Surface Albedo Mapping From Satellites: Present Capabilities and Future Needs

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Key summary points

1. Albedo is not a extremely critical variable for <u>modeling HR and atm</u> absorption, although quite important for determining these quantities from <u>flux observations, as well as surface and TOA radiation budgets;</u>
2. WMO/CEOS-Global Climate Observing System (GCOS) specs doc (2006) has recently included albedo in the list of required parameters to be retrieved from satellites: 250m – daily resolution;
3. Current system (primarily MODIS) deliver albedo/BRDF at 16-day, 1-km resolution. Our team at CCRS produced albedo/BRDF product over large ARM SGP area at 500m, 10-day for 2000-04 period (1km: 1995-2004);
4. CCRS has developed a downscaling scheme (adaptive regression) to produce albedo for <u>7 MODIS land bands at 250m, 10-day intervals</u> (over Canada). Can be expanded to cover ARM SGP and NSA areas;
5. Current observational systems (MODIS, MISR etc) does not provide adequate sampling of angular domain for accurate unambiguous retrievals of BRDF => new approach/sat mission is required: 200-300m spatial resolution, >= 7 angles (45°), ~ 2000km swath, 10-15 bands;
6. Albedo validation is a challenging task, requires up-scaling of hi-res imagery. Direct comparison between ground-based albedometers and satellite coarse resolution data <u>is not appropriate validation</u> procedure.

Surface albedo is a boundary condition for computing atmospheric radiative fluxes.

It is not a constant !

This is quite a complex function of solar and view angles, relative azimuth, wavelength, time, surface conditions and sky-conditions

The most complete description of surface reflective properties is achieved with

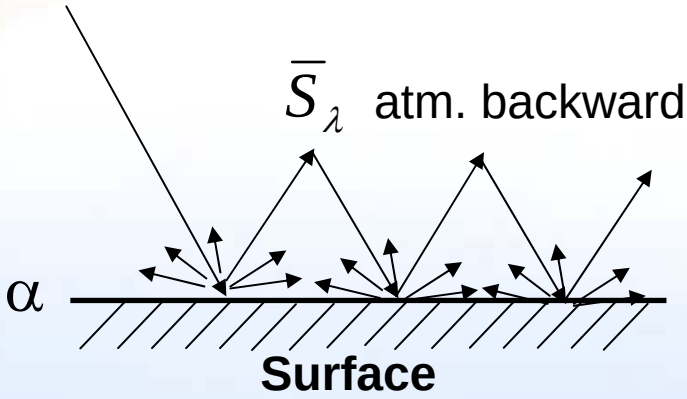
bi-directional reflectance distribution function (BRDF)

$$f(\vec{r}, \lambda, t, \theta_r, \phi_r, \theta_i, \phi_i)$$

Although surface albedo is important to get TOA albedo and surface absorbed flux correctly, it is of relatively less importance for modeling HR & atm. absorption

It is still an important factor in determining HR & atm. absorption from flux observations

Albedo effects on atm. absorption



$\bar{S}_\lambda$ atm. backward scattering or spherical albedo

$$M_\lambda^{TOA}(\theta_0) = M_{\lambda,0}^{TOA}(\theta_0) + \frac{\alpha_\lambda}{1-\alpha_\lambda \bar{S}_\lambda} E_{\lambda,0}(\theta_0)\bar{T}_\lambda$$

$$E_\lambda(\theta_0) = E_{\lambda,0}(\theta_0) + \frac{\alpha_\lambda}{1-\alpha_\lambda \bar{S}_\lambda} E_{\lambda,0}(\theta_0)\,\bar{S}_\lambda$$

Surface absorbed solar flux

$$\Delta E_\lambda(\theta_0) = (1-\alpha_\lambda)E_\lambda(\theta_0) = \frac{1-\alpha_\lambda}{1-\alpha_\lambda \bar{S}_\lambda} E_{\lambda,0}(\theta_0)$$

$$A_\lambda(\theta_0) = \Delta A_{\lambda,0}(\theta_0) + \alpha_\lambda\, E_{\lambda,0}(\theta_0)\frac{1-\bar{S}_\lambda - \bar{T}_\lambda}{1-\alpha_\lambda \bar{S}_\lambda} = \Delta A_{\lambda,0}(\theta_0) + E_{\lambda,0}(\theta_0)\frac{\alpha_\lambda\, \bar{A}_\lambda}{1-\alpha_\lambda \bar{S}_\lambda}$$

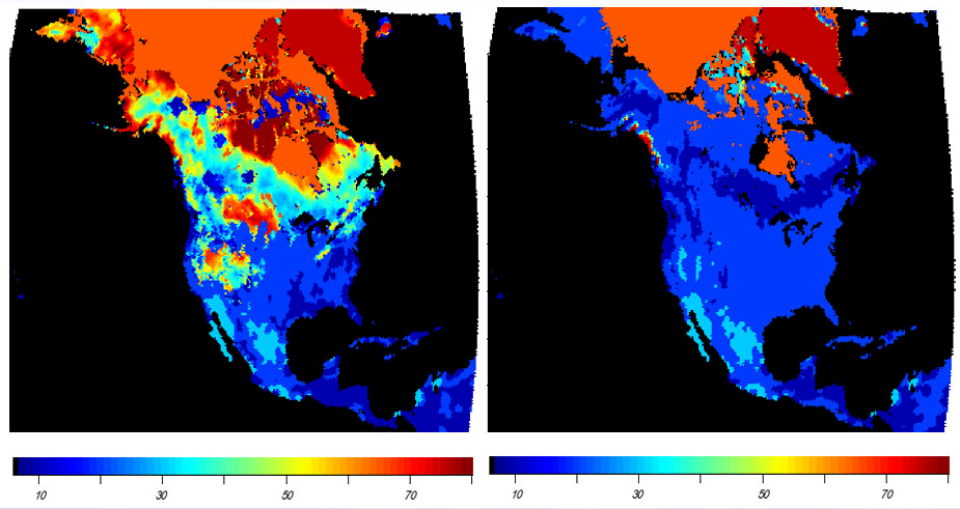
Atmosphere absorbed solar flux

$E_{\lambda,0}(\theta_0)$ **and** $M_{\lambda,0}^{TOA}(\theta_0)$ **Surface irradiance and TOA reflected flux for the case of black (non-reflecting) surface**

