Remote sensing- assisted mapping of bark beetle-induced tree mortality

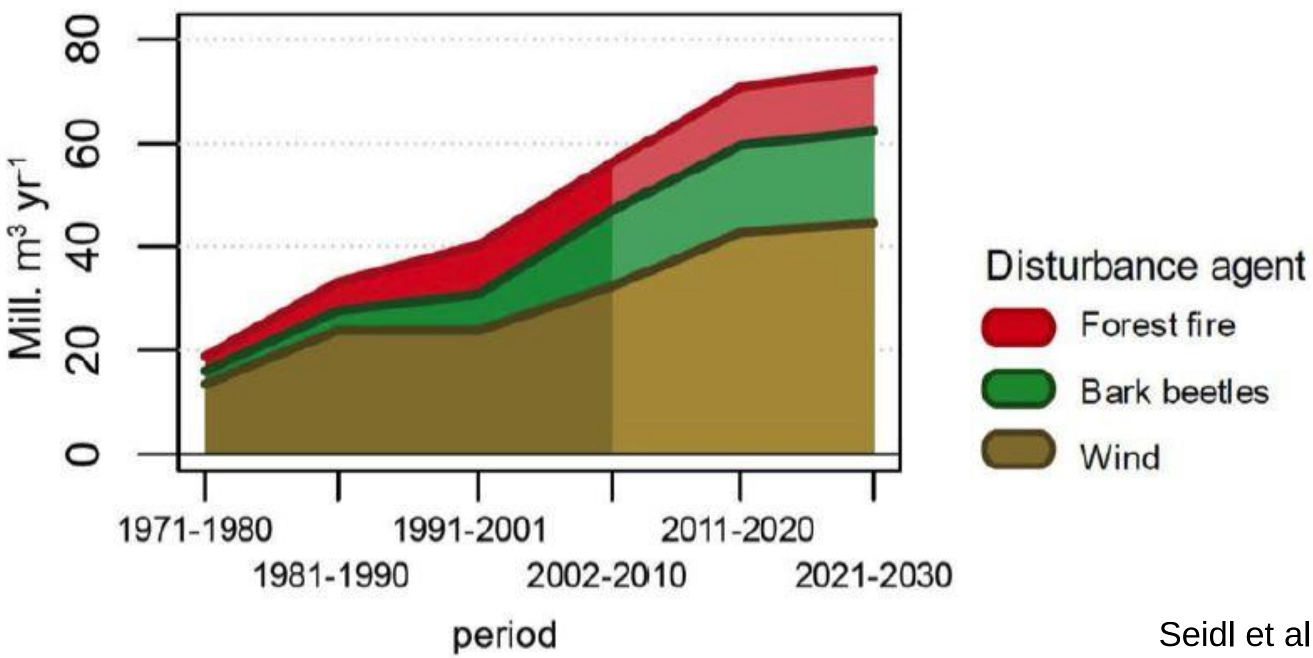
Hooman Latifi

Dept. of Remote Sensing in cooperation with German Aerospace Center, University of Würzburg, Oswald-Külpe-Weg 86, 97074 Würzburg

monitoring of stand dynamics in Białowieża Forest supported
with remote sensing techniques
Conference @
BIAŁOWIEŻA, 2016

Natural disturbances

- Integral part of forest ecosystems
- Strongly influence the forest structure, composition and function
- Influence the forest spatial and temporal patterns



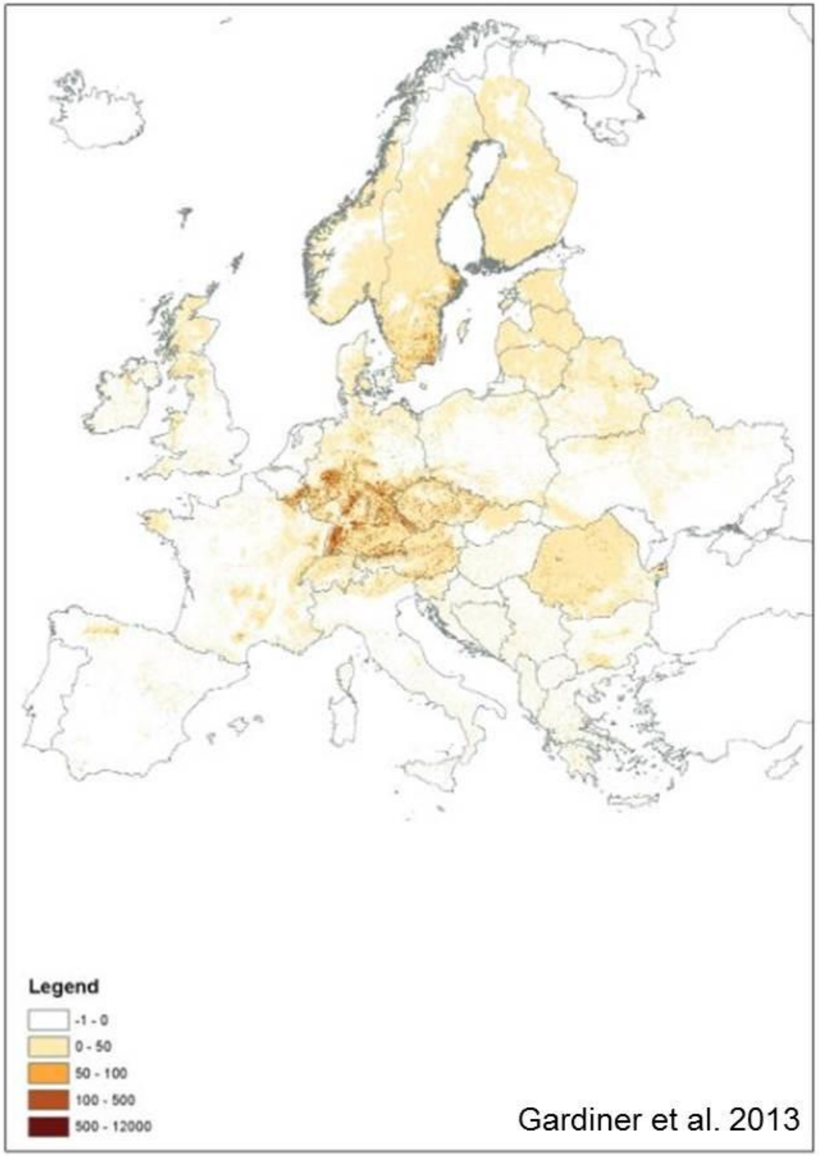
Seidl et al. 2014. *Nature*.

Example: Forest disturbance caused by *Ips typographus* L.

- Biological agents account for over 60% of all calamities in European forest ecosystems

- Large-scale forest disturbances
- Mostly by *Ips typographus* L. in conifeorus and mixed stands

- Effects on:
  - growth forms
  - wood production (living biomass)
  - landscape aesthetics



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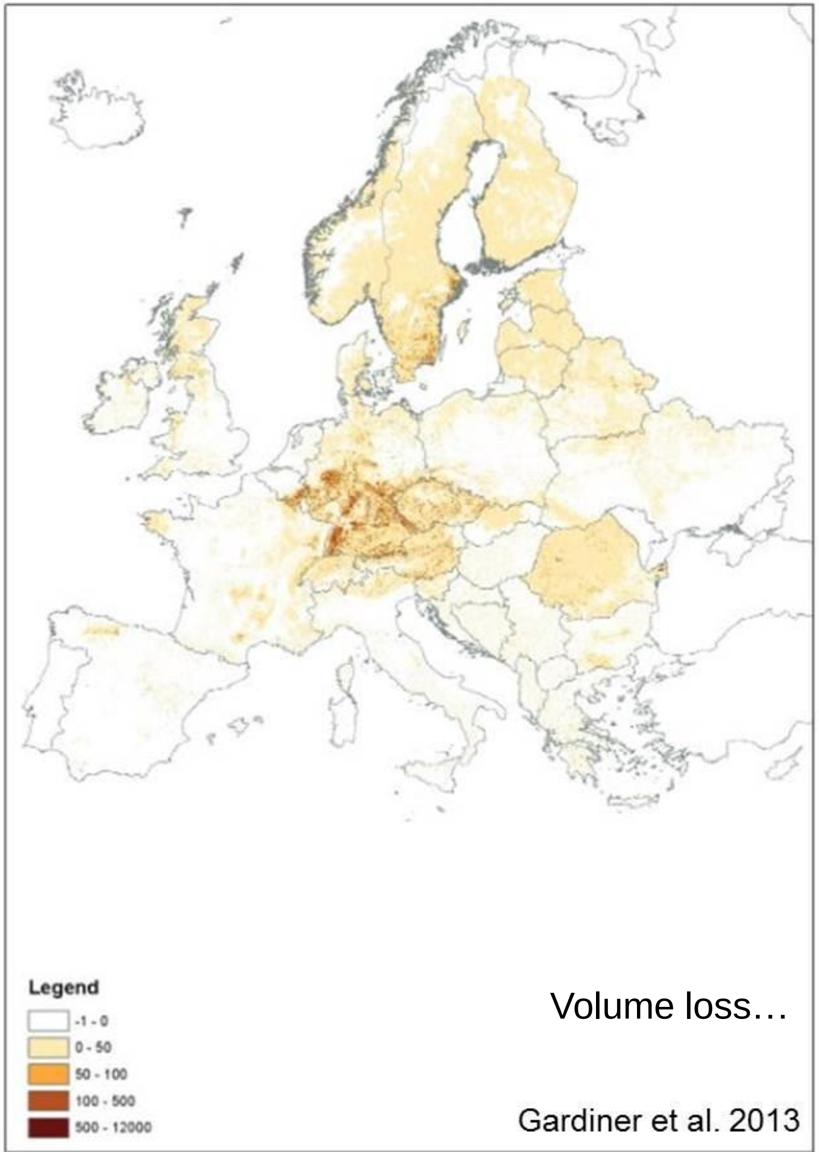
Multitemporal and time series of optical imagery can help to assess the trajectories in space and time



Volume loss…

Gardiner et al. 2013

Many ways to die…

Photos by S.Thorn

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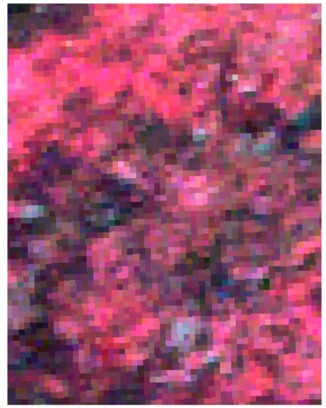
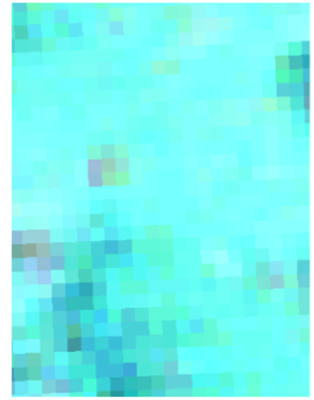
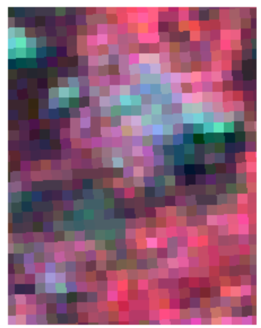
non-attacked in 2003



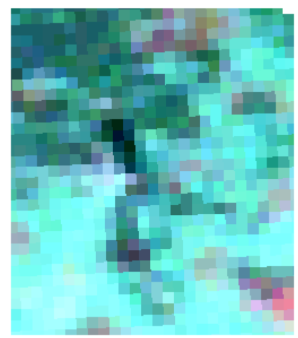
old-attacked in 2003



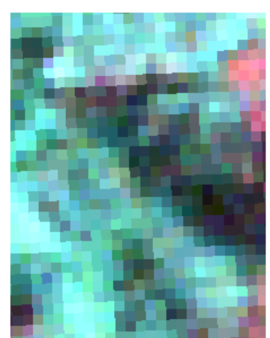
attacked 2003



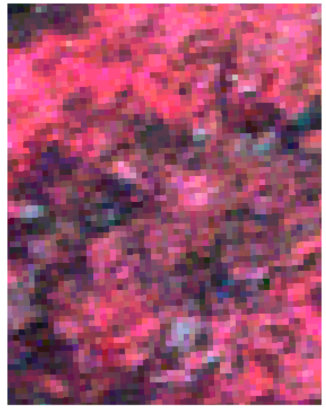
attacked 2002



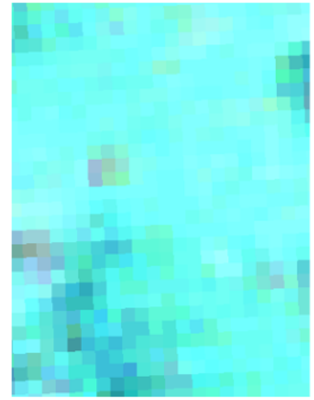
attacked 2001



Latifi, H et al. 2014. *Env. Monit. Asses.* 186: 441-456 non-attacked in 2003



old-attacked in 2003



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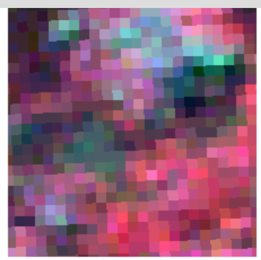
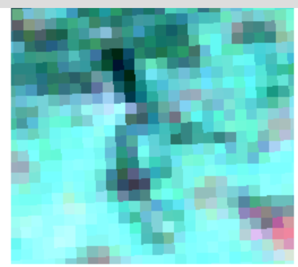
…a real challenge for optical remote sensing





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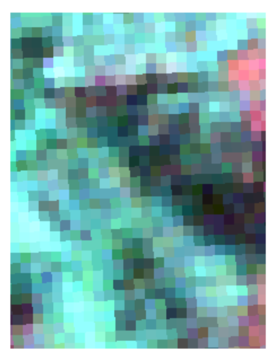

Latifi, H et al. 2014. *Env. Monit. Asses.* 186: 441-456

How to separate the damage classes?

I. Spatial separation → damage types (common classes)

   I. Green-attacked
   II. Red- attacked
   III. Grey-attacked

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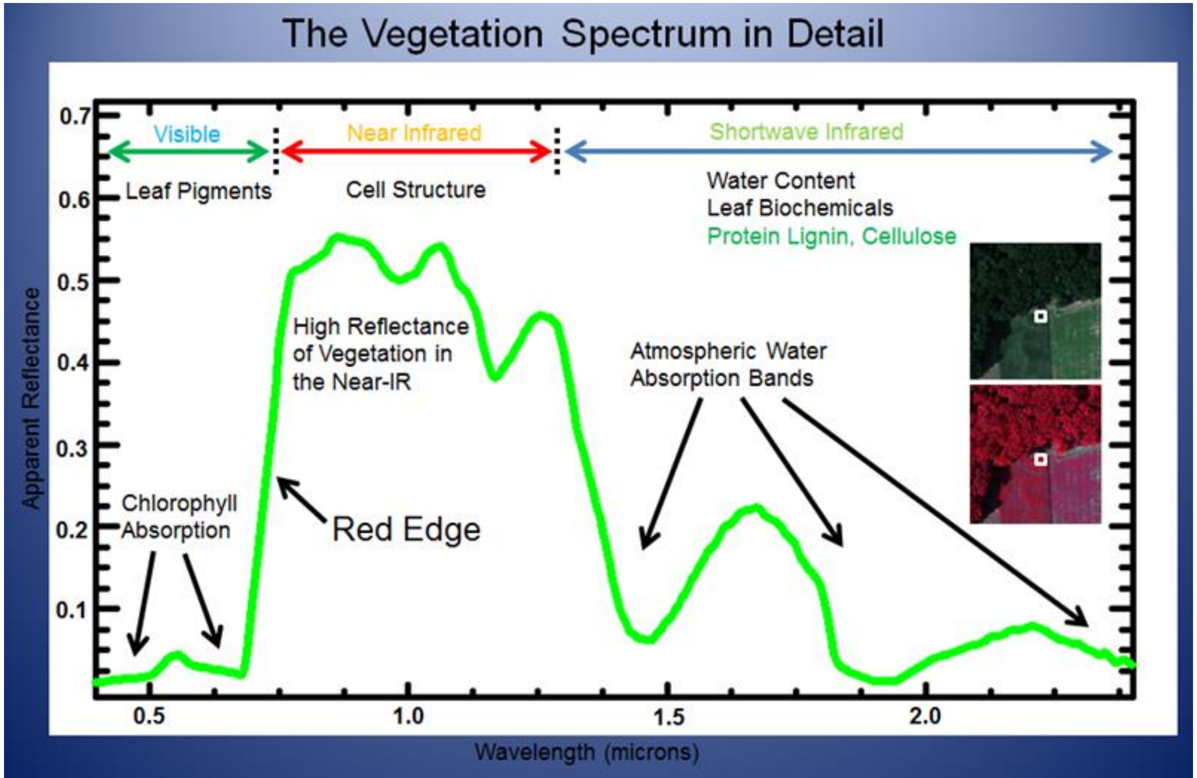
Traditional optical solution includes e.g. using vegetation indices



www.exelisvis.com

How to separate the damage classes?

Groups of Vis:

I. Ratio and Normalized Difference Indices (RNDI)
   - E.g. NDVI or Simple Ratio (SR)

II. RNDI which incorporate correction factors
   - E.g. SAVI

III. Derivative indices (narrow band)
   - E.g. Red edge position techniques

IV. Indices which calculate areas (integral-based)
   - E.g. Triangular VI (TVI)

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V. One approach: calculating the angles within a spectral triangle, instead of its area

Groups of

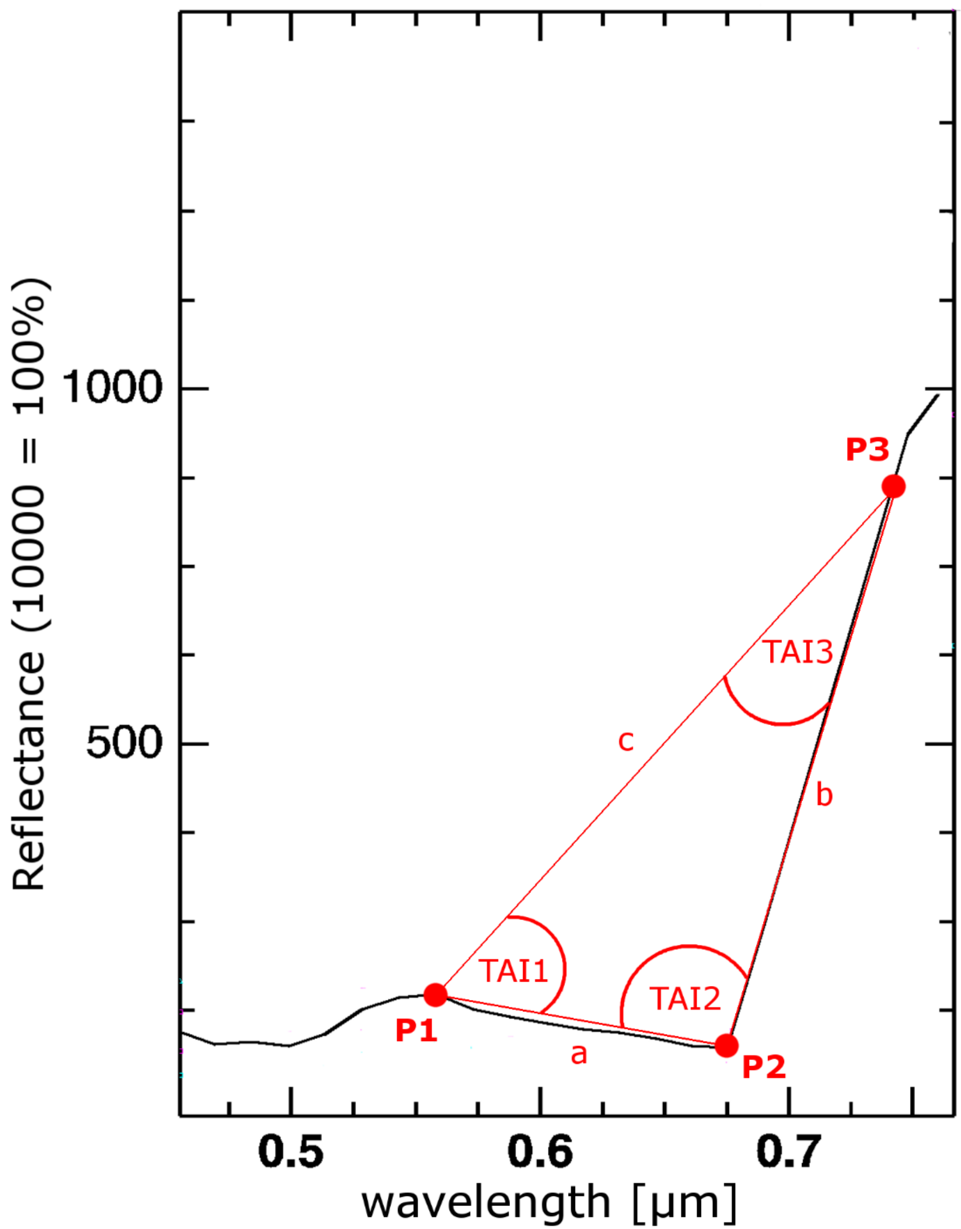
I. Ratio a
- E.

