Climate Change and Landscape Resilience:

Is the Current Concept of Landscape Resilience Adequate?

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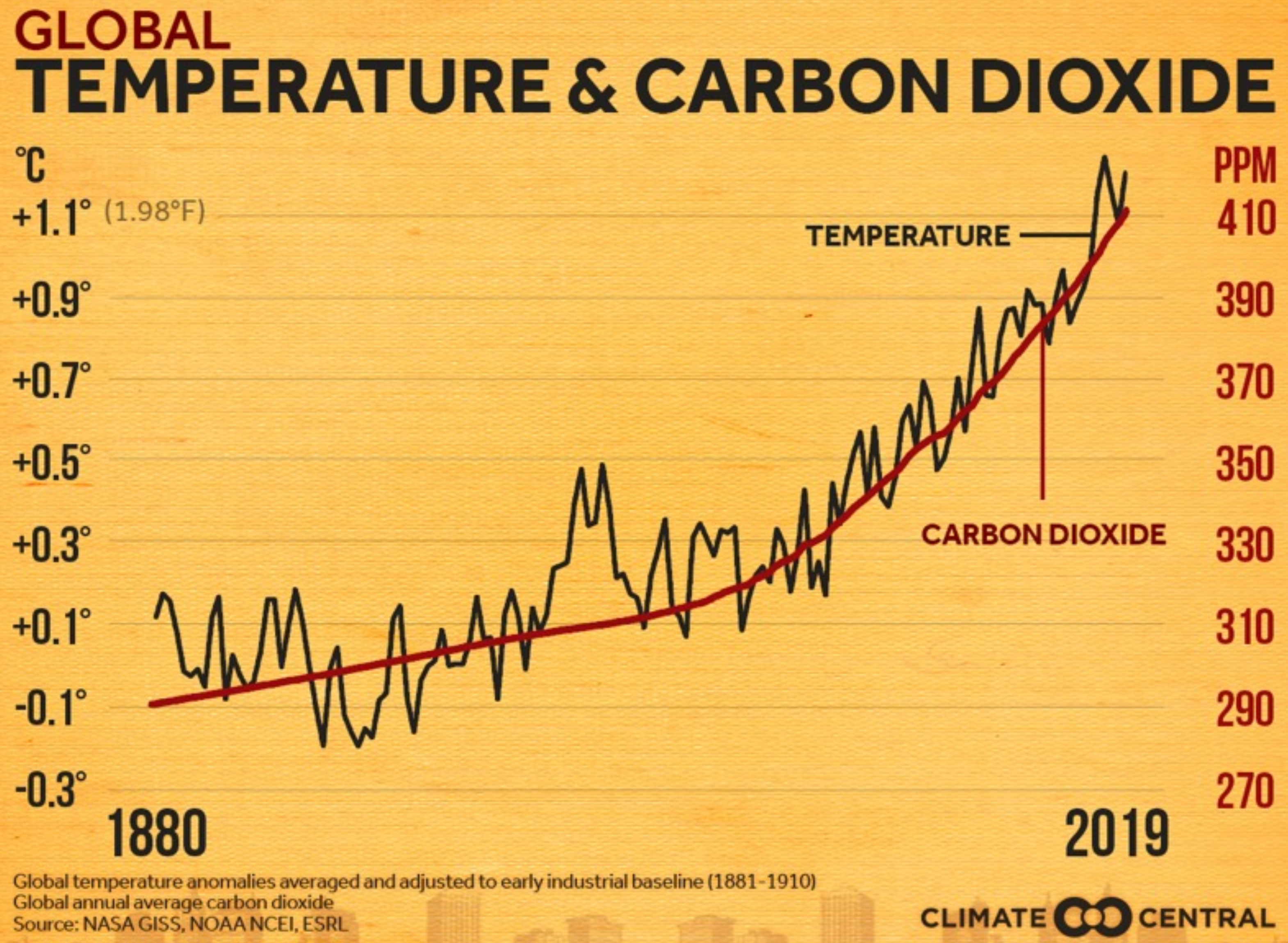
- **The growing pace of global warming with increasing frequency of extreme temperature and rainfall events, droughts and wildfires due to increasing atmospheric carbon emission content, requires immediate and drastic action.**

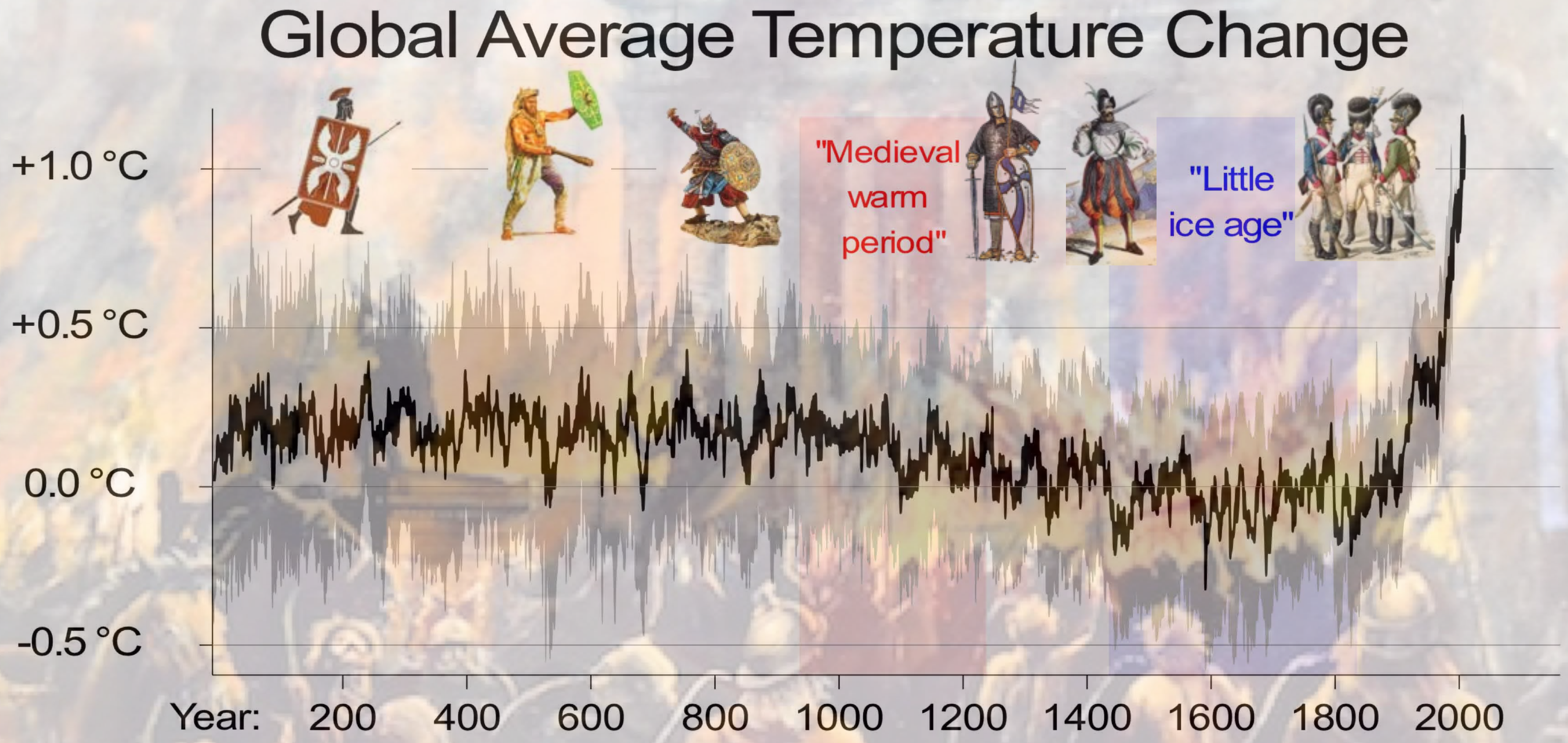
- **There are the two sides of the atmospheric carbon problem.**
  - **In order to lower atmospheric carbon content, two approaches must be taken**
    - **1) reduce emissions**
    - **2) remove what is already in the atmosphere**

(The Caldor wildfire summer of 2021, 100 km south of my home in Reno, Nevada, at one time we had three fires like this burning south, west and east of Reno. One fire in 2020 burned up to the fence next to my house.)

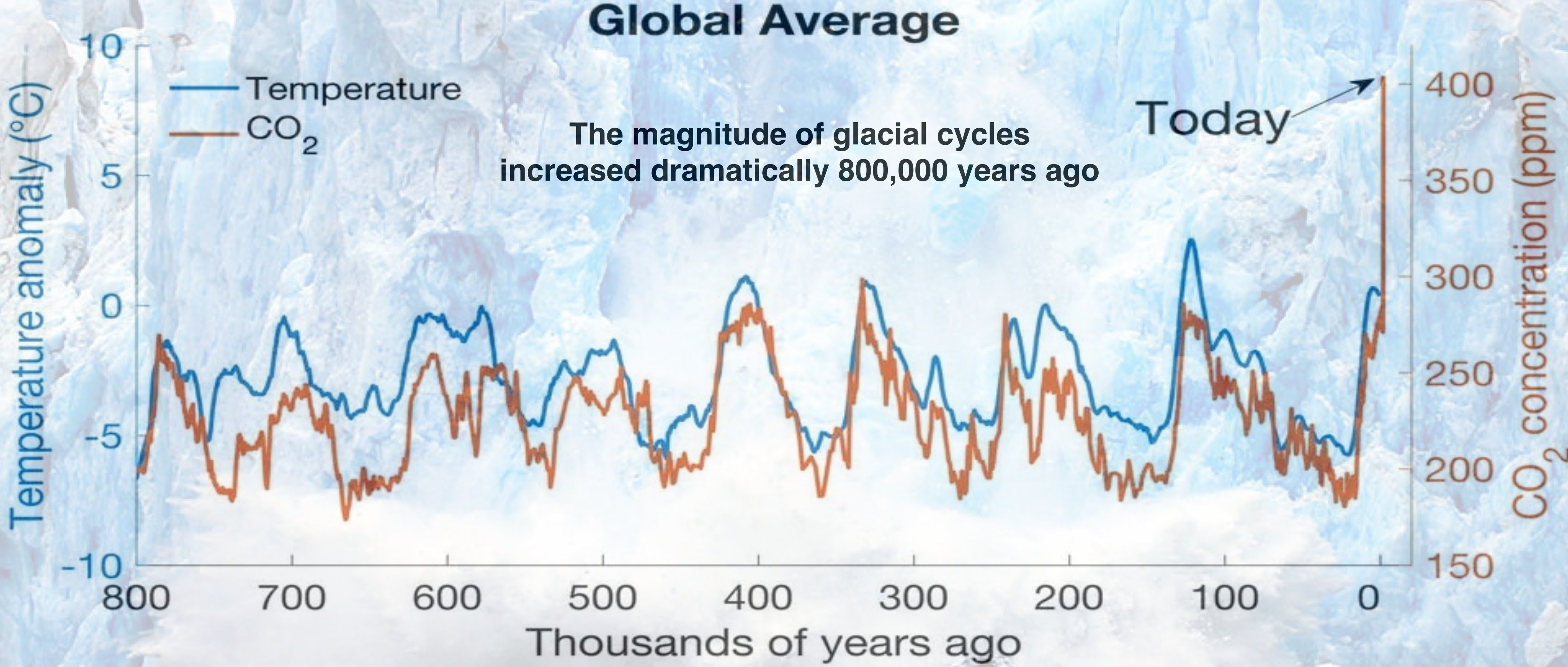
Our Problem: Can we control it?