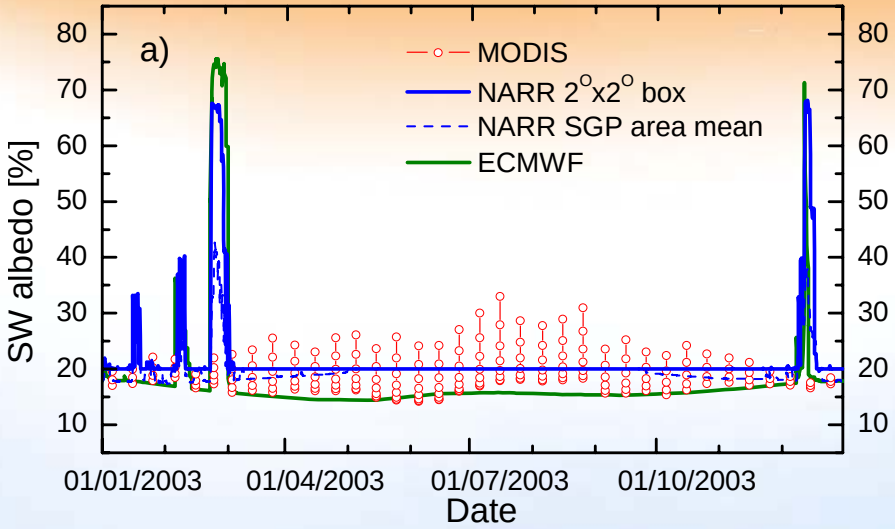
Chandrasekhar. Radiative transfer (1960) (Lambertian albedo case)

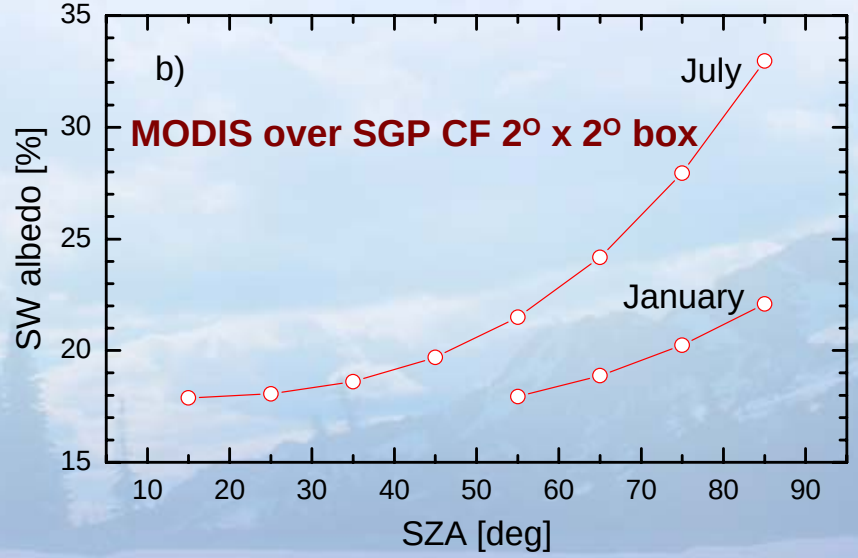
MODIS and GCM Albedo

NARR Albedo



January 1, 2003 **July 1, 2003**





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

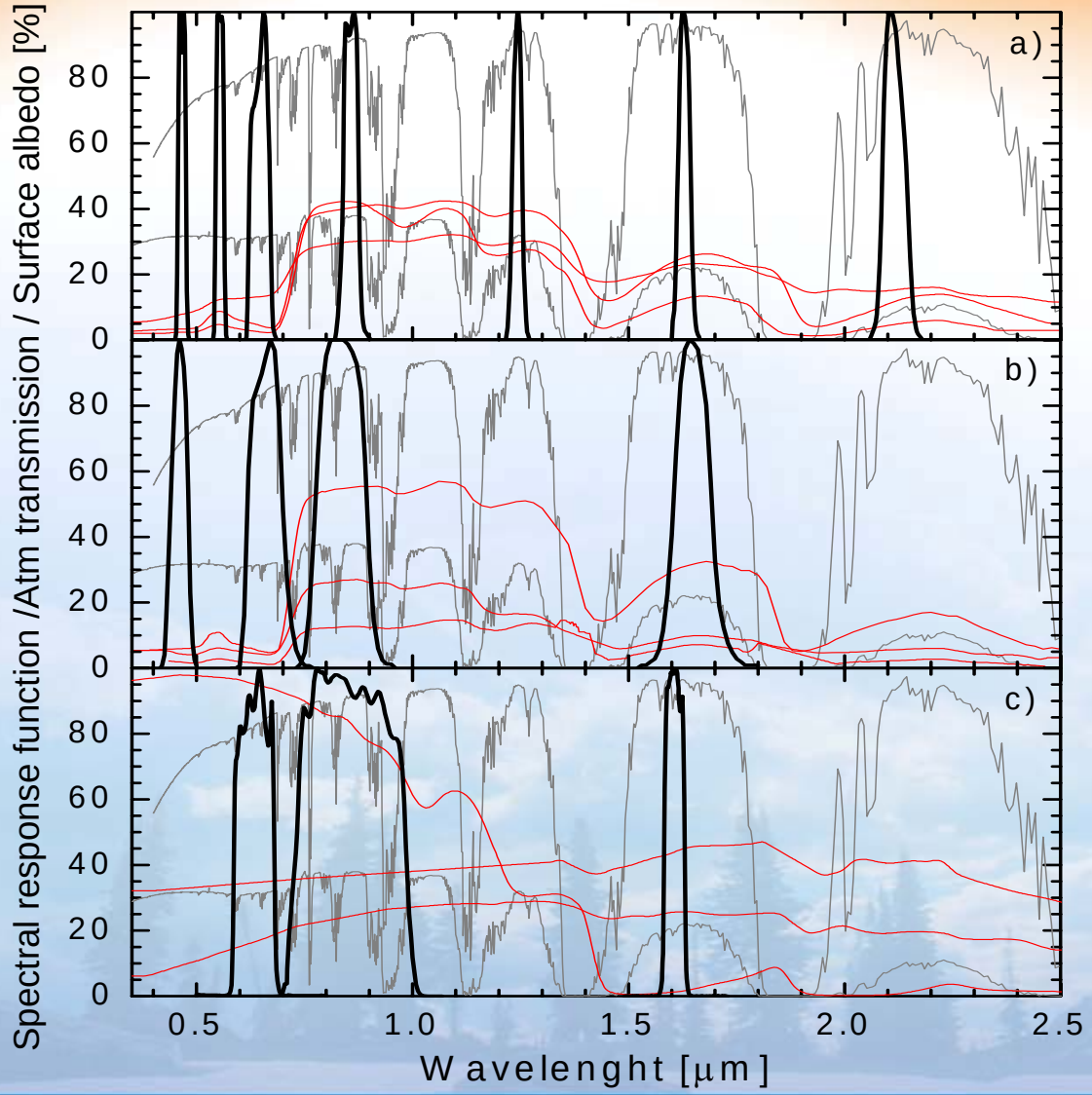
(GCOS-107, WMO/TD-1338)