II. RNDI v
- E.

III. Deriva
- E.

IV. Indices
- E.

V. Our … nstead or its



Fassnacht, F.E, Latifi, H. et al. 2012. *Int. J. Appl. Earth Obs. Geoinf*. 19: 308-321

Approach within the BFNP

- 27417 Indices fom all possible band combinations of 39 narrow band HyMap-channels in the VIS–NIR spectral range(0.455–0.986 µm)
- Genethic Algorithm for feature selection
- 6 response classes including damage and non-damage stages, drawn form aerial orthophotos

Fassnacht, F.E, Latifi, H. et al. 2012. *Int. J. Appl. Earth Obs. Geoinf*. 19: 308-321

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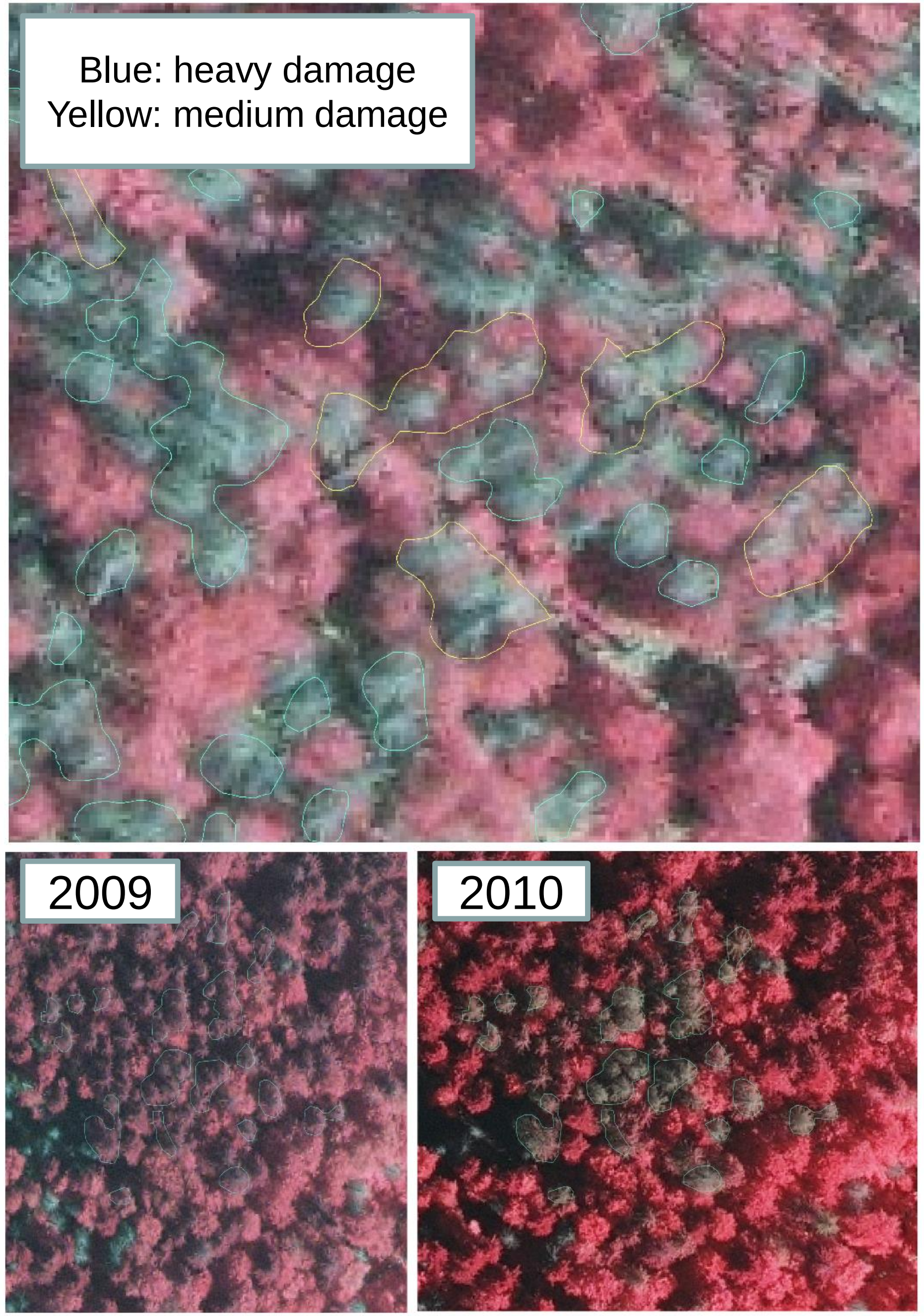

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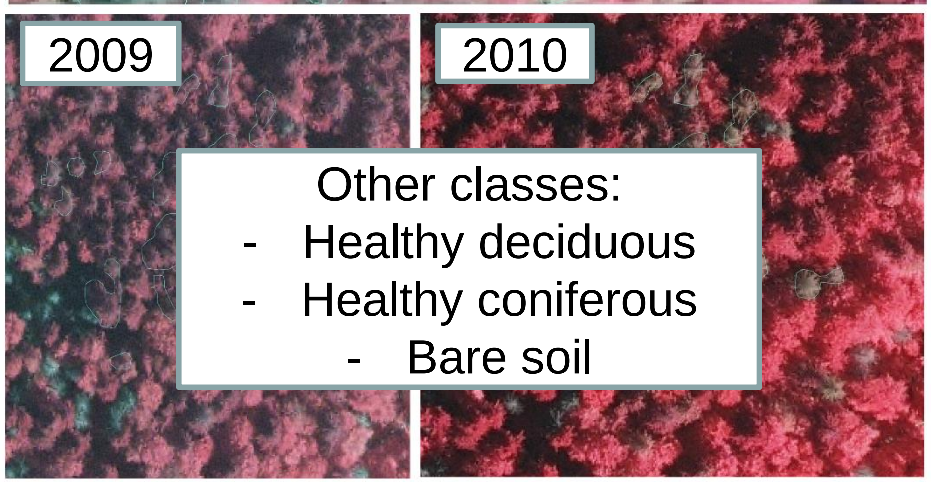

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Results of GA

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Results of GA

Table 1
Confusion matrix of the best GA run using NC classifier for 2500 solutions. Producer's and user's accuracy are additionally given as measures of the overall prediction per class. Percentages of correctly classified samples are marked in gray.

	Heavy dam	Med dam	Green dam	Coniferous	Broadleaved	Bare Soil
Heavy dam	0.800	0.117	0	0.013	0	0.004
Med dam	0.171	0.792	0	0.031	0.003	0
Green dam	0	0	0.971	0.007	0.003	0
Coniferous	0.016	0.090	0	0.95	0.001	0
Broadleaved	0	0	0.028	0	0.989	0
Bare soil	0.013	0.001	0	0	0.004	0.996
Producers's accuracy	0.800	0.792	0.971	0.95	0.989	0.996
User's accuracy	0.902	0.727	0.989	0.889	0.973	0.969
Overall accuracy	0.9052		Kappa	0.888		

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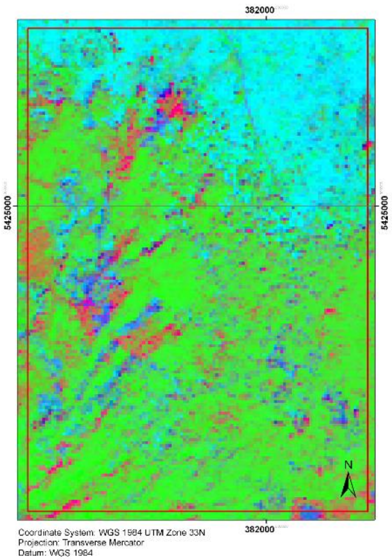
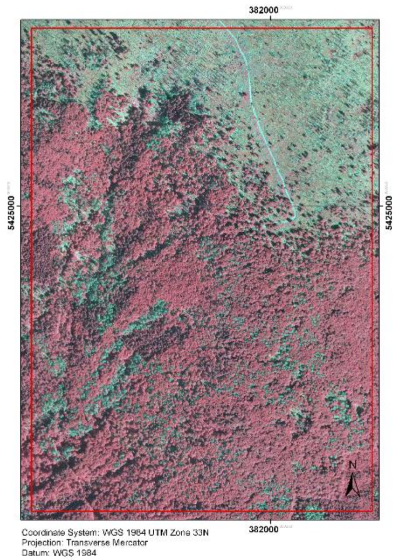
Table 4
Confusion matrix of the best GA-run using NC classifier for 2500 solutions. The descriptions follow those from Table 1.

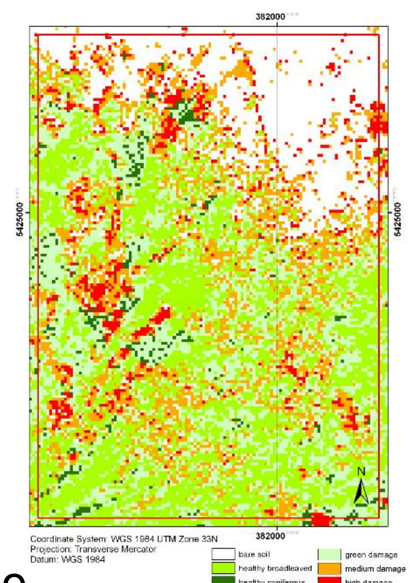
	Heavy dam	Med dam	Green dam	Coniferous	Broadleaved	Bare soil
Heavy dam	0.884	0.203	0.006	0	0	0.009
Med dam	0.094	0.626	0.099	0.002	0	0.002
Green dam	0.015	0.1	0.702	0.123	0.009	0
Coniferous	0	0.034	0.168	0.873	0.002	0
Broadleaved	0	0.008	0.025	0.002	0.989	0
Bare soil	0.006	0.03	0.001	0	0	0.988
Producer's accuracy	0.884	0.626	0.702	0.873	0.989	0.988
User's accuracy	0.862	0.715	0.739	0.803	0.967	0.952
Overall accuracy	0.8438		Kappa	0.811		

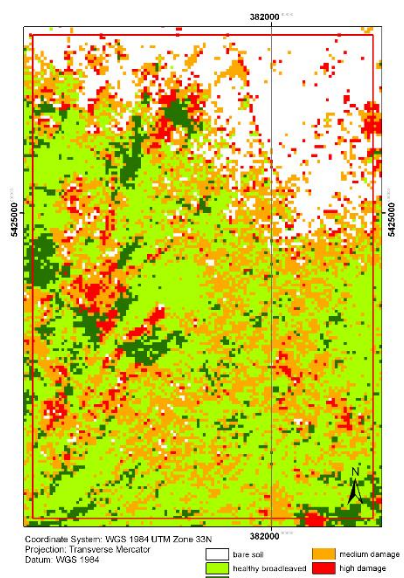
Fassnacht, F.E, Latifi, H. et al. 2012. *Int. J. Appl. Earth Obs. Geoinf.* 19: 308-321

Visual inspection of SVM results









- Overestimation by classifying „green attacked“ class
- “medium” and “high” damage classes were not completely separable
- No field data available → green damage separation infeasible

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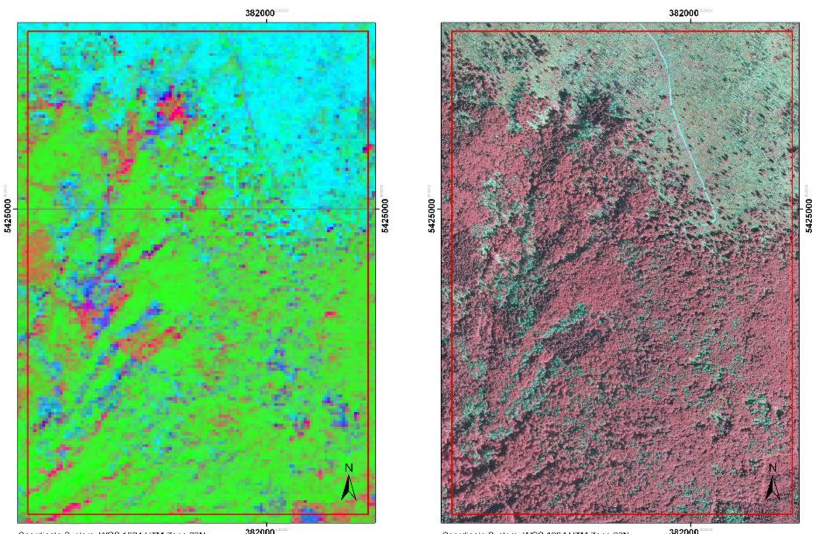

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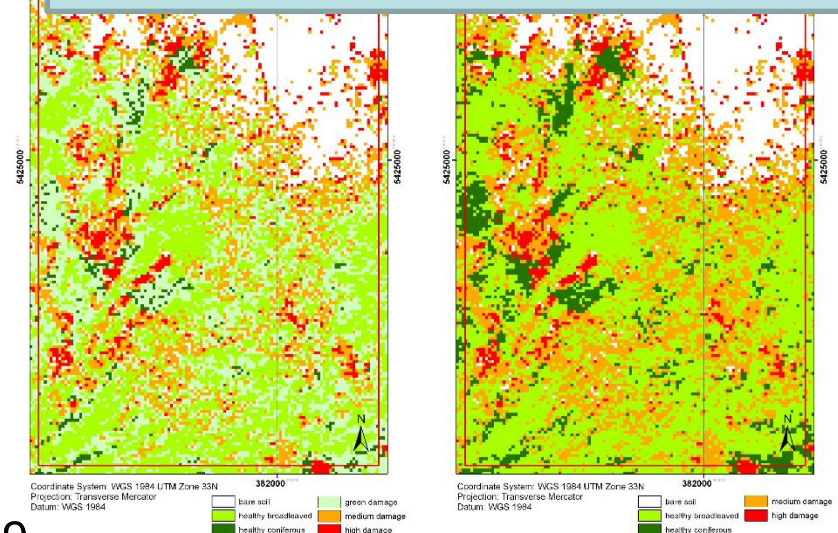
Is there any way to map the early stages of tree mortality?



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Let‘s change the perspective…

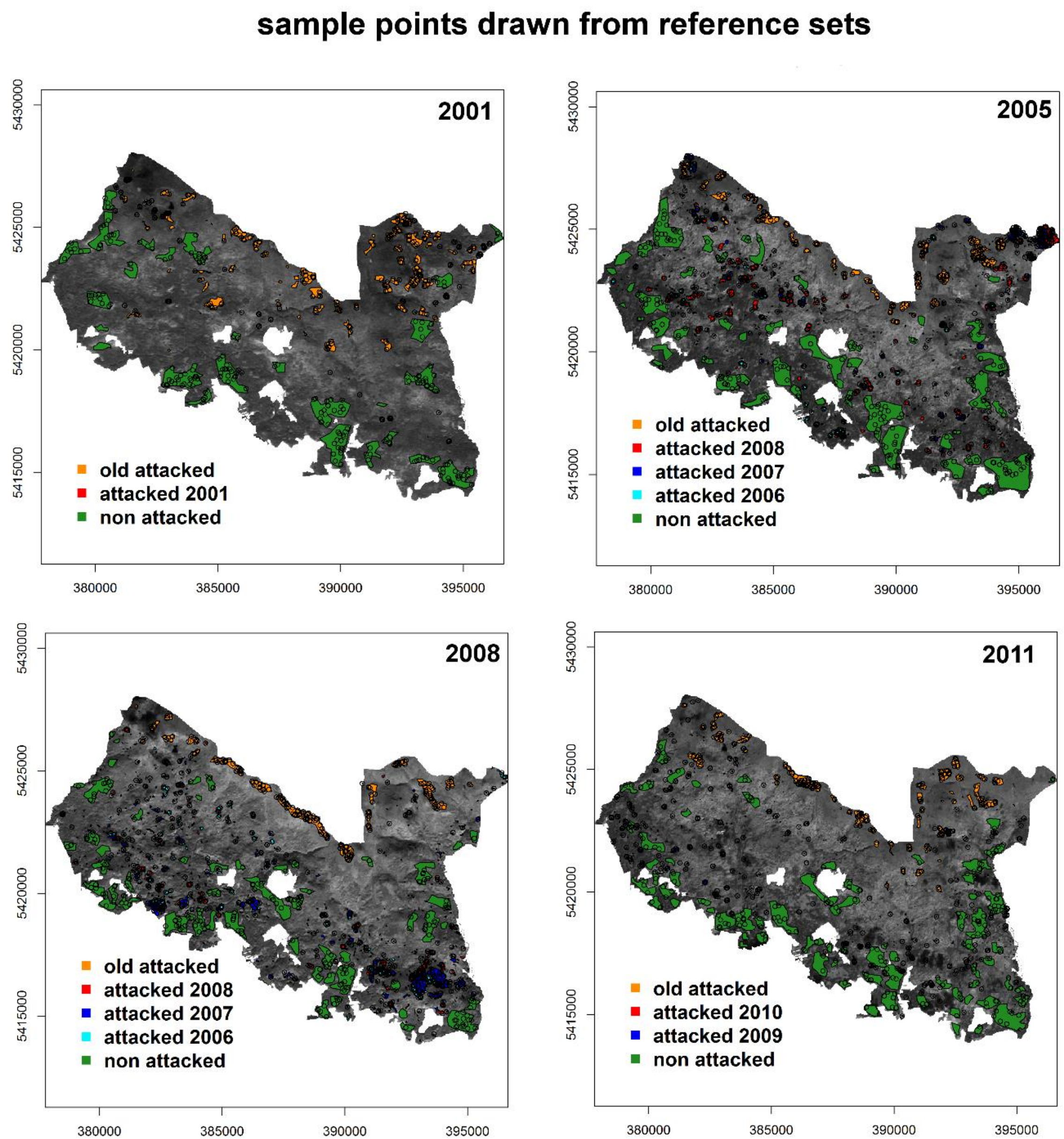
Does this framework help?

