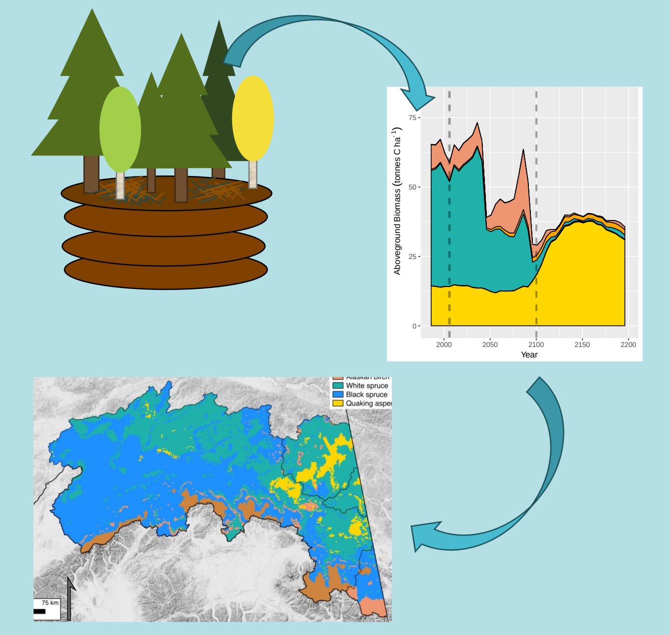
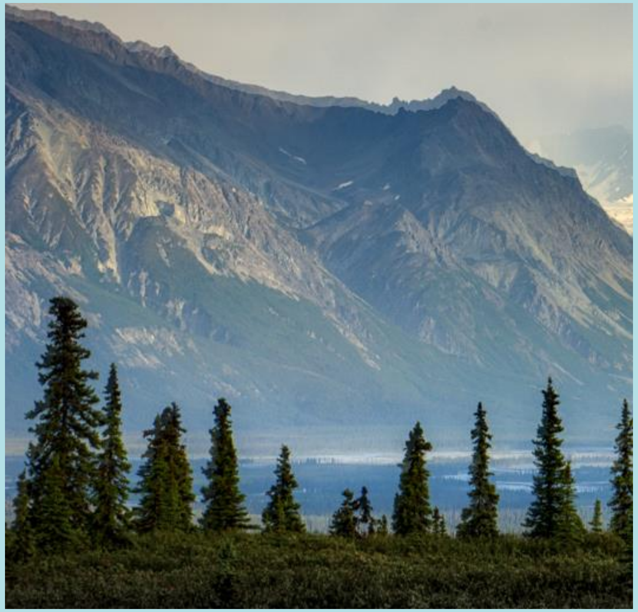
High-resolution forest modeling in the cloud

Leveraging the ASC to simulate individual tree growth across interior Alaska



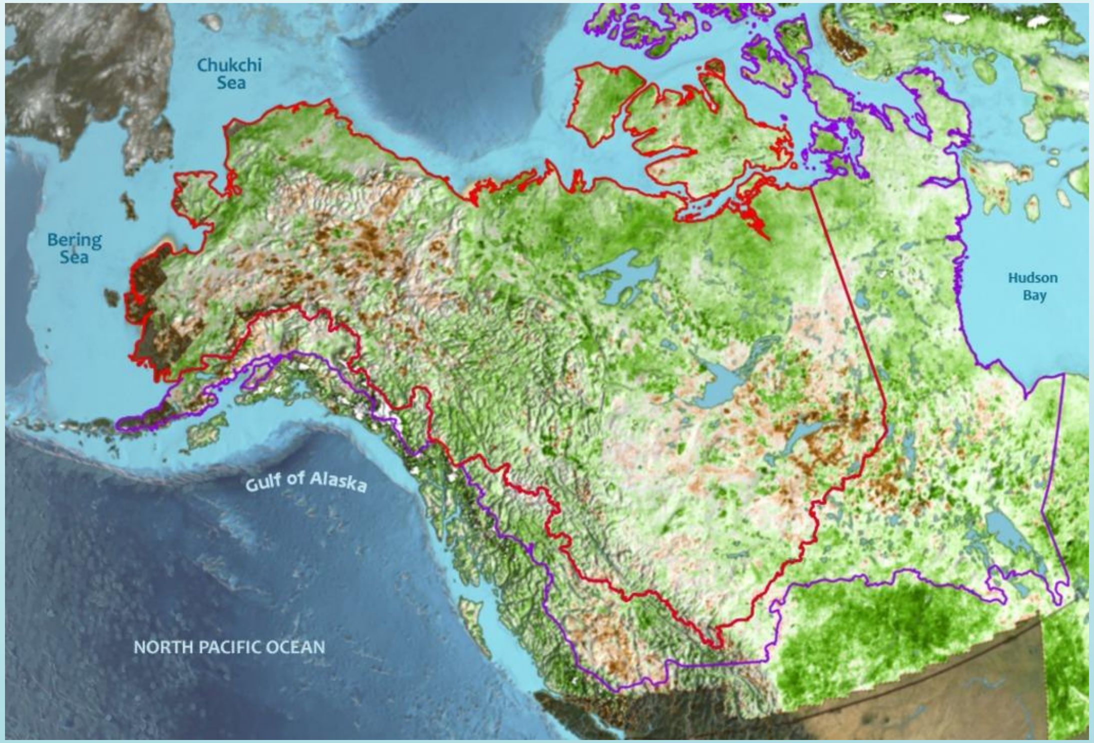


Adrianna Foster, NASA Postdoctoral Fellow

ABoVE Science Cloud Webinar

Friday, April 20, 2018

Uncertainty in future vegetation trajectories in Alaska



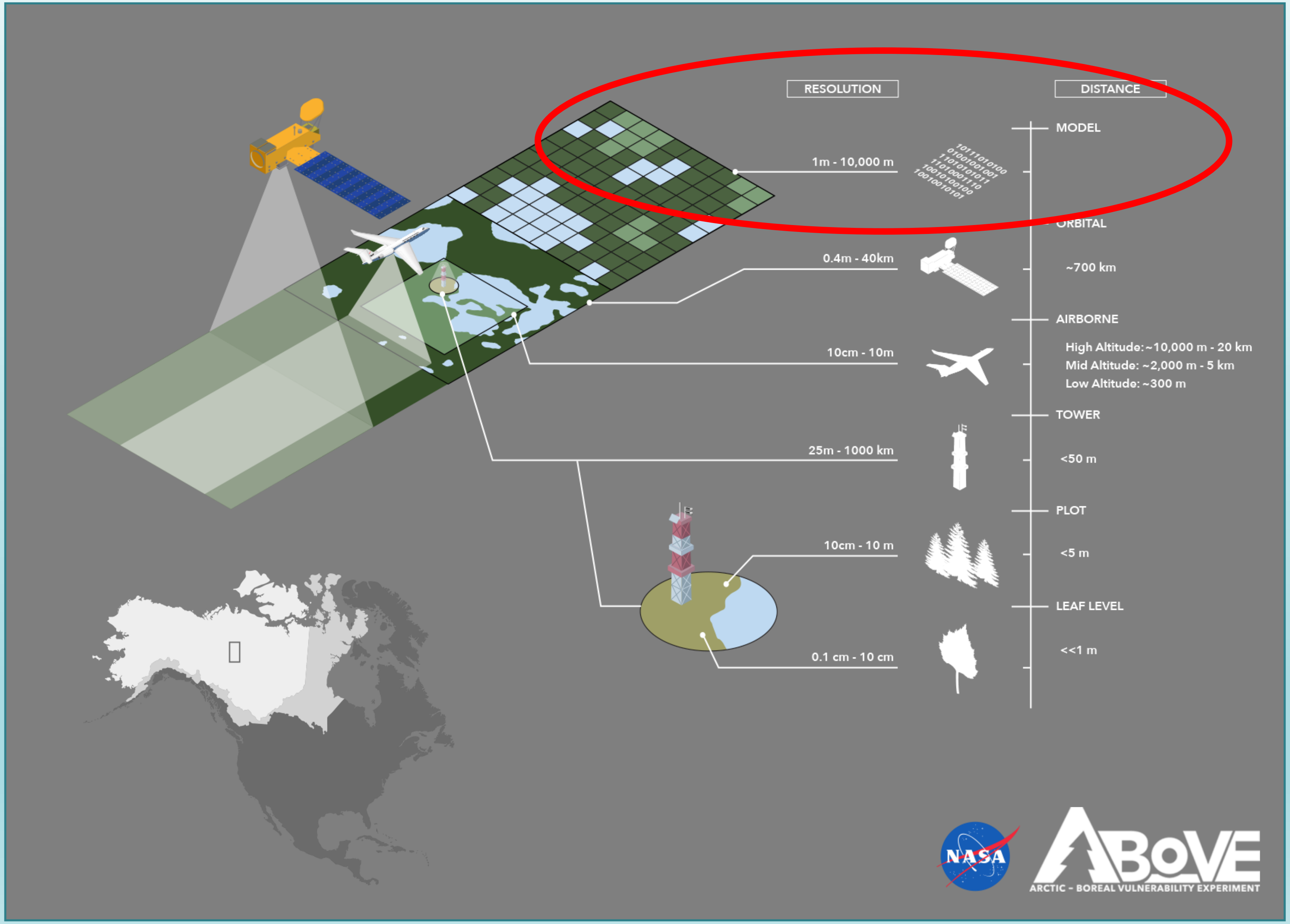
Greening vs. browning?

Increasing fires frequency and severity?

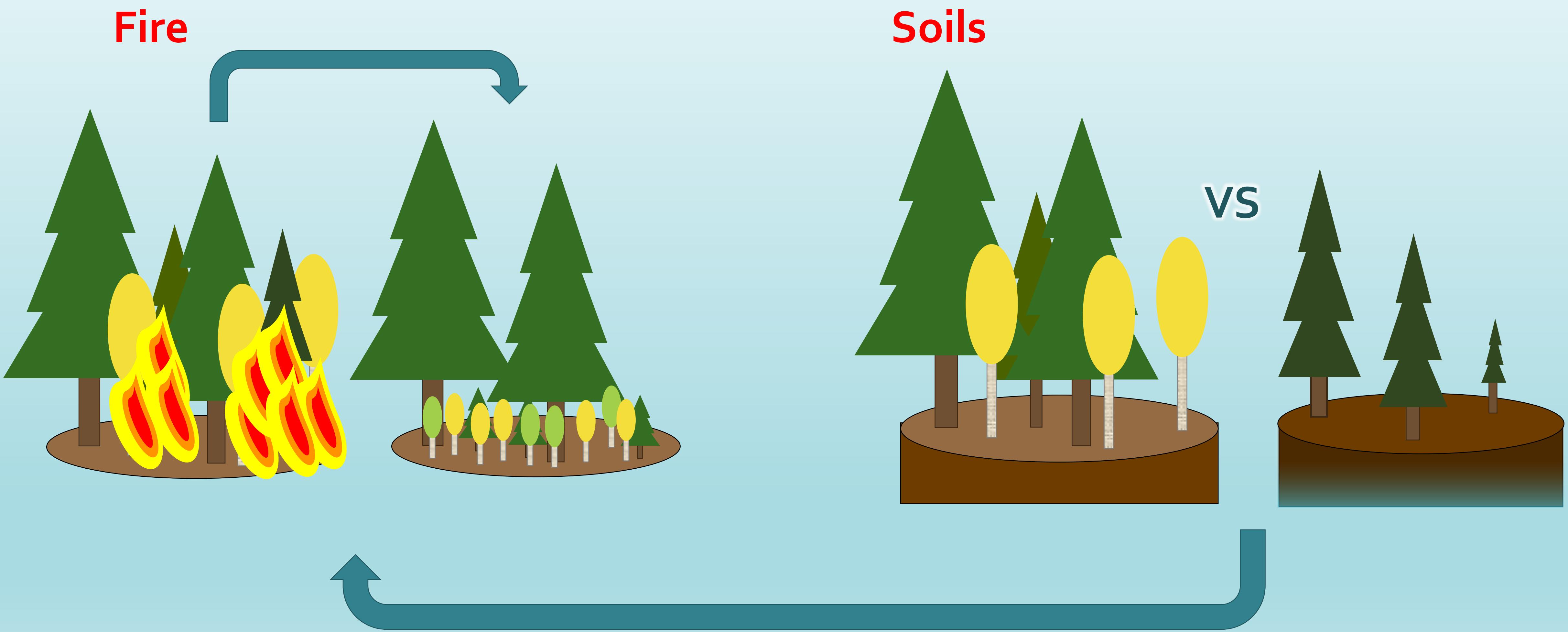
Changing permafrost?

Insects?

Uncertainty in future vegetation trajectories in Alaska

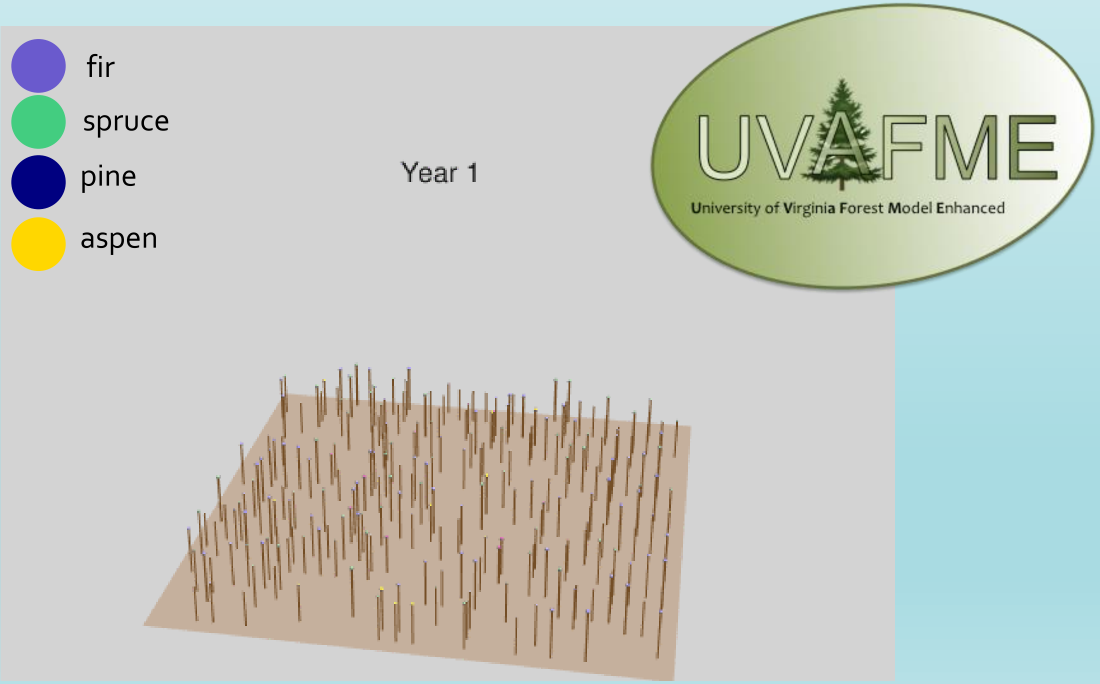


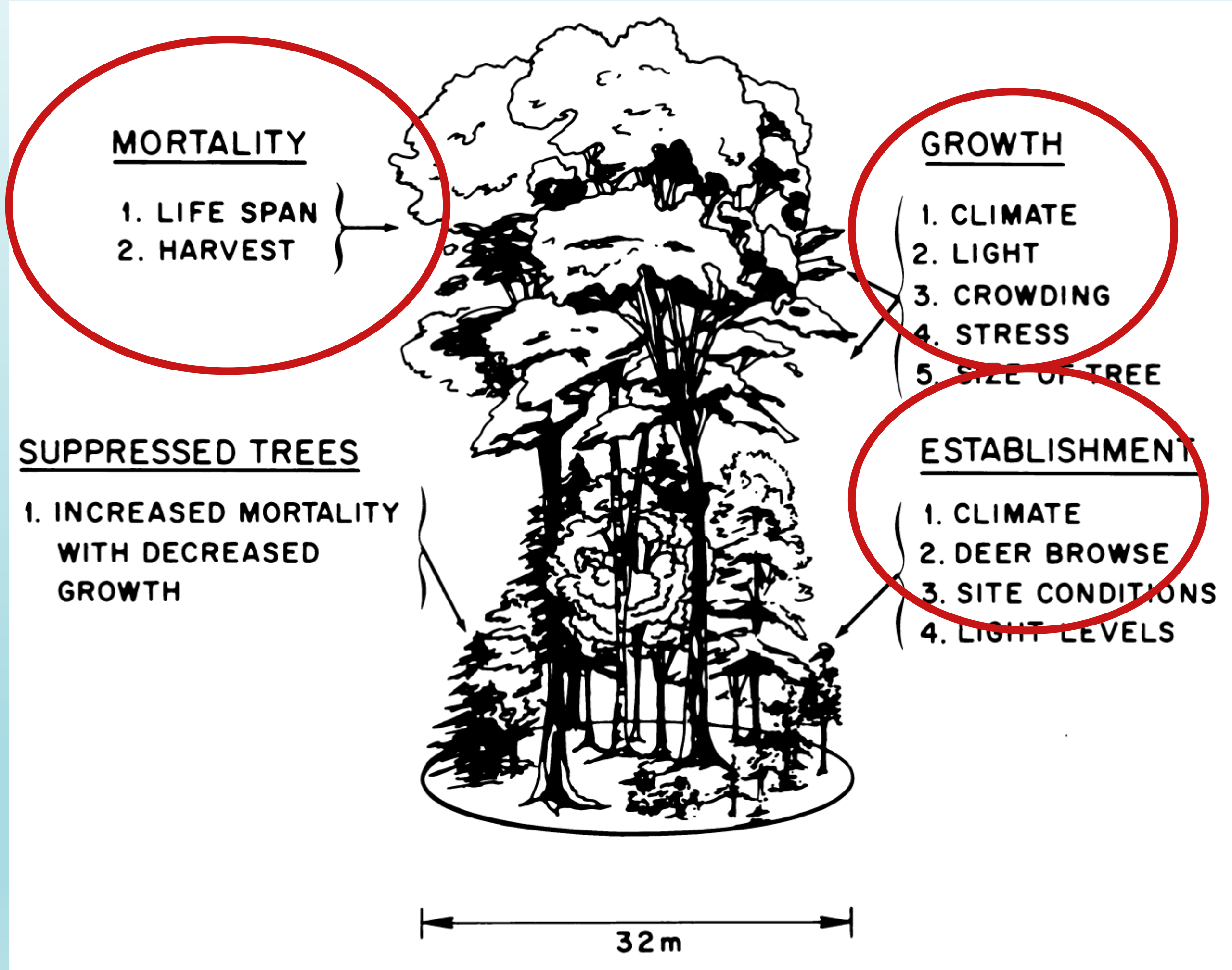
Species- and tree-level interactions are important



Ecological modeling

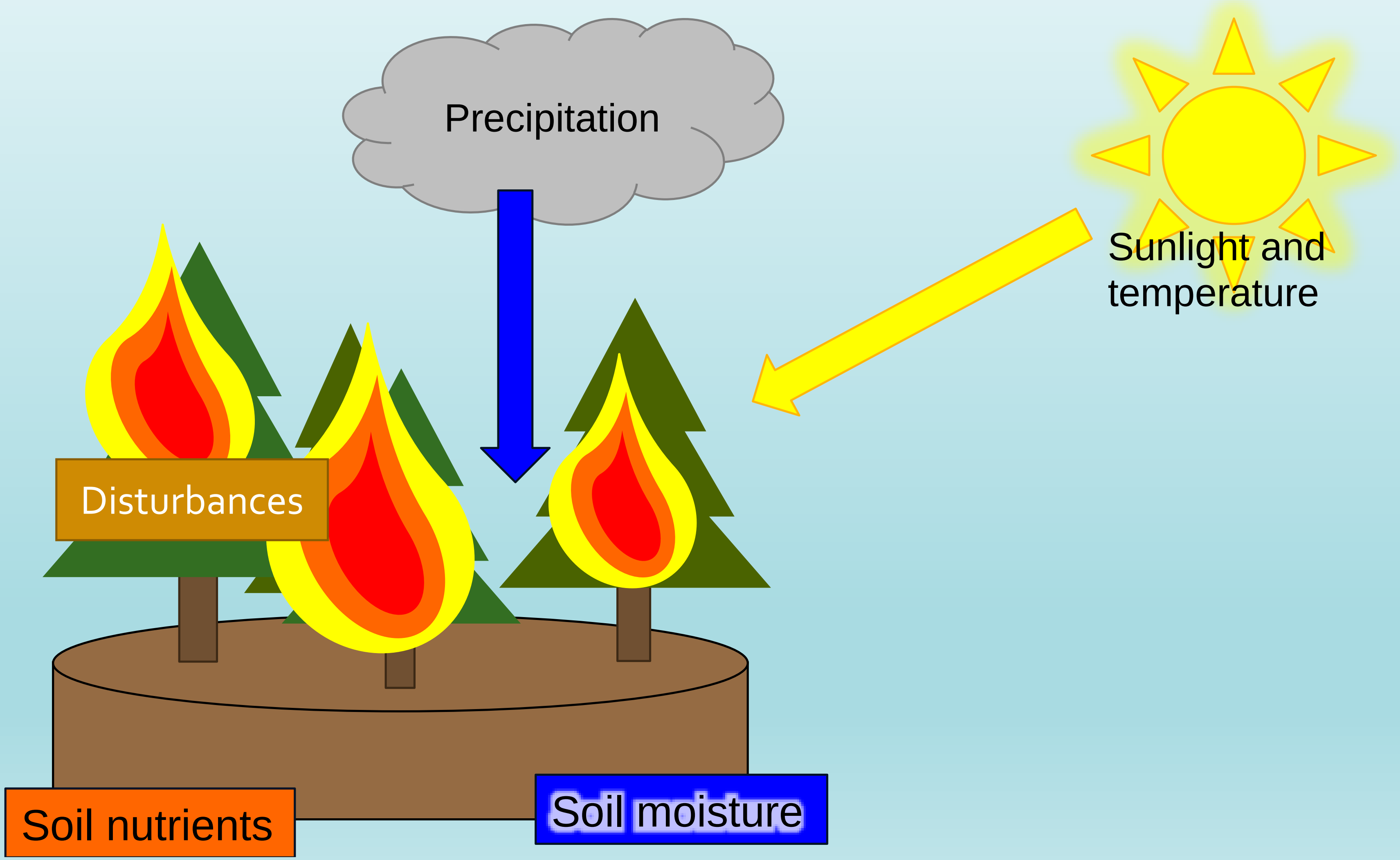
Individual-based gap models



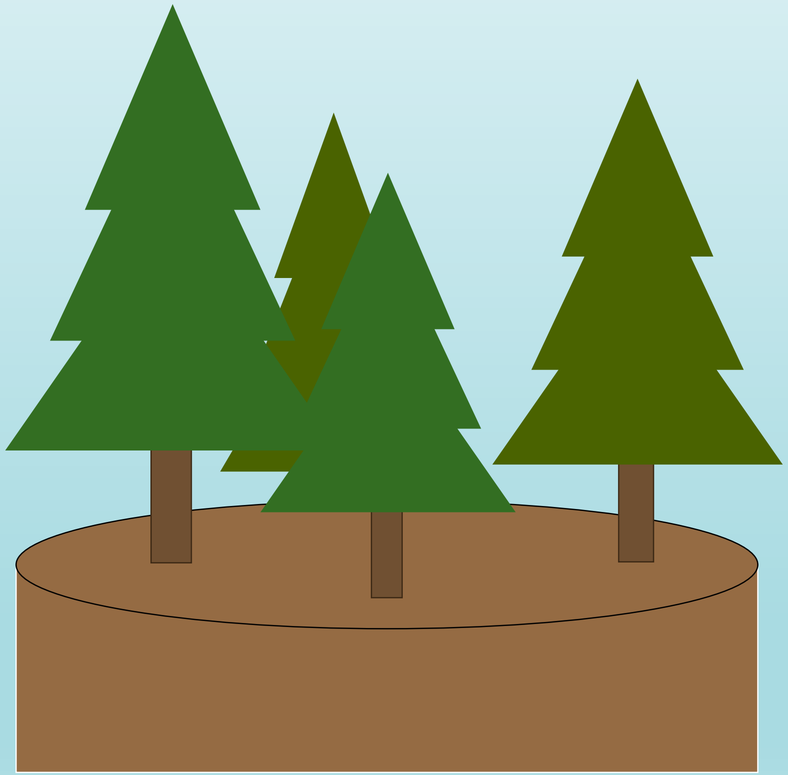


Shugart 1998

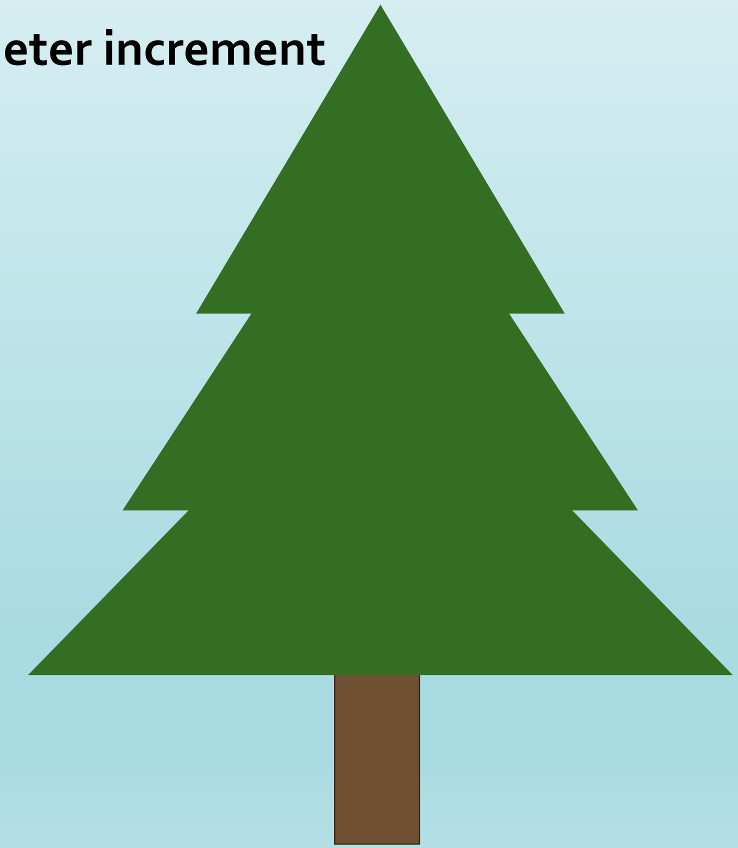
Gap models use equations to simulate tree growth and response to external forces