Altogether, there are 16 parameters identified by GCOS that can be retrieved from satellite data from observations in optical, thermal and microwave bands. 10 of them + 1 atm. param (Radiation budget) are listed below

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

Spectral properties



Atmospheric windows for clear-sky and overcast conditions

Short vegetation MODIS/Terra&Aqua land channels

Forest types VEGETATION/SPOT channels

Non-vegetated surfaces AVHRR/NOAA channels

Source of satellite data for surface albedo mapping

- Medium resolution sensors (250m-1km)
  - MODIS/Terra&Aqua
    - 16-day 1-km NASA global product,
    - **10-day 500m (7 bands) CCRS product over ARM SGP (2000-2005)**
    - **10-day 1-km (7 bands) CCRS product over ARM SGP (1995-2005)**
  - AVHRR/NOAA &METOP,
  - VGT/SPOT,
  - MERIS/Envisat
  - MISR, POLDER – limited use due to pixel size and coverage
- High-resolution sensors (<=30m) for local mapping. Cannot provide regular large scale (global) coverage
  - LandSat, ASTER, IKONOS, SPOT/HRV
- SW Broadband, coarse resolution sensors, for climate applications
  - Current CERES and historical ScaRaB, ERBE radiometers

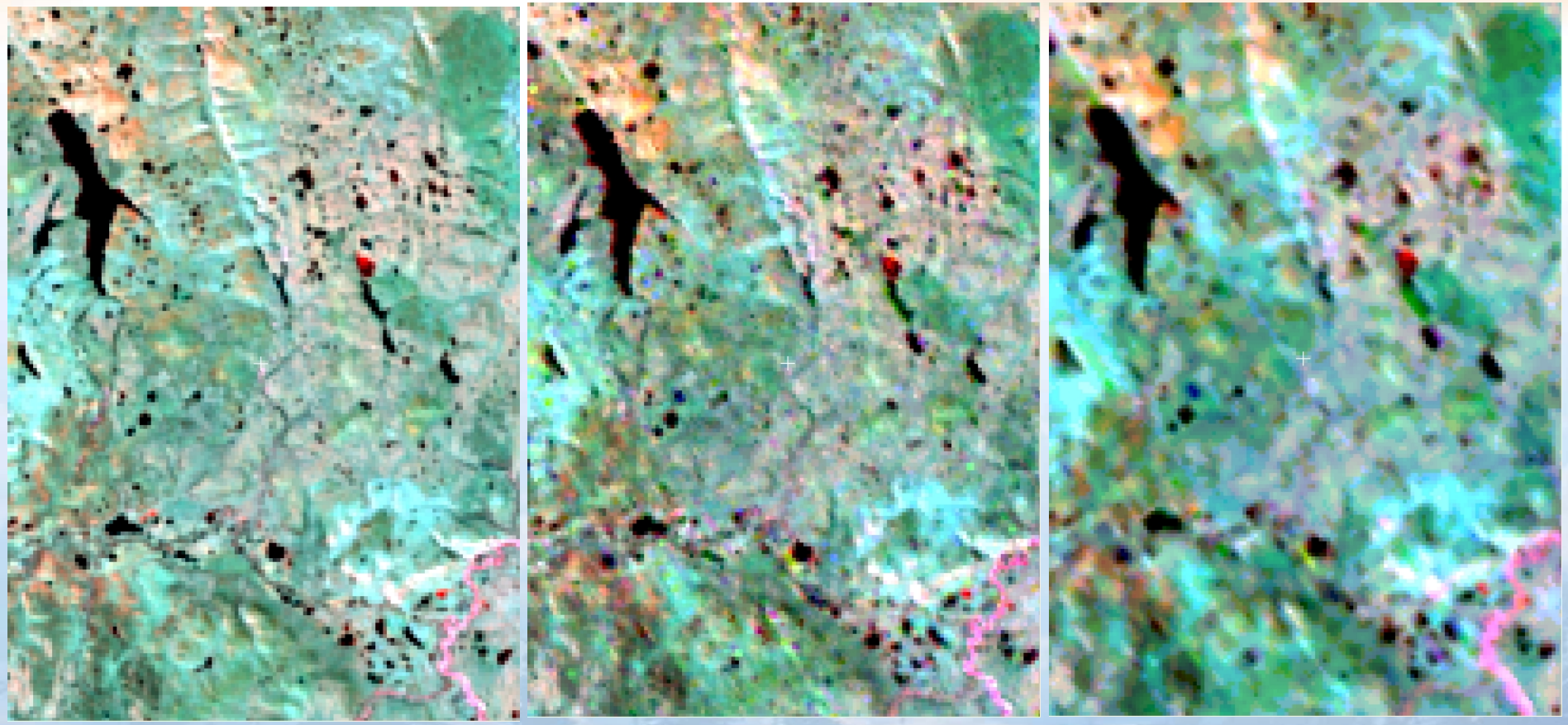
Mapping surface albedo at 250-m spatial scale from MODIS: New CCRS product over Canada (under development)

- MODIS imagery covers entire country (land, water, ocean ice);
- It is generated at 10-day time intervals from L1B swath data (no ISIN projection);
- 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 swath imagery and retains all spatial details;
- New cloud screening and cloud shadow detection ;
- Objective: to generate 1-day and 10-day Canada-wide coverage at 250m spatial resolution for monitoring of land mass dynamics and land cover changes;
- 22800 x 19200 pixels (~825Mb for 1 layer): large data volume