- Multispectral, Multitemporal data → freely available
- Area-based scale → compromise the details
- Terminology: let‘s rename the classes to approximate the terms
- High-density sampling from aerial imagery

Latifi, H. et al. 2014. *Env. Monit. Asses.* 186: 441-456

Does this

- Multispe eely available
- Area-bas
- Terminol ate the terms
- High-der



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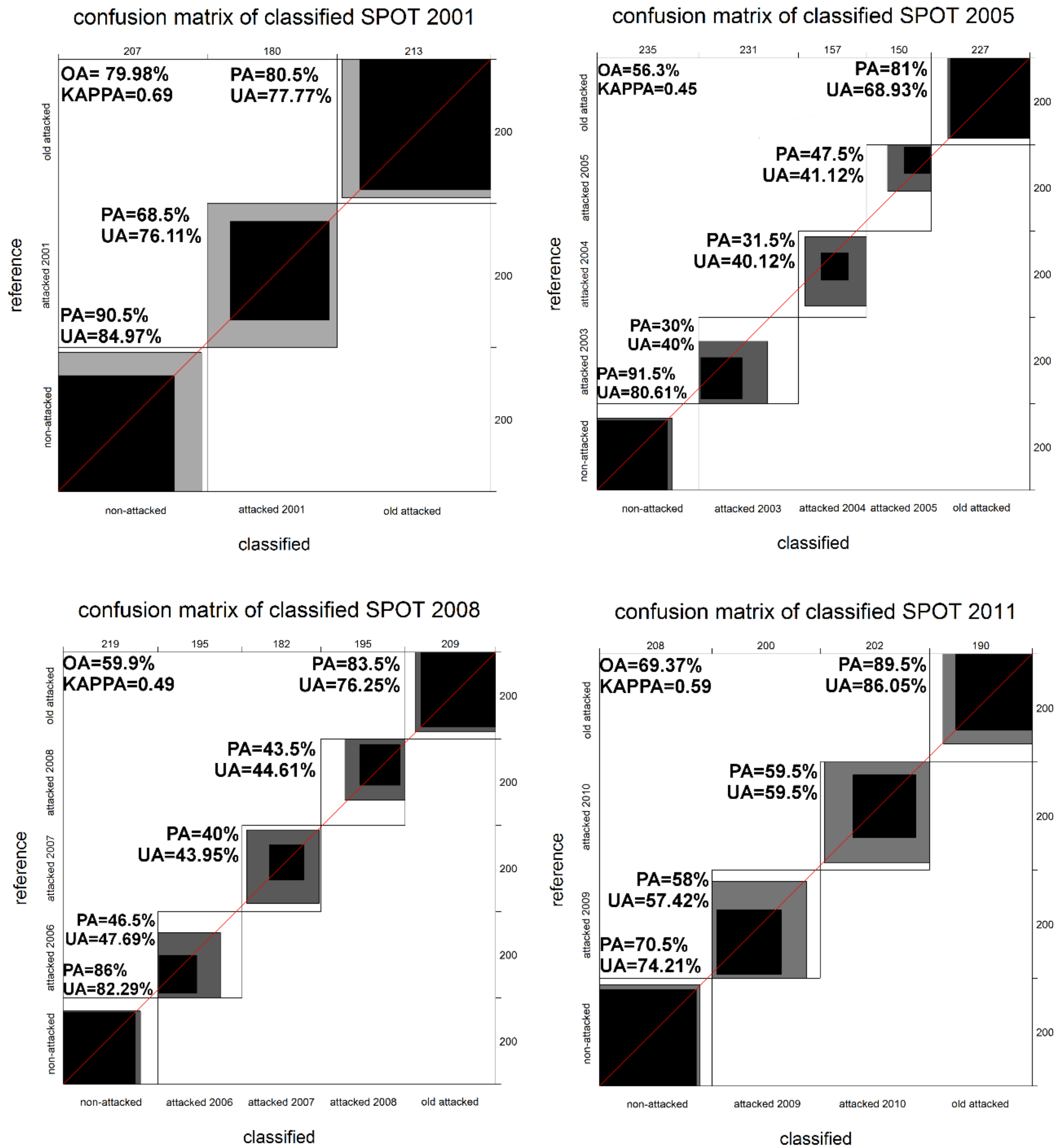

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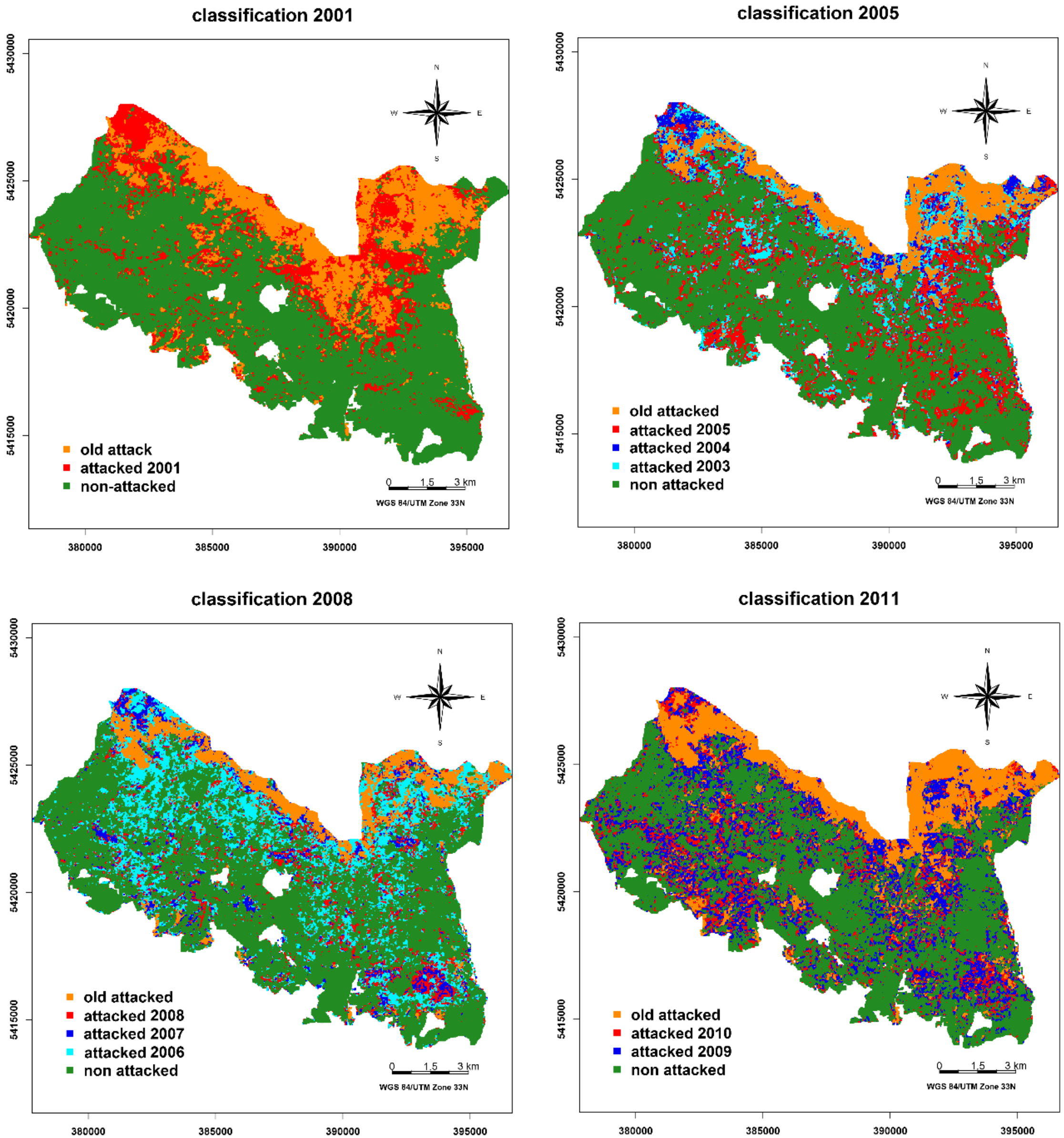

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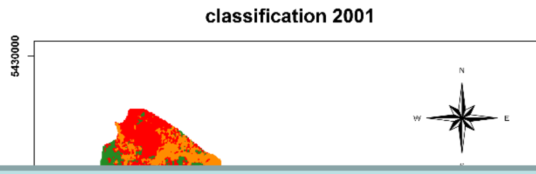
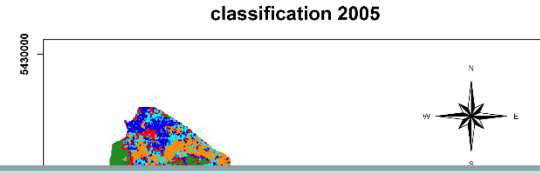
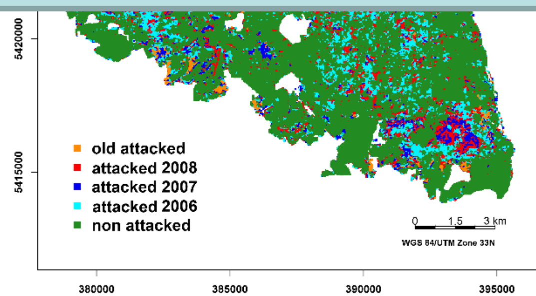
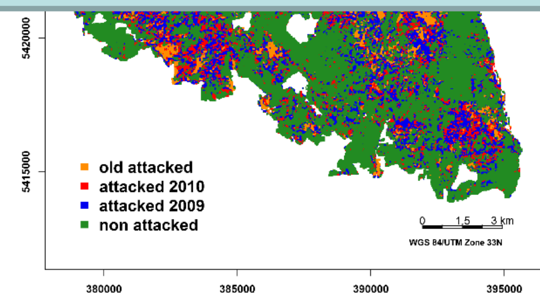




- Take-Home messages:
  - visually-identifiable infested patches can be accurately classified
  - Medium- and green stages (i.e. current year-1 and current year-2) are mostly comissioned or omissioned
  - Non-attacked class may contain green-attack
  - Decessive factors in classification:
    - Quality of reference data
    - Size of infested patches
    - Spatial resolution of imagery





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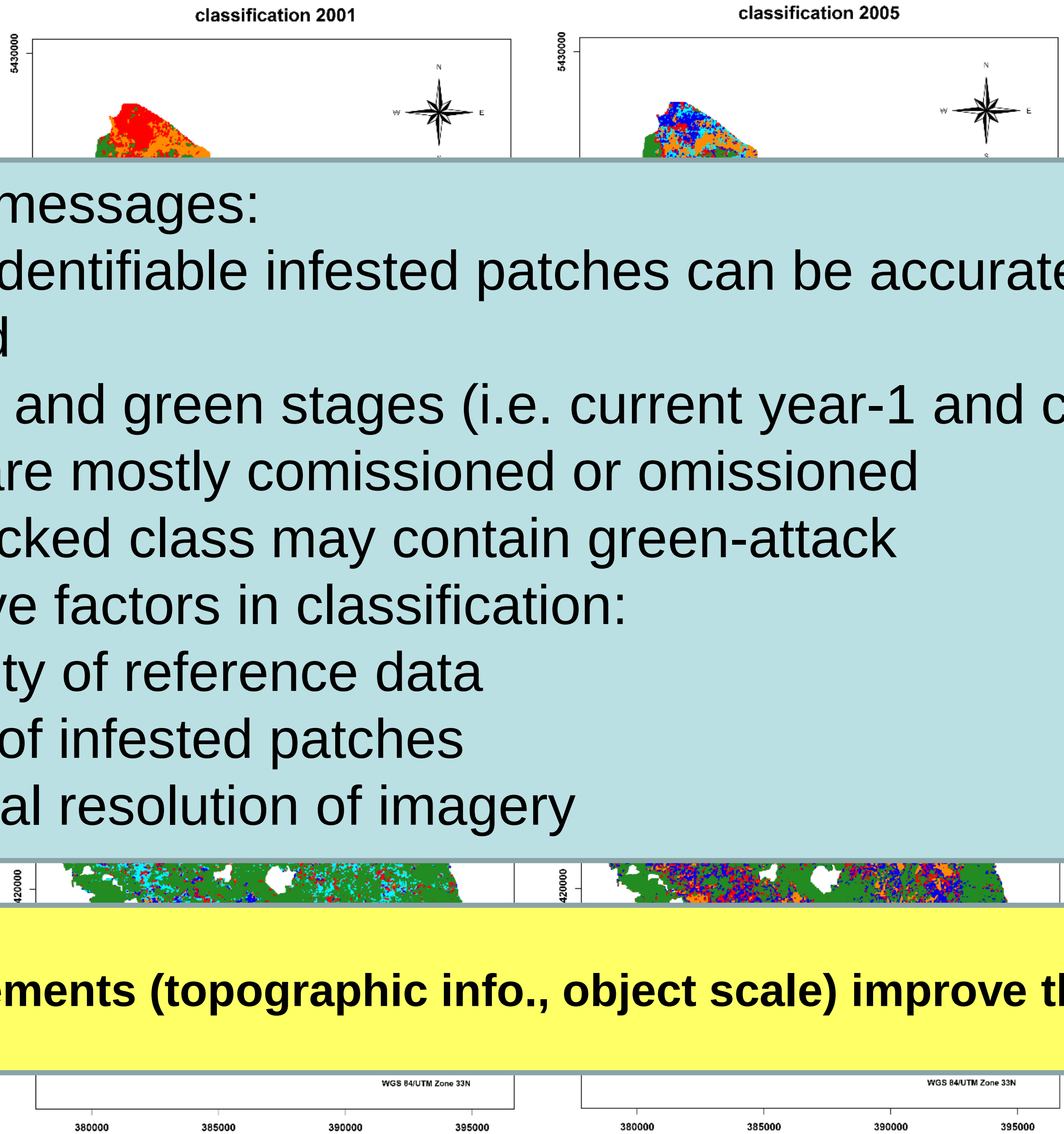

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Do further refinements (topographic info., object scale) improve the results?

Latifi, H. et al. 2014. *Env. Monit. Asses.* 186: 441-456

High-end object-base framework

- 11-years of Landsat and SPOT data (one scene per year)
- Full object-based paradigm
- Testing:
  - Object size
  - Object aggregation
  - Pan-sharpening imagery
  - LiDAR DTM for deriving topographical metrics
  - Texture metrics

Latifi, H. et al. 2014. *Progress in Physical Geography.* 38(6): 755-785

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- 11-year time
- Full object-ba
- Testing:
  - Object si
  - Object a
  - Pan-sha
  - LiDAR D
  - Texture r

Acquisition date (aerial images)	Acquisition date (satellite images)	Satellite sensor	Bands used
30.08.2001	13.10.2001	SPOT 2	Band 1: NIR Band 2: red Band 3: green
01.10.2002	30.09.2002	LANDSAT 7 ETM+	Band 1: blue-green Band 2: green Band 3: red Band 4: NIR Band 5: SWIR Band 7: SWIR
11.08.2003	25.09.2003	LANDSAT 5 TM	Band 1: blue-green Band 2: green Band 3: red Band 4: NIR Band 5: SWIR Band 7: SWIR
03.09.2004	10.08.2004	LANDSAT 5 TM	Band 1: blue-green Band 2: green Band 3: red Band 4: NIR Band 5: SWIR Band 7: SWIR
30.08.2005	19.09.2005	SPOT 2	Band 1: NIR Band 2: red Band 3: green
07.09.2006	11.09.2006	SPOT 4	Band 1: NIR Band 2: red Band 3: green
16.09.2007	08.10.2007	SPOT 2	Band 1: NIR Band 2: red Band 3: green
31.08.2008	06.11.2008	SPOT 4	Band 1: NIR Band 2: red Band 3: green
20.08.2009	24.08.2009	LANDSAT 5 TM	Band 1: blue-green Band 2: green Band 3: red Band 4: NIR Band 5: SWIR Band 7: SWIR
22.08.2010	21.09.2010	LANDSAT 5 TM	Band 1: blue-green Band 2: green Band 3: red Band 4: NIR Band 5: SWIR Band 7: SWIR
22.08.2011	24.09.2011	SPOT 4	Band 1: NIR Band 2: red Band 3: green

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Object-based set-up

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Object-based set-up

- Scale level (necessary for good delineation of the boundaries of features)
    - = 50 for Landsat scenes
    - = 70 for SPOT scenes
    - = 50 for pan-sharpened images (2001, 2002, 2005 and 2011)

- a higher scale value = higher variability within each object = larger objects

Latifi, H. et al. 2014. *Progress in Physical Geography.* 38(6): 755-785

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- a higher scale value = higher variability within each object = larger objects

- Object aggregation (merging adjacent objects) → representing over- and under-segmentation
  - 0, 25, 50 and 75%

Latifi, H. et al. 2014. *Progress in Physical Geography.* 38(6): 755-785

Object-based set-up

Latifi, H. et al. 2014. *Progress in Physical Geography.* 38(6): 755-785

Object-based set-up

- Object metrics

  - Area
  - Compactness
  - Roundness
  - Form factor
  - No. of holes
  - Mean and STDV
  - Texture (3×3 kernel)
  - Mean/STDV, Mean/STDV of texture from DTM

