A graph-cut-based method for spatio-temporal segmentation of fire from satellite observations

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July 25, 2013

Outline

1. Introduction
2. Proposed spatio-temporal segmentation method
3. Conclusions and perspectives

Automated mapping of burned areas

- **Biomass burning** has a significant impact on a climate system

$\Downarrow$

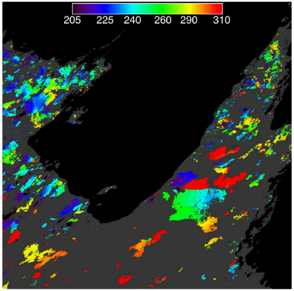
- Automated **mapping of burned areas** to:
  - help heal the scars
  - prevent future fires

Objective:

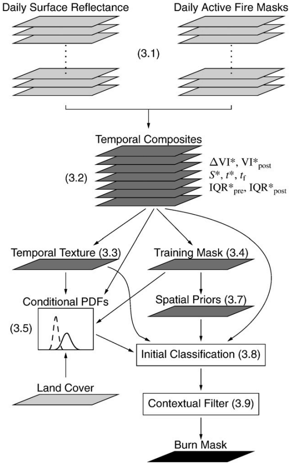
- Segment growing burned areas in time series of images
- By analyzing Terra Moderate Resolution Imaging Spectroradiometer (MODIS) measurements

State of the art

- MODIS Collection 5.1 Direct Broadcast Monthly Burned Area Product (MCD64A1)
  - change detection approach [Giglio 2009]
  - uses MODIS Level 2G (bands 1, 5, 7) and Level 3 daily active fire products
  - spatial filtering within the closest fixed neighborhoods

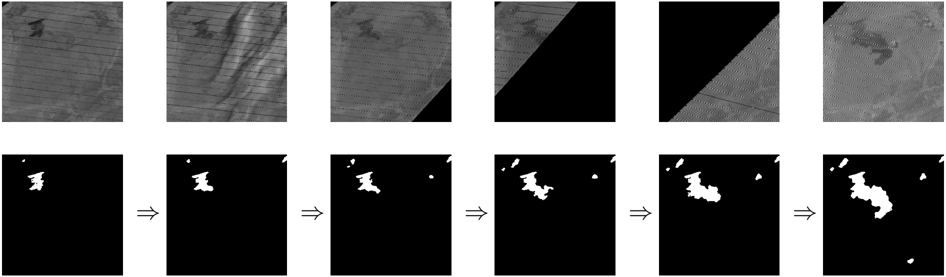


Estimated days of burn, MODIS tile h31v10



Our objective

- Compute **globally-optimal spatio-temporal** segmentation of **growing burned areas**
- From a time series of very noisy data
  - Cloud contamination, missing data
- In a low computational time



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- Compute **globally-optimal spatio-temporal** segmentation of **growing burned areas**
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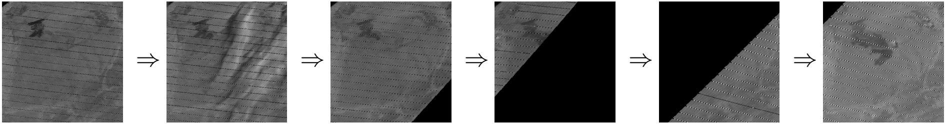
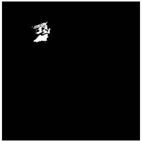
- **We propose a new graph-cut-based method**
  - For simultaneous segmentation of an image sequence
  - With the constraint of shape growth

Data set



- **Forty days** of **Terra MODIS** Level 2G measurements (MOD09GA)
  - Over tropical savannas in the Northern Australia (tile h31v10)
  - Acquired in September - October 2011 (days 244-283)
  - Band 5 (1.24 µm) 500-m land surface reflectance data
  - $T = 40$ images with spatial dimensions of 400×400 pixels

- **MCD64A1** burned area product
  - Training: computing an initial histogram of burned areas
  - Validation

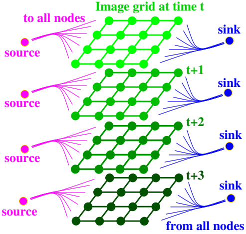


Training mask (days 213-243)

Graph cut for image segmentation

- **Goal:** Compute $T (t \in [1, T])$ segmentation maps $L^t = \{L^t_{(x,y)} \in [0, 1], x = [1..H], y = [1..W]\}$,

$$L^t_{(x,y)} = \begin{cases} 1, & \text{if } (x, y) \in \text{burned area at time t;} \\ 0, & \text{otherwise.} \end{cases}$$



