The terrestrial carbon balance of Alaska and projected changes in the 21st Century: synthesis and state of progress

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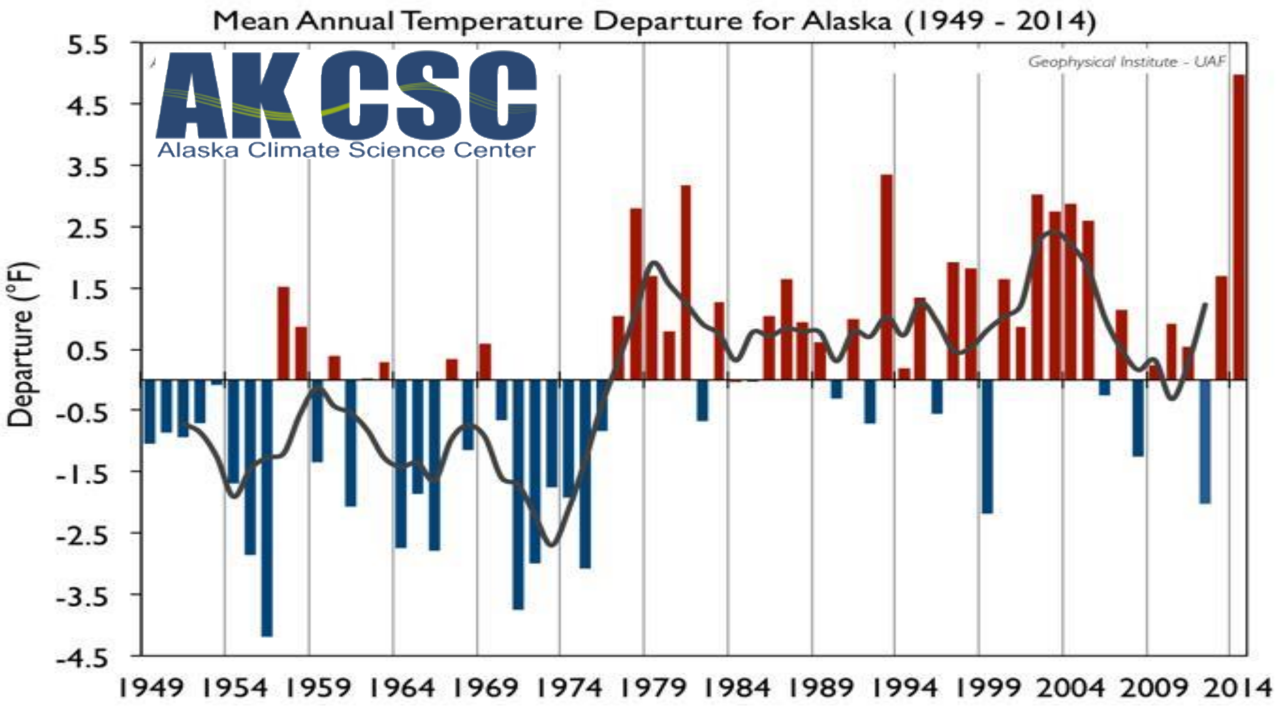
Vulnerability of boreal and arctic ecosystems

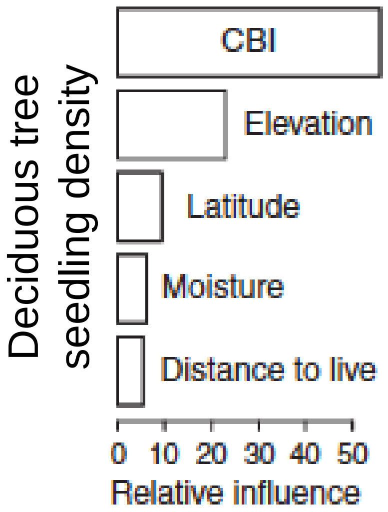
Ecosystems in Alaska are facing rapid climate change and more frequent and severe disturbances.



Consequences for ecosystem structure and functions

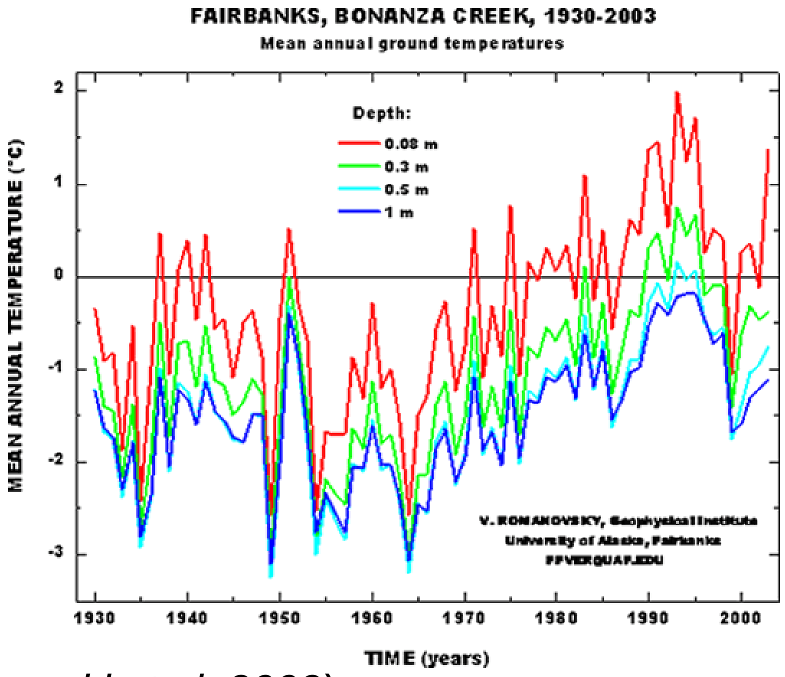
These environmental changes can drive gradual modification or precipitate abrupt ecological shifts of ecosystems.

Vegetation composition



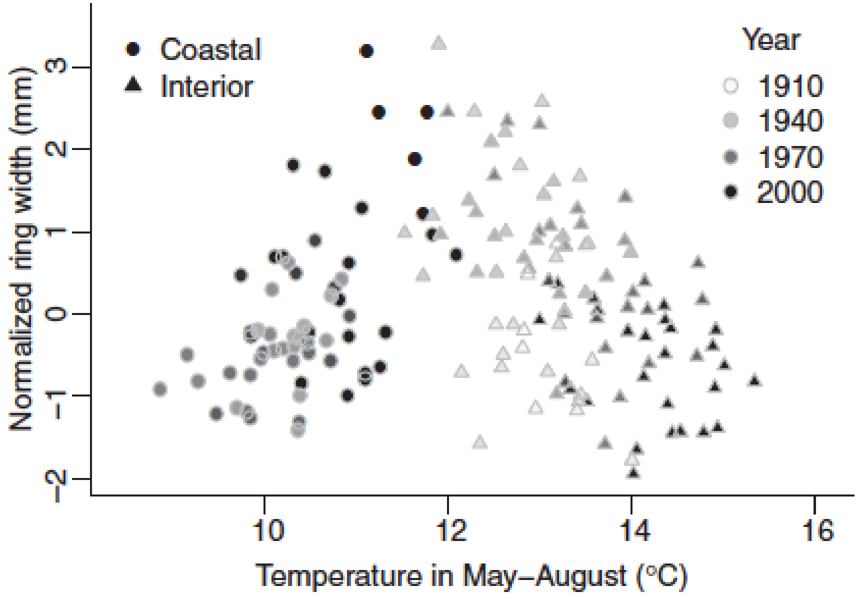
(Johnstone et al. 2010)

Soil thermal regime



(Romanovski et al. 2002)

Forest productivity



(Beck et al. 2011)

Consequences for ecosystem services

Changes in the state of the boreal forest can drastically affect major ecosystem services at the local and the regional scales.