Latifi, H. et al. 2014. *Progress in Physical Geography.* 38(6): 755-785

Results
I- Predictor Importance

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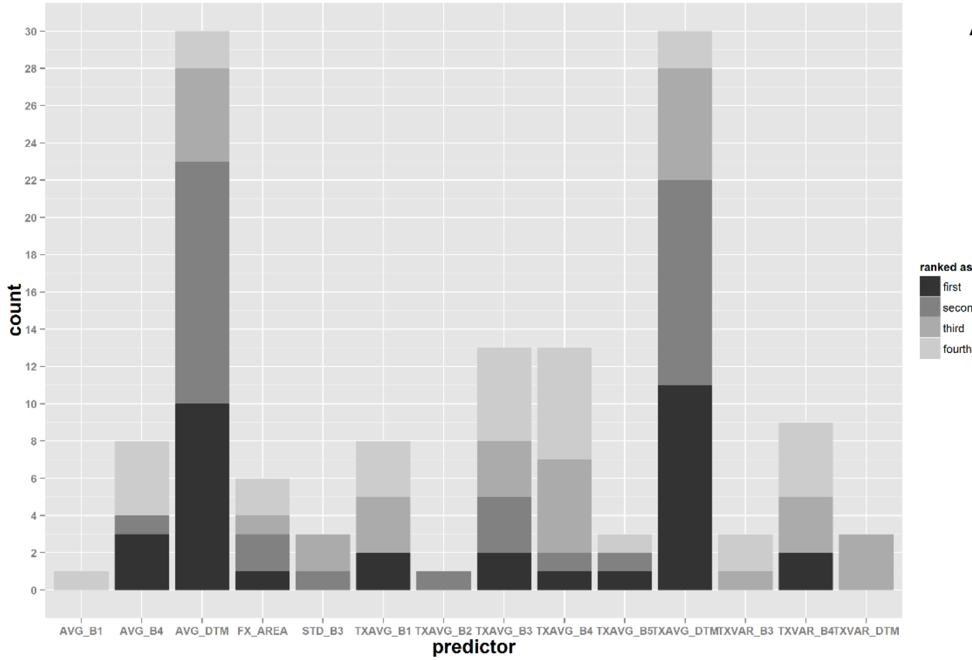
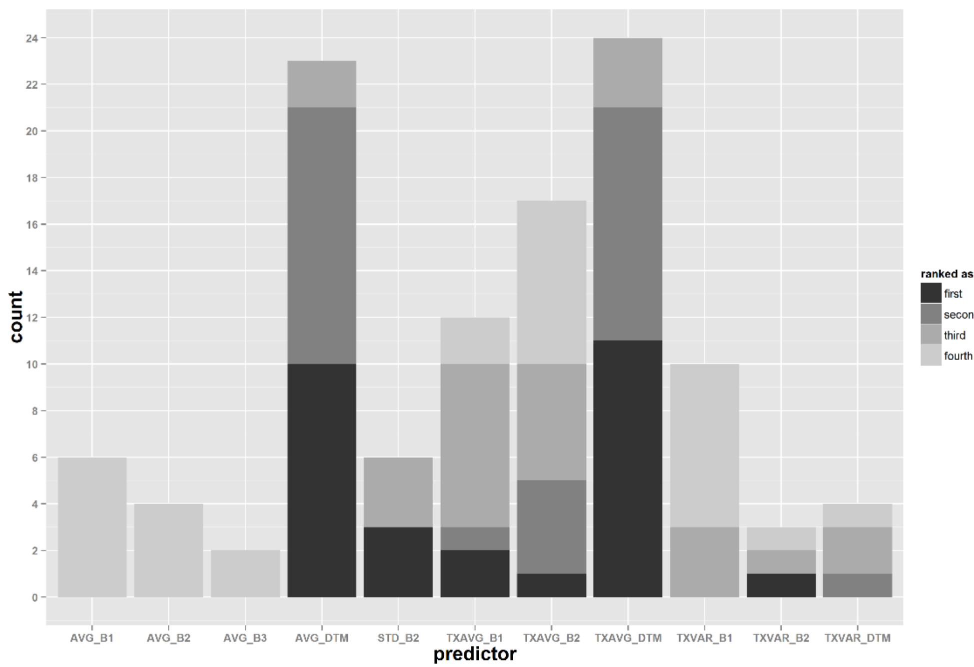
DLR

A



Landsat time series

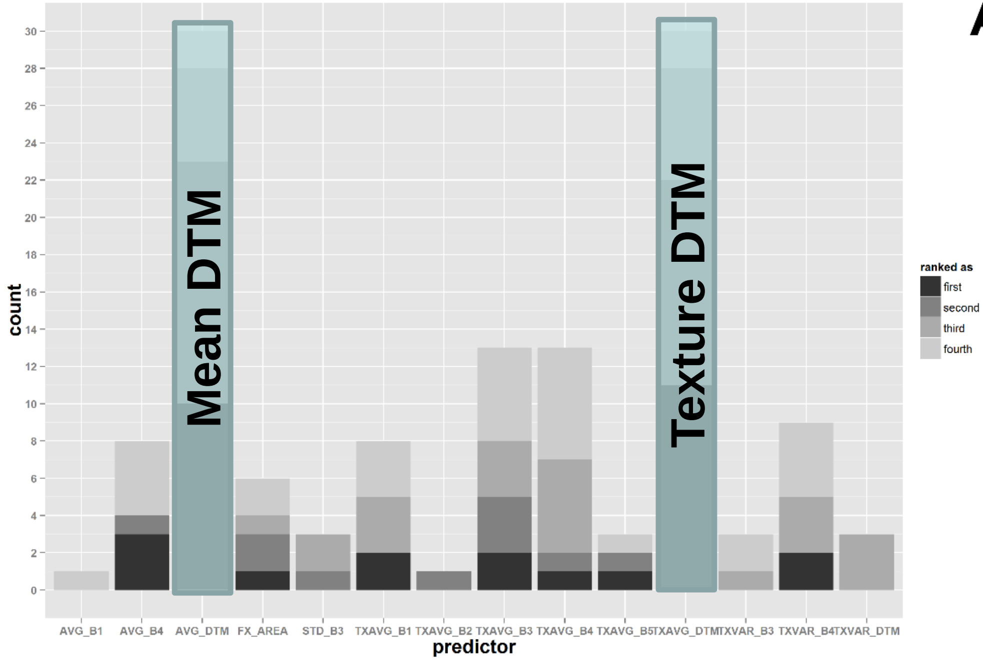
B



SPOT time series

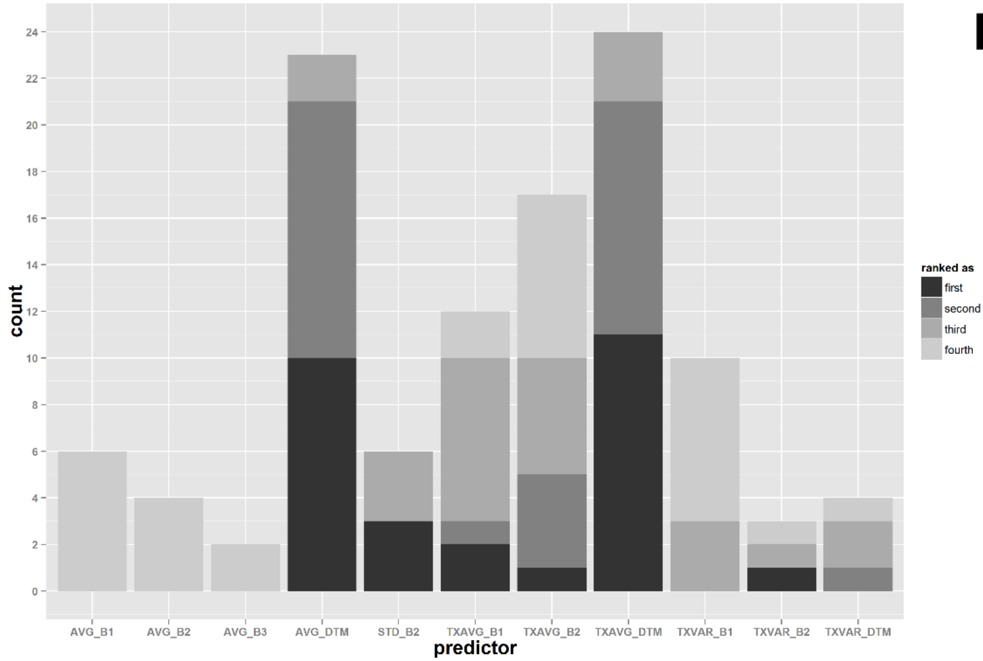
. *Progress in Physical*
’55-785

A



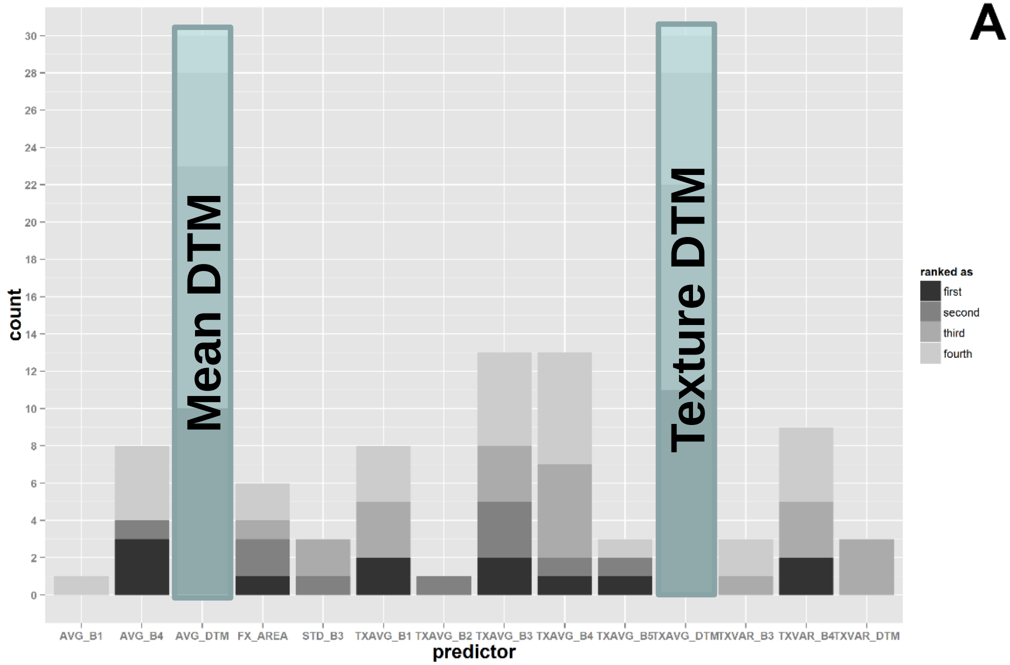
Landsat time series

B

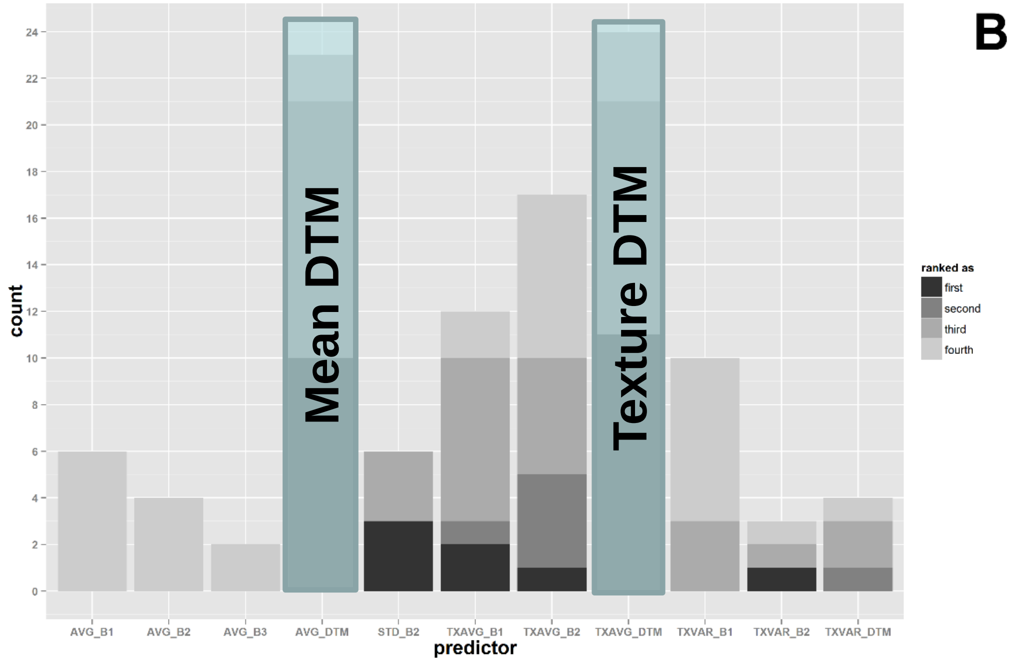


SPOT time series

. *Progress in Physical*
'55-785



Landsat time series



SPOT time series

. *Progress in Physical*
’55-785

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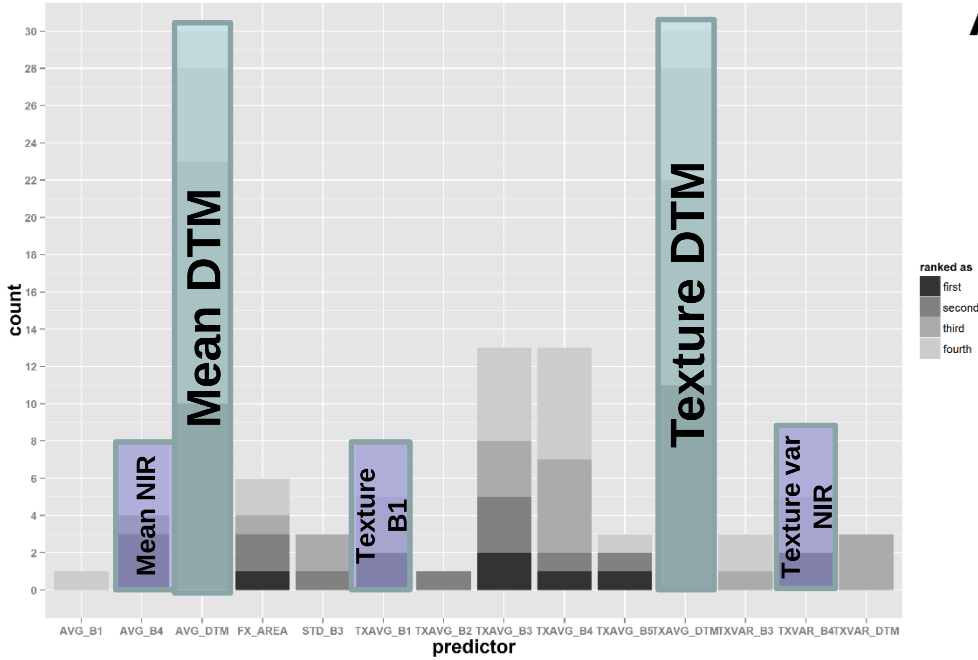
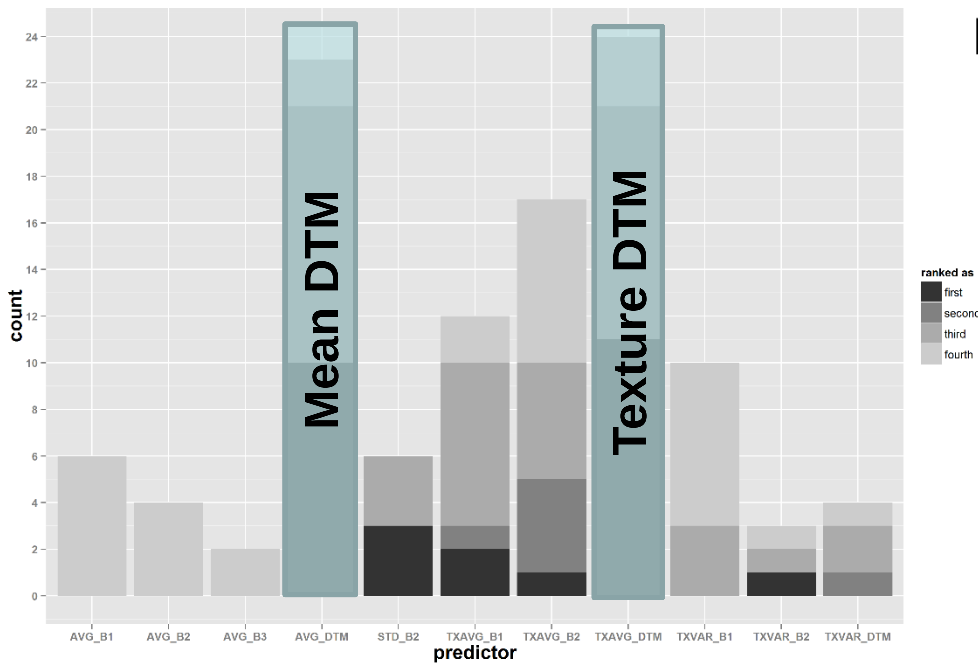
A



