A Terrestrial Surface Climate Data Record for Global Change Studies

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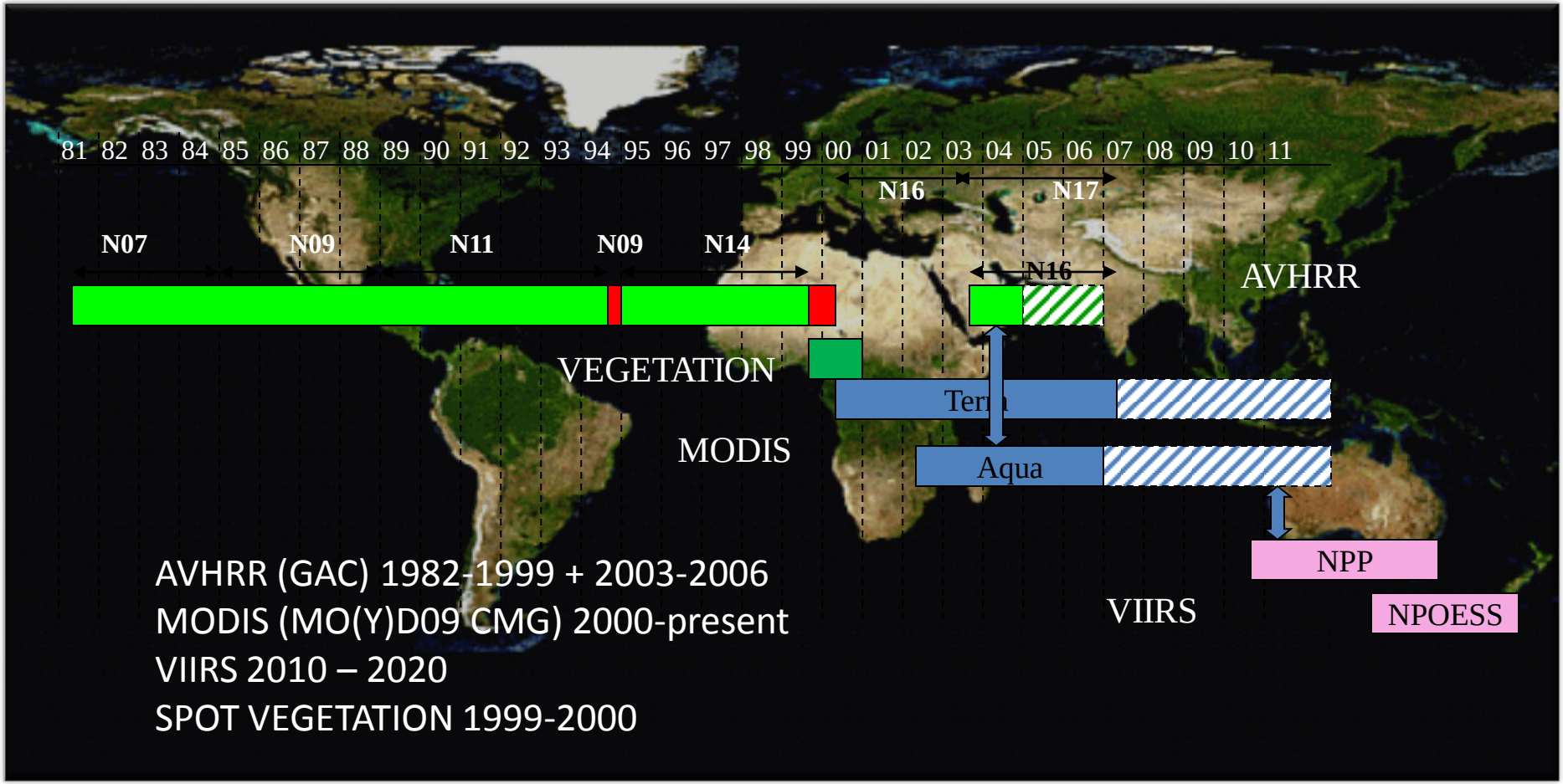
Land Climate Data Record

Multi instrument/Multi sensor Science Quality Data Records used to quantify trends and changes



Emphasis on data consistency – characterization rather than degrading/smoothing the data

Coarse (Moderate) Long Term Data Record

- ESDRs, CDRs, ECVs = Science Quality Data Records
  - Single instrument
- Long term data records
  - a special data set with which to quantify trends and changes
  - Multi instrument/Multi sensor
    - Issues of calibration
    - Addressing Spatial –Geometric / Spectral / Radiometric /Temporal
    - Differences between sensors
  - Emphasis on data consistency – characterization rather than degrading/smoothing the data
- Increasing recognition of importance – what is really needed (GCOS, GEO)
- **This project focus on producing 0.05deg Surface Reflectance (Nadir with Sun at 45degree), Vegetation Index and LAI / FPAR and is the continuation of the REASON-CAN LTDR project**

AVHHR AND MODIS daily time series used to investigate vegetation onset in Europe

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L02404, doi:10.1029/2007GL032472, 2008

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Mild winter and spring 2007 over western Europe led to a widespread early vegetation onset

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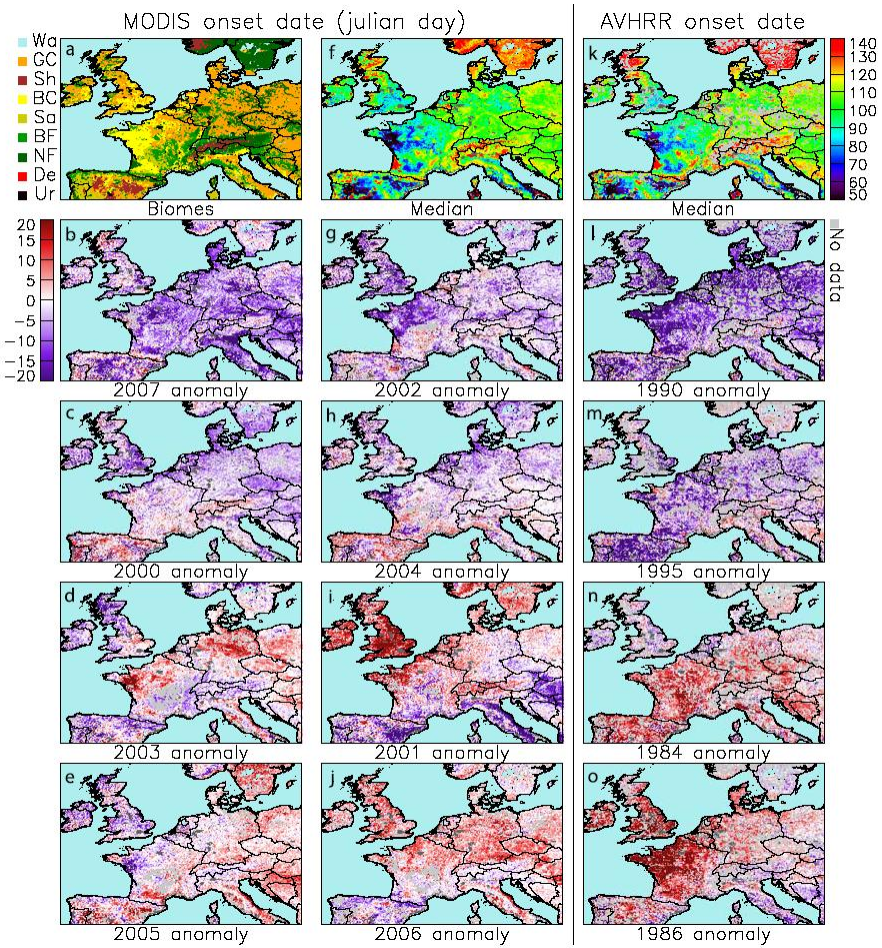


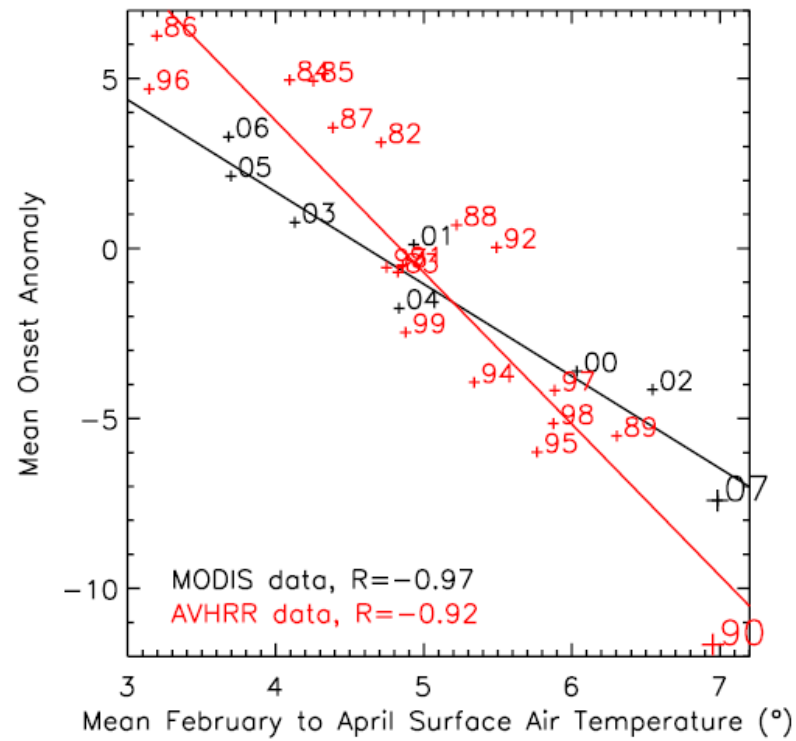


Figure 2. Scatterplot of the vegetation onset date anomaly against the February–April mean temperature. Both parameters have been averaged at the subcontinent scale. The phenology parameters have been derived from the MODIS data for the 2000–2007 period and AVHRR data for the 1982–1999 period. The temperatures are 2m air temperatures from the NCEP reanalysis [*Kalnay et al.*, 1996].

Coarse/Moderate Land Sensors

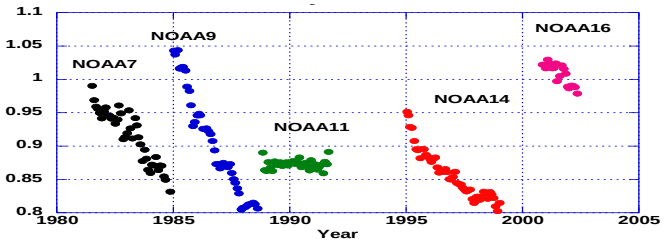
- AVHRR > MODIS > VIIRS
- MODIS is probably as good as we can get for a while: calibration, geolocation, spectral (inc. thermal, instrument characterization, validation efforts) – using this as the ‘reference’
- AVHRR is the big challenge - unique record back to 81 – focus of the project and previous effort (LTDR)
  - Calibration, Cloud Mask, Geolocation, Atm Corr etc
- VIIRS is to come

Land Climate Data Record

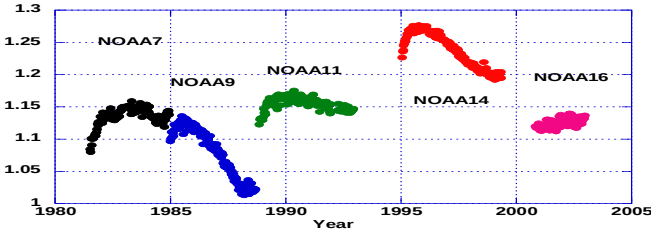
Needs to address calibration, atmospheric/BRDF correction issues

CALIBRATION

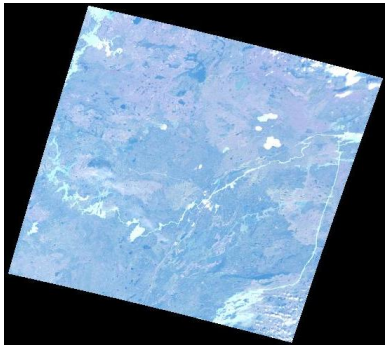
Degradation in channel 1
(from Ocean observations)

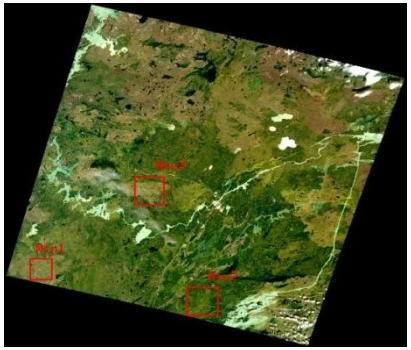


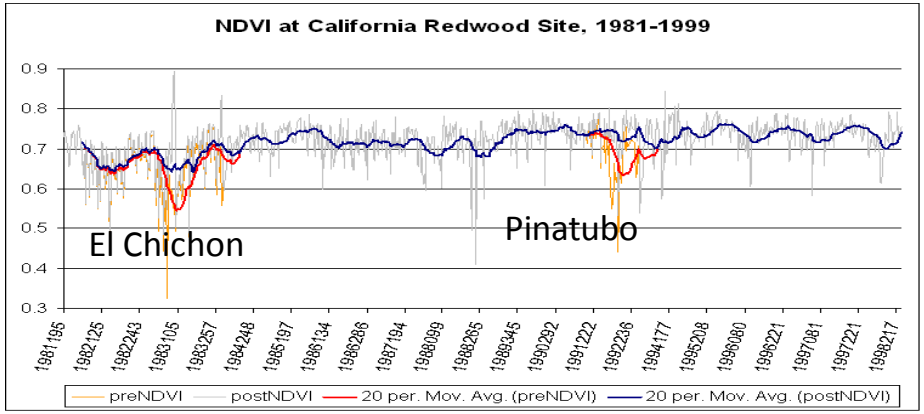
Channel1/Channel2 ratio
(from Clouds observations)



