMATE AND CO_2 CHANGE
MC1 DYNAMIC VEGETATION MODEL

2100

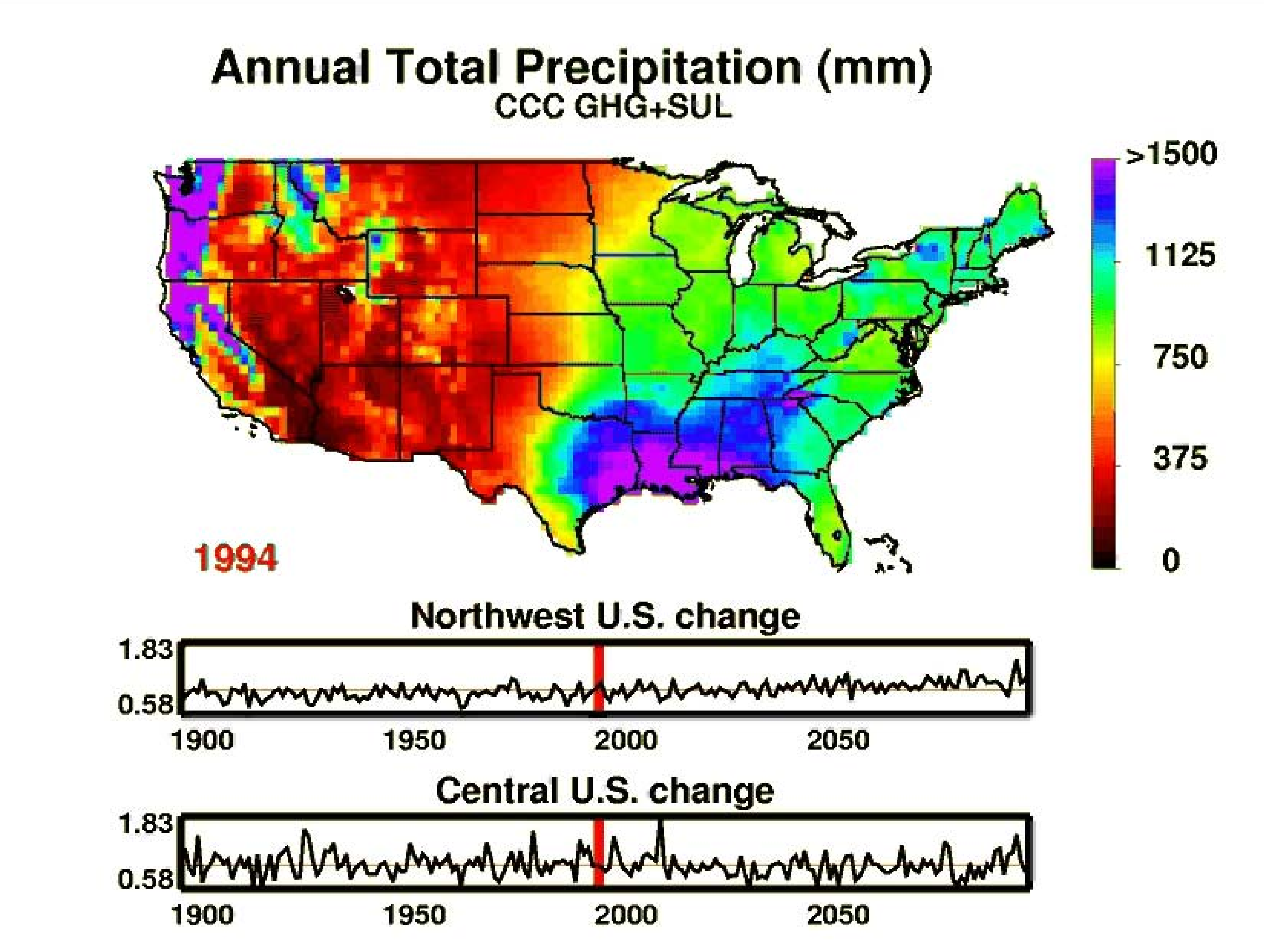
Historical Climate 1895-1994



VEMAP2 Dataset – Kittel et al., NCAR

REGIONAL CLIMATE RESPONSE

AOGCM Simulated Climate 1994-2100 with Greenhouse Gas+Sulfate Increases



Canadian Coupled Model (Boer et al., Flato et al.) – VEMAP2 Dataset (Kittel et al., NCAR)