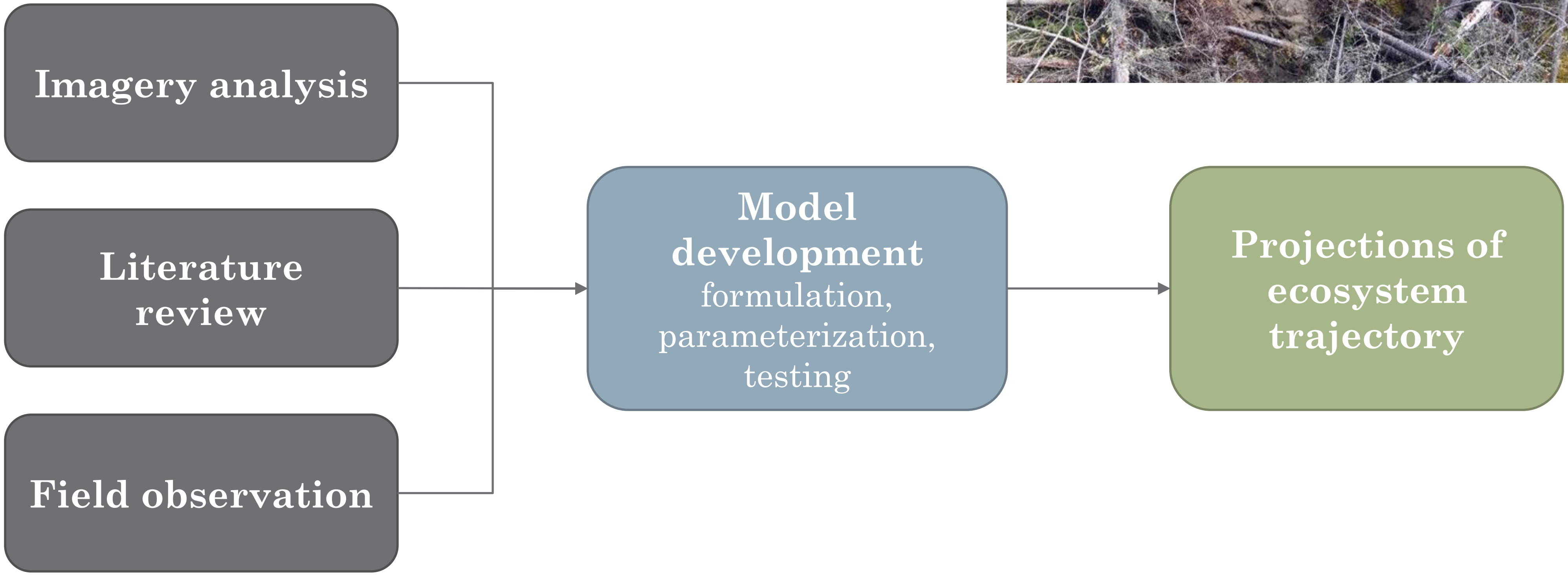
Carbon sequestration

Infrastructures

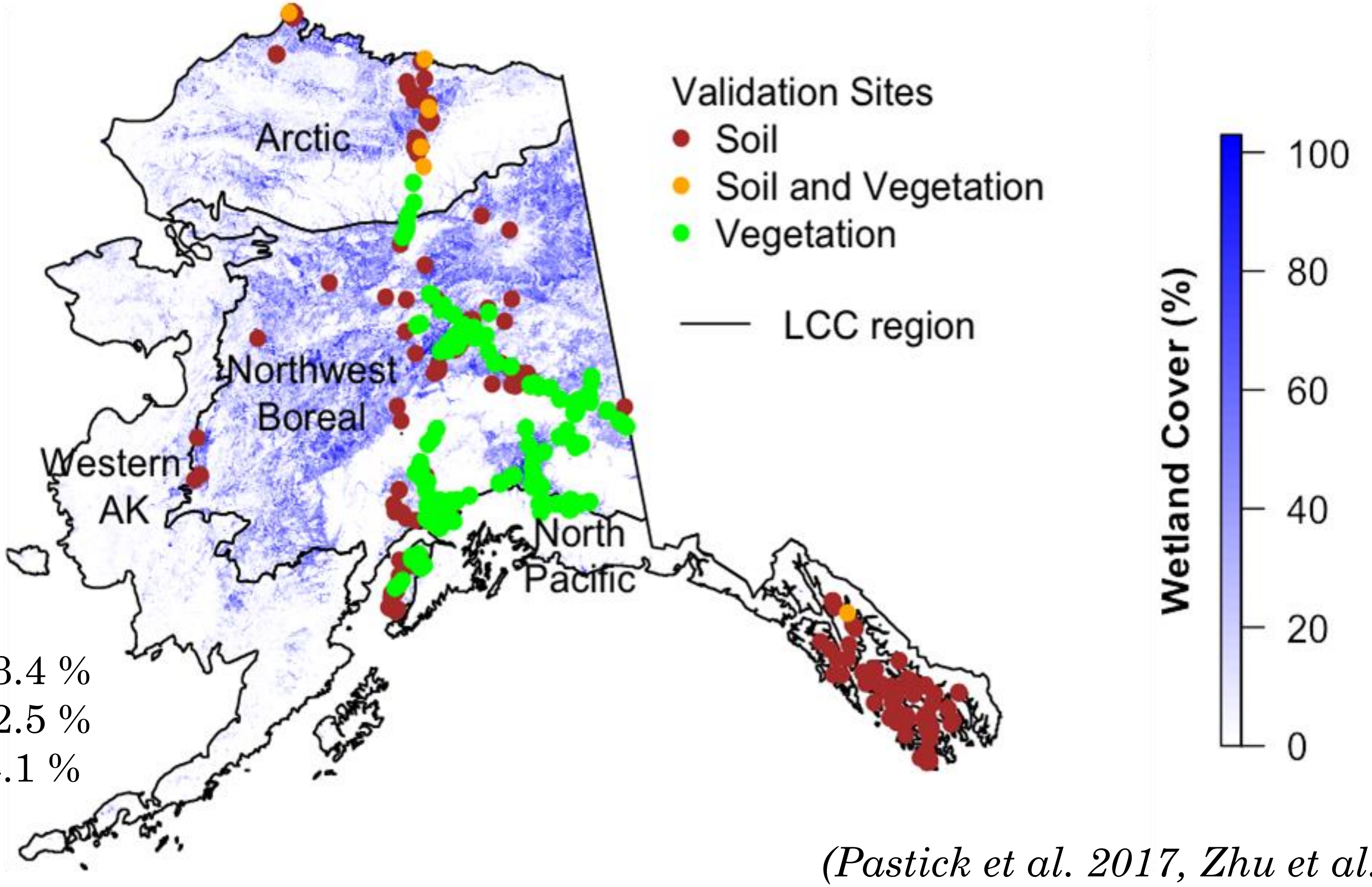
Wildlife habitat and subsistence

Human Health

Integrative analysis of the response of ecosystem to current and projected climate change



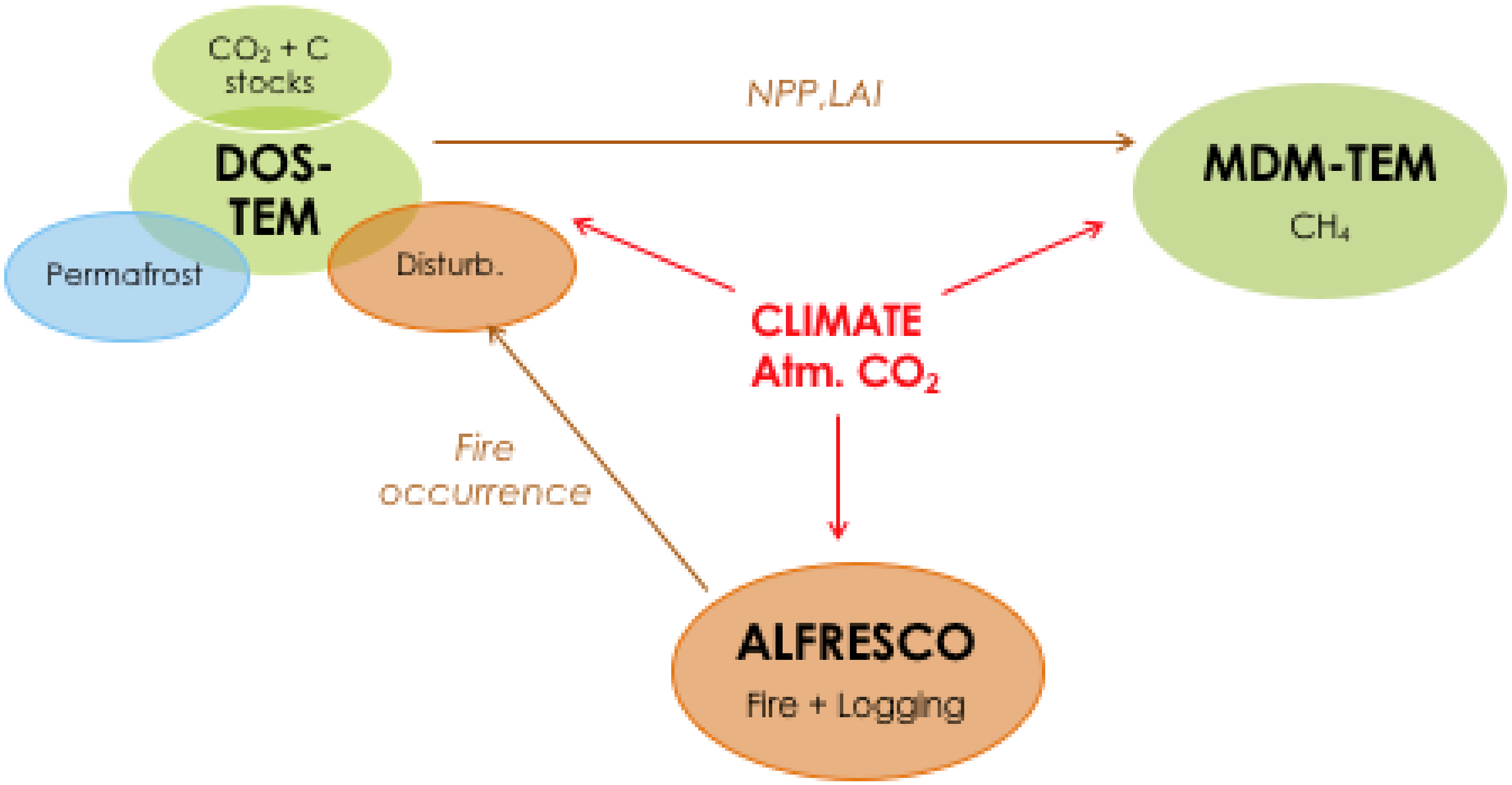
The terrestrial carbon balance of Alaska and Projected Changes in the 21st Century