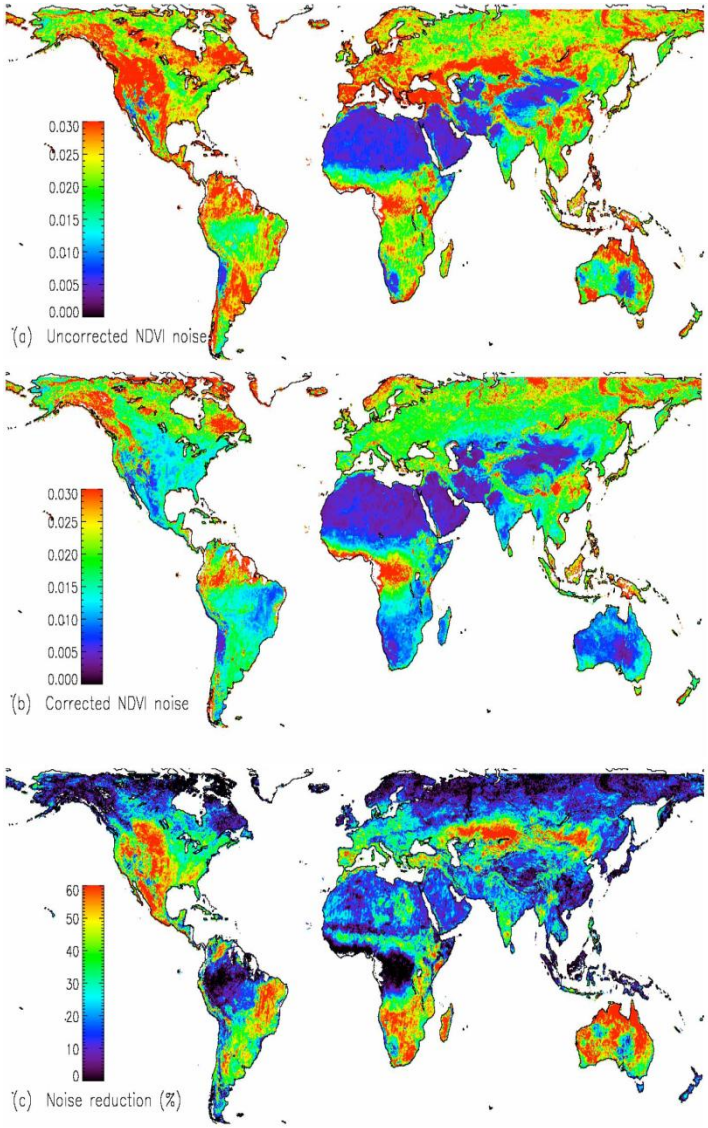
ATMOSPHERIC CORRECTION





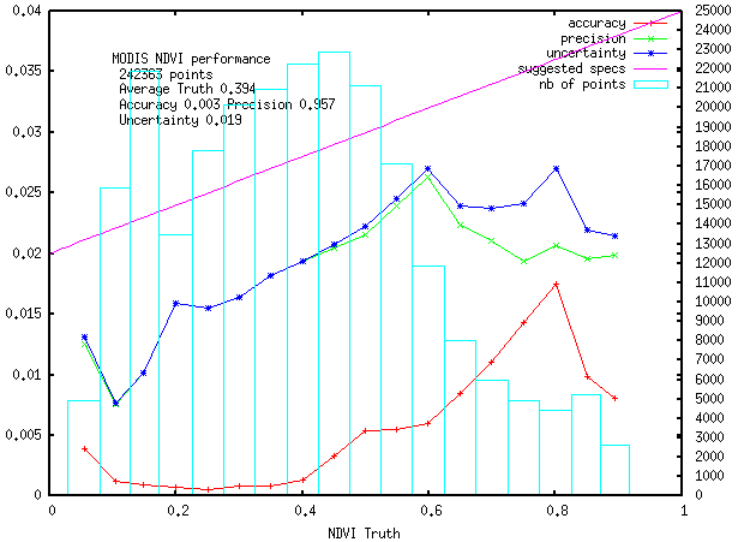


BRDF CORRECTION

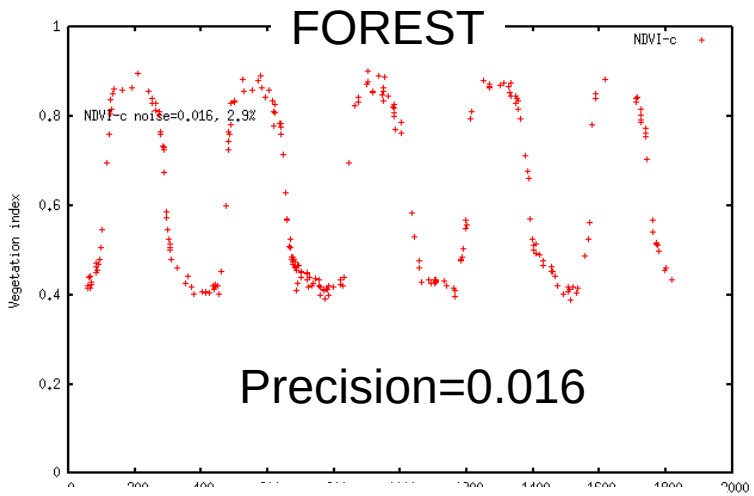


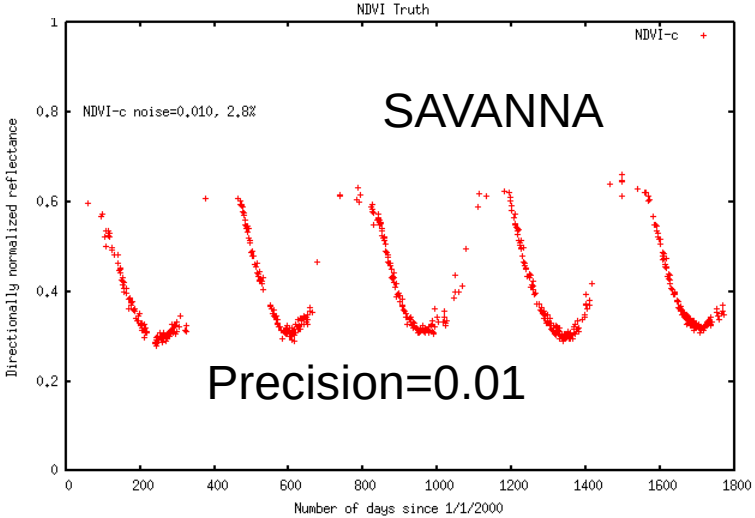
MODIS used as a reference for past and future land data record (example NDVI)

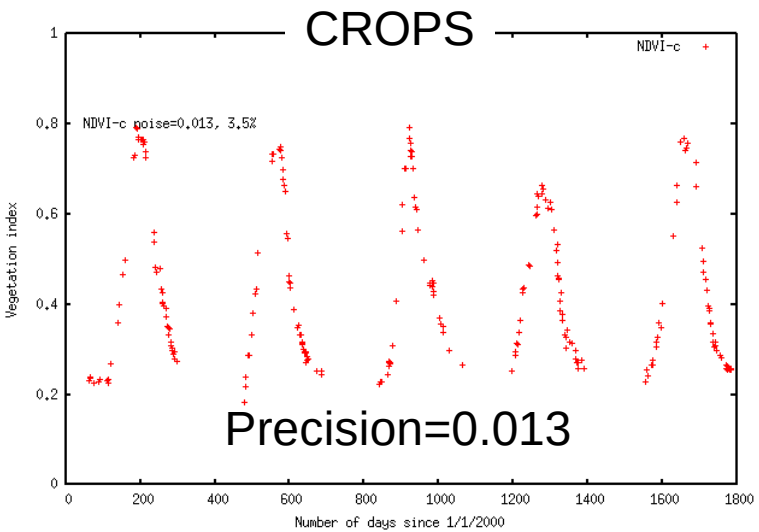
Evaluation over AERONET (2003)
0.007 <Precision < 0.017



Independent evaluation of the precision
Over 2000-2004 CMG daily time series







I. LTDR-AVHRR is one of many AVHRR data sets

(but not all publically available)

1. From GLOBAL – GAC (4-15km spatial resolution)

- (GVI)
- PAL (successive improvements, stops in 2000)
- Other global Area Coverage products (e.g. JRC)
- **GIMMS** (successive improvements, continues to present)
- **This dataset LTDR**
  - New pre-processing methods being implemented
  - Aim is continuity with current MODIS and future VIIRS sensors
  - Processing methods under development – ver3 expected in 2009

Pedelty, J., Devadiga, S., Masuoka, E., Brown,M., Pinzon,J., Tucker, C.J., Vermote, E., Prince, S., Nagol, J., Justice, C., Roy, D., Schaaf, C., Liu, J., Privette, J., Pinheiro, A.,2007. Generating a Long-term Land Data Record from the AVHRR and MODIS Instrument. IGARRS '07, Barcelona, Spain, July 23-27.

2. From Local (1-4km LAC)

- Global 1-km AVHRR data – IGBP/USGS
- Many regional data sets

(e.g. South Africa's Council for Scientific and Industrial Research's (CSIR's) Satellite Applications Centre, Senegal CSE/DANIDA/Univ Copenhagen, UK Univ Durham)

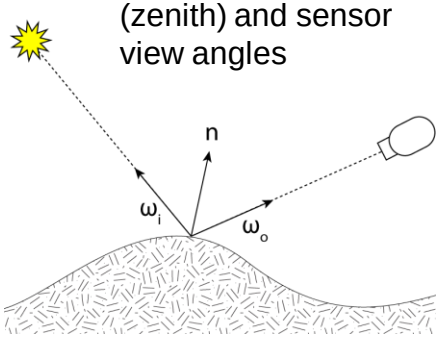
LTDR land surface properties from AVHRR data
II. Processing steps (see http://ltdr.nascom.nasa.gov/ltdr/docs2.html)

1. Estimation of land surface reflectances from satellite data

- AVHRR GAC record 1981-1999 (-2000 in ver.3*)
- Orbit selection *
  - one complete global data set per day
- Sensor calibration *
  - Vicarious cloud/ocean technique (~1% accuracy)
    (shttp://ltdr.nascom.nasa.gov/ltdr/avhrr_calib_1.html
- Cloud screening *
  - MODIS thresholds applied to VIS, NDVI, and TIR
- Data mapping * (georeferencing) channels
  - Orbital model run with corrected on-board clock and ephemeris data
- Corrections for atmospheric composition
  - Water vapor – NCEP climate data
  - Ozone – TOMS UV
  - Rayleigh scattering – atmos pressure
  - Aerosols *
    - using ch1 (VIS) and ch3 (SWIR)
- Bidirectional reflectance distribution function * (BRDF)
  - Applies correction parameters from POLDER in Ross-Li-Maignan model (~3% error)

* ver.3 implements new or significantly different methods

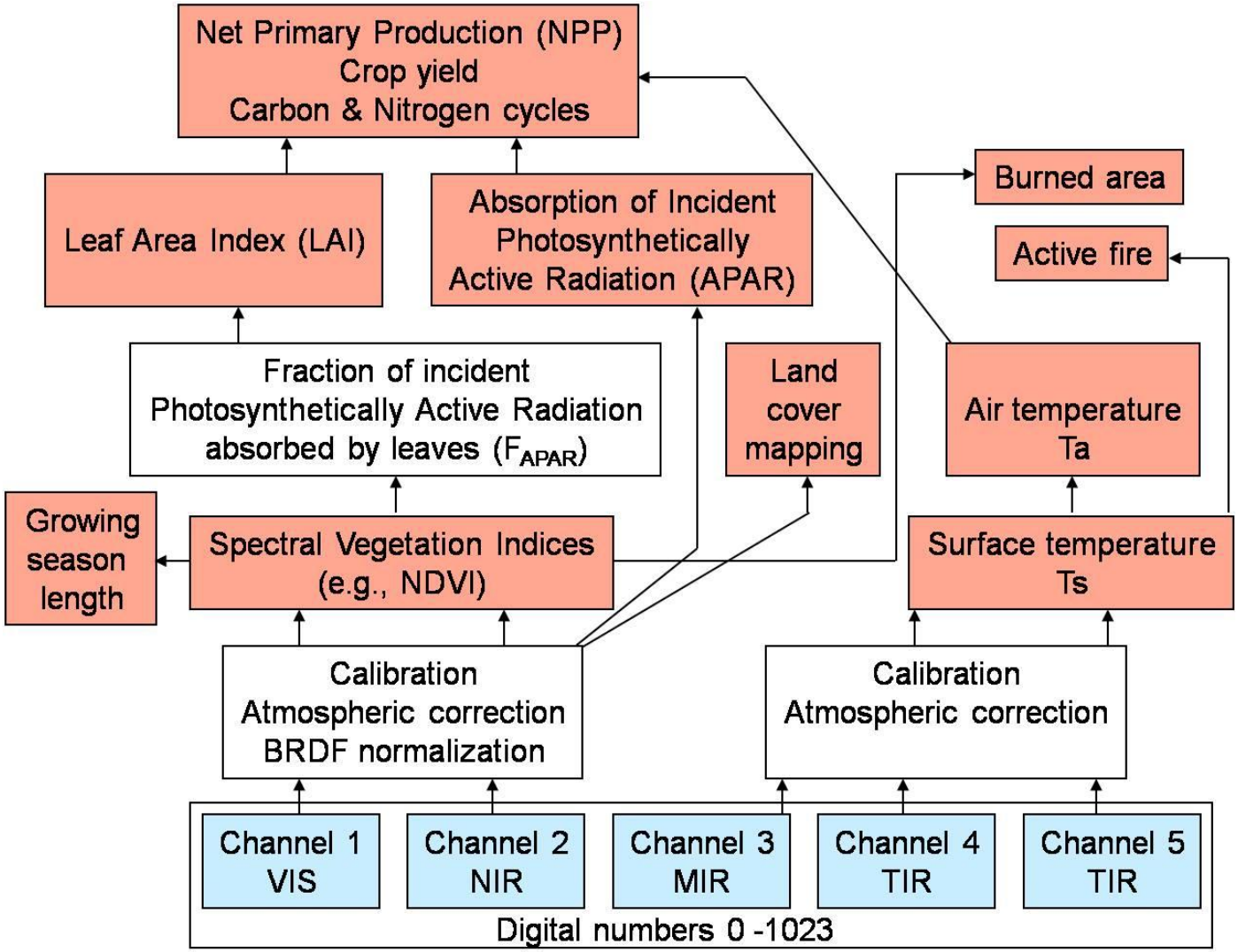
Solar illumination (zenith) and sensor view angles



LTDR data of land surface properties from AVHRR data

II. Processing steps

2. Estimation of vegetation properties from reflectances



LTDR data of land surface properties from AVHRR data

III. User perspectives

1. LTDR's processing methods under development
2. Ver3 to be released in 2009
3. Daily data
4. Data accuracy
    1. Single pixels
    2. Spatial and temporal averaging

LTDR data of land surface properties from AVHRR data

IV. Data contents

http://ltdr.nascom.nasa.gov/ltdr/docs/LTDR_Version2_Data_Products.pdf

AVH09 Surface Reflectance Product

Array Name	Description	Units	Data Type1	Valid Range [low, high]	Scale Factor2	Fill Value
SREFL_CH1	Surface reflectance for	Unitless	int16	[0, 1]	104	-9999
	channel 1 (0.5–0.7 ìm)					
SREFL_CH2	Surface reflectance for	Unitless	int16	[0, 1]	104	-9999
	channel 2 (0.7–1.0 ìm)					
SREFL_CH3	Surface reflectance for	Unitless	int16	[0, 1]	104	-9999
	ch. 3 (~3.55 – 3.93 ìm)					
BT_CH3	TOA brightness	Degrees	int16	[varies]	10	-9999
	temperature for channel	Kelvin				
	3 (~3.55 – 3.93ìm)					
BT_CH4	TOA brightness	Degrees	int16	[varies]	10	-9999
	temperature for channel	Kelvin				
	4 (10.3 – 11.3 ìm)					
BT_CH5	TOA brightness	Degrees	int16	[varies]	10	-9999
	temperature for channel	Kelvin				
	5 (11.5 –12.5 ìm)					
SZEN	Solar zenith angle	Degrees	int16	[0°, 90°]	102	-9999
VZEN	View zenith angle	Degrees	int16	[-90°, 90°]	102	-9999
RELAZ	Relative azimuth	Degrees	int16	[varies]	102	-9999
QA	Quality Assessment	NA	int16	NA	NA	NA
	Field (see section 1.4)					

LTDR data of land surface properties from AVHRR data

IV. Data contents

http://ltdr.nascom.nasa.gov/ltdr/docs/LTDR_Version2_Data_Products.pdf

AVH13 NDVI Product

Array Name	**Description**	**Units**	**Data**	**Valid**	**Scale**	**Fill**
			Type1	Range	Factor2	Value
				[low, high]		
NDVI	Normalized Difference	Unitless	int16	[-1, 1]	104	-9999
	Vegetation Index					
QA	Quality Assessment	NA	int16	NA	NA	NA
	Field (see section 1.4)					

LTDR data of land surface properties from AVHRR data

IV. Data contents

http://ltdr.nascom.nasa.gov/ltdr/docs/LTDR_Version2_Data_Products.pdf

Quality Assessment Field Description

Bit Number	Description	Meaning
15	Polar flag: latitude > 60° (land) or > 50° (ocean)	1 = yes, 0 = no
14	Desert flag	1 = yes, 0 = no
13	RHO3 value is invalid	1 = yes, 0 = no
12	Channel 5 value is invalid	1 = yes, 0 = no
11	Channel 4 value is invalid	1 = yes, 0 = no
10	Channel 3 value is invalid	1 = yes, 0 = no
9	Channel 2 value is invalid	1 = yes, 0 = no
8	Channel 1 value is invalid	1 = yes, 0 = no
7	Channels 1 – 5 are valid	1 = yes, 0 = no
6	Pixel is at night (high solar zenith angle)	1 = yes, 0 = no
5	Pixel is over dense dark vegetation	1 = yes, 0 = no
4	Pixel is over sun glint	1 = yes, 0 = no
3	Pixel is over water	1 = yes, 0 = no
2	Pixel contains cloud shadow	1 = yes, 0 = no
1	Pixel is cloudy	1 = yes, 0 = no
0	Pixel is partly cloudy	1 = yes, 0 = no

