Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

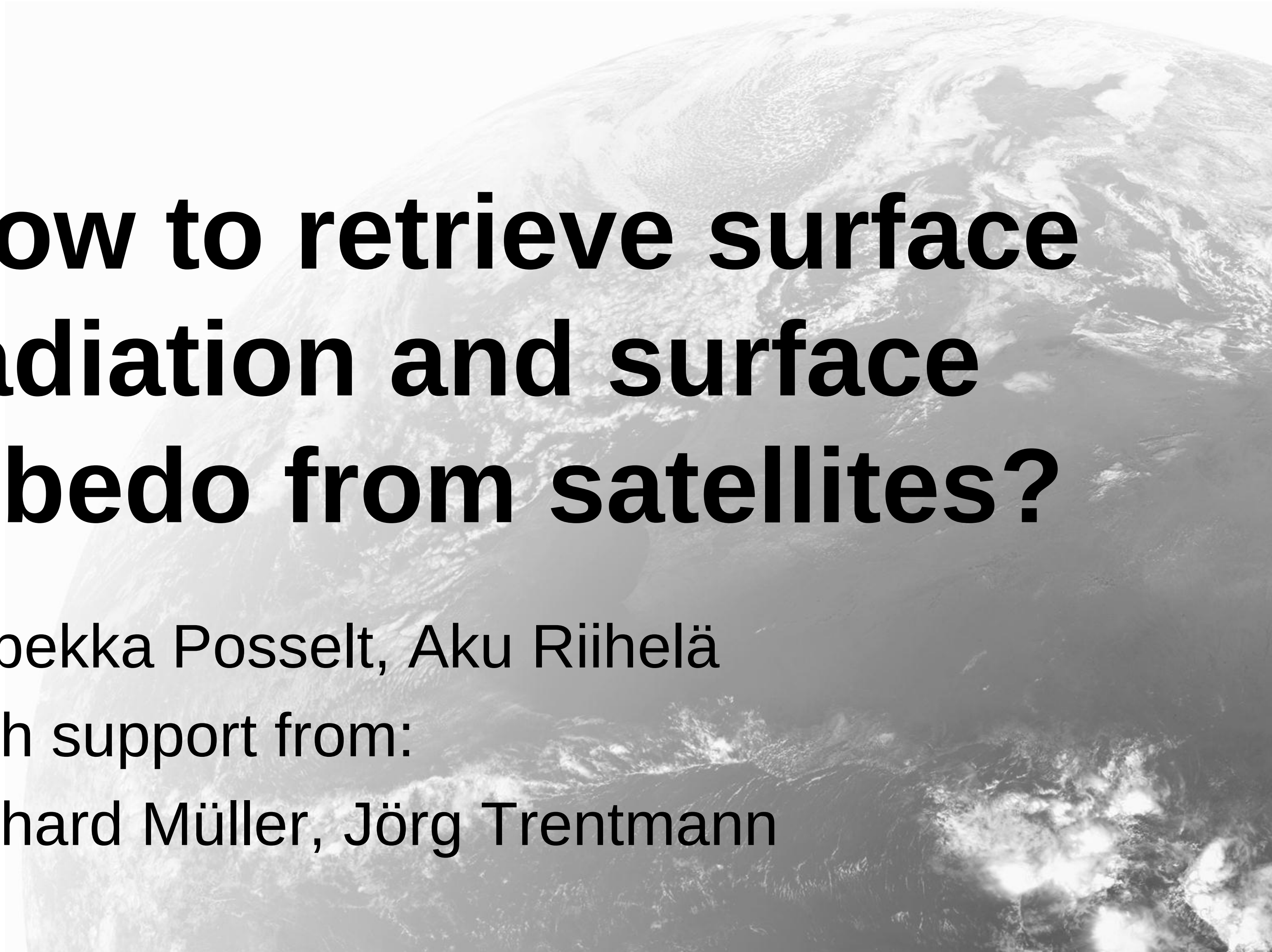
CM SAF
Climate Monitoring

How to retrieve surface radiation and surface albedo from satellites?

Rebekka Posselt, Aku Riihelä

With support from:

Richard Müller, Jörg Trentmann



Outline

PART I

Solar radiation (SIS, SID)

- MagicSol – Retrieval for historical radiation datasets
- LookUpTable radiation retrieval

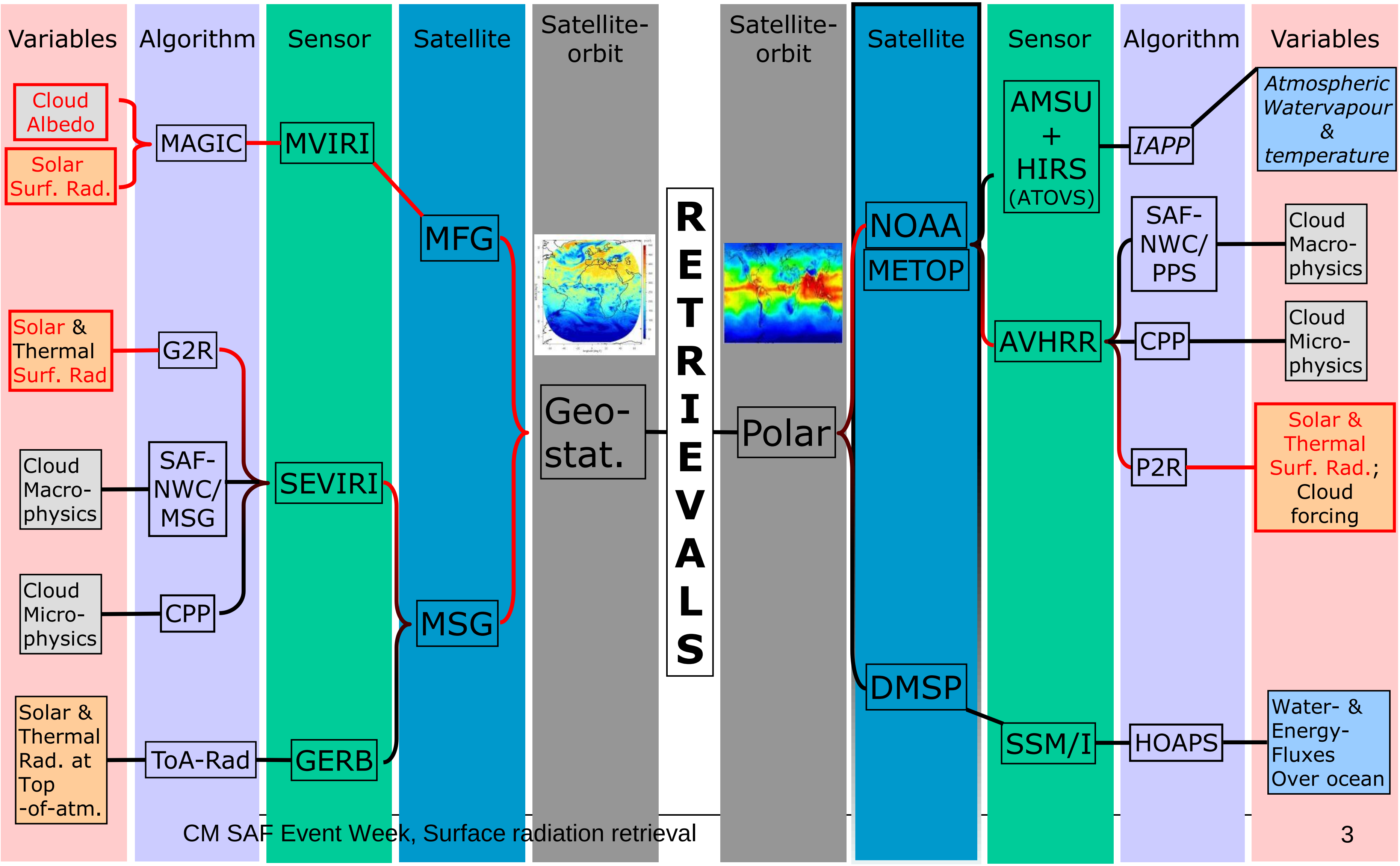
Longwave radiation (SDL)

