

TIMESAT – a program for analyzing time-series of satellite sensor data

Users manual

Users of the TIMESAT program are welcome to contact the authors in order to receive the most updated version of the program. The authors are also happy to answer questions on optimal parameter settings.

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1 Organization of the package

The TIMESAT program package has the following directory structure

```
-- DATA
-- F90
-- MFILES
-- RUN
```

The 10-day maximum-value composites NDVI AVHRR and CLAVR data over West Africa needed for the test runs are in the directory `DATA`. The data are organized in binary image files of dimension 200×200 . The FORTRAN source code and the MATLAB script files reside in the `F90` and `MFILES` directories. The NDVI and cloud file lists (see section 3, Fig. 1 and Fig. 2) needed for a run are placed in the directory `RUN`.

2 Compiling and linking

The program package comes with an executable file, `TIMESAT.EXE`, which is placed in the `F90` directory. If needed the source code residing in the `F90` directory can be compiled using a Compaq F90 compiler for Windows. To compile: start a DOS window, change to the `F90` directory and give the commands

```
>f90 -c /check:bounds /traceback *.f90
>link *.obj /out:timesat.exe
```

3 Input parameters to TIMESAT

The TIMESAT program can be used in MATLAB or image mode. In MATLAB mode the user interactively steps through the pixels. For each pixel the program outputs a number of ASCII files that can be processed by the M-files in the `MFILES` directory. This is useful for debugging purposes and for testing parameter settings for the program. In image mode the program automatically loops through all pixels and outputs a number of image files of seasonal parameters.

To run TIMESAT the user must prepare two text files containing, respectively, a list of the NDVI image files and the cloud image files to be read. In addition a number of input parameters have to be supplied.

Input parameters

1. Number of data points in the time-series

A time-series comprises three years of data. Using 10-day maximum-value composites the number of data points is $3 \times 36 = 108$. Using daily data the number of data points is $3 \times 365 = 1095$. The program allows time-series with any number of data points.

2. Name of the NDVI file list

The NDVI file list is a text file containing a list of the NDVI image files to be read. The first line in the file gives the number of image files and should equal the number of data points in the time-series. As an example part of the NDVI file list `ndvilistwa.txt`, which is placed in the `RUN` directory, is given below.

```

108
..\data\wa_nd98011.img
..\data\wa_nd98012.img
..\data\wa_nd98013.img

.....

..\data\wa_nd00121.img
..\data\wa_nd00122.img
..\data\wa_nd00123.img

```

Figure 1: The NDVI file list `ndvilistwa.txt`

3. Format of the NDVI image files; 1=byte, 4=real

The image files should be in unformatted binary format, without header data. To correctly read the image files the format needs to be specified. Byte format (1) is 8-bit unsigned integers with values between 0 and 255. Real format (4) is 32-bit single-precision real values in Intel byte order.

4. Number of columns in the image files.

To correctly read the image files the number of columns needs to be specified.

5. Rows to begin and end processing.

6. Columns to begin and end processing.

It is possible to process selected parts of an image. Specifically, it is possible to process along a horizontal line (rows to begin and end processing are equal) and a vertical line (columns to begin and end processing are equal).

7. Range for which NDVI data are regarded as missing.

NDVI data in this range are regarded as missing and their weights are set to zero.

8. Number of consecutive missing data points, number of total missing data points.

Data points with the weight zero are considered as missing. If the number of consecutive missing data points or the number of total missing data points in the time-series are greater than the specified numbers, then the processing of the time-series is terminated.

9. Cloud image files; 1=yes, 0=no

Specify if cloud image files should be used or not.

10. Name of the cloud file list

The cloud file list is a text file containing a list of the cloud image files to be read. The first line in the file gives the number of image files and should equal the number of data points in the time-series.

As an example part of the NDVI file list `cloudlistwa.txt`, which is placed in the `RUN` directory, is given below.

```
108
..\data\wa_c198011.img
..\data\wa_c198012.img
..\data\wa_c198013.img

.....

..\data\wa_c100121.img
..\data\wa_c100122.img
..\data\wa_c100123.img
```

Figure 2: The cloud file list `cloudlistwa.txt`

11. **Number of intervals in the cloud image files.**

12. **Weight together with upper and lower boundaries for the intervals.**

The cloud image files contain some sort of classification indicating presence or absence of clouds. For CLAVR data values lie between 1 and 30, and represent the three broad groups; cloudy (1 – 11), mixed (12 – 21), and clear (22 – 30). Each cloud interval is assigned a weight. The weights are then transformed into measurement uncertainties σ using the relation

$$\sigma = \frac{1}{w + 0.0001}. \quad (1)$$

13. **Cutoff for spike, noise and desert.**

NDVI data are known to contain single spikes due to detector problems etc. To identify single spikes one may look at

$$\min(|I_i - I_{i-1}|, |I_i - I_{i+1}|)$$

If this value is greater than the specified cutoff for spike then the weight w_i corresponding to the data value I_i is set to zero.