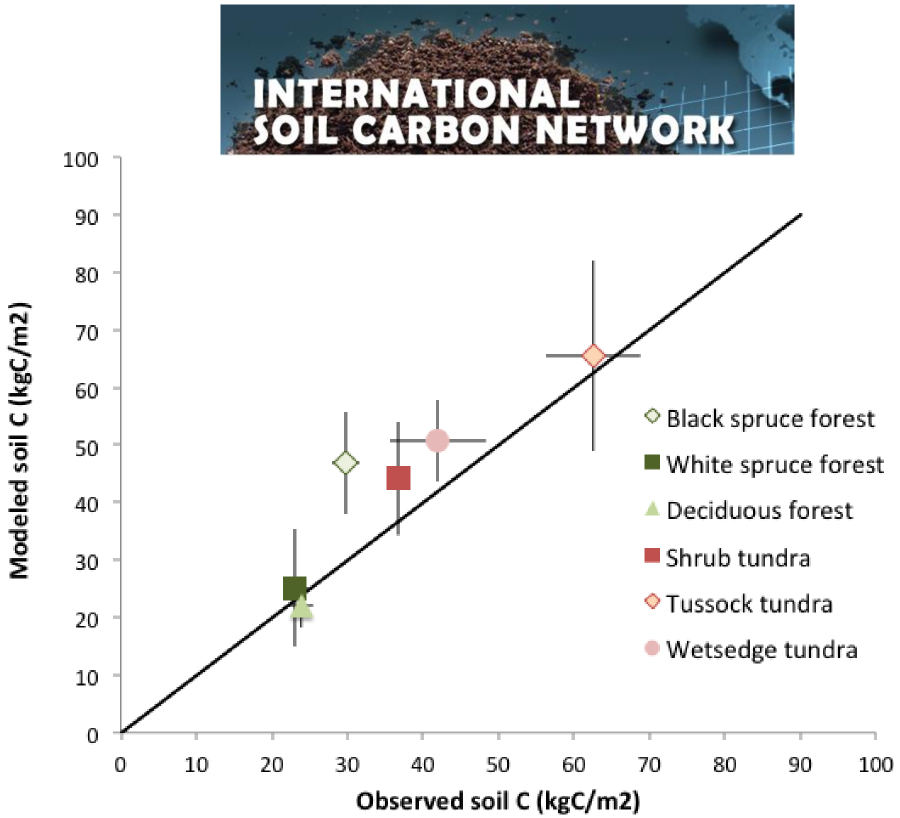
Uplands	83.4 %
Lowlands	12.5 %
Open waters	4.1 %

(Pastick et al. 2017, Zhu et al. submitted)

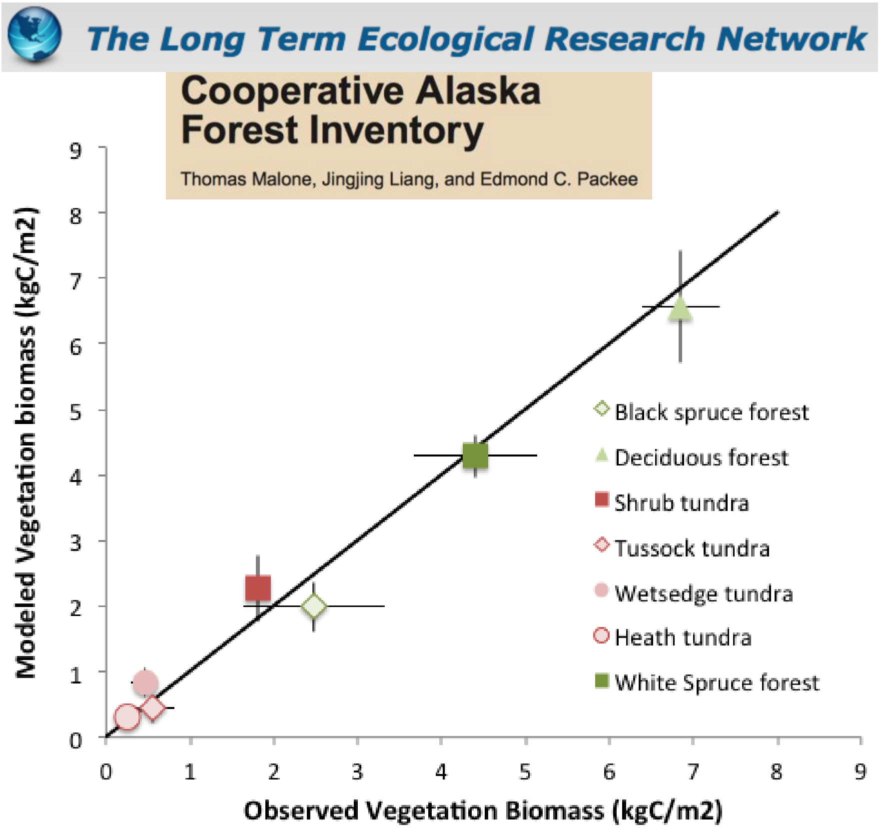
Modeling framework



Evaluation of Model Performance



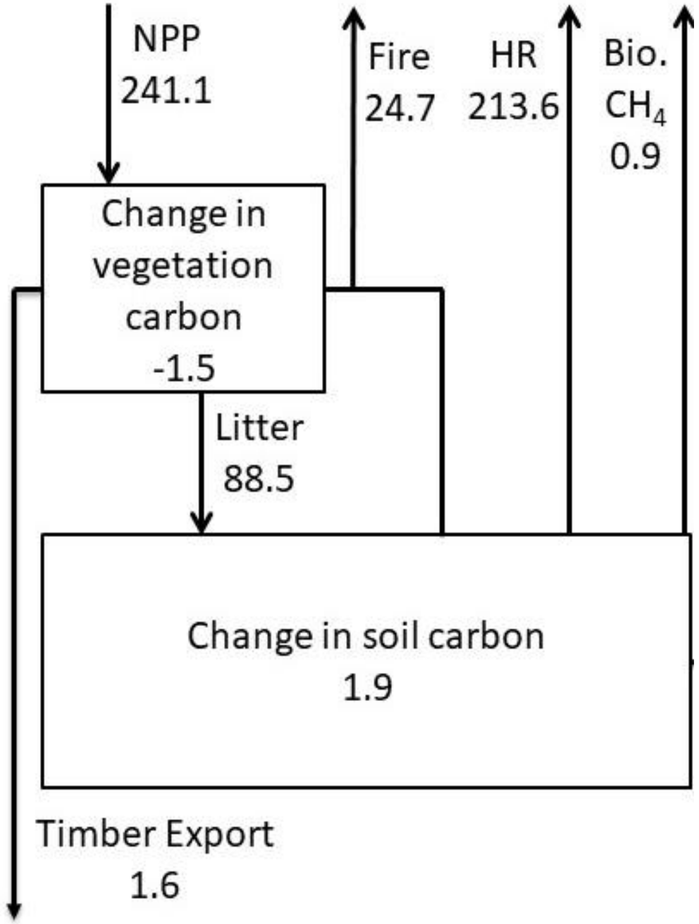
TEM soil C stocks compared with soil C stocks based on 315 samples collected in Alaska (Johnson et al. 2011). Both simulated and observed soil C stock estimates are for the organic and 0-1m mineral horizons.



Evaluation of TEM for vegetation biomass using data from 190 permanent study plots of the Cooperative Alaska Forest Inventory (CAFI) for boreal forest communities and LTER data for the arctic tundra communities.

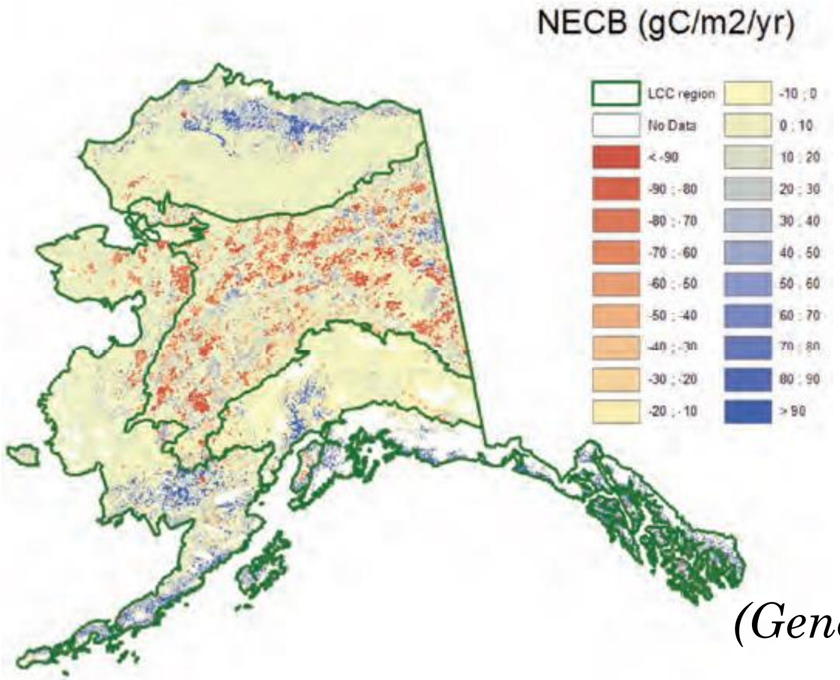
(Genet et al. 2018)