- AVHRR-CLARA (GAC) algorithm (very short)

PART II

Surface albedo (SAL)

Retrieval Overview



Variables | Algorithm | Sensor | Satellite | Satellite-orbit | RETRIEVALS | Satellite-orbit | Satellite | Sensor | Algorithm | Variables

Geostationary side:

- Cloud Albedo; Solar Surf. Rad. — MAGIC — MVIRI — MFG
- Solar & Thermal Surf. Rad — G2R — SEVIRI — MSG
- Cloud Macro-physics — SAF-NWC/MSG — SEVIRI — MSG
- Cloud Micro-physics — CPP — SEVIRI — MSG
- Solar & Thermal Rad. at Top -of-atm. — ToA-Rad — GERB — MSG
- MFG, MSG — Geo-stat.

Polar side:

- Polar — NOAA, METOP, DMSP
- NOAA, METOP — AMSU + HIRS (ATOVS) — *IAPP* — *Atmospheric Watervapour & temperature*
- NOAA, METOP — AVHRR — SAF-NWC/PPS — Cloud Macro-physics
- NOAA, METOP — AVHRR — CPP — Cloud Micro-physics
- NOAA, METOP — AVHRR — P2R — Solar & Thermal Surf. Rad.; Cloud forcing
- DMSP — SSM/I — HOAPS — Water- & Energy-Fluxes Over ocean

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

CM SAF
Climate Monitoring

Part I
Surface radiation retrievals

Rebekka Posselt
(MeteoSwiss)

Contact me at: rebekka.posselt@meteoswiss.ch

Outline

PART I

Solar radiation (SIS, SID)

- **MagicSol – Retrieval for historical radiation datasets**
- LookUpTable radiation retrieval

Longwave radiation (SDL)

- AVHRR-CLARA (GAC) algorithm (very short)

PART II

Surface albedo (SAL)

MagicSol

Retrieval for historical radiation datasets

- Historical = Meteosat 2 – 7 (1983 – 2005)
  = MVIRI instrument

- Benefits:
  - 23 years of high resolution data → climatology

- Challenges:
  - Only three available channels (VIS, IR, WV)
  - Satellite operations not designed for climate studies
    - Different satellites (inhomogeneities)
    - Poorly documented (M2-4 → missing calibration)

MagicSol

Retrieval for historical radiation datasets

- Historical = Meteosat 2 – 7 (1983 – 2005)
  = MVIRI instrument

- Benefits:
  - 23 years of high resolution data → climatology

- Challenges:
  - Only three available channels (**VIS**, IR, WV)
  - Satellite operations not designed for climate studies
    - Different sa (inhomogeneities)
    - Poorly documented (M2 g calibration)

Self-calibration

MagicSol

Retrieval for historical radiation datasets

- Retrieval scheme
  1. Get cloud information
     - “Effective Cloud Albedo” (CAL)
     - From satellite
  2. Get clear sky information
     - “Clear Sky Radiation” (Rad_{cs})
     - From LookUpTables
  3. Combine 1. & 2.

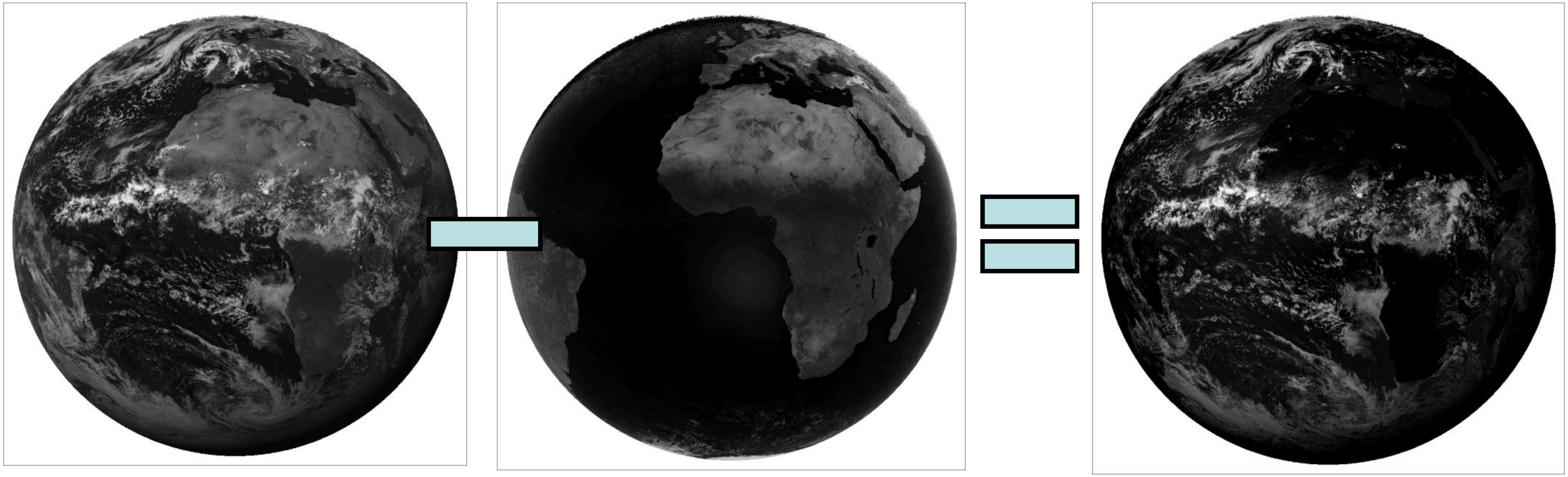
$$\boxed{Rad = f(CAL) \cdot Rad_{cs} \approx (1 - CAL) \cdot Rad_{cs}}$$

→ Rad = SIS or SID

MagicSol

Retrieval for historical radiation datasets

1. Get cloud information
   - Get clear sky = cloud free = surface only image from a series of original images (usually the darkest pixel in the series)