In areas with almost persistent cloud coverage the time-series are often very noisy. A measure of the degree of noise is given by

$$\frac{\sum_{i=1}^N w_i |I_i - \tilde{I}_i|}{\sum_{i=1}^N w_i}$$

where \tilde{I}_i is the NDIV value from a running window averaging. If the weighted sum of differences is greater than the cutoff for noise the processing of the time-series is terminated.

In arid areas, such as deserts, the variation of the time-series is very small. A measure of the variation is given by

$$\frac{\sum_{i, I_i > I_0} w_i I_i}{\sum_{i, I_i > I_0} w_i} - \frac{\sum_{i, I_i < I_0} w_i I_i}{\sum_{i, I_i < I_0} w_i}$$

where I_0 is the weighted average of all NDVI values. If the difference above is smaller than the cutoff for desert the processing of the time-series is terminated.

14. **Harm (1/0) ; Gauss (1/0) ; output second season (1/0).**

Savitzky-Golay filtering is always performed. Fits to the combined polynomial and harmonic basis and to the asymmetric Gaussian functions are optional. Processing of the second season is also optional.

15. **Fraction of amplitude used to determine the number of seasons.**

If the amplitude of the secondary maximum from the fit to the combined polynomial and harmonic basis exceeds a certain fraction of the amplitude of the primary maximum we have two annual seasons. For cases where the amplitude of the secondary maximum is smaller, the number of annual seasons is set to one.

16. **Number of upper envelope iterations.**

17. **Multiplicative factors for the iterations.**

To take into account that most noise, even for data classified as clear by the cloud mask, is negatively biased, the determination of the parameters of the fitting function is done iteratively. In the first iteration the parameters are obtained by solving the system of normal equations with σ_i obtained from the ancillary cloud data. Data points above the function of the first fit are thought of as being more important, and in the next iteration the system is solved with the σ_i multiplied by some factor. The factor for the first iteration should always be set to one. A small factor, e.g. 0.1, for the second iteration strongly forces the fitted function to adopt to the upper envelope.

18. **One- and two-season windows for Savitzky-Golay.**

Global window settings for Savitzky-Golay.

19. **Parameters for adaptive Savitzky-Golay; *winfact*, n_1 and n_2**

The Savitzky-Golay procedure is adaptive. If, in the specified global window, the range of NDVI values is larger than a factor *winfact* of the seasonal amplitude the window is tighten by n_1 if we have one annual season and by n_2 if we have two annual seasons.

20. **Parameters for local fits to asymmetric Gaussians; n and *sigfact***

In the asymmetric Gaussian method local functions describing the left minimum, the central peak and the right minimum are merged to a global function. The fitting of the local functions can be modified by multiplying the σ in centrally placed subinterval of length L/n with a factor *sigfact*. Here L is the length of the full fitting interval. A small value of *sigfact*, say 0.1, makes the central part of the fitting interval relatively more important.

21. **Boundaries for a_2 and a_4**

22. **Boundaries for a_3 and a_5**

The parameters a_2 and a_4 determine the width of the left and right halves of the asymmetric Gaussian. The values depend on the number of data points in the time-series. The parameters determine

the shape of the function. Large values of a_3 and a_5 make the fitted function look like a top hat.

23. MATLAB processing; 1=yes, 0=no

Determine if processing should be in MATLAB or image mode.

24. Total number of output files

25. Specify the output files

TIMESAT outputs files with the following properties

- 1) time for which the left edge has increased to the 10 % level
- 2) time for which the left edge has increased to the 90 % level
- 3) time for which the right edge has decreased to the 10 % level
- 4) time for which the right edge has decreased to the 90 % level
- 5) average of left and right minimum values (base level)
- 6) time for the peak of the season
- 7) NDVI value for the peak
- 8) seasonal amplitude
- 9) asymmetry coefficient
- 10) large seasonal integral
- 11) small seasonal integral
- 12) number of annual growing seasons

Specify output files from the list above.