LETS PUT THESE TEMPERATURES IN PERSPECTIVE SINCE ROME BURNED 1,400 YEARS AGO

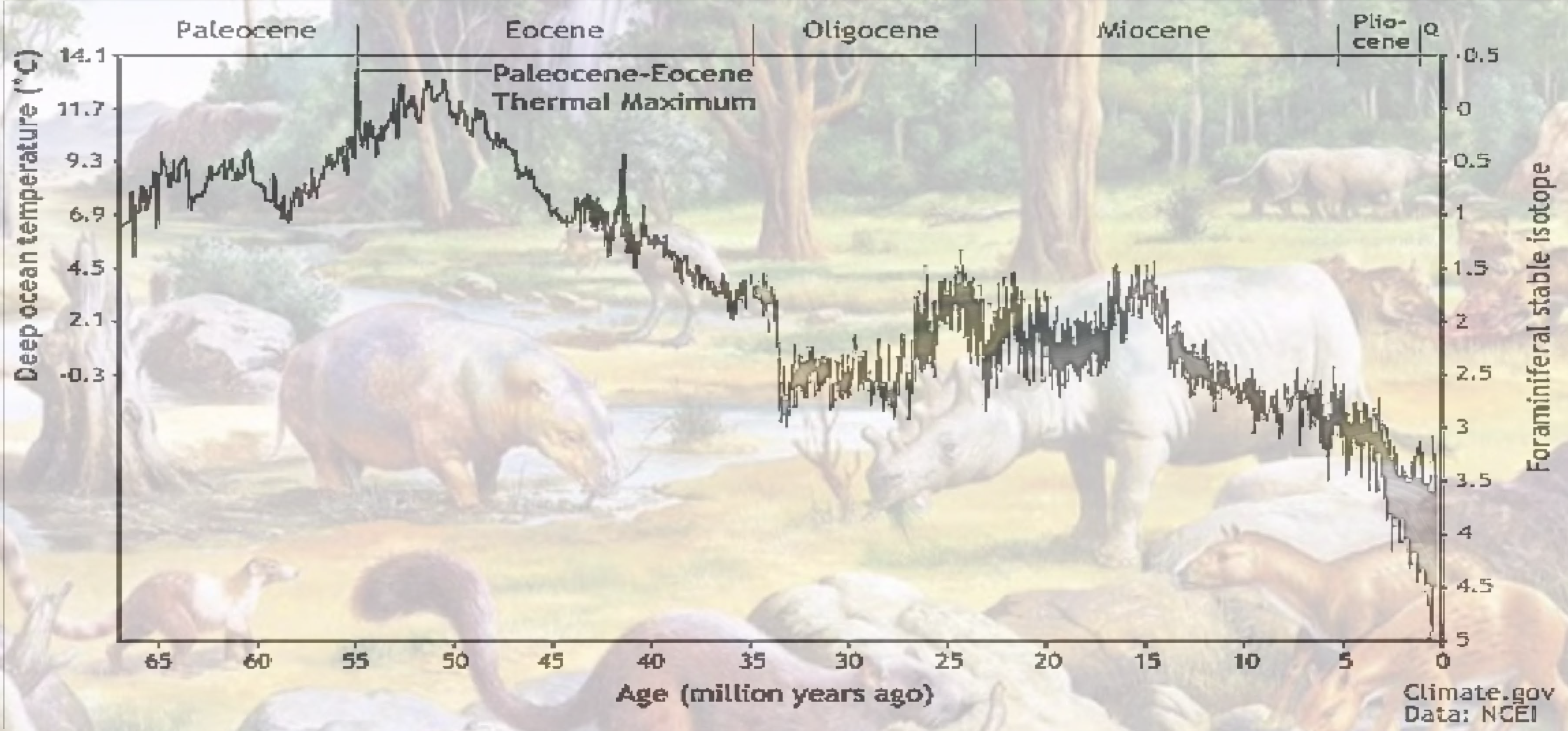


LETS PUT THESE TEMPERATURES IN PERSPECTIVE FOR THE LAST 800,000 YEARS

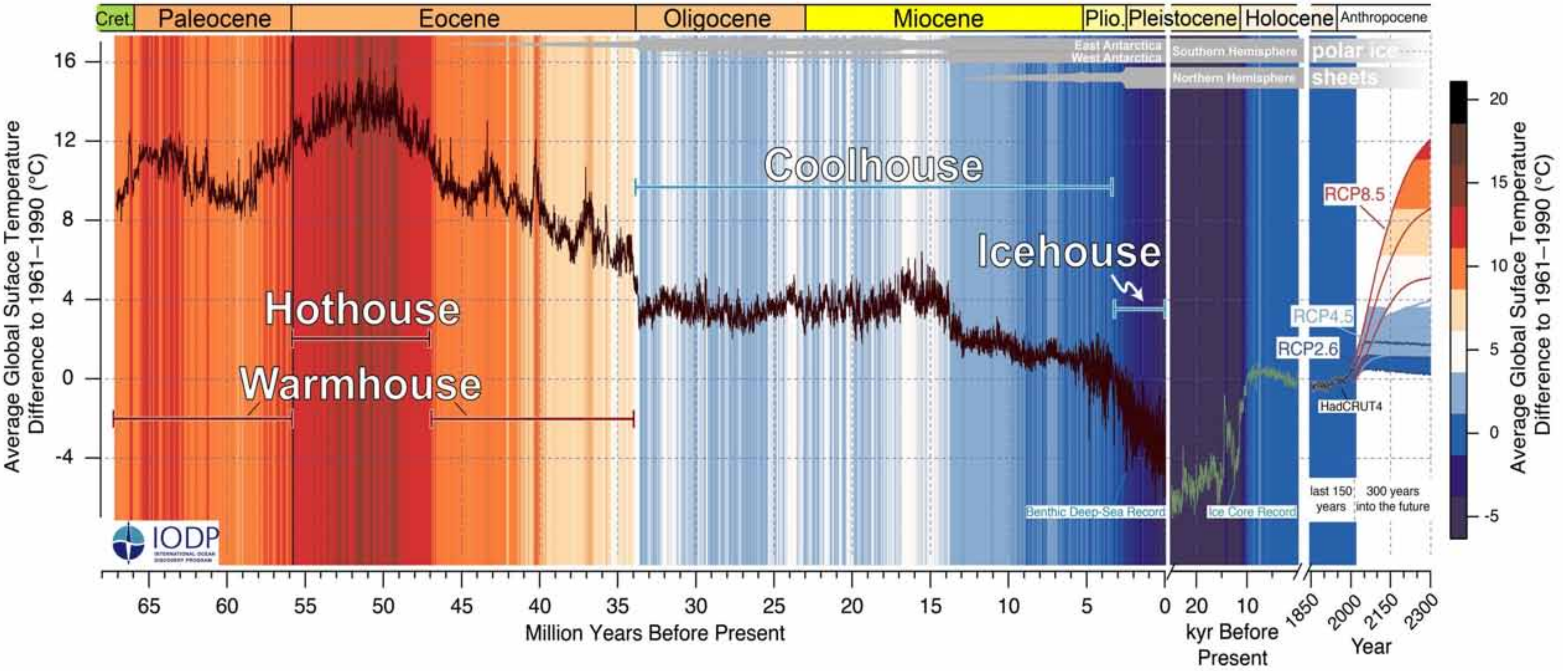


@benhenley, @dr_nerilie

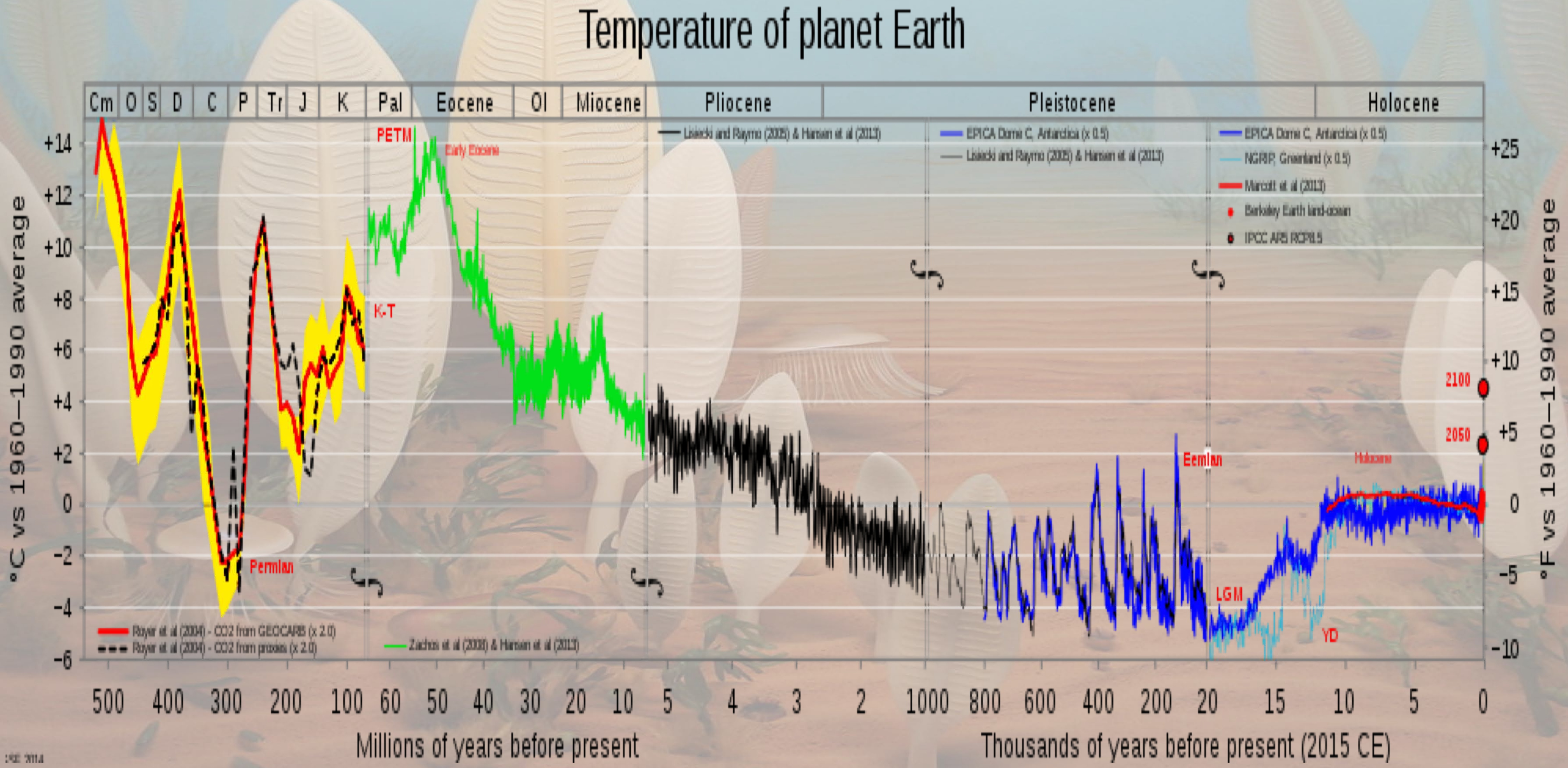
LETS PUT THESE TEMPERATURES IN PERSPECTIVE SINCE THE END OF THE AGE OF DINOSAURS 65,000,000 YEARS AGO



LETS PUT THESE TEMPERATURES IN PERSPECTIVE: LAST 65,000,000 YEARS

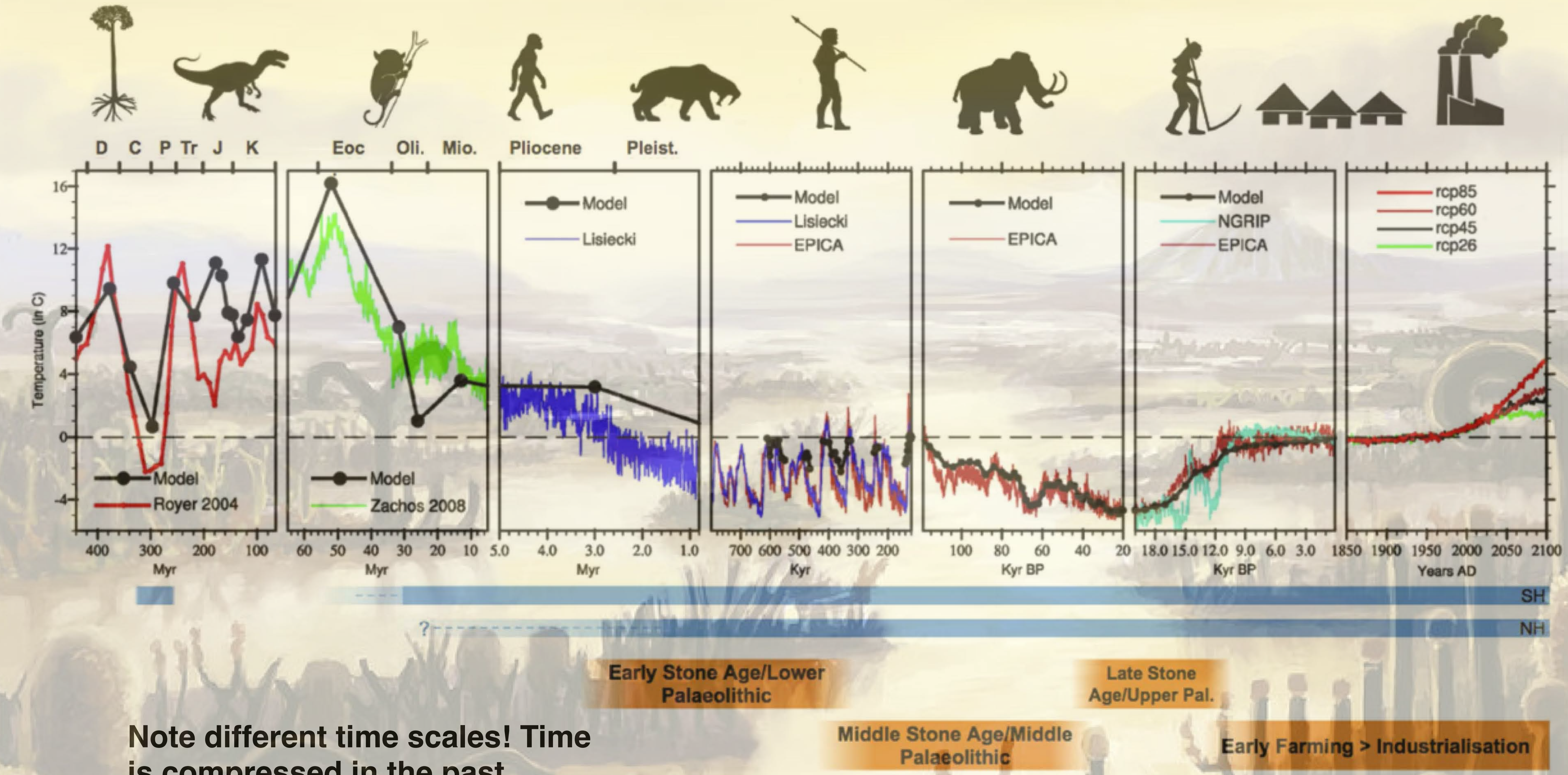


LETS PUT THESE TEMPERATURES IN PERSPECTIVE SINCE THE PROTEROZOIC 500,000,000 YEARS AGO



Note different time scales! Time is compressed in the past.

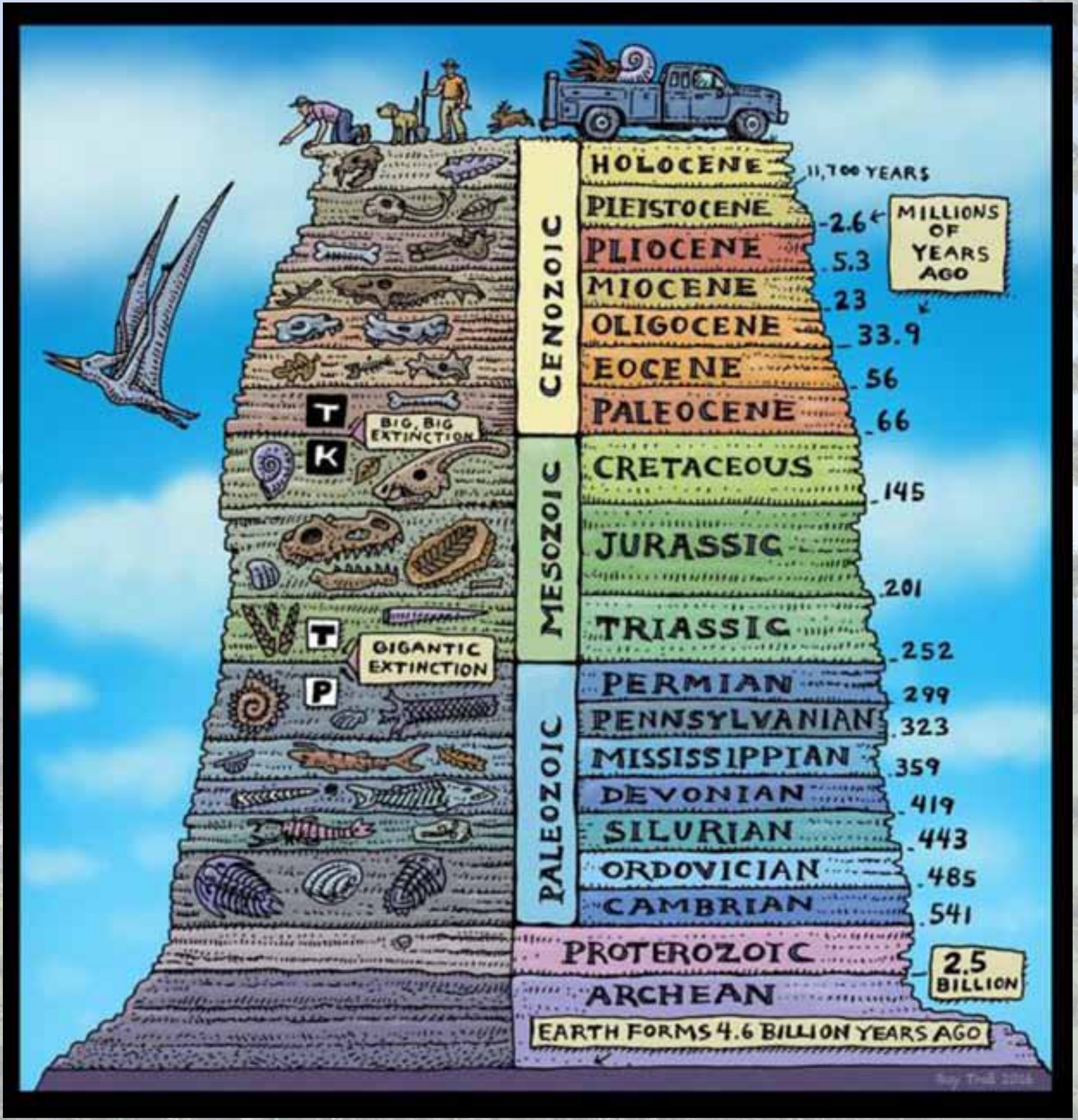
Comparison of life forms with past temperature regimes



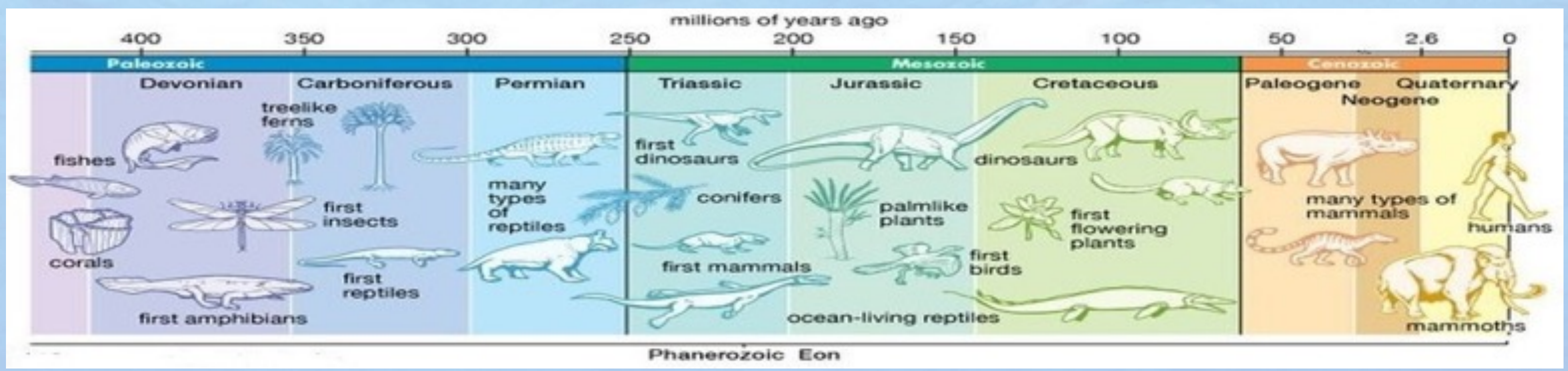
Note different time scales! Time is compressed in the past.

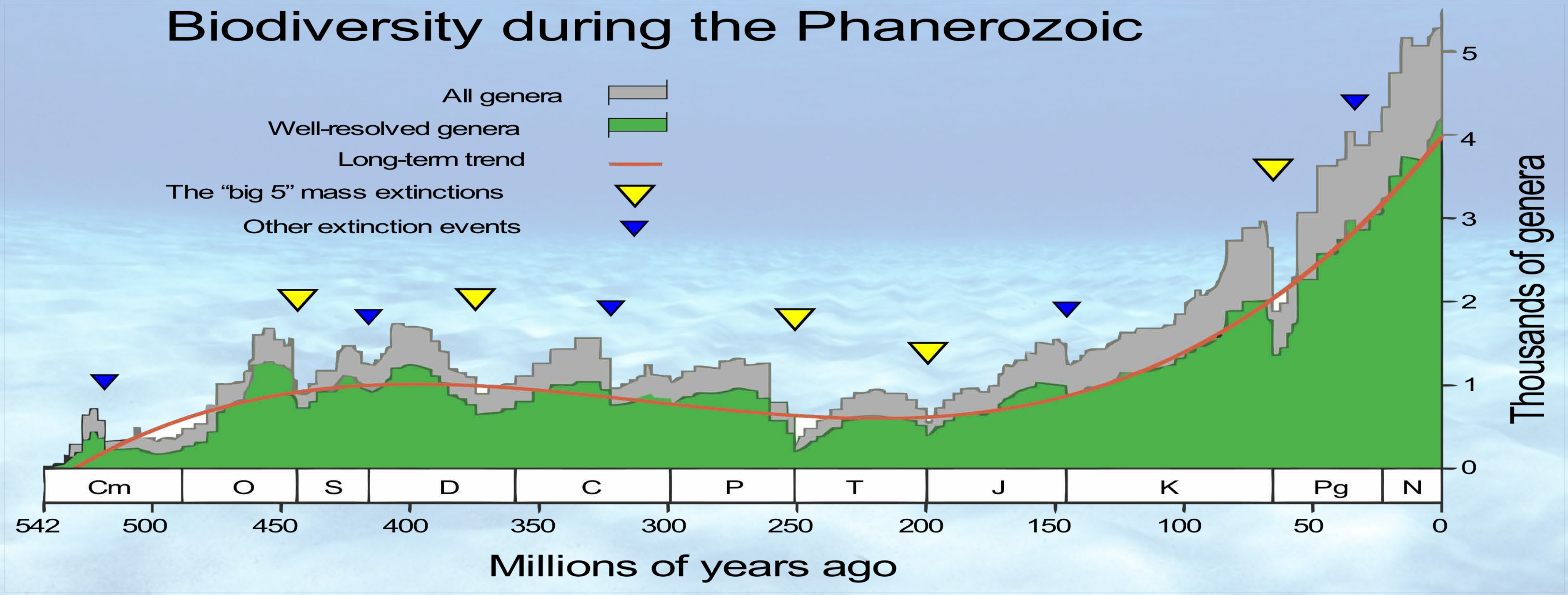
BIOTIC CHANGE OF LIFE ON EARTH DURING THE LAST 500,000,000 YEARS

WHY ARE THESE CHANGES SO DRAMATIC?

