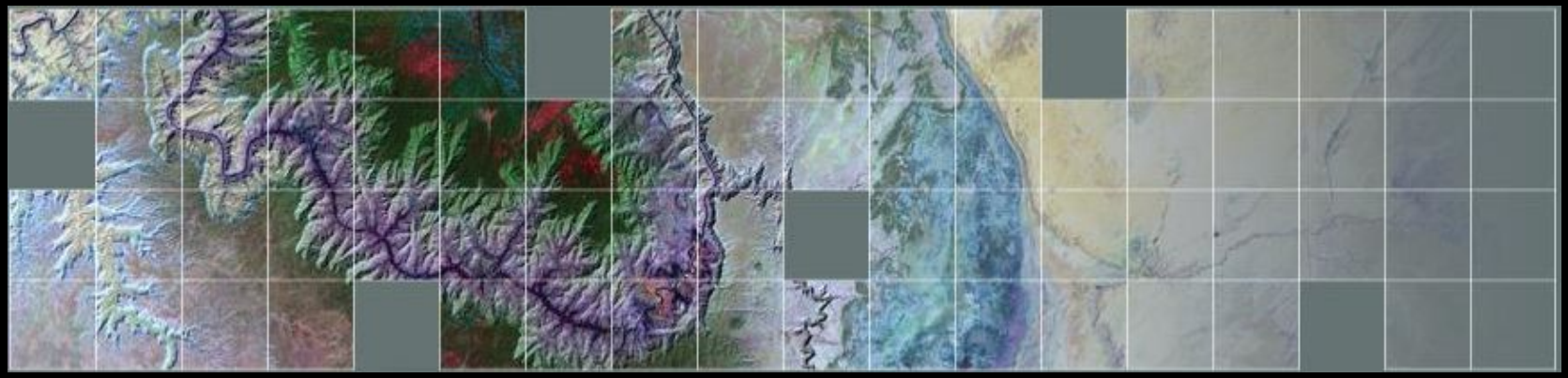
USGS
science for a changing world

Climate and Land Use Change
Earth Resources Observation and Science (EROS) Center



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January 5, 2017

[1] SGT, Inc., Contractor to the USGS EROS Center. 47914 252nd Street, Sioux Falls, SD 57198. Work performed under USGS contract G15PC00012.

U.S. Department of the Interior
U.S. Geological Survey

Stinger Ghaffarian Technologies

Agenda

- Background
- ARD
- Basic Terminology
- Standard Modeling Components
    - Variogram (Madogram)
    - LASSO Regression
    - Robust Regression
    - Tmask
- Walk Through Change Detection Processing Steps
- Describe Output Results

Background, Context

- Provide understanding of Continuous Change Detection (CCD) algorithm as implemented to aid evaluation, analysis, recommendations for future updates
- Corresponds to Matlab Version 12.30 used for processing Chesapeake Bay
- Implemented in python
  - Open source, eliminating licensing restrictions and cost
  - Platform-independent
  - Information Warehouse + Data Store (IW + DS) interaction
  - Science Execution Environment (SEE) processing
  - python and associated tools, modules, common to HPC Systems
  - Increase modularity, decrease complexity
- Enable sending results to Information Warehouse for subsequent interaction
- Future ARD access through API, eliminating file-system data management:

"Answers, Not Data"

ARD

- Pixel Alignment
- Consistent Projection
- Standardized Extents (tiles)
- Standard Level 2 Products Suite
- Eliminates Swath Overlap
- Adds Side-lap, (Temporal Density)
- User-defined Area of Interest (AOI)
- ARD Named Future Standard Landsat Product

Landsat WRS-2 Side-lap*

Table 5.1 Image Sidelap of Adjacent Swaths	
Latitude (degrees)	**Image Sidelap (%)**
0	7.3
10	8.7
20	12.9
30	19.7
40	29.0
50	40.4
60	53.6
70	68.3
80	83.9

CONUS:

TX/FL	≈ 24° N	≈ 15.62%
WA/ME	≈ 36° N	≈ 20.28%
Avg.	≈ 30° N	≈ 19.70%

* From the Landsat 7 Data Users Handbook

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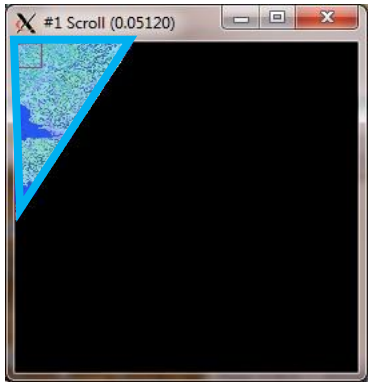
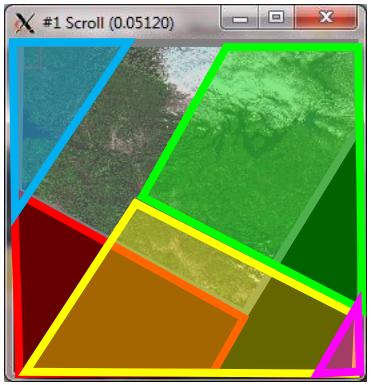
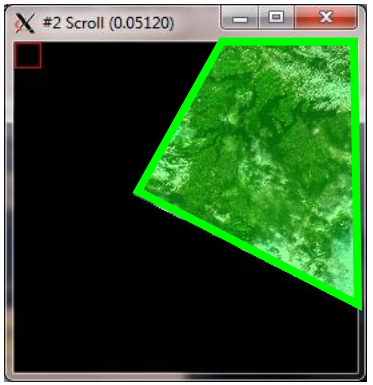
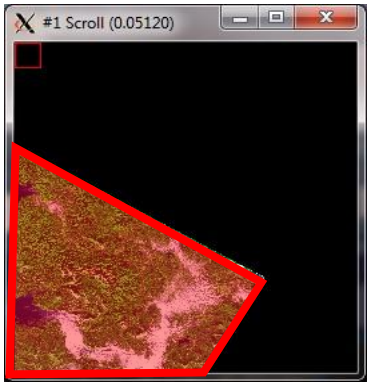
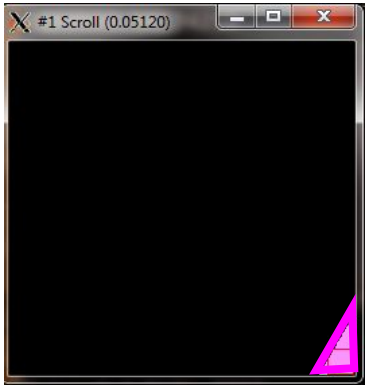
Input – Analysis Ready Data (ARD)
WA grid07 Example, 1982 – 2015 TM, ETM+, OLI/TIRS

	Path 48	Path 47	Path 46	Path 45
Row 27				
Row 28				

Terminology

Model	regression fit of points to a curve
Variogram	Variogram is a description of the spatial continuity of the data, usually the squares of the differences. Madogram is instead the abs of the diffs, and the “distance” between points is ignored.
MEOW	Minimum Expected Observation Window (number of coefficients * 3)
Tmask	time-series mask, outliers determined by regression fit using green (SWIR1) band
Window	current sliding array of X # number of observations (model window, peek window, fit window)
Fit Window	observations that are used to fit a regression model to, subset of the model window
Model Window	observations that are currently represented by a fitted regression model
Peek Window	observations that are currently being analyzed / under statistical scrutiny
Stable Model	generalized fit 4 coefs (min) from LASSO Regression
Detection Bands	subset of spectral bands used to determine outliers and detect change: red, green, NIR, SWIR1, SWIR2
LASSO Regression	Initial first attempt at fitting points to curve, and subsequent start detection, change detection
Robust Regression	more general purpose curve fitting for identifying outliers
Residual	predicted value from a curve fit - actual value, used as a measure of error
Persistent Processing Mask	Application of Tmask, cfmask, etc.., to maks, not eliminate data from input arrays

Current CCD Operational Parameters

Change Probability Threshold

Inverse of chi^2 (0.99, number of detection bands)

```
In [6]: from scipy.stats import chi2
        chi2.ppf(0.99, 5)
Out[6]: 15.086272469388987
```

Outlier Threshold

inverse of chi^2 (***1-1e-6***, number of detection bands)

```
In [5]: from scipy.stats import chi2
        chi2.ppf(1-1e-6, 5)
Out[5]: 35.888186879610423
```

Minimum Number of Consecutive Observations required to identify a change

6

Maximum Number of Model Coefficients Produced

8 (insert FFT graphic)

Clear count threshold percent = 0.25

Snow count threshold percent = 0.75

LASSO Regression lambda value = 20 (limiting cross-validation saves processing time)

pyccd Input Landsat Data

Spectral Band	LT4, LT5, LE7	LC8
	Surface Reflectance (SR) Band #	
Red	1	2
Green	2	3
Blue	3	4
Visible Near InfraRed (NIR)	4	5
Short Wave InfraRed (SWIR) 1	5	6
Short Wave InfraRed (SWIR) 2	7	7
	Brightness Temperature Band # (Top Of Atmosphere (TOA) Band)	
Thermal	6	10
	CFMASK Band	
MASK	cfmask	cfmask

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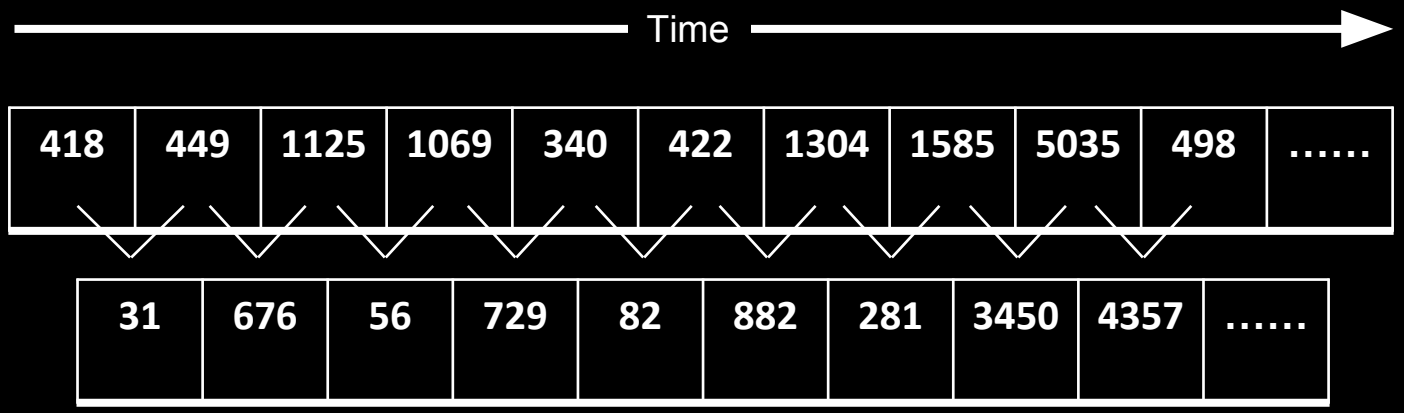
Variogram (Median Madogram) Example

Example Red Band DN Values



Absolute value of differences of consecutive pixels

Median of differences: 676

note: Individual Variograms calculated independently for each band

LASSO Regression

$$C + c_1 \text{date} + c_2 \sin\left(2\pi^* \frac{\text{date}}{365.25}\right) + c_3 \cos\left(2\pi^* \frac{\text{date}}{365.25}\right) + c_4 \sin\left(2^* 2\pi^* \frac{\text{date}}{365.25}\right) + c_5 \cos\left(2^* 2\pi^* \frac{\text{date}}{365.25}\right) + c_6 \sin\left(3^* 2\pi^* \frac{\text{date}}{365.25}\right) + c_7 \cos\left(3^* 2\pi^* \frac{\text{date}}{365.25}\right)$$

C	constant or intercept
C_1	slope or trend line
C_2 thru C_7	sinusoid amplitudes

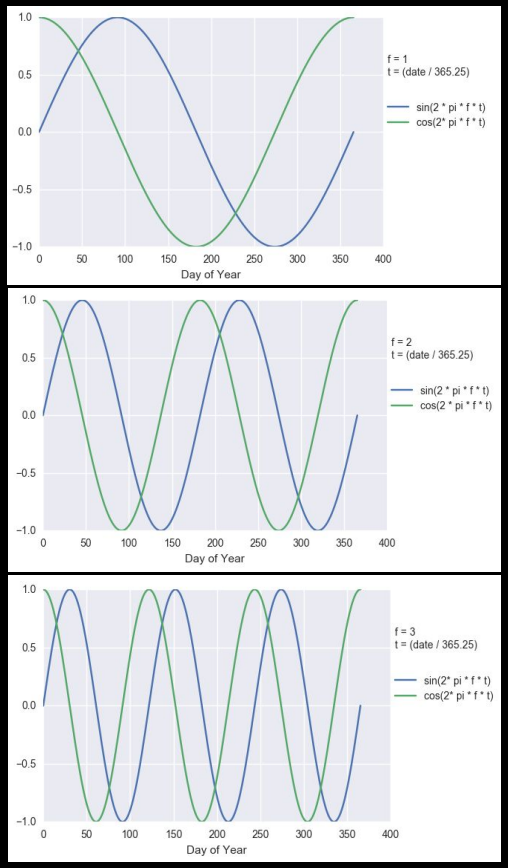
4 Coefficients defined as (referred to as a generalized fit):
$C + C_1 + C_2 + C_3$

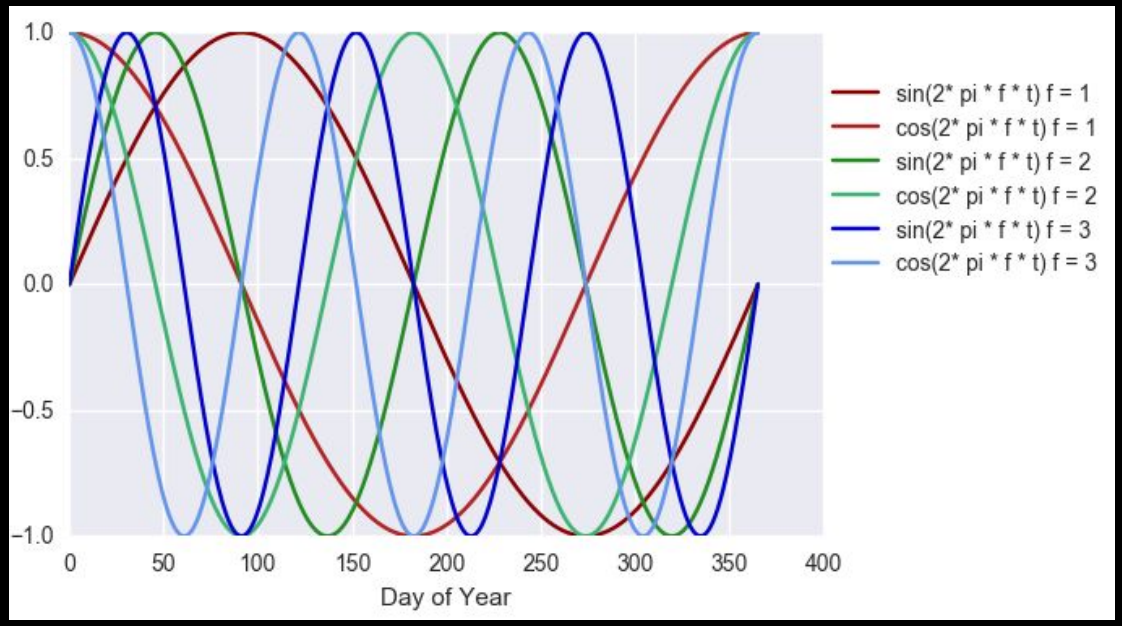
6 Coefficients adds:
$C_4 + C_5$

8 further adds:
$C_6 + C_7$

Minimum number of observations required for a fit is defined as:
number of coefficients (4,6,8) * NUM_OBS_FACTOR (3)

Sine Wave Visualization





Robust Regression
(Ordinary Least Squares)

$$C + C_1 \text{date} + C_2 \cos\left(2\pi * \frac{\text{date}}{365.25}\right) + C_3 \sin\left(2\pi * \frac{\text{date}}{365.25}\right) + C_4 \cos\left(2\pi * \frac{\text{date}}{365.25} * \frac{1}{\text{num yrs}}\right) + C_2 \sin\left(2\pi * \frac{\text{date}}{365.25} * \frac{1}{\text{num yrs}}\right)$$

Number of years refers to the span of years represented by the model window, rounded up

Tmask

Use the Robust Regression method to fit curves for the green and SWIR1 bands, for a given observation window.

