What should a high resolution global land cover look like and how might we get there?

- Curtis Woodcock
- Pontus Olofsson
- Zhe Zhu
  - Boston University

Essential Climate Variable (UNFCCC): Land Cover Requirements

- Annual coarse resolution products (250-1km)
- High resolution land cover (every 5 years)
  - Maybe GLS datasets?????

Draft: GCOS Implementation Plan (June 09)

- Summary of Land Cover related Actions

Action T22	International standards for land cover maps	Good Progress
Action T23	Methods for land cover map accuracy assessment	Good Progress
Action T24	Sustained fine-resolution land imaging from space	Good Progress
Action T25	Development of *in situ* reference network for land cover	Low Progress
Action T26	Annual land cover products	Moderate-Low Progress
Action T27	Regular fine-resolution land cover maps	Low Progress

What should it look like?

- Accurate representation of land cover at any time (maps)
- The differences between times (maps) are representative of change in land cover

The Problem

- The assignment of land cover classes to individual pixels (or groups of pixels) has a signficant stocastic component --
- Or, spectral/temporal/spatial signatures of land cover classes are not highly distinct
- Evidence:
  - Take the same remote sensing data and the same land cover legend and give it to different people and they will produce different maps
  - Take the same training data and same input remote sensing data, change the classifier and you get a different map
  - Take the same reference training data and change the remote sensing data, and you get a different map
  - Ad infinitum

The Problem (cont)

- The amount of land cover change between two times (maybe a 5 year period) is typically small compared to the apparent change resulting from the stochastic component in the maps of land cover at the end points of the period
- Thus, the comparison of land cover maps from two different time periods to estimate the change in land cover doesn’t work!!!

MODIS Land Cover Experience: If you process each year of MODIS data with the same training sites for different years, about 30% of the pixels change classes (the green bars)!! The yellow bars employ a constraining process based on the posterior probabilities

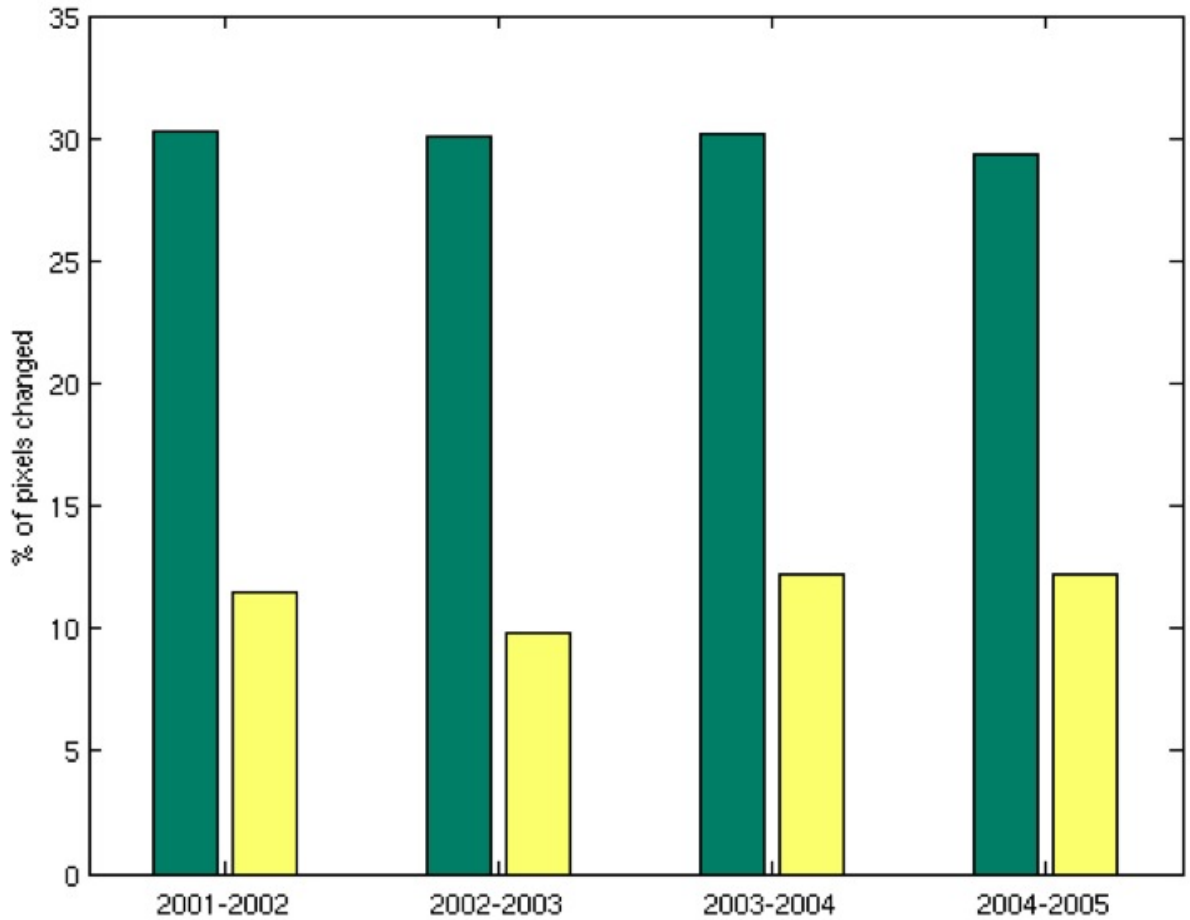


Figure courtesy of Mark Friedl

So how are we going to get to a record of land cover and when it has changed?

- Focus the analysis on time rather than space
  - For any location, identify the times when land cover changes -- and between those times assign a single land cover

Time Series from Landsat?

Both Intra- and Inter Annual Temporal Effects!!

- Take all images of the same scene (solved via free access to the archive)
- Register the images (solved via L1T)
- Convert to a stable measurement (surface reflectance, solved via LEDAPS)
- Screen out the clouds, their shadows (and maybe snow) (not solved)
- Compile and analyze the resulting time series (not solved)

What have we done so far?

- Really, just getting started!
  - 68 L7 images of “Boston” Scene in the *Golden Years* (2000-2002)
  - Atmospherically corrected (LEDAPS)
  - Cloud screened (two ways - Zhe Zhu)
  - Begin simple time series analysis
    - Landsat phenologies
    - Explore improvements in separability of classes through use of the time domain

Cloud, Shadow and Snow Screening

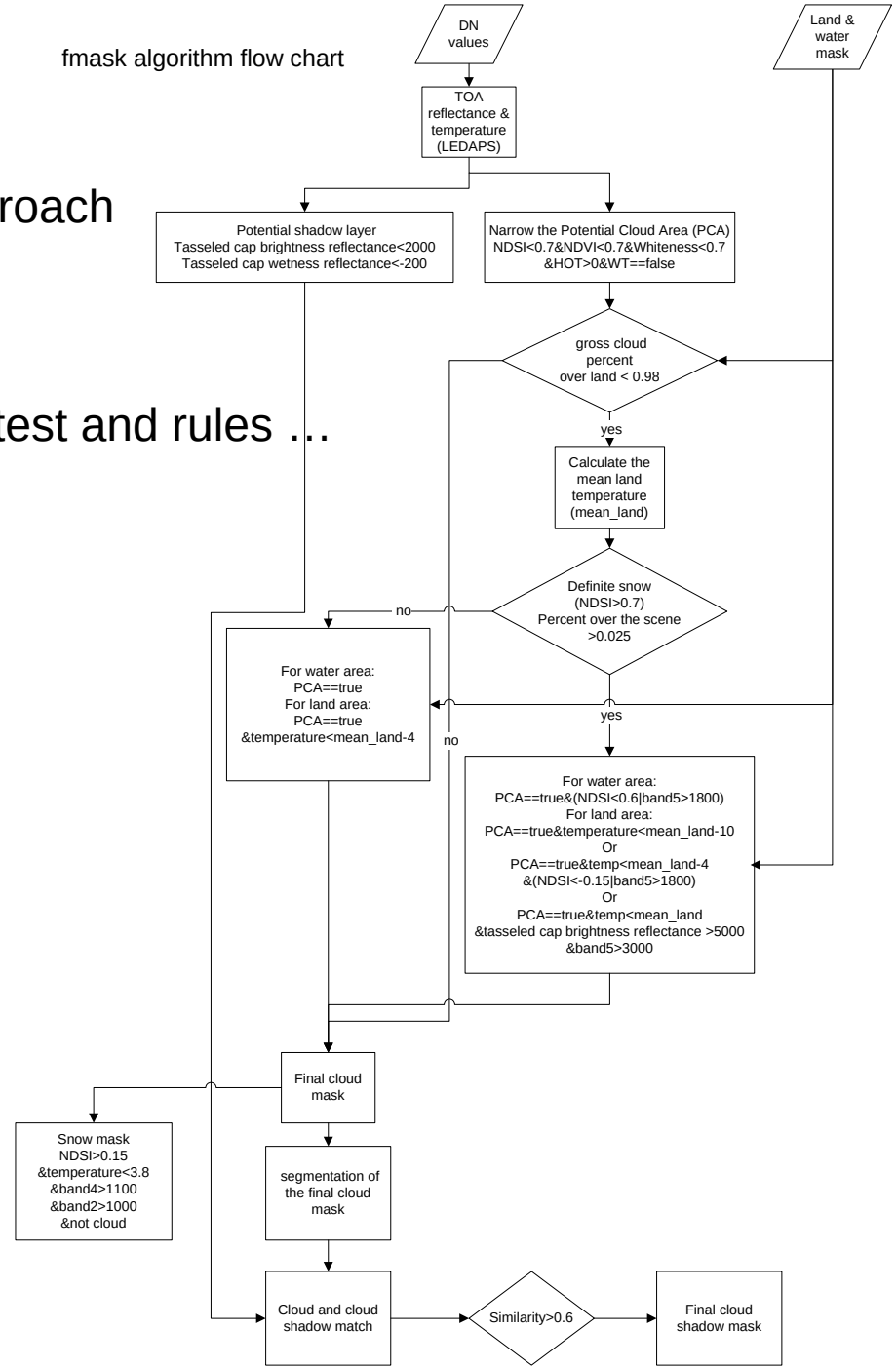
- We've been testing two approaches
  - Assume you know nothing
    - Single image approach
  - Use Geographic and Temporal Context
    - Multiple image approach

Our Bias: When in doubt error on the side of errors of comission for clouds, shadows and snow -- based on the idea that missing clouds or shadows is a bigger problem than throwing out useful observations!

fmask algorithm flow chart

Single Image Approach

ACCA-like, lots of test and rules …



Cloud/Shadow/Snow Detection Inputs

- TOA reflectance (from LEDAPS)
- Temperature
- NDSI
- NDVI
- Water Mask
- Band 5
- Whiteness
- HOT
- Water Mask

Used in the Cloud Detection

- Haze Optimized Transform (HOT):

$$HOT = band1 - 0.6 * band3 - 600$$

- Water Test (WT):

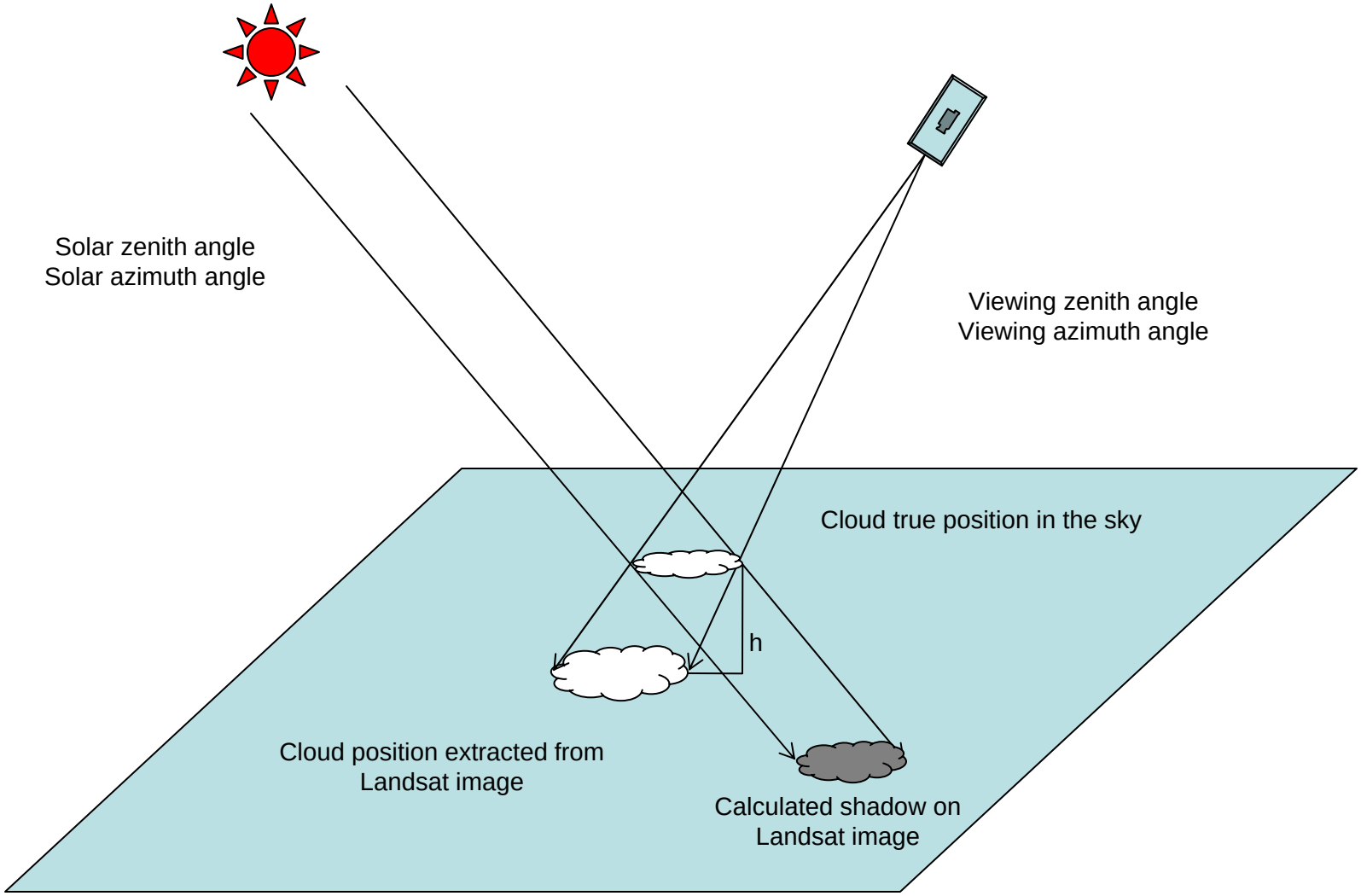
$$WT = NDVI < 0.1 \& band4 < 505 \& band5 < 405$$

- Whiteness:

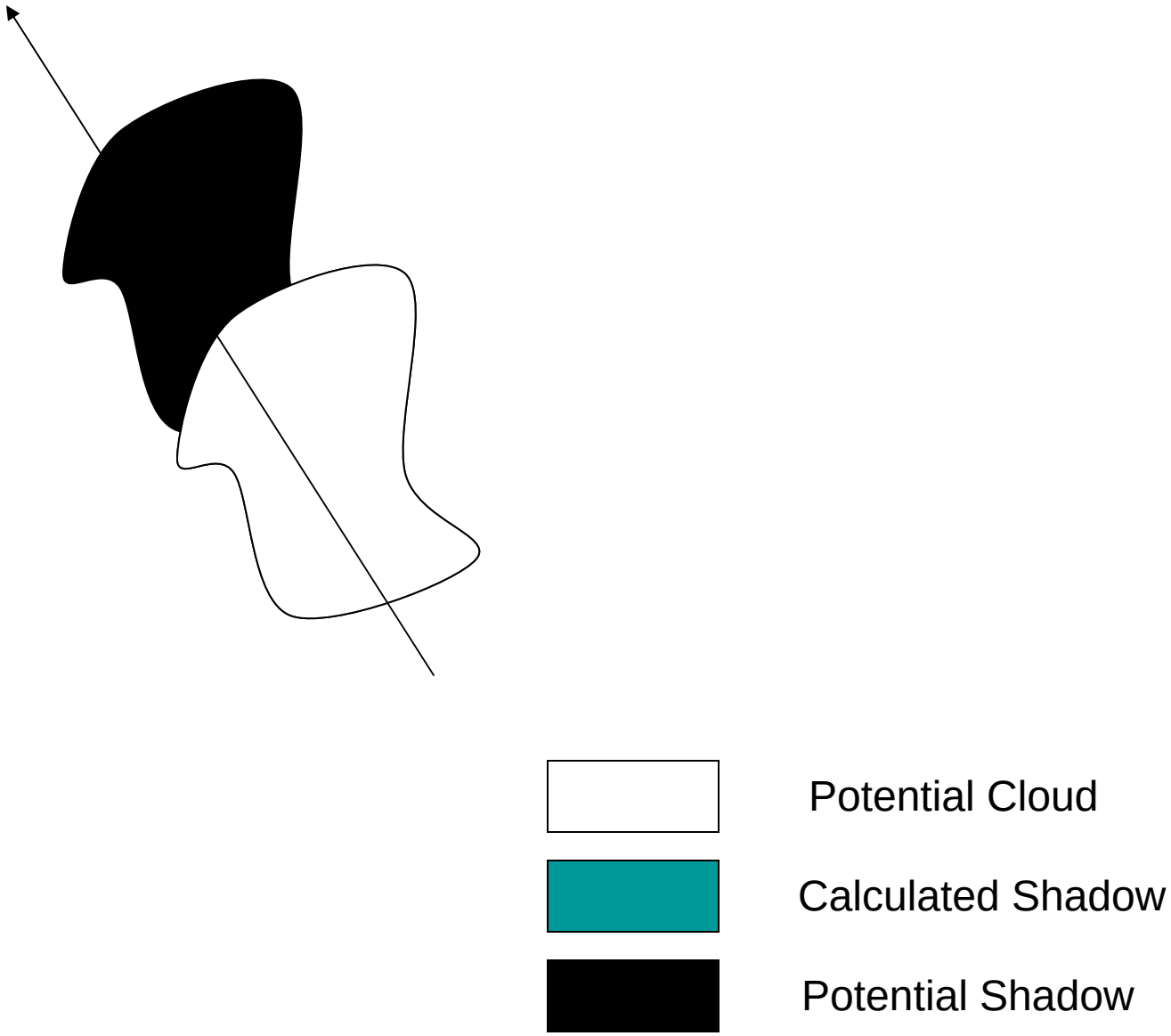
$$mean_visi = mean(band1, band2, band3)$$

$$whiteness = |band1 / mean_visi - 1| + |band2 / mean_visi - 1| + |band3 / mean_visi - 1|$$

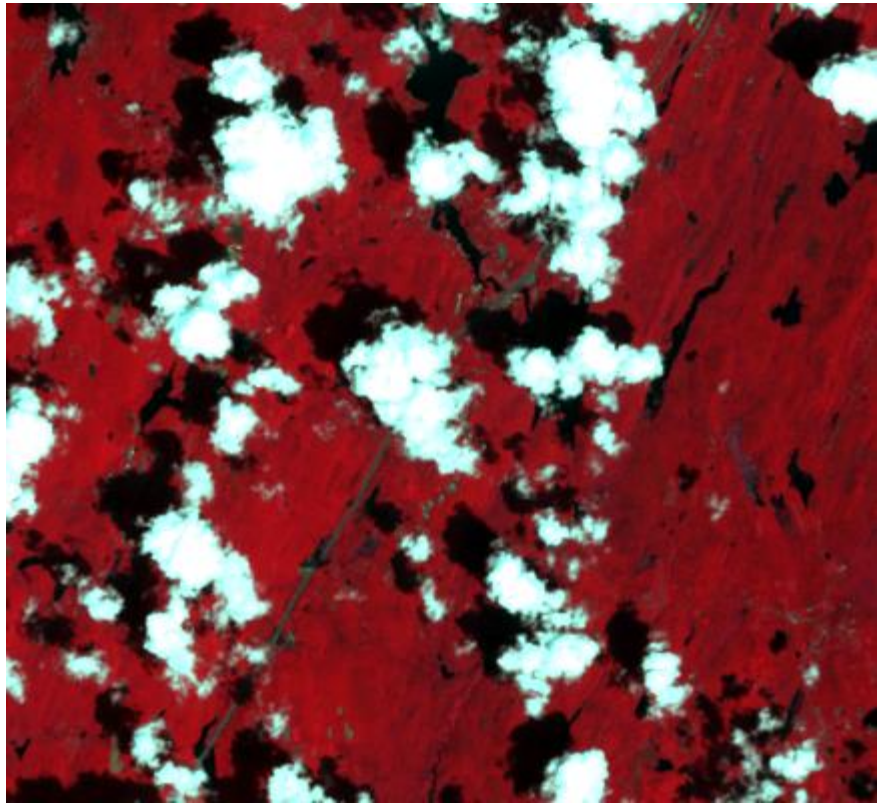
Cloud Shadows - Geometry Relationship



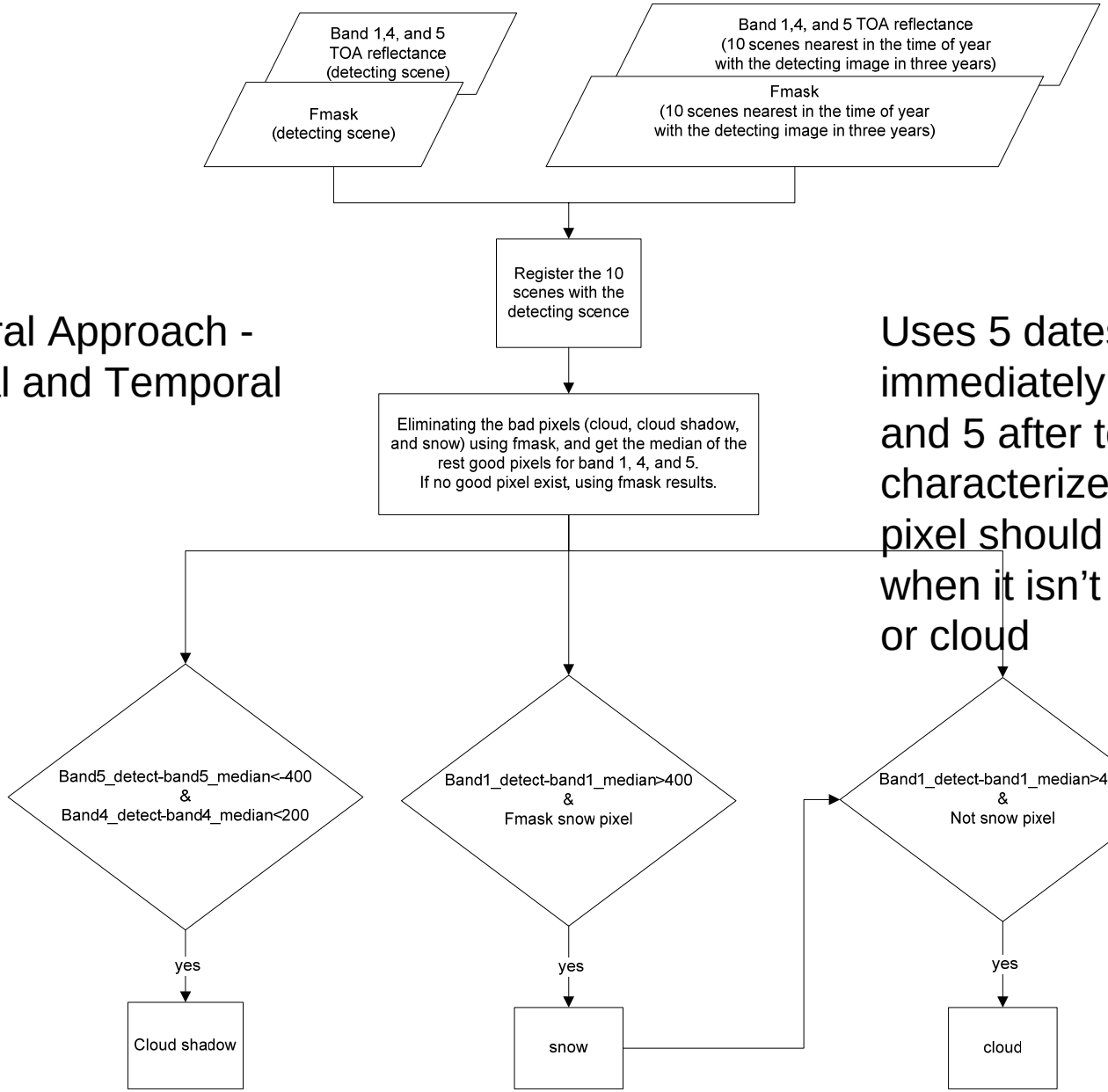
Object Based Cloud and Shadow Match (OBCSM) algorithm



Matched Shadows and Clouds



Multi-temporal cloud, cloud shadow, and snow detection algorithm flow chart



Multitemporal Approach - Geograhical and Temporal Context

Uses 5 dates immediately before and 5 after to help characterize what a pixel should look like when it isn't shadow or cloud

Well-behaved clouds & cloud shadows (easily identified)

06/23/2000 ETM+

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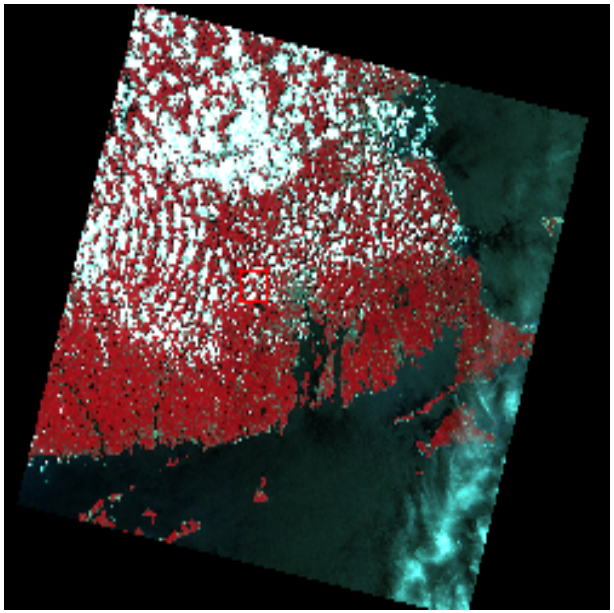

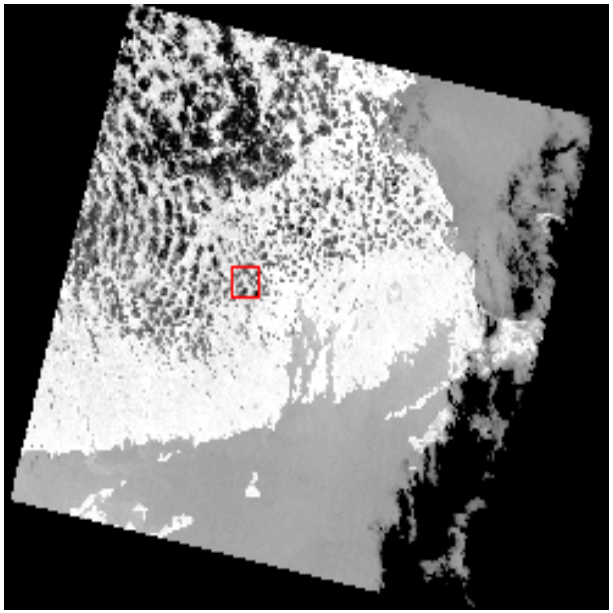

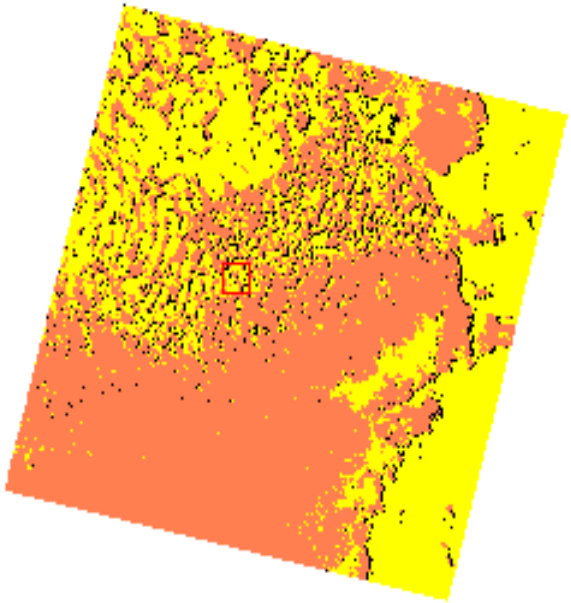

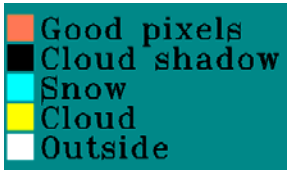

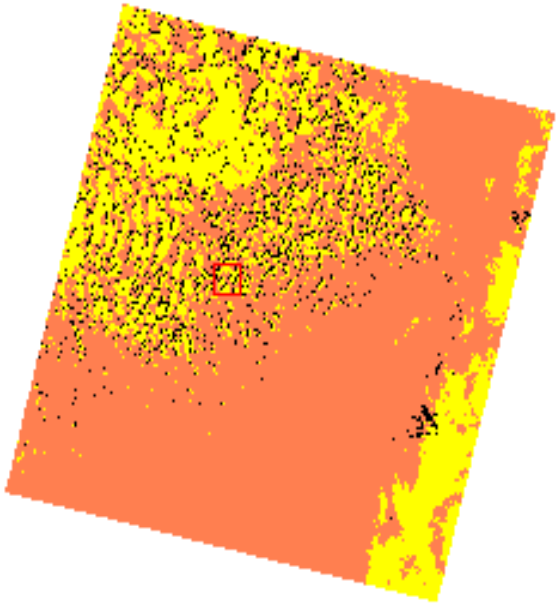

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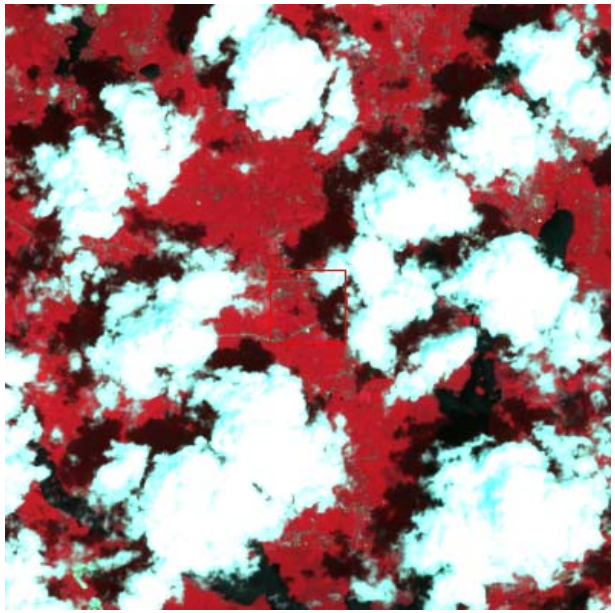