26. File type for output; 0=ASCII, 1=binary

Select file type for the output files. For ASCII files the M-file `outing.m`, residing in the `MFILES` directory, can be used to display the properties. For binary files IDRISI, PCI, or any equivalent image processing software can be used.

27. 0=No function files, 1=Sav-Gol, 2=harmonic, 3=asym. Gauss

Write values of the fitted function for the central year as images.

4 Test run in MATLAB mode

4.1 Input

Open a DOS window. Add F90 to the search path and change to the directory RUN. Complete the following dialog

```
>timesat
```

```
-----  
T I M E S A T  
-----
```

A program for processing time-series of satellite sensor data

written by

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```
Number of data points in the time-series  
>108  
Name of the NDVI file list  
>ndvilistwa.txt  
Format of the NDVI image files; 1=byte, 4=real  
>1  
Number of columns in the image files  
>200  
Rows to begin and end processing  
>100,110  
Columns to begin and end processing  
>100,100  
Range for which NDVI data are regarded as missing  
>0,2  
Number of consecutive missing data points, number of total missing data points  
>5,10  
Cloud image files; 1=yes, 0=no  
>1  
Name of the cloud file list  
>clavrlistwa.txt  
Number of intervals in cloud image files  
>3  
Weight together with lower and upper boundaries for interval 1  
>0.0,0,12  
Weight together with lower and upper boundaries for interval 2  
>0.7,13,22  
Weight together with lower and upper boundaries for interval 3  
>1.0,23,31  
The TIMESAT program looks for single spikes in the data. In addition it  
performs test to detect noisy time-series as well as time-series with  
very little variation, that is typical for deserts. By setting the cutoff  
for noise to something high like 999 this check is turned of. The desert  
check is turned of by setting the cutoff to 0.  
  
Cutoff for spike, noise, desert.  
>60,999,0
```

```

Harm, 1/0 ; Gauss, 1/0 ; output second season, 1/0
>1,1,0
  Fraction of amplitude used to determine the number of seasons
>0.8
  Number of upper envelope iterations. No more than three
>2
  The multiplicative factor for iteration 1 should be set to 1
  For the remaining iterations the factors should be between 0
  and 1. A small value, say 0.1, strongly forces the fitted
  function to adopt to the upper envelope of the NDVI

  Multiplicative factor for iteration 1
>1
  Multiplicative factor for iteration 2
>0.1
  One and two-season windows for Savitzky Golay
>6,3
  The Savitzky Golay procedure is adaptive. If, in the specified window,
  the range of NDVI values is larger than a factor winfact of the seasonal
  amplitude then the window is tighten by n1 if we have one annual season
  and by n2 if we have two annual seasons.

  Parameters for adaptive Savitzky-Golay; winfact, n1 and n2
>0.4,2,0
  In Gauss local functions describing the left minimum, the central peak,
  the right minimum are merged to a global function. When fitting the
  local functions it is possible to modify the weighting within the
  central part of the fitting interval. The length of the central part
  is L/n where L is the length of the total interval. In the central
  part of the interval the uncertainty sigma is multiplied with some
  factor sigfact in the range between 0 and 1. A small value of sigfact,
  say 0.1, makes the central part relatively more important.

  Parameters for local fits to asymmetric Gaussians; n, sigfact
>3,0.8
  Set boundaries for the non-linear parameters a(2),...,a(5) in the asymmetric
  Gaussian function. The values are dependent on the number of data points, npt,
  in the time-series.

  Boundaries for a(2) and a(4). Guide values are npt/54, npt/6
>2,18
  Boundaries for a(3) and a(5). Guide values are 2 and 6
>2,6
  MATLAB processing; 1=yes, 0=no
>1
  Image file          1 opened
  Image file          2 opened
  Image file          3 opened

  .....

  Mask file           106 opened
  Mask file           107 opened
  Mask file           108 opened

  Line =              100 Pixel =              100

```


Savitzky-Golay		
Left 10% value	45.88594	172.9047
Right 10% value	75.54305	164.6113
Season value	58.41906	211.8763
Base level, amplitude	163.9535	48.04509

Harm		
Left 10% value	45.83022	171.3545
Right 10% value	76.60297	163.2566
Season value	58.06252	209.1122
Base level, amplitude	162.3571	49.48502

Asymmetric Gauss		
Left 10% value	48.08255	174.5426
Right 10% value	74.76913	166.0228
Season value	57.58277	210.2740
Base level, amplitude	165.8361	44.46579

Do you want to continue (Y/N)

>y

.....

Finished

4.2 Logging the input

The input is logged and written to a file `input.txt` that is displayed in Fig. 3. This file can be used as input to the TIMESAT. In this case simply write