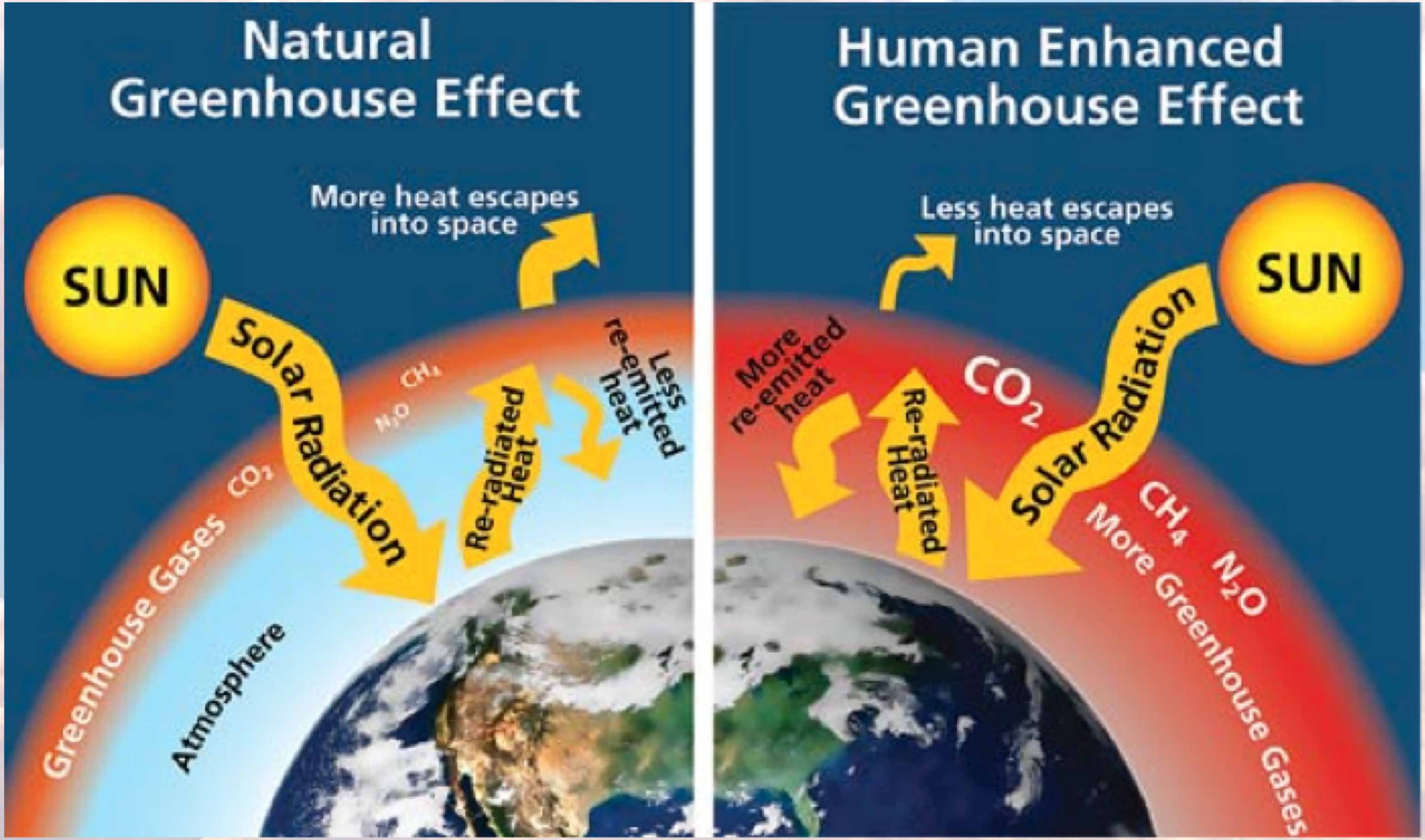


MASS EXTINCTION EVENTS: TIMES WHEN LANDSCAPE RESILIENCE FAILED





THE IMPACT OF HUMAN CARBON EMISSIONS



PREDICTED FUTURE GLOBAL WARMING

- **Models predict that Earth will warm between 2 and 6 degrees Celsius in the next century.**
- **When global warming has happened at various times in the past two million years, it has taken the planet about 5,000 years to warm 5 degrees.**
- **The predicted rate of warming for the next century is at least 20 times faster.**
- **This rate of change is extremely unusual as will be indicated below.**

HOW CAN RESILIENCE SCIENCE BE INTEGRATED INTO LANDSCAPE CONSERVATION, MANAGEMENT, AND DESIGN TO DEAL WITH THESE EVENTUALITIES OR CAN IT EVEN DO SO?

- **The concept of resilience focuses upon creating systems that are robust enough to persist and adapt over the long term.**
- **It is assumed to be vital in managing ecosystems to sustain biodiversity and ecological functions in an uncertain future.**
- **Resilience-based management has become the darling of the ecological crowd and has widespread appeal and assumed potential.**
- **However!**
  - **It is notoriously difficult to operationalize.**
  - **And it is unclear how it can be integrated into landscape design and ecosystem restoration.**
- **The goal of the Landscape Resilience Framework is to facilitate application of resilience principles to ecosystem management, identifying the key landscape elements that sustain biodiverse, ecologically functional landscapes during climate change and other anthropogenic stresses over the coming century and beyond.**

HOW IS LANDSCAPE RESILIENCE OPERATIONALIZED?

HOW CAN BIODIVERSITY AND ECOLOGICAL FUNCTION BE ENHANCED AT THE LANDSCAPE SCALE?

- **The Landscape Resilience Framework identifies seven landscape attributes that contribute to landscape resilience.**

- **The Landscape Resilience Framework synthesizes empirical ecological studies and social-ecological resilience theory, and has been reviewed by a many expert advisors.**

THE SEVEN PRINCIPLES OF LANDSCAPE RESILIENCE

1 Setting - Unique geophysical, biological, and cultural aspects of a landscape that determine potential constraints and opportunities for resilience

2 Process - Physical, biological, and chemical drivers, events, and processes that create and sustain landscapes over time

3 Connectivity - Linkages between habitats, processes, and populations that enable movement of materials and organisms

4 Diversity & Complexity - Richness in the variety, distribution, and spatial configuration of landscape features that provide a range of options for species

5 Redundancy - Multiple similar or overlapping elements or functions within a landscape that promote diversity and provide insurance against loss

6 Scale - The spatial extent and time frame at which landscapes operate that allows species, processes, and functions to persist

7 People - The individuals, communities, and institutions that shape and steward landscapes

8 What is missing?

Indicator Assessment: Flies in the ointment = problems

Distribution shifts of plant and animal species

- **Observed climate change is having significant impacts on the distribution of European flora and fauna, with distribution changes of several hundred kilometres projected over the 21st century. These impacts include northwards and uphill range shifts, as well as local and regional extinctions of species.**

- **The migration of many species is lagging behind the changes in climate owing to intrinsic limitations, habitat use and fragmentation, and other obstacles, suggesting that they are unable to keep pace with the speed of climate change. Observed and modelled differences between actual and required migration rates may lead to a progressive decline in European biodiversity.**

- **Climate change is likely to exacerbate the problem of invasive species in Europe. As climatic conditions change, some locations may become more favourable to previously harmless alien species, which then become invasive and have negative impacts on their new environments.**

- **Climate change is affecting the interaction of species that depend on each other for food or other reasons. It can disrupt established interactions but also generate novel ones.**

A Palaeoecological Example Highlighting the Problems in the Resilience Concept :

The Yucca Mountain High-Level Nuclear Waste Site Characterization
Hancock Summit Area: Pahranagat Range, Northern Mojave Region, Nevada

Limestone ridgeline at southeast end of Hancock Summit Pass. I used the evidence provided by plant remains from numerous woodrat middens here and dozens of other places to establish the local vegetation history for the past 36,000 years. The vegetation history was then used to reconstruct past climate history.

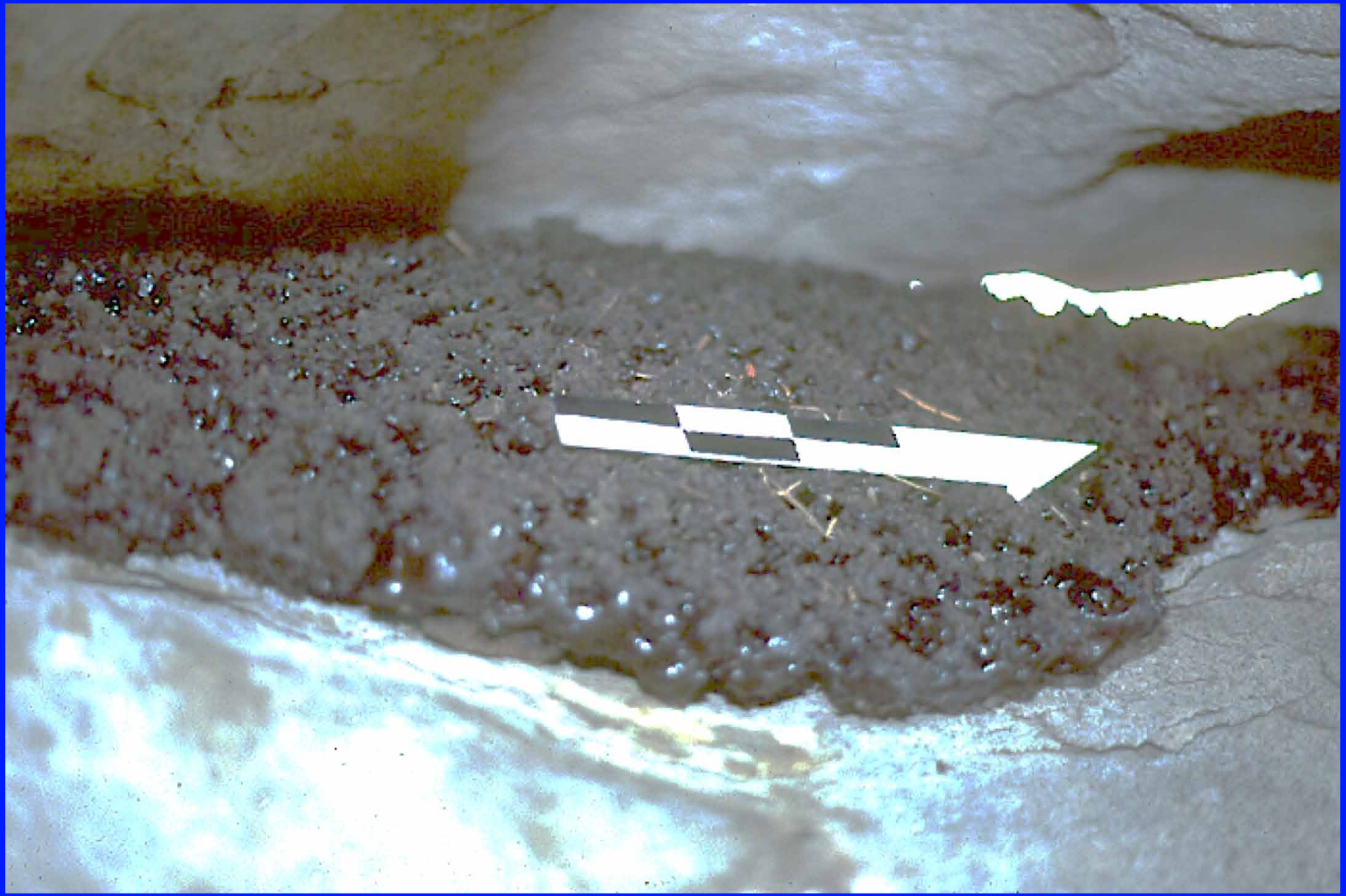
Ancient Woodrat Midden: Limber Pine

- Oldest woodrat midden on the ridge with well a developed, very hard, rind characteristic of very old middens.
- This midden contains a record of vegetation from 7,000 to 36,000 years ago.
- It contains macrofossils of limber pine *(Pinus flexilis),* a sub-alpine tree species, as well as of Utah juniper *(Juniperus osteosperma),* which grows at middle elevations today.
- The ancient nest lies well above and away from drainages that could have contributed down-stream contamination from higher elevations.
- It was guarded by a Mojave green rattlesnake.

Limber Pine Woodland today

This modern limber pine *(Pinus flexilis)* woodland is in the Roberts Mountains of central Nevada. Except for the absence of common juniper *(Juniperus communis)* this community is almost identical in composition to that recovered from the middens in the Hancock Summit area almost 200 km to the south and 36,000 years earlier.

Ancient Woodrat Midden: White Fir



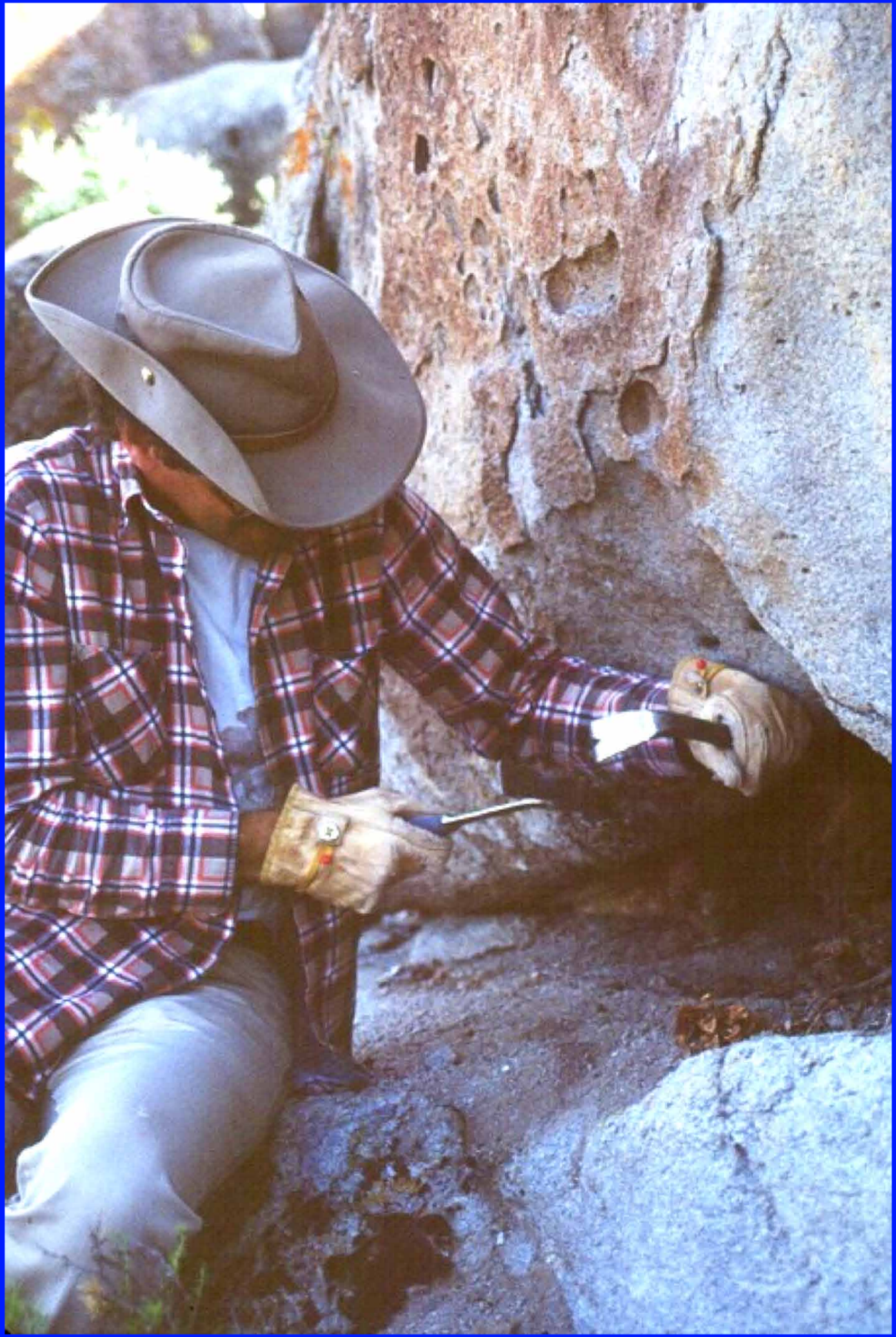
This midden from the Pahranagat Range contained limber pine *(Pinus flexilis)* and juniper in addition to white fir *(Abies concolor)*.

This modern Great Basin white fir woodland is in Kyle Canyon in the Spring Range west of Las Vegas.

