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An open source framework for processing daily satellite images (AVHRR) over last 28 years

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FOSS4G EUROPE, JULY 15 – 17, 2015

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Introduction

- *WarmLakes* – Study the long term warming trends of sub-alpine lakes using temperature derived from satellite data
- Using the dual window thermal bands in 10 – 12 μm ; to apply split window technique
- Moderate spatial resolution of 1 km pixel size
- Daily observations
- Satellite sensors used in *WarmLakes* study:
  - AVHRR **(1978 - 2014)** – by NOAA
  - ATSR1, ATSR2, A(A)TSR **(1991 – 2012)** – by ESA
  - MODIS **(2000 – 2014)** – by NASA

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AVHRR – importance and limitations

- AVHRR – Advanced Very High Resolution Radiometer
- Along track push-broom sensor aboard multiple NOAA satellites (TIROS-N, NOAA / 7/8/9/10/11/12/14/15/16/17/18/19)
- Longest time series at moderate spatial resolution (1 km) and daily images with gaps
- Ideal for trend analysis in climate change research at regional level
- Free data from NOAA CLASS website - http://www.class.ncdc.noaa.gov/saa/
- Ample research done dealing with different issues of AVHRR processing, **BUT**:
  - Often limited to specific region
  - Work done by institutes with receiving stations
  - Non-availability of processed data
  - Non-availability of libraries to read the data, correct, calibrate and 'pixelize' them
  - Need of universally adaptable solution using open source tools

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AVHRR data

Spectral characteristics

Channels	AVHRR/1	AVHRR/2	AVHRR/3
1	0.58 – 0.68	0.58 – 0.68	0.58 – 0.68
2	0.725 – 1.00	0.725 – 1.00	0.725 – 1.00
3A	N.A	N.A	1.58 – 1.68
3;3B	3.55 – 3.93	3.55 – 3.93	3.55 – 3.93
4	10.50 – 11.50	10.3 – 11.3	10.3 – 11.3
5	channel 4 repeated	11.5 – 12.5	11.5 – 12.5

Satellite	Start Date	End Date	Sensor
TIROS-N	1979-04-05	1979-11-04	AVHRR/1
NOAA-6	1980-04-24	1986-10-02	AVHRR/1
NOAA-7	1981-08-24	1985-02-01	AVHRR/2
NOAA-8	1985-07-02	1985-10-13	AVHRR/1
NOAA-9	1985-04-08	1988-11-07	AVHRR/2
NOAA-10	1986-11-17	1991-09-16	AVHRR/1
NOAA-11	1988-11-08	1994-10-01	AVHRR/2
NOAA-12	1991-09-17	2001-03-19	AVHRR/2
NOAA-14	1995-01-04	2001-11-19	AVHRR/2
NOAA-15	1998-07-28	2000-07-28	AVHRR/3
NOAA-16	2001-02-26	Present	AVHRR/3
NOAA-17	2002-09-30	Present	AVHRR/3
NOAA-18	2005-07-01	Present	AVHRR/3
NOAA-19	2009-04-19	Present	AVHRR/3

- 2048 points in a scan line, at every 40th point - angles and GCP's are sampled
- data available only in L1B format
- Sensor data are stored in binary
- Two major types of data
  - Local Area Coverage (LAC) at 1.1 km spatial resolution
  - Global Area Coverage (GAC) at 4 km spatial resolution – resampled at every 4th sample of LAC data

POD Series
KLM Series

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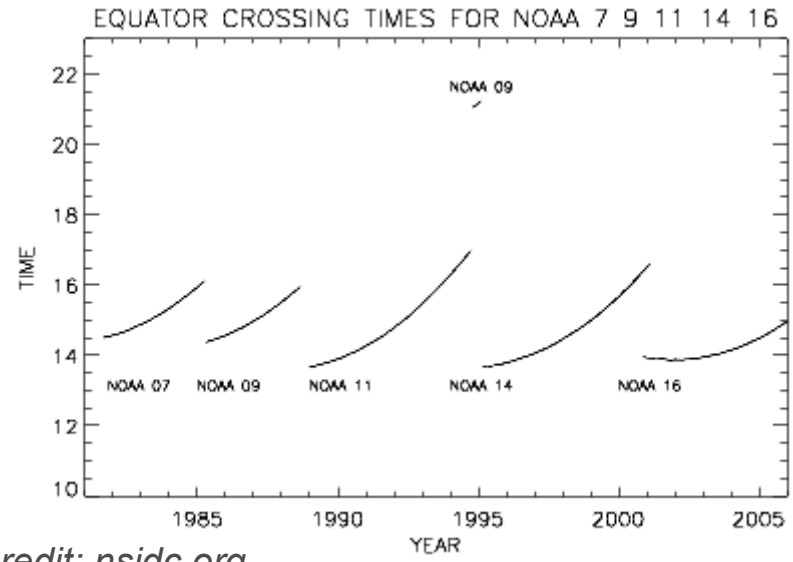
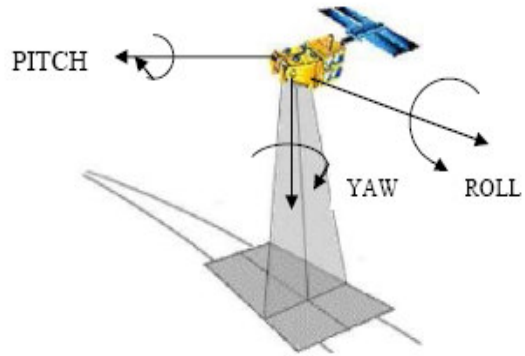
Curious case of AVHRR

- Satellite clock drifts – periodic clock resets
- Attitude errors – affects the satellite orientation in the desired geodetic direction, controlled by raw, pitch and yaw angles
- Orbital drifts due to satellite decaying over time – lack of orbit adjustment systems



Credit: nsidc.org

Attitude angles



Credit: http://www.teledet.com.uy

We developed a framework using open source tools to process all the LAC data from NOAA - 7/9/11/12/14/1516/18/19

