Carbon loss and radiative forcings of gaseous emissions from tundra wildfires during the Yukon Kuskokwim River Delta 2015 fire season

Michael Moubarak[1], Sue Natali[2], Brendan Rogers[2], Seeta Sistla[3], William Pfitsch[1], Sol Cooperdock[2], Anne-Katrine Selbmann[4], Sarah Ludwig[5], and Daniel S. Ward[6]

Hamilton College[1], Woods Hole Research Center[2], California Polytechnic Institute[3], University of Bayreuth[4], Columbia University[5], and Karen Clark and Company[6]

Introduction

Fire frequency is increasing rapidly in the Arctic, and fires are a significant source of greenhouse gas emissions. Better accounting of emissions through combustion from fires is necessary for understanding their effect on the climate. Estimating the effect of greenhouse gases from remote fires is difficult because it requires measuring the biomass and carbon loss *in situ* in order to calculate radiative forcing.

We studied a 2015 burn scar in the Yukon-Kuskokwim Delta, AK to identify potential carbon loss and radiative forcing from a tundra fire using a new method to estimate organic matter loss with plant markers and temporally-explicit radiative forcings of gaseous emissions.

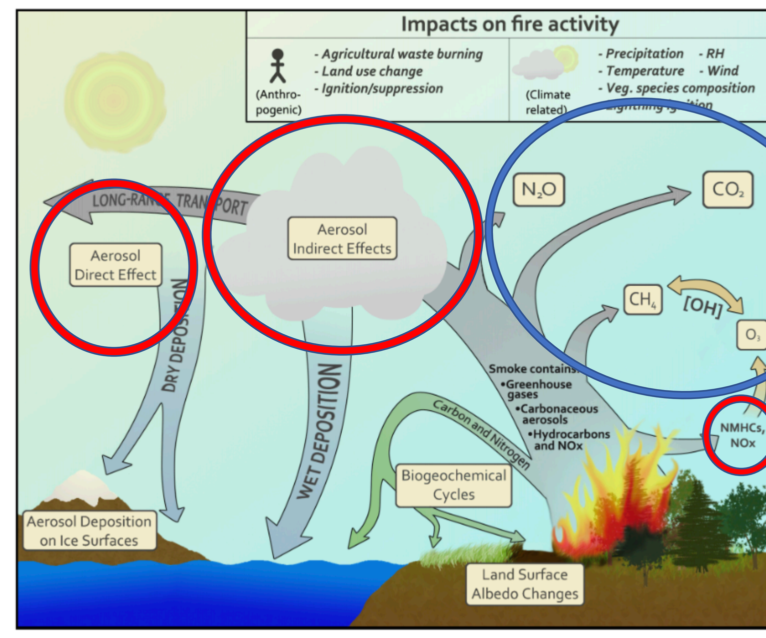

Figure 1. A visual representation of climate feedback pathways from wildfires[2]

Methodology

Estimate biomass and carbon loss

Two genera of moss, *Dicranum* and *Sphagnum*, and tussock grass, *Eriophorum vaginatum*, survive the fire and indicate pre fire soil level.

Equation 1. Burn depth equation based on heights of vegetation markers from soil level