Independent segmentation of T images

*[Boykov&Kolmogorov 2004]

- **Graph-cut globally-optimal segmentation*:**
  1. map each image $I(t)$ onto a graph
  2. minimize a submodular energy of the form:

$$E^t(L) = \sum_{\text{pixels } i} V^t_i(L^t_i) + \sum_{i \sim j} W^t_{i,j}(L^t_i, L^t_j)$$

- L^t_i = label of pixel i at time t
- individual potential $V^t_i(L^t_i)$ = penalty for a pixel i to have a label L^t_i
- $W^t_{i,j}(L^t_i, L^t_j)$ = interaction term between neighboring pixels i and j

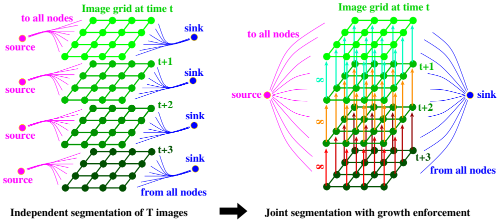
Joint segmentation with fire growth enforcement

t_1

$\Rightarrow$

$t > t_1$

- **Enforcing fire growth:**
  - = if $L_i^{t_1} = 1 \rightarrow L_i^{t>t_1} = 1$
  - = pair of pixels $((x, y, t), (x, y, t+1))$ cannot have pair of labels (1,0)
  - = we set a **directed infinite link** from each pixel to its predecessor in time



- **Criterion to be minimized:**

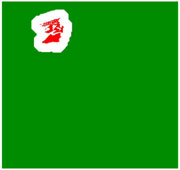
$$E = \sum_t E^t$$

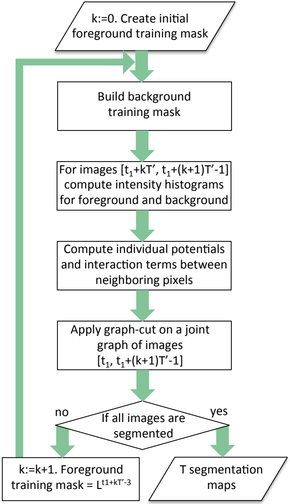
under the constraint of shape growth

- Apply **graph cut** to find globally-optimal solution

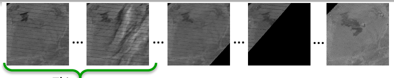
Proposed spatio-temporal segmentation method

0. **Initialization:**
   - $k := 0$
   - MCD64A1$[t_1 - D, t_1 - 1] \rightarrow$ initial **burned** training mask R_k^B
1. **Unburned** training mask
   R_k^U = complementary (dilation (R_k^B))

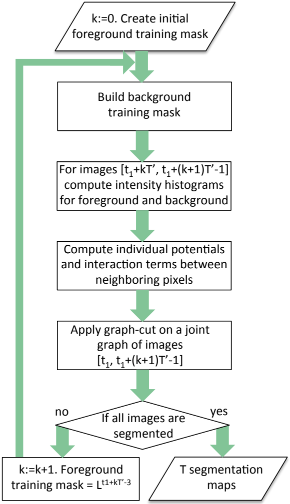




Proposed spatio-temporal segmentation method



T' images



For images $t = [t_1 + kT', t_1 + (k+1)T' - 1]$:

2. Compute intensity **histograms** of MODIS band 5 for burned $p^t(I|B)$ and unburned $p^t(I|U)$ areas
   - using masks R_k^B and R_k^U
3. Compute **individual potentials** and **interaction terms**, assuming $p^t(B) = p^t(U) = 1/2$:

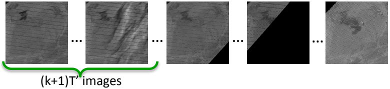
$$V_i^t(1) = -ln[p^t(B|I_i^t)] = -ln\left[\frac{p^t(I_i^t|B)}{p^t(I_i^t|B) + p^t(I_i^t|U)}\right],$$

$$V_i^t(0) = -ln[p^t(U|I_i^t)] = -ln\left[\frac{p^t(I_i^t|U)}{p^t(I_i^t|B) + p^t(I_i^t|U)}\right],$$

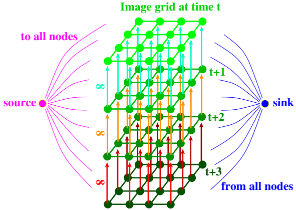
$$W_{i,j}^t = \delta_{L_i \neq L_j}\, \beta \, \exp\left[-\frac{(I_i^t - I_j^t)^2}{2\sigma^2}\right],$$