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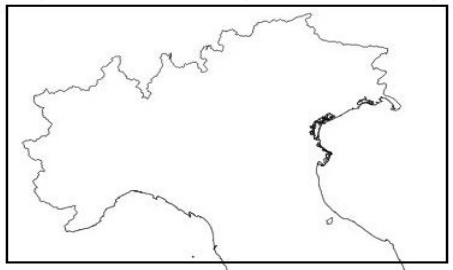
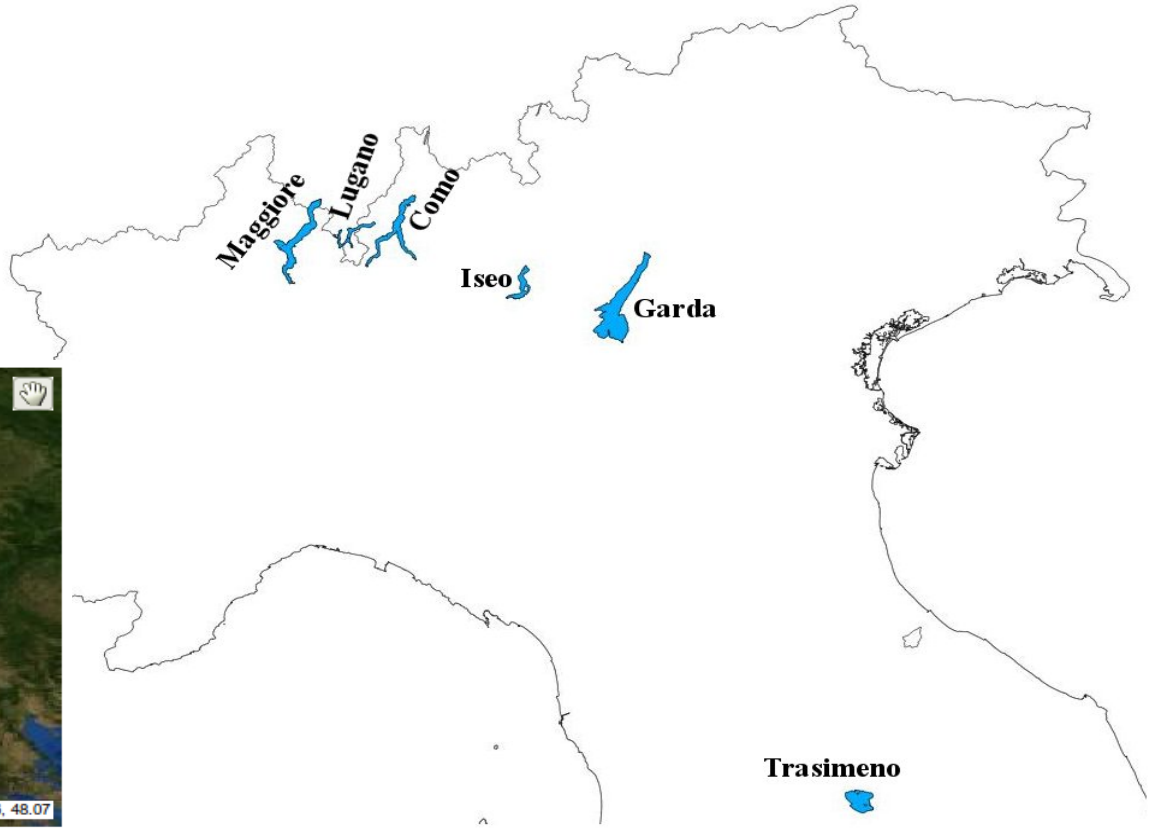
Study Area





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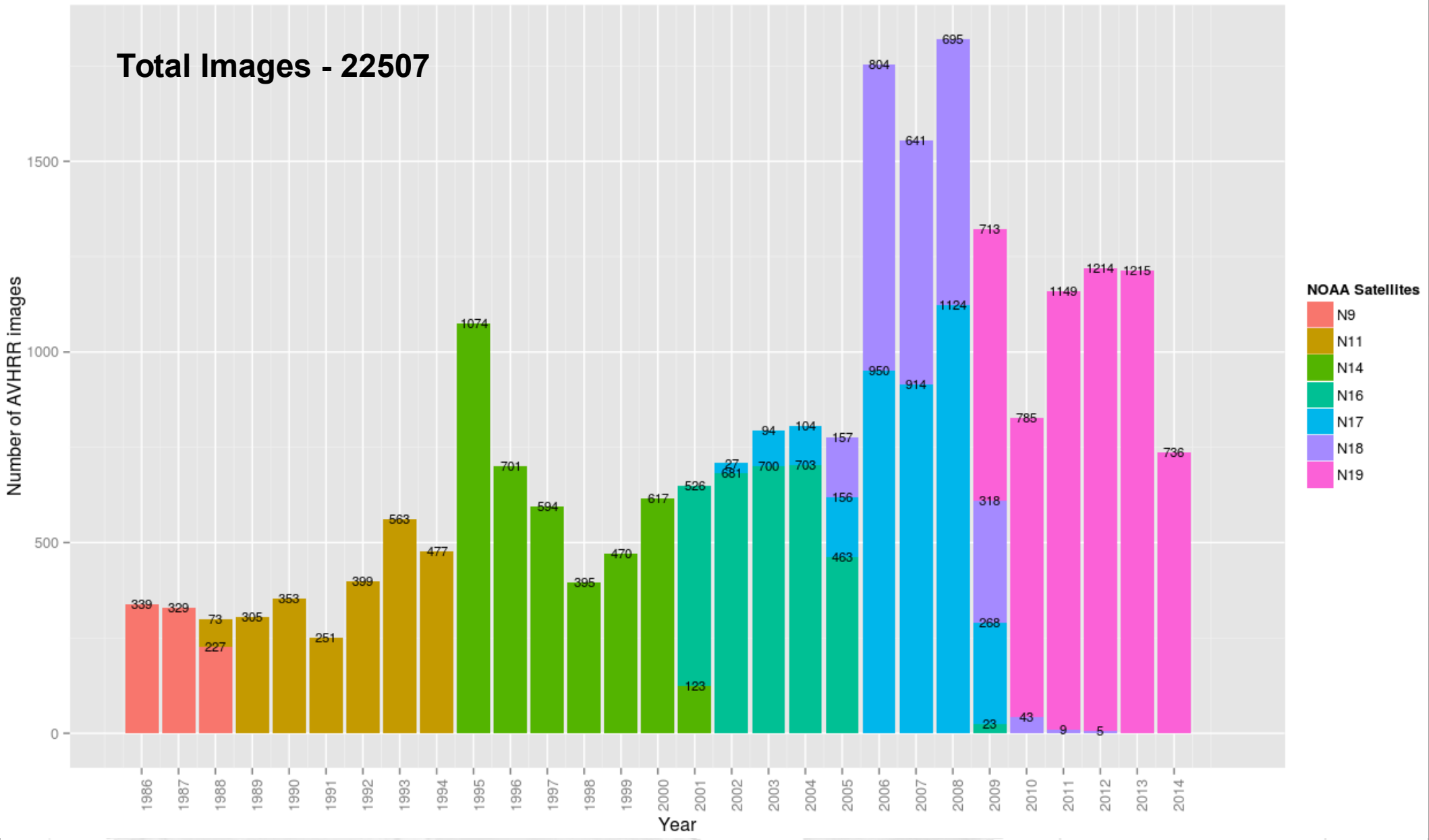
Data distribution