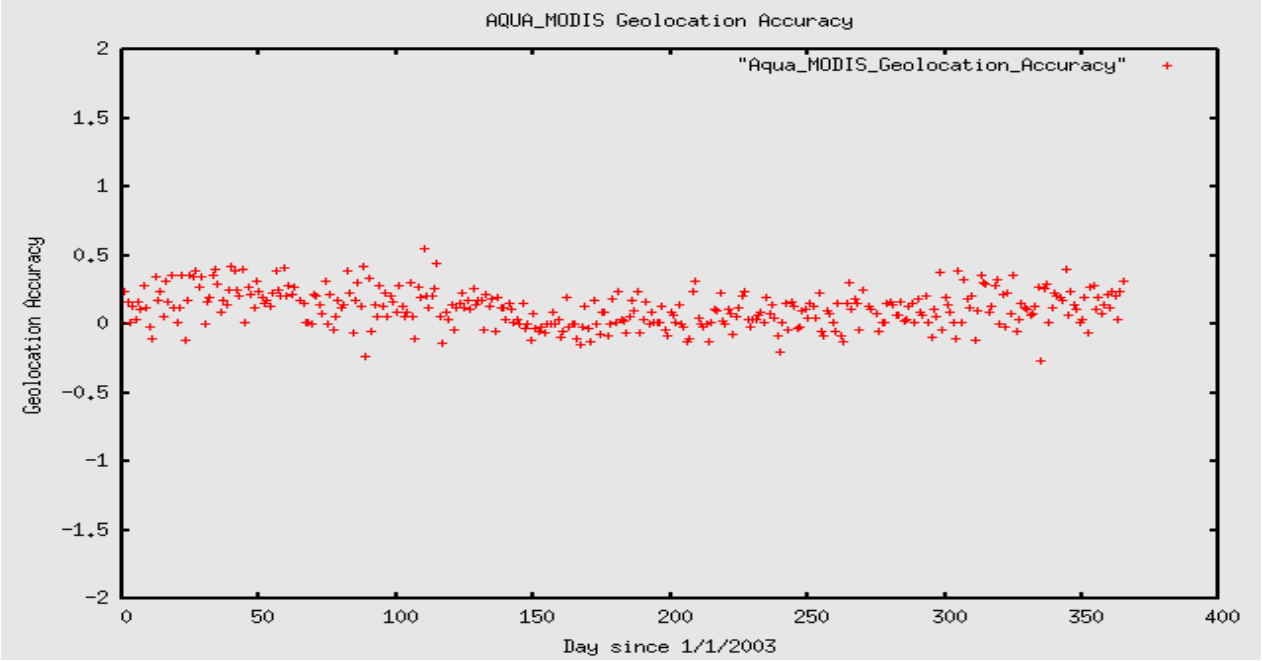
Generating Improved AVHRR products

Goal to make the AVHRR data set temporally consistent and spectrally consistent with MODIS by using:

- Reliable and consistent calibration across the different NOAA platforms.
- BRDF correction to address differences in the solar and viewing geometry.
- Apply MODIS algorithms to AVHRR where possible, e.g.: the MODIS aerosol retrieval and atmospheric correction approach.
- Coincident AVHRR/MODIS to evaluate and improve AVHRR products and quantify accuracy.

Improving AVHRR geolocation (1/2)

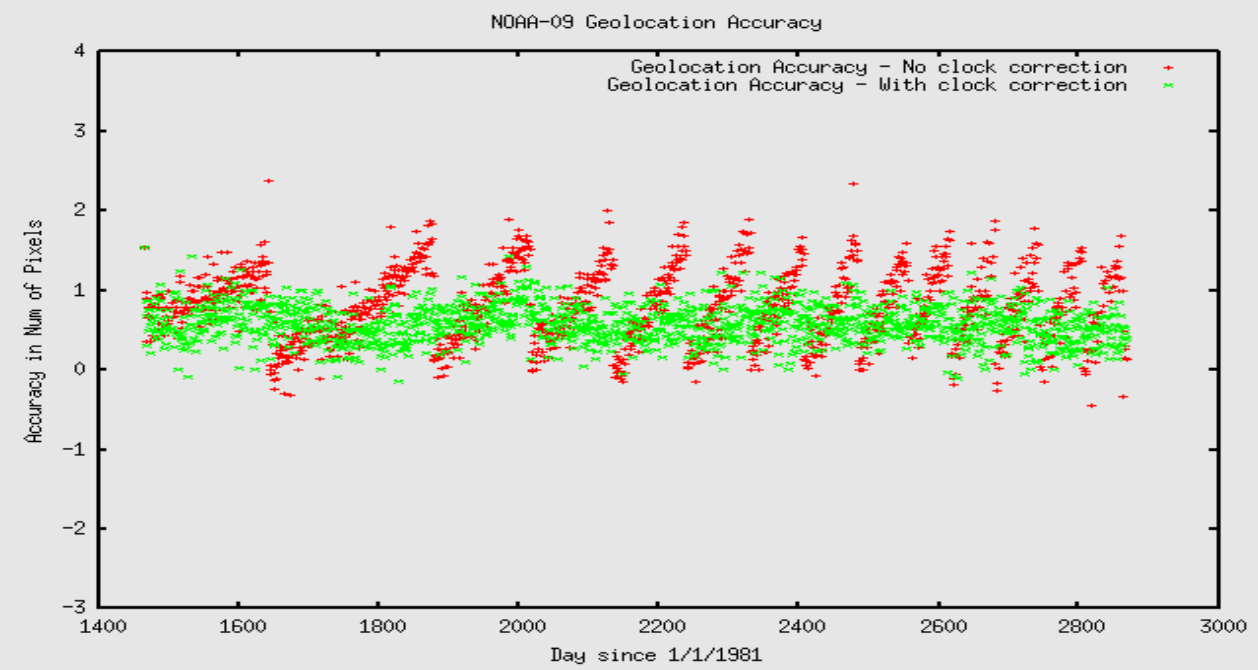
- Use MODIS to define the approach the assess geolocation accuracy (Coastal chips)



Accuracy assessment of the geolocation of MODIS aqua products using the coastal chips database (in fraction of pixels)

Improving AVHRR geolocation (2/2)

- Use MODIS to define the approach the assess geolocation accuracy (Coastal chips)



Accuracy assessment of the geolocation of AVHRR products using the coastal chips database (in fraction of pixels) Green is with clock correction, red is without clock correction

Improving AVHRR calibration (1/2)

- Use clear ocean to determine the absolute calibration in the red band (Rayleigh).
- Use high reflective clouds to determine the red/NIR ratio.
- Validate using desert sites and MODIS data

Calibration of NOAA 16 AVHRR

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Remote Sensing of Environment

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Calibration of NOAA16 AVHRR over a desert site using MODIS data

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Abstract

This paper presents a new approach to AVHRR-sensors cross-calibration in the visible to shortwave-infrared spectral domain using an a-priori, well calibrated sensor (MODIS). The approach has been tested over a stable Sahara desert site and was initially applied to compare the absolute calibration coefficients of three different bands of the Terra and Aqua MODIS instruments. The observed agreement was better than 1% for bands 1 (0.67 μm), 2 (0.87 μm) and 7 (2.13 μm). The approach was then applied to cross-calibrate the AVHRR sensor onboard NOAA16. The absolute calibration coefficients derived for bands 1 and 2, using the Terra MODIS as a reference, were compared to the vicarious coefficients derived using the ocean and clouds method [Vermote E.F. and Kaufman Y.J. (1995). Absolute calibration of AVHRR visible and near-infrared channels using ocean and cloud views, International Journal of Remote Sensing, 16, 13, 2317–2340]. The coefficients were consistent within less than 1%.
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Keywords: Calibration; AVHRR; MODIS

Fig. 2. Location of the 20 km by 20 km calibration site (centered on the red square) The image represents an area of 1000 km by 1000 km

The coefficients were consistent within less than 1%

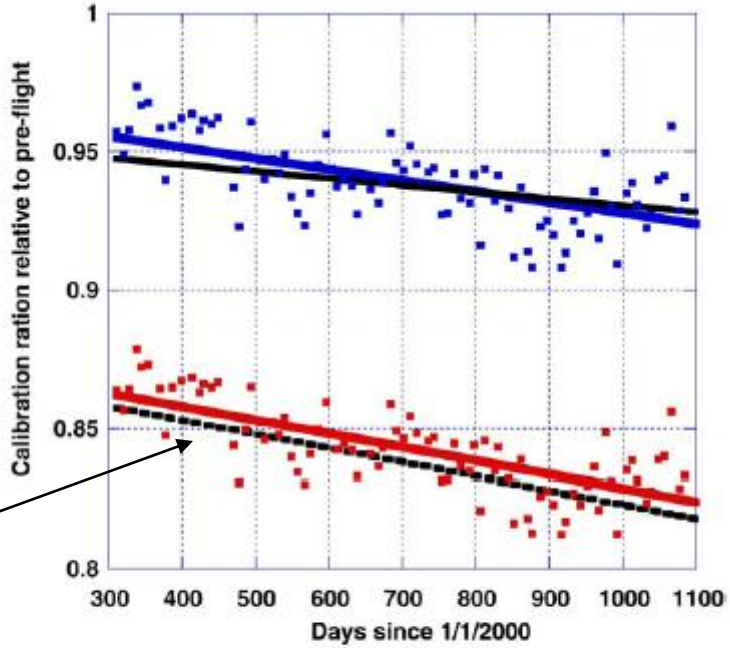
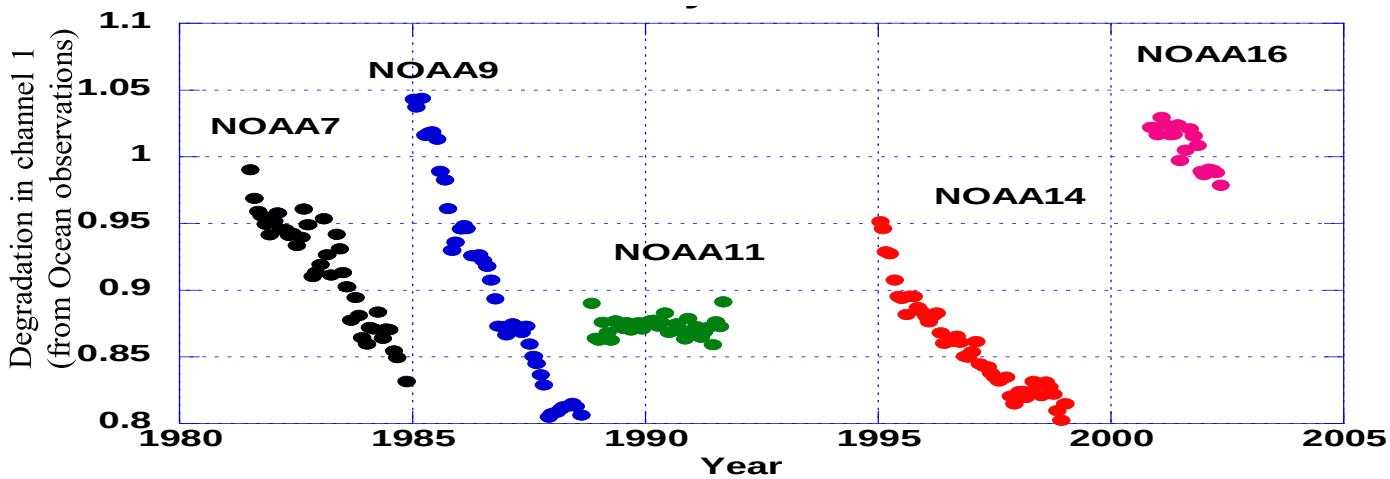
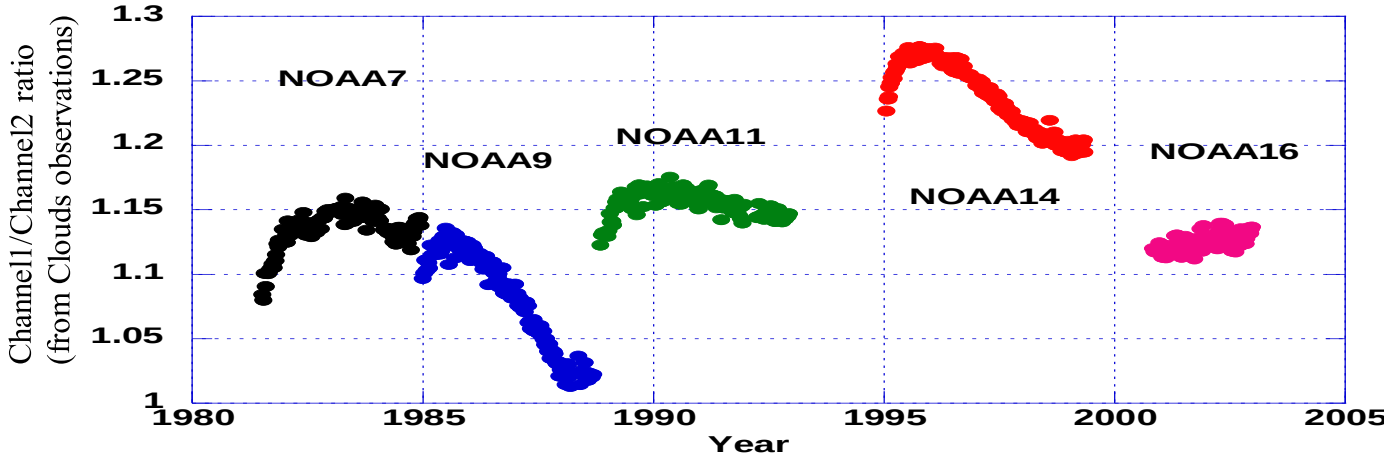


Fig. 11. Comparison of the desert calibration trends for band 1 (black solid line) and band 2 (black interrupted line), with the trends obtained using the Ocean and Clouds method (Vermote and Kaufman, 1995) for band 1 (blue line and square) and band 2 (red line and square).

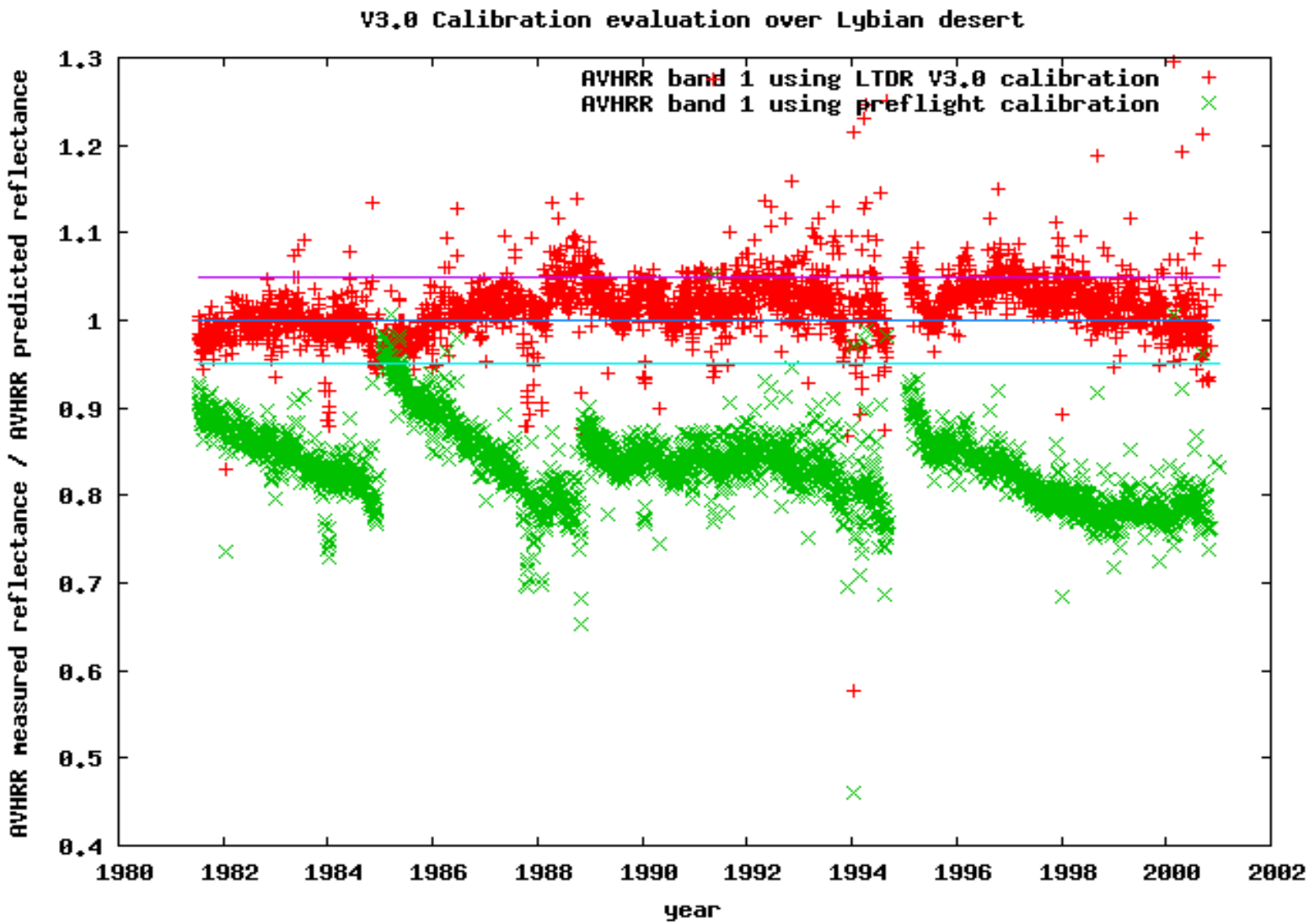
Consistent AVHRR calibration across platforms