Typical Woodrat Midden

This one spans 34,000 years

Sampling Ancient Packrat Nests

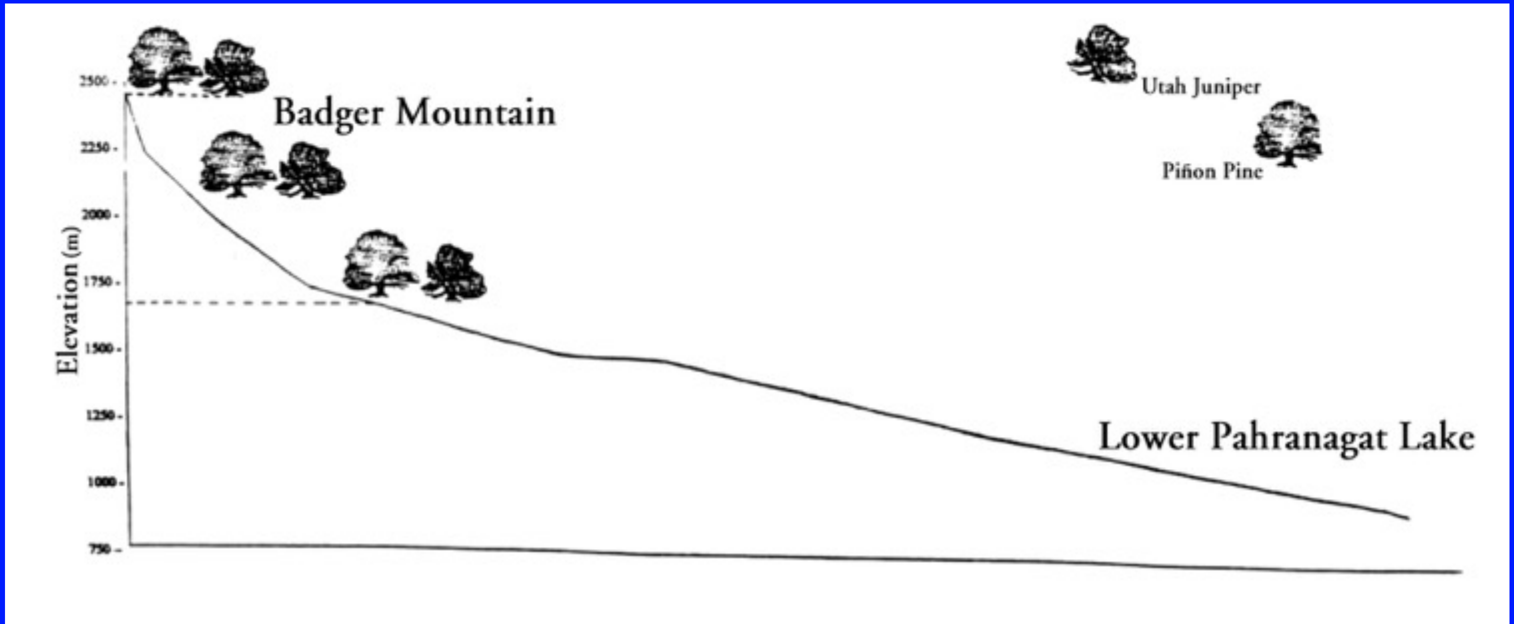


Middens are sampled with chisel & hammer

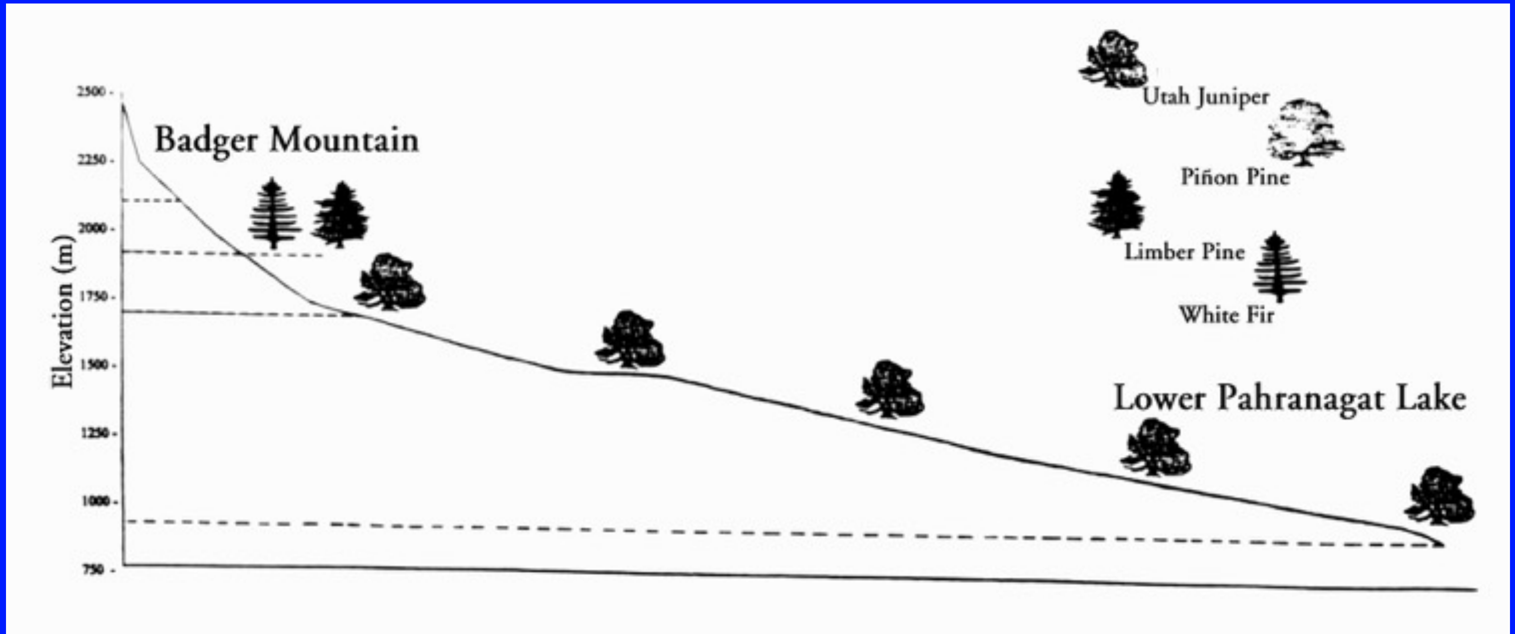
Middens survive in protected, often inaccessible areas

Sub-sampling Middens… What do the Woodrat Midden Data tell us about Plant Response to climate change?

Elevational Displacement of Woodland

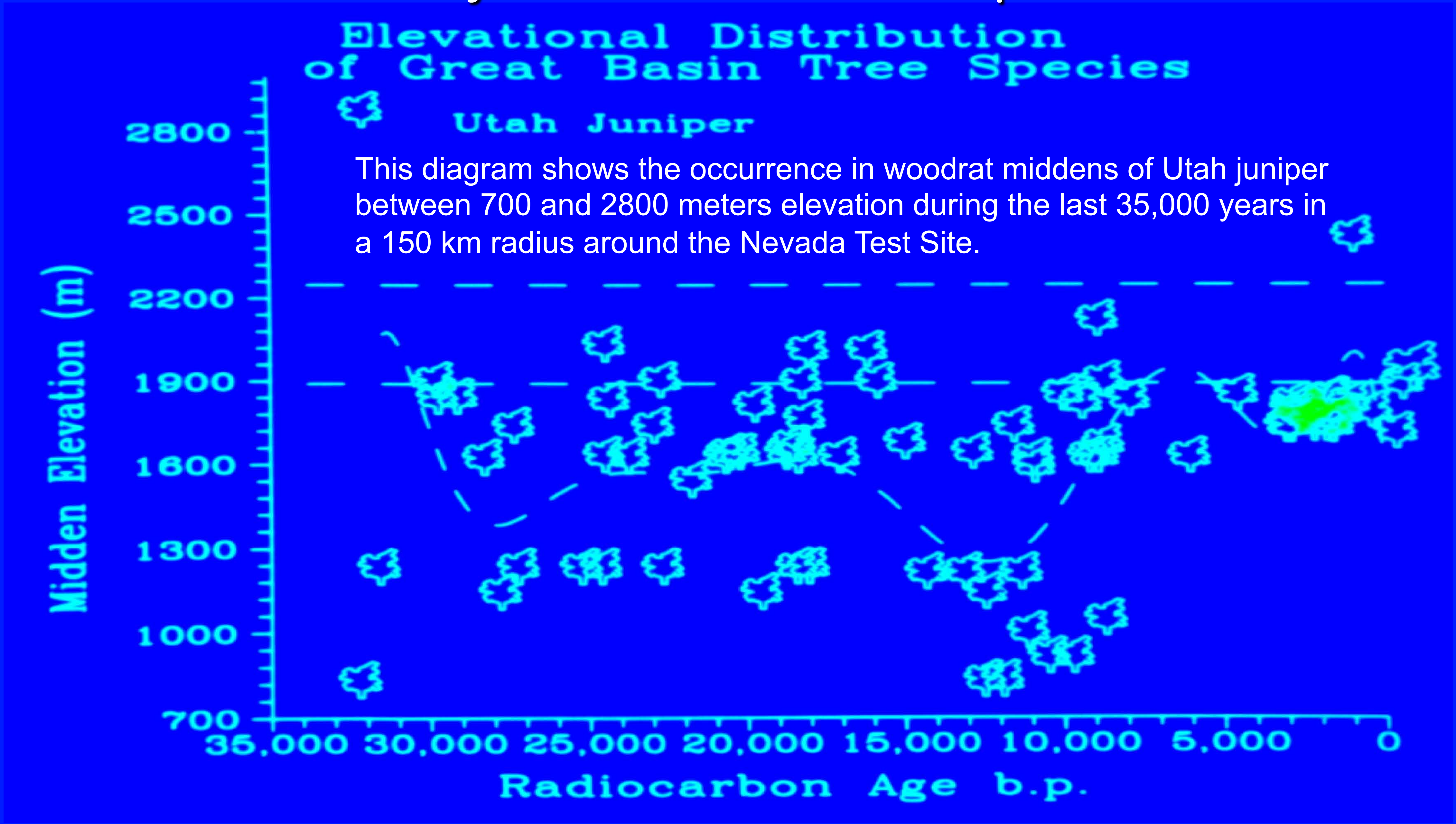


Modern vegetation distribution

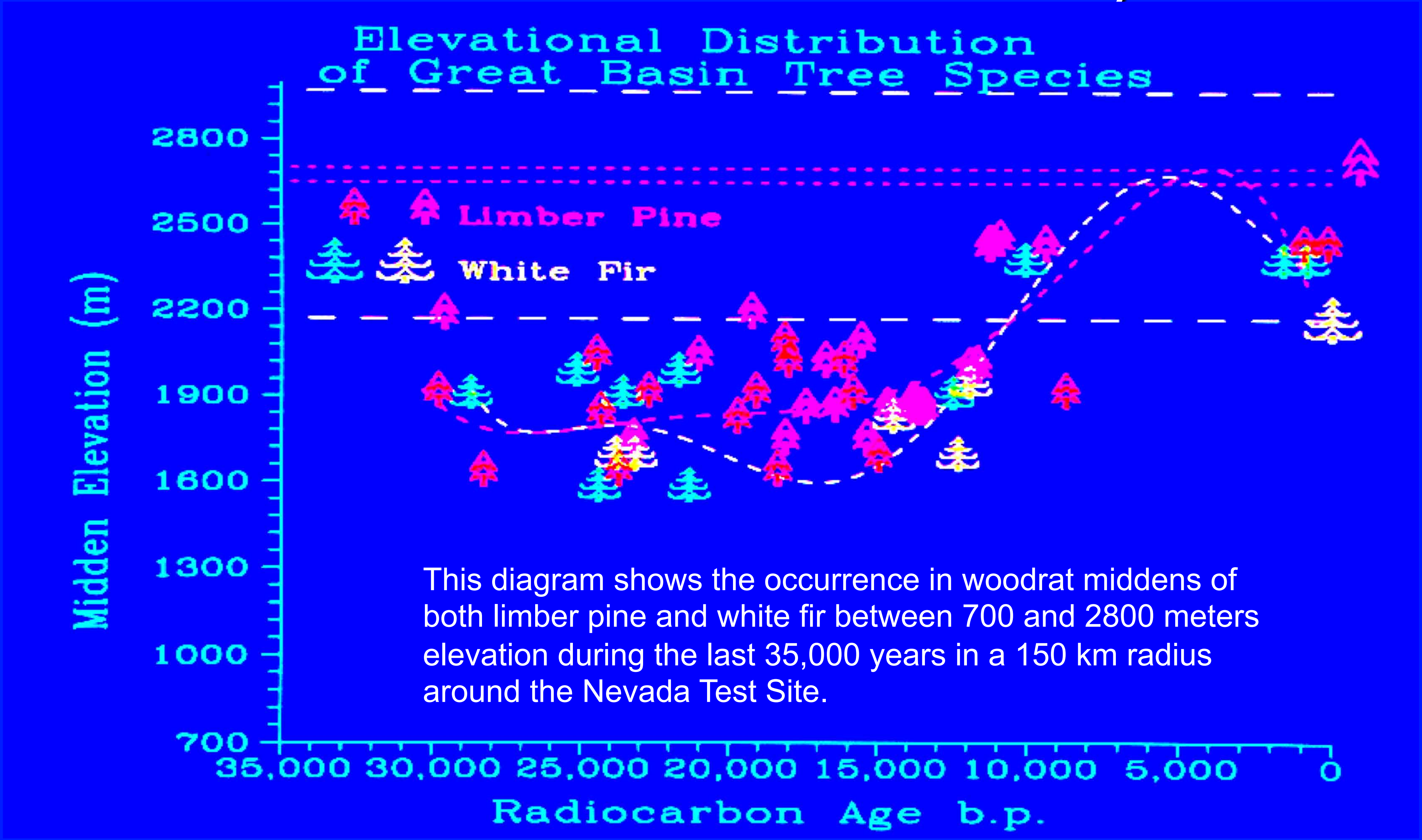


Pleistocene vegetation distribution

Northern Mojave Desert Utah Juniper Woodland



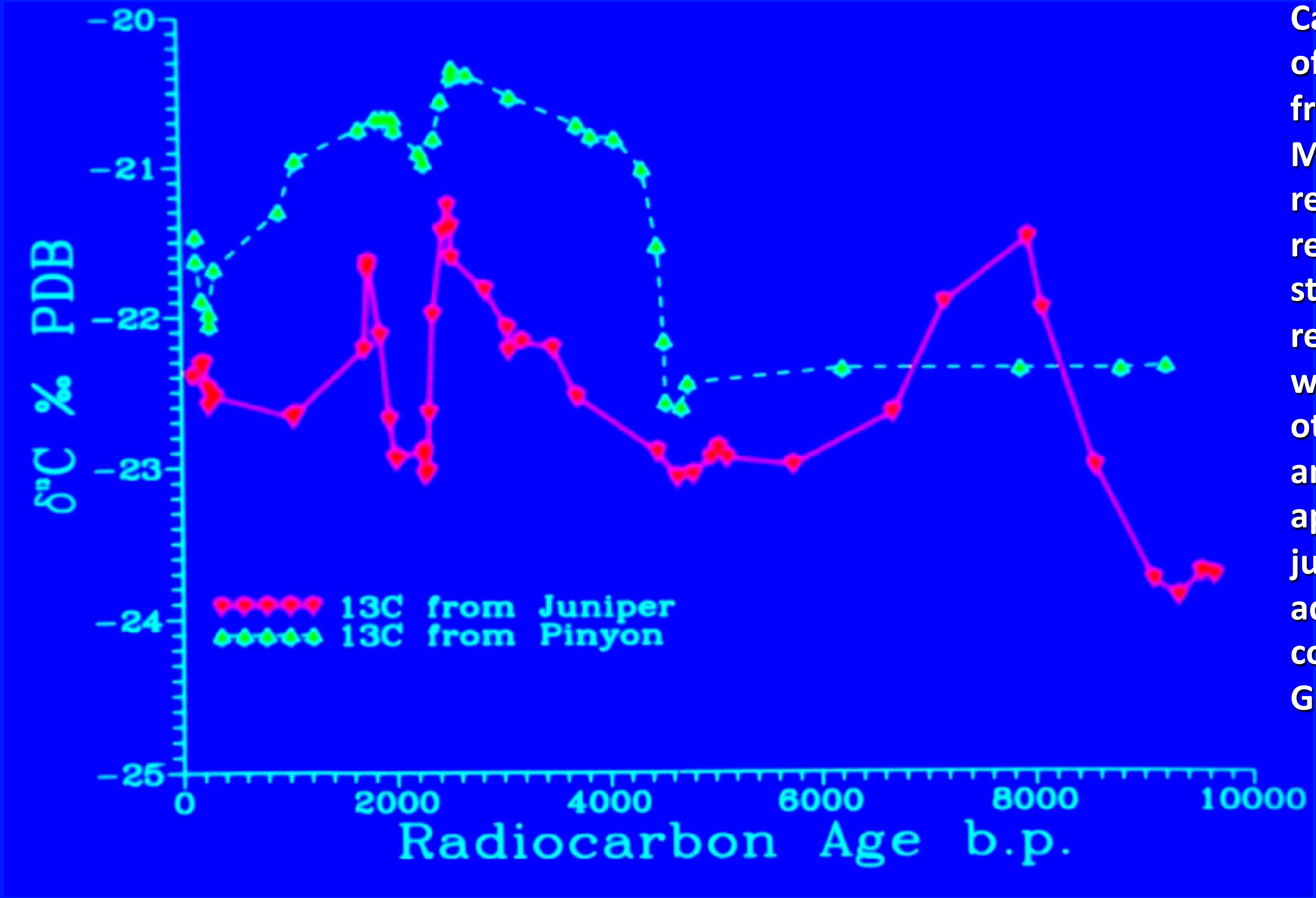
Limber Pine and White Fir History



This diagram shows the occurrence in woodrat middens of both limber pine and white fir between 700 and 2800 meters elevation during the last 35,000 years in a 150 km radius around the Nevada Test Site.

Stable Isotope Analysis of Midden Plant Materials Indicates the same for two tree species that occur together in some situations and not in others.

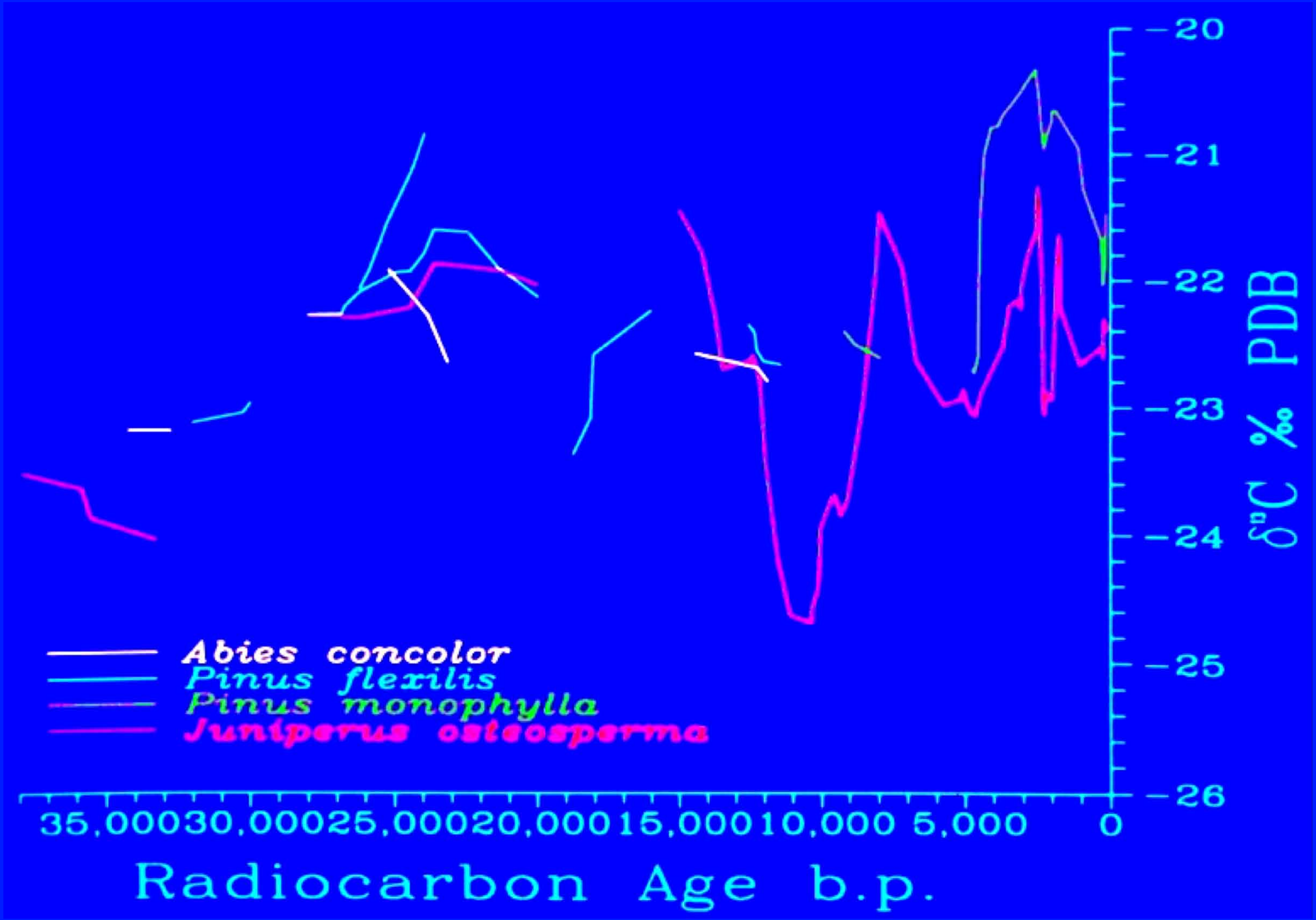
(Note: Increasing enrichment values [upward on the scale] indicate greater physiological stress on the plant)



Carbon 13 analyses of juniper and piñon from the northern Mojave Desert reveal information regarding climate stress and their relative hardiness with respect to each other. From these analyses it is apparent that Utah juniper is better adapted to conditions in the Great Basin.