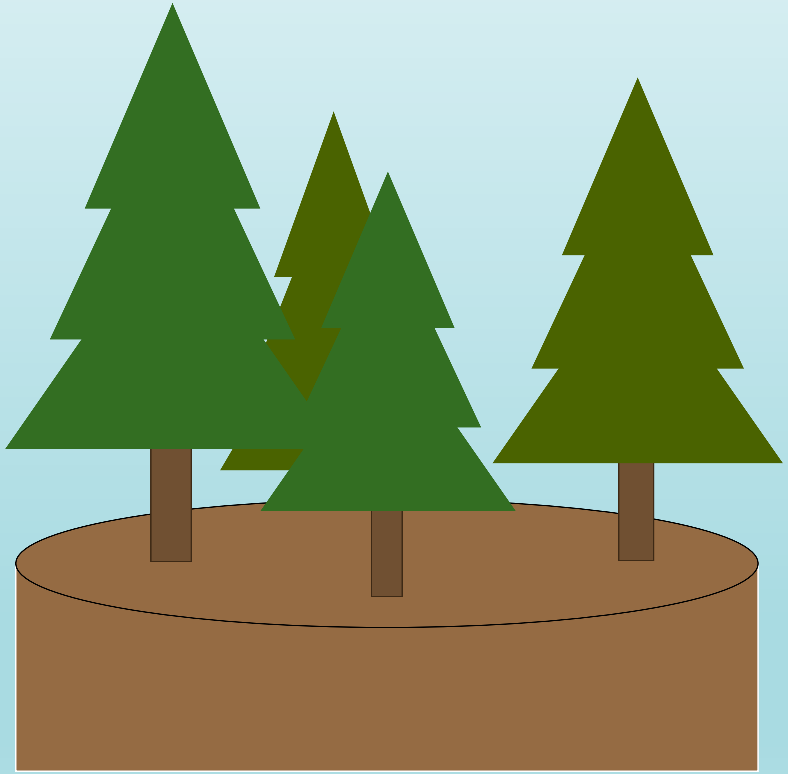
Individual tree growth



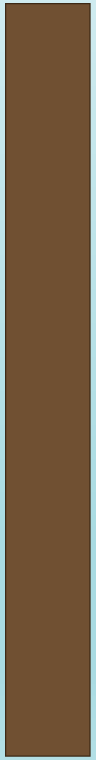
annual diameter increment
growth



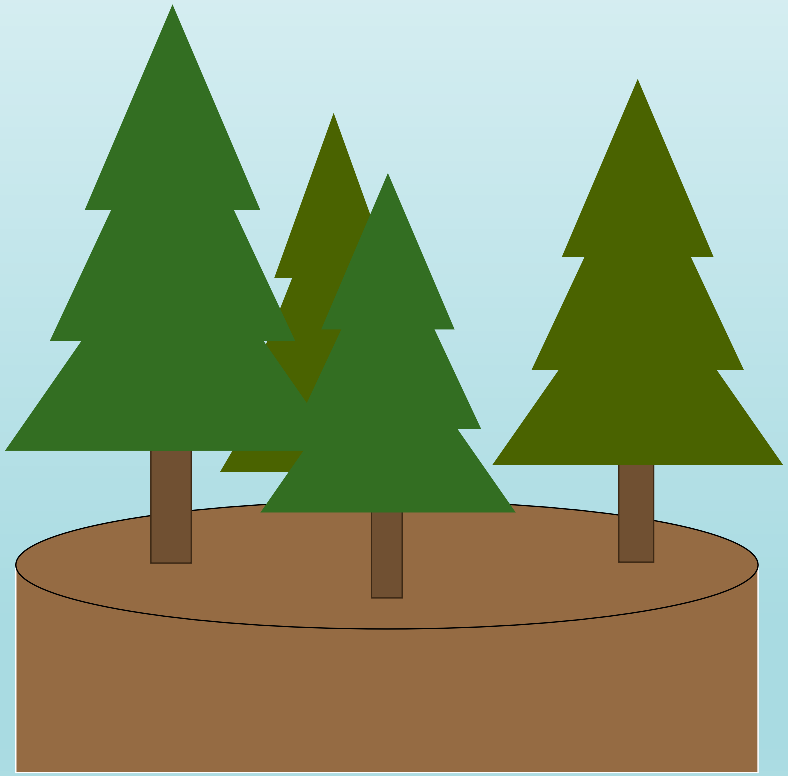
Individual tree growth



annual diameter increment
growth

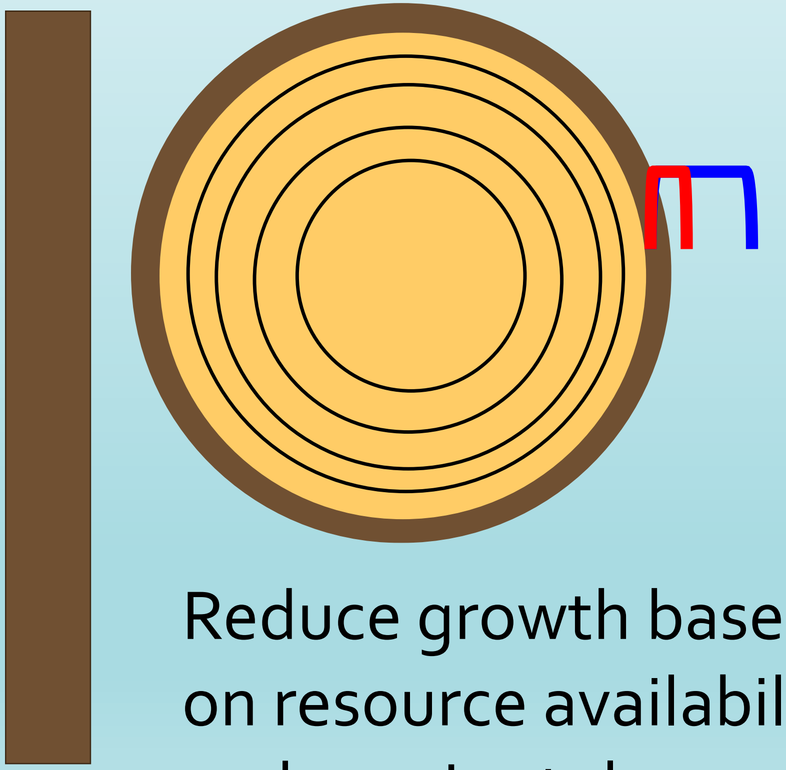


Individual tree growth



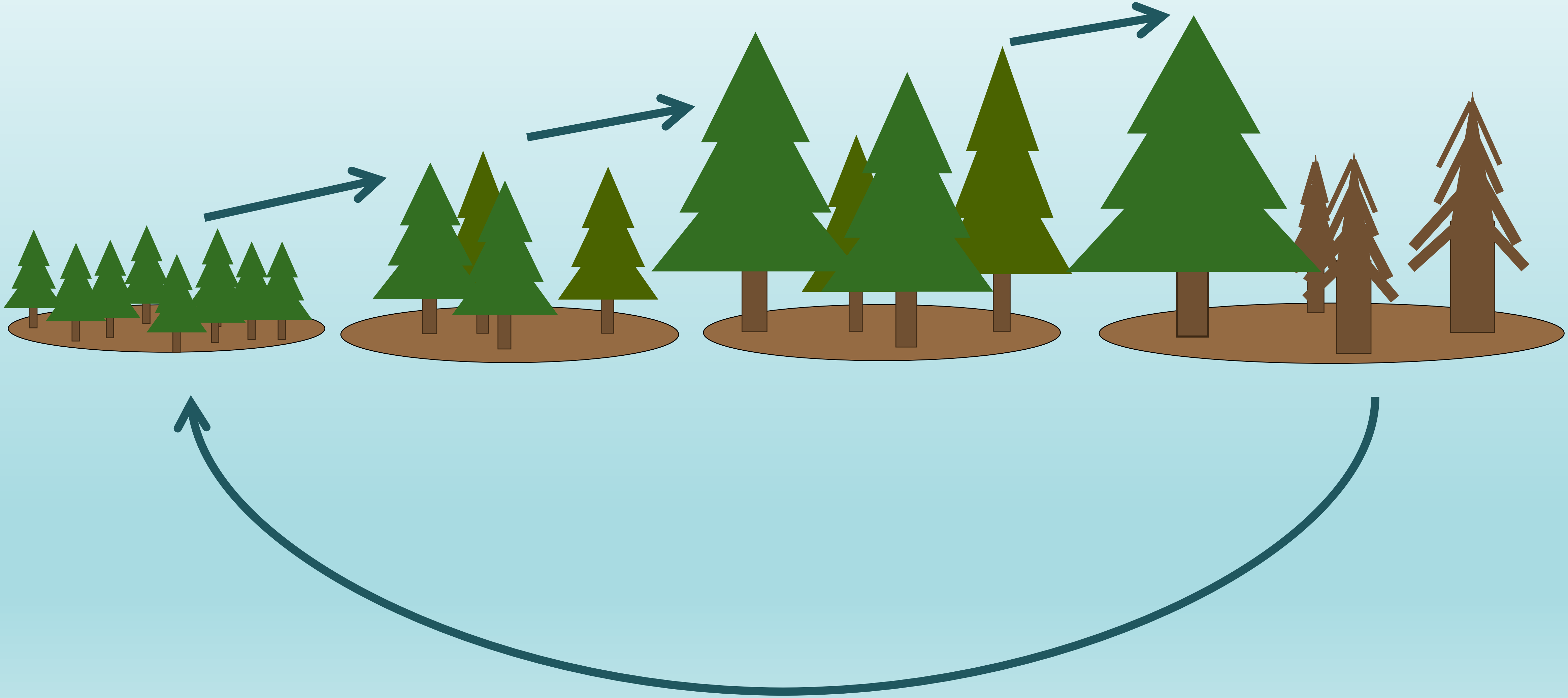
Calculate optimal DBH increment growth given optimal conditions

annual diameter increment growth

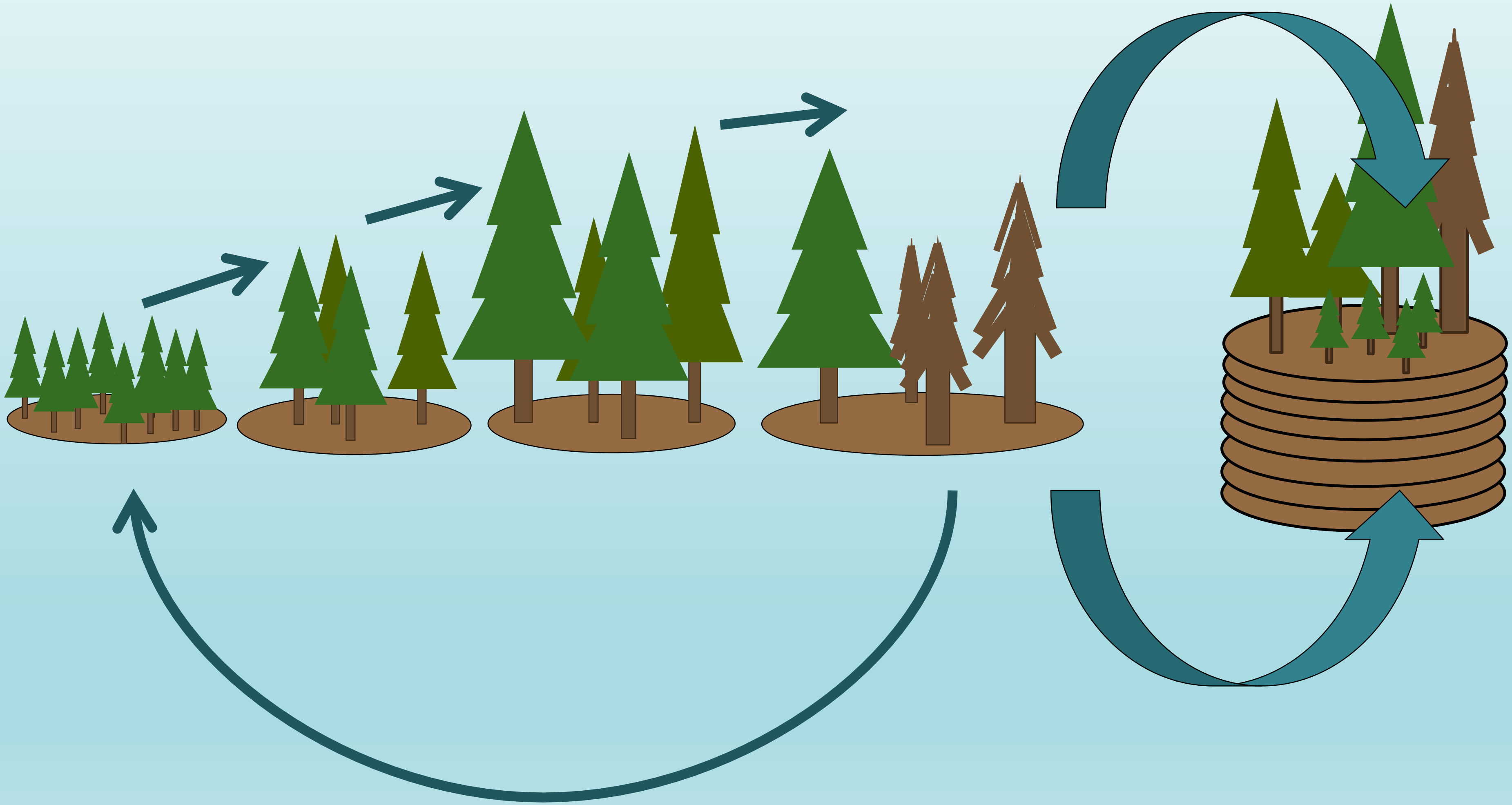


Reduce growth based on resource availability and species tolerances

Individual plots simulate gap dynamics



Average of hundreds of plots produces landscape-scale output



biomass
(tonnes C ha^{-1})

basal area
(m^2 ha^{-1})

size structure
(stems size $class^{-1}$ ha^{-1})

Application of UVAFME in interior AK

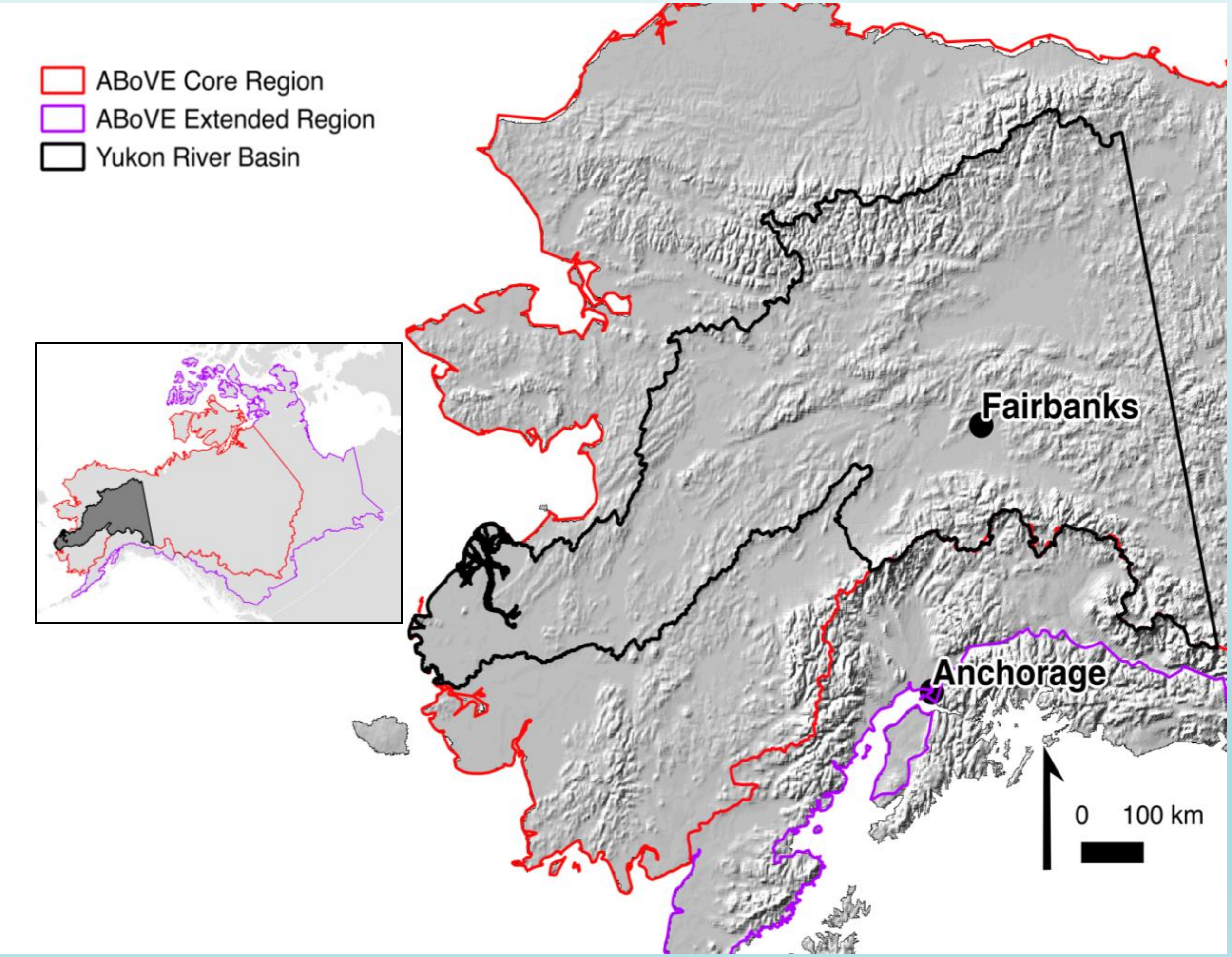
Yukon River Basin – Interior AK

Final products from project:

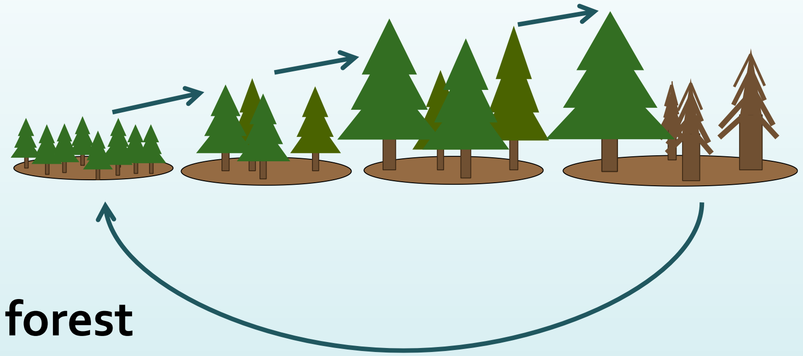
2km wall-to-wall gridded simulations across YRB

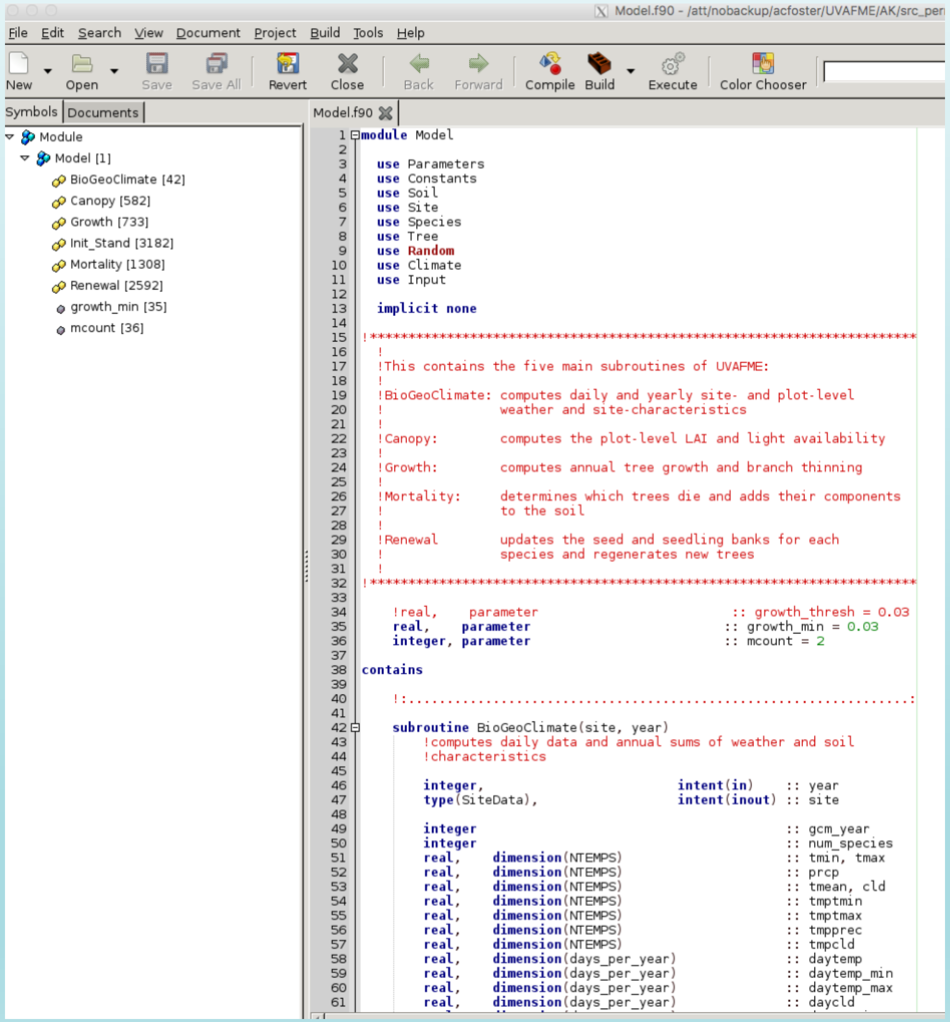
~131,000 sites

Initial testing in Tanana Valley



University of Virginia Forest Model Enhanced





Fortran program that simulates forest growth at individual point locations

25 modules

~157,000 lines of code

Initially – FAREAST (Yan & Shugart 2005)

Developed for boreal Eurasia

Out of similar gap-models: JABOWA, FORET, etc.

2014 – FAREAST became UVAFME (Shuman et al. 2015)

Updated to Fortran 90, **object-oriented**, flexible structure

Has since been applied within US Rocky Mountains, eastern US, Russia, Canada, and interior AK

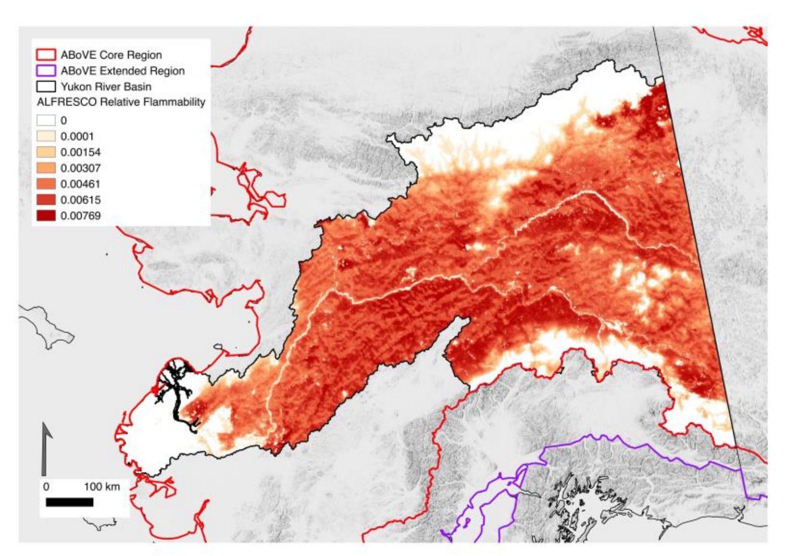
Required input data

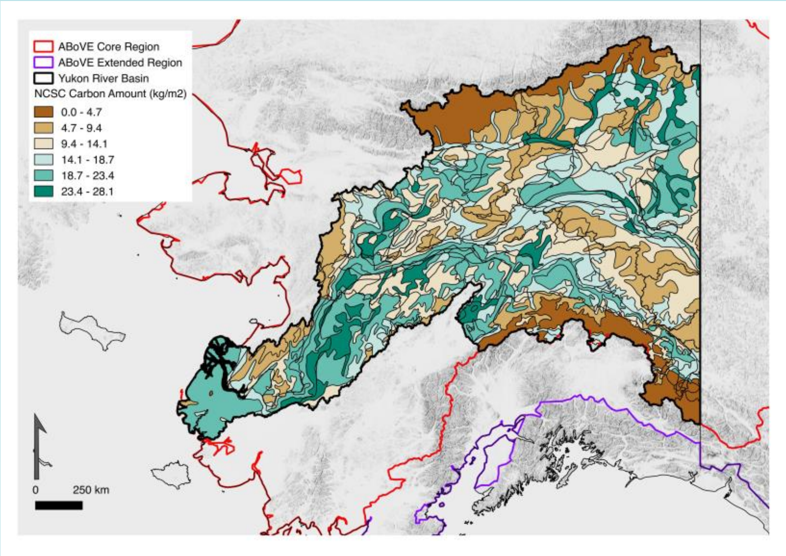
For each site/point-location:

- mean monthly minimum & maximum temperature, monthly precipitation, mean monthly cloudiness
- standard deviations of above climate variables
    - AK study: ClimateNA for temperature & precipitation; CRU for monthly cloudiness

- site & soil characteristics (e.g. latitude, longitude, slope, aspect, drainage conditions, FRI, etc.)
    - AK study: NCSC database, SSURGO, ALFRESCO maps of fire probability

- rangelist: species presence/absence
    - AK study: range maps from Little 1971 & Viereck & Little 2007





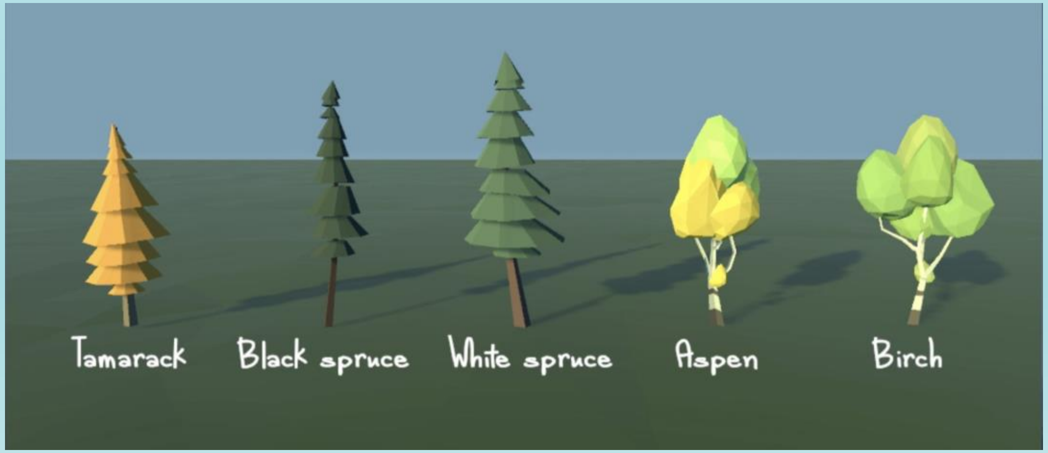
Wang et al. 2016
Harris et al. 2014
Hugelius et al. 2013
Mann et al. 2014

Required input data

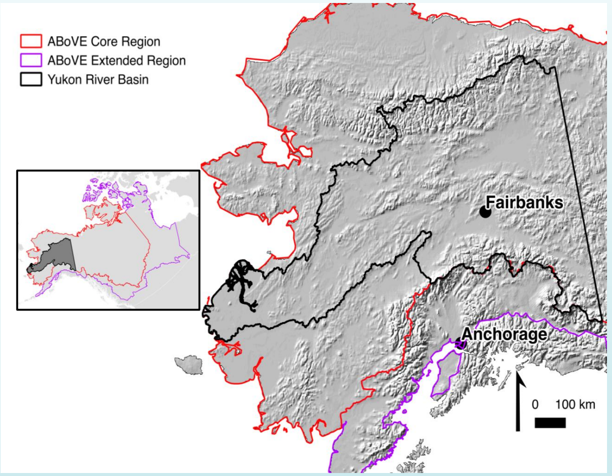
Other input data

- Species input file: species-level characteristics (e.g. average maximum DBH, height, age; drought tolerance, nutrient tolerance, etc.) (Burns & Honkala 1990; Viereck & Little 2007)

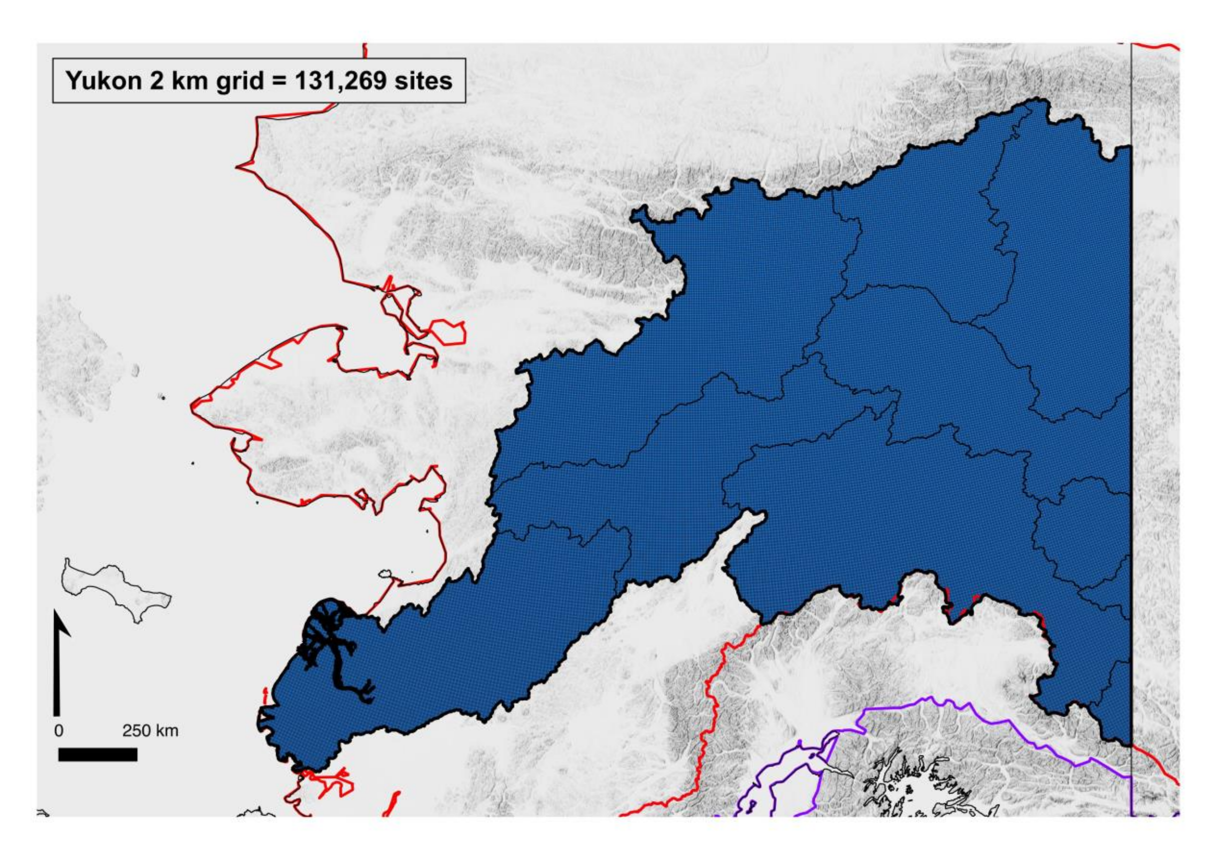
Species	Common Name	Maximum Age (years)[*, §]	Maximum DBH (cm) [*, §, ¶]	Maximum Height (m) [*, §, ¶]	s[@]	g[@]	DD_{min}[*, §]	DD_{opt}[*, §]	DD_{max}[*, §]
Betula kenaica	Kenai birch	140	30	24	1.66	1.469	300	2000	3619
Betula neoalaskana	Alaskan paper birch	140	76	30	0.6	1.887	280	1158	2036
Larix laricina	Tamarack	335	33	24	1.49	0.617	280	1986	3692
Picea glauca	White spruce	200	76	34	0.9	1.473	280	1096	1911
Picea mariana	Black spruce	250	30	27	1.87	0.918	220	1079	1911
Populus balsamifera	Balsam popular	200	75	25	0.67	1.107	401	1550	2700
Populus tremuloides	Quaking aspen	150	75	30	0.81	1.747	320	1371	2461
Populus trichocarpa	Black cottonwood	200	180	38	0.43	1.67	347	2268	4176