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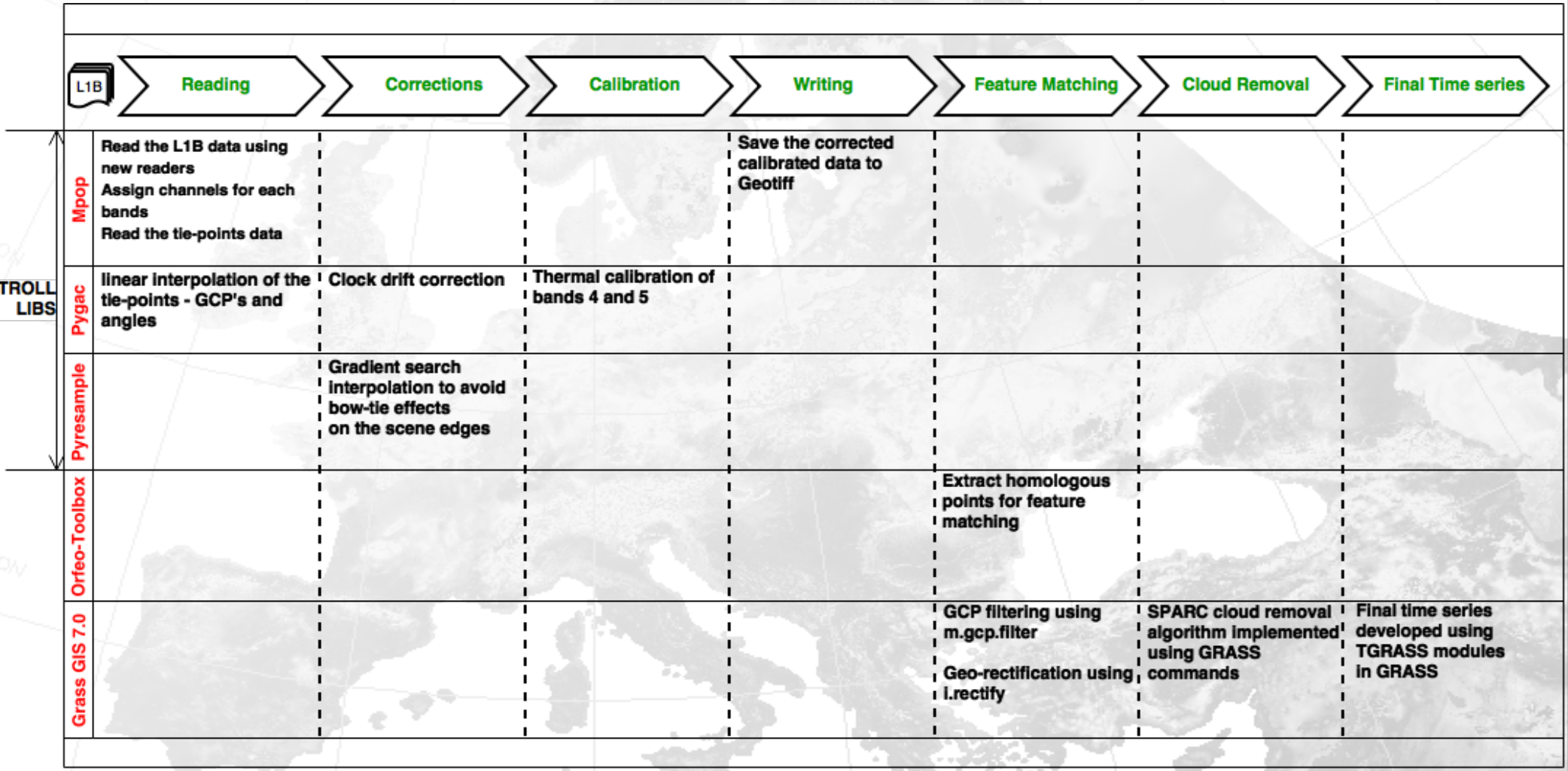
Workflow



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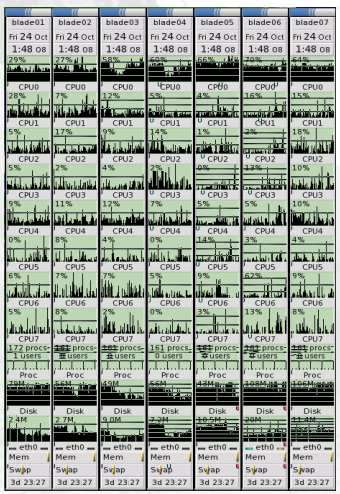
High Performance Computing with PGIS cluster

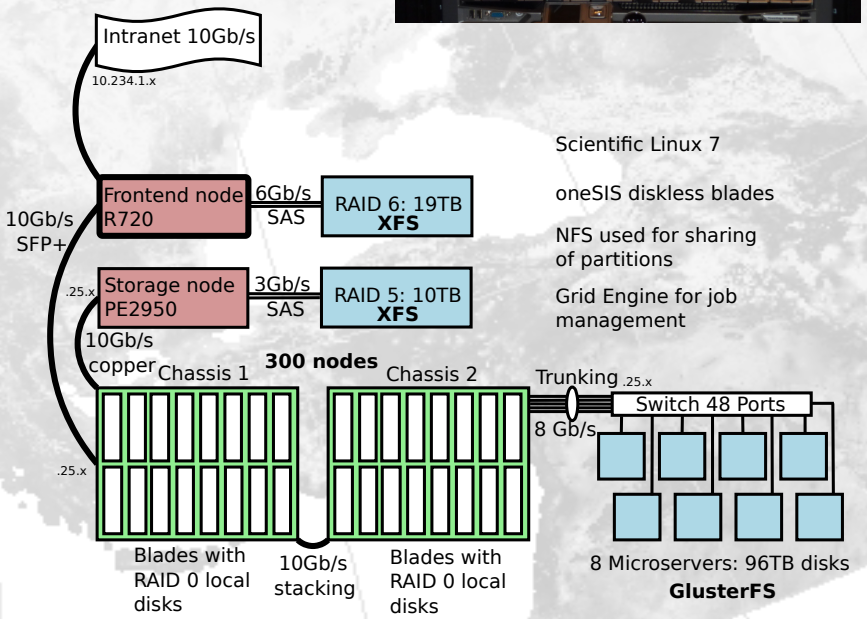
Hardware

- 300 nodes with 610 GB RAM
- 135 Terabytes of disk space
- Internal 10 Gb/s network

Software

- Scientific Linux 7
- OSGeo stack components installed: PROJ4, GDAL, GRASS GIS, OTB
- R
- Grid Engine (job manager)
- XFS, GlusterFS





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Libraries

Library/software	Source	Roles	License
Pytroll – mpop	https://github.com/mraspaud/mpop	Read and write L1B data	GNU GPL
Pytroll – pygac	https://github.com/adybbroe/pygac	Corrections and calibration	GNU GPL
Pytroll – pyresample	https://github.com/mraspaud/pyresample/	Gradient search interpolation to correct bow tie effects	GNU GPL
Orfeo-toolbox 4.2	https://www.orfeo-toolbox.org/	Homologous point extraction using SIFT for precise geometric correction	CeCILL
GRASS GIS 7.0	http://grass.osgeo.org/	GCP filtering, rectification, cloud removal, split window algorithm and time series development,	GNU GPL

GRASS GIS

PyTROLL

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pytroll – Python libraries

- Set of python libraries to read, calibrate, correct, visualize meteorological and polar orbiting satellite images at L1B level
- mpop – to read and process polar orbiting satellite images, incl. L1B formats
- pygac – to calibrate and apply corrections on AVHRR L1B images
- pyresample - Different resample algorithms satellite data and tie-point data

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NEXT

PyTROLL

Welcome to pytroll!

This is the home of the pytroll project. The pytroll project started out in 2009 as a collaboration on weather satellite data processing between DMI and SMHI. Pytroll now has a growing international user base and is used operationally at several National Met Services.

Its objective is provide different free and open source python modules for the reading, interpretation, and writing of weather satellite data.

The provided python packages are designed to be used both in R&D environments and in 24/7 operational production.

