Climate Change Implications to Vegetation Production in Alaska

Christopher S. R. Neigh [1, 2]

[1] *Hydrospheric and Biospheric Processes Laboratory,*
NASA, Goddard Space Flight Center, Code 614.4, Greenbelt, Maryland 20771
[2] *Science Systems Application Inc., Lanham, Maryland, 20706*
Contact: christopher.s.neigh@nasa.gov ***10-15-08***

Abstract

Investigation of long-term meteorological satellite data revealed statistically significant vegetation response to climate drivers of temperature, precipitation and solar radiation with exclusion of fire disturbance in Alaska. Abiotic trends were correlated to satellite remote sensing observations of normalized difference vegetation index to understand biophysical processes that could impact ecosystem carbon storage. Warming resulted in disparate trajectories for vegetation growth due to precipitation and photosynthetically active radiation variation. Interior spruce forest low lands in late summer through winter had precipitation deficit which resulted in extensive fire disturbance and browning of undisturbed vegetation with reduced post-fire recovery while Northern slope moist alpine tundra had increased production due to warmer-wetter conditions during the late 1990s and early 2000s. Coupled investigation of Alaska's vegetation response to warming climate found spatially dynamic abiotic processes with vegetation browning not a result from increased fire disturbance.

Keywords: NDVI, Arctic, climate warming, Alaska, vegetation dynamics

1.0 Introduction

The global warming imprint has left an indelible mark on Arctic terrestrial processes observable from satellite remote sensing instruments [*Kimball et al.*, 2007]. Future decades hold high latitude changes from abiotic impacts to biophysical processes. Mean annual surface temperature increased > 2° C in Alaska during the past 25 years which has been observed to have marked regional impacts altering ecosystem functioning through processes of snow melt modifying albedo and/or hydrology [*Chapin et al.*, 2005; *Dye and Tucker*, 2003; *Sturm et al.*, 2001], thawed permafrost increasing depth of active layer [*Osterkamp and Romanovsky*, 1999], enhanced vegetation growth via growing season extension [*Epstein et al.*, 2004; *Jia et al.*, 2003; *Stow et al.*, 2003; *Walker et al.*, 2003], increased fire disturbance periodicity due to summer drought [*Stocks et al.*, 2003], reduced growth from temperature induced drought stress [*Barber et al.*, 2000], and changed shrubland cover [*Tape et al.*, 2006]. Increased regional warming could produce carbon sinks [*Sitch et al.*, 2007] or sources [*Goetz et al.*, 2005; *Pisaric et al.*, 2007] due to disturbance interval [*Amiro et al.*, 2001] or variance in cycling rate [*Kimball et al.*, 2007] which could feedback to global climate.

Ecosystem dynamics altered by climate change are complex in cold regions, which has produced future carbon status uncertainty [*Cornelissen et al.*, 2007]. Warming in Alaska has accelerated from 0.15 ± 0.02 to 0.3 ± 0.1 per decade and now Arctic summers are warmer than 400 years prior, resulting in large impacts to water dependent processes [*Barber et al.*, 2004; *Chapin et al.*, 2005; *Riordan et al.*, 2005]. Alaska is an ideal to understand northern biomes as it exhibits increased Arctic slope vegetation productivity while negative trends exist in the interior [*Neigh et al.*, 2008; *Verbyla*, 2008]. Climate and biophysical ecosystem interaction change is critical to understand as it may be indicative of future high-latitude processes. To address this the hypothesis herein was long-term summer climate warming has produced photosynthetic trends either positive or negative depending on regional temperature and precipitation requirements while fire and/or insect outbreak disturbance processes are second order. Prior studies have not provided spatially contiguous correlation results of abiotic forces on vegetation growth with fire disturbance regimes in Alaska. This study seeks to understand ecosystem dynamics observable through satellite measurements.

2.0 Experiment Design and Data

Multiple geospatial datasets were acquired to understand vegetation production variance throughout Alaska. Distinguishing between multiple processes and feedbacks is difficult considering they are often driven by one another, for example warming drought-stress inducing fire followed by insect-outbreak. To illustrate Alaskan vegetation processes, a figure was developed for disturbance agents to vegetation production indicated with boxes, and feedbacks shown as ovals (Figure 1). To further explore intra-seasonal dynamics, data trends were calculated on monthly values.

