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Dynamical Basin-scale Responses of Taiga Forest and Soil C Stocks to Climate Changes and Wild Fire History in the Yukon River Basin from 1960 - 2006

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Introduction

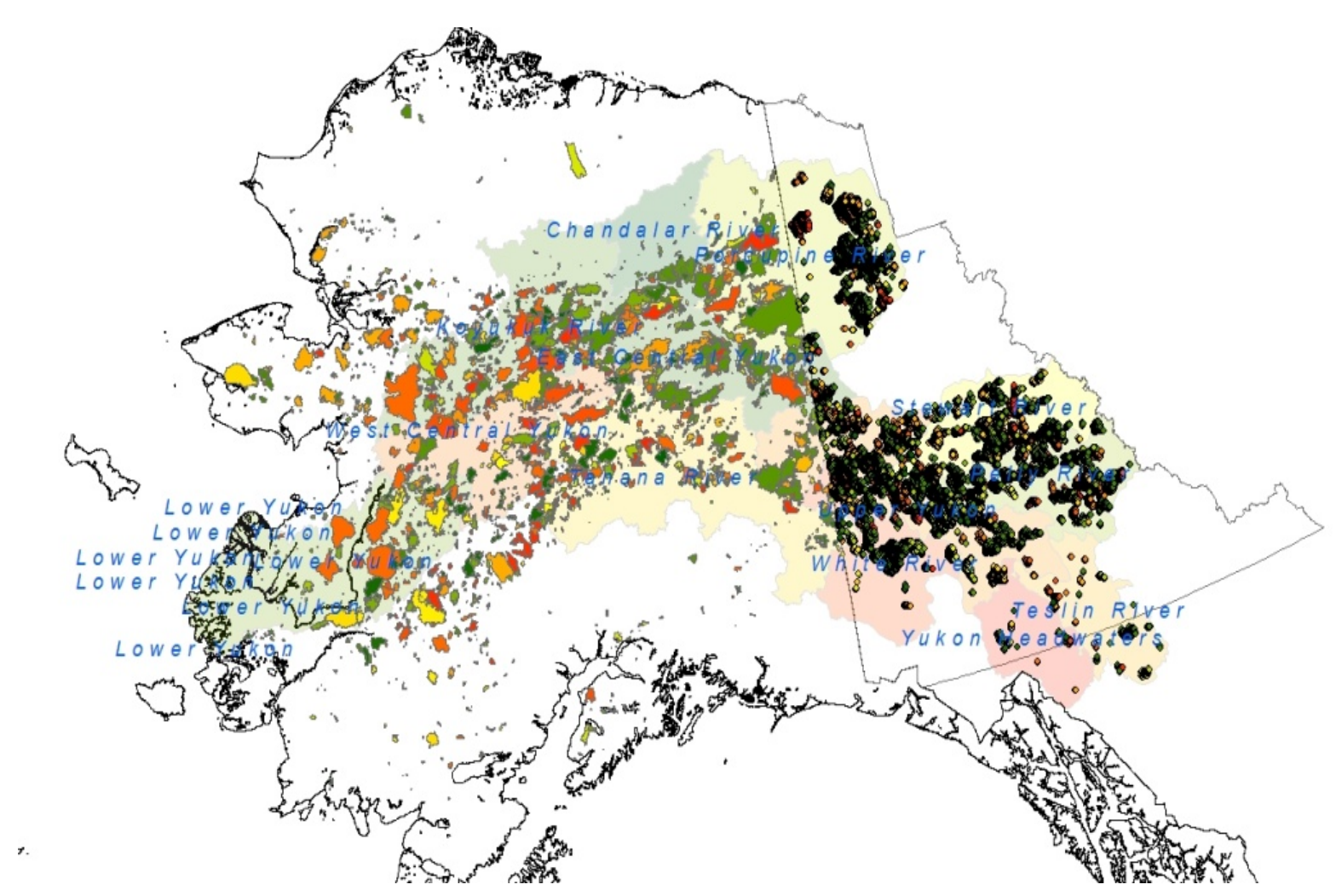

Fig. 1 The Yukon River Basin (YRB) and wildfire occurrence from 1960 - 2006.