If you want to contact us, you can use the following mailing list: https://groups.google.com/group/pytroll or the pytroll IRC channel on freenode: irc://irc.freenode.net/pytroll

Note

Pytroll workshop Norrköping 2015

A one week workshop was
different corners of the wo
Slovakia) working on enhan

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- Recipes: Operational Pytroll
- Workshop 2012
- Workshop 2013
- Pytroll manifest
- Five years with Pytroll
- Shop

SEARCH

Go

www.pytroll.org

- pyresample for resampling satellite data
- mipp for reading weather satellite data
- mpop for processing weather satellite data
- python-bufr for reading bufr files
- pycoast for putting coastlines, borders and rivers on an image
- pyorbital for computing satellite orbital parameters and reading TLE's
- posttroll a higher-level messaging library for pytroll
- pykdtree for really fast nearest neighbour search
- python-geotiepoints for interpolating (and extrapolation) geographic tiepoints
- trollimage the new image packagse for pytroll (replaces and enhances the image.py module in mpop)
- trollsift for the formatting, parsing and filtering of satellite granule file names
- pyspectral to read and manipulate satellite sensor spectral responses and solar irradiance spectra
- pydecorate to simplify the drawing of logos, text labels, color scales and legends onto images

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New LAC data readers in pytroll

- Two separate readers for POD-LAC and KLM-LAC AVHRR data are developed in mpop – *lac_klm_l1b.py* & *lac_pod_l1b.py*
- Mapping all the header variations with bit locations and size
- Can handle all the L1B data by NOAA
- Could leverage the existing methods for calibration in pytroll-pygac
- New readers available in github: https://github.com/spareeth/mpop

```
# LAC header object
header = np.dtype([("data_set_creation_site_id", "S3"),
                   ("ascii_blank_x20", "S1"),
                   ("noaa_level_1b_format_version_number", ">u2"),
                   ("noaa_level_1b_format_version_year", ">u2"),
                   ("noaa_level_1b_format_version_day_of_year", ">u2"),
                   ("reserved_for_logical_record_length", ">u2"),
                   ("reserved_for_block_size", ">u2")
```

```
# video data object
scanline = np.dtype([("scan_line_number", ">u2"),
                     ("scan_line_year", ">i2"),
                     ("scan_line_day_of_year", ">u2"),
                     ("satellite_clock_drift_delta", ">i2"),
                     ("scan_line_utc_time_of_day", ">u4"),
                     ("scan_line_bit_field", ">u2"),
                     ("zero_fill0", ">i2", (5, )),
                     # QUALITY INDICATORS
                     ("quality_indicator_bit_field", ">u4"),
                     ("scan_line_quality_flags_reserved", ">u1"),
```

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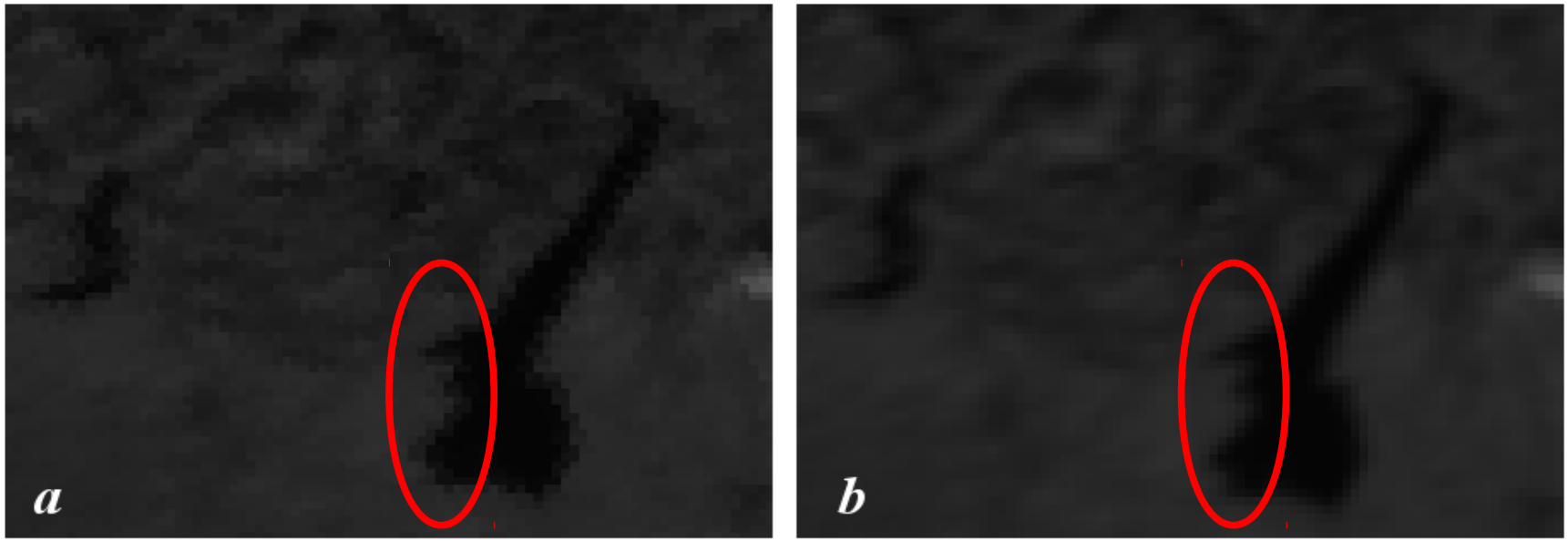
Gradient search resampling

- AVHRR – wide scan angle ± 55.4°
- Spatial resolution also varies with zenith angle
- Artefacts due to bow-tie effects on the wider angles
- Based on 2D gradient search in the lat and long geolocation fields using their local gradients
- Using Pyresample library in pytroll

K. Khlopenkov (2008)



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Clock drift correction

- POD satellites experienced small drifts in on-board clocks
- Location error upto 4km
- Corrected by applying the offsets released by NOAA
- Missing GCP's are then predicted using ephemeris data – Two Line Element (TLE) data available online
- Applied using pygac library in pytroll

Due to missing correction parameters, Attitude error cannot be corrected: remaining location error has to be solved using automated image to image correction procedure.

