# Satellite Climate Data Records of Canada's Landmass from AVHRR and MODIS at high resolution: Radiometric Calibration, Cloud Detection and Product Consistency

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# Two conclusions I can make right now

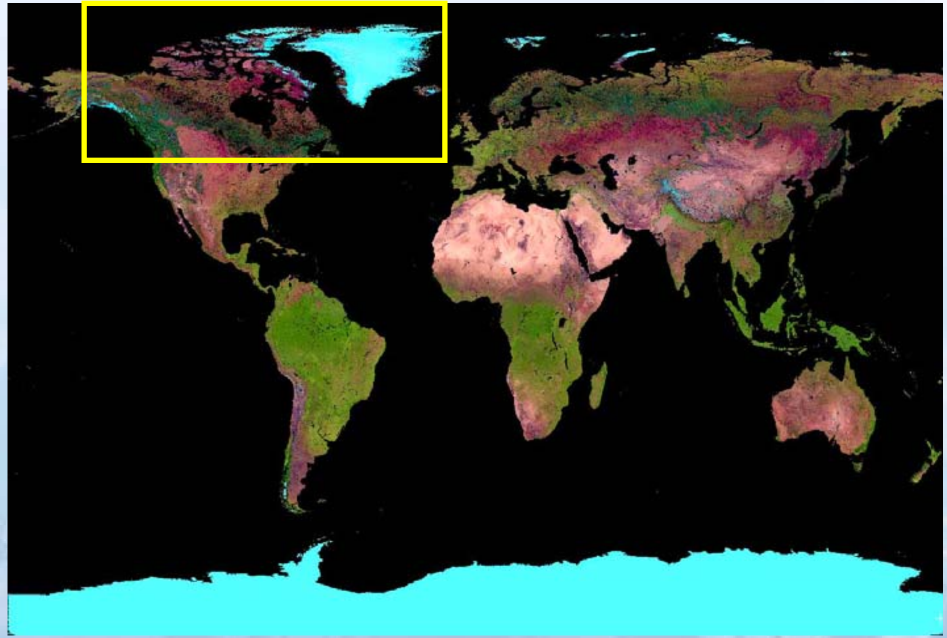
1) It is a very nice thing to combine business travel to DC with St.Petersburg Mariinsky (Kirov) ballet tour the same week;
2) Do not miss your change to see “Romeo and Juliet” . We saw it on Wednesday, we highly recommend it.

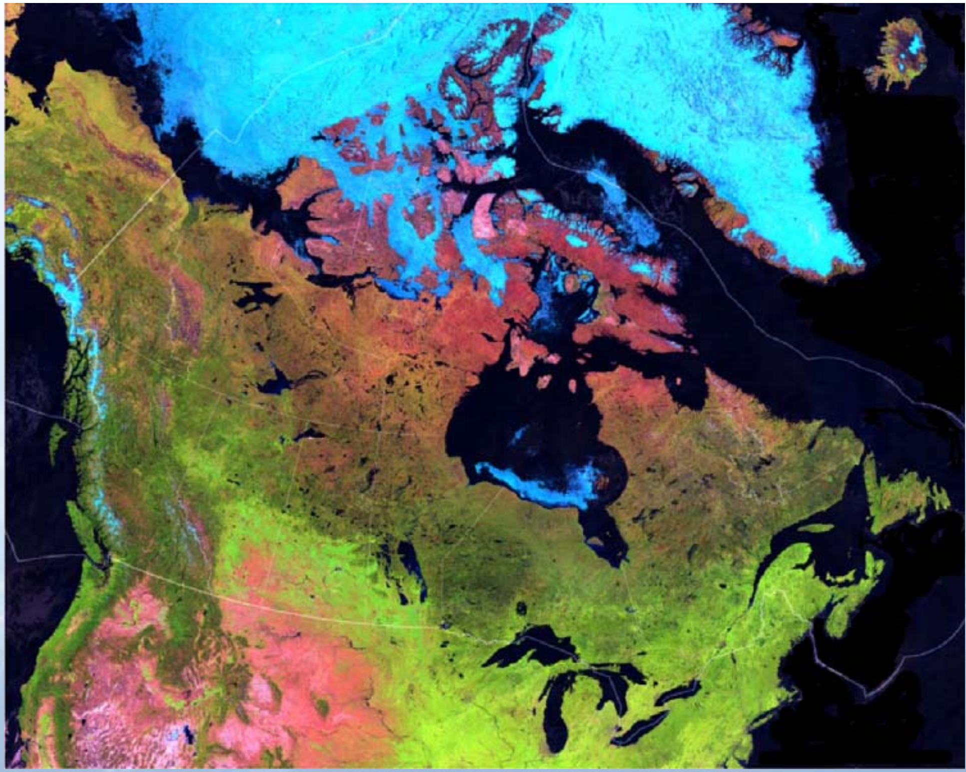
# Outline

- **GCOS requirements for satellite terrestrial observations**
- **Medium/coarse resolution data of Canada-wide coverage and processing system at the Canada Centre for Remote Sensing**
  - Calibration, calibration and calibration …
- **Corrections**
- **Cloud detection scheme**
- **Preliminary examples of long-term data series analysis**
- **Issues with angular sampling => new mission required**
- **Additional MODIS data processing over Canada**
- **Conclusions**

For country as big and sparsely populated as Canada, the satellite observations are frequently the only source of information about terrestrial, oceanic and atmospheric processes

MODIS July 21-31, 2004





# Objectives of CCRS Project

- It is a component of project J35 "Earth Science for National Scale Characterization of Climate Change Impacts on Canada's Landmass" of the ERCC Program
- Goal is to produce long-term consistent satellite based time series of land products suitable for climate change impact studies.

According to WMO approach a 30 year time span is required to produce climate norms.

Major requirements: 1km - AVHRR, 250m – MODIS
10-day intervals (3 per month)
LCC projection

# Parameters of terrestrial ecosystems required by Global Climate Observing System (GCOS) (2006)

## (GCOS-107, WMO/TD-1338)

Altogether, there are 16 parameters identified by GCOS that can be retrieved from satellite data from observations in optical, thermal and microwave bands. We are presently targeting 11 parameters listed in the Table below. Albedo is one the most fundamental parameters

| Parameter | Spatial resolution | Obs. cycle | Req. Accuracy | Min accuracy |
|---|---|---|---|---|
| Surface Albedo | 250m | 1day | 5% | 10% |
| Surface radiation budget (SW and LW) | 25km | 3h-1day | $5Wm^{-2}$ | $10Wm^{-2}$ |
| Land cover (incl. vegetation type) | 10m-1km | 1yr | 5% | 10% |
| Leaf Area Index (LAI) | 250m | 1day | 5% | 10% |
| Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) | 0.1-2km | 10day | 5% | 10% |
| Snow/ice cover | 250m | 1day | 5% | 10% |
| Fire disturbance | 250m | 30d | 5% | 10% |
| Biomass | 250m | 1d | 5% | 10% |
| Wetland extent | 250m | 7d | 5% | 10% |
| Glaciers and ice caps extent * | 0.01-0.1km | 1yr | 5% | 10% |
| Lake level/extent* | 0.01-0.1km | 7d | 5% | 10% |

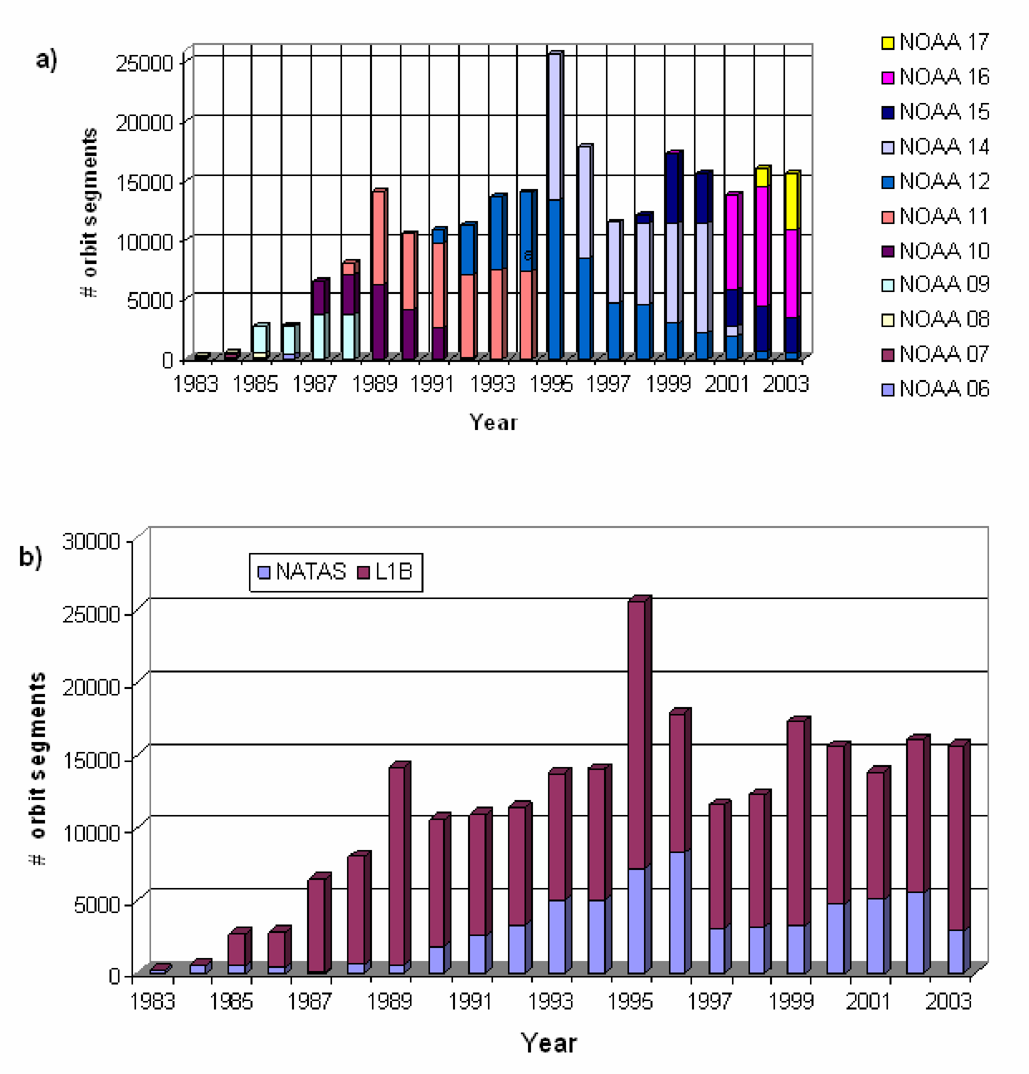
* Presently can be derived at 0.25-1km spatial resolution

# AVHRR/NOAA

## (Advanced Very High Resolution Radiometer) provides the longest period of observations

- Collected all available HRPT and LAC AVHRR from NOAA CLASS (SAA) archive and Canadian sources;
- Close to 20TB of L1B data were collected for AVHRR/NOAA-6 to NOAA-18 (1979-2006);
- New data processing system Earth Observation Data Manager (EODM) has been developed at the Canada Centre for Remote Sensing. It includes
  - Updated geolocation package
  - Updated calibration package (? Solar spectrum/constant ?)
  - New clear-sky/cloud/snow&ice/**cloud shadow(!)** package:
    SPARC – **S**eparation of **P**ixels using **A**ggregated **R**ating over **C**anada
  - New clear-sky compositing scheme
  - Updated atm.correction, BRDF correction, spectral correction modules
  - Updated geophysical product generation package
- 1-day and 10-day clear-sky composites were generated over the area of 5700x 4800 $km^2$ that covers Canada, northern USA, Greenland and surrounding oceans

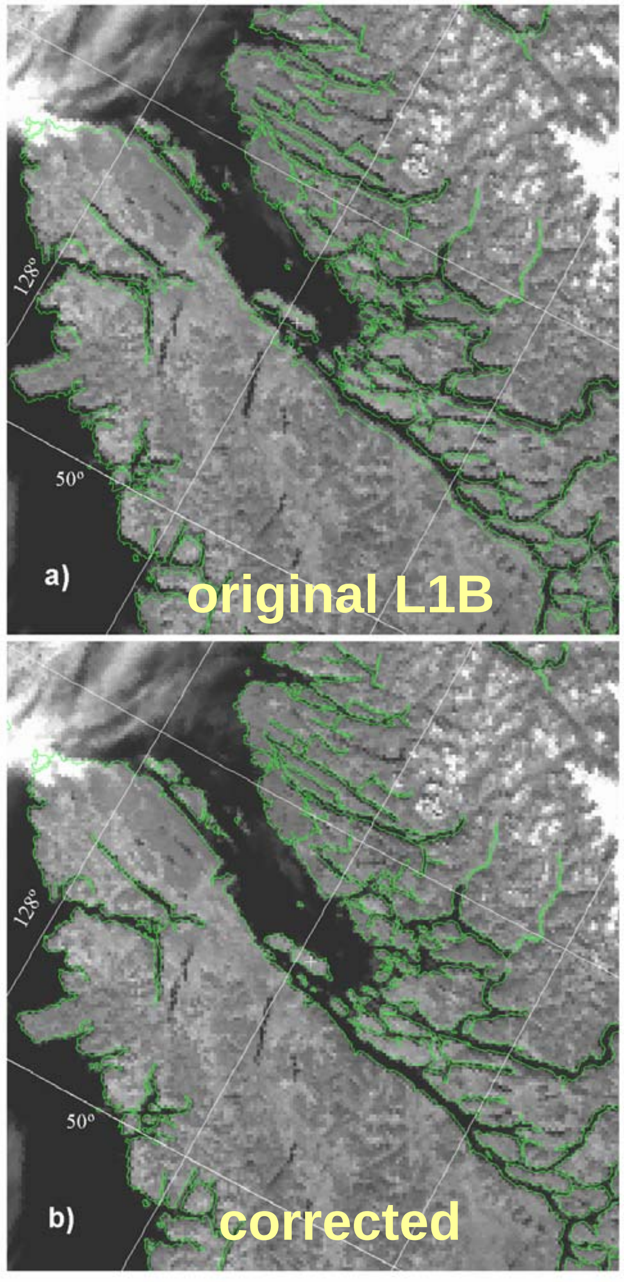
# AVHRR 1-km data

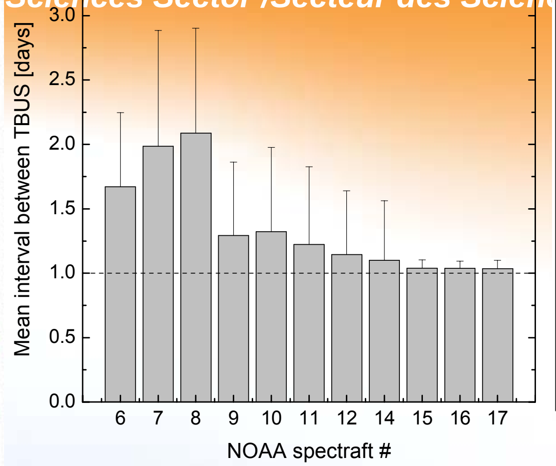


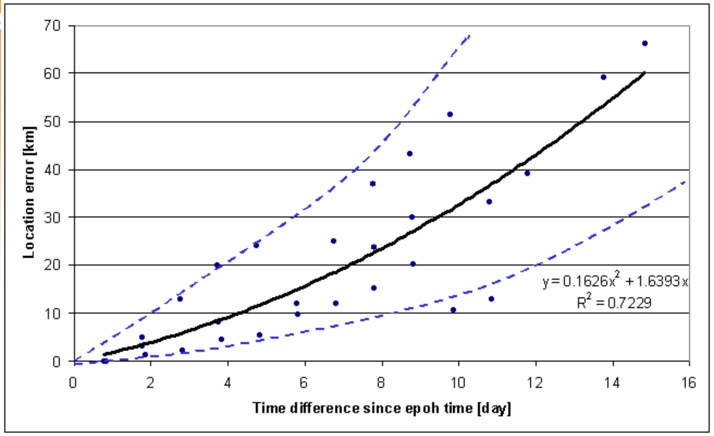

**~ 20 TB of raw/L1B data HRPT and LAC ~300,000 scenes over Canada**

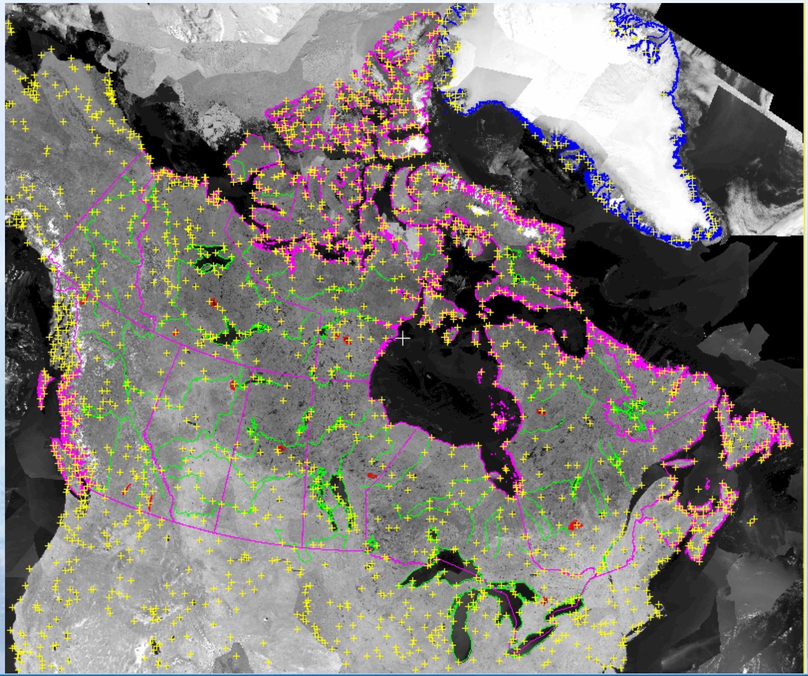
processed with new CCRS developed data processing system

**Sources of data:**
**NOAA CLASS**
**CCRS PARS**



**New:**
**GCP database**
**cloud detection**
**compositing**
**atm correction**
**product algorth**
**60 CPU system**

# Radiometric calibration

- Thermal channels are calibrated using onboard measurements and techniques developed at CCRS (my previous visit to NOAA/NESDIS):
  - Trishchenko, A. P., et al., 2002: Trends and uncertainties in thermal calibration of the AVHRR radiometers onboard NOAA-9 to -16. *JGR*, 107, D24, ACL 17-1 to ACL 17-13, doi:10.1029/2002JD002353
  - Trishchenko, A. P., 2002: Removing unwanted fluctuations in the AVHRR thermal calibration data using robust techniques. *JTech.* 19, 1939-1954.
  - Trishchenko, A.P., Z.Li, 2001: A Method for the correction of AVHRR onboard IR calibration in the event of short-term radiative contamination. *IJRS*. 22, 3619-3624.
- Optical channels were calibrated using recommendations developed at CCRS and based on analysis of various approaches and NOAA recommendations
  - Latifovic, Trishchenko et al., 2005: Generating historical AVHRR 1 km baseline satellite data records over Canada suitable for climate change studies. *Can Journal Remote Sensing*, V.31, No 5, 324-346.
  - Currently, we are revising the calibration of optical channels using deep-convective cloud approach, as described in Trishchenko et al., *12th Atmospheric Radiation Conference*, Madison, WI, July 2006.

# Several calibration results are available for various AVHRR/NOAA optical bands

(list may not be complete)

1) NOAA pre-lunch
2) ISCCP (ch. 1) (Brest et al.)
3) Cao et al (NOAA)
4) Che and Price
5) Doelling et al
6) Heidinger at al
7) Leroy et al (POLDER vs AVHRR)
8) Loeb
9) Masonis and Warren
10) Minnis et al
12) Nguyen et al
13) Rao and Chen
14) Kaufman and Holben
15) Tahnk and Coakley
16) Teillet and Cihlar
17) Teillet and Holben
18) Trishchenko et al., 2006
19) Vermote and Kaufman & LTDR - 2006

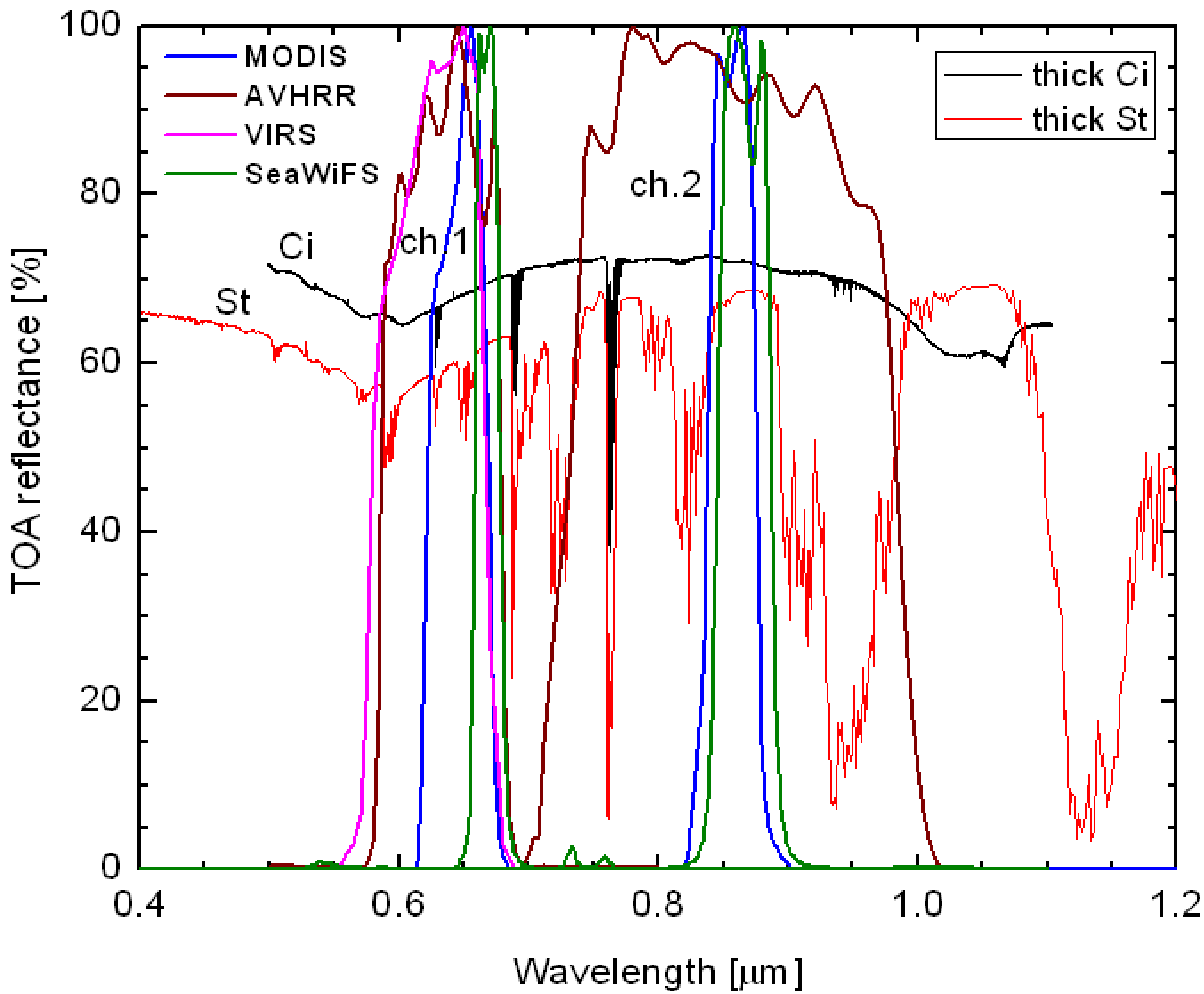
# How best to calibrate the uncalibrated AVHRR

- Comparison with other sensors (intercalibration)
- Vicarious calibration => stable targets
- Stable targets
  - Do they exists?
  - Surface targets vs Clouds
    - Surface:
      - Large sensor footprint, characterization of inhomogeneity
      - Seasonal cycle (vegetation, snow, SZA, BRDF, wind erosion, sand dunes)
      - Energy: SZA and magnitude of reflectance
      - Variability of atmospheric state: WV, O3, aerosol
      - Examples: desert areas, designed sites, Greenland, Antarctic
    - Clouds
      - Problems: Variability of optical properties, cloud top geometry, 3-D
      - Advantage: Can be selected at small SZA (large energy), highly reflective, high clouds tops reduce influence of variable atmosphere (except O3 and stratospheric aerosol)
      - Selecting nadir view and tropical deep convective clouds looks as good potential calibration approach, providing that they are stable targets

# There is an alternative appoach

"To normalize the calibrations of the series of AVHRRs on the NOAA polar orbiting weather satellites, **the whole earth, excluding clouds, is assumed to represent a set of calibration targets that are more nearly constant in time, as a statistical ensemble**, than any of the available radiometers or of any available calibrations of them. In other words, based on the post facto assessment, we conclude that the accuracy of independent calibrations attainable with todays satellite radiometers is less than that obtained by assuming that Earth *as a whole except for clouds* does not change with time. This is a stricter assumption than made originally. Now, in effect, any real and systematic changes of the whole Earth become the (smaller) error. Even excluding the clouds in this procedure, these data cannot be used to monitor any *slow linear* trends of the global mean cloud properties retrieved from the radiances that might accompany a changing global climate (*Rossow and Cairns 1995*) because there is no independent confirmation of the long-term calibration. However, shorter-term (e.g., interannual or nonlinear decadal) and/or regional changes in clouds can now be reliably assessed with these data because we assume only that the whole earth is constant over the whole data record, which would remove only a linear trend in global mean quantities".
***William B. Rossow and Robert A. Schiffer, Advances in Understanding Clouds From ISCCP, BAMS, November, 1999***

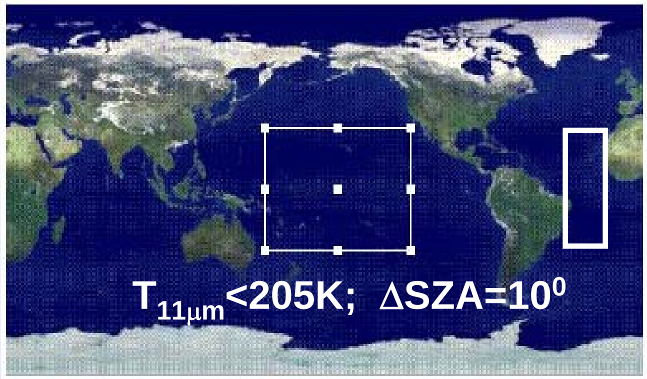
excluding clouds => reliability of cloud detection, possibility of cloud contamination !