- Use the Vermote/Kaufman calibration approach (Pathfinder II)

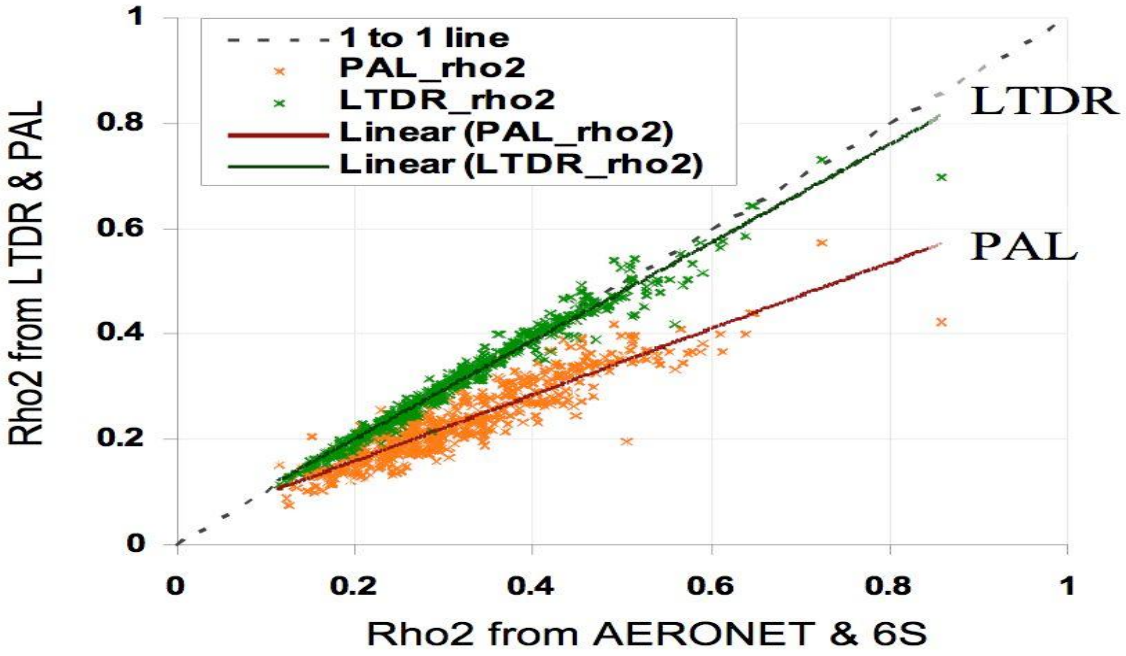




Extension of calibration evaluation to NOAA 7,9,11 and 14



Validating AVHRR atmospheric correction using MODIS methodology (AERONET)



Comparison of LTDR and PAL data for channel 2 at 48 AERONET sites for 1999. The x-axis shows the surface reflectance values (rho2) determined from the 6S code supplied with atmospheric parameters from an AERONET sunphotometer, while the y-axis shows the surface reflectances retrieved from the AVHRR data using LTDR and PAL algorithms.

2.1. Analytical estimates of quality

Geometric & atmospheric conditions used to calculate surface reflectances & uncertainties in AVHRR observations

Variable	Values applied		
Geometric (Lambertian surface)	Solar zenith	View zenith	Relative azimuth
	30	0	0
	30	30	0
	30	30	180
	30	60	0
	30	60	180
	60	0	0
	60	30	0
	60	30	180
	60	60	0
	60	60	180
Aerosol optical depth	0.05 (clear)	0.30 (average)	0.50 (high)
Water vapor (gcm^{-2})	1.0 ± 0.2	3.0 ± 0.2	5.0 ± 0.2
Ozone (cm.atm)	0.25 ± 0.02	0.30 ± 0.02	0.35 ± 0.02

Calibration
4% absolute
2% relative
(band-to-band)

2.1. Analytical estimates of quality: TOA

Calculated values and quadratic mean errors

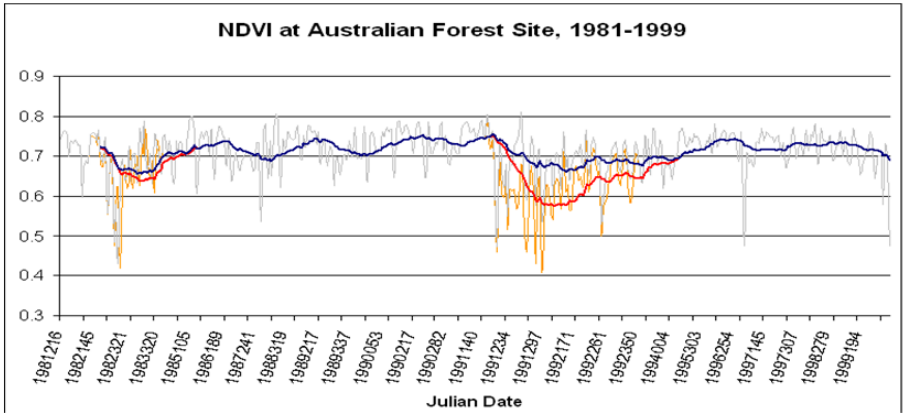
Reflectance/ Vegetation index	Forest				Savanna				Semi-arid			
		Aerosol Optical Depth				Aerosol Optical Depth				Aerosol Optical Depth		
	Value	clear	avg	hazy	Value	clear	avg	hazy	Value	clear	avg	hazy
ρ Ch1 (VIS)	0.045	0.004	0.051	0.08	0.086	0.004	0.046	0.073	0.143	0.006	0.039	0.063
ρ Ch2 (NIR)	0.237	0.017	0.02	0.032	0.196	0.014	0.022	0.036	0.217	0.015	0.02	0.034
ρ Ch3 (MIR)	0.045	0.001	0.002	0.003	0.086	0.002	0.002	0.003	0.143	0.004	0.004	0.004
NDVI	0.682	0.031	0.195	0.266	0.392	0.036	0.124	0.168	0.206	0.038	0.067	0.089

Error estimate checked over AERONET

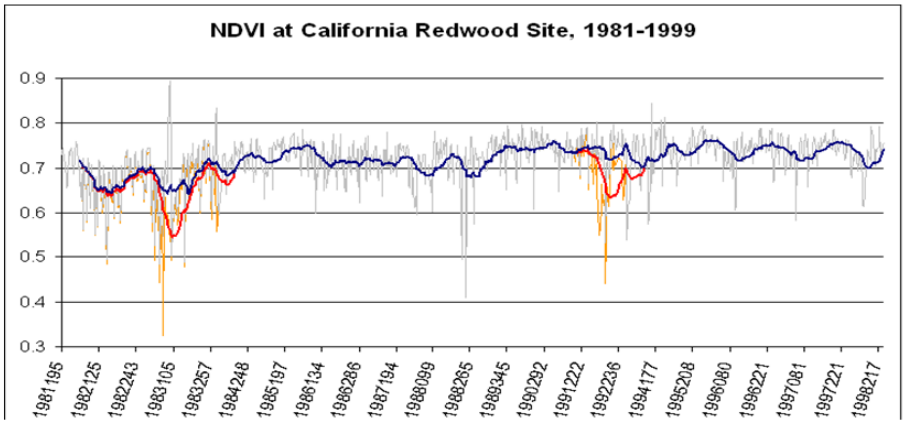
Table 2: Accuracy (Eq. 1), precision (Eq. 2), and uncertainty (Eq. 3) for NDVI from simulated TOA, PAL, and LTDR datasets. For the forest site; 20 (4%), 376 (75%), and 105 (21%) of 501 data points had clear, average, and hazy atmospheres respectively. For the savanna site; 40 (9%), 317 (71%), and 89 (20%) of 446 data points had clear, average, and hazy atmosphere respectively. For the semi arid site; 384 (52%), 348 (47%), and 8 (1%) of 740 data points had clear, average, and hazy atmosphere respectively.

Simulated Data	Land cover	Clear *(AOT < 0.05)*			Average *(AOT = 0.05 to 0.25)*			Hazy *(AOT > 0.25)*		
		Accuracy	Precision	uncertainty	Accuracy	Precision	uncertainty	Accuracy	Precision	uncertainty
TOA	semi-arid	-0.0616	**0.0226**	0.0656	-0.0667	**0.0234**	0.0707	-0.1400	**0.0629**	0.1509
TOA	savanna	-0.1701	**0.0436**	0.1755	-0.1770	**0.0510**	0.1842	-0.3047	**0.1816**	0.3546
TOA	forest	-0.2469	**0.0821**	0.2595	-0.2804	**0.0849**	0.2930	-0.5861	**0.1880**	0.6154
PAL	semi-arid	-0.0393	**0.0114**	0.0409	-0.0514	**0.0155**	0.0536	-0.1323	**0.0781**	0.1496
PAL	savanna	-0.0792	**0.0154**	0.0807	-0.1072	**0.0426**	0.1153	-0.2523	**0.1711**	0.3047
PAL	forest	-0.0555	**0.0263**	0.0611	-0.1242	**0.0719**	0.1434	-0.5077	**0.2185**	0.5526
LTDR	semi-arid	-0.0071	**0.0061**	0.0094	-0.0109	**0.0109**	0.0154	-0.0846	**0.0850**	0.1137
LTDR	savanna	-0.0137	**0.0105**	0.0172	-0.0379	**0.0356**	0.0520	-0.1661	**0.1641**	0.2334
LTDR	forest	-0.0252	**0.0206**	0.0322	-0.0845	**0.0611**	0.1042	-0.4291	**0.1988**	0.4728

Validation of Stratospheric aerosol correction on time series



Comparison of the NDVI time series observed at an Australian evergreen forest site with (blue curve) or without (red curve) the stratospheric aerosol correction (using the optical thickness data from figure 7b). The impact of Pinatubo eruption (1991) ~0.1 decrease in NDVI is clearly visible.



Comparison of the NDVI time series observed at a USA West coast evergreen forest site with (blue curve) or without (red curve) the stratospheric aerosol correction (using the optical thickness data from figure 7b). The impacts of the Mt. El Chichon eruption (1982) and to a lesser extent the Mt. Pinatubo eruption (1991) are visible.

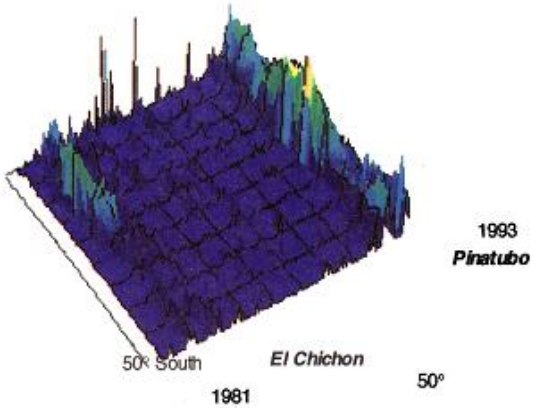


Figure 7b: Monthly average of the stratospheric aerosol optical depth derived from the AVHRR data showing the major eruptions of El Chichon (1982) and Pinatubo (1991) from [*Vermote et al.*, 1997b].

Assessing CLAVR using MODIS shows the need of an improved cloud mask (1/2)

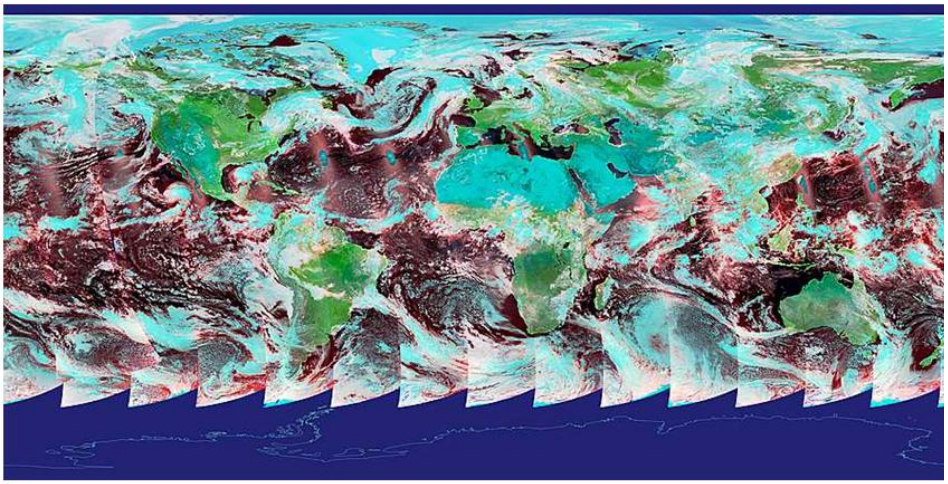


***Figure 5a**:AVHRR (NOAA16) LTDR surface reflectance product (B:0.67µm G:0.87µm,R:3.75µm) for day 193 of 2003.*

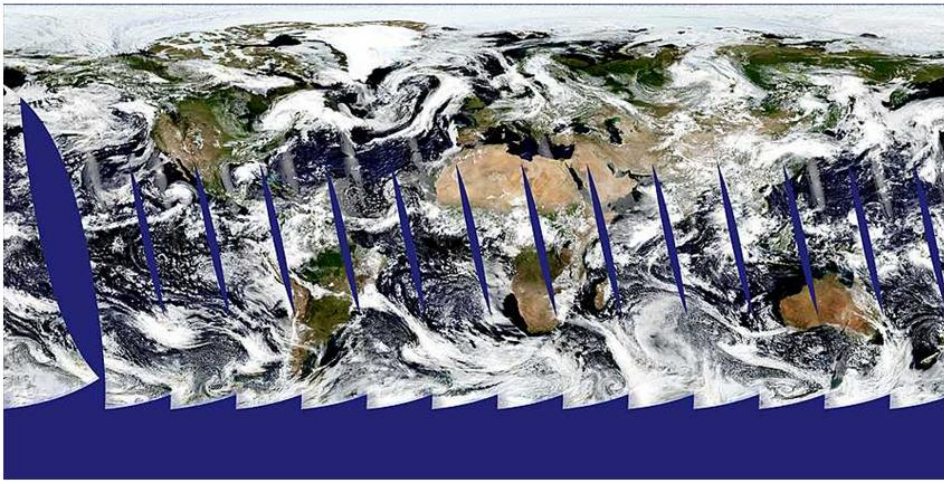


***Figure 5b**:MODIS Aqua LTDR surface reflectance product (B:0.47µm, G:0.55µm,R:0.67µm) for day 193 of 2003 near coincident with the AVHRR data.*

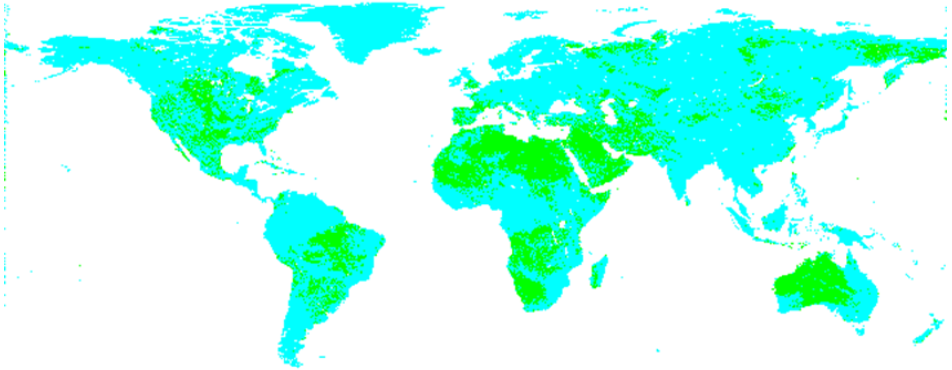


***Figure 5c** :Results of the CLAVR cloud mask over land (mixed and cloudy) for NOAA16 AVHRR Day 193 year 2003, cloud are in blue and clear pixels are in green*