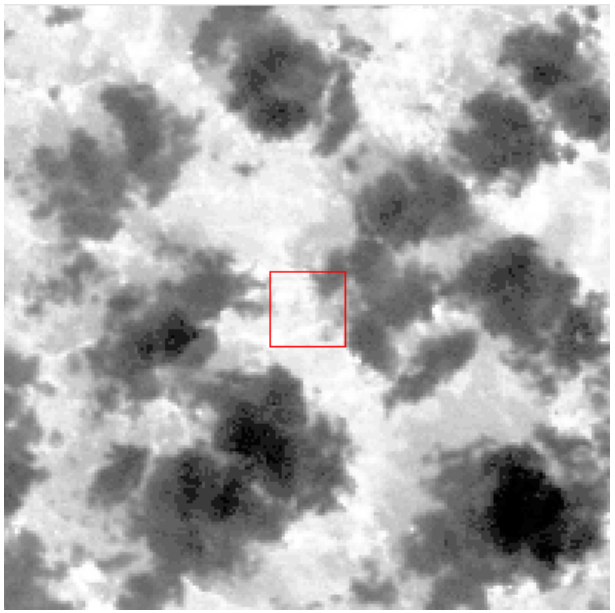

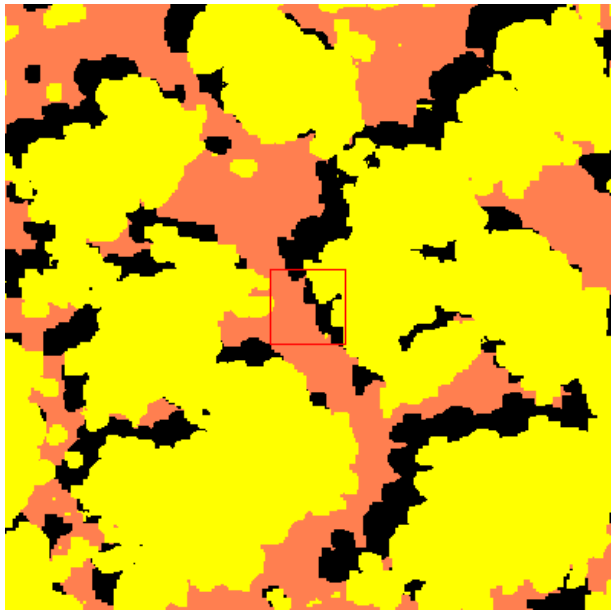

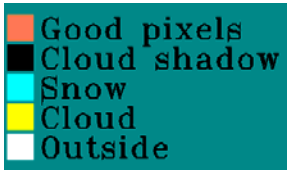

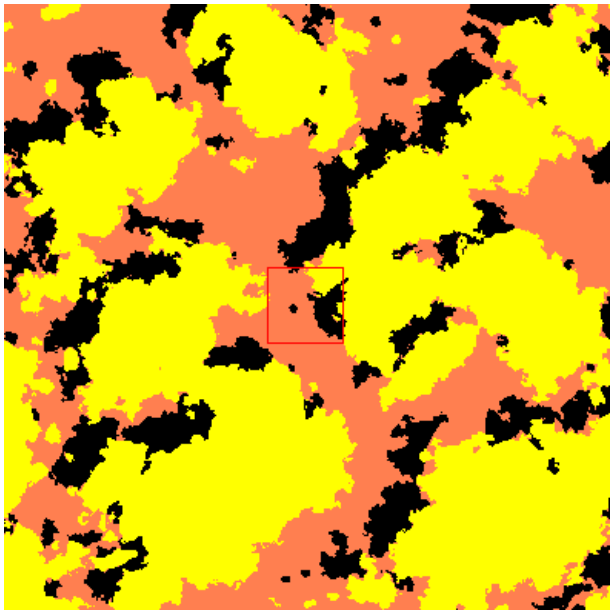

08/10/2000 ETM+

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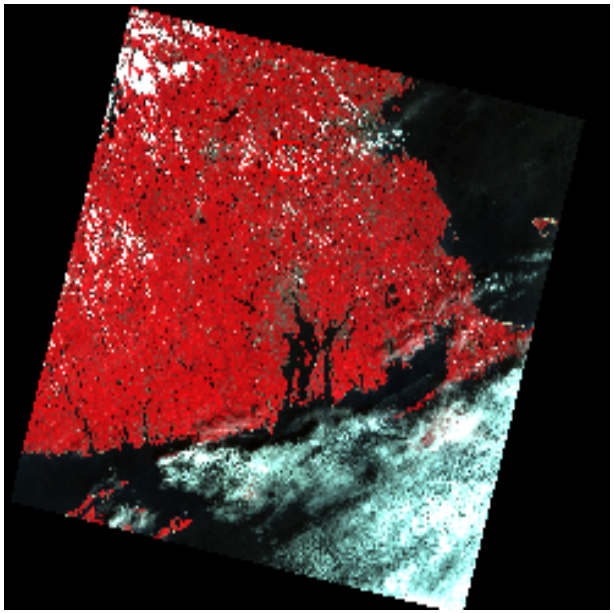

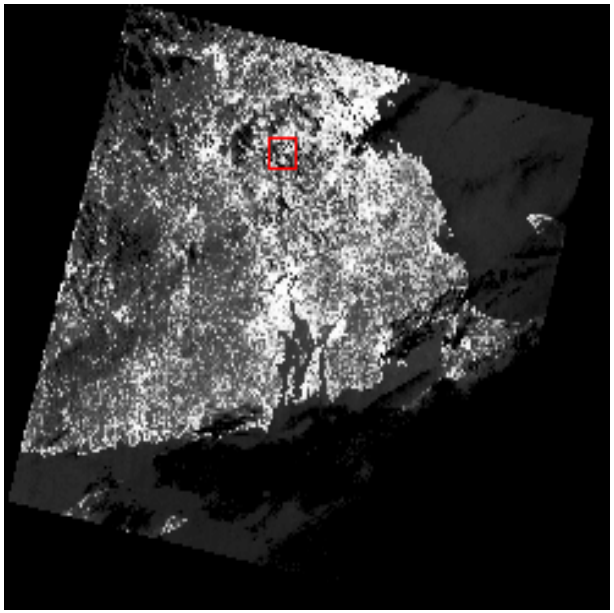

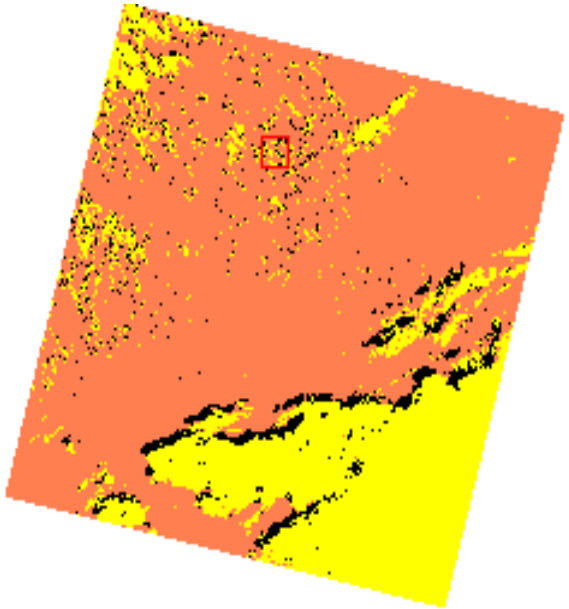

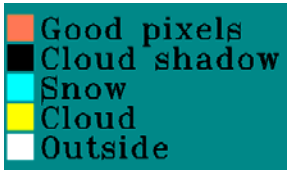

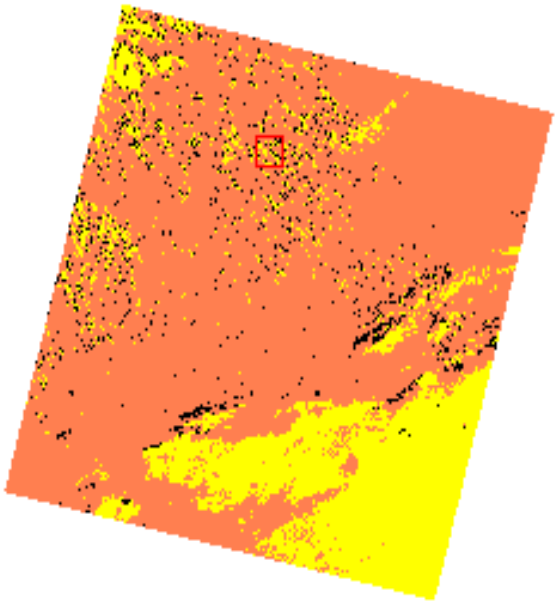

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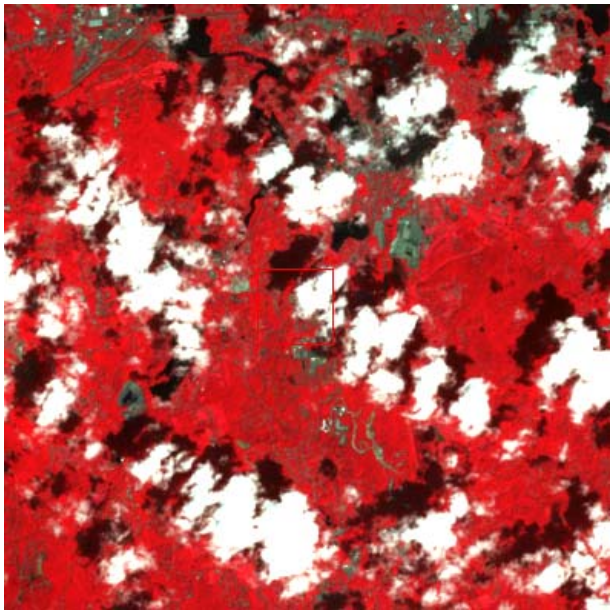

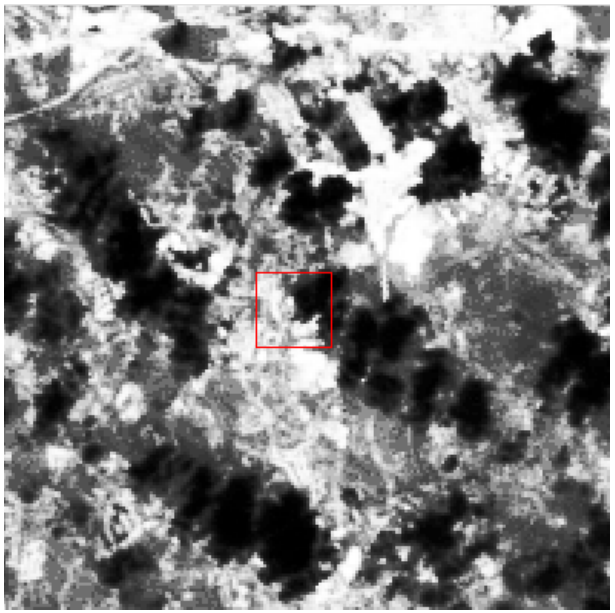

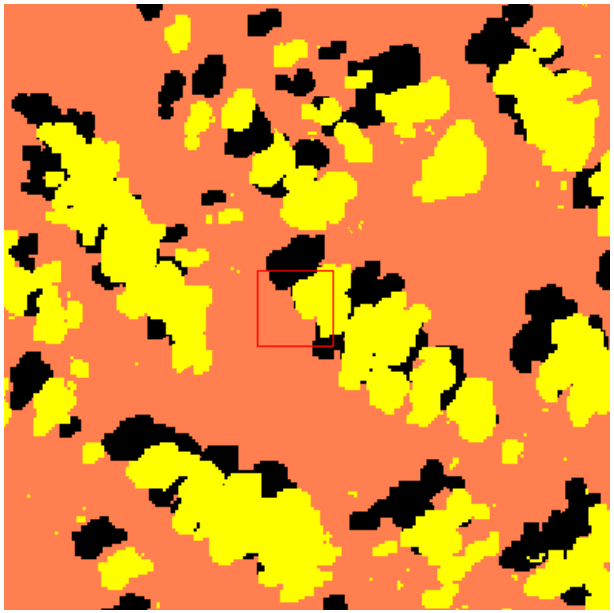

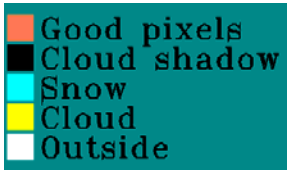

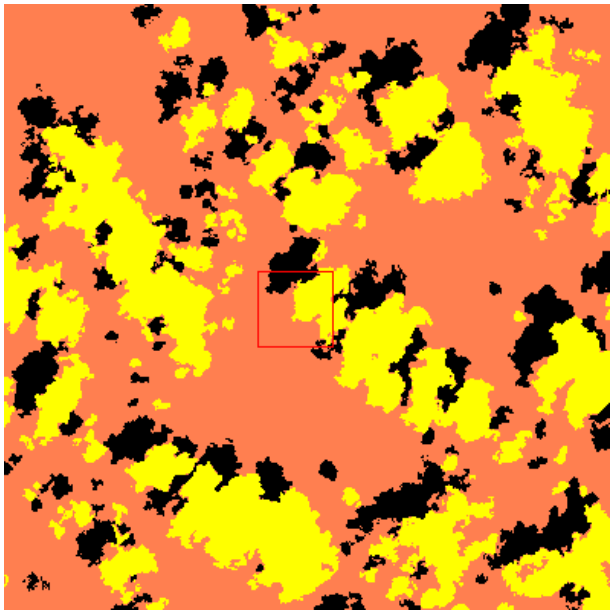

04/07/2001 ETM+

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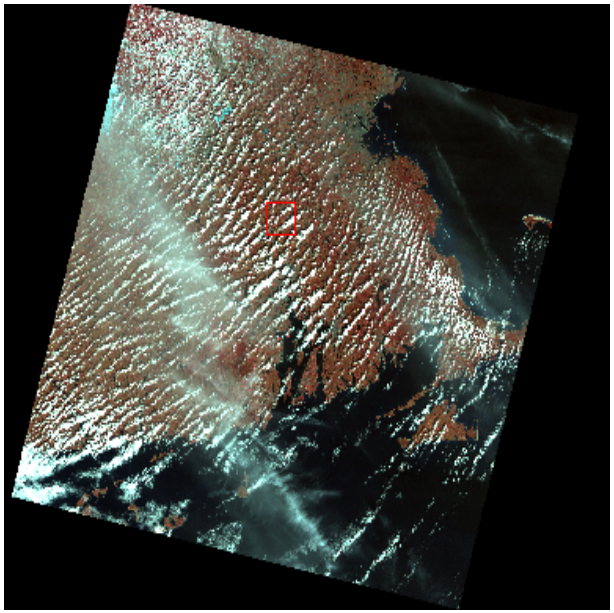

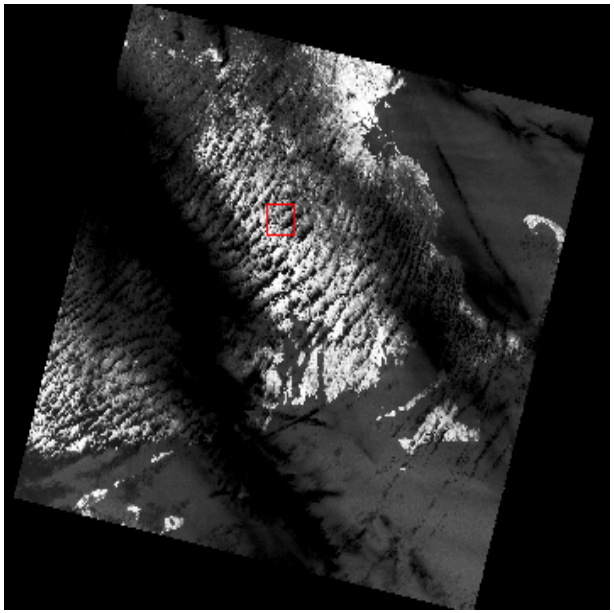

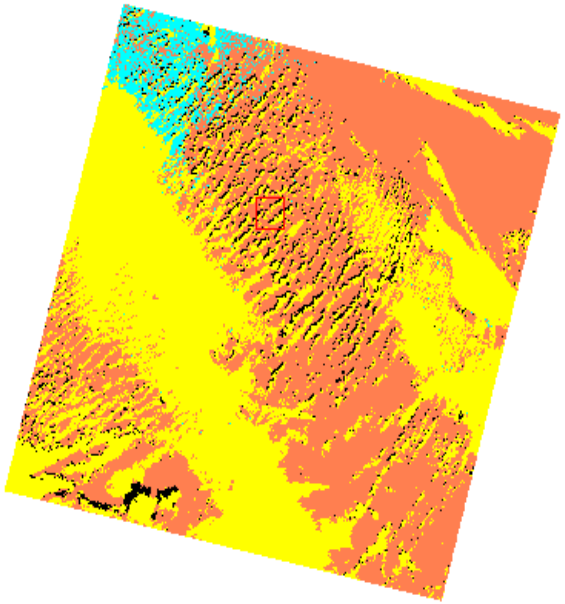

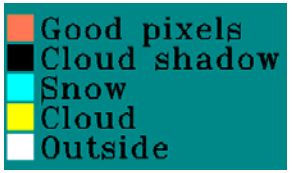

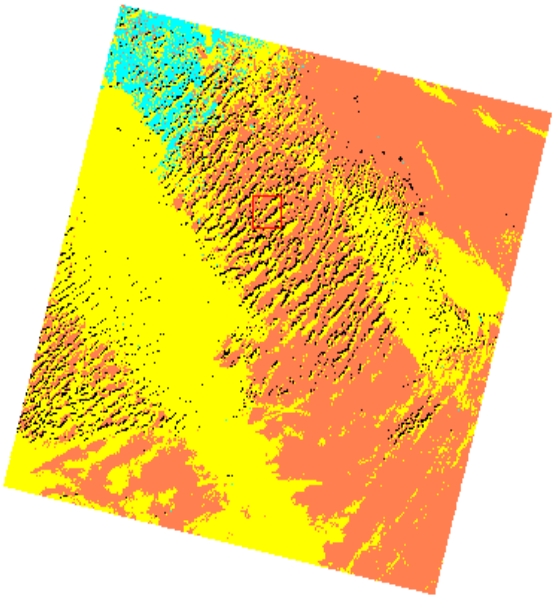

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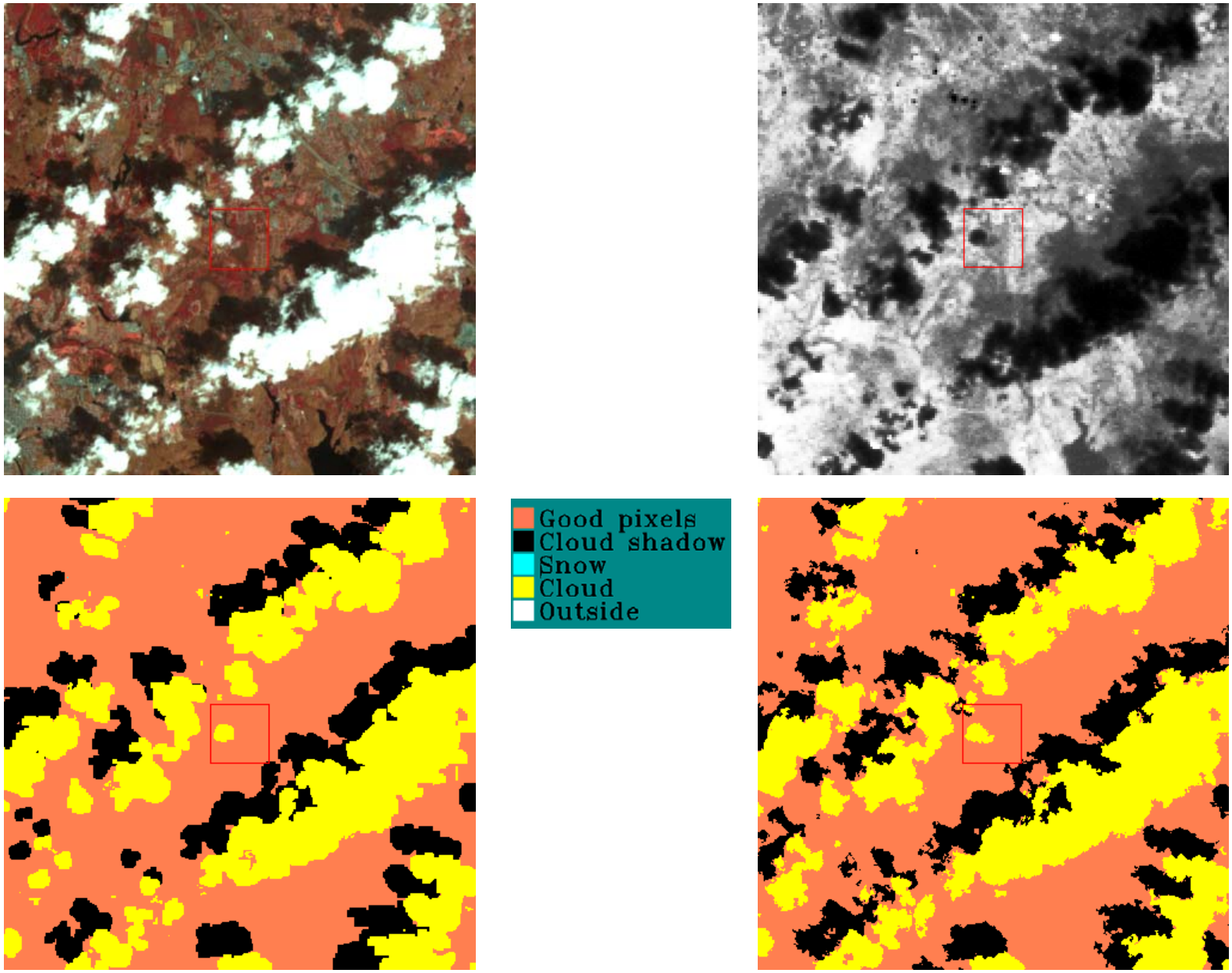

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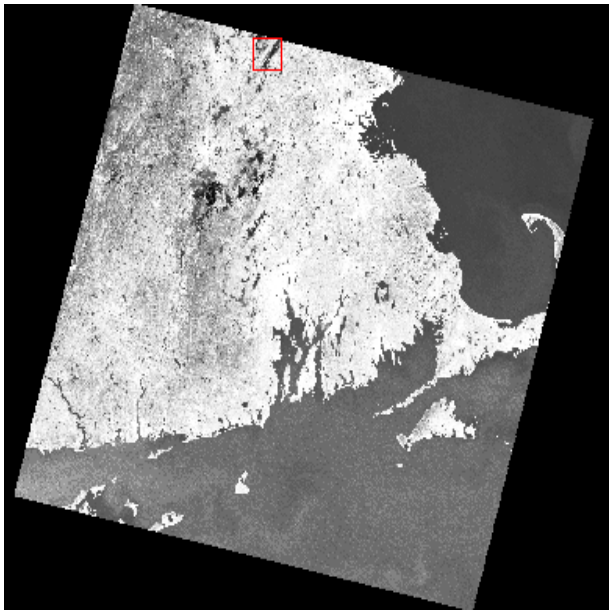

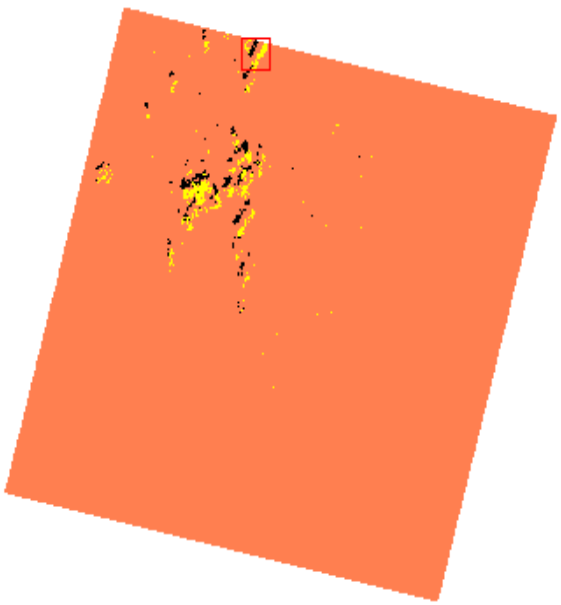

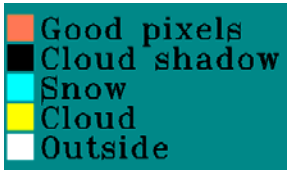

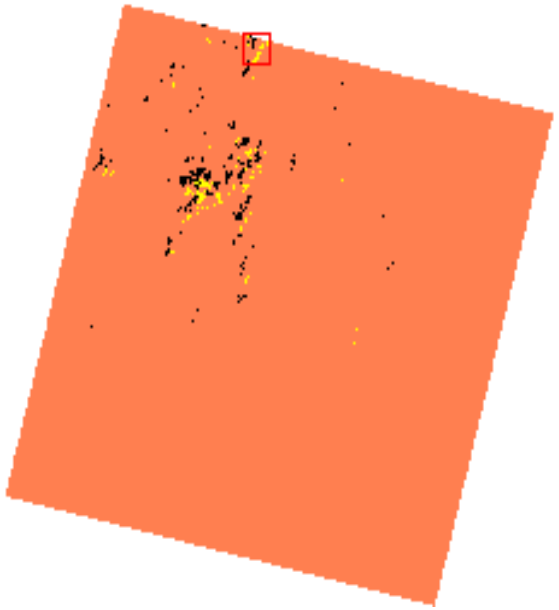

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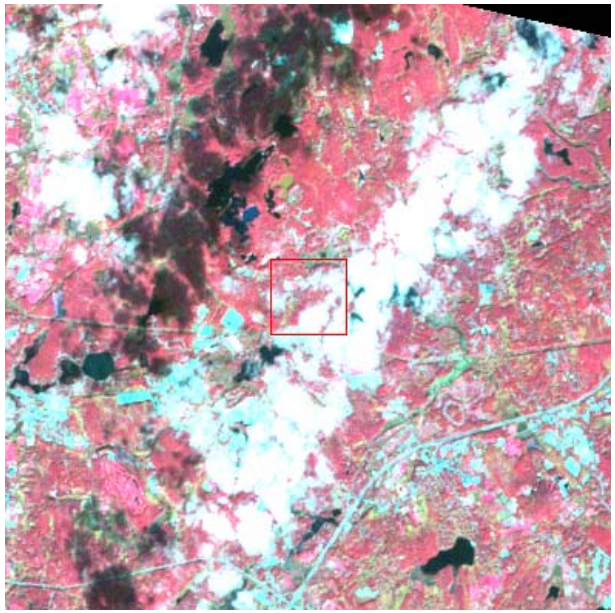

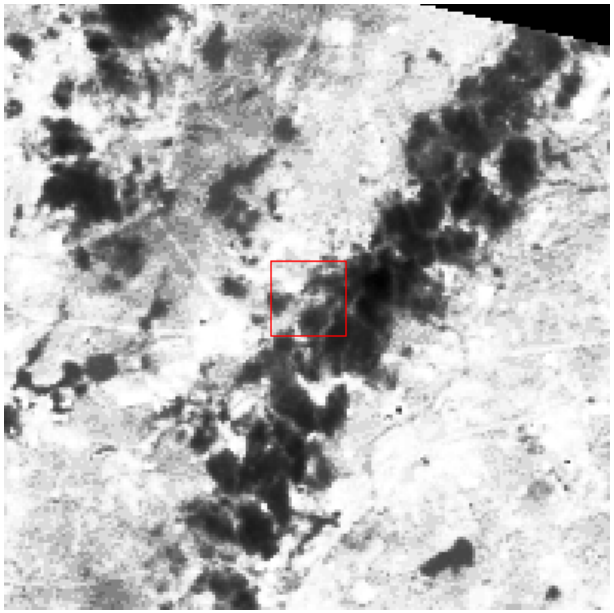

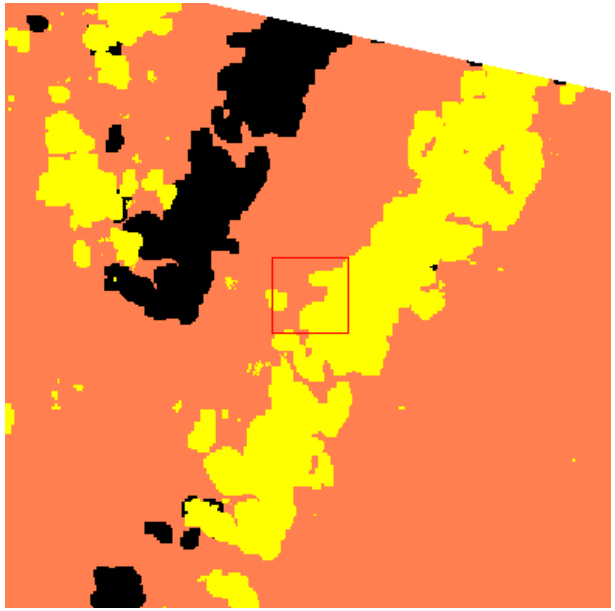

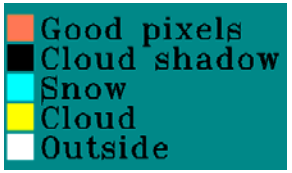

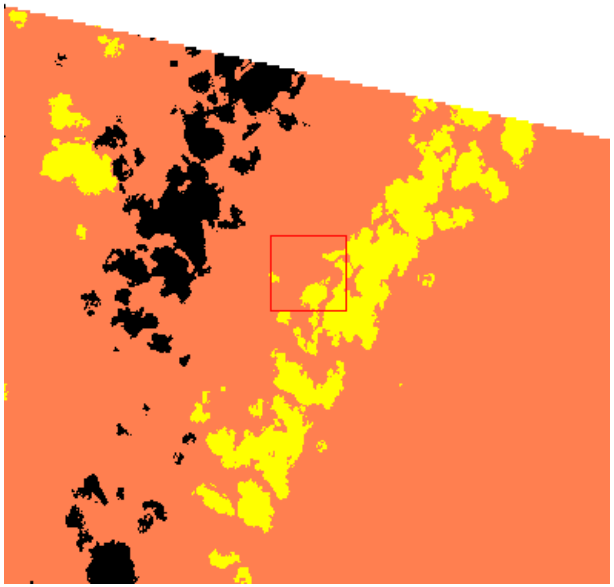

thin clouds & cloud shadows

07/15/2002 ETM+

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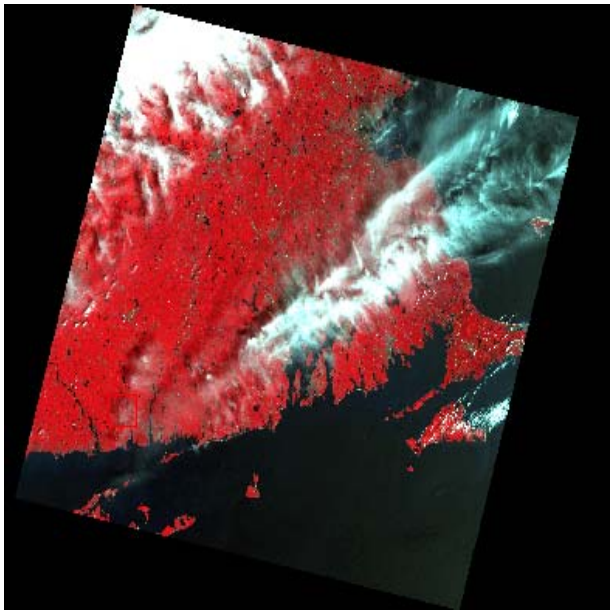