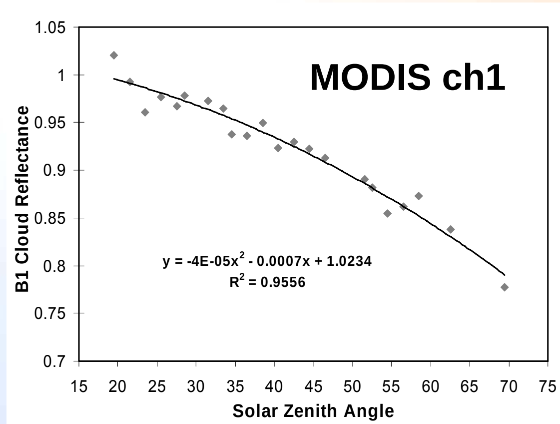


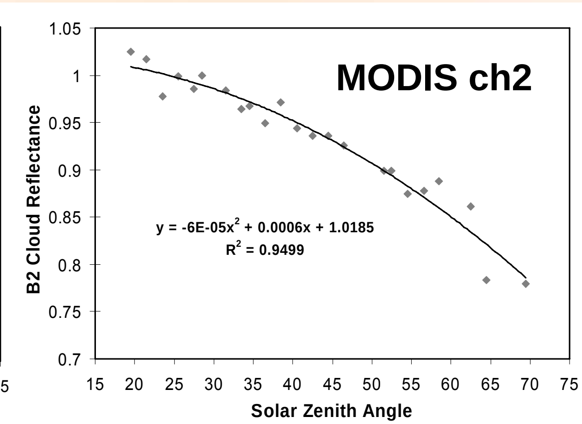

Deep convective clouds provide much flatter spectrum => smaller spectral correction

The major question:
Is this target stable?

# Statistics of deep convective clouds from MODIS



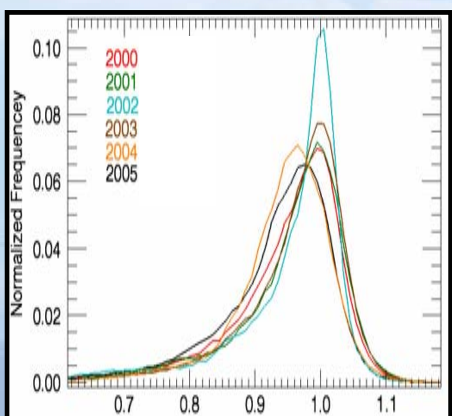



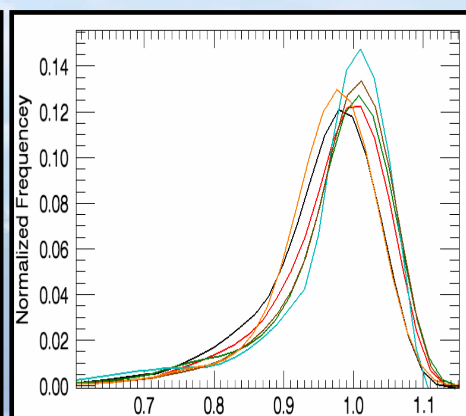

Nadir view VZA <$10^0$

MODIS SZA in tropical zone has a limited range

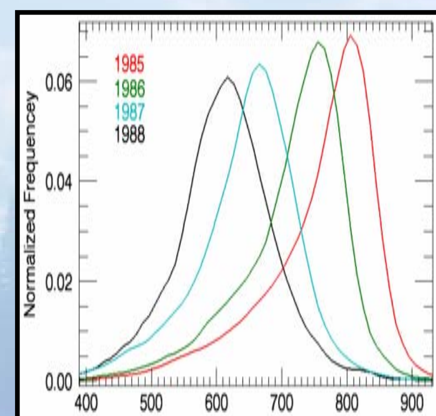
**MODIS ch1**



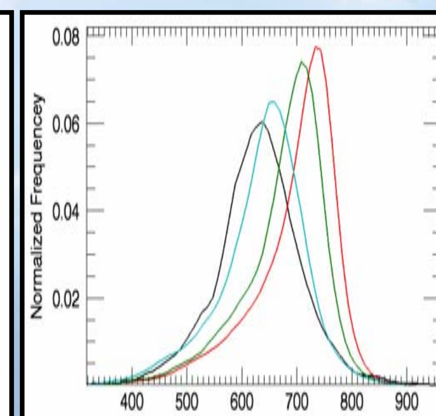

**MODIS ch2**




**AVHRR/NOAA-9 ch1**

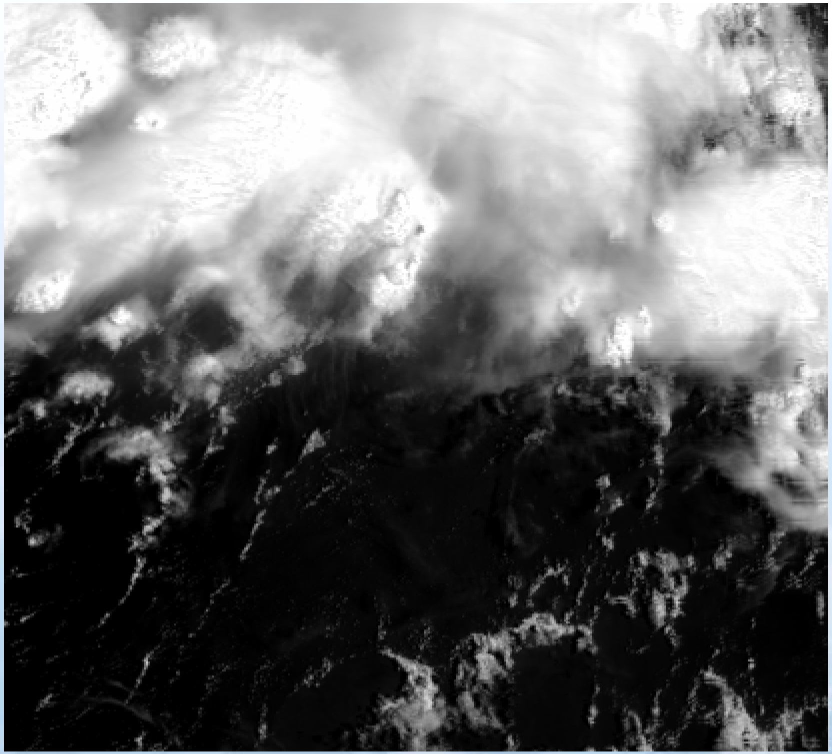



**AVHRR/NOAA-9 ch2**

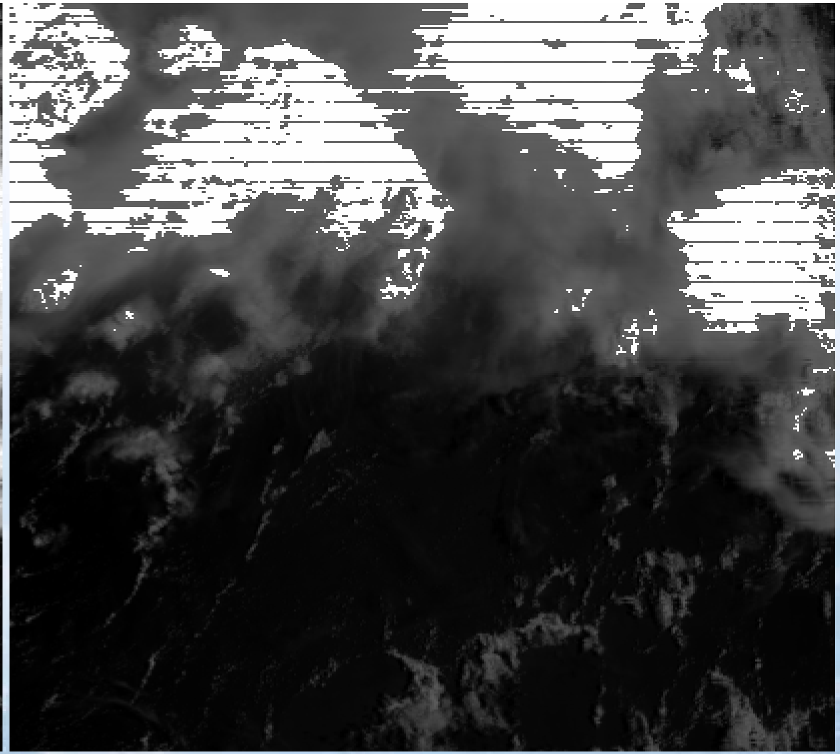


# Saturation of MODIS ch 2 for bright clouds

**MODIS Band 1**



**MODIS Band 2**



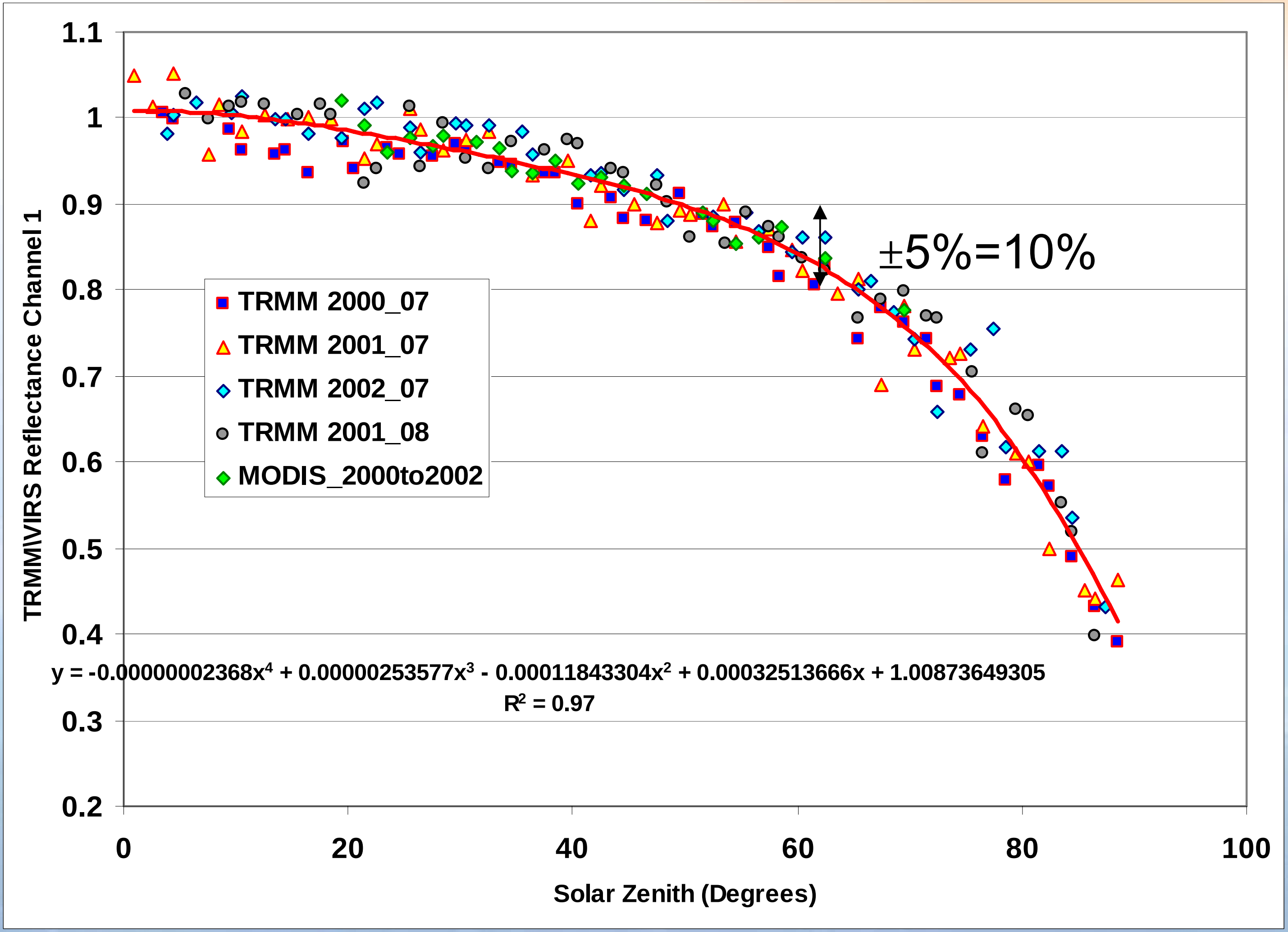
# Sampling

- MODIS orbit is sun-synchronous
- Sampling of SZA from MODIS and SeaWiFS is limited for calibrating all AVHRRs with LST varying from near noon to late afternoon or early morning
- High inclination VIRS/TRMM orbit is the best choice !

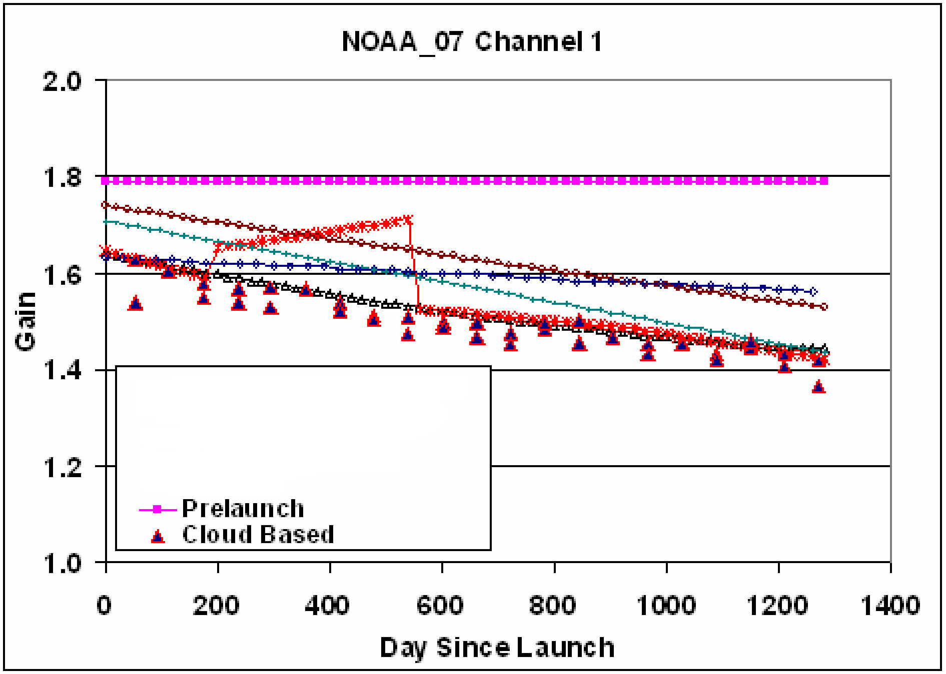
# Strategy

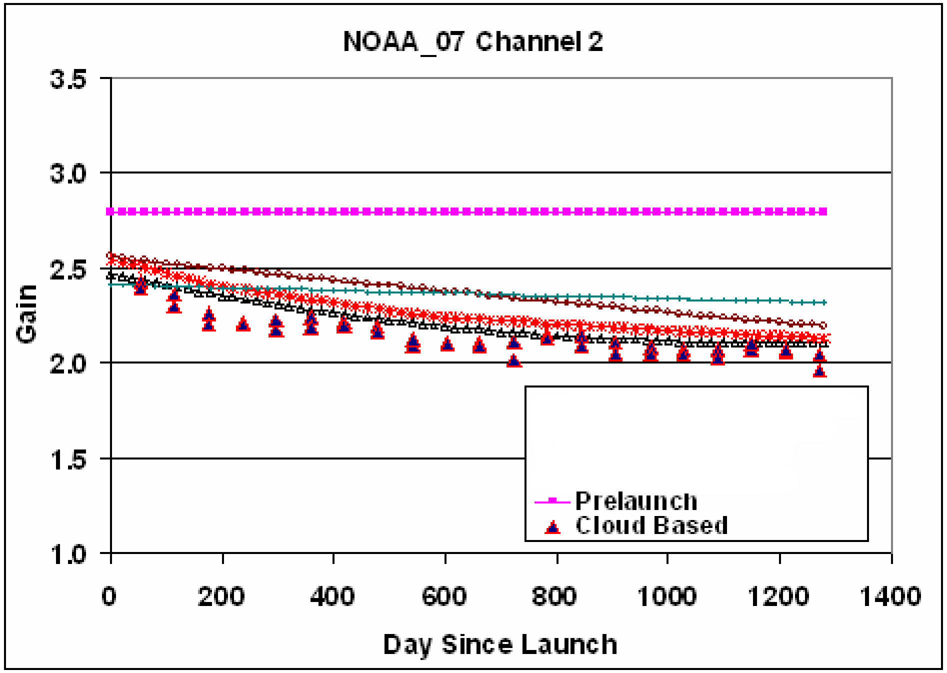
- Develop calibration curve for nadir view and various SZA using MODIS and VIRS observations of tropical deep convective clouds (TDCC) ($T<205K$)
- Produce monthly distribution of AVHRR counts for (ch.1 and 2) using GAC data over tropical ocean for all sensors NOAA-6 to NOAA-14
- Derive gain and offset using TDCC calibration curve for every month
- Dual gain concept for AVHRR/3: N-15,16,17,18 requires calibration of these sensors by intercomparison with MODIS&VIRS&SeaWiFS

# Nadir view ADM produced for TDCC from VIRS/TRMM and MODIS

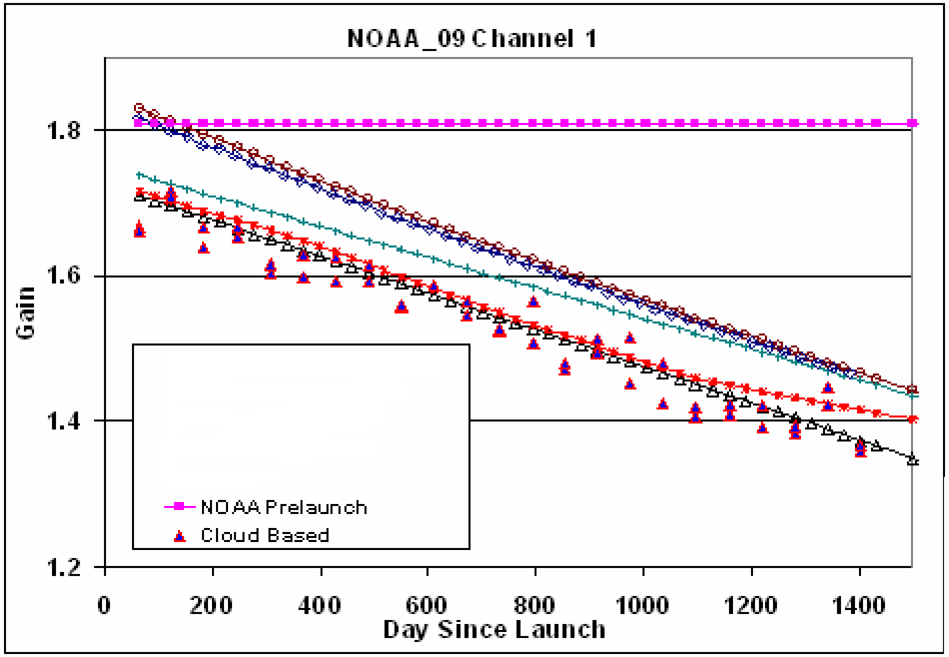


# AVHRR NOAA-7


NOAA_07 Channel 1
Gain
2.0
1.8
1.6
1.4
1.2
1.0
0
200
400
600
800
1000
1200
1400
Day Since Launch
Prelaunch
Cloud Based


NOAA_07 Channel 2
Gain
3.5
3.0
2.5
2.0
1.5
1.0
0
200
400
600
800
1000
1200
1400
Day Since Launch
Prelaunch
Cloud Based

# AVHRR NOAA-9


NOAA_09 Channel 1
Gain
1.8
1.6
1.4
1.2
0
200
400
600
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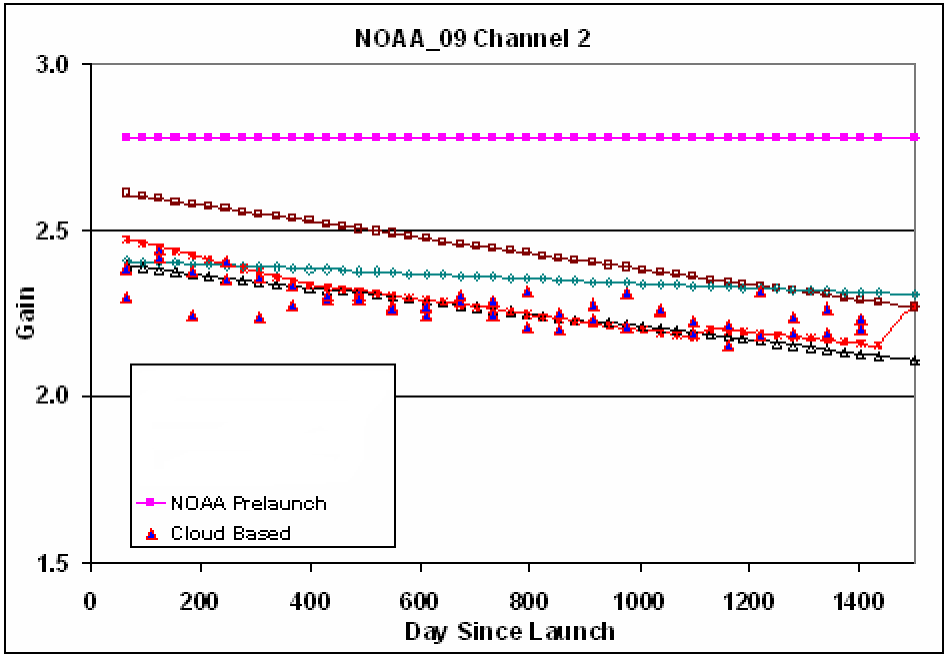
1400
Day Since Launch
NOAA Prelaunch
Cloud Based


NOAA_09 Channel 2
Gain
3.0
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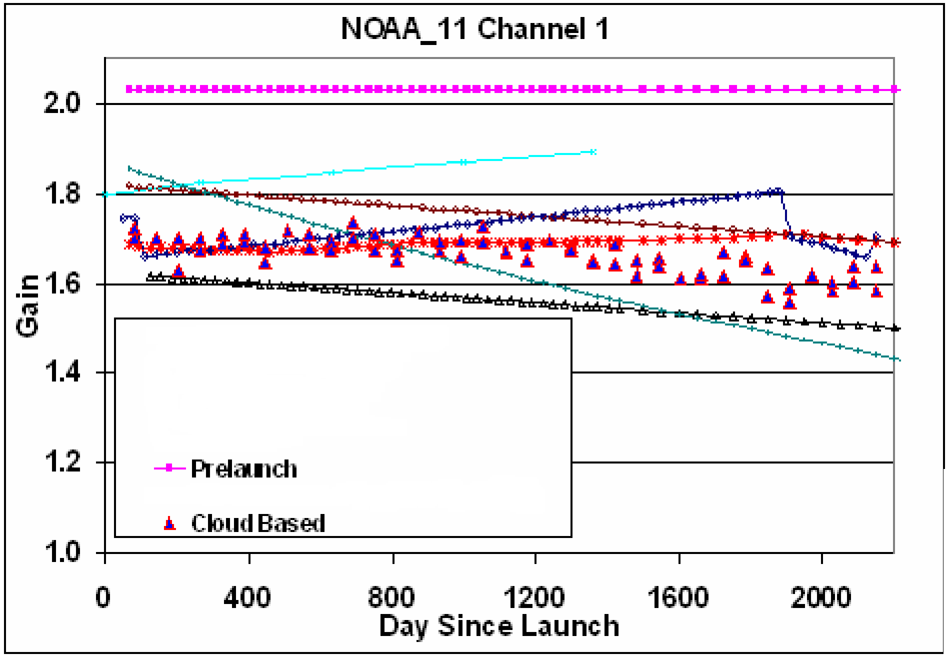
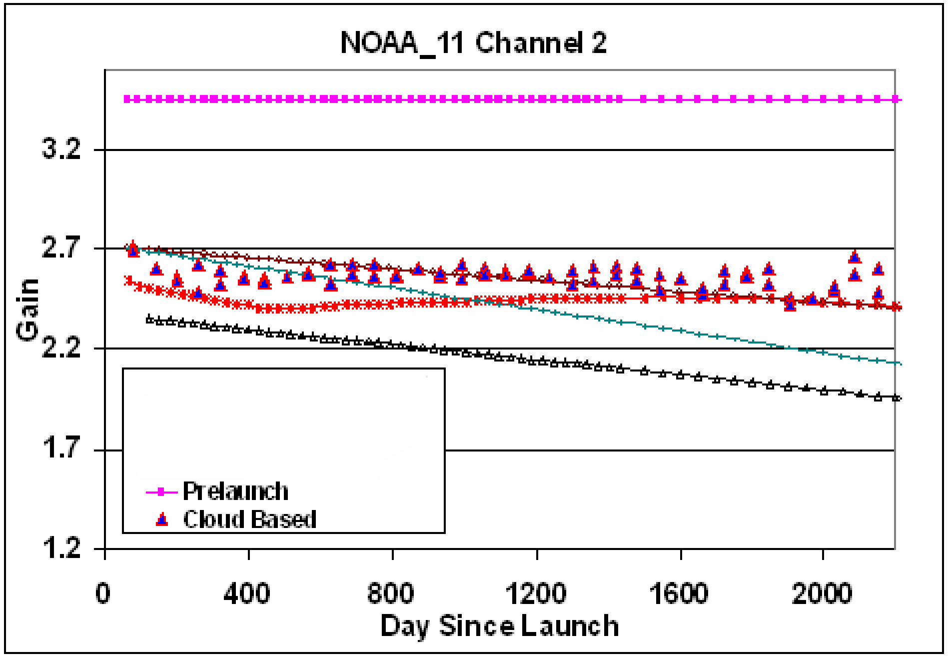
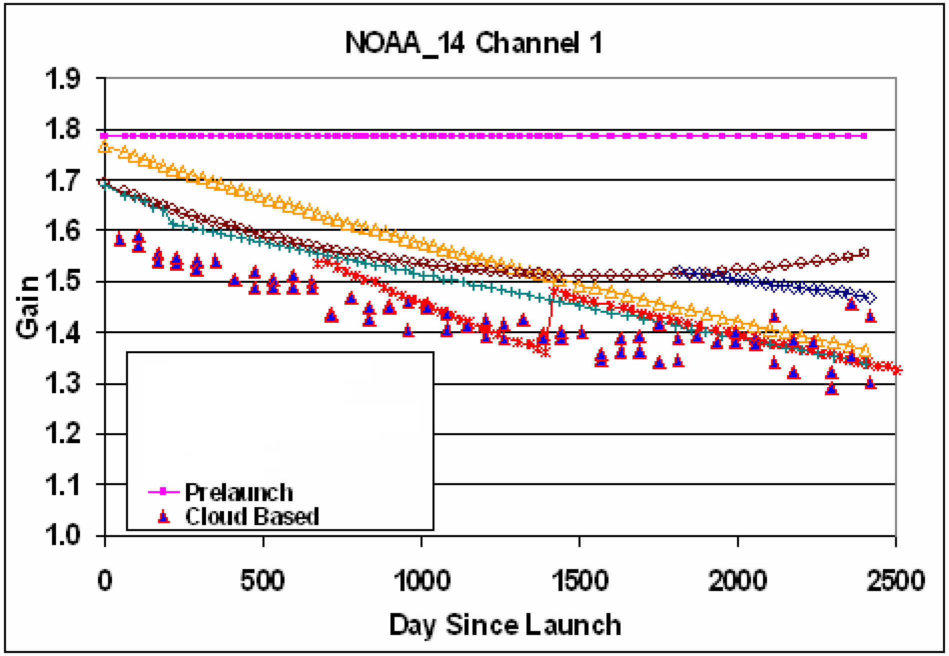
Day Since Launch
NOAA Prelaunch
Cloud Based

