B33I-0578: Optimizing burn severity assessments in Alaskan tussock tundra from optical imagery

Loboda TV [1] (loboda@umd.edu), Jenkins LK[2], French NHF[2], Bourgeau-Chavez LL[2]

[1] Department of Geographical Sciences, University of Maryland, College Park, MD, USA
[2] Michigan Tech Research Institute, Michigan Technological University, Ann Arbor, MI, USA

Background

Over the past decade Alaskan tundra has experienced an increase in fire occurrence prompting rising concerns in the scientific community. Fire occurrence in tundra has the potential to release a large amount of organic carbon stored in the deep organic layer, modify soil moisture and respiration, and make more organic matter available for decomposition and future burning through impacts on the active depth layer.

Monitoring and characterization of fire occurrence and impacts in extensive, remote, and largely inaccessible tundra regions rely on satellite observations of land surface and require robust approaches to burn severity measurements. The relatively low fire activity in tundra regions between 1950 and 2000 has resulted in overall lack of understanding of fire impacts on tundra landscapes outside the Seward Peninsula where tundra fire record is better known. Thus satellite-based mapping of burn severity is limited by the lack of quantified knowledge of fire-induced physical changes on the landscape on the one hand and the capabilities of optical remote sensing systems to capture those characteristics on the other.

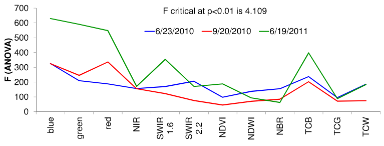
North American tundra

Typical open tussock tundra vegetation away from stream beds is a combination of tussocks, other grasses, low shrubs (< 1m), and moss/lichens. Exact proportional compositions of these lead to large variability in tundra surface reflectance in visible, NIR, and SWIR spectrum and vegetation indices.

Mostly tussock

Mostly shrub

Mostly moss



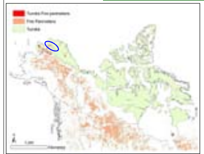
TCB, TCG, and TCW – Tasseled Cap Brightness, Greenness, Wetness, respectively

Landsat-based ANOVA analysis of 6000 random pixels within unburned regions immediately adjacent to 2010 scars (1,000 pixels per unburned sample) in the Noatak Nature Preserve (left) for 3 images:

- Pre-burn 6/23/2010
- Post-burn 9/20/2010
- 1st post-fire season 6/19/2011

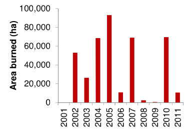
show strong statistically significant dissimilarity across tussock tundra within 200 km stretch along Noatak River (see lower right image next pane)

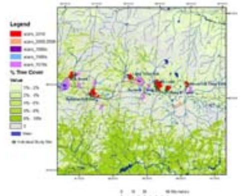
Fire in the tundra



- Fire occurrence in tundra is limited mostly to Alaska (left)
  - Seward Peninsula
  - Noatak River Canyon (blue oval right and map below)
  - North Slope
- Fires tend to cluster to previously burned areas and appear to be limited by biomass available for burning and

MODIS-based regional burned area estimates (Loboda et al. 2011) show a total of 404,221 hectares burned 2001-2011 (below)





Field assessments of burn severity

Composite Burn Index (CBI):

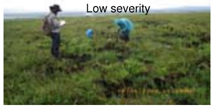
- Currently operationally applied by management agencies across the US (Key & Benson, 2006)
- Ocular assessment and scoring of burn impact magnitude on duff, ground layer, shrubs, and trees
- Combined into a single value following:
  CBI = sum scores per category / # rated categories

Burn Severity Index (BSI):

- Based on Viereck et al., 1979
- Ocular overall (i.e. combined for al vegetation types) assessment of burn severity within a plot by fractional composition (e.g. 25% low severity, 40% moderate severity, 35% high severity)
- Combined into a single index following:
  BSI = 1 * unburned fraction + 2 * low severity fraction + 3 * moderate severity fraction + 4 * high severity fraction

Unburned

Low severity



Substrates:
- Consumed 50% litter, 20% tussock basal area, 10% heavy fuels,
- Light char, 10% exposed mineral soil

Herb, low shrub:
- Consumed/blackened 30% moss, 30% foliage
- 90% frequency of living, no colonizers