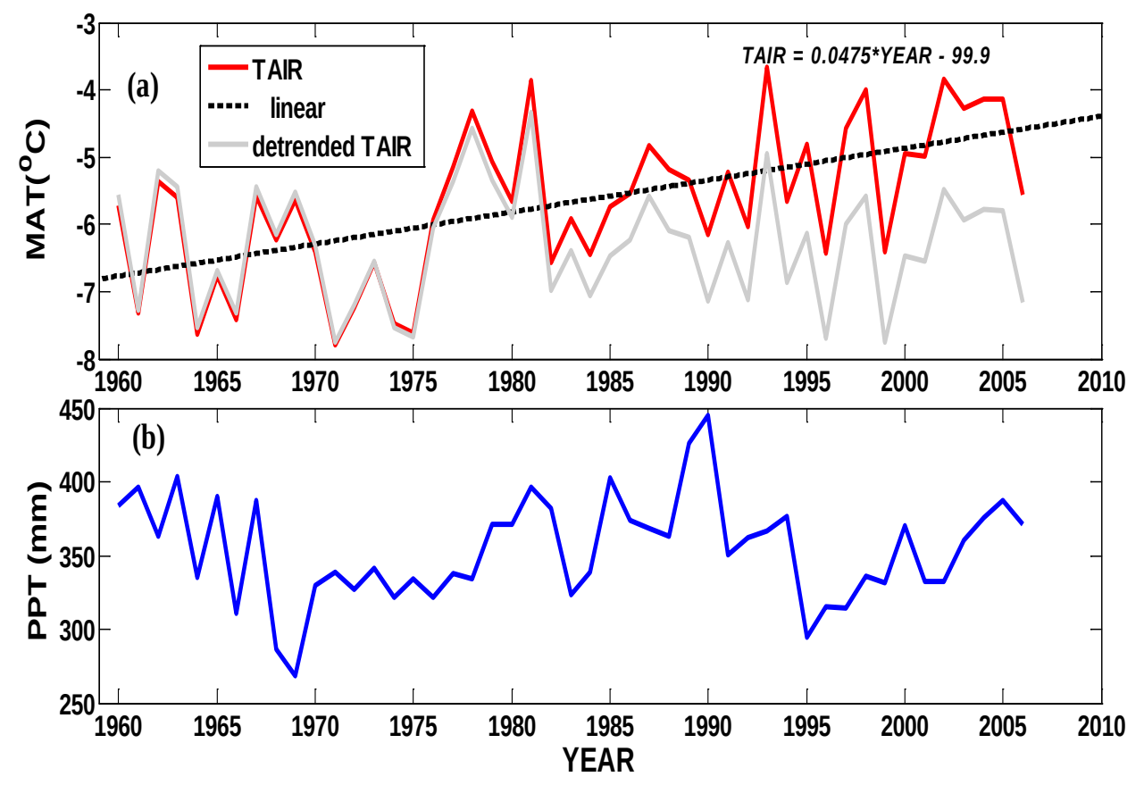

Fig. 2 (a)The mean air temperature (MAT) warming trend and (b)annual precipitation (PPT), averaged over YRB from 1960 – 2006.

Boreal forests have been estimated as significant arbon-sink ecosystems since contemporary climate warming and atmospheric CO_2 rising. However, this scene f boreal forests' role in terrestrial C budgets likely have een changing due to changing fire regime, such as ncreasing fire occurrence and severity, and more late-eason fires since 1990s. There existed some prospective hat boreal and arctic regions might already have been in a iminishing process as carbon sink.

It's well known how CO2 fertilization and warming weather benefit ecosystem C uptakes, but fires may exert a omplexity of direct impacts (e.g., C emission) and indirect ffects on ecosystem structure, properties and functions. For high-latitude region, soil organic layer burning, among others, may remarkably change soil thermal and hydrological properties, which are very critical to one of the world largest soil C storage, especially those in permafrost.

In order to assess the relative importance of climate changes (mainly warming) and wildfires on boreal forest C and SOM C storage, this study validate and apply Terrestrial Ecosystem Model (TEM), with a specifically designed multiple layer and multiple component dynamic soil organic module (DOS-TEM), in the Yukon River Basin (YRB) at 1 km X 1 km resolution from 1960 – 2006 (Fig.1 and Fig.2). Specifically, this study aims to understand:

1) Plant and SOM C storage changes impacted by warming and historical fire disturbance; and,
2) Possible differentiating of those impacts over landscape and sub-basins.

TEM Validation Using Forest Inventory Databases

In the Yukon River Basin there are three distinguished forest types in terms of C growth and release: black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), and deciduous trees including quaking aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsmifera* L. spp. *balsamifera*) and birch (*Betula*). Investigations indicated that plant growth, SOM C accumulation, and fire behaviors exert significant differences between upland (usually well-drained) and lowland (poorly drained) landscape positions. Therefore, we parameterized DOS-TEM for these 6 composites of 3 forest types and 2 landscape positions, based on information from intensively studied field sites in the Bonanza Creek LTER, interior Alaska,

In order for the calibrated model to reliably apply for basin-scale analysis, it was verified using vegetation biomass and soil organic layer thickness datasets from the Cooperative Alaska Forest Inventory (CAFI) database (Malone et al., 2009). We ran DOS-TEM for 120 of 191 CAFI permanent sample plots (PSPs), which black spruce, white spruce and deciduous trees are dominant (>75%). The climatic variables for those plots were extracted from the same 0.5ºx0.5º climate database for the YRB region from 1901 - 2006. Because of unknown stand ages of those plots, we estimated ages from the same historical fire database for YRB, assuming forest regrowth since the last known fire, otherwise as old-growth forests.

TEM Analysis for Relative Importance of Warming and Fire on YRB C Changes

The DOS-TEM then is applied for the boreal forest vegetation and soil C storage change analysis in the whole YRB. YRB is about 856,385 km², which contains 13 sub-basins (Fig. 1). The forested area is 422,794 km² (about 49%), of which about 71% is distributed in the lower- and mid-YRB 7 sub-basins, mostly within Alaska, and the rest in Canadian upper-YRB sub-basins. About half of forests are black spruce, and white spruce and deciduous species each occupies about 25%.