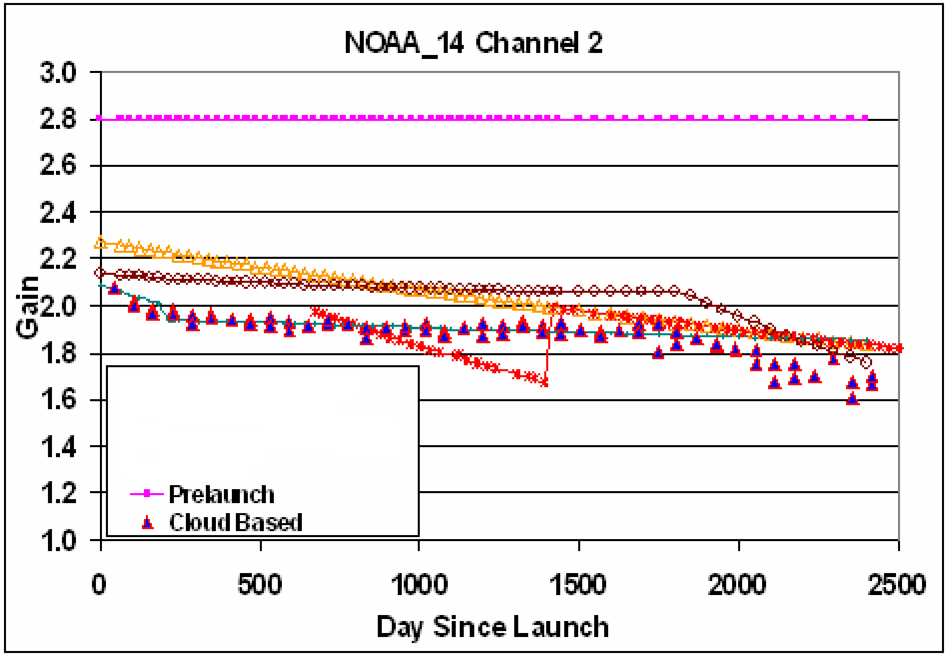



# AVHRR NOAA-11



# AVHRR NOAA-14



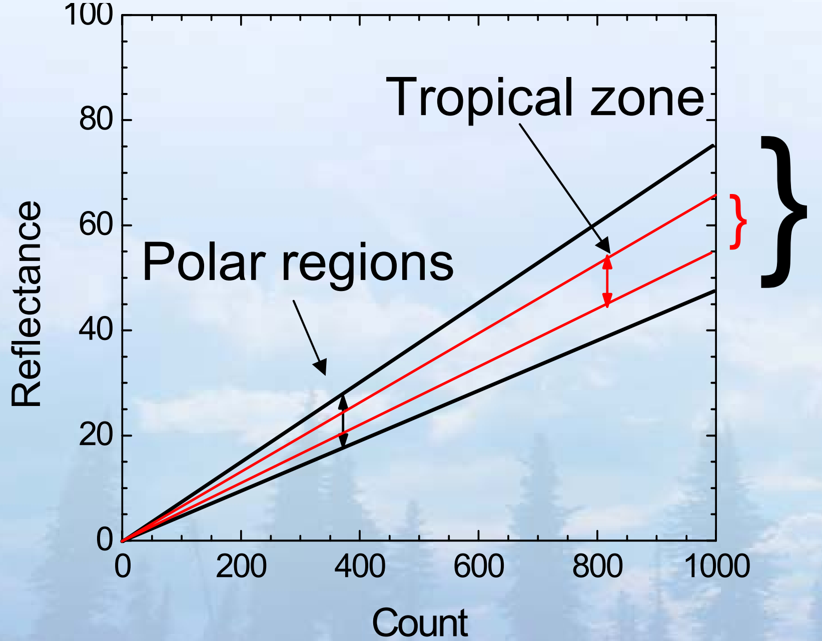



**Assuming a linear system, the best way to calibrate it would be to determine the darkest and brightest points and draw the line**

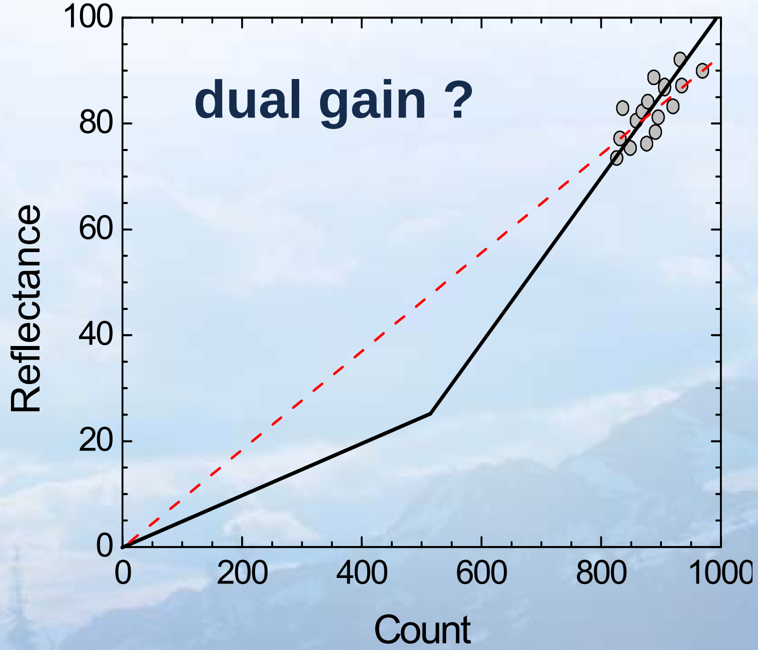
**- The darkest point is a "zero" count**

**- The brightest point can be either**

1) sun, or 2) highly reflective object in the tropical zone, which is *deep-convective cloud systems*



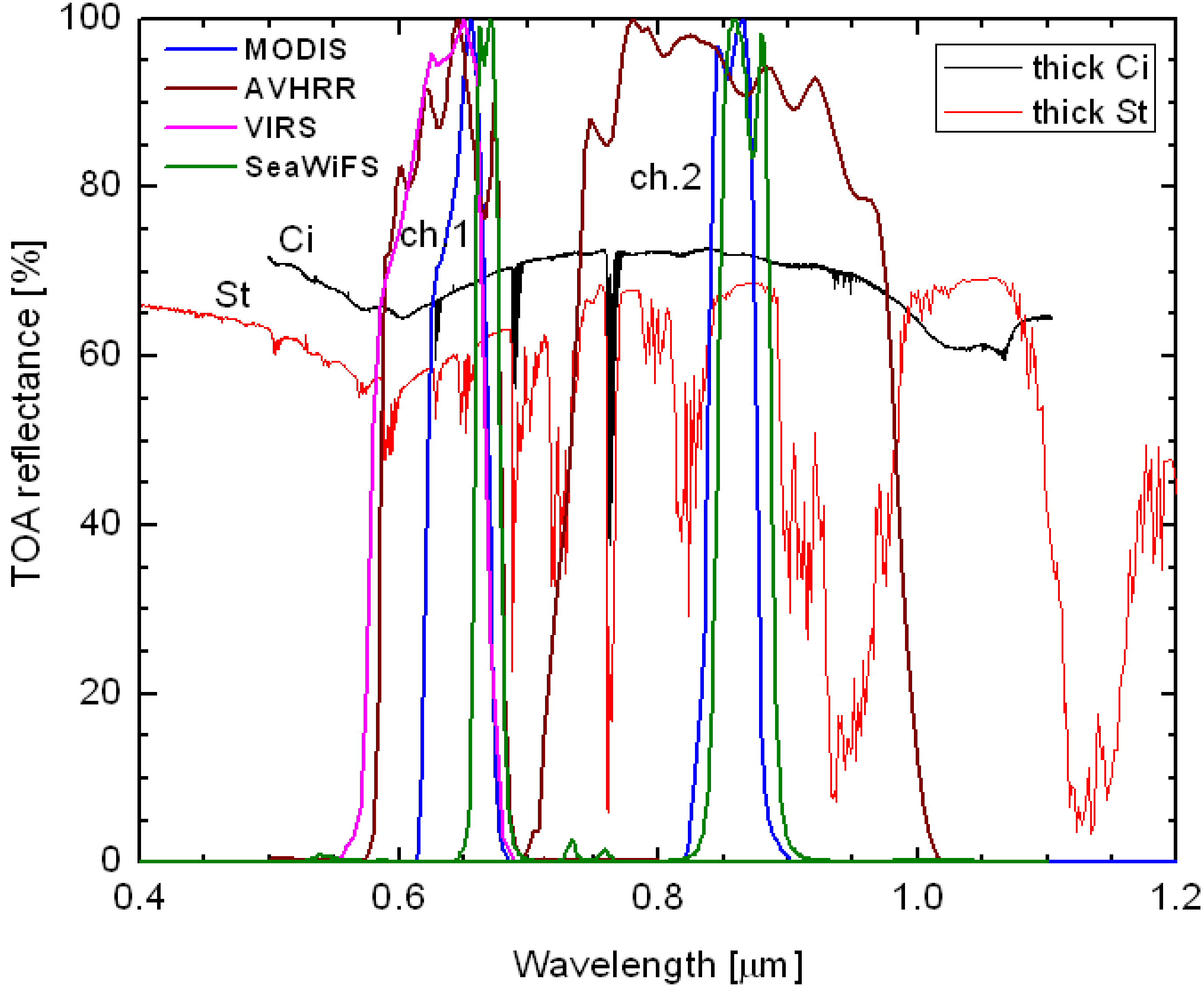

**AVHRR-1,2 (N6 - 14)**




**AVHRR-3 (N15 - 18)**

# Corrections

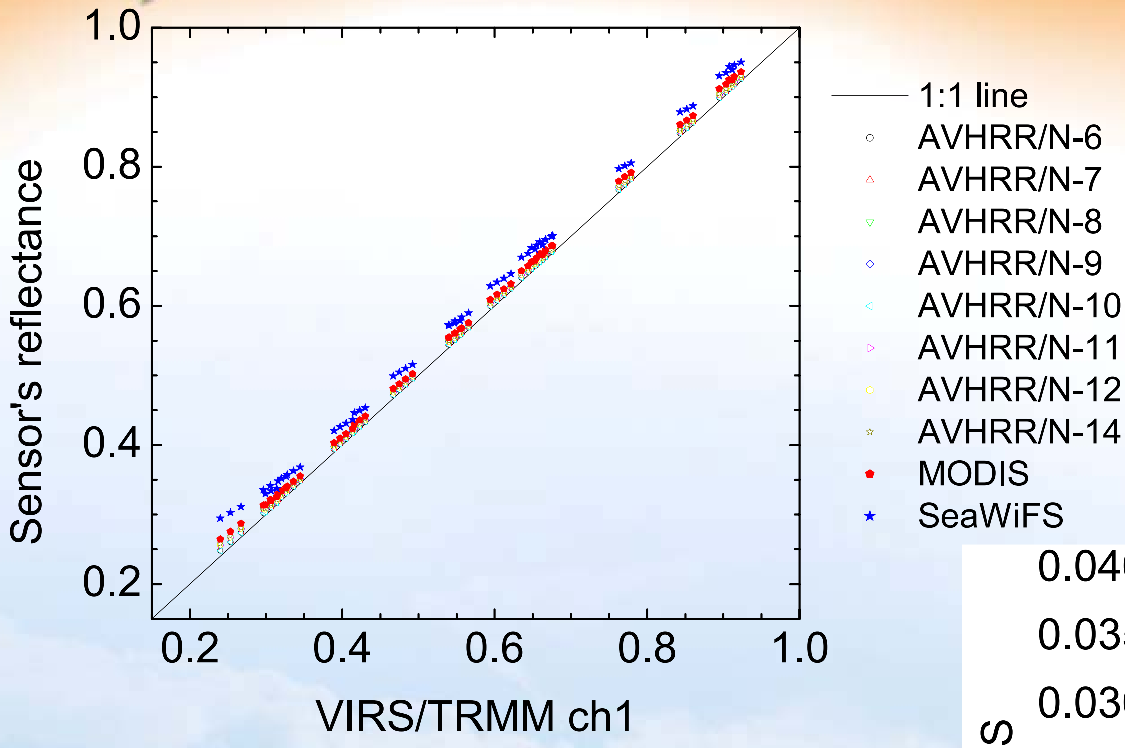
1) Spectral response function differences
    a) impact on calibration
    b) impact on reflectances and land products
2) Differences in solar reference spectrum
3) Ozone, WV, **aerosol**

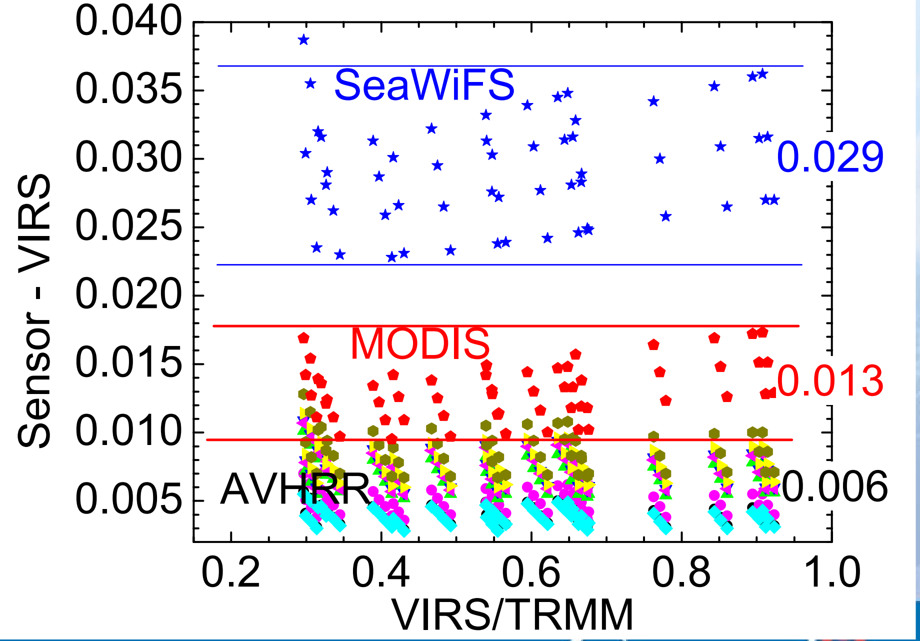



Deep convective clouds provide much flatter spectrum => smaller spectral correction

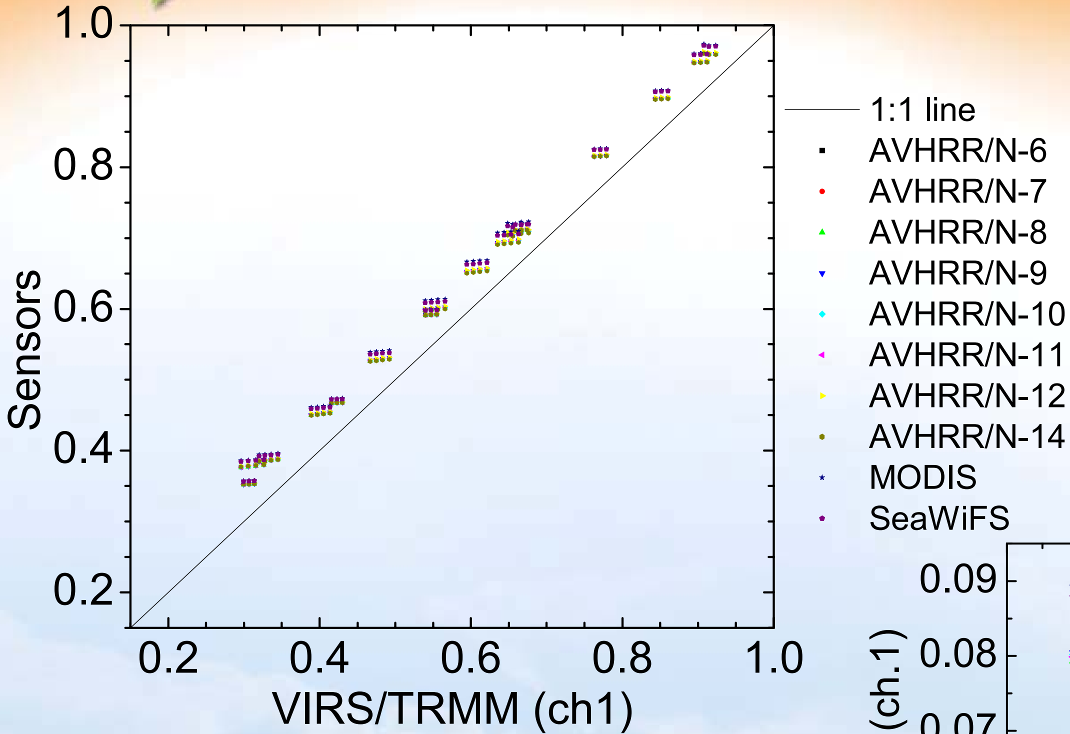
The major question: Is this target stable?

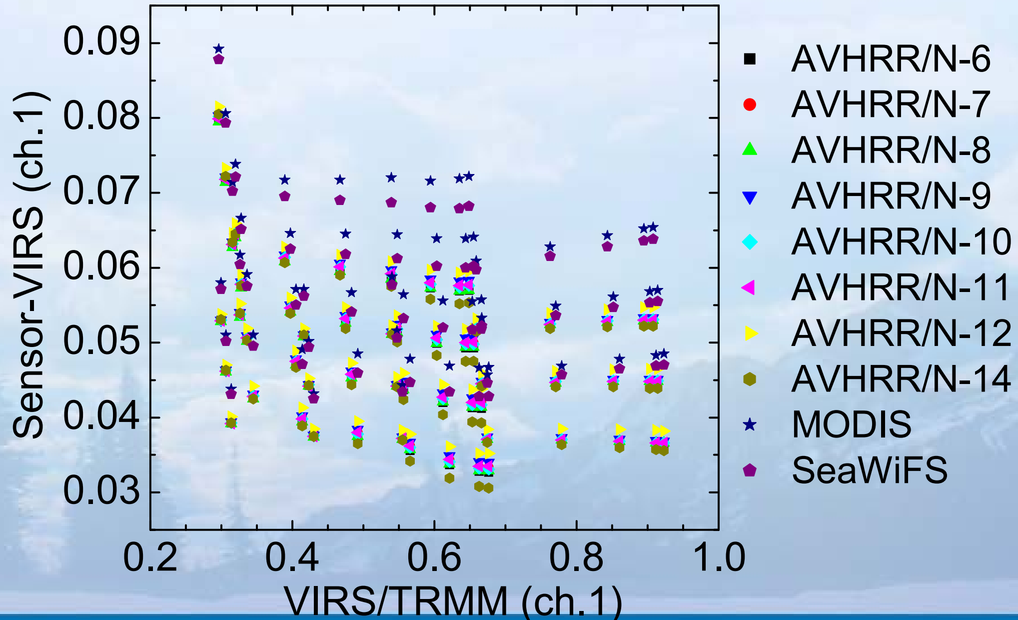
# Channel 1 (red)



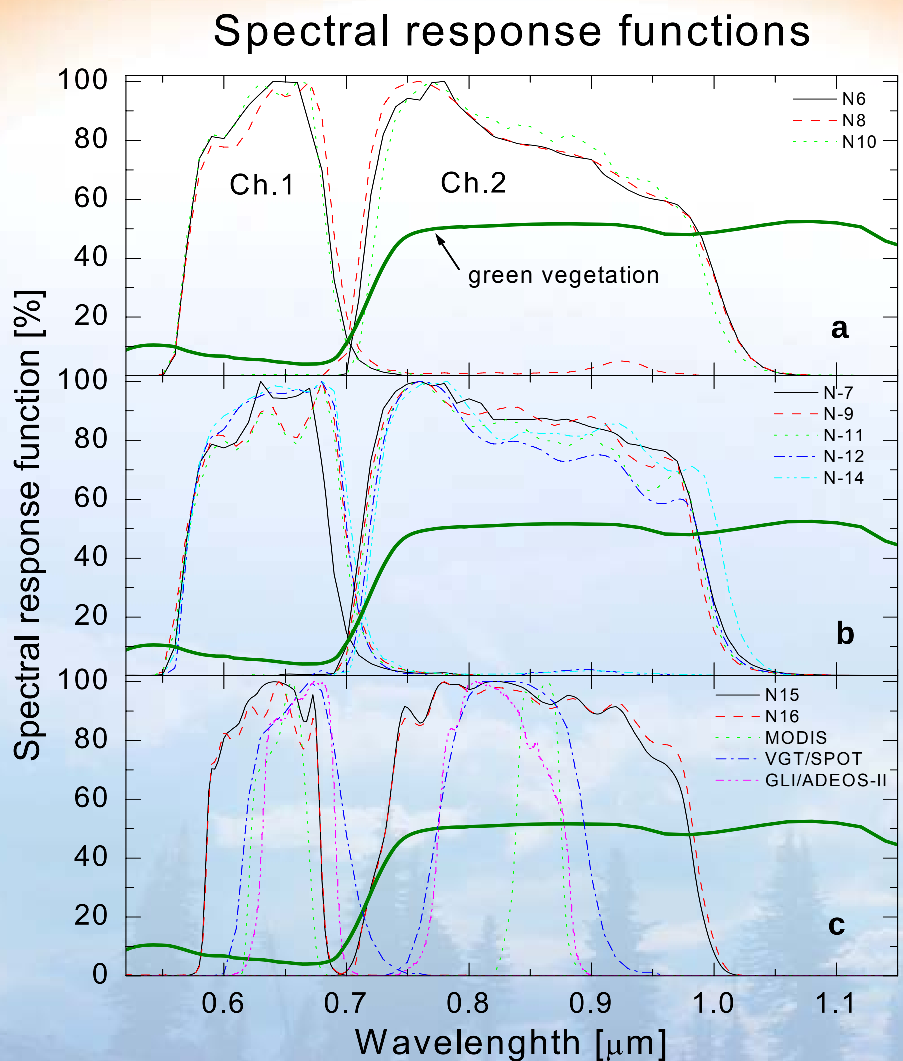



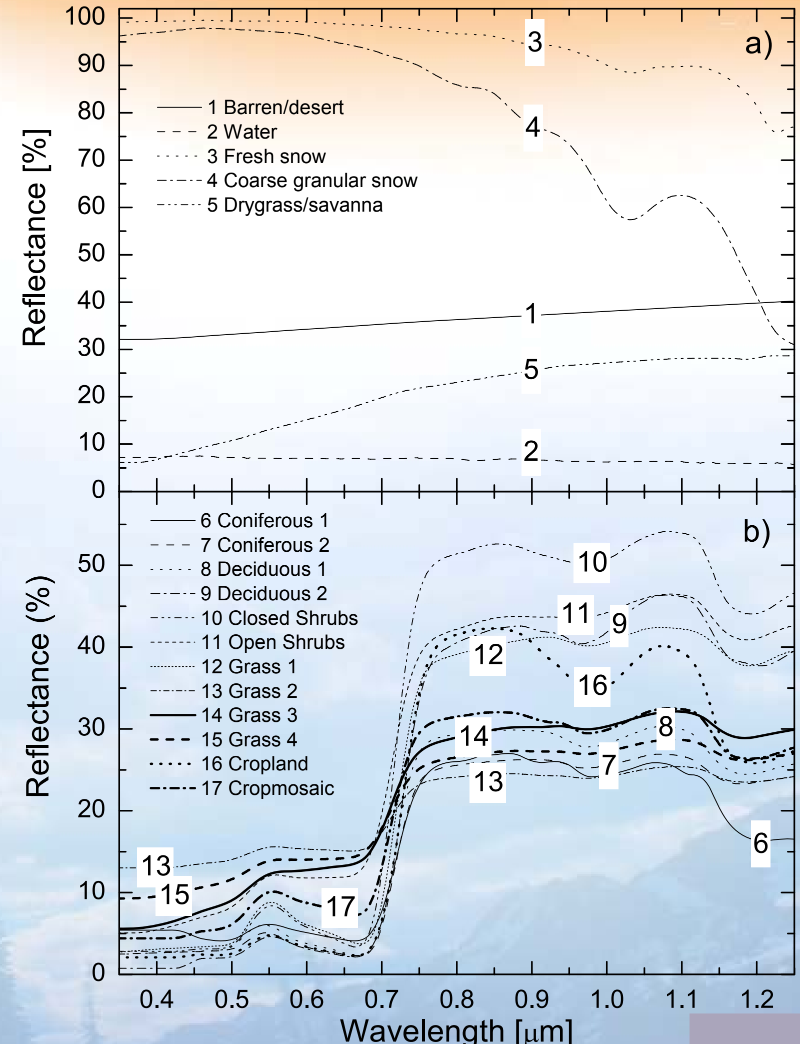
# Ch. 2 (NIR) vs VIRS ch1



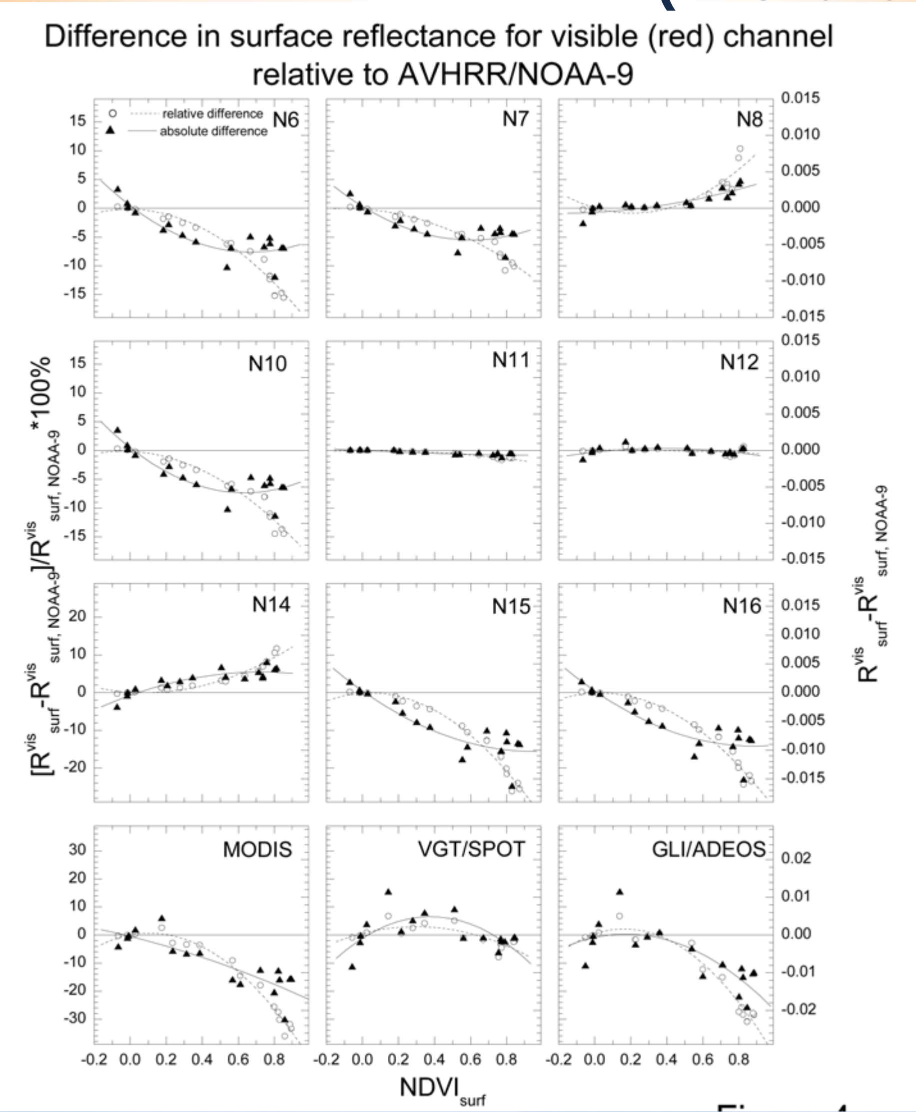
# Spectral correction surface refl / NDVI