σ = standard deviation of I^t,
β controls the importance of spatial interaction.
If I_i^t is missing, $V_i^t(1) = V_i^t(0) = 0$

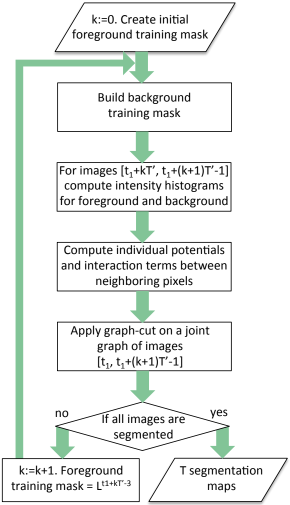
Proposed spatio-temporal segmentation method



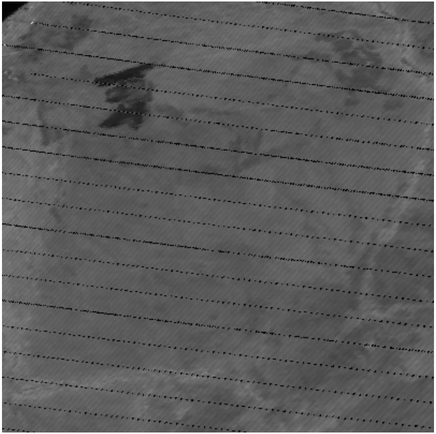
4. Apply graph-cut on a joint graph of images $[t_1, t_1 + (k+1)T' - 1]$



5. If all images are segmented, exit. Otherwise:
   - $k := k + 1$
   - **Burned** training mask $R_k^B = L^{t_1 + kT' - 3}$
   - Go to step 1 (Consider the next T' images)



Segmentation results ($\beta = 2$, $T' = 20$)



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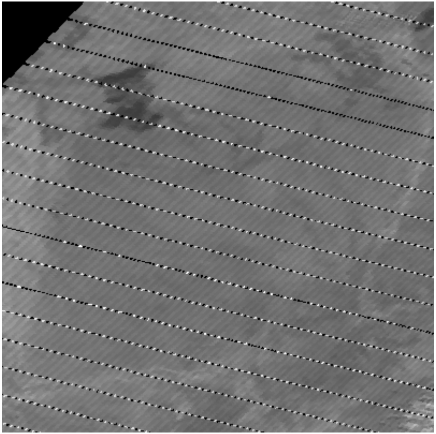

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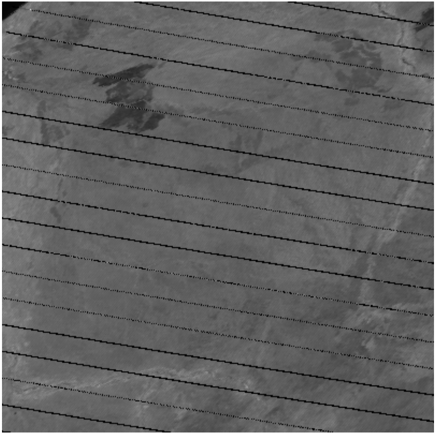

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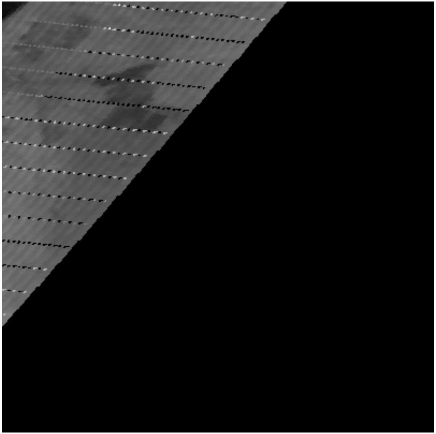

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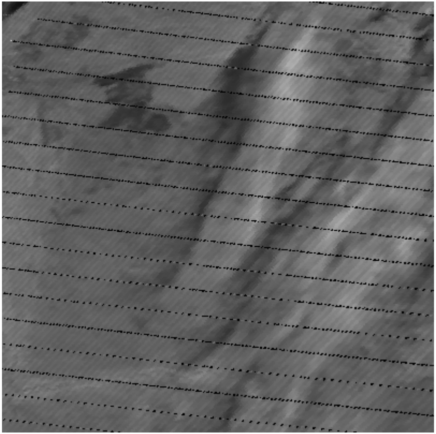