Two experiments were conducted to understand climate-vegetation relationship and implication of fire disturbance. Experiment one calculated per-pixel correlation between normalized difference vegetation index (NDVI) the measure of photosynthetic capacity of vegetation, surface air temperature, precipitation, and photosynthetically active radiation data (PAR). Experiment two examined ecoregion mean of positive or negative significant abiotic - NDVI correlation with and without fire disturbance.

2.1 Geospatial & Disturbance Data

Historical burned area perimeters were derived from the Alaska Fire Service GIS Group, US Department of the Interior, Bureau of Land Management [*AFS*, 2008] [http://agdc.usgs.gov/data/blm/fire/index.html]. Burned area data quality varied to 1945 due to development method and resources available. A marked increase in burned area from the 1980s ~1.6 million hectares to 2000s ~6.5 occurred throughout interior Alaska. This change in fire history could impact ecosystem productivity and/or recovery observed with coarse resolution AVHRR. Burned area was reprojected to Global Inventory Modeling and Mapping Studies (GIMMS) North America Albers projection and converted to fractional 64 km^2 from 2 km^2 using average pixel aggregations.

Historical insect outbreak data were derived from Alaska GIS Group, US Department of the Interior, Bureau of Land Management [*USFS*, 2008] [http://agdc.usgs.gov/data/projects/fhm/#K] and converted to 8 km^2 average pixel aggregations. Outbreak area was collected for > 40 disturbance types with varying implications to vegetation health from reduction in leaf area inducing early senescence to mortality. Aspen leaf miner was the most extensive insect disturbance throughout interior and southeast regions during the 2000s although it does not cause mortality [*Wagner et al.*, 2007]. However it could impact NDVI measurements [*Verbyla*, 2008]. All insect disturbances were prevalent in bottom lands of closed spruce hardwood forests, and open, low growing spruce forest neighboring river banks.

To spatially understand remote observations of disturbance, ecoregions were subset based upon US Department of Agriculture Forest Service ECOMAP Version 2.0 [*Nowacki et al.*, 2001], to 34 sub-regions based upon dominant vegetation cover, climate, and altitude. Investigation sought to understand if disturbance processes initiated interior NDVI decline and

ECOMAP provided a means to subset National Oceanic Atmospheric Administration's polar orbiting (NOAA) satellite measurements of vegetation photosynthetic capacity. Most ecoregions include large samples > 130, 8-km pixels (Table 2).

2.2 Remote Sensing and Climate Data

GIMMS version 'g', 1982 to 2005 bimonthly AVHRR NDVI data [*Tucker et al.*, 2005] provide a consistent inter-calibrated record for long-term vegetation studies. These data were corrected to account for orbital drift, minimize cloud cover, compensate for sensor degradation, and stratospheric volcanic aerosols effects [*Tucker et al.*]. GIMMS Alaska data contains nearly ~25,000 8 km^2 pixels extending back to 1982 from 2005 yielding 144 growing season months for correlation. July NDVI > 0.5 was used as a threshold to exclude glaciers and sparsely vegetated mountainous regions from calculations.

Monthly climate data were derived from Leemans & Cramer climatology [*Leemans and Cramer*, 1991] and GISSTEMP anomalies [*Hansen et al.*, 1999], solar radiation from the International Satellite Cloud Climatology Project (ISCCP) [*Bishop and Rossow*, 1991], and precipitation from the Global Precipitation Climatology Project version 2 (GPCP) [*Adler et al.*, 2003]. Climate data were detrended and reprojected to GIMMS North America Albers projection and bilinear interpolated to AVHRR NDVI grid cell resolution. Climate trends are calculated in a similar manner as prior NDVI investigations [*Slayback et al.*, 2003] with a least squares linear fit per pixel from 1982 through 2005 applied with pixels having a significance of less than 0.1 or a confidence of 90% retained. Values presented are slope multiplied by 24-years, between 1982 – 2005. Correlation of climate to NDVI has been performed in numerous studies to understand implications of abiotic changes to ecosystems [*Braswell et al.*, 1997;

Myneni et al., 1996; *Neigh et al.*, 2007; *Potter and Brooks*, 1998]; similar methods are employed herein to understand browning of interior Alaska.