```
>timesat input.txt
```

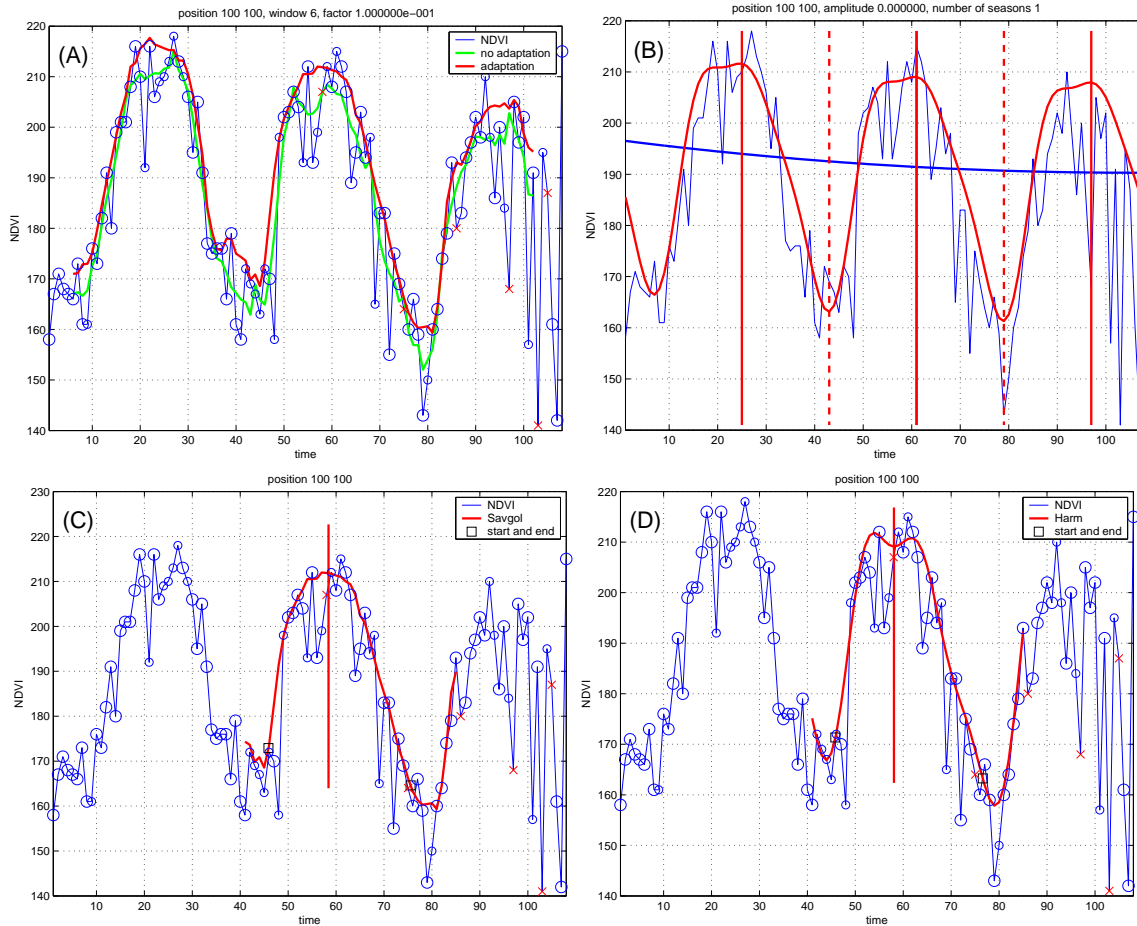
and the program will read all the needed input parameters from the file. Modifying an existing input file is perhaps the most convenient way to run the TIMESAT program.