Original image (clouds and surface) = **ρ**

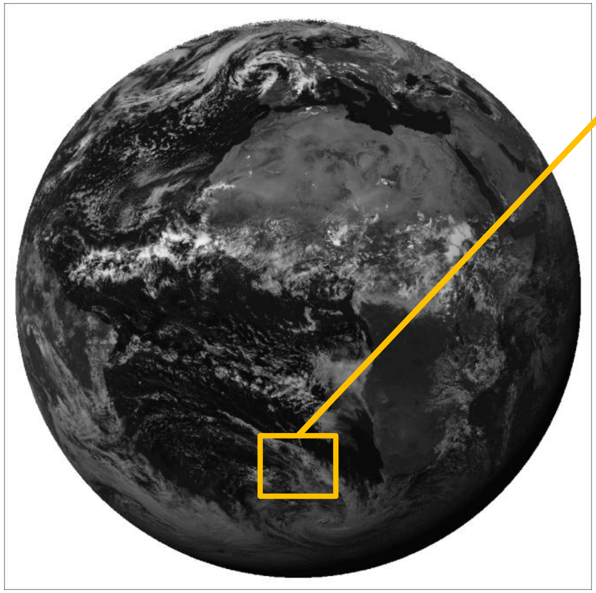
Clear sky image (clouds removed, only surface) = **ρ_{min}**

Cloud image (surface removed, only clouds)

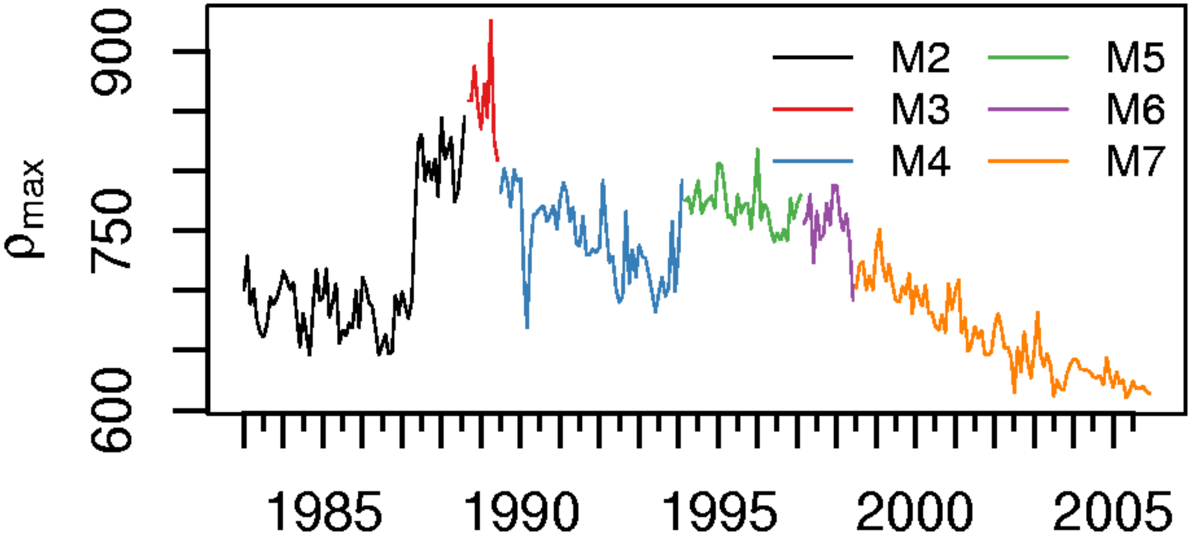
MagicSol

Retrieval for historical radiation datasets

1. Get cloud information
   - Get Selfcalibration via $\boldsymbol{\rho}_{\mathbf{max}}$ = 95% percentile of all counts in target region (South Atlantic)



Original image



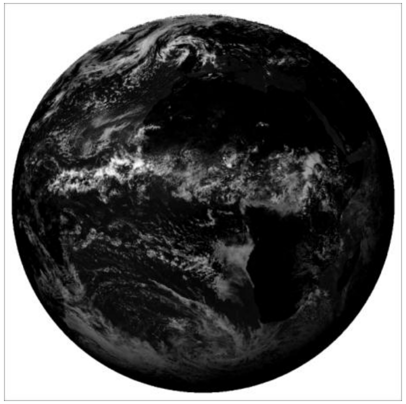
MagicSol

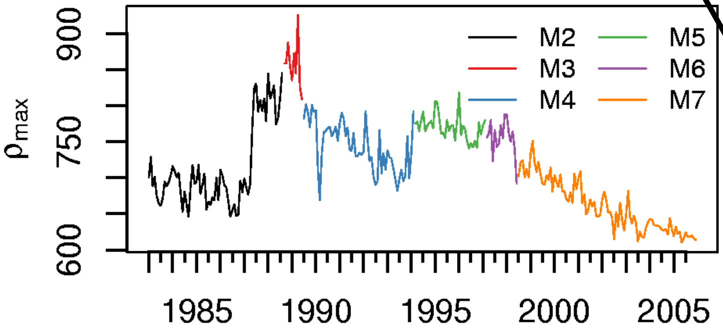
Retrieval for historical radiation datasets

1. Get cloud information
    - All information together give the “effective cloud albedo” (CAL, a.k.a. cloud index) → Heliosat method

$$CAL = \frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}}$$

Cloud image





~ Maximum range of pixel brightnesses

MagicSol

Retrieval for historical radiation datasets

1. Get cloud information
   - All information together give the “effective cloud albedo” (CAL, a.k.a. cloud index) → Heliosat method