The model is driven by a 0.5ºx0.5º climate database (monthly from 1901 - 2006) and a historical fire database for Alaska portion from 1950s and for Canadian portion from 1960s. The model first spin-up runs using 1901 – 1930 climate data and a fire return interval database for 900 years until 1900, and continues using historical climate data until 1960. The TEM runs for the whole YRB since 1960 in 4 series in order to analyze the relative importance of warming and fire disturbance factors:

1. under historical climate (from 1901 – 2006) and wildfire (1960 – 2006), referred as "+warming & +fire" and representing the contemporary conditions;
2. under de-trended air temperature history but with fire ("-warming & +fire");
3. under historical climate but assuming no fire since 1960 ("+warming & -fire"); and,
4. under de-trended air temperature history and assuming no fire since 1960 ("-warming & -fire").

Results and Discussions

• Plausibility and challenge of regional-scale model validation using available field databases

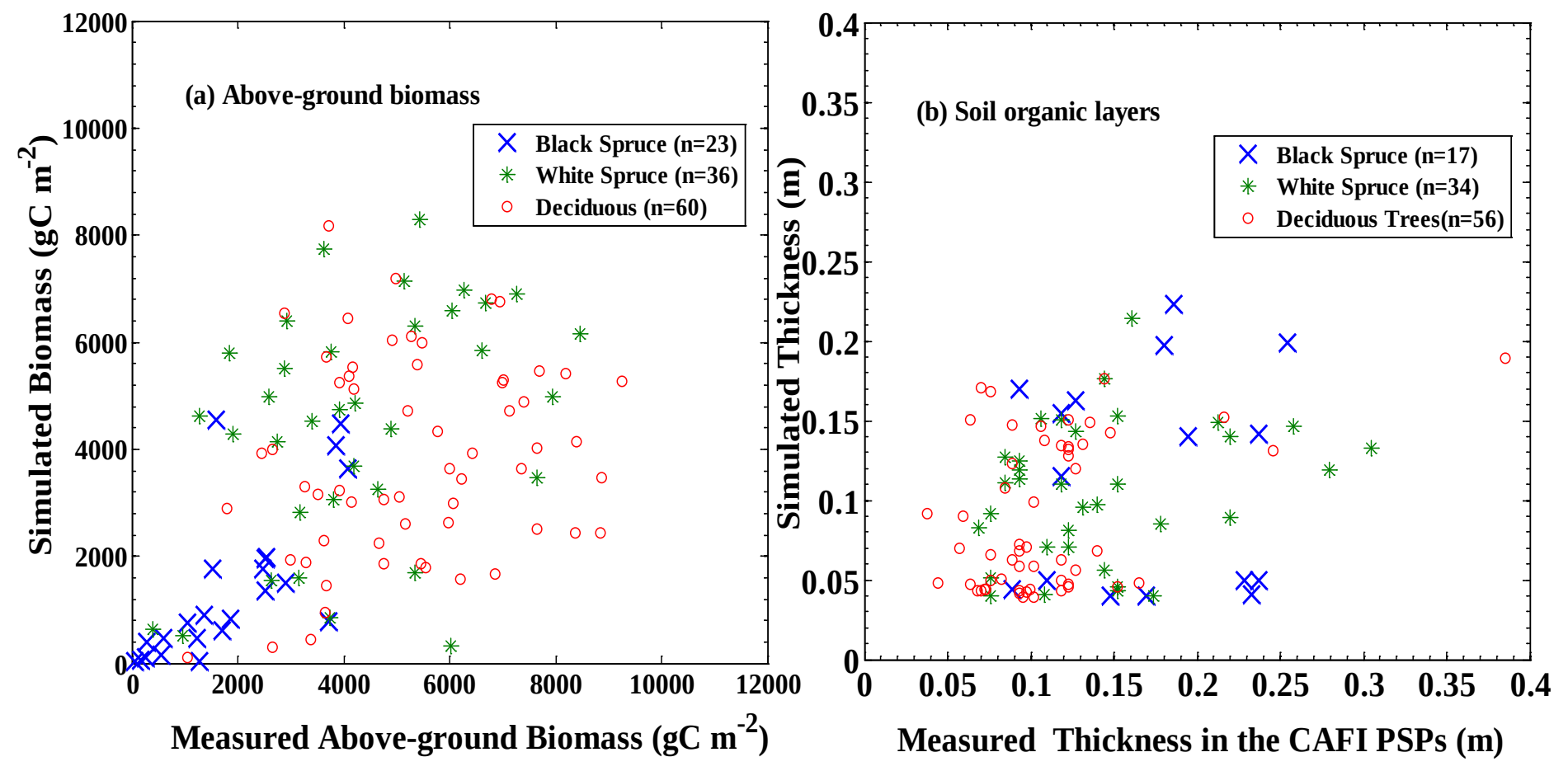

Fig. 3 *Comparison of (a) above-ground biomass C; and (b) soil organic layer thickness between TEM simulation and measurements in the CAFI permanent sampling plots (Malone et al., 2006).*

Our simulation shows that DOS-TEM can reasonably well simulate forest biomass C accumulation in the region, although we run those plot-scale forests using climate data of half degree resolution (Fig.3a). Another factor to contribute to the simulation bias is the stand age uncertainty, which unfortunately are not measured in situ rather than approximated from fire history.