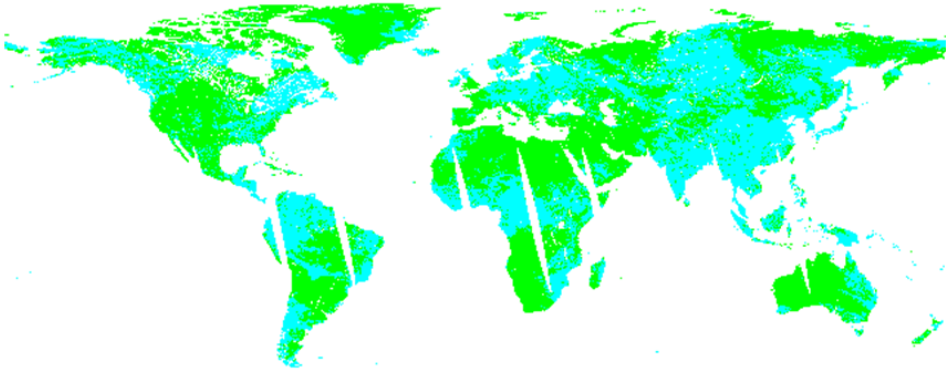
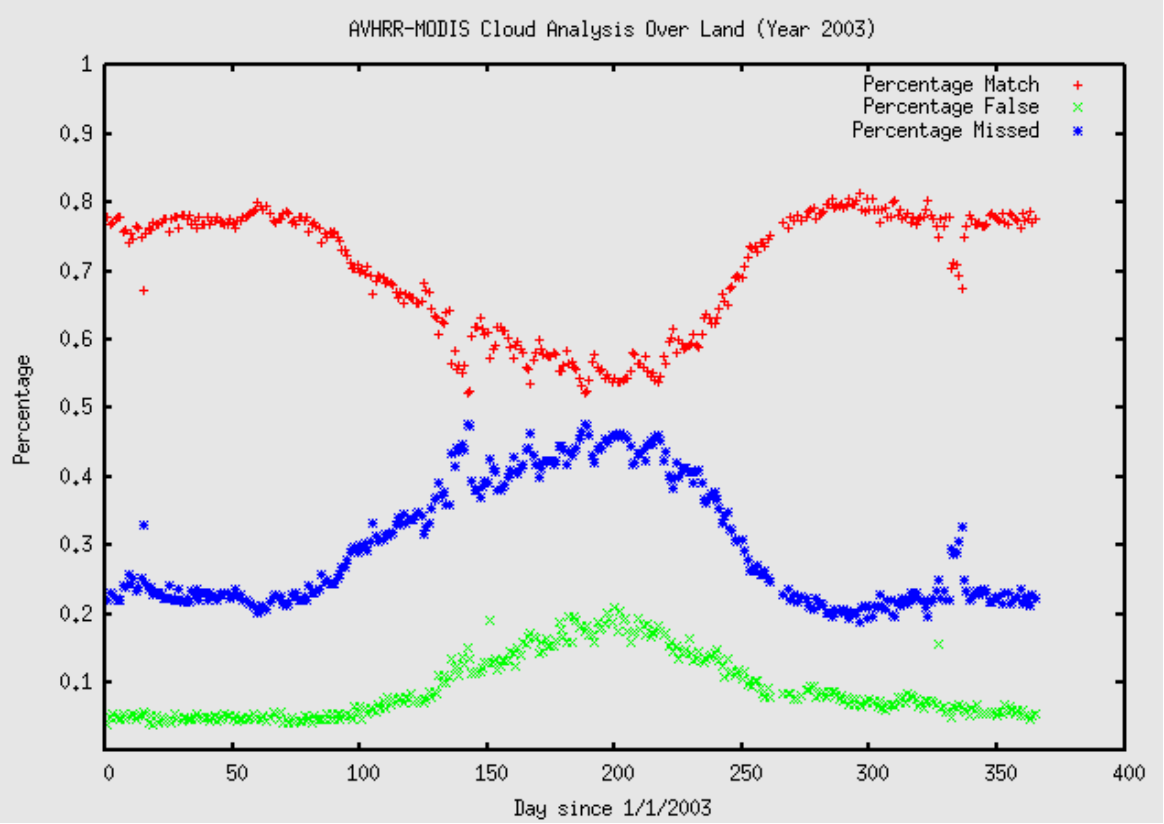


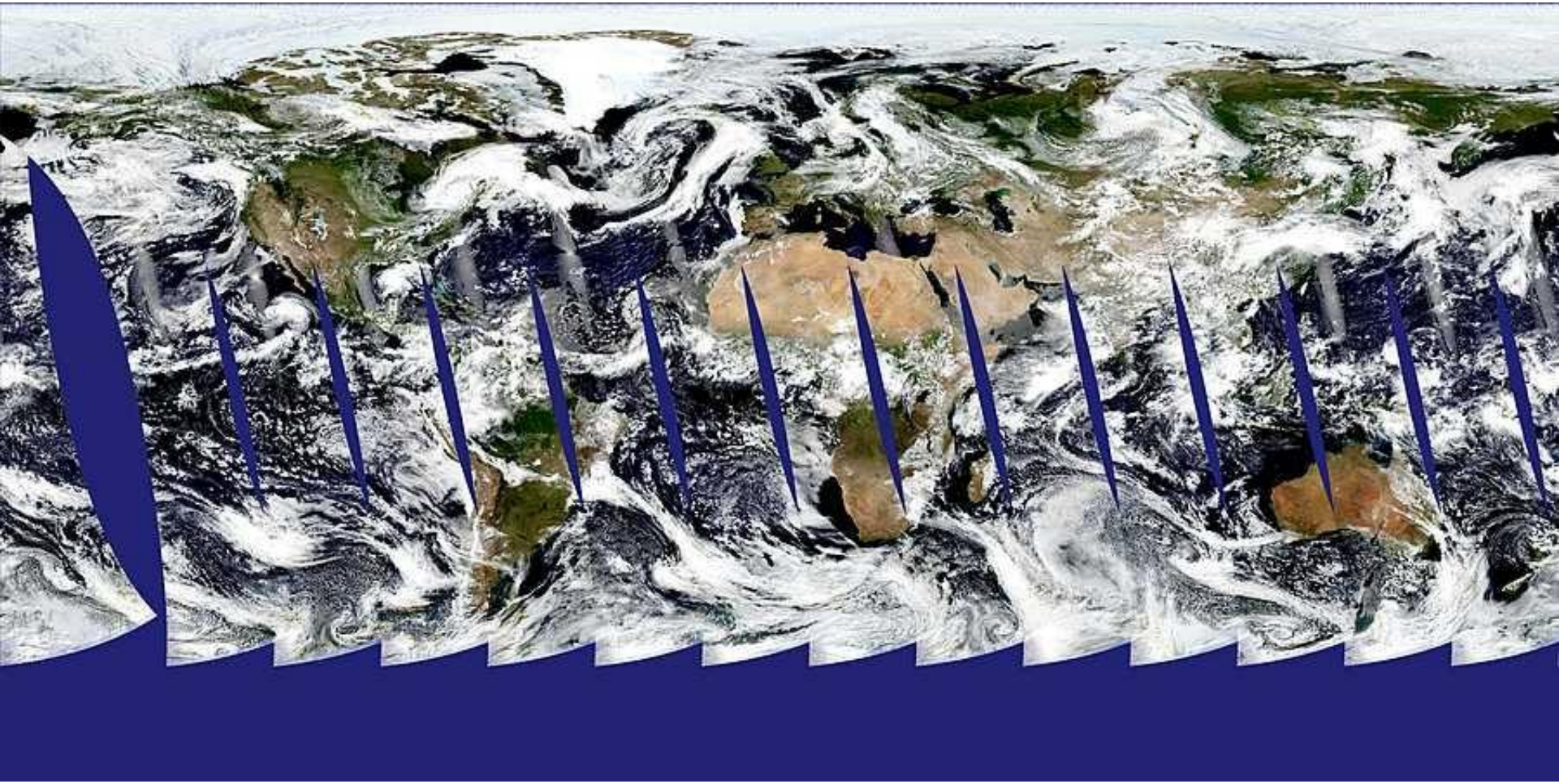
***Figure 5d**:Result of the MODIS internal cloud mask over land for Aqua Day 193 year 2003 cloud are in blue and clear pixels are in green*

Assessing CLAVR using MODIS shows the need of an improved cloud mask (2/2)

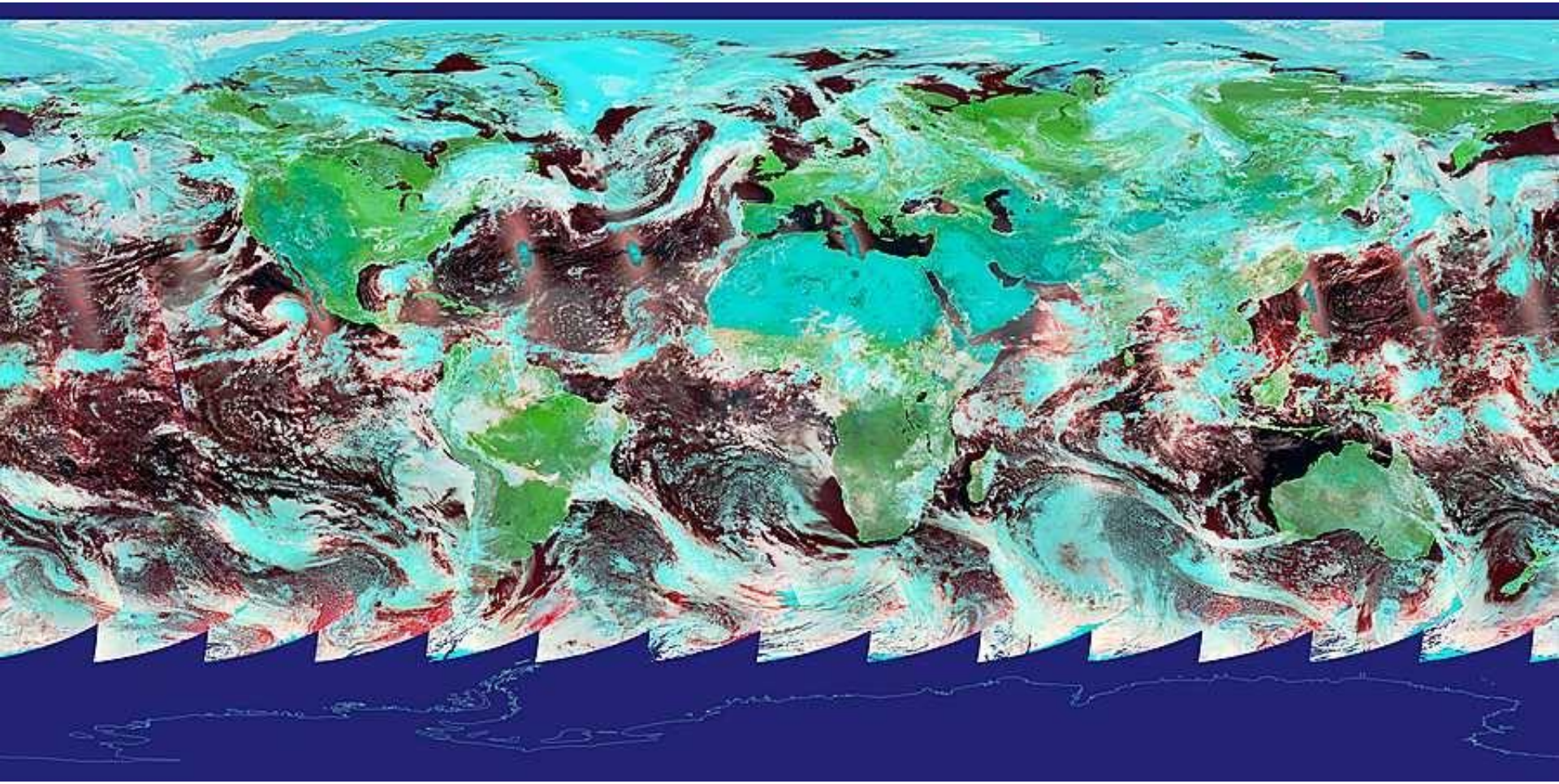


Evaluation of the global performance of the CLAVR Algorithm reported as percentage. Overall CLAVR identified only 2/3 of the cloud flagged by MODIS (red points), and labeled about 1/3 of the observation flagged as clear by MODIS as cloudy (blue points).