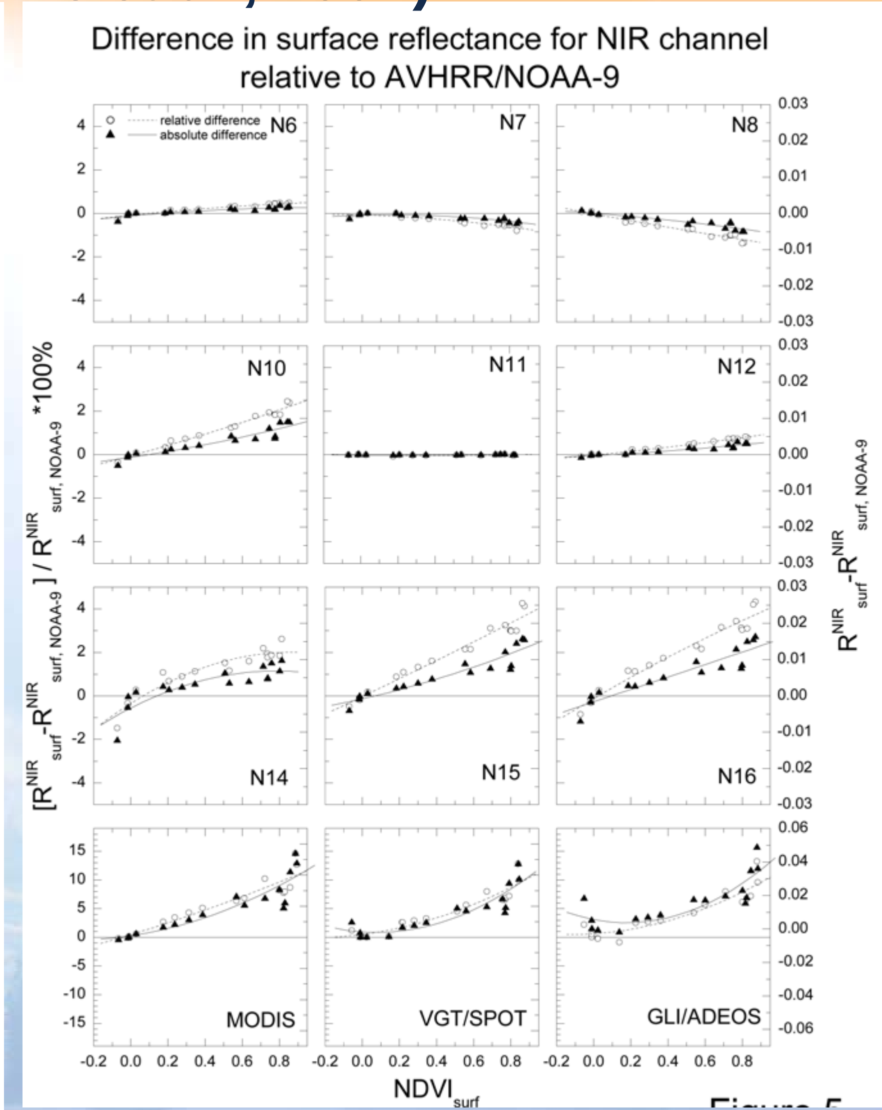


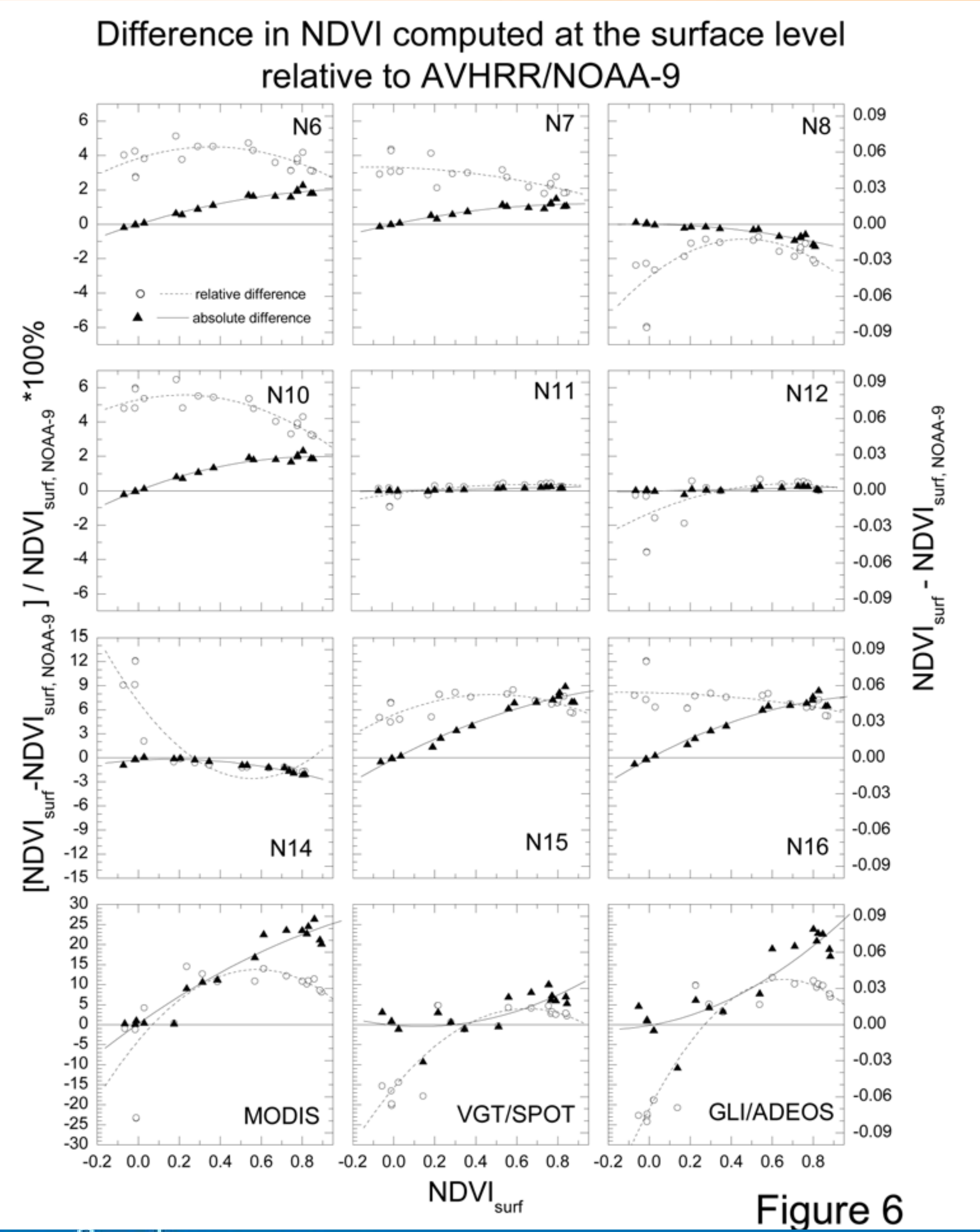

Trishchenko et al., *Rem. Sens. Environ*, 2002

# MODIS-AVHRR spectral adjustment of reflectances (Trishchenko et al., 2002)



# MODIS-AVHRR spectral adjustment



# Solar spectrum

AVHRR - *Neckel and Labs* (1984)
MODIS - combination of *Thuillier et al*. (0.4-0.8 μm),
and *N&L* (0.8-1.1 μm)
VIRS/TRMM - Wehrli, WMO, 1985
SeawWiFS - *Thuillier et. al.*

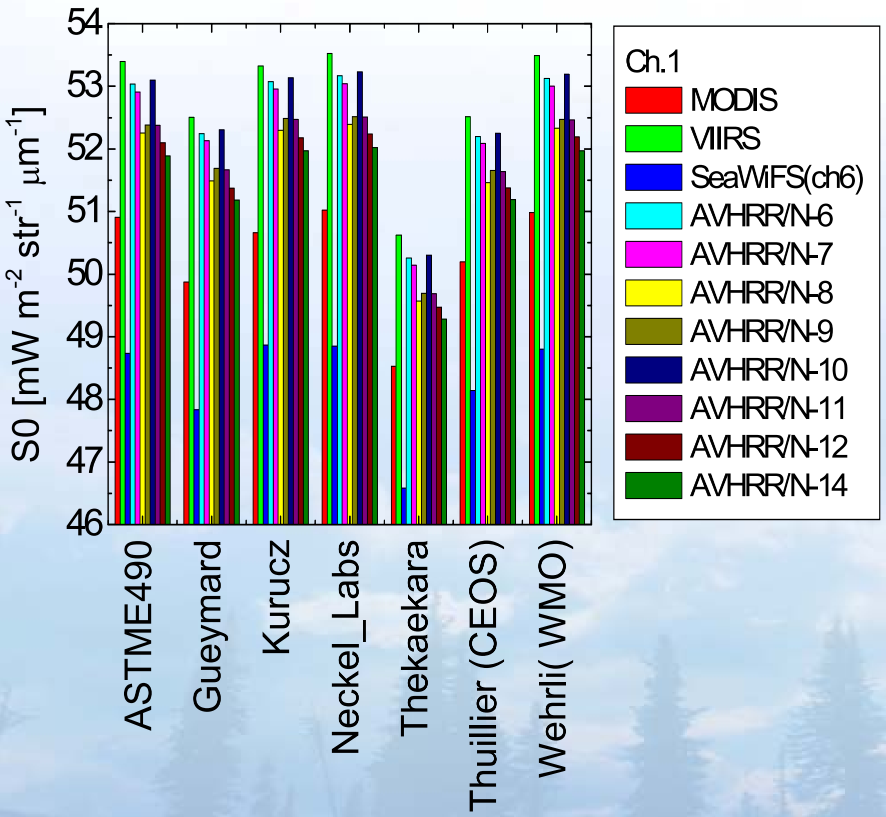
Other popular spectra are Kurucz (Modtran), ASTM (2000), Gueymard (2004)

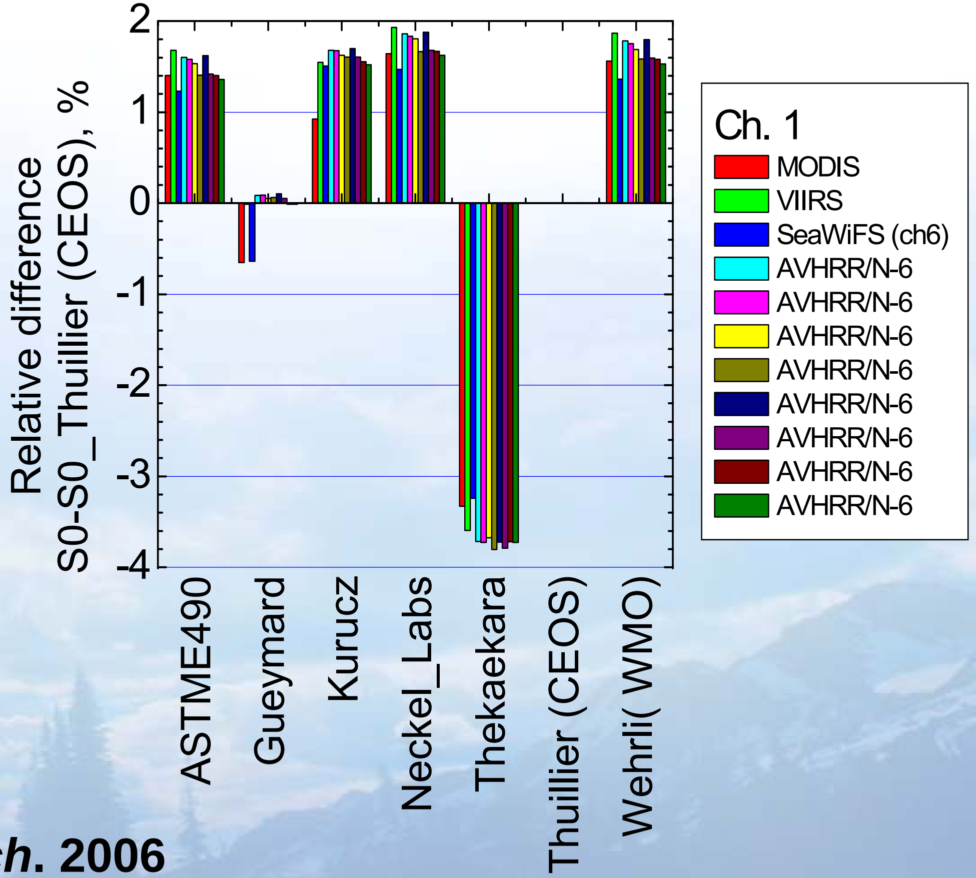
CEOS recommended the spectrum of *Thuillier et. al. 2002*

New spectrum has been discussed and proposed recently *(P.Pilewskie, J. Harder and J. M. Fontenla, 2006)*

**Differences in solar spectrum used for processing data from different sensors may bias or contaminate climate change signal**

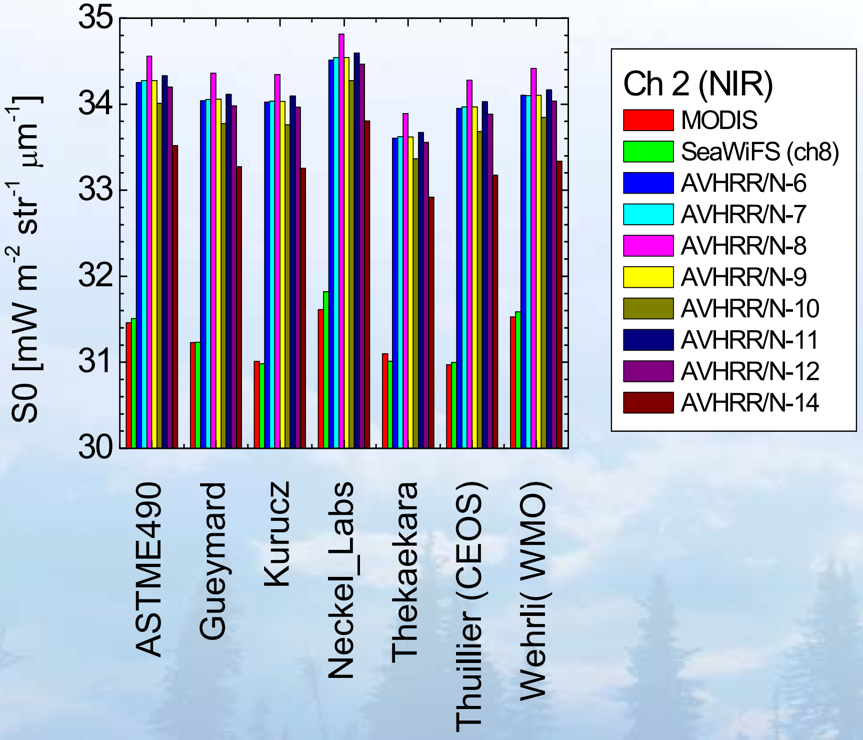
# Differences in solar constants for channel 1 (red)

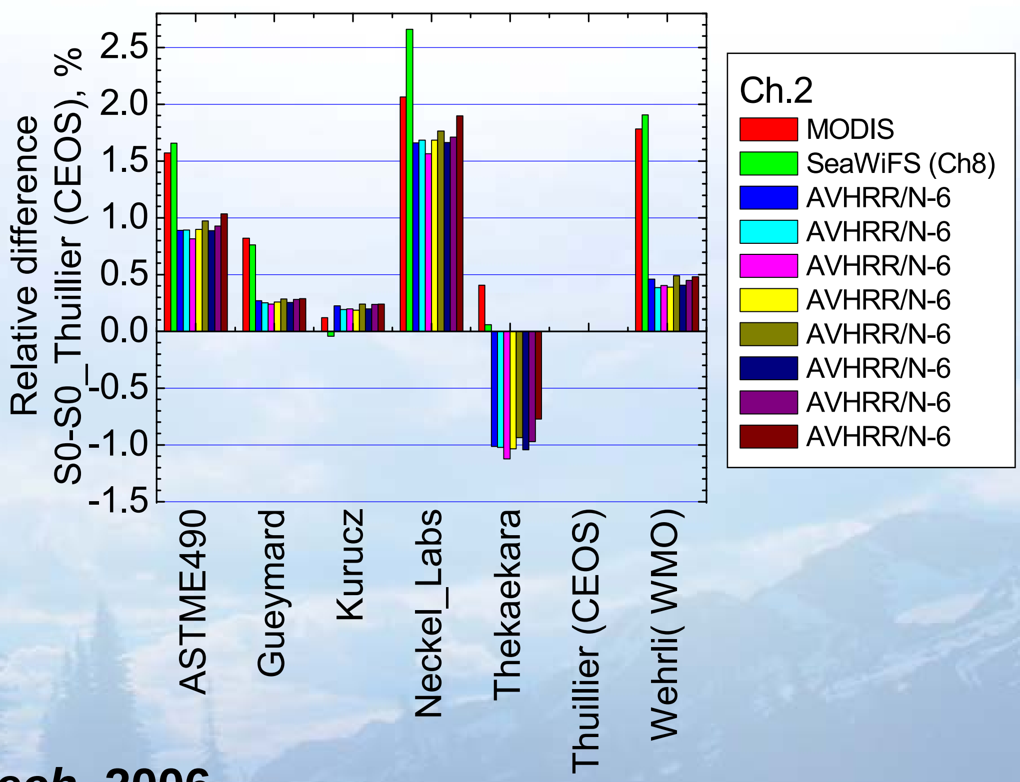



**Trishchenko. *JTech*. 2006**

# Differences in solar constants for channel 2 (NIR)




**Trishchenko. *JTech*. 2006**

# Highlights of the SPARC cloud detection algorithm

**( Separation of Pixels using Aggregated Rating over Canada )**

- For each AVHRR pixel, the output cloud map contains **effective cloud contamination index** in the range of 1 to 255 which helps choose the clearest pixel for scene compositing;
- **Snow mask** is generated for the cloud-free and thin-cloud pixels;
- **Cloud shadow** flag is generated as the additional bit in the mask;
- **Dynamic temperature threshold** based on the skin temperature from the North American Regional Reanalysis;
- Ch.3 reflectance histogram is analyzed **to avoid the data noise**;
- Dynamic **correction for the sun glint**;
- Different schemes are used for **land and ocean** pixels;
- Different algorithms are applied for the **daytime and nighttime**;
- Algorithm is designed to work for all **AVHRR/NOAA-6 to 18 and MODIS**;
- Parameters are tuned to **work most efficiently over Canada**.

**Khlopenkov and Trishchenko. *JTech*. In press. 2007**

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/Pages/ams/xjtech/131599/jtech1987







# SPARC: New Cloud, Snow, and Cloud Shadow Detection Scheme for Historical 1-km AVHRR Data over Canada

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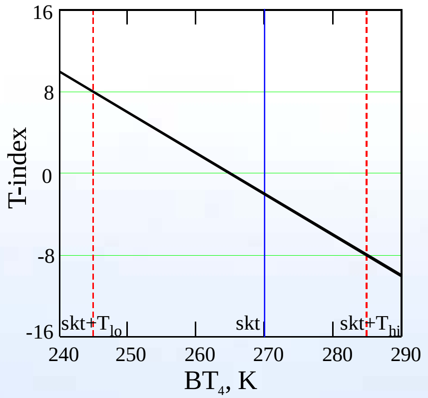
(Manuscript received 14 February 2006, in final form 10 July 2006)

ABSTRACT

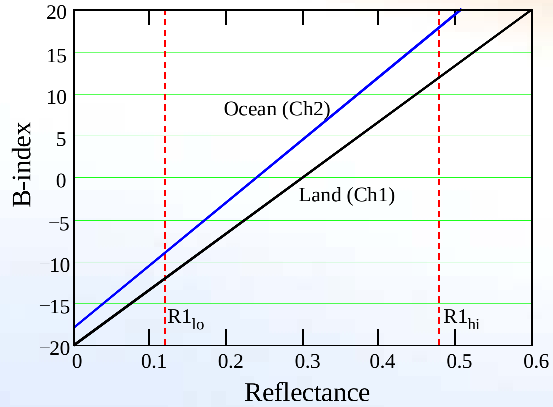
The identification of clear-sky and cloudy pixels is a key step in the processing of satellite observations. This is equally important for surface and cloud–atmosphere applications. In this paper, we present the Separation of Pixels Using Aggregated Rating over Canada (SPARC) algorithm, a new method of pixel identification for image data from the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA satellites. The SPARC algorithm separates image pixels into clear-sky and cloudy categories based on a specially designed rating scheme. A mask depicting snow/ice and cloud shadows is also generated. The SPARC algorithm has been designed to work year-round (day and night) over the temperate and polar regions of North America, for current and historical AVHRR/NOAA High-Resolution Picture Trans-