$$CAL = \frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}}$$

Cloud image

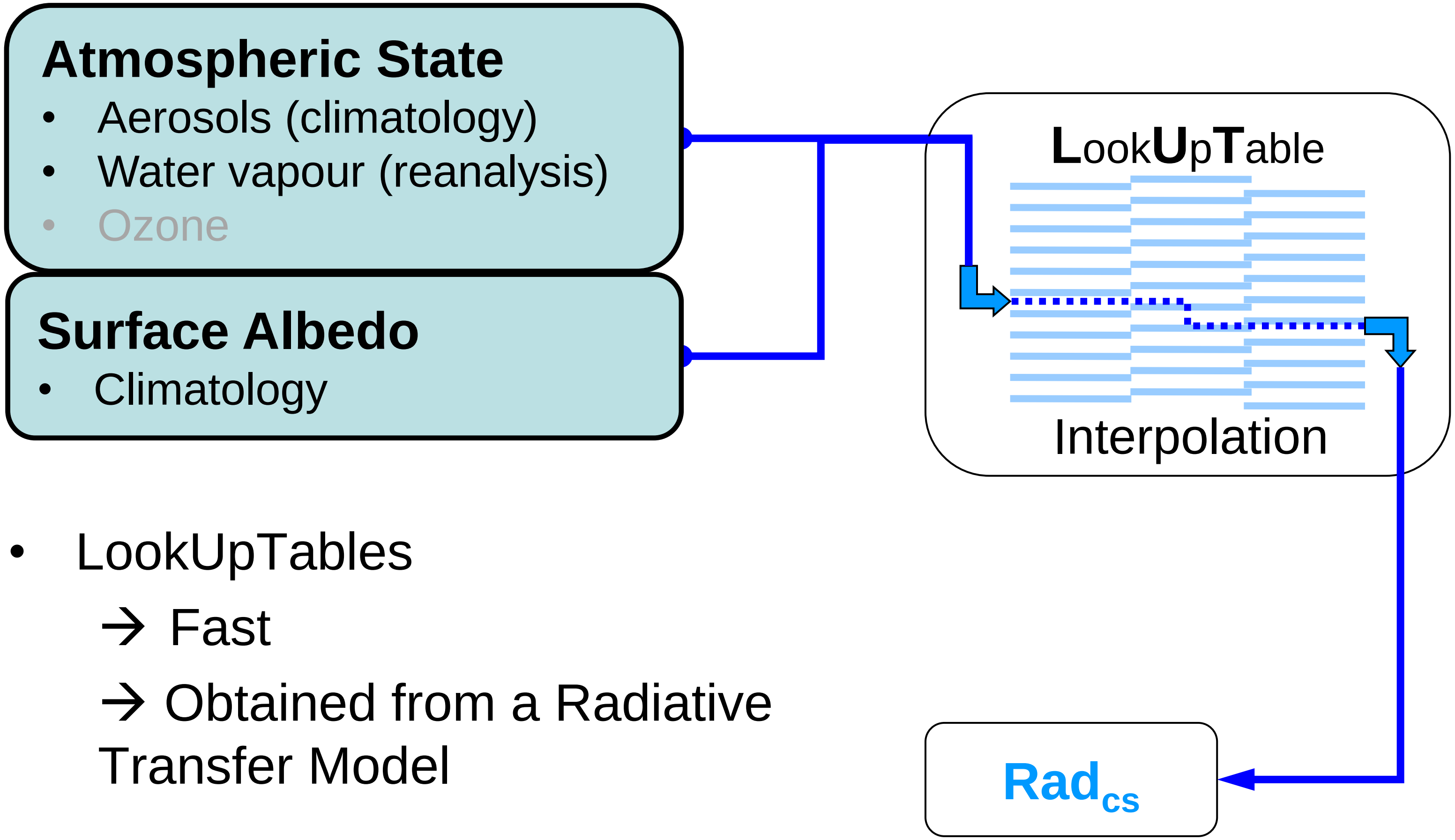
~ Maximum range of pixel brightnesses

- Overcast → $CAL = ?$
- Clear-sky → $CAL = ?$
- Fresh snow → $CAL < 0,\ 0 < CAL < 1,\ CAL > 1$

MagicSol

Retrieval for historical radiation datasets

2. Get clear sky radiation (gnu-magic)



Atmospheric State

- Aerosols (climatology)
- Water vapour (reanalysis)
- Ozone

Surface Albedo

- Climatology

- LookUpTables

  → Fast

  → Obtained from a Radiative Transfer Model

Müller et al. (2009)

http://sourceforge.net/projects/gnu-magic

MagicSol

Retrieval for historical radiation datasets

- Retrieval scheme
  1. Get cloud information
     - "Effective Cloud Albedo" (CAL)
     - From satellite
  2. Get clear sky information
     - "Clear Sky Radiation" (Rad_{cs})
     - From LookUpTables
  3. Combine 1. & 2.

$$\boxed{Rad = f(CAL) \cdot Rad_{cs} \approx (1 - CAL) \cdot Rad_{cs}}$$

→ Rad = SIS or SID

Outline

PART I

Solar radiation (SIS, SID)

- MagicSol – Retrieval for historical radiation datasets
- **LookUpTable radiation retrieval**

Longwave radiation (SDL)

- GAC algorithm (very short)

PART II

Surface albedo (SAL)

LookUpTable

radiation retrieval

- Used for
  - Operational (= regularly updated) radiation products
  - AVHRR-CLARA (GAC) radiation dataset

- Benefits:
  - Physical approach
  - Applicable to geostationary and polar orbiting satellites

- Challenges:
  - Multispectral information required for cloud detection
  - Auxiliary data required (e.g., surface albedo)

LookUpTable

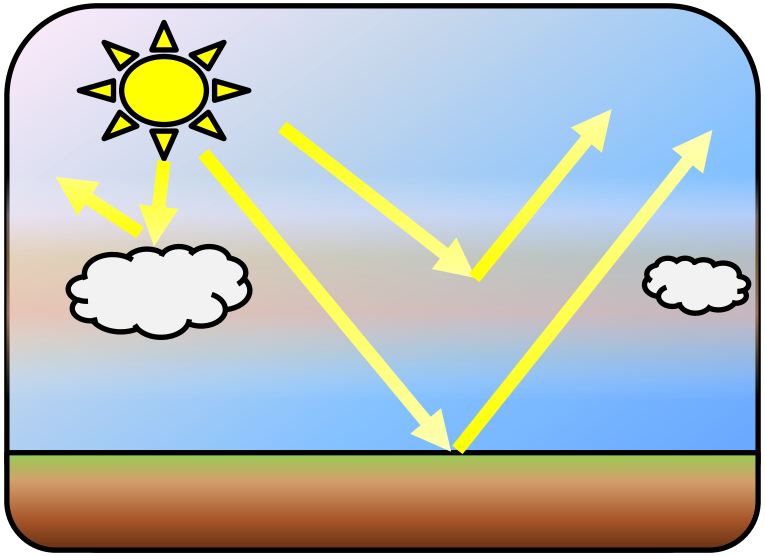
radiation retrieval

- Retrieval scheme
  1. Cloud detection
  2. Cloud free: use clear-sky gnu-magic (see MAGICSOL)

LookUpTable

radiation retrieval

- Retrieval scheme
  1. Cloud detection
  2. <u>Cloudy:</u> Get atmospheric trans-missivity τ from LUT
     - Use satellite and model data as input
  3. Calculate Rad



$$\boxed{Rad = E_0 \cdot cos\Theta_z \cdot \tau}$$

E_0 = solar constant = 1362 Wm^{-2}

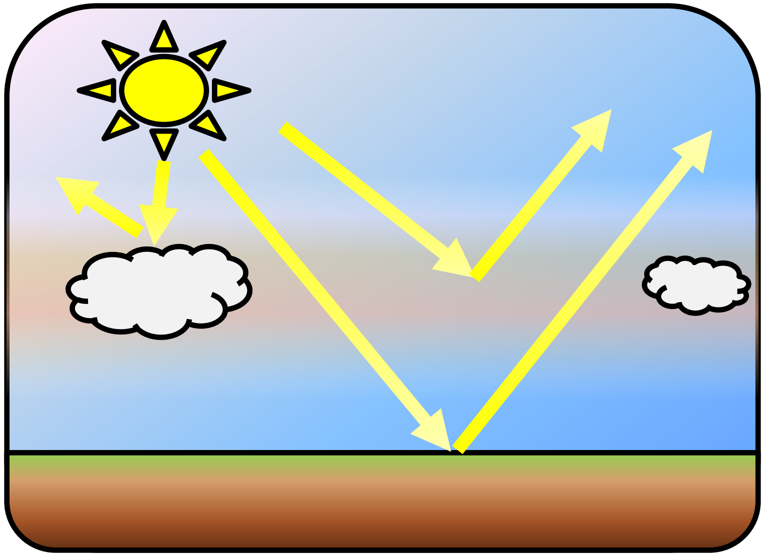
Θ_z = sun-zenith angle

τ = atmospheric transmissivity

LookUpTable

radiation retrieval

- Retrieval scheme
  1. Cloud detection
  2. Cloudy: Get atmospheric trans-missivity τ from LUT
     - Use satellite and model data as input
  3. Calculate Rad