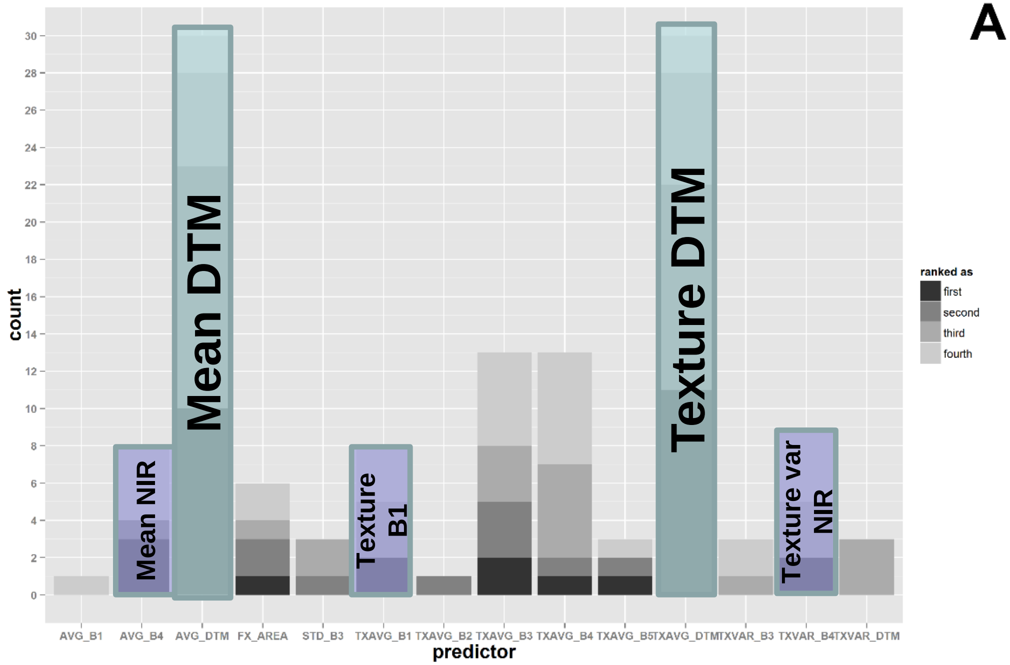
Landsat time series

B

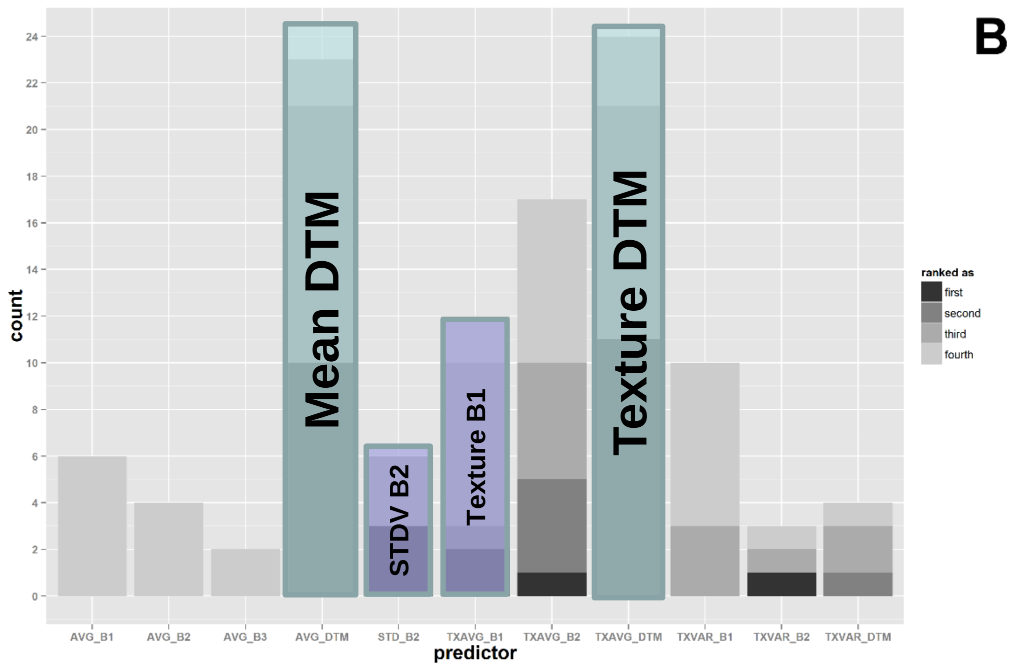


SPOT time series

. *Progress in Physical*
'55-785



Landsat time series



SPOT time series

. *Progress in Physical*
'55-785

Results
II- performance

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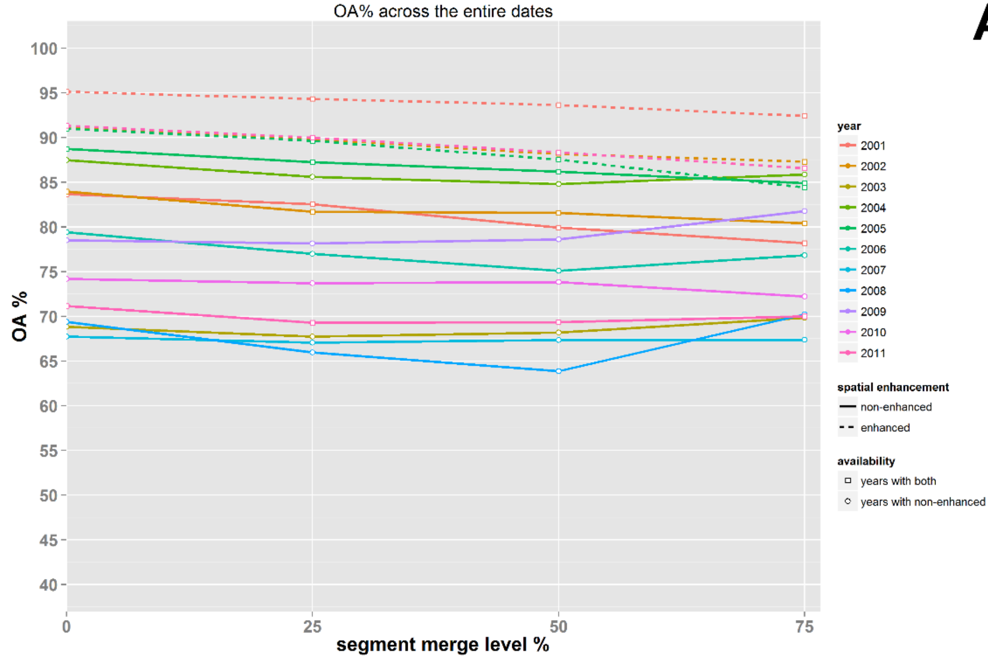
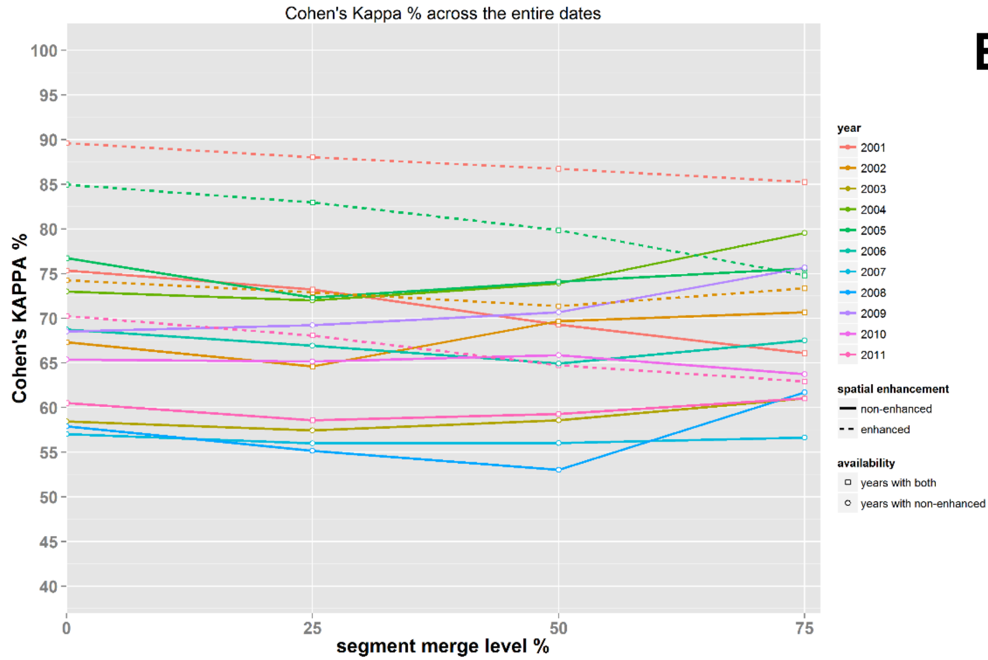
A



OA%

B



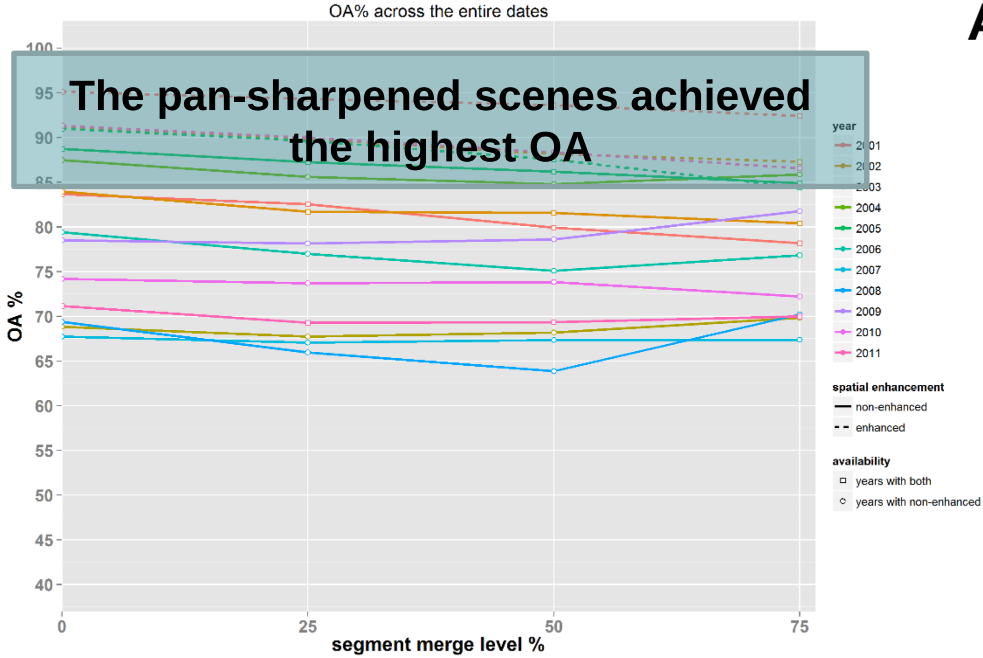
Kappa%

. *Progress in Physical*

'55-785

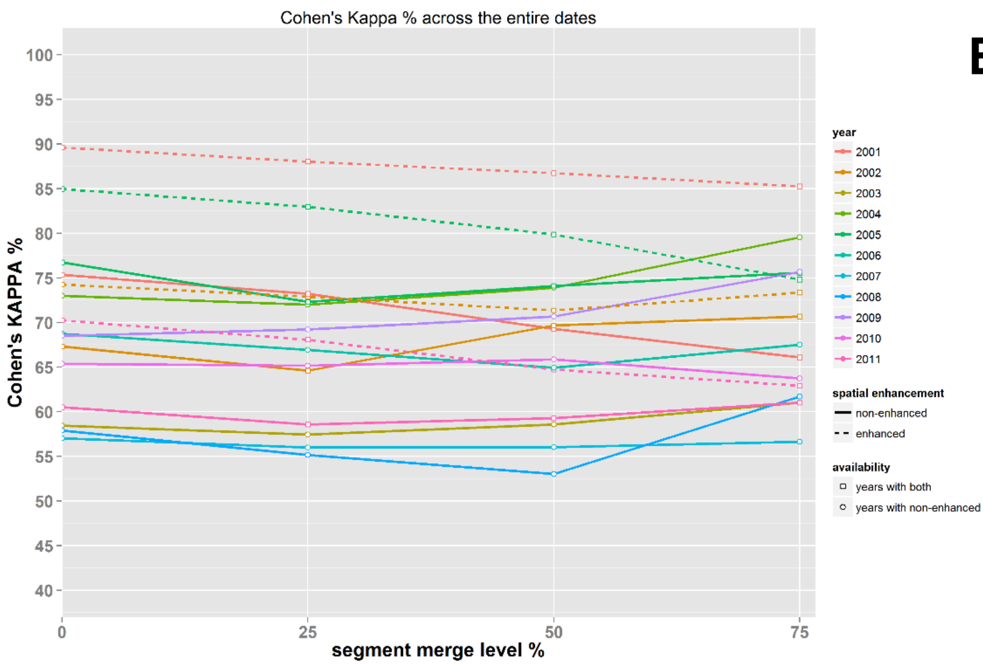
The pan-sharpened scenes achieved the highest OA

A



OA%

B



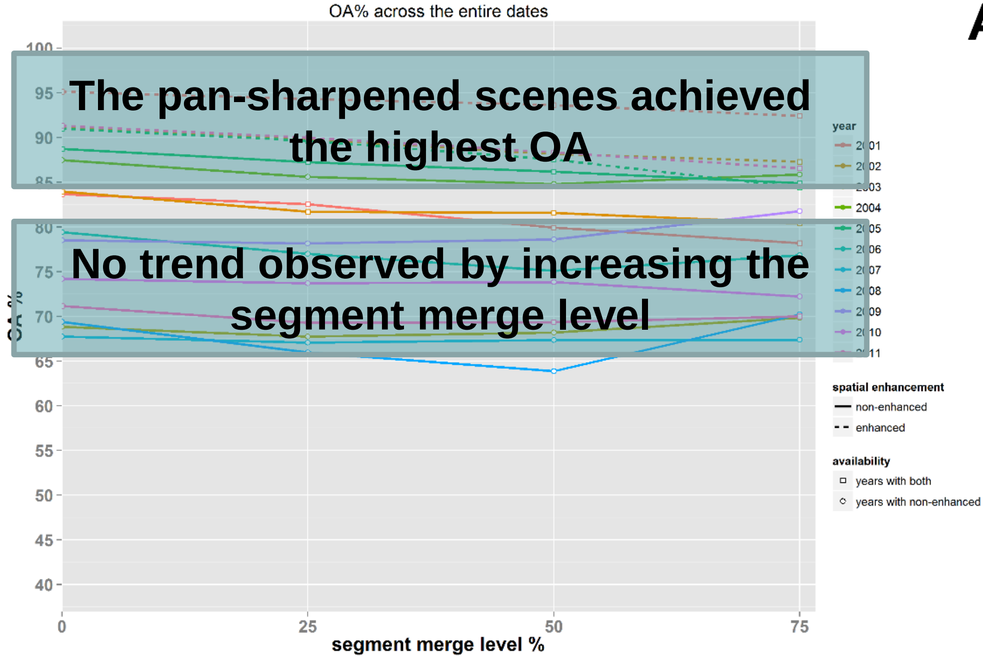
Kappa%

. *Progress in Physical*
'55-785

The pan-sharpened scenes achieved the highest OA

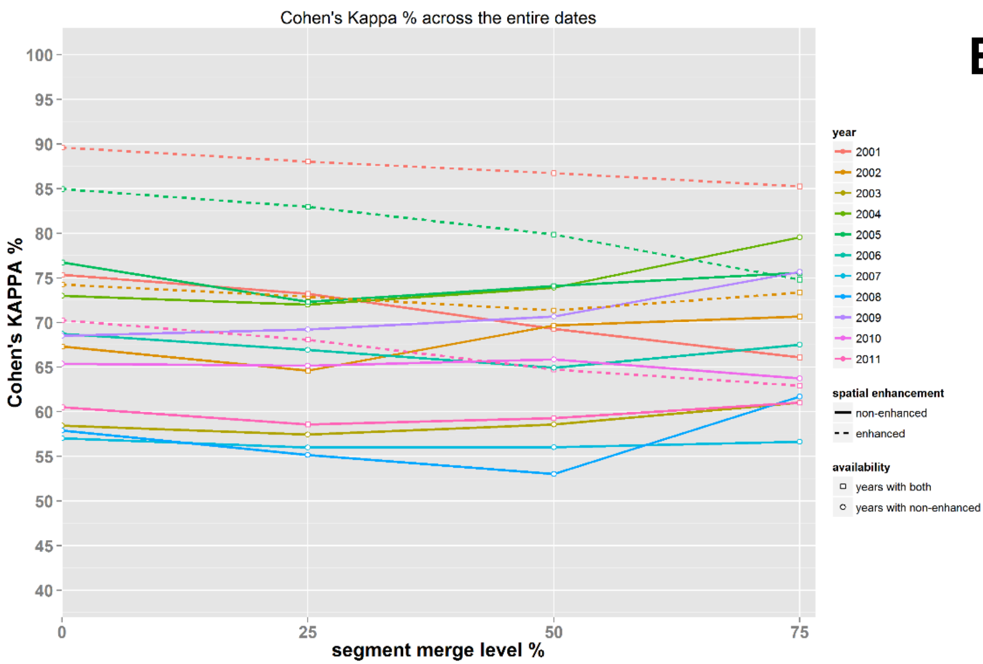
No trend observed by increasing the segment merge level