3.0 Results & Discussion

Calculation of monthly mean climate and trends correlated with NDVI from 1982 through 2005 revealed changes in productive growing season. North Slope mean July temperature ranged ~5 − 10 °C with prior and later months experiencing temperatures close to freezing potentially allowing snow cover altering growing season NDVI measurements. It is considered a polar desert with most precipitation occurring late growing season and seasonal snow thaw contributes to early productivity. Warmest Alaskan summer temperatures > 15 °C occur in the continental climate of the interior and monthly precipitation was low < ~20 mm throughout early and mid-growing season increasing to the southeast > ~150 mm in September. Available High-latitude PAR varies markedly in Alaska > 150 W/m^2 in June, and < 50 W/m^2 in September. Note mean seasonal vegetation growth is greatest in July during temperature maxima, while having limited water availability throughout interior and northern Alaska. Abiotic driver change could alter early and mid-season production depending upon temperature impact on vapor pressure deficit.

Alaska exhibited strong Arctic Slope vegetation growth with declining interior trends (Figure 2). Temperature trends > 2 °C are prevalent during early months with little late season variation. All of Alaska experienced May – June increased precipitation totaling > ~20 mm from 1982 – 2005 except for the southeast handle which has the greatest precipitation. North Slope and southeastern coastal Alaska had increased late season precipitation, while a declining interior trend extended through winter months. PAR changes were minimal < ±10 W/m^2.

Experiment one found abiotic drivers of temperature, and precipitation had intra-seasonally moderate positive or negative relationship to vegetation productivity, while PAR had weak correlation. Temperature correlation to NDVI revealed > 0.5 in May and June throughout Alaska indicating earlier growing season start (Figure 3). Precipitation was positively correlated > 0.4 to vegetation growth in May and June on the North Slope, while late season precipitation decline and winter snowpack correlated > -0.5 negatively.

Experiment two calculated NDVI correlation to abiotic variables in locations of fire disturbance > 50%, 8-km pixel burned (Figure 3, inset black bars) and with fire exclusion 0%, 8-km pixel burned (Figure 3, inset white bars). Subtle ecoregion difference between burned-unburned occurred early season with larger difference during mid to late season months. Negative NDVI interior regions had moderate negative correlation with surface temperature and precipitation, with weak positive correlation to PAR within unburned sites and slightly stronger negative correlation in burned sites. Most ecoregions had similar correlation whether burned or unburned with few ecoregions exhibiting stronger negative precipitation correlation and less positive correlation to temperature in burned sites.

Regional vegetation growth and browning due to climate change occurred from 1982 through 2005. Results presented are similar to prior North Slope reports with temperature increases driving growth in vegetation; however increased precipitation was also found to have an impact. Suspected interior lowland drying appeared during late season and through reduced snowpack. Satellite observations found spatially contiguous regions of vegetation productivity change which had moderate relationship to temperature and/or precipitation. North Slope vegetation growth appeared from warmer-wetter conditions while interior drying-browning vegetation appeared late growing season, followed by reduced winter snow pack leading to reduced spring moisture. Coupled warming-drying climate with poor post disturbance recovery is suspected driver for early season browning. Warming permafrost could contribute through nutrient cycling and surface saturation [*Chapin et al.*, 2005]. However, capturing active layer dynamics is beyond the scope of this investigation. No marked mid-growing season interior climate trends were found. Fire and insect outbreak could reduce mid-season vegetation productivity although correlation difference between disturbed and undisturbed sites was minimal. Increased fire disturbance interval appeared not to cause browning, but is a result of long-term drying. Correlated data revealed regional climate change could impact vegetation production and Alaskan terrestrial carbon cycle balance. Long-term spatial climate records appear to be robust using simple correlation significance to understand climate influence on vegetation growth. Future investigation will quantify regional carbon budget disturbances in ecosystem simulations.