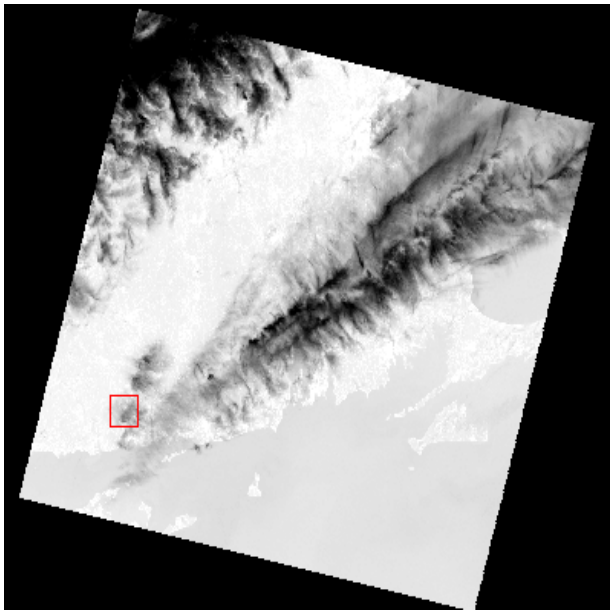

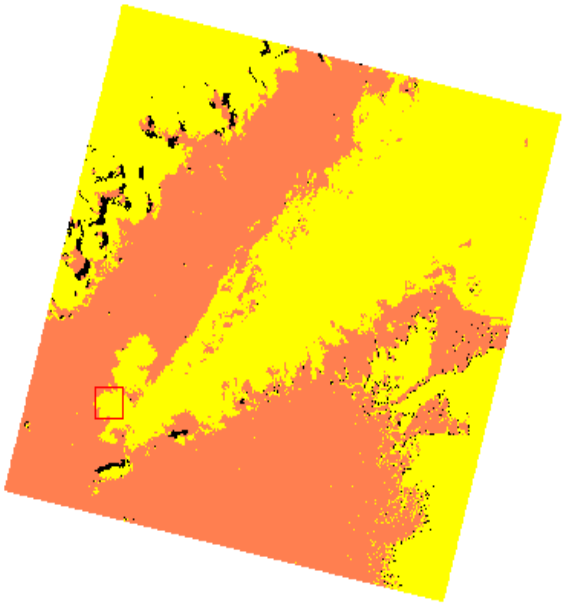

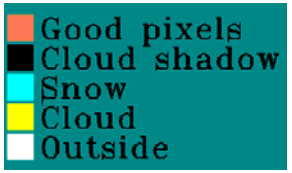

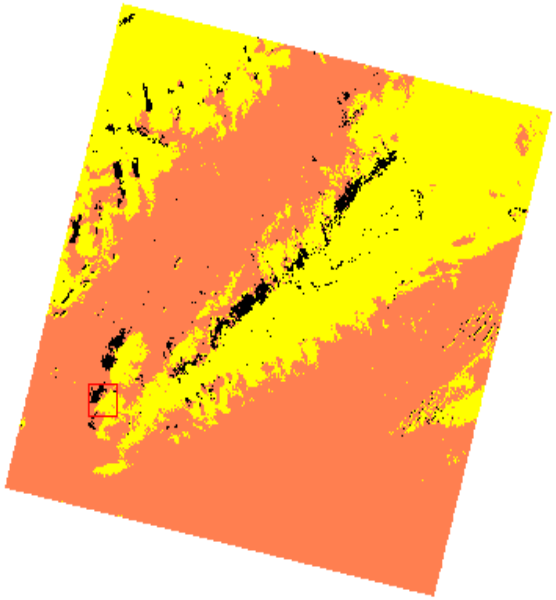

07/15/2002 ETM+

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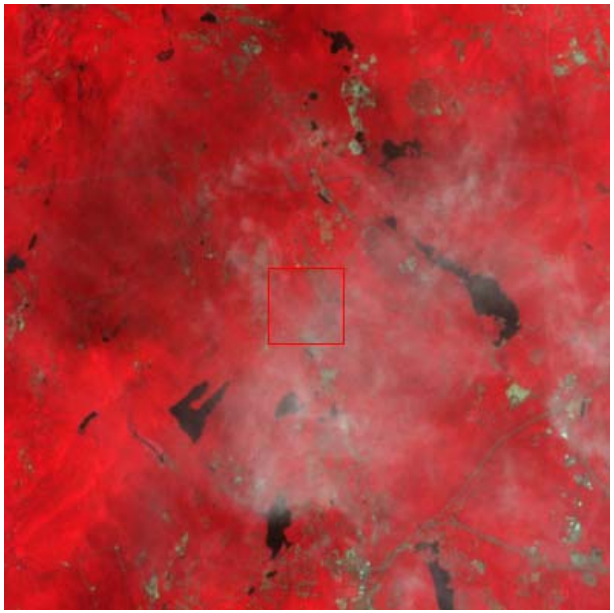
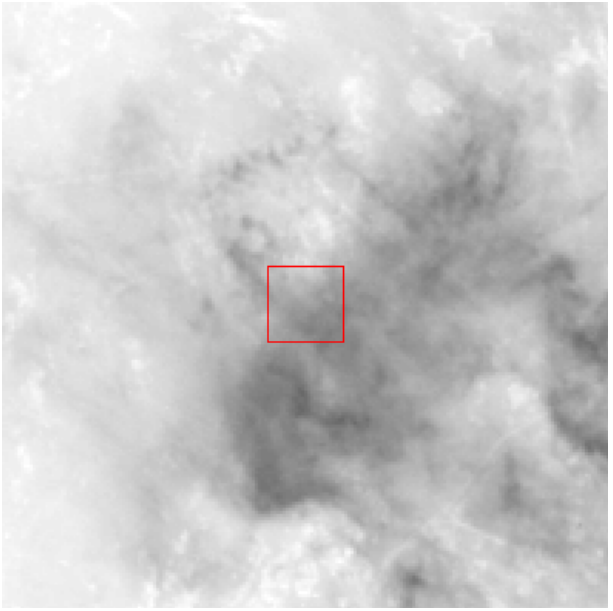
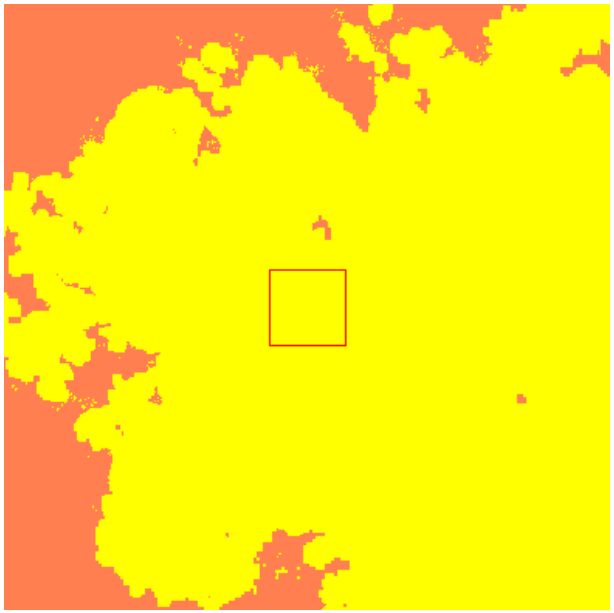
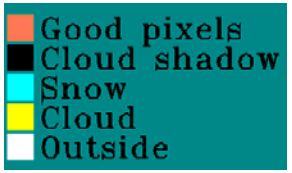
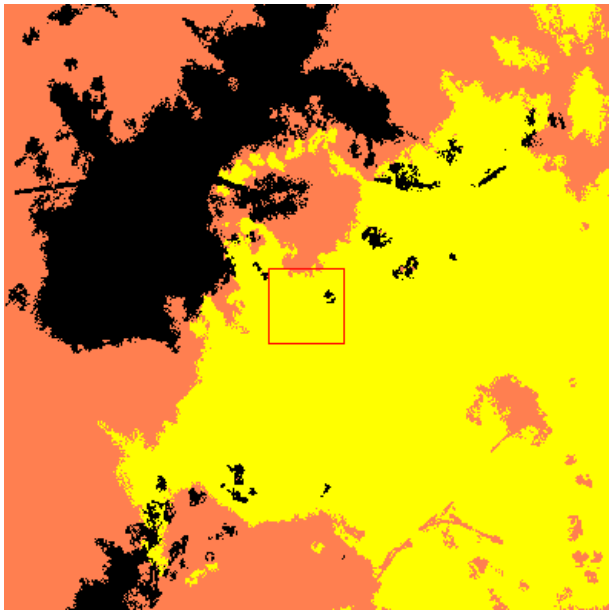




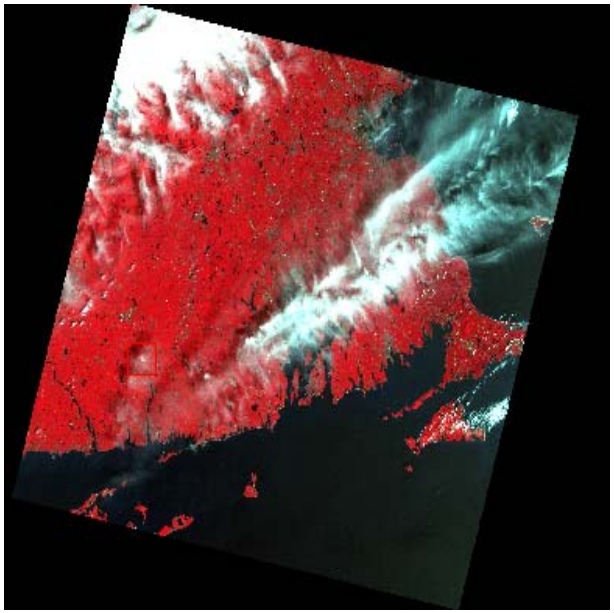


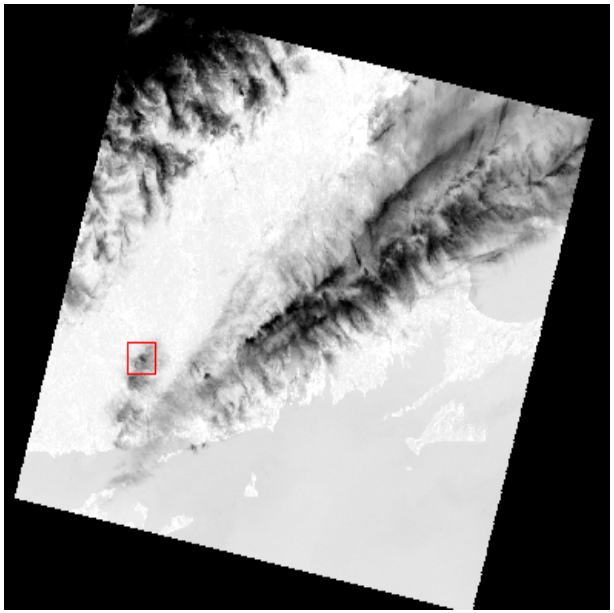


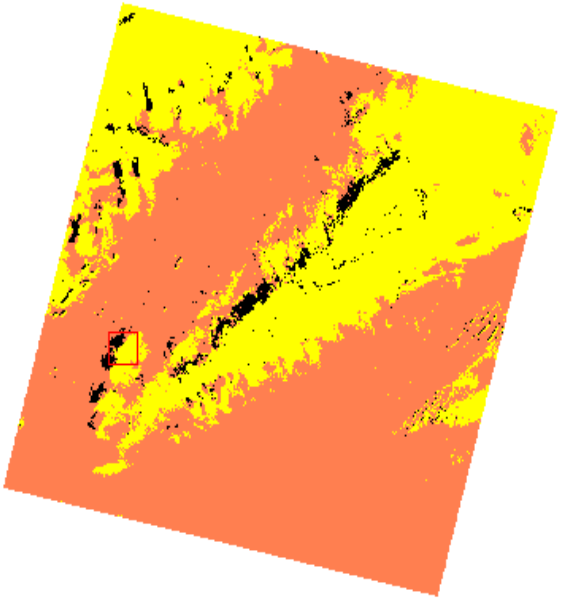


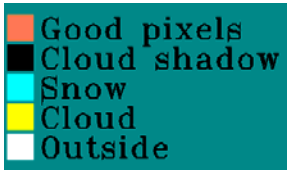
07/15/2002 ETM+

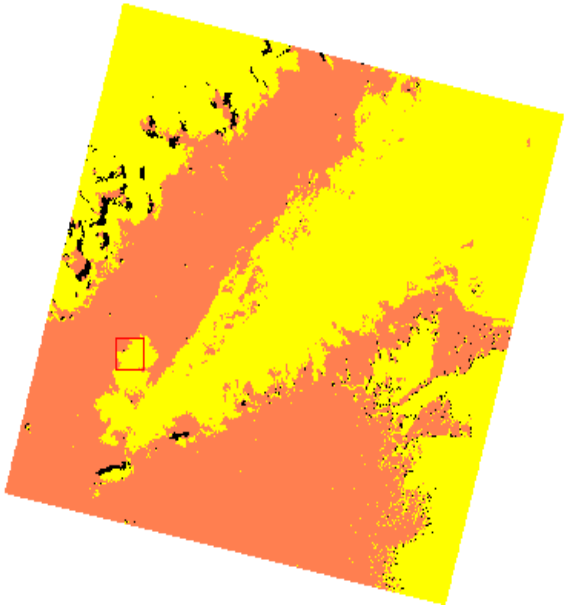
upper-left: RGB(432) composite
lower-left: fmask results
upper-right: thermal band
lower-right: multi-temporal results











07/15/2002 ETM+

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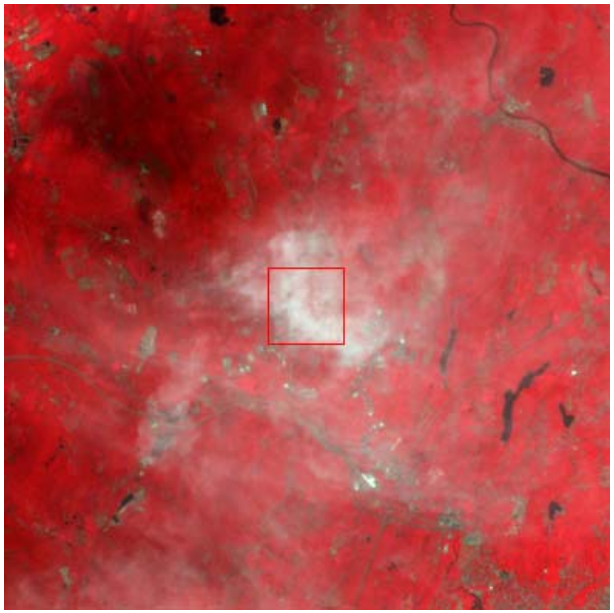
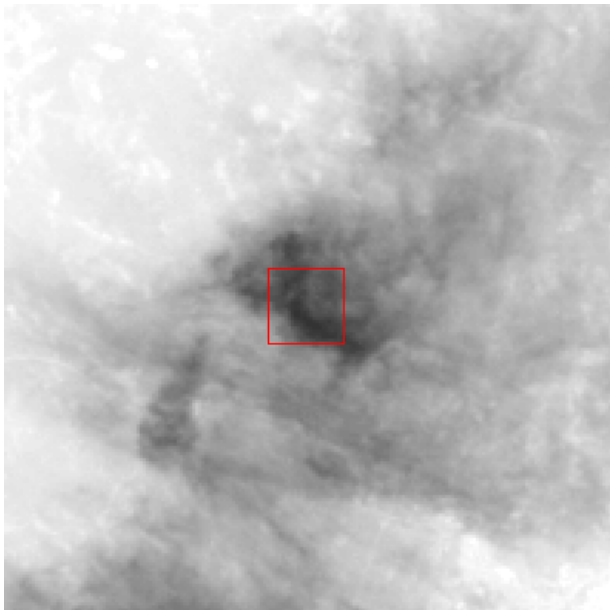
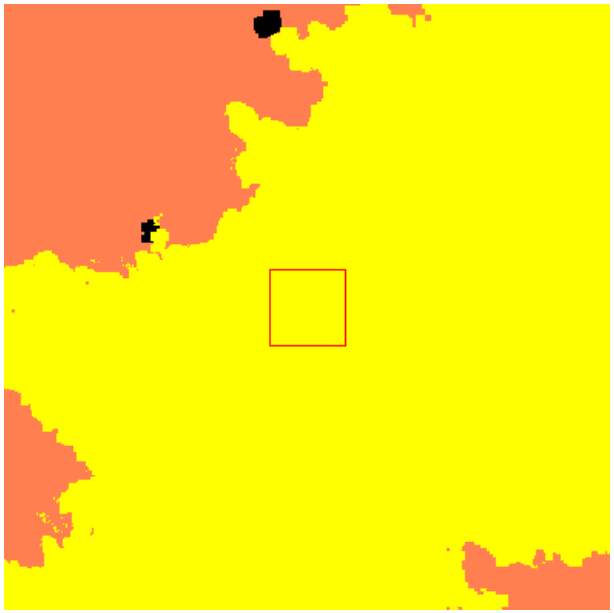
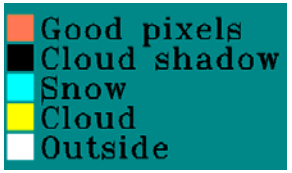
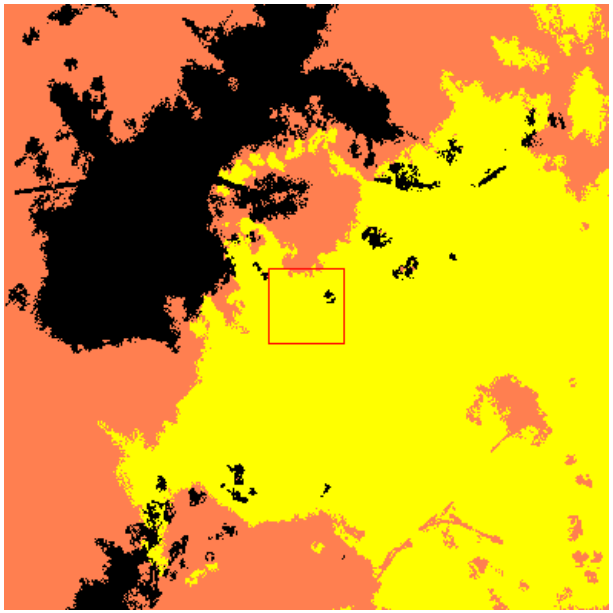
lower-left: fmask results
lower-right: multi-temporal results





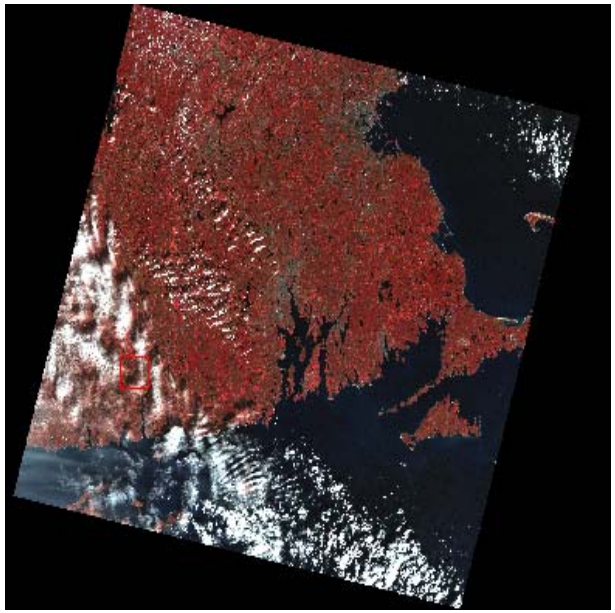


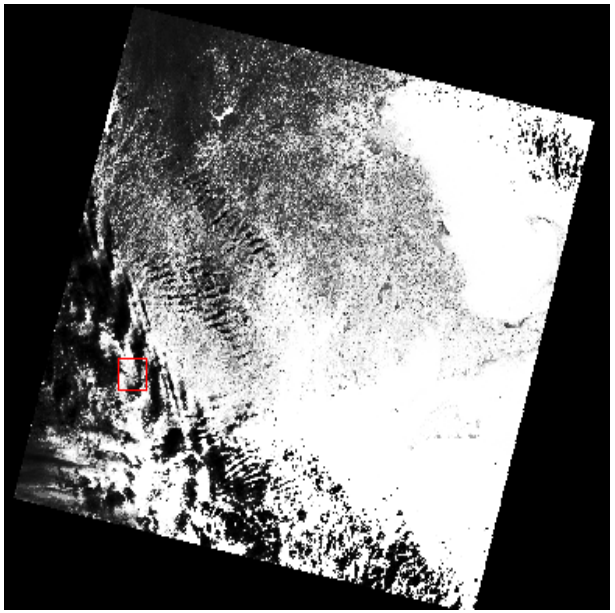


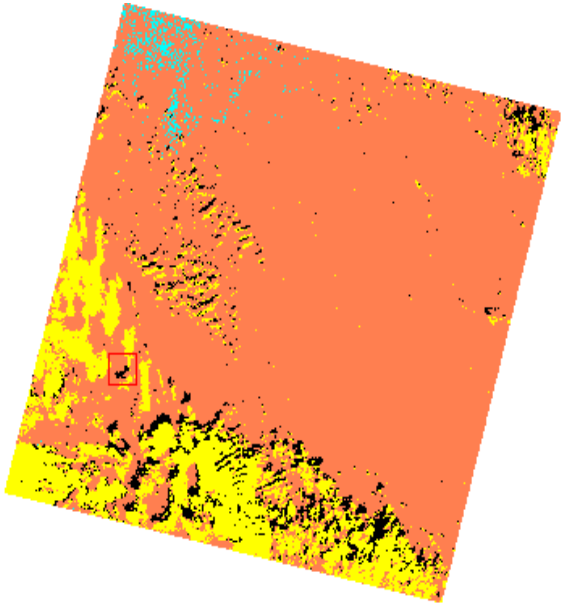


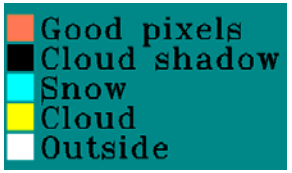
12/19/2001 ETM+

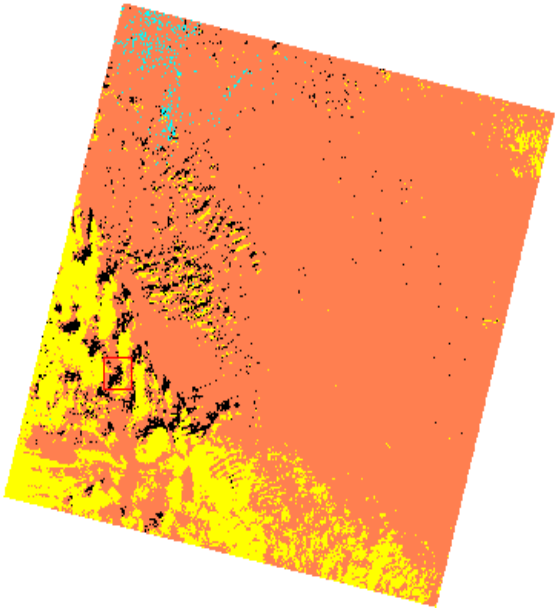
upper-left: RGB(432) composite
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results











12/19/2001 ETM+

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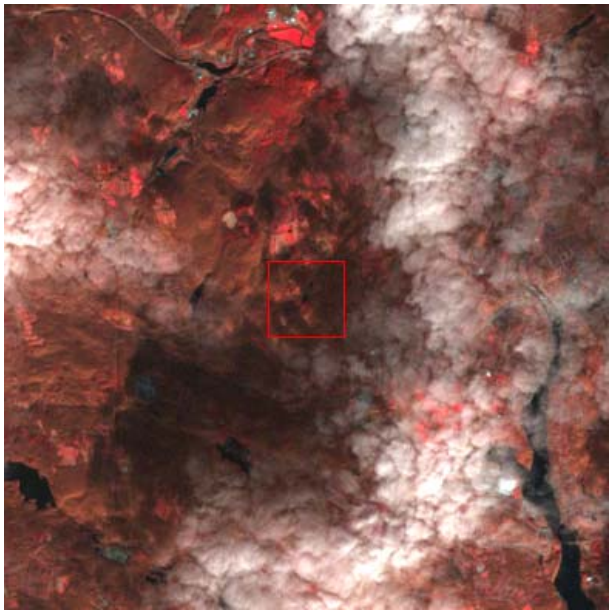

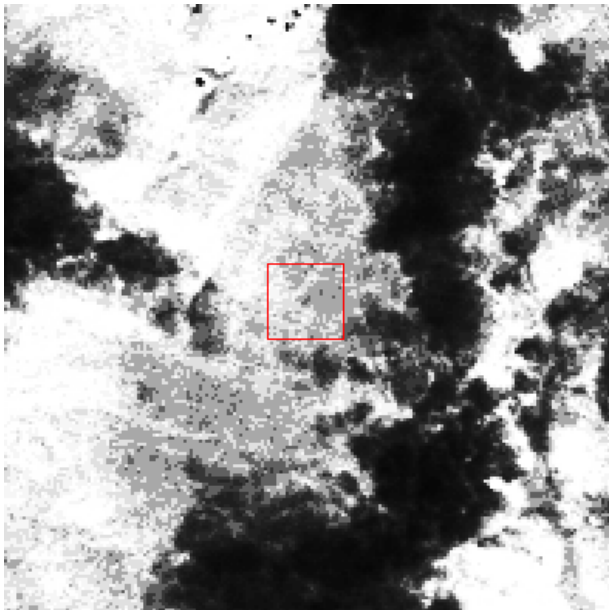

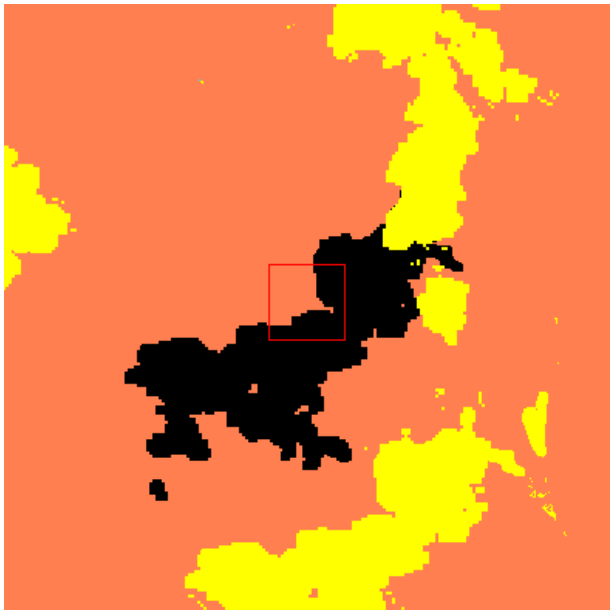

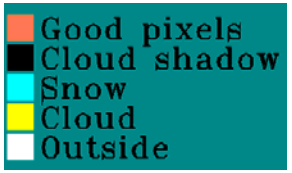

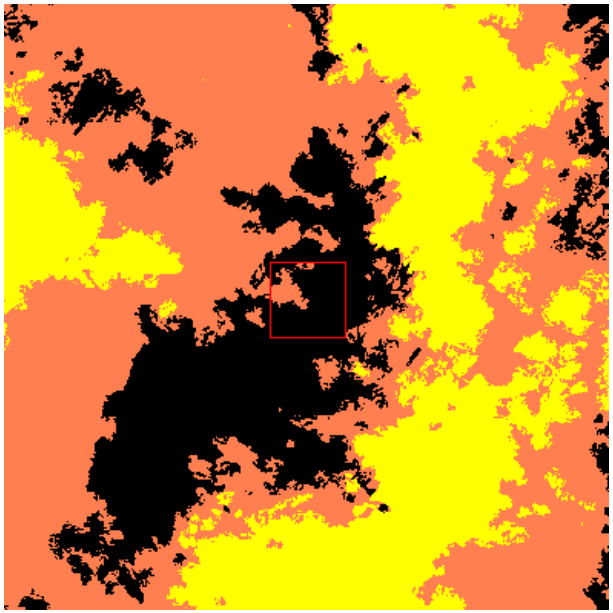

11/01/2001 ETM+

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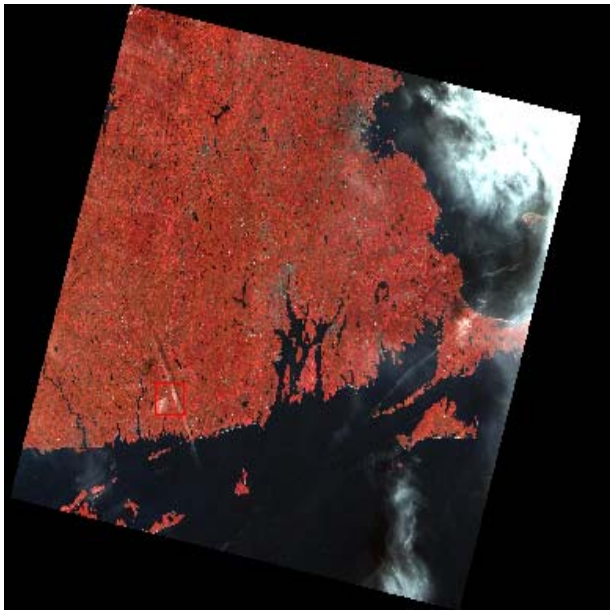
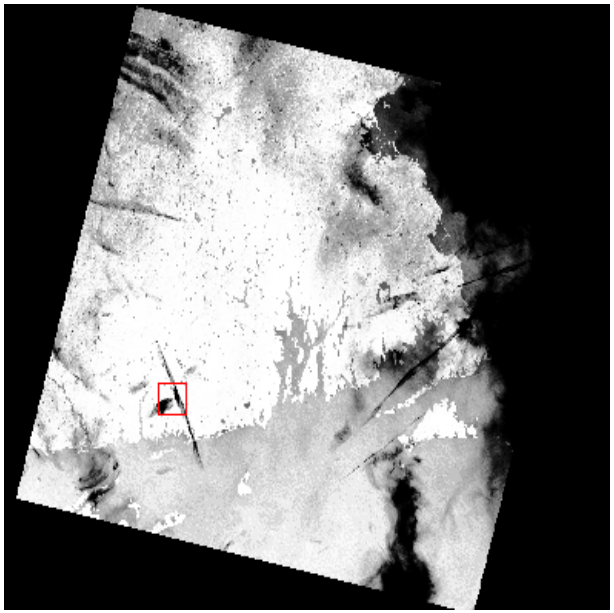
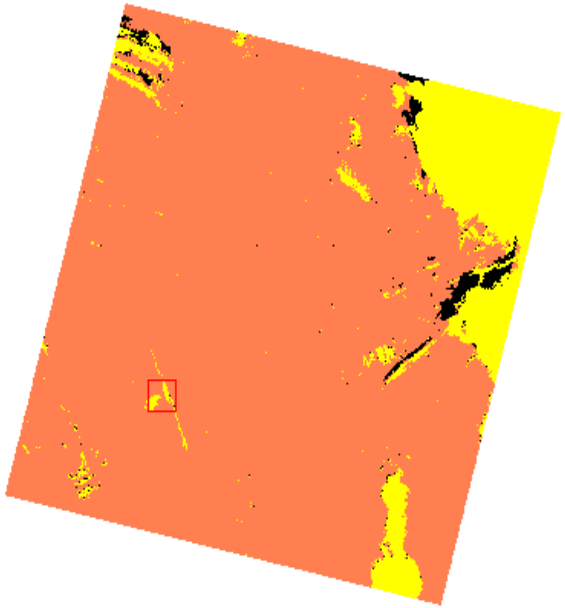
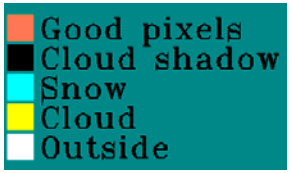
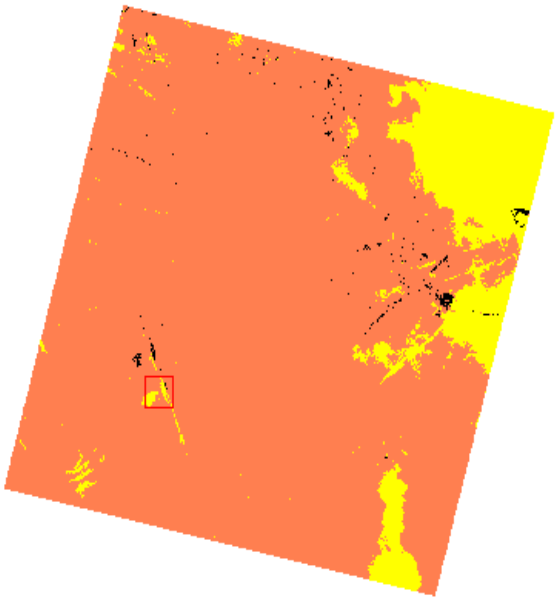
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results