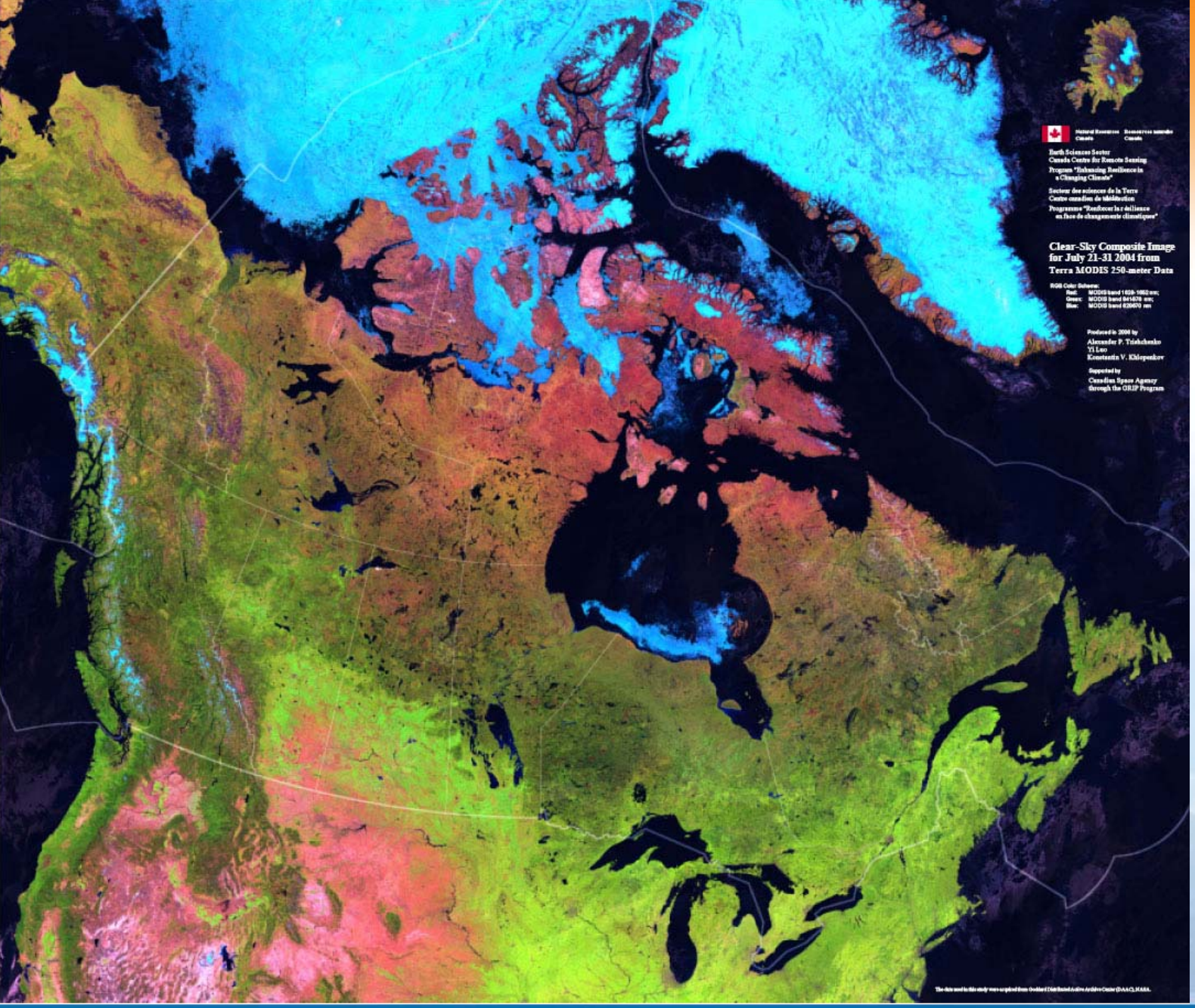
Trishchenko et al 2006

Comparison MODIS-Landsat

Landsat aggregated to 250m | **MODIS 250m** | **MODIS 500m**



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



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

Trishchenko et al., 2006

Key issues are atmospheric correction and BRDF sampling

- Atmospheric correction is somewhat a ”chicken and egg” problem, especially from cross-track scanners
  - Atm. correction needs aerosol properties, which in turn are derived assuming some knowledge of surface reflectance
- BRDF as a combination of kernel functions
  - Ross-Thick –Li-Sparse - MODIS
  - Modified Rahman – MISR team
  - Minnaert, Hapke
  - Many others …
- BRDF from the canopy structure model (LAI, gap fraction distribution)
- Fitting satellite data points *(that cover limited range of angles)* to obtain kernel amplitudes *fk(λ), LAI or canopy structure*
  - Observations for individual pixel – very few data points, S/N issues
  - Land cover based grouping and fitting – enough data, less sensitive to individual point features
  - Multi-angular observations – MISR, POLDER, PARASOL, AATSR.
  - Multi-angular observations are most promising but need to optimized in a new mission (250-300m pixel size, +/- 40deg swath, 7 angles, 10 channels
- Integrating kernel functions to get albedo