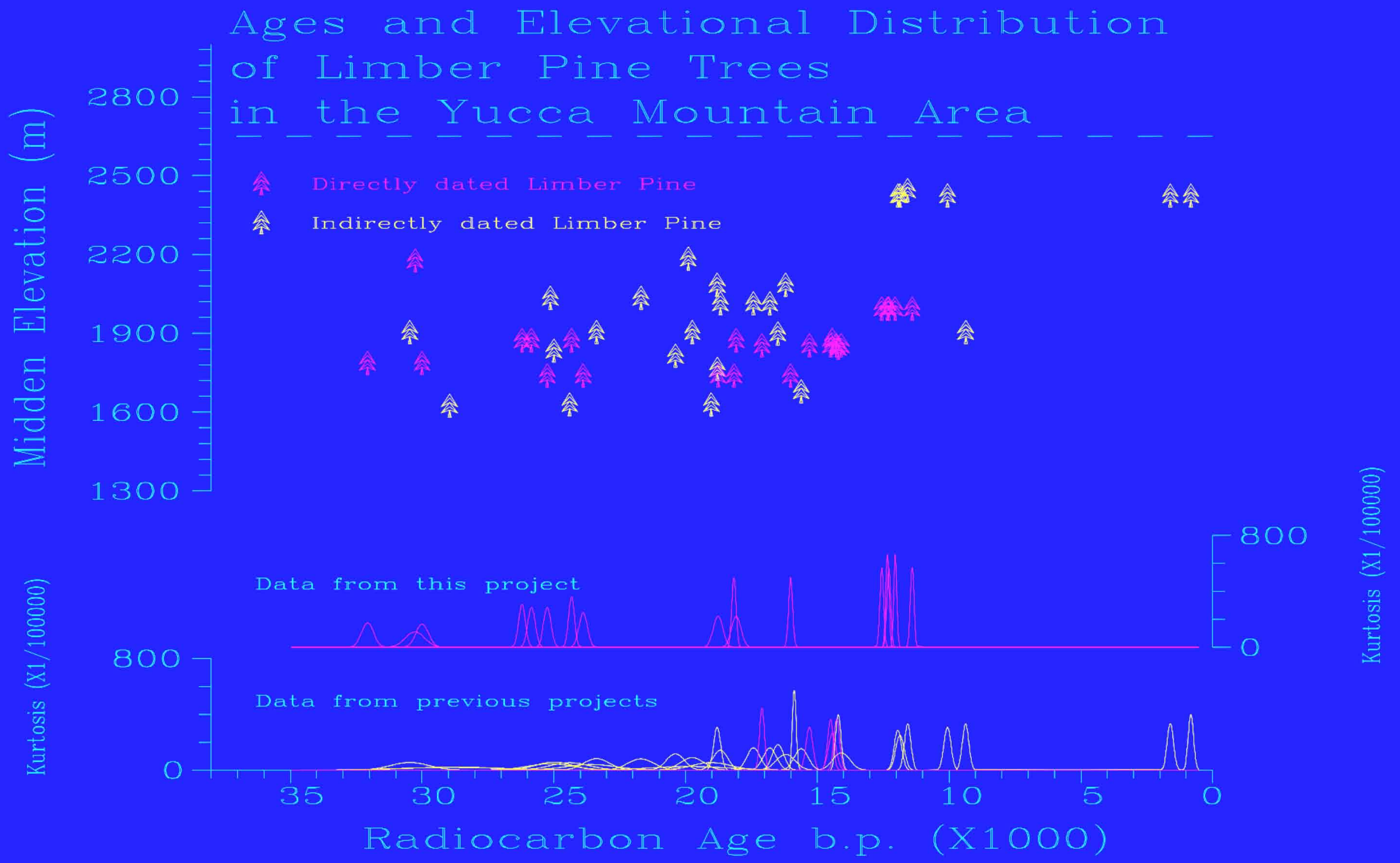
Stable isotope analysis of midden plant materials indicates the same for four other tree species that occur together in some situations and not in others.

(Note: Increasing enrichment values [upward on the scale] indicate greater physiological stress on the plant)

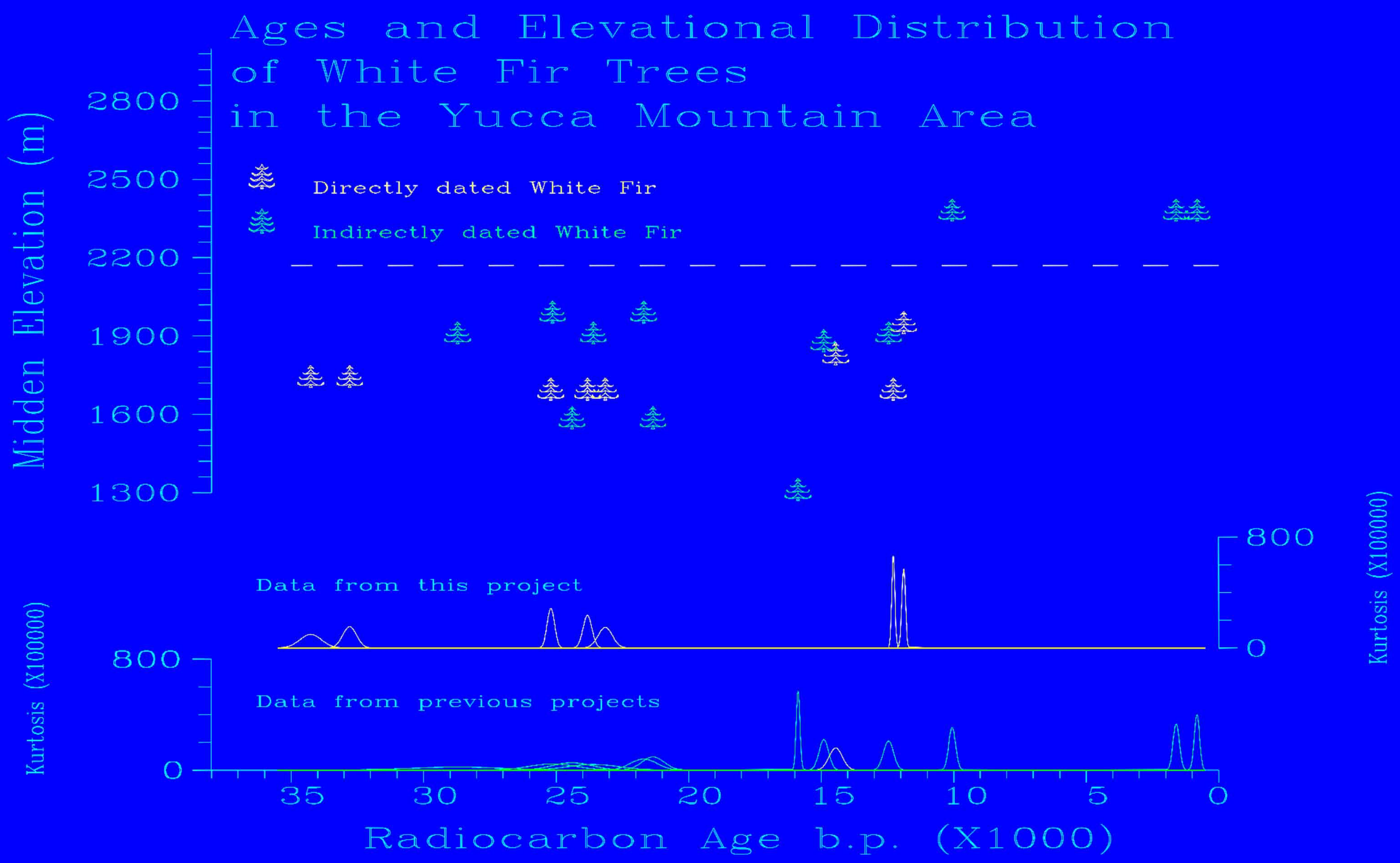


Carbon 13 analyses of Utah juniper, piñon pine, limber pine, and white fir from the northern Mojave Desert reveal information regarding climate stress and their relative hardiness with respect to each other. From these analyses it is apparent that Utah juniper is better adapted to conditions in the Intermountain West.

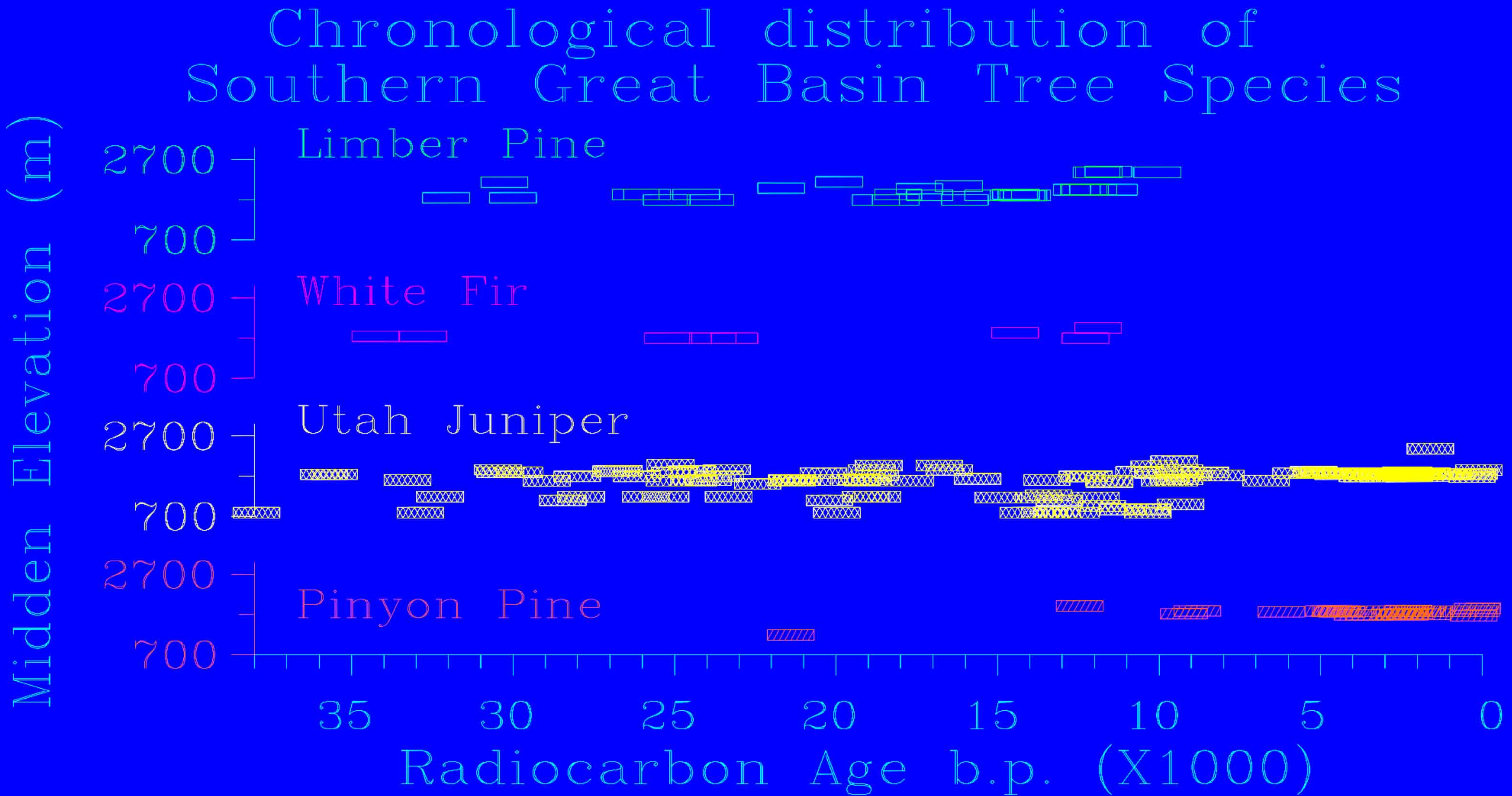
Limber Pine History



White Fir History



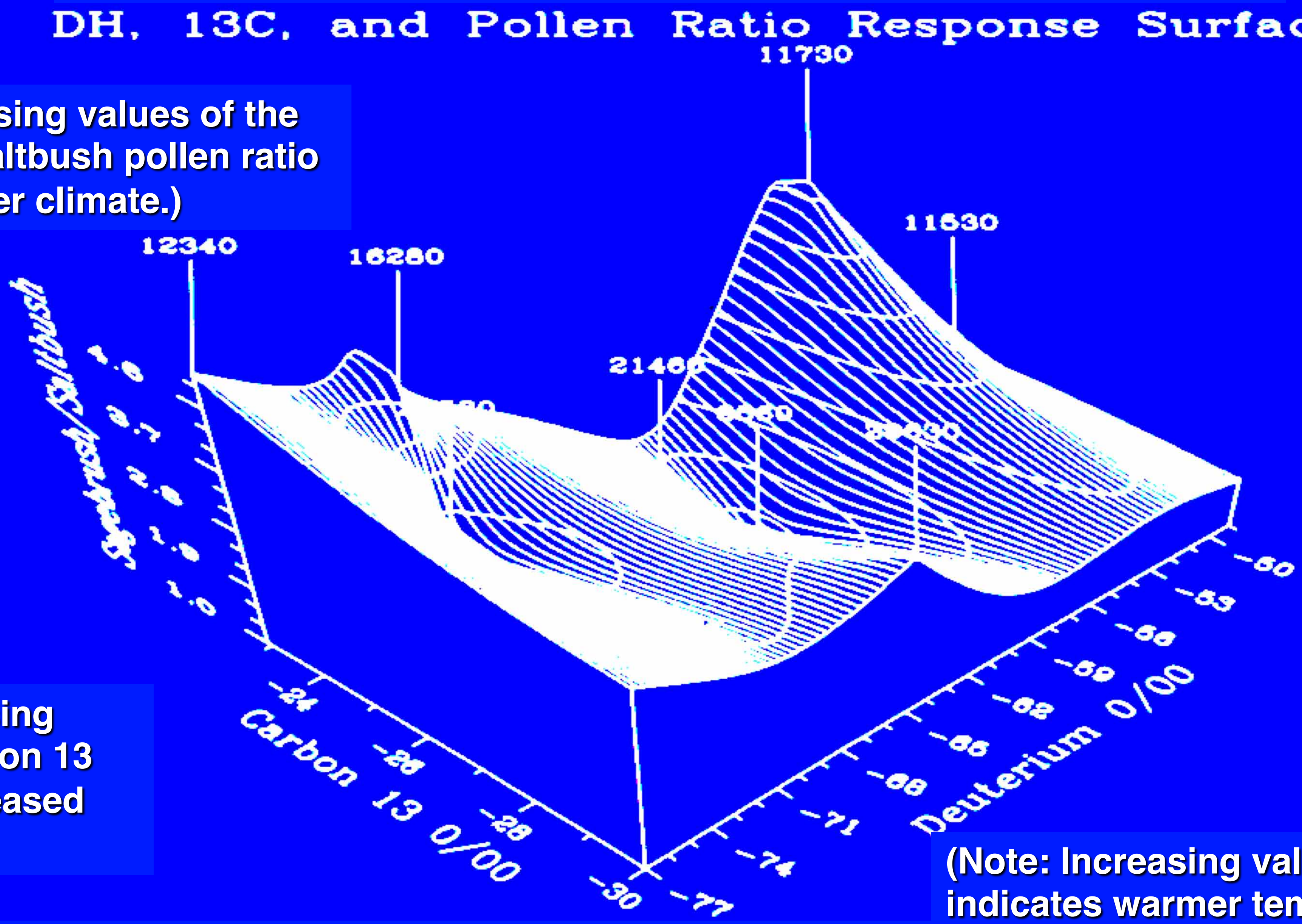
Summary of the Elevational Distribution of Major Conifers within a 200 km radius of Yucca Mountain based upon Woodrat Midden Evidence



(Note: The elevational and chronometric distribution of midden samples are almost continuous for the region indicating that the appearance of limber pine and white fir are not artifacts of sampling, but rather real events.

Multiple Variable Analysis

(Note: Increasing values of the sagebrush/saltbush pollen ratio indicate wetter climate.)