The historical carbon balance assessment



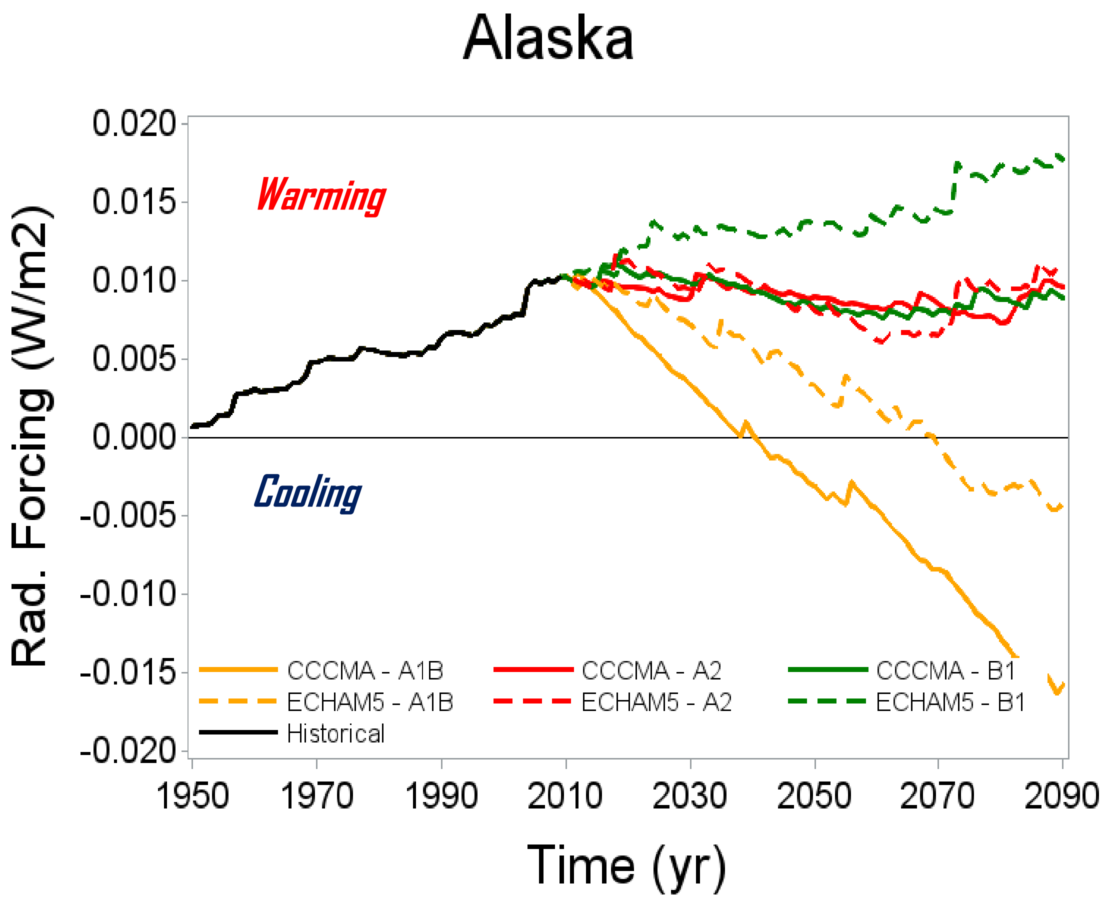
Between 1950 and 2009, upland and wetland ecosystems of Alaska sequestered **0.4 Tg C yr^{-1}**.

However, this sequestration is spatially variable with the region of the Northwest boreal LCC losing C because of fire disturbance, while other regions gained C.



(Genet et al. 2016)

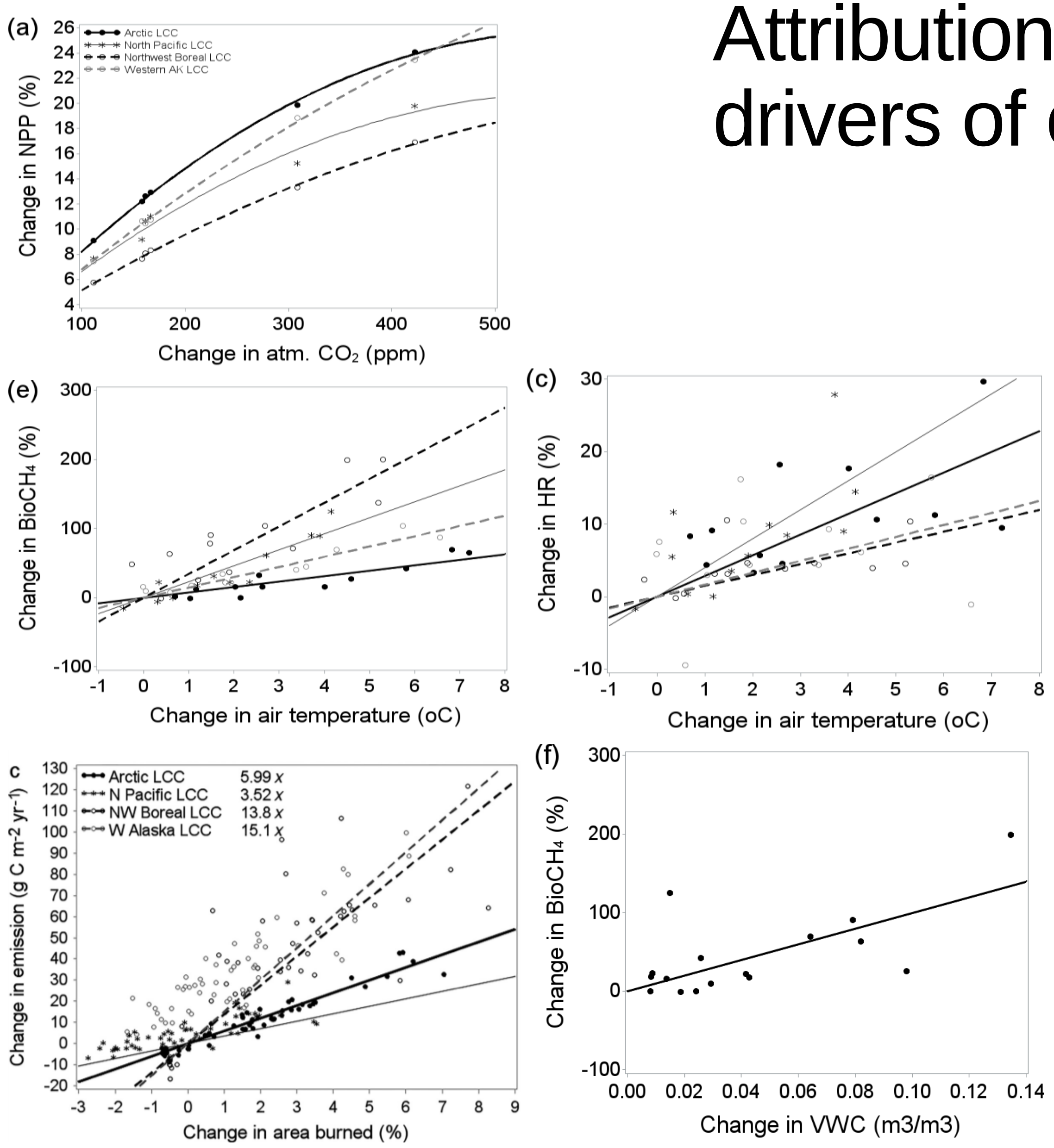
Projected change in the ecosystem C dynamic



(McGuire et al. submitted)

- C sequestration of upland and wetland ecosystems was projected to increase substantially (22.5 to 70.0 Tg C yr^{-1}).
- Wetland biogenic methane emissions increased by 47.7% on average across the projections, compare to the historical period.
- C dynamics of upland and wetland ecosystems were projected to continue to warm the climate for four of the future projections, and cool the climate for two of the projections.