Application of UVAFME in interior AK



Yukon River Basin – Interior AK

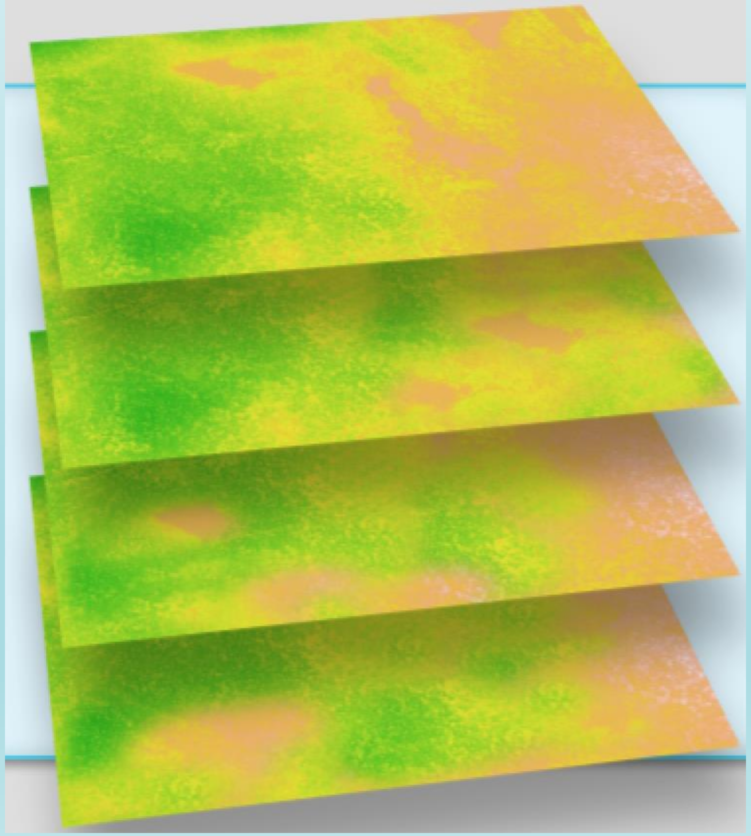


High number of sites requires a big(ish)-data approach to parameterization

QGIS and R scripts to reduce workflow tedium and increase reproducibility

Example – climate change file

Convert stacks of monthly Geotiffs of climate projections to the appropriate UVAFME climate change file



site	latitude	longitude	year	tmin_jan	tmin_feb	tmin_mar	tmin
1001	64.804303	-148.25752	0	-25.535484	-22.377419	-16.248387	-6.1
1001	64.804303	-148.25752	1	-24.935485	-23.577419	-15.948388	-4.0
1001	64.804303	-148.25752	2	-24.735485	-22.377419	-11.648388	-4.7
1001	64.804303	-148.25752	3	-26.335485	-21.877419	-14.448387	-3.
1001	64.804303	-148.25752	4	-23.835485	-21.47742	-17.648388	-5.5
1001	64.804303	-148.25752	5	-22.935484	-25.077419	-13.448387	-5.3
1001	64.804303	-148.25752	6	-24.735485	-22.27742	-16.748387	-5.5
1001	64.804303	-148.25752	7	-26.335485	-23.97742	-14.348387	-4.2
1001	64.804303	-148.25752	8	-23.835485	-22.67742	-17.948388	-5.0
1001	64.804303	-148.25752	9	-24.835485	-23.377419	-14.948387	-5.1
1001	64.804303	-148.25752	10	-27.835485	-21.17742	-13.248388	-4.6
1001	64.804303	-148.25752	11	-23.335485	-21.17742	-14.248388	-5.9
1001	64.804303	-148.25752	12	-22.035485	-22.877419	-15.748387	-6.1
1001	64.804303	-148.25752	13	-22.635484	-24.577419	-15.648388	-6.1
1001	64.804303	-148.25752	14	-25.135484	-22.877419	-12.548387	-6.1
1001	64.804303	-148.25752	15	-27.935485	-21.47742	-12.648388	-6.3
1001	64.804303	-148.25752	16	-23.935484	-23.077419	-10.448387	-5.3
1001	64.804303	-148.25752	17	-24.935485	-20.47742	-13.348387	-6.7
1001	64.804303	-148.25752	18	-23.635484	-20.77742	-14.348387	-6.9
1001	64.804303	-148.25752	19	-22.235485	-25.47742	-13.348387	-6.1
1001	64.804303	-148.25752	20	-23.935484	-20.077419	-12.248388	-1.
1001	64.804303	-148.25752	21	-22.035485	-22.377419	-12.848387	-2.
1001	64.804303	-148.25752	22	-24.935485	-22.577419	-13.648388	-4.7
1001	64.804303	-148.25752	23	-25.535484	-22.77742	-13.748388	-3.8
1001	64.804303	-148.25752	24	-19.935484	-20.77742	-12.348387	-3.2
1001	64.804303	-148.25752	25	-24.835485	-23.17742	-14.248388	-6.2
1001	64.804303	-148.25752	26	-24.635484	-22.67742	-12.248388	-6.7

Example – climate change file

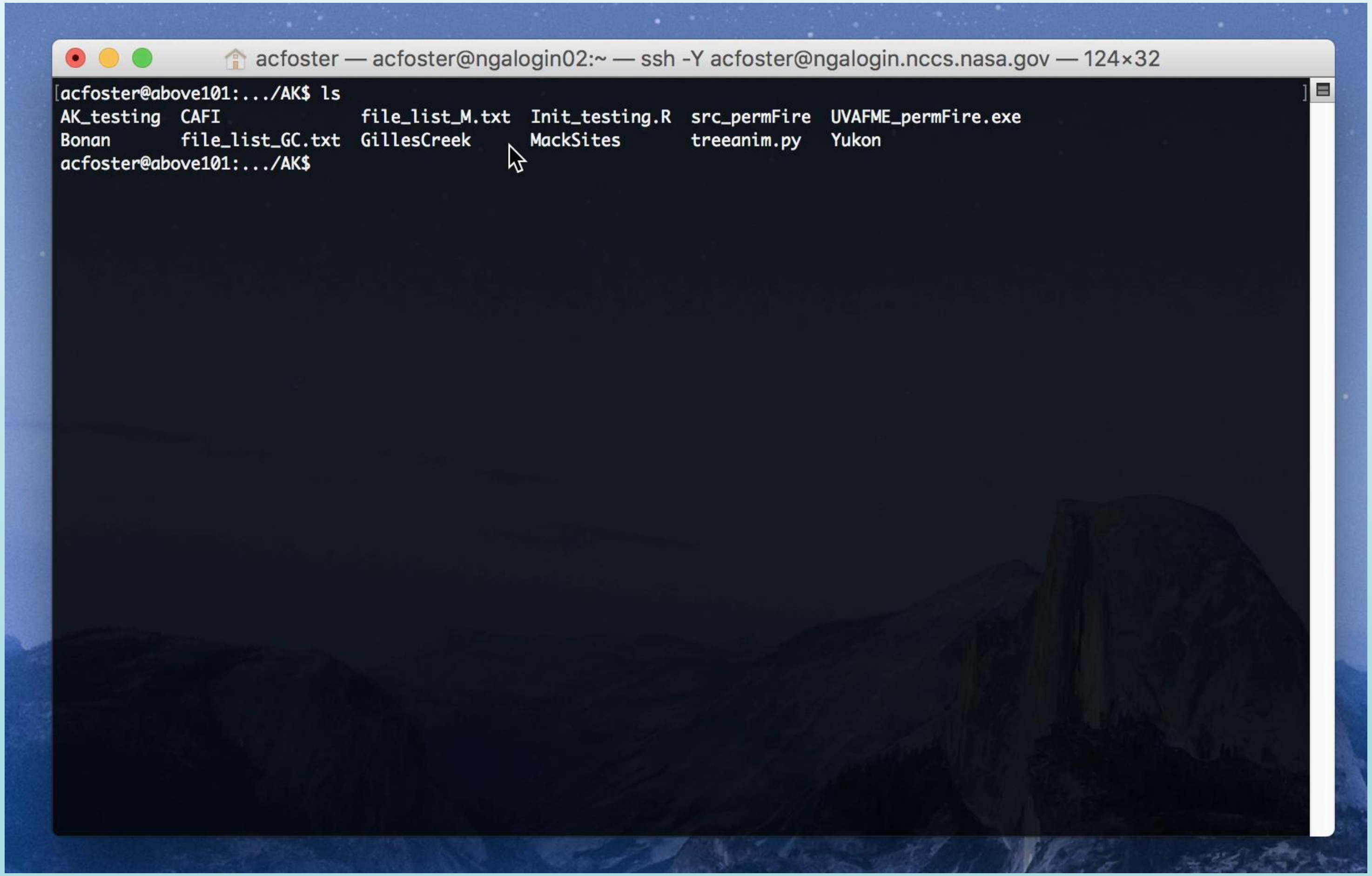
Convert stacks of monthly Geotiffs of climate projections to the appropriate UVAFME climate change file

```
        #temporary difference raster for that month
        diff_temp <- rasterStack[[i]] - baseRaster[[i]]

        #stack with others
        rstack <- stack(rstack, diff_temp)
    }

    return(rstack)
}

print_diffRasters <- function(type, scen, years, baseRaster){
    #function to print out difference rasters for easier computation later
    #inputs:
        #type - 'tas' or 'pr'
        #scen - '45', '60', or '85'
        #years - list of years to compute
        #baseRaster - base raster data (i.e. year 0 of climate change)

    #get output directory and basefile name
    outdir <- paste(type, '_', 'rcp', scen, '_diff', sep = '')
    if (type == 'tas'){
        fnamebase <- paste(type, '_mean_C_diff_AR5_5modelAvg_rcp', scen, sep = '')
    } else if (type == 'pr') {
        fnamebase <- paste(type, '_total_mm_diff_AR5_5modelAvg_rcp', scen, sep = '')
    }

    for (y in 1:length(years)){

        #get list of raster files for that year
        ylist <- get_rasterList(type, diff = FALSE, scen, years[y])

        #get rasterStack for those files
        yStack <- get_rasterStack(type, scen, diff = FALSE, ylist)

        #compute the difference raster for that stack
        yDiff <- compute_diffRaster(baseRaster, yStack)
```

Create difference rasters
Map to point locations
Put into correct format for UVAFME

Optimization of this code and distribution across nodes on ASC: ~18 day run time to 30 minute run time

How to run individual sites



Running UVAFME

./UVAFME.exe file_list.txt

file_list.txt: specifies input and output directory locations

<u>Testing</u>:

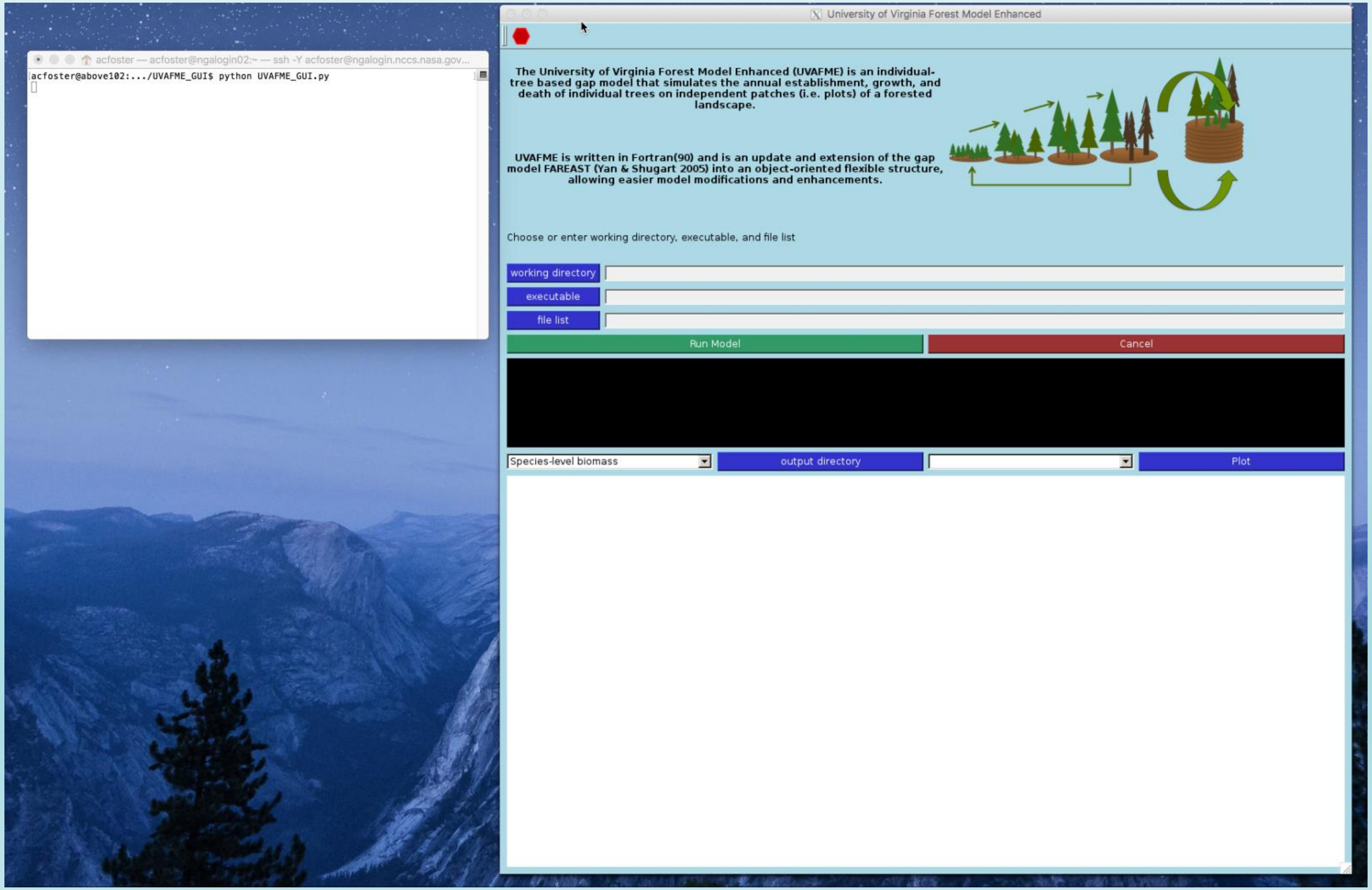
Interactive mode – command line

Generally use above101-104 nodes

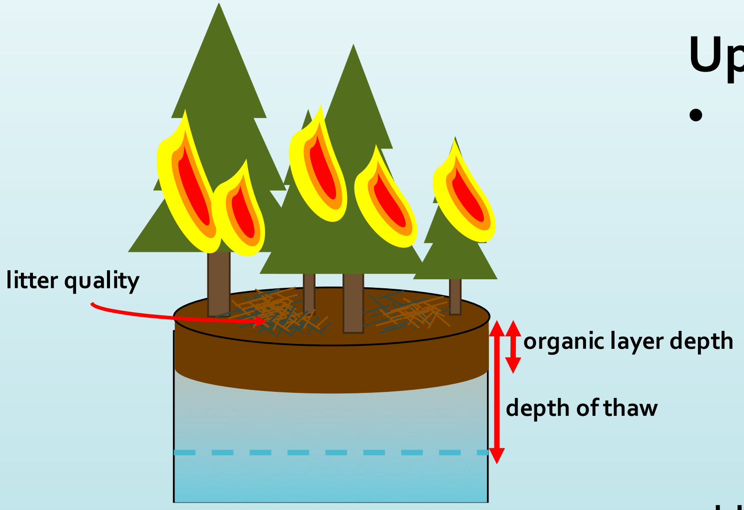
Each site: 20-60 seconds depending on output data requirement

GUI Development

If command line interfaces terrify you…



UVAFME Code Updates

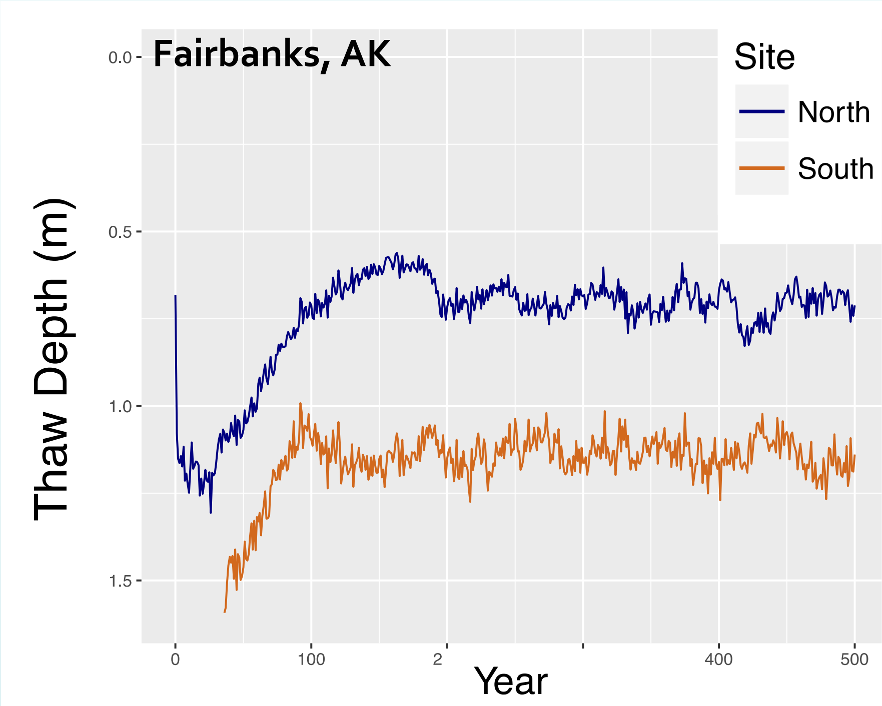


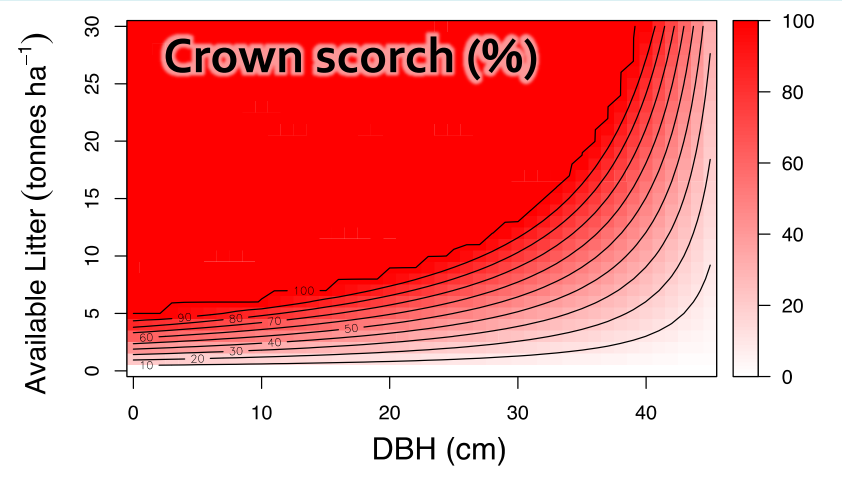
Updates to UVAFME

- Simulation of **permafrost depth** based on:
    - soil moisture & depth
    - climate
    - topographic effects
    - vegetation cover

- Update of **litter and nutrient** modules:
    - genus- and cohort-specific decay

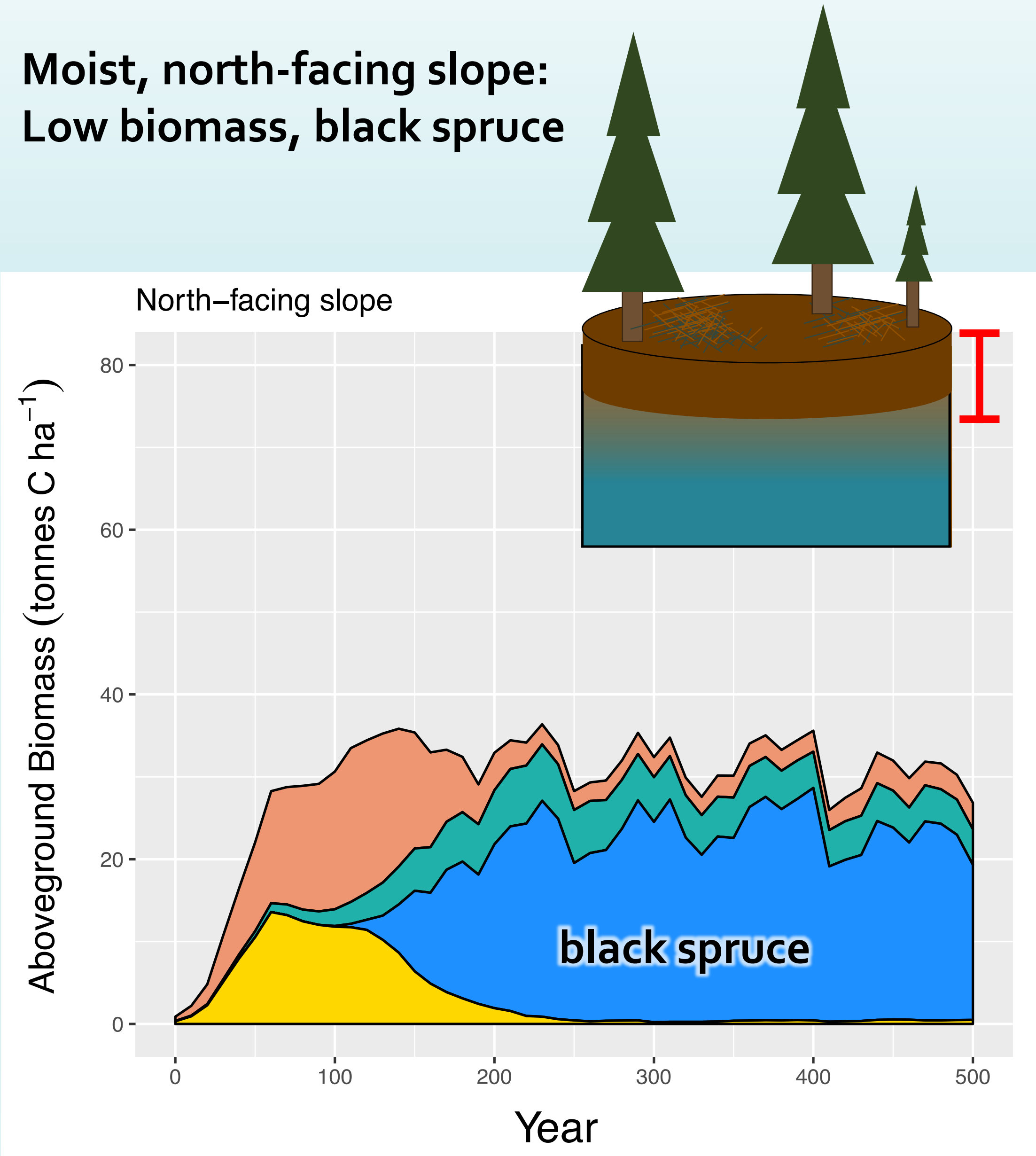
- Incorporation of **fuels tracking** and **consumption**
    - fire intensity & fuels consumption based on aridity and fuel amount

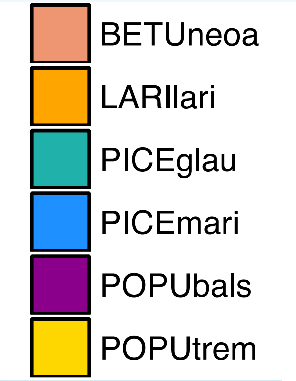




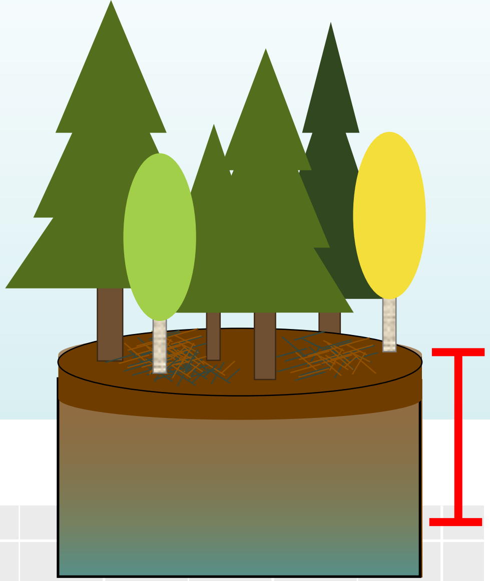
Code updates based on Bonan (1989); Bonan et al. (1990); Pastor & Post (1985); Schumacher et al. (2006); Keane et al. (2011)

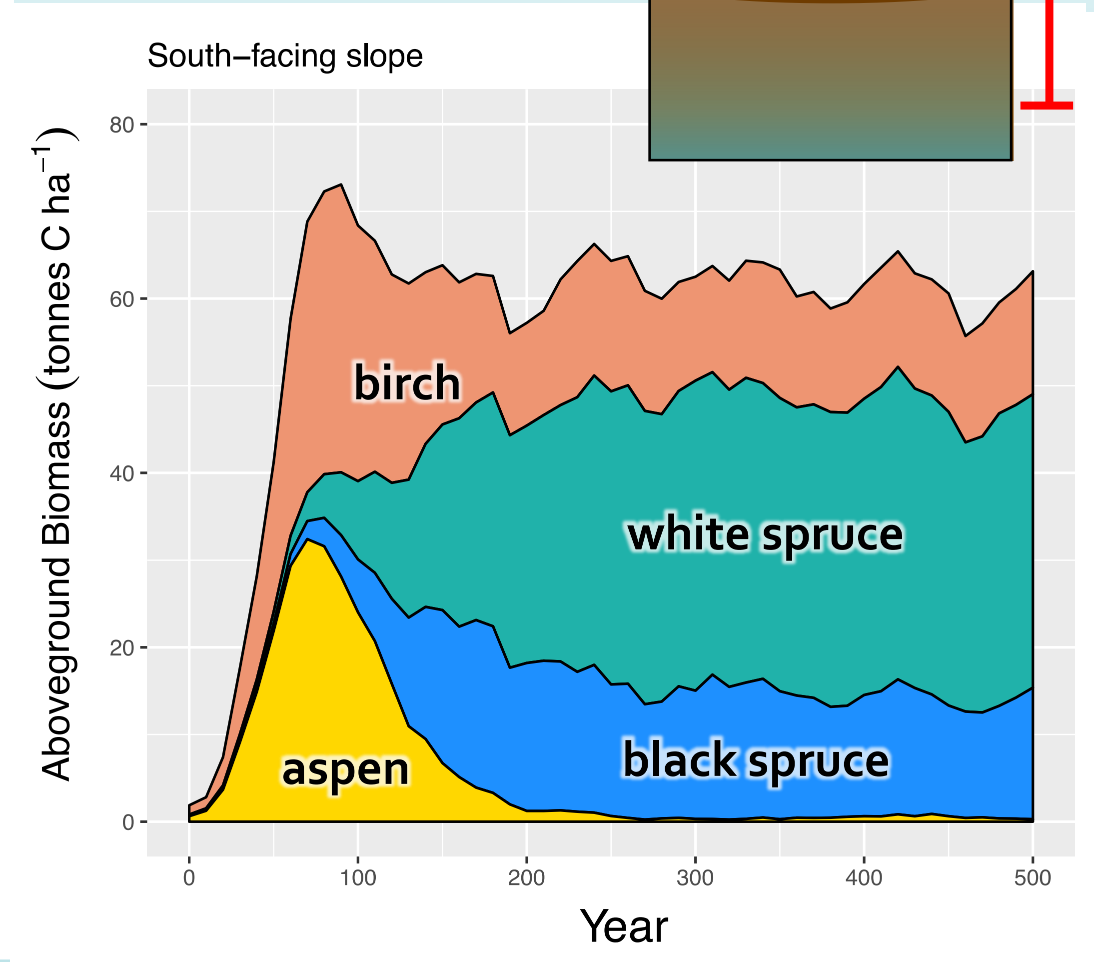
Moist, north-facing slope:
Low biomass, black spruce