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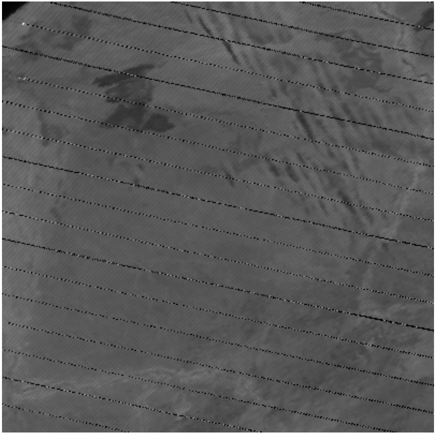

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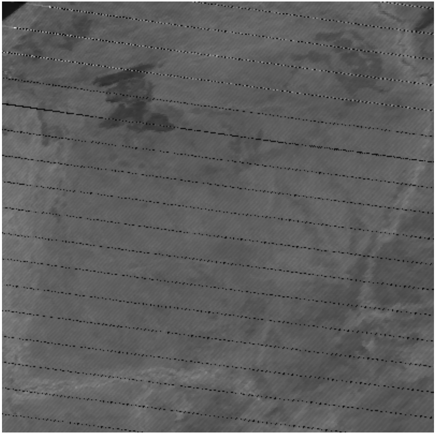

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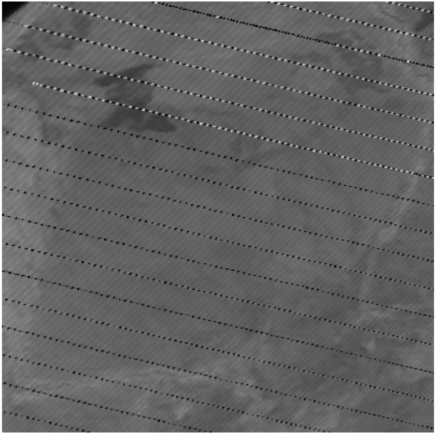

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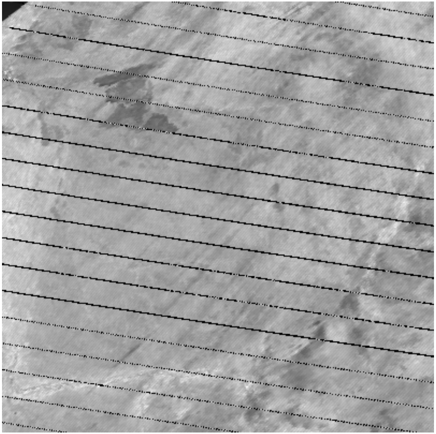

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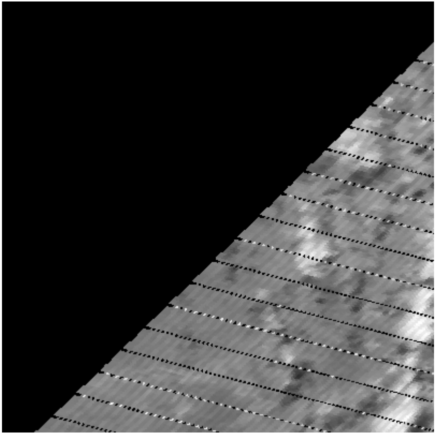

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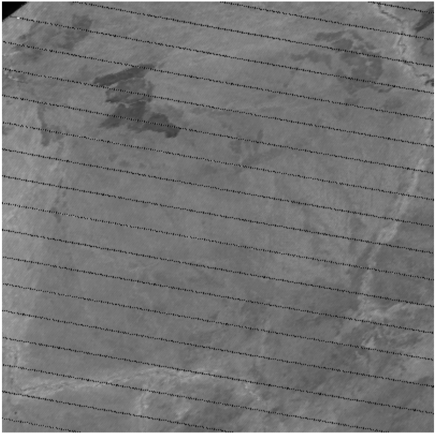

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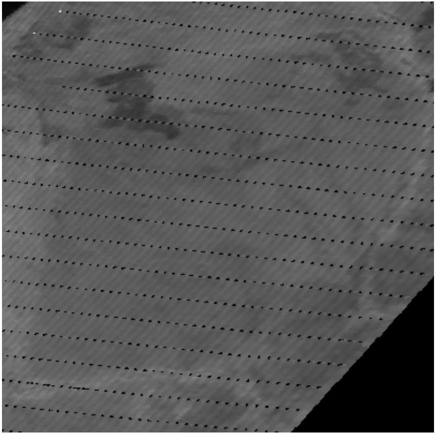