11/01/2001 ETM+

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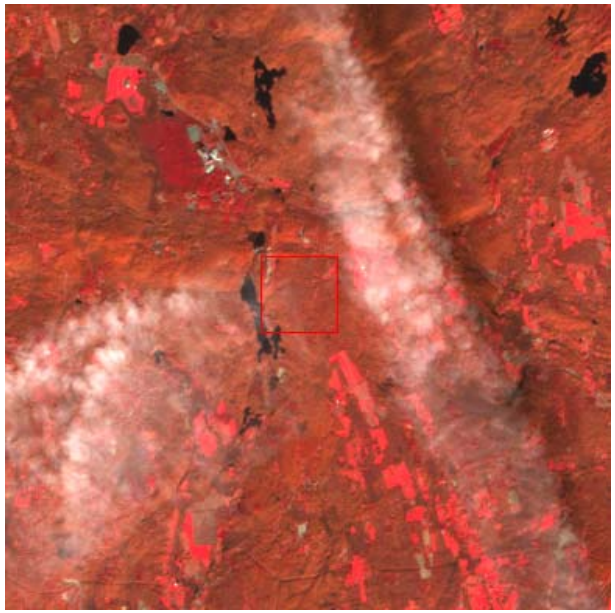
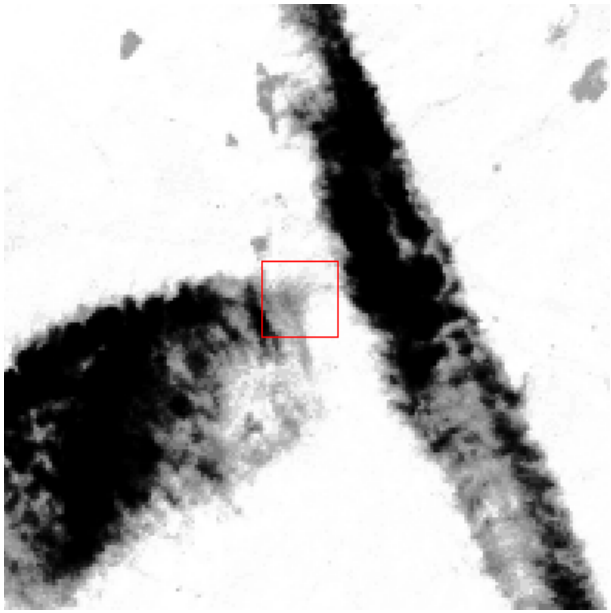
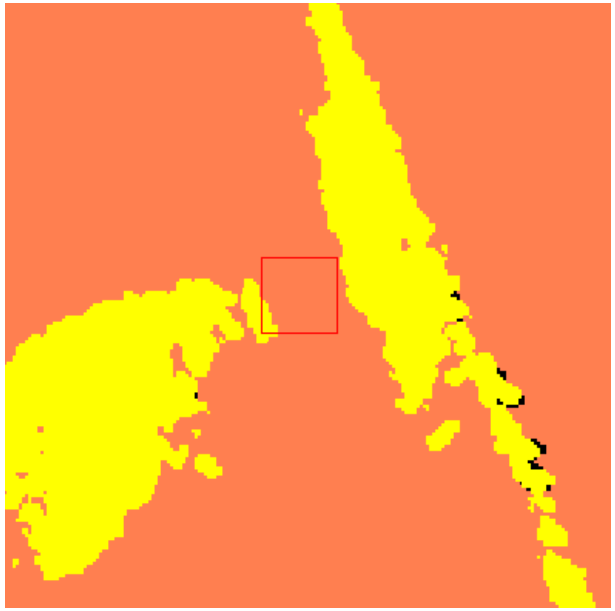
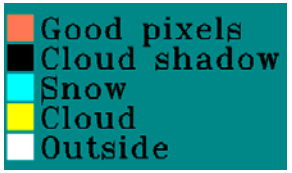
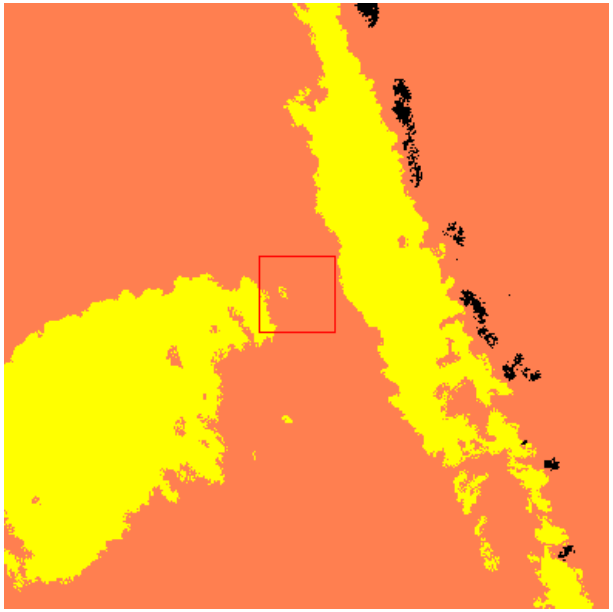
lower-left: fmask results
lower-right: multi-temporal results







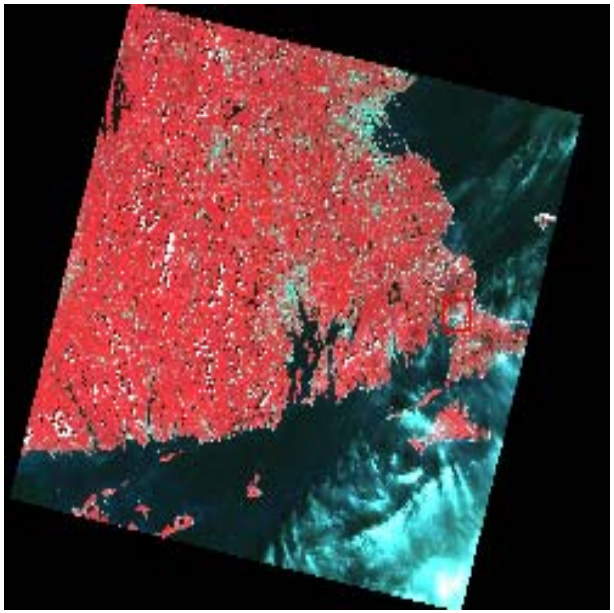


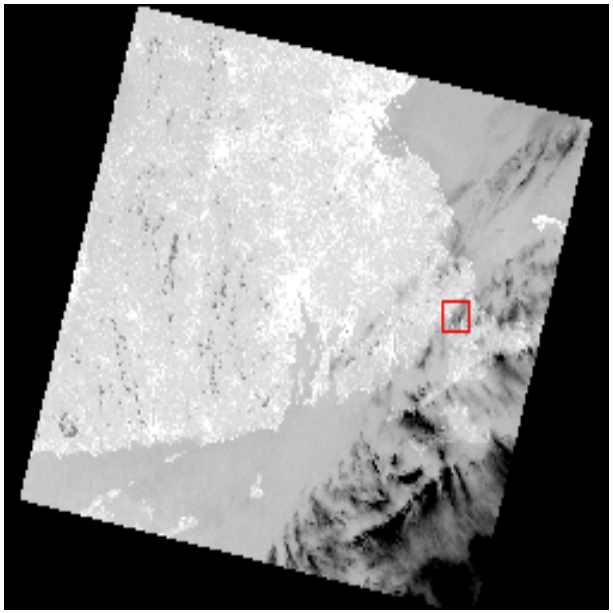


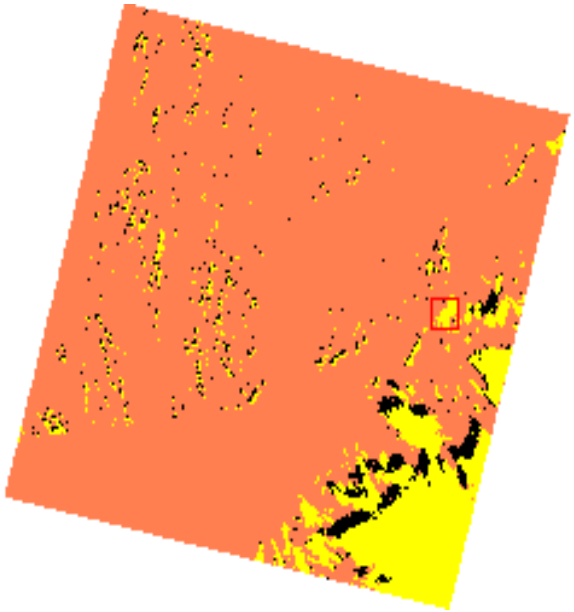
hardly seen clouds or haze

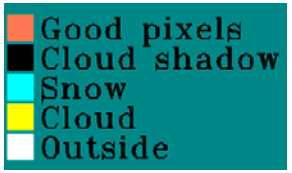
08/26/2000 ETM+

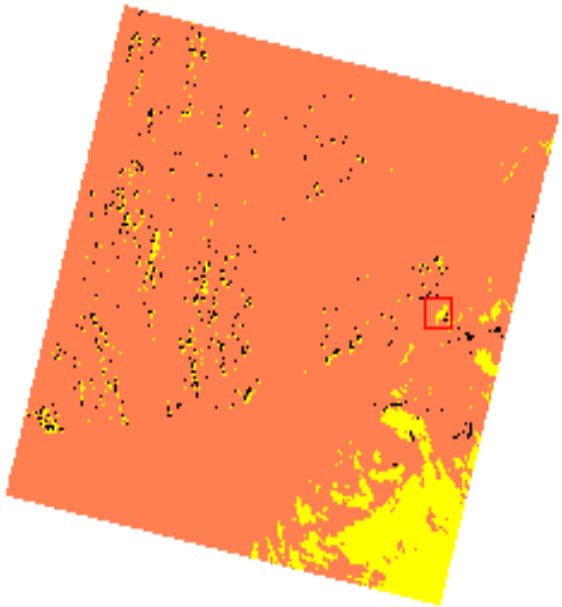
upper-left: RGB(432) composite
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results











08/26/2000 ETM+

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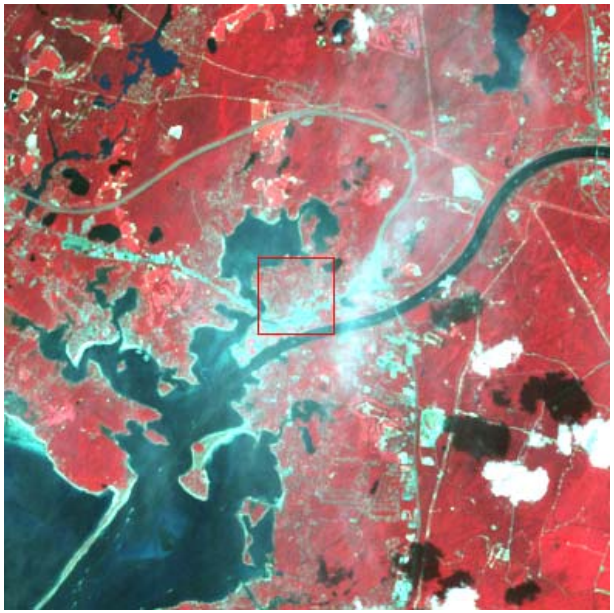
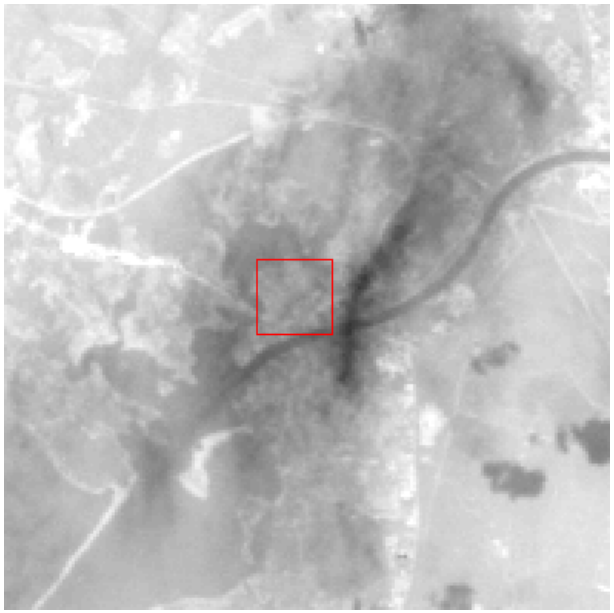
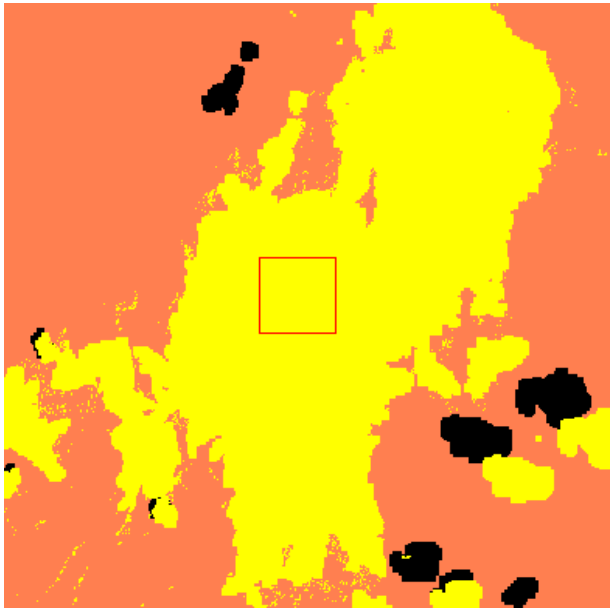
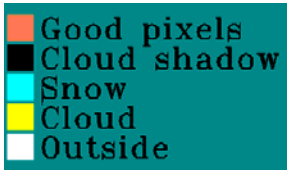
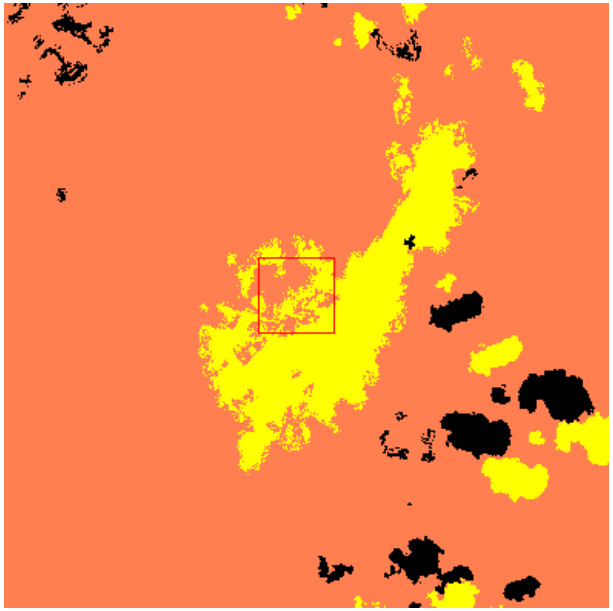
lower-right: multi-temporal results











09/11/2000 ETM+

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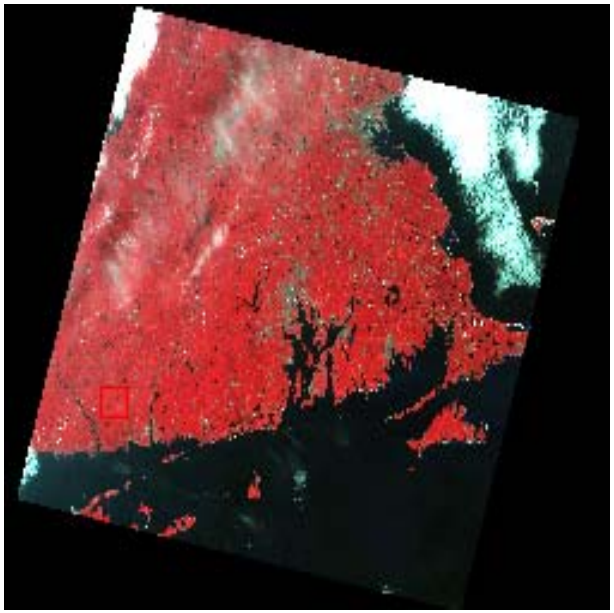
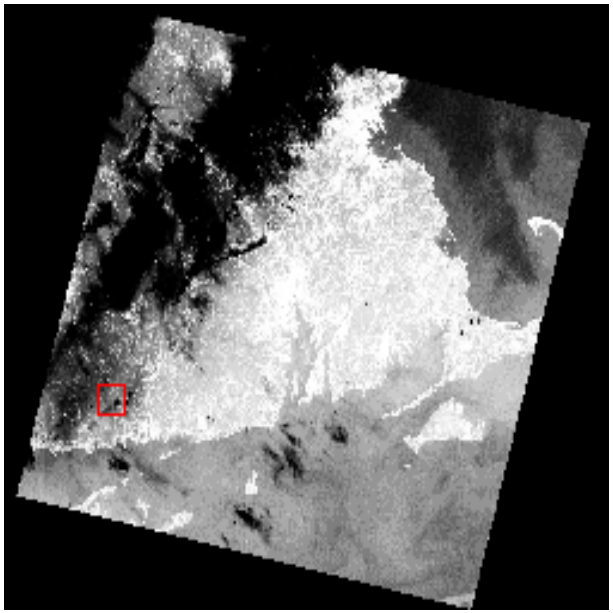
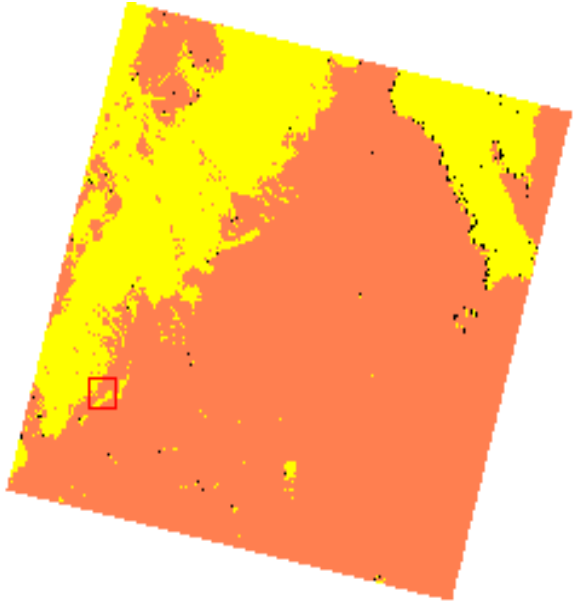
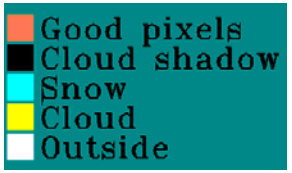
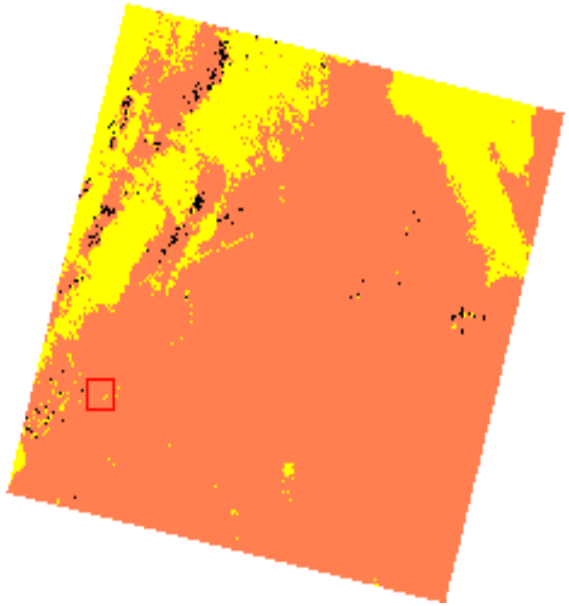
lower-left: fmask results
lower-right: multi-temporal results











09/11/2000 ETM+

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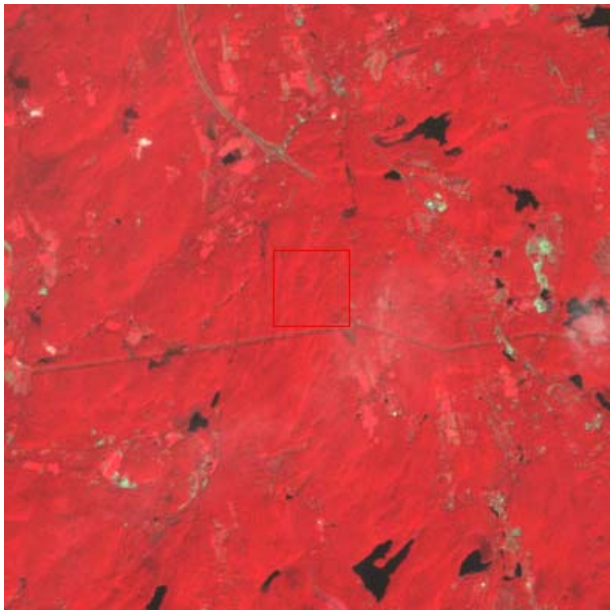

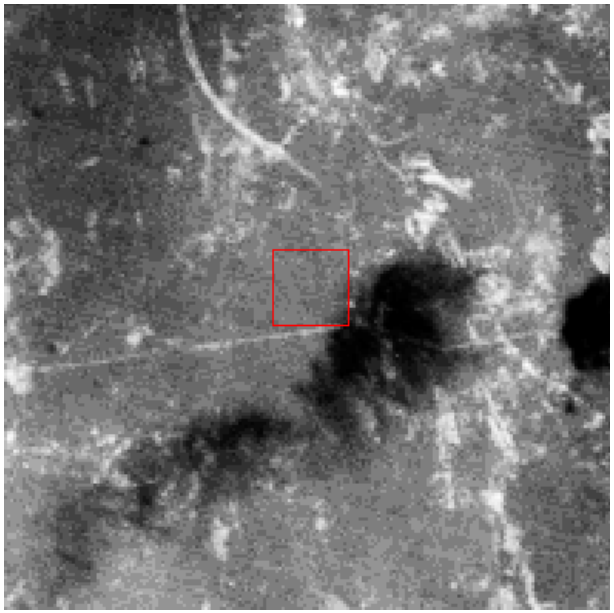

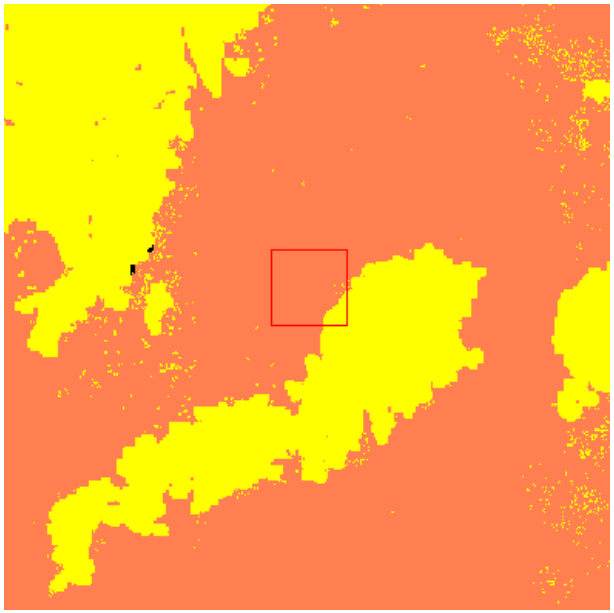

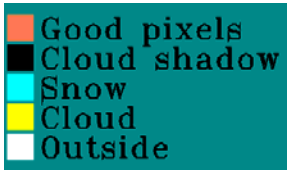

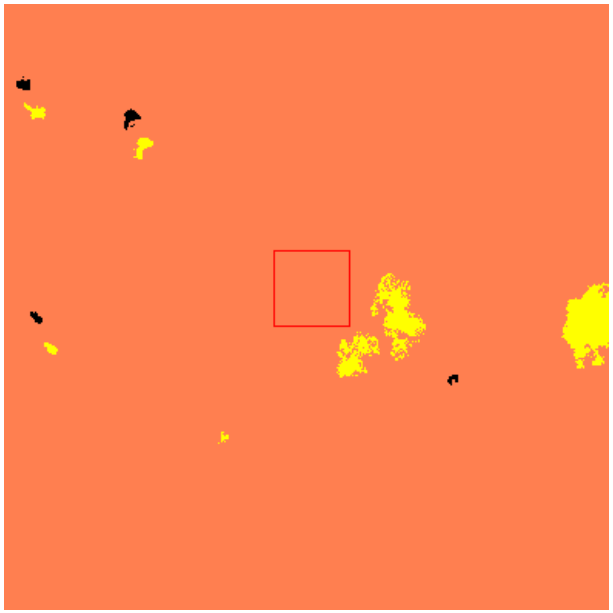

07/28/2001 ETM+

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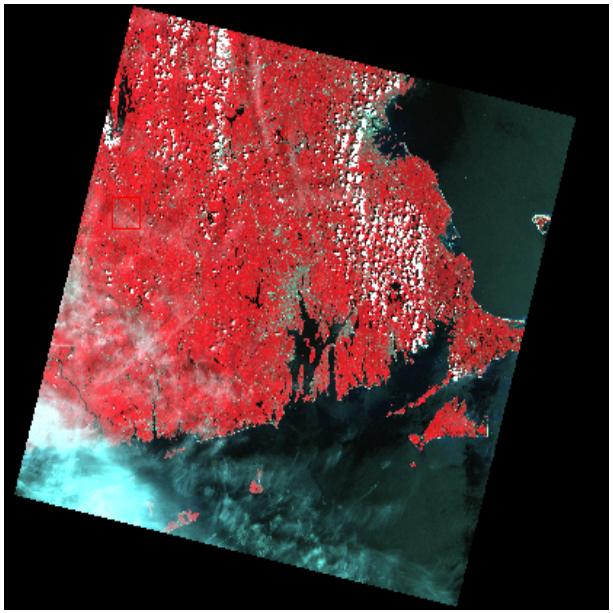
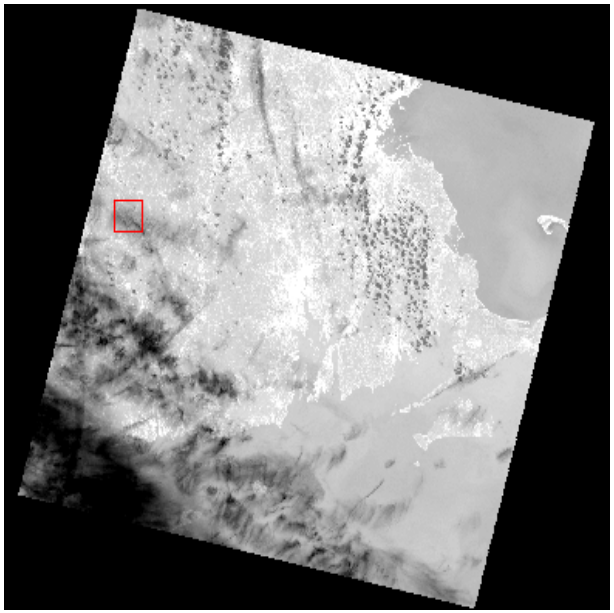
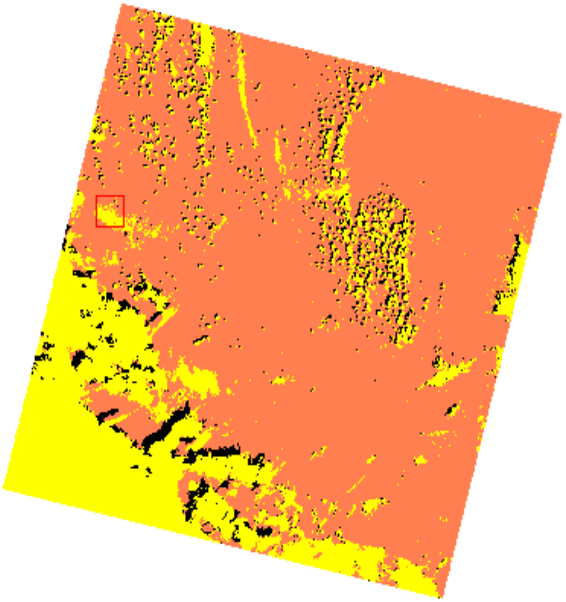
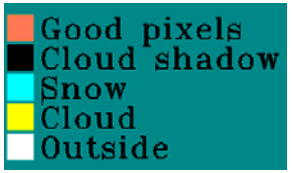
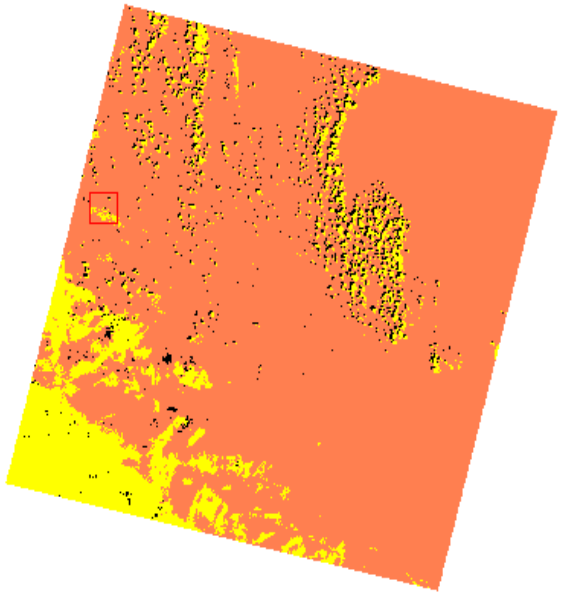
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results