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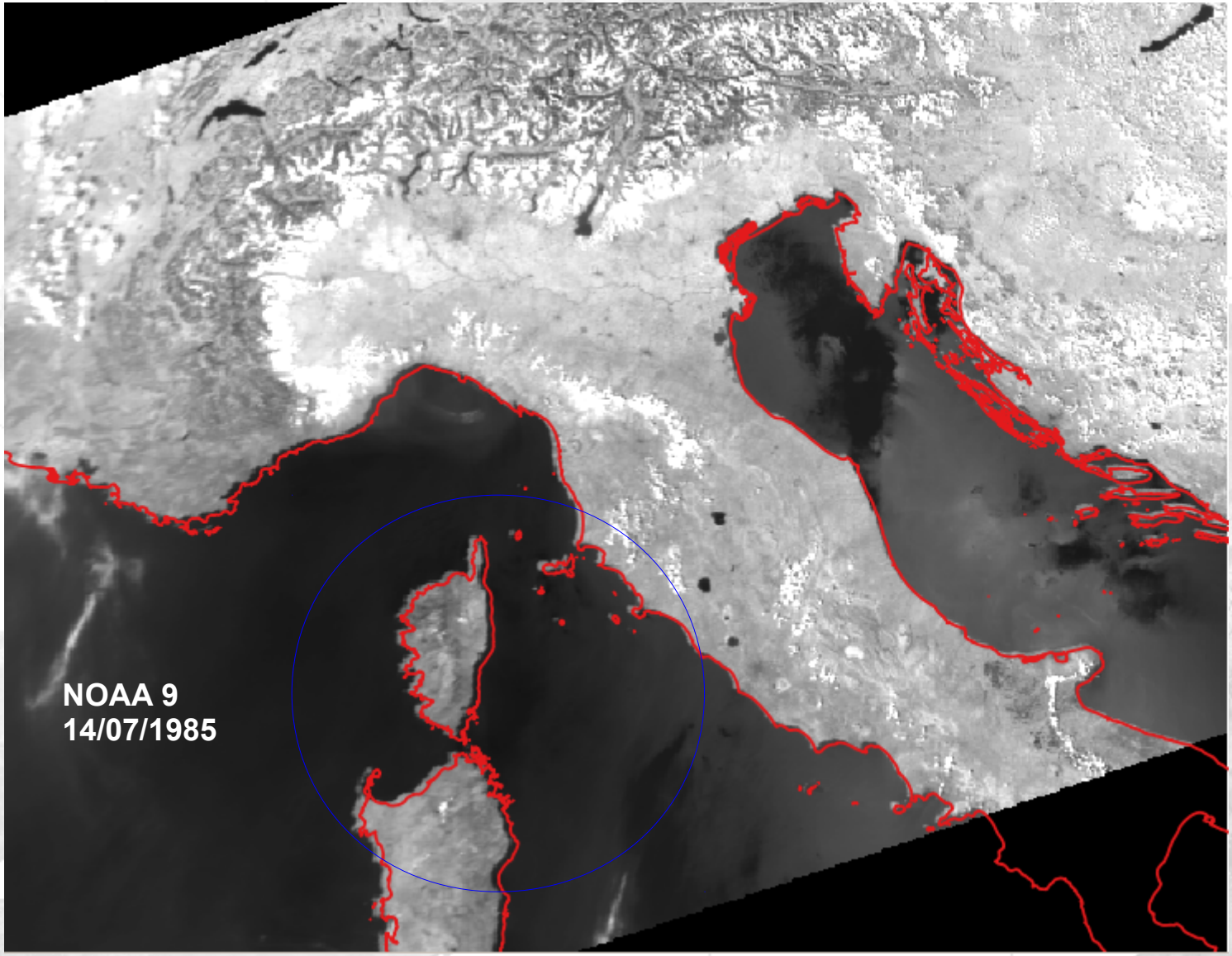
Calibrated AVHRR data



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Precise Geometric correction

- Feature matching technique
- Computer vision algorithm SIFT – Scale-Invariant Feature Transform
- Image to Image correction using an ideal cloud free AVHRR image as reference
- Using Homologous Point Extraction module in Orfeo Toolbox
- Filtering the GCP's using *m.gcp.filter* addon in GRASS 7
- Geo-rectification using *i.rectify* in GRASS 7
- Automated procedure

```
otbcli_HomologousPointsExtraction -in1 ip_band1.tif -band1 1 -in2 ref_b1.tif -band2 1 -algorithm sift -mode full -out $OUTB1
otbcli_HomologousPointsExtraction -in1 ip_band2.tif -band1 1 -in2 ref_b2.tif -band2 1 -algorithm sift -mode full -out $OUTB2
otbcli_HomologousPointsExtraction -in1 ip_band4.tif -band1 1 -in2 ref_b4.tif -band2 1 -algorithm sift -mode full -out $OUTB4
otbcli_HomologousPointsExtraction -in1 ip_band5.tif -band1 1 -in2 ref_b5.tif -band2 1 -algorithm sift -mode full -out $OUTB5
cat $OUTB1$OUTB1 $OUTB1 $OUTB1> $OUTB_all.txt
m.gcp.filter group=${i} order=1 threshold=500 -b -u
i.rectify -a group=${i} extension=_rectified order=1 method=nearest --o
```

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Automated GCP extraction and filtering

otbcli_HomologousPointsExtraction -in1 ip_band1.tif -band1 1 -in2 ref_b1.tif -band2 1 -algorithm sift -mode full -out

```
##Feature matchin (SIFT) using OTB starts here##
## Finding points for NSS.LHRR.NH.D89128.S1200_b1 ##

2015 Jul 09 22:13:17  :  Application.logger  (INFO) Elevation management: setting default height above ellipsoid to 0 meters
2015 Jul 09 22:13:17  :  Application.logger  (INFO) Using SIFT points
2015 Jul 09 22:13:18  :  Application.logger  (INFO) Found 8532 sift points in image 1.
2015 Jul 09 22:13:18  :  Application.logger  (INFO) Found 9611 sift points in image 2.
2015 Jul 09 22:13:37  :  Application.logger  (INFO) Found 33 homologous points.
2015 Jul 09 22:13:37  :  Application.logger  (INFO) 0 points discarded
```

otbcli_HomologousPointsExtraction -in1 ip_band2.tif -band1 1 -in2 ref_b2.tif -band2 1 -algorithm sift -mode full -out

```
## Finding points for NSS.LHRR.NH.D89128.S1200_b2 ##
2015 Jul 09 22:13:50  :  Application.logger  (INFO) Elevation management: setting default height above ellipsoid to 0 meters
2015 Jul 09 22:13:50  :  Application.logger  (INFO) Using SIFT points
2015 Jul 09 22:13:51  :  Application.logger  (INFO) Found 8102 sift points in image 1.
2015 Jul 09 22:13:52  :  Application.logger  (INFO) Found 8660 sift points in image 2.
2015 Jul 09 22:14:08  :  Application.logger  (INFO) Found 221 homologous points.
2015 Jul 09 22:14:08  :  Application.logger  (INFO) 0 points discarded
```