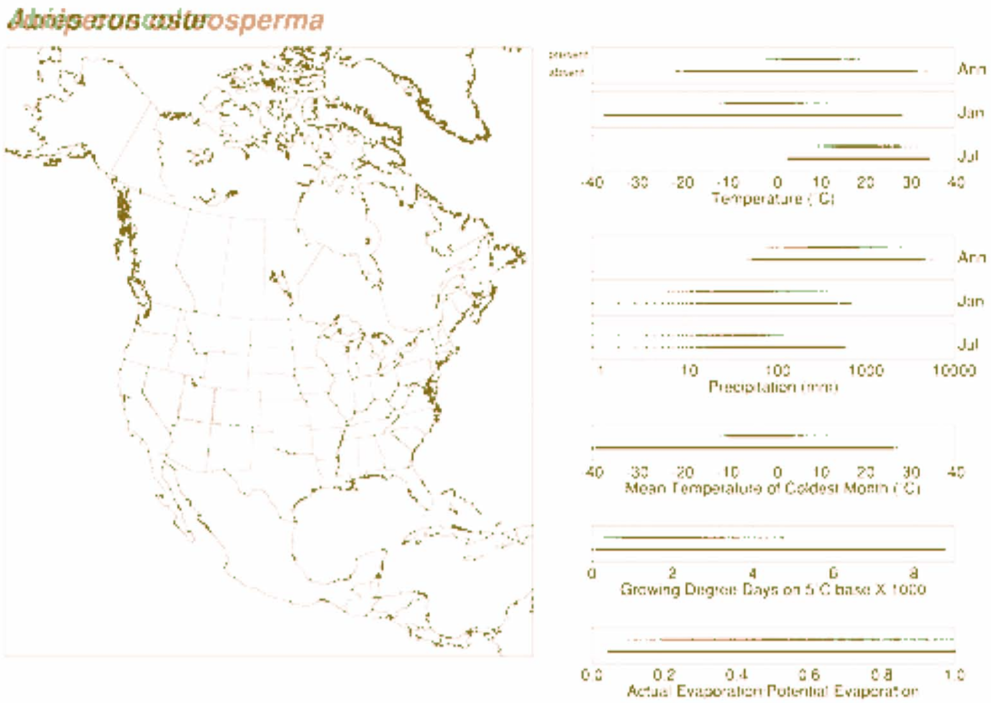


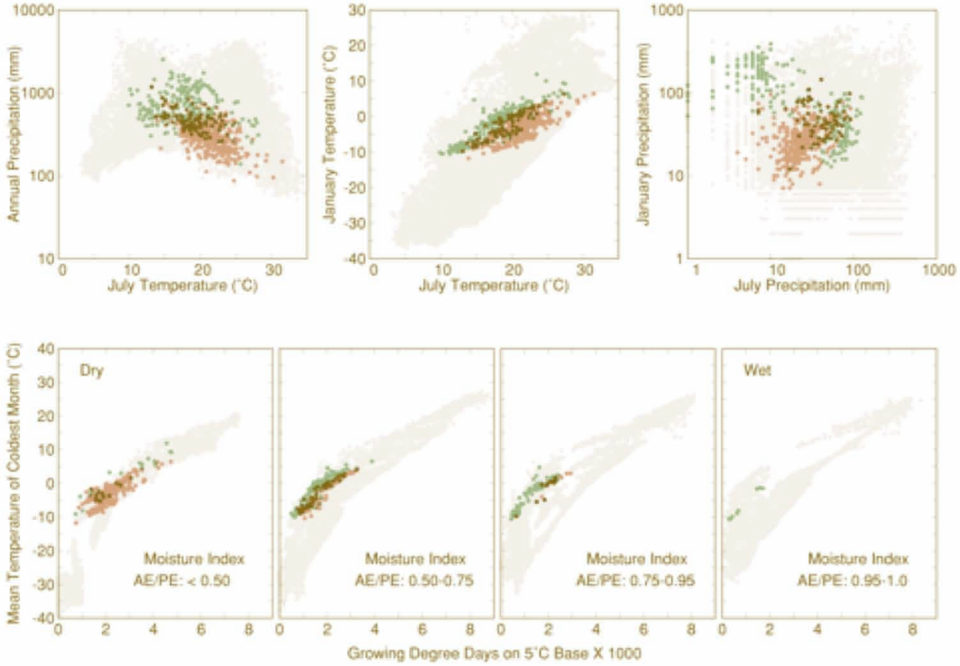
Moisture and cold stress (Carbon 13 values), temperature (Deuterium values), and plant response (Sagebrush to Saltbush ratio) can be linked in this response surface diagram.

(Note: Increasing values of Carbon 13 indicates increased plant stress.)

(Note: Increasing values of deuterium indicates warmer temperature.)

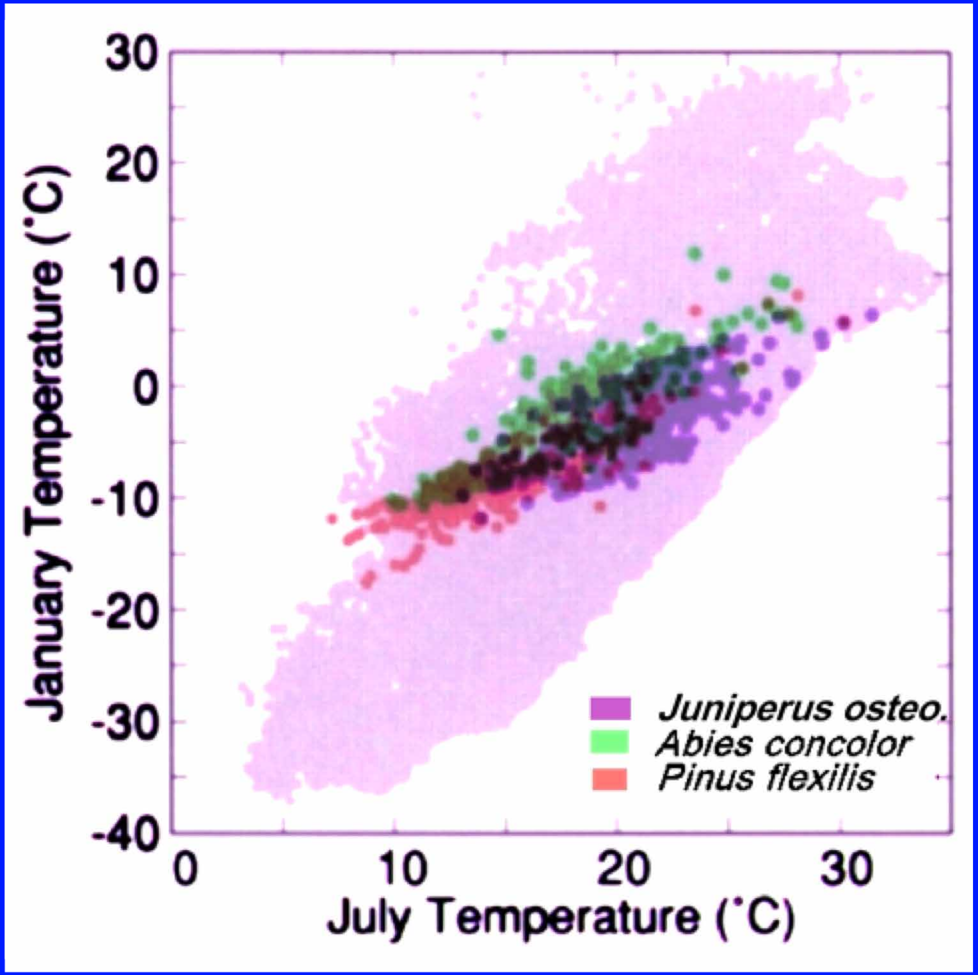
The modern comparison of two of these species, Limber Pine and Utah Juniper, which grew together during the Pleistocene, but do not today

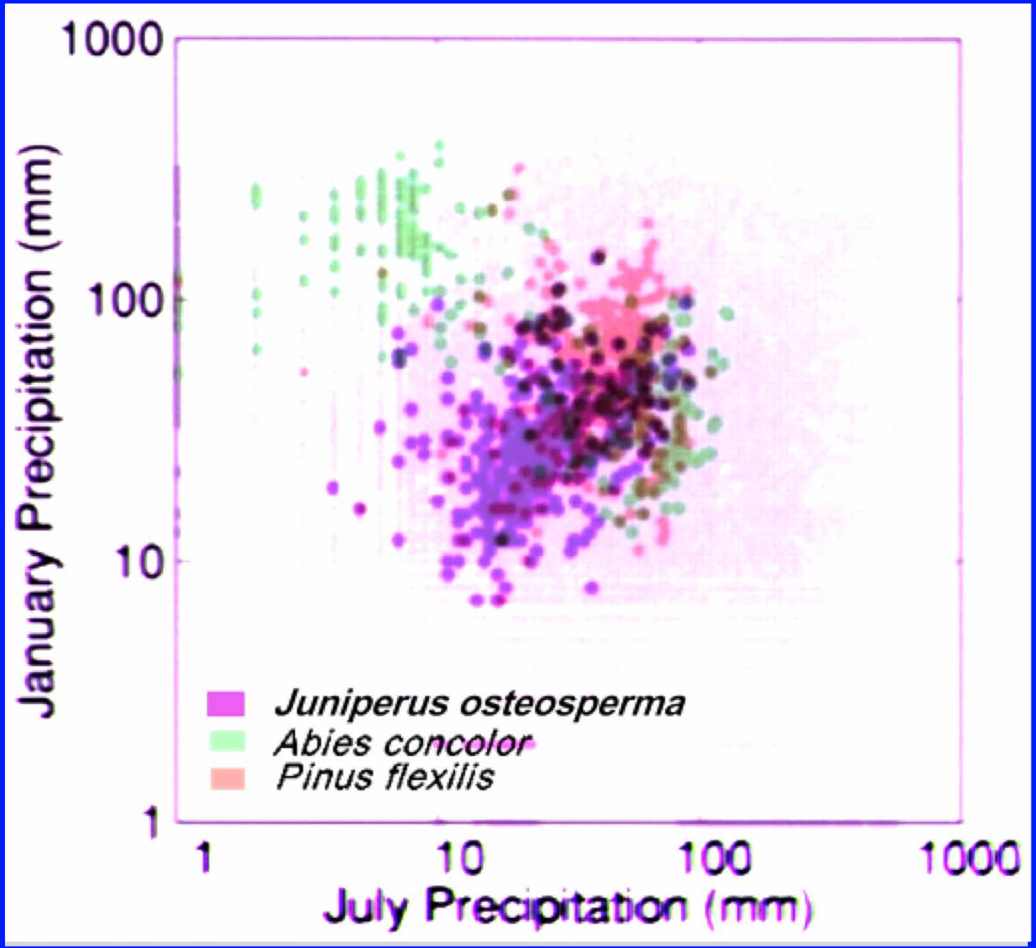




Each plant species has its own unique climate parameters, and will respond differently to changes in climate.

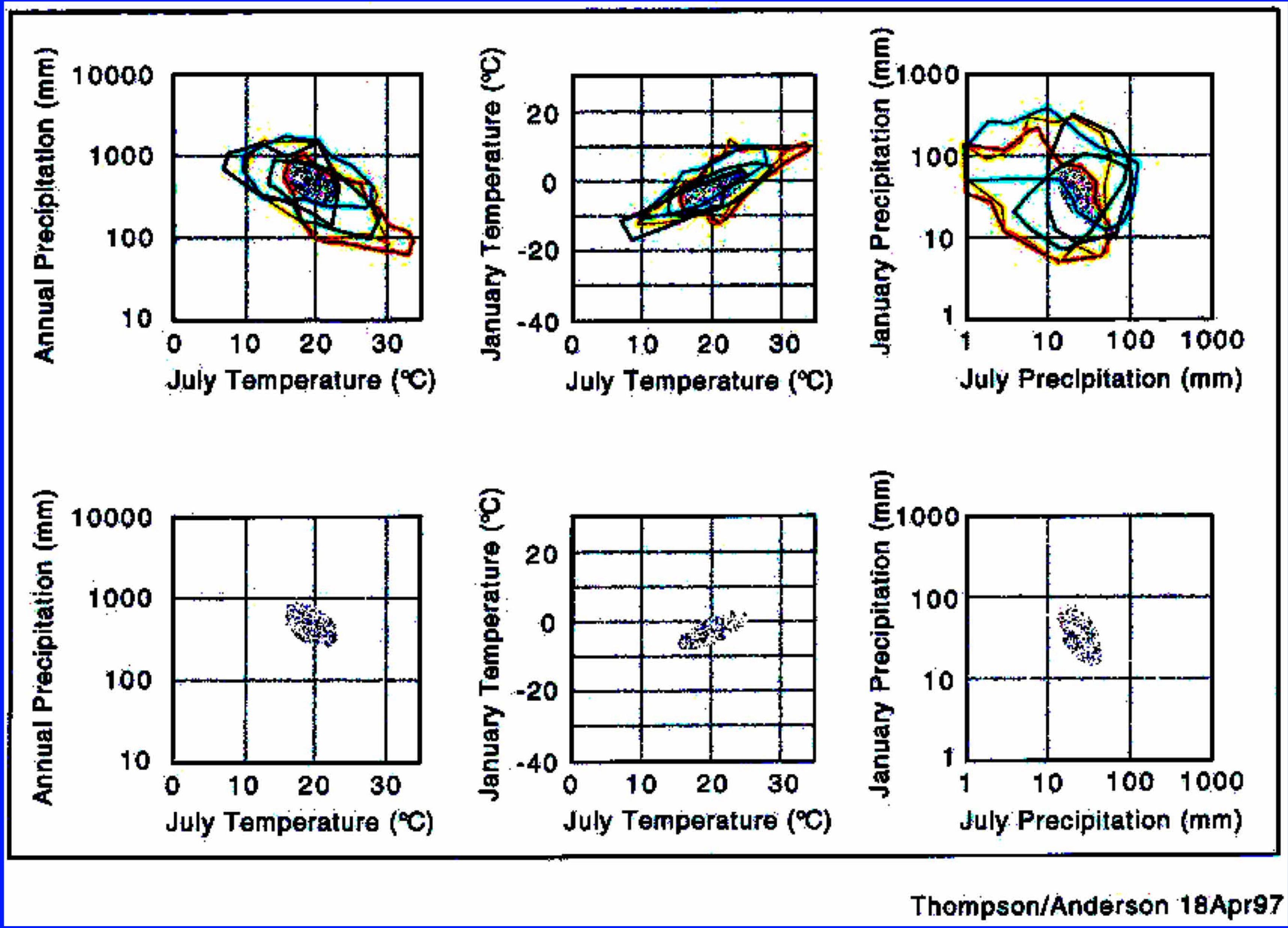
Climatic Parameter Comparison





Abies concolor and Pinus flexilis occur together when July and January temperature ranges are narrowly distributed toward the cooler climate distribution range of Abies. July precipitation is near the high range of both species, but January rainfall is highly variable. Of the two varieties of Abies concolor it is the Rocky Mountain variety that seems to have dominated the southern Great Basin during the late Pleistocene. Utah juniper is in most cases the omnipresent woodland species.

Indicator Plant Species' Overlap



Modern overlap in climatic terms of *Abies concolor* (white fir), *Pinus flexilis* (limber pine), *Juniperus osteosperma* (Utah juniper), *Artemisia tridentata* (big sagebrush), and *Atriplex confertifolia* (shadscale)

Assembling a list of the macro-fossils recovered from each radiocarbon dated woodrat midden stratum, we can reconstruct the plant community for that point in time. Overlapping the modern analogue climate parameters for each species, we derive a plot area where all species overlap. This comprises the actual climatic window for that period in the past.

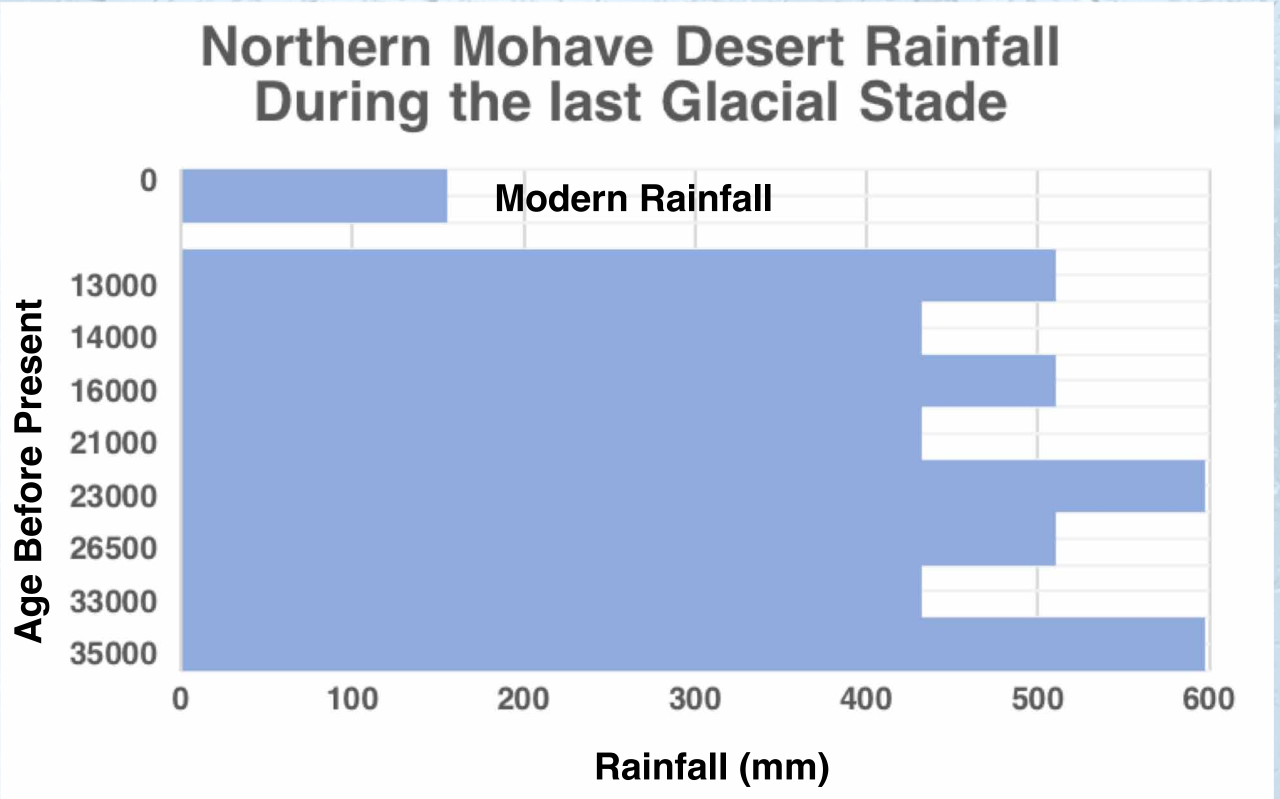
Abies concolor (white fir)
Pinus flexilis (limber pine)
Juniperus osteosperma (Utah juniper)
Artemisia tridentata (big sagebrush)
Atriplex confertifolia (shadscale)

Summary:

- Based upon occurrences of Limber Pine and/or White Fir and using the MAPs derived from the vegetation data summarized above we generated the following sequence of climate between 35 and 12 k. This applies only for elevations around 1,500 m. At elevations around 750 m estimates should be about 50 percent of those at 1,500 m. Above 2,000 m absence of data prevents estimation. Today the average is about 155 mm.