$$\boxed{Rad = E_0 \cdot cos\Theta_z \cdot \tau}$$

E_0 = solar constant = 1362 Wm^{-2} ← known

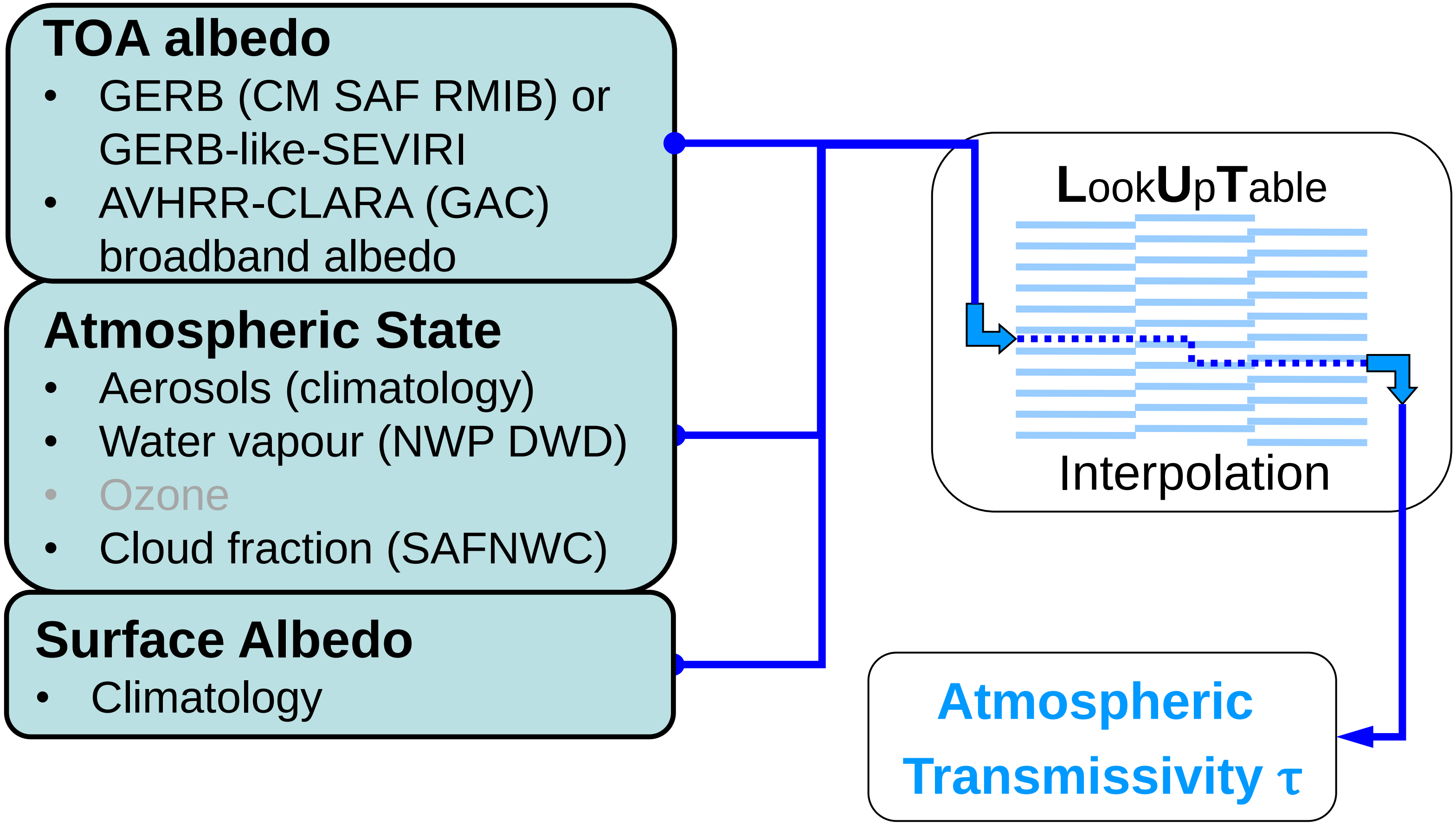
Θ_z = sun-zenith angle ← known

τ = atmospheric transmissivity ← **use cloud-magic**

LookUpTable

radiation retrieval

1. Get atmospheric transmissivity τ (cloud-magic)



TOA albedo

- GERB (CM SAF RMIB) or GERB-like-SEVIRI
- AVHRR-CLARA (GAC) broadband albedo

Atmospheric State

- Aerosols (climatology)
- Water vapour (NWP DWD)
- Ozone
- Cloud fraction (SAFNWC)

Surface Albedo

- Climatology

Atmospheric Transmissivity τ

Müller et al. (2009)

http://sourceforge.net/projects/gnu-magic

LookUpTable

radiation retrieval

- Retrieval scheme
  1. Cloud detection
  2. Cloudy: Get atmospheric trans-missivity τ from LUT
     - Use satellite and model data as input
  3. Calculate Rad

2. Cloud free: use clear-sky gnu-magic (see MAGICSOL)

$$\boxed{Rad = E_0 \cdot cos\Theta_z \cdot \tau}$$

E_0 = solar constant = 1362 Wm^{-2}

Θ_z = sun-zenith angle

τ = atmospheric transmissivity

Outline

PART I

Solar radiation (SIS, SID)

- MagicSol – Retrieval for historical radiation datasets
- LookUpTable radiation retrieval

Longwave radiation (SDL)

- **AVHRR-CLARA (GAC) algorithm** (very short)

PART II

Surface albedo (SAL)

- Arctic-SAL

AVHRR-CLARA (GAC) SDL retrieval - very short

- GAC = “global area coverage”

  = AVHRR instrument (1982-present), polar orbiting

- SDL mainly determined by Temperature and humidity close to the earth’s surface
  - Cannot be observed by satellites

  → all SDL products from satellites need additional data (e.g., reanalysis, NWP)

- CM SAF GAC SDL uses ERA Interim SDL as basis
- Cloud information of GAC are used to refine ERA SDL

Outline

PART I

Solar radiation (SIS, SID)

- MagicSol – Retrieval for historical radiation datasets
- LookUpTable radiation retrieval

Longwave radiation (SDL)

- GAC algorithm (very short)

PART II

Surface albedo (SAL)