Dry, south-facing slope:
High biomass, mixed/white spruce





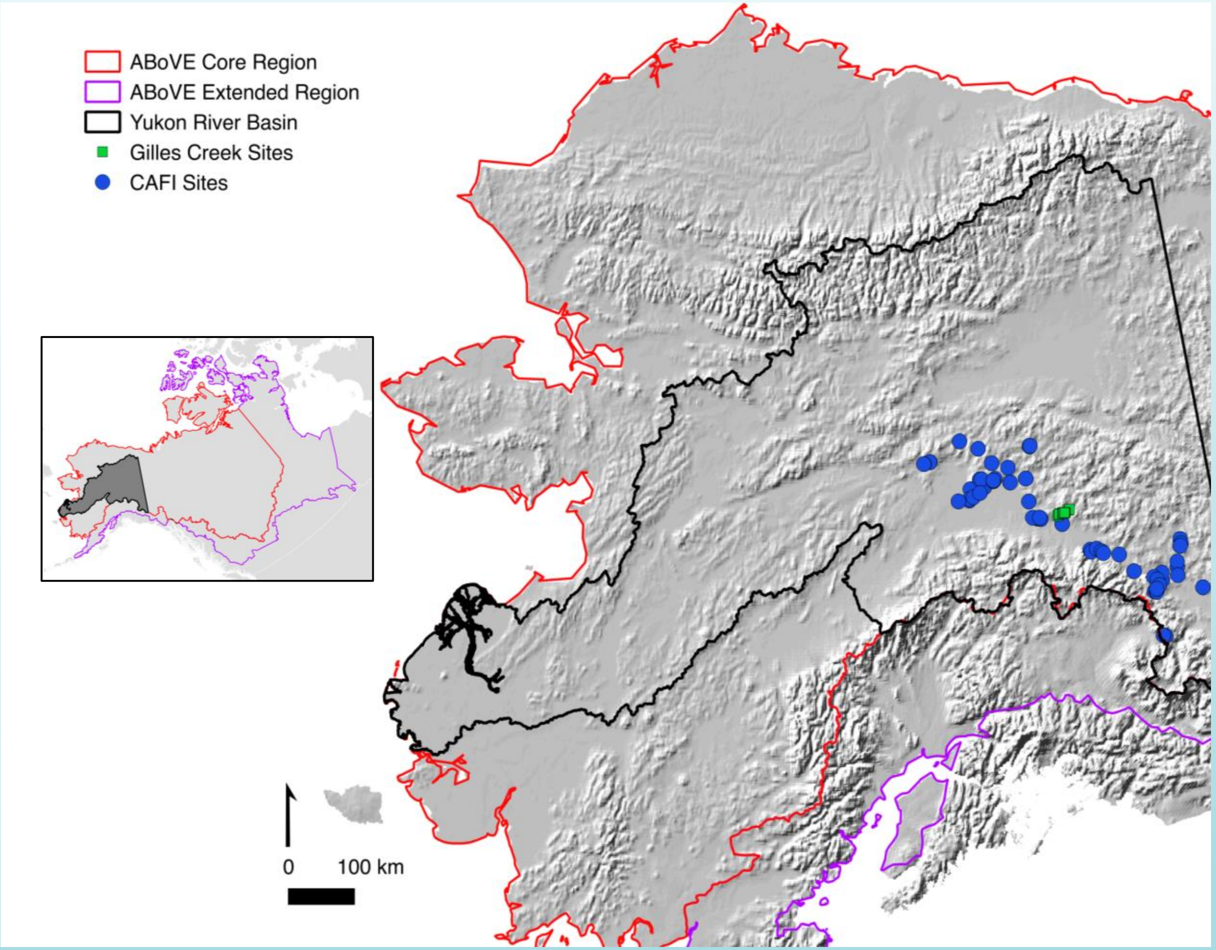
Simulations at inventory sites

Cooperative Forest Inventory Data (CAFI) (Malone et al. 2009)

77 sites in Yukon River Basin
mostly mixed white spruce & deciduous
some black spruce

Gilles Creek Sites*

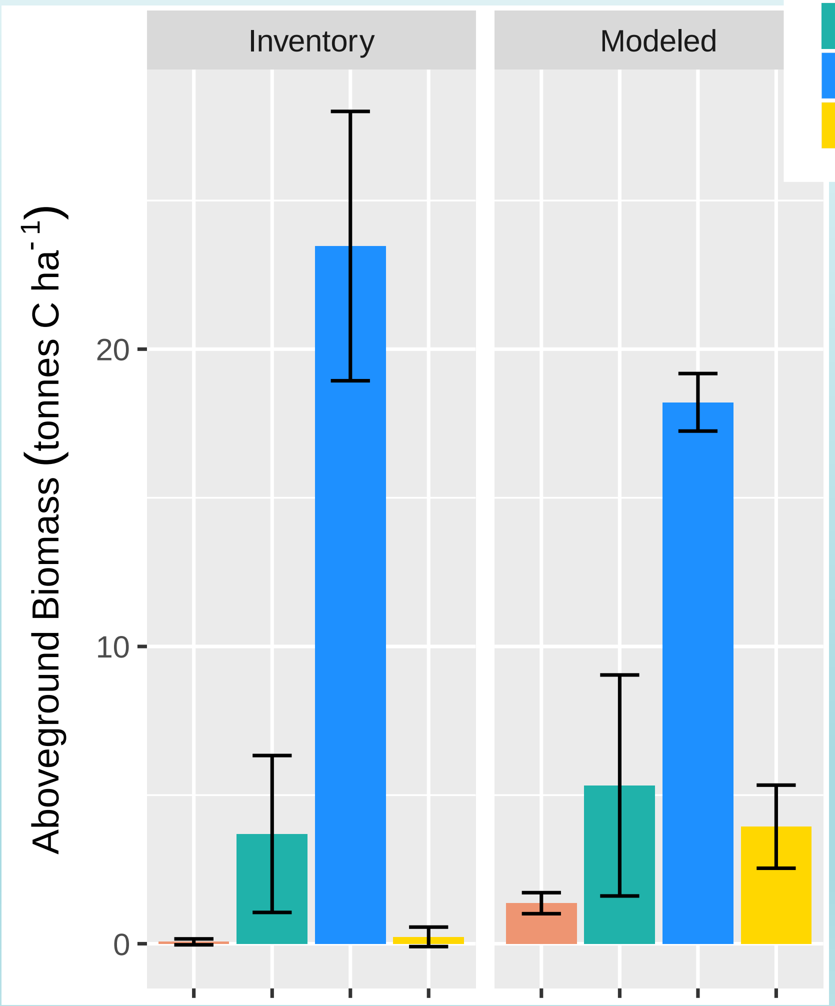
30 sites in Tanana Valley
both black spruce and white spruce sites



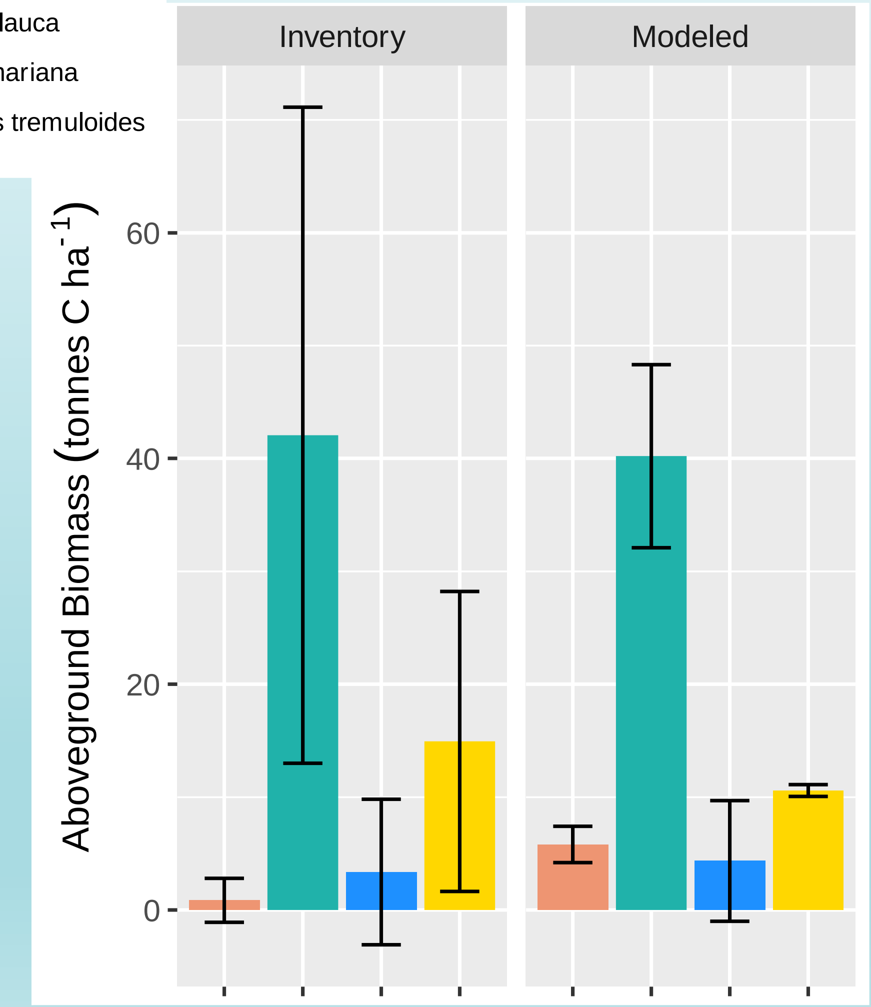
*Gilles Creek inventory from B. Rogers, WHRC

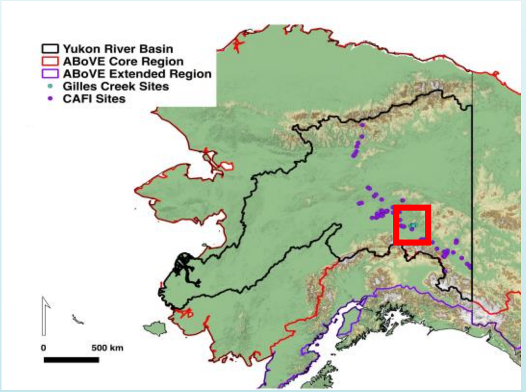
UVAFME updates improved agreement with inventory data

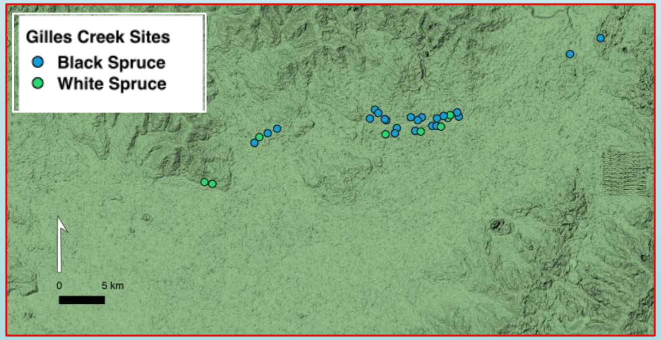
Black Spruce Sites: n = 22



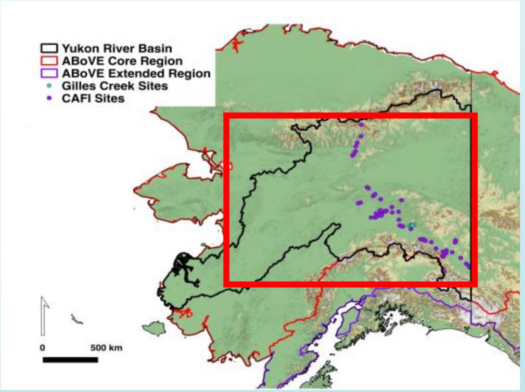
White Spruce Sites: n = 8

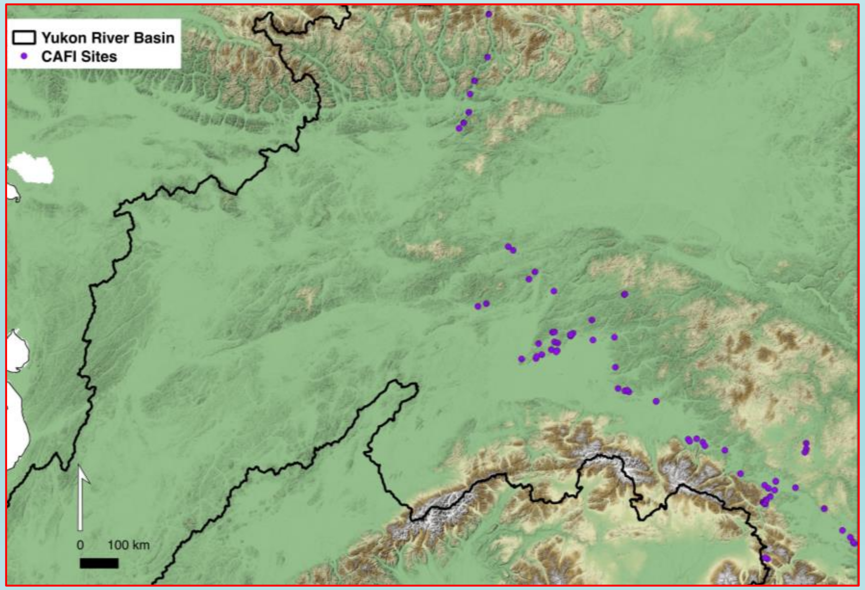






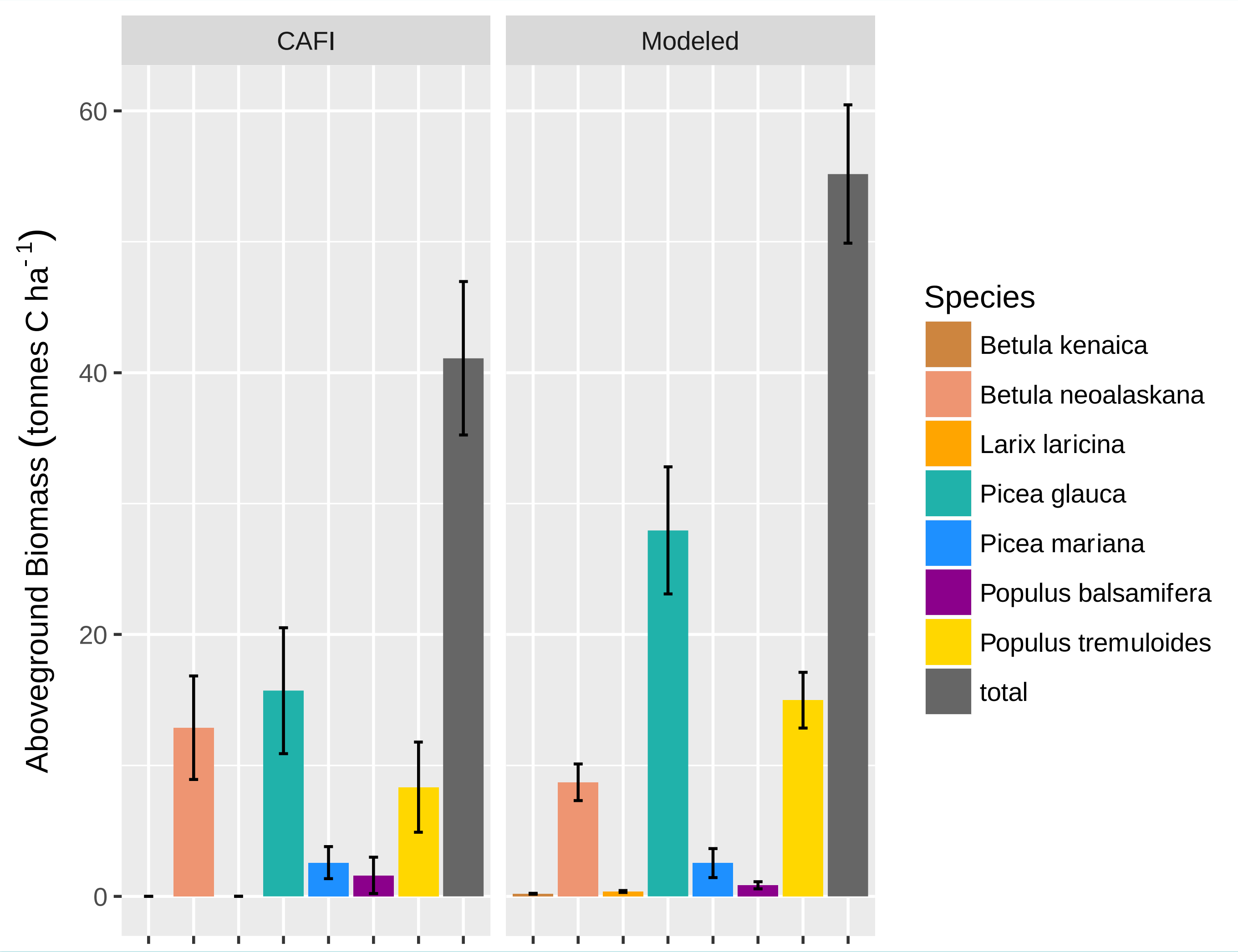
UVAFME updates improved agreement with inventory data





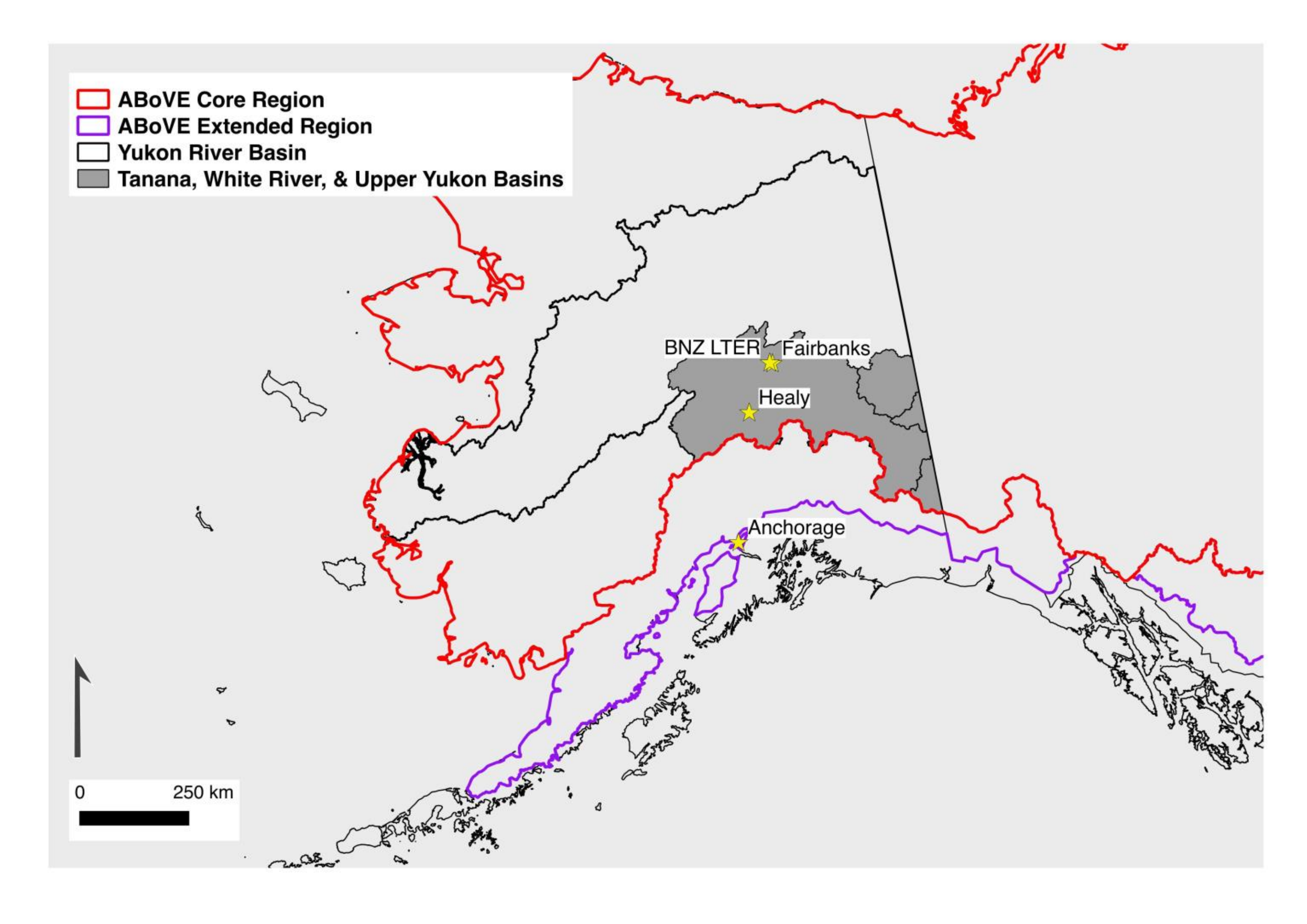
Average biomass across all CAFI sites

n = 77



Apply UVAFME across the Tanana Valley

Climate change analyses across Tanana
Gridded, wall-to-wall runs
2 km resolution ~ 35,000 sites



Running multiple sites

Sitelist file

Allows user to specify IDs of sites to run in one simulation

UVAFME will run each site in succession (sites are independent and do not interact)

Distribute sites across available nodes

~50 second run * 35,000 sites =1,750,000 seconds = 29,167 minutes = 487 hours = **20 days (!!!)**

Across 10 nodes & 4 cores each ~ 0.5 days

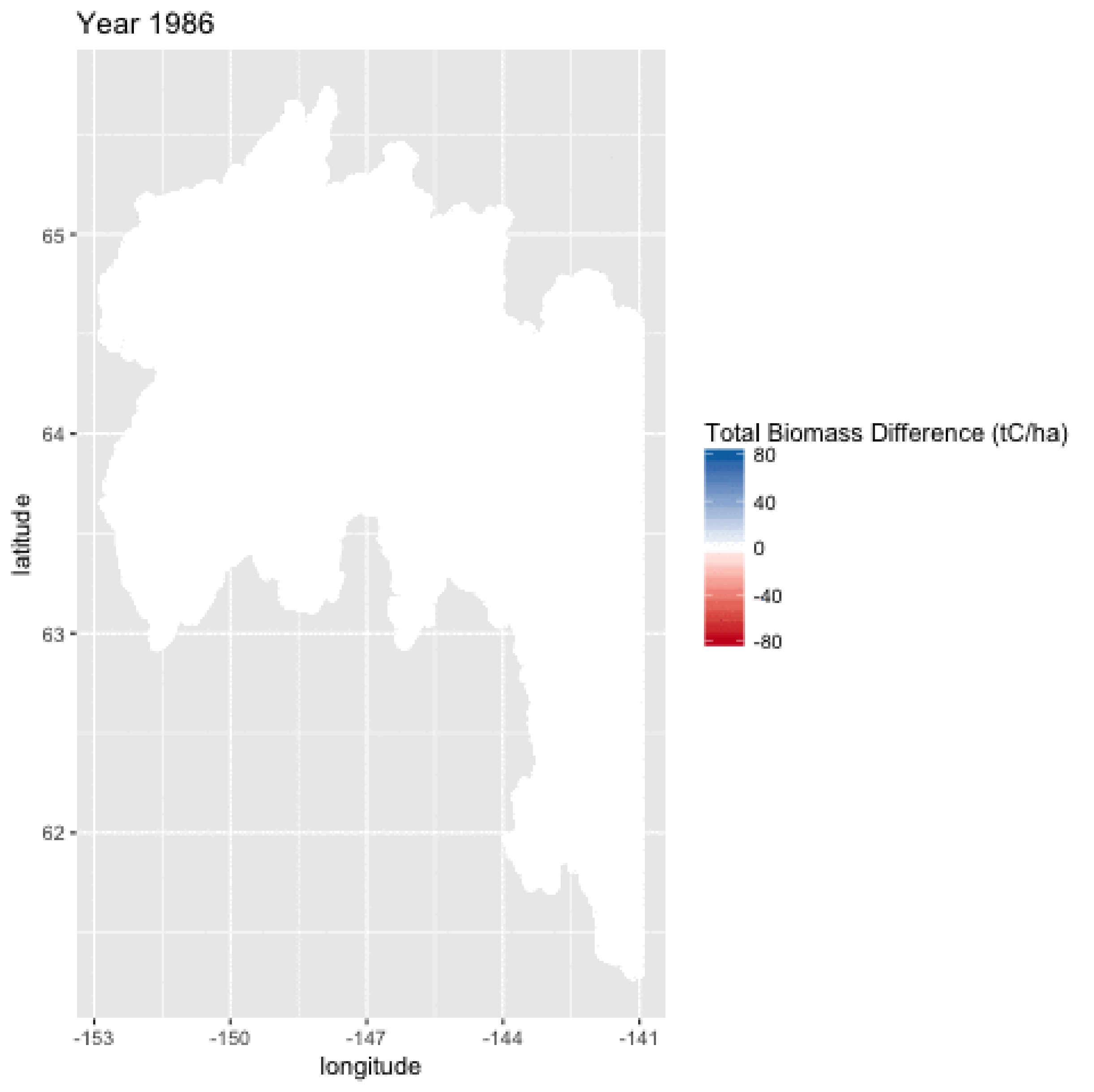
SLURM script for batch runs

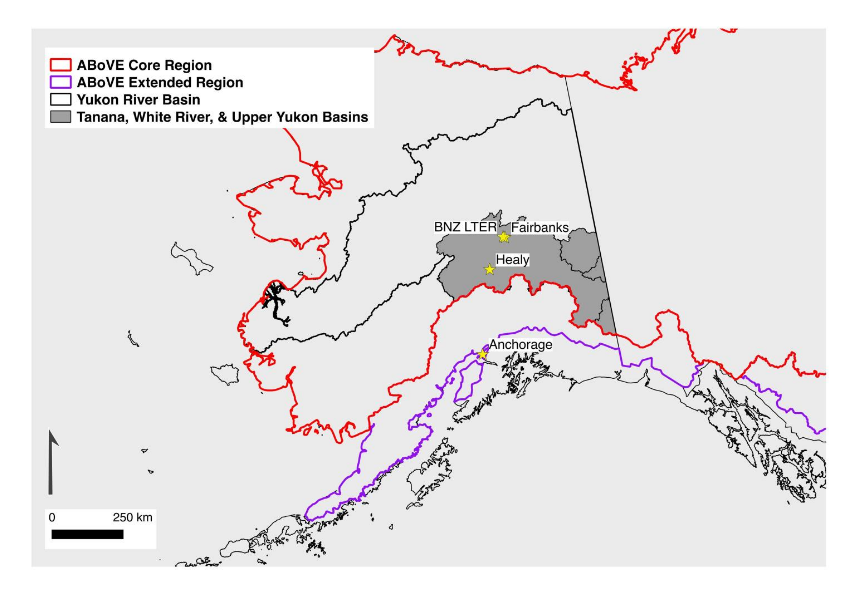
SLURM allows you to check runtime of all jobs

Error files for diagnosing issues

UVAFME output site_log.txt file tells me which sites have been finished

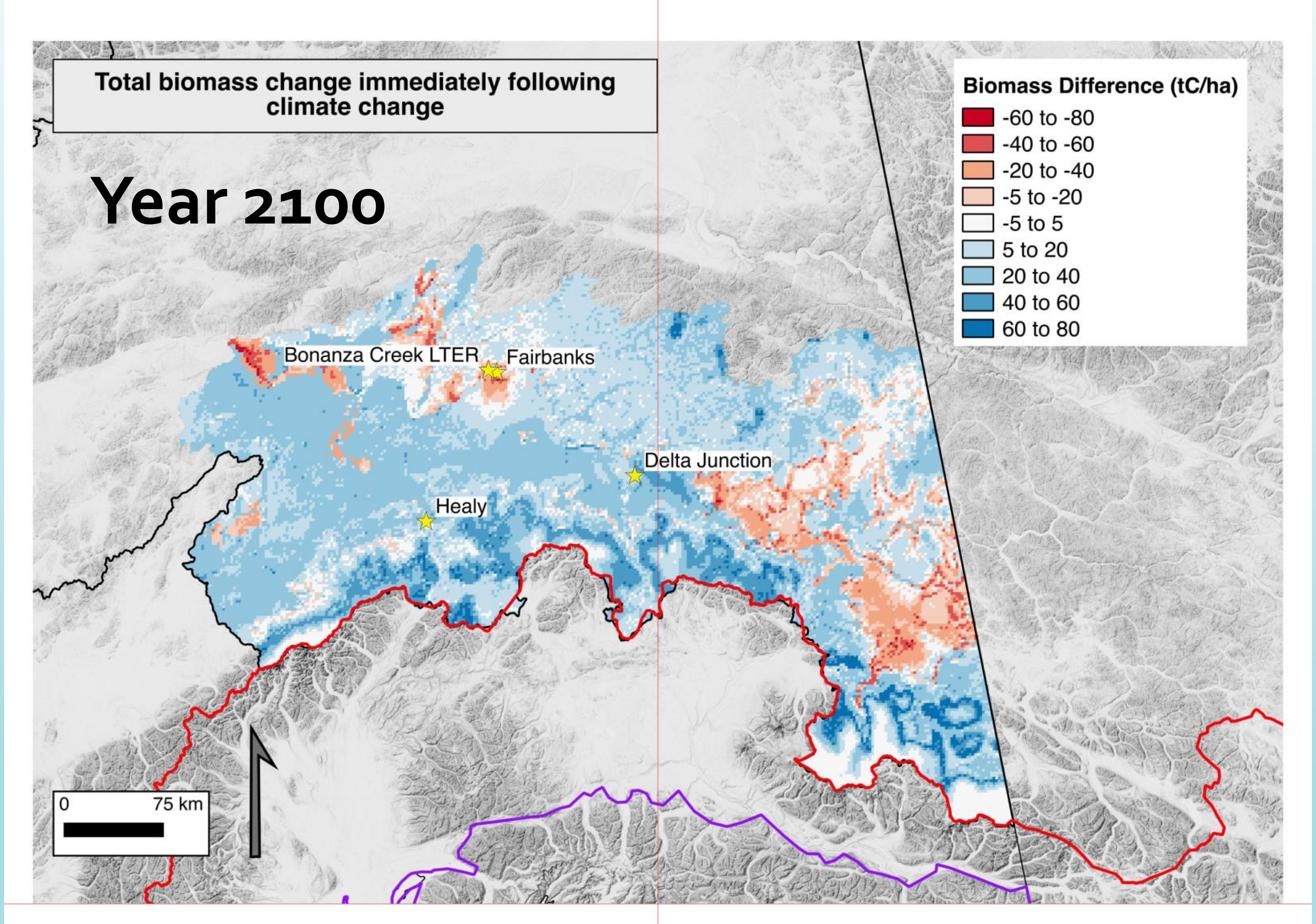
```
#!/bin/bash
#

for i in 0{1..10}; do

    echo "#!/bin/bash" >>job_$i.slurm
    echo "#SBATCH --job-name=Tan_$i" >> job_$i.slurm
    echo "#SBATCH --time=200:00:00" >> job_$i.slurm
    echo "#SBATCH -o outjob_$i" >> job_$i.slurm
    echo "#SBATCH -e erjob_$i" >> job_$i.slurm
    echo "#SBATCH -A acfoster" >> job_$i.slurm
    echo "#SBATCH --workdir=/att/nobackup/acfoster/UVAFME/AK/Yukon/Tanana/jobs" >> job_$i.slurm
    echo "./UVAFME_permFire.exe file_list_$i.txt" >> job_$i.slurm
    sbatch job_$i.slurm
done
```