$$Burn\ Depth(m) = (Post\ fire\ height\ - Pre\ fire\ height)(m)$$

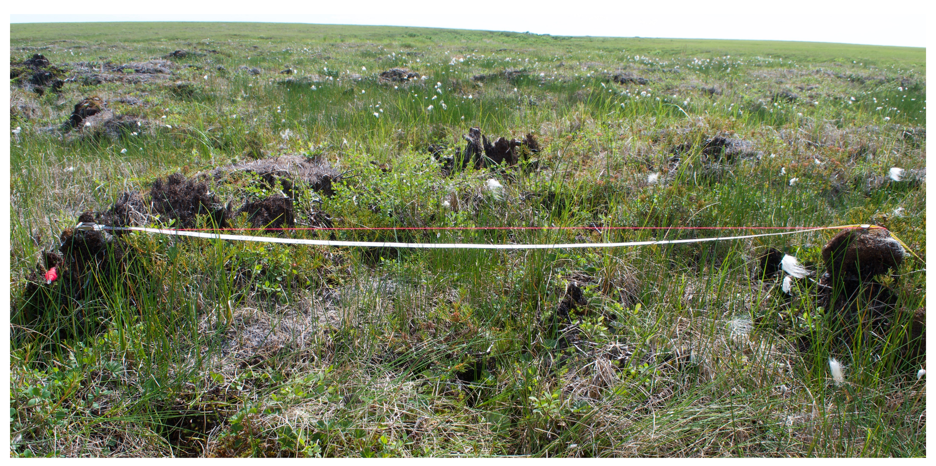

Figure 2. Example measurement of burn depth of *Dicranum*

Equation 2. Amount of biomass or carbon lost from combustion based on soil characteristics of nearby unburned soil

$$Biomass\ or\ Carbon\ \left(\frac{kg}{m^2}\right) = \frac{Dry\ Mass\ (kg)}{Volume\ (m^3)} \times \frac{Biomass\ or\ Carbon\ (kg)}{Dry\ Mass\ (kg)} \times Burn\ Depth(m)$$

Equation 3. Amount of biomass burned in the fire

$$Burned\ biomass\ (kg) = Biomass\ \left(\frac{kg}{m^2}\right) \times Fire\ area\ (m^2)$$

Fire area = 726 km^2, determined from Landstat dNBR, pixels were assigned severity based on magnitude of dNBR value

Calculate greenhouse gases released and their radiative forcing

Model Inputs: year of burn, time after fire analyzed, scenario, dry biomass combusted

Steps:

- Convert dry biomass to mass of gas species emitted using emissions factors
- Calculate the amount of that species in the atmosphere per year after fire
- Calculate radiative forcing from concentration of species in the atmosphere per year

Methods for calculating remaining perturbation concentration:

Box Model- Assume one inflow and one outflow, use for CH_4, O_3, and N_2O

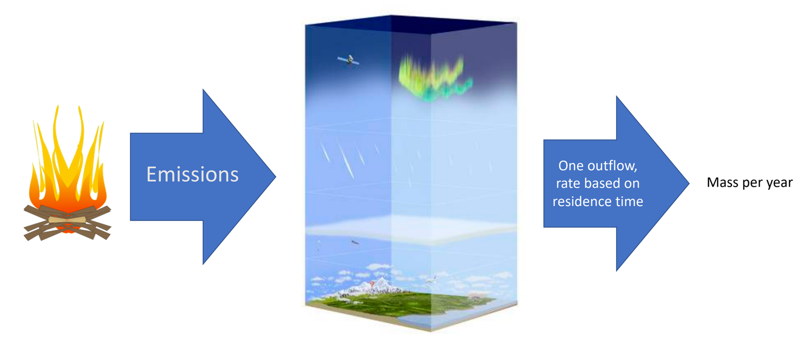

Figure 3. A visual representation of the box model method for calculating remaining perturbation concentration

Impulse Response Function- Derived from model simulations, expressed as fraction of initial concentration remaining, use for CO_2

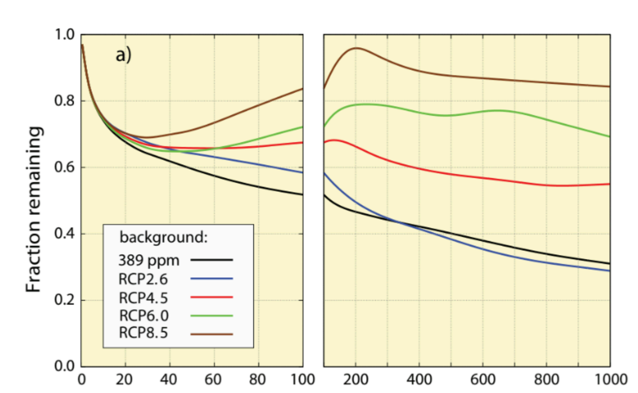

Figure 4. The impulse response function derived from multiple model simulations for CO_2[1]

RCP scenarios (future emissions projections): Radiative forcing and atmospheric lifetime depend on ambient concentration of species.