If any residual is > the Tmask Threshold
(4.89 * variogram value),
mark the observation as an outlier and update the Persistent Processing Mask

main

if the percentage of clear pixels < clear threshold:
    if the percentage of snow > snow threshold:
        Persistent Snow Procedure
    else:
        Insufficient Clear Procedure
else:
    Standard Procedure

Persistent Snow Procedure

Include observations flagged as snow by the QA

Total observations = snow observations + clear observations

Use only acceptable values (unsaturated)

```
if num  (observations )  > meow size threshold ( default = 12 ):
        for band in bands:
                if thermal band:
                        do a generalized curve fit for entire thermal set
                else:
                        if number of observations < meow size threshold (default=12)
                                set intercept value to constant value
                                set coefficients to zero
                        else:
                                do a generalized  curve fit for observation set
```

Insufficient Clear Procedure

Use the insufficient clear observations

Using the green band, update Persistent Processing Mask to exclude observations exceeding:

green_band_median + 400

Do a generalized curve fit for observation set

Initial Change Detection Setup

Mask out duplicate observations using first of two swath overlap observations

Sort temporally

Convert thermal values from degrees Kelvin to Celsius:

value = value * 10 – 27315

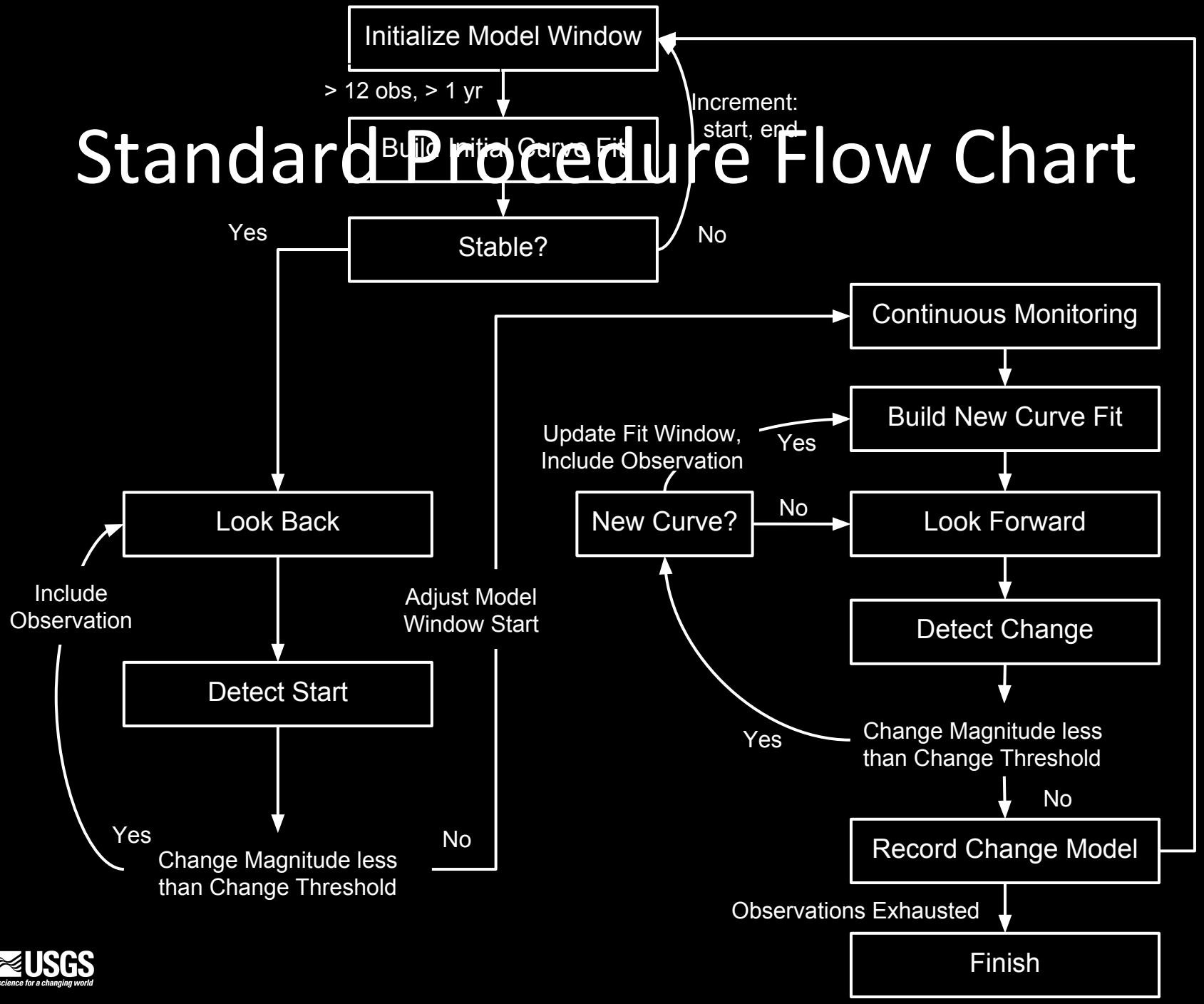
Create mask(s) of values that fall outside of acceptable ranges, considered saturated if > acceptable maximum:

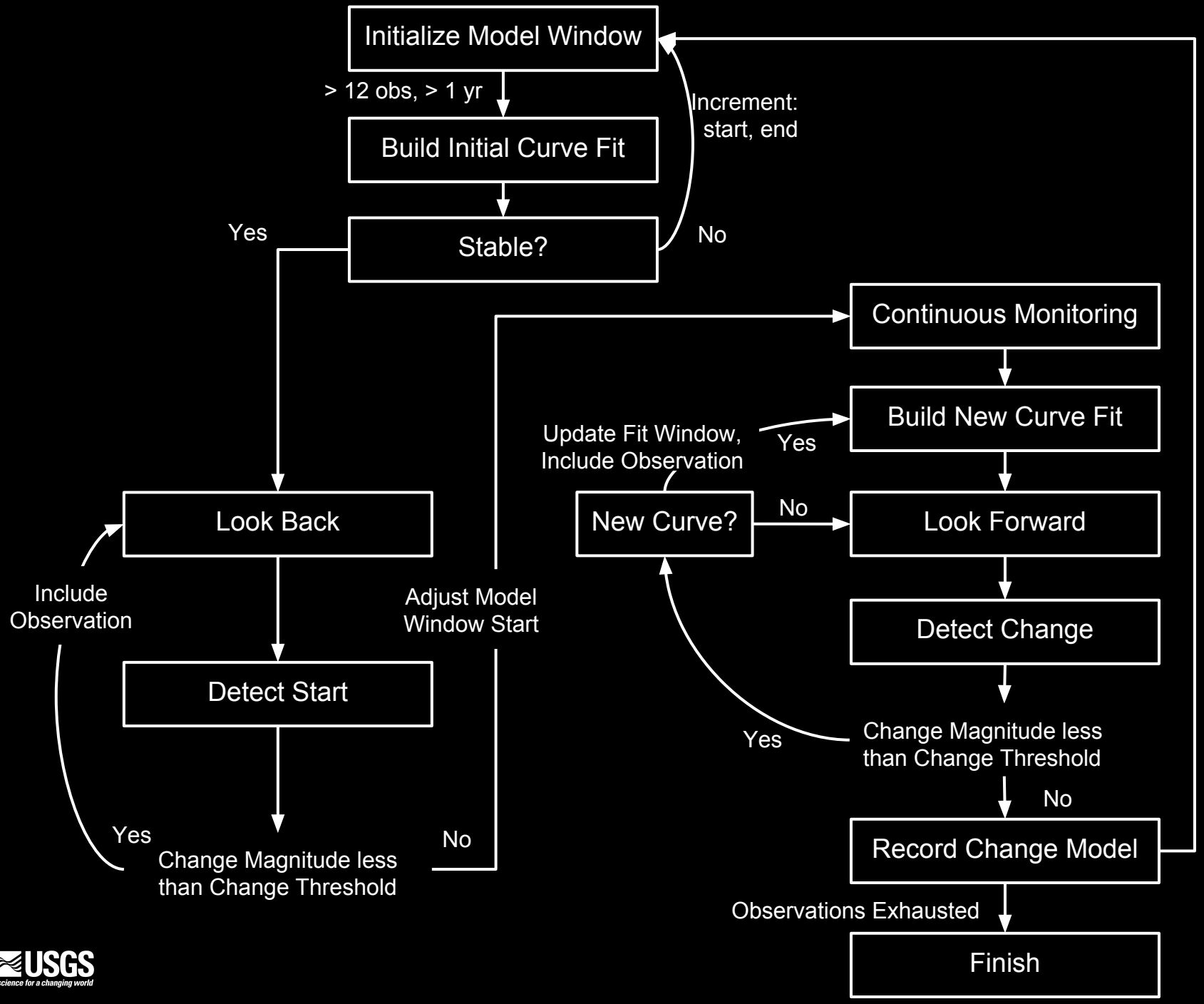
Reflectance acceptable range: 0 -> 10,000

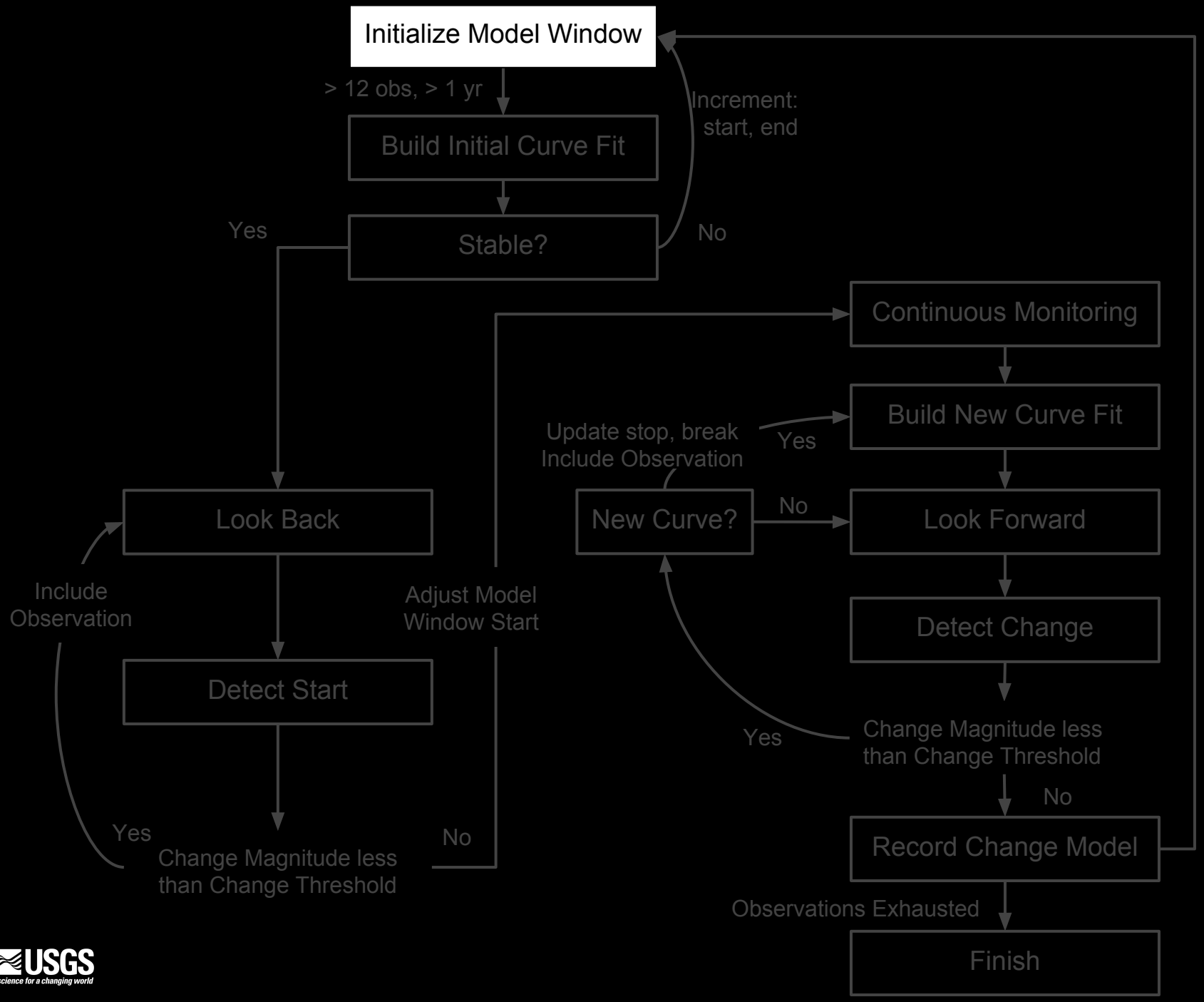
Thermal acceptable range: -9,320 -> 7,070