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

PART II
SAL retrieval algorithm

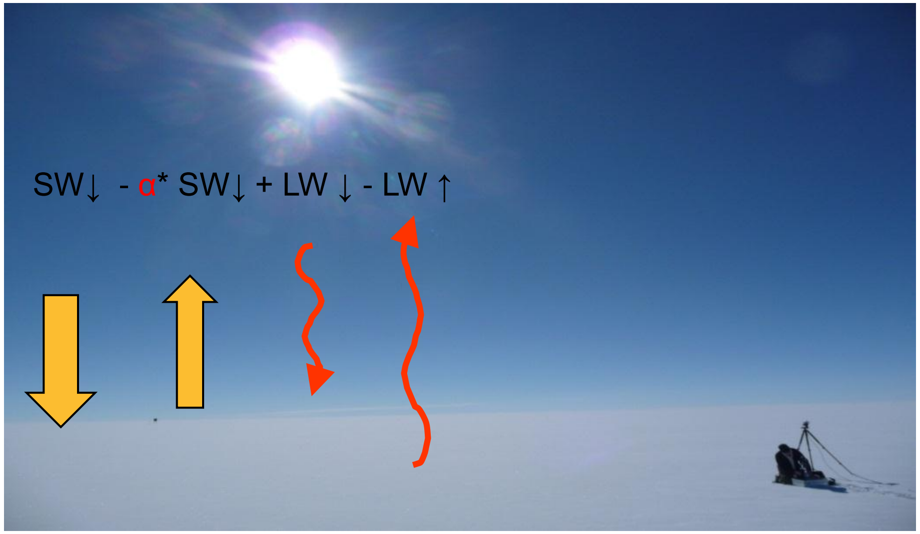
Aku Riihelä

FMI

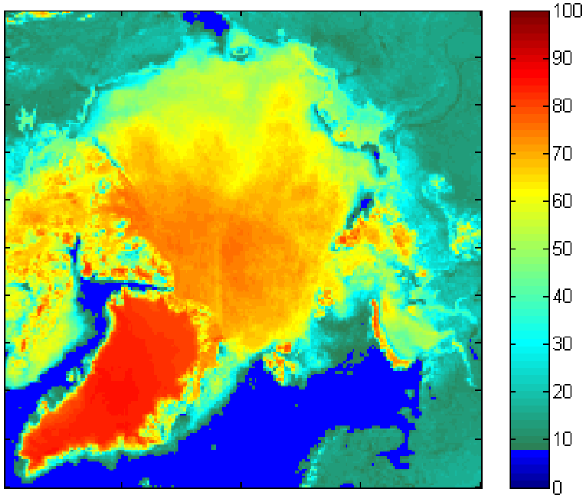
Surface albedo

Radiation budget at surface:
E_{net} = SW↓ – α * SW↓ + LW ↓ - LW↑

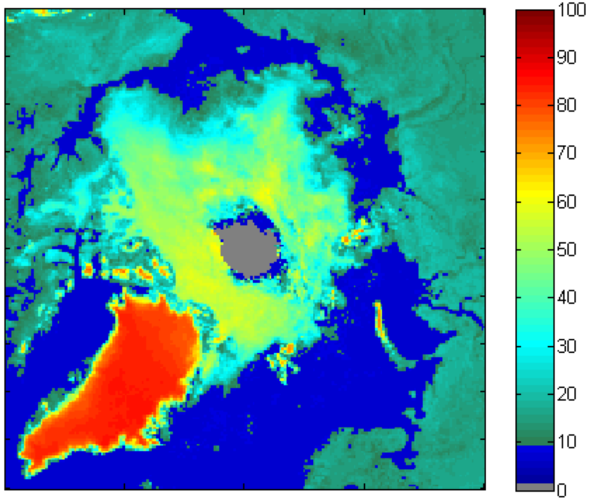
The resulting net energy is available for surface heating, snow melt, heat fluxes etc.



Mean surface albedo of the Arctic, June 2009

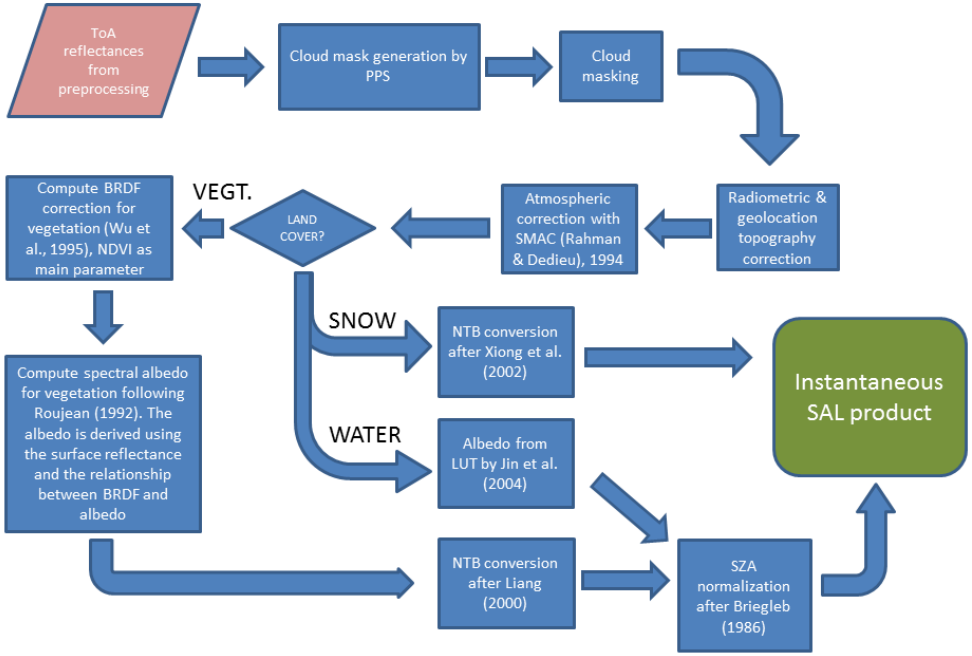


Mean surface albedo of the Arctic, August 2009



The SAL algorithm

- A shortwave black-sky surface albedo product
    - Black-sky = direct solar flux only, all atmospheric effects removed
- A radiometric and geolocation correction for topography effects on AVHRR images
- Dedicated algorithms for vegetated surfaces, snow/ice, and water
- Atmospheric correction with SMAC
- BRDF correction over vegetated surfaces



ToA reflectances from preprocessing

Cloud mask generation by PPS

Cloud masking

Radiometric & geolocation topography correction

Atmospheric correction with SMAC (Rahman & Dedieu), 1994

LAND COVER?

VEGT.

Compute BRDF correction for vegetation (Wu et al., 1995), NDVI as main parameter

Compute spectral albedo for vegetation following Roujean (1992). The albedo is derived using the surface reflectance and the relationship between BRDF and albedo

SNOW

NTB conversion after Xiong et al. (2002)

WATER

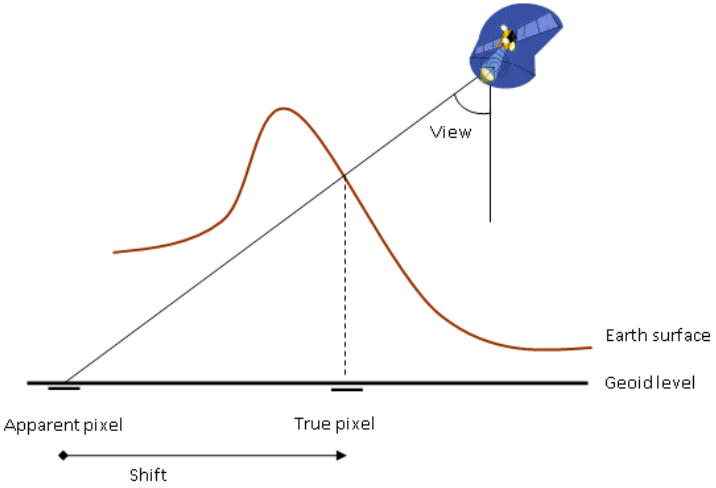
Albedo from LUT by Jin et al. (2004)