Historic- ambient concentration set at 2018 value

RCP4.5- moderate emissions reduction

RCP8.5- business as usual

Methods for calculating radiative forcing:

- Temporally explicit equations, use for CH_4, O_3, CO_2, and N_2O
- Interpolation between GWPs, use for short-lived climate forcers
- Atmospheric model outputs, use for aerosols

Equation 4. The radiative forcing for a perturbation concentration of CO_2.[1]

$$RF_{CO_2}(\Delta N_{CO_2}) = 5.35\,W\,m^{-2} \ln\left(\frac{N_{CO_2,0} + \Delta N_{CO_2}}{N_{CO_2,0}}\right)$$

Results - The 2015 fire season released 1.32 Tg of carbon to the atmosphere.

Burn depth and carbon loss varied across burn severity

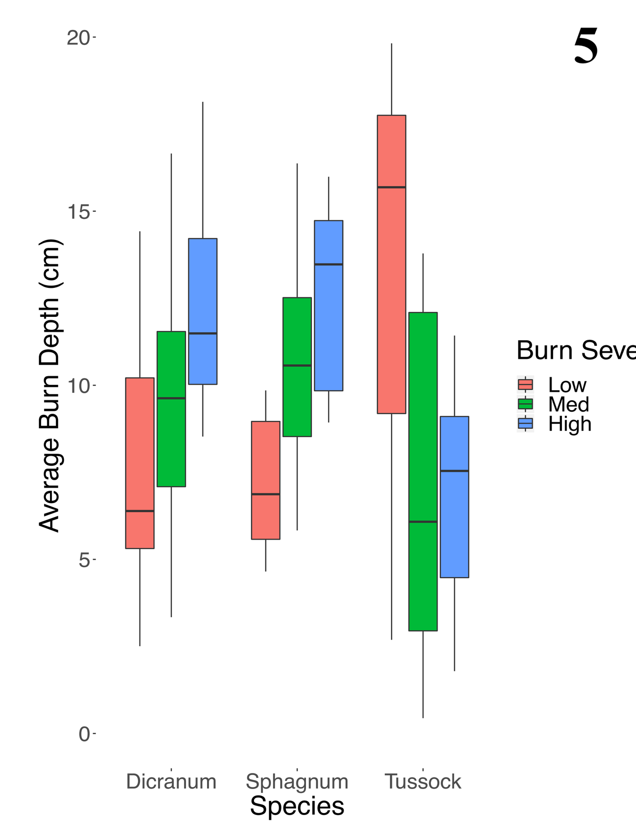

Figure 5. The average burn depth per transect calculated for each vegetative marker (Eq. 1). Means between *Dicranum* and *Sphagnum* were comparable, but means between moss genera and tussock differed. All means across burn severity were significant for moss genera ($p < 0.05$) but not for tussocks.