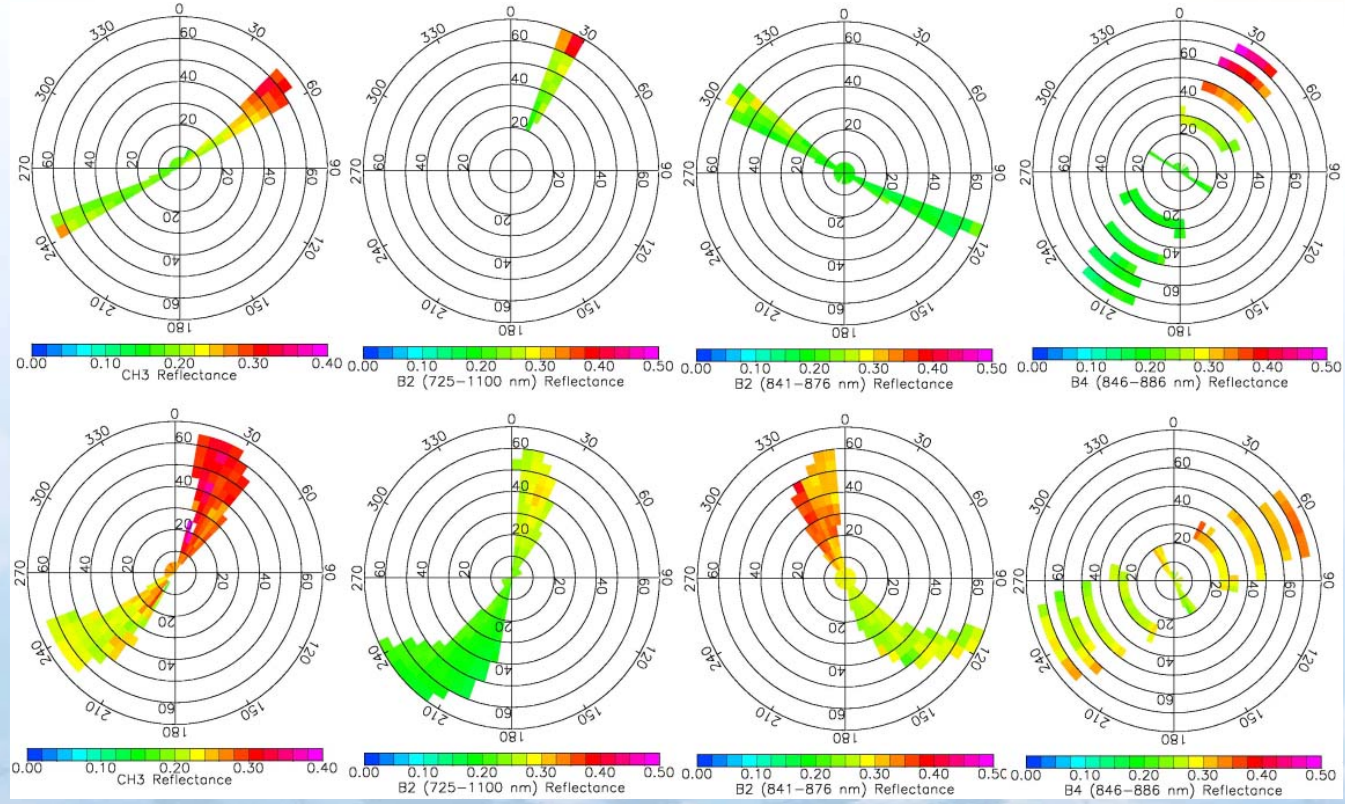
Issues with angular sampling

- Satellite sensors observe surface directional reflectance at discrete set of angles in cloudy-free conditions

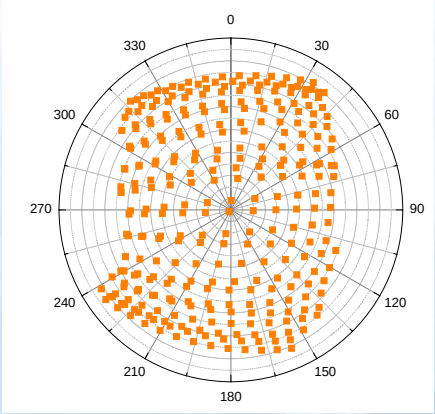
- To derive BRDF one needs to cover entire 3D-space of SZA, VZA and RELAZ angles. This condition is not possible to satisfy! **Clear-sky pixels assembled from multiple passes cover only a limited range of angular variables**