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Table 1. ECOMAP ecoregions (34) used in spatial analysis of abiotic variables and NDVI. Code numbers referred to in Fig 3.

Ecoregion	Code	# Pixels	Area (10^3 km^2)
Beaufort Coastal Plain	1	818	52.4
Brooks Range Foothills	2	1659	106.2
Brooks Range Mountains	3	2345	150.0
Olgivie Mountains	4	641	41.0
Ray Mountains	5	992	63.5
Yukon Flats	6	528	33.8
Upper Kobuk-Koyukuk	7	872	55.8
Kotzebue Sound Lowlands	8	338	21.6
Nulato Hills	9	815	52.2
Seward Mountains	10	778	49.8
Yukon Bottomlands	11	1013	64.8
Dawson Range	12	1021	65.3
Yukon-Kuskokwim Delta	13	1367	87.5
Kuskokwim Colluvial Plain	14	791	50.6
Kuskokwim Mountains	15	1142	73.1
Alaska Range	16	1431	91.6
Copper River Basin	17	270	17.3
Cook Inlet Lowlands	18	427	27.3
Wrangell Mountains	19	394	25.2
Nushagak-Lime Hills	20	558	35.7
Northern Chugach Range	21	227	14.5
Northern Aleutian Range	22	579	37.1
Chugach Range	23	295	18.9
Kenai Mountains	24	161	10.3
St. Elias Range	25	489	31.3
Ahklun Mountains	26	531	34.0
Gulf of Alaska Fjordlands	27	350	22.4
Boundary Range	28	311	19.9
Gulf of Alaska Forelands	29	133	8.5
Alexander Archipelago	30	870	55.7
Bristol Bay Lowlands	31	635	40.6
Alaska Peninsula	32	481	30.8
Aleutian Islands	33	193	12.4
Aleutian Colluvial Plain	34	179	11.5

Figure 1. Spatial-temporal vegetation productivity dynamics with interacting feedbacks in Alaska.

Figure 2. (A) May, (B) June, (C) July, (D) August, and (E) September 1982-2005, slope multiplied 24-years of NDVI, surface air temperature, precipitation, and photosynthetically active radiation.

Figure 3. ECOMAP ecoregions, AFS burned area perimeters converted to fraction of 8 km pixel displaying severe burn years 2004-2005 overlaid upon a digital elevation model. (Lower) Mean of positive or negative deseasonalized detrended significant correlation coefficients for the spatial regression of NDVI versus temperature (red bars), precipitation (blue bars), and photosynthetically active radiation (orange bars) by month and ecoregion presented as mean of entire ecoregion, without fire (white inset bars), and burn locations > 50% of 8 km^2 pixel (black inset bars). (A) May, (B) June, (C) July, (D) August, and (E) September 1982-2005, values with a significance > 0.05 and July NDVI < 0.5 excluded.