For soil organic layer thickness, the scatterness of simulation vs. measurement appeared larger than for vegetation (Fig.3b), but it's still in the range of acceptance. Beside coarse resolution of climate data and uncertain stand age, fire return intervals during model spin-up possibly contributed the uncertainty.

• Climate Warming vs. Fire Occurrence on C storage change of YRB

Warming over YRB was very impressive since mid-1970s (see Fig 2a), and there were 3 major fire occurrences, in late 1960s, around 1990, and 2004-2005.

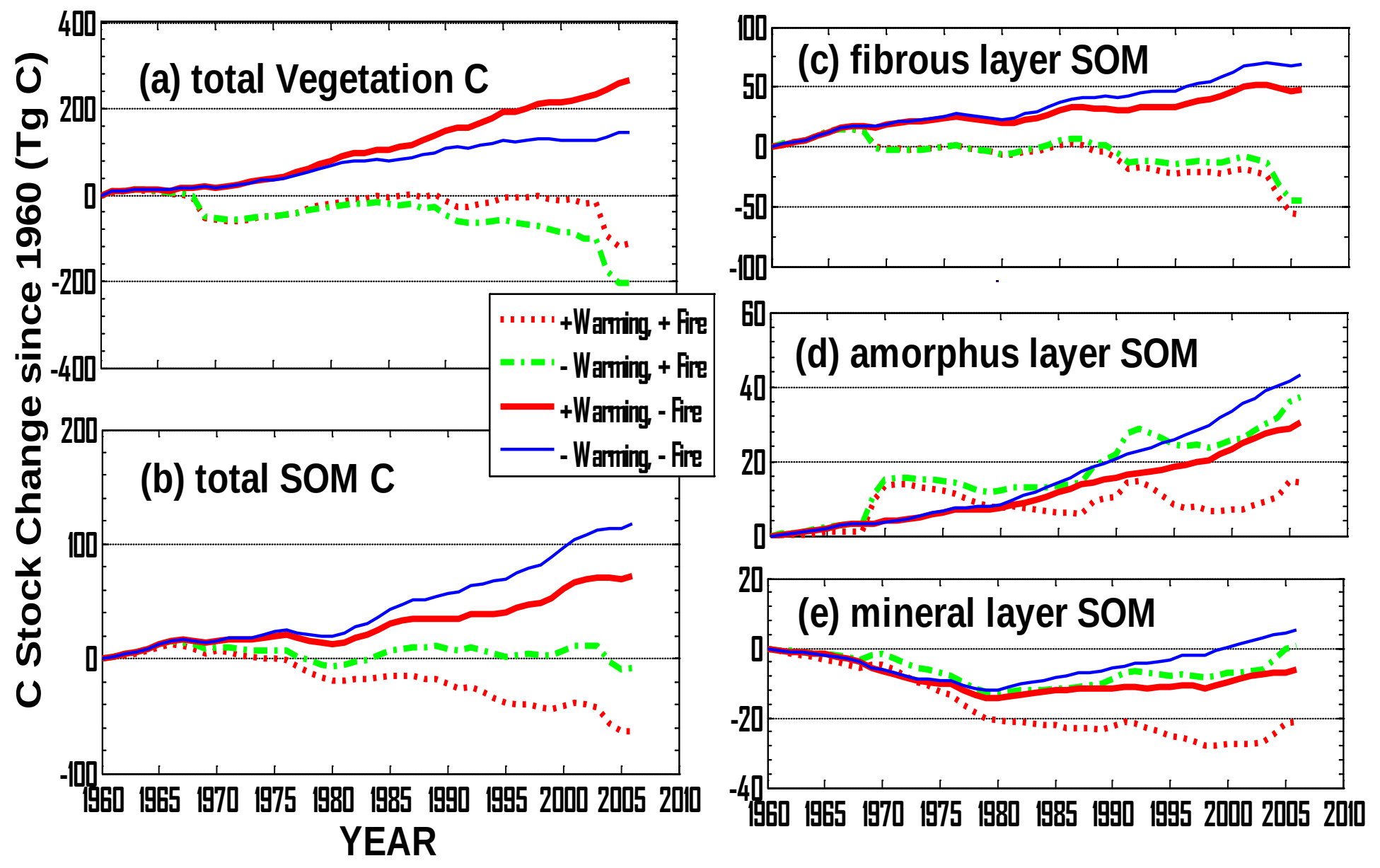

Fig. 4 *The total C storage change affected by warming and fire in the YRB boreal forest from 1960 - 2006.*

