Cross-Sensor Continuity Science Algorithm

- Long Term Vegetation Index and Phenology Workshop -

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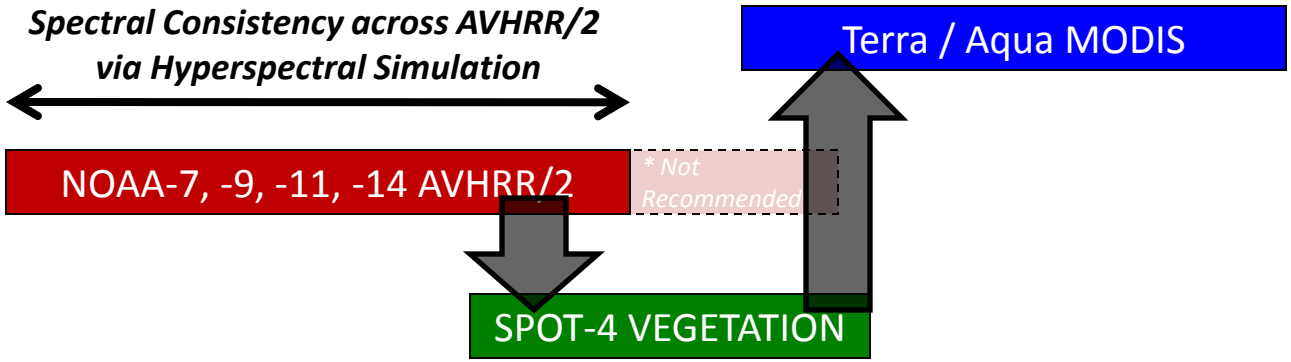
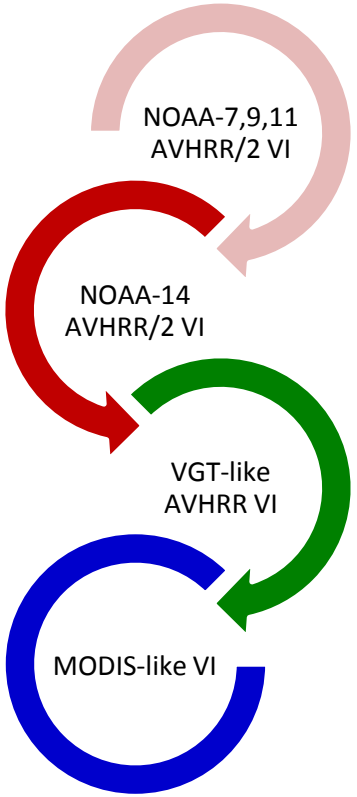
The Continuity Algorithm Goal

- To translate LTDR AVHRR NDVI and EVI2 to Terra MODIS-compatible VIs for the generation of a continuous VI time series dataset
  - Accounting for biases among sensors due to differences in:
    - Sensor characteristics
    - Product generation algorithms

Science Algorithm Approaches

- Two approaches used:
  - Top-down, direct image comparison using overlapping periods of observations
    - Used to obtain equations for translating NOAA-14 AVHRR to "MODIS-like" values
  - Bottom-up, simulation analysis using hyperspectral imagery
    - Used to derive equations for the spectral corrections from NOAA-7, 9, 11 AVHRRs to NOAA-14 AVHRR

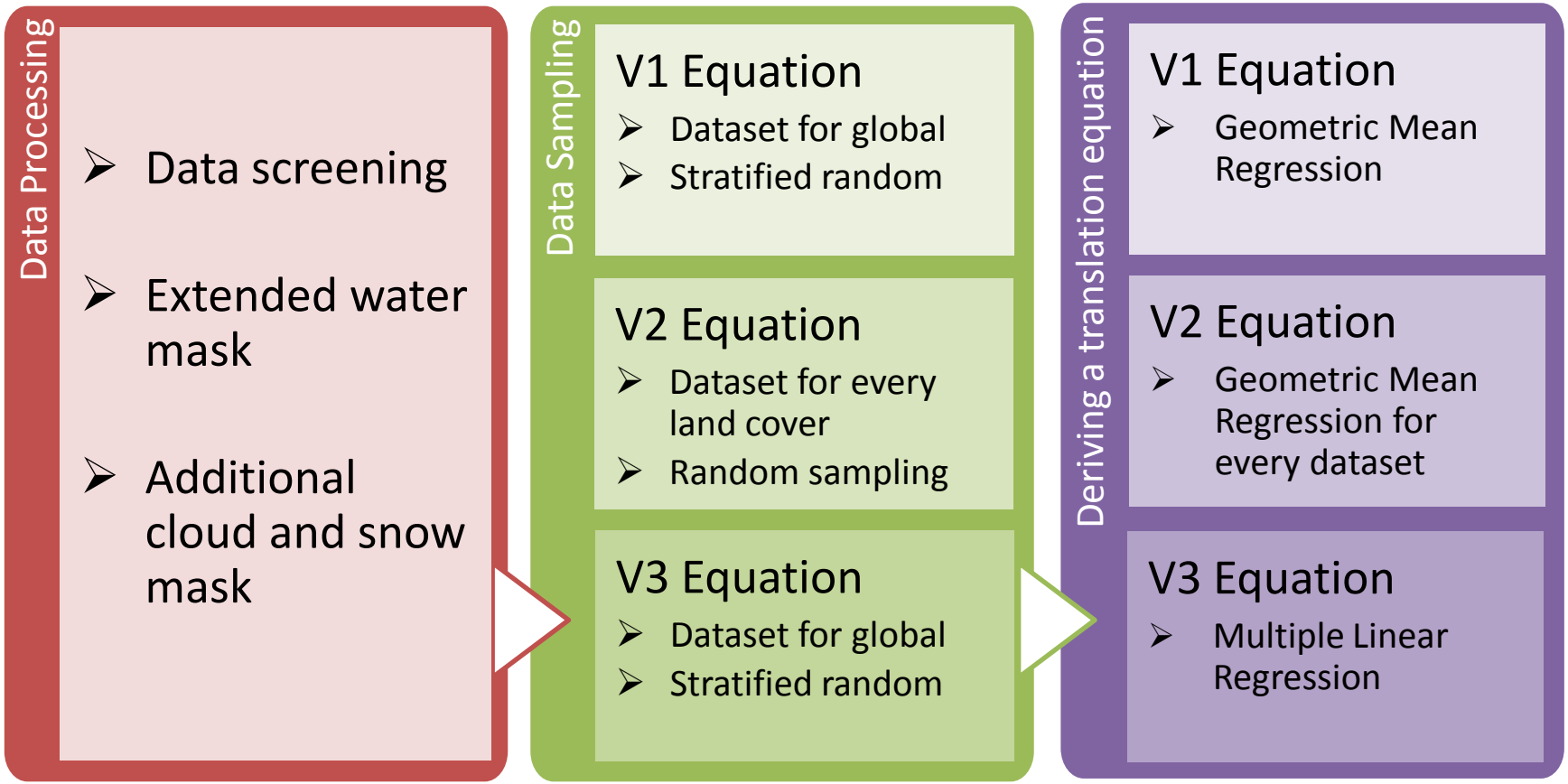




Top-Down, Direct Image Comparison

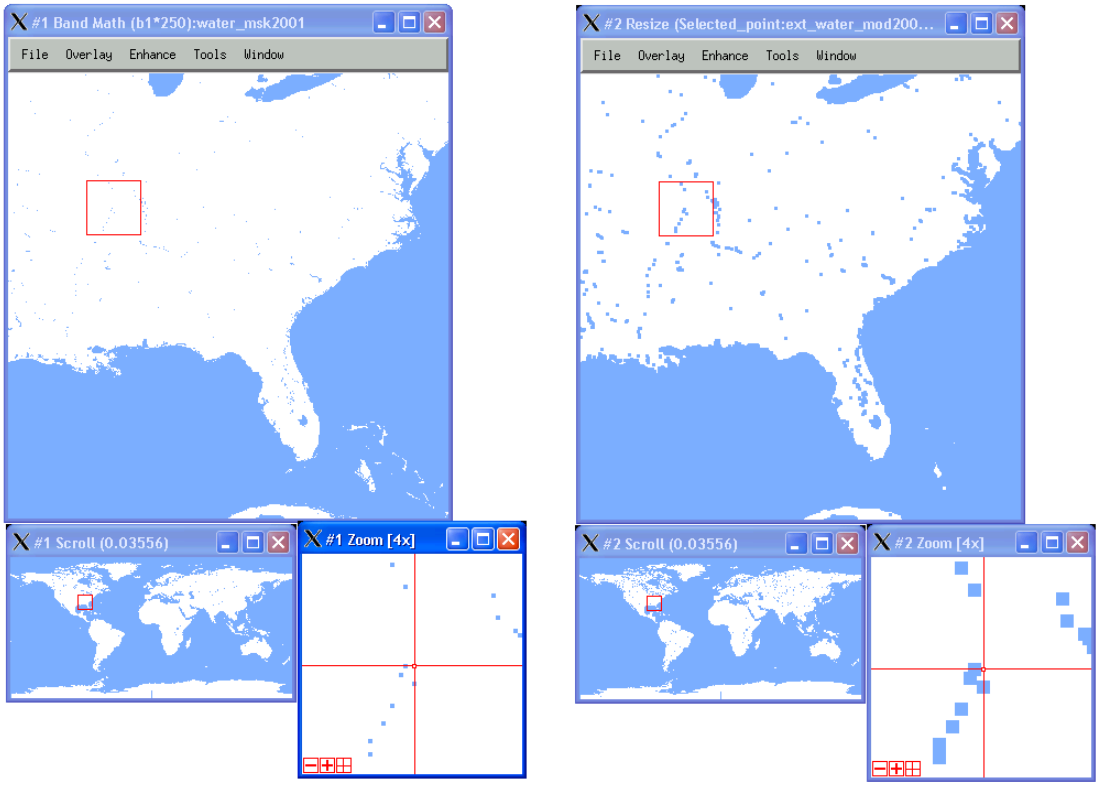
- Three versions of translation equations developed progressively:
  - Version 1.0 (V1)
    - We developed a single translation equation.
    - The translation equation does not consider any land cover dependency.
  - Version 2.0 (V2)
    - We derived one equation per land cover.
    - The translation equations reduce overall systematic biases in the translation results due to land cover differences.
  - Version 3.0 (V3)
    - We developed a single translation equation.
    - The translation equation dynamically adjusts with land cover conditions without using any existing land cover maps.

Methods for Deriving Multi-sensor Translation Equations



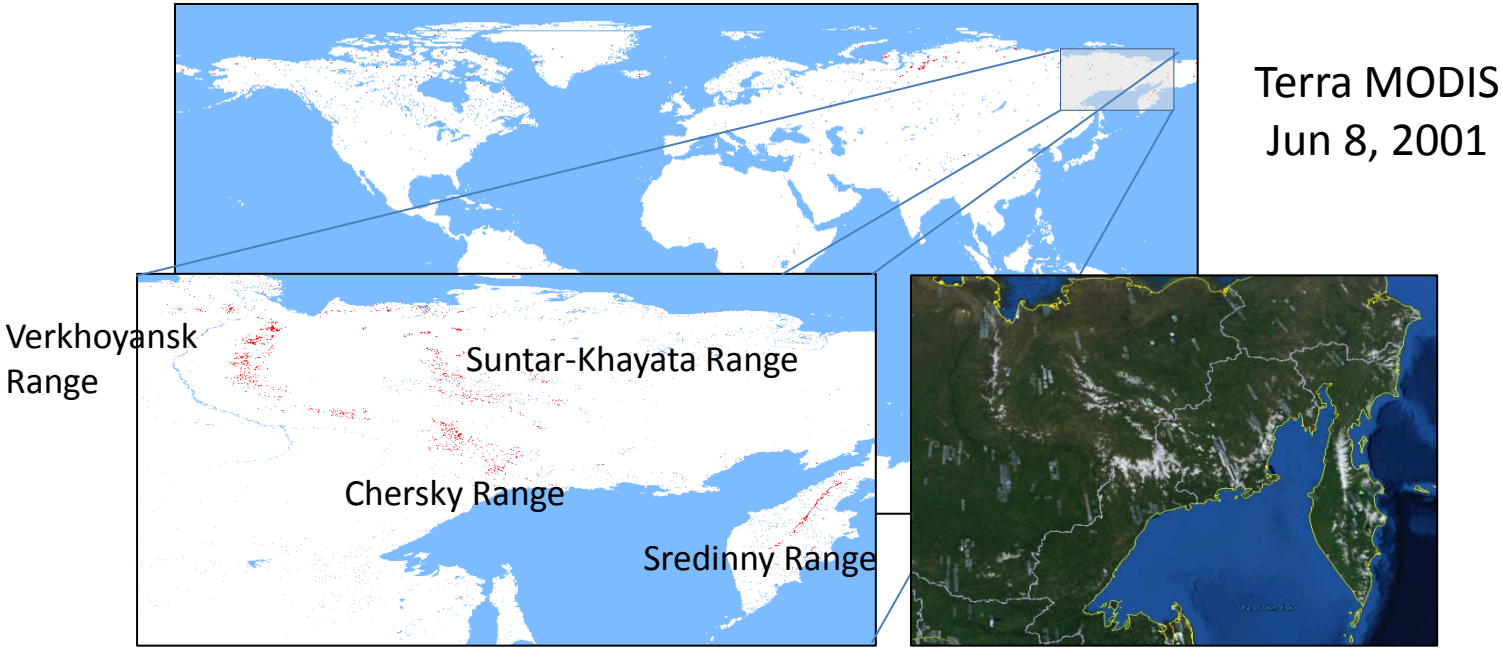
Data Processing: Extended Water Mask

- The MODIS Land cover 2001 water mask expanded by one pixel



Data Processing: Additional Mask

- The additional daily mask created using MODIS NDVI and surface reflectance thresholds