# Cloud tests

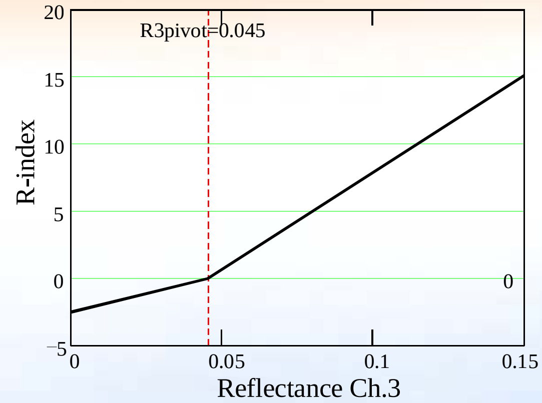
## Temperature test

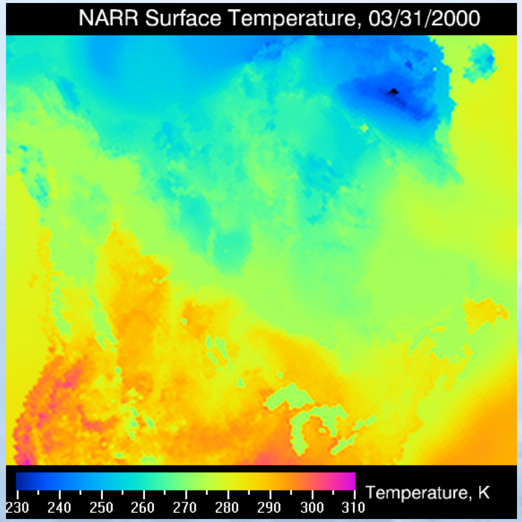



## Brightness test



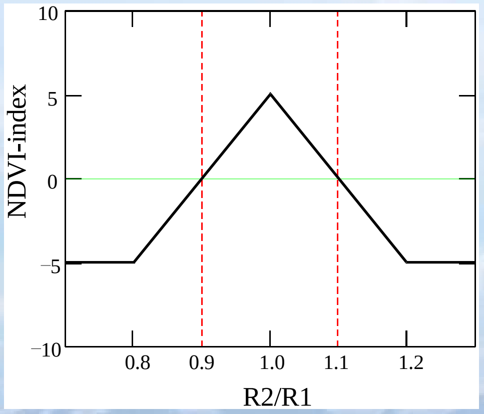

## Reflectance Ch.3 test




**Skin temperature map of Canada built from Regional Reanalysis data.**

## NDVI test

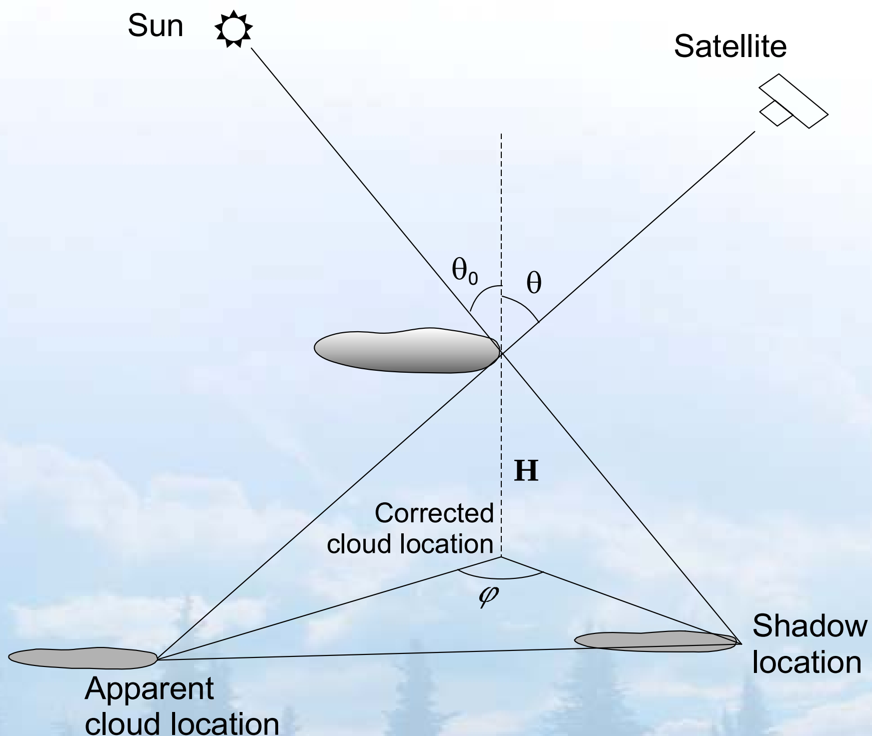


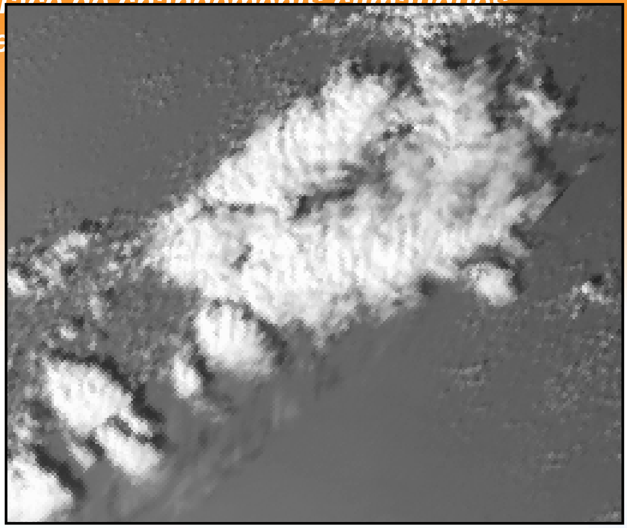

## Basic principle:

$$F = T + B + R + N$$

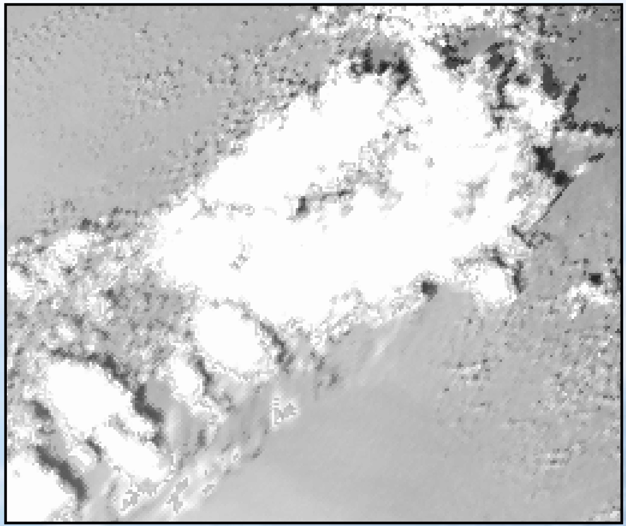
- **Flexibility**
- **Variable weights**
- **Scalability**

# Cloud shadow detection



**AVHRR channel 1 reflectance**

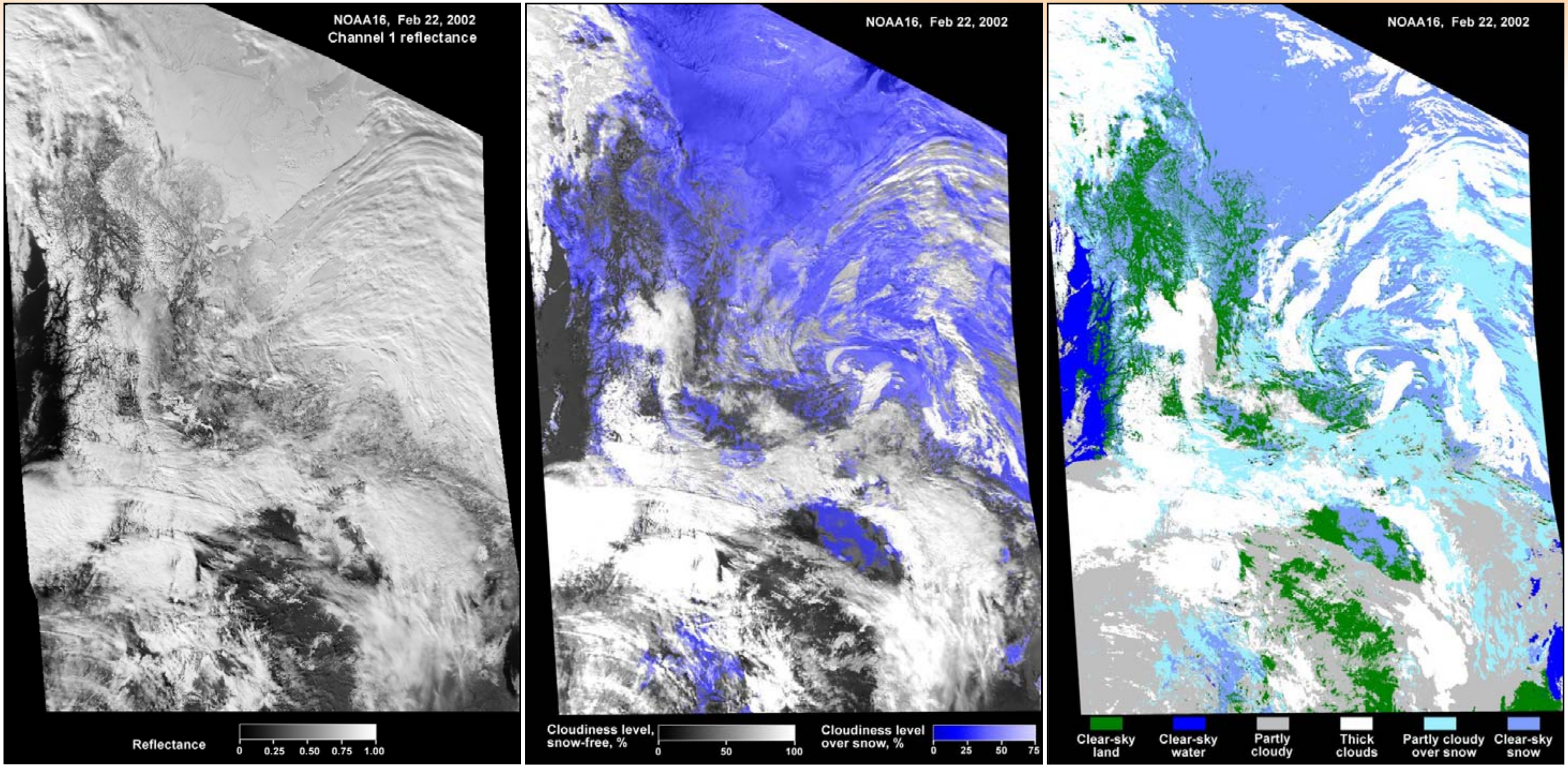


**Cloud and shadow mask**

Cloud shadows are also important. Depending on satellite overpass time, season and cloud properties, they may occupy up to 10% of the area. Unlike MODIS spectral approach, CCRS SPARC algorithm uses cloud shadow identification using geometrical method

**Khlopenkov and Trishchenko. *JTech*. In press. 2007**

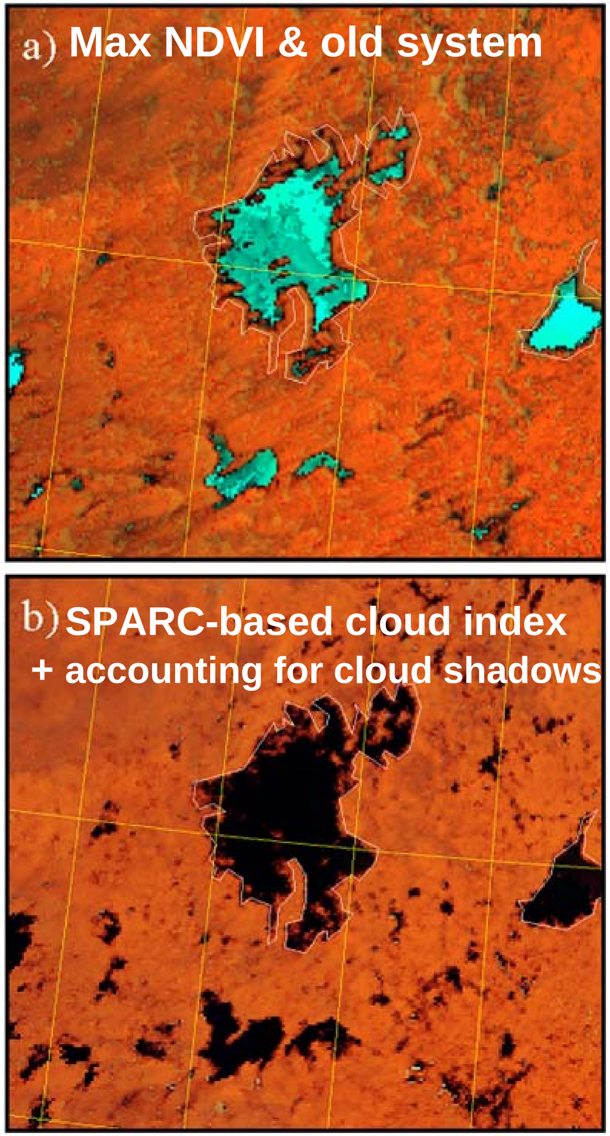
# Comparison with supervised classification

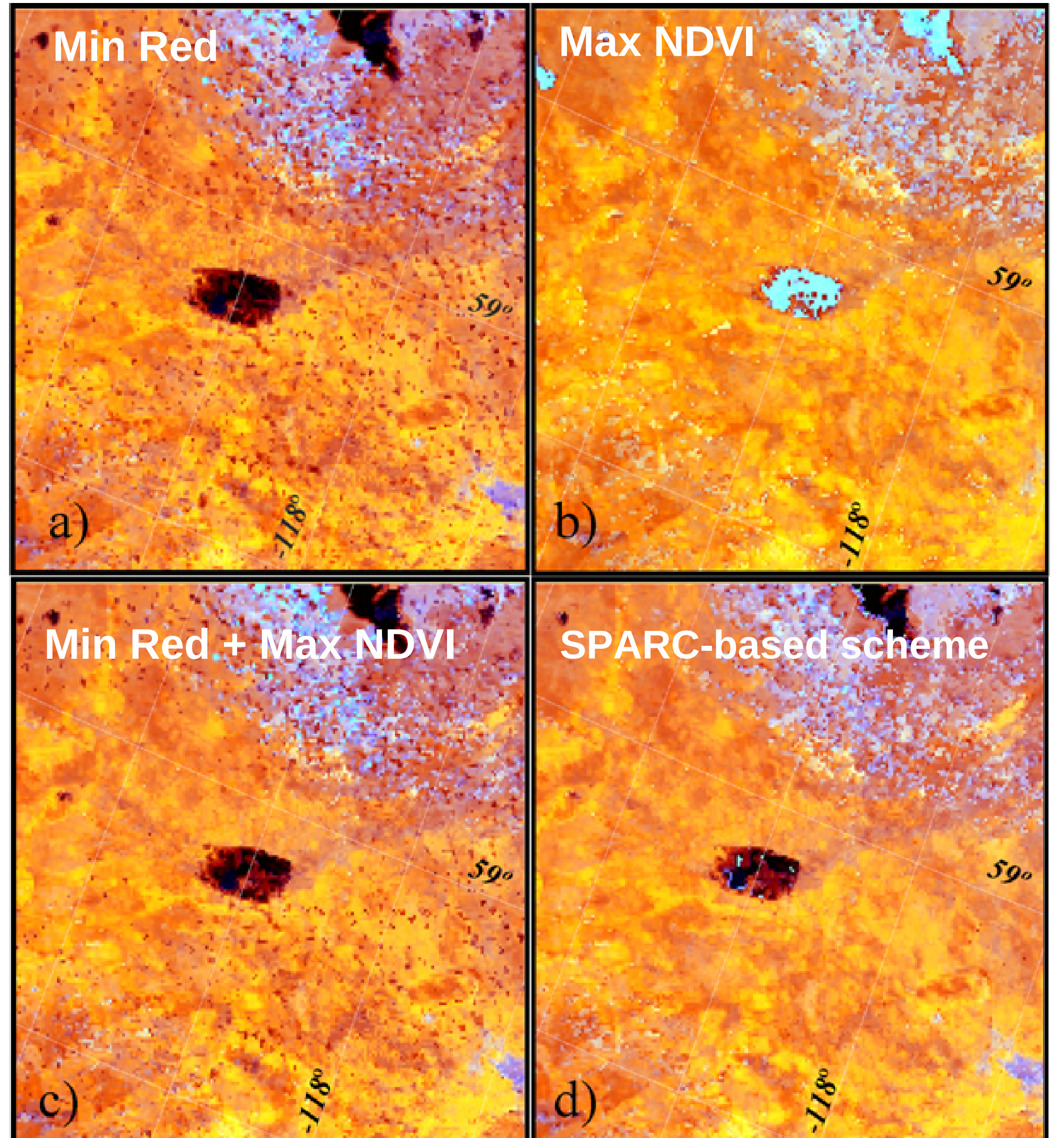



AVHRR Channel 1 reflectance | Automated algorithm (SPARC) | Supervised classification using Maximum Likelihood Classifier

**The agreement MLC routine is 89%–91% in summer and 84%–88% for winter scenes**
**Khlopenkov and Trishchenko. *JTech*. In press. 2007**

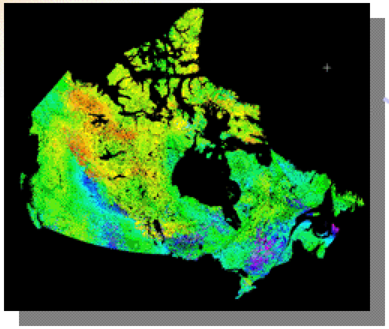
# Clear-sky compositing



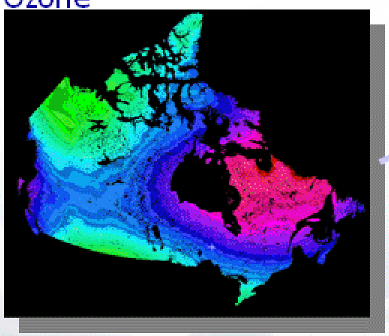



# Atmospheric correction

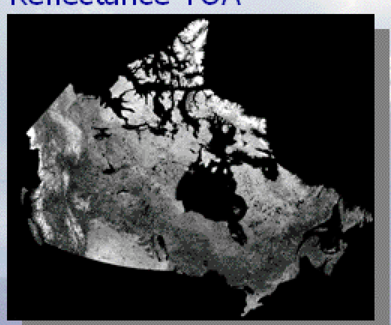
Water vapour



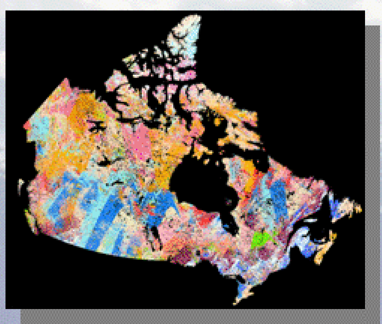
Ozone



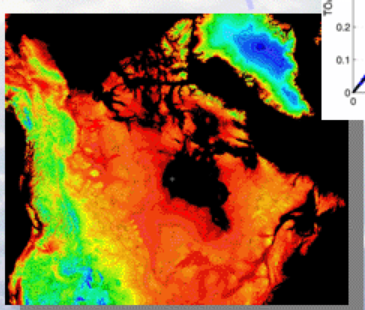
Reflectance TOA



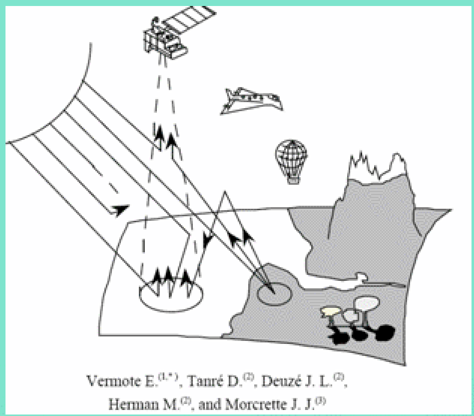
Viewing geometry(SZ.VZ,AZ)



Topography

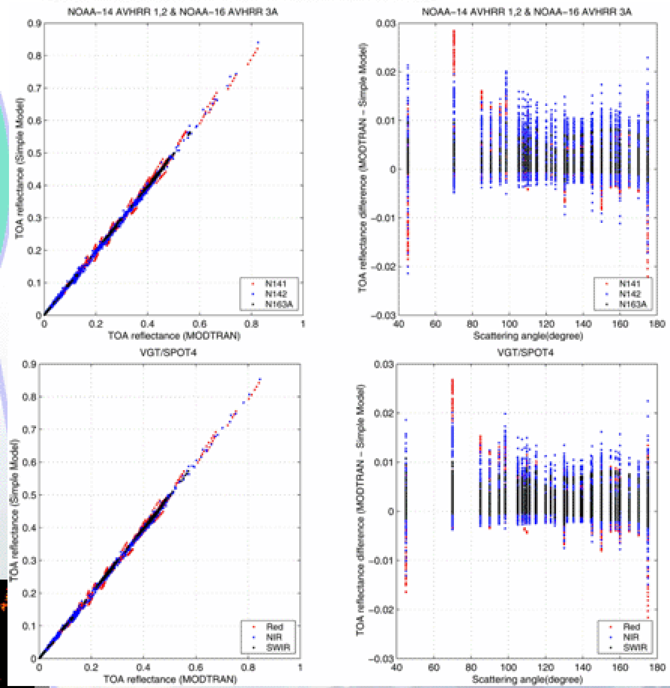


## Atmosphere Model




**Semi-analytical scheme tuned to MODTRAN-4**

$$\rho_{TOA} = T_g * [\ \rho_{R+A} + T(\theta_s)*T(\theta_v)*\rho_s / (1- S*\rho_s)\ ]$$




Sensor characteristics

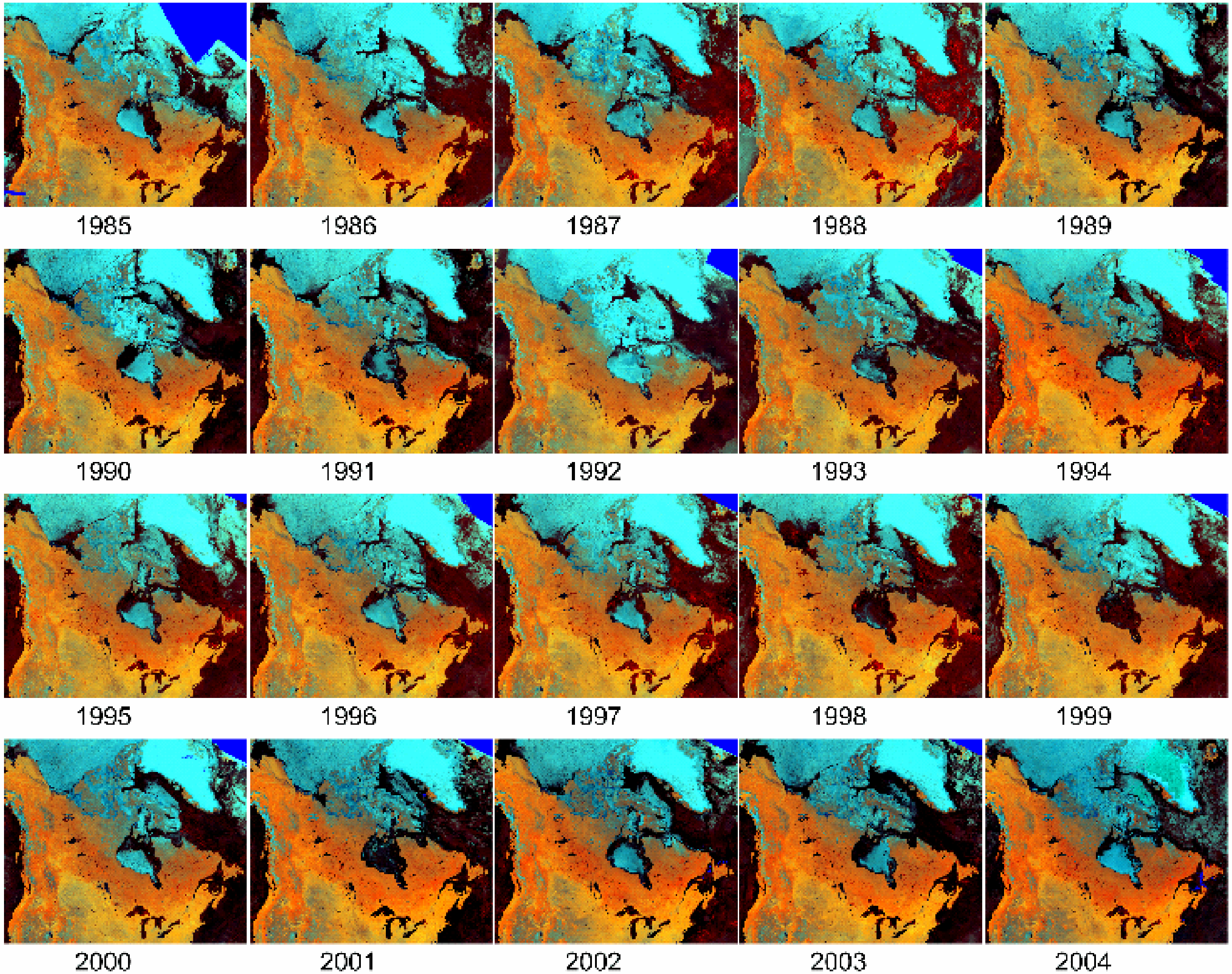
Trishchenko et al., 2002

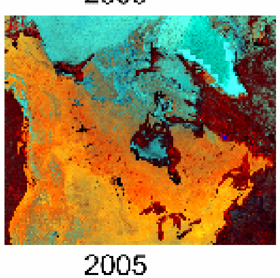
# Atmospheric correction: Aerosol

Aerosol is still an issue …

Especially for historical data before MODIS/MISR time, as there is no reliable source of tropospheric aerosol properties over land.