m.gcp.filter group=${i} order=1 threshold=500 -b

FILTERING

```
use=407
filtered=34
rms=497.926
```

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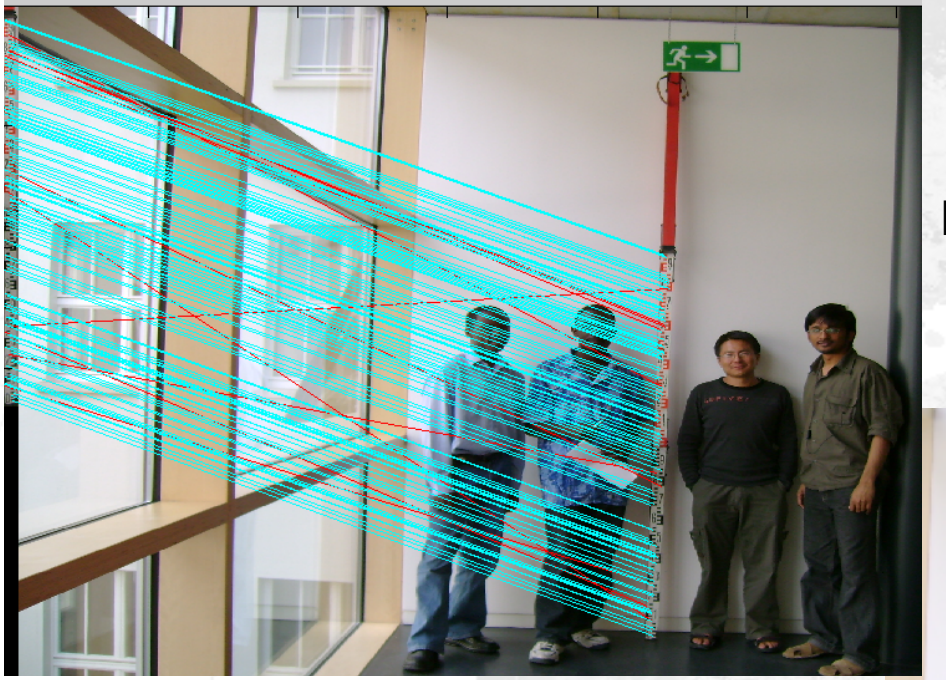
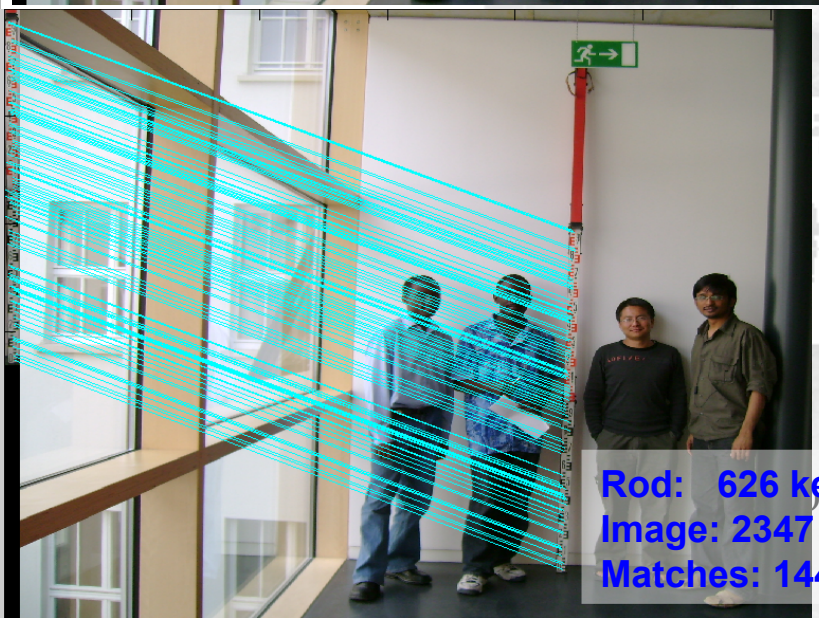
SIFT – on normal images



Rod: 626 keypoints found
Image: 2347 keypoints found
Matches: 155

Photogrammetry studio exercise @ hft-Stuttgart



Rod: 626 keypoints found
Image: 2347 keypoints found
Matches: 144

Michael Mutale
Gabriel Sanya
Sonam Tashi

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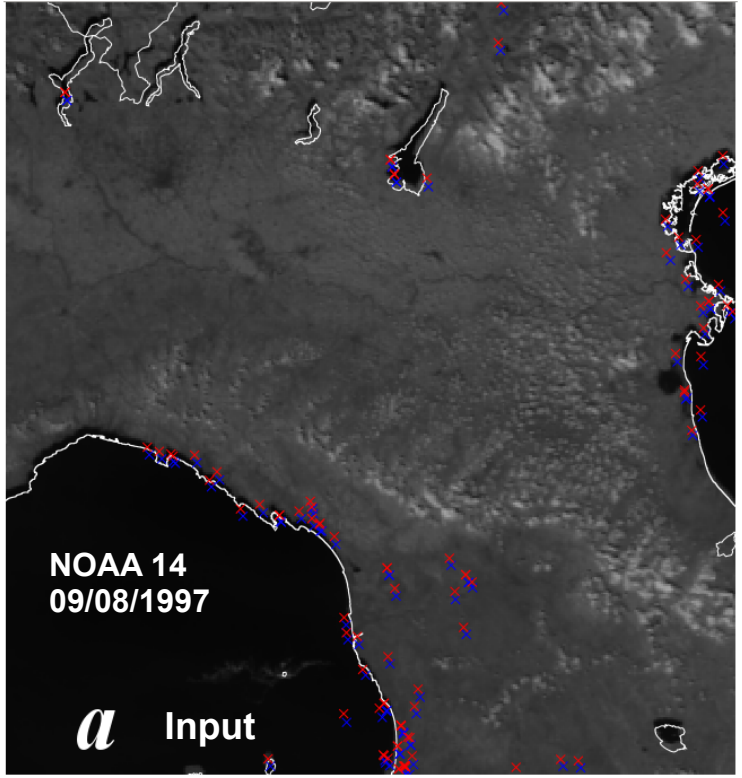
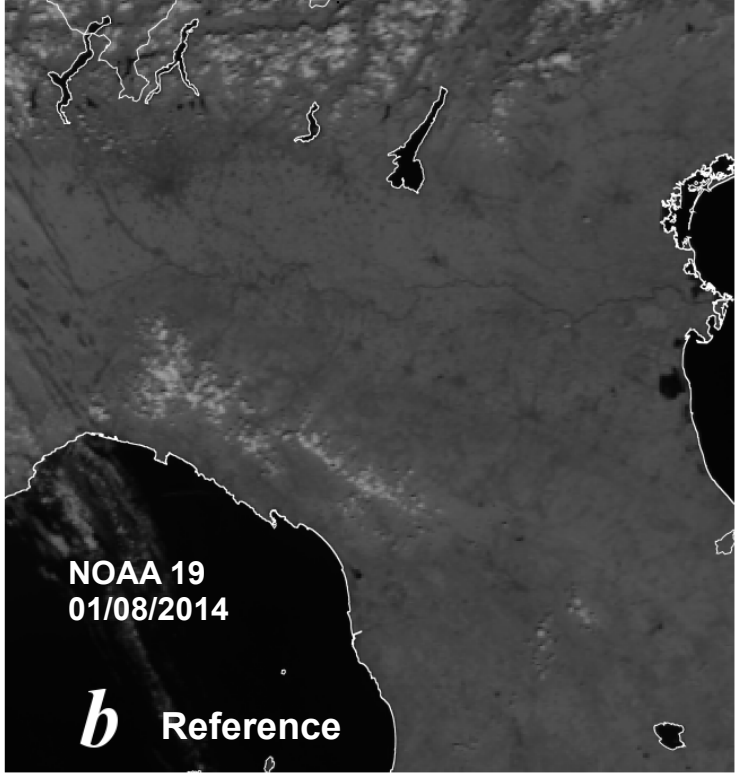
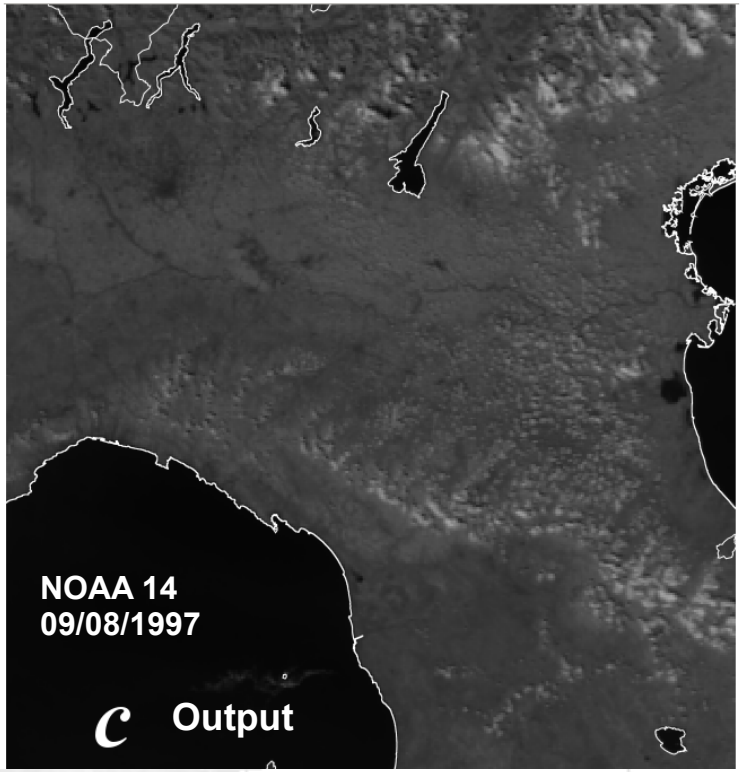
Automated Geometric Correction