Single Translation Equation- V1

Data sampling

- Stratified random sampling
  - 2001 MODIS International Geosphere-Biosphere Programme (IGBP) Land Cover (MCD12Q1)
- 40% of the good quality near-nadir observation pairs (VZA ≤10) selected randomly

$$N = 0.4 \times \sum_{i=1}^{16} n_i$$

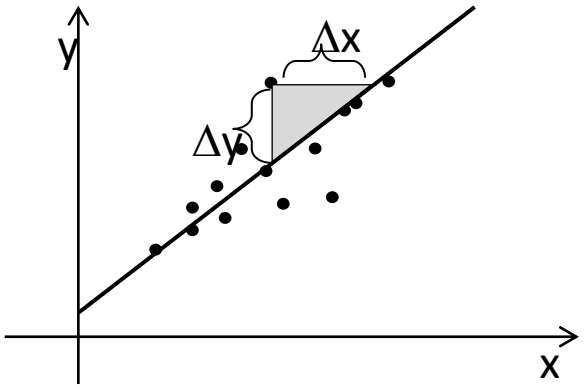
N: Sample size

n_i: Number of good quality near-nadir observation pairs for land cover *i*

Single Translation Equation- V1

Deriving the translation equation

- Geometric Mean (GM) Regression was used to derive the VI (NDVI and EVI2) translation equation
  - $VI_{VGT-like\ AVH_{N14}} = f(VI_{AVH_{N14}})$ for the NOAA-14 AVHRR vs. VGT pair
  - $VI_{MOD-like\ VGT} = g(VI_{VGT})$ for the VGT vs. MODIS pair



- A method to quantify a linear relationship where both variables are subject to errors
- Instead of minimising $e^2=(Y-y)^2$, GM regression minimises $e^2= \Delta y^2+ \Delta x^2$

Land Cover Dependent Equations- V2

- One dataset per land cover class (IGBP 16 land cover classes, excluding water)
  - 2001 MODIS IGBP Land Cover Type (MCD12Q1)
- 40% of good quality near-nadir observation pairs (VZA ≤10) selected randomly

$$N_i = 0.4 \times n_i$$

N_i: Sample size (no. pairs) for land cover *i*

n_i: Number of good quality near-nadir observation pairs for land cover *i*

Land Cover Dependent Equations- V2

- GM regression also used to derive VI translation equations for every land cover classes

$VI^{i}_{VGT-like\ AVH_{N14}} = f_i(VI_{AVH_{N14}})$ for the VGT vs. AVHRR pair

$VI^{i}_{MOD-like\ VGT} = g_i(VI_{VGT})$ for the MODIS vs. VGT pair

VI: $NDVI$ or $EVI2$

$i = 1, \ldots 16$ land cover classes

Single Translation Equation- V3

- Stratified random sampling
  - 2001 MODIS IGBP Land Cover Type (MCD12Q1)
- Sample size adjusted for global land cover area

$$\frac{N_i}{\sum_{j=1}^{16} N_j} = \frac{A_i}{\sum_{j=1}^{16} A_j}$$

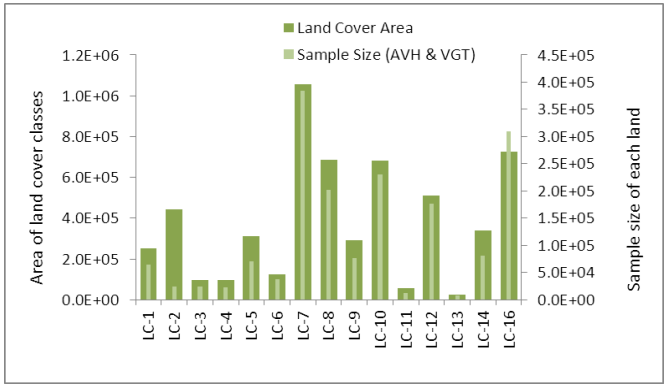
N_i: Sample size (no. pairs) for land cover *i*

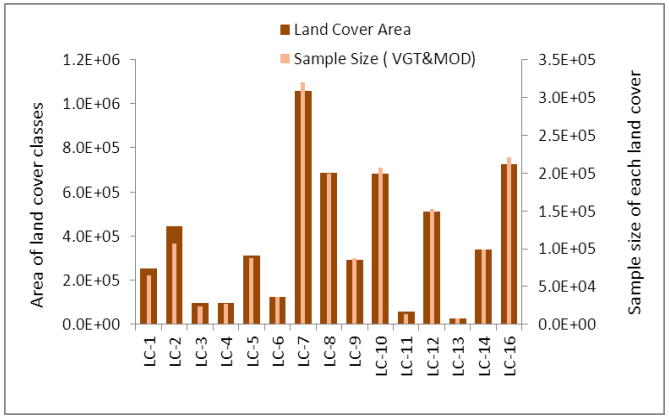
A_i: Global areal coverage of land cover *i*

- Near-nadir observations

$$VZ_{MOD} \leq 10 \text{ and } VZ_{VGT} \leq 10$$

VZ_x: View zenith angle for sensor *x*





Single Translation Equation- V3

The translation equation for NDVI is formulated as:

$$NDVI_{VGT-like\ AVH_{N14}} = f\left(NDVI_{AVH_{N14}}\right) = L_1\ (Land\ cover) \times NDVI_{AVH_{N14}} + L_2\ (land\ cover)$$

$$L_1(Land\ cover) = \alpha_0 + \alpha_1 \times EVI2_{AVH_{N14}}$$

$$L_2(Land\ cover) = \alpha_2 + \alpha_3 \times EVI2_{AVH_{N14}}$$

$$NDVI_{MOD-like\ VGT} = g(NDVI_{VGT}) = C_1(Land\ cover) \times NDVI_{VGT} + C_2(Land\ cover)$$

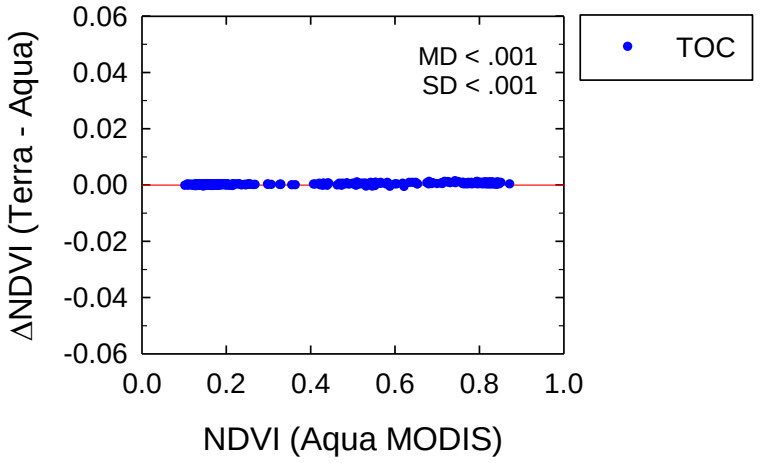
$$C_1(Land\ cover) = \beta_0 + \beta_1 \times EVI2_{VGT}$$

$$C_2(Land\ cover) = \beta_2 + \beta_3 \times EVI2_{VGT}$$

Bottom-up, Hyperspectral Analysis

- Spectral correction equations for the adjustments from NOAA-7, 9, 11 AVHRRs to NOAA-14 AVHRR
- Dataset for V1 spectral correction equations
  - 20 Level 1R EO-1 Hyperion scenes over 5 AERONET sites
    - Limited land cover conditions, including Broadleaf Forest, Open Shrubland, Grasslands, and Croplands
    - A range of atmospheric conditions: AOT at 550 nm from 0.02 (clean) to 0.27 (turbid)
- Dataset for V2 spectral correction equations
  - 37 Level 1R EO-1 Hyperion scenes over 15 AERONET sites
    - All IGBP land cover classes with the exception of Evergreen Broadleaf Forest, Permanent Wetlands, Snow/Ice, and Water
    - A range of atmospheric conditions: AOT at 550 nm from 0.02 (clean) to 0.53 (turbid)

Spectral Correction Equations from N-7, 9, and 11 to N-14 AVHRR (V1)



Spectral Correction Equations (V1)

(Trishchenko et al., 2002; Cohen et al., 2003)

N-7 AVHRR/2:

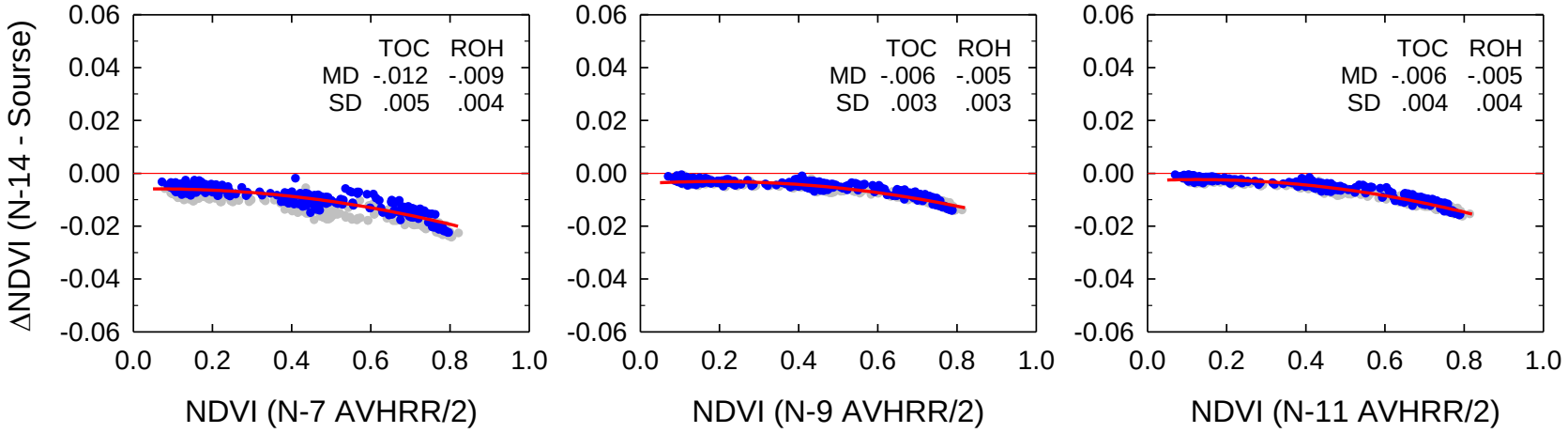
$y = -.0060 + 1.0030\,x - .0246\,x^2$ (±.004, 95%PI)

N-9 AVHRR/2:

$y = -.0040 + 1.0093\,x - .0248\,x^2$ (±.002, 95%PI)

N-11 AVHRR/2:

$y = -.0028 + 1.0068\,x - .0271\,x^2$ (±.002, 95%PI)



Translation Equations to MODIS-equivalents (TOC, CMG)