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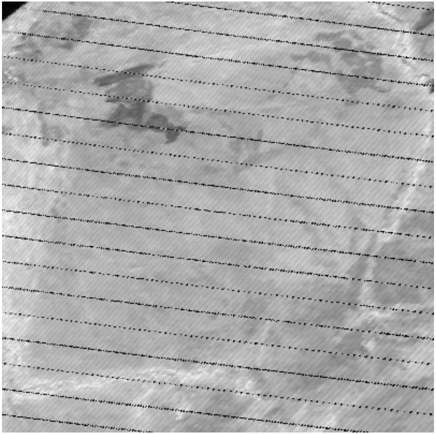

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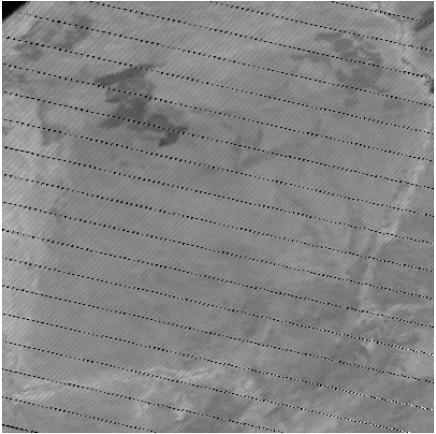

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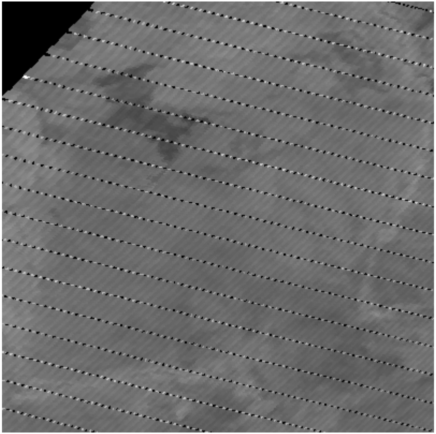

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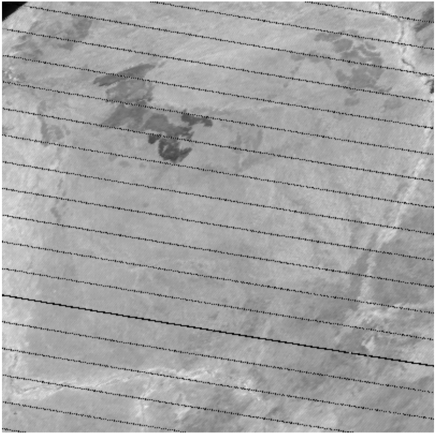

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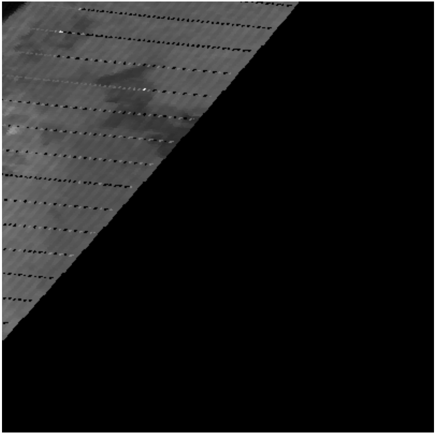

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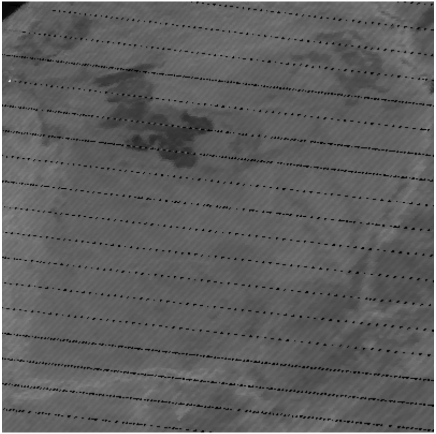

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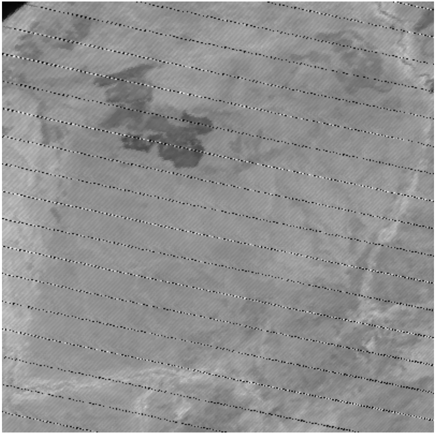