Angular sampling

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



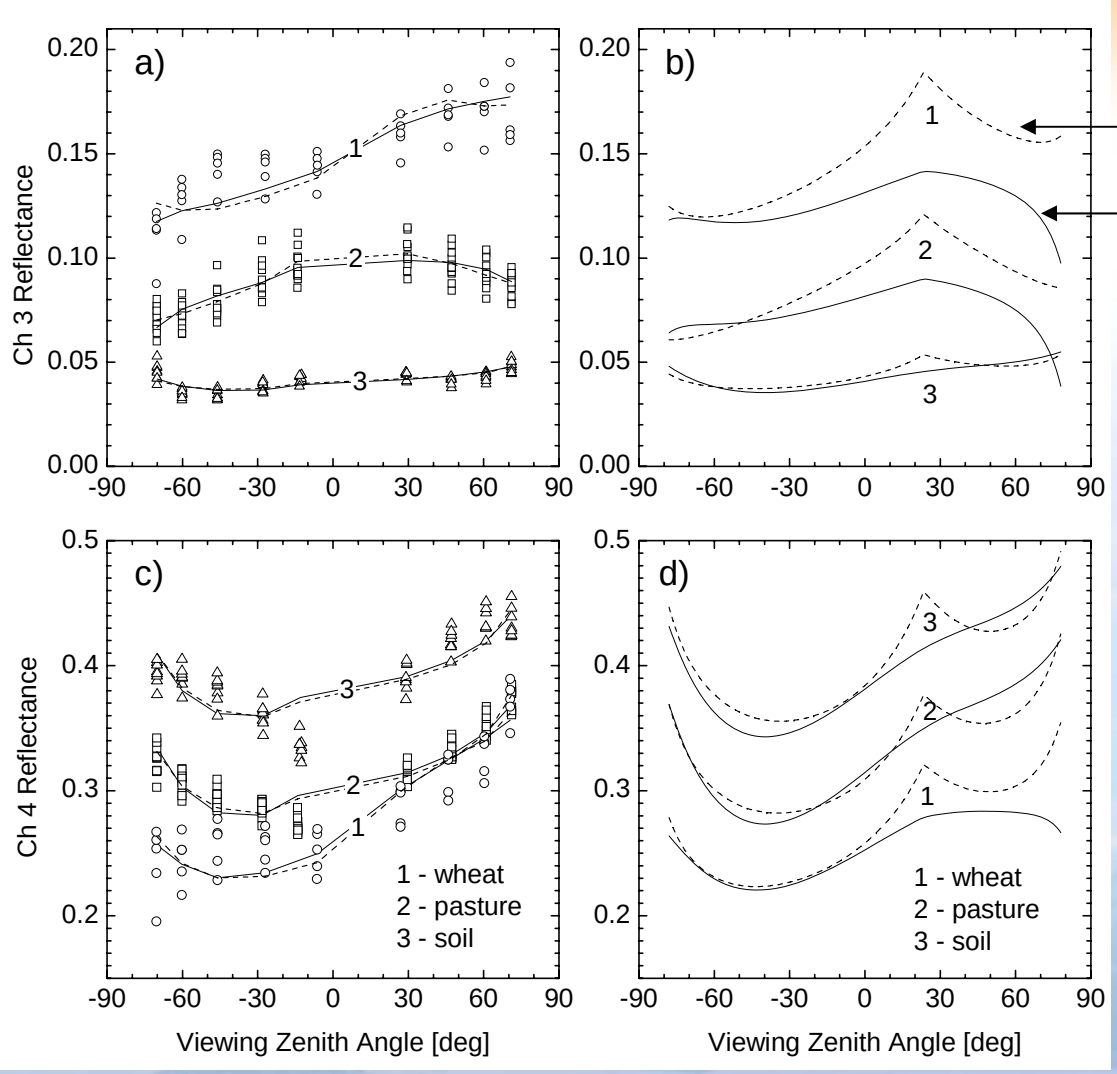
POLDER



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

Issues in BRDF retrievals

Off PP In PP



Raman

Ross-Li

Summary about current capabilities

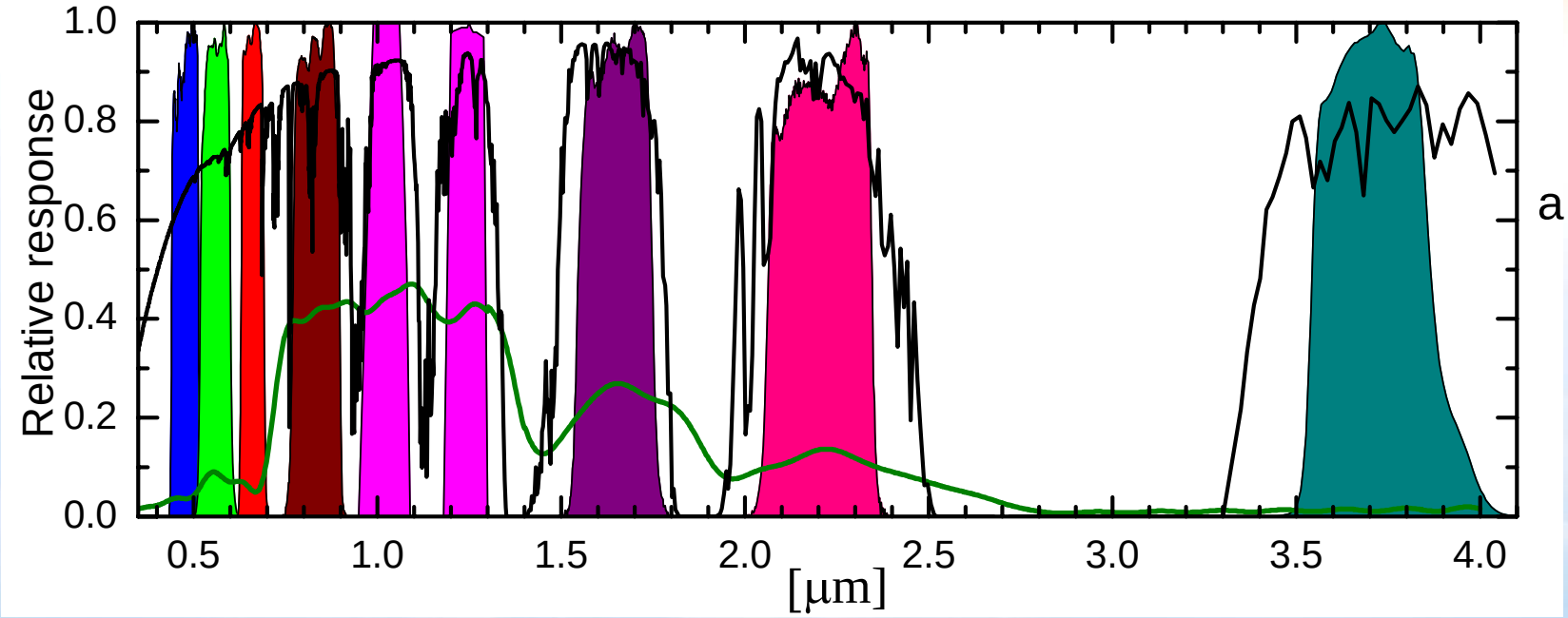
- While existing satellite Earth Observing (EO) systems provide many baseline observations, they are lacking an important combination of capabilities in terms of angular sampling, spectral coverage, and spatial resolution
- ***None of these missions has the optimal combination of parameters*** to satisfy 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