NTB conversion after Liang (2000)

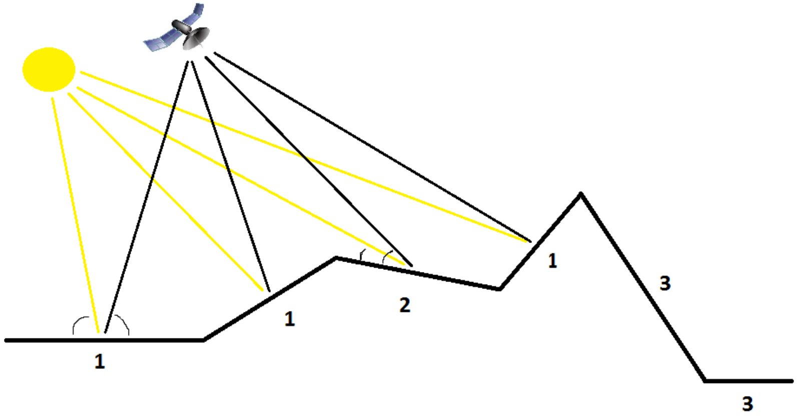
SZA normalization after Briegleb (1986)

Instantaneous SAL product

0. Topography correction



In the first part, we correct the geolocation of the AVHRR pixels for the true terrain height effects using a global DEM



In the second part, we correct the observed reflectances for effects caused by the various slopes and shadowed areas in an AVHRR pixel

1. Atmospheric correction

- Atmospheric effects need to be removed from the observed TOA reflectances

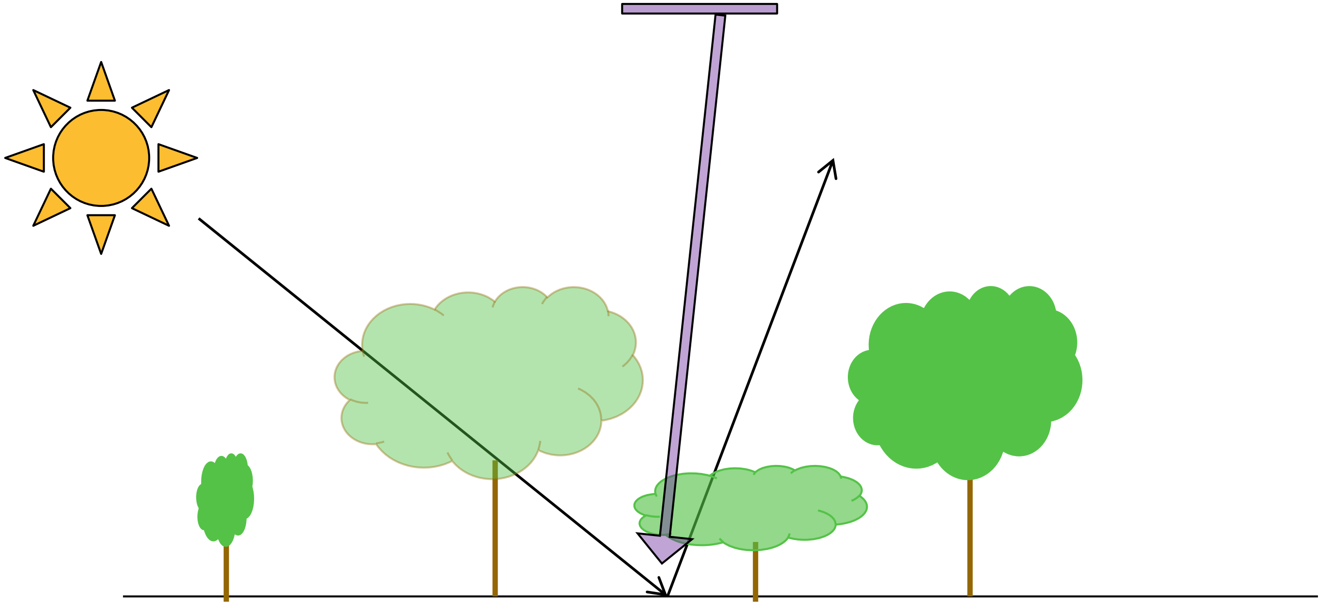
- We use the Simplified Model for Atmospheric Correction (SMAC) [Rahman & Dedieu, 1994].

- **Required Inputs**
  - Visible + near IR TOA reflectances
  - Aerosol Optical Depth (AOD) content of the atmosphere (set constant to 0.1)
  - Total ozone column (O3) (constant at 0.35 (atm cm))
  - Total column water vapour and surface pressure (taken from atmospheric model, ECMWF / DWD (g/cm^2))

2. BRDF correction

- Applied the model of Roujean (1992) with an update by Wu et al. (1995).
- The model considers the bidirectional reflectance of a surface to consist of three ”kernels”:

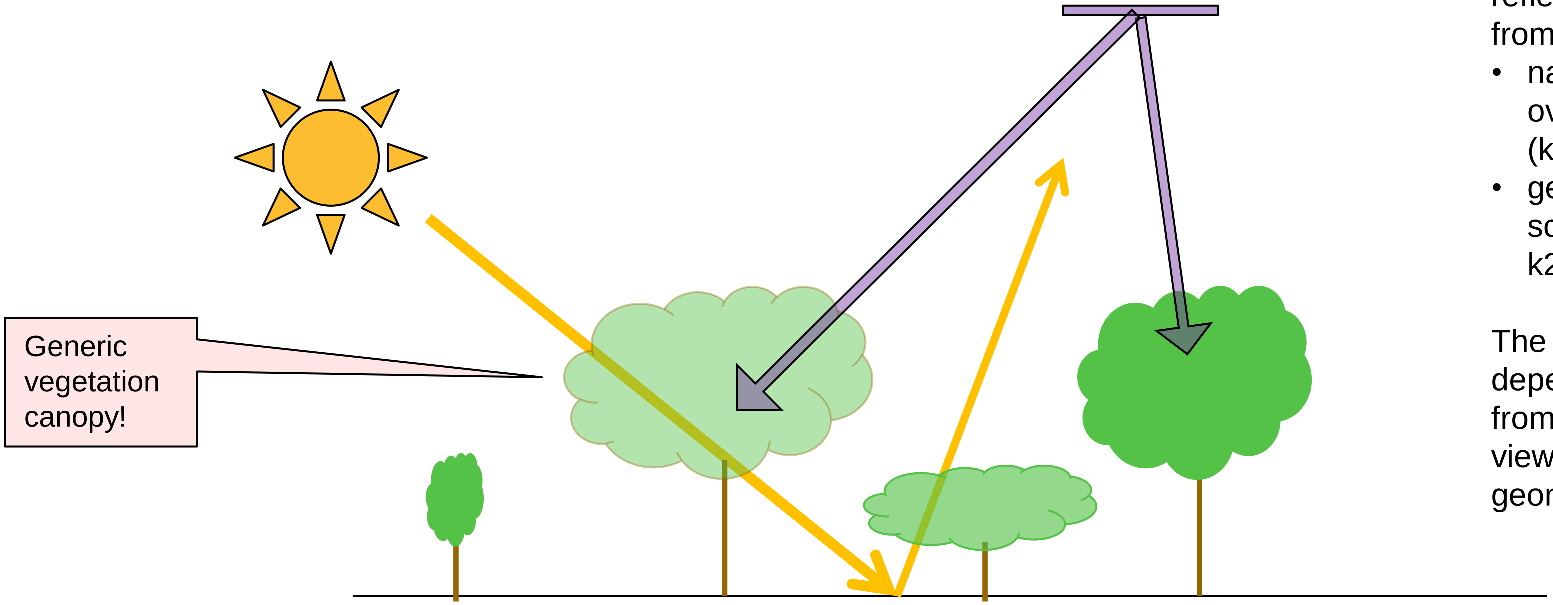
$$\rho = k_0 + \underbrace{k_{geo} f_{geo}} + k_{vol} f_{vol}$$