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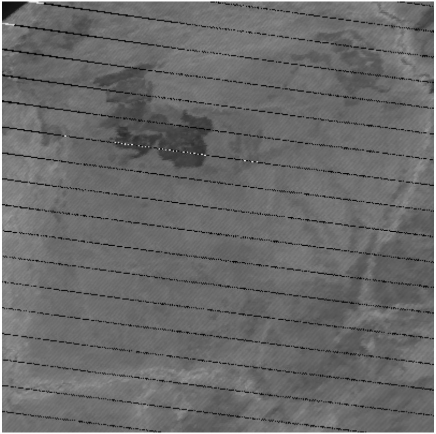

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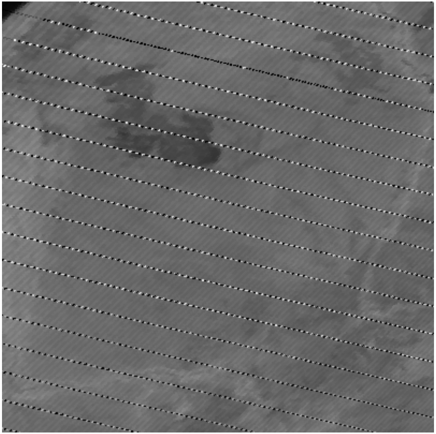

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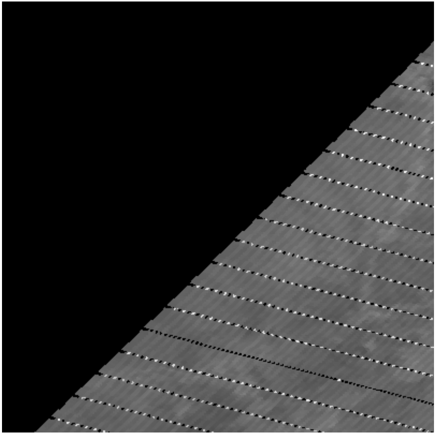

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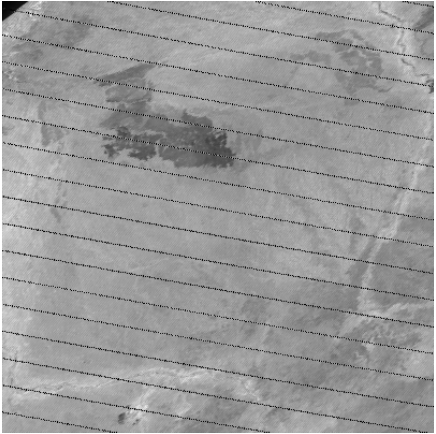

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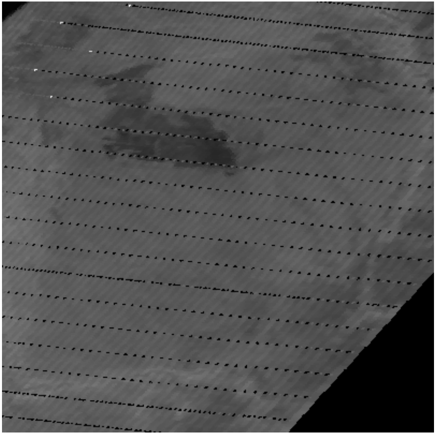

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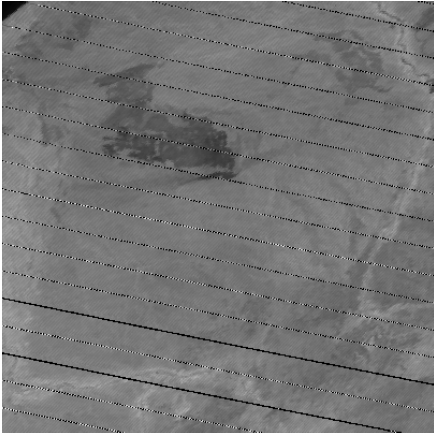

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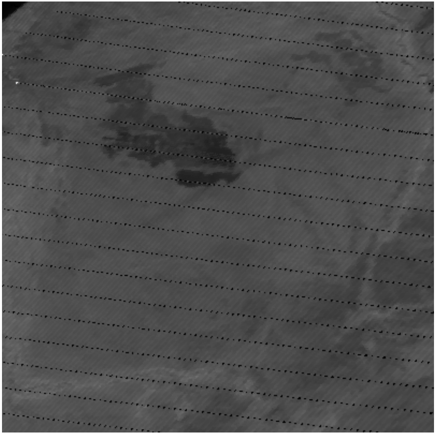