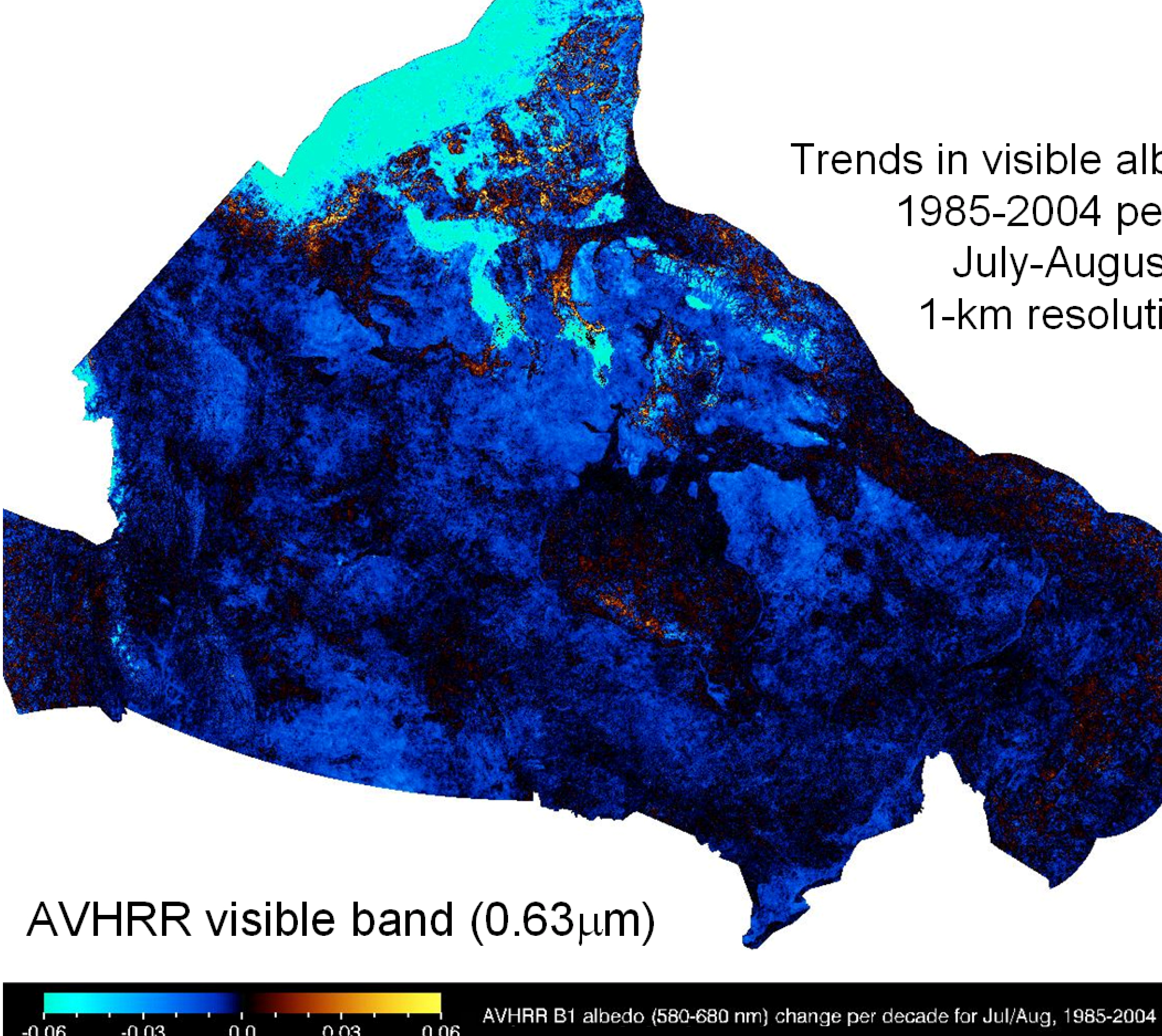
Stratospheric aerosol can be taken from SAGE




21 years of AVHRR/NOAA over Canada, June
Latifovic et al., 2006 (CCRS)

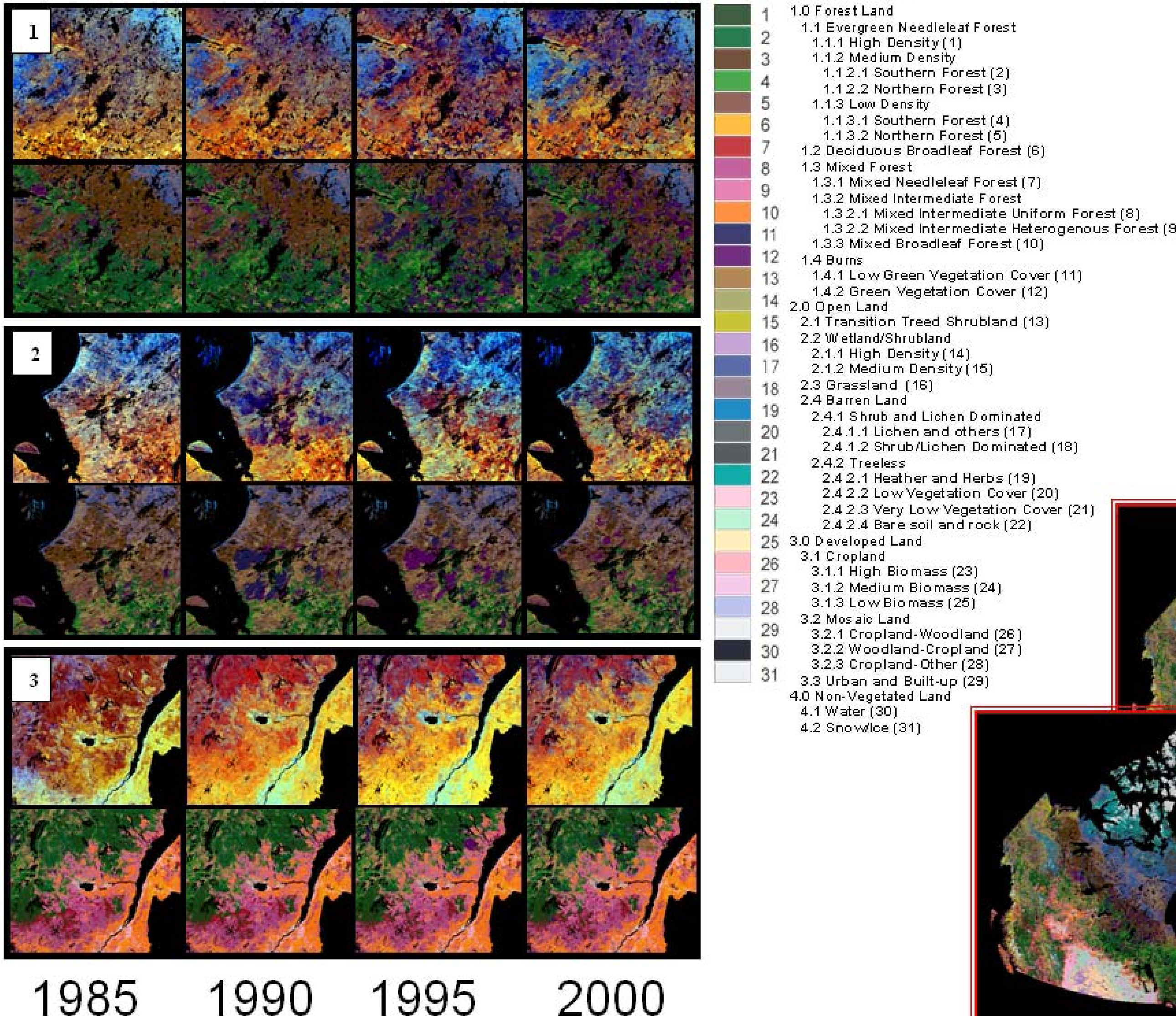
Trends in visible albedo over
1985-2004 period
July-August
1-km resolution

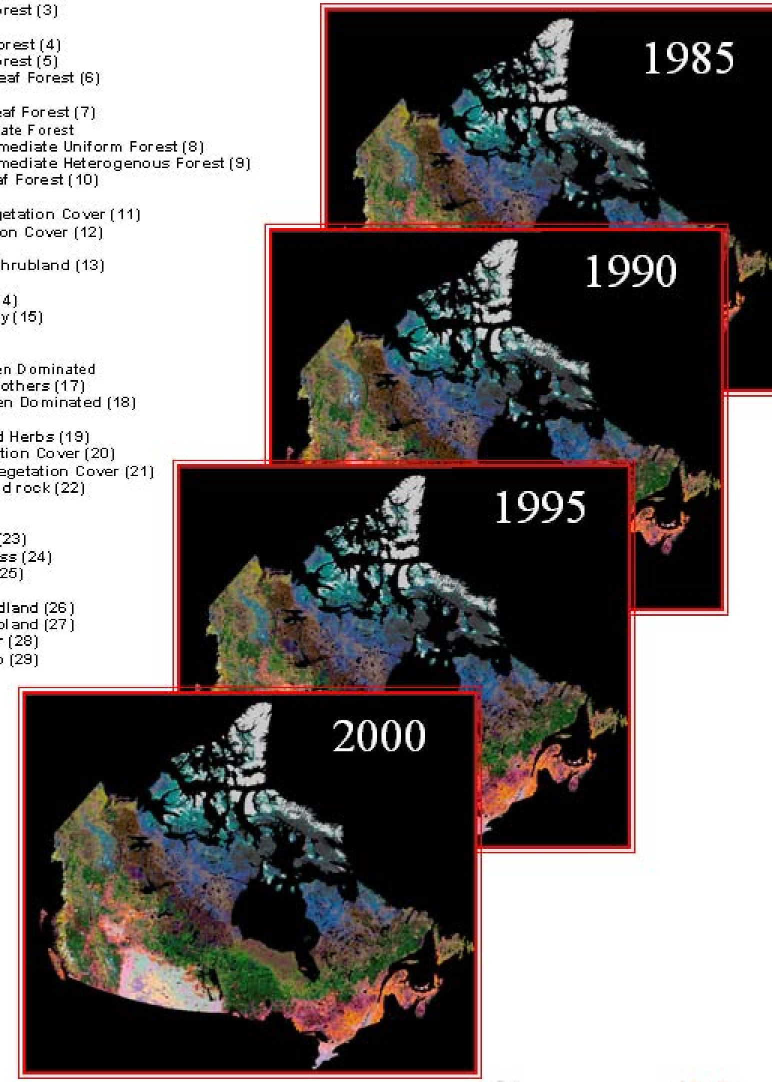



AVHRR visible band (0.63μm)

Canada

# Temporal land cover mapping and change detection

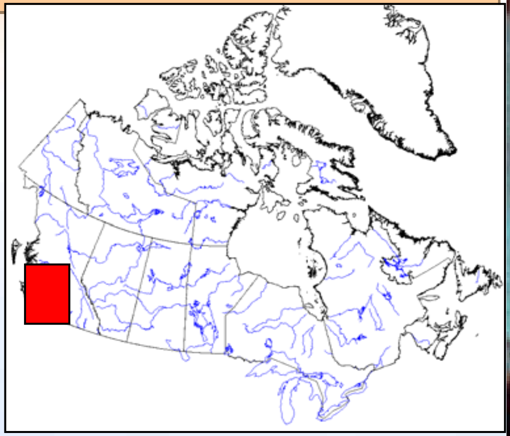


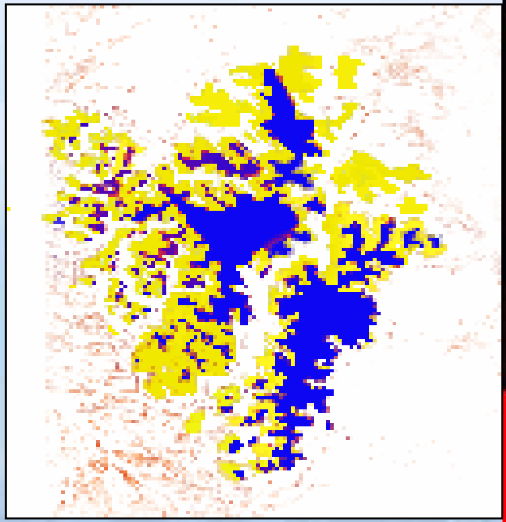



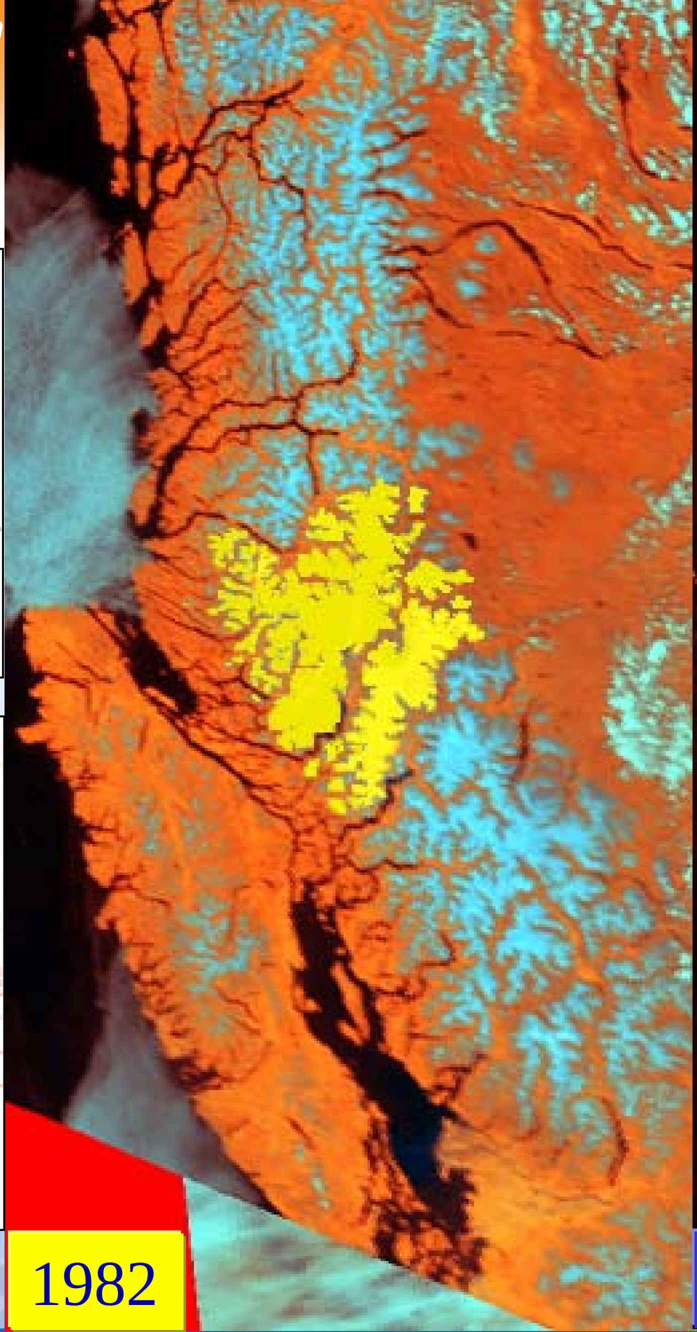

R. Latifovic and D.Pouliot, CJRS, Vol.31(5), 347-363, 2005

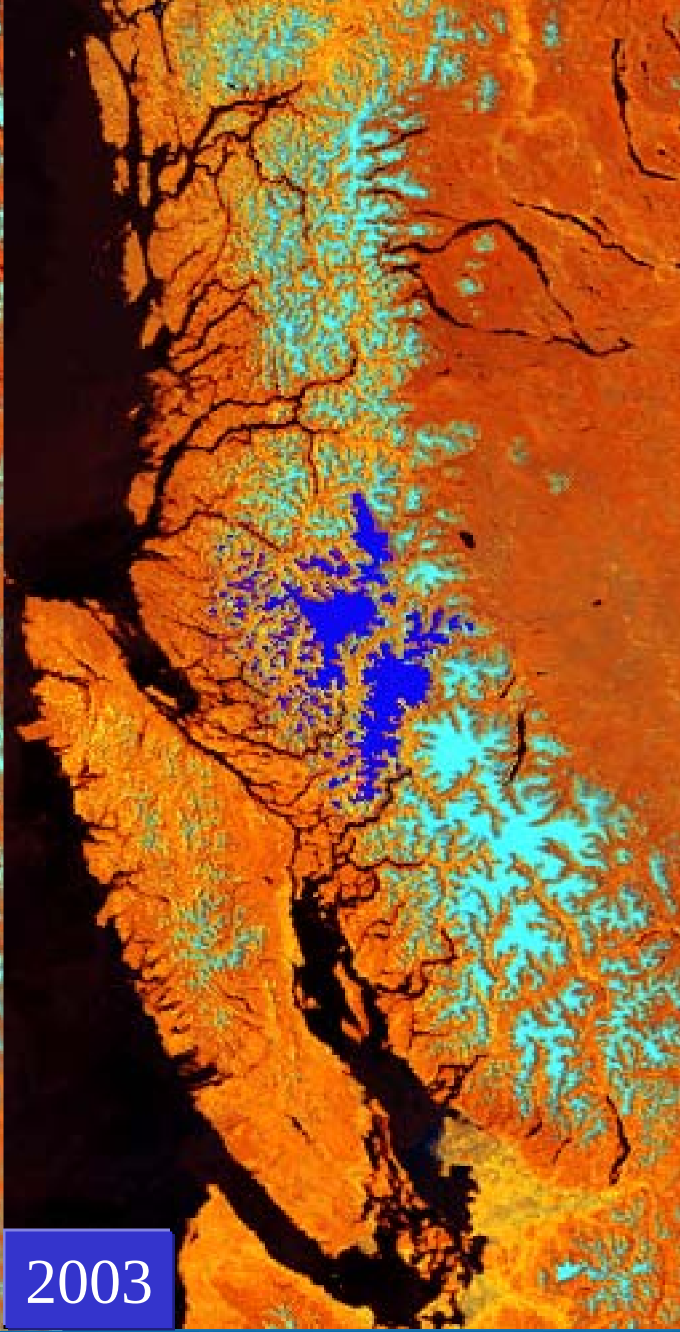
Canada

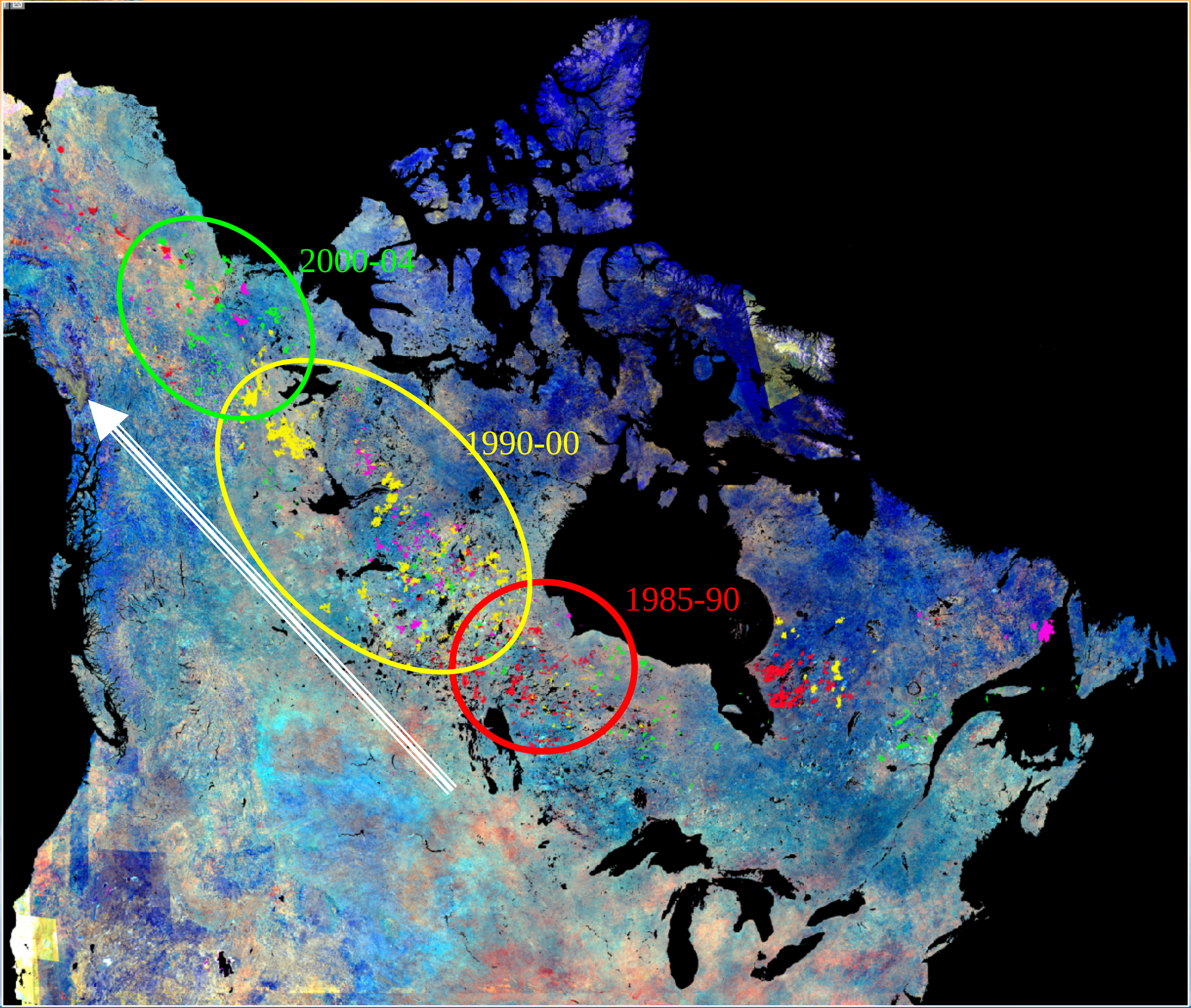
# Melting glaciers (Late summer)









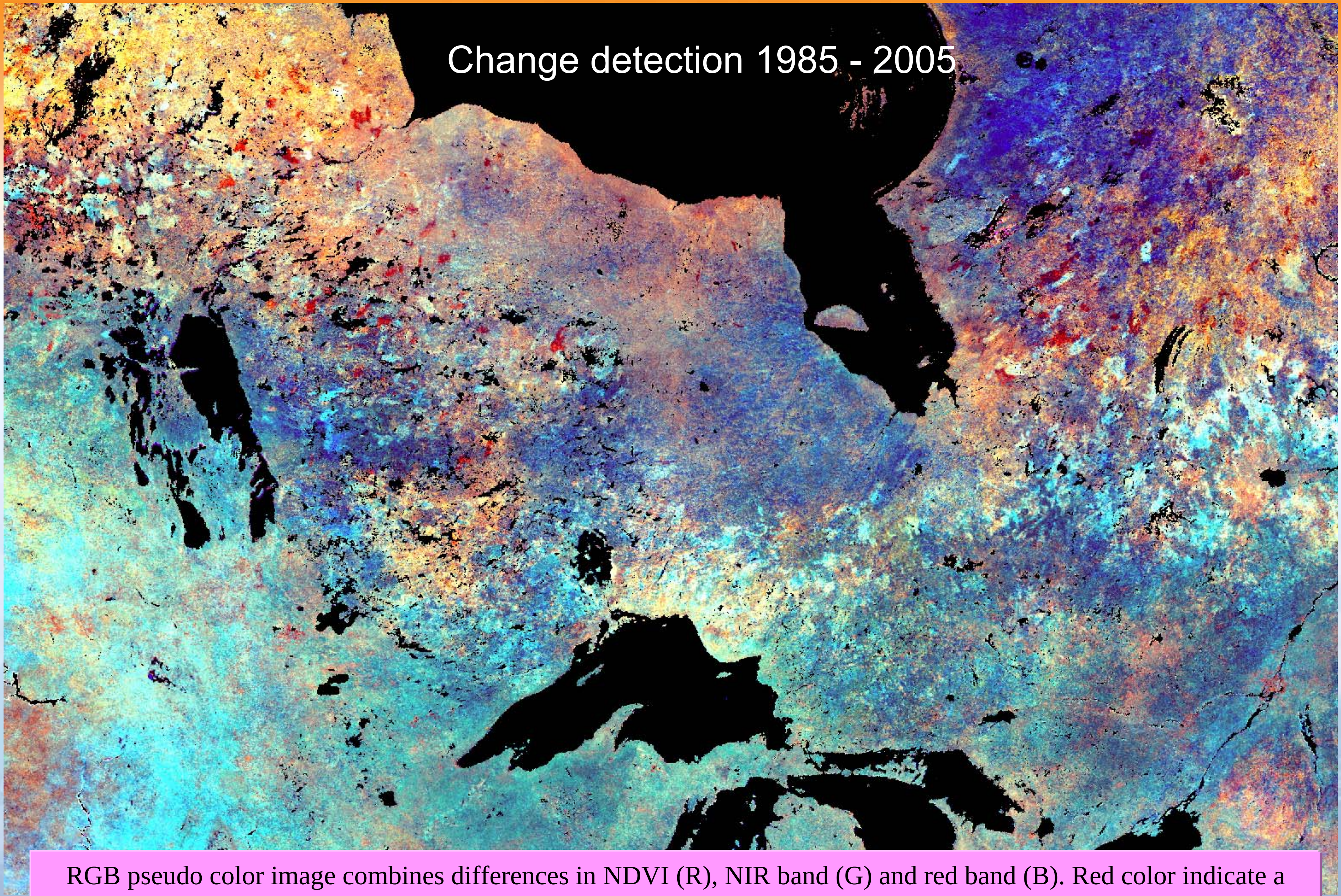

Boreal forest fire spatial and temporal pattern from AVHRR 1985-2004

| | |
|---|---|
| (red) | 1985-90 |
| (yellow) | 1990-95 |
| (pink) | 1995-00 |
| (green) | 2000-04 |

Cycles present areas with more frequent fire occurrence during the time step.