Climate designations of very wet, wet, and dry are relative.

- 13-12 ka wet period MAP - 460-560 mm
- 14-13 ka dry period MAP - 405-460 mm
- 16-14 ka wet period MAP - 460-560 mm
- 21-16 ka dry period MAP - 405-460 mm
- 23-21 ka very wet period MAP - 560-635 mm
- 26.5-23 ka wet period MAP - 460-560 mm
- 33-26.5 ka dry period MAP - 405-460 mm
- 35-33 ka very wet period MAP - 560-635 mm



How is the Environment is going to Respond?

- Previous studies indicate that we must look at the palaeological record and not just at the modern ecology of vegetation to see how it will respond to global warming.
- Vegetation responds as individual species not as a community.
- Factors such as migration rates, and the ability of plant species to respond to incredibly rapid rates of climate change must be taken into account.
- Some species will respond more quickly than others to global warming.
- Many species may immediately, become extinct because they cannot respond or simply because changes in seasonality or amount of rainfall may exterminate them.
- The past record provides some of that information, but in the final analysis we cannot predict the accidents of chance as well, that is routes of escape via valleys, mountain ranges, and animal seed dispersal.
- These are just some of the factors that might influence the survival of plant species and their role in carbon sequestration in the final analysis is a luck of the draw.

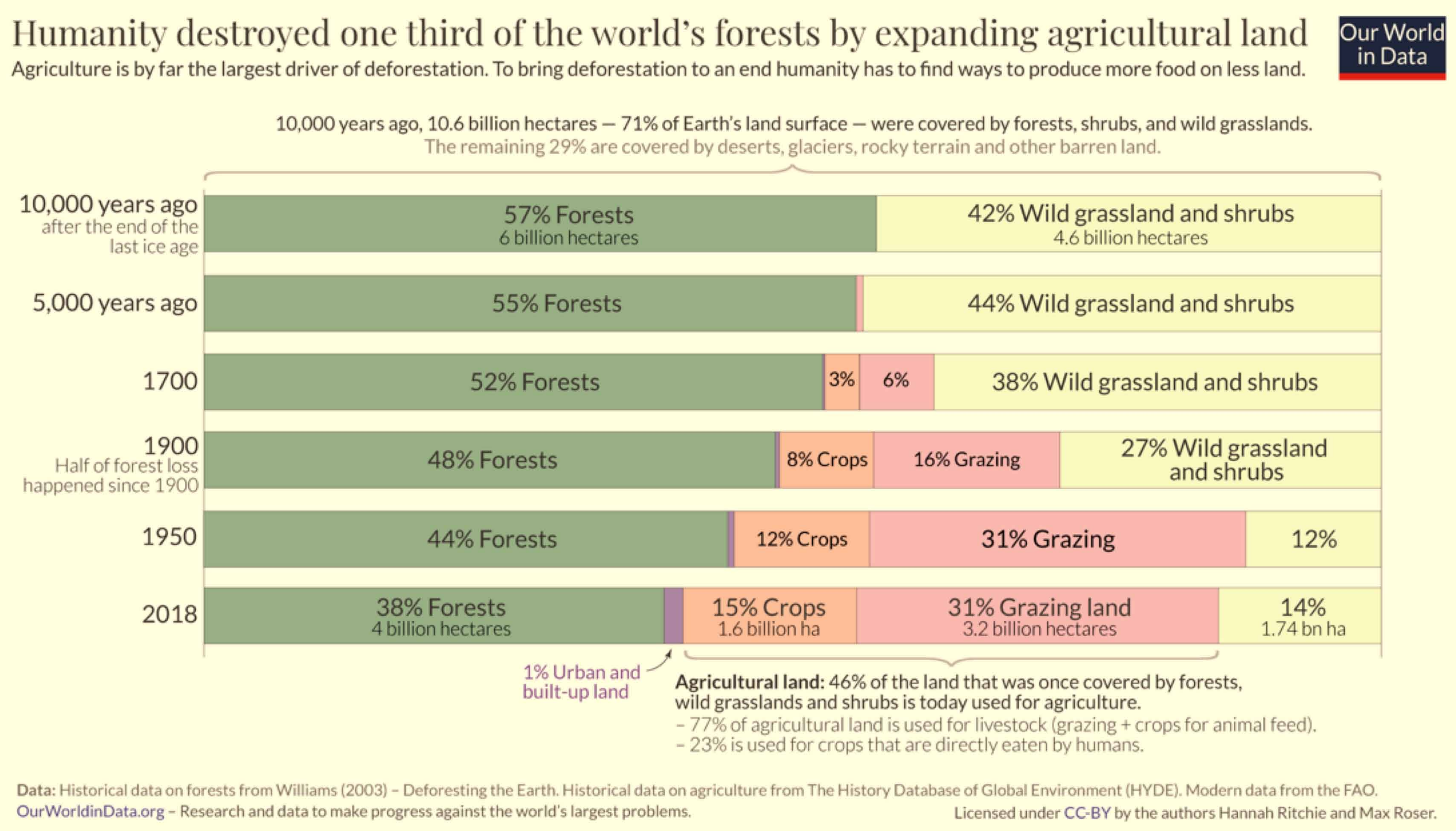
Atmospheric Carbon Removal

- Although “Green Energy” is being given the big push right now, on the flip-side of the coin, removing what is already there is being given short shrift.
  - The problem is that the atmospheric content of carbon is already great enough to cause irreversible damage to the earth’s environment.

Atmospheric Carbon Goal

- So we must not only reach zero emissions, but must achieve the goal of a 33% reduction in the current atmospheric carbon content of over 412.5 ppm to achieve the ~280 ppm that was the average prior to the 1850s.

Loss of the Earth's forests



“Land Carbon Sink”

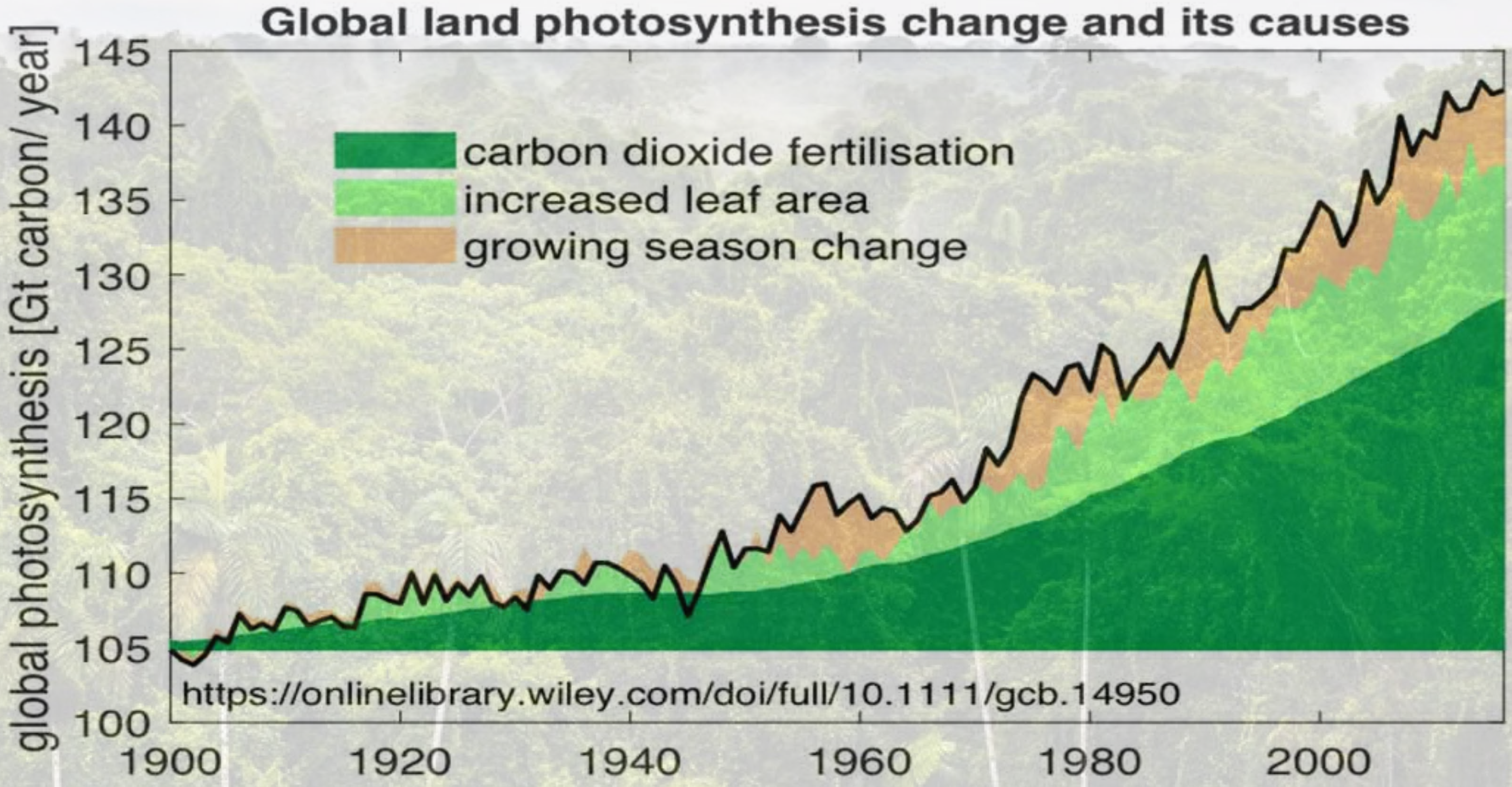
- Despite large losses of vegetation to land clearing, drought and wildfires, carbon dioxide is absorbed and stored in vegetation and soils at a growing rate.

- This is the “land carbon sink”. It describes how vegetation and soils around the world are absorbing more carbon dioxide from photosynthesis than they release. During the past 50 years the difference between uptake and release of carbon dioxide by plants has been increasing, absorbing at least a quarter of human emissions in an average year.

- It is getting larger because of a rapid increase in plant photosynthesis, and recent research shows rising carbon dioxide concentrations are the primary driver of this increase.

- So, although people are producing more carbon dioxide. This carbon dioxide is causing more plant growth, and a higher capacity to absorb carbon dioxide. This process is called the “carbon dioxide fertilisation effect” – a phenomenon whereby carbon emissions boost photosynthesis and lead to increased plant growth.

Forests become more efficient Atmospheric carbon sinks as CO_2 increases



“Carbon Dioxide Fertilization Effect”

- The “carbon dioxide fertilisation effect” demonstrates the ability of vegetation to absorb a proportion of human emissions, slowing the rate of climate change.

- It dramatically highlights the urgent need to protect and restore terrestrial ecosystems i.e., forests, savannas, chaparrals and grasslands.

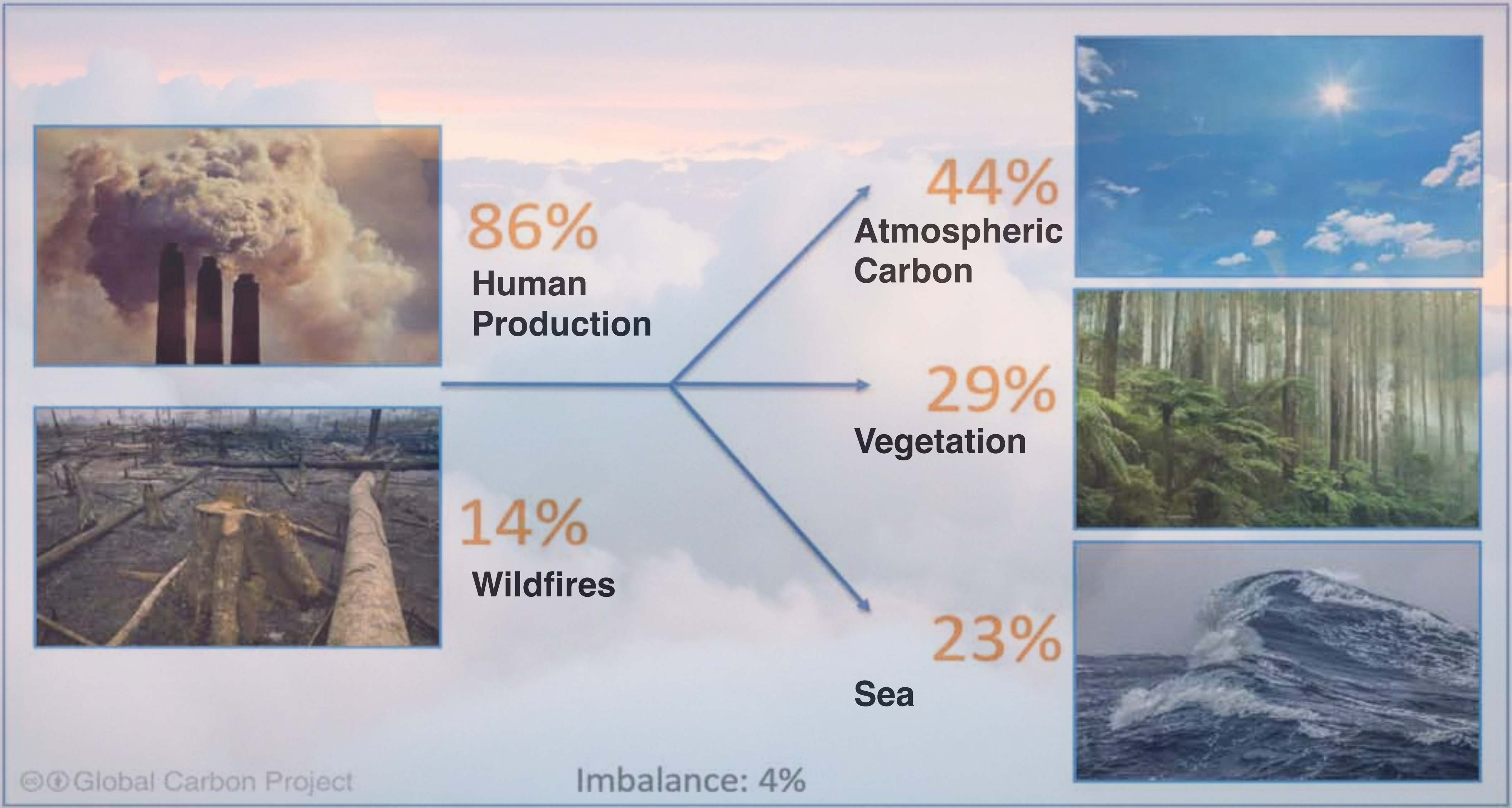
- Although more carbon dioxide in the atmosphere allows landscapes to absorb more carbon dioxide, almost half or **44% of human emissions still remains in the atmosphere.**

- Carbon dioxide fertilisation is responsible for at least 80% of the increase in photosynthesis.

- About 20% of the increase in photosynthesis is due to longer growing season in the rapidly warming boreal forests and Arctic.

Where Carbon Comes from vs Where it Goes

Fate of anthropogenic CO_2 emissions (2009–2018)



Increased Water Efficiency

- More carbon dioxide also means water savings for plants.
  - More carbon dioxide available causes the pores (Stomata) on the surface of plant leaves regulating evaporation to close slightly.
  - They still absorb the same amount or more of carbon dioxide, but reduce water loss.
  - The net water savings can benefit vegetation in semi-arid landscapes.

Old Vs Young Forests

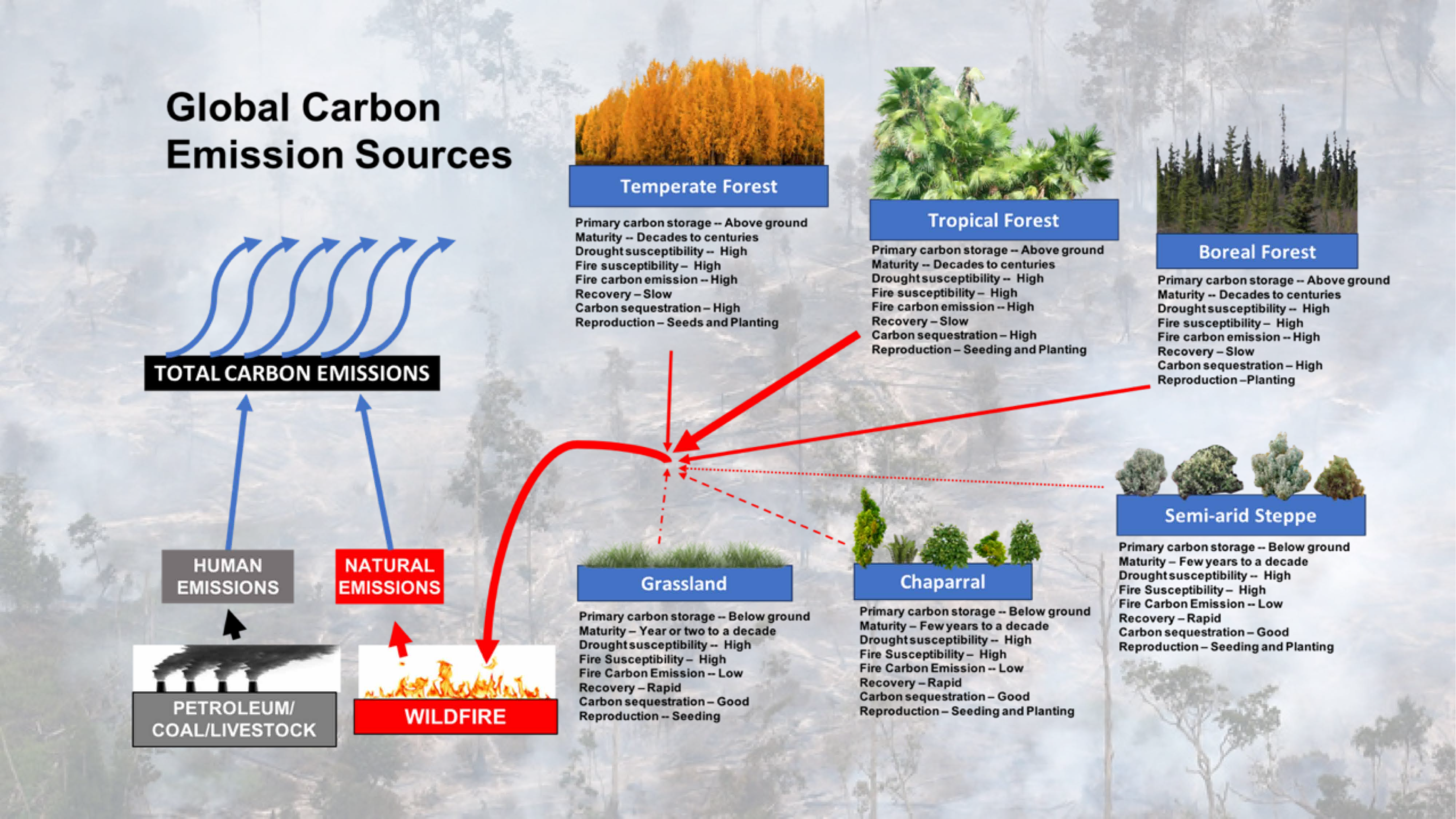
- In a mature forest, death of old trees balances the amount of new wood grown each year. Old trees lose wood to the soil and then to the atmosphere through decomposition.