- Final translation equations from AVHRR/2 to MODIS were obtained by cascading three equations:

$$NDVI_{MOD-like\ AVH_{Nj}} = g\left(f\left(k^j\left(NDVI_{AVH_{Nj}}\right)\right)\right), j=7,9,11$$

where

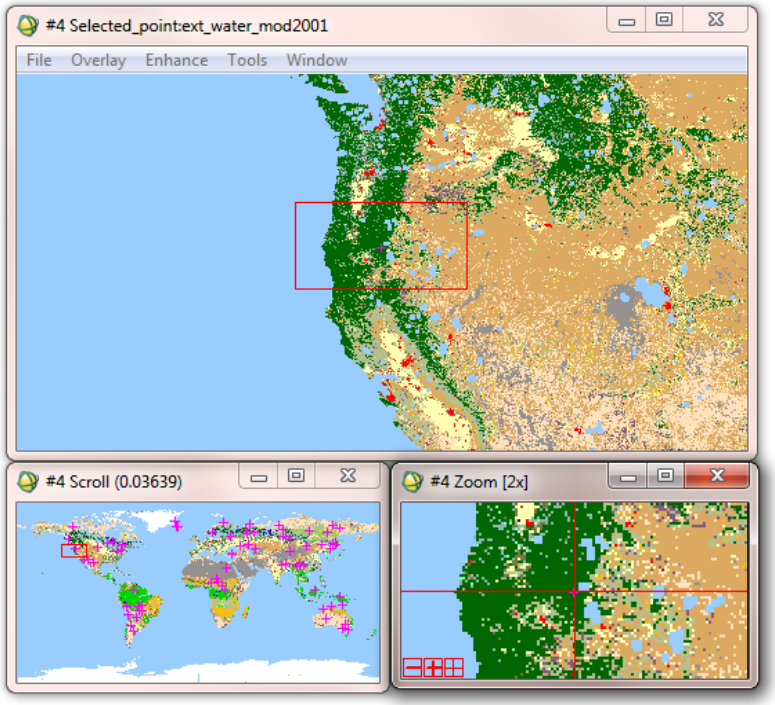
$g()$: Translation equation from SPOT-4 VGT to MODIS

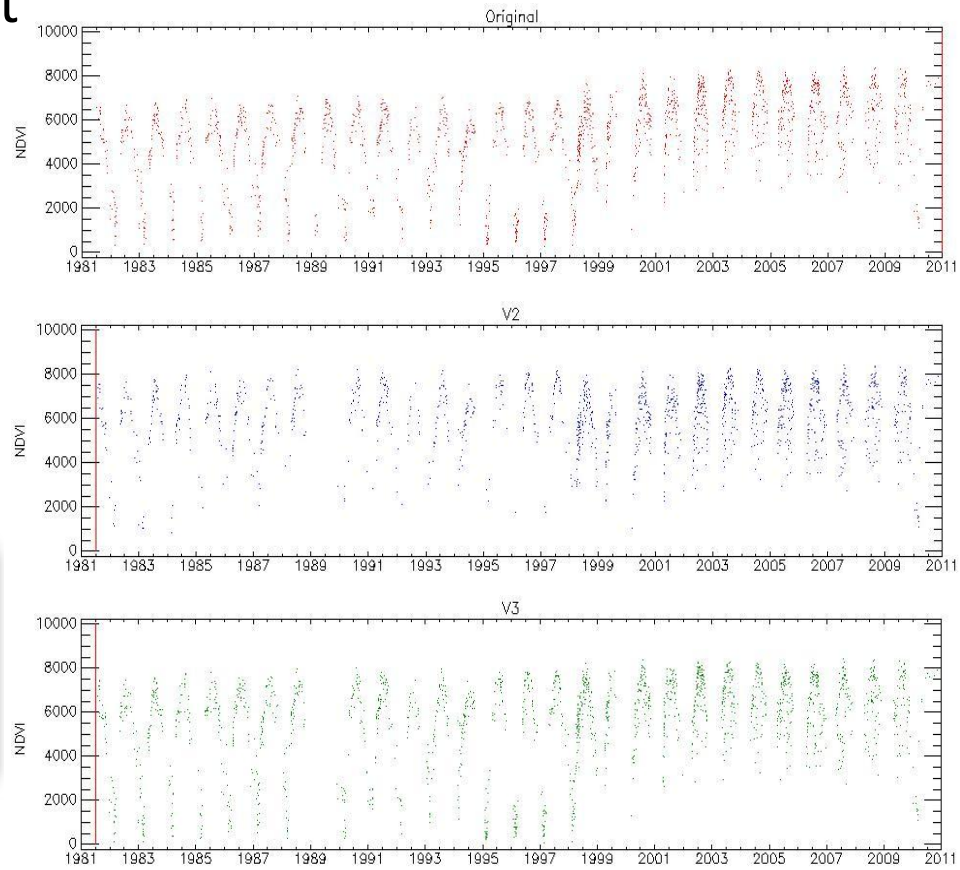
$f()$: Translation equation from N-14 AVHRR to SPOT-4 VGT

$k()$: Spectral correction equation from N-7, 9, or 11 AVHHR/2 to N-14 AVHRR/2

NDVI Temporal Profile

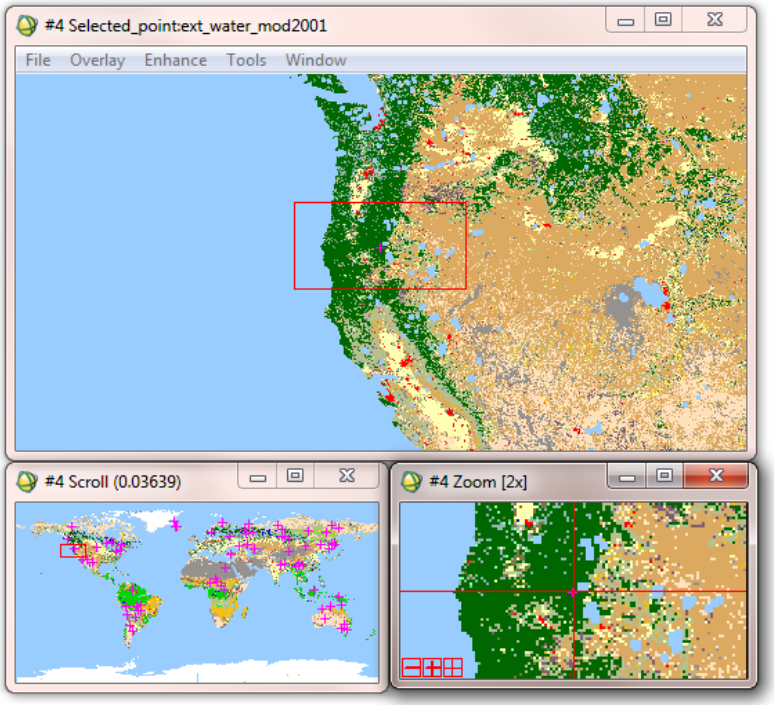
- Evergreen Needleleaf forest

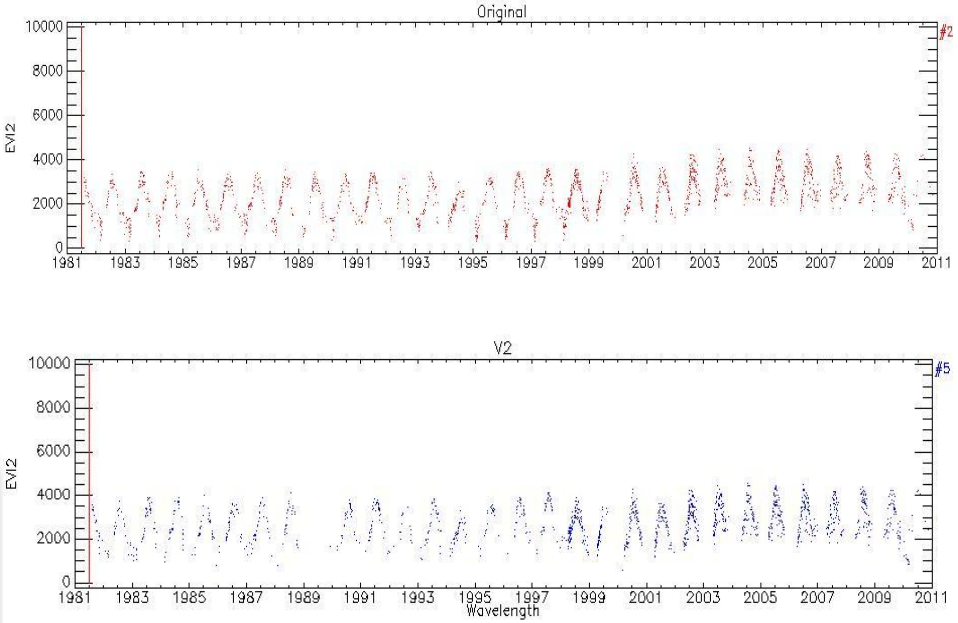




EVI2 Temporal Profile

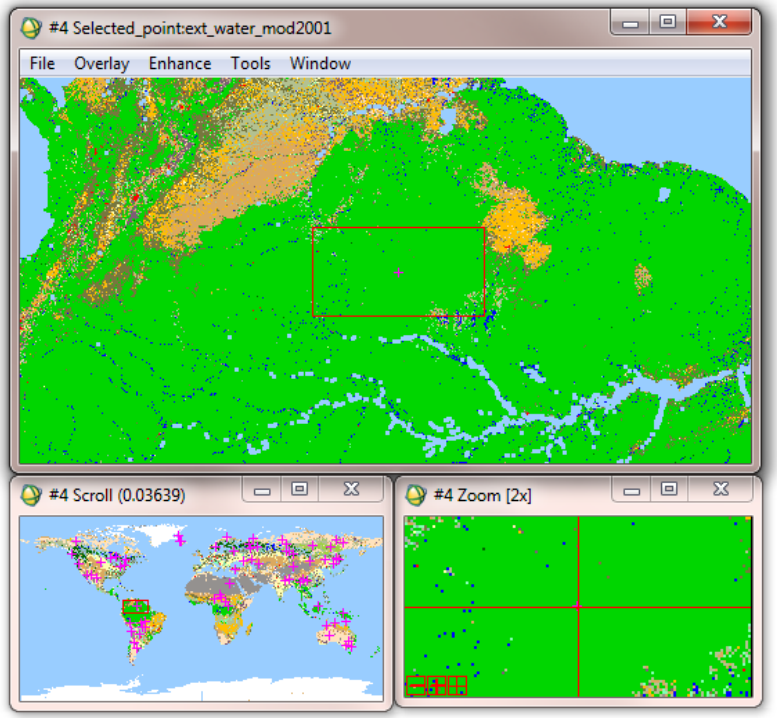
- Evergreen Needleleaf forest

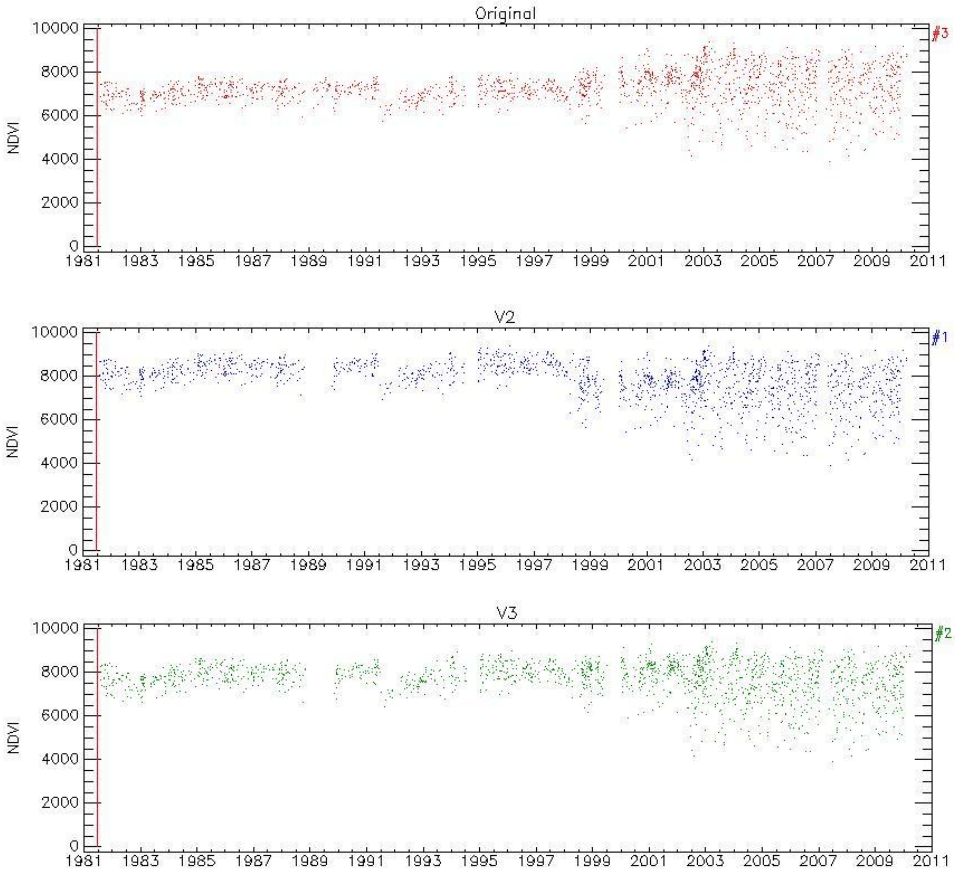




NDVI Temporal Profile (Cont.)