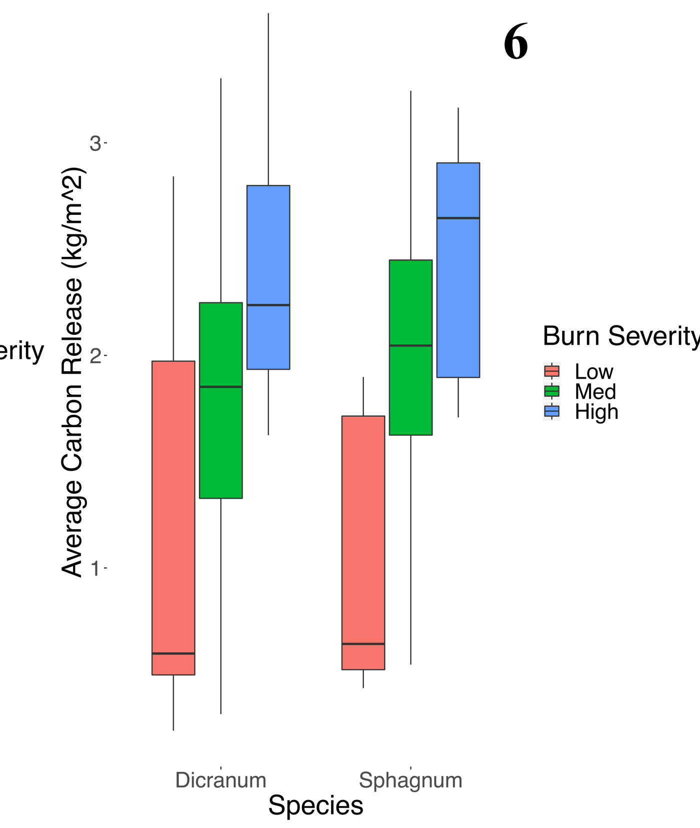

Figure 6. The average carbon released per transect calculated for each vegetative marker using Eq. 3. Inter-species means agreed, but means across severity varied ($p < 0.01$).

Burn depth varied by transect length for tussocks

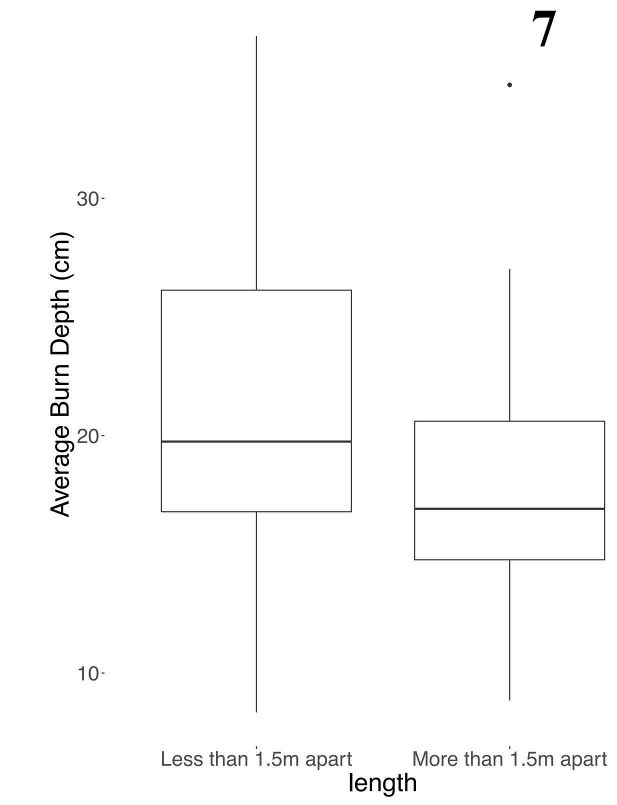

Figure 7. The average burn depth across tussock transects separated by transect length ($p < 0.1$).