- Char: visible but mostly at an angle as it is obscured by re-growing tussocks and shrubs
- Moss: singed but not burned
- Tussocks: burned off senescent grass with no damage to the core; vigorous regrowth
- Shrubs: > 30cm singed but not top-killed; < 30cm top-killed but robust regrowth from root

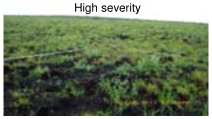
Moderate severity

Substrates:
- Consumed 100% litter, 40% tussock basal area, 25% heavy fuels, 50% duff
- deep char, 40% exposed mineral soil

Herb, low shrub:
- Consumed/blackened 80% moss, 80% foliage
- 50% frequency of living, moderate # colonizers

- Char: large amount exposed
- Moss: singed and dead along the periphery
- Tussocks: burned to the core with robust regrowth of the core; a part of tussock may be killed
- Shrubs: top-killed with robust regrowth from root

High severity

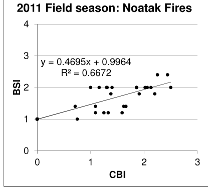


Substrates:
- Consumed 98% light fuel, 60% tussock basal area, 40% heavy fuels, 100% duff
- deep char, 80% exposed mineral soil

Herb, low shrub:
- Consumed/blackened 100% moss, 100% foliage
- No living, low # colonizers

- Char: large amount exposed, dominant feature on the plot
- Moss: mostly killed with some surviving patches
- Tussocks: burned to the core with partial or complete tussock mortality, moderate regrowth
- Shrubs: top-killed with moderate root regrowth

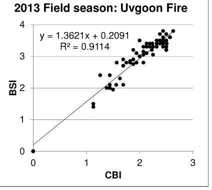
2011 Field season: Noatak Fires



CBI and BSI measures of burn severity were obtained from 2 field seasons at the Noatak Nature Preserve, Alaska

1. 2011 Field season (left): NPS crew sampled 5 moderate and low severity burns of 2010 fire season (completed burning July 9, 2010), UMD/MTRI crew sampled 1 moderate/high severity burn of 2010 and collected only BSI measurements (data not shown in the graph on the left)
2. 2013 Field season (right): UMD/MTRI crew sampled 1 moderate/high severity burn of 2012 fire season (completed burning by July 8, 2012).

2013 Field season: Uvgoon Fire



Landsat-based assessment of burn severity

	image date	n	blue	green	red	NIR	SWIR 1.2	SWIR 2.2	NDVI	NDWI	NBR	TCB	TCG	TCW
	CBI													
Pre-burn	06/04/09	25	0.01	0.02	0.05	0.01	0.01	0.00	0.18	0.00	0.01	0.00	0.06	0.01
Pre-burn	06/20/09	14	0.19	0.23	0.20	0.20	0.20	0.19	0.16	0.11	0.15	0.22	0.08	0.18
Pre-burn	08/16/09	26	0.02	0.02	0.01	0.07	0.03	0.00	0.01	0.02	0.01	0.03	0.10	0.01
Pre-burn	05/30/10	17	0.06	0.06	0.05	0.02	0.00	0.00	0.00	0.29	0.05	0.01	0.00	0.02
Pre-burn	06/23/10	21	0.29	0.14	0.38	0.00	0.20	0.23	0.39	0.14	0.17	0.18	0.18	0.14
Post-burn	07/09/10	10	0.04	0.15	0.36	0.93	0.94	0.04	0.82	0.77	0.93	0.91	0.92	0.40
Post-burn	09/20/10	27	0.64	0.71	0.73	0.80	0.74	0.27	0.36	0.35	0.67	0.81	0.75	0.48
Post-burn	05/25/11	12	0.24	0.80	0.65	0.77	0.73	0.56	0.62	0.12	0.50	0.81	0.71	0.56
Post-burn	06/19/11	27	0.38	0.61	0.70	0.78	0.72	0.11	0.46	0.52	0.68	0.77	0.77	0.01
Post-burn	09/22/11	11	0.27	0.25	0.17	0.44	0.04	0.15	0.63	0.40	0.64	0.01	0.84	0.00
	BSI													
Pre-burn	06/04/09	42	0.00	0.00	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Pre-burn	06/20/09	52	0.10	0.06	0.14	0.00	0.07	0.12	0.18	0.04	0.10	0.06	0.04	0.09
Pre-burn	08/16/09	64	0.04	0.05	0.10	0.02	0.04	0.08	0.18	0.01	0.10	0.05	0.00	0.05
Pre-burn	05/30/10	51	0.02	0.00	0.00	0.09	0.19	0.09	0.14	0.05	0.00	0.11	0.10	0.16
Pre-burn	06/23/10	59	0.01	0.07	0.23	0.00	0.00	0.01	0.24	0.01	0.01	0.03	0.06	0.00
Post-burn	07/09/10	10	0.04	0.08	0.12	0.69	0.59	0.14	0.72	0.57	0.67	0.61	0.72	0.17
Post-burn	09/20/10	65	0.34	0.66	0.77	0.74	0.75	0.27	0.40	0.50	0.70	0.78	0.67	0.54
Post-burn	05/25/11	50	0.72	0.79	0.81	0.82	0.73	0.28	0.63	0.51	0.69	0.84	0.75	0.35
Post-burn	06/19/11	65	0.68	0.76	0.78	0.79	0.80	0.15	0.30	0.63	0.79	0.81	0.75	0.19
Post-burn	09/22/11	33	0.08	0.16	0.11	0.00	0.22	0.45	0.12	0.13	0.46	0.16	0.14	0.39