```
108          Number of data points in the time-series
ndvlistwa.txt
  1          Format of the NDVI image files; 1=byte, 4=real
200          Number of columns in the image files
100 110      Rows to begin and end processing
100 100      Columns to begin and end processing
  0  2       Range for which NDVI data are regarded as missing
  5  10      Number of allowed missing data points
  1          Cloud image files; 1=yes, 0=no
clavlistwa.txt
  3          Number of intervals in cloud image files
0.0  0  12   Weight, lower and upper boundaries for interv. 1
0.7  13  22   Weight, lower and upper boundaries for interv. 2
1.0  23  31   Weight, lower and upper boundaries for interv. 3
60.0 999.0 0.0 Cutoff for spike, noise, desert
  1  1  0     Harm, Gauss, out sec. season., 1/0
0.8          Fraction of amplitude to determine the number of seasons
  2          Number of upper envelope iterations
1.0          Multiplicative factor for iteration 1
0.1          Multiplicative factor for iteration 2
  6  3       One and two-season windows for Savitzky Golay
0.4  2  0     Parameters adapt. Sav-Gol
  3  0.8     Local fitting parameters for Gauss
2.0 18.0     Boundaries for a(2) and a(4)
2.0  6.0     Boundaries for a(3) and a(5)
  1          MATLAB processing; 1=yes, 0=no
```

Figure 3: The logged input file `input.txt` from a run in MATLAB mode.

4.3 View the fits

For each pixel TIMESAT outputs a number of files that can be used to view the time-series and cloud data together with the different function fits. The files are read by the M-files in the MFILES directory. To view the time-series and cloud data together with the different function fits: start MATLAB, add the MFILES directory to the MATLAB path, select the RUN directory as the MATLAB Working Directory and type the name of the appropriate M-file at the MATLAB Command Prompt. Observe that the fits should be viewed before TIMESAT is stepped to a new pixel by answering y to the question 'Do you want to continue (Y/N)'. In Fig 4. plots of the different fits to the time-series in pixel 100,100 are displayed.



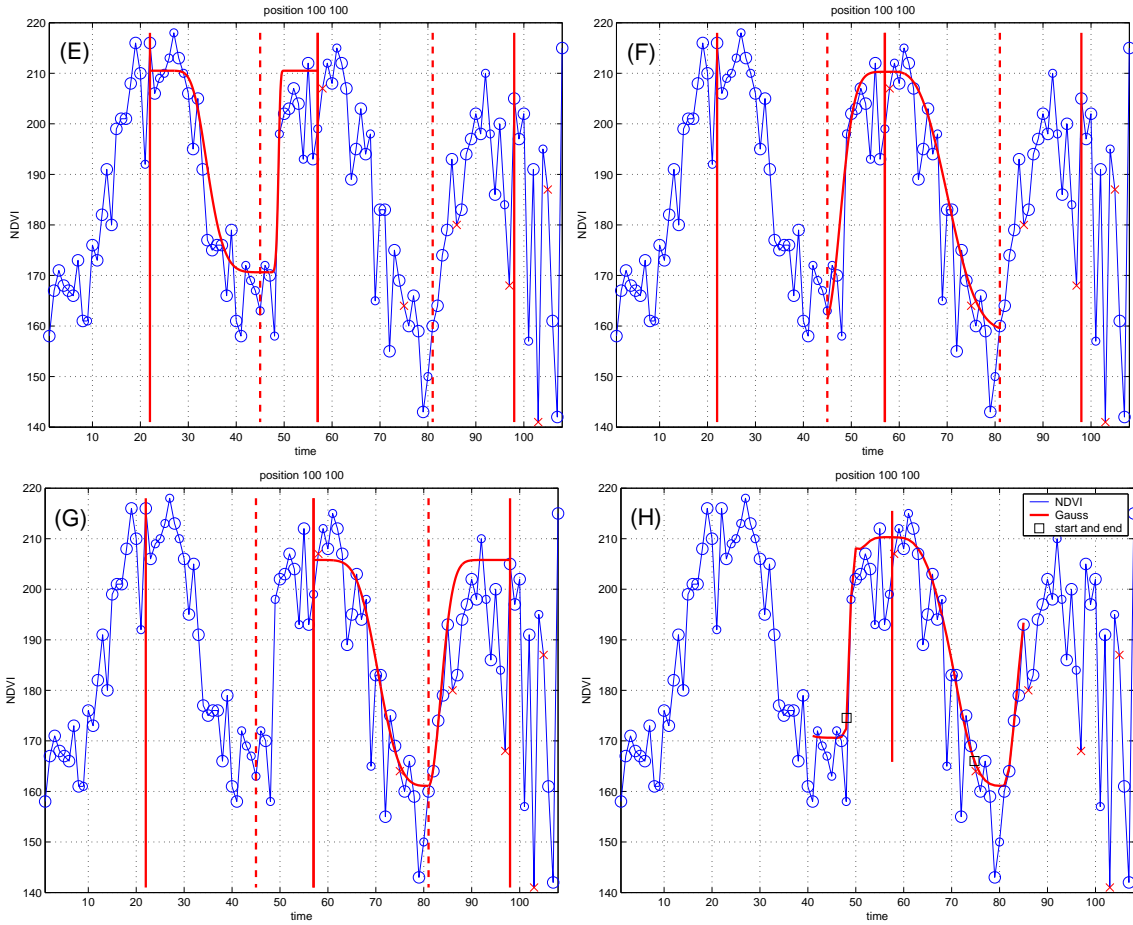


Figure 4: (A) Savitzky-Golay filtered values displayed using `data.m`. Cloudy pixels with weight $w_i = 0$ are marked with red crosses. The radii of the blue circles are proportional to the weight w_i of a pixel. A circle with a large radius indicate that this point is important in the initial least-squares procedure. The M-file `data.m` allows the user to test different settings for windows and upper envelope weighting. (B) Fitted polynomial and harmonic functions used to determine the number of annual seasons displayed using `season.m`. (C) Savitzky-Golay filtered values together with the start and end of the season displayed using `savgol.m`. (D) Fitted polynomial and harmonic functions together with the start and end of the season displayed using `harm.m`. (E–G) Fitted asymmetric Gaussian functions displayed using `gauss1.m`. (H) Merged asymmetric Gaussian functions together with the start and end of the season displayed using `gauss2.m`.

5 Test run in image mode

5.1 Input

Open a DOS window. Add F90 to the search path and change to the directory RUN. Complete the following dialog

>timesat