Radiative forcing remains positive after fires for long time horizons

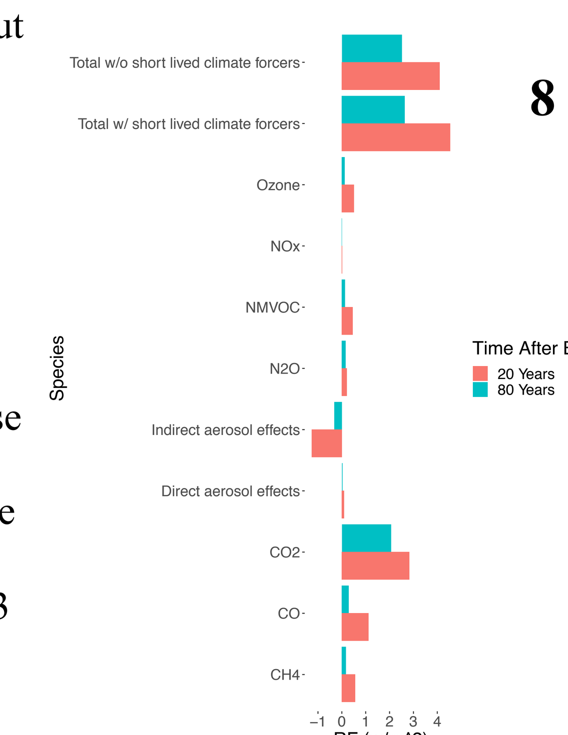

Figure 8. Cumulative mean radiative forcing at 20- and 80-years post fire of main greenhouse gas species, short lived climate forcers, and aerosol effects for the RCP 8.5 scenario based on an average combustion value of 2.83 $\left(\frac{kg}{m^2}\right)$ of dry biomass

Radiative forcing varied by gas and through time

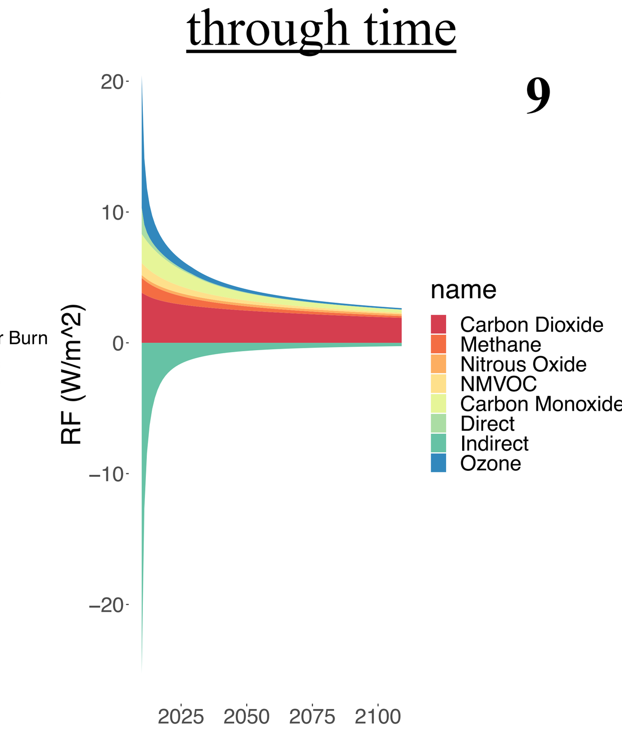

Figure 9. Cumulative radiative forcing of greenhouse gas species 100 years post fire for the RCP 8.5 scenario based on an average combustion value of 2.83 $\left(\frac{kg}{m^2}\right)$ of dry biomass

Conclusions

- Estimating burn depth was consistent across moss genera, but varied between mosses and tussock.
- Difference in burn depth across moss genera and tussocks and tussock burn depth across transect length is suggestive of altered microclimate by tussock grasses that affect flammability. Bulk density measurements also do not agree between moss genera and tussocks. Further research is needed to identify plant proxies for estimating plant and soil loss with fire.
- Radiative forcing persists over long timescales and varies by gas and through time. Tundra fires have a significant warming effect for which should be accounted with accurate combustion measurements and radiative forcing models.

Acknowledgements

I would like to thank the Woods Hole Research for their generous support of this project and my mentors, including ones listed as co-authors, John Schade, and Greg Fiske, for their patient help and useful guidance. Finally I would like to thank my peers in the Polaris Project for their assistance with gathering data and project development.

References

1. Joos, F., et al. (2013). Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis, Atmospheric Chemistry and Physics, 13, 2793-2825.
2. Ward, D. S, et al. (2012). The changing radiative forcing of fires: global model estimates for past, present and future, Atmospheric Chemistry and Physics, 12(22), 10857-10886.