**Source: R.Latifovic**

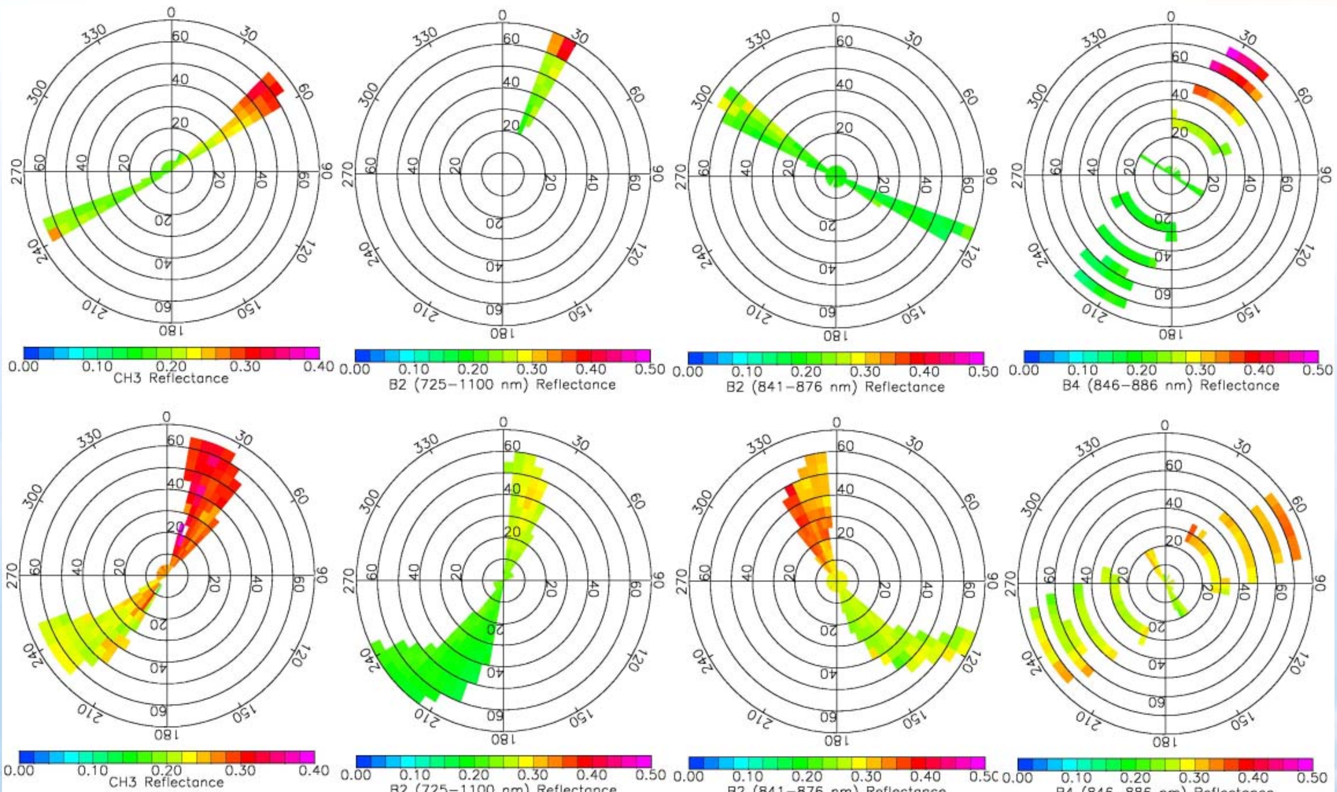
# Change detection 1985 - 2005



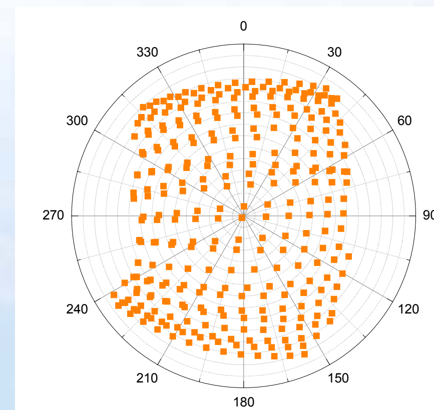
RGB pseudo color image combines differences in NDVI (R), NIR band (G) and red band (B). Red color indicate a decrease in vegetation greenness while blue an increase. **Source: R.Latifovic**

# Angular sampling & BRDF

**VGT** **AVHRR** **MODIS** **MISR**

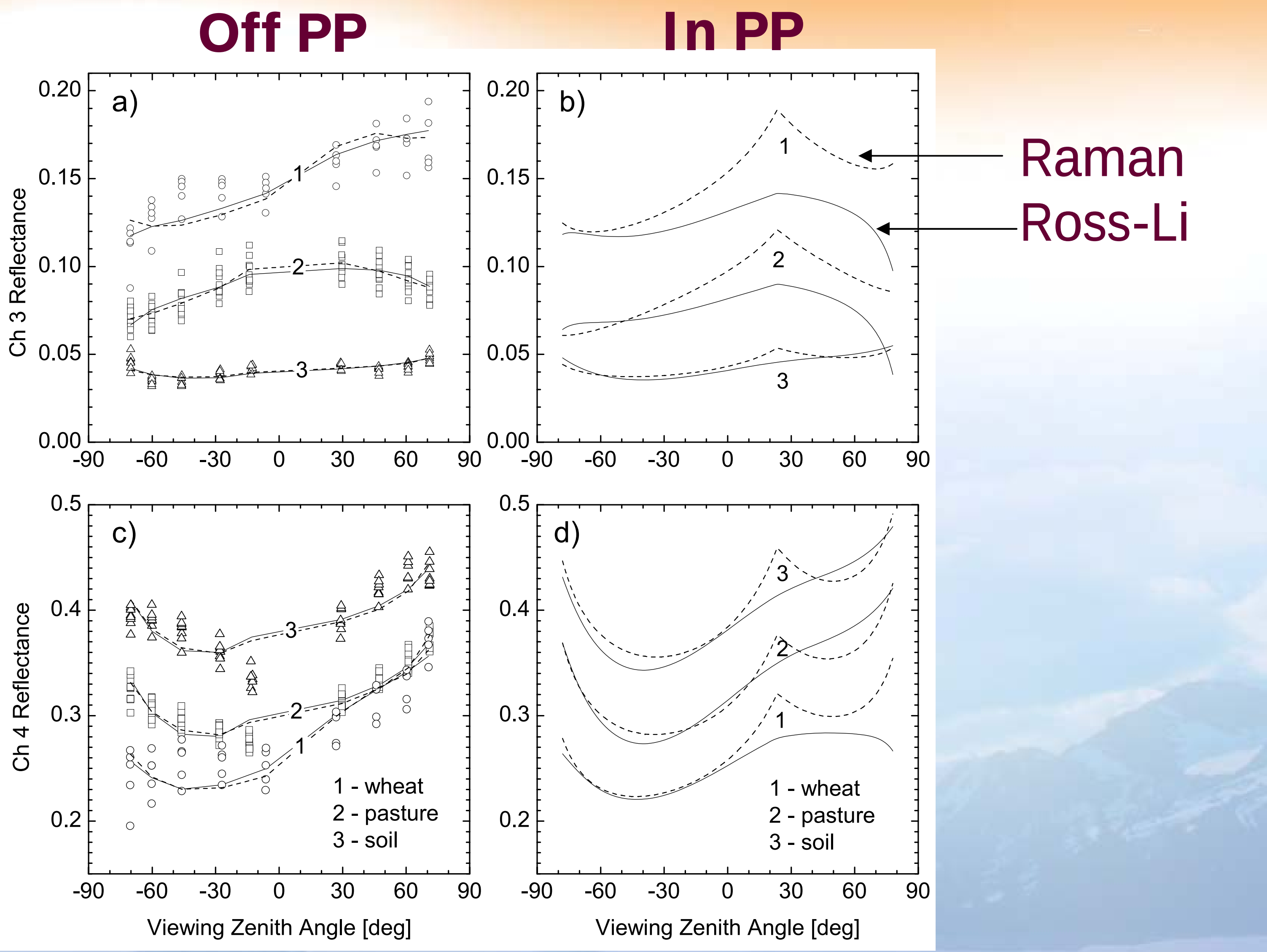



**POLDER**




Trishchenko, 2004. *SPIE, 5549, 97-108*

# Issues in BRDF retrievals



# Summary about current BRDF capabilities

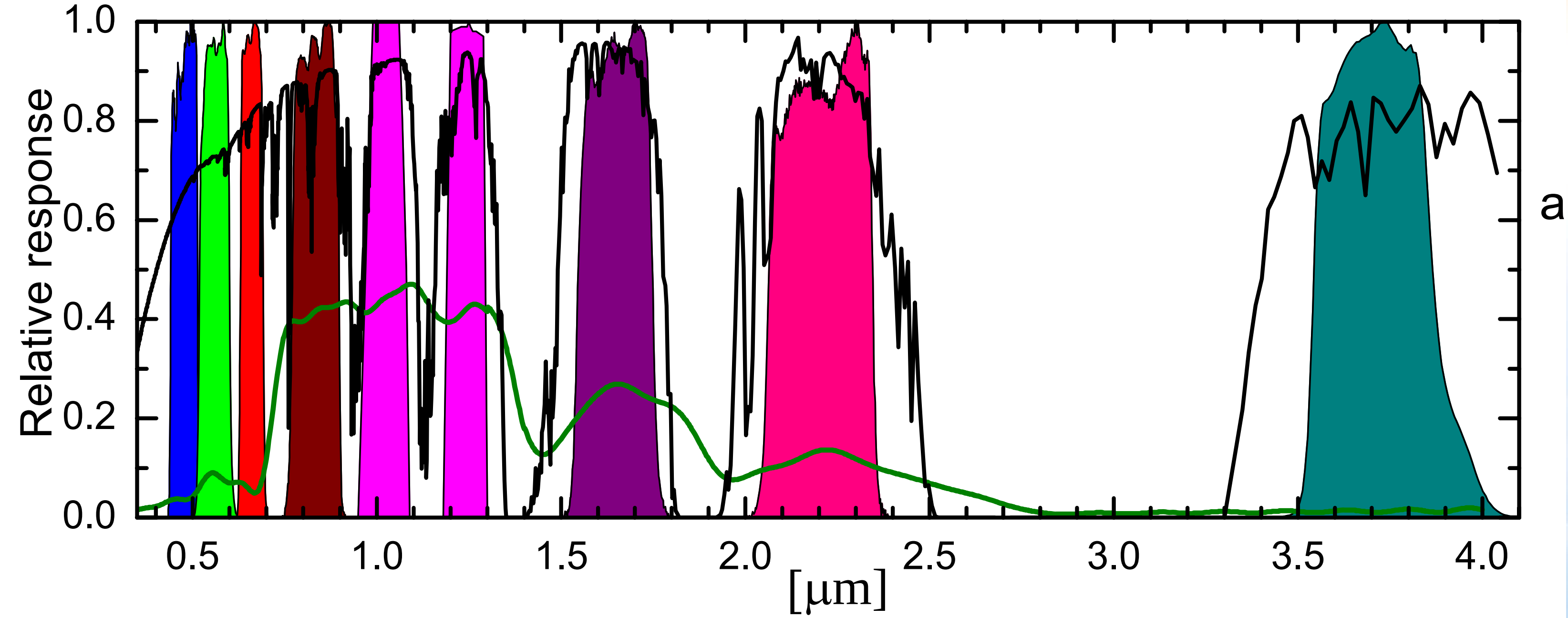
- **While existing satellite Earth Observing (EO) systems provide many baseline observations, they are lacking an important combination of capabilities in terms of angular sampling, spectral coverage, and spatial resolution**
- *None of these missions has the optimal combination of parameters* **to satisfy simultaneously the following four requirements:**
  1. Large swath to provide the capability for large-scale regional and global operational monitoring on a daily basis;
  2. Small enough pixel size to resolve the essential spatial features of the terrestrial ecosystems;
  3. Spectral coverage in the entire solar spectrum range and TIR to satisfy most land and ocean applications;
  4. Multiangular observations that cover the entire angular domain of VZA and RAA to retrieve surface BRDF with a good accuracy
- **I would propose a new mission -Advanced Multiangular MEdium Resolution System -** AMMERS **to address this gap**

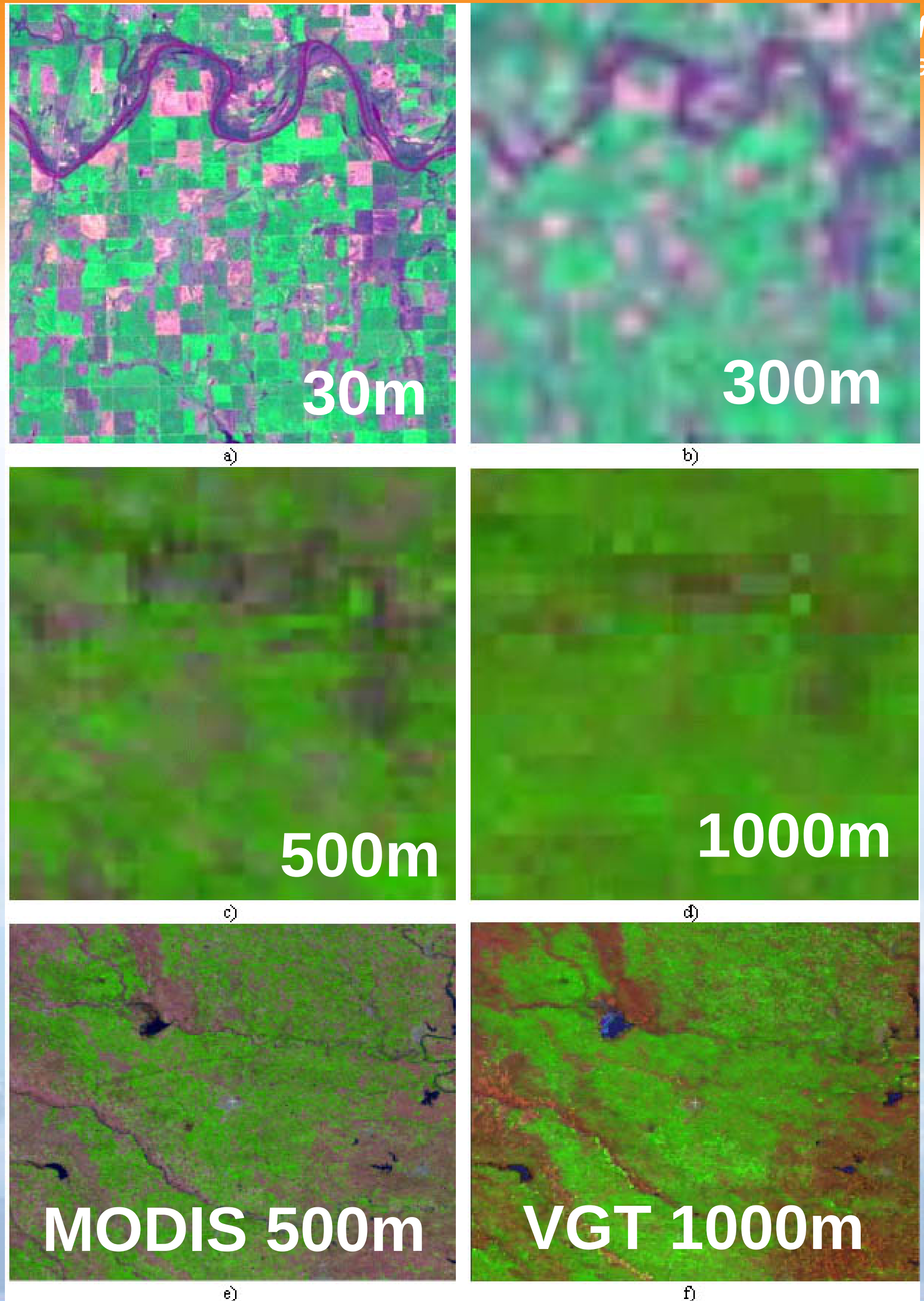
# Multiangular missions

| Parameter | POLDER | MISR | AATSR | ASTER* | SPECTRA | AMMERS |
|---|---|---|---|---|---|---|
| # Spectral bands, range | 9<br>443-910 nm | 4<br>443-865 nm | 7<br>0.550-12 μm | 14<br>VNIR, SWIR, TIR | 60 chs (10nm) in VIS, NIR, SWIR and 2 chs in TIR | 10-15<br>0.44-12 μm; SW, LW |
| Pixel size | $6x7km^2$ | 275m/ 1.1km | 1-2 km | 15-90m | 50m | 200-300m |
| # Angles | 14 | 9 | 2 | 2 | 7 | 7 |
| Swath/Max angle Crosstrack | 2400 km/ $51^0$ | 360km | 512km/2 $3.5^0$ | $60x60km^2$ scenes | $50x50km^2$ scenes | 2000km/ $45^0$ |
| Max angle Along track | $43^0$ | $70.5^O$ | $47^O$ | $27.6^O$ | up to $70^O$ | $48^0$ |
| Principal plane | YES | NO | NO | NO | YES | YES |
| Encoding, bits | 12 | 12 | 12 | 8-12 | - | 12 |
| Global coverage, days | 1 | 8 | 3-4 | NO, Selected scenes | NO, selected scenes | 1-2 |
| Data rate, Mbit/sec | 0.86 | 9 (peak)<br>3.3 (average) | 0.63 | 69 (day)<br>4.2 (night) | 8.5 GBit/orbit | Upper limit<br>33 (day)<br>12 (night)<br>23 (average) |

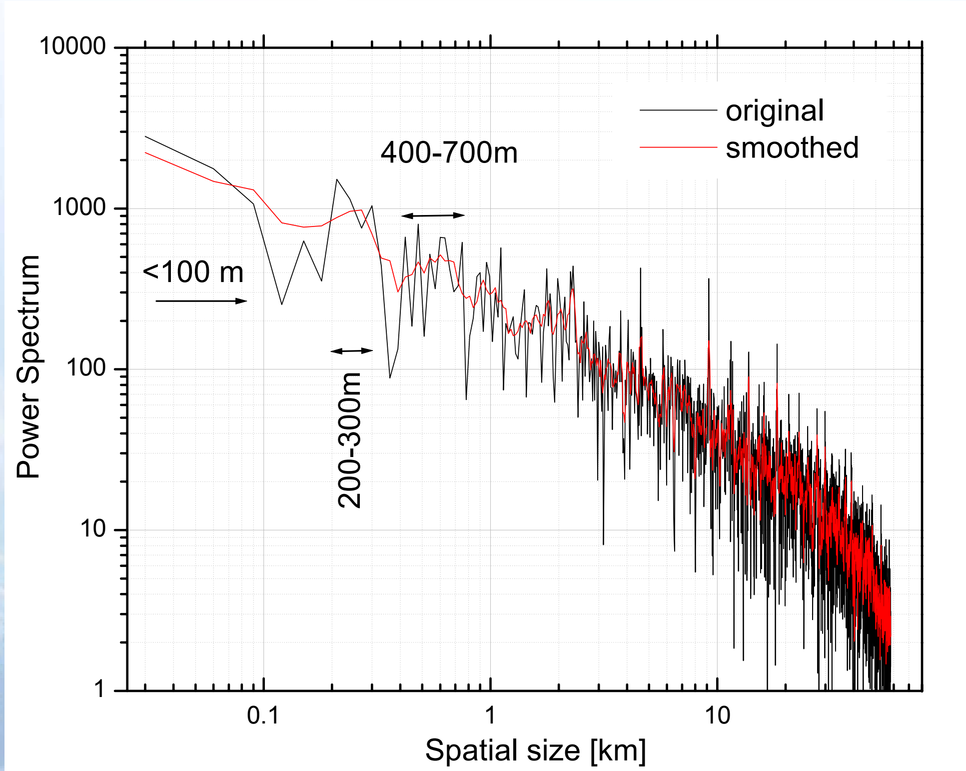
* - limited stereoscopic capabilities

# Spectral channels for AMMERS

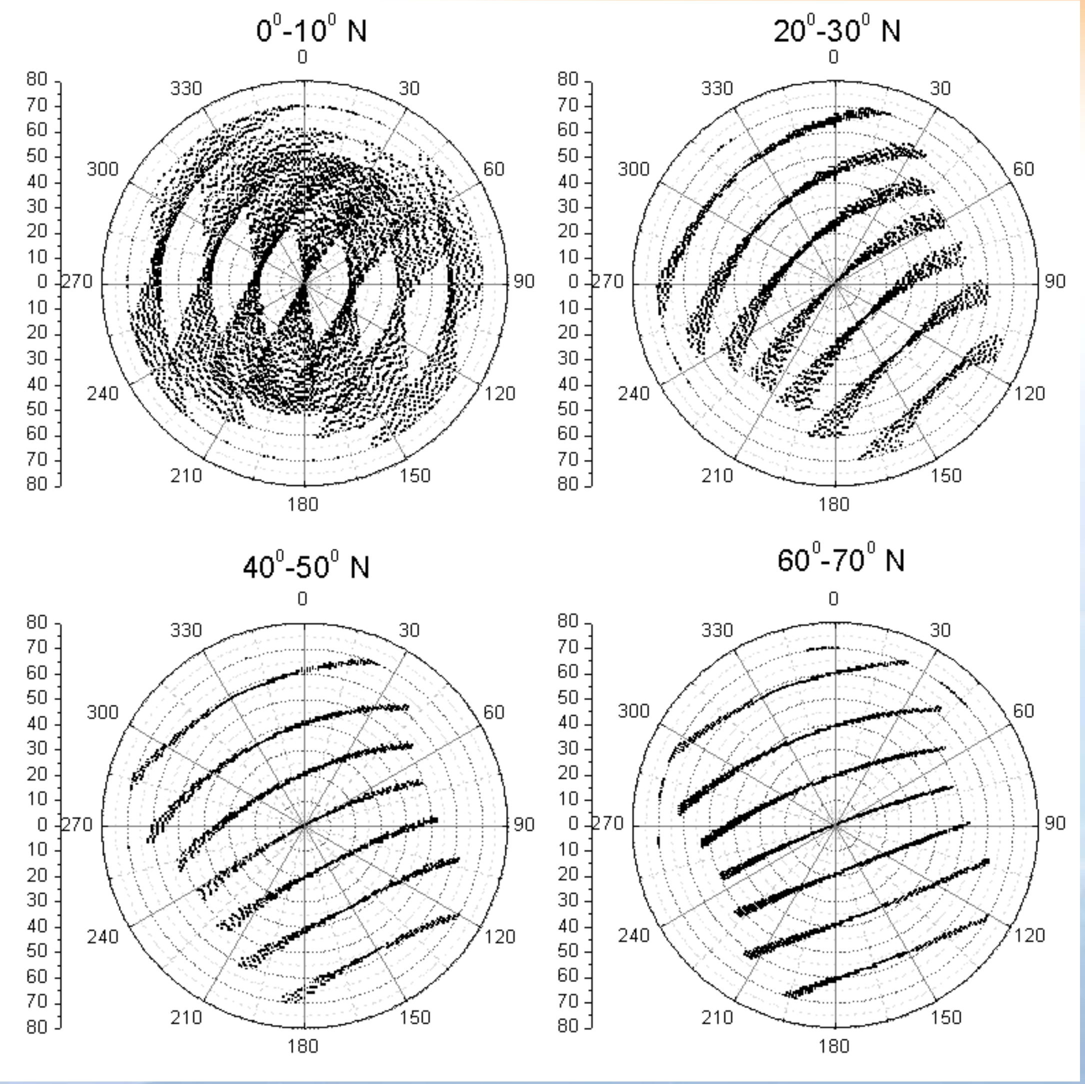





# Spatial resolution



# Example of angular sampling for AMMERS



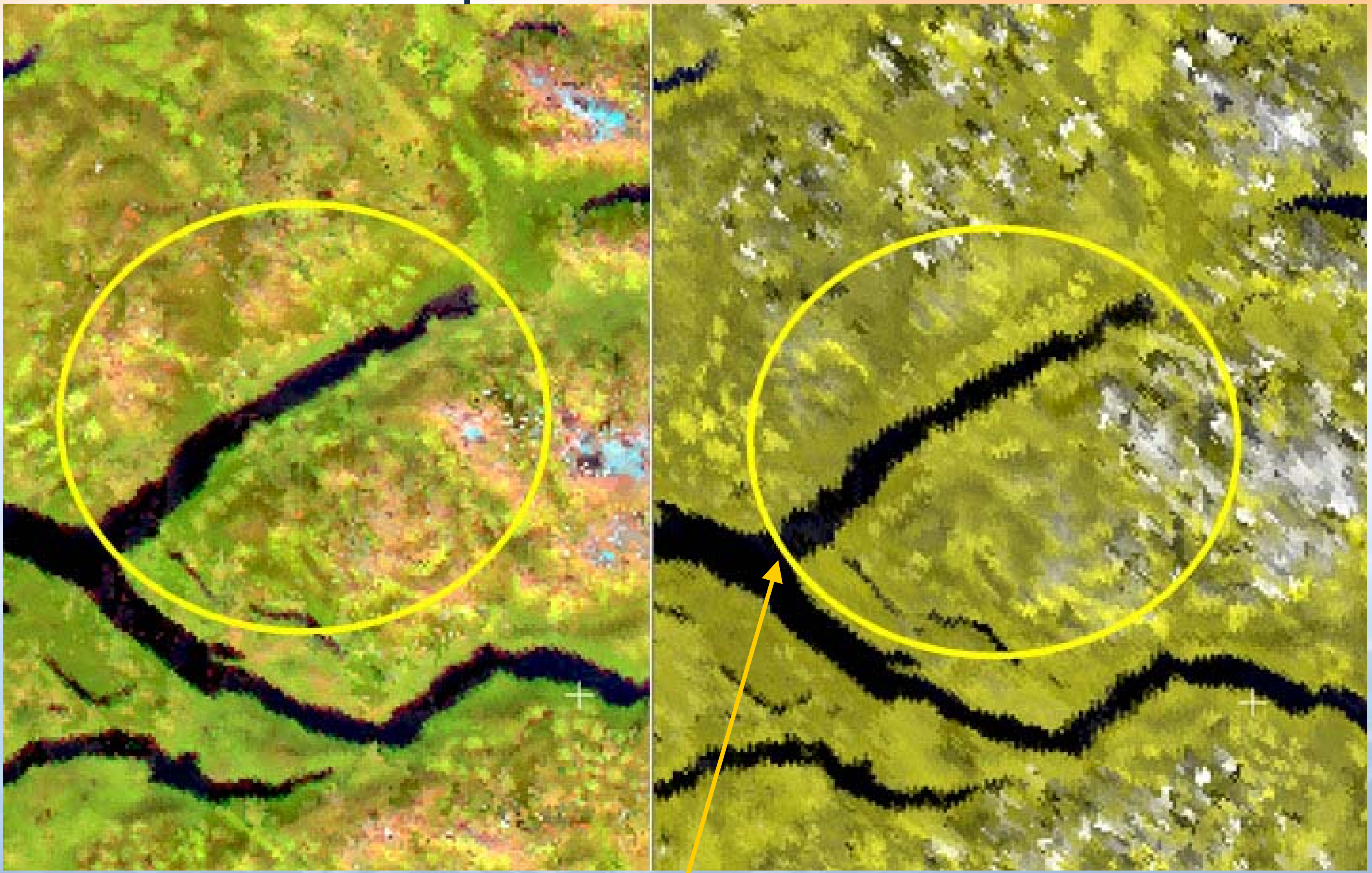
# Mapping Canada's territory at 250-m spatial scale from MODIS (under development)

- **10-day time intervals compositing from L1B swath data (no sinusoidal projection step);**
- **Contains 7 spectral bands: VIS and NIR [0.85 um] + 5 more channels** down-scaled from 500m to 250m**. Very rich spectral and detailed spatial information for land cover classification;**
- **Product is generated from original L1B swath imagery and retains all spatial details;**