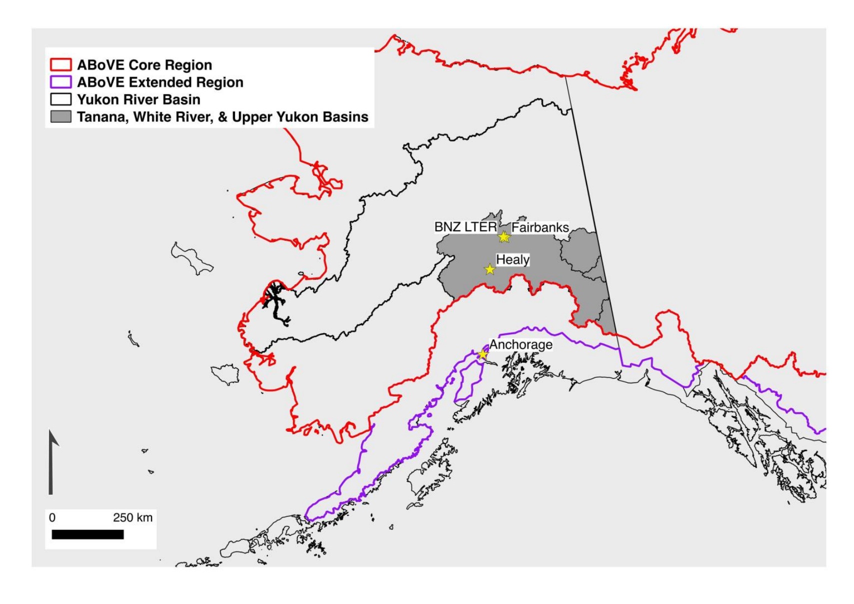


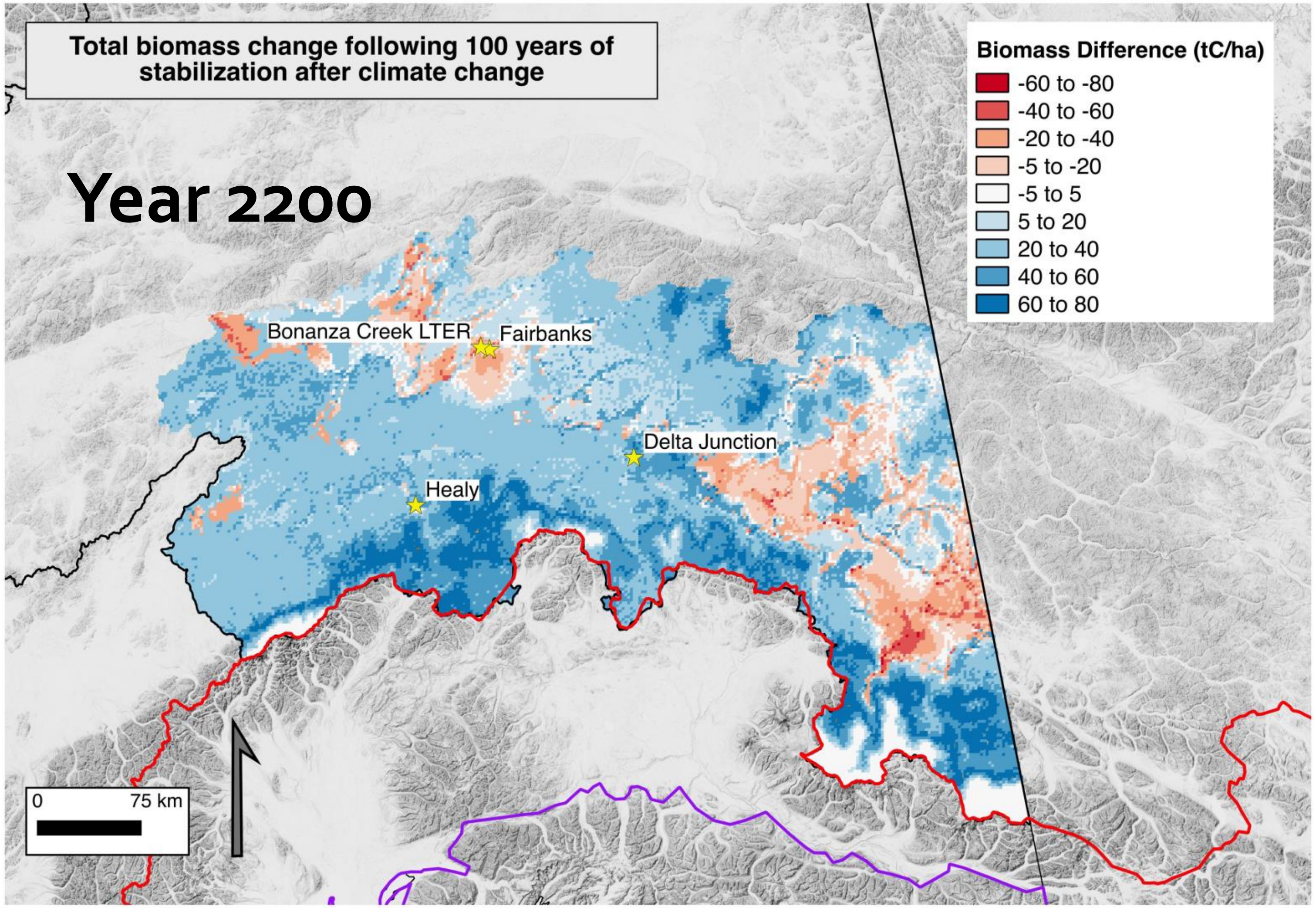


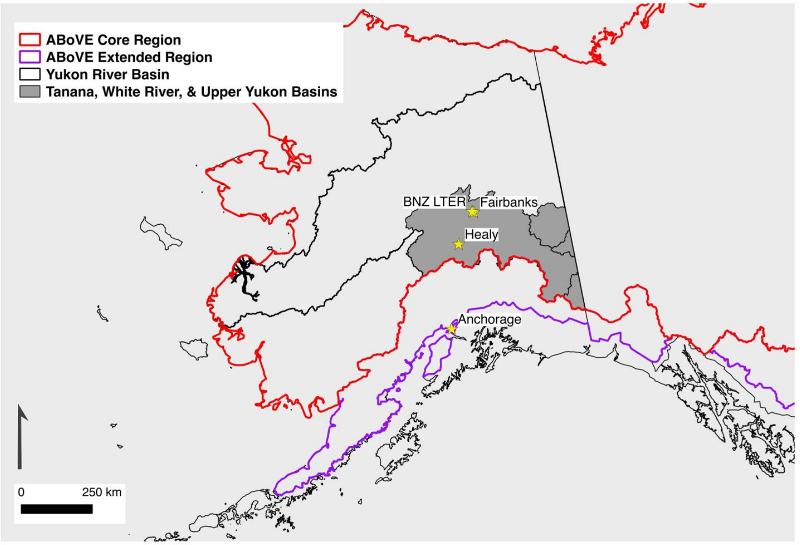
Climate change: RCP 8.5 Scenario

2006 – 2100 climate change + 100 years 'stabilization'
MAT Change: ~ +6ºC
Precipitation Change: ~ +170 mm

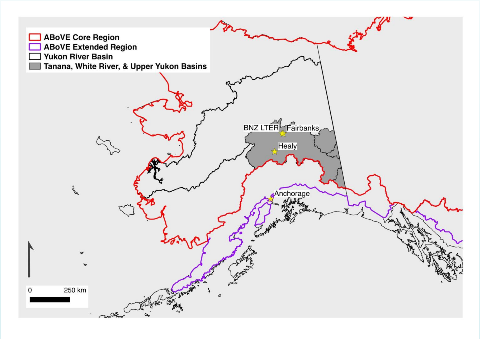

Total biomass change immediately following climate change
Year 2100
Biomass Difference (tC/ha)
-60 to -80
-40 to -60
-20 to -40
-5 to -20
-5 to 5
5 to 20
20 to 40
40 to 60
60 to 80
Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
0
75 km


ABoVE Core Region
ABoVE Extended Region
Yukon River Basin
Tanana, White River, & Upper Yukon Basins
BNZ LTER
Fairbanks
Healy
Anchorage
0
250 km

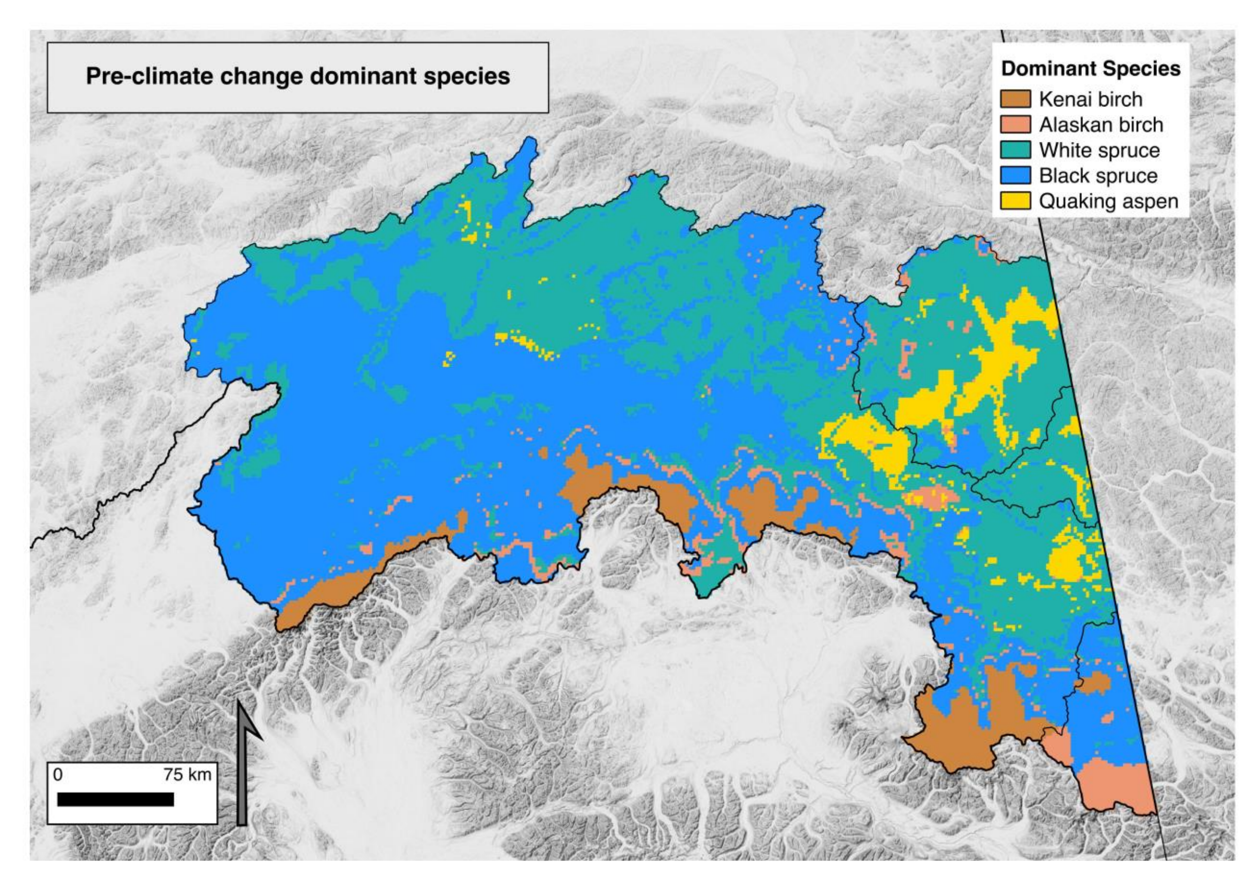


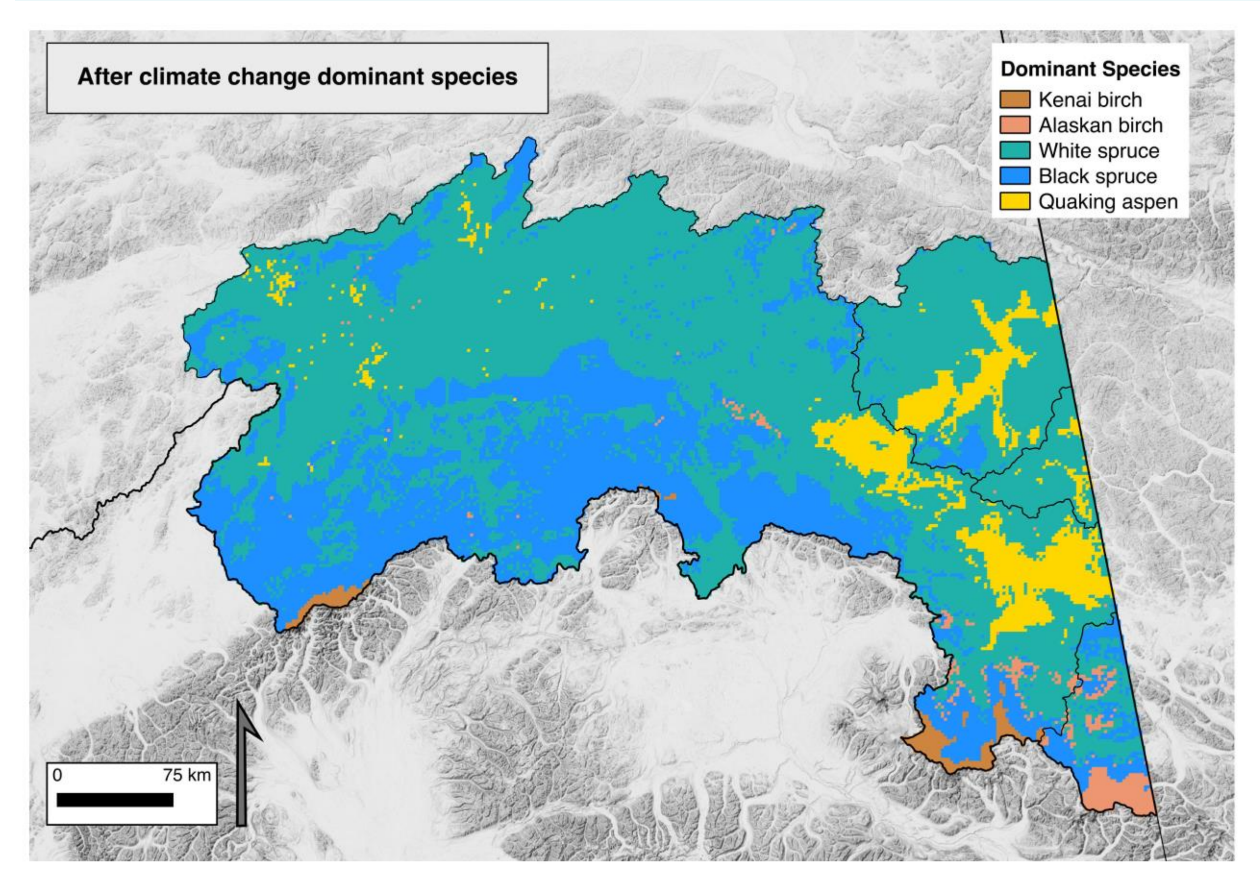


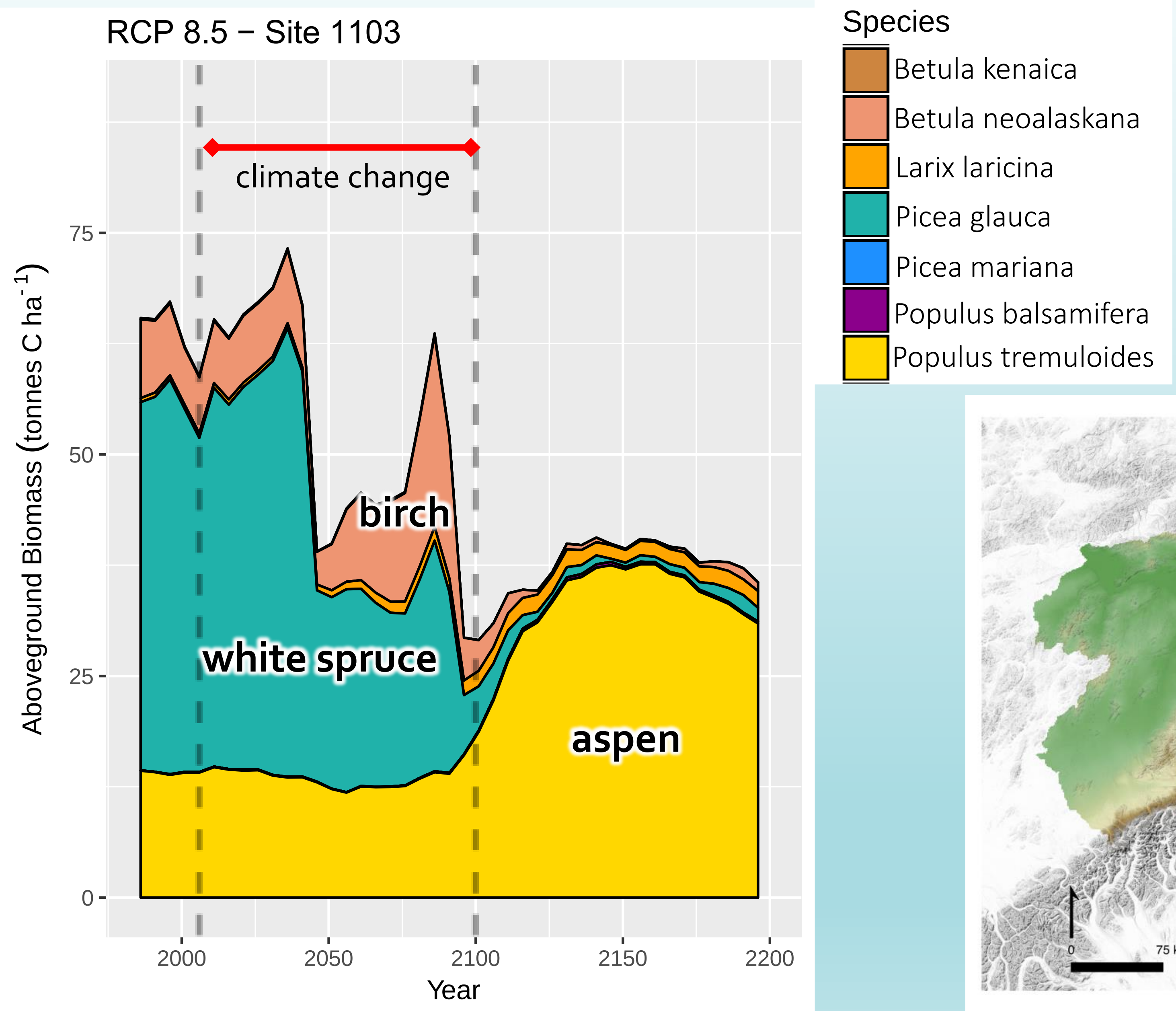
Suggests overall increase in biomass with increasing precipitation and temperatures, with pockets of biomass loss

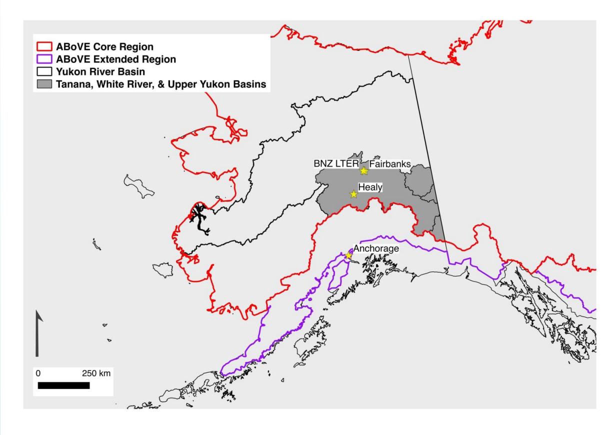


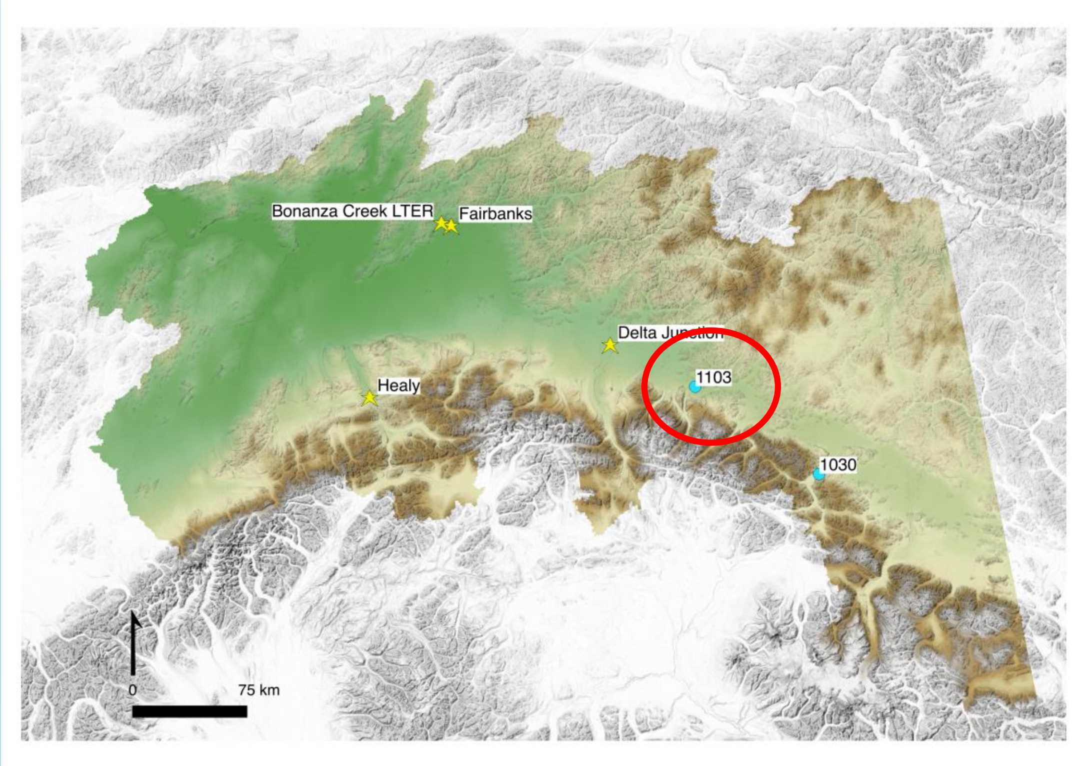
Shift towards white spruce and expansion of aspen