07/28/2001 ETM+

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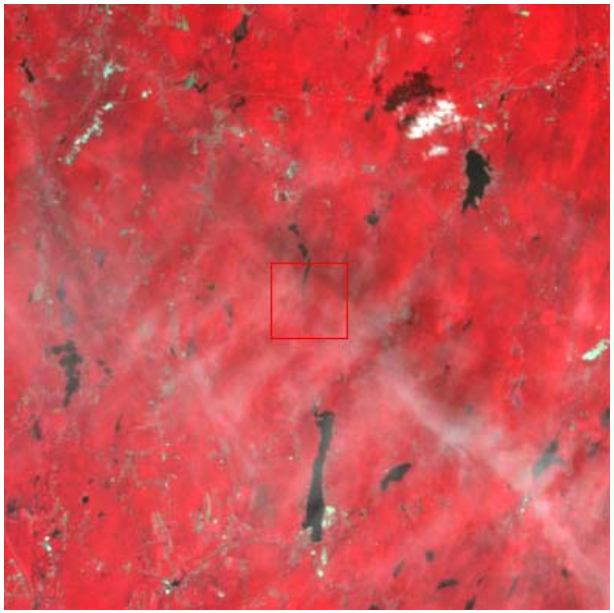
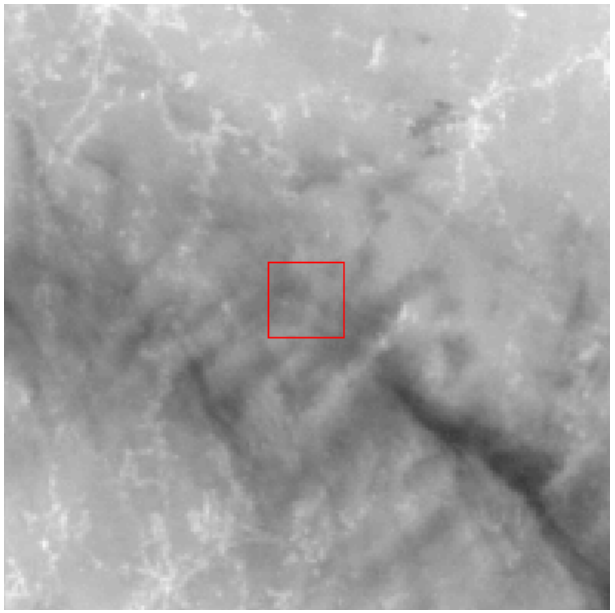
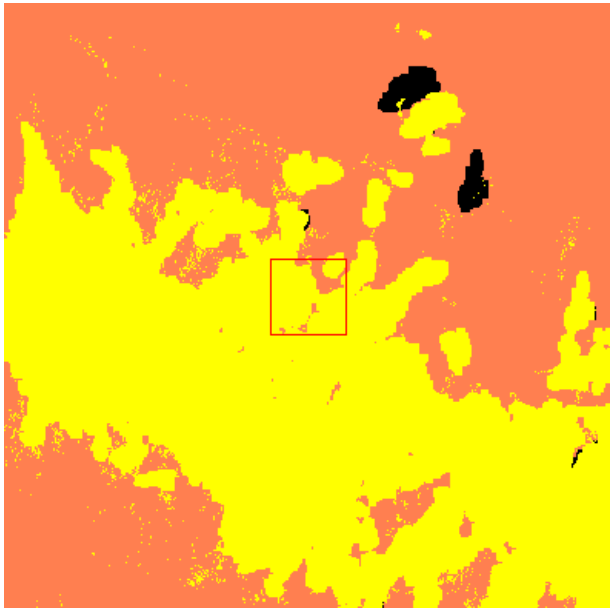
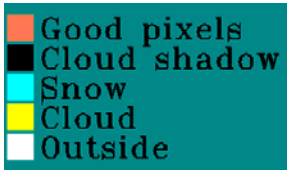
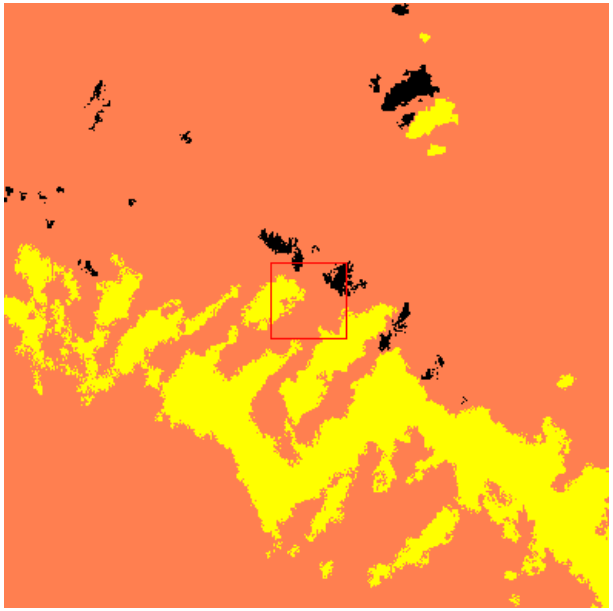
lower-left: fmask results
lower-right: multi-temporal results





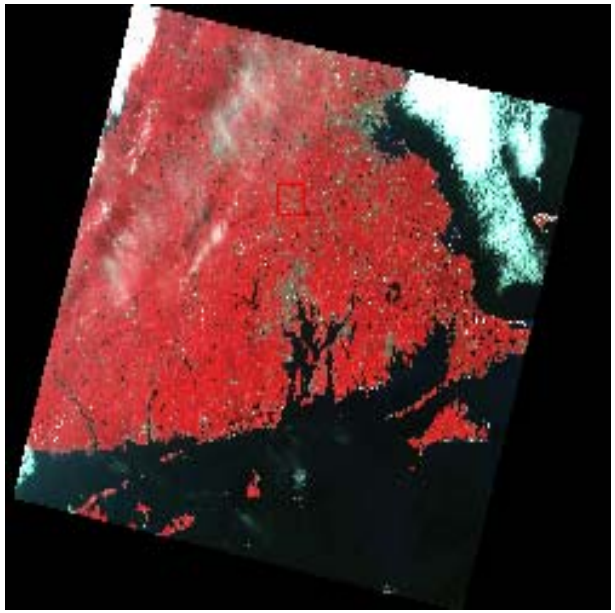


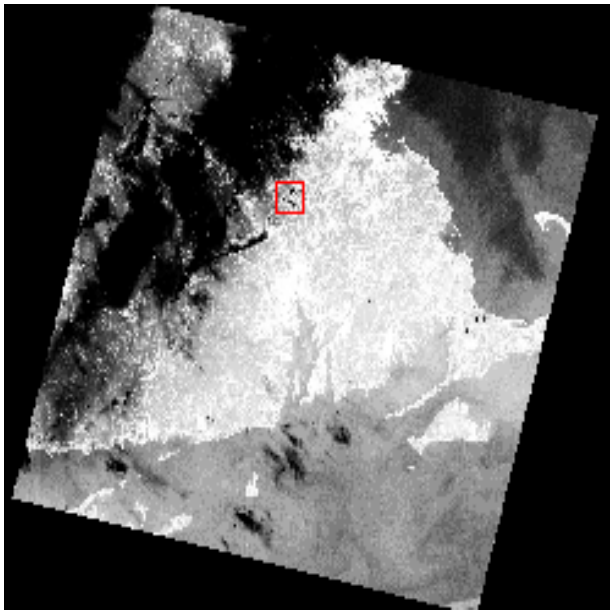


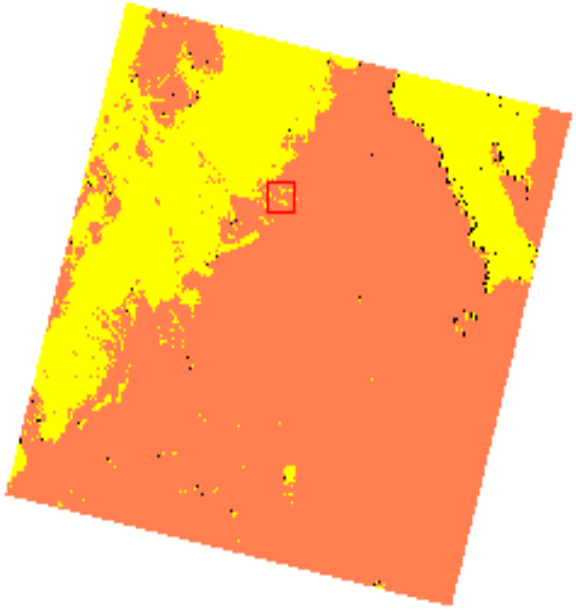


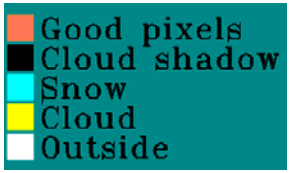
09/11/2000 ETM+

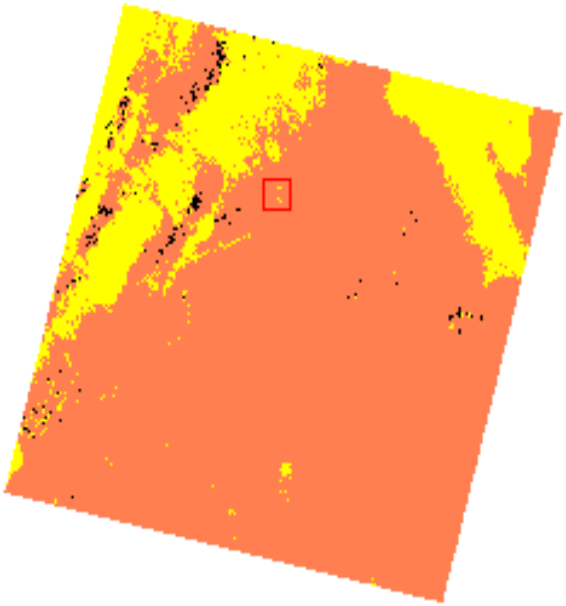
upper-left: RGB(432) composite
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results





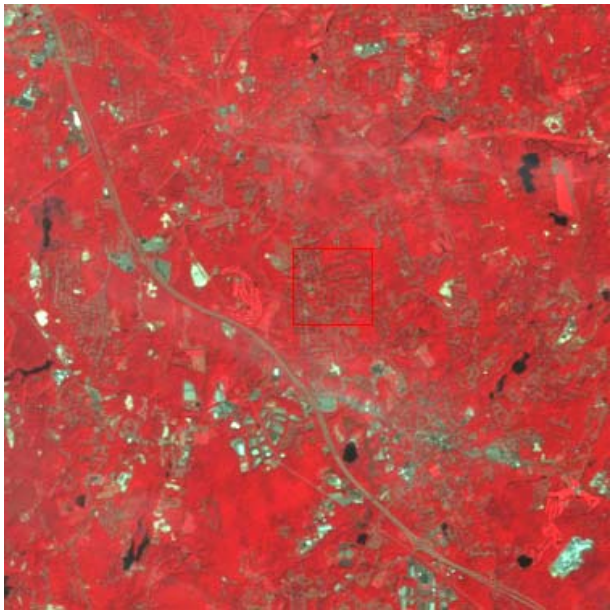


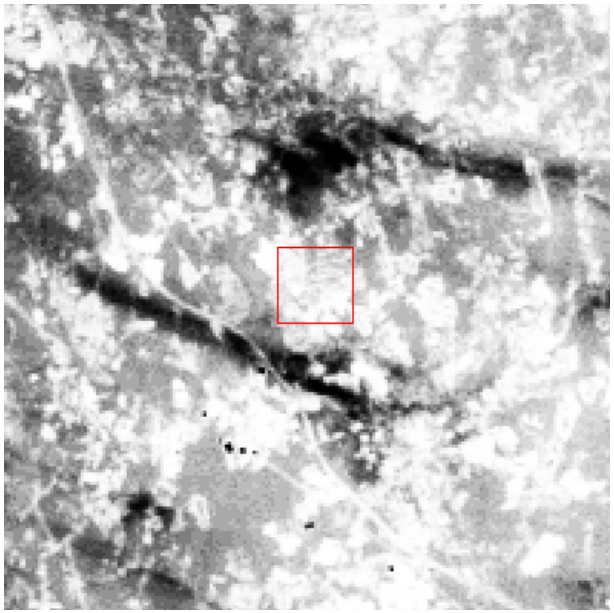


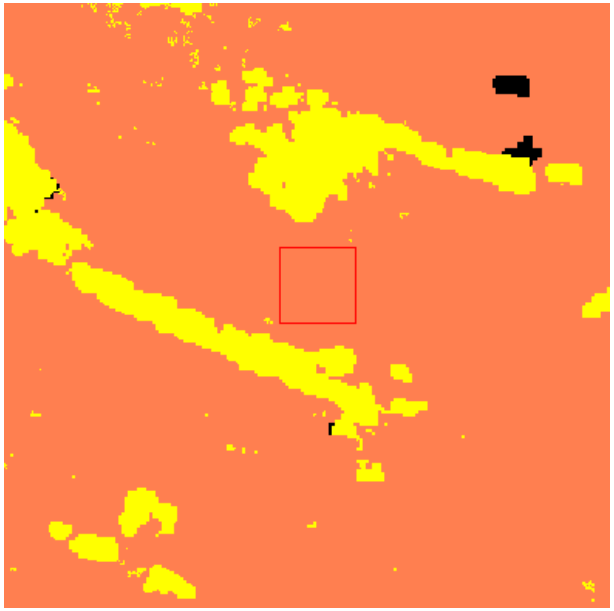


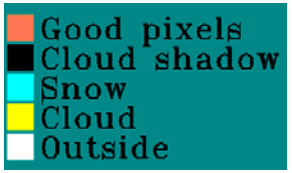
09/11/2000 ETM+

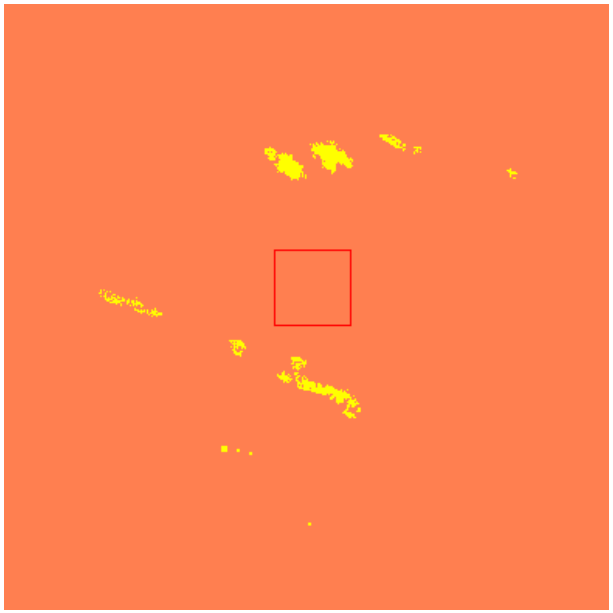
upper-left: RGB(432) composite
upper-right: thermal band
lower-left: fmask results
lower-right: multi-temporal results



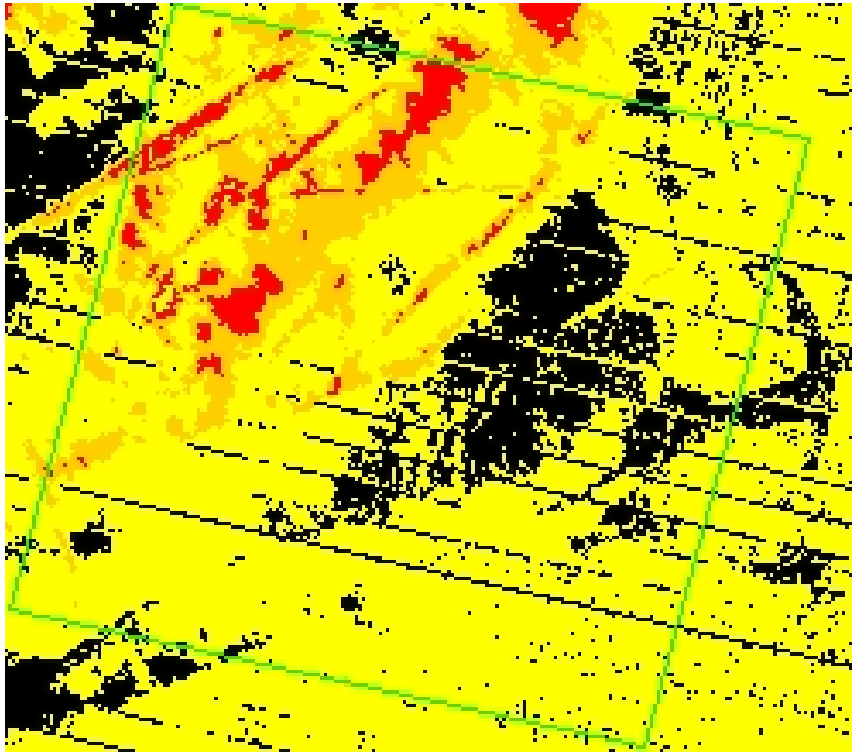


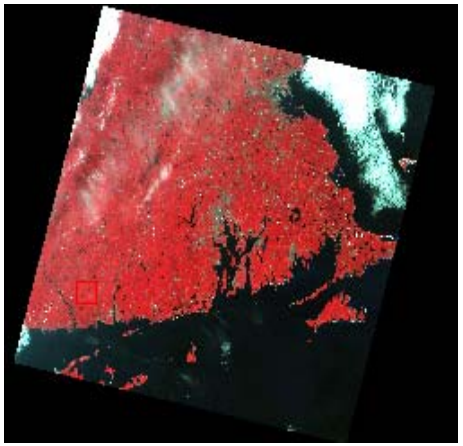




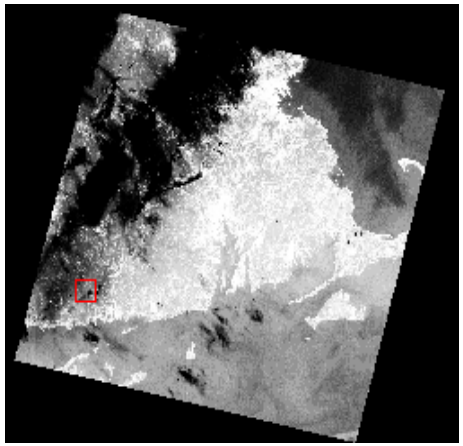


MODIS Cirrus band Reflectance
Black: Ref < 0
Yellow: 0 < Ref < 0.01
Orange: 0.01 < Ref < 0.03
Red: 0.03 < Ref < 0.08

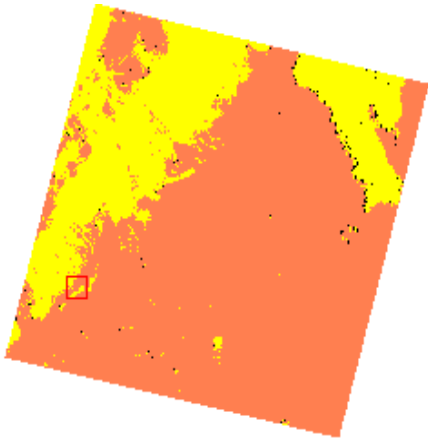




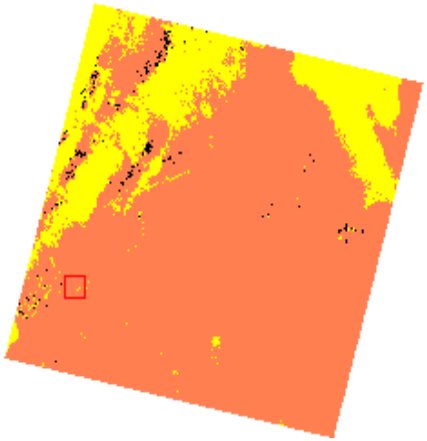
RGB(432) composite (ETM+)



Thermal band (ETM+)

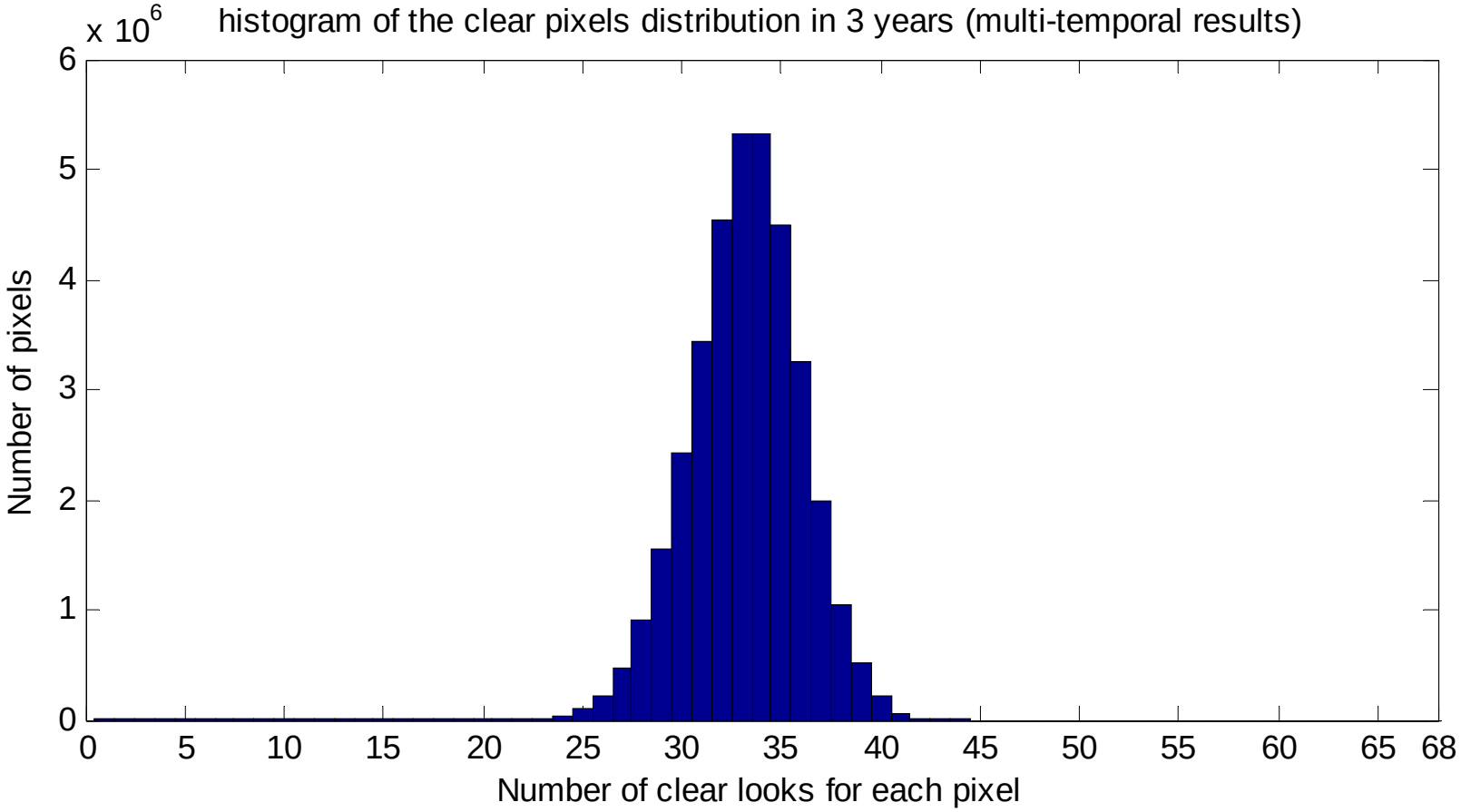


Fmask results (ETM+)



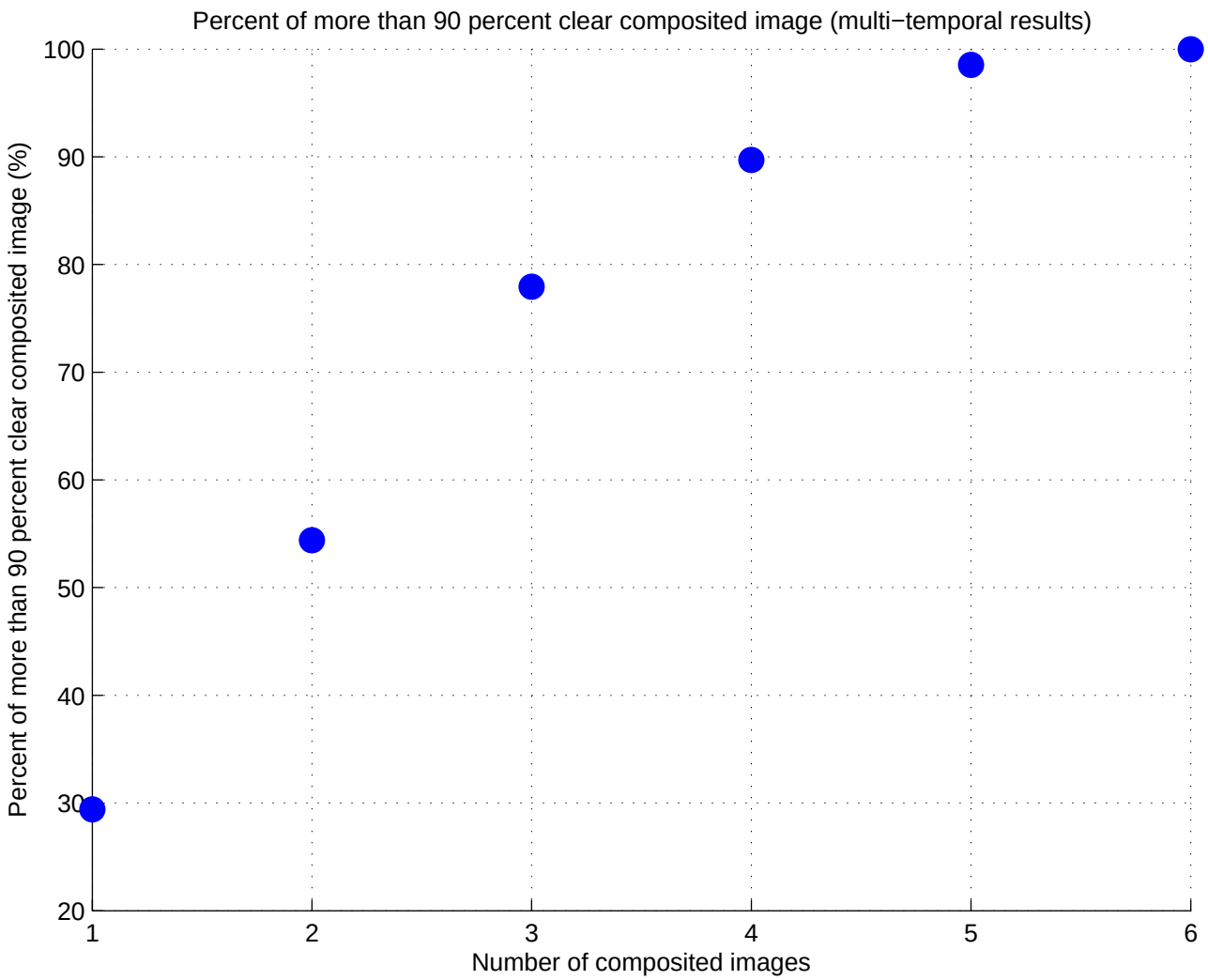
Multi-temporal results

Distribution of “clear” looks (out of 68)