- The 3 major fires caused vegetation C large losses, after which vegetation C could recover to the original level in early 1980s, except for the 2004-2005 fire, there after forests not yet started to regrow (red-dash line in Fig.4a).
- The effects of warming and fire on SOM C appeared much complicate, although it generally lost since mid-1970s (red-dash line in Fig. 4b).
- Fire caused fibrous SOM loss, but which compensated by forest regrowth (Fig. 4c). Fire increased amorphous SOM by return burning residues (Fig. 4d). However mineral layer SOM slightly increased in fire, and then decomposed quickly during the post-fire forest recovery (Fig. 4e).
- Warming had increased forest vegetation C in YRB very much since 1980s (Fig. 4a, red-dash line vs. green-dash line, or, red line vs. blue line). However, fire burning might have offset all vegetation C increase due to warming (plus CO2 fertilization effect since 1901) (Fig. 4a, solid lines vs. dash lines), that is to say, fire impacts on vegetation C appeared much larger than climate warming.
- Both warming and fire greatly reduced SOM C storage, but fire reduced more (Fig. 4b, difference between blue and red line smaller compared to that between blue and green-dash line).

• Drought

The drought effect can be inspected by ratios of actual evapotranspiration (ET) to potential ET (Fig. 5). Drought seemed not very common in the whole YRB from 1960 – 2006, except for 1969, however which was correspondingly a large fire year.

Drought apparently had the annual net primary productivity (NPP) reduced (Fig. 5b). But its impact on yearly C changes was not distinguishable (Fig. 5c). It probably was covered by the effects of warming and fire.

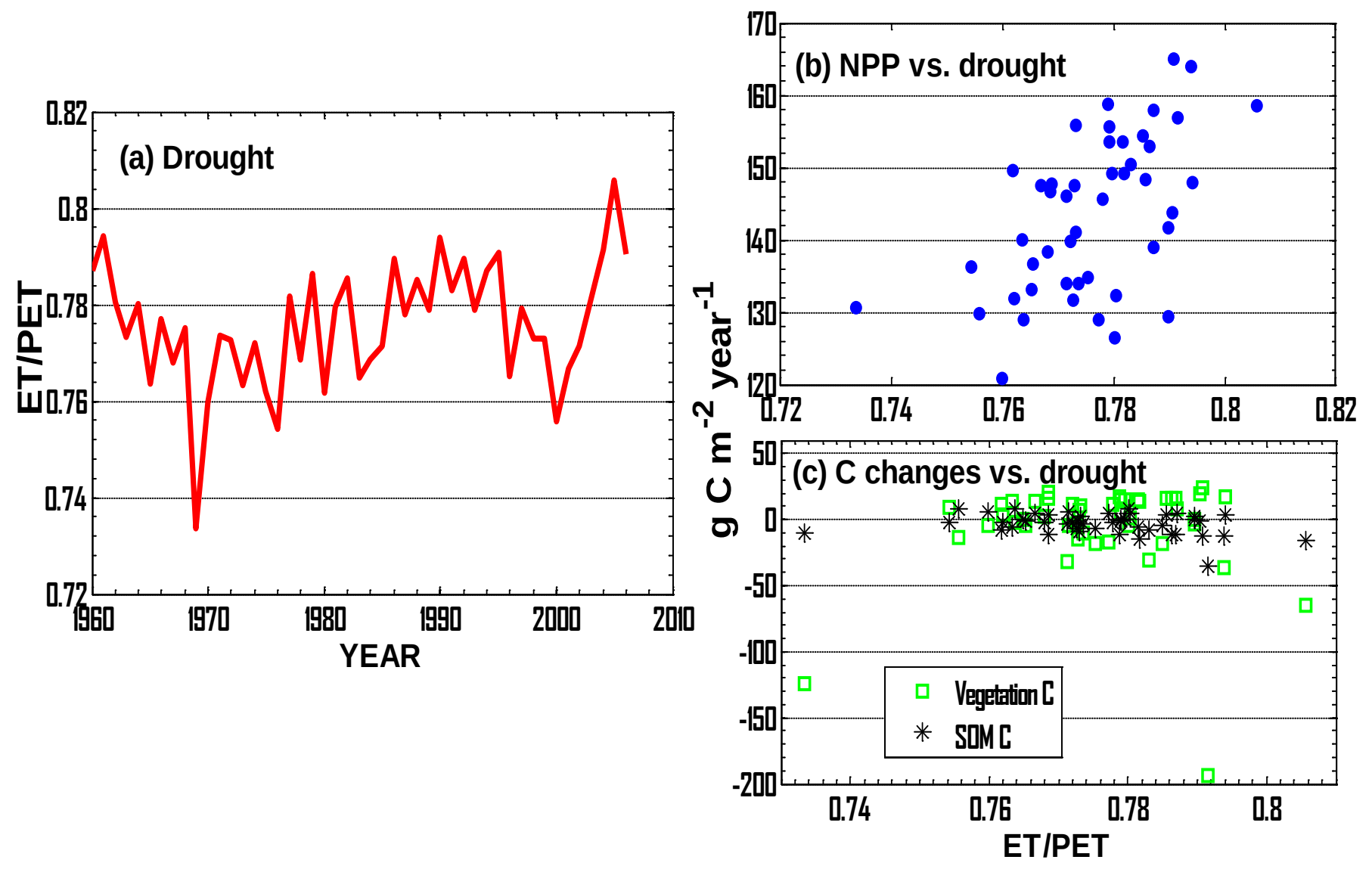

Fig. 5 *Drought and NPP and annual total C storage change in the YRB boreal forest from 1960-2006.*

• Upland vs. Lowland

Fig. 6 shows that impacts of warming and fire disturbance on vegetation C storage were similar for lowland and upland forests (Fig. 6a vs. Fig. 6c).