2. BRDF correction

- Applied the model of Roujean (1992) with an update by Wu et al. (1995).
- The model considers the bidirectional reflectance of a surface to consist of three ”kernels”:

$$\rho = k_0 + k_{geo} f_{geo} + k_{vol} f_{vol}$$



k terms describe the reflectance contributions from:

- nadir-viewing & overhead Sun situation (k0),
- geometric and volume scattering terms k1 and k2.

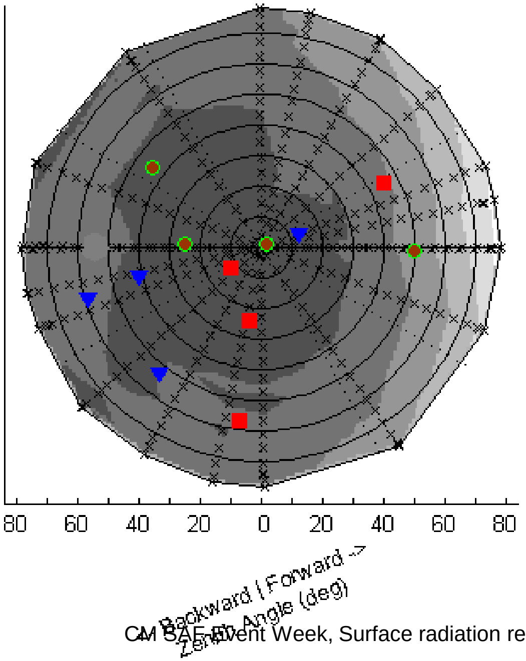
The *f* terms describe the dependency of the model from the viewing/illumination geometry of the scene.

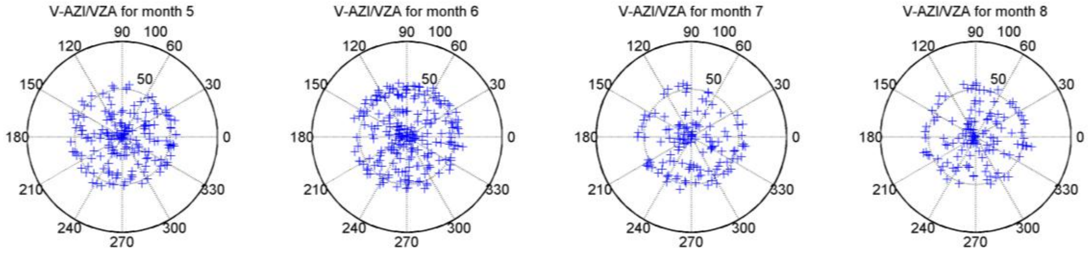
2.5. Anisotropy sampling of snow

- The reflectance anisotropy properties of snow vary widely with snow type!
  - Very difficult to model universally without universal data on snow physical characteristics

- Our solution: sample the anisotropy directly and consider the mean of the samples to represent the albedo.

- The strategy works if we have enough samples of the BRDF…which fortunately is the case when using AVHRR in the high latitudes (where snow exists)!

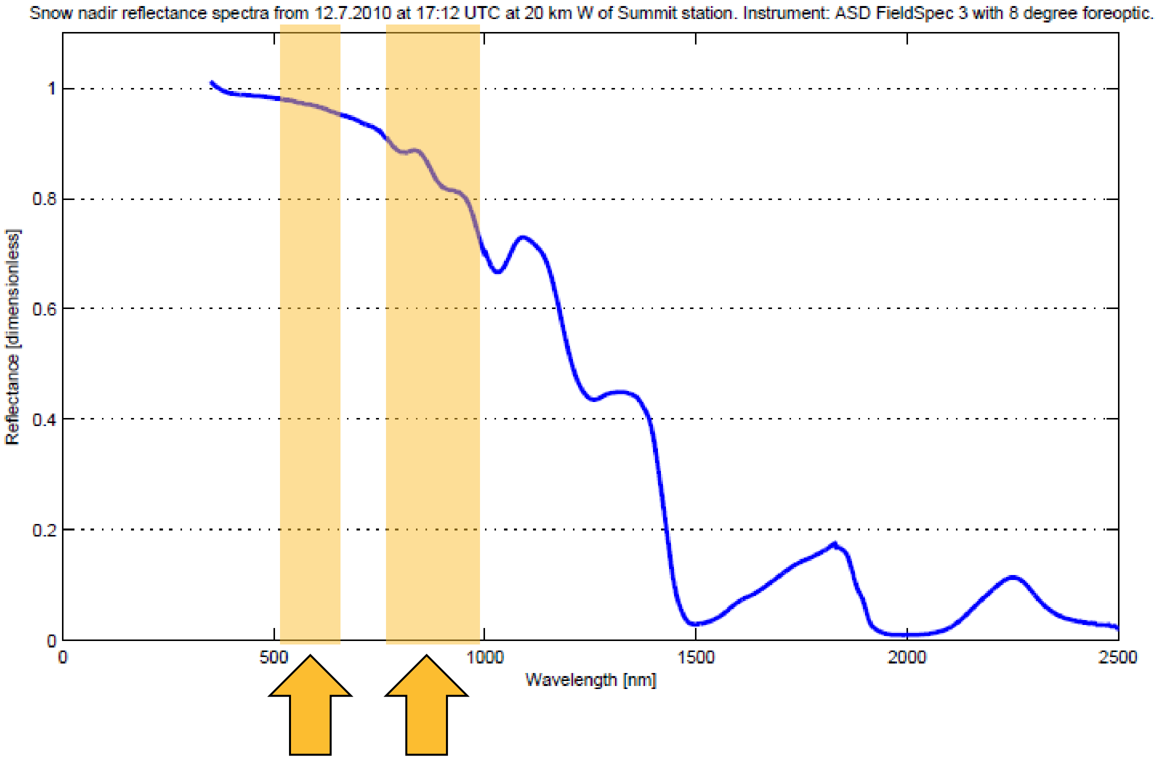




Reflectance sampling distribution at Summit Camp, Greenland Ice Sheet, summer 2005

3. Narrow-to-broadband conversion

Satellite imagers cover only a part of the solar spectrum – algorithms needed to convert observed (spectral) albedo to full broadband albedo!



AVHRR channels 1 & 2

NTBC algorithms separated by instrument (SEVIRI / AVHRR) and land cover (vegetation, snow, water)

Vegetation-AVHRR:
Liang (2000)