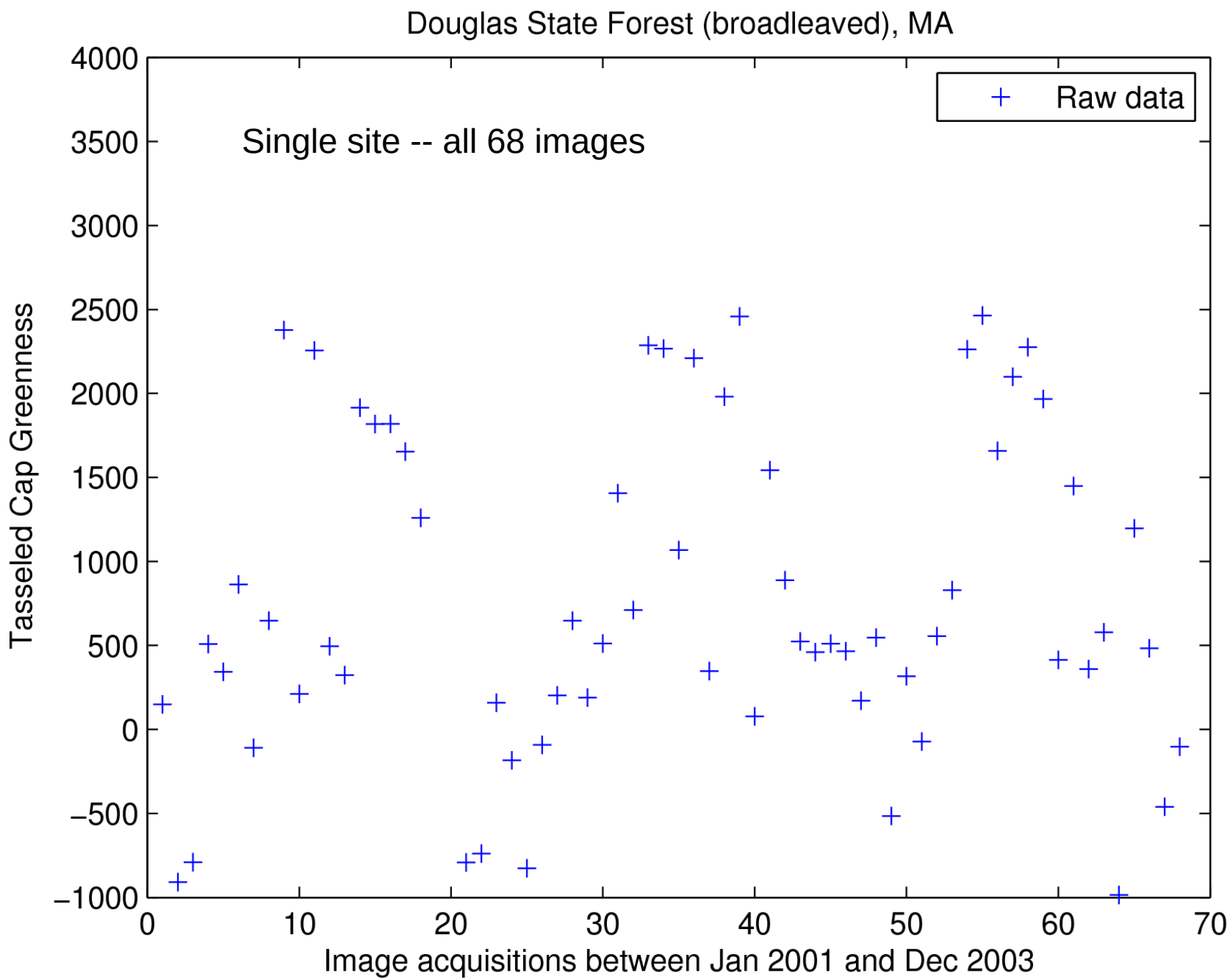


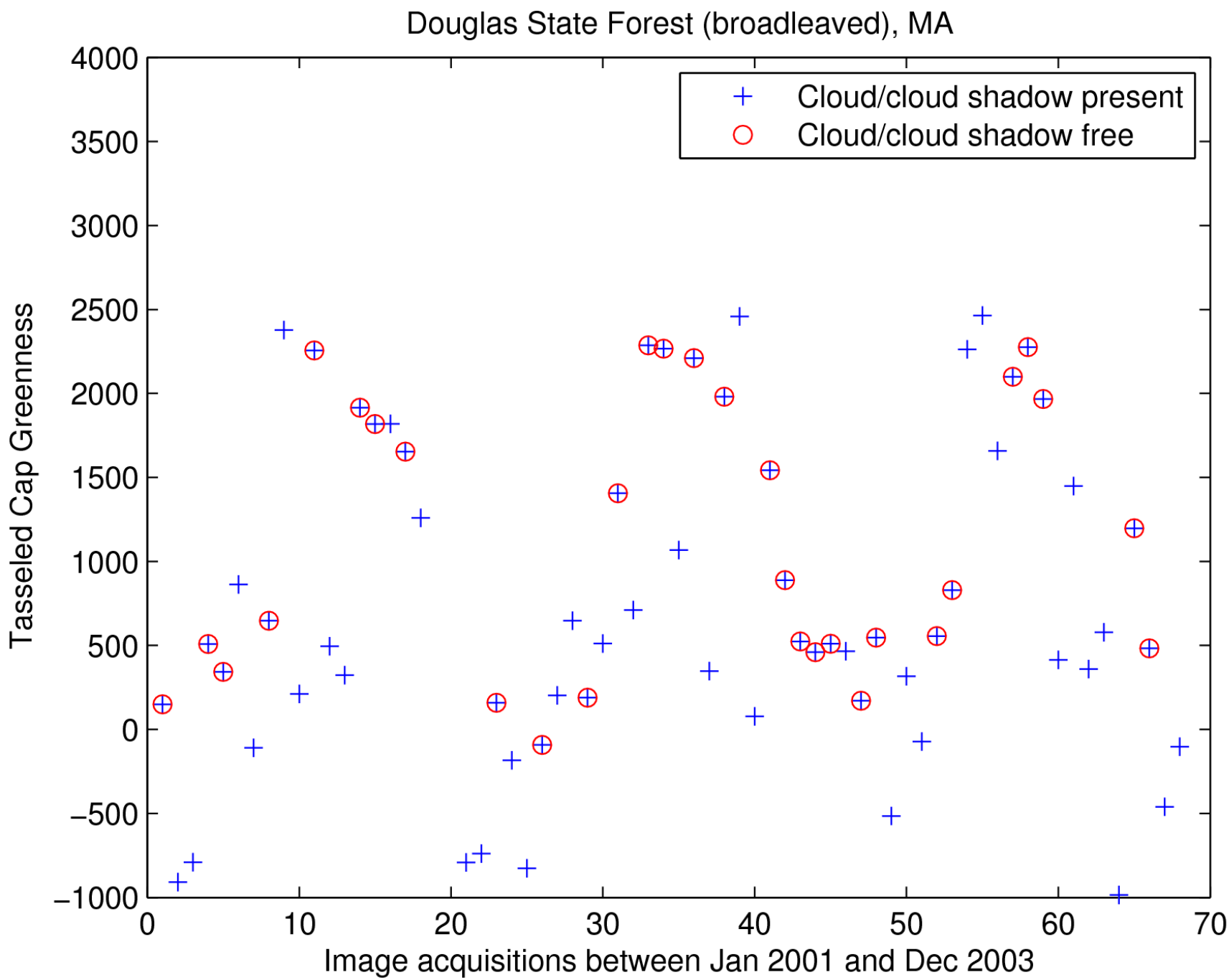
Pixels are clear (no cloud, shadow or snow) about half the time

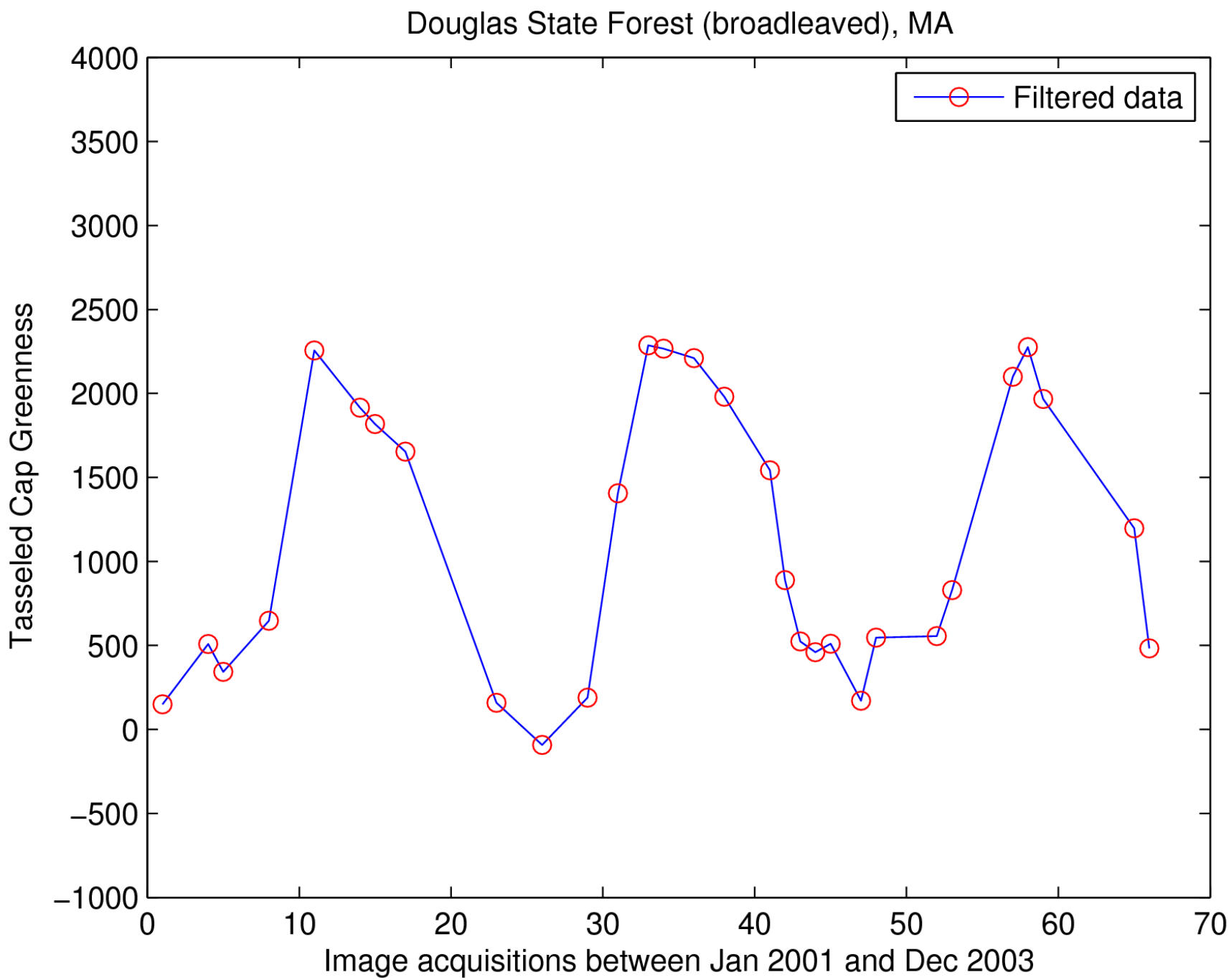
If you composite on successive images (all possible combinations)



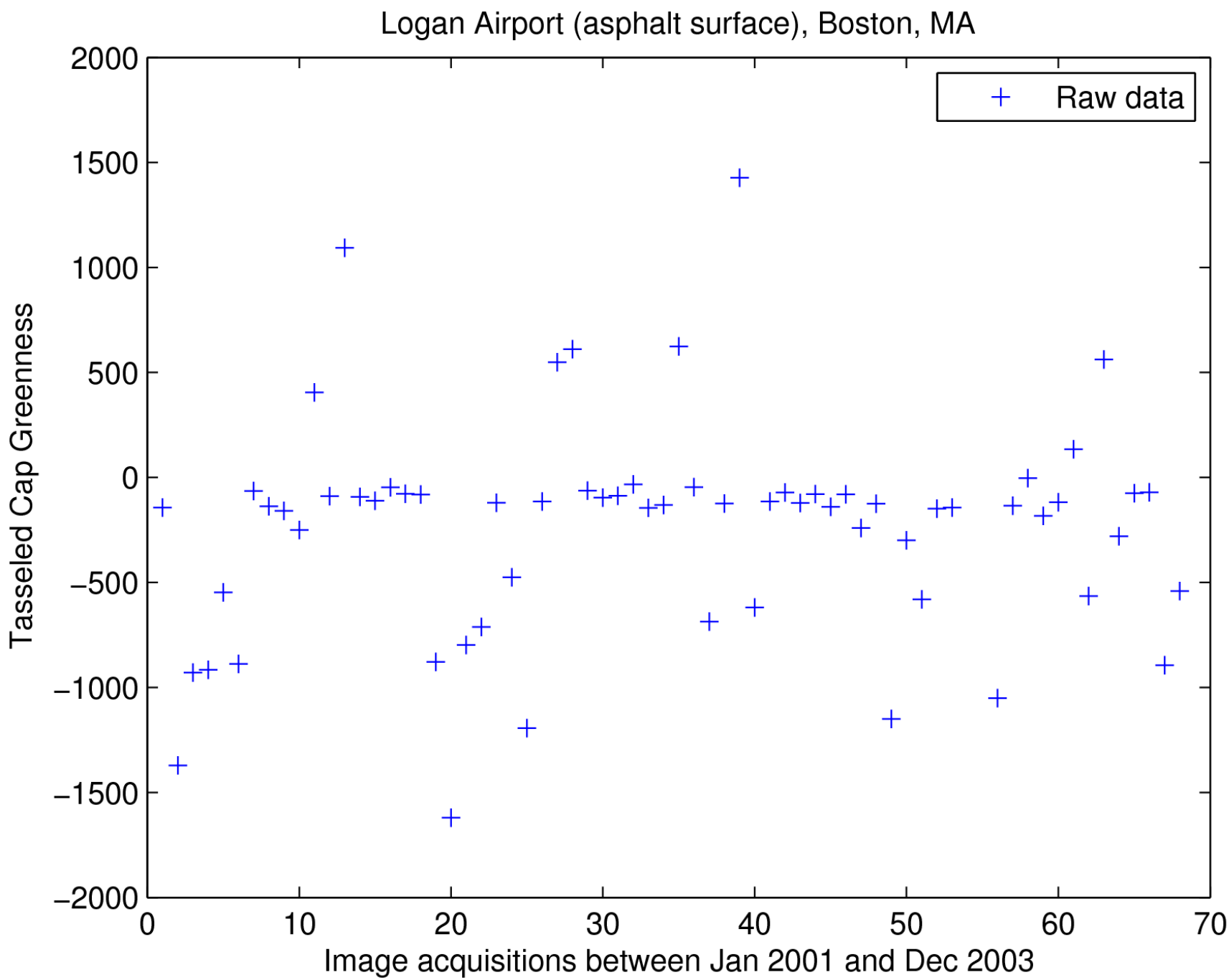
Stable Broadleaved Forest - Three year temporal trajectories

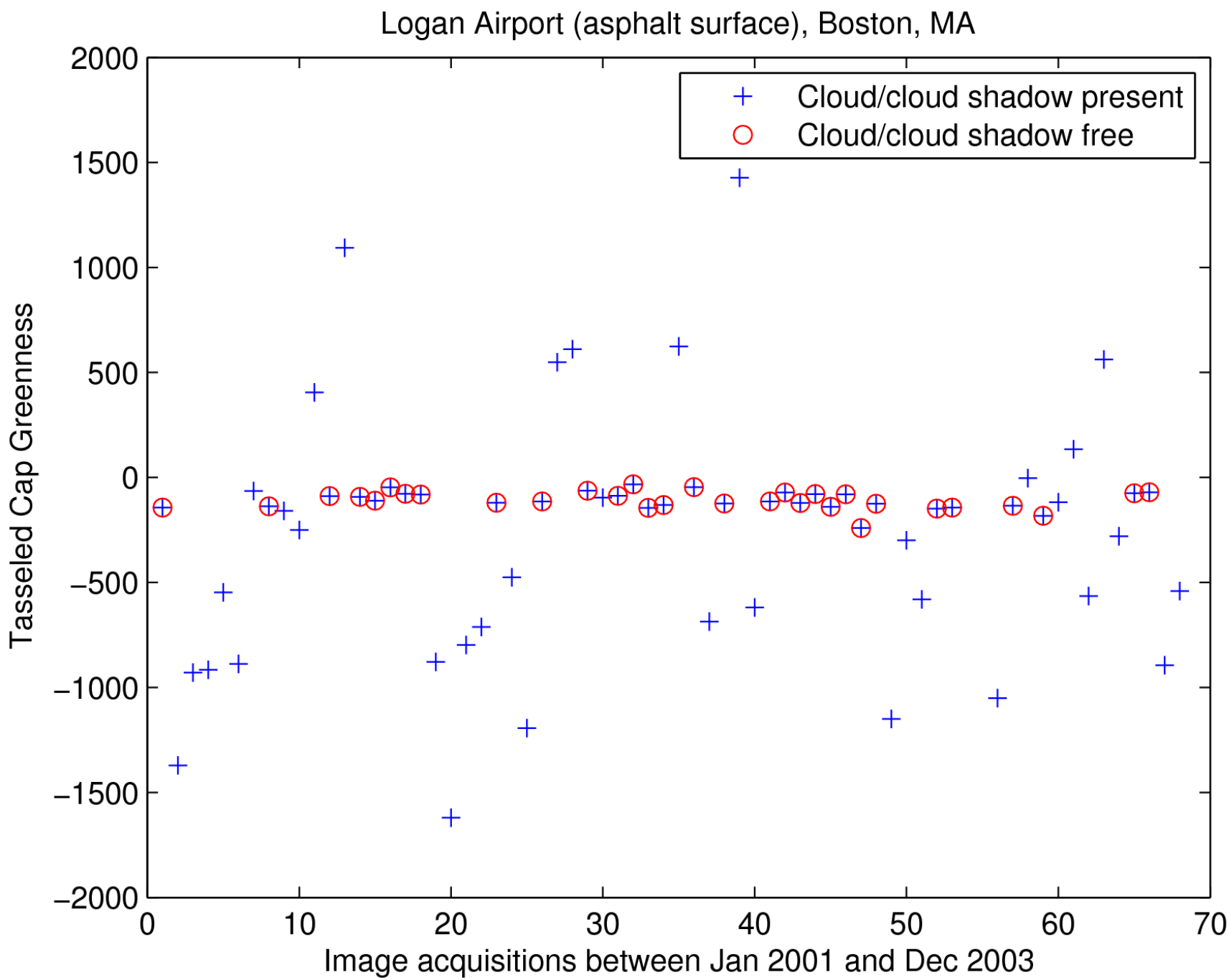

Douglas State Forest (broadleaved), MA
Raw data
Single site -- all 68 images
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

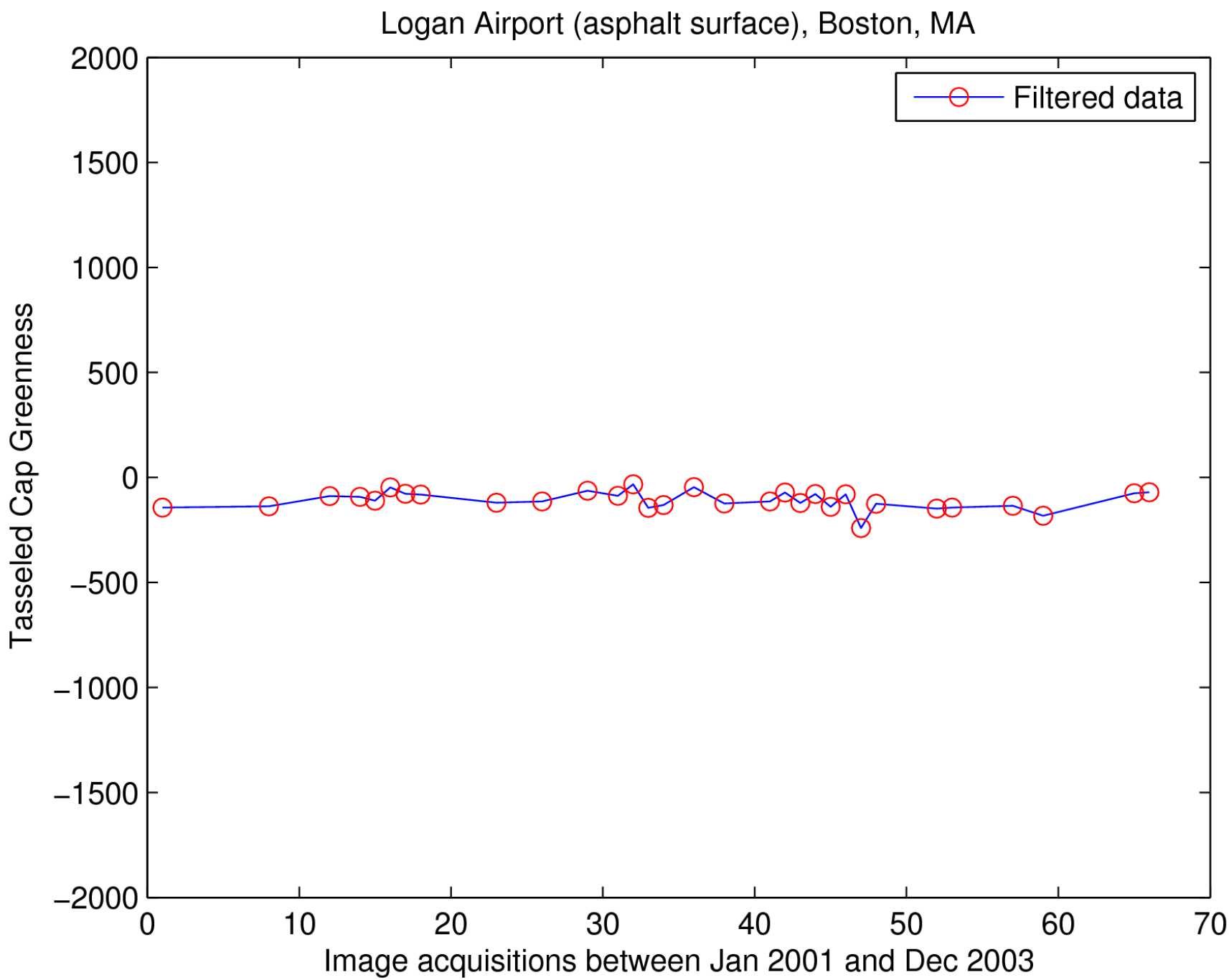

Douglas State Forest (broadleaved), MA
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70


Douglas State Forest (broadleaved), MA
Filtered data
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

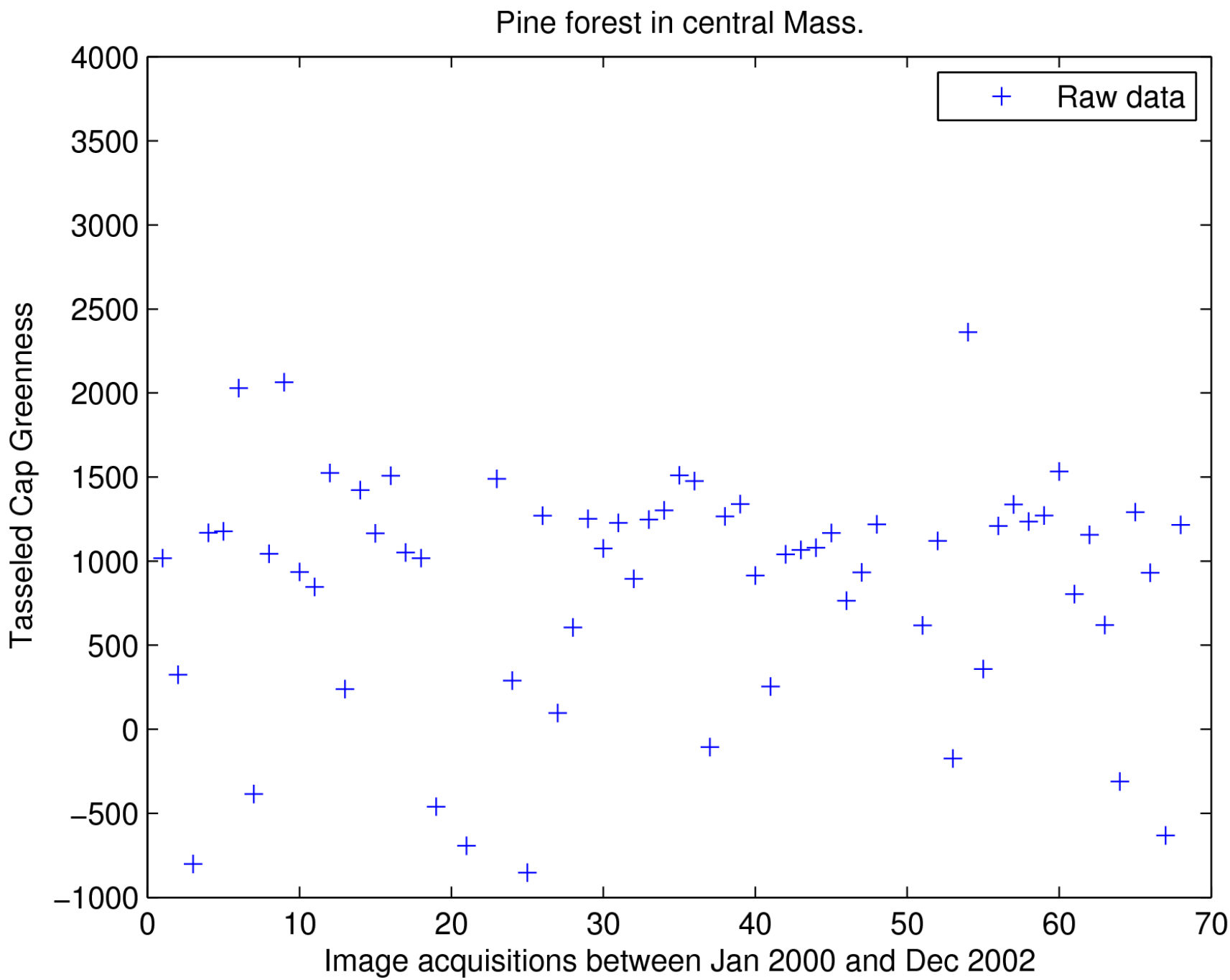
Asphalt surface

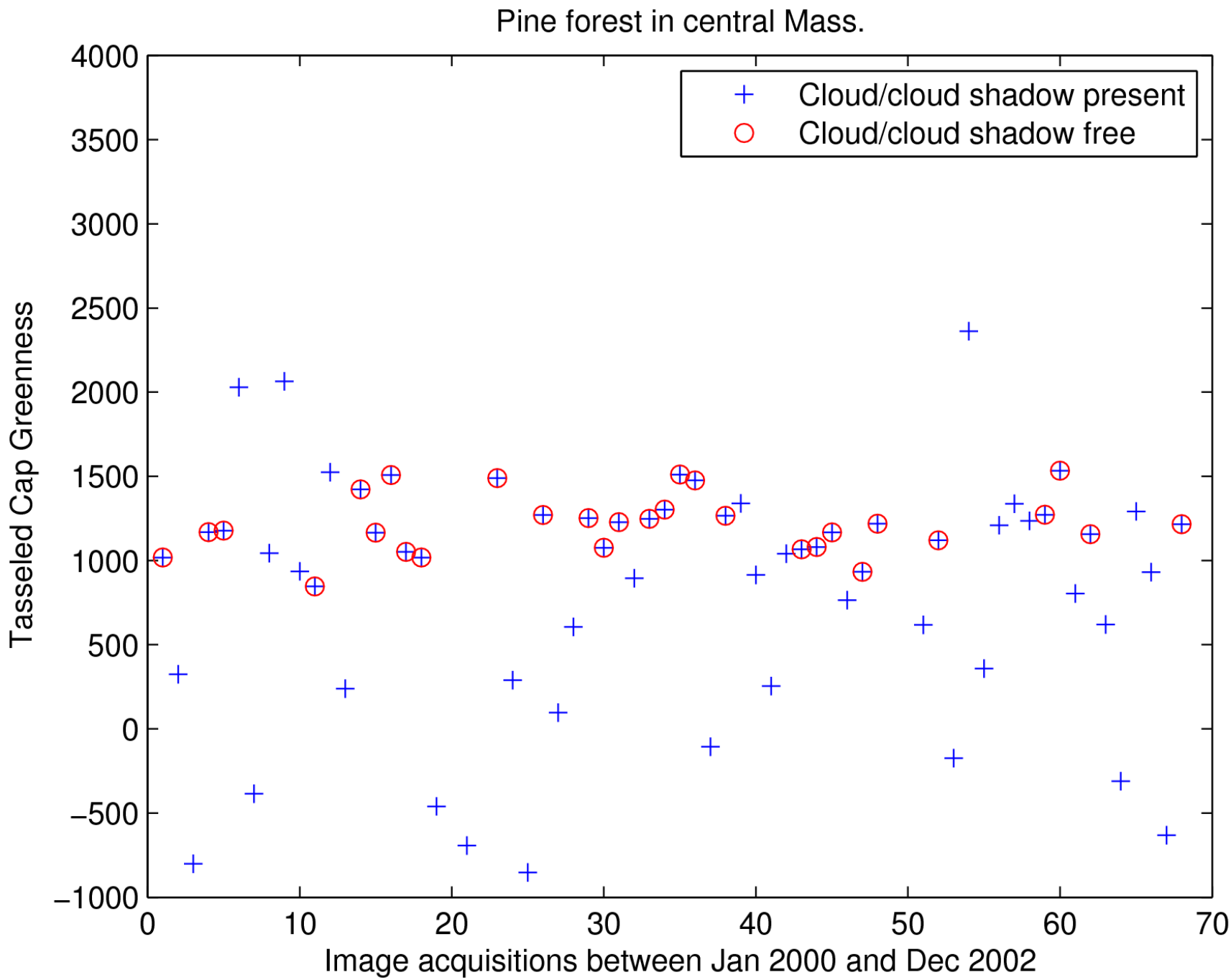

Logan Airport (asphalt surface), Boston, MA
Raw data
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
10
20
30
40
50
60
70

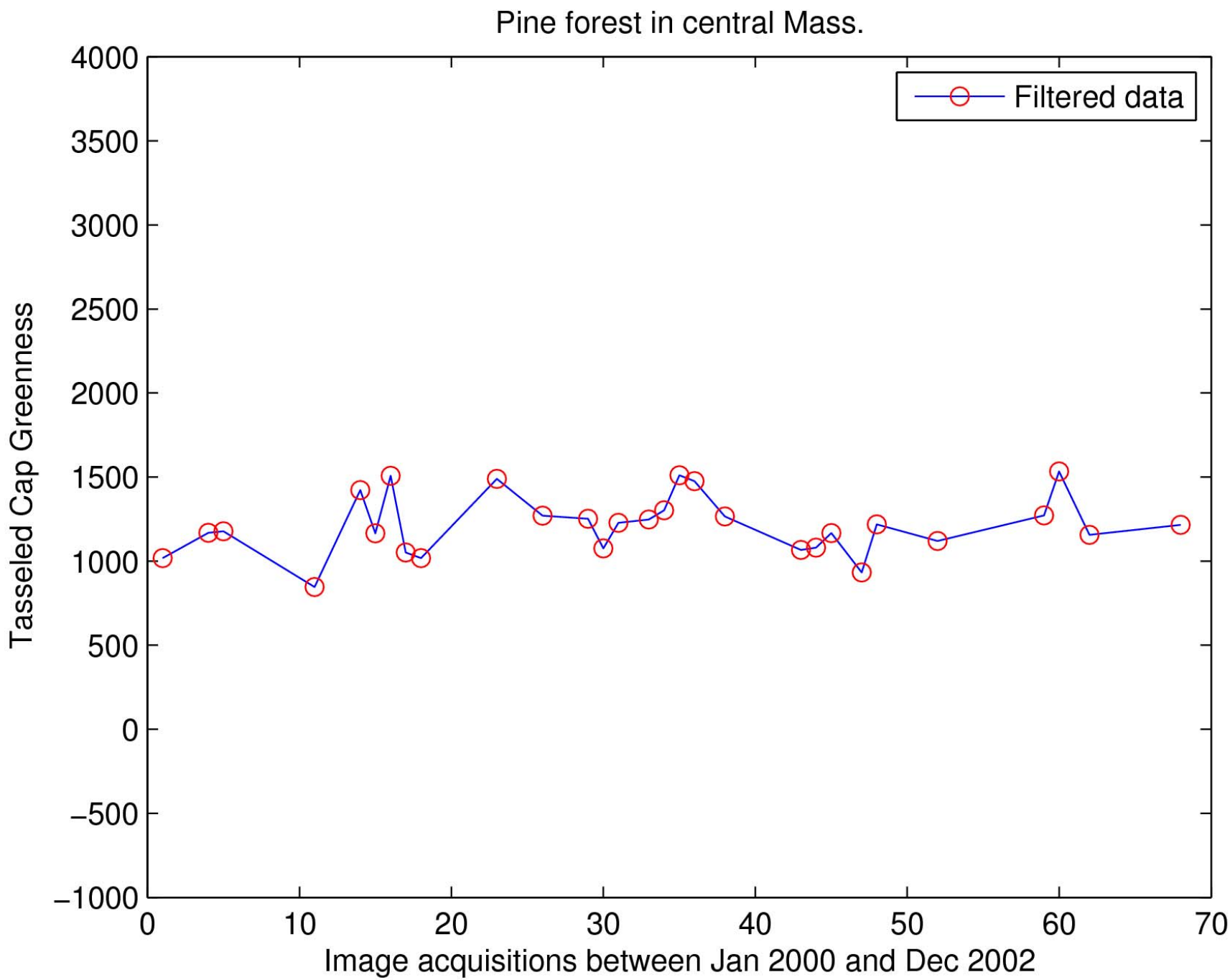

Logan Airport (asphalt surface), Boston, MA
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
10
20
30
40
50
60
70


Logan Airport (asphalt surface), Boston, MA
Filtered data
Tasseled Cap Greenness
Image acquisitions between Jan 2001 and Dec 2003
2000
1500
1000
500
0
−500
−1000
−1500
−2000
0
10
20
30
40
50
60
70