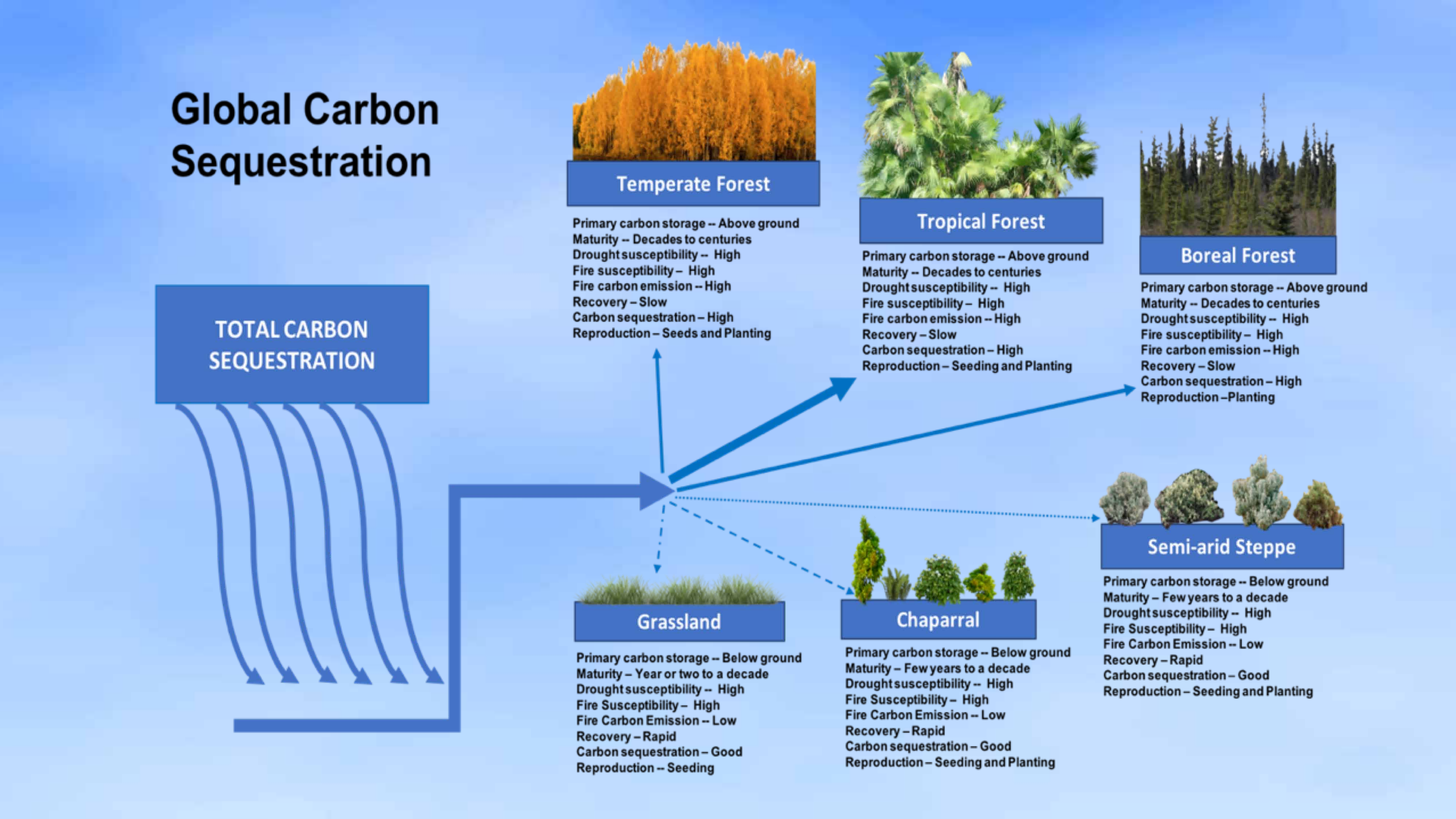
- A young forest is accumulating wood, and acts as a major sink for carbon until tree mortality and decomposition begins.

- This age effect is superimposed on the carbon dioxide fertilisation effect, making young forests potentially very strong sinks.

- Globally, young forests are responsible for ~ 60% of the total carbon dioxide removal by forests, suggesting that their expansion by reforestation is vital.

- This global imperative applies to the re-growth of sustainable savannahs, chaparrals and grasslands too.


Global Carbon Emission Sources
TOTAL CARBON EMISSIONS
HUMAN EMISSIONS
NATURAL EMISSIONS
PETROLEUM/ COAL/LIVESTOCK
WILDFIRE
Temperate Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction – Seeds and Planting
Tropical Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction – Seeding and Planting
Boreal Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction –Planting
Grassland
Primary carbon storage -- Below ground
Maturity – Year or two to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction -- Seeding
Chaparral
Primary carbon storage -- Below ground
Maturity – Few years to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction – Seeding and Planting
Semi-arid Steppe
Primary carbon storage -- Below ground
Maturity – Few years to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction – Seeding and Planting


Global Carbon Sequestration
TOTAL CARBON SEQUESTRATION
Temperate Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction – Seeds and Planting
Tropical Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction – Seeding and Planting
Boreal Forest
Primary carbon storage -- Above ground
Maturity -- Decades to centuries
Drought susceptibility -- High
Fire susceptibility – High
Fire carbon emission -- High
Recovery – Slow
Carbon sequestration – High
Reproduction –Planting
Grassland
Primary carbon storage -- Below ground
Maturity – Year or two to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction -- Seeding
Chaparral
Primary carbon storage -- Below ground
Maturity – Few years to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction – Seeding and Planting
Semi-arid Steppe
Primary carbon storage -- Below ground
Maturity – Few years to a decade
Drought susceptibility -- High
Fire Susceptibility – High
Fire Carbon Emission -- Low
Recovery – Rapid
Carbon sequestration – Good
Reproduction – Seeding and Planting

The Potential Role of Forests in Carbon Sequestration

- Recent research has shown that regenerated forests could remove up to two thirds of the atmospheric carbon required to reduce global temperatures.

- As a result global governments are assuming that they can rely upon the earth's forests to do this. However, this is becoming an empty hope.

- Increasing frequency and magnitudes of heat waves and drought has resulted in increasingly more common and severe wildfires.

- This is actually turning many. forests into carbon emitters rather than carbon sequesters, and into an ever growing source of atmospheric carbon.

- In just the last decade many of the most important forests have now switched from being atmospheric carbon sinks into major sources of atmospheric carbon when they are burned by wildfire.

  - (This fire just north of my home in Reno, Nevada, forced the evacuation of the town of Doyle, and burned over a month.)

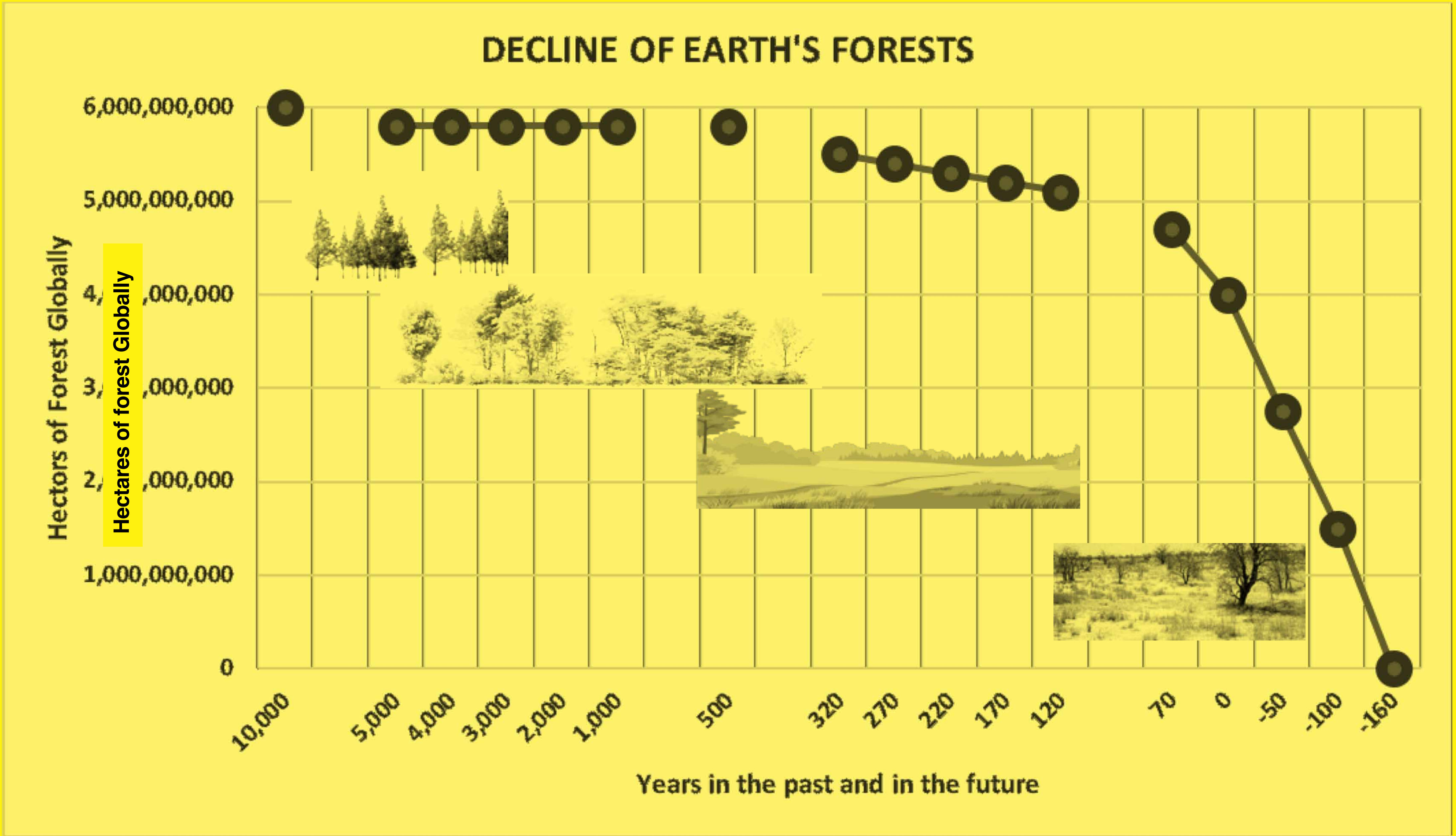
The Sad Fate of Our Forests

- Unfortunately, even the forests we plant today may not survive the effects of ever increasing drought severity and extreme and widespread wildfire caused by increased global temperature and reduced annual precipitation.

- A simple calculation of the rate of global forest loss based upon past and current rates, indicates that our global forests will not last beyond AD 2180, 160 years from now.

- However, this maybe an optimistic view. Rates of forest loss are increasing every year, and perhaps a more realistic view of forest survival should be only 80 to 100 years from now**!**

EARTH'S FORESTS AS CARBON SINKS



Where Should the Emphasis be for Future Sustainable Ecosystems?

- Emphasis on the regeneration of shrub and grass land habitats, and even the pollarding of established broad-leafed forests would provide a more rapid means of atmospheric carbon removal.

- In particular, the regreening of agricultural lands around the Mediterranean with shrub communities, especially with shrubs such as *Pistacia lentiscus* (Cyrus sumac)

    - Which could also serve to rejuvenate small-scale local green businesses. For example: Pistacia has important food uses ranging from Turkish delight to chewing gum, to flavorings in dishes, and important medicinal (anti-bacterial and anti-fungal) applications for digestive problems and skin disorders, and even as a furniture varnish!

Grasslands and Chaparral are more Resilient Carbon Sinks than Forests Today

- **Modelled simulations show that grasslands can store more carbon than forests, because they are impacted less by droughts and wildfires.**
- **Whereas forests sequester carbon primarily in woody biomass and leaves, grasslands sequester most of their carbon underground.**
  - **Forest wildfires release the carbon that had been stored above ground in stems, branches and leaves into the atmosphere.**
  - **Grasslands fix the carbon underground in their roots and in the soil as compost, where wildfires have minimal effect. This leaves the carbon they sequester behind so it does not contribute even more to atmospheric carbon emissions.**

Sustainable Carbon Sink Creation

- Establishment of sustainable ecosystems that can be highly efficient carbon sinks as well, must be a top priority. Without it the atmospheric carbon problem will not be solved.

Conclusions:

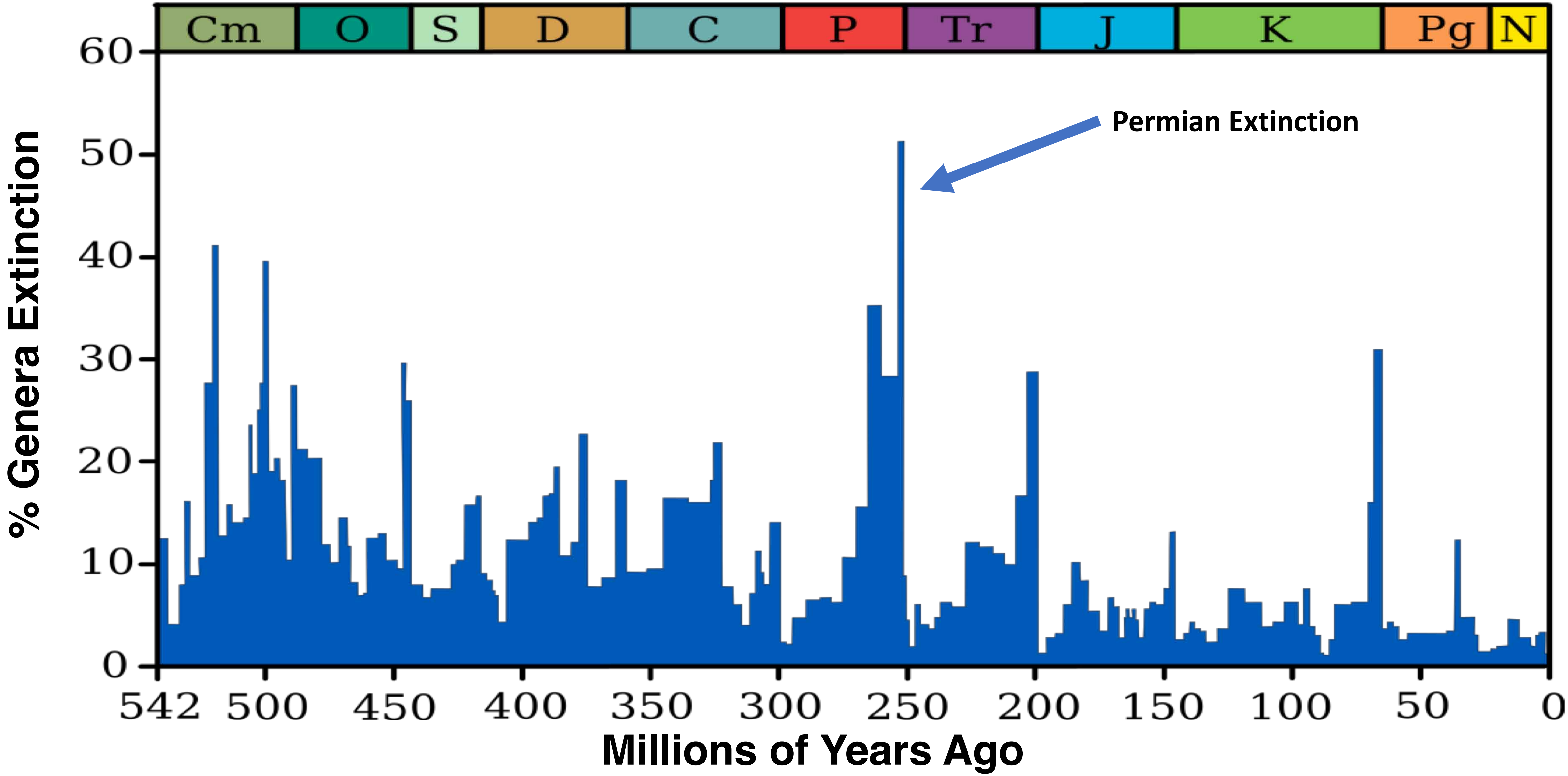
- It is clear that global warming is proceeding at an unprecedented rate, 20 times faster than at anytime in the past, except for the Permian-Triassic extinction event 251.9 million years ago when the Earth’s most severe extinction event occurred.

- At that time 57% of all biological families, 83% of genera, 81% of marine species and 70% of terrestrial species became extinct, and the largest known mass extinction of insects also occurred.

  - The cause was rapid global temperature increase due large amounts of carbon dioxide emitted by the eruption of the Siberian Traps and in the marine realm widespread oceanic anoxia and acidification due to large amounts of carbon dioxide released by the eruption of the Siberian Traps. And possibly due to the emission of additional large volumes of carbon dioxide generated by the thermal decomposition of hydrocarbon deposits, including oil and coal, by the Siberian Traps and emissions of methane by methanogenic microorganisms.

- The establishment of sustainable ecosystems is just as critical as is the switch to “green energy”, but we need to take into account the growing risk to forests of extreme drought and wildfire, and consider the greater potential losses of carbon to the atmosphere that forests would have in comparison to chaparrals, savannahs, and grasslands during increasingly more common wildfire events.

Extinction events: It could happen now!



Thank You, Grazie mille