```
-----  
T I M E S A T  
-----
```

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Lund University, Lund, Sweden

Number of data points in the time-series
>108
Name of the NDVI file list
>ndvilistwa.txt
Format of the NDVI image files; 1=byte, 4=real
>1
Number of columns in the image files
>200
Rows to begin and end processing
>1,200
Columns to begin and end processing
>1,200
Range for which NDVI data are regarded as missing
>0,2
Number of consecutive missing data points, number of total missing data points
>5,10
Cloud image files; 1=yes, 0=no
>1
Name of the cloud file list
>clavrlistwa.txt
Number of intervals in cloud image files
>3
Weight together with lower and upper boundaries for interval 1
>0.0,0,12
Weight together with lower and upper boundaries for interval 2
>0.7,13,22
Weight together with lower and upper boundaries for interval 3
>1.0,23,31
The TIMESAT program looks for single spikes in the data. In addition it performs test to detect noisy time-series as well as time-series with very little variation, that is typical for deserts. By setting the cutoff for noise to something high like 999 this check is turned of. The desert check is turned of by setting the cutoff to 0.

Cutoff for spike, noise, desert.
>60,999,0

Harm, 1/0 ; Gauss, 1/0 ; output second season, 1/0
>1,1,0
Fraction of amplitude used to determine the number of seasons
>0.8
Number of upper envelope iterations. No more than three
>2
The multiplicative factor for iteration 1 should be set to 1
For the remaining iterations the factors should be between 0
and 1. A small value, say 0.1, strongly forces the fitted
function to adopt to the upper envelope of the NDVI

Multiplicative factor for iteration 1
>1
Multiplicative factor for iteration 2
>0.1
One and two-season windows for Savitzky Golay
>6,3
The Savitzky Golay procedure is adaptive. If, in the specified window,
the range of NDVI values is larger than a factor winfact of the seasonal
amplitude then the window is tighten by n1 if we have one annual season
and by n2 if we have two annual seasons.

Parameters for adaptive Savitzky-Golay; winfact, n1 and n2
>0.4,2,0
In Gauss local functions describing the left minimum, the central peak,
the right minimum are merged to a global function. When fitting the
local functions it is possible to modify the weighting within the
central part of the fitting interval. The length of the central part
is L/n where L is the length of the total interval. In the central
part of the interval the uncertainty sigma is multiplied with some
factor sigfact in the range between 0 and 1. A small value of sigfact,
say 0.1, makes the central part relatively more important.

Parameters for local fits to asymmetric Gaussians; n, sigfact
>3,0.8
Set boundaries for the non-linear parameters a(2),...,a(5) in the asymmetric
Gaussian function. The values are dependent on the number of data points, npt,
in the time-series.

Boundaries for a(2) and a(4). Guide values are npt/54, npt/6
>2,18
Boundaries for a(3) and a(5). Guide values are 2 and 6
>2,6
MATLAB processing; 1=yes, 0=no
>0
The TIMESAT program outputs files with following properties

1. time for which the left edge has increased to the 10 % level
2. time for which the left edge has increased to the 90 % level
3. time for which the right edge has decreased to the 10 % level
4. time for which the right edge has decreased to the 90 % level
5. average of left and right minimum values (base level)
6. time for the peak of the season
7. NDVI value for the peak
8. seasonal amplitude
9. asymmetrycoefficient

10. large seasonal integral
11. small seasonal integral
12. number of annual growing seasons

Total number of output files

>4

Specify the output files

>1

Specify the output files

>7

Specify the output files

>8

Specify the output files

>9

File type for output; 0=ASCII, 1=binary

>0

0=No function files, 1=Sav-Gol, 2=harmonic, 3=asym. Gauss

>0

Image file 1 opened

Image file 2 opened

Image file 3 opened

.....

Mask file 106 opened

Mask file 107 opened

Mask file 108 opened

Line = 1 Pixel = 100

Line = 1 Pixel = 200

Line = 2 Pixel = 100

Line = 2 Pixel = 200

.....

Line = 200 Pixel = 100

Line = 200 Pixel = 200

Finished

5.2 Logging the input

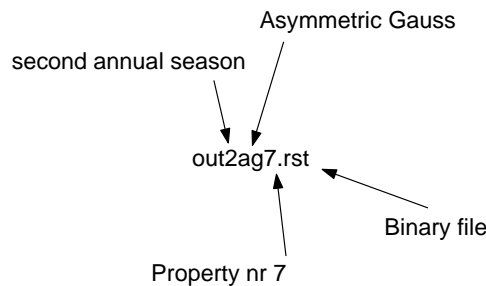
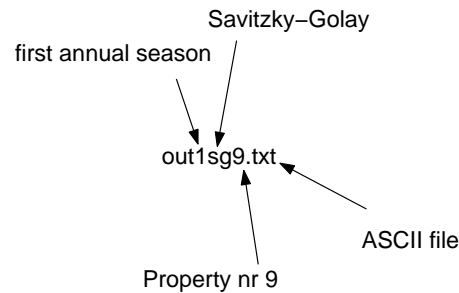
The logged input is written to the file `input.txt` which is displayed in Fig. 5