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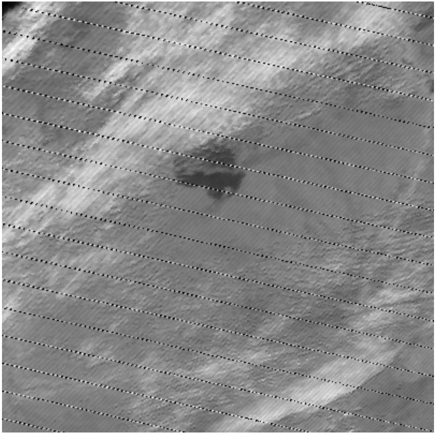

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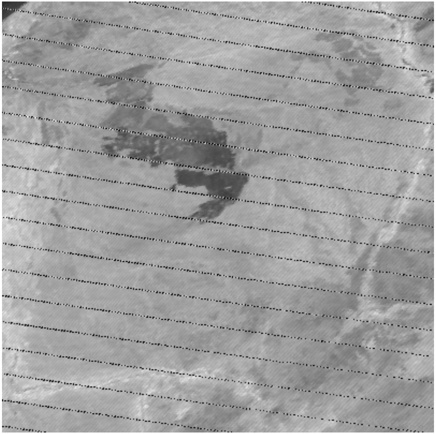

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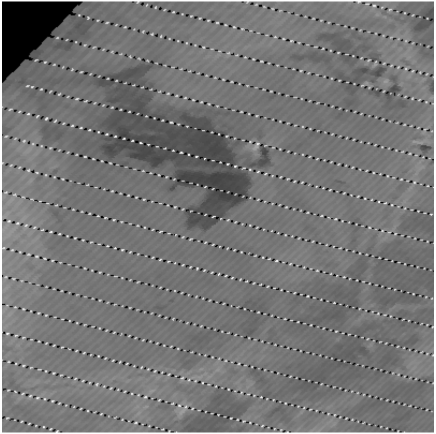

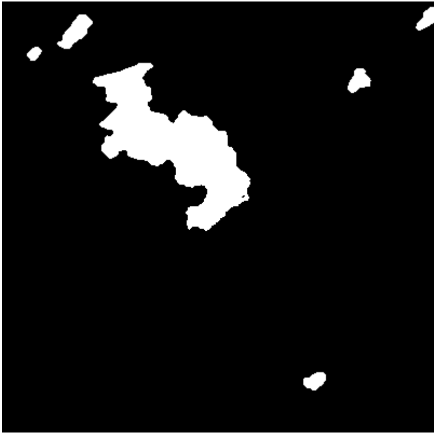

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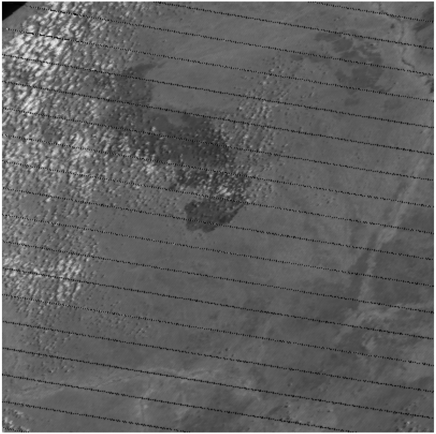

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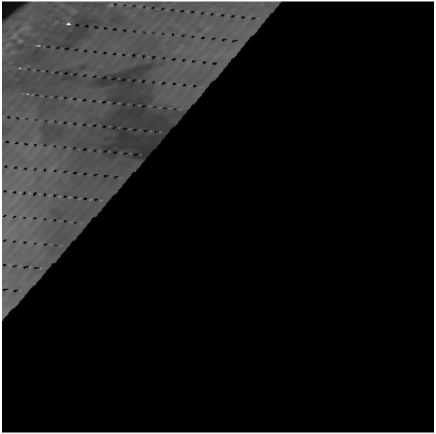

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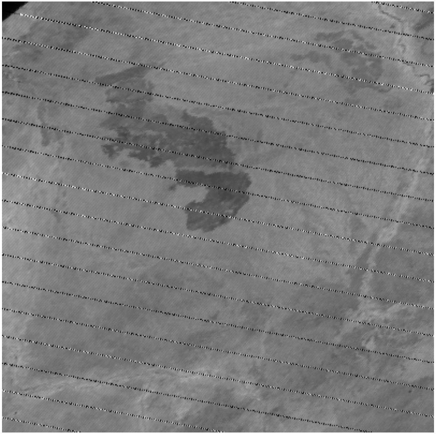