Attribution analysis of the environmental drivers of changes in C dynamic

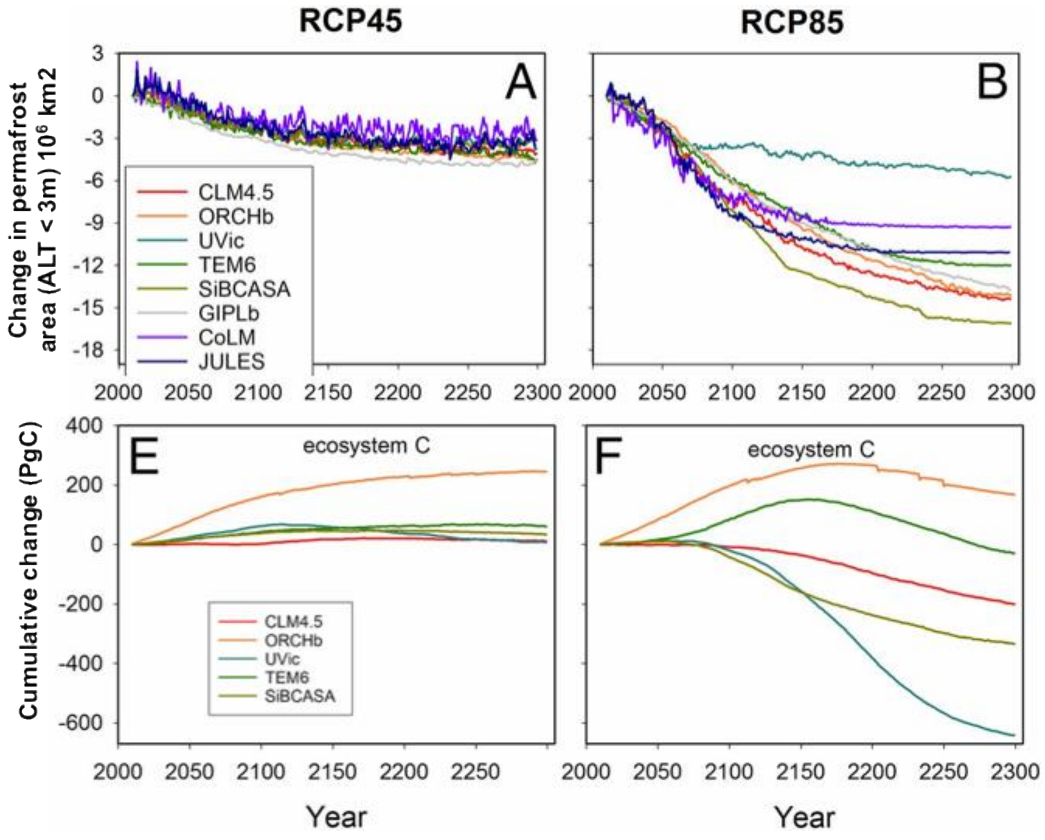


- The response of NPP to rising atmospheric CO_2 (~5% per 100 ppmv CO_2) saturates as CO_2 increases.

- The decreasing sensitivity of NPP to atm. CO_2 and the linear sensitivity of heterotrophic respiration and wetland methane emissions to air/soil temperature, and soil moisture, in addition to the increase in C loss from wildfires weakens the C sink from Alaska ecosystems.

Conclusions

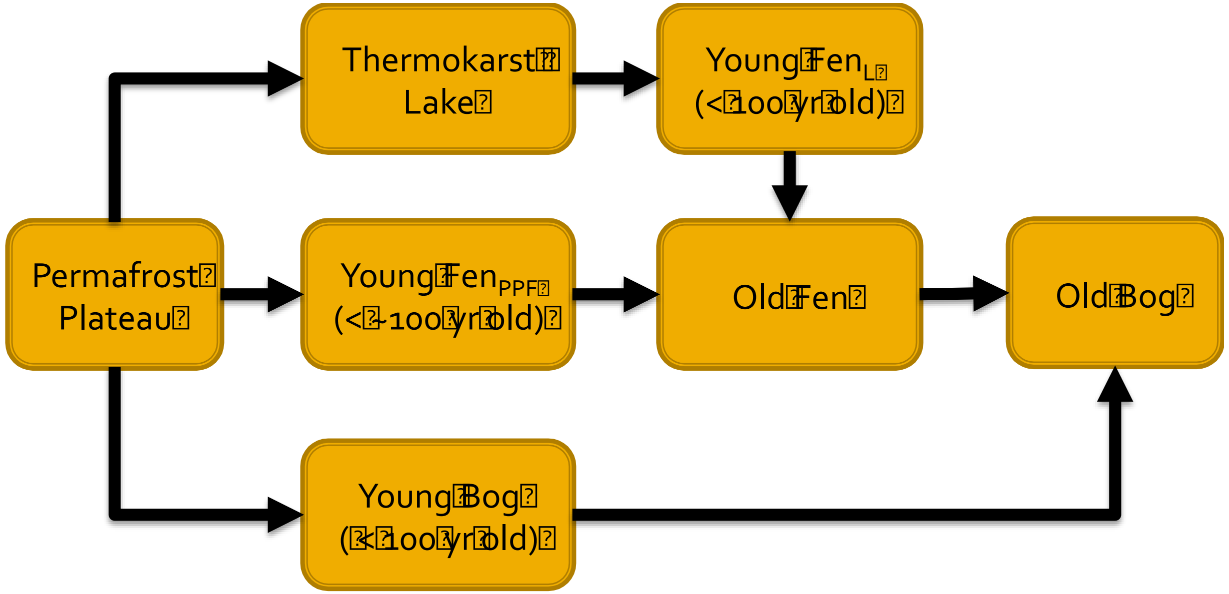
- This response, along with the expectation that permafrost thaw would be much greater and release large quantities of permafrost carbon after 2100, suggests that projected C sequestration in upland and wetland ecosystems of Alaska may be transitional.
- Furthermore, comparison with eddy-covariance data suggests that our model may underestimate **winter carbon loss**.
- Finally, the modelling framework did not include the effect of **thermokarst** disturbance on wetland distribution and associated C dynamic.



(McGuire et al. 2018)

Modeling thermokarst dynamic in the boreal forest

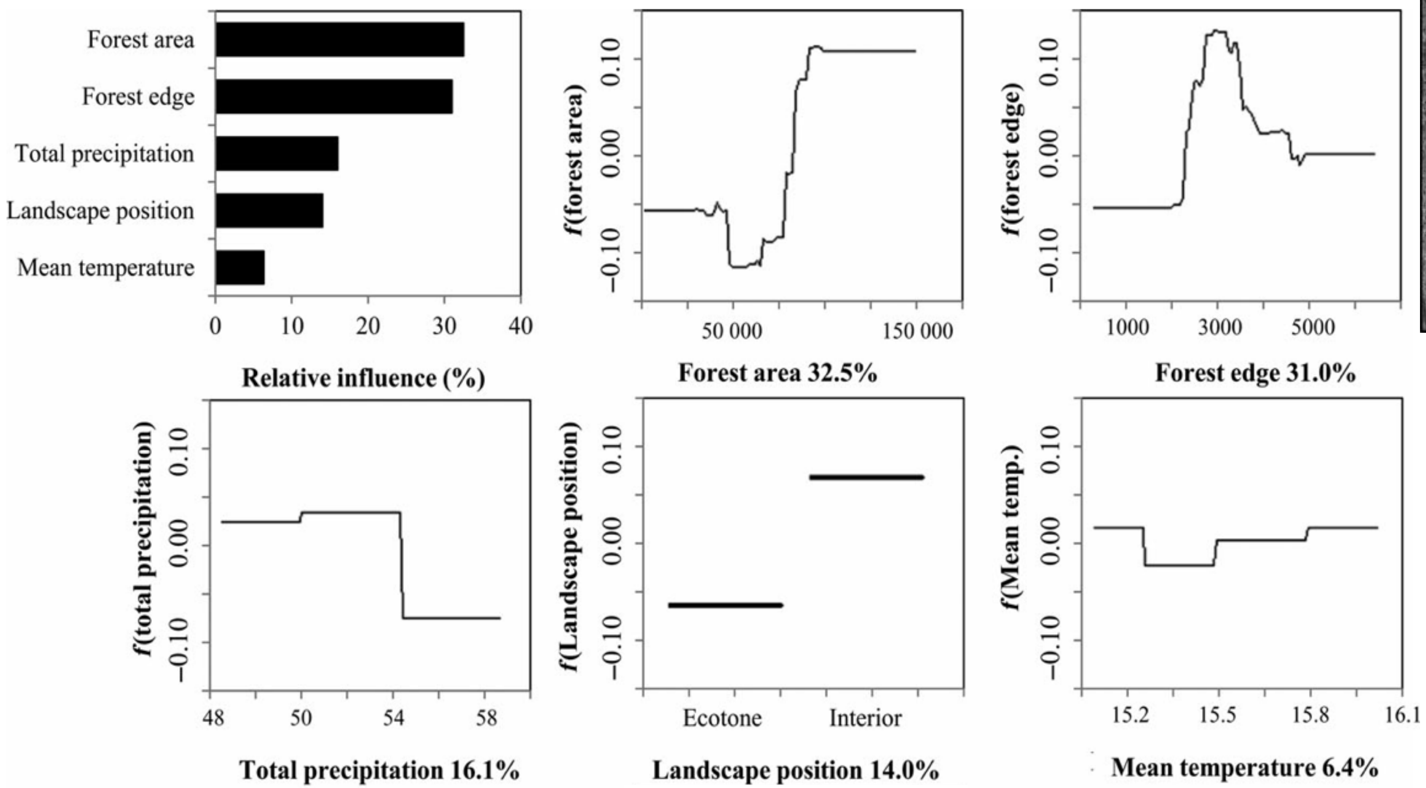
- The Alaska Thermokarst model is a state-and-transition model developed to track land cover change resulting from thermokarst disturbance.