Create Variogram (madogram) for each band

Standard Procedure Flow Chart




Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
Yes
No
Increment:
start, end
Look Back
Include
Observation
Detect Start
Yes
Change Magnitude less
than Change Threshold
No
Adjust Model
Window Start
Continuous Monitoring
Build New Curve Fit
Update Fit Window,
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Yes
Change Magnitude less
than Change Threshold
No
Record Change Model
Observations Exhausted
Finish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Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Yes
Change Magnitude less
than Change Threshold
No
Record Change Model
Observations Exhausted
Finish

Initialize Model Window

initialize first model window

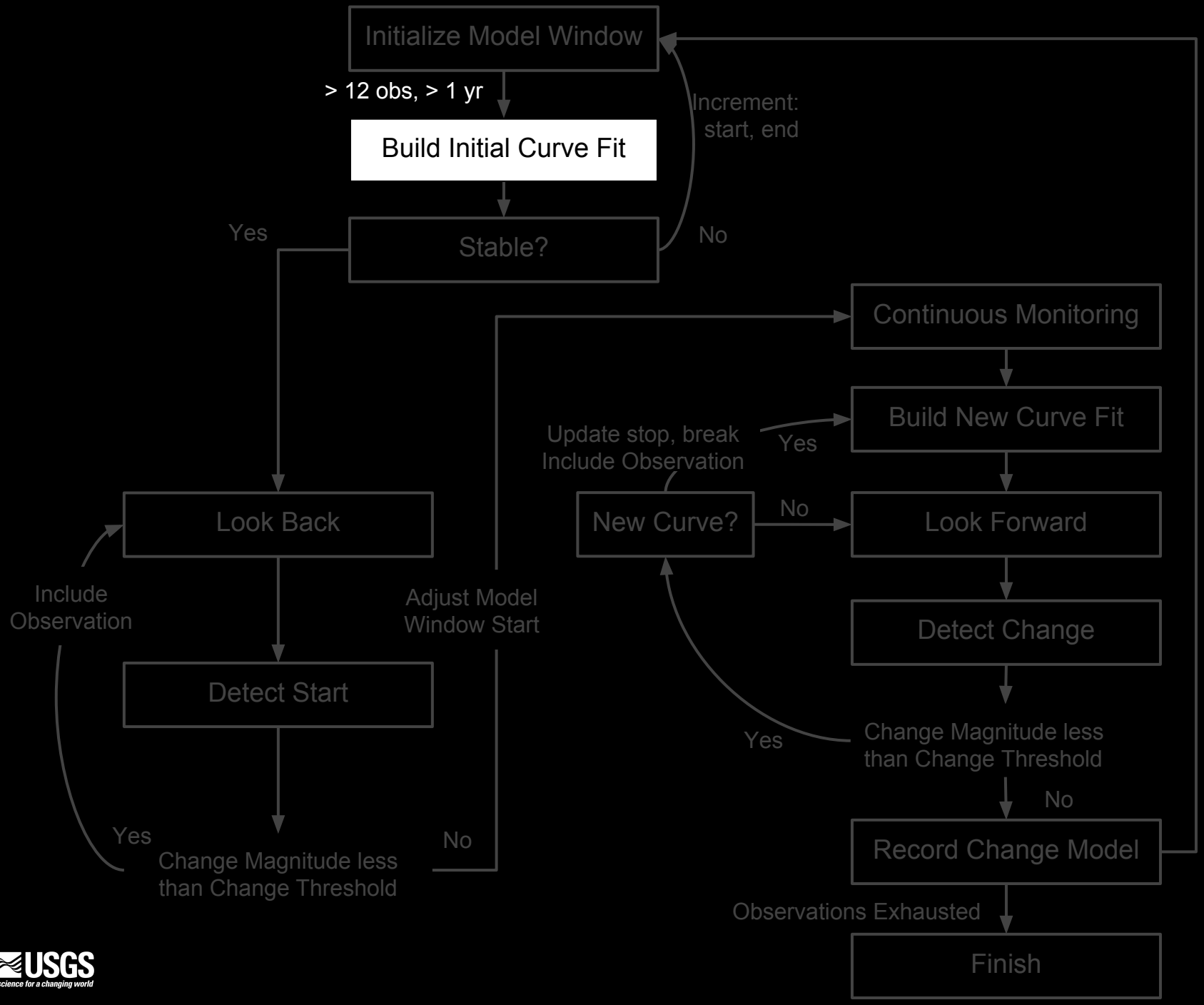
(start is set to previous break point; window size set to contain 12 observations)

while there are clear observations:

mask outliers in current window as defined by tmask

if not enough observations (12) and minimum temporal span (1 year) in the window:

increase window size by 1 continue to the next observation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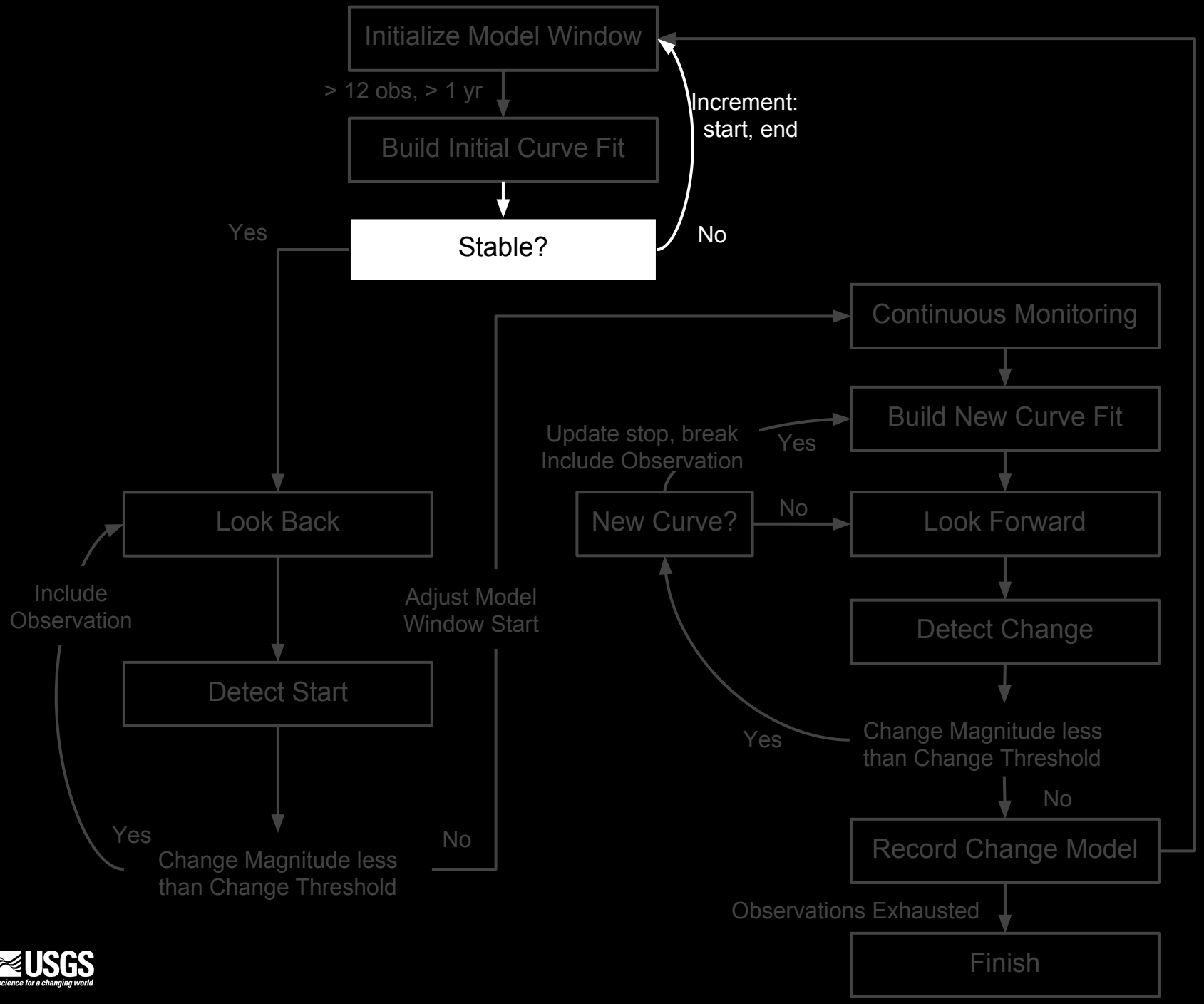
Build Initial Curve Fit

perform LASSO Regression using 4-coefficient model


Initialize Model Window
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Build Initial Curve Fit
Increment:
start, end
Stable?
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Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
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New Curve?
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Look Forward
Detect Change
Change Magnitude less
than Change Threshold
Yes
No
Record Change Model
Observations Exhausted
Finish
Look Back
Include
Observation
Detect Start
Yes
Change Magnitude less
than Change Threshold
Adjust Model
Window Start
No

Stable?

for each of the detection bands (r, g, n, s1, s2)

model slope coef * diff (end – start dates)

check_vals = (|slope| + |first model residual| + |last model residual|) / MAX

(where MAX = max (variogram, model RMSE))

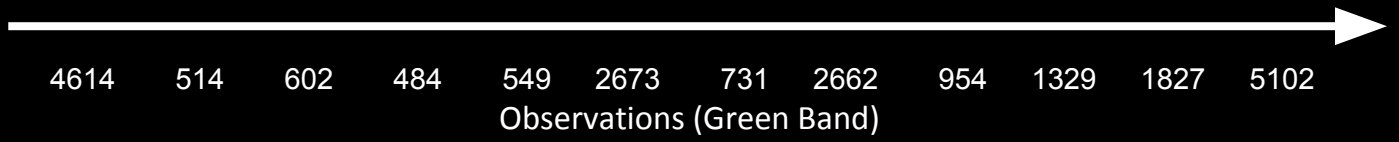
if summation of (check_vals)^2 < change threshold:

stable

else:

increment model window start and end by 1

Stable? (example)



Fitted Model (Green Band)

C = -44782.78

C_1 = 0.062 (slope coefficient)

C_2 = 194.19

C_3 = 0

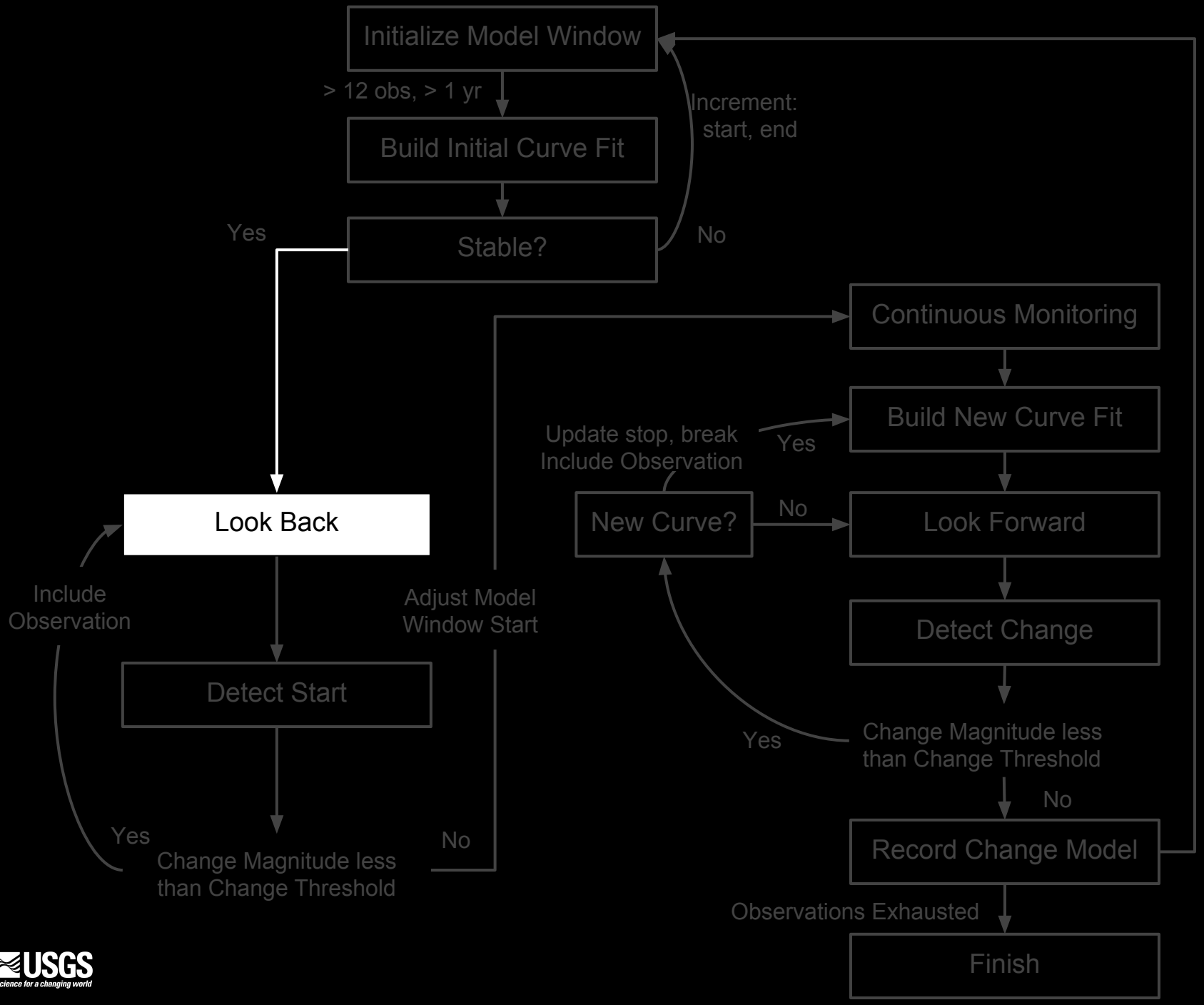
Model Window = start: 724785 end: 725777

First Residual = 200 Last Residual = -56

Green check value = (|0.062 * (725777 - 724785)| + |200| + |-56|) / 32.56 = 9.751351351351351