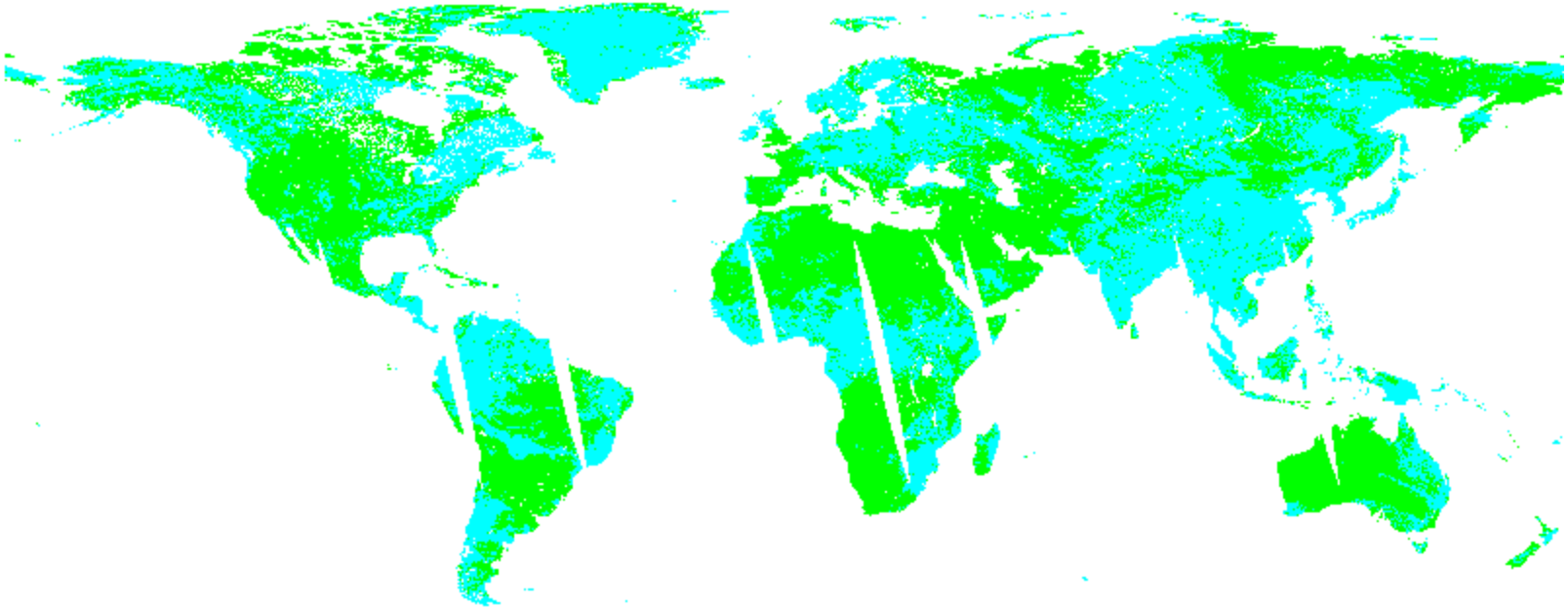
MYD09CMG .A2003193.005



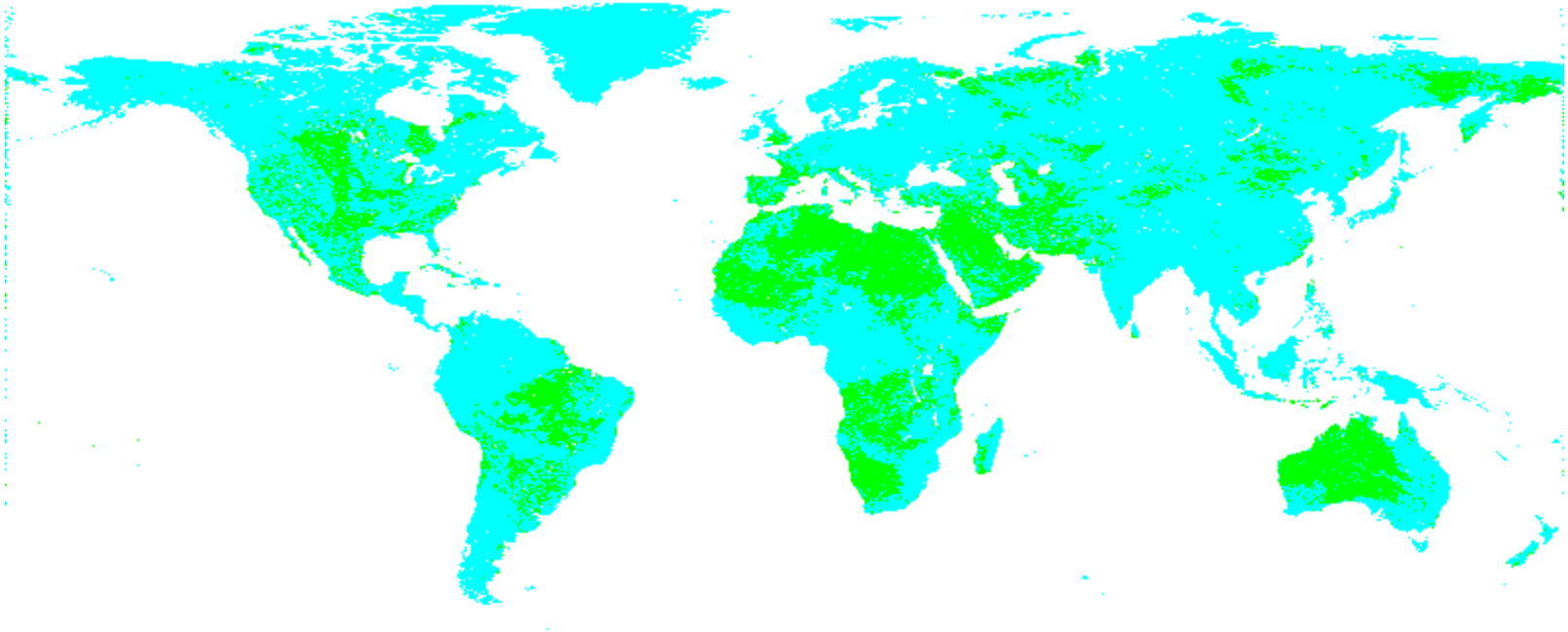
AVH09C1 .A2003193.003



Cloud MODIS : MYD09CMG .A2003193.005



Cloud: AVH09C1 .A2003193.002
CLAVR



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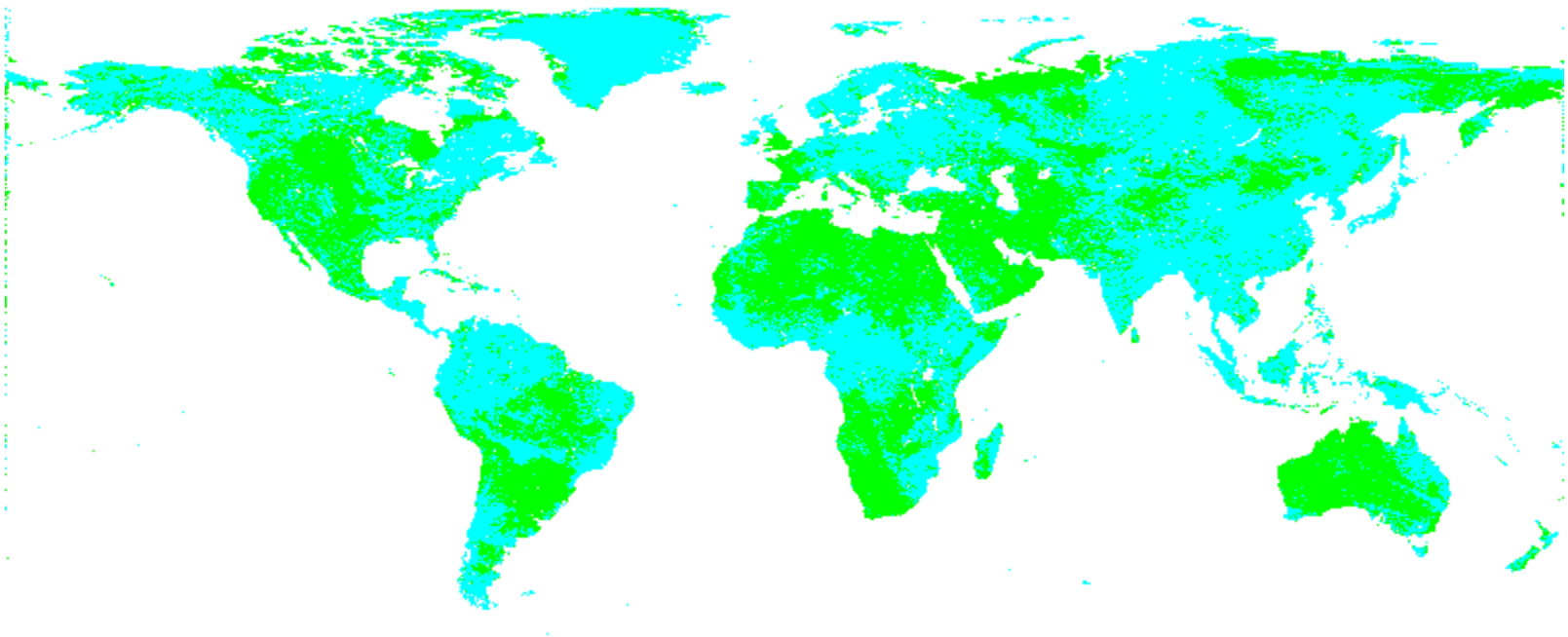
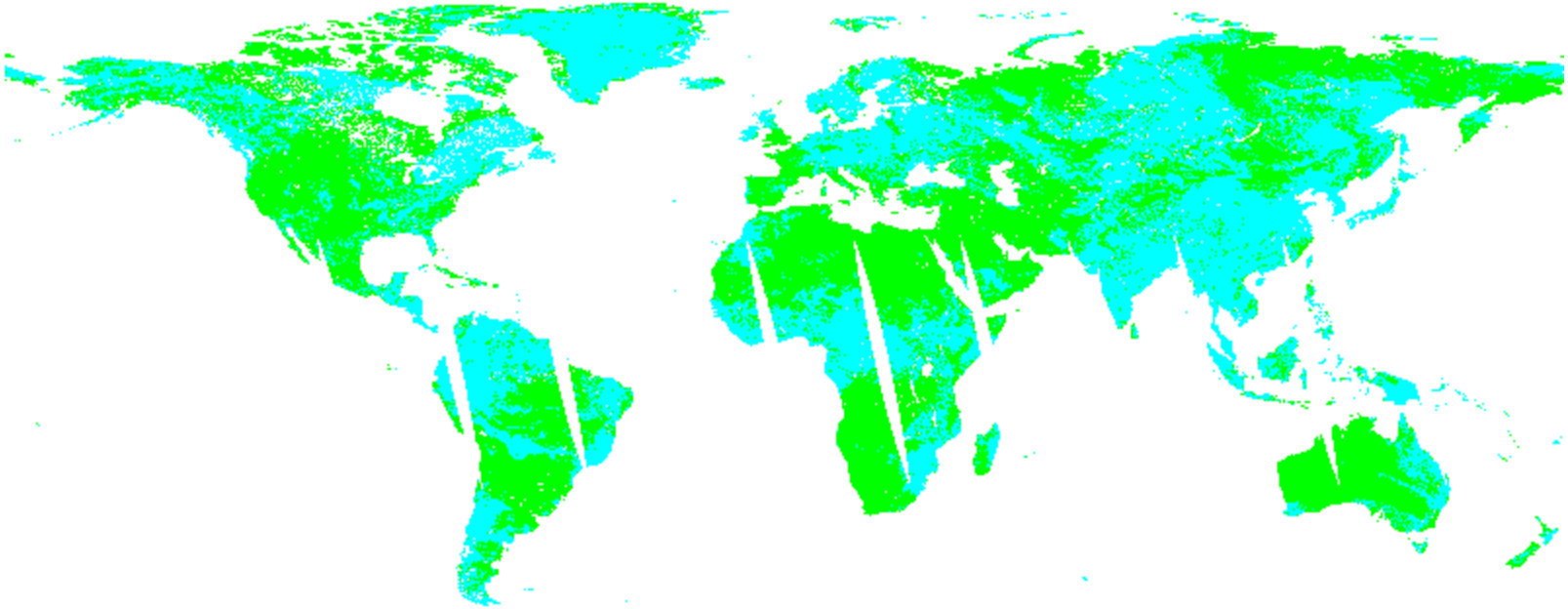
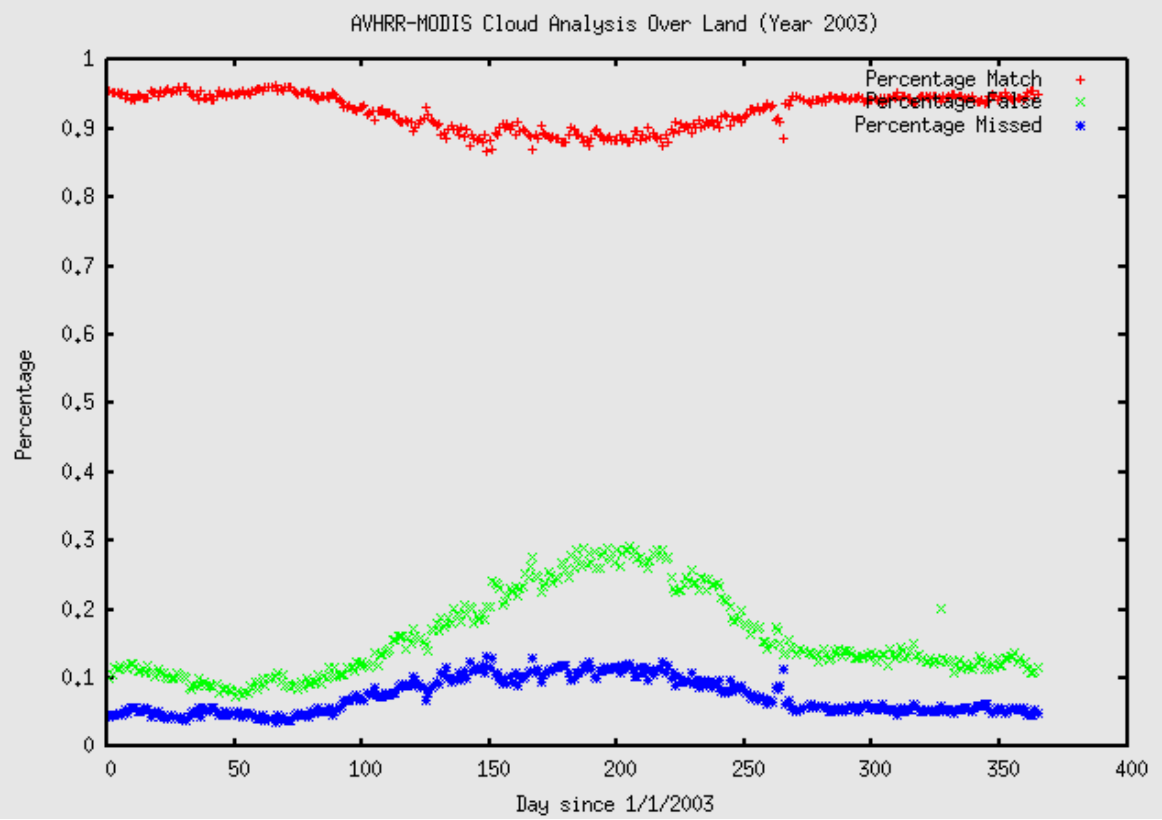


Cloud MODIS : MYD09CMG .A2003193.005



New improved cloud mask for AVHRR



Evaluation of the global performance of the LTDR v3 cloud mask Algorithm reported as percentage.

Using MODIS to develop global generalized BRDF correction and improved NDVI Time series

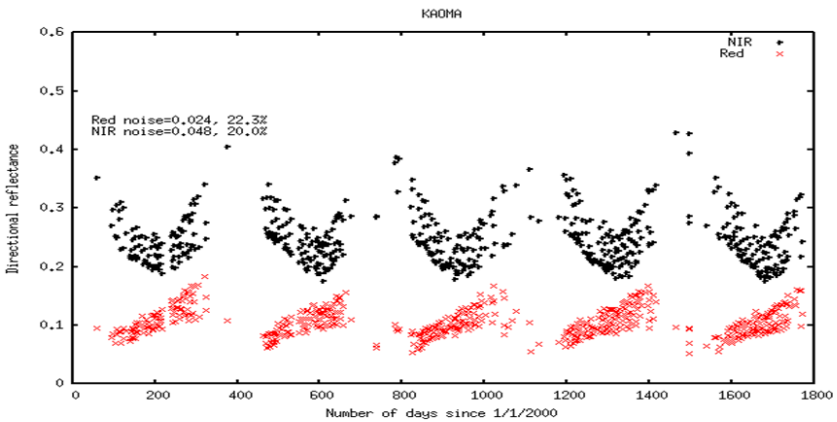


Figure 8a: Time series of the directional surface reflectance over a Savannah site, Kaoma (Zambia).

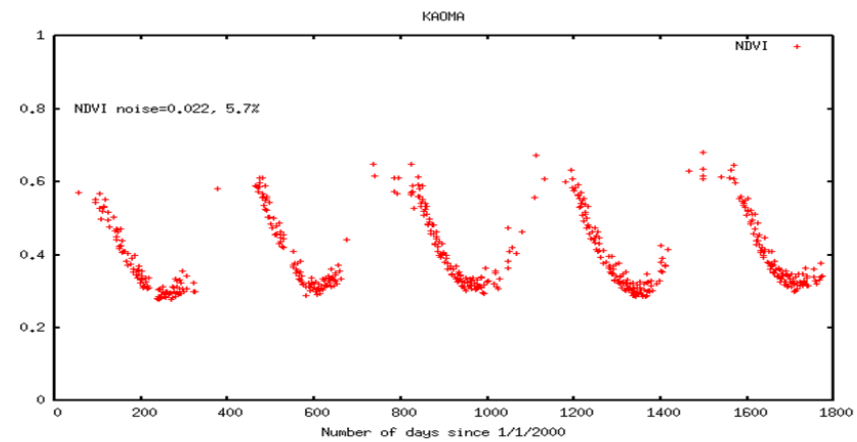


Figure 8c: Time series of the NDVI over a Savannah site, Kaoma (Zambia).