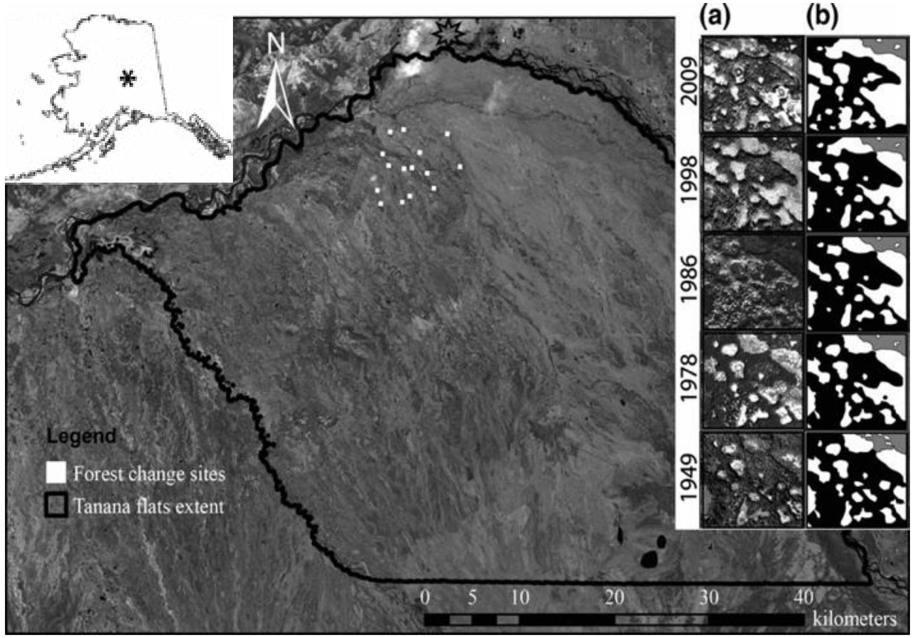


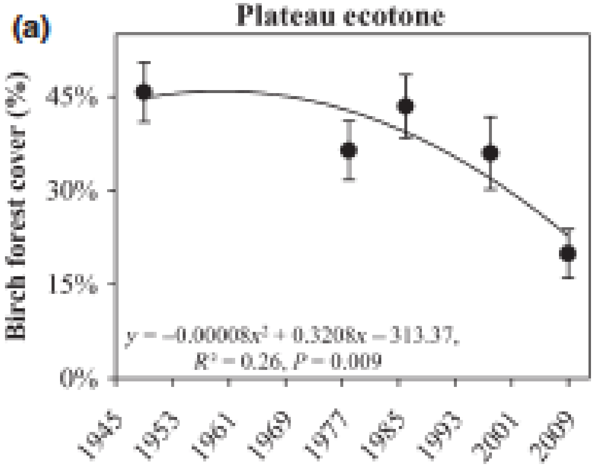
The environmental drivers of thermokarst disturbance

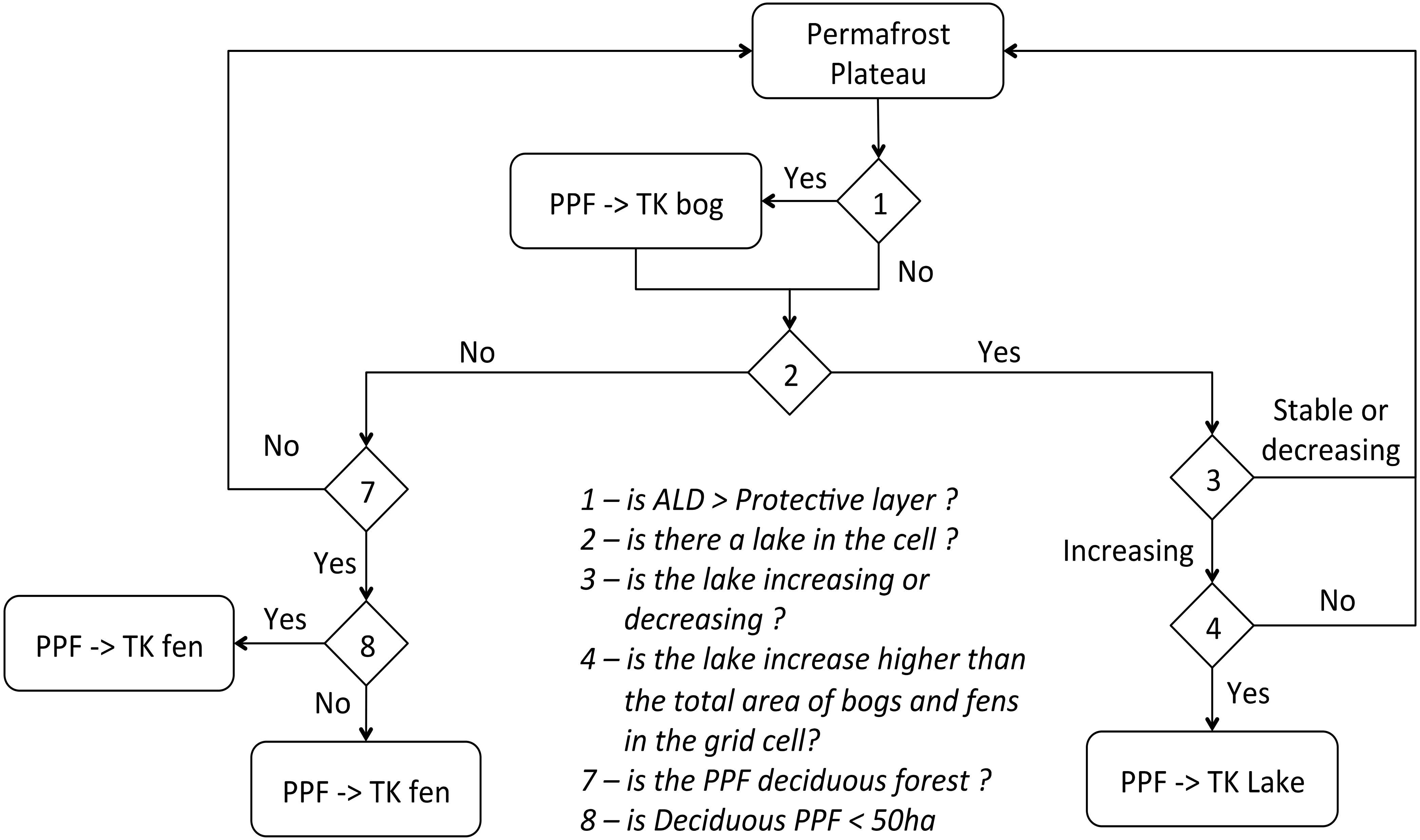
Lara et al. 2016

- Evaluation of long-term land cover change in unburned boreal forest, from 1949 to 2009 using repeated imagery analysis.



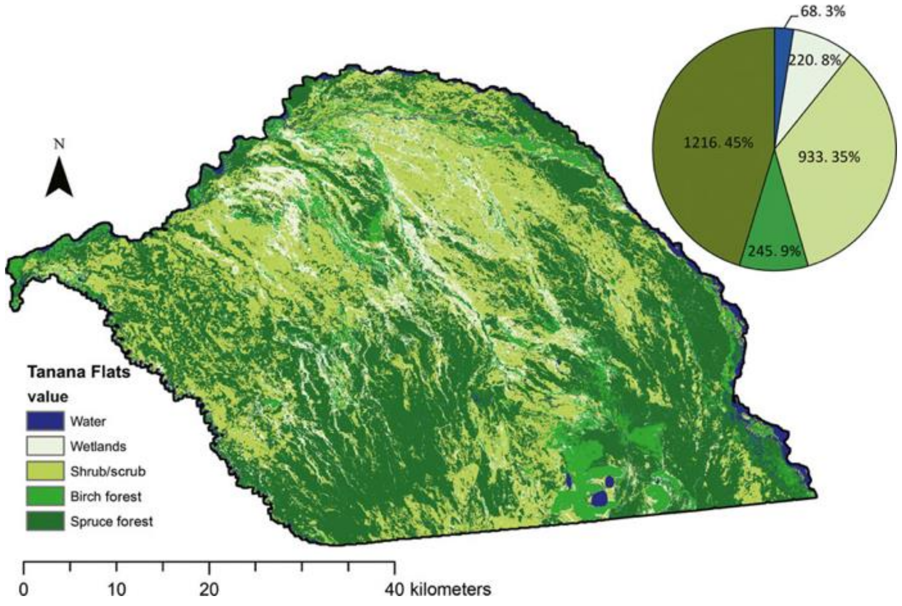





Permafrost Plateau
PPF -> TK bog
Yes
1
No
No
2
Yes
No
7
Yes
Yes
8
No
PPF -> TK fen
PPF -> TK fen
3
Stable or decreasing
Increasing
4
No
Yes
PPF -> TK Lake
1 – is ALD > Protective layer ?
2 – is there a lake in the cell ?
3 – is the lake increasing or decreasing ?
4 – is the lake increase higher than the total area of bogs and fens in the grid cell?
7 – is the PPF deciduous forest ?
8 – is Deciduous PPF < 50ha