Single-date regressions between CBI and BSI field burn severity measures and Landsat surface reflectance and related indices (left)

- Reported $R^2 > 0.1$ are for $p < 0.1$
- No relationship between pre-burn conditions and burn severity

CBI
- Strongly relates to the greenness
- Strongest relationships immediately post-fire and during peak greenness
- Relates well to RS measure of greenness and surface brightness
- Tasseled Cap Brightness (TCB) - the most consistent sequentially

BSI
- Relates to surface brightness
- Best detection is before greenup of the 1st post-fire season
- TCB – the most consistent

Multi-date regressions between CBI and BSI field burn severity measures and Landsat surface reflectance and related indices (right)

- Reported $R^2 > 0.1$ are for $p < 0.1$
- Late-season pre-burn (Aug 16, 2009) and post-burn (Sept 22, 2011) are not suitable for burn severity mapping
- Little consistency among indices for best mapping conditions

CBI
- Relates primarily to RS vegetation metrics :
  - NIR and TCG consistently best predictors
  - NDVI, however, is not the best predictor
- RdNBR does **not** offer advantages over NBR
- At least one of differenced images must be from peak greenness for best differentiation
- Offers stronger relationship with satellite data

BSI
- Offers weaker relationship with satellite data
- TCB – the most consistent especially when differenced with a pre-greenup of the 1st post-fire season image

Caveats:
- CBI data used is collected by NPS collaborators while BSI are computed from joint NPS and UMD/MTRI field data
- Only data from fires 2010 fires are included