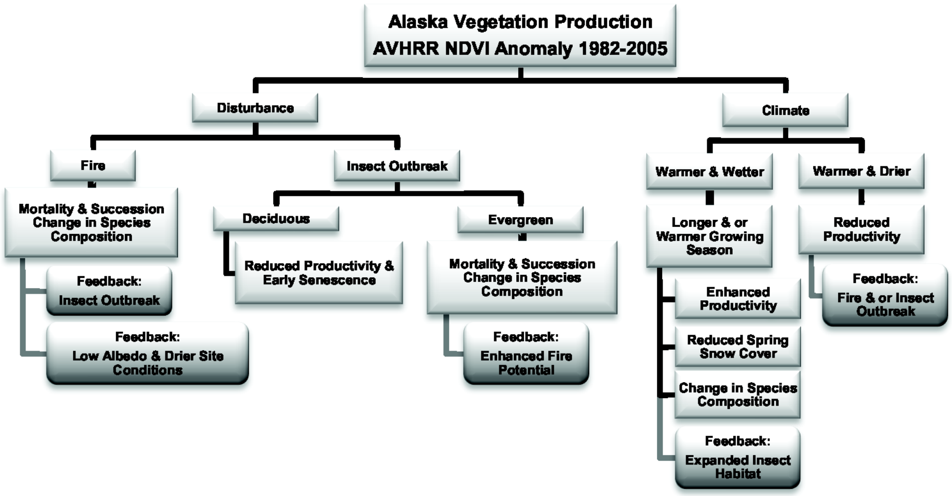
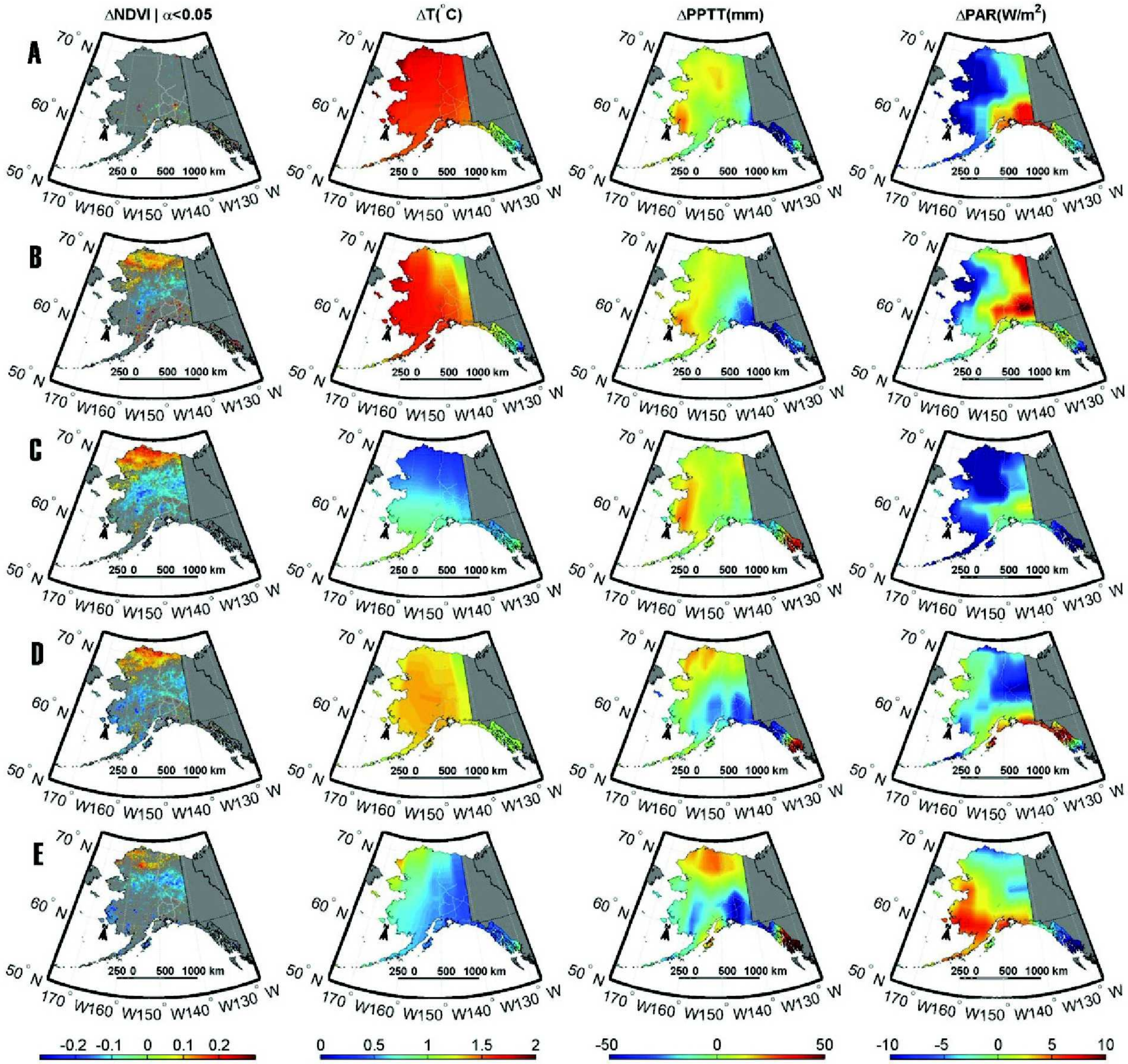


Figure 1. Hypothesized spatial-temporal vegetation productivity dynamics potentially observed with meteorological satellite measurements with interacting feedbacks in Alaska.