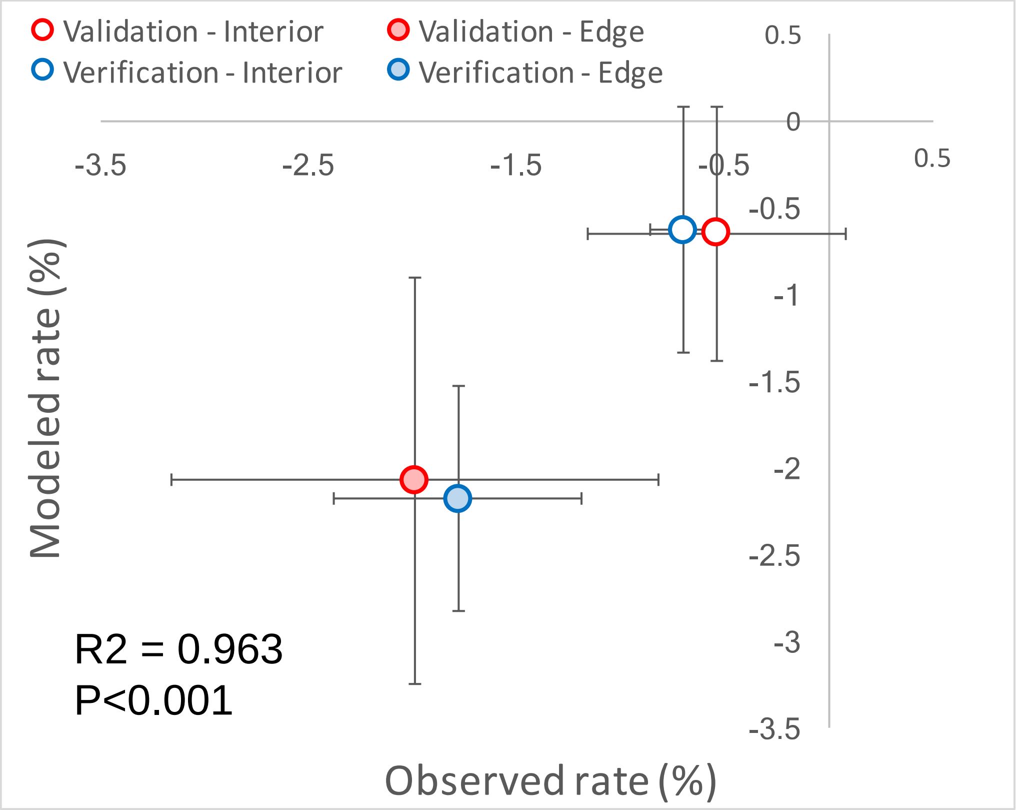
Consequences of thermokarst on land cover

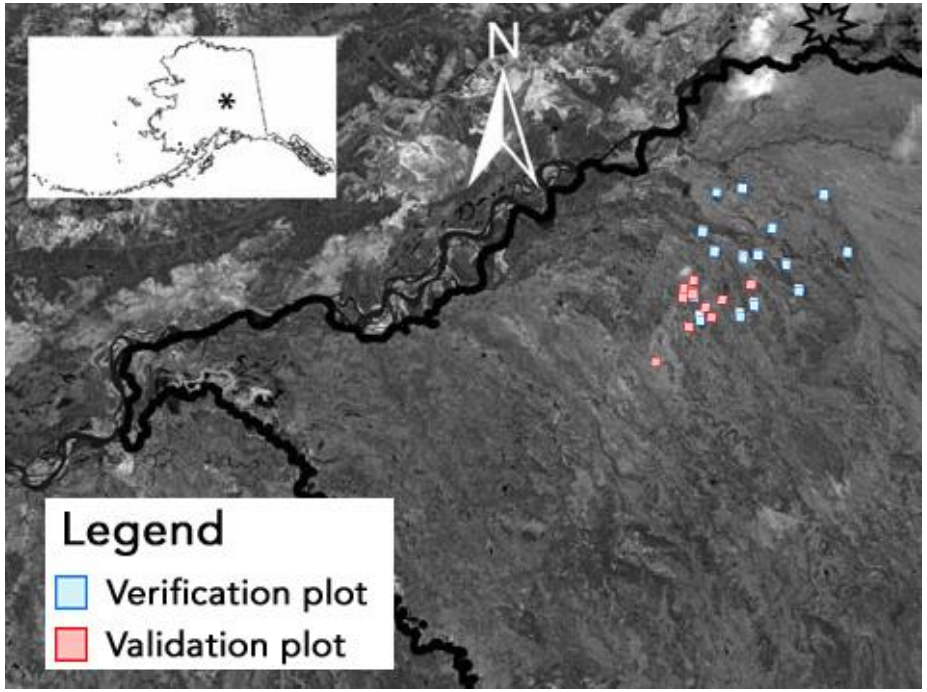
- Model application from 1950 to 2100 in the Tanana Flats (~2,600 km^2).
  - Land cover initialization – NLCD 2001
  - Historical backward simulations [1950-2000]
    - CRU TS3.2
    - Model verification and validation
  - Future projections [2001-2100]
    - Four AR5 emission scenarios (RCP 2.6, 4.5, 6.0 and 8.5)
    - Five climate models (CCSM4, GISS-E2, MRI-CGC, GFDL-CM, IPSL-CM)



Consequences of thermokarst on land cover

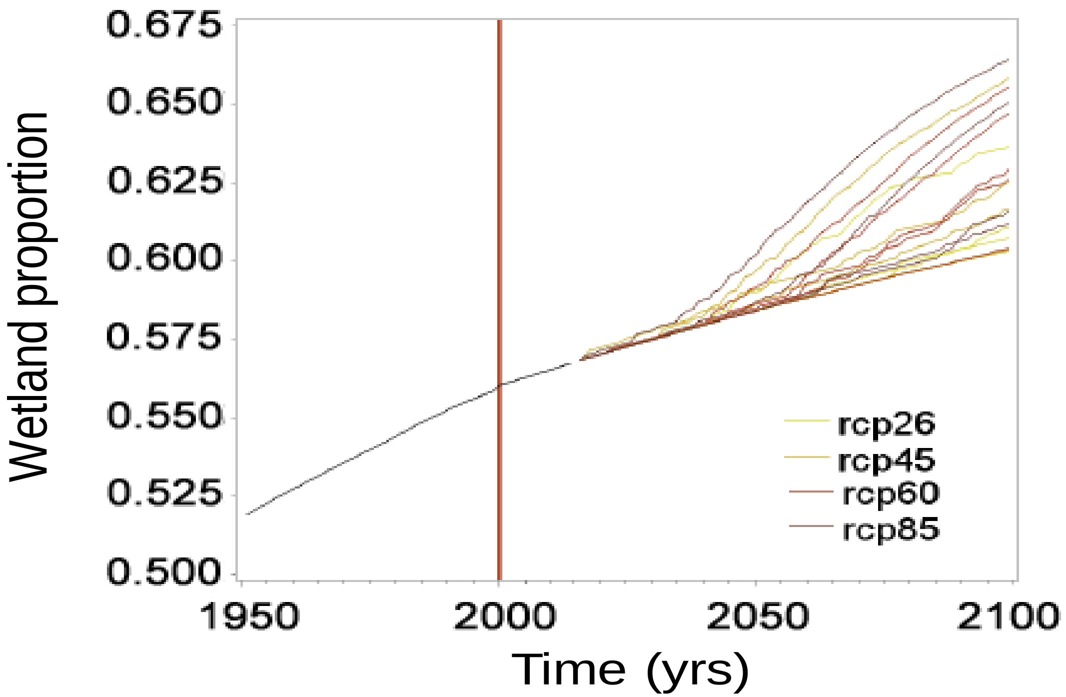
- Comparison between observed and modeled rates of loss of permafrost plateau in 15 verification plots and 10 validation plots from 1950 to 2009.



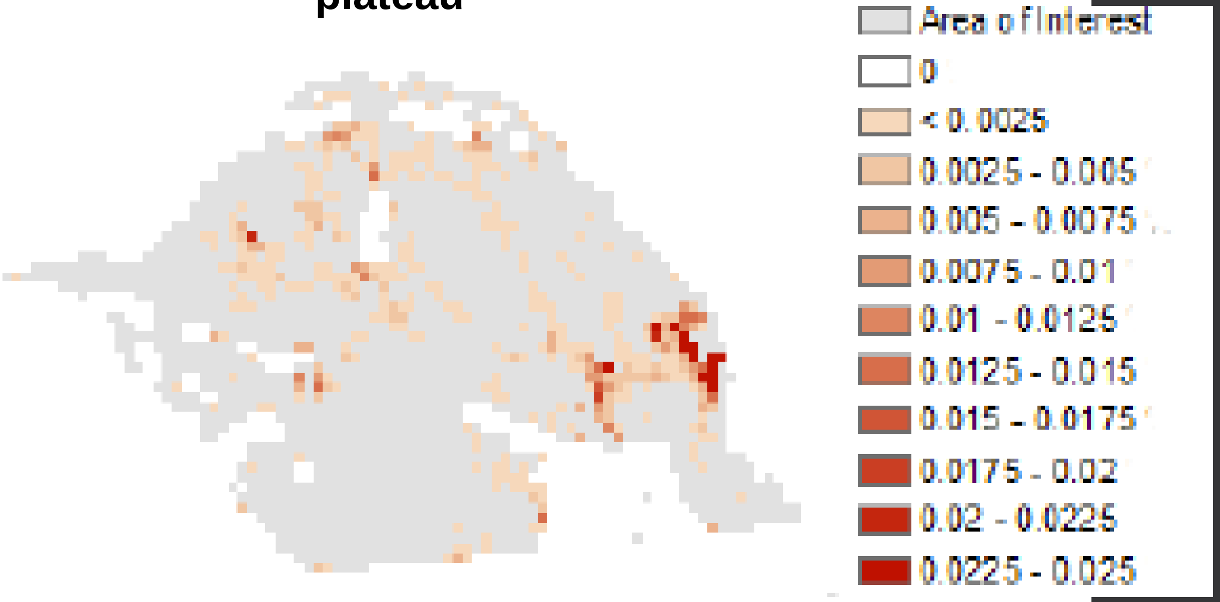


Consequences of thermokarst on land cover

- The proportion of wetlands in the Tanana Flats increased by 26.5% (s.d. 7.2%) from 1950 to 2100, i.e. ~ 36,000 ha.