Multi-date (differenced) CBI/BSI comparison

Image date	n	NIR	SWIR 1.2	NDVI	NDWI	NBR	RdNBR	TCB	TCG
4-Jun-09 - 9-Jul-10	8/8	0.95/0.71	0.61/0.53	0.88/0.81	0.67/0.46	0.88/0.69	0.93/0.75	0.78/0.57	0.98/0.77
4-Jun-09 - 20-Sep-10	25/42	0.64/0.47	0.54/0.44	0.52/0.36	0.42/0.66	0.74/0.73	0.72/0.76	0.58/0.48	0.65/0.48
4-Jun-09 - 25-May-11	12/29	0.89/0.62	0.62/0.53	0.71/0.5	0.16/0.61	0.51/0.69	0.52/0.70	0.82/0.65	0.84/0.42
4-Jun-09 - 16-Jun-11	25/42	0.63/0.57	0.31/0.27	0.49/37	0.52/0.66	0.67/0.72	0.66/0.77	0.46/0.46	0.69/0.53
4-Jun-09 - 22-Sep-11	9/26	0.01/0.01	0/0.15	0.6/0.16	0.2/0.48	0.91/0.54	0.89/59	0.1/0.13	0.4/0.09
20-Jun-09 - 9-Jul-10	10/10	0.94/0.66	0.94/0.61	0.77/0.58	0.72/0.49	0.92/0.60	0.93/0.65	0.92/0.64	0.93/0.66
20-Jun-09 - 20-Sep-10	14/52	0.86/0.76	0.76/0.72	0.47/0.43	0.6/0.53	0.78/0.67	0.79/0.68	0.62/0.72	0.85/0.66
20-Jun-09 - 25-May-11	2/40	na/0.83	na/0.76	na/0.61	na/0.43	na/0.61	na/0.62	na/0.86	na/0.68
20-Jun-09 - 16-Jun-11	14/52	0.83/0.76	0.4/0.77	0.68/0.46	0.8/0.64	0.87/0.77	0.87/0.80	0.45/0.76	0.9/0.72
20-Jun-09 - 22-Sep-11	11/33	0.4/0.04	0.02/0.25	0.52/0.13	0.28/0.12	0.53/0.41	0.56/0.43	0.01/0.24	0.73/0.11
16-Aug-09 - 9-Jul-10	10/10	0.91/0.76	0.87/0.86	0.71/0.35	0.8/0.48	0.91/0.48	0.95/0.58	0.64/0.85	0.85/0.49
16-Aug-09 - 20-Sep-10	26/64	0.54/0.41	0.35/0.4	0.24/0.48	0.36/0.58	0.56/0.69	0.65/0.68	0.34/0.26	0.66/0.54
16-Aug-09 - 25-May-11	12/50	0.77/0.68	0.52/0.59	0.52/0.67	0.1/0.63	0.12/0.71	0.2/0.71	0.62/0.63	0.85/0.63
16-Aug-09 - 16-Jun-11	26/64	0.59/0.48	0.27/0.37	0.32/0.43	0.67/0.64	0.68/0.76	0.76/0.77	0.3/0.29	0.8/0.58
16-Aug-09 - 22-Sep-11	10/32	0.47/0.06	0.03/0.23	0.51/0.22	0.26/0.26	0.56/49	0.63/49	0.02/0.18	0.61/0.1
30-May-10 - 9-Jul-10	8/8	0.8/0.68	0.87/0.49	0.89/0.69	0.54/0.73	0.81/0.85	0.86/0.84	0.73/0.53	0.85/0.74
30-May-10 - 20-Sep-10	17/51	0.43/0.76	0.37/0.74	0.12/0.4	0.13/0.49	0.52/0.68	0.61/73	0.4/78	0.31/63
30-May-10 - 25-May-11	5/39	0.86/0.83	0.81/0.71	0.88/0.63	0.03/0.53	0.44/0.68	0.54/0.72	0.65/0.87	0.92/0.72
30-May-10 - 16-Jun-11	17/51	0.47/0.81	0.24/0.71	0.16/0.39	0.43/0.51	0.59/0.75	0.63/0.81	0.36/0.81	0.41/0.73
30-May-10 - 22-Sep-11	10/28	0.01/0.0	0.01/0.07	0.22/0.22	0.04/0.17	0.41/0.44	0.48/0.48	0.02/0.09	0.65/0.32
23-Jun-10 - 9-Jul-10	10/10	0.92/0.63	0.93/0.61	0.79/0.56	0.79/0.49	0.95/0.64	0.95/0.65	0.86/0.58	0.91/0.62
23-Jun-10 - 20-Sep-10	21/59	0.92/0.75	0.87/0.77	0.62/0.42	0.57/0.53	0.78/0.67	0.79/0.69	0.91/0.77	0.86/0.66
23-Jun-10 - 25-May-11	8/46	0.91/0.83	0.95/0.75	0.97/0.62	0.33/0.54	0.72/0.66	0.67/0.67	0.89/0.84	0.95/0.7
23-Jun-10 - 16-Jun-11	21/59	0.94/0.77	0.79/0.85	0.82/0.44	0.79/0.62	0.86/0.75	0.86/0.77	0.92/0.83	0.94/0.71
23-Jun-10 - 22-Sep-11	11/33	0.4/0.04	0.02/0.2	0.62/0.12	0.26/0.09	0.51/0.34	0.55/0.38	0.02/0.21	0.75/0.08

Conclusions

- CBI overall is a more robust measure of burn severity in terms of linkages to satellite mapping - relates well with RS metrics related to vegetation structure (NIR, TCG, NBR, and RdNBR) in single- and multi-date assessments
- BSI has a weaker relationship with RS observations but can be successfully used with TCB
- NIR and TCG are stronger and more consistent predictors of burn severity than operationally applied NBR and RdNBR
- Single-date burn severity mapping can be done with sufficient ($R^2 > 0.8$) accuracy

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