Red = 10.56 NIR = 15.23 SWIR1 = 18.78 SWIR2 = 37.96

Check Value = $9.75^2 + 10.56^2 + 15.23^2 + 18.78^2 + 37.96^2 = 1440.96$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Record Change Model
Observations Exhausted
Finish

Look Back

for each observation preceding current model window start and end of previous model window:

If change magnitude < change threshold:

add observation to current model window

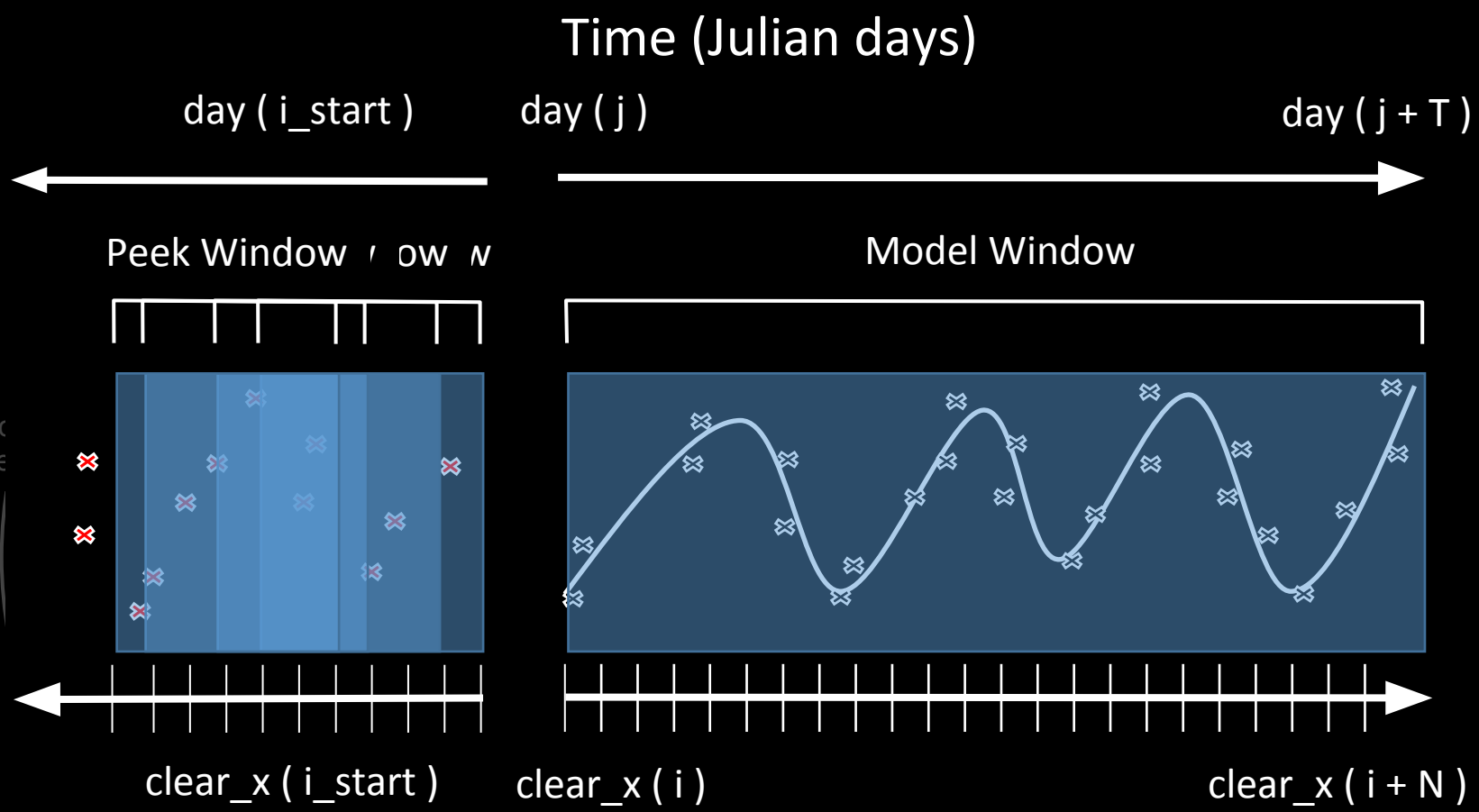
else:

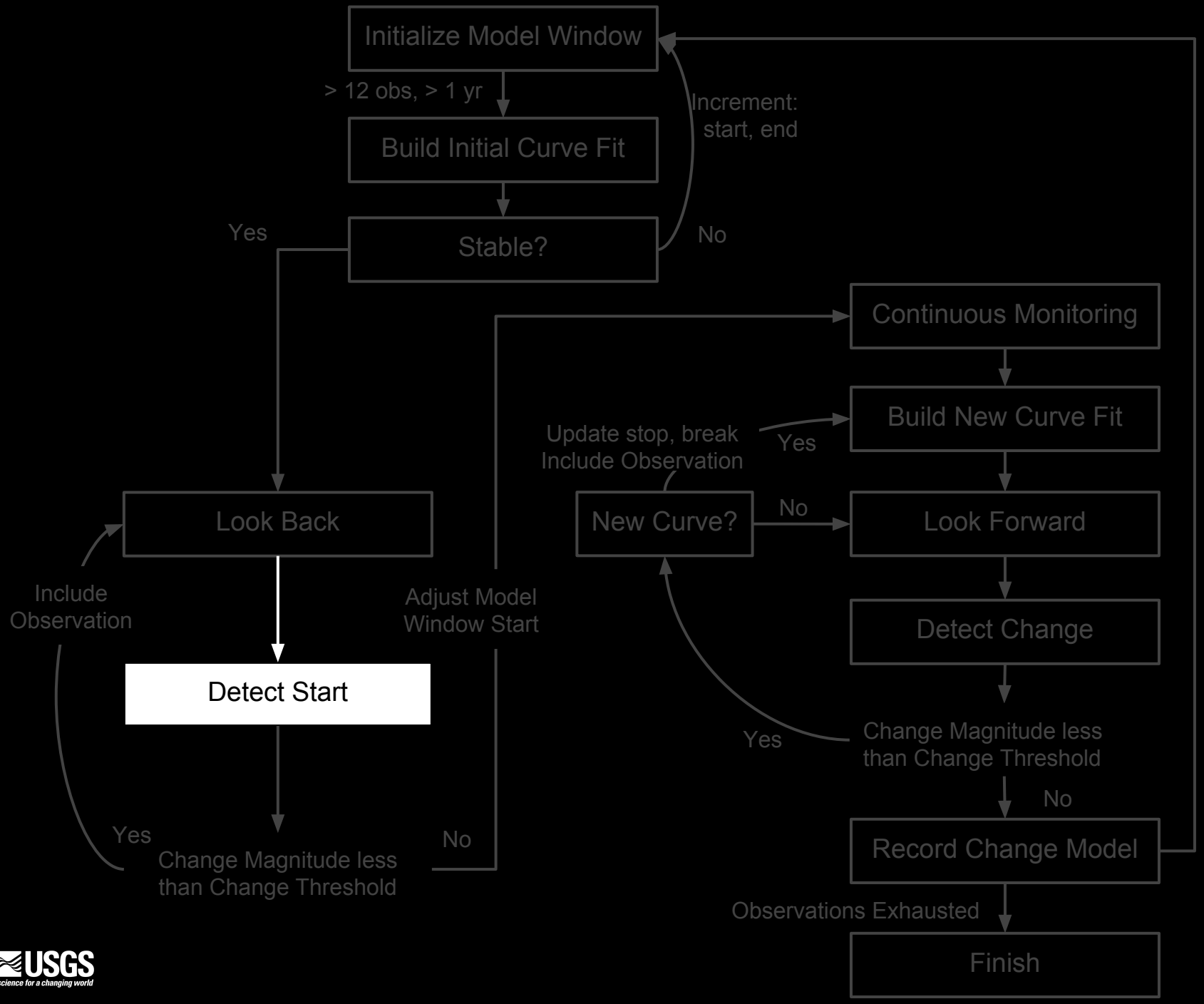
proceed with continuous monitoring

note: when look-back is complete, if this is the very first model window, and there 6 or more unused observations, do a general curve fit on them

Look Back

(adjusting the model start)

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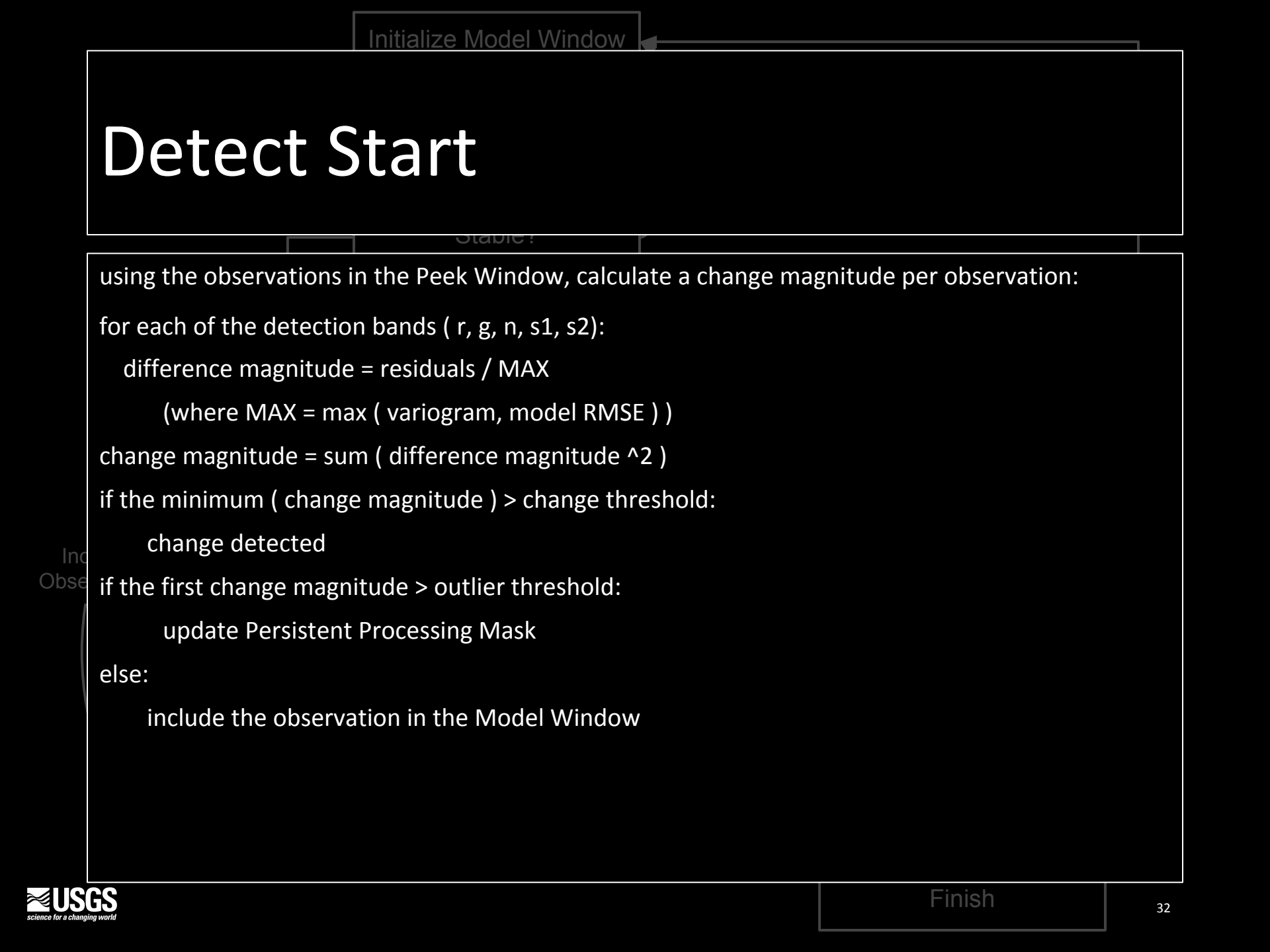


Detect Start

using the observations in the Peek Window, calculate a change magnitude per observation:

for each of the detection bands (r, g, n, s1, s2):

difference magnitude = residuals / MAX

(where MAX = max (variogram, model RMSE))

change magnitude = sum (difference magnitude ^2)

if the minimum (change magnitude) > change threshold:

change detected

if the first change magnitude > outlier threshold:

update Persistent Processing Mask

else:

include the observation in the Model Window

Detect Start
(Calculate Change Magnitudes example)

Peek Window

Observations

Green	793	652	803	968	1514	840	361
Red	853	745	1034	1305	1662	1052	383
NIR	2389	2168	2217	2322	2240	1602	610
SWIR1	2779	2622	2974	3195	1786	2740	545
SWIR2	1708	1595	1770	2134	1157	1994	350

Predictions

Green	812	662	823	979	1530	857	373
Red	868	760	1044	1312	1681	1058	398
NIR	2396	2173	2222	2336	2250	1612	622
SWIR1	2796	2629	2981	3209	1805	2752	554
SWIR2	1714	1600	1780	2148	1162	2014	362