However, the effects on SOM C storage were different whether in lowland or upland. Total SOM C in lowland almost did not have net loss from 1960 – 2006 (red-dash line in Fig. 6b), but there was a large amount of net SOM C loss in upland (red-dash line in Fig. 6d). In lowland forests, cool weather in first half of the 1970s benefited SOM accumulation while thereafter warming decomposed more. In the meantime, 3 large fire occurrences had brought a large burning residue back to SOM pools in the lowland. Just because of SOM C losses in upland, the YRB soil C storage appeared a net loss.

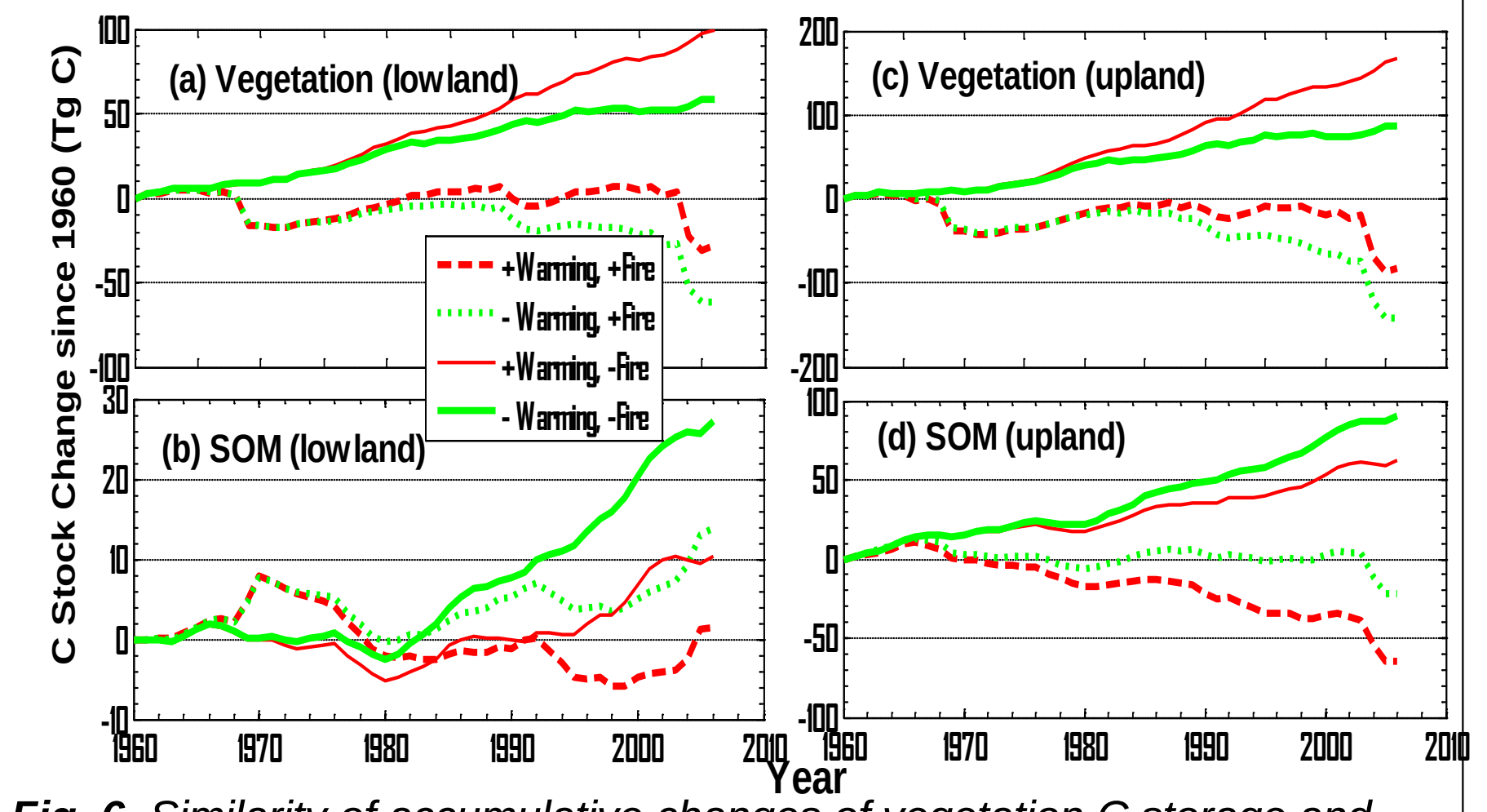

Fig. 6 *Similarity of accumulative changes of vegetation C storage and SOM C between lowland and upland forests in YRB from 1960 - 2006.*