A



OA%

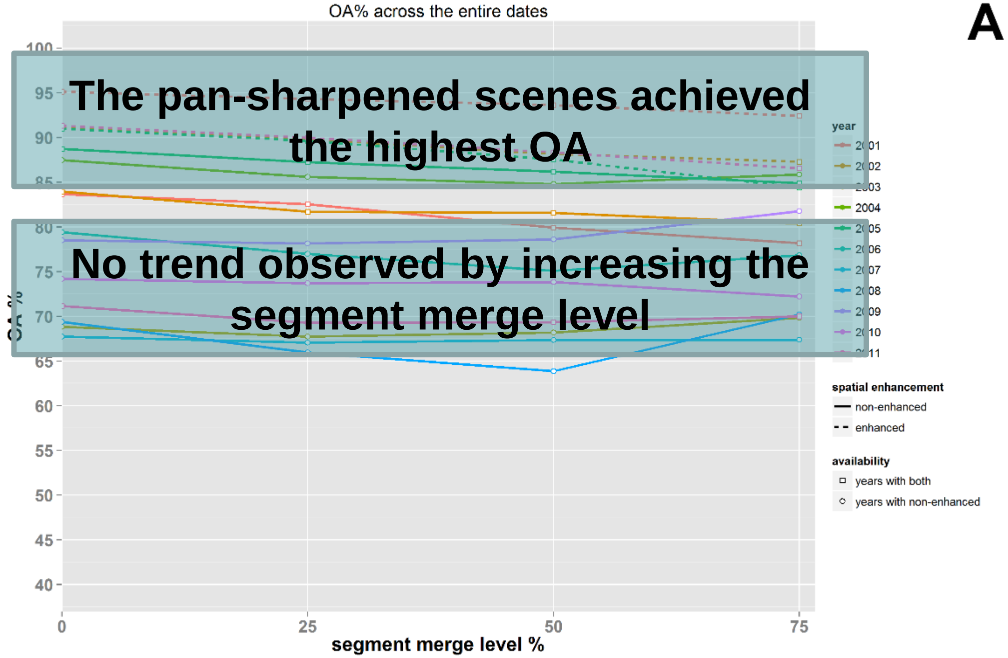
B



Kappa%

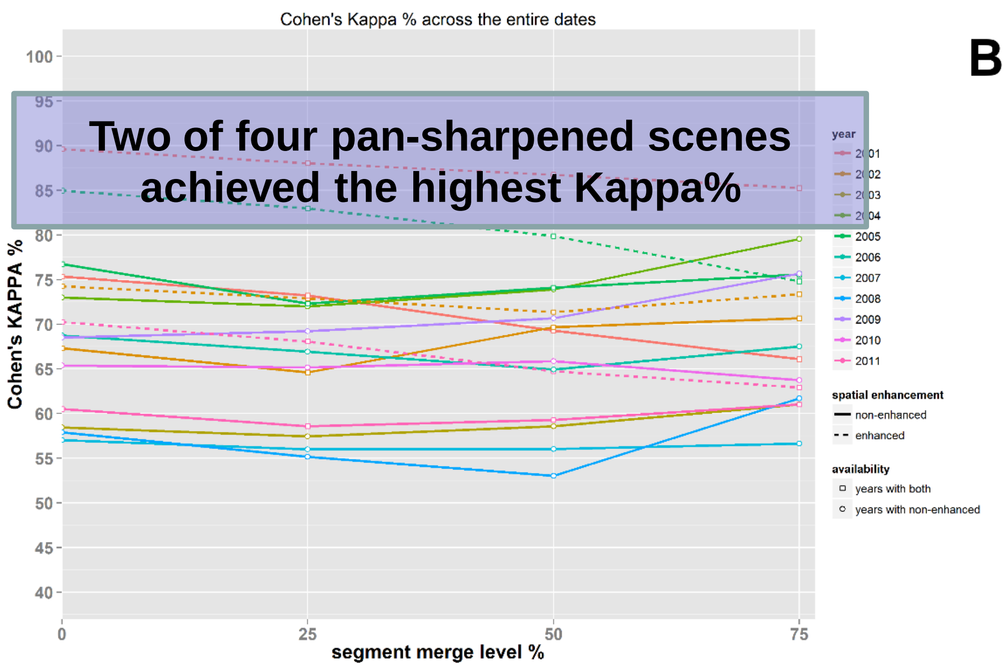
. *Progress in Physical*
'55-785

A



OA%

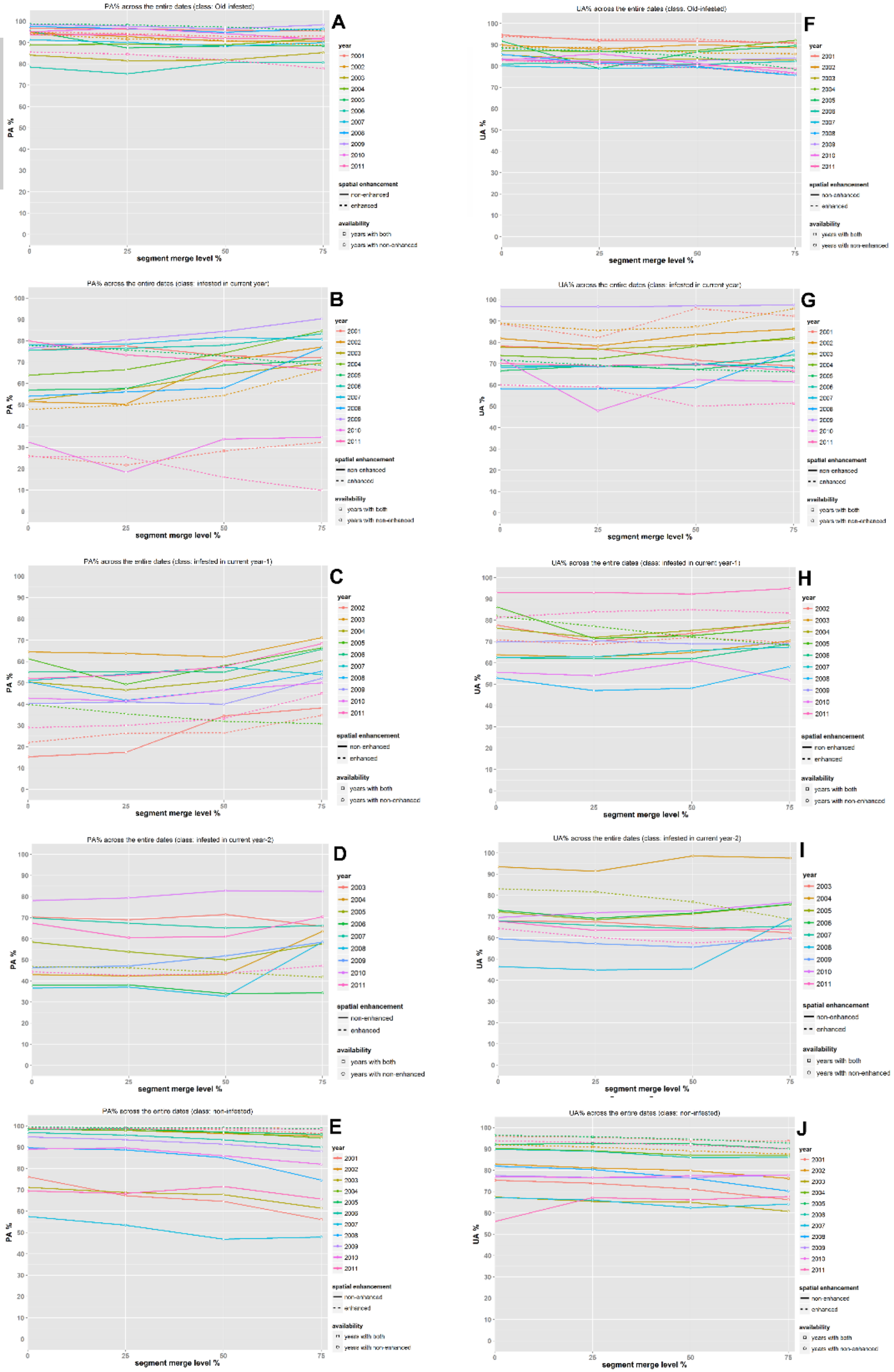
B



Kappa%

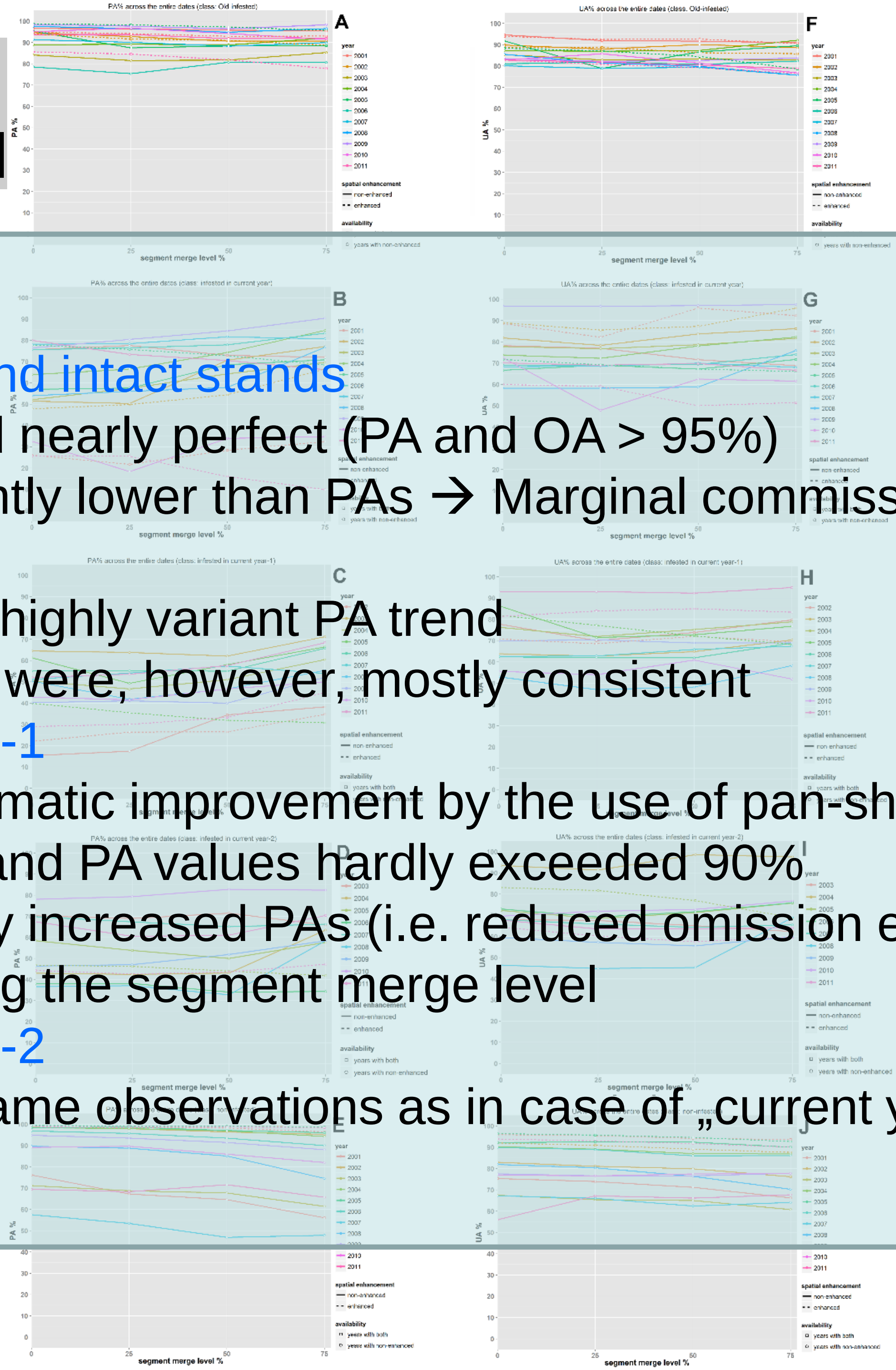
. Progress in Physical
'55-785

ll



s

.4. *Progress in Physical*
: 755-785



Summary:

- Deadwood and intact stands
  - classified nearly perfect (PA and OA > 95%)
  - UAs slightly lower than PAs → Marginal commission error
- Current year
  - showed highly variant PA trend
  - UA rates were, however, mostly consistent
- Current year -1
  - No systematic improvement by the use of pan-sharpened data
  - The UA and PA values hardly exceeded 90%
  - Generally increased PAs (i.e. reduced omission errors) by increasing the segment merge level
- Current year -2
  - Nearly same observations as in case of „current year-1“ class

.4. *Progress in Physical*
: 755-785

Results
IV- Probability surfaces for correct classification

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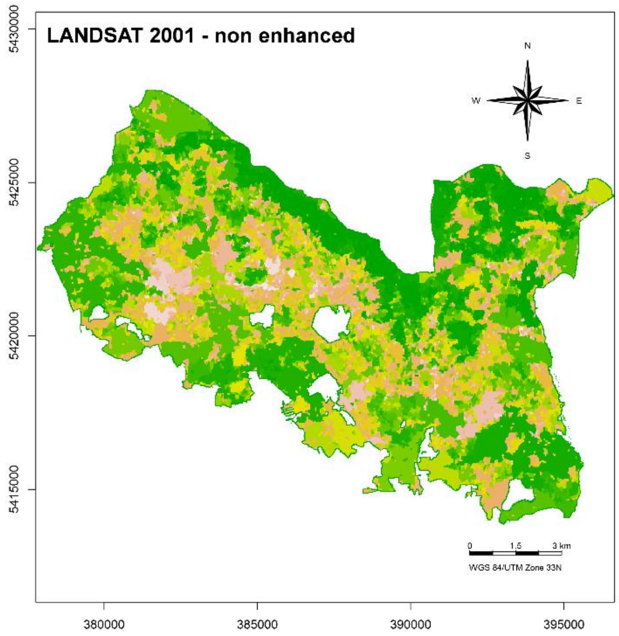
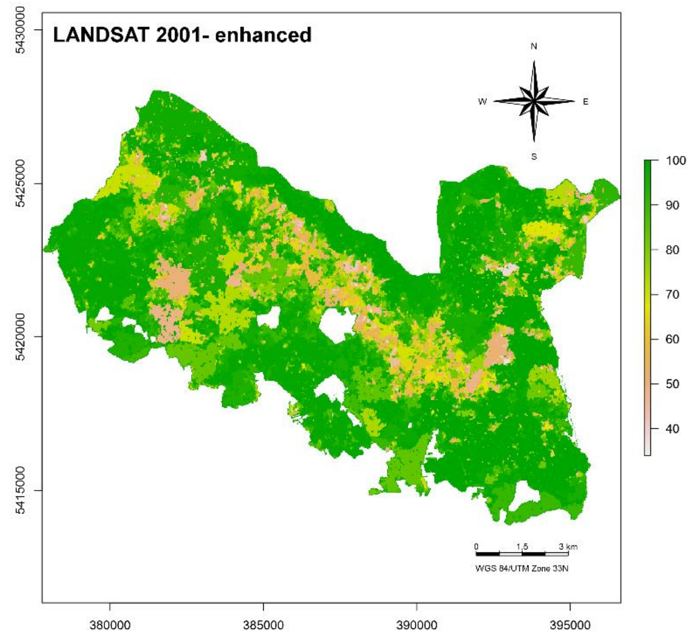

LANDSAT 2001 - non enhanced
N
W
E
S
0 1,5 3 km
WGS 84/UTM Zone 33N
5430000
5425000
5420000
5415000
380000
385000
390000
395000


LANDSAT 2001- enhanced
N
W
E
S
0 1,5 3 km
WGS 84/UTM Zone 33N
100
90
80
70
60
50
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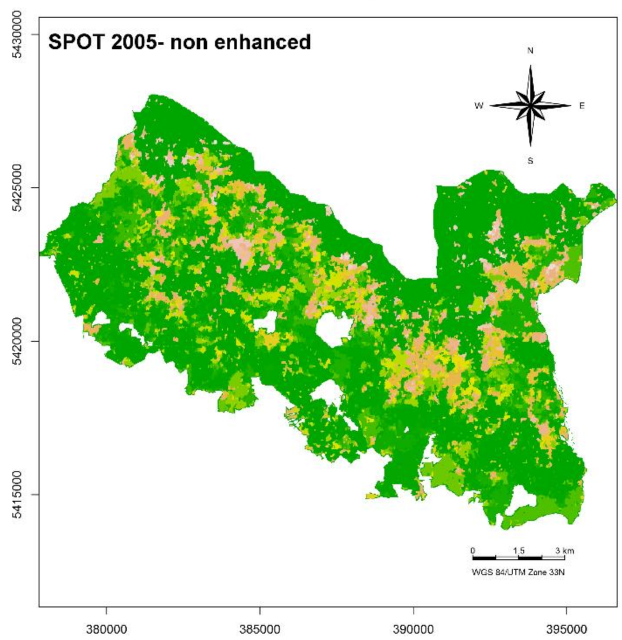
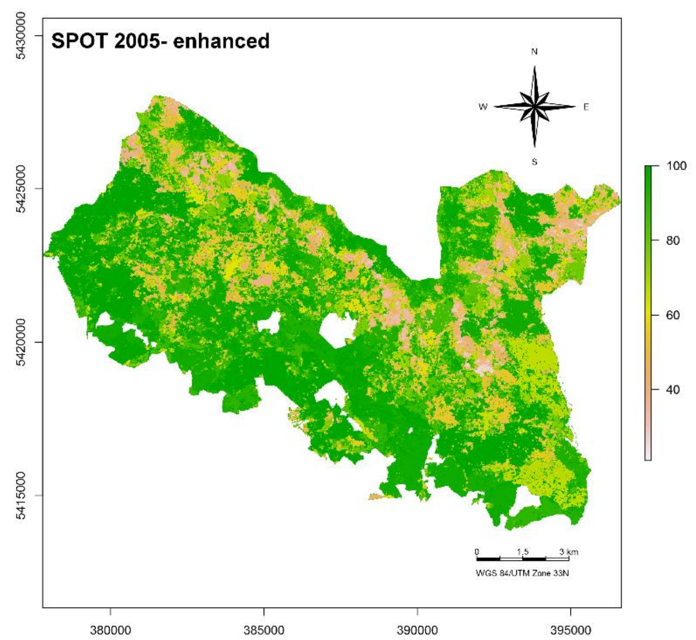
380000
385000
390000
395000


SPOT 2005- non enhanced
N
W
E
S
0 1,5 3 km
WGS 84/UTM Zone 33N
5430000
5425000
5420000
5415000
380000
385000
390000
395000


SPOT 2005- enhanced
N
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0 1,5 3 km
WGS 84/UTM Zone 33N
100
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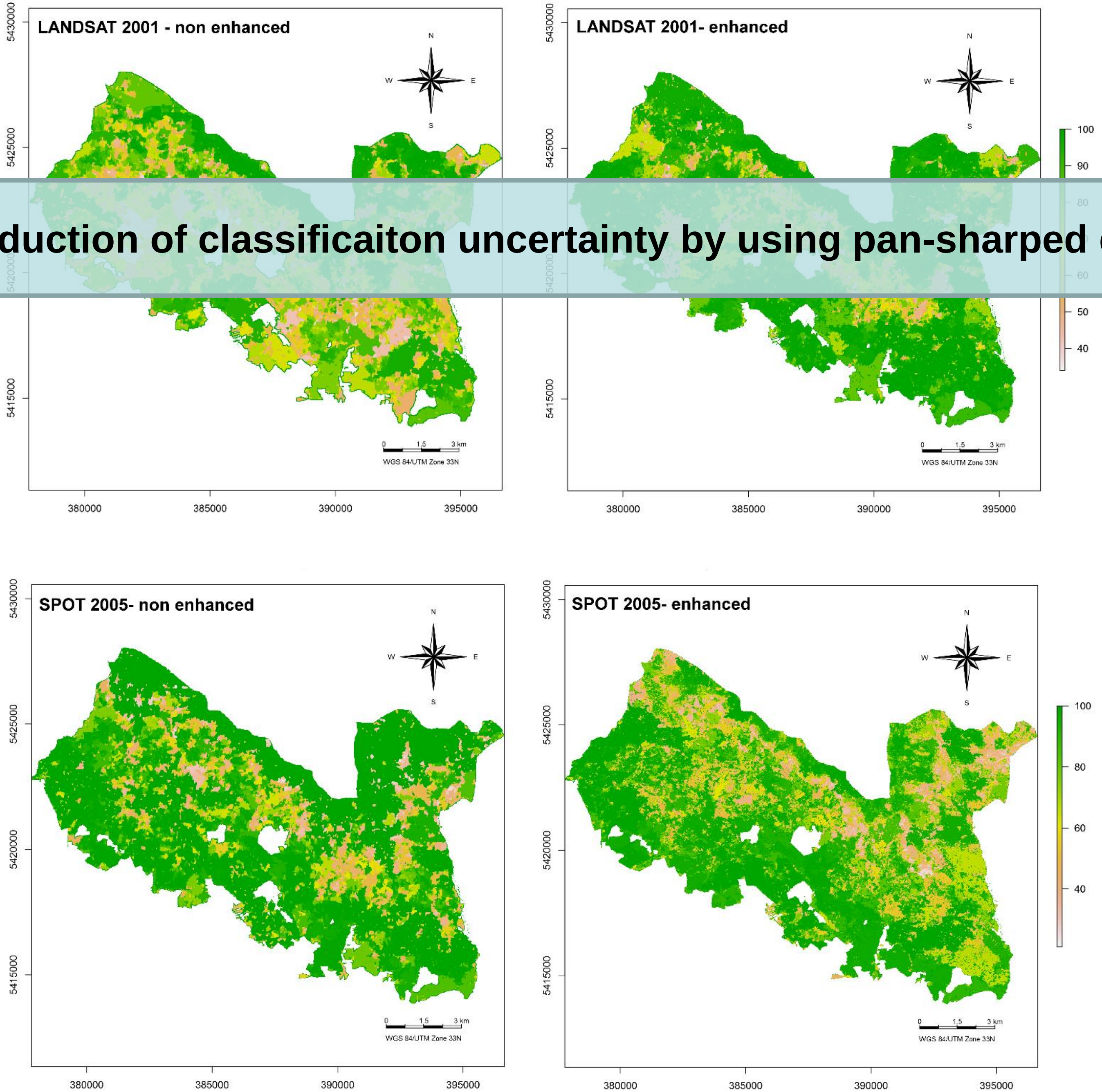
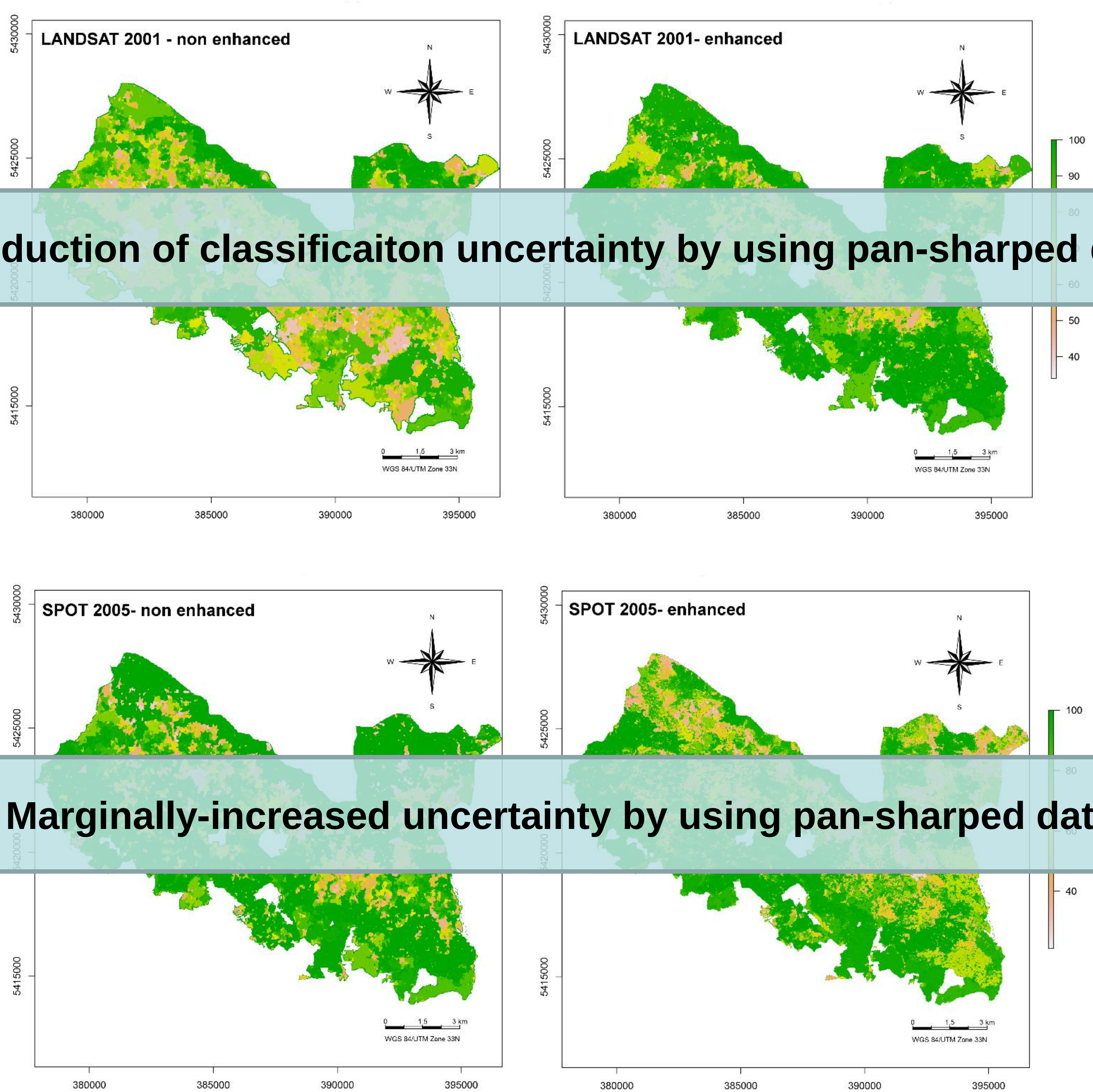
Physical