Residuals

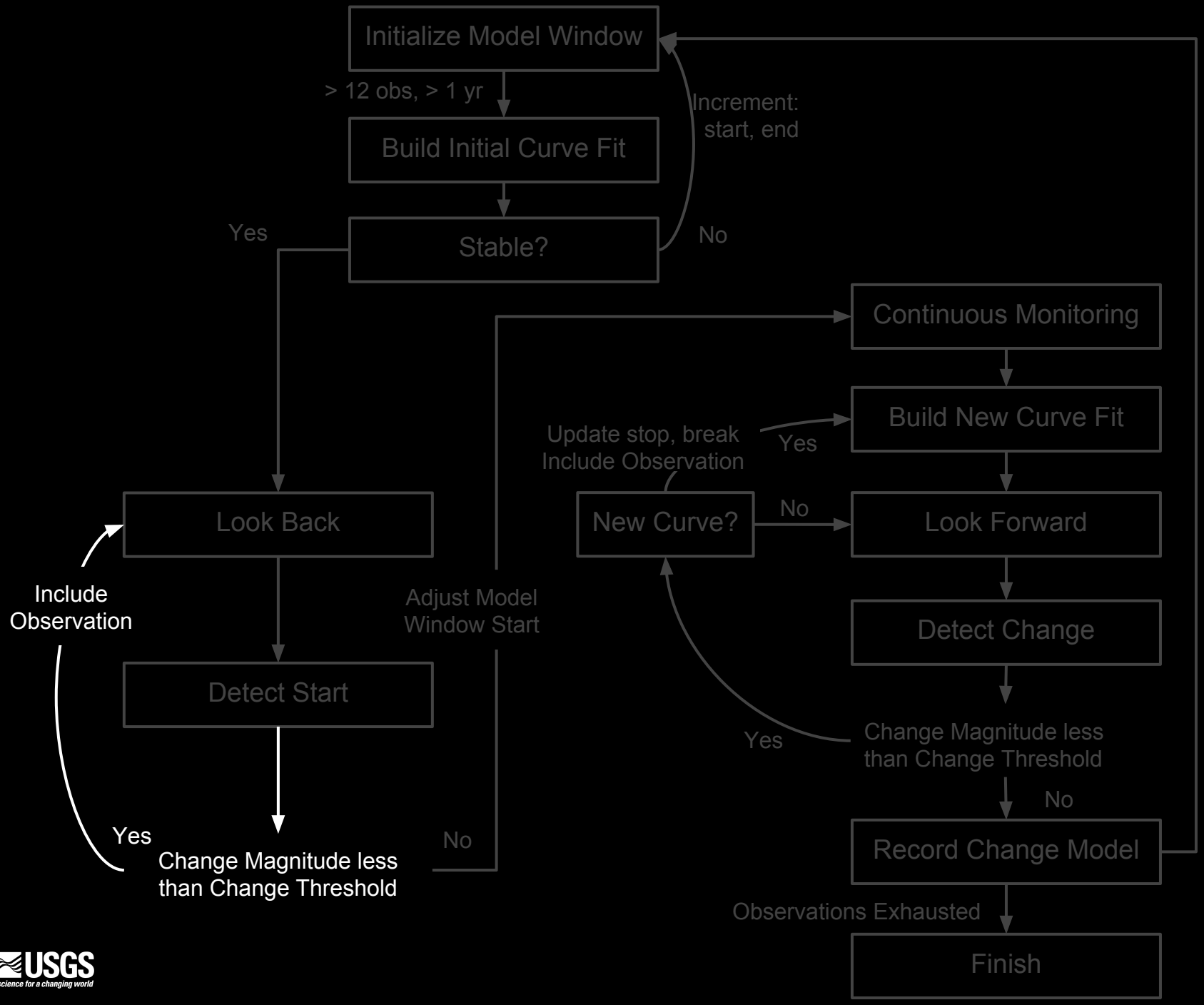
Green	19	10	20	11	16	17	12
Red	15	15	10	7	19	6	15
NIR	7	5	5	14	10	10	12
SWIR1	17	7	7	14	19	12	9
SWIR2	6	5	10	14	5	20	12

Difference Magnitudes

Green	0.339286	0.178571	0.357143	0.196429	0.285714	0.303571	0.214286
Red	0.267857	0.267857	0.178571	0.125	0.339286	0.107143	0.267857
NIR	0.125	0.089286	0.089286	0.25	0.178571	0.178571	0.214286
SWIR1	0.303571	0.125	0.125	0.25	0.339286	0.214286	0.160714
SWIR2	0.107143	0.089286	0.178571	0.25	0.089286	0.357143	0.214286

Change Magnitudes

	0.306122	0.135204	0.214923	0.241709	0.351722	0.308992	0.235332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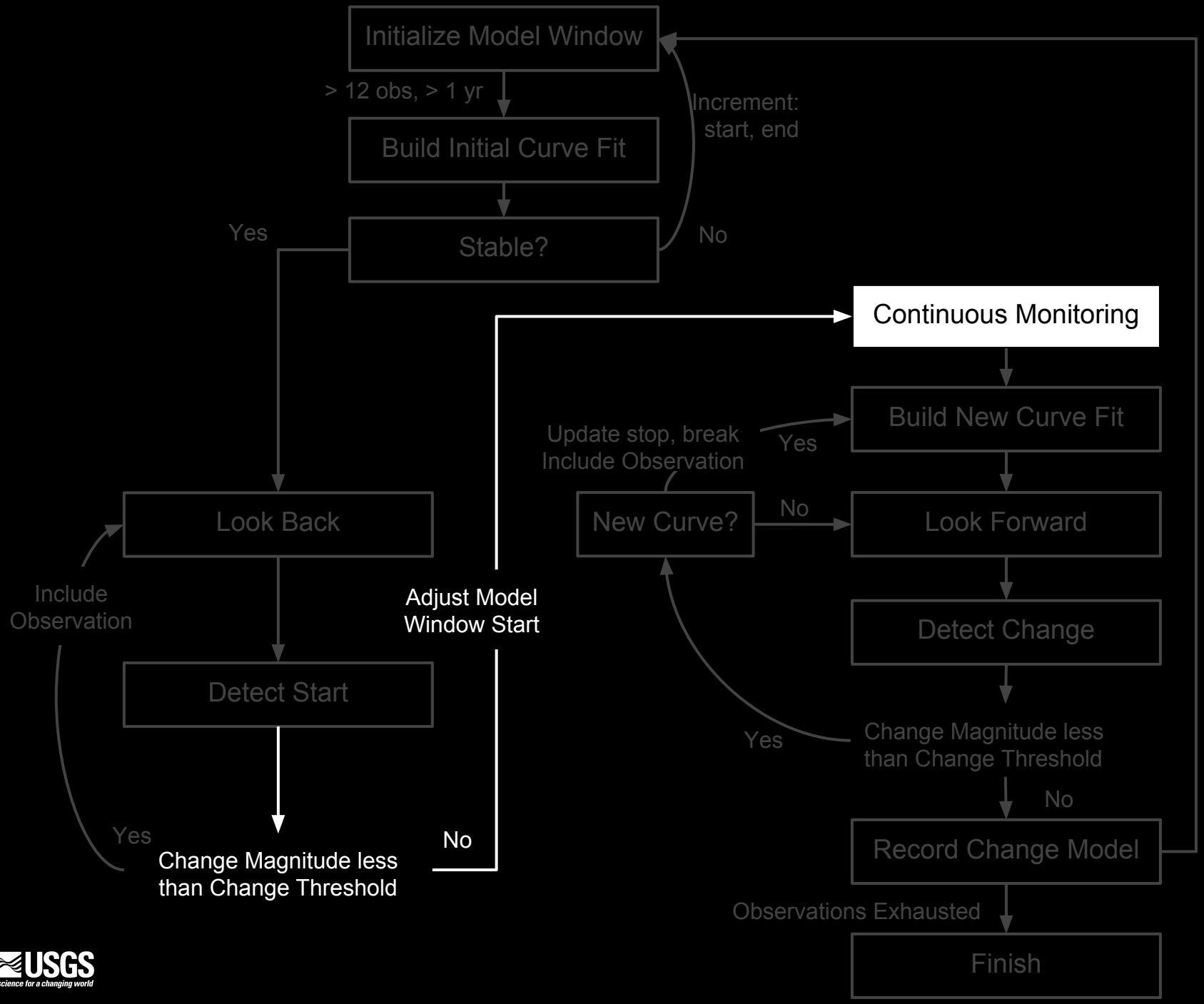
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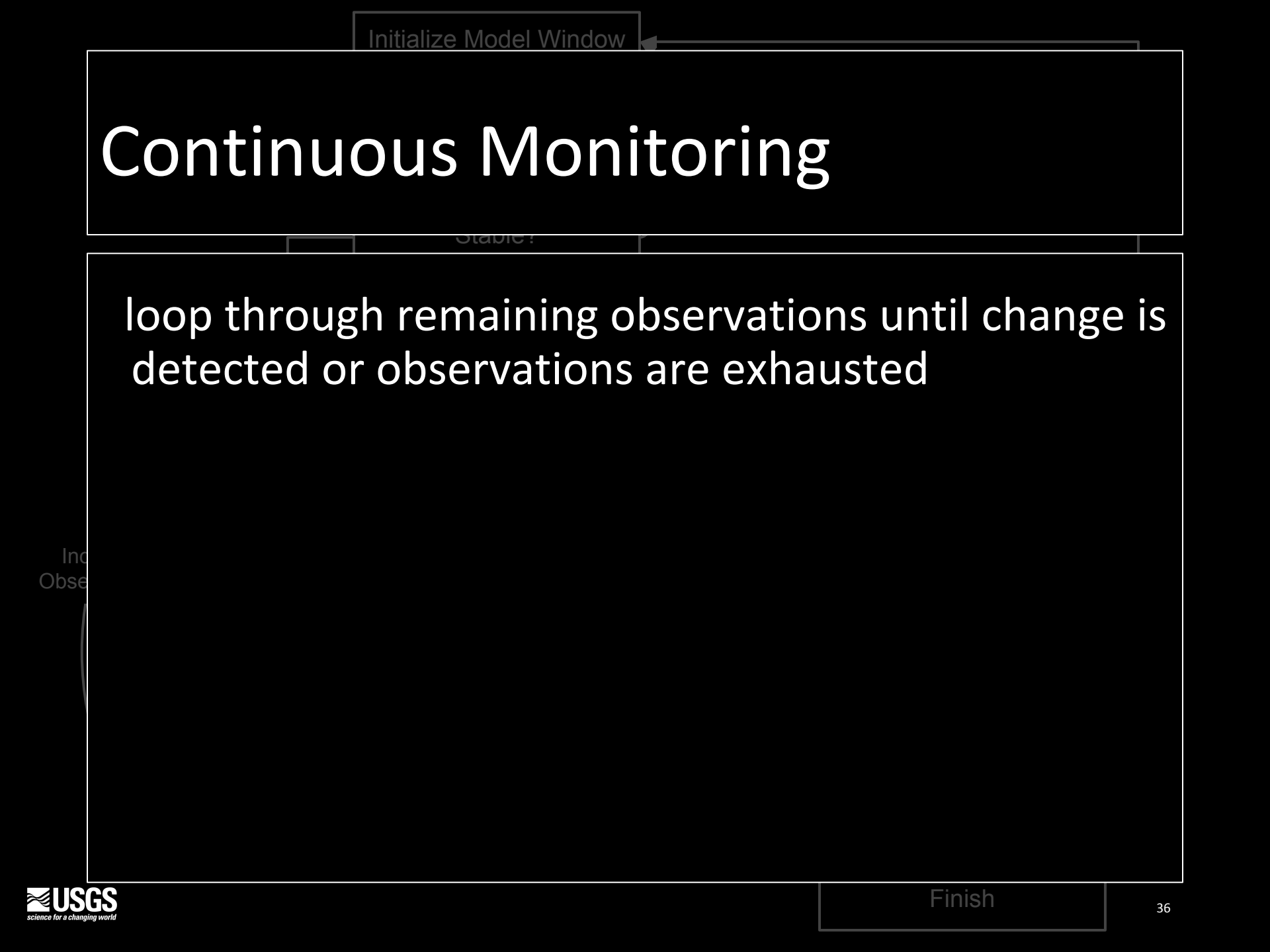
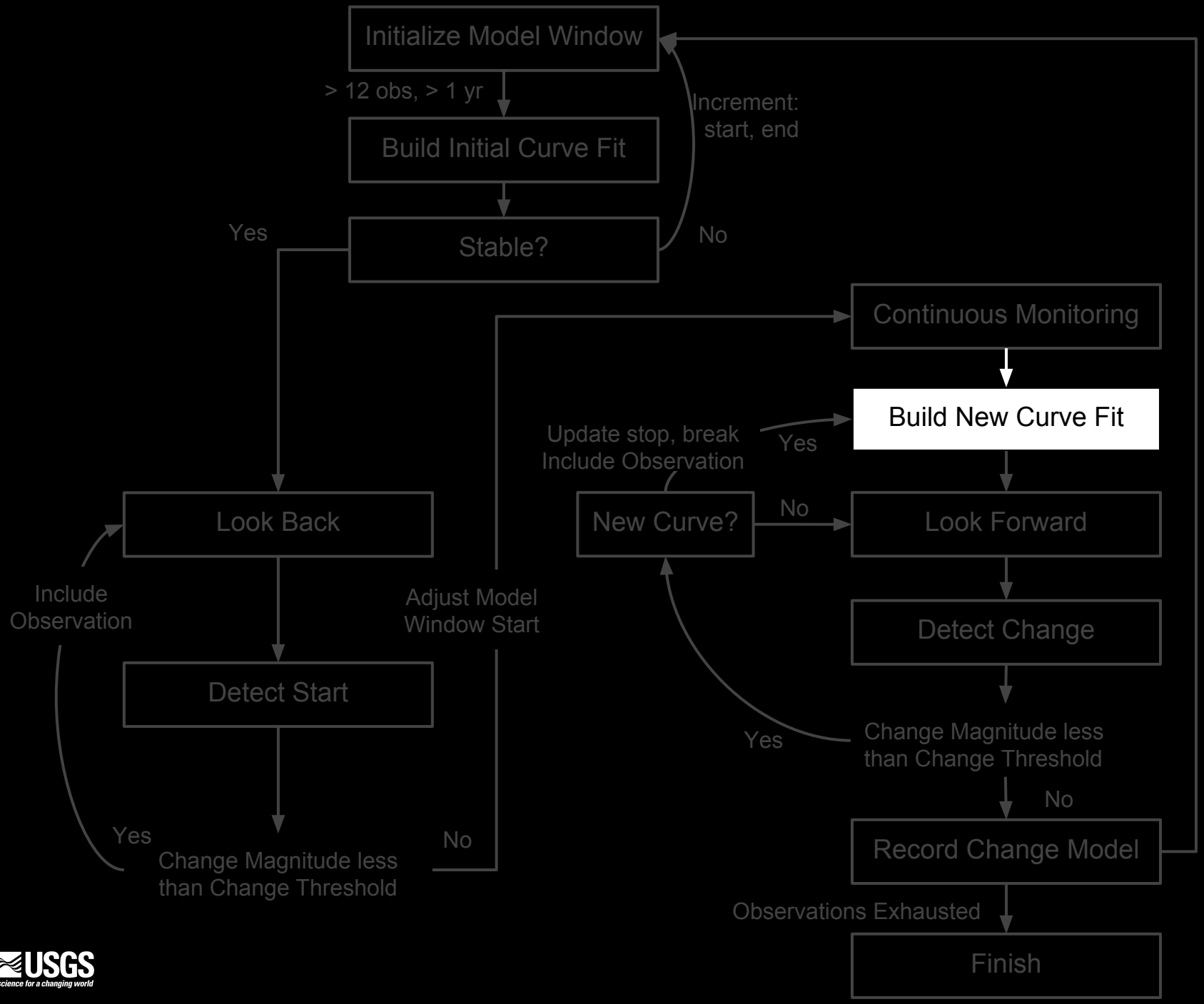