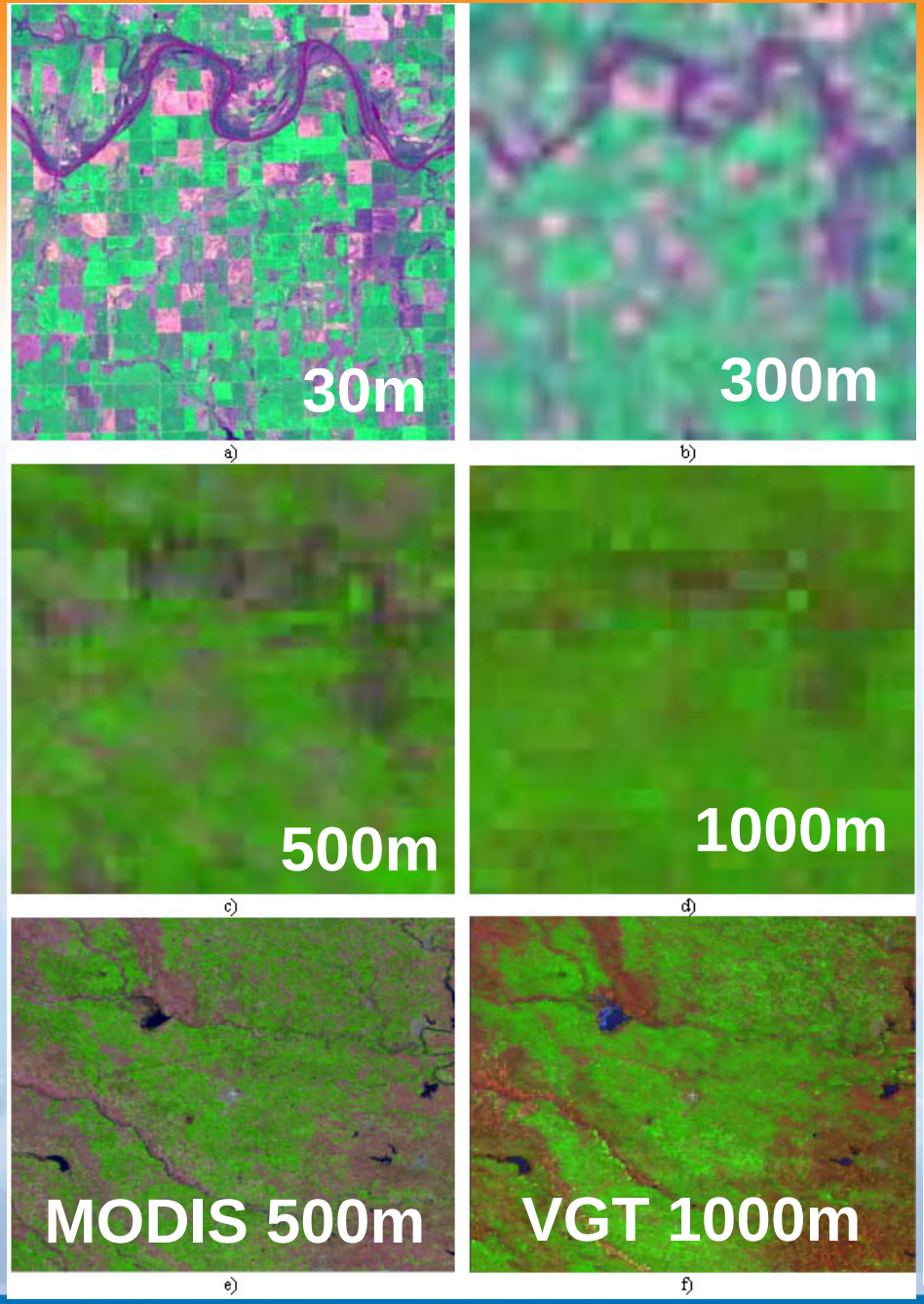
Parameter	POLDER	MISR	AATSR	ASTER*	SPECTRA	AMMERS
# Spectral bands, range	9 443-910 nm	4 443-865 nm	7 0.550-12 μm	14 VNIR, SWIR, TIR	60 chs (10nm) in VIS, NIR, SWIR and 2 chs in TIR	10-15 0.44-12 μm; SW, LW
Pixel size	$6x7km^2$	275m/ 1.1km	1-2 km	15-90m	50m	200-300m
# Angles	14	9	2	2	7	7
Swath/Max angle 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°	27.6^O	up to 70°	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) 3.3 (average)	0.63	69 (day) 4.2 (night)	8.5 GBit/orbit	Upper limit 33 (day) 12 (night) 23 (average)