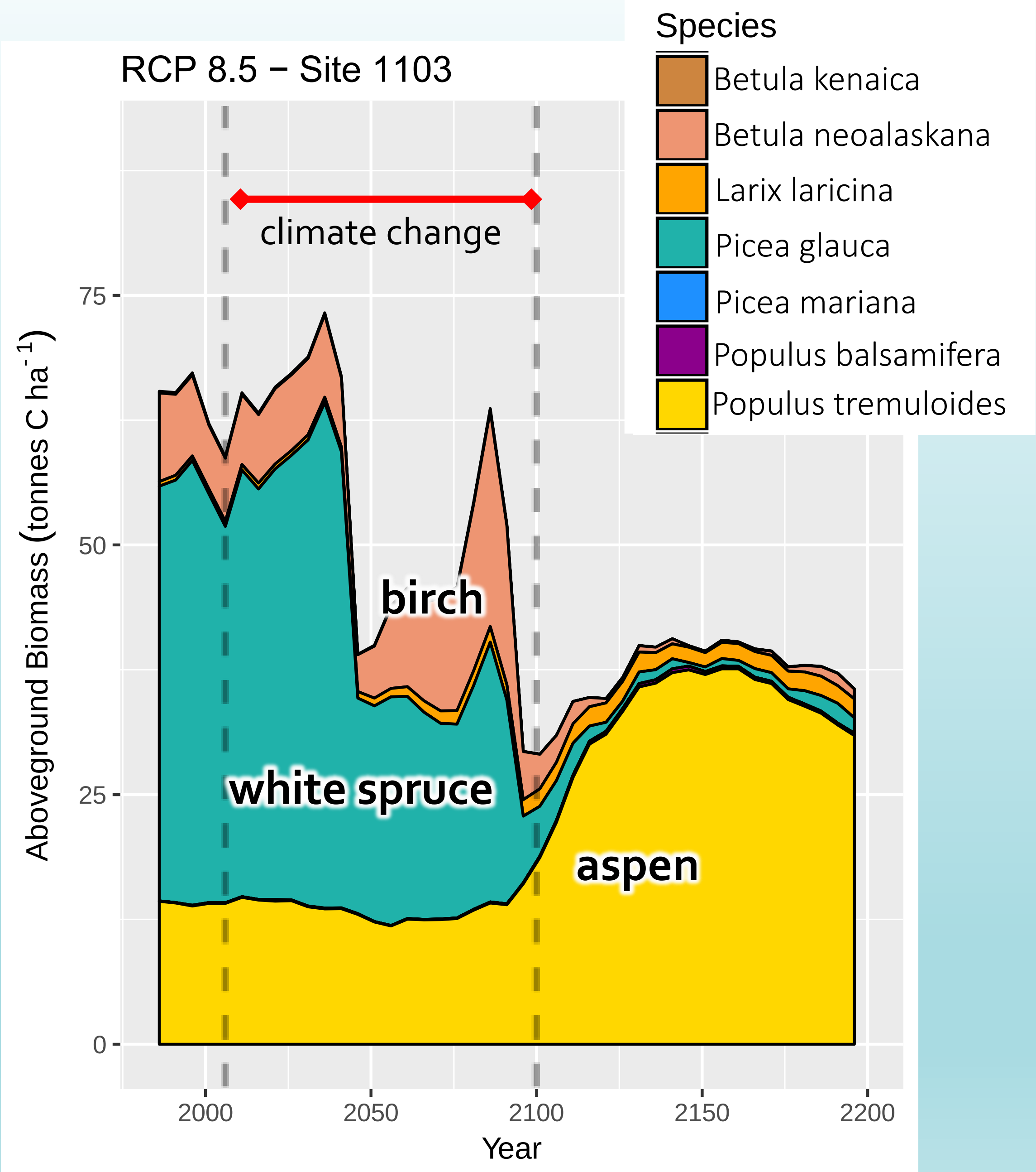


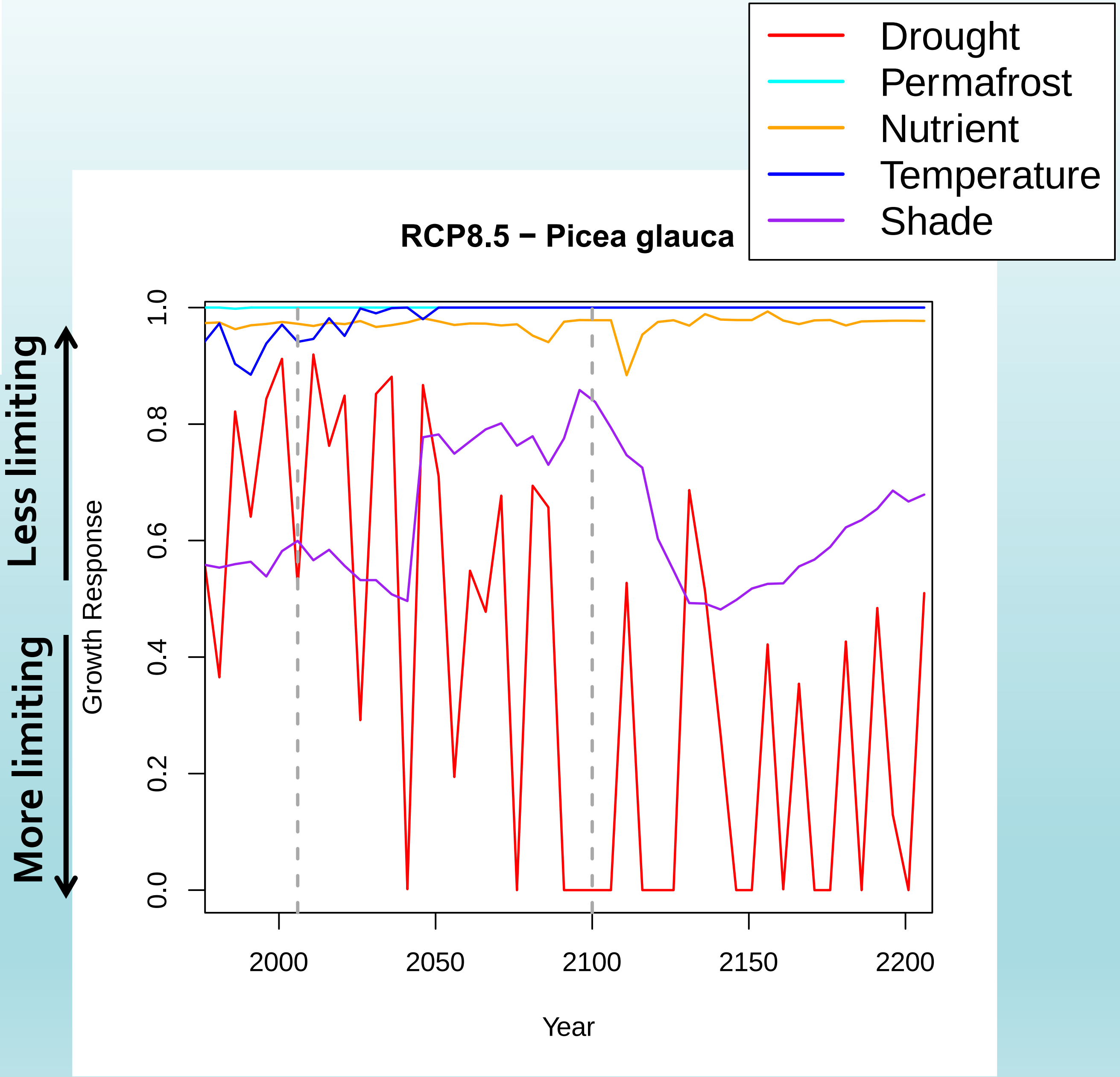


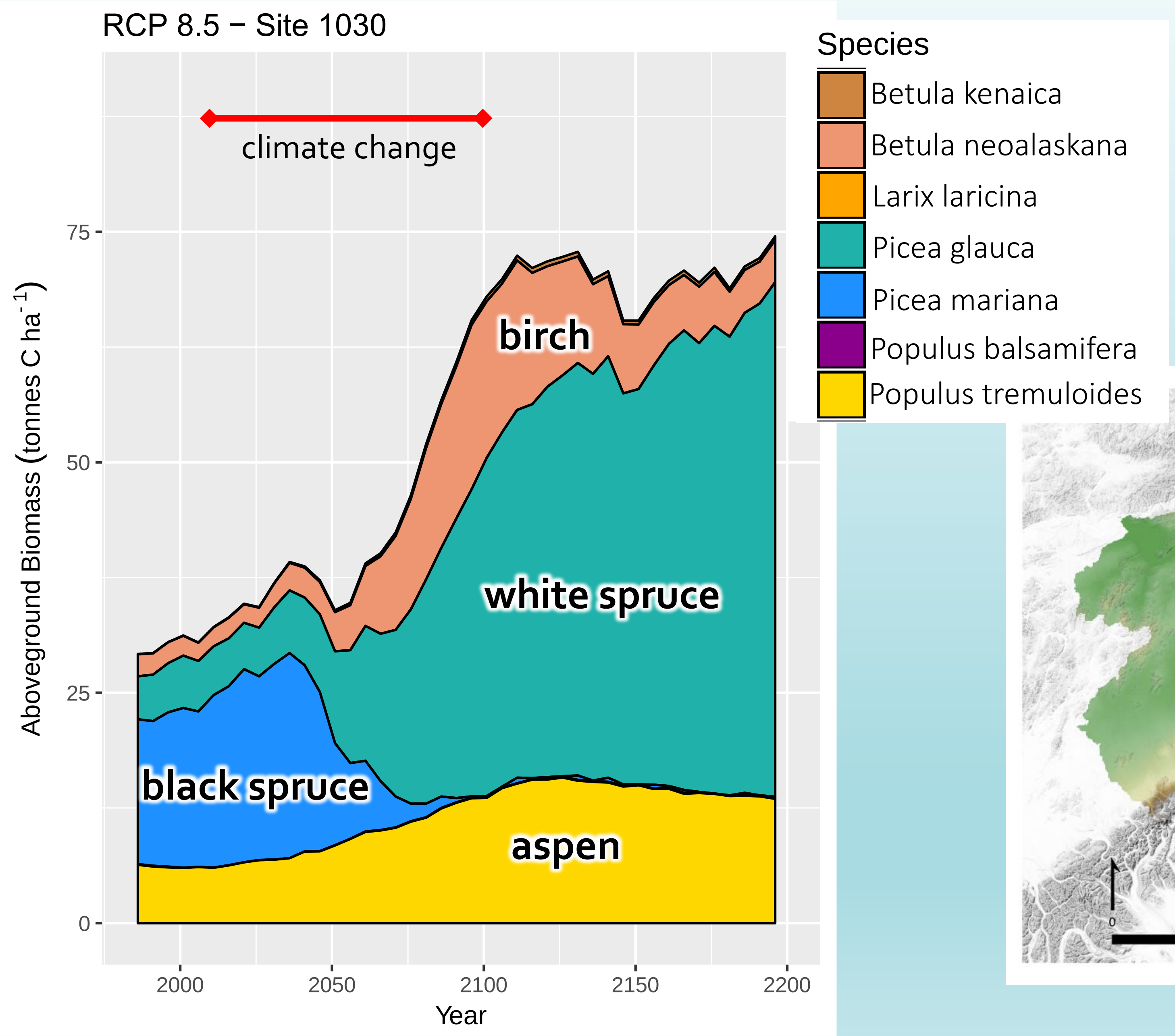

RCP 8.5 − Site 1103
climate change
birch
white spruce
aspen
Aboveground Biomass (tonnes C ha⁻¹)
0
25
50
75
2000
2050
2100
2150
2200
Year
Species
Betula kenaica
Betula neoalaskana
Larix laricina
Picea glauca
Picea mariana
Populus balsamifera
Populus tremuloides

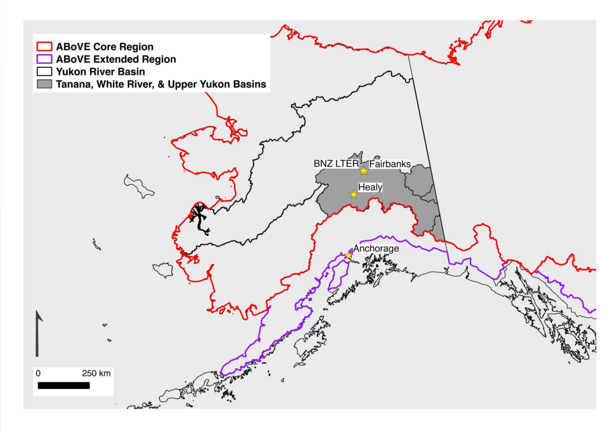

ABoVE Core Region
ABoVE Extended Region
Yukon River Basin
Tanana, White River, & Upper Yukon Basins
BNZ LTER
Fairbanks
Healy
Anchorage
0
250 km

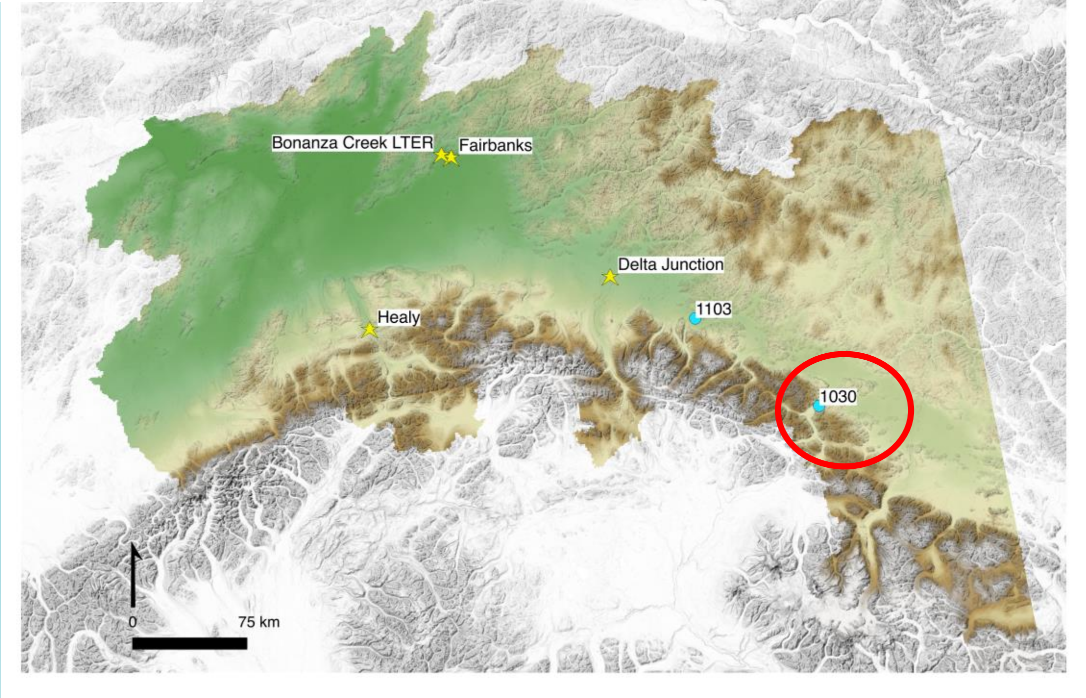

Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
1103
1030
0
75 km

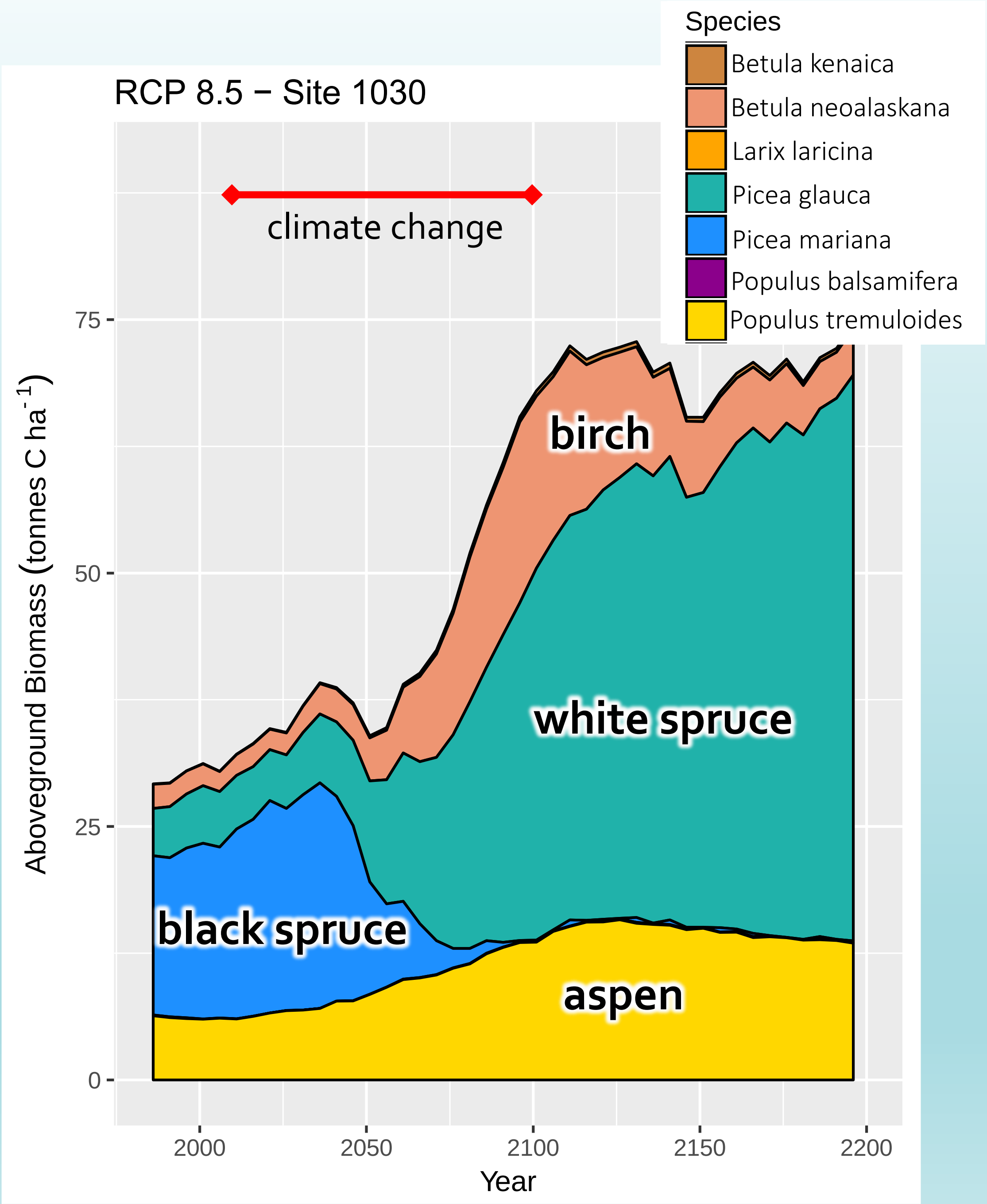

RCP 8.5 − Site 1103
Species
Betula kenaica
Betula neoalaskana
Larix laricina
Picea glauca
Picea mariana
Populus balsamifera
Populus tremuloides
climate change
birch
white spruce
aspen
Aboveground Biomass (tonnes C ha-1)
0
25
50
75
2000
2050
2100
2150
2200
Year

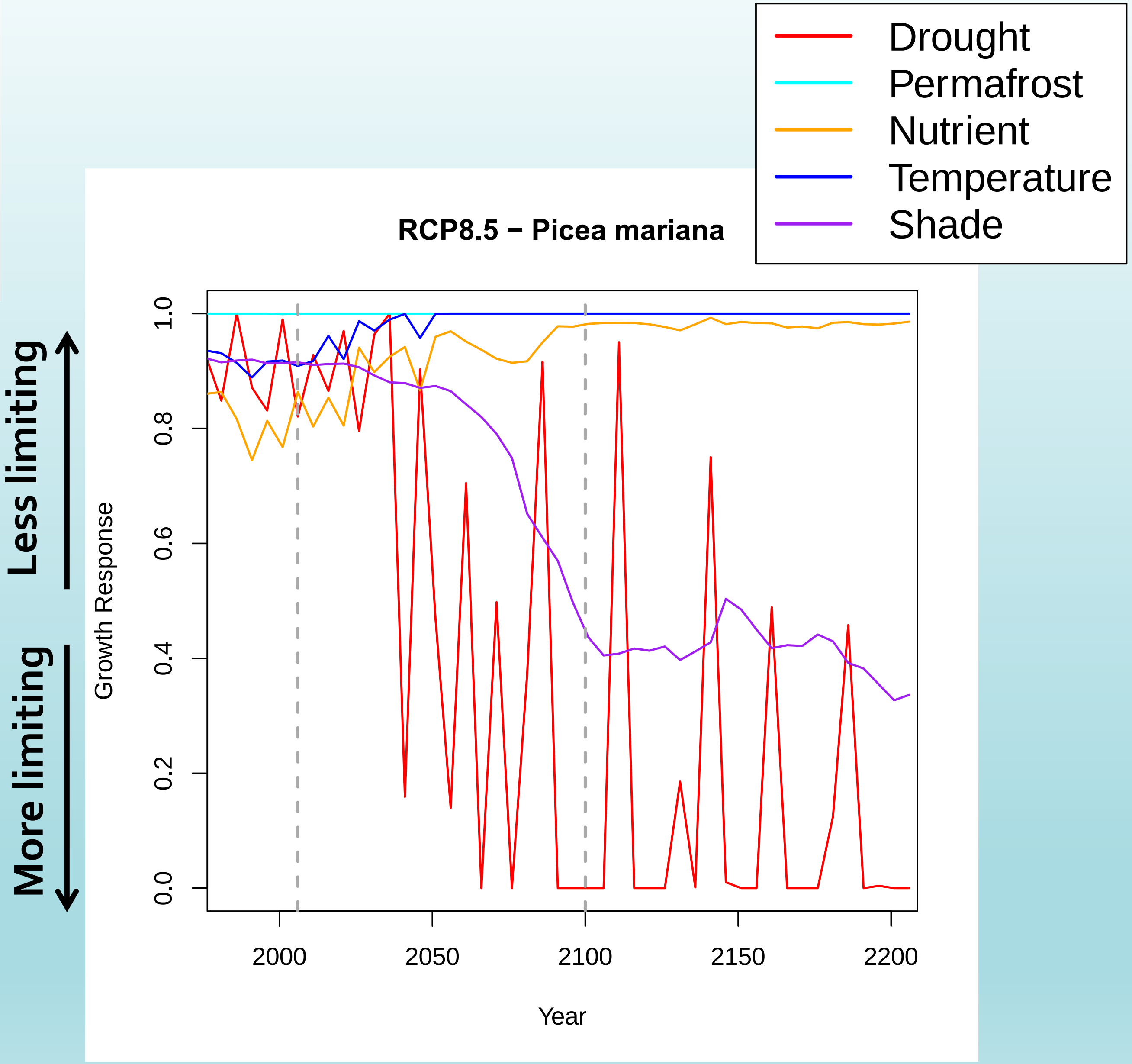

Drought
Permafrost
Nutrient
Temperature
Shade
RCP8.5 − Picea glauca
Less limiting
More limiting
Growth Response
0.0
0.2
0.4
0.6
0.8
1.0
2000
2050
2100
2150
2200
Year

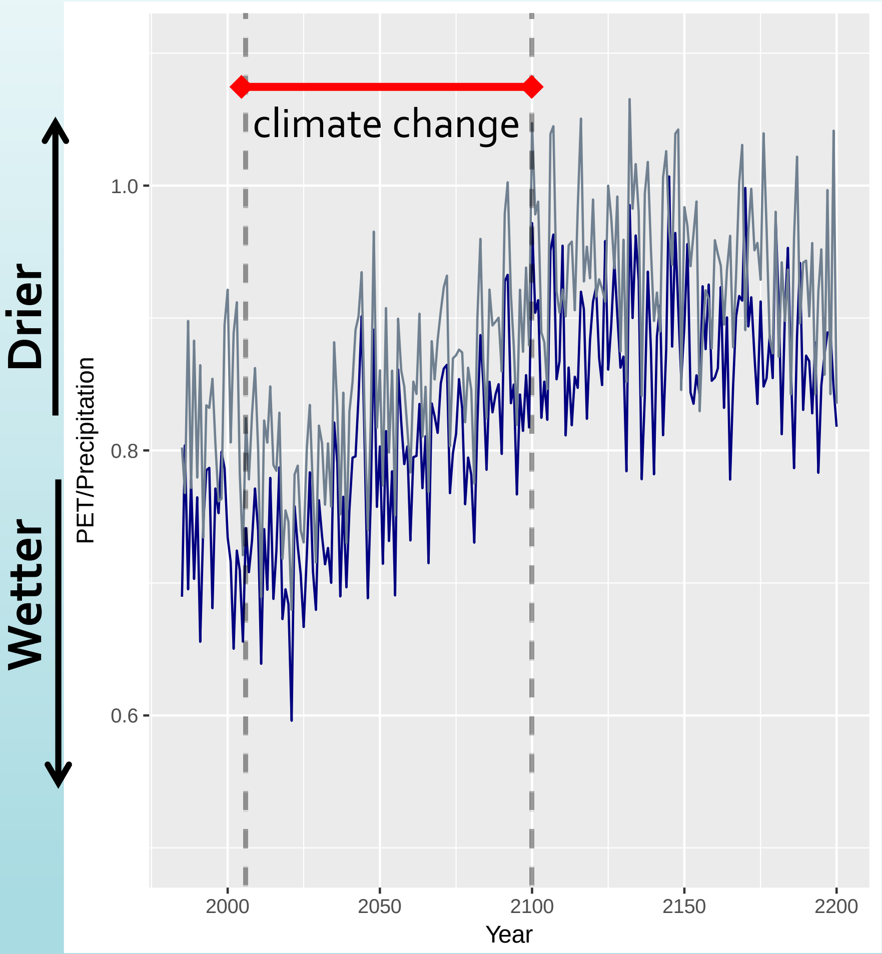

RCP 8.5 − Site 1030
climate change
birch
white spruce
black spruce
aspen
Aboveground Biomass (tonnes C ha-1)
0
25
50
75
2000
2050
2100
2150
2200
Year
Species
Betula kenaica
Betula neoalaskana
Larix laricina
Picea glauca
Picea mariana
Populus balsamifera
Populus tremuloides

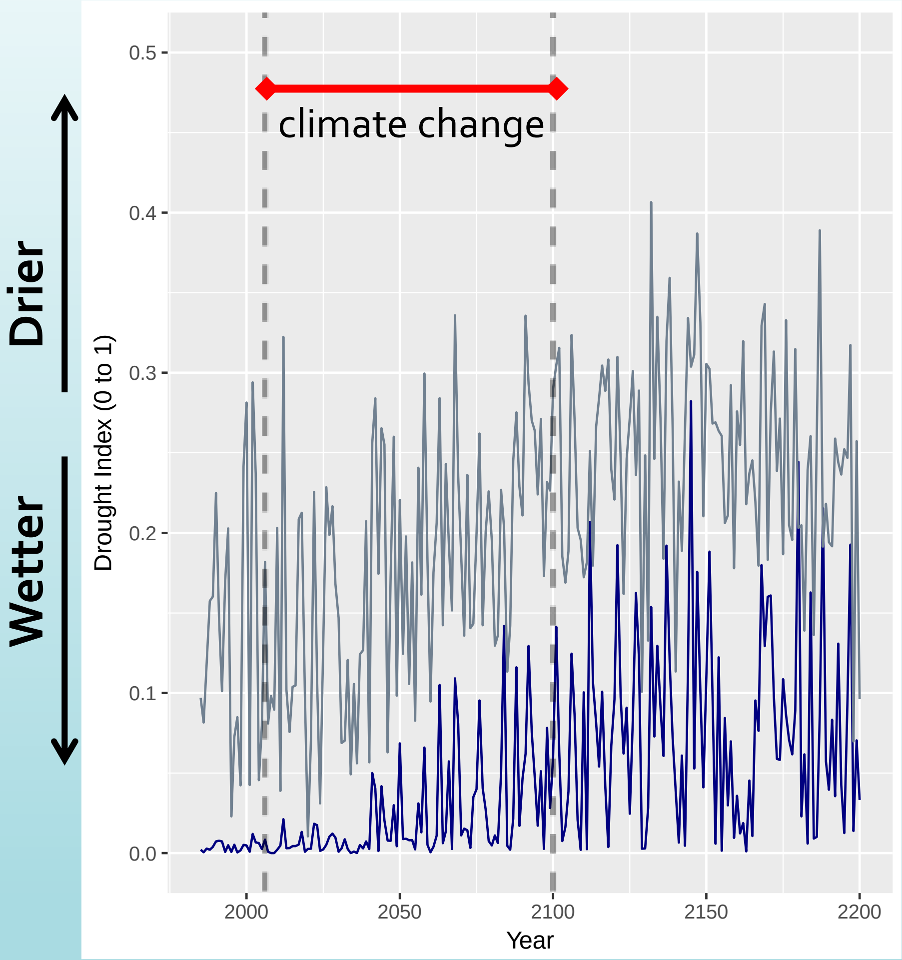

ABoVE Core Region
ABoVE Extended Region
Yukon River Basin
Tanana, White River, & Upper Yukon Basins
BNZ LTER
Fairbanks
Healy
Anchorage
0
250 km

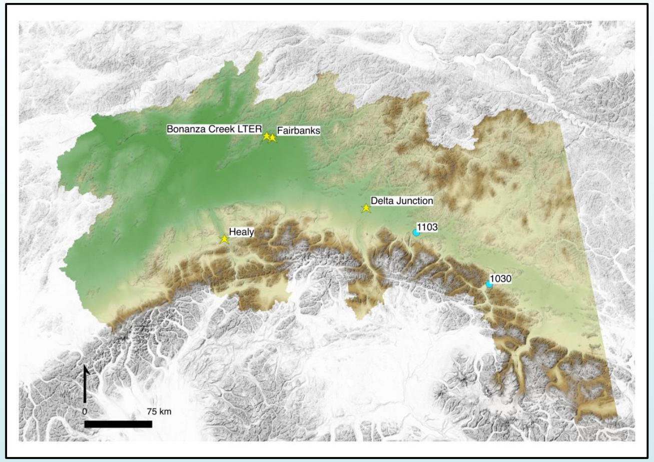

Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
1103
1030
0
75 km

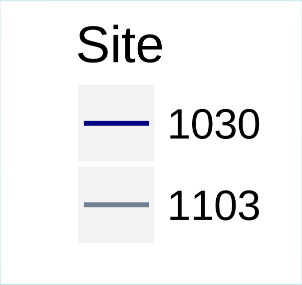

RCP 8.5 − Site 1030
Species
Betula kenaica
Betula neoalaskana
Larix laricina
Picea glauca
Picea mariana
Populus balsamifera
Populus tremuloides
climate change
birch
white spruce
black spruce
aspen
Aboveground Biomass (tonnes C ha^{-1})
75
50
25
0
2000
2050
2100
2150
2200
Year

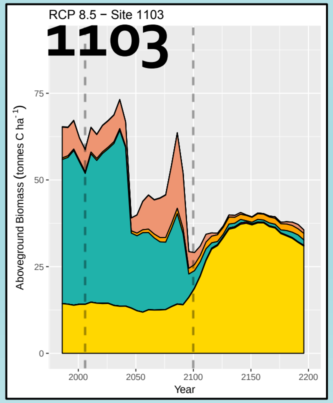

Drought
Permafrost
Nutrient
Temperature
Shade
RCP8.5 − Picea mariana
Less limiting
More limiting
Growth Response
1.0
0.8
0.6
0.4
0.2
0.0
2000
2050
2100
2150
2200
Year

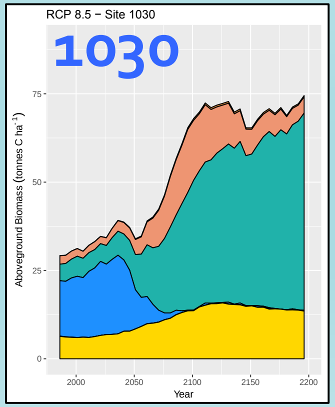

Drier
Wetter
climate change
PET/Precipitation
1.0
0.8
0.6
2000
2050
2100
2150
2200
Year


Drier
Wetter
climate change
Drought Index (0 to 1)
0.5
0.4
0.3
0.2
0.1
0.0
2000
2050
2100
2150
2200
Year