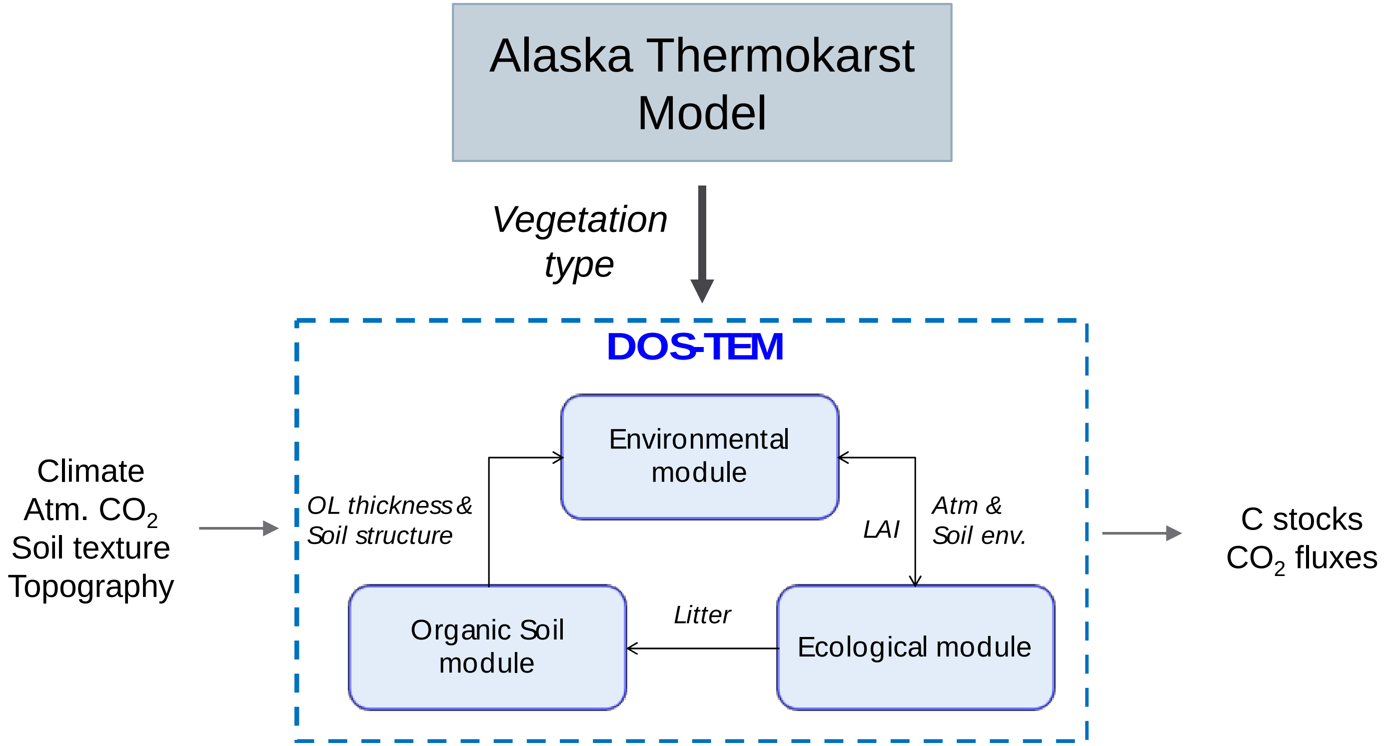


Annual rate of loss of permafrost plateau



Toward the representation of thermokarst disturbance in ecosystem model

- The Alaska thermokarst model was asynchronously coupled with a process-based ecosystem model that simulate the response of vegetation and soil C and N dynamics to climate, atmospheric CO_2 and fire disturbance.

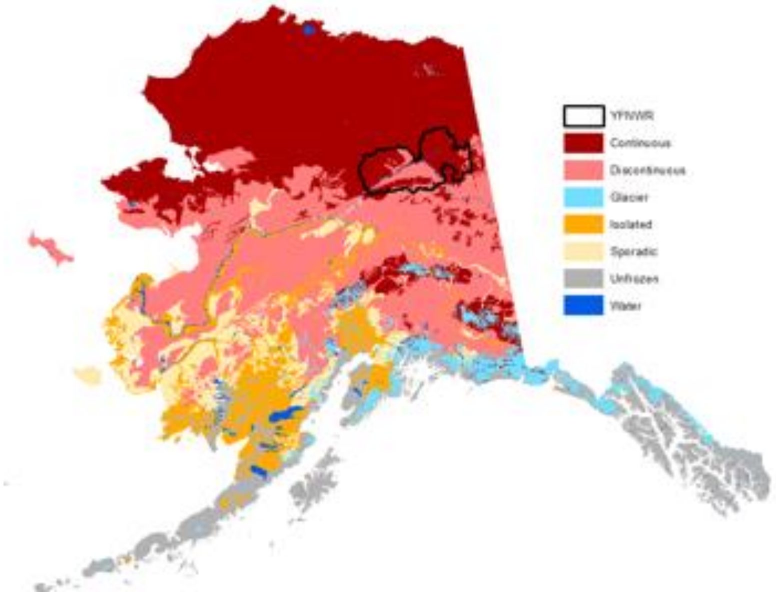


Implications for the regional carbon balance

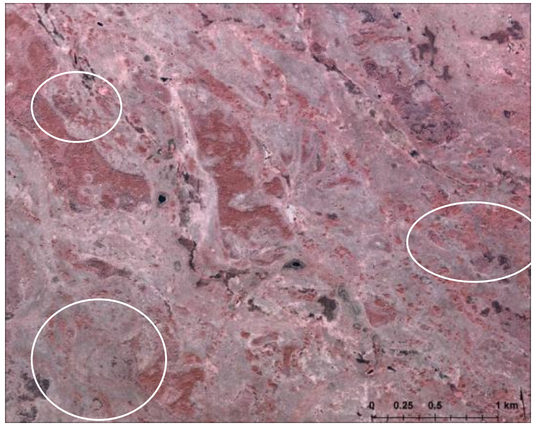
- Alaska Peatland Experiment started in 2004 in the Tanana Flats. Sites were monitored to assess the effects of drought, flooding, and soil warming on peatland vegetation, greenhouse gas fluxes, and hydrology.
- Eddy covariance estimates of GPP and ER, and quantification of vegetation biomass and soil C and N stocks were used to calibrate the rate limiting parameters of TEM.

Variable	Target value	Simulated value
GPP (g C m^{-2} yr^{-1})	530	572
NPP (g C m^{-2} yr^{-1})	297	324
Vegetation C (g m^{-2})	536	514
Fibric C (g m^{-2})	6029	6048
Amorphous C (g m^{-2})	40300	33269
Fibric horizon thickness (m)	0.33	0.12
Amorphous horizon thickness (m)	0.9	0.66
CH4 flux (mg m^{-2})	4981	3800

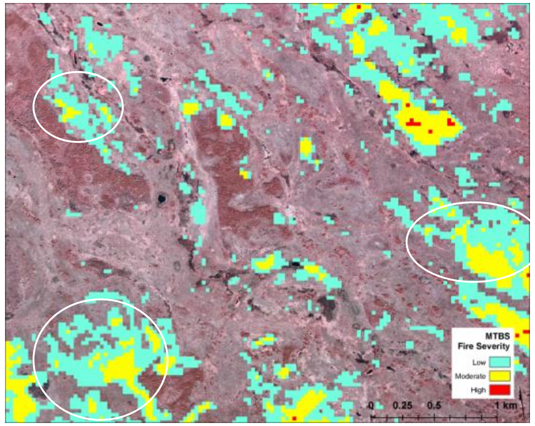
Evaluating the effect of fire on thermokarst disturbances



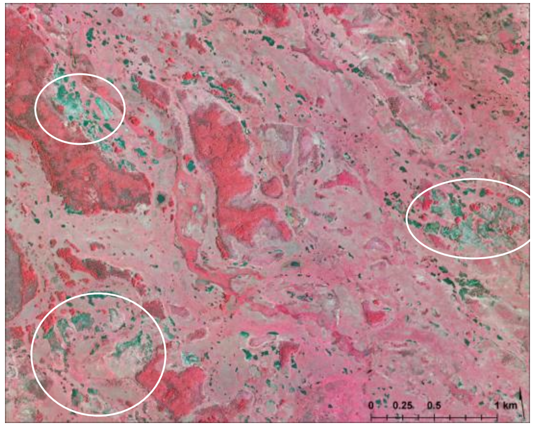
Repeated imagery analysis in the Yukon Flats to assess the impact of wildfire on thermokarst and associated land cover change.



1980 false color aerial image



2008 fire



2011 false color aerial image

Supports :

BONANZA CREEK LTER
Institute of Arctic Biology, University of Alaska Fairbanks

USGS

AK CSC
Alaska Climate Science Center

NORTHWEST BOREAL
Landscape Conservation Cooperative

Western Alaska LCC

Arctic Landscape Conservation Cooperative

Data available at:

ScienceBase

Scenarios Network
FOR ALASKA + ARCTIC PLANNING