Continuous Monitoring

loop through remaining observations until change is detected or observations are exhausted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New Curve?
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Detect Change
Change Magnitude less
than Change Threshold
Yes
No
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Observations Exhausted
Finish

Build New Curve Fit

utilize LASSO Regression with a set number of coefficients based on the number of observations encompassed by the model window

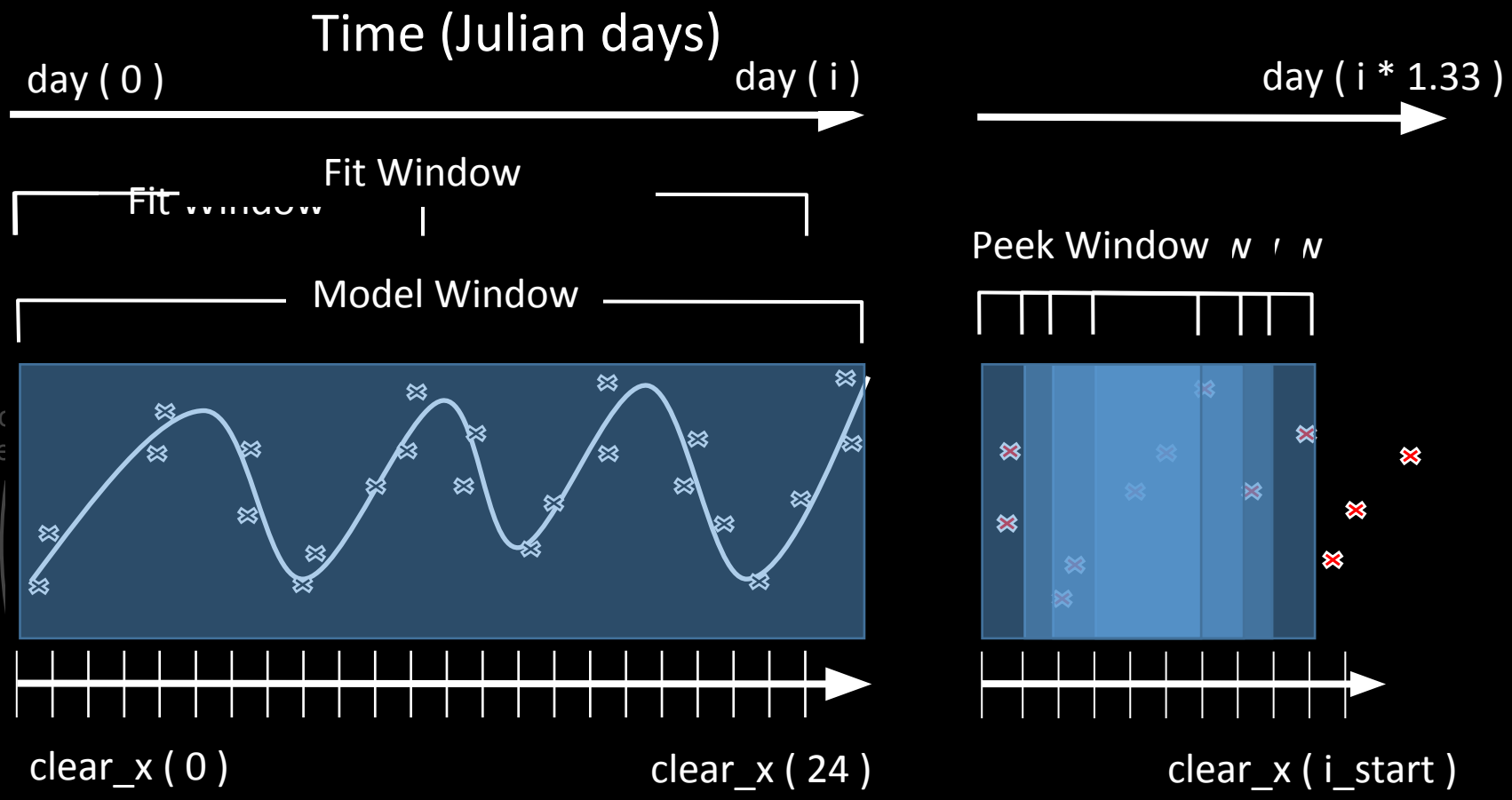
Number of Coefficents per Model Window size:

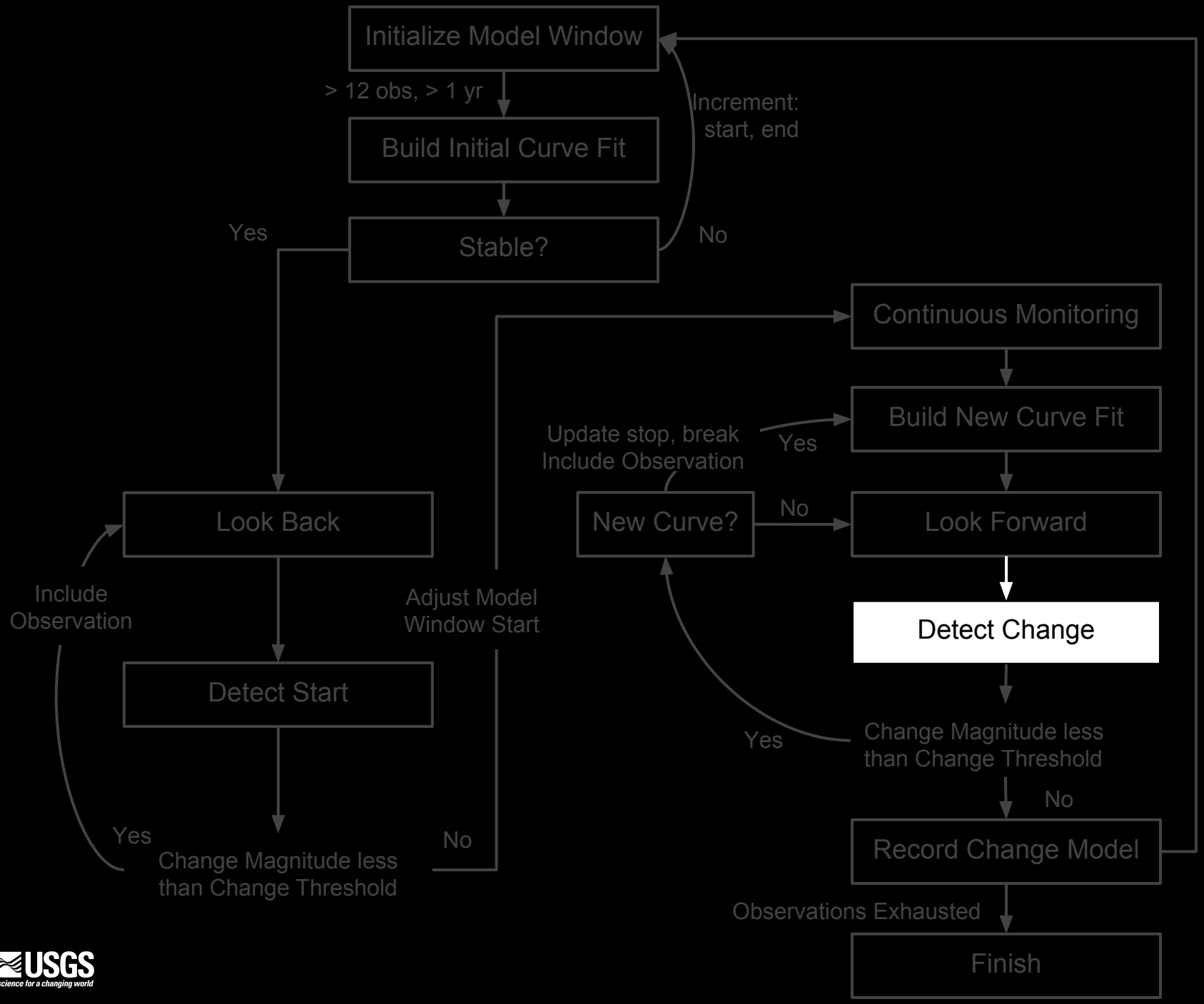
# coefficents	observation count*
4	12
6	18
8	24

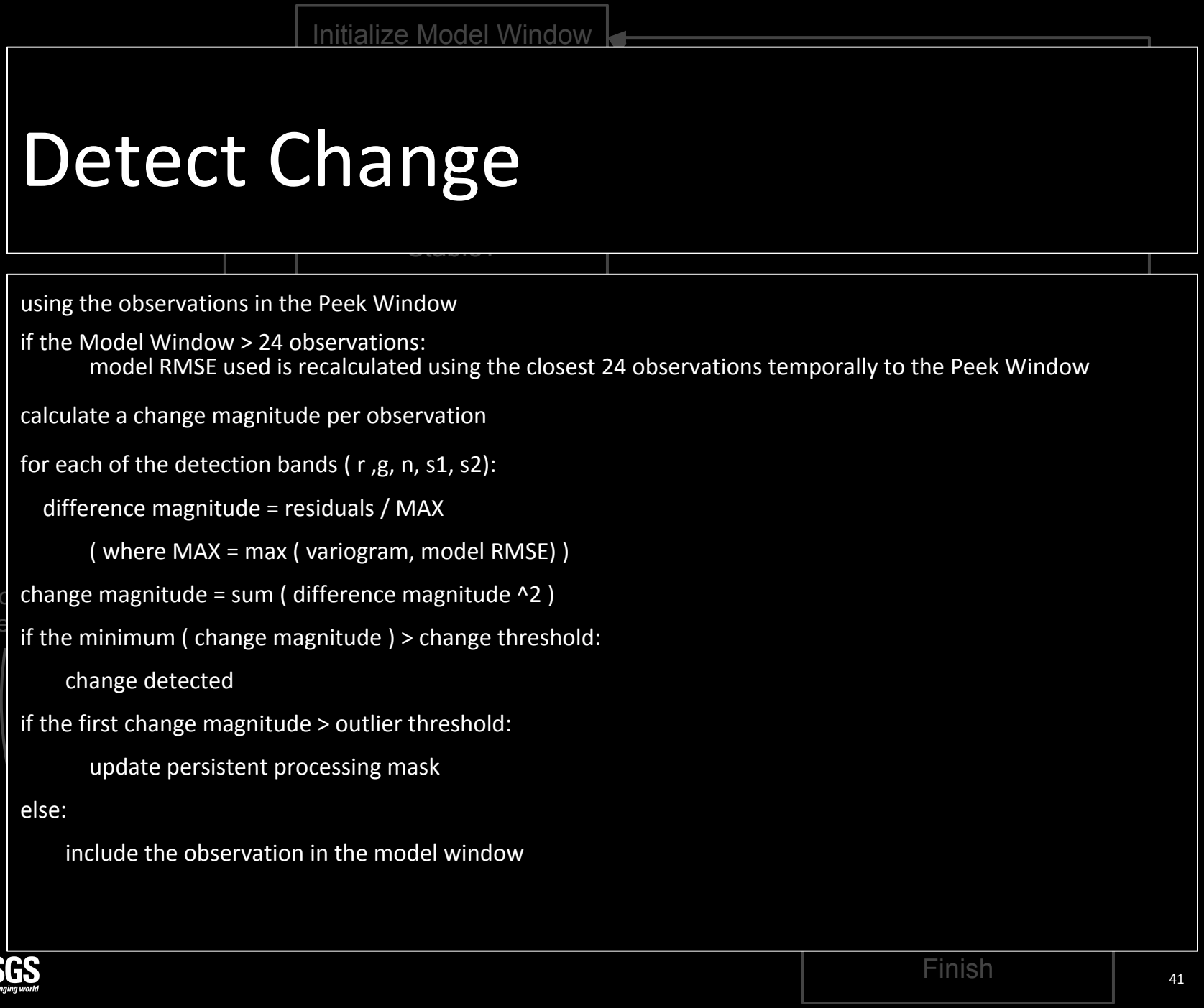
*number of coefficient times the NUM_OBS_FACTOR (3)

Look Forward

(extending the model in time)




Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
Increment:
start, end
Yes
No
Look Back
Include
Observation
Detect Start
Yes
Change Magnitude less
than Change Threshold
No
Adjust Model
Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Change Magnitude less
than Change Threshold
Yes
No
Record Change Model
Observations Exhausted
Finish



Detect Change

using the observations in the Peek Window

if the Model Window > 24 observations:
    model RMSE used is recalculated using the closest 24 observations temporally to the Peek Window

calculate a change magnitude per observation

for each of the detection bands (r ,g, n, s1, s2):

  difference magnitude = residuals / MAX

    (where MAX = max (variogram, model RMSE))

change magnitude = sum (difference magnitude ^2)

if the minimum (change magnitude) > change threshold:

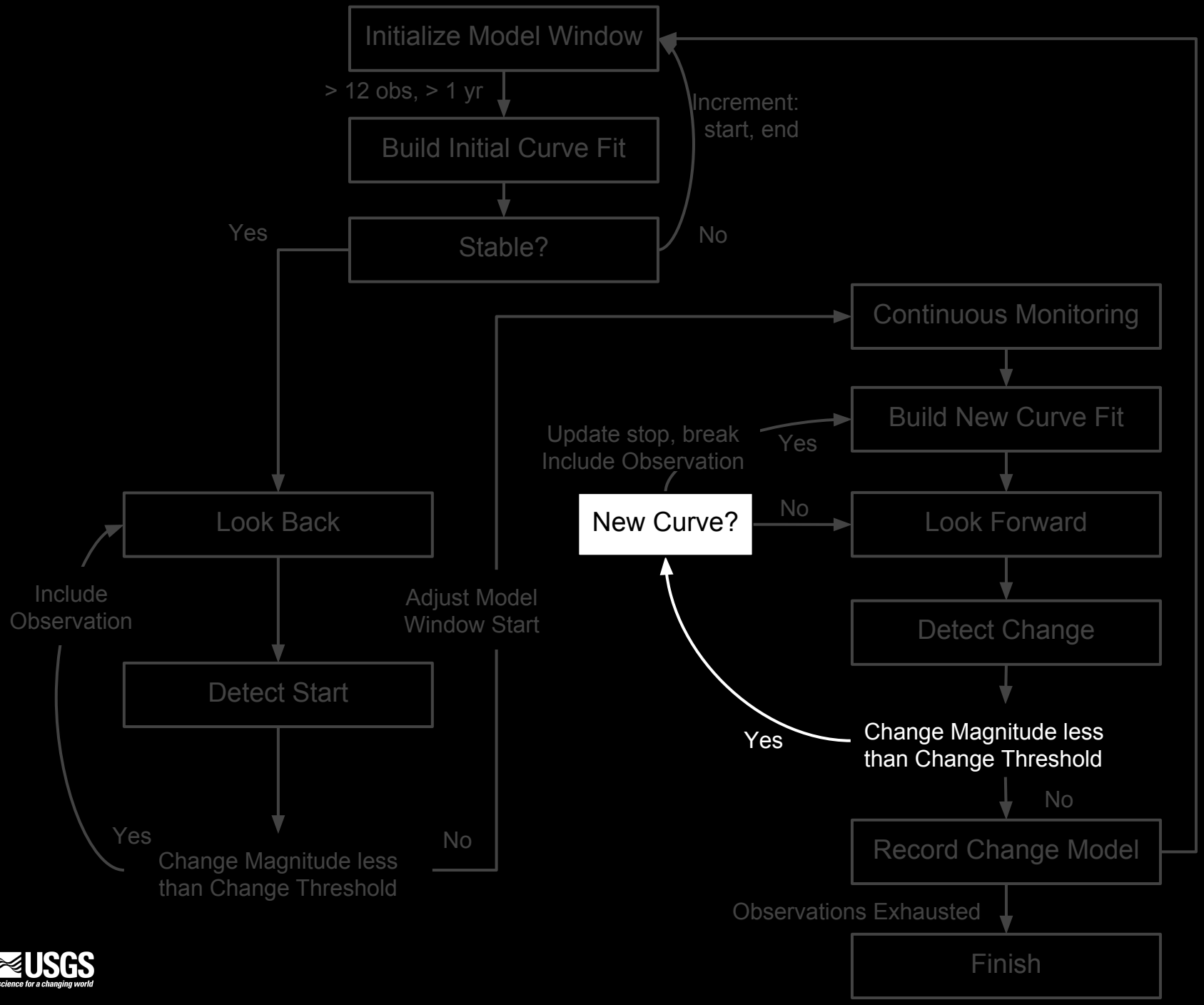
    change detected

if the first change magnitude > outlier threshold:

    update persistent processing mask

else:

    include the observation in the model window


Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
Yes
No
Increment:
start, end
Look Back
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Detect Start
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Change Magnitude less
than Change Threshold
No
Adjust Model
Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Yes
Change Magnitude less
than Change Threshold
No
Record Change Model
Observations Exhausted
Finish

New Curve?

If < 24 observations:

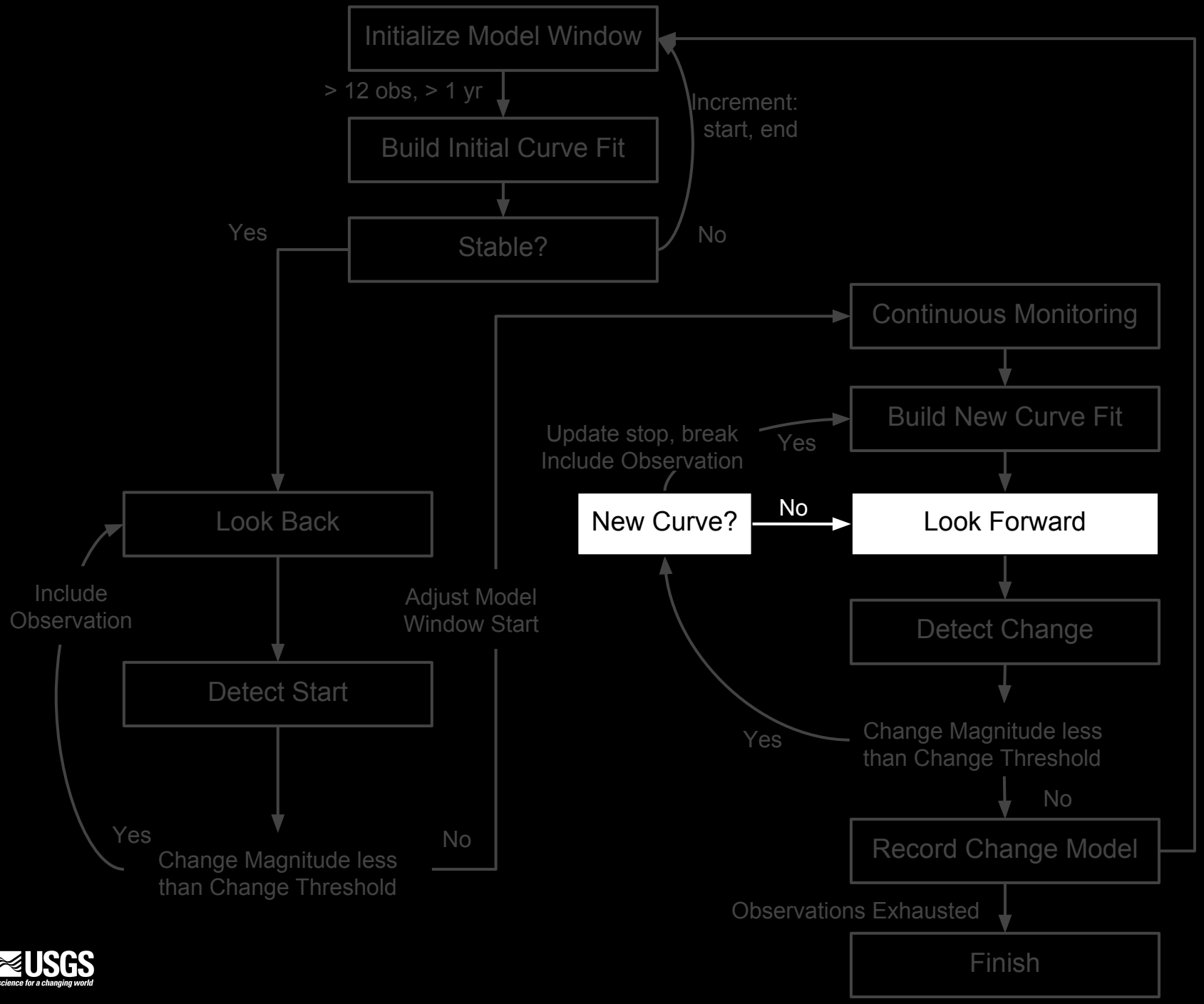
model new curve with LASSO Regression

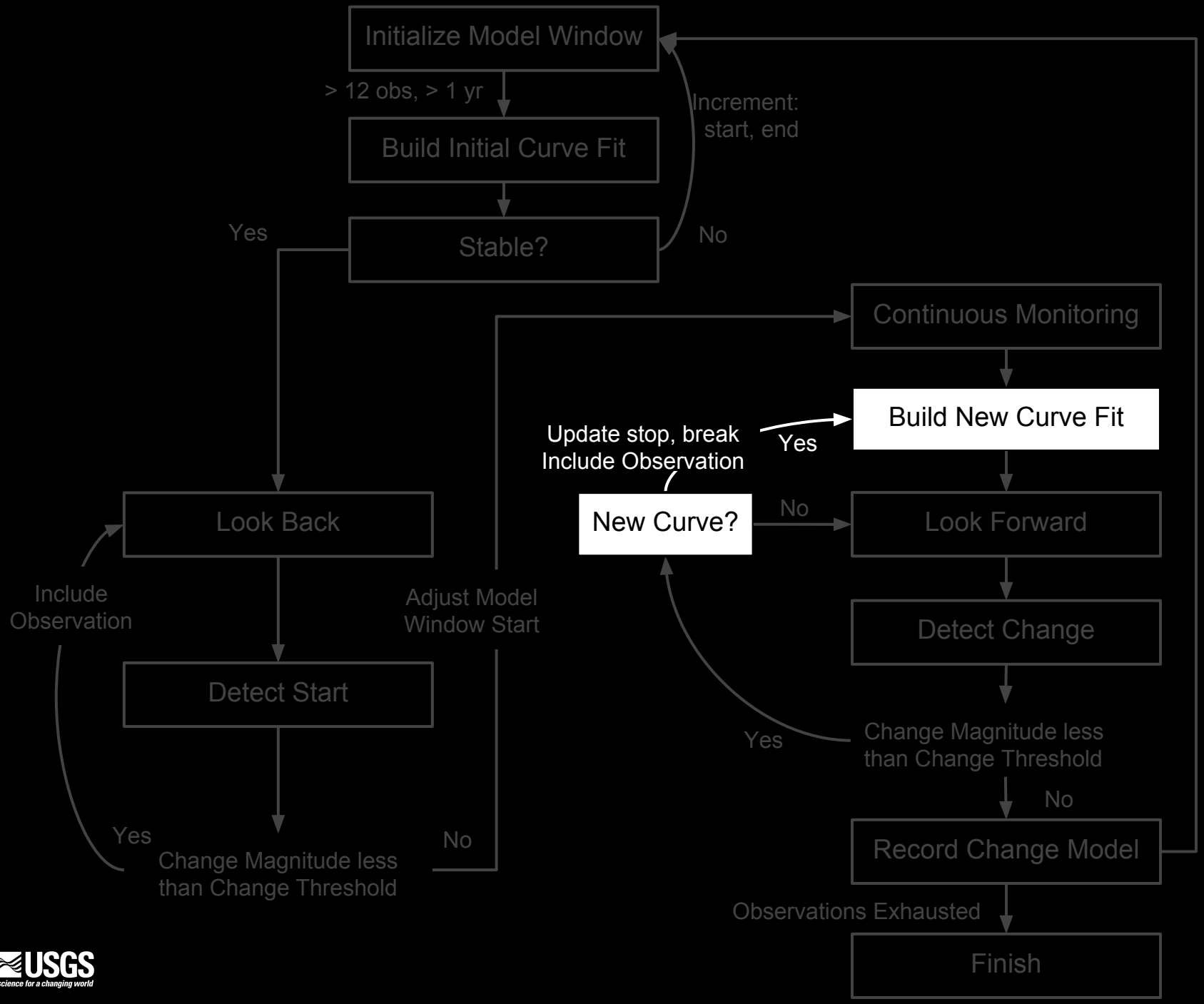
if > 24 observations and the time span of observations has increased by a factor of 1.33 since the last curve fit:

model new curve LASSO Regression

else:

continue to use existing model curve


Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
Increment:
start, end
Yes
No
Look Back
Include
Observation
Detect Start
Yes
Change Magnitude less
than Change Threshold
Adjust Model
Window Start
No
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Change Magnitude less
than Change Threshold
Yes
No
Record Change Model
Observations Exhausted
Finish


Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
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start, end
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Look Back
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Detect Start
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Change Magnitude less
than Change Threshold
Adjust Model
Window Start
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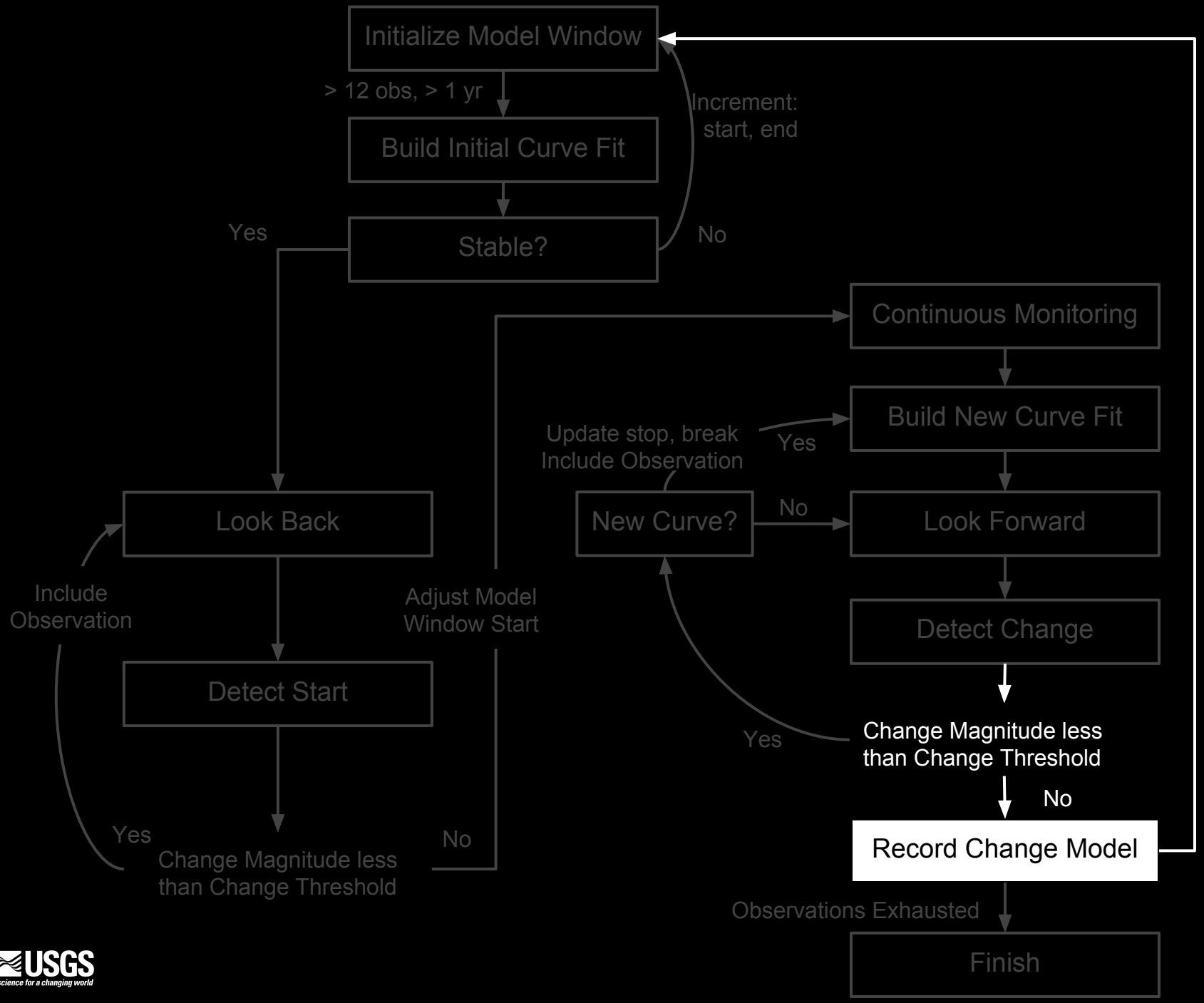
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Change Magnitude less
than Change Threshold
Yes
No
Record Change Model
Observations Exhausted
Finish