Reduction of classificaiton uncertainty by using pan-sharped data



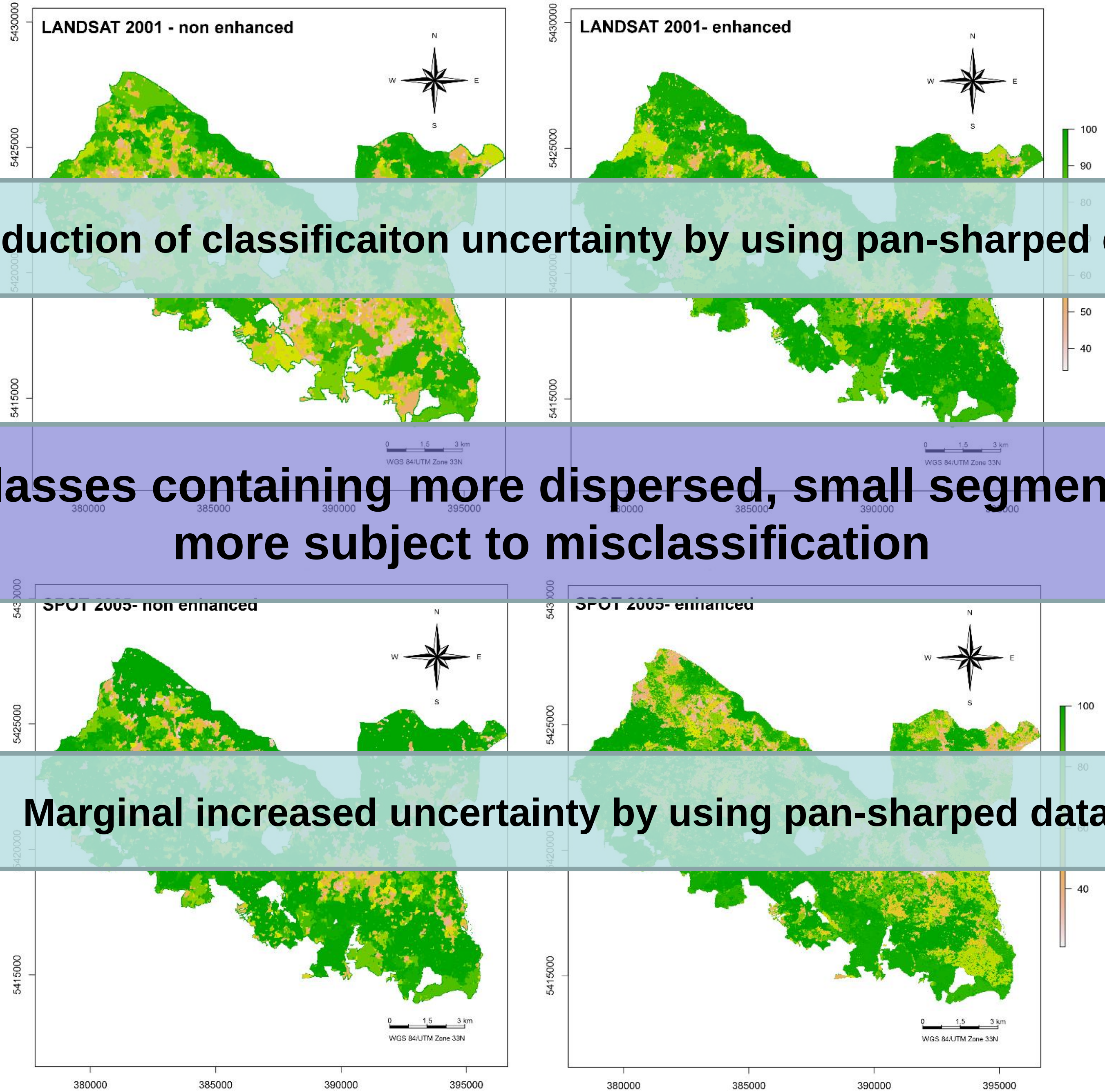
Physical



Reduction of classificaiton uncertainty by using pan-sharped data

Marginally-increased uncertainty by using pan-sharped data

Physical



Reduction of classificaiton uncertainty by using pan-sharped data

The classes containing more dispersed, small segments are more subject to misclassification

Marginal increased uncertainty by using pan-sharped data

Physical

Conclusions

- Medium resolution EO data could be leveraged to classify tree mortality, provided that:
  - The image Acquisition dates lie near to the reference data collection
  - An object based paradigm is applied
  - The infested patches conform the spatial resolution of the imagery
  - The right classifier is employed
  - The classes are realistically defined
  - Terrain information is there → DTM or DSM
  - An in-depth assessment of uncertainty is on-board !

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Conclusions

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Limitations

- The lack of narrow-band informaiton on Rededge and SWIR domains
  - Suggestions: RapidEye or Sentinel II data (yet in shorter time spans)

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- The lack of narrow-band informaiton on Rededge and SWIR domains
  - Suggestions: RapidEye or Sentinel II data (yet in shorter time spans)

- Heterogeneity of object forms, sizes and texture
- Segment merging level and pan-sharpening are still of uncertain status for their contribution to mapping quality

Conclusions

Limitations

- The lack of narrow-band informaiton on Rededge and SWIR domains
  - Suggestions: RapidEye or Sentinel II data (yet in shorter time spans)

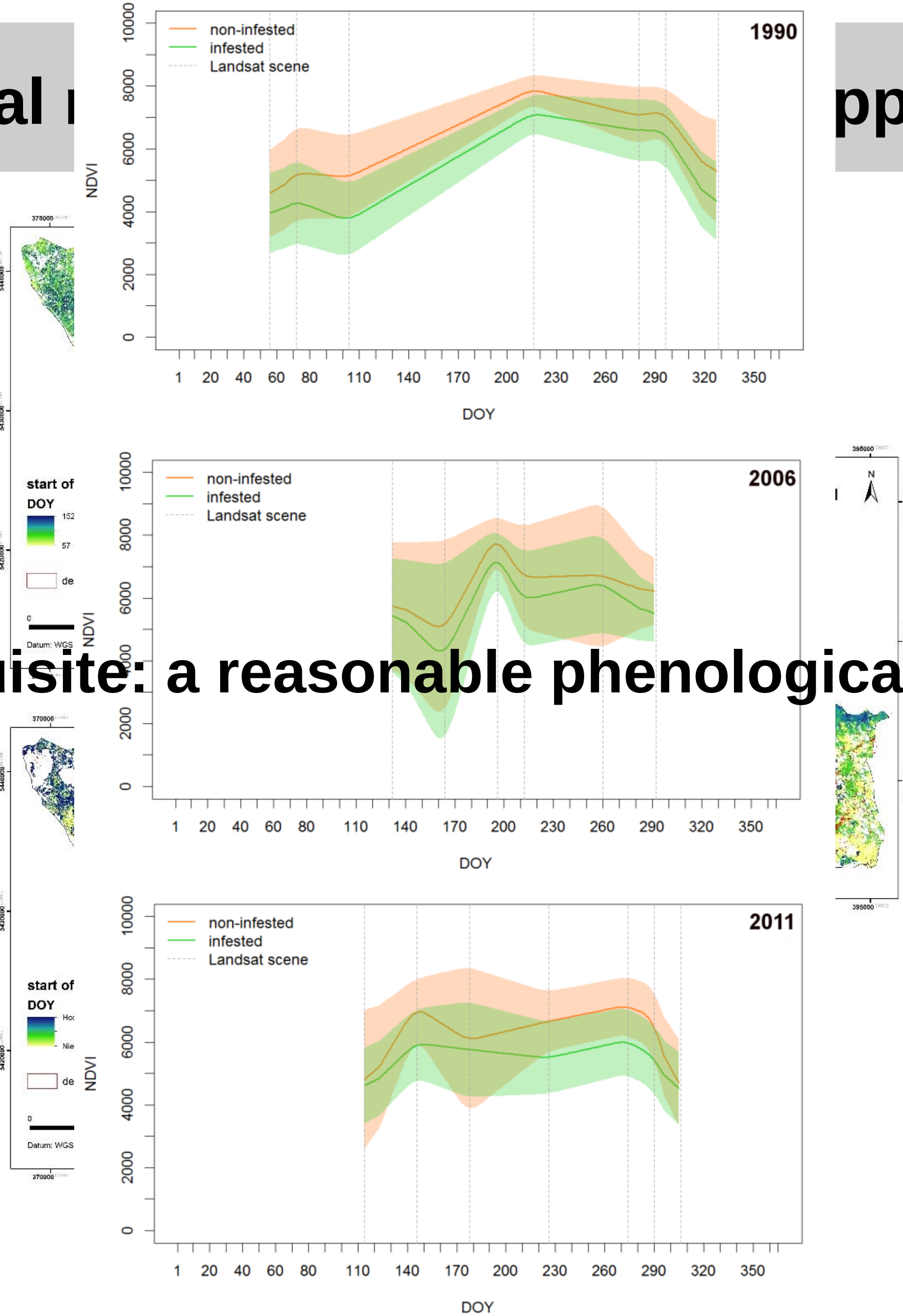
- Heterogeneity of object forms, sizes and texture

Take-Home messages

- Early detection of tree mortality by mid-res optical data still is (and further remain) a challenge
- Coupling the inherently-uncetain reference (in whatsoever form) and satellite-based EO data adds to the complexity

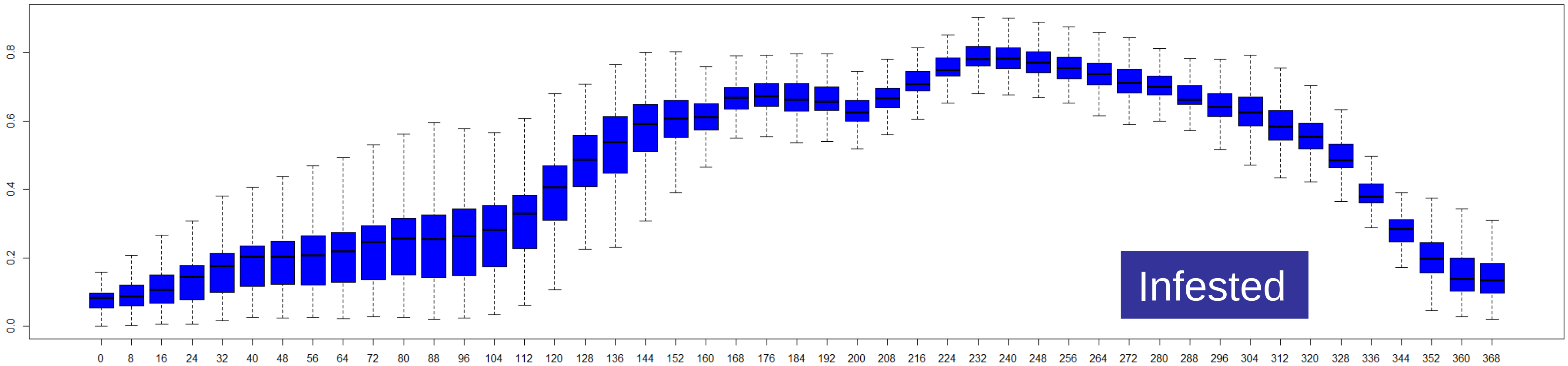
Final remark: a phenological approach

Final r pproach

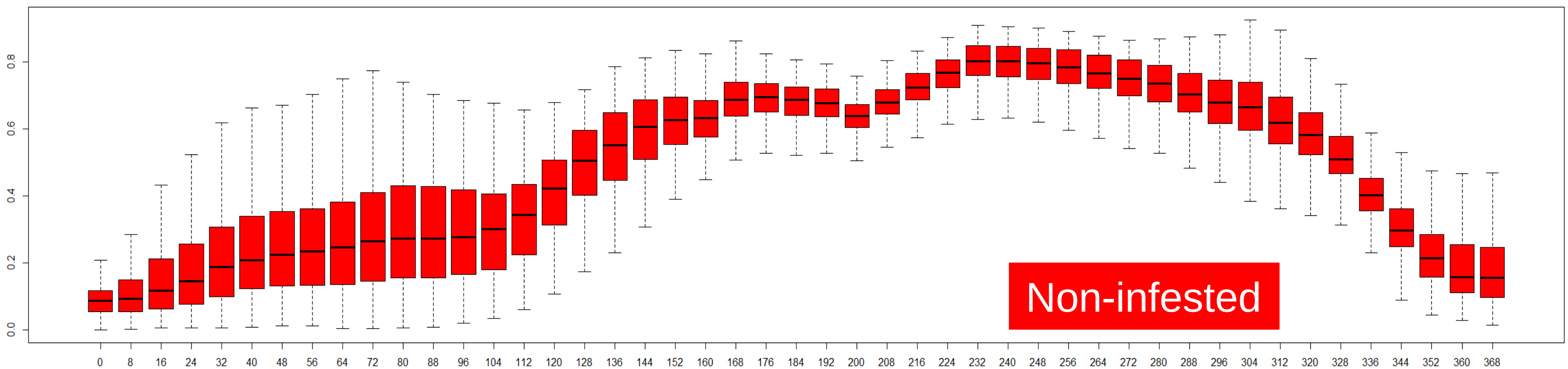


Prerequisite: a reasonable phenological curve!