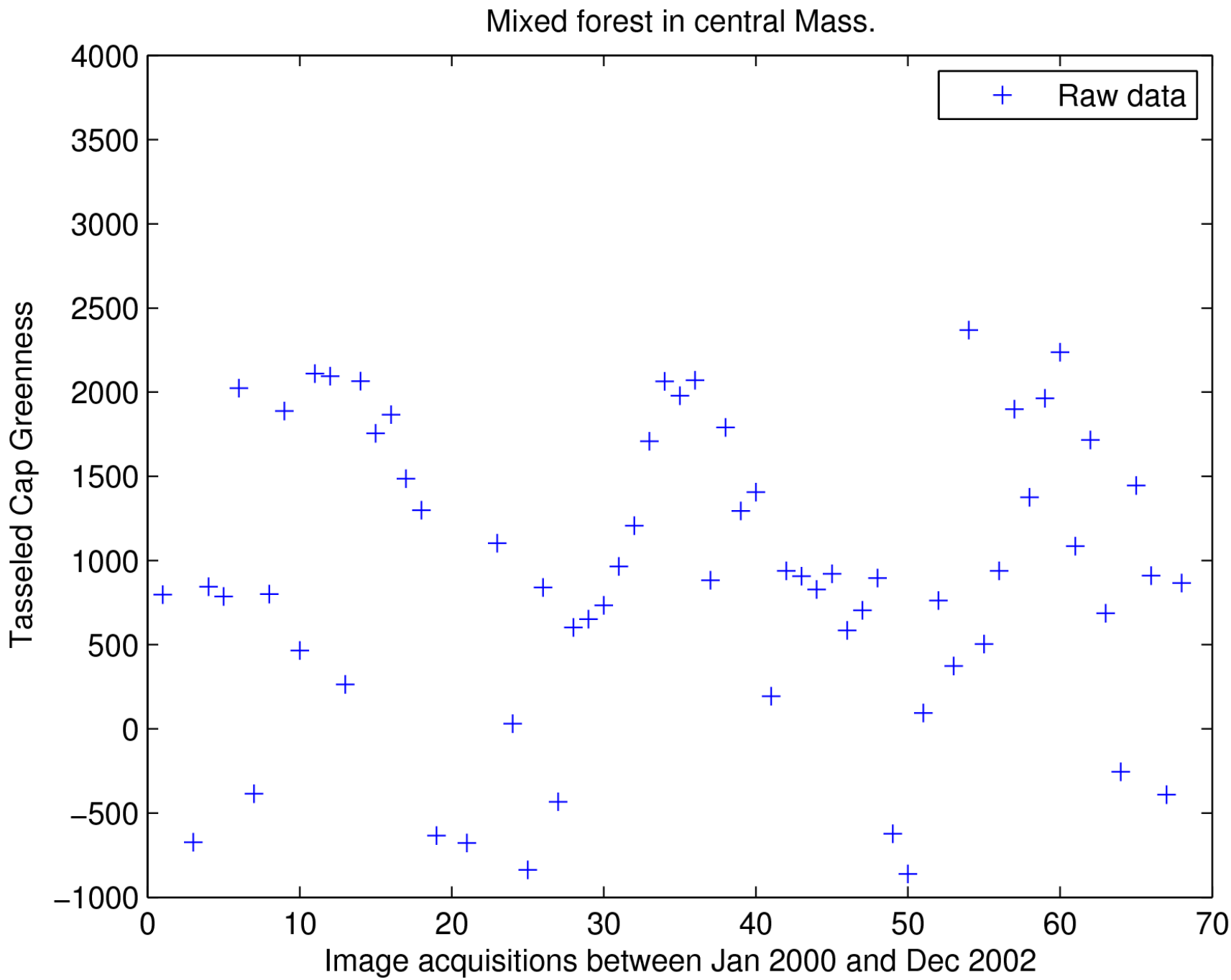
Stable Pine Forest

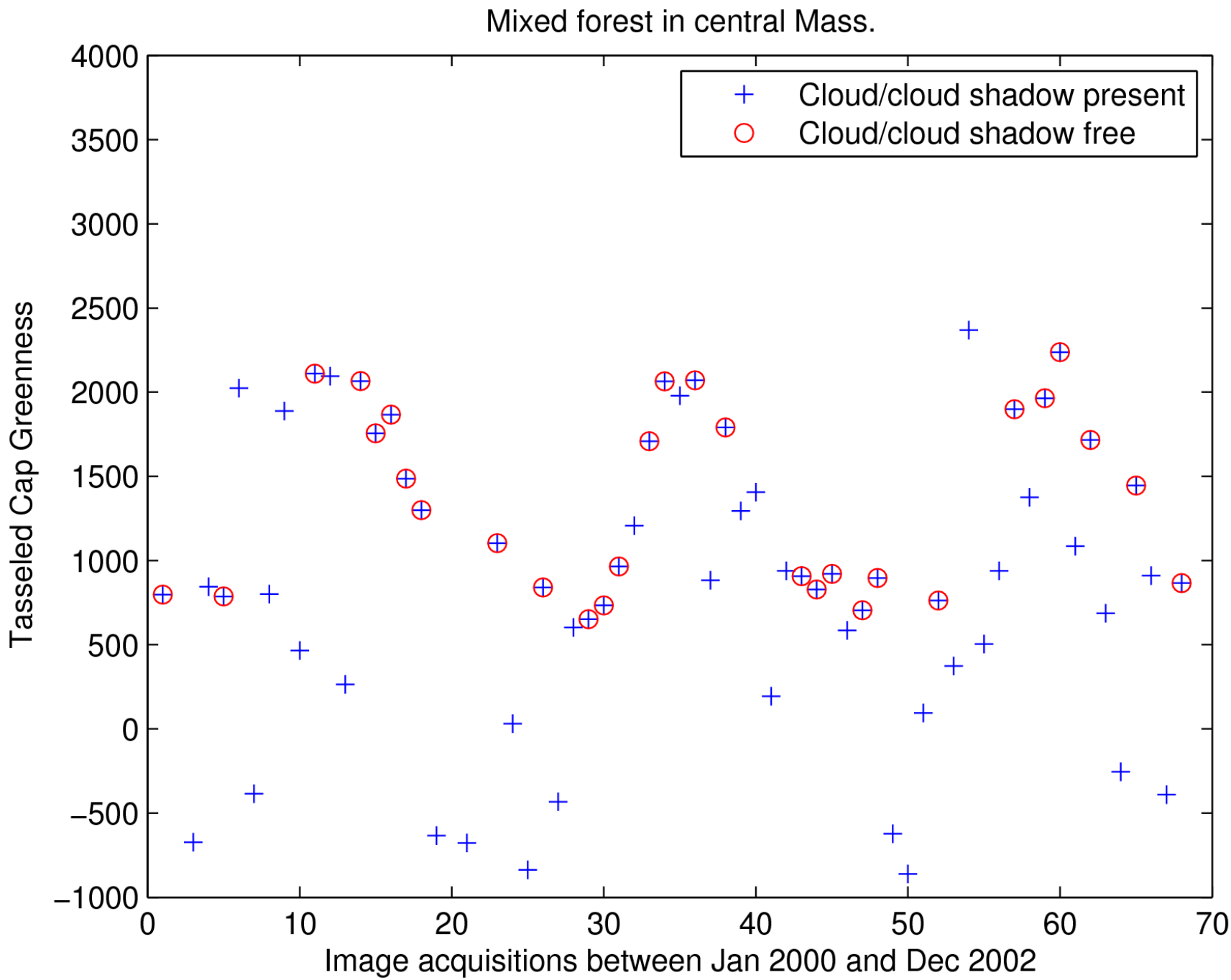

Pine forest in central Mass.
Raw data
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

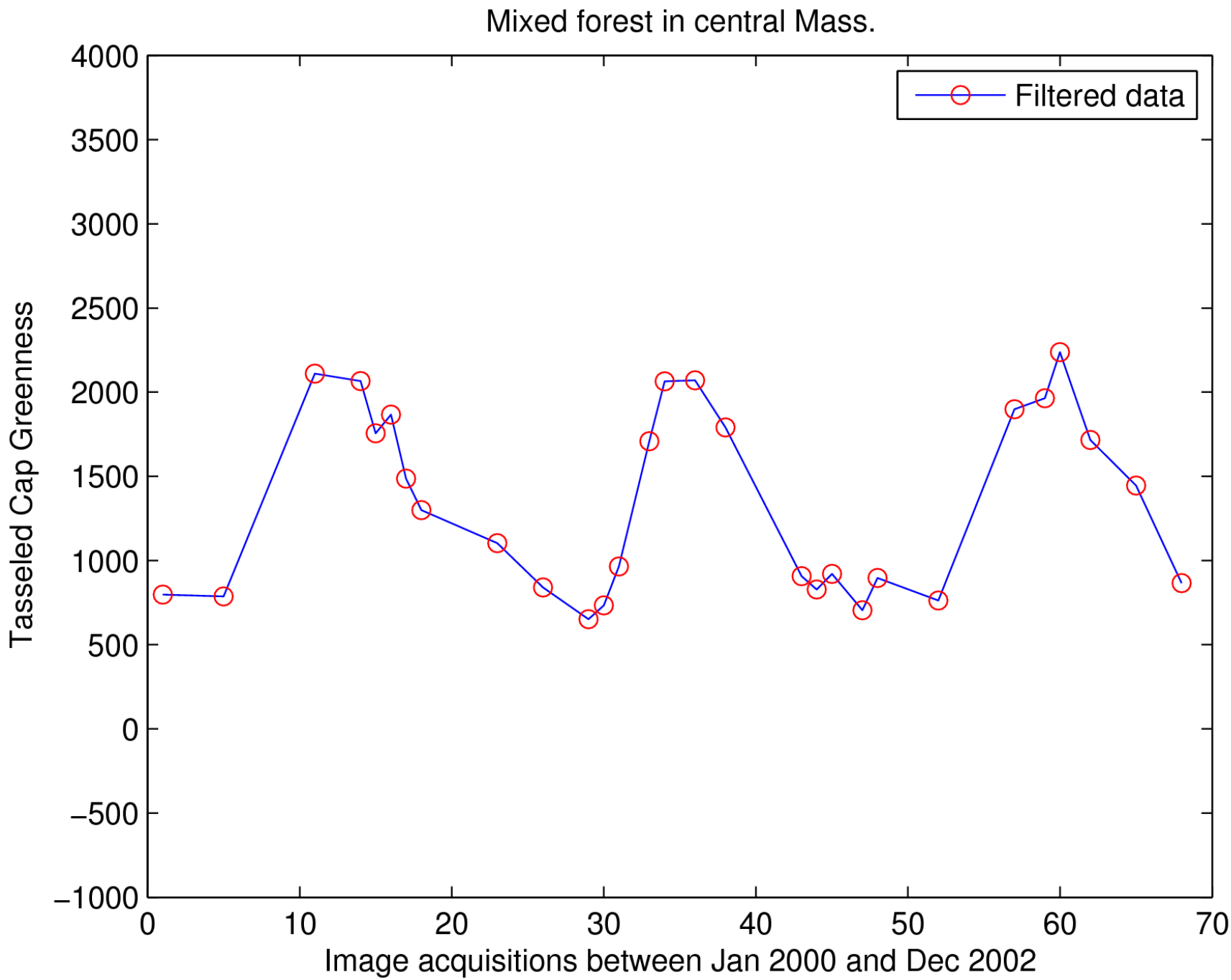

Pine forest in central Mass.
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70


Pine forest in central Mass.
Filtered data
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

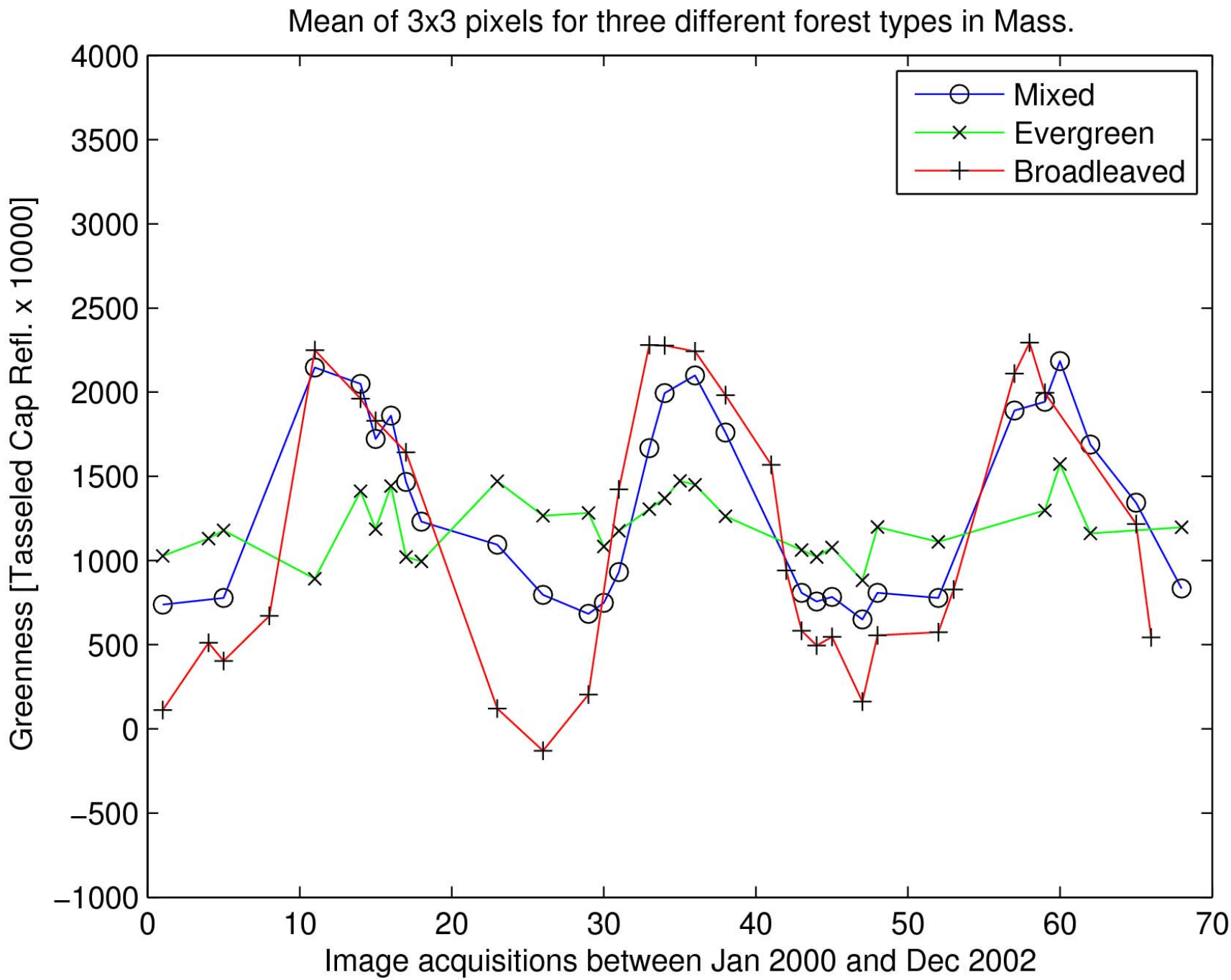
Stable Mixed Broadlevead/Evergreen Forest

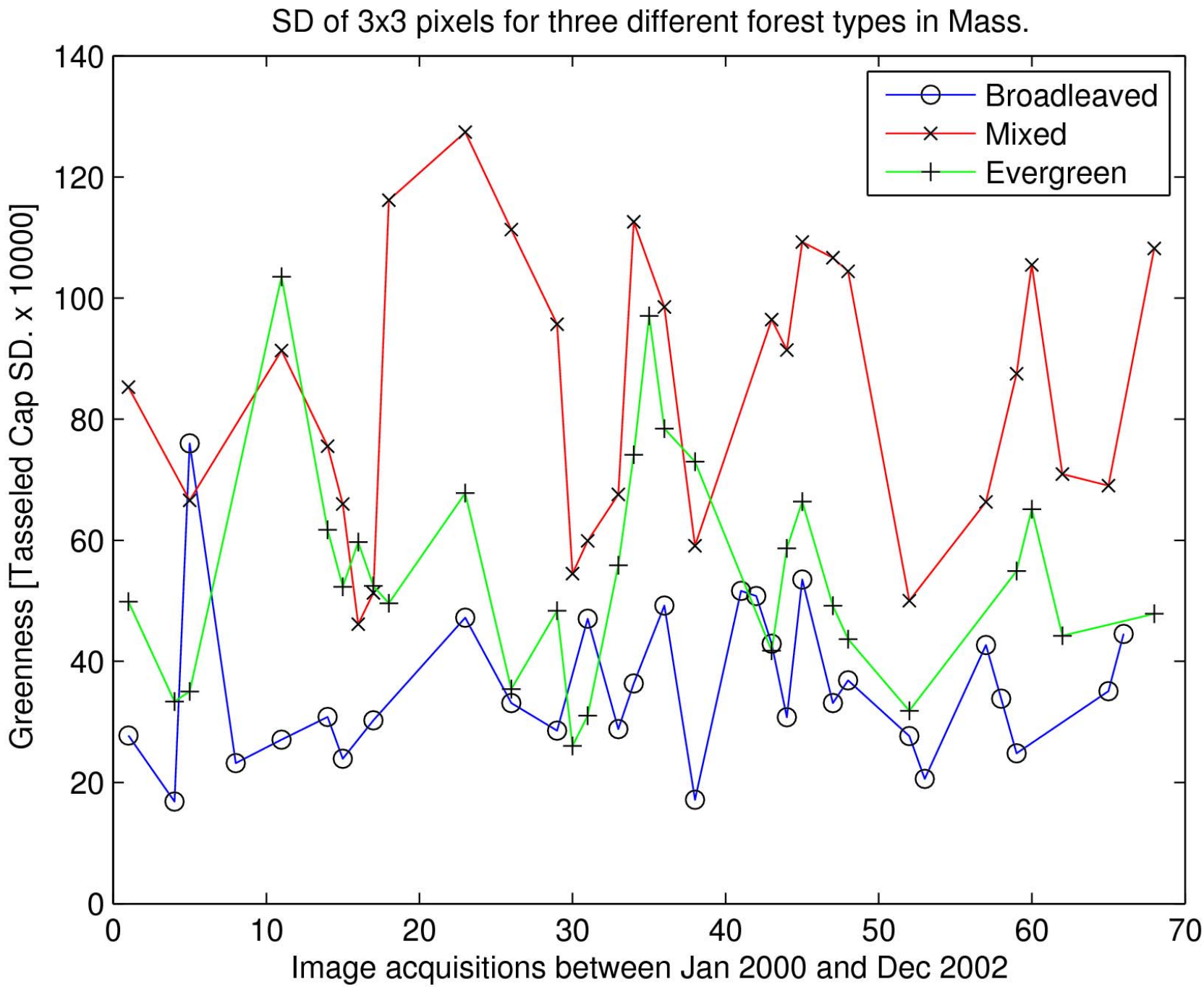

Mixed forest in central Mass.
Raw data
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

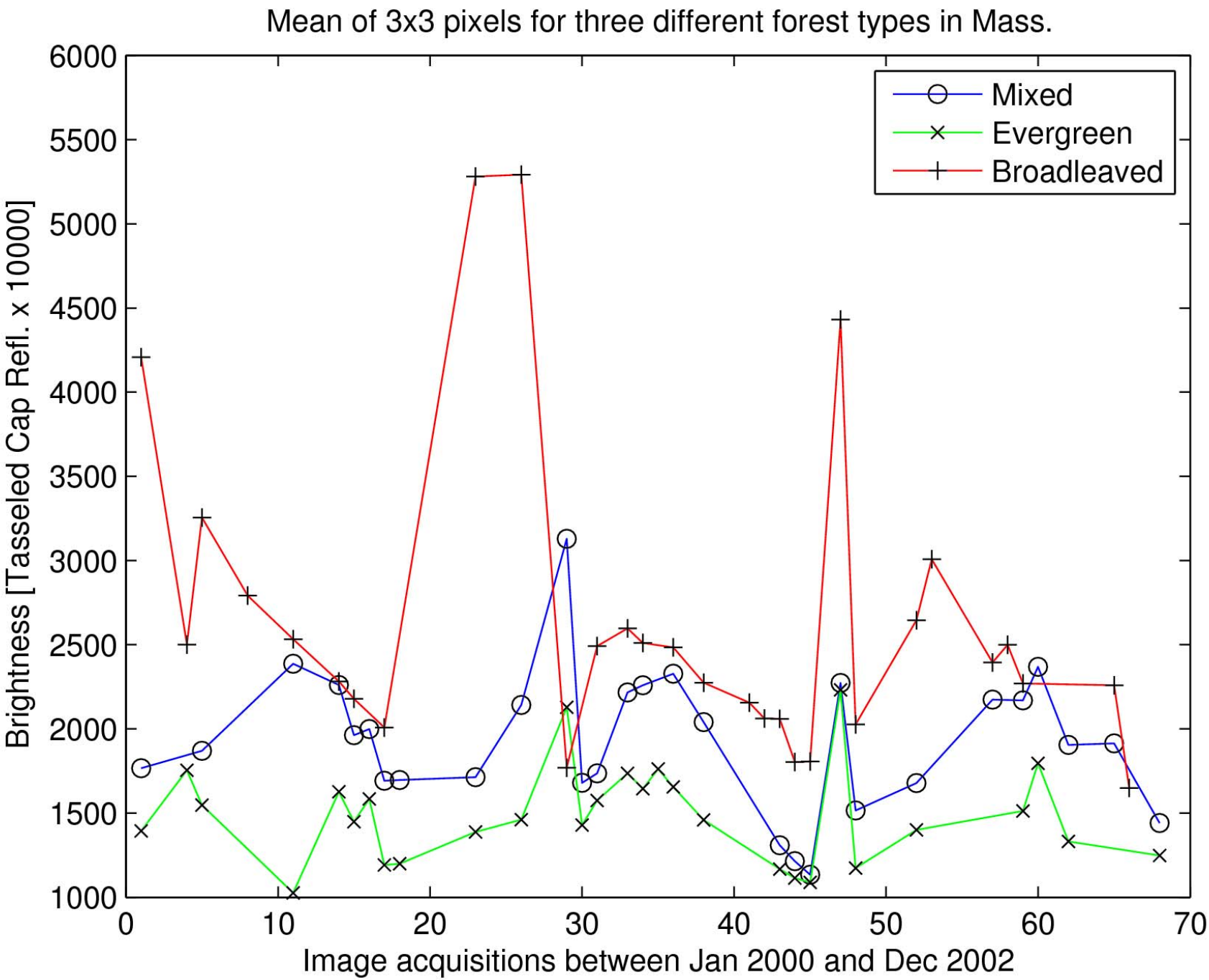

Mixed forest in central Mass.
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

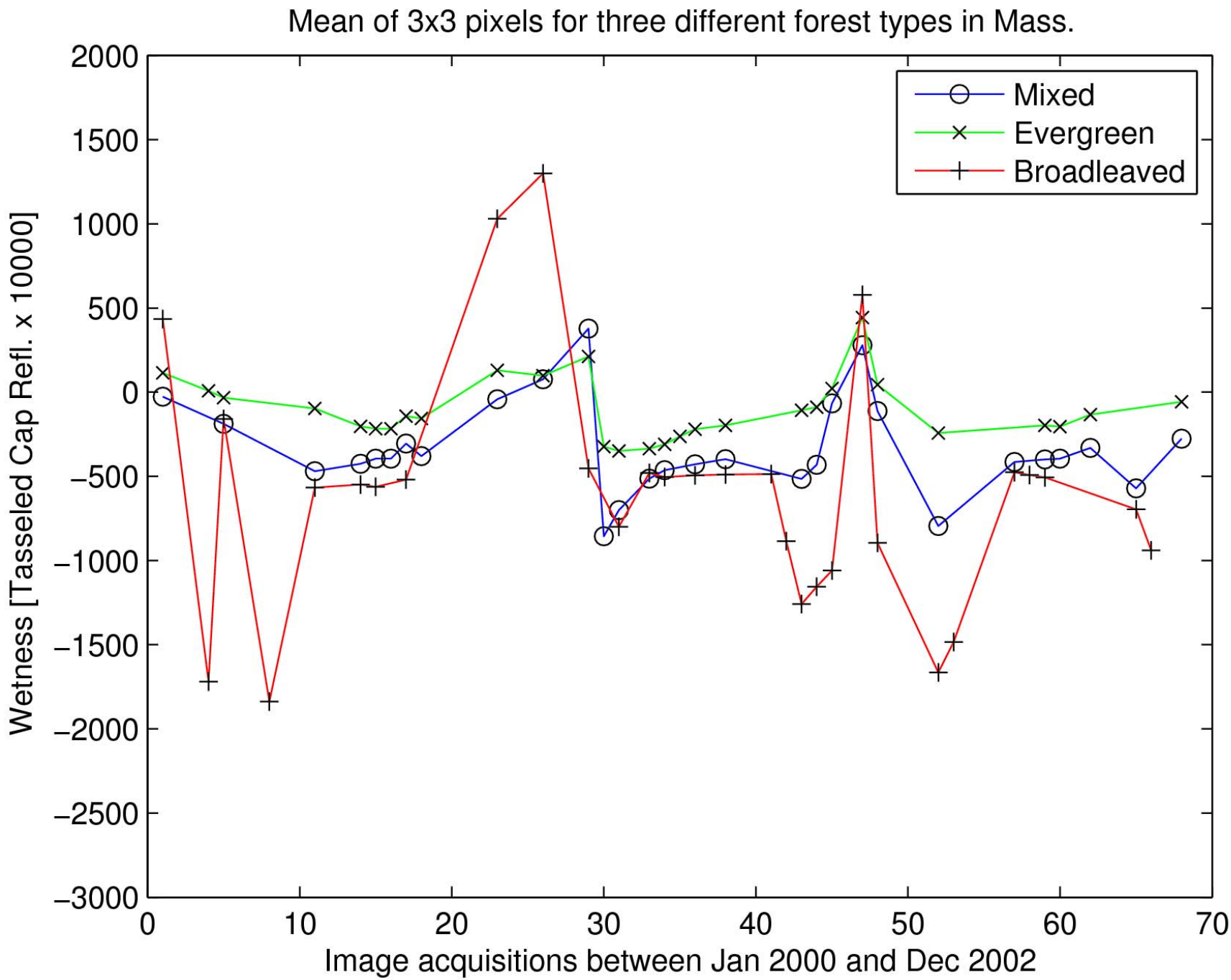

Mixed forest in central Mass.
Filtered data
Tasseled Cap Greenness
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

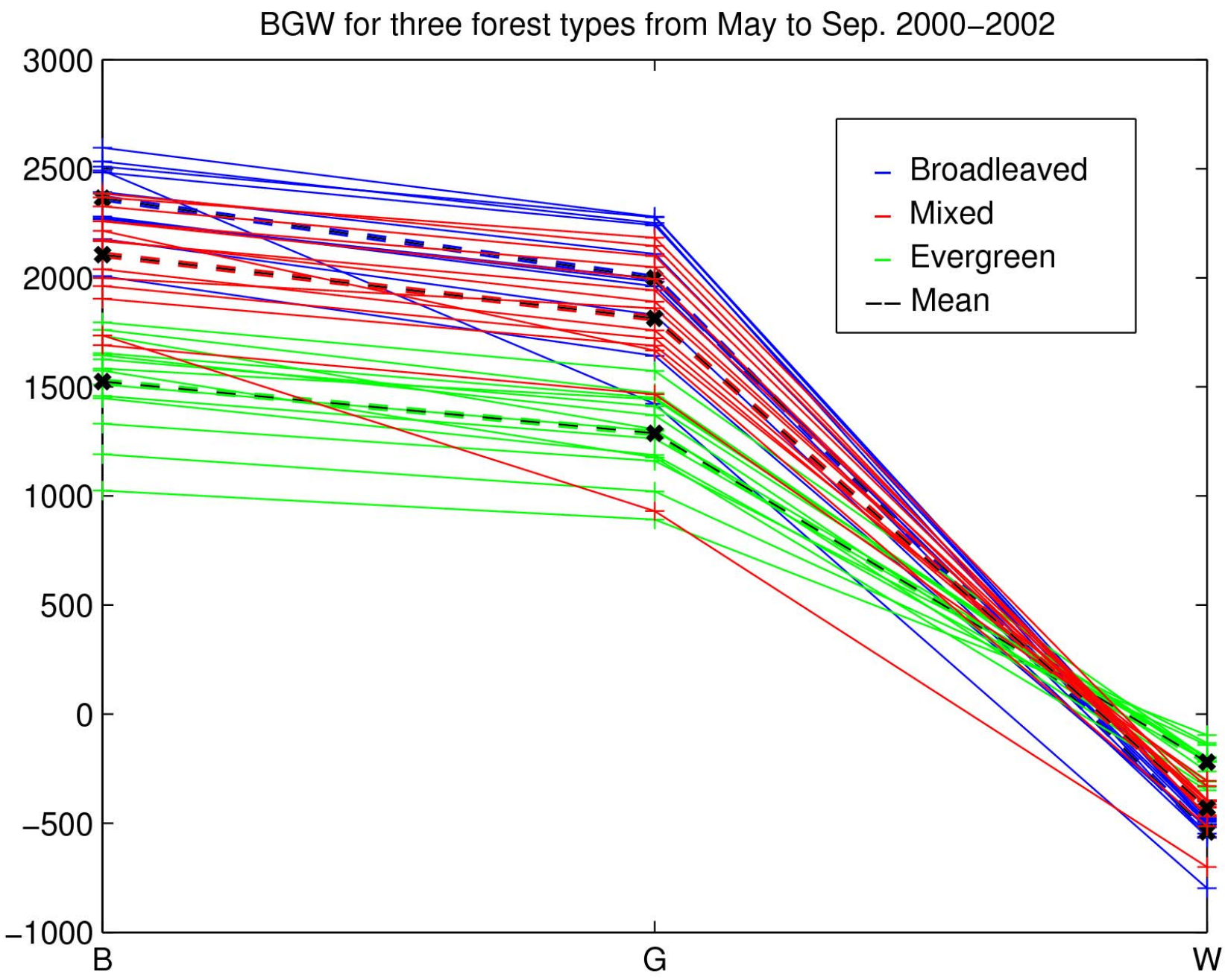
Tasseled Cap BGW, three Forest Types

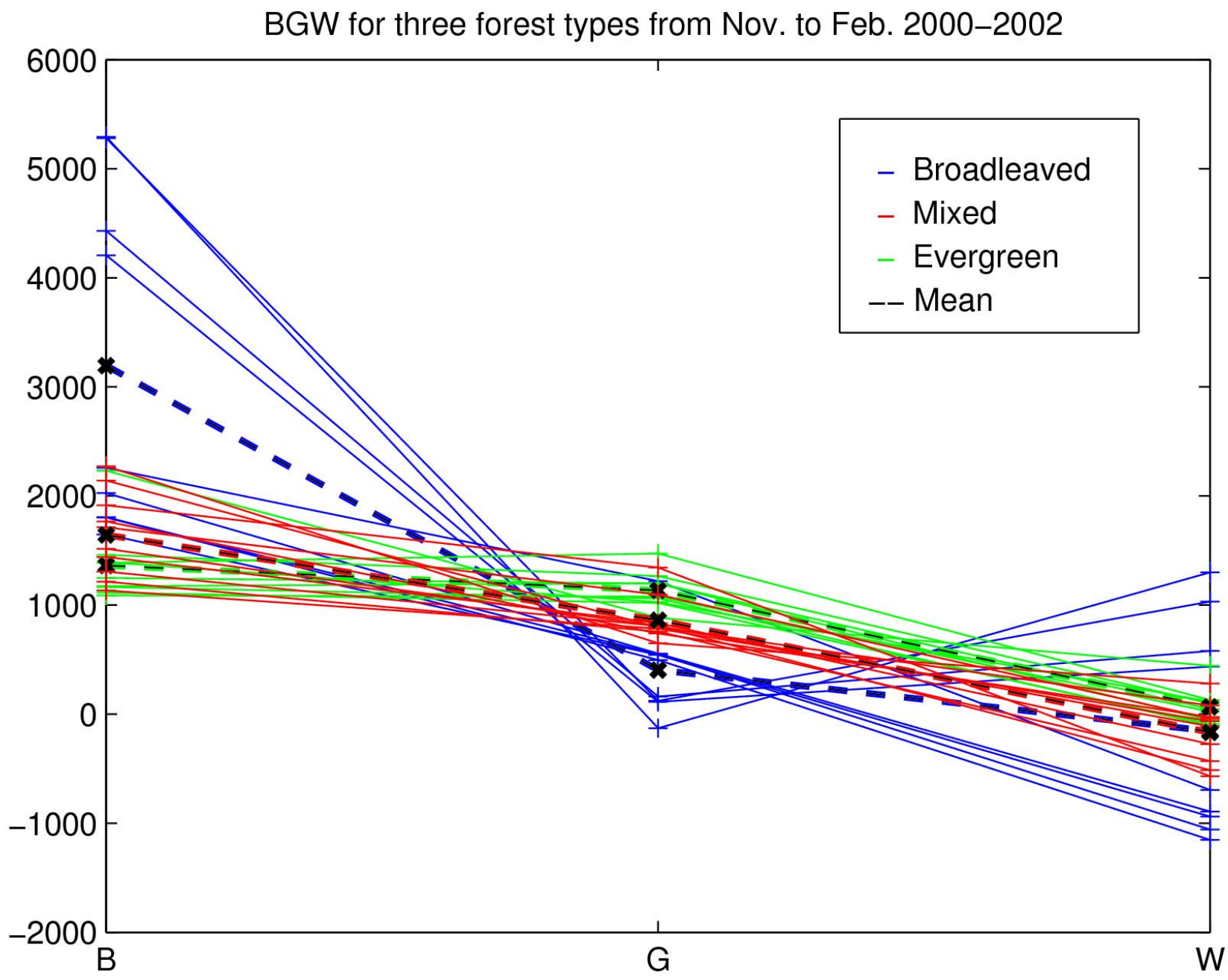

Mean of 3x3 pixels for three different forest types in Mass.
Mixed
Evergreen
Broadleaved
Greenness [Tasseled Cap Refl. x 10000]
Image acquisitions between Jan 2000 and Dec 2002
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70