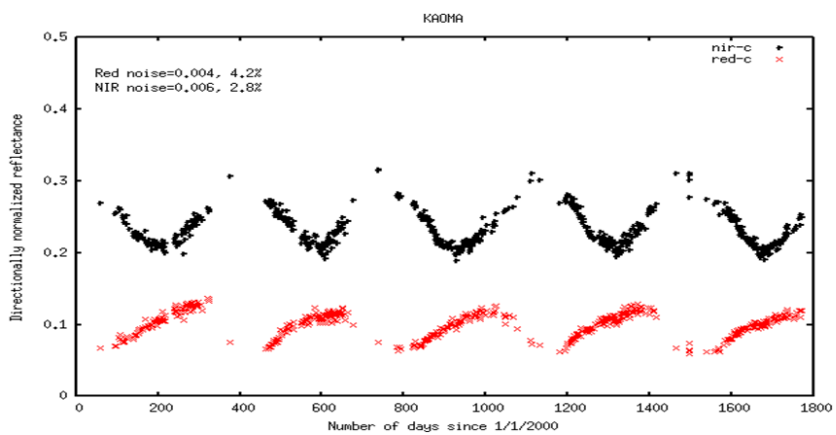


Figure 8b: Time series of the directional normalized surface reflectance over a Savannah site, Kaoma (Zambia). The approach used for correcting directional effect is described in [*Vermote et al.*, 2008]

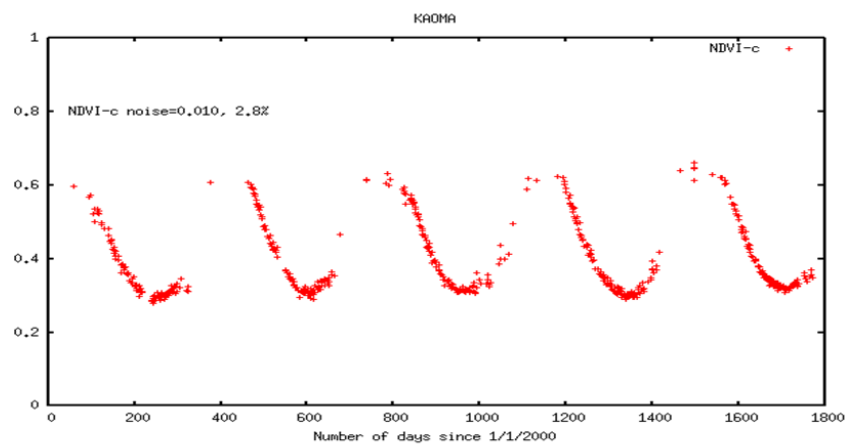
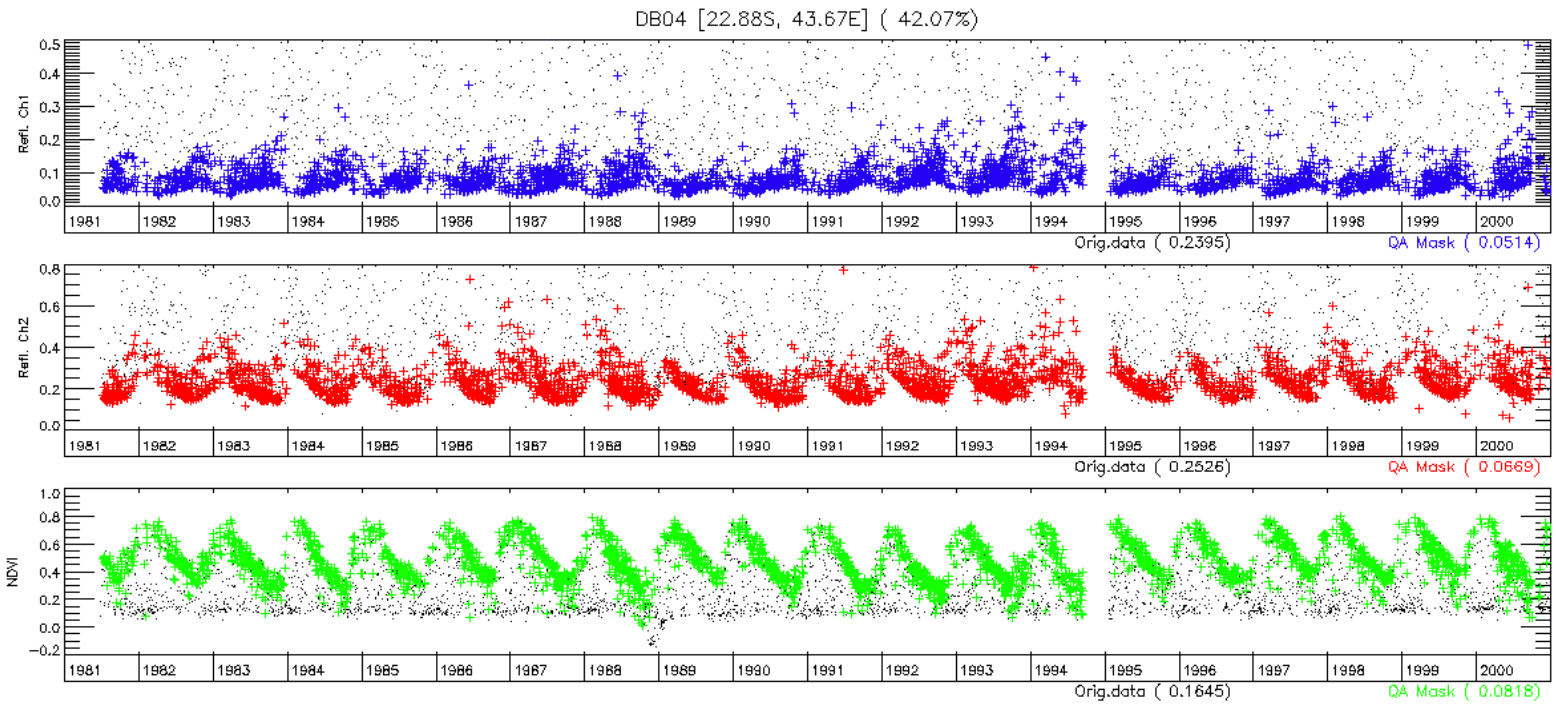
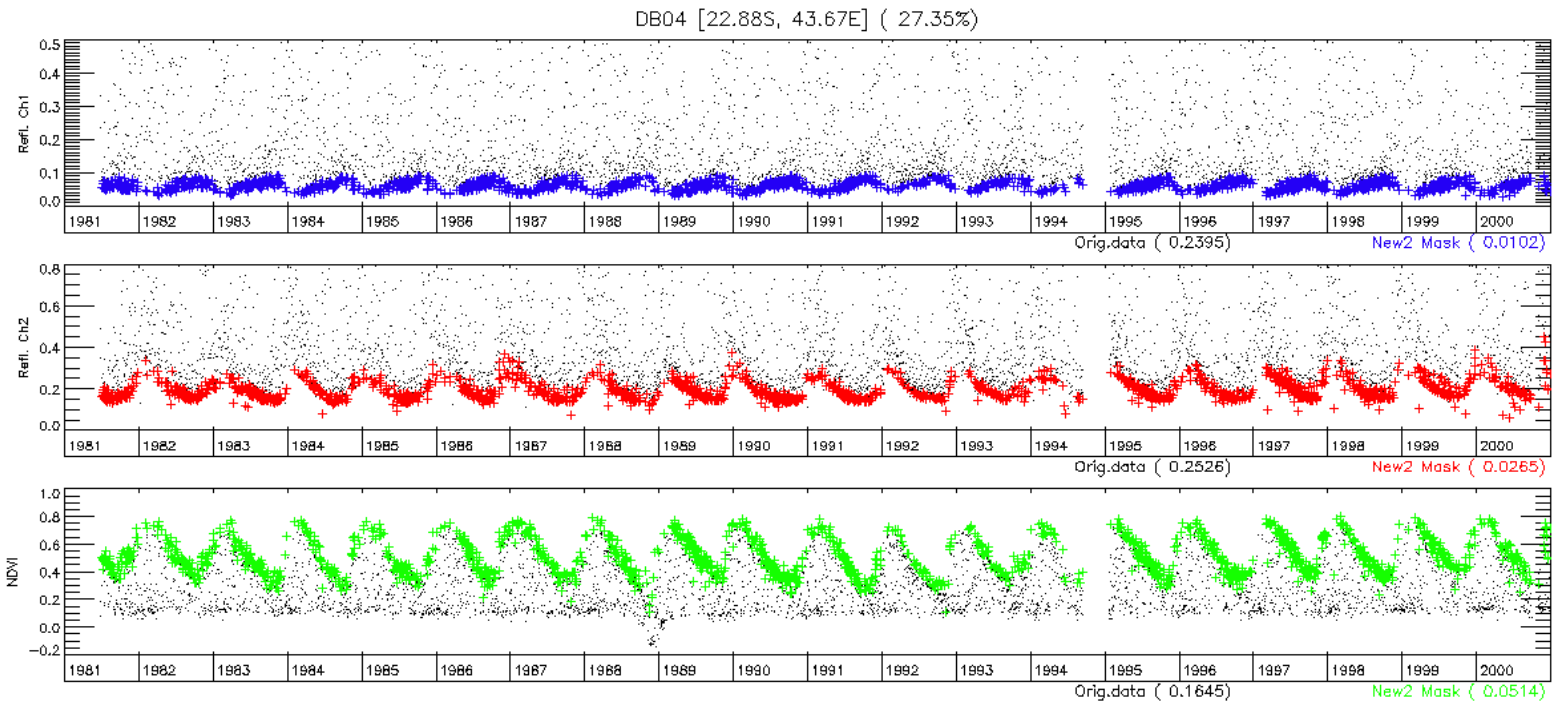


Figure 8d: Time series of the NDVI corrected for directional effect over a Savannah site, Kaoma (Zambia).

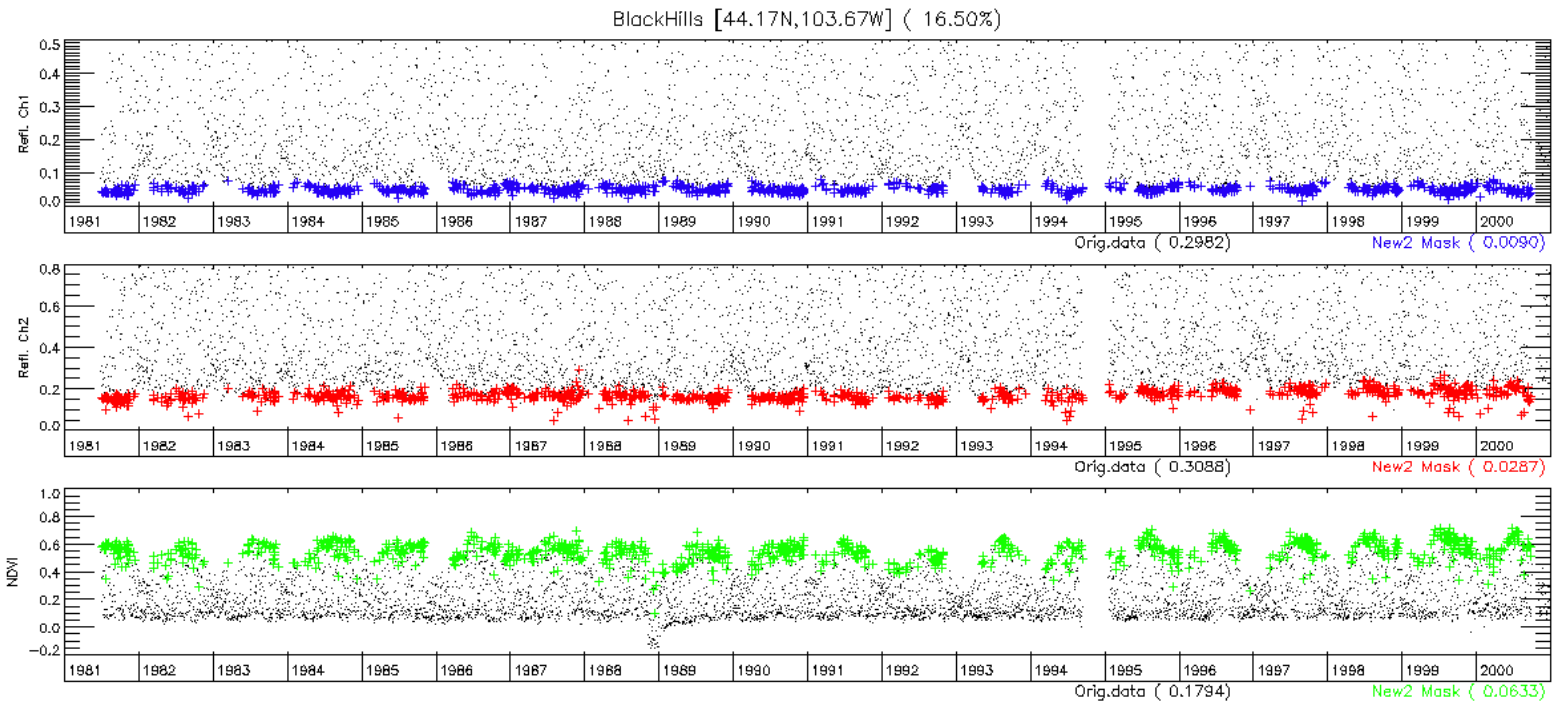
AVHRR Time series CLAVR mask



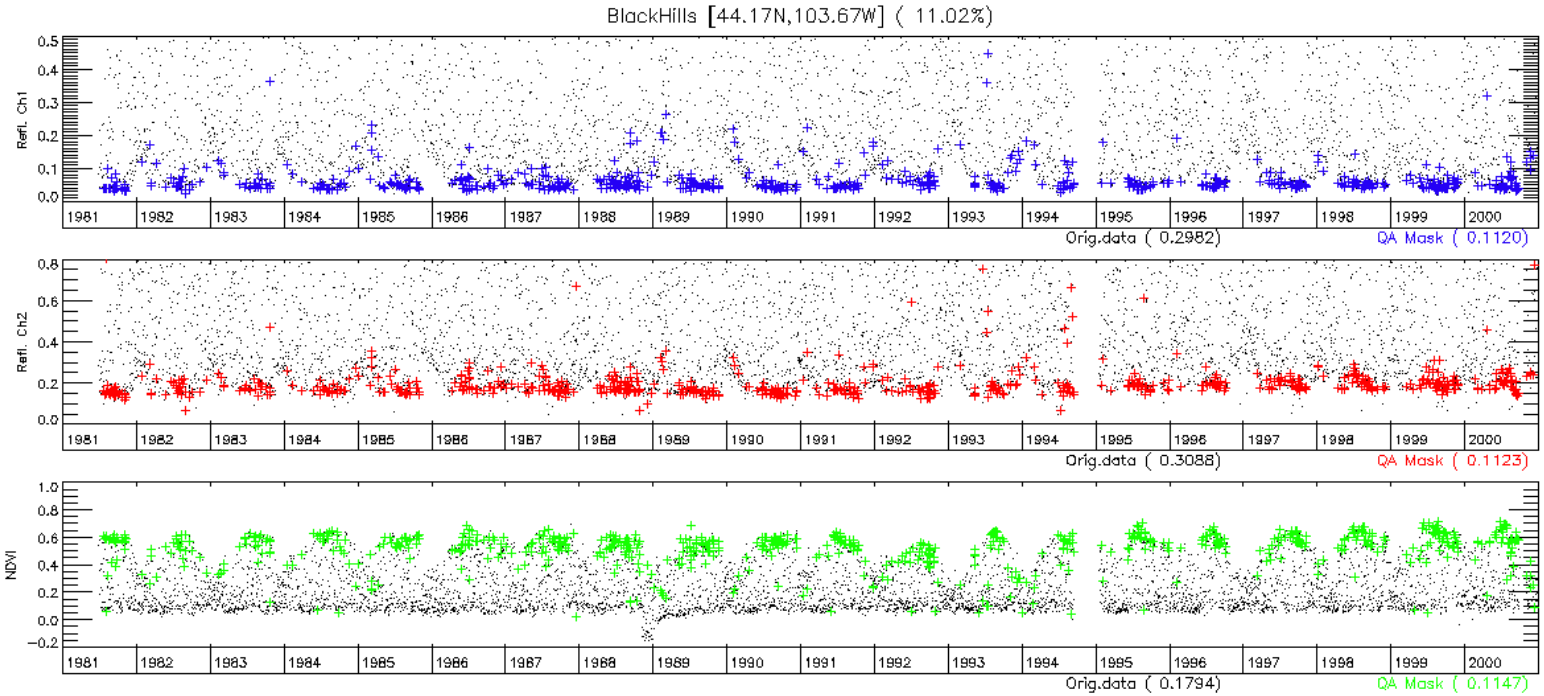
AVHRR Time series LTDR cloud mask



LTDR cloud mask



CLAVR cloud mask



Using MODIS to develop global generalized BRDF correction and improved NDVI Time series

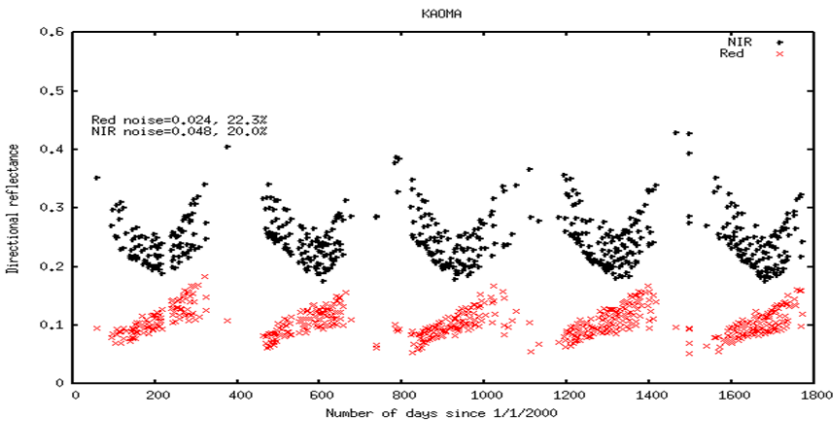


Figure 8a: Time series of the directional surface reflectance over a Savannah site, Kaoma (Zambia).