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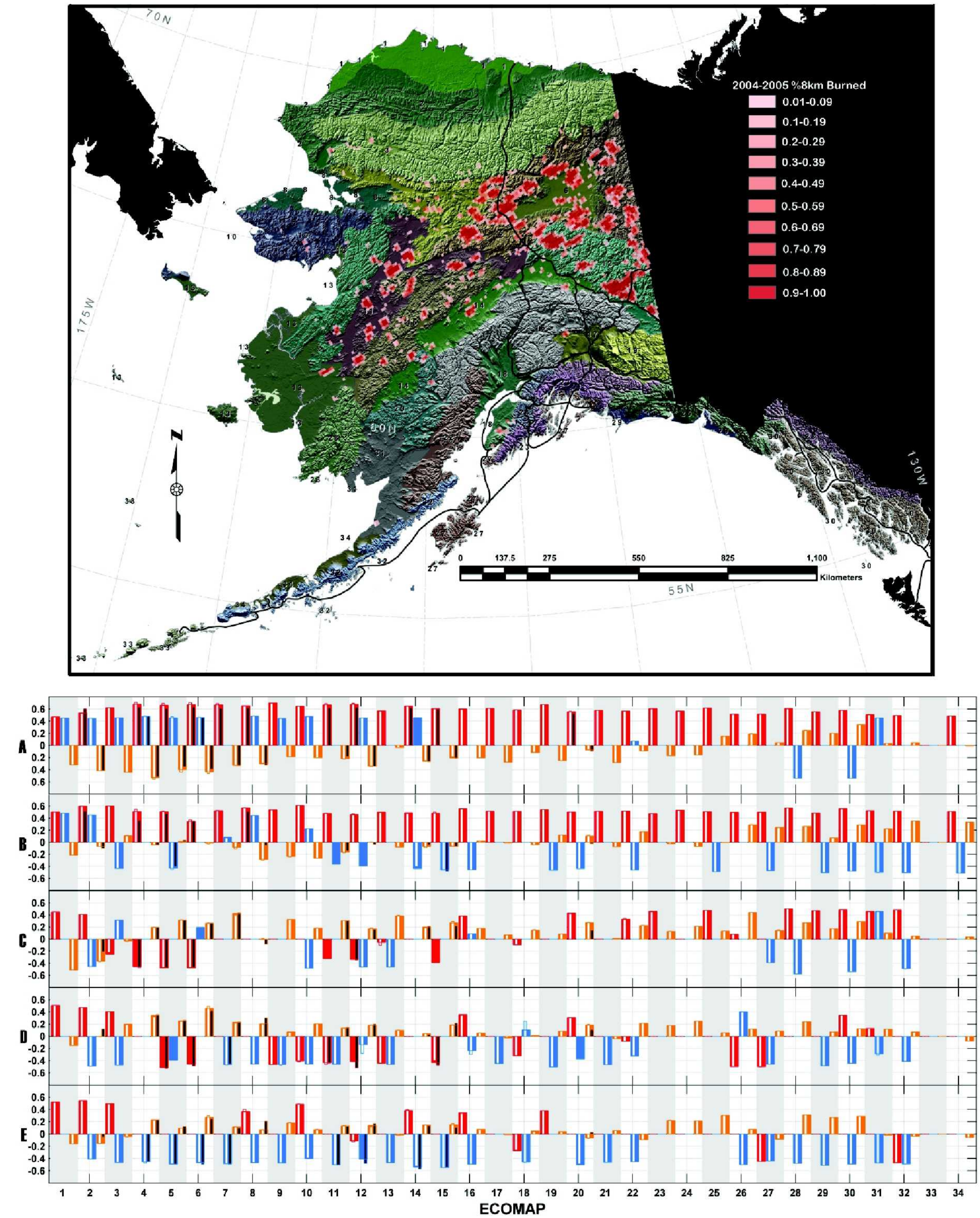

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