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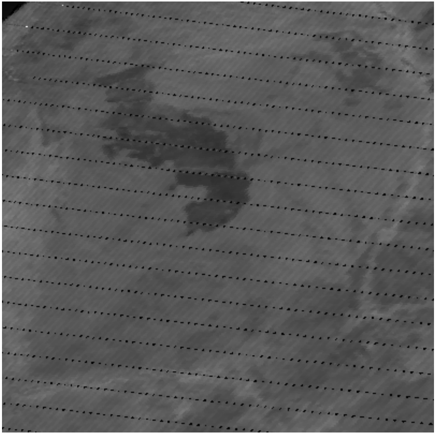
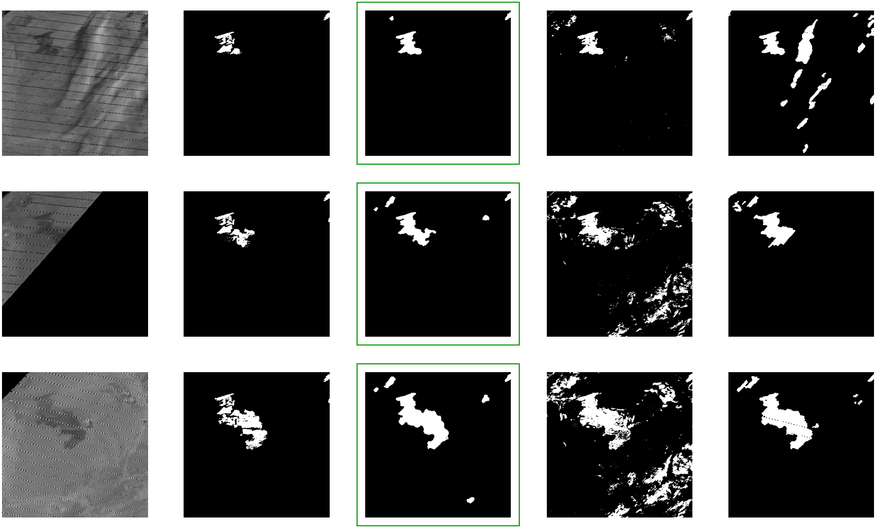
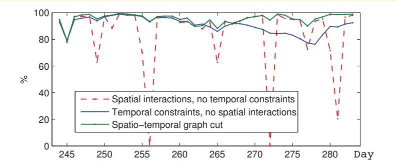


Segmentation results

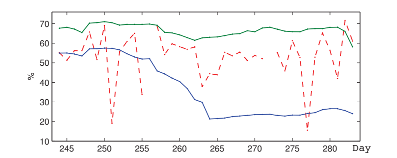
Day | MODIS band 5 | MCD64A1 map (day 213 - current) | **Proposed method** | No spatial interactions | No temporal constraints



Segmentation results

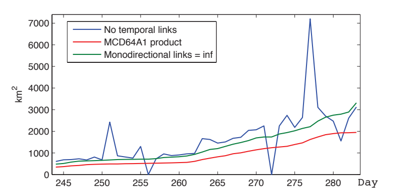


Percentage of pixels identified as burned by the **proposed method** method *AMONG* the pixels identified as burned during [day 244 - current] by MCD64A1

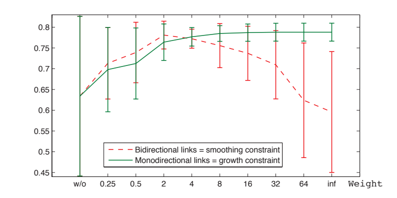


Percentage of pixels identified as burned during [day 213 - current] by MCD64A1 *AMONG* the pixels identified as burned by the **proposed method**

Segmentation results



Burned area as a function of time, when using no temporal links, monodirectional infinite links and MCD64A1 product



Mean and standard deviation for the dice score (proposed *versus* MCD64A1) as a function of the temporal link's weight, when using mono- and bidirectional temporal links

Conclusions and perspectives

Conclusions

1. We proposed a new graph-cut-based method
   - for segmentation of burned areas from time series of satellite observations
2. We introduced directed infinite links in spatio-temporal graph to enforce fire growth
3. The new method:
   - proved to be robust to low-contrast images and missing data
   - showed linear complexity

Perspectives

- Extend the method for segmenting long time series of satellite data

Thank you for your attention!

A graph-cut-based method for spatio-temporal segmentation of fire from satellite observations

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July 25, 2013

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