• Sub-basin variation of accumulative C storage change from 1960-2006

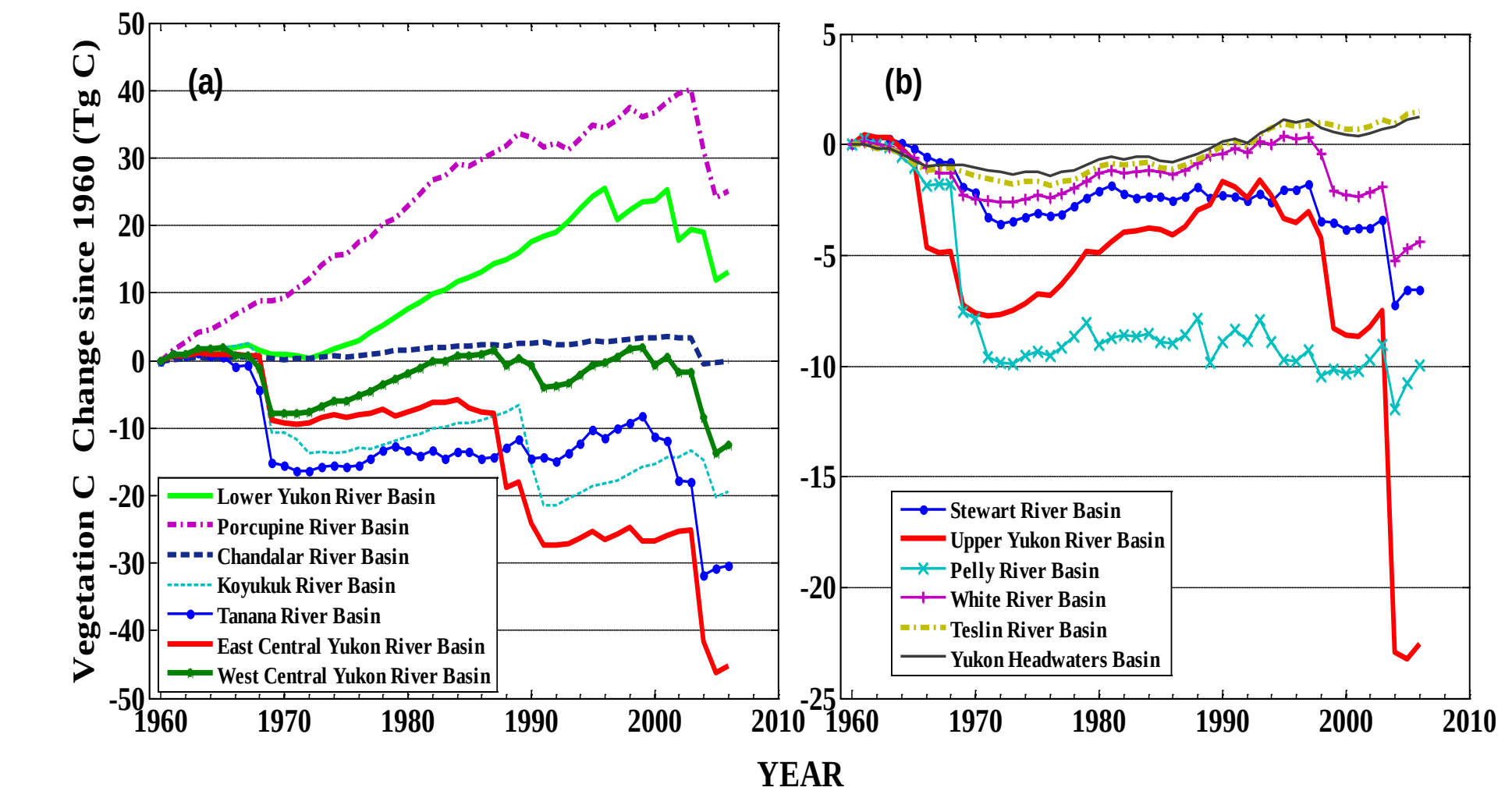

Fig. 7 *Variations of accumulative vegetation C changes across 13 sub-basins in YRB from 1960 – 2006. (a) lower- and mid-YRB; and (b) upper YRB.*

Fig. 7 shows that vegetation biomass C change in YRB had very large variation over individual sub-basins. Among all others, the late 1960s fires appeared not large enough to burn forests in Porcupine River Basin and Lower Yukon River Basin (Fig. 7a), and Yukon Headwater Basin and Teslin River Basin (Fig. 7b). The recovery after the late 1960s fire in some basins seemed not obvious. The highly heterogeneity of wildfires spatially and temporally in YRB contributed much of this variations.

Fig. 8 demonstrated that SOM C storage changes even more varied over 13 sub-basins, compared to vegetation biomass C.

Two lower-and mid-YRB sub-basins' vegetation C net gain just lead to almost no net gain/loss of SOM C (Fig. 8a). In two sub-basins in lower- and mid-YRB (West Central Yukon and Tanana River Basin), SOM C was gaining from 1960, where except for the late 1960s fire removal of vegetation, the vegetation C actually not much changed (see Fig. 7a).

Generally the upper-YRB sub-basins had been losing SOM C continuously since the late 1960s, although not much portion over the entire YRB (Fig. 8b). The climate warming might dominate this process, because fire usually caused more abrupt C losses.