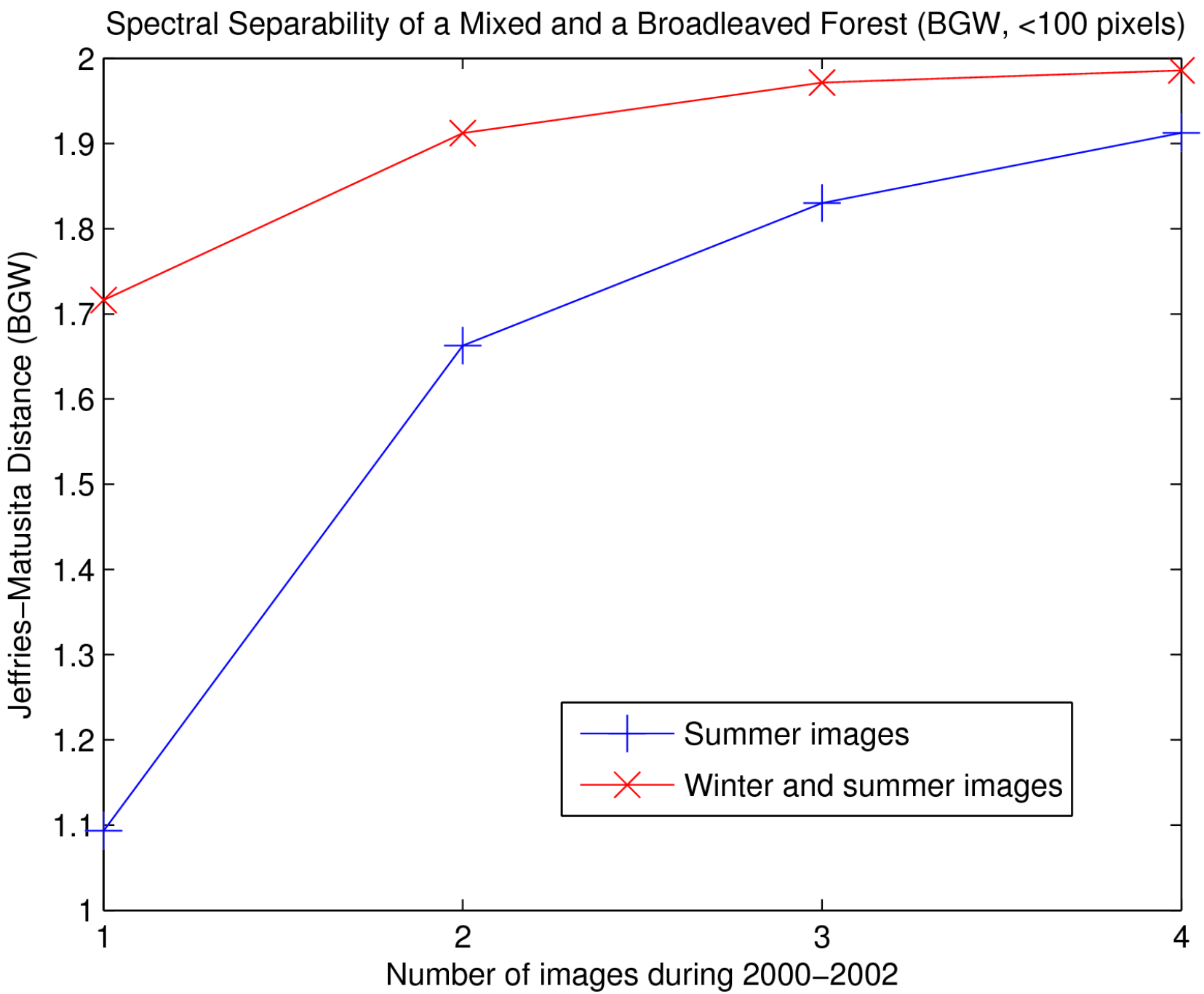

SD of 3x3 pixels for three different forest types in Mass.
Broadleaved
Mixed
Evergreen
Greenness [Tasseled Cap SD. x 10000]
Image acquisitions between Jan 2000 and Dec 2002
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70


Mean of 3x3 pixels for three different forest types in Mass.
Mixed
Evergreen
Broadleaved
Brightness [Tasseled Cap Refl. x 10000]
Image acquisitions between Jan 2000 and Dec 2002
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
10
20
30
40
50
60
70

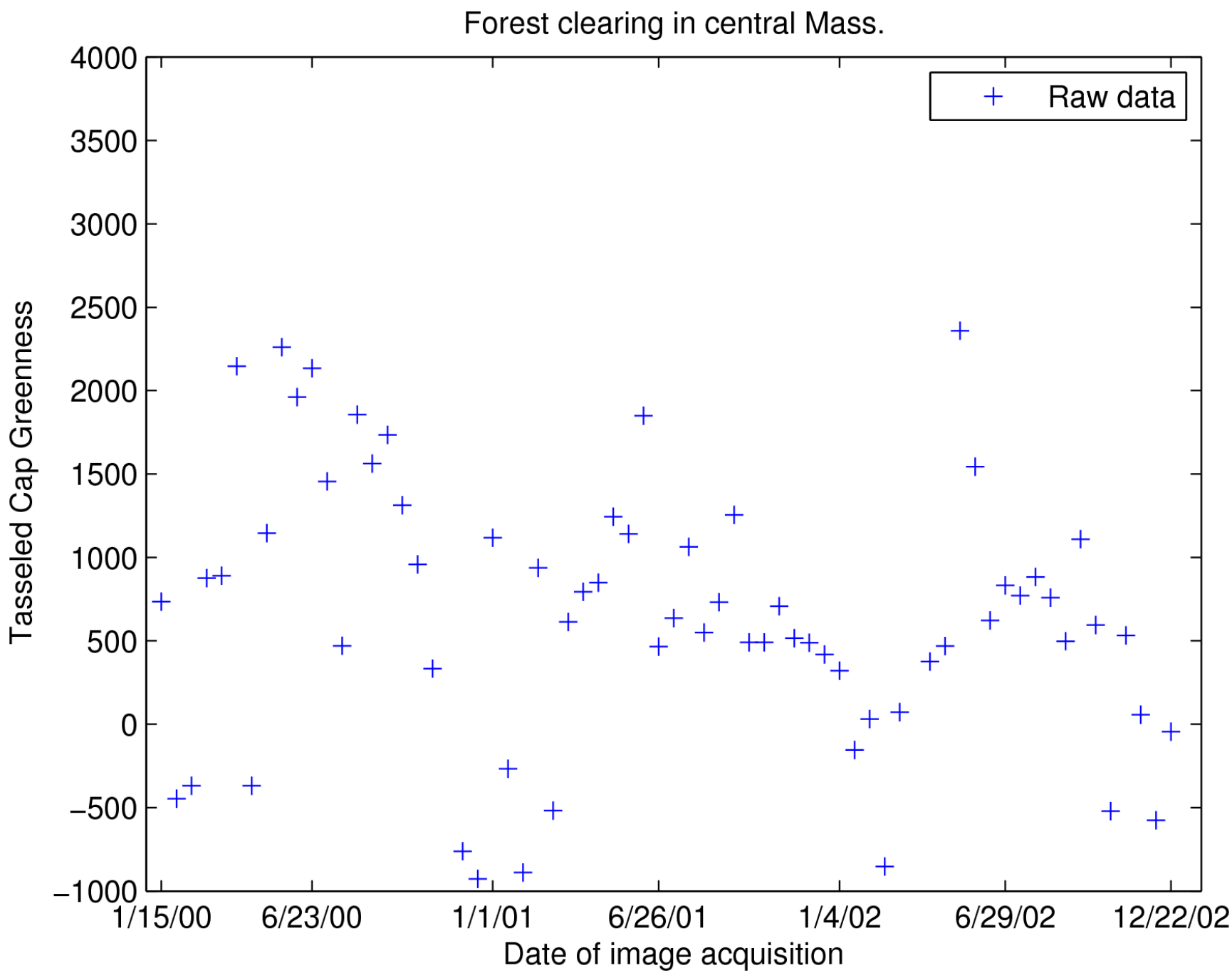

Mean of 3x3 pixels for three different forest types in Mass.
Mixed
Evergreen
Broadleaved
Wetness [Tasseled Cap Refl. x 10000]
Image acquisitions between Jan 2000 and Dec 2002
2000
1500
1000
500
0
−500
−1000
−1500
−2000
−2500
−3000
0
10
20
30
40
50
60
70

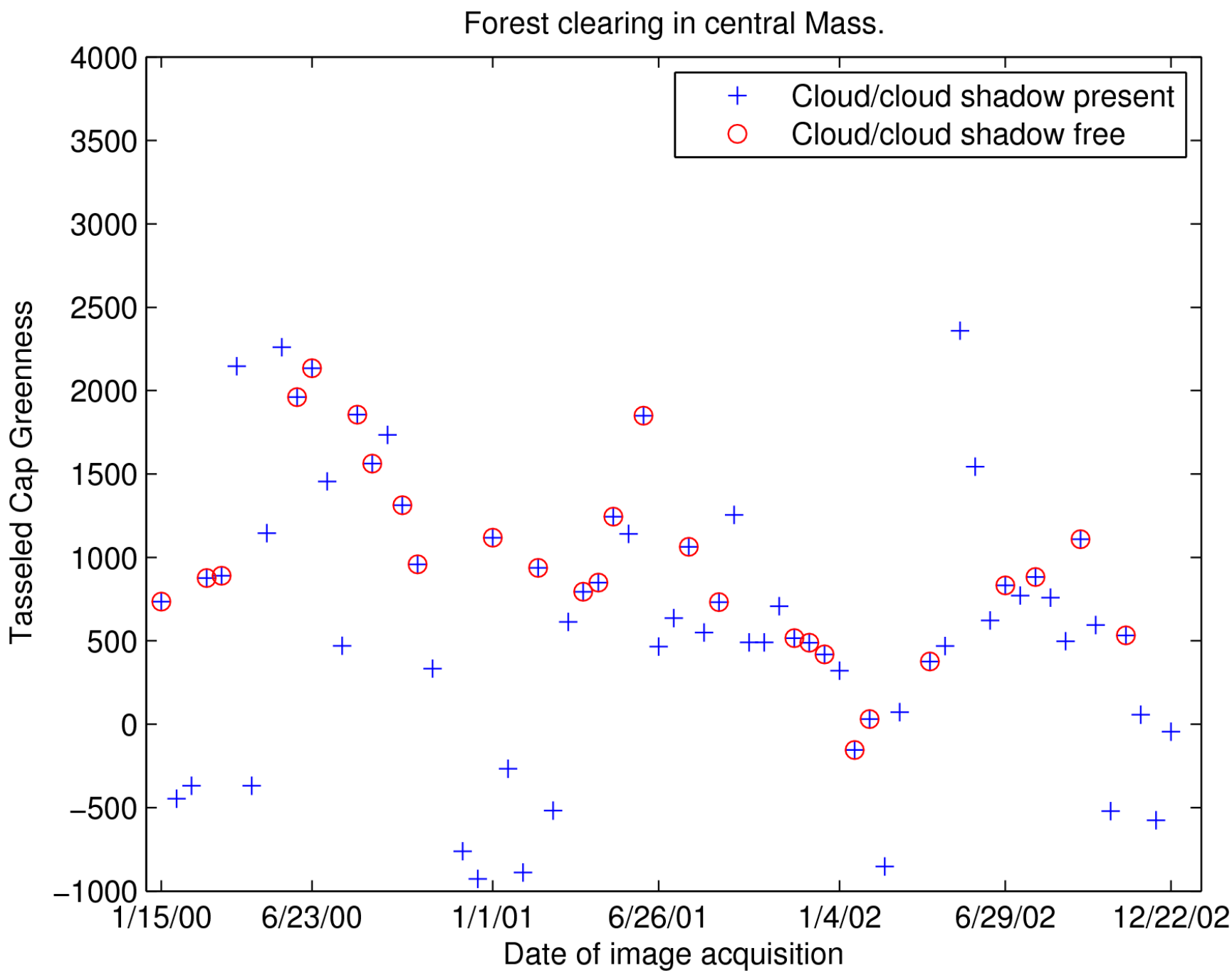

BGW for three forest types from May to Sep. 2000−2002
3000
2500
2000
1500
1000
500
0
−500
−1000
B
G
W
Broadleaved
Mixed
Evergreen
Mean

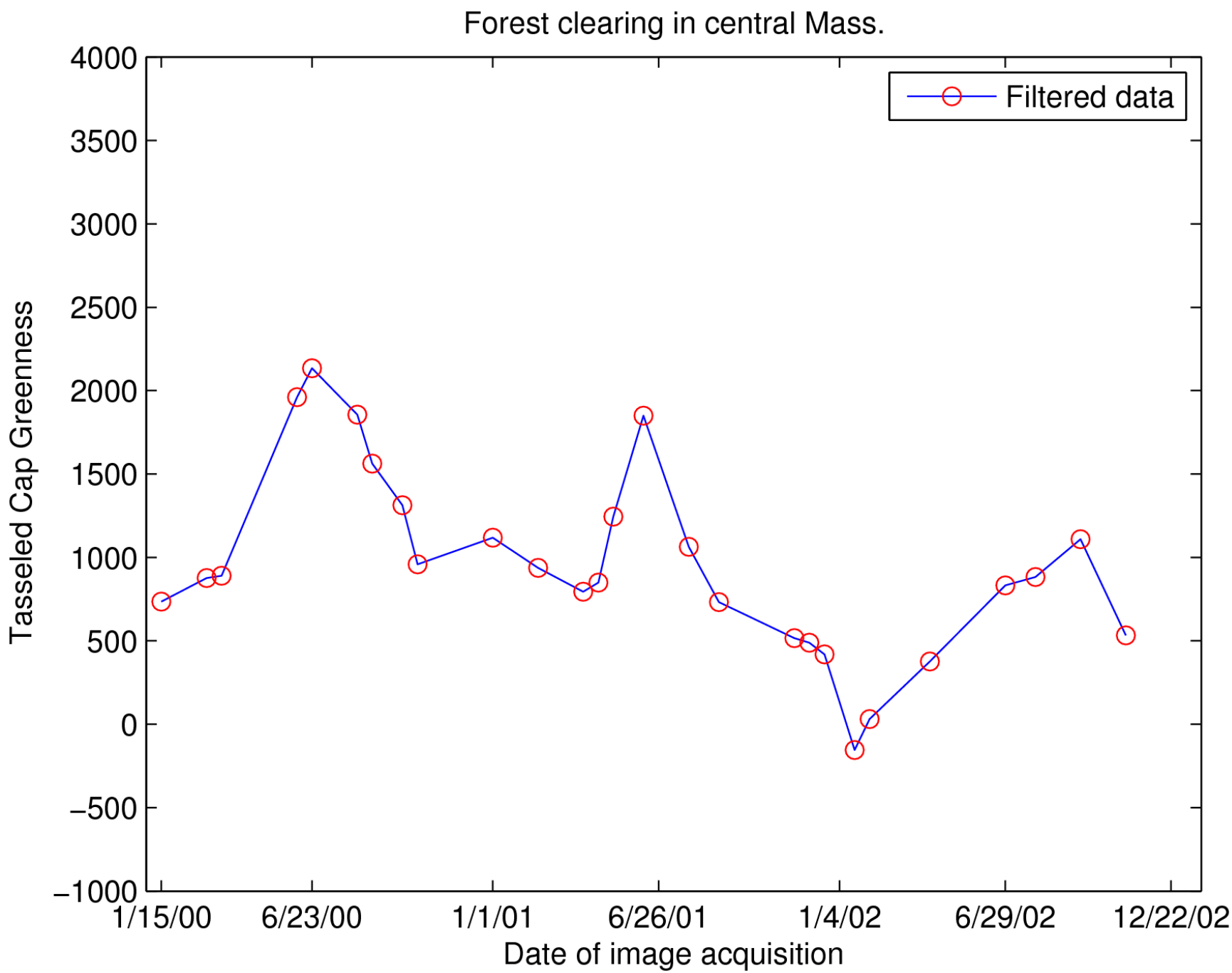

BGW for three forest types from Nov. to Feb. 2000–2002
6000
5000
4000
3000
2000
1000
0
−1000
−2000
B
G
W
Broadleaved
Mixed
Evergreen
Mean


Spectral Separability of a Mixed and a Broadleaved Forest (BGW, <100 pixels)
Jeffries–Matusita Distance (BGW)
Number of images during 2000–2002
Summer images
Winter and summer images
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
1
2
3
4

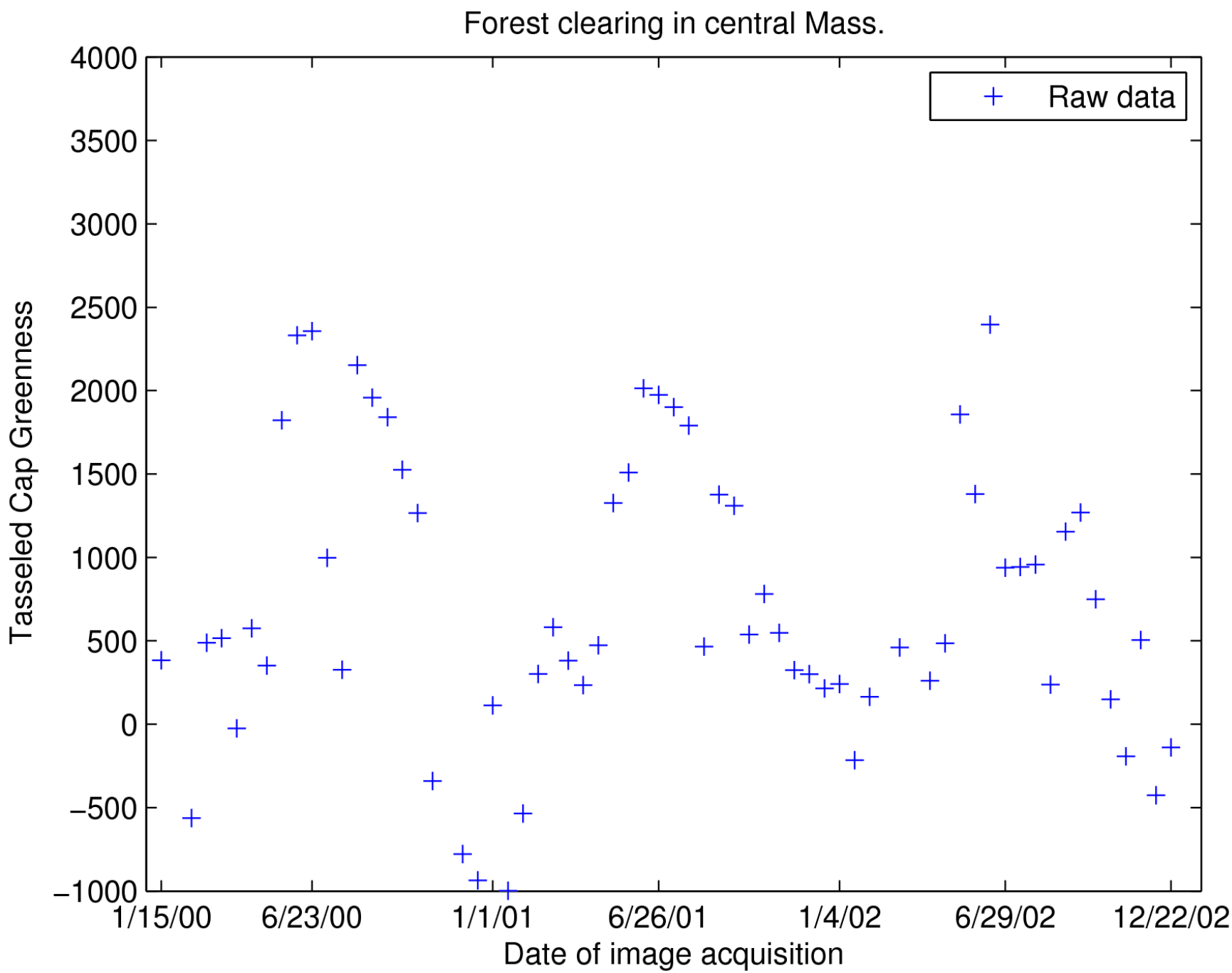
Change Event, Mixed Forest

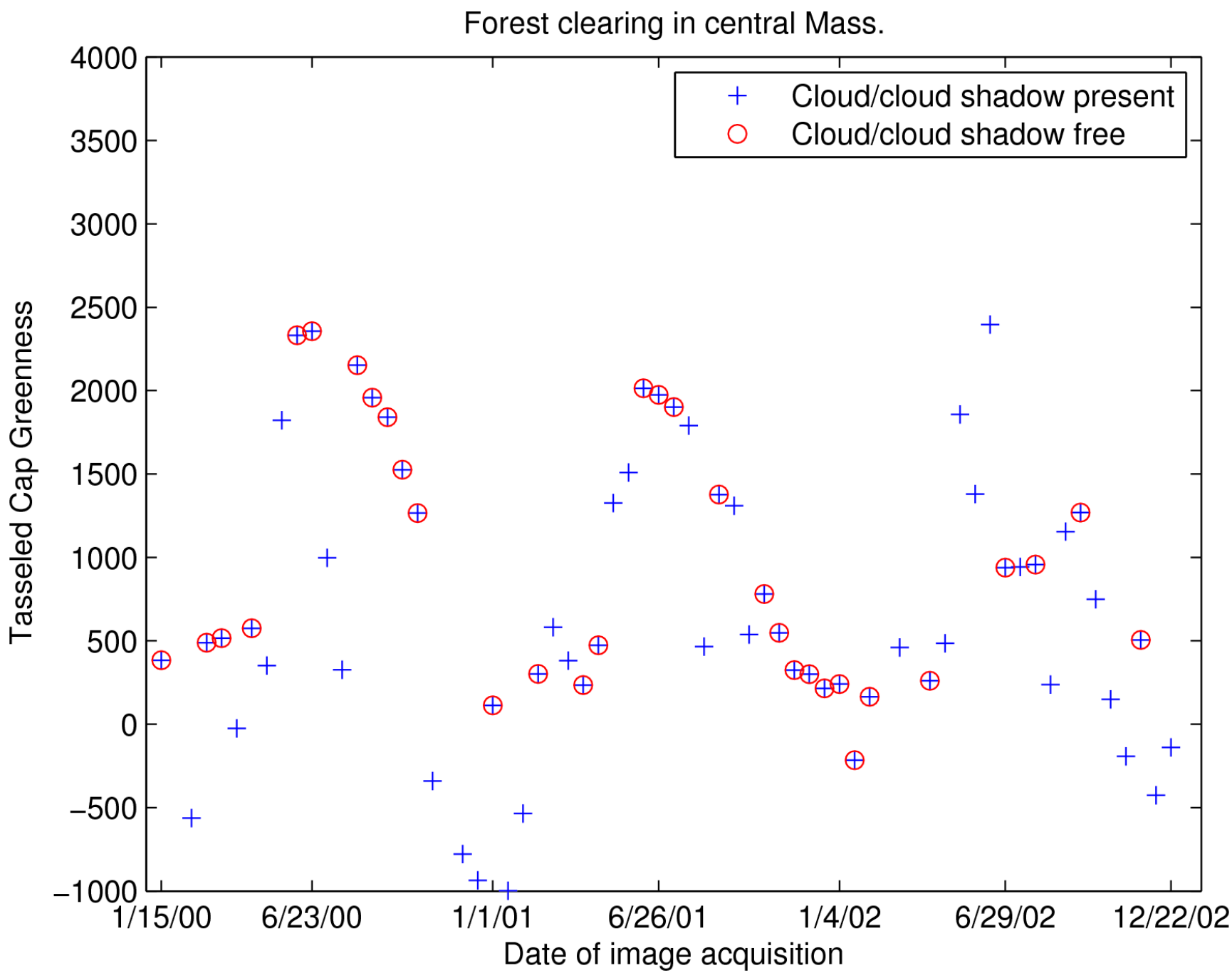

Forest clearing in central Mass.
Raw data
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition

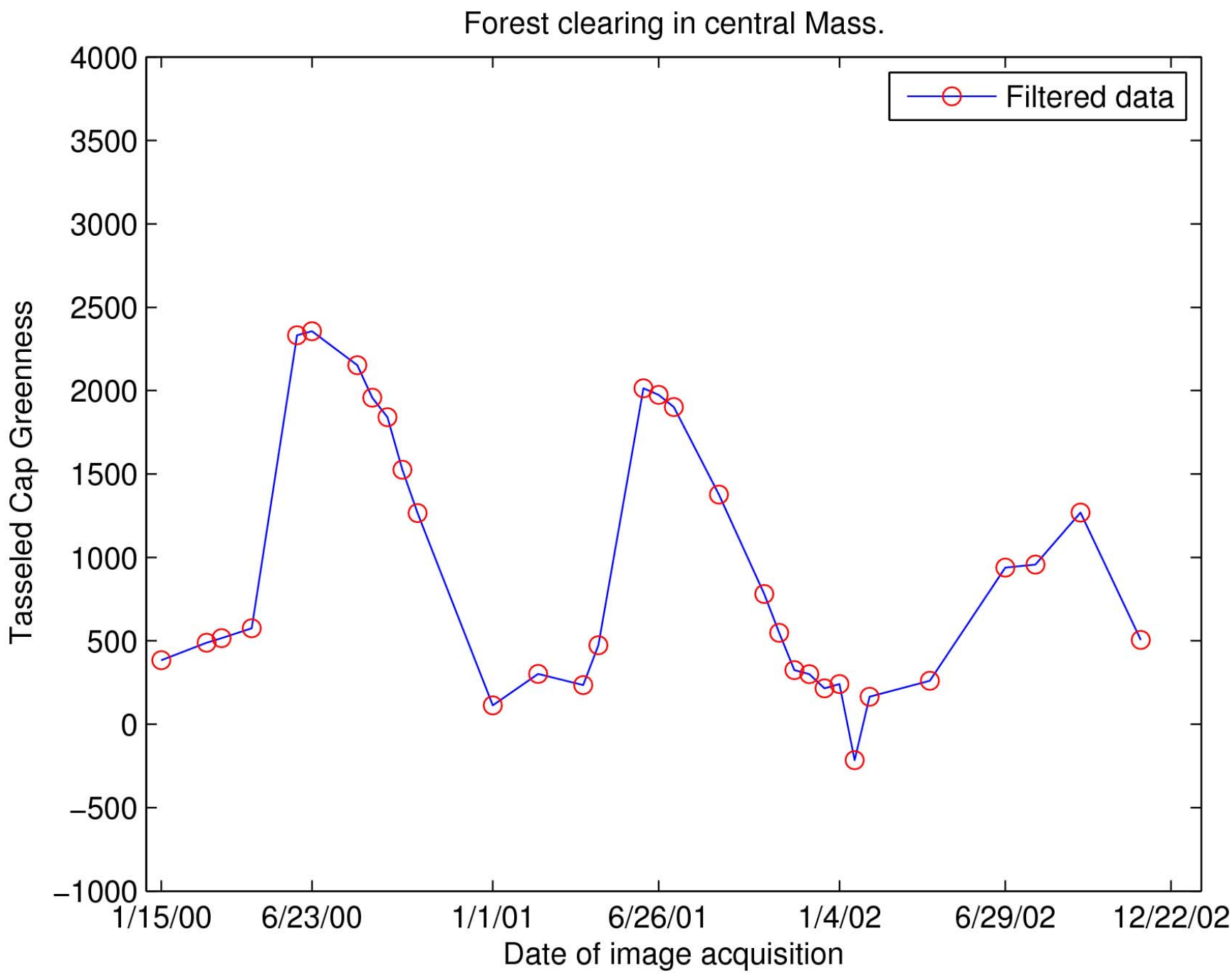

Forest clearing in central Mass.
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition


Forest clearing in central Mass.
Filtered data
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition

Change Event, Broadleaved Forest


Forest clearing in central Mass.
Raw data
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition


Forest clearing in central Mass.
Cloud/cloud shadow present
Cloud/cloud shadow free
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition


Forest clearing in central Mass.
Filtered data
Tasseled Cap Greenness
4000
3500
3000
2500
2000
1500
1000
500
0
−500
−1000
1/15/00
6/23/00
1/1/01
6/26/01
1/4/02
6/29/02
12/22/02
Date of image acquisition

Conclusions

- We should be working toward a global history of the land surface in the Landsat era (deforestation, urban growth, changes in agricultural lands, reforestation, disturbances, fire, …)
- We should be using all the imagery in the archive and a fundamentally different approach that damps out the stochastic noise inherent in land cover classifications of single times
- There are considerable technical challenges that remain
  - More effective cloud and shadow screening
  - New tools based on analysis of time series of data