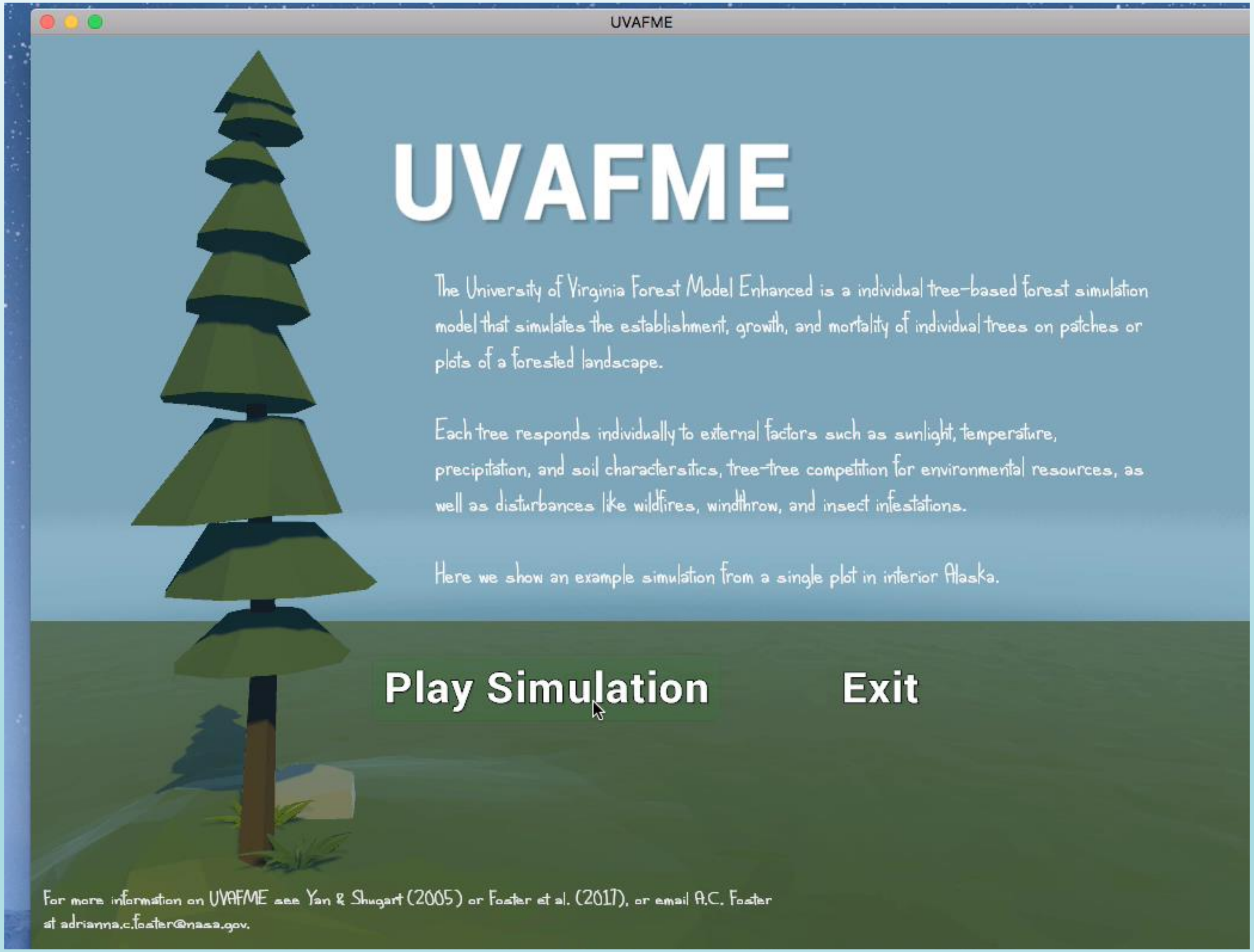

Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
1103
1030
0
75 km

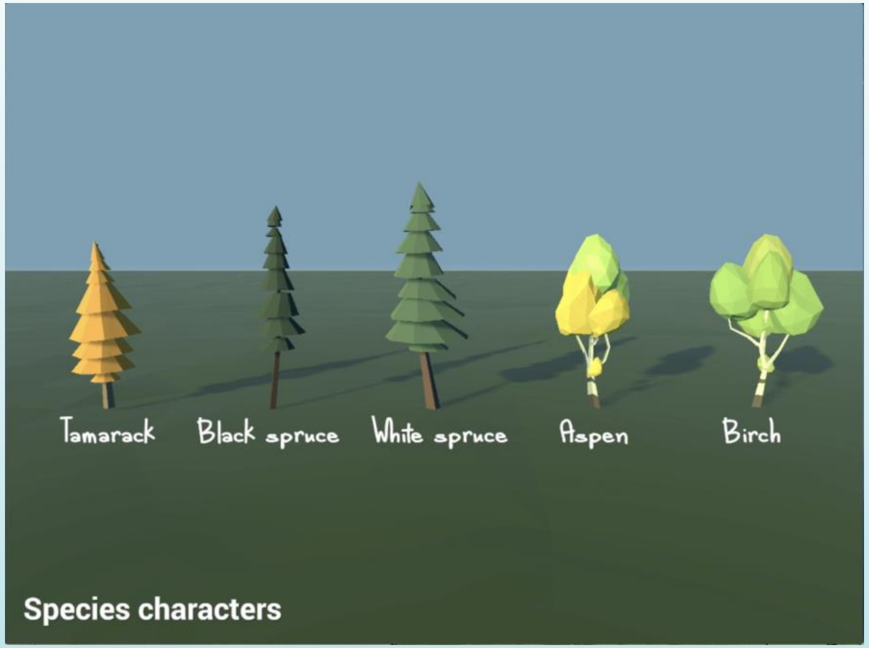

Site
1030
1103

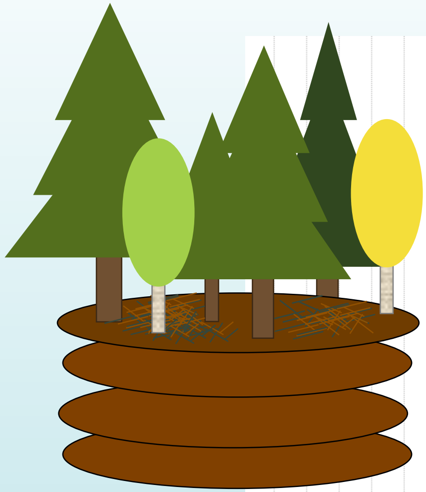

RCP 8.5 – Site 1103
1103
Aboveground Biomass (tonnes C ha-1)
75
50
25
0
2000
2050
2100
2150
2200
Year


RCP 8.5 – Site 1030
1030
Aboveground Biomass (tonnes C ha-1)
75
50
25
0
2000
2050
2100
2150
2200
Year

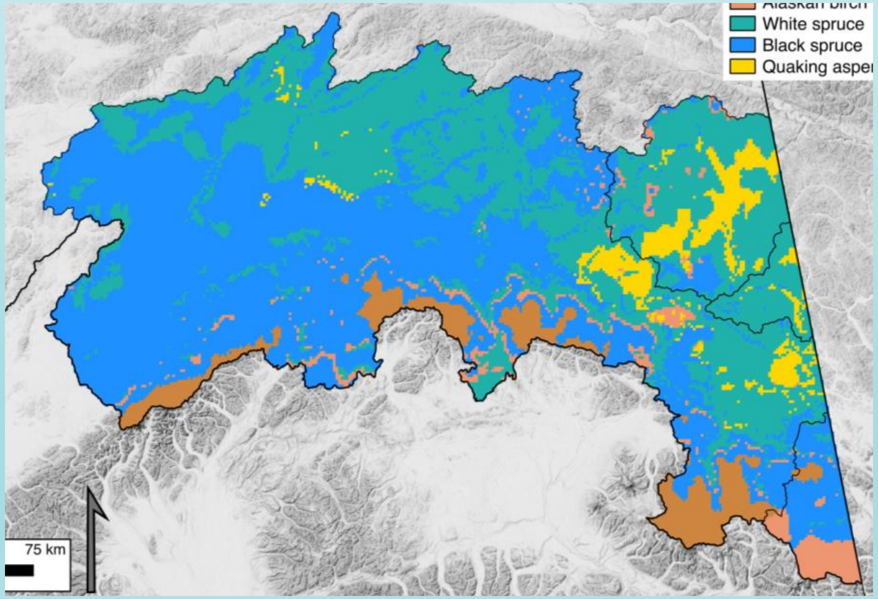
Other visualizations

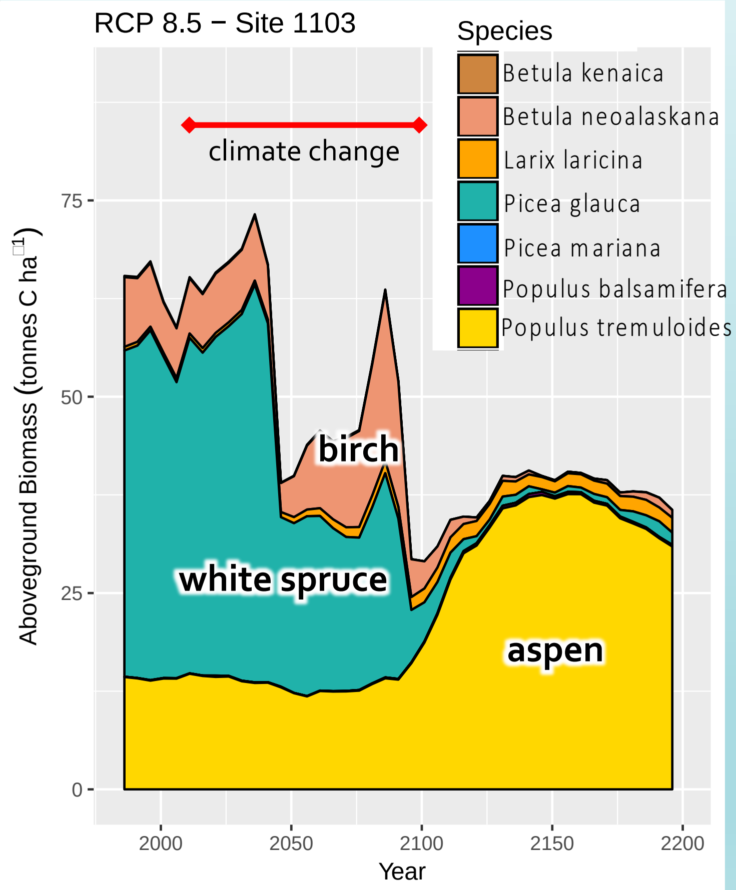






```
        site%plots(ip)%trees(it)%mort_count =          &
            site%plots(ip)%trees(it)%mort_count + 1

        if (site%plots(ip)%trees(it)%mort_count      &
                .ge. mcount) then
            site%plots(ip)%trees(it)%mort_marker = &
                    .true.
        endif

    else
        site%plots(ip)%trees(it)%mort_count = 0
        site%plots(ip)%trees(it)%mort_marker =     &
                .false.
    endif
else
    if ((dt .le. pp) .or.                              &
            (fc_n .le. growth_thresh)) then
        site%plots(ip)%trees(it)%mort_count =      &
            site%plots(ip)%trees(it)%mort_count + 1

        if (site%plots(ip)%trees(it)%mort_count      &
                .ge. mcount) then
            site%plots(ip)%trees(it)%mort_marker = &
                    .true.
        endif

    else
        site%plots(ip)%trees(it)%mort_count = 0
        site%plots(ip)%trees(it)%mort_marker =     &
                .false.
    endif
end if


!compute N_used and NPP

! compute actual height and diameter w/o
!intermediate adjustments
call forska_height(site%plots(ip)%trees(it))
```





Acknowledgements

Funding sources

NASA Postdoctoral Program

Co-authors

Jon Ranson

Amanda Armstrong

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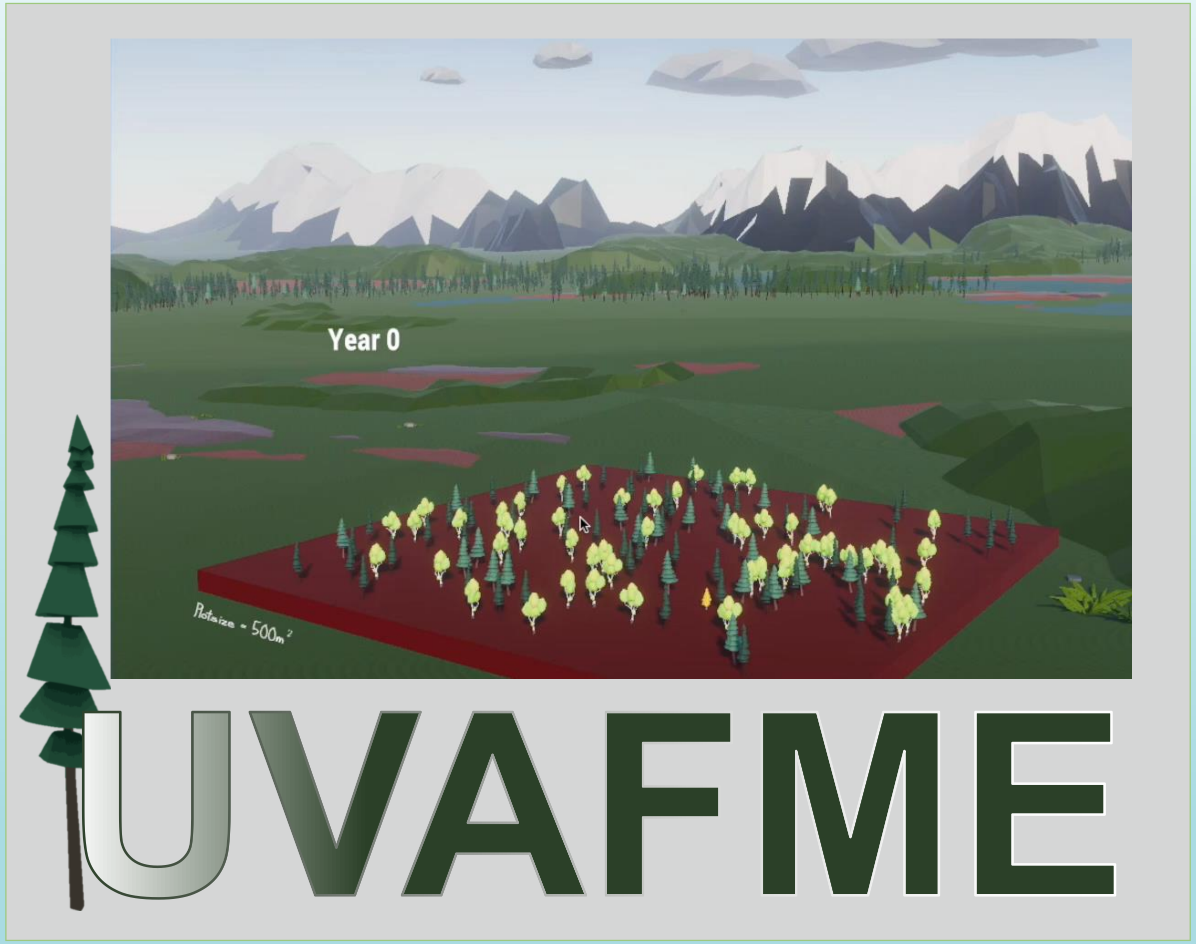
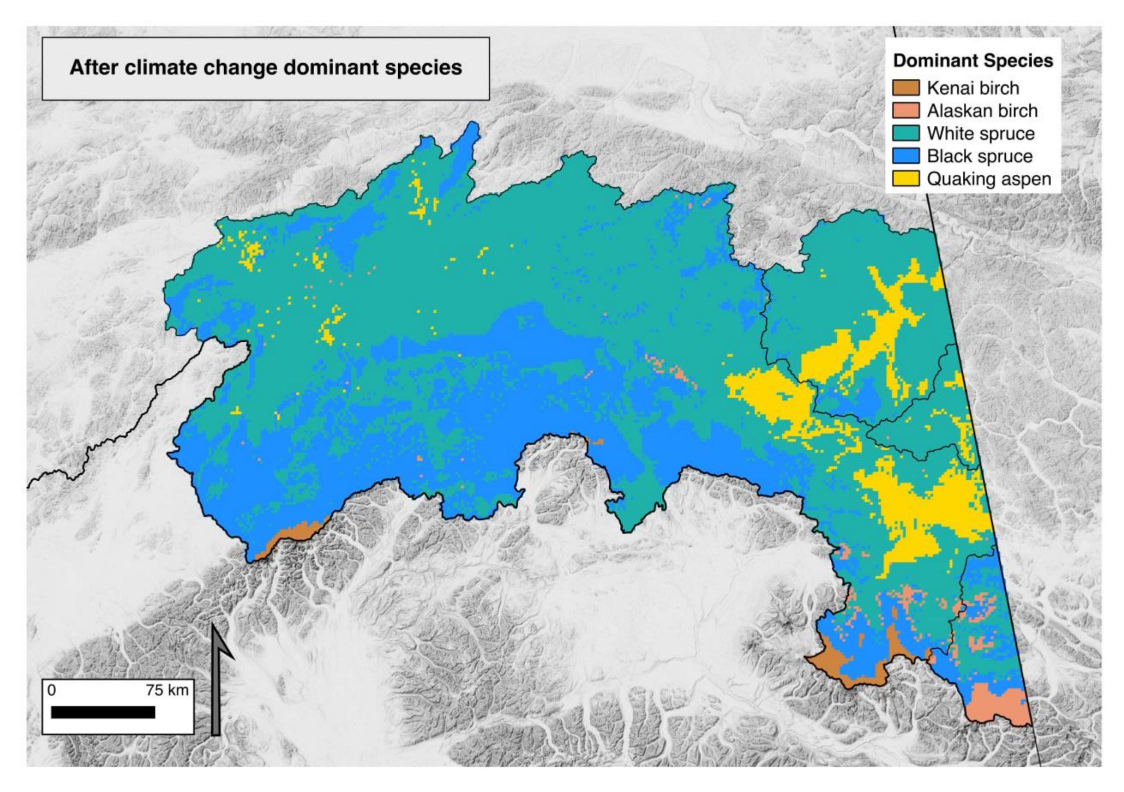
Brendan Rogers

Scott Goetz

Questions?


Year 0
UVAFME


After climate change dominant species
Dominant Species
Kenai birch
Alaskan birch
White spruce
Black spruce
Quaking aspen
0
75 km

References

Harris, I., Jones, P.D., Osborn, T.J., Lister, D.H., 2014. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. International Journal of Climatology 34, 624–642.

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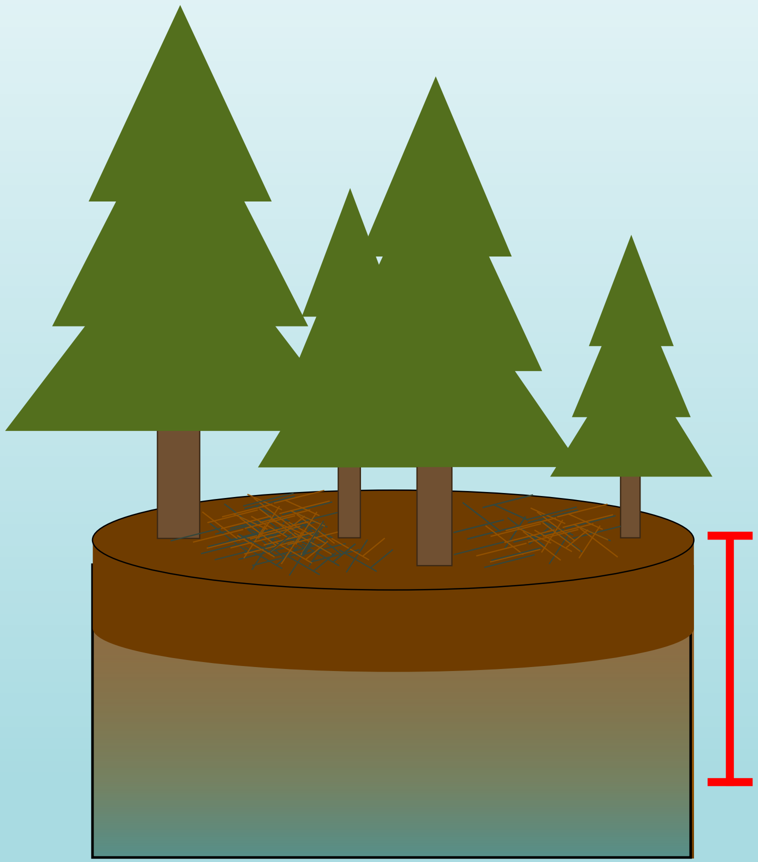
Yan, X., Shugart, H.H., 2005. FAREAST: a forest gap model to simulate dynamics and patterns of eastern Eurasian forests: Simulation of eastern Eurasian forests. Journal of Biogeography 32, 1641–1658. https://doi.org/10.1111/j.1365-2699.2005.01293.x

Updated UVAFME to include calculations for permafrost depth

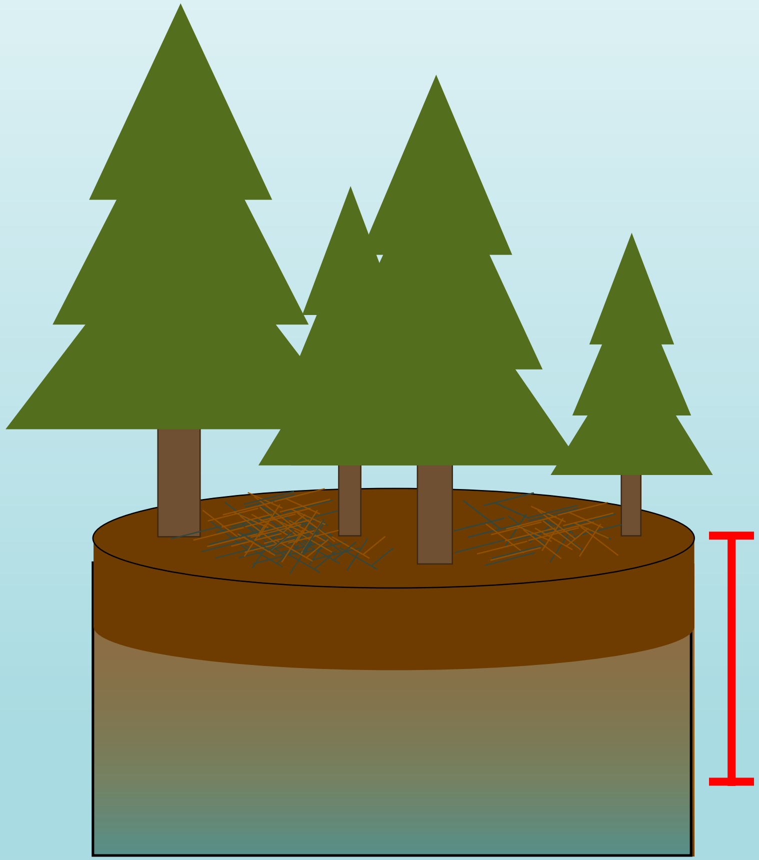


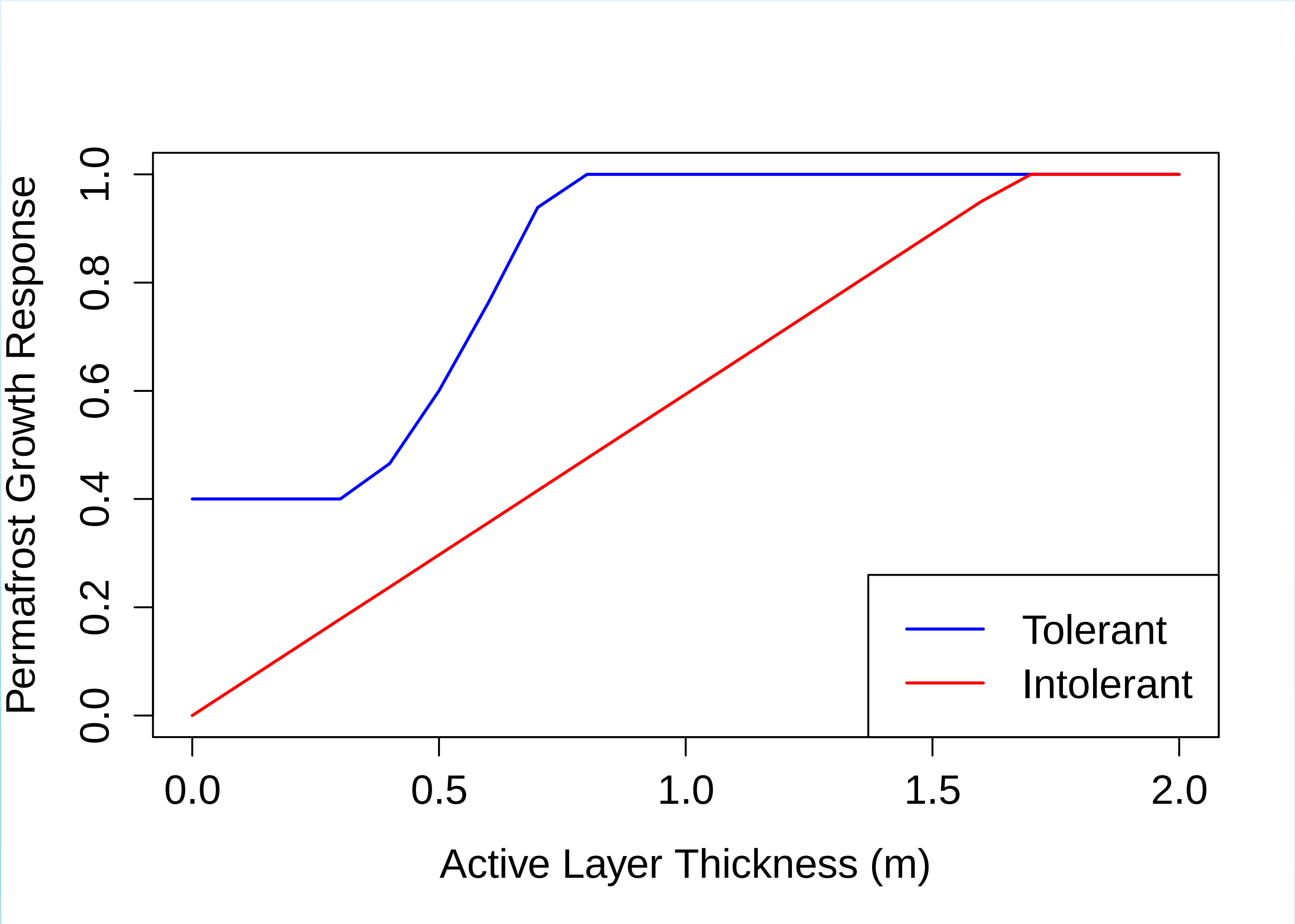
Depth of thaw based on:

- degree day sums
- soil moisture
- organic layer and moss thickness
- effect of slope/aspect on radiation
- canopy closure

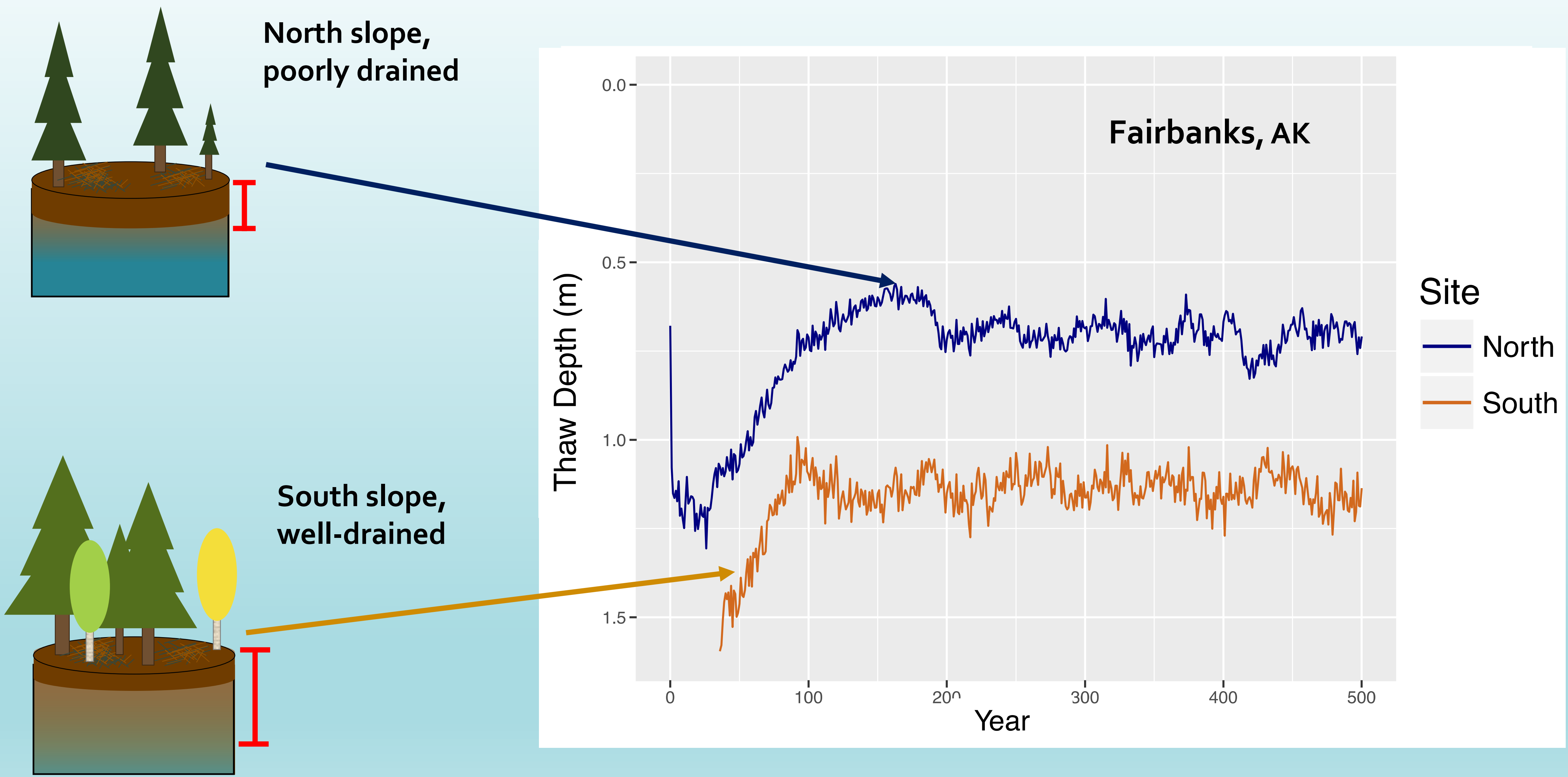
Bonan 1989

Species-specific permafrost tolerance affects tree growth



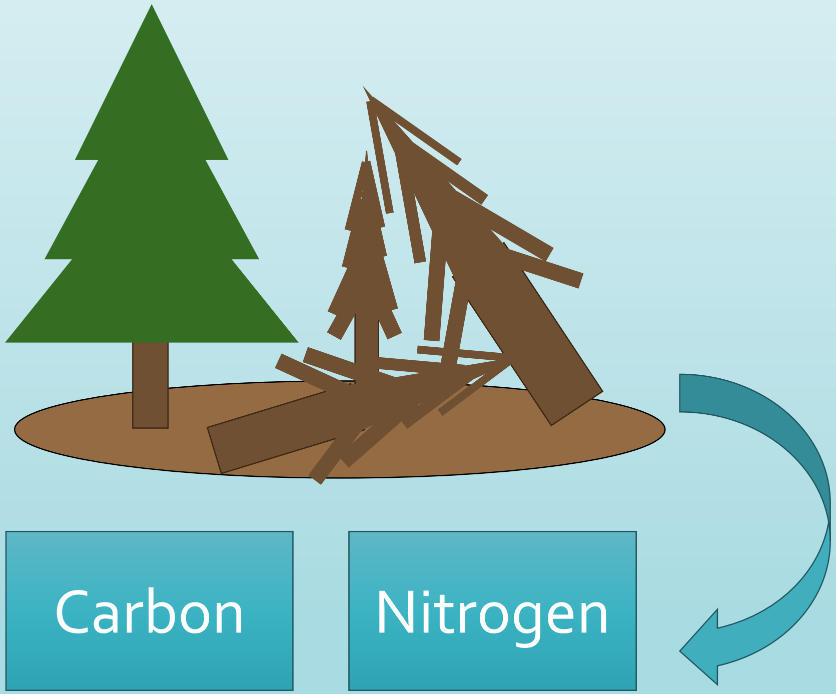


Bonan 1989


North slope,
poorly drained
South slope,
well-drained
Fairbanks, AK
Thaw Depth (m)
0.0
0.5
1.0
1.5
0
100
200
300
400
500
Year
Site
North
South