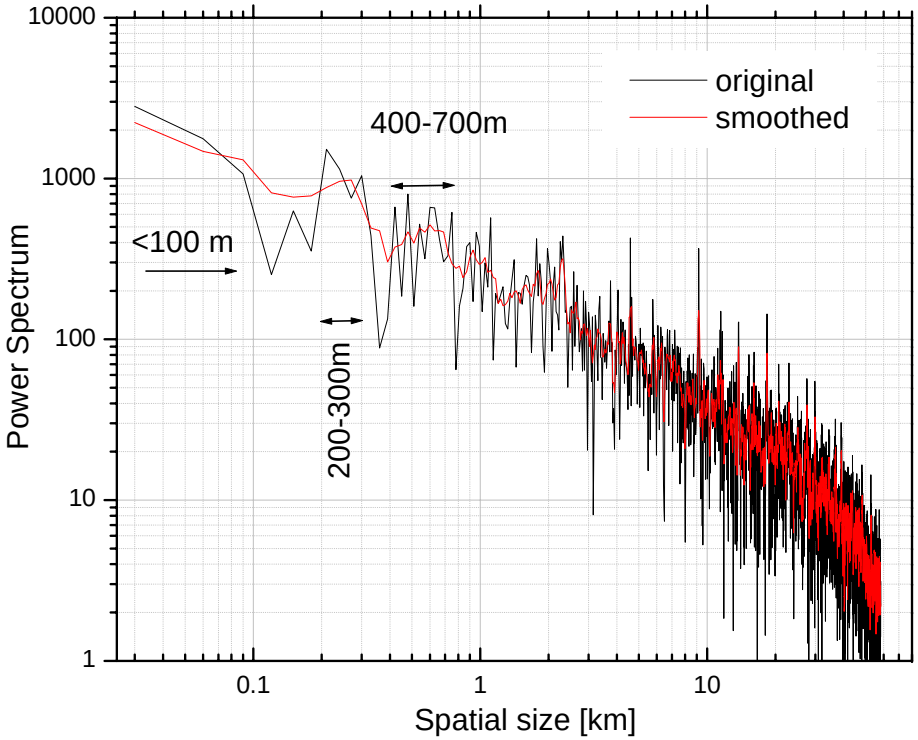
* - limited stereoscopic capabilities

Spectral channels for AMMERS

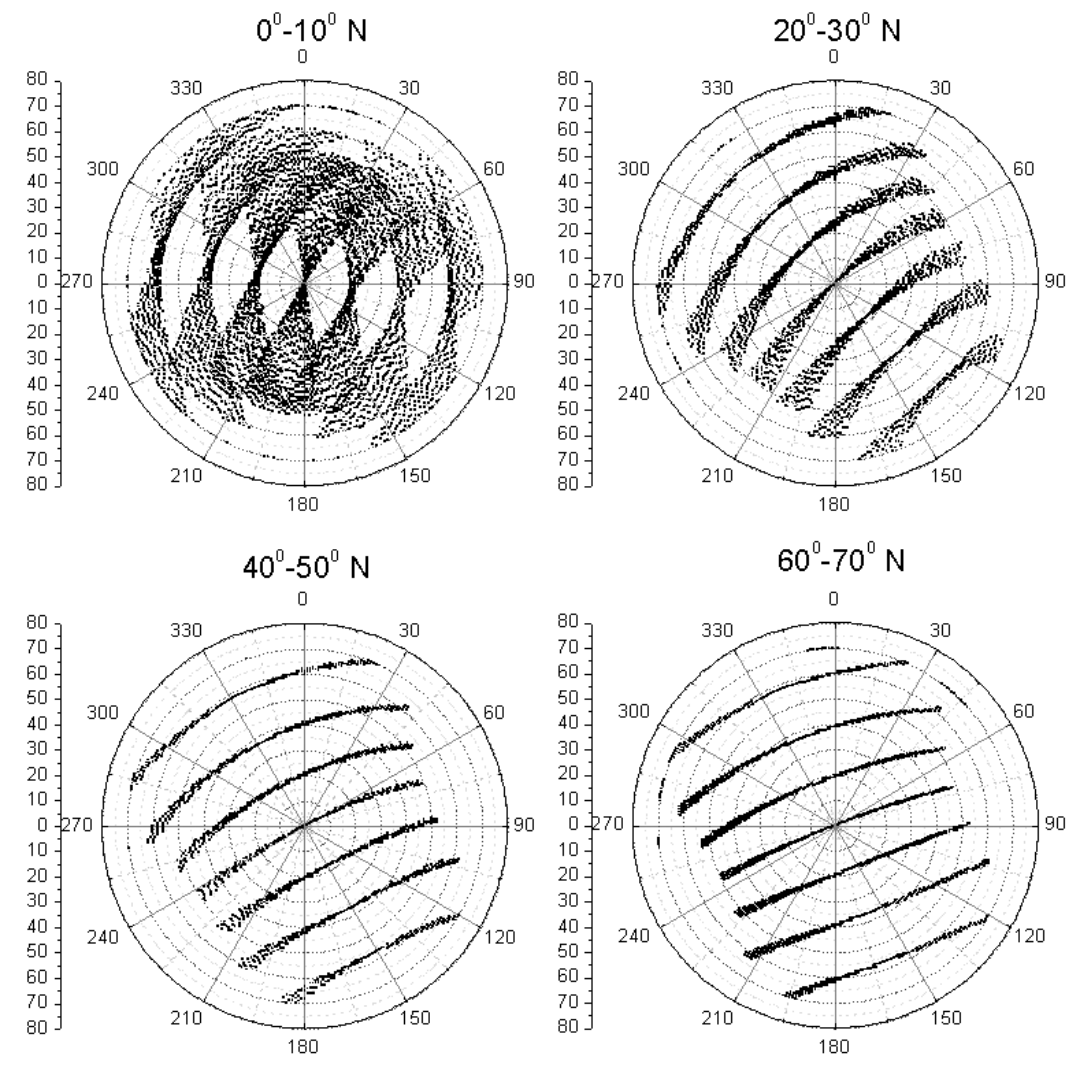


Spatial resolution

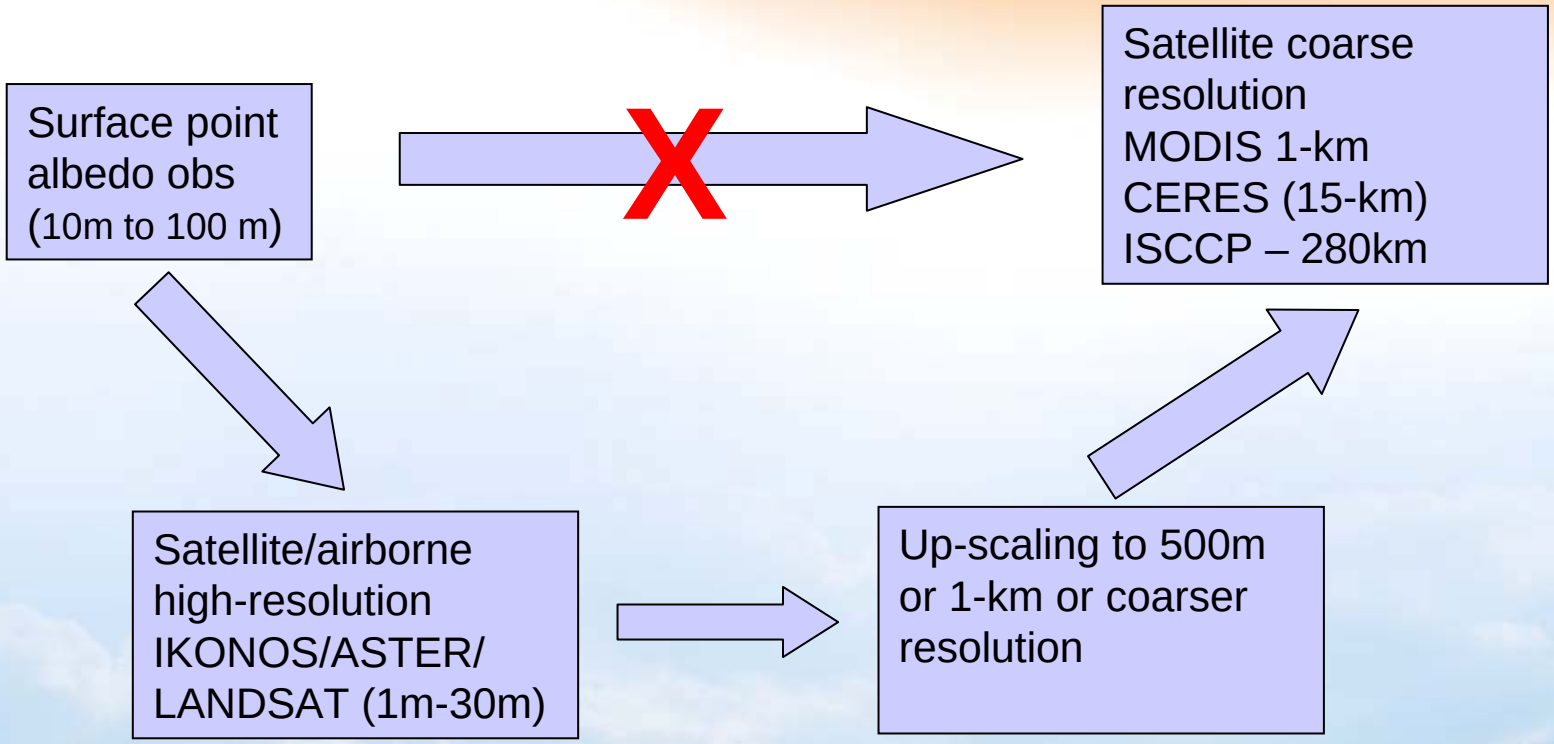




Example of angular sampling for AMMERS



Albedo validation

- When validating or intercomparing albedo products they must be obtained at similar spatial (FOV) and temporal resolution.
- Temporal averaging cannot be exchanged with spatial averaging (time averaging of point albedometer observations is not directly comparable to time series of satellite 1-km products).
- Validation can be achieved through upscaling procedure, however, this is very expensive and quite limited procedure.

Albedo validation …