```
108          Number of data points in the time-series
ndvlistwa.txt
  1          Format of the NDVI image files; 1=byte, 4=real
200          Number of columns in the image files
  1  200     Rows to begin and end processing
  1  200     Columns to begin and end processing
  0   2     Range for which NDVI data are regarded as missing
  5  10     Number of allowed missing data points
  1         Cloud image files; 1=yes, 0=no
clavrlistwa.txt
  3          Number of intervals in cloud image files
0.0  0  12  Weight, lower and upper boundaries for interv. 1
0.7  13  22  Weight, lower and upper boundaries for interv. 2
1.0  23  31  Weight, lower and upper boundaries for interv. 3
60.0 999.0 0.0 Cutoff for spike, noise, desert
  1   1   0  Harm, Gauss, out sec. season., 1/0
0.8          Fraction of amplitude to determine the number of seasons
  2          Number of upper envelope iterations
1.0          Multiplicative factor for iteration 1
0.1          Multiplicative factor for iteration 2
  6   3          One and two-season windows for Savitzky Golay
0.4   2   0  Parameters adapt. Sav-Gol
3.0  0.8        Local fitting parameters for Gauss
2.0  18.0       Boundaries for a(2) and a(4)
2.0   6.0       Boundaries for a(3) and a(5)
  0          MATLAB processing; 1=yes, 0=no
  4          Number of output files
  1          time for which the left edge has increased to the 10 % level
  7          NDVI value for the peak
  8          seasonal amplitude
  9          asymmetrycoefficient
  0          File type for output; 0=ASCII, 1=binary
  0          0= No function files, 1=Sav-Gol, 2=harmonic, 3=asym. Gauss
```

Figure 5: The logged input file `input.txt` from a run in image mode.

5.3 View output files

TIMESAT outputs a number of image files containing seasonal parameters. The naming convention is illustrated by some examples.



The binary image files can be viewed using IDRISI, PCI, or any equivalent image processing software. The ASCII files can be viewed using the M-file `outimg.m`. To view property 1 (time for which the left edge has increased to the 10 % level) from the Savitzky-Golay filtered values: start MATLAB, add the `MFILES` directory to the MATLAB path, select the `RUN` directory as the MATLAB Working Directory and complete the following dialog at the MATLAB Command Prompt

```
>outimg
Give the number of columns
>200
Give the number of rows
>200
Give name of file
>out1sg1.txt
Mean value
    48.5107