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Final steps in GRASS GIS 7

- Cloud removal using the threshold based SPARC algorithm implemented in GRASS GIS 7 (*Khlopenkov et.al; 2006*)
- Temporal database using TGRASS modules in GRASS GIS 7
- Lake Surface Water Temperature (LSWT) using split window technique
- Outlier detection

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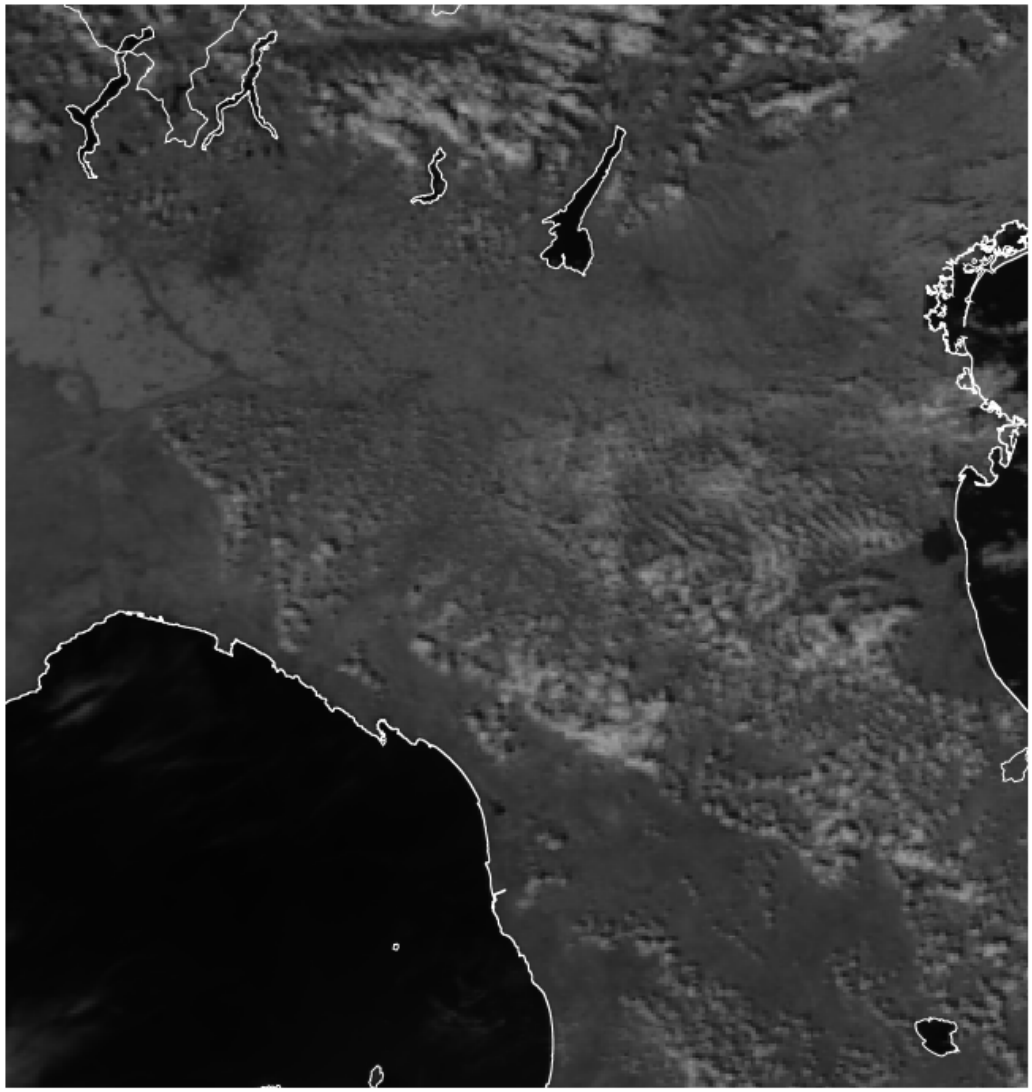
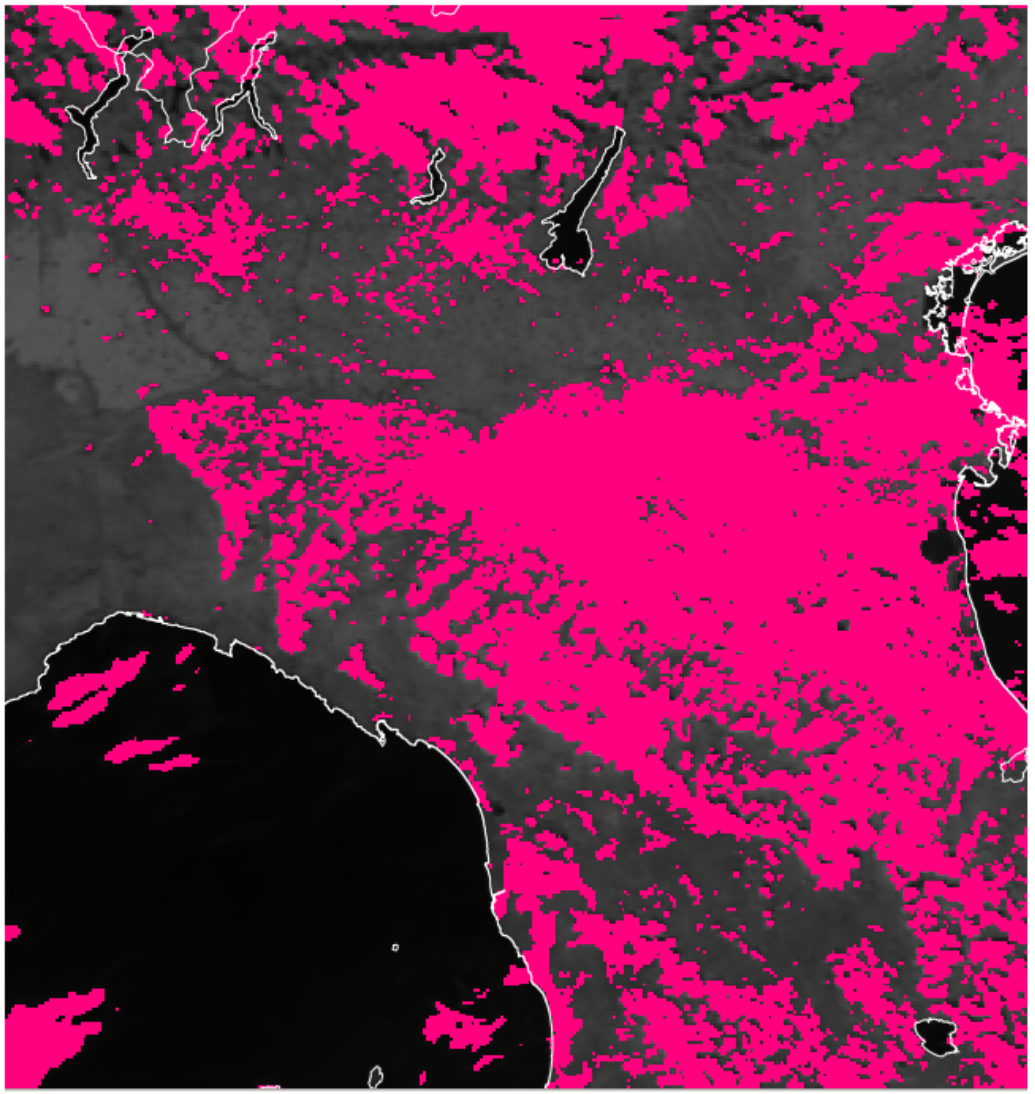
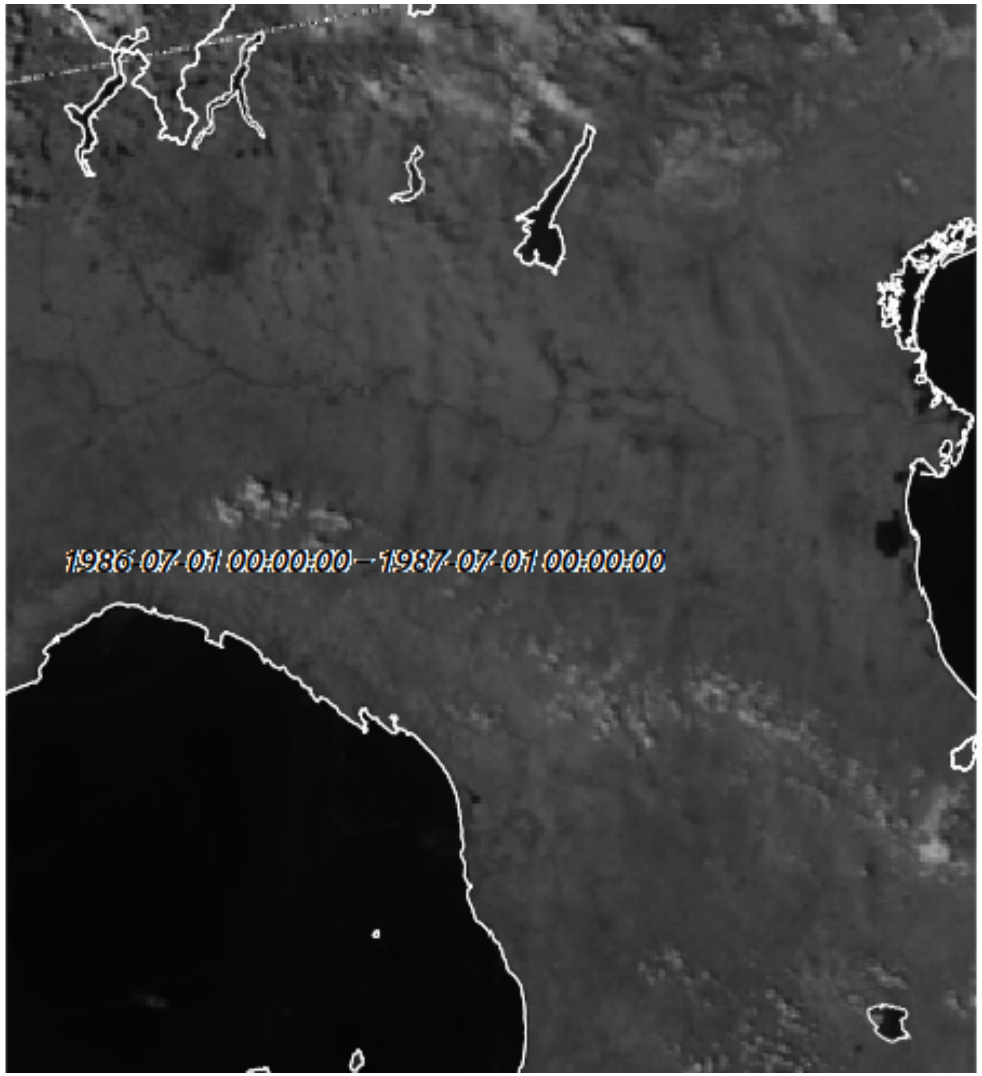
Cloud removal