**Trishchenko et al *SPIE*, 6366, 2006**

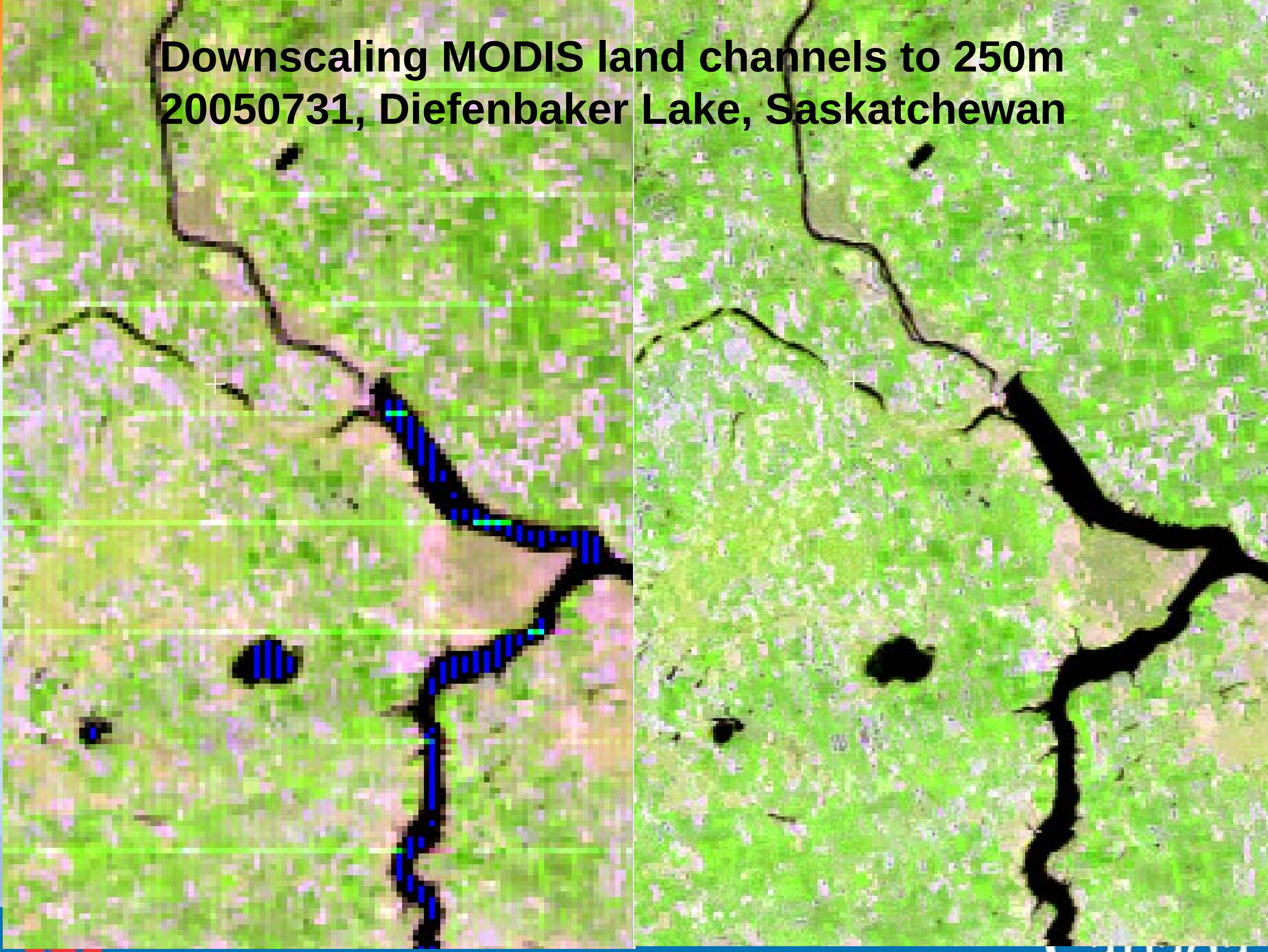
# MODIS

**New CCRS product** **Standard Product**



**Data distortion due to double re-projection**

# Downscaling MODIS land channels to 250m
## 20050731, Diefenbaker Lake, Saskatchewan



# Adaptive regression

- **Take 1 MODIS granule (L1B 5 min swath) containing all 7 bands B1-B7 at 500m spatial resolution**
- **Split image into 5x5= 25 blocks**
- **Generate parameters of non-linear regression relating channels B3-7 with B1, B2 and NDVI for each block and generic surface types : vegetation, land, cloud, water**

$$B_{i(3-7)} = a_{0,i} + (a_{1,i}B_1 + a_{2,i}B_2)(1 + a_{3,i}NDVI + a_{4,i}NDVI^2)$$

- **Take corresponding 250m (L1B 5 min swath) containing two bands B1 and B2 at 250m spatial resolution**
- **Apply above regression and produce intermediate synthetic channels B3-B7 at 250m spatial resolution**
- **Apply normalization ( next slide) to ensure that spatially enhanced images are radiometrically consistent and unbiased relative to original data at the pixel level**

# Normalization step

- Crude normalization removes any large biases by simple 2x2 running filter
- Final normalization involves precise replication of MODIS 500m data from 250m imagery – moving (3x2) window of 250m pixels is used

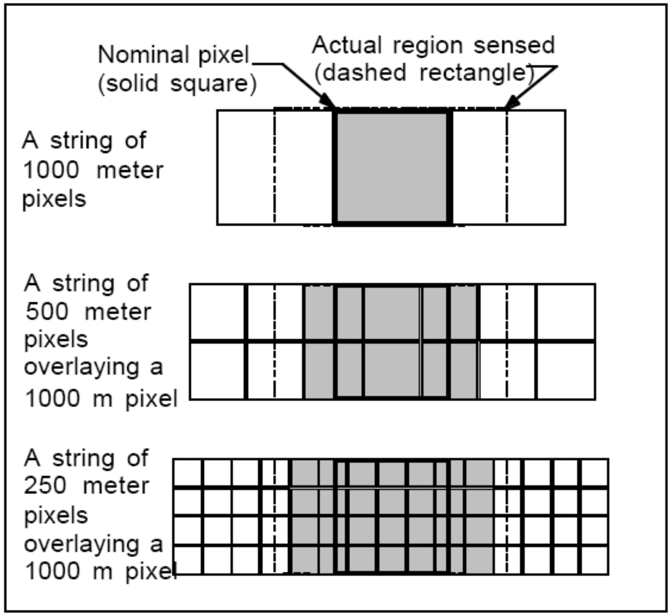



Figure 2-8. Higher Resolution Pixels Needed to Generate 1 km Pixels

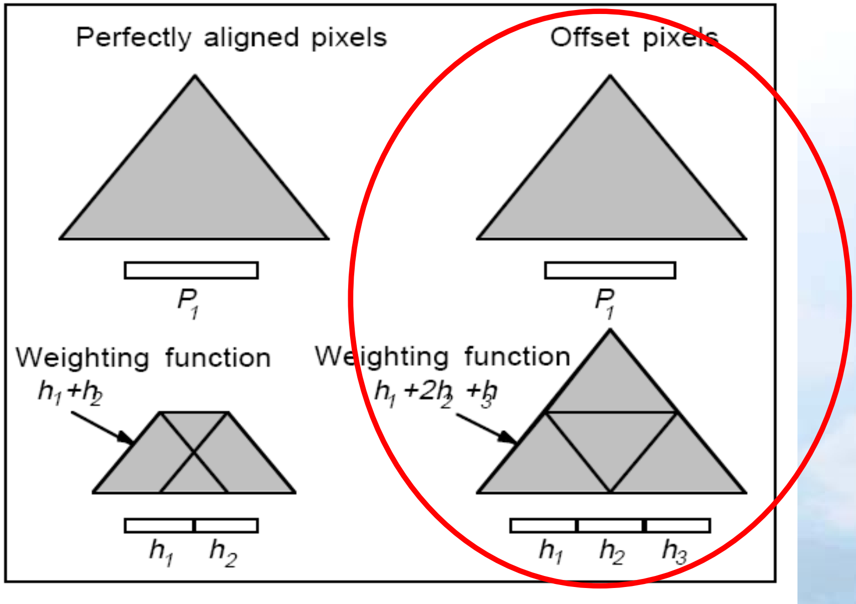



Figure 2-9. Equivalent 500 m Weighting Functions*

**Source:** MODIS Level 1A Earth Location: Algorithm Theoretical Basis Document Version 3.0. 1997

- Weighting rule: $P_{500} = h_{250,1} + 2h_{250,2} + h_{250,3}$

# Normalization step

$$2a_1\rho_1 + a_2\rho_2 = 3r_1$$

$$a_2\rho_2 + 2a_3\rho_3 + a_4\rho_4 = 4r_2$$

$$a_4\rho_4 + 2a_5\rho_5 + a_6\rho_6 = 4r_3$$

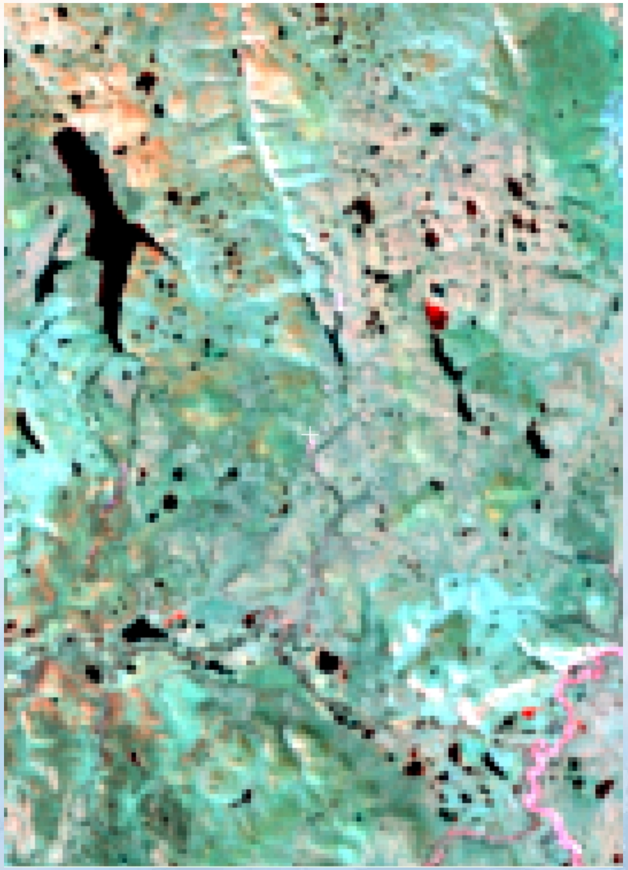
. . . . . . . . .

$$a_{2n-2}\rho_{2n-2} + 2a_{2n-1}\rho_{2n-1} + a_{2n}\rho_{2n} = 4r_n$$

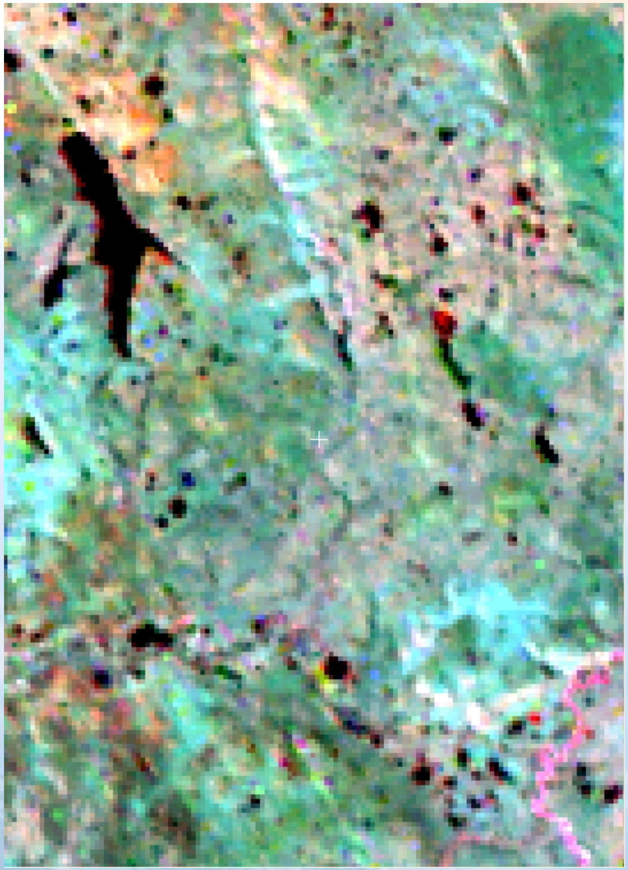
- Because the number of unknown constants exceeds the number of equations, the underdetermined system shown above can only be solved if additional conditions are imposed.
- First, we assume that factors $a_1$ and $a_2$ in the first line of system are equal to each other, and solve the system from the top to bottom, assuming that in each line the last two factors are also equal to each other. This method gives us a solution which we call a “forward” solution.
- In a similar way one can obtain a “backward” solution by starting normalization procedure from bottom to top. In this a case, we assume that all factors $\{a_i\}$ in the bottom line of system are equal each other, and the first two factors in the upper lines are also equal to each other. In the very first line, there is no need anymore to assume that factors $a_1$ and $a_2$ are equal. They can be determined separately. This gives us “backward” solution. The final normalization is achieved by taking average of “forward” and “backward” set of normalization factors, i.e. $a_i=0.5(a_{i,f} + a_{i,b})$

# Comparison MODIS-Landsat

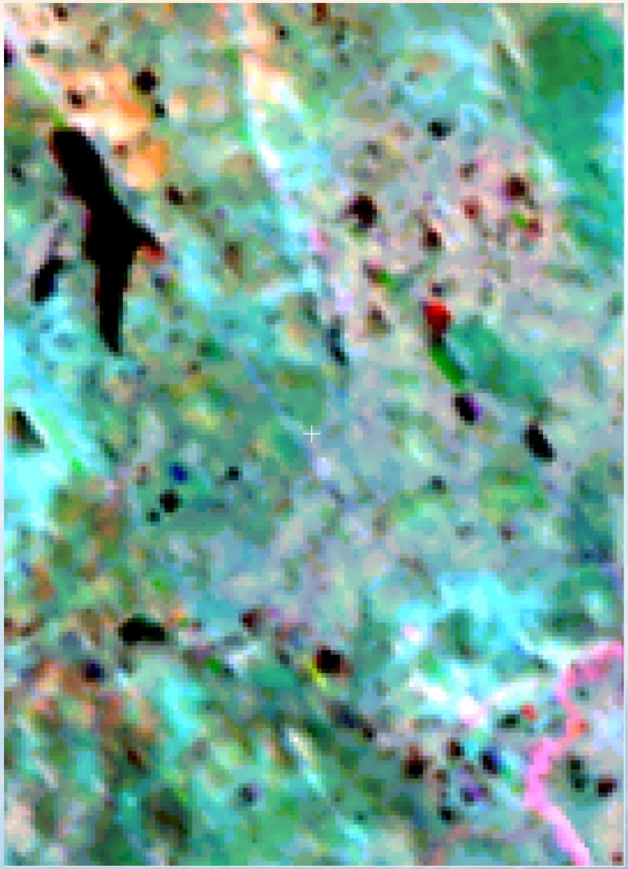
**Landsat aggregated to 250m**



**MODIS 250m**



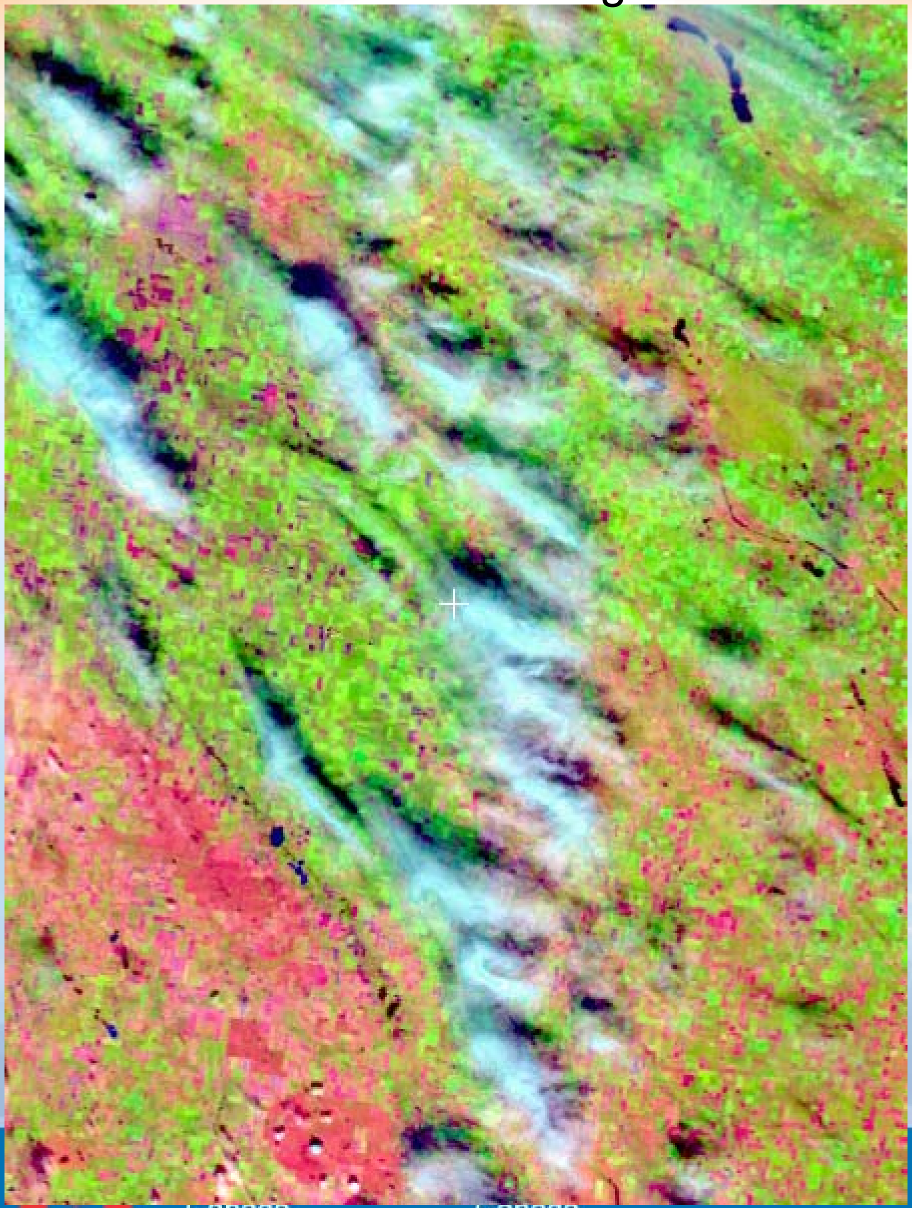
**MODIS 500m**



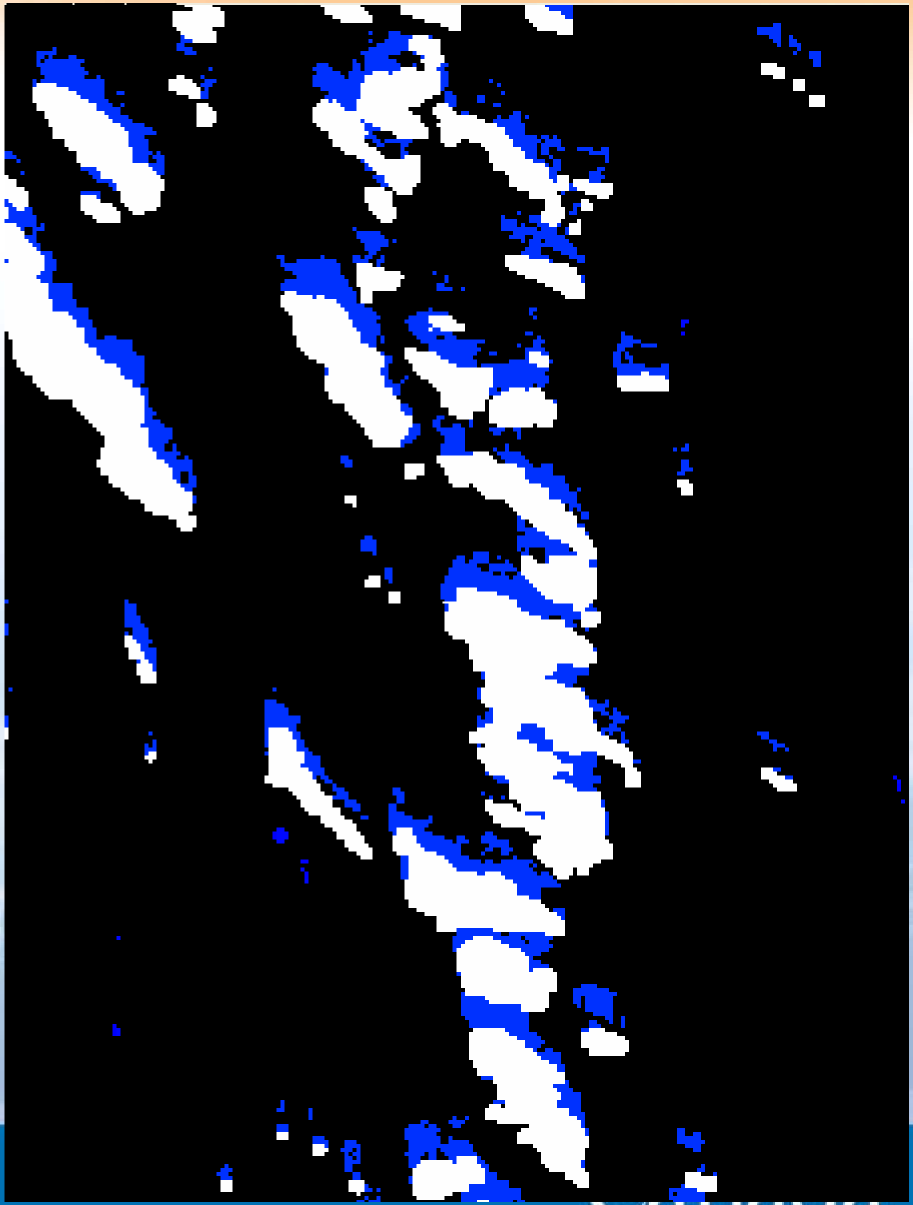
R-B4 (0.55µm) G-B6 (1.6µm) B-B7 (2.1µm)

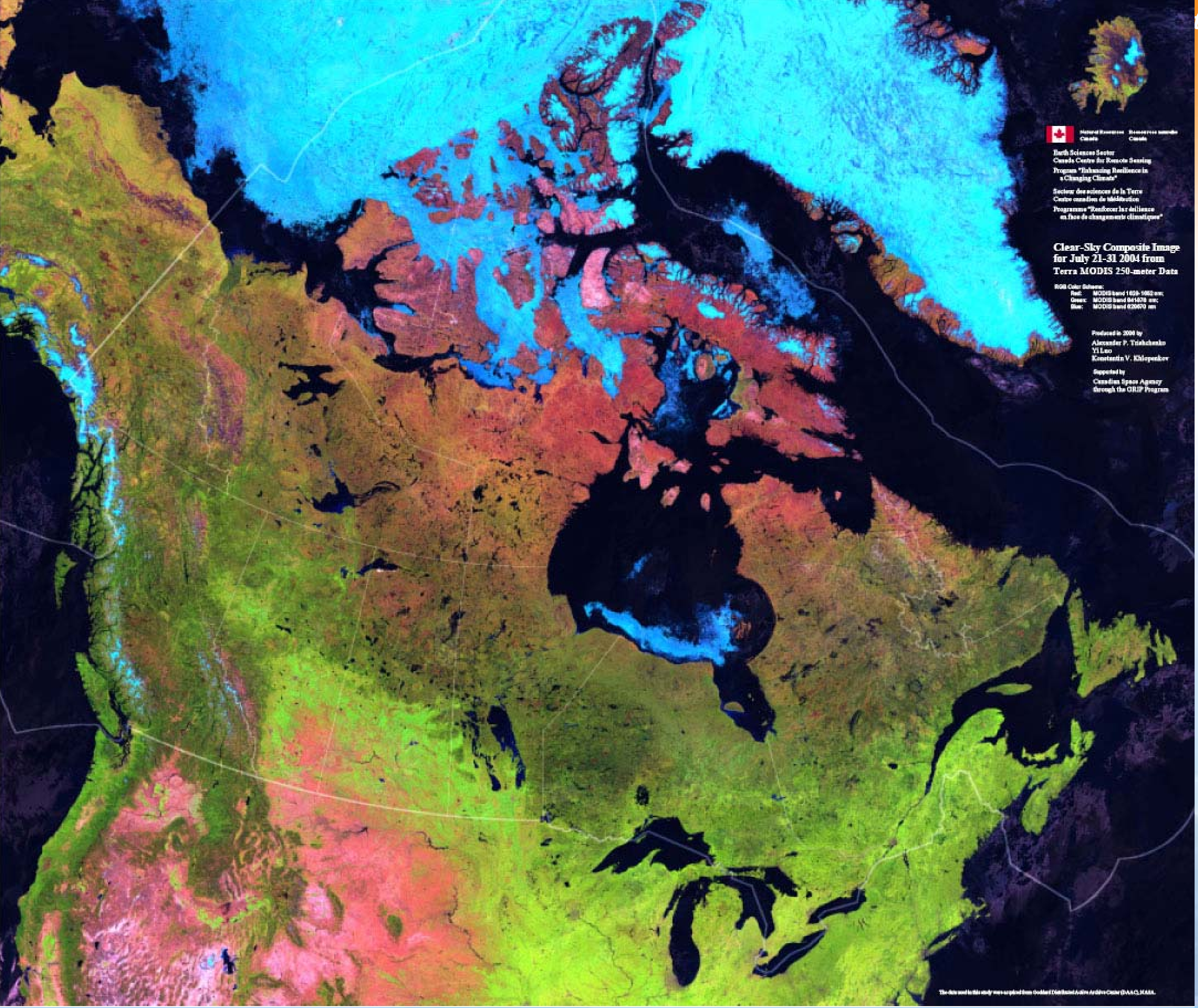
# MODIS Composite Process: Cloud and Cloud Shadow Detection

MODIS RGB Image



Cloud and Cloud Shadow Mask






**Canada-wide coverage is available now at 250m spatial resolution using MODIS data processing at CCRS July 21-31, 2004 22800 x 19200 pixels**

Trishchenko et al., 2006

# Additional Major Lessons

- If you want to get what you want, you have to do it yourself
- Multi-sensor data sets require application of physically-based correction procedures to ensure consistency between similar spectral channels and products

# Conclusions

- Approx. 25 years of AVHRR data over Canada are available at **1-km** resolution ( looking to start AVHRR FRAC/METOP);
- MODIS data over Canada are processed at **250m** spatial resolution
- Compositing is done at **10-day time intervals** (3 per month) ;
- Some additional efforts and international consensus are required regarding historical **AVHRR optical calibration**.
- CCRS is willing to share data/results with all interested parties and is interested in participation in various product intercomparison activities and preparation for VIIRS/NPOESS.

# Acknowledgements

- Substantial amount of AVHRR and all original MODIS data were acquired from the NOAA and NASA archives.
- Work is supported by the CSA under the GRIP Program.