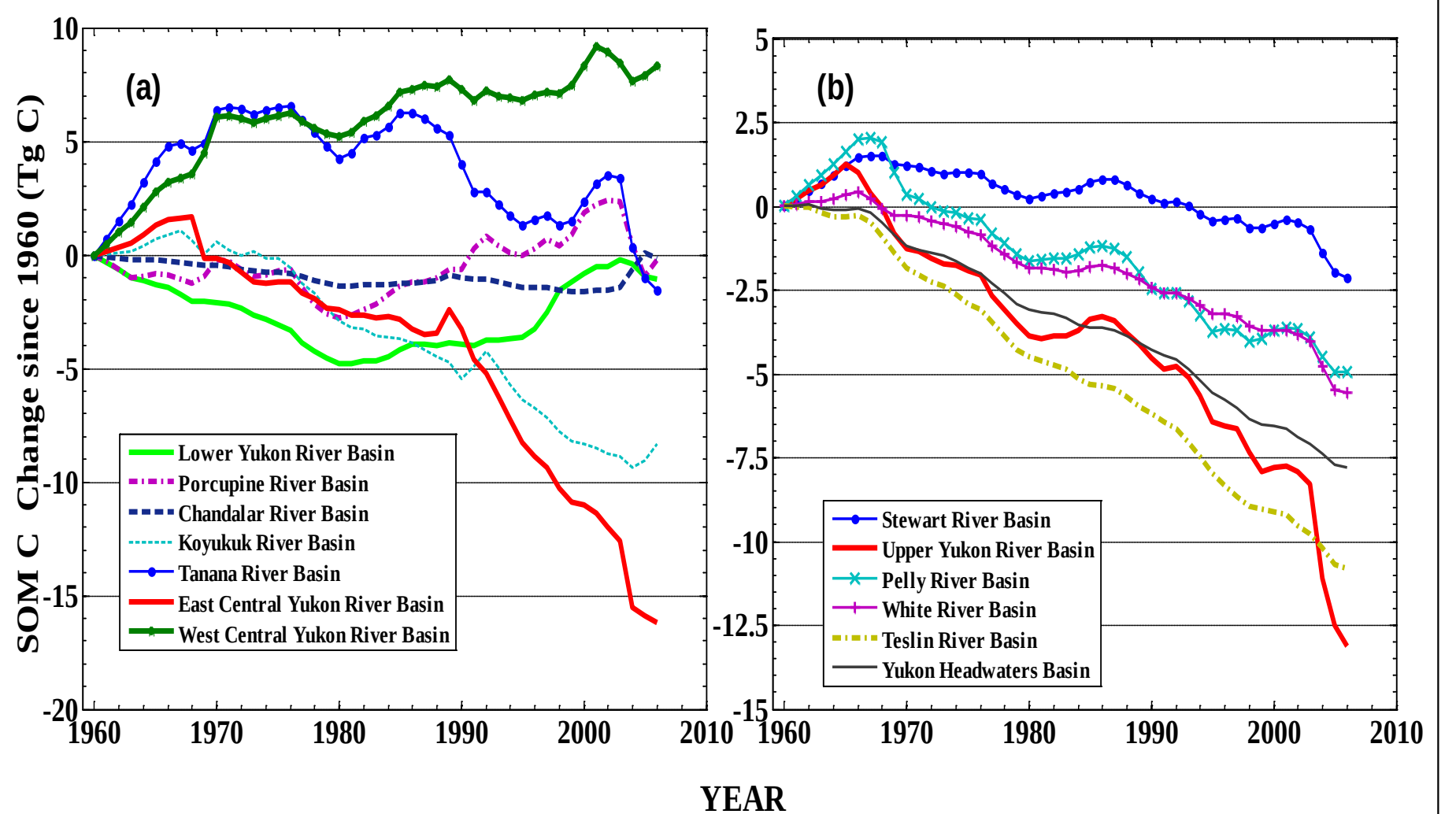

Fig. 8 *Variations of accumulative changes of soil organic C storage across 13 sub-basins in YRB from 1960 – 2006.*

Summary

- The DOS-TEM developed in this study is capable of predicting plot-size biomass C stocks and soil organic layer thickness in Alaska boreal forests reasonably well, although uncertainty still not ignorable.
- The YRB forest vegetation C since 1960 was mainly affected by 3 major fires, which almost offset the warming caused forest C increase under CO2 fertilization effects since mid-1980s. Fires had worsen the SOM C loss due to warming since mid-1970s.
- The YRB C storage appeared not affected by drought, but there existed large difference in SOM C changes between upland and lowland.
- The YRB C storage changes from 1960 – 2006 showed highly heterogeneity over its 13 sub-basins.

Acknowledgements:

Funding for this study was provided by the USDA and NASA Carbon Cycle Science Project titled "Assessing the Impacts of Fire and Insect Disturbance on The Terrestrial Carbon Budgets of Forested Areas in Canada, Alaska, and the Western United States".

This poster is presented at the 3rd NACP All Investigators Meeting held in New Orleans, LA , January 31 – February 4, 2011.