Results



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Conclusion

- We have developed an open source frame work for reading, calibrating, correcting historical AVHRR LAC data
- Combining multiple open source libraries
- Extended pytroll libraries to support AVHRR L1B data
- Need to take care of change in observation times due to orbital drifts before trend analysis

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Thank you

GRASS GIS

PyTROLL

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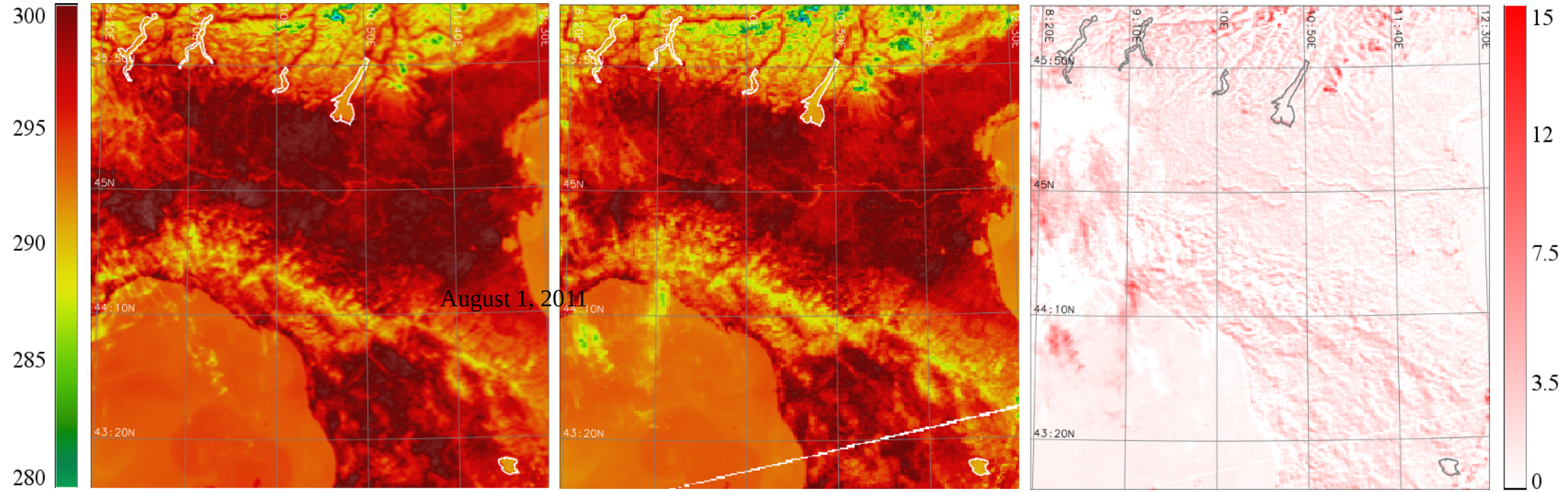
AVHRR vs MODIS

Brightness Temperature Band 4 - August 1, 2011



NOAA-19 12:10 PM MODIS 12:41 PM Difference image