Initialize Model Window
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Build Initial Curve Fit
Stable?
Increment:
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Detect Start
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Change Magnitude less
than Change Threshold
No
Adjust Model
Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Yes
Change Magnitude less
than Change Threshold
No
Record Change Model
Observations Exhausted
Finish

Record Change Model

start

end

break

per band coefficients

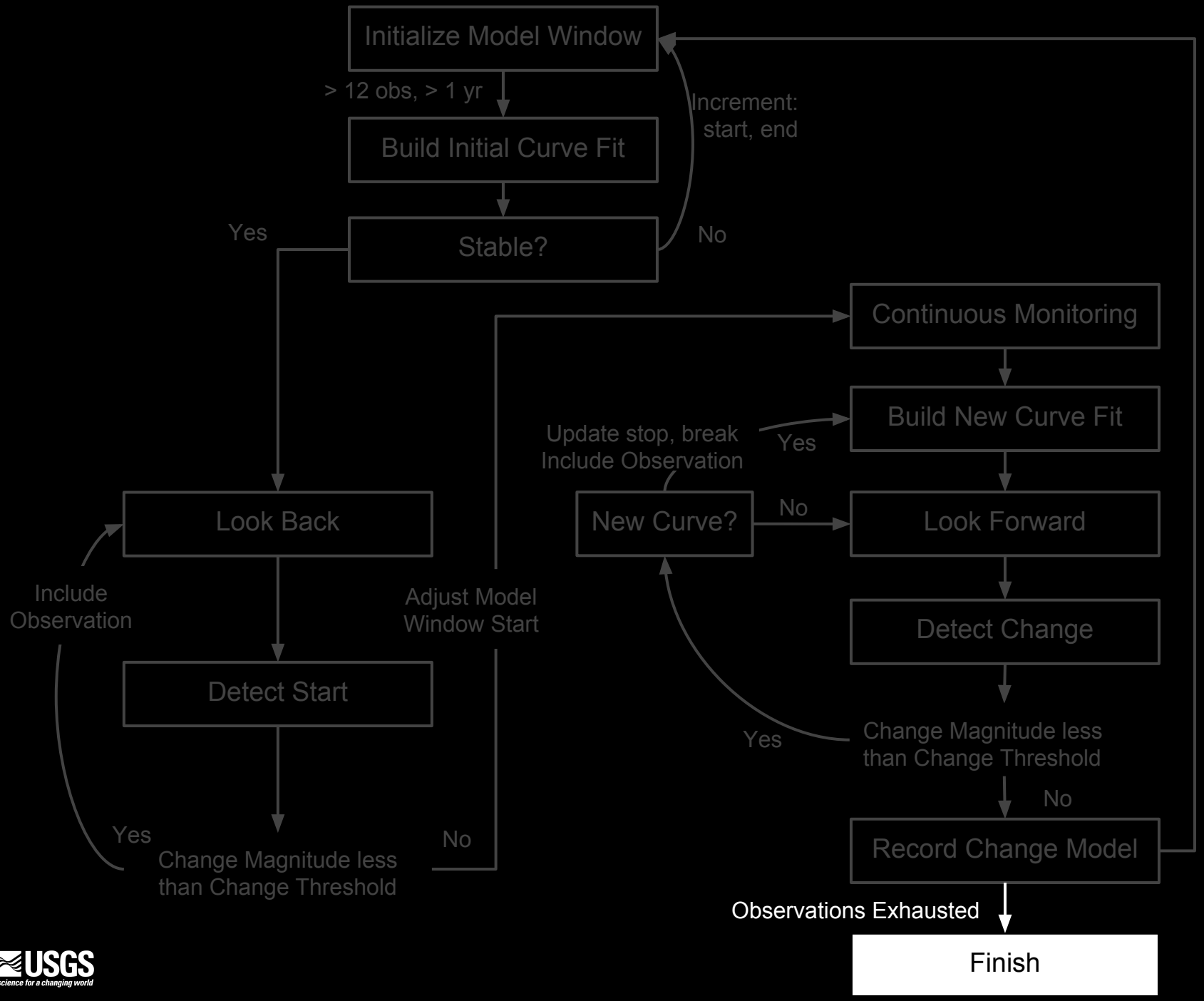
per band RMSE's

per band median of the last used Peek Window residuals

number of observations

number of fitted coefficients

change probability


Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
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No
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Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
Yes
New Curve?
No
Look Forward
Detect Change
Change Magnitude less
than Change Threshold
Yes
No
Record Change Model
Observations Exhausted
Finish

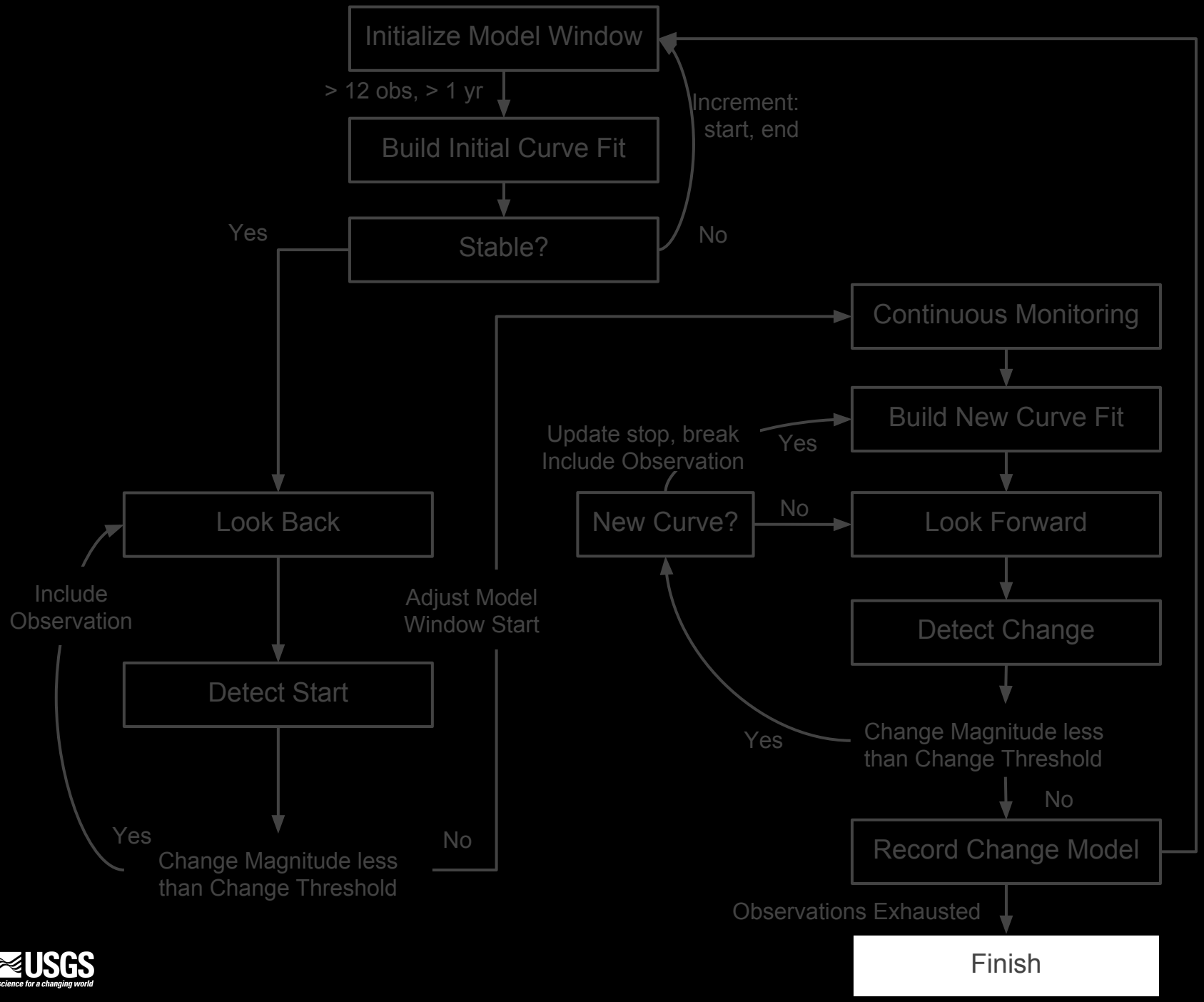
Finish

if the number of remaining observations is < MEOW size but >= Peek Size:

fit a generalized model is for remaining observations

send/save output results

exit


Initialize Model Window
> 12 obs, > 1 yr
Build Initial Curve Fit
Stable?
Yes
No
Increment:
start, end
Look Back
Include
Observation
Detect Start
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Change Magnitude less
than Change Threshold
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Adjust Model
Window Start
Continuous Monitoring
Build New Curve Fit
Update stop, break
Include Observation
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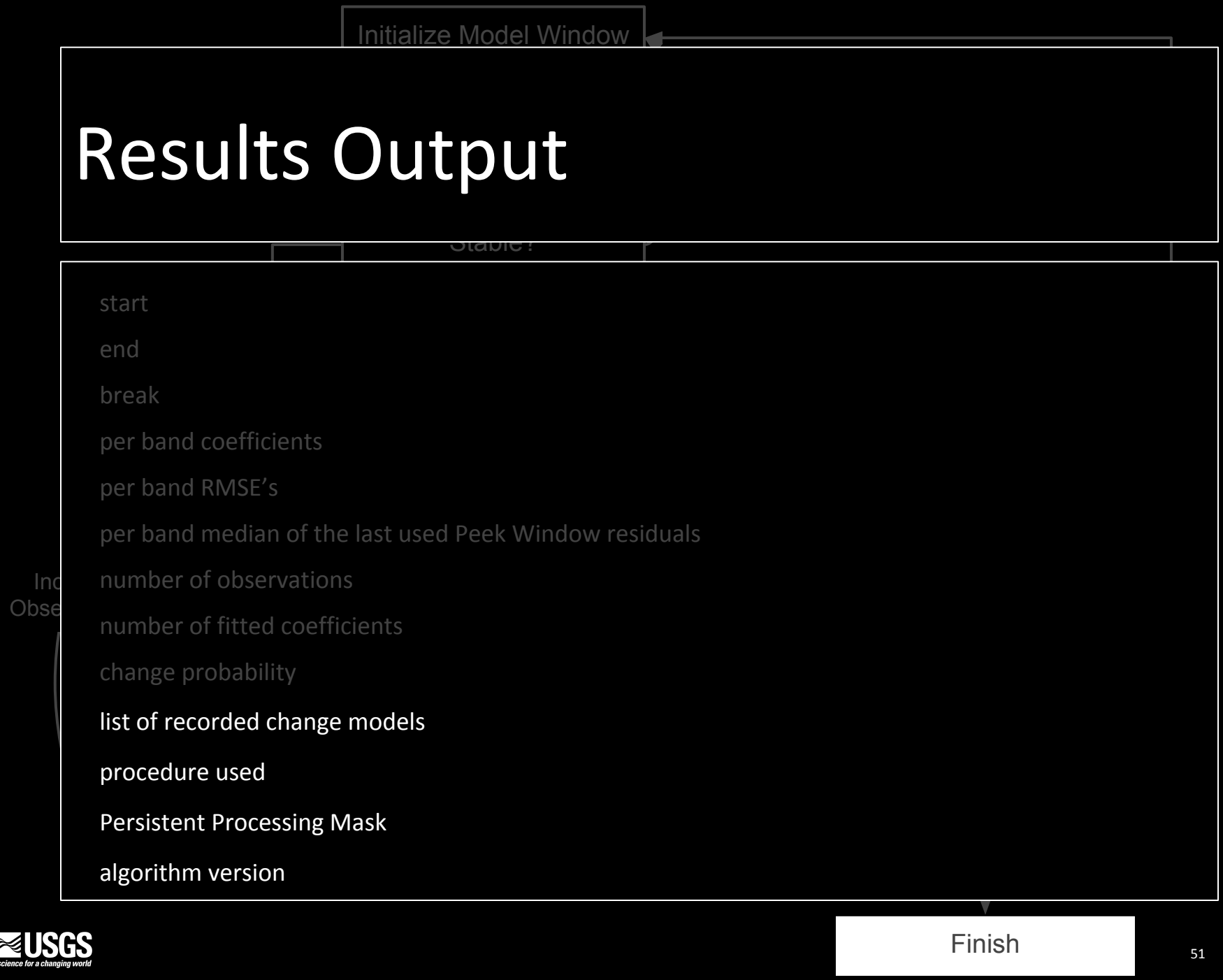
New Curve?
No
Look Forward
Detect Change
Yes
Change Magnitude less
than Change Threshold
No
Record Change Model
Observations Exhausted
Finish



Results Output

start

end

break

per band coefficients

per band RMSE's

per band median of the last used Peek Window residuals

number of observations

number of fitted coefficients

change probability

list of recorded change models

procedure used

Persistent Processing Mask

algorithm version

Questions / Discussion

Acronym List

AOI	Area Of Interest
API	Application Programming Interface
ARD	Analysis Ready Data
CCD	Continuous Change Detection
CFMASK	C version of Function of MASK
DN	Digital Number
EROS	Earth Resources Observation and Science
IW+DS	Information Warehouse + Data Store
LASSO	Least Absolute Shrinkage and Selection Operator
LCMAP	Land Change Monitoring and Projection
MEOW	Minimum Expected Observation Window
NIR	Near InfraRed
SR	Surface Reflectance
SWIR	Short Wave InfraRed
TOA	Top Of Atmosphere

Bibliography

CCD:

http://www.sciencedirect.com/science/article/pii/S0034425714000248

http://www.sciencedirect.com/science/article/pii/S0034425715000590

http://www.sciencedirect.com/science/article/pii/S0034425712000387

ARD:
https://drive.google.com/drive/folders/0B5wwu78kdogOfmZIWGI1S2dNRE5LeDVNeGxDU1phUndyTHpMbUVuNFdFNTZBV2RsbVhqMjQ

https://drive.google.com/a/doi.gov/file/d/0B5wwu78kdogONnN5N1BGTjFvdGM/view?usp=sharing

ADD, these slides:
https://drive.google.com/drive/folders/0BzELHvbrg1pDREJlTF8xOHBZbEU?usp=sharing

git Repository:
https://github.com/USGS-EROS/lcmap-pyccd/tree/develop