Standard deviation
    6.8520
```

```
The data range [m - n * std,m + n * std] is displayed
Give n
>2
More plots? (1) Yes, (0) No
>0
```

The displayed data range is centered around the mean value. To get good scalings a number of different values of n should be tested. In Fig. 6 a number of seasonal images are displayed.

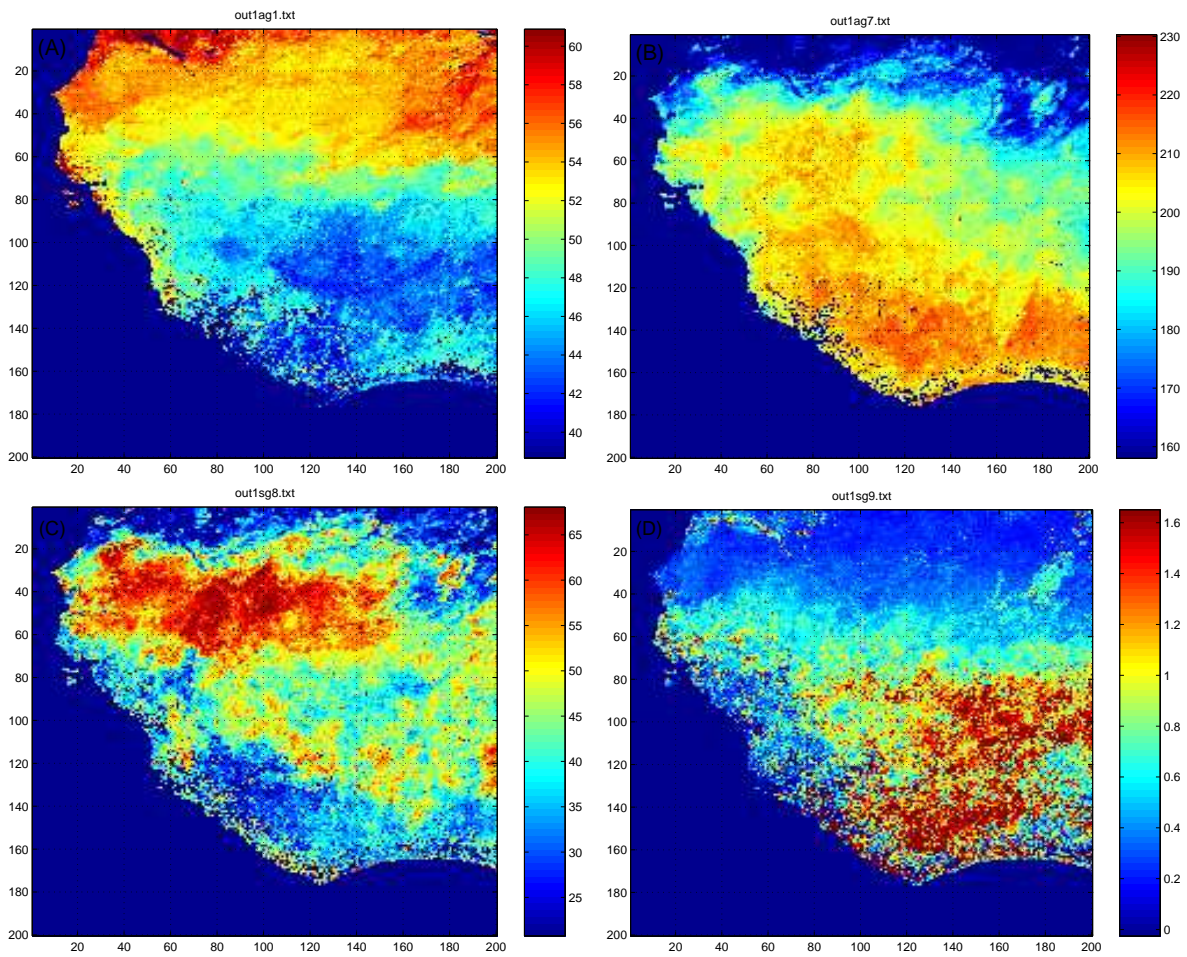


Figure 6: (A) start of the first annual growing season from fitted asymmetric Gaussians. (B) NDVI value for the peak of the first annual growing season from fitted asymmetric Gaussians. (C) Amplitude of the first annual growing season from Savitzky-Golay filtered values. (D) Asymmetry coefficient of the first annual growing season from Savitzky-Golay filtered values.