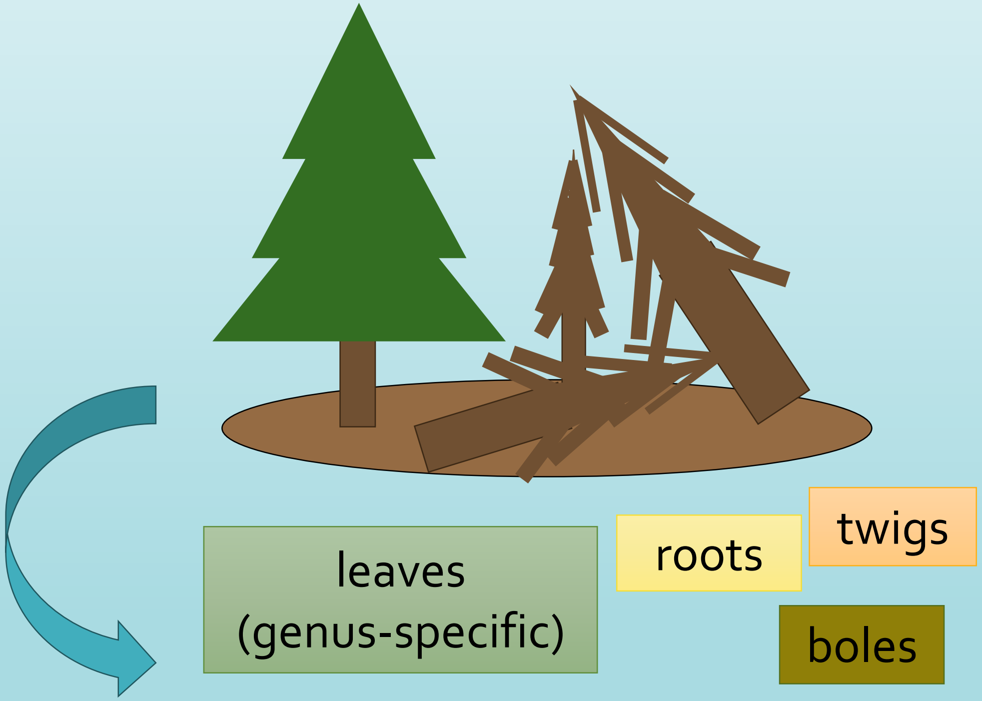
Updated litter and nutrient equations

Previous UVAFME



Linear equations for respiration amount & N availability, based on temperature and soil moisture

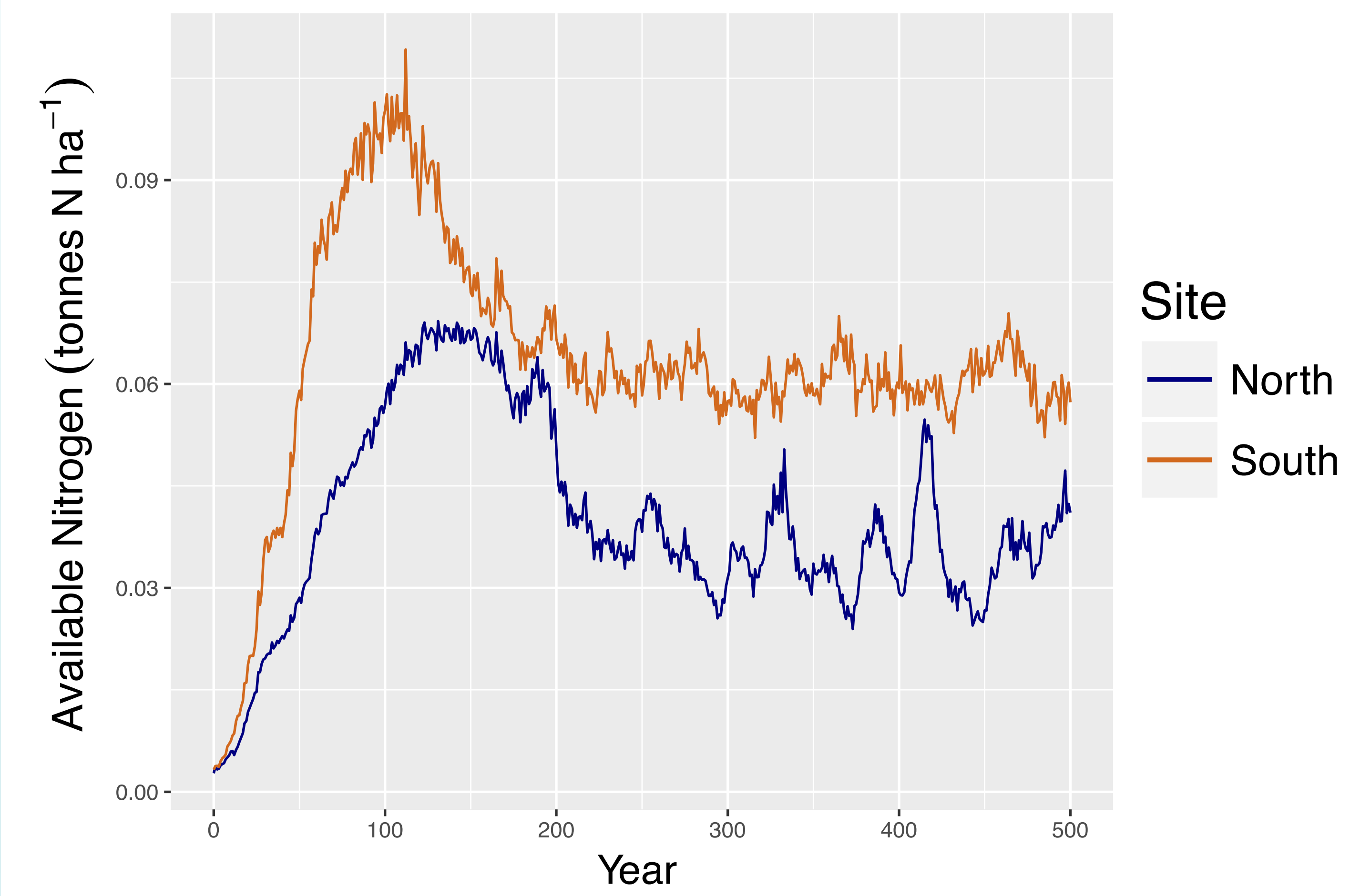
Updated UVAFME



Individual cohorts decay according to %N, %lignin, moisture, light level, and permafrost depth

Bonan et al. 1990
Pastor & Post 1985

Updated litter and nutrient equations

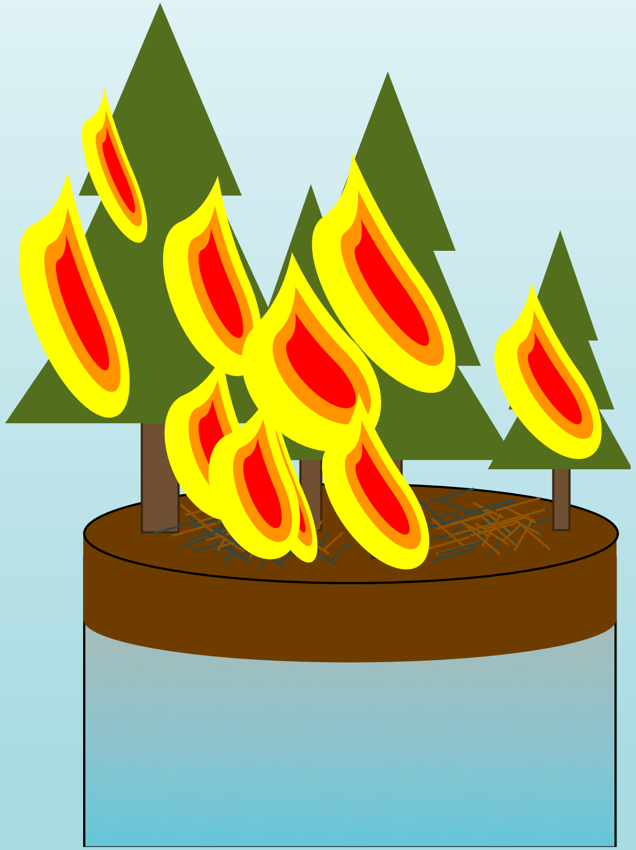


Litter quality determines decomposition rate, organic layer depth, and plant-available nitrogen

- **Feedbacks to species composition & biomass**

Bonan et al. 1990
Pastor & Post 1985

Introduction of fuels tracking and consumption of litter and organic layer



Fire intensity and litter/organic layer consumption based on:

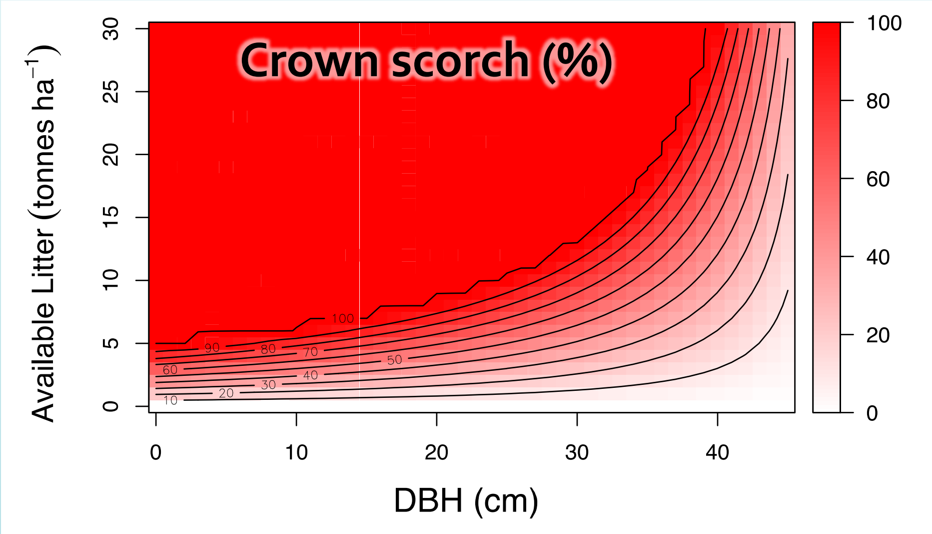
leaf, twig, and bole litter amounts
soil/litter dryness and site aridity

Crown scorch based on:

fire intensity and tree size

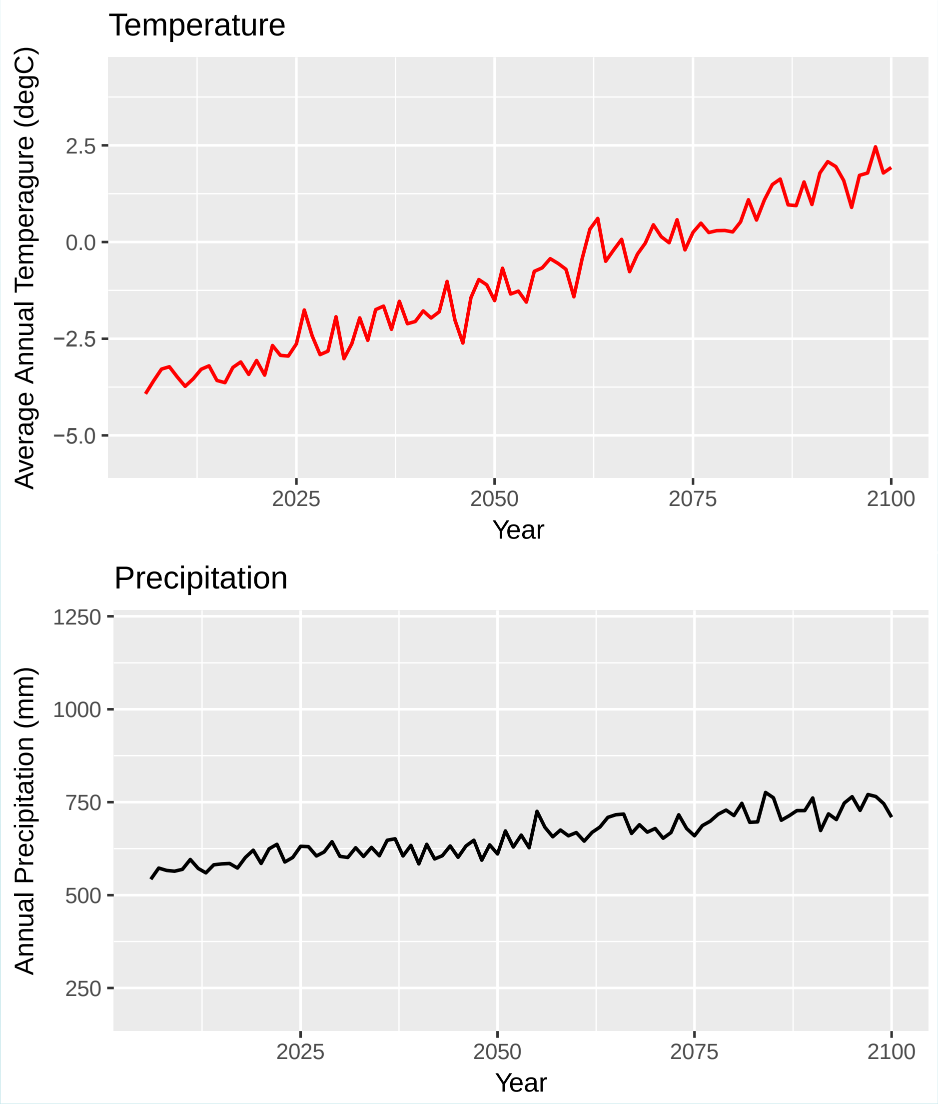
Fire mortality determined by:

crown scorch, tree size, species-specific bark thickness



Schumacher et al. 2006
Keane et al. 2011

Climate change simulations



Climate change: RCP 8.5 Scenario

MAT Change: ~ +6ºC
Precipitation Change: ~ +170 mm

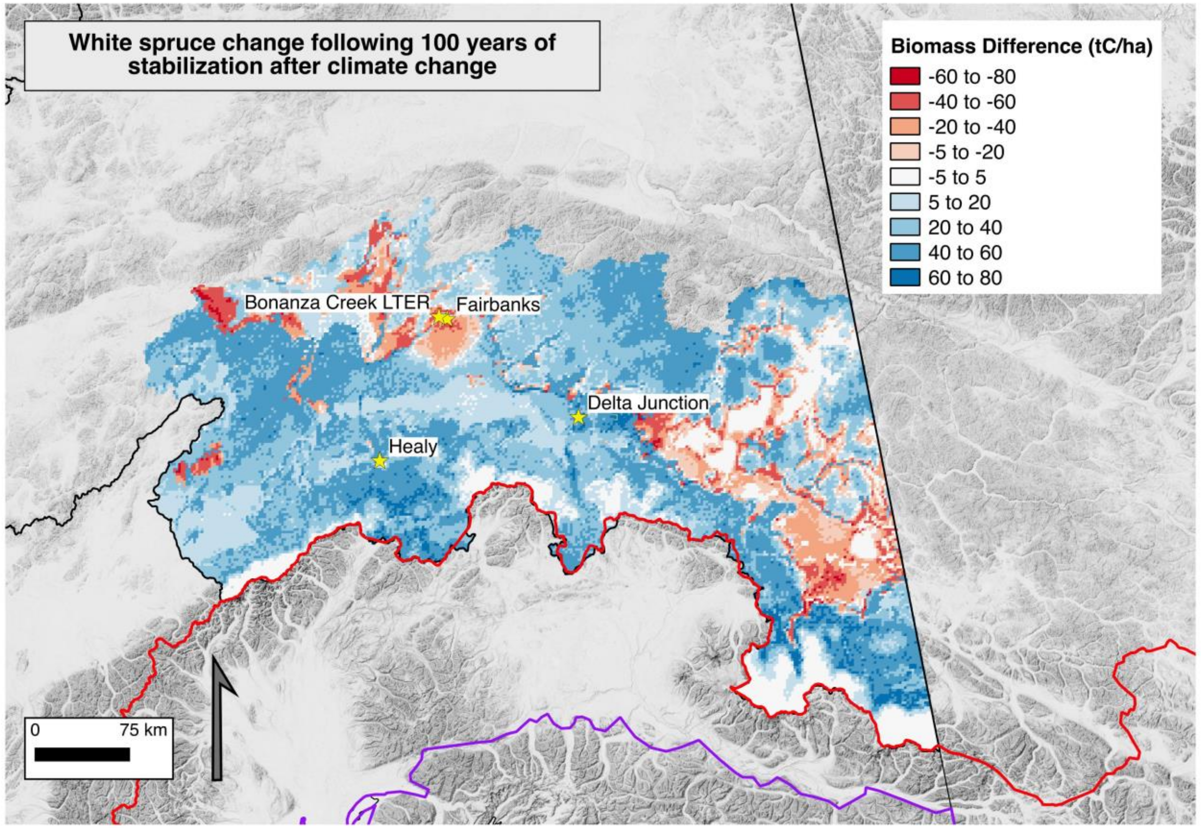
Climate change inputs from downscaled (771 m) projections (2006-2100) from a CMIP 5-model average of 5 top-ranked global circulation models
(CCSM4, GGDL-CM3, GISS-E2-R, IPSL-CM5A-LR, & MRI-CGCM3)

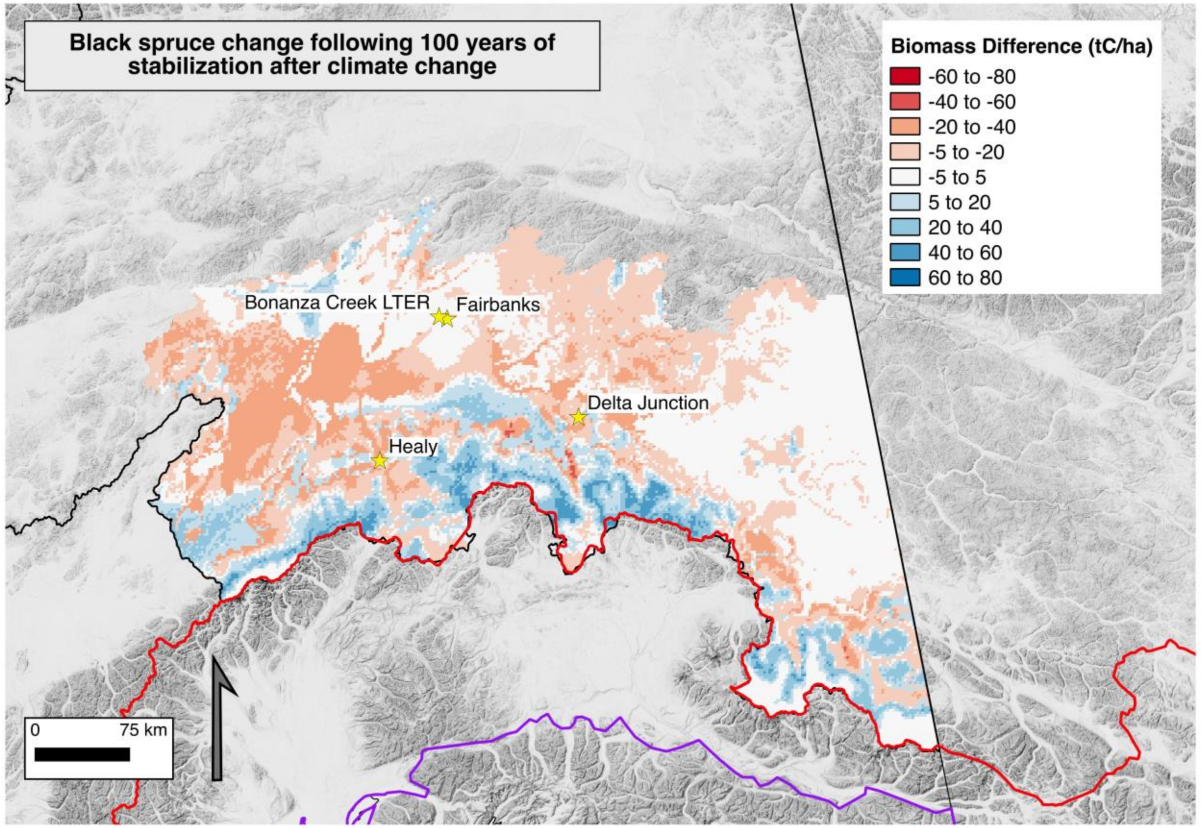
UVAFME Simulations

- Started climate change runs at mature forest state (400 years from bare ground simulation)
- Allowed forest to stabilize at new climate values for 100 years after climate change

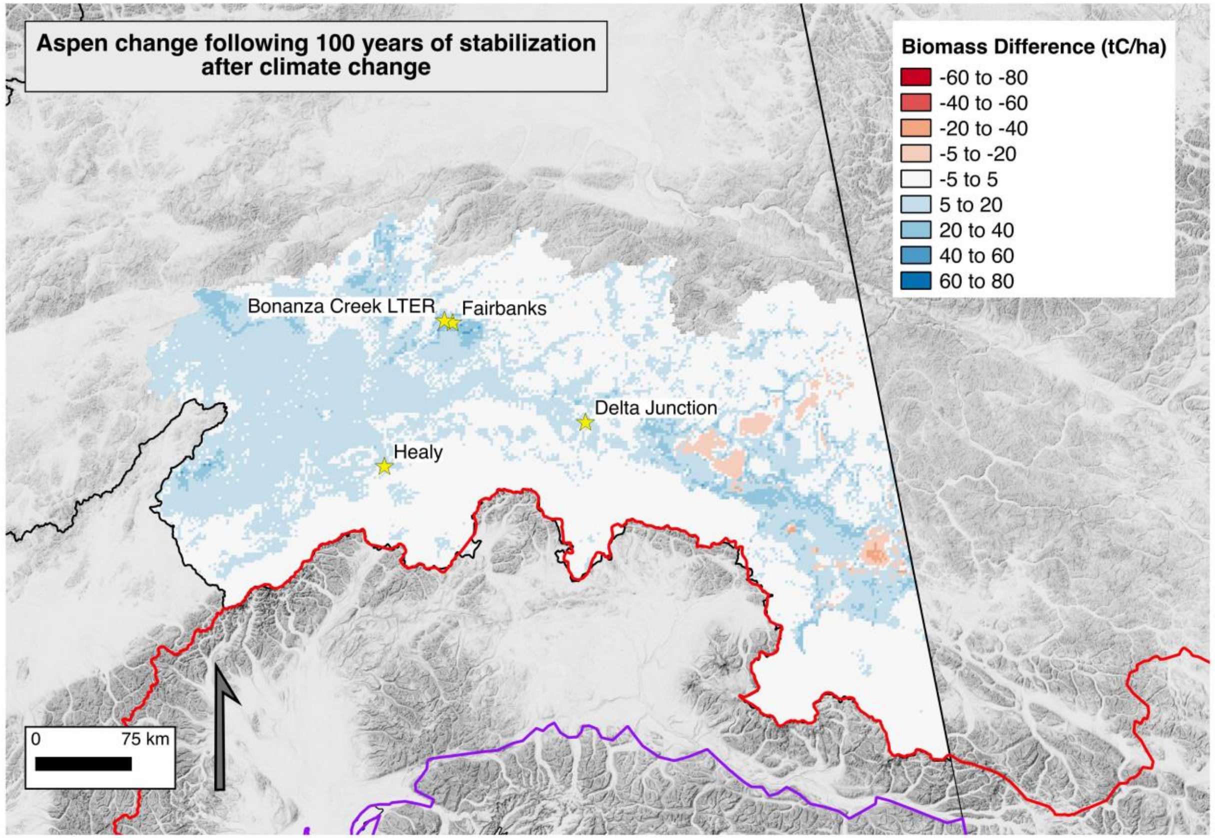
GCM data credit: Leonawicz, M., M. Lindgren, T. Kurkowski, S. Rupp, & J. Walsh, (2015) SNAP Database (http://ckan.snap.uaf.edu/dataset)

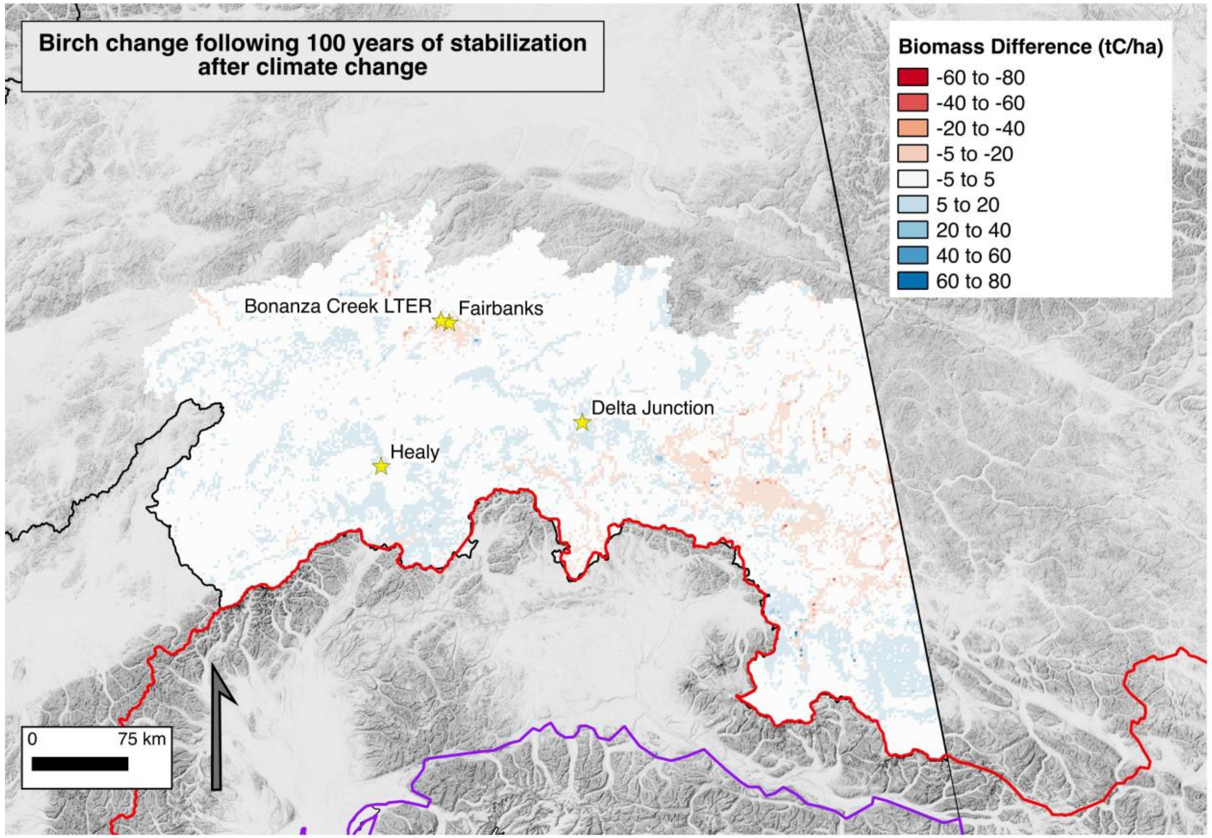
Year 2200


White spruce change following 100 years of stabilization after climate change
Biomass Difference (tC/ha)
-60 to -80
-40 to -60
-20 to -40
-5 to -20
-5 to 5
5 to 20
20 to 40
40 to 60
60 to 80
Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
0
75 km


Black spruce change following 100 years of stabilization after climate change
Biomass Difference (tC/ha)
-60 to -80
-40 to -60
-20 to -40
-5 to -20
-5 to 5
5 to 20
20 to 40
40 to 60
60 to 80
Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
0
75 km

Year 2200


Aspen change following 100 years of stabilization after climate change
Biomass Difference (tC/ha)
-60 to -80
-40 to -60
-20 to -40
-5 to -20
-5 to 5
5 to 20
20 to 40
40 to 60
60 to 80
Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
0
75 km


Birch change following 100 years of stabilization after climate change
Biomass Difference (tC/ha)
-60 to -80
-40 to -60
-20 to -40
-5 to -20
-5 to 5
5 to 20
20 to 40
40 to 60
60 to 80
Bonanza Creek LTER
Fairbanks
Delta Junction
Healy
0
75 km