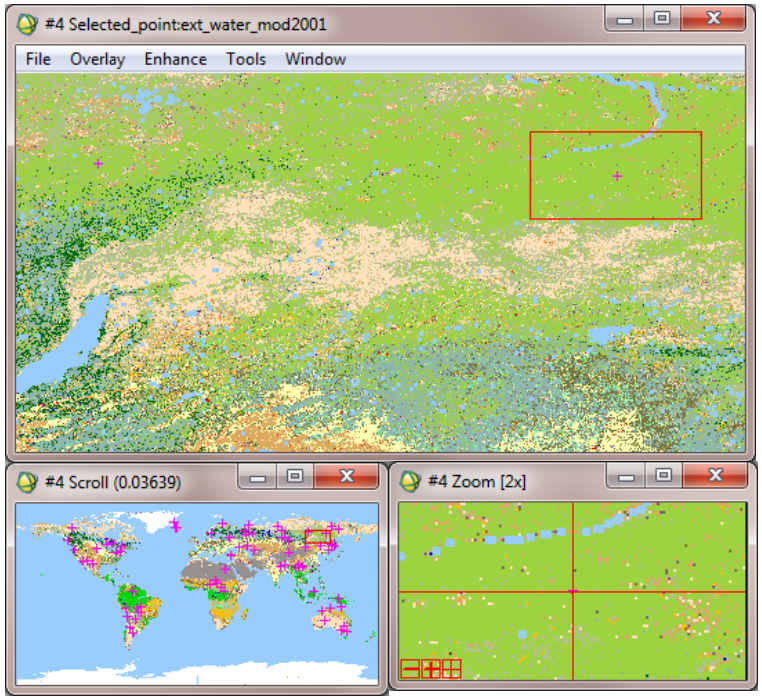
- Evergreen Broadleaf forest

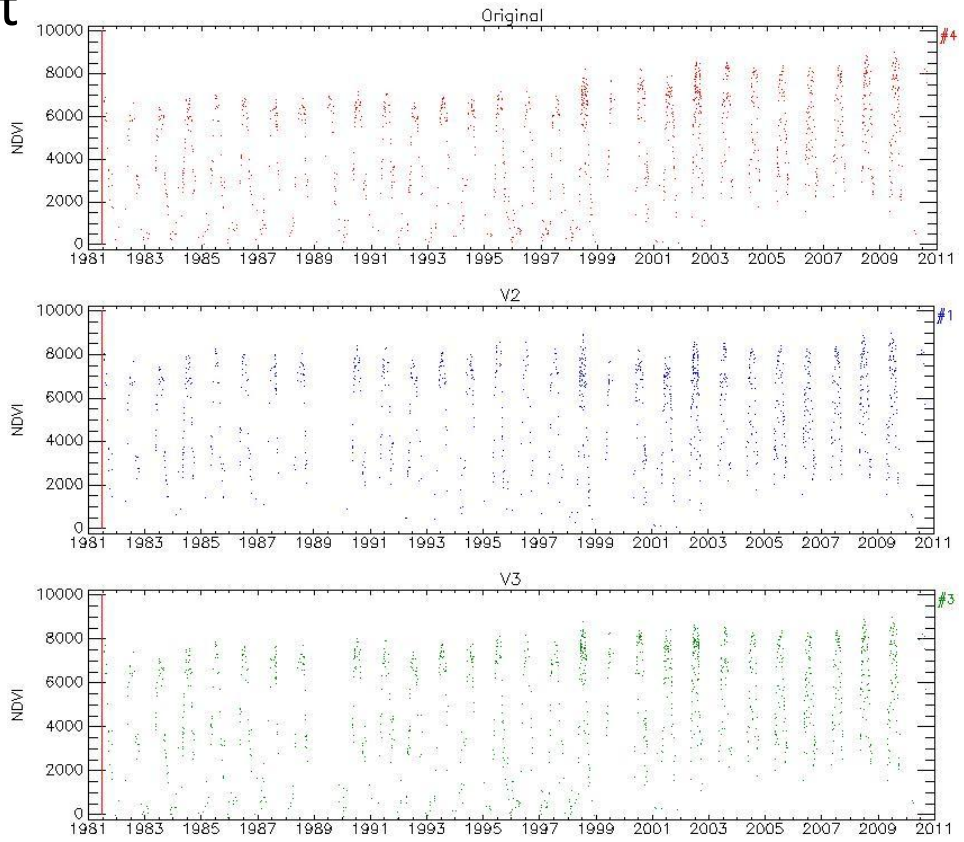




NDVI Temporal Profile (Cont.)

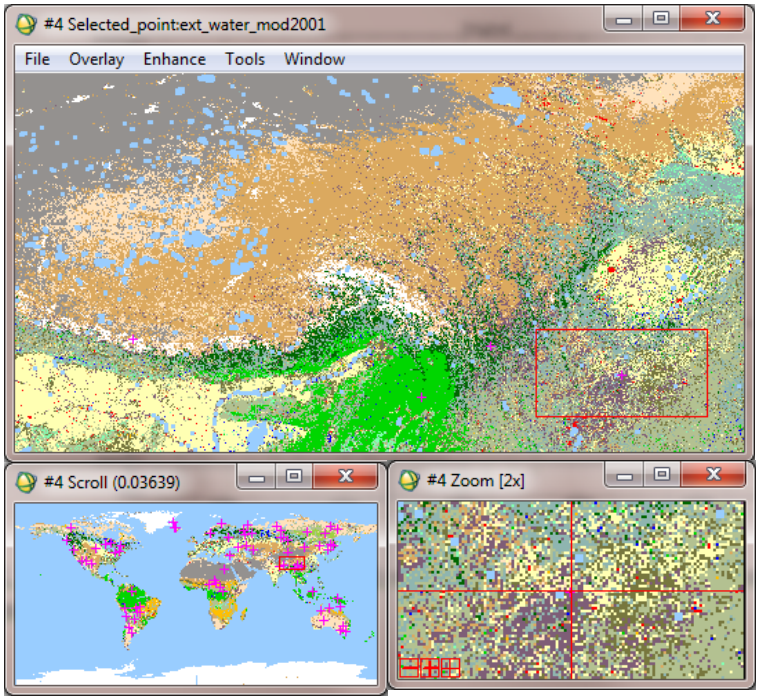
- Deciduous Needleleaf forest

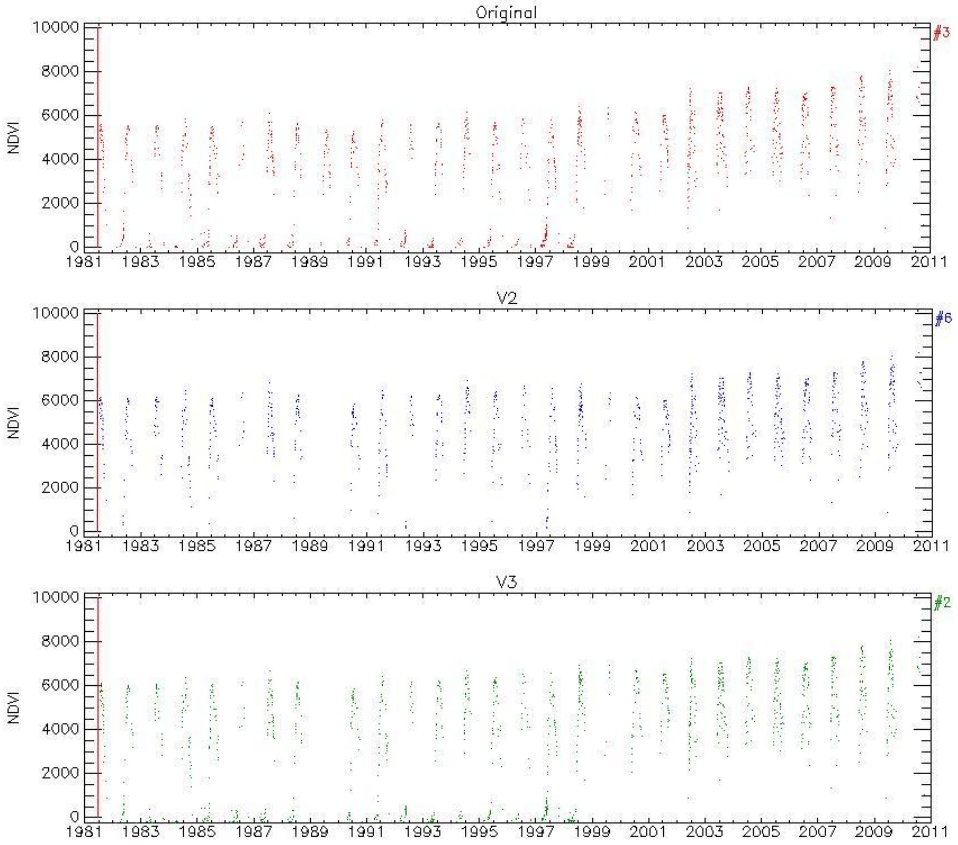




NDVI Temporal Profile (Cont.)

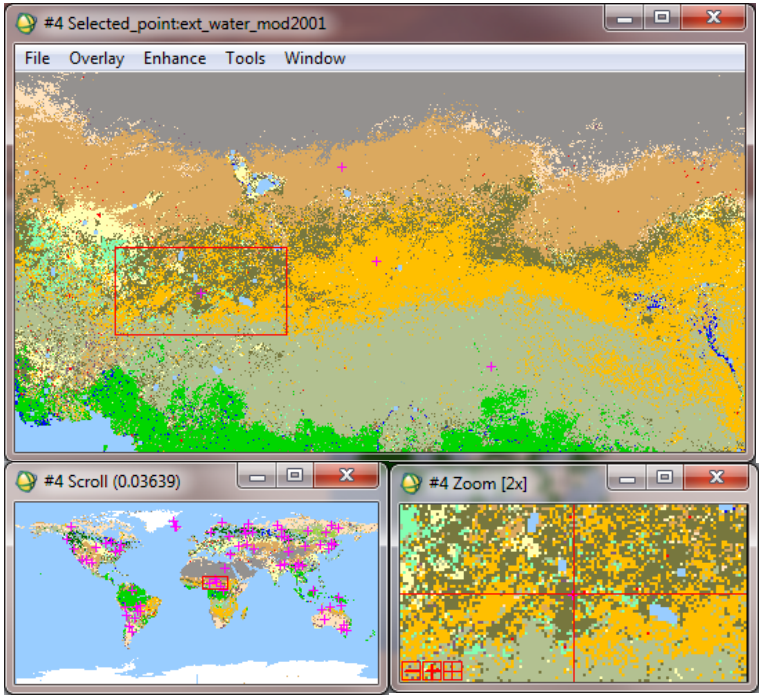
- Closed shrublands

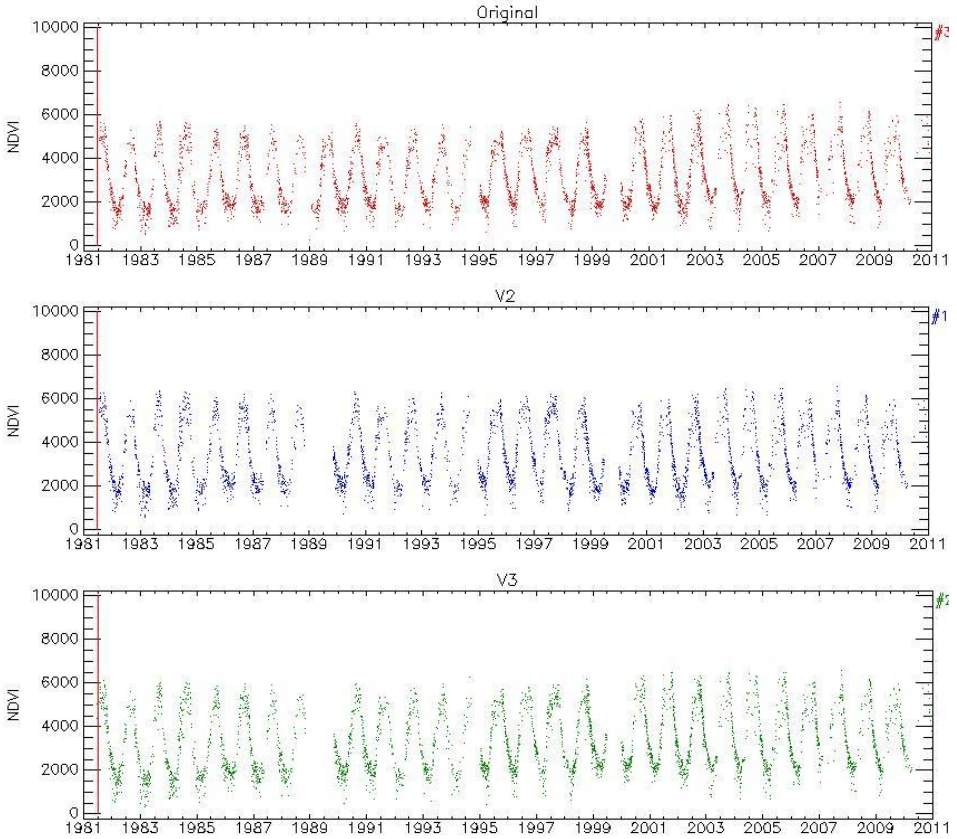




NDVI Temporal Profile (Cont.)