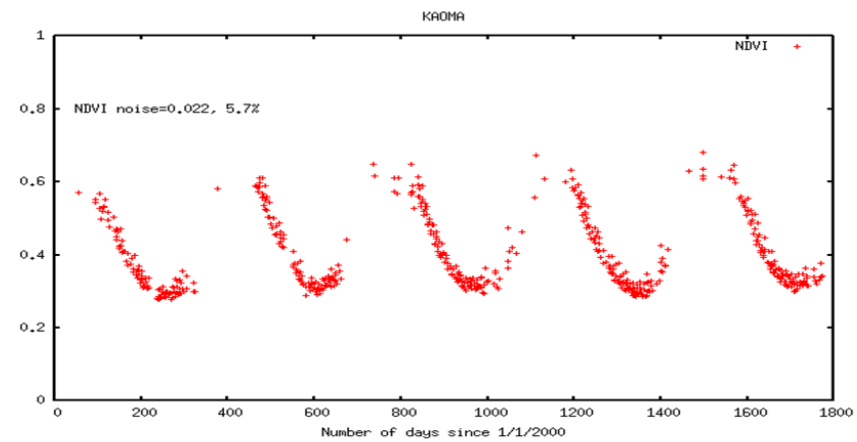


Figure 8c: Time series of the NDVI over a Savannah site, Kaoma (Zambia).

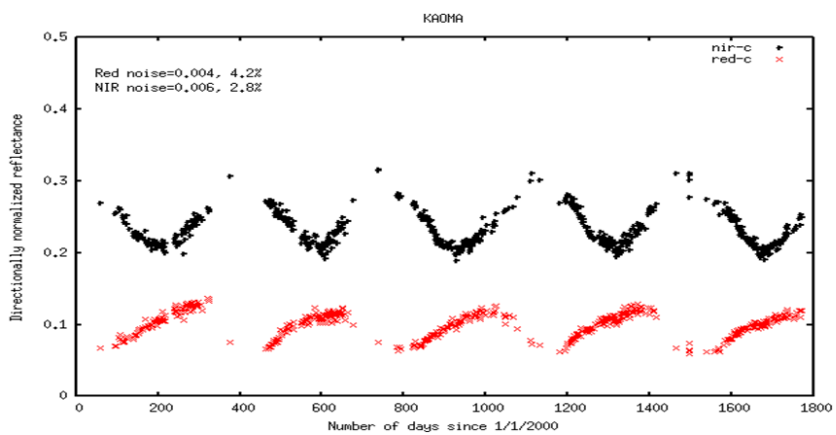


Figure 8b: Time series of the directional normalized surface reflectance over a Savannah site, Kaoma (Zambia). The approach used for correcting directional effect is described in [*Vermote et al.*, 2008]

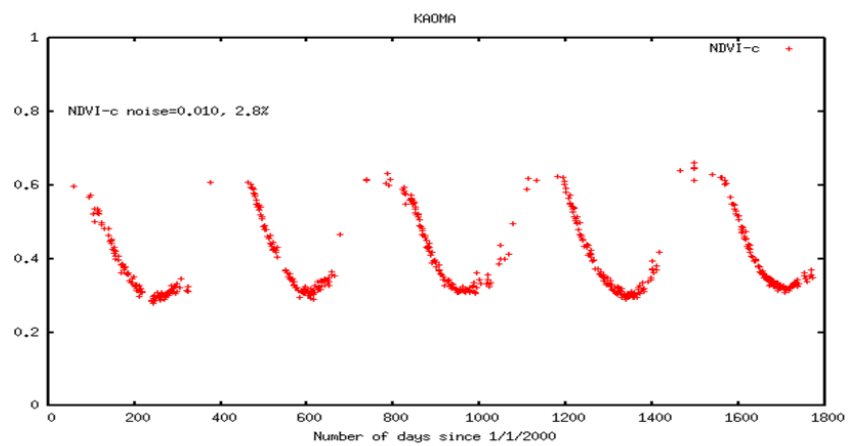


Figure 8d: Time series of the NDVI corrected for directional effect over a Savannah site, Kaoma (Zambia).

Applying MODIS BRDF correction and atmospheric correction to account for AVHRR orbital drift

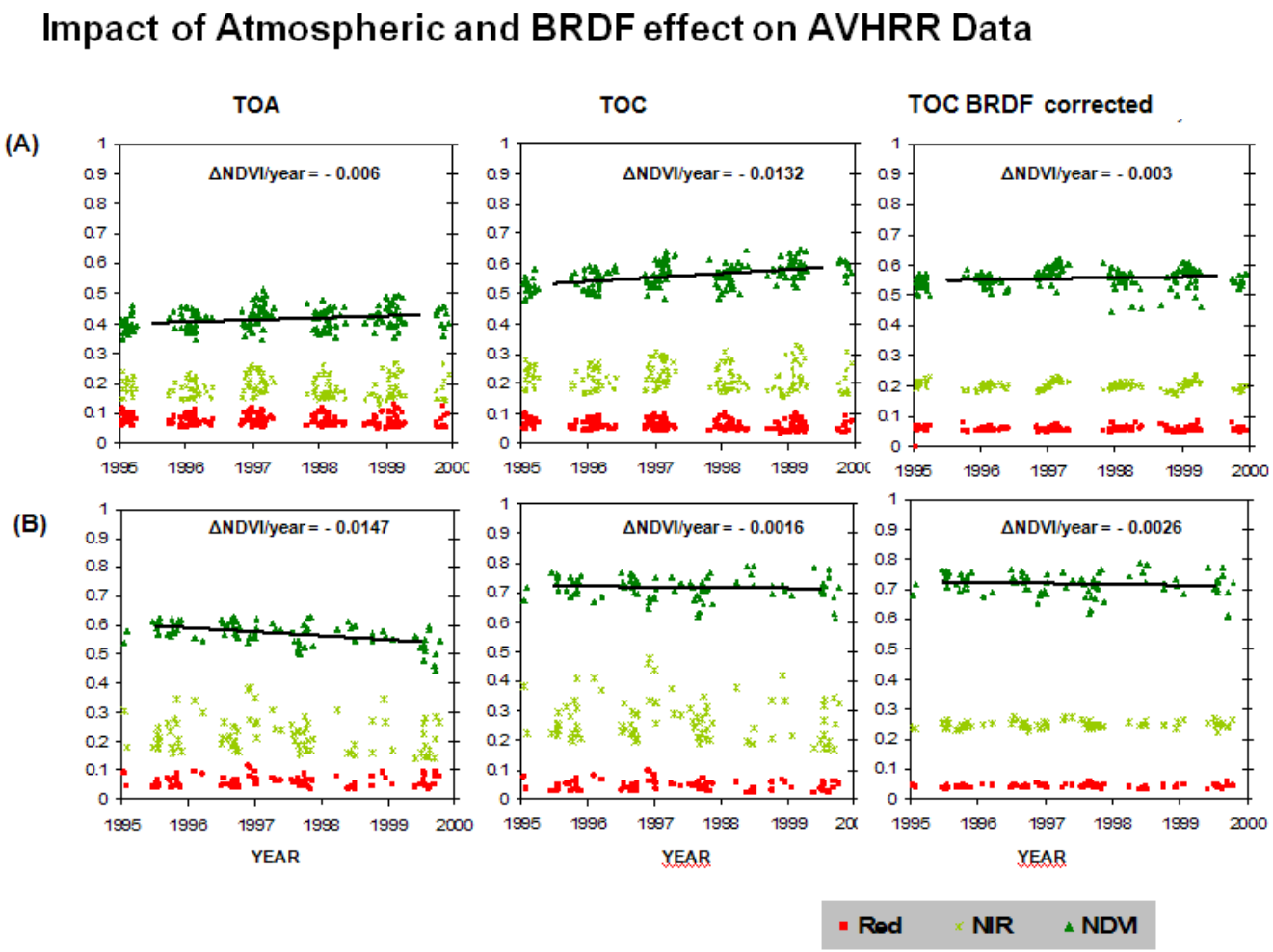
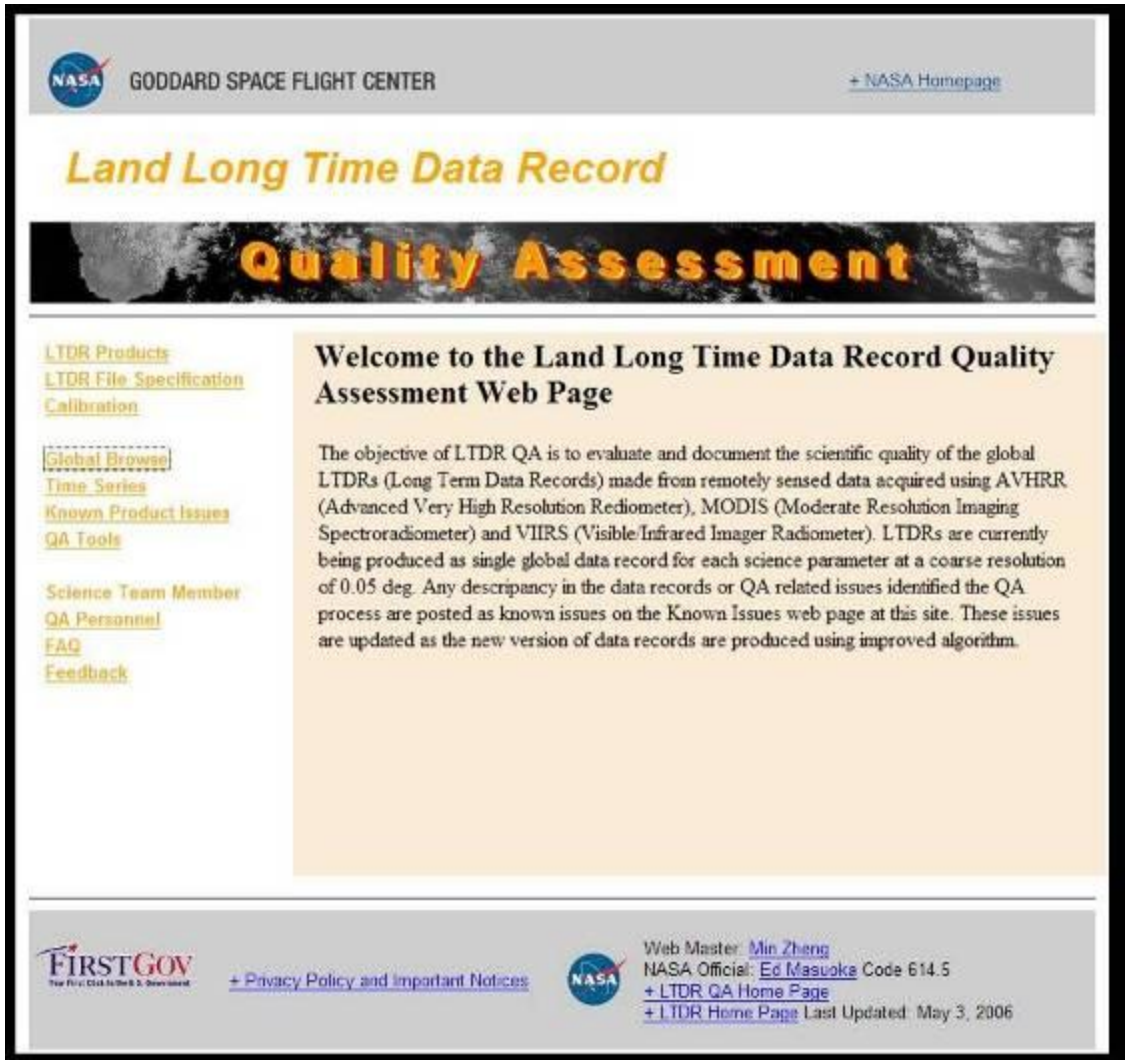


Figure 2a: Impact of the orbital drift on NOAA14 (1995-1999) data for two evergreen forest sites in Australia, (A) with 50% tree cover, (B) with 95% tree cover. TOA is top of the atmosphere, TOC is the Top of the canopy, BRDF corrected uses the correction described in 2.3.5.

Operational Quality Assurance



Operational QA : Known Issues

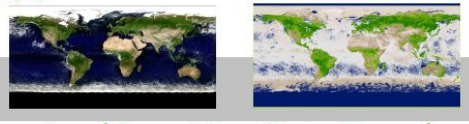
Color Key	Case pending	Case closed	Case reopened	QA note

Case number	Opening Date	Last Update (Sort)	Status	Description
CC_AVH09C1_06135b	05/18/06	05/18/06	Pending	Discontinuities in image resolution
CC_AVH09C1_06135a	05/18/06	05/18/06	Pending	Cloud mask for some pixels inconsistent with surroundings
CC_AVH09C1_06111g	04/21/06	04/21/06	Note	Some pixels labeled as "dark dense vegetation"
CC_AVH09C1_06111f	04/21/06	05/17/06	Pending	Striping in cloud mask, T3, RHO3 fields
CC_AVH09C1_06111e	04/21/06	05/17/06	Pending	River and delta flagged as cloud
CC_AVH09C1_06111d	04/21/06	04/21/06	Note	No flag indicating dust or heavy aerosol in AVHRR data
CC_AVH09C1_06111c	04/21/06	04/21/06	Pending	Cloud mask labels some clear pixels as cloudy
CC_AVH09C1_06111b	04/21/06	05/18/06	Pending	Areas of data inconsistent with surroundings
CC_AVH09C1_06111a	04/21/06	05/11/06	Pending	Some RHO1 and RHO2 reflectance values exceed 1.0

LTDR web pages

GODDARD SPACE FLIGHT CENTER + NASA Homepage

LTDR



Land Long Term Data Record

LTDR is a NASA-funded REASoN project to produce a consistent long term data set from AVHRR and MODIS instruments for climate studies. The project will create daily surface reflectance and NDVI products at a resolution of 0.05 degrees. Higher order products such as LAI/FPAR, burned area, albedo, and BRDF will be created at monthly temporal resolution. The LTDR project will reprocess data from AVHRR sensors onboard NOAA satellites from 1981 - present by applying the preprocessing improvements identified in the AVHRR Pathfinder II project and the atmospheric and BRDF corrections used in MODIS preprocessing. The LTDR project will compare the AVHRR results with MODIS products where the two instruments overlap in time (from 2000 on for MODIS Terra and mid-2002 for MODIS Aqua). This Land Long Term Data Record will lay the foundation for continued climate monitoring with the VIIRS instruments onboard the NPP and NPOESS satellites.

- *Version 2 Products Available (15 October, 2007)*
- *Project Overview and Science Background*
- *Documents and Presentations*
- *AVHRR Vicarious Calibration*
- *Data Products*
- *Quality Assessment (QA)*
- *Participants*

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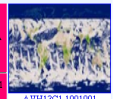
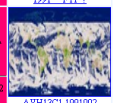
AVHRR Browse Products

NOAA_Satellite: NOAA_11
Products: AVHRR NDVI - daily
Time period: From: 1991/01/01 to 1991/01/31 or Julian-date(1991001 to 1991031)

Product / Date	AVHRR NDVI - daily
NOAA N11 1991 1991001	 AVH13C1 1991001 1991 FTP ?
NOAA N11 1991 1991002	 AVH13C1 1991002 1991 FTP ?
NOAA N11 1991 1991003	

Main web page contains necessary information
http://ltdr.nascom.nasa.gov
File specs and publications/presentations are posted at:
http://ltdr.nascom.nasa.gov/ltdr/docs2.html
Data can be ordered and downloaded from:
http://ltdr.nascom.nasa.gov/ltdr/productSearch.html
The calibration LUTs are posted at
http://ltdr.nascom.nasa.gov/ltdr/avhrr_calib_1.html

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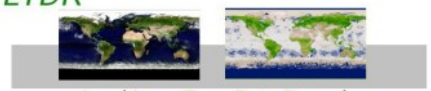
LTDR



Land Long Term Data Record

Documents and Presentations

Outreach Workshops

LTDR Workshop Agenda	Agenda and presentations from the January 18, 2007 LTDR Workshop in College Park, MD

Data Format Documents

LTDR Data Products Description (PDF)	A description of the surface reflectance and NDVI products (version 2.0: October 15, 2007)

Project Presentations