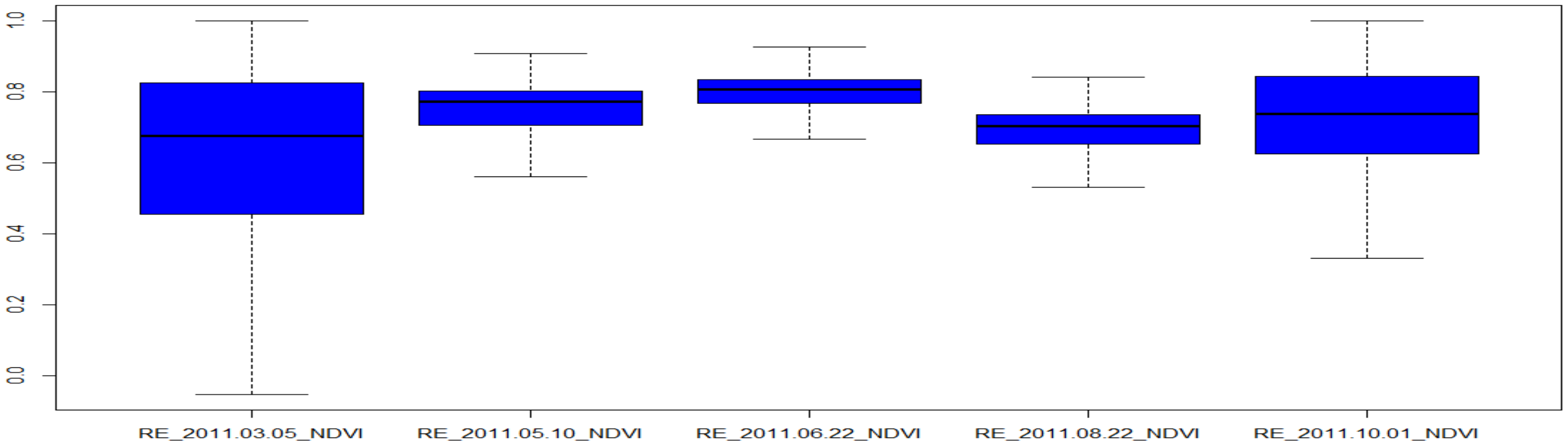
MODIS curve

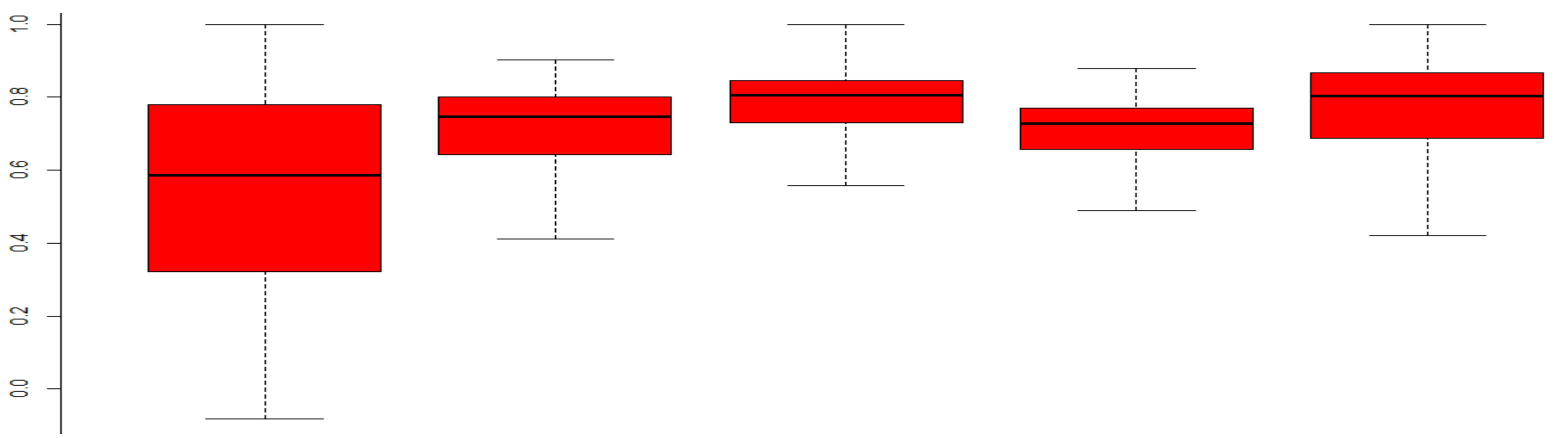


DOY

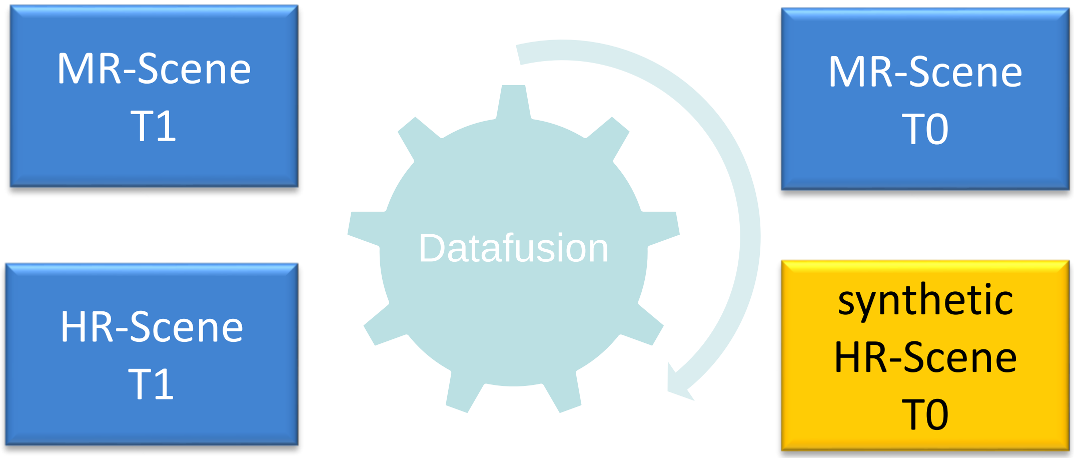


RapidEye Curve

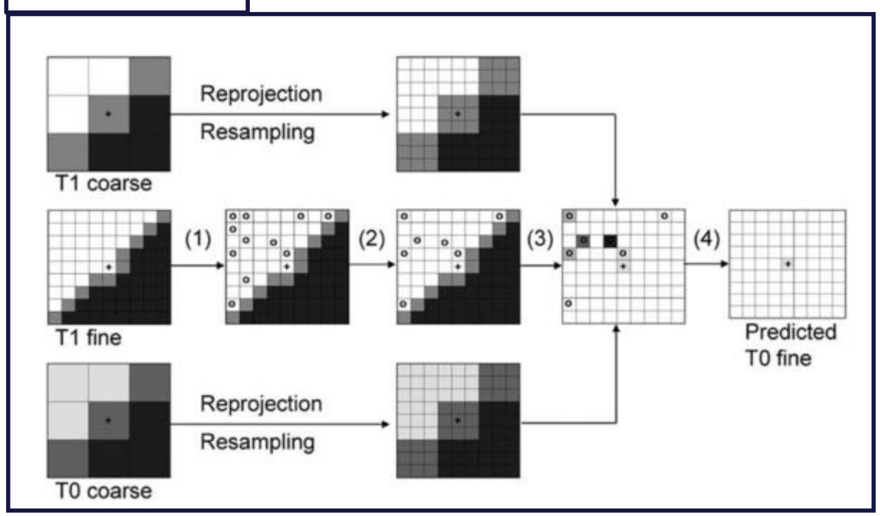




How does spatial-temporal data fusion work?



Local Part



$$L\left(x_{w/2}, y_{w/2}, t_0\right) = \boxed{\sum_{i=1}^{w}\sum_{j=1}^{w}\sum_{k=1}^{n} W_{ijk}}$$

$$\boxed{\times \left(M(x_i, y_j, t_0) + L(x_i, y_j, t_k) - M(x_i, y_j, t_k)\right)}$$

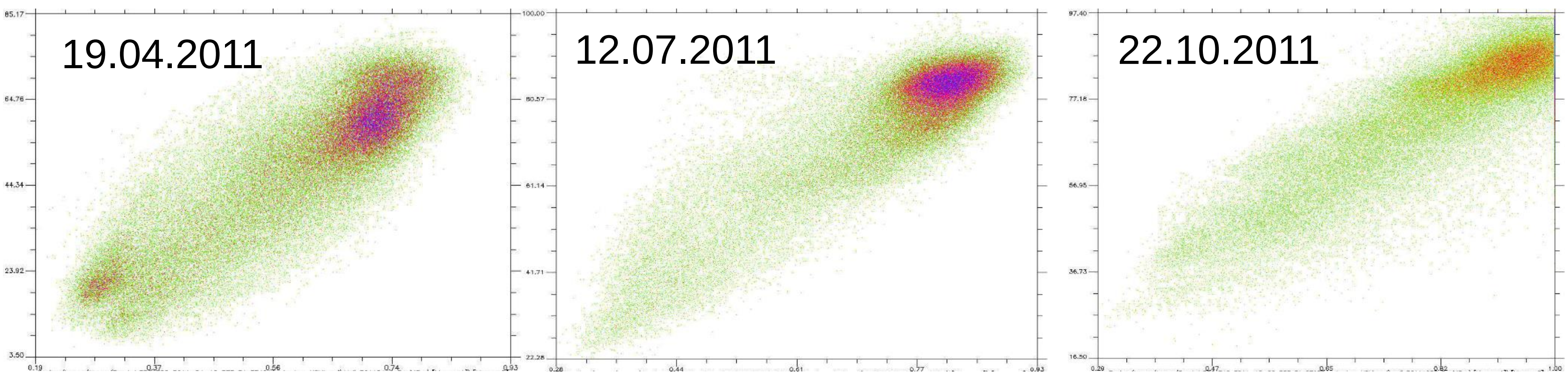
Gobal Part

MR: MODIS
HR: RapidEye

STARFM (Gao et al., *2006. IEEE Trans.Geosci..Remote Sens.*

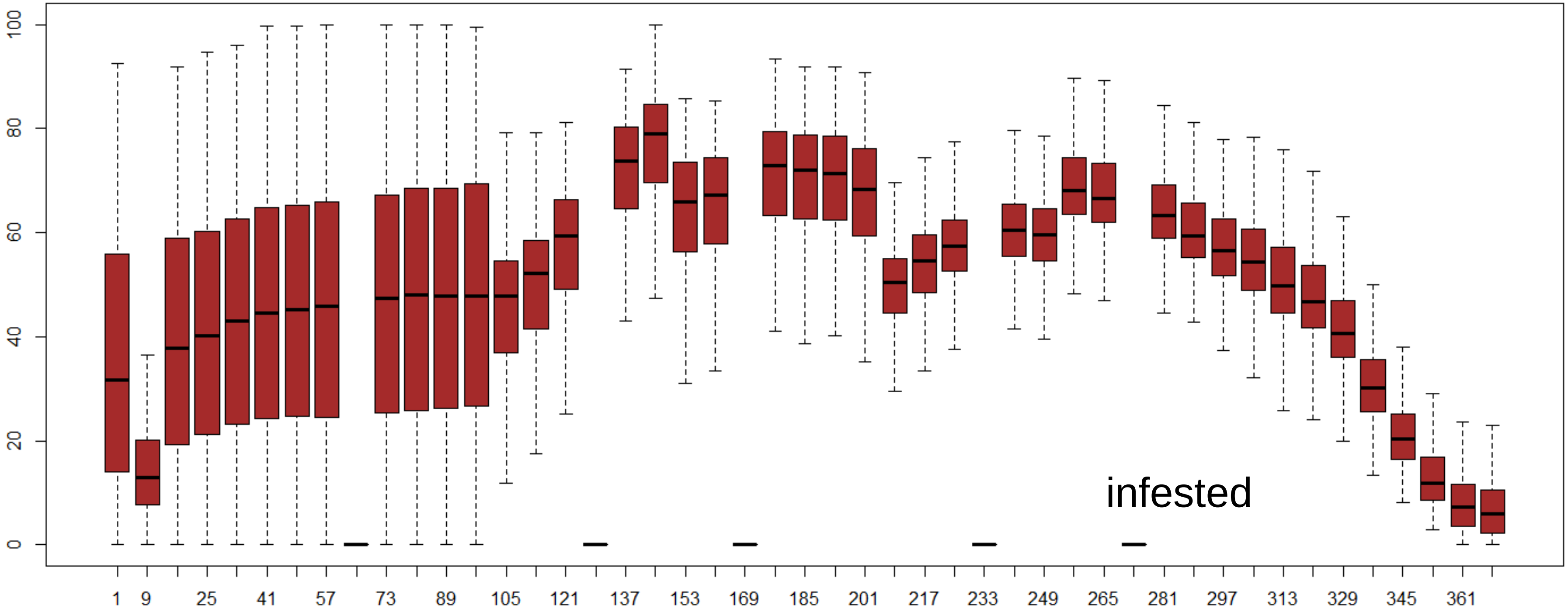
Fusion results

Date	R^2	RMSE	MAE
2011.04.19	0.54	0.13	0.11
2011.07.12	0.53	0.13	0.11
2011.10.22	0.53	0.13	0.11



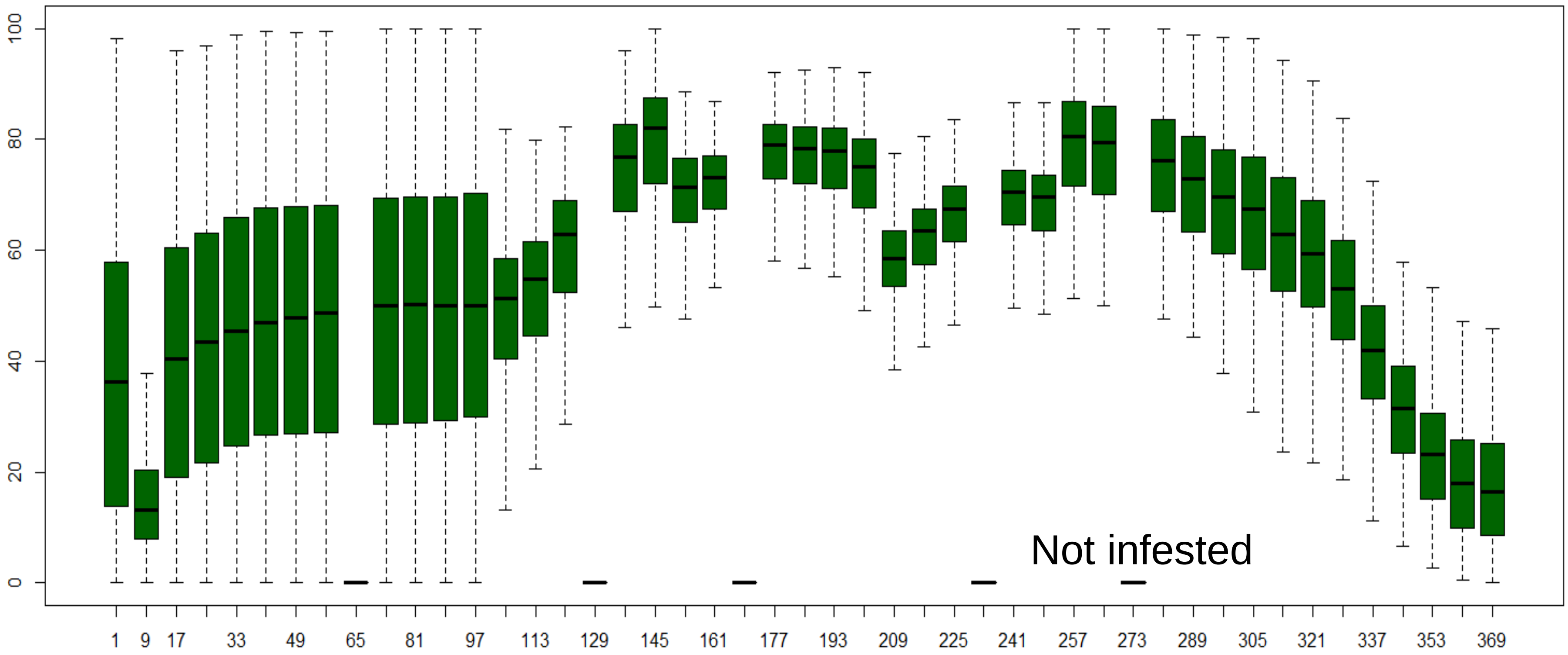
Fused curve

Fused curve



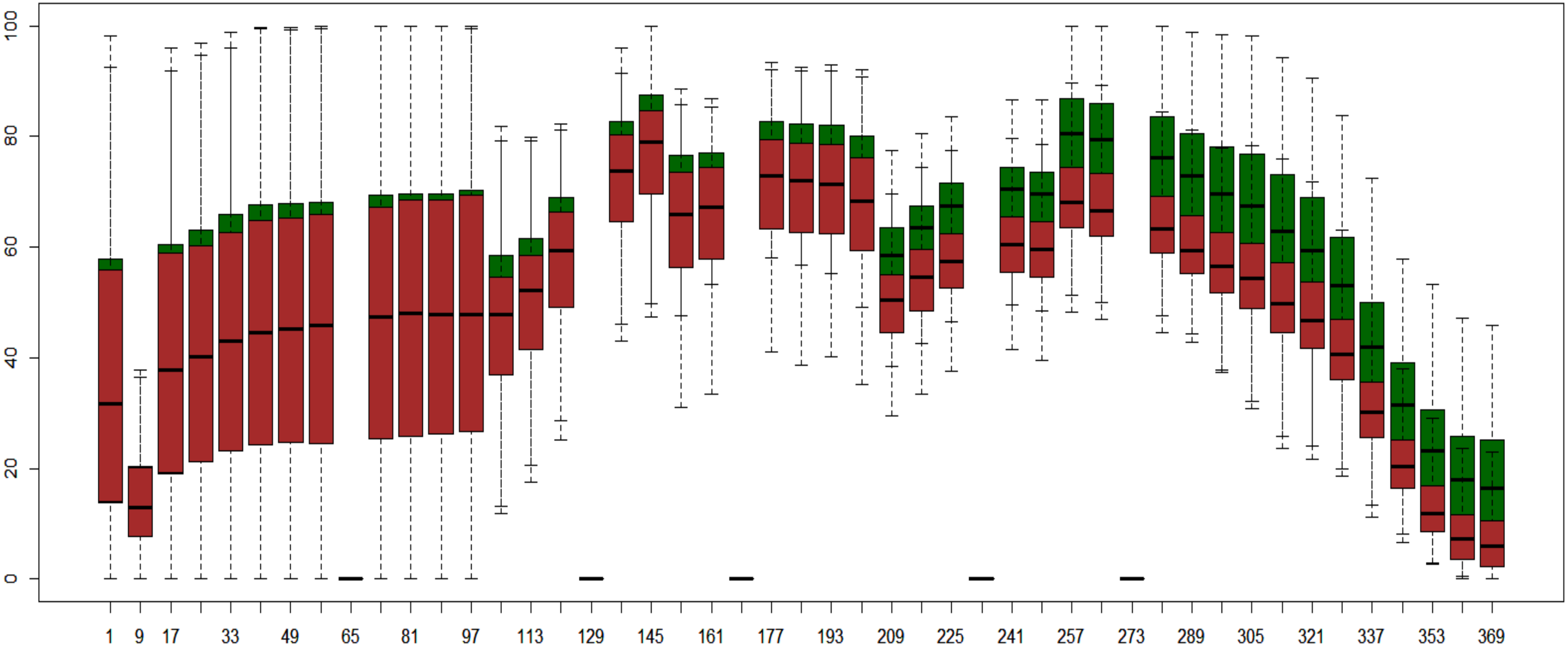
0
20
40
60
80
100
1
9
25
41
57
73
89
105
121
137
153
169
185
201
217
233
249
265
281
297
313
329
345
361
infested

Fused curve



100
80
60
40
20
0
1
9
17
33
49
65
81
97
113
129
145
161
177
193
209
225
241
257
273
289
305
321
337
353
369
Not infested

Fused curve


0
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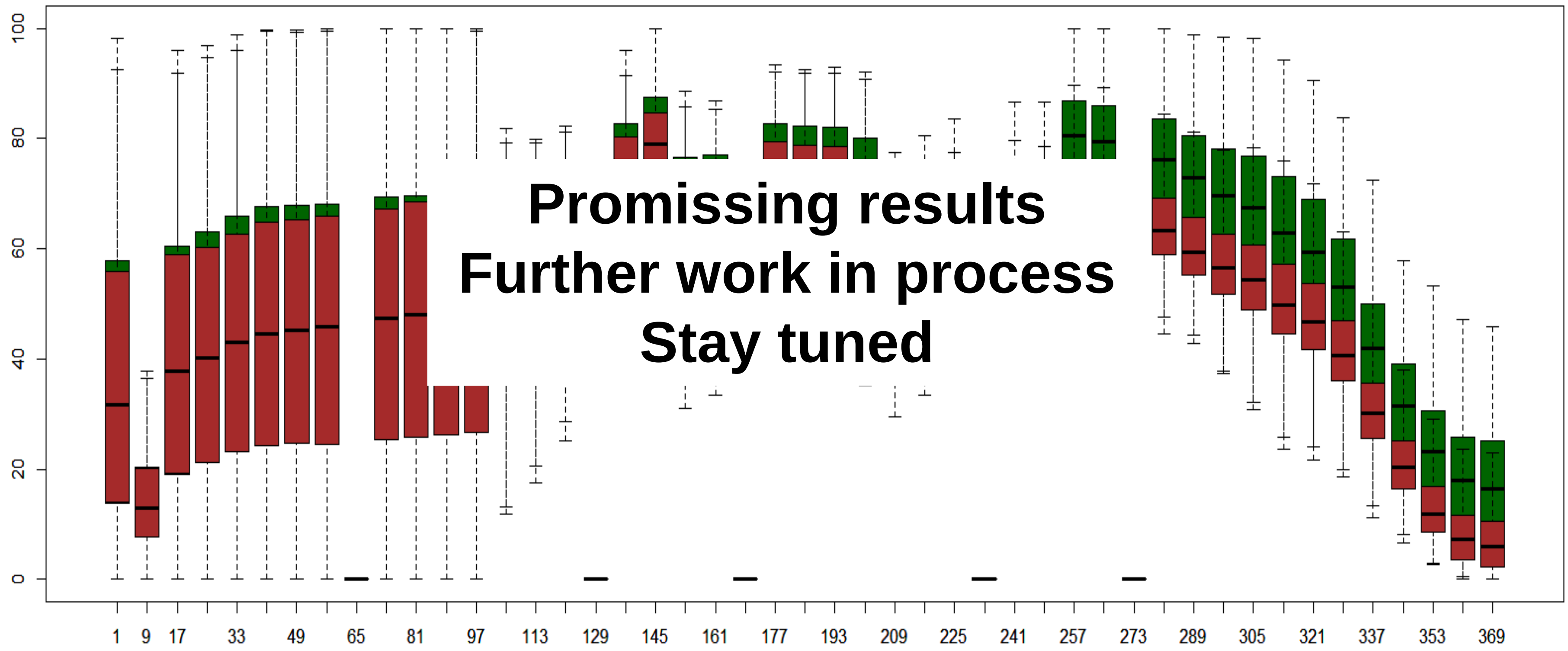
Fused curve



Promissing results
Further work in process
Stay tuned

Acknowledgements:
- BFNP administration
- ESA, SPOT Image and Planet Action
- RapidEye, DLR, BlackBridge and Planet Labs
- F. Fassnacht
- And many more

Thank you !

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