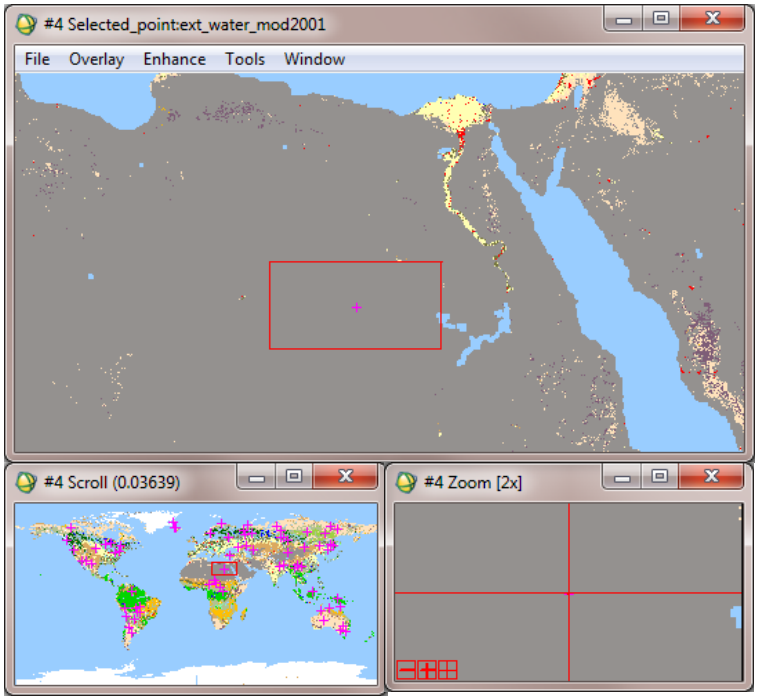
- Cropland/Natural vegetation mosaic

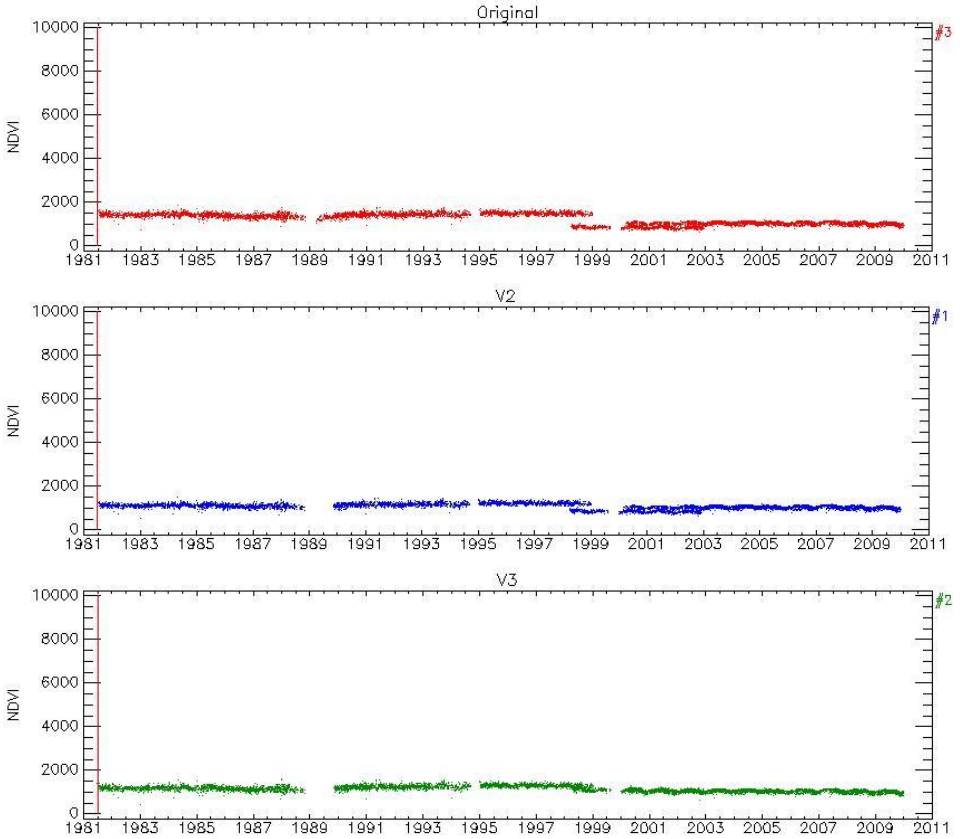




NDVI Temporal Profile (Cont.)

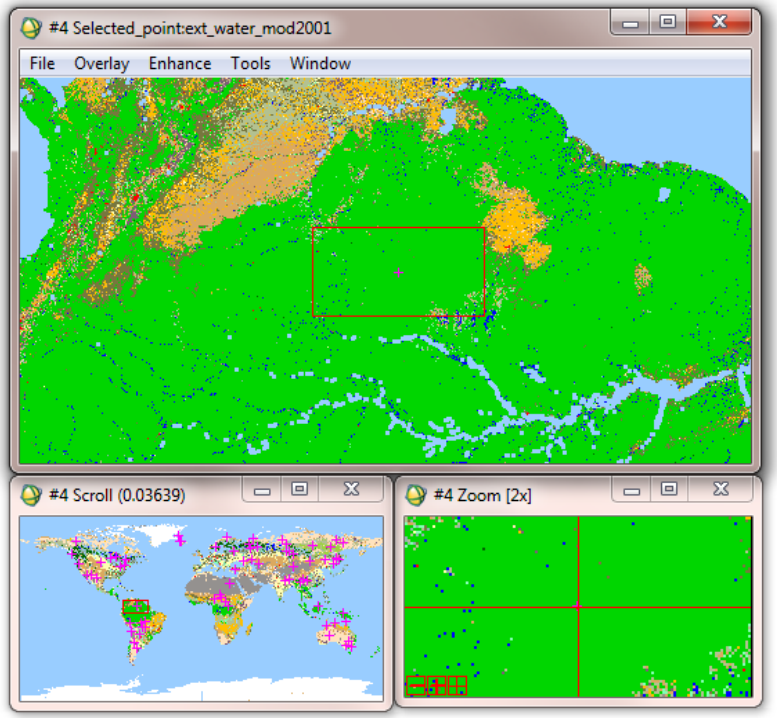
- Barren/Sparsely vegetated

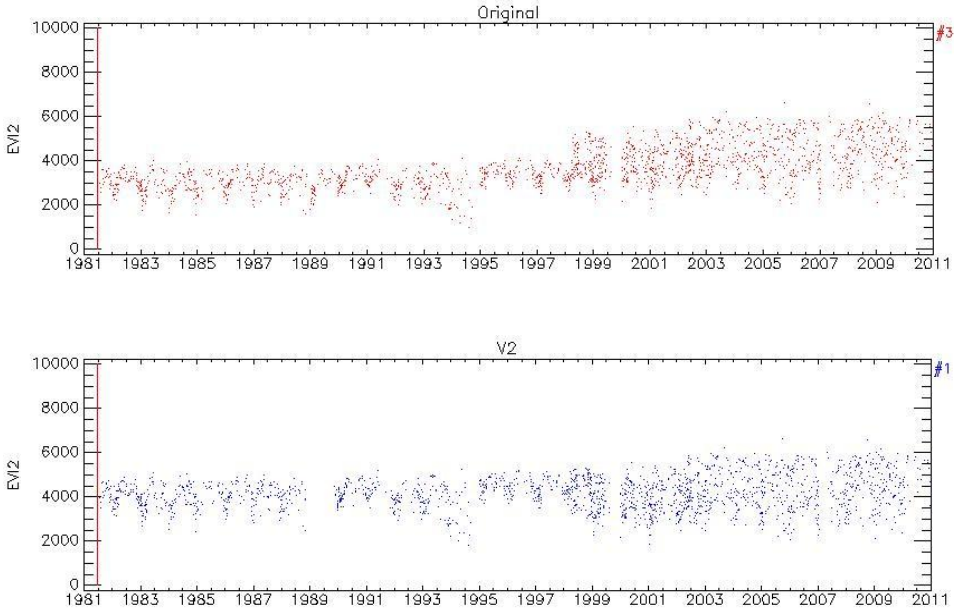




EVI2 Temporal Profile (Cont.)

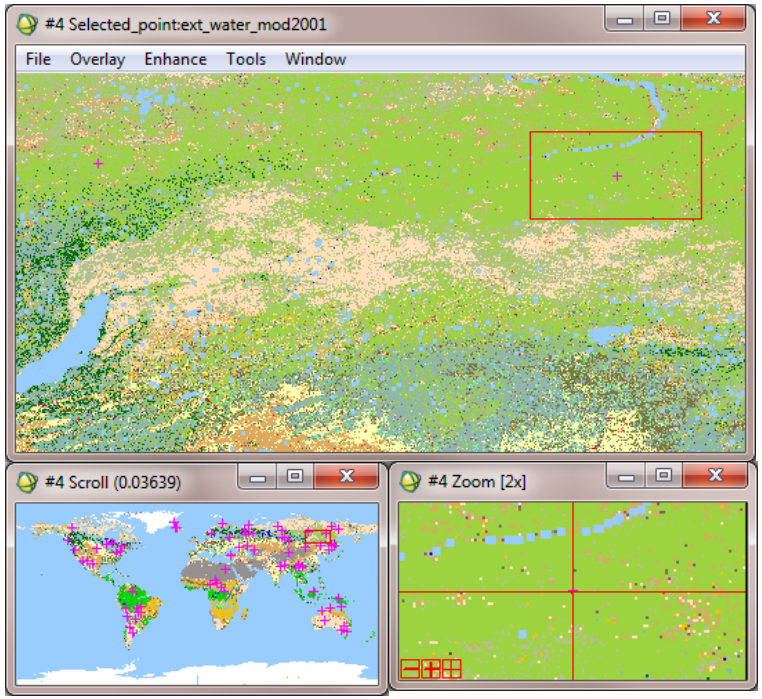
- Evergreen Broadleaf forest

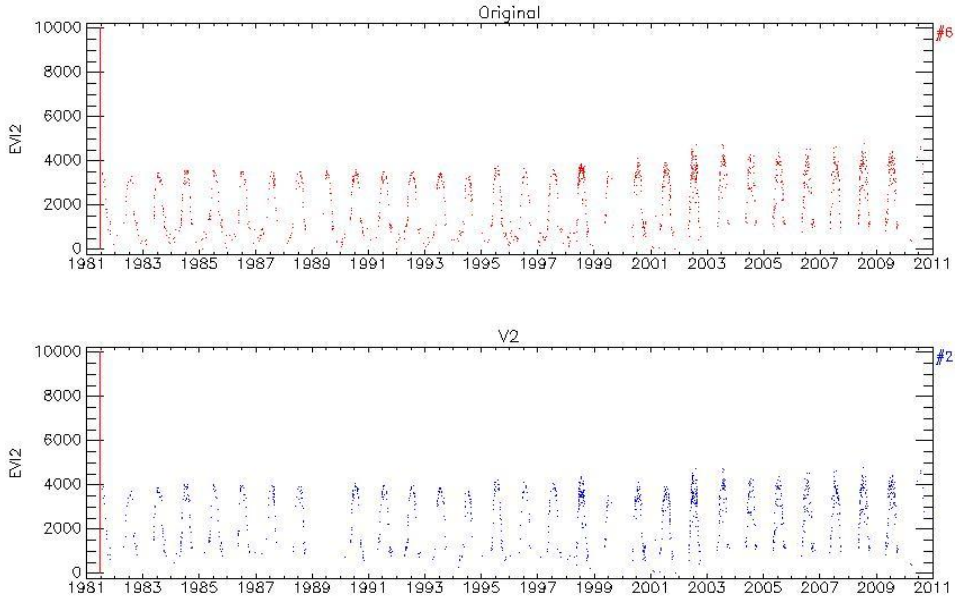




EVI2 Temporal Profile (Cont.)

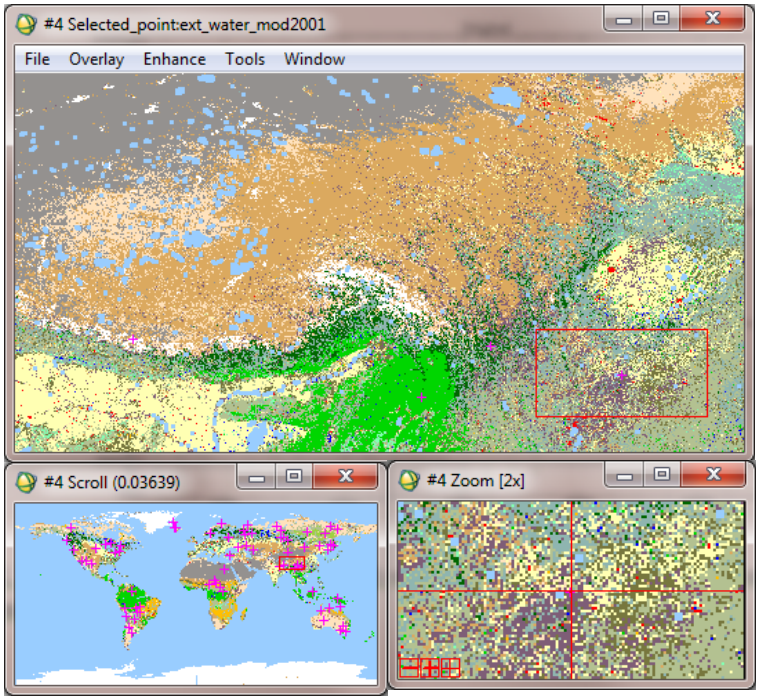
- Deciduous Needleleaf forest

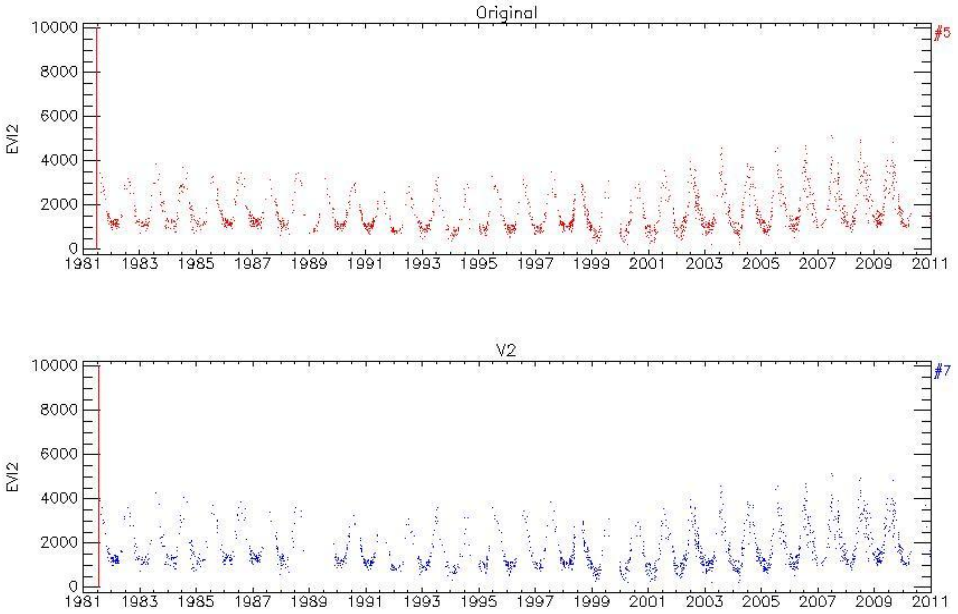




EVI2 Temporal Profile (Cont.)

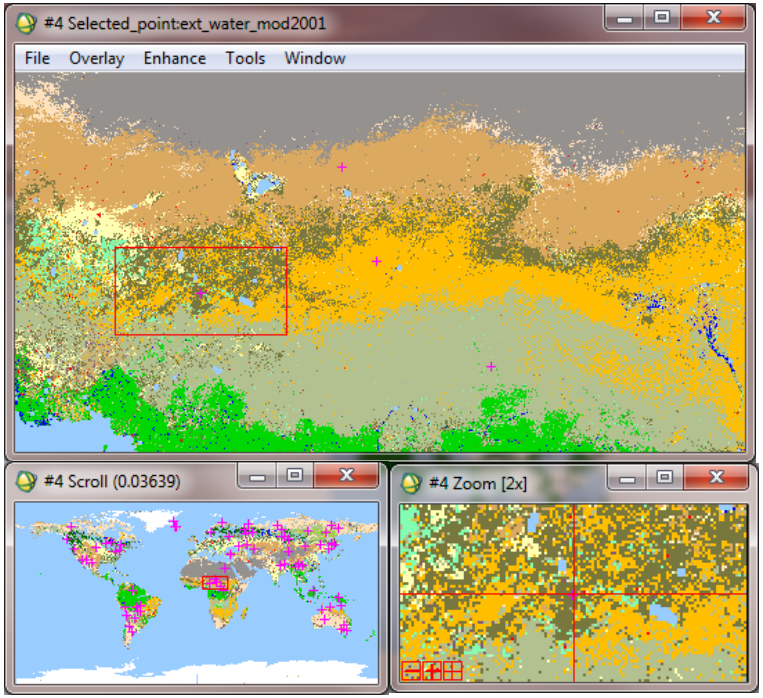
- Closed shrublands

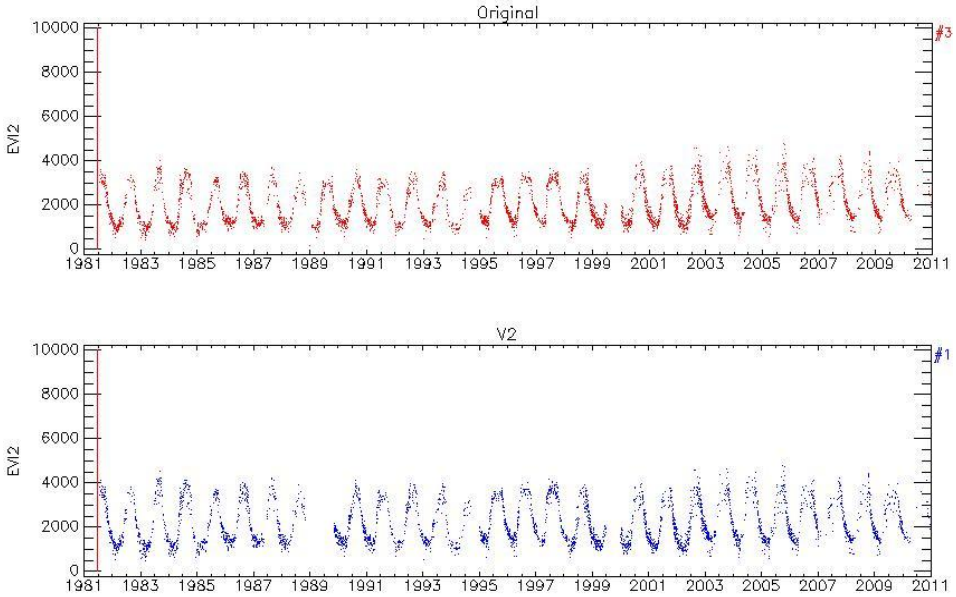




EVI2 Temporal Profile (Cont.)

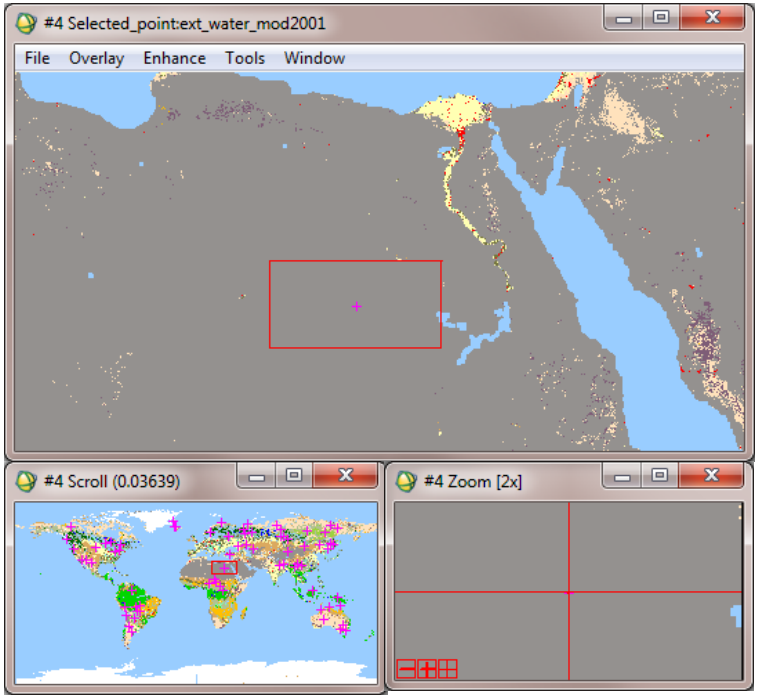
- Cropland/Natural vegetation mosaic

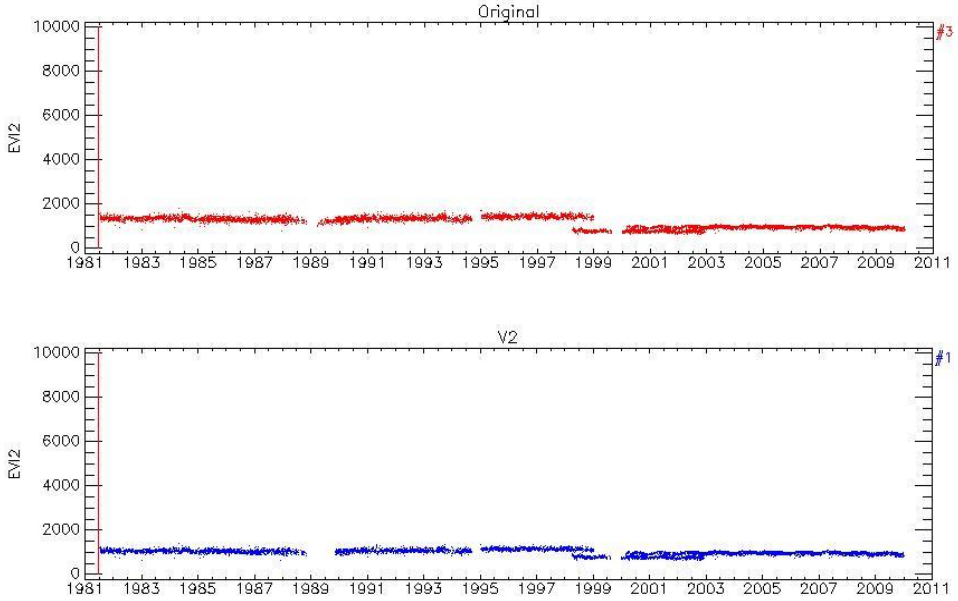




EVI2 Temporal Profile (Cont.)

- Barren/Sparsely vegetated





Summary and Future Plan

- Validation: Landsat TM /ETM ++ time series
- V3 algorithm for EVI2
- Evaluation of the integrity of GAC data with respect to MODIS CMG & mis-registration

Thank you

V1 Translation Algorithm

NDVI (x variable)	Equation
N-7 AVHRR, ROW, GAC	$y = -0.0646111 + 1.2409713x - 0.0304219x^2$
N-9 AVHRR, ROW, GAC	$y = -0.0621082 + 1.2487272x - 0.0307315x^2$
N-11 AVHRR, ROW, GAC	$y = -0.0606805 + 1.2456808x - 0.0335204x^2$
N-14 AVHRR, ROW, GAC	$y = -0.0571829 + 1.2372178x$
S-4 VEGETATION, TOC, CMGV	$y = 0.0156834 + 1.0610148x$

EVI2 (x variable)	Equation
N-7 AVHRR, ROW, GAC	$y = -0.0403338 + 1.2400319x$
N-9 AVHRR, ROW, GAC	$y = -0.0403338 + 1.2400319x$
N-11 AVHRR, ROW, GAC	$y = -0.0403338 + 1.2400319x$
N-14 AVHRR, ROW, GAC	$y = -0.0403338 + 1.2400319x$
S-4 VEGETATION, TOC, CMGV	$y = 0.0085842 + 1.1557716x$

V2 Translation Equations

NDVI (MOD <- AVH14)	Offset	Slope
LC-1: Evergreen Needleleaf forest	-0.0418	1.2521
LC-2: Evergreen Broadleaf forest	0.0637	1.1014
LC-3: Deciduous Needleleaf forest	-0.0800	1.3087
LC-4: Deciduous Broadleaf forest	0.0496	1.1008
LC-5: Mixed forest	0.0037	1.1590
LC-6: Closed shrublands	-0.0330	1.1879
LC-7: Open shrublands	-0.0596	1.2343
LC-8: Woody savannas	-0.0178	1.1952
LC-9: Savannas	-0.0310	1.1940
LC-10: Grasslands	-0.0420	1.1754
LC-11: Permanent wetlands	-0.0572	1.2372
LC-12: Croplands	0.0020	1.1252
LC-13: Urban and built-up	-0.0572	1.2372
LC-14: Cropland/Natural vegetation mosaic	0.0059	1.1295
LC-15: Snow/Ice	-0.0572	1.2372
LC-16: Barren or sparsely vegetated	-0.0071	0.8658

NDVI (MOD <- VGT)	Offset	Slope
LC-1: Evergreen Needleleaf forest	0.0568	1.0262
LC-2: Evergreen Broadleaf forest	0.0495	1.0127
LC-3: Deciduous Needleleaf forest	0.0482	1.0306
LC-4: Deciduous Broadleaf forest	0.0473	1.0186
LC-5: Mixed forest	0.0722	0.9912
LC-6: Closed shrublands	0.0243	1.0516
LC-7: Open shrublands	0.0135	1.0678
LC-8: Woody savannas	0.0350	1.0283
LC-9: Savannas	0.0312	1.0106
LC-10: Grasslands	0.0234	1.0393
LC-11: Permanent wetlands	0.0157	1.0610
LC-12: Croplands	0.0356	1.0182
LC-13: Urban and built-up	0.0157	1.0610
LC-14: Cropland/Natural vegetation mosaic	0.0354	1.0213
LC-15: Snow/Ice	0.0157	1.0610
LC-16: Barren or sparsely vegetated	0.0157	1.0575

V1 Spectral Correction Equations

Spectral Correction to N-14 AVHRR NDVI (y)

N-7 AVHRR/2 NDVI: $y = -.0060 + 1.0030\,x - .0246\,x^2$

N-9 AVHRR/2 NDVI: $y = -.0040 + 1.0093\,x - .0248\,x^2$

N-11 AVHRR/2 NDVI: $y = -.0028 + 1.0068\,x - .0271\,x^2$

V2 Translation Equations

EVI2 (MOD <- AVH14)	Offset	Slope
LC-1: Evergreen Needleleaf forest	-0.0030	1.1602
LC-2: Evergreen Broadleaf forest	0.0754	1.0878
LC-3: Deciduous Needleleaf forest	-0.0150	1.1718
LC-4: Deciduous Broadleaf forest	0.0111	1.1652
LC-5: Mixed forest	-0.0011	1.1717
LC-6: Closed shrublands	-0.0099	1.1128
LC-7: Open shrublands	-0.0241	1.1201
LC-8: Woody savannas	0.0007	1.1332
LC-9: Savannas	-0.0140	1.1757
LC-10: Grasslands	-0.0204	1.1212
LC-11: Permanent wetlands	-0.0403	1.2400
LC-12: Croplands	0.0016	1.1014
LC-13: Urban and built-up	-0.0403	1.2400
LC-14: Cropland/Natural vegetation mosaic	0.0028	1.1367
LC-15: Snow/Ice	-0.0403	1.2400
LC-16: Barren or sparsely vegetated	0.0022	0.7791

EVI2 (MOD <- VGT)	Offset	Slope
LC-1: Evergreen Needleleaf forest	0.0100	1.1786
LC-2: Evergreen Broadleaf forest	0.0175	1.1340
LC-3: Deciduous Needleleaf forest	0.0124	1.1655
LC-4: Deciduous Broadleaf forest	0.0167	1.1366
LC-5: Mixed forest	0.0214	1.1352
LC-6: Closed shrublands	0.0087	1.1518
LC-7: Open shrublands	0.0048	1.1618
LC-8: Woody savannas	0.0141	1.1369
LC-9: Savannas	0.0142	1.1235
LC-10: Grasslands	0.0115	1.1373
LC-11: Permanent wetlands	0.0086	1.1558
LC-12: Croplands	0.0164	1.1197
LC-13: Urban and built-up	0.0086	1.1558
LC-14: Cropland/Natural vegetation mosaic	0.0153	1.1297
LC-15: Snow/Ice	0.0086	1.1558
LC-16: Barren or sparsely vegetated	0.0108	1.1213

V3 Translation Equations

$$NDVI_{mod\ -Like\ AVH\_N7} = 0.0136 + 0.0539 \times EVI2_{vgt\ -Like\ AVH\_N7} - (1.0956 + 0.1878 \times EVI2_{vgt\ -Like\ AVH\_N7}) \times NDVI_{vgt\ -Like\ AVH\_N7}$$
$$NDVI_{mod\ -Like\ AVH\_N9} = 0.0136 + 0.0539 \times EVI2_{vgt\ -Like\ AVH\_N9} - (1.0956 + 0.1878 \times EVI2_{vgt\ -Like\ AVH\_N9}) \times NDVI_{vgt\ -Like\ AVH\_N9}$$
$$NDVI_{mod\ -Like\ AVH\_N11} = 0.0136 + 0.0539 \times EVI2_{vgt\ -Like\ AVH\_N11} - (1.0956 + 0.1878 \times EVI2_{vgt\ -Like\ AVH\_N11}) \times NDVI_{vgt\ -Like\ AVH\_N11}$$
$$NDVI_{mod\ -Like\ AVH\_N14} = 0.0136 + 0.0539 \times EVI2_{vgt\ -Like\ AVH\_N14} - (1.0956 + 0.1878 \times EVI2_{vgt\ -Like\ AVH\_N14}) \times NDVI_{vgt\ -Like\ AVH\_N14}$$
$$NDVI_{mod\ -Like\ VGT} = 0.0136 + 0.0539 \times EVI2_{VGT} - (1.0956 + 0.1878 \times EVI2_{VGT}) \times NDVI_{VGT}$$

where,

$$NDVI_{vgt\ -Like\ AVH\_N7} = -0.0269 - 0.4179 \times EVI2_{AVH\_N7 \rightarrow AVH\_N14} + (1.2493 + 0.1844 \times EVI2_{AVH\_N7 \rightarrow AVH\_N14}) \times NDVI_{AVH\_N7 \rightarrow AVH\_N14}$$
$$NDVI_{vgt\ -Like\ AVH\_N9} = -0.0269 - 0.4179 \times EVI2_{AVH\_N9 \rightarrow AVH\_N14} + (1.2493 + 0.1844 \times EVI2_{AVH\_N9 \rightarrow AVH\_N14}) \times NDVI_{AVH\_N9 \rightarrow AVH\_N14}$$
$$NDVI_{vgt\ -Like\ AVH\_N11} = -0.0269 - 0.4179 \times EVI2_{AVH\_N11 \rightarrow AVH\_N14} + (1.2493 + 0.1844 \times EVI2_{AVH\_N11 \rightarrow AVH\_N14}) \times NDVI_{AVH\_N11 \rightarrow AVH\_N14}$$

V2 Spectral Correction Equations

- NOAA-14 AVHRR like

NOAA-7 AVHRR NDVI:

$$k^7(NDVI_{avh_{N7}}) = -0.0062 + 1.0082 \times NDVI_{avh_{N7}} - 0.0309 \times NDVI^2_{avh_{N7}}$$
$$k^7(EVI2_{avh_{N7}}) = -0.0049 + 1.0255 \times EVI2_{avh_{N7}} - 0.0377 \times EVI2^2_{avh_{N7}}$$

NOAA-9 AVHRR NDVI:

$$k^9(NDVI_{avh_{N9}}) = -0.0040 + 1.0136 \times NDVI_{avh_{N9}} - 0.0309 \times NDVI^2_{avh_{N9}}$$
$$k^9(EVI2_{avh_{N9}}) = -0.0030 + 1.0241 \times EVI2_{avh_{N9}} - 0.0416 \times EVI2^2_{avh_{N9}}$$

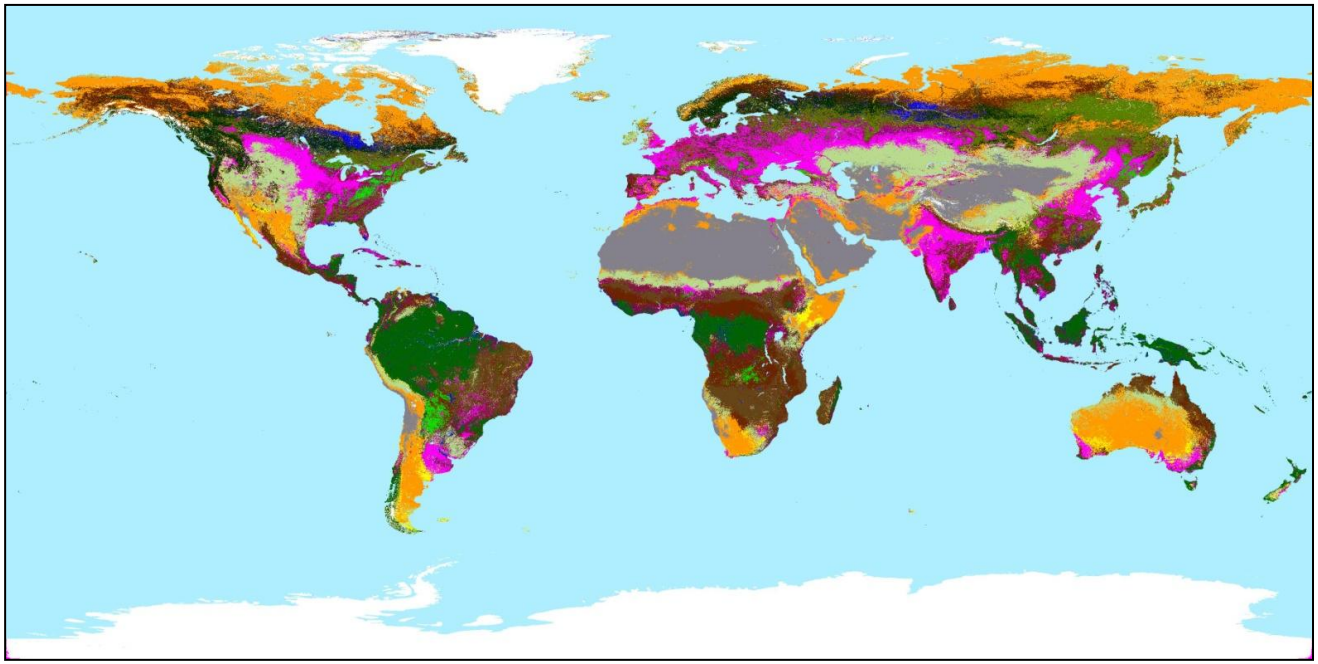
NOAA-11 AVHRR NDVI:

$$k^{11}(NDVI_{avh_{N11}}) = -0.0028 + 1.0107 \times NDVI_{avh_{N11}} - 0.0326 \times NDVI^2_{avh_{N11}}$$
$$k^{11}(EVI2_{avh_{N11}}) = -0.0022 + 1.0209 \times EVI2_{avh_{N11}} - 0.0418 \times EVI2^2_{avh_{N11}}$$

Datasets

- MOD09CMG Collection 5
  - Year 2001-2002
- LTDR AVHRR Ver.3
  - Year 1998-1999
- SPOT VGT-4 S1
  - Year 1998-2002

2001 MODIS IGBP Land Cover (MCD12Q1)



- Water
- Evergreen Needleleaf forest
- Evergreen Broadleaf forest
- Deciduous Needleleaf forest
- Deciduous Broadleaf forest
- Mixed forest
- Closed shrublands
- Open shrublands
- Woody savannas
- Savannas
- Grasslands
- Permanent wetlands
- Croplands
- Urban and built-up
- Cropland/Natural vegetation mosaic
- Snow and ice
- Barren/sparsely vegetated

Backup Slides

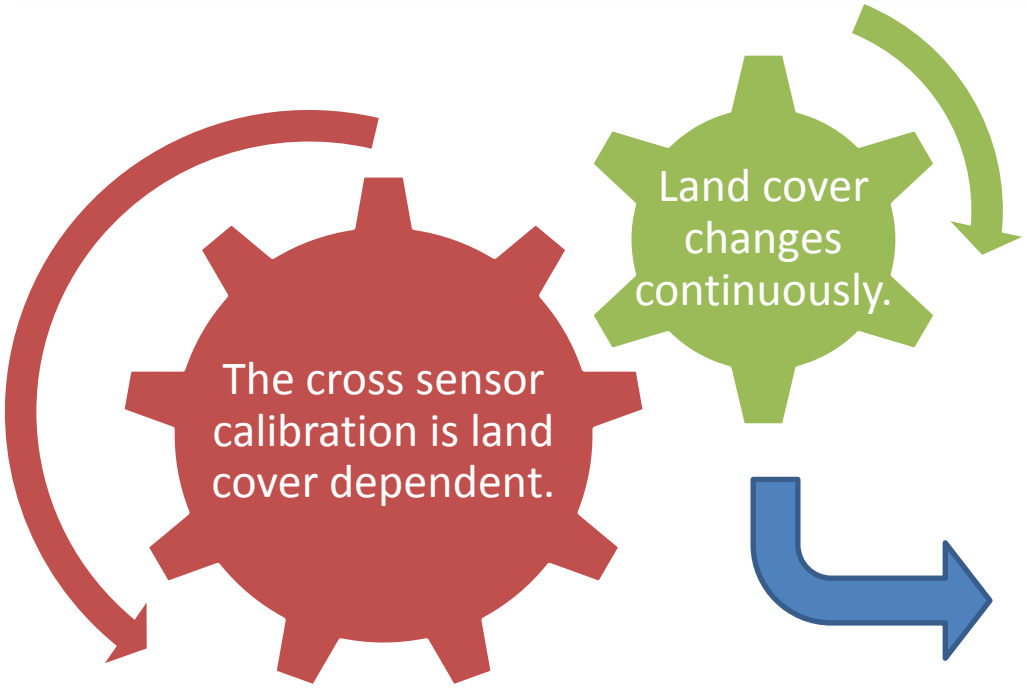
Outline

- The Objective of the Algorithm
- Previous Studies
- Science Algorithm Approaches
  - Compatibility across AVHRR/2 and MODIS Based on Direct Image Comparison (V1, V2, and V3)
  - Compatibility across AVHRR/2 via Hyperspectral Simulation
- Comparison of V3 and V2
- Summary and Future Plan

Previous Studies

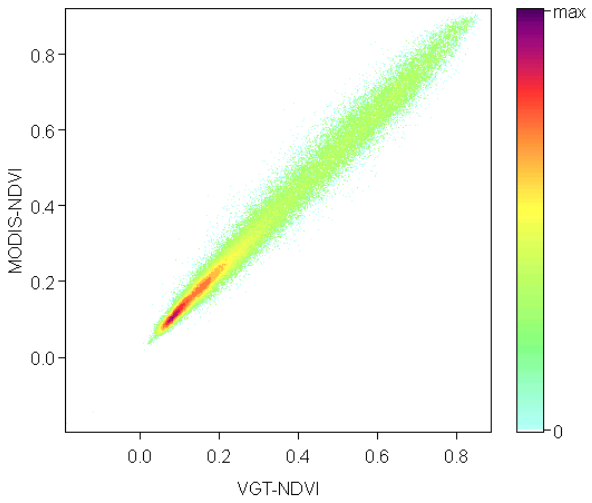
- Empirical approaches
  - Weighted averages of two or more spectral bands (Gao, 1992; Gitleson and Kaufman, 1998)
  - Polynomials
    - 1st order (Steven et al., 2003; van Leeuwen et al., 2006, Gallo et al., 2005; Ji et al., 2008)
    - 2nd order (Trishchenko et al., 2002; Miura et al., 2006; Trischenko, 2009, e.g., Swinnen & Veroustraete, 2008)
- Theoretical approach (Yoshioka et al., 2003; 2005; 2006; Miura et al., 2008)
  - Physics of atmosphere-vegetation-photon interactions

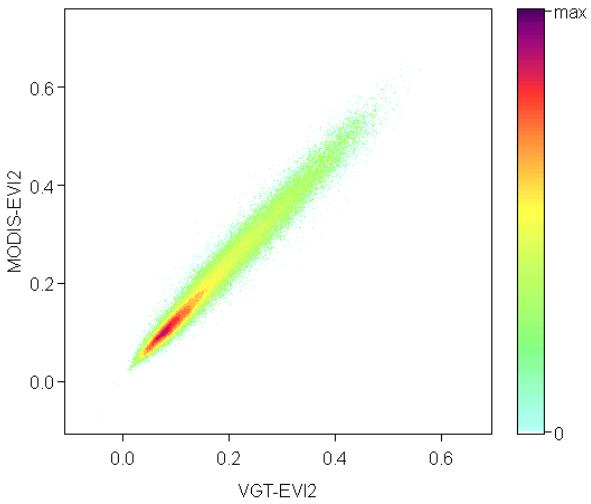
Single Translation Equation- V3



We derived a translation equation that dynamically adjusts with land cover conditions without using any existing land cover maps.

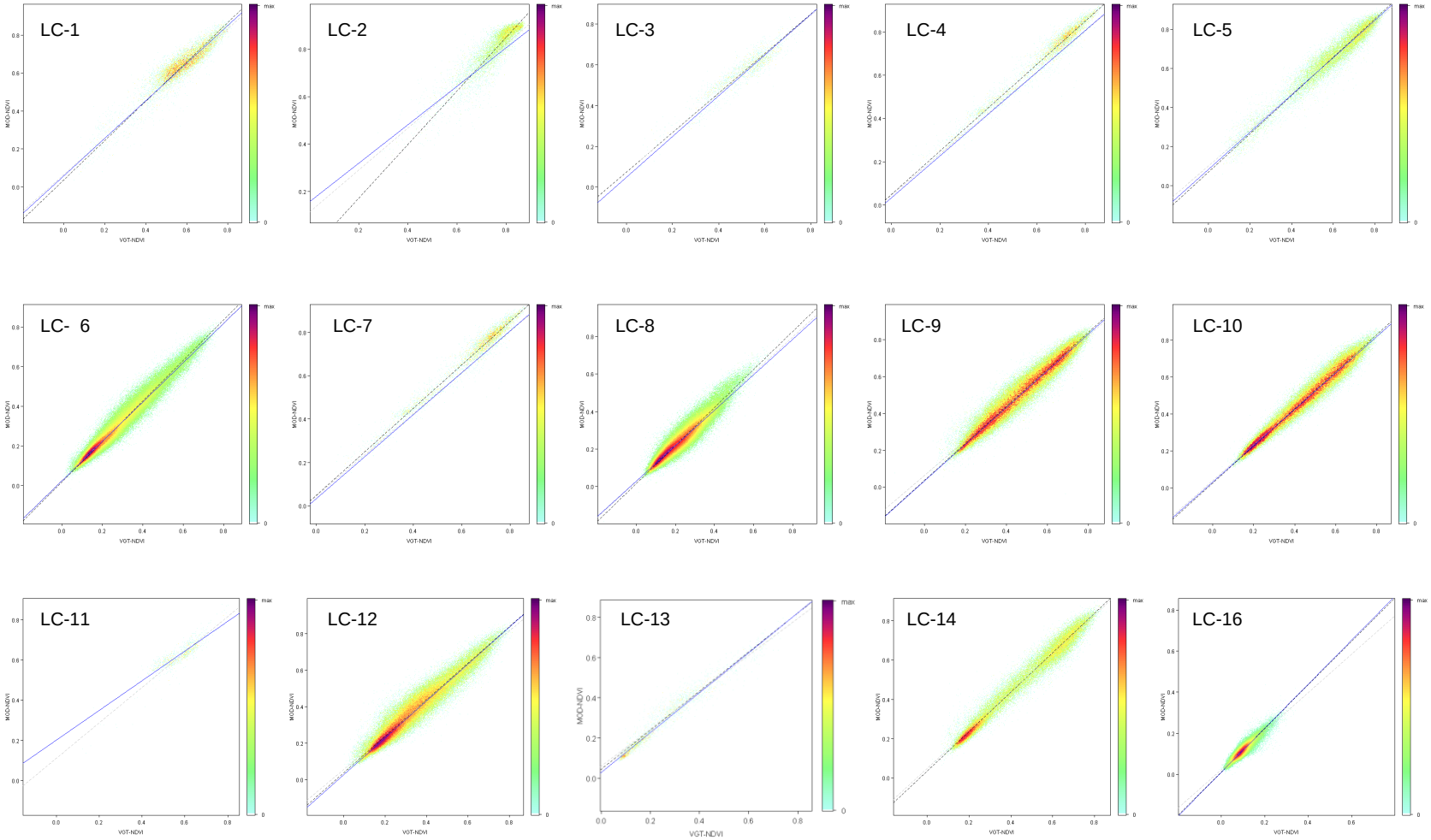
MODIS vs. VEGETATION VI





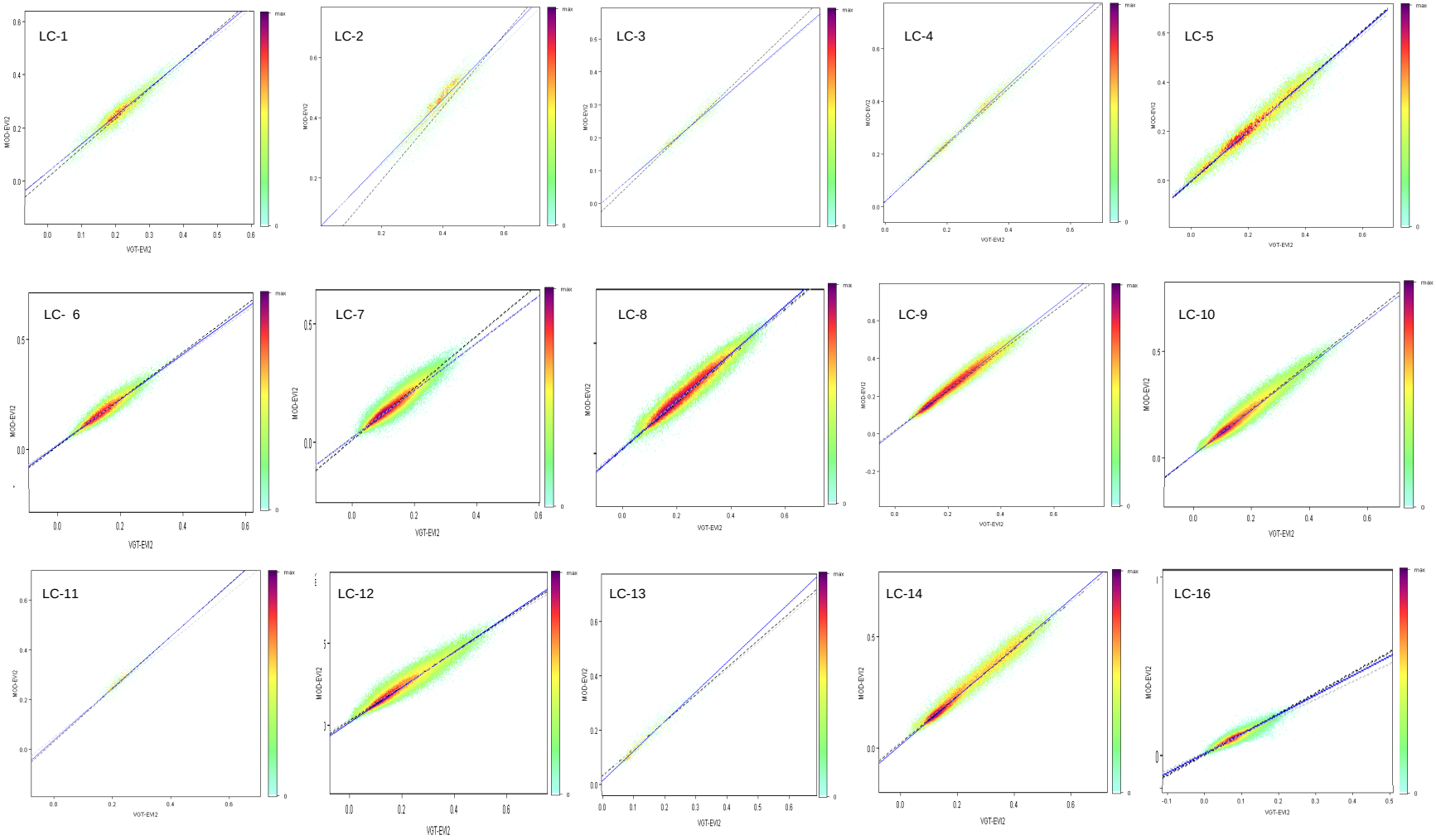
MODIS vs. VEGETATION NDVI:

View zenith angle differences less than 10 degrees



MODIS vs. VEGETATION EVI2:

View zenith angle differences less than 10 degrees



Translation Equations to MODIS-equivalents (TOC, CMG)

- The two translation equations of $f\left(NDVI_{AVH_{N14}}\right)$ and $g(NDVI_{VGT})$ were cascaded to derive a single NDVI translation equation from NOAA-14 AVHRR to MODIS.

$$NDVI_{MOD-like\ AVH_{N14}} = g\left(f\left(NDVI_{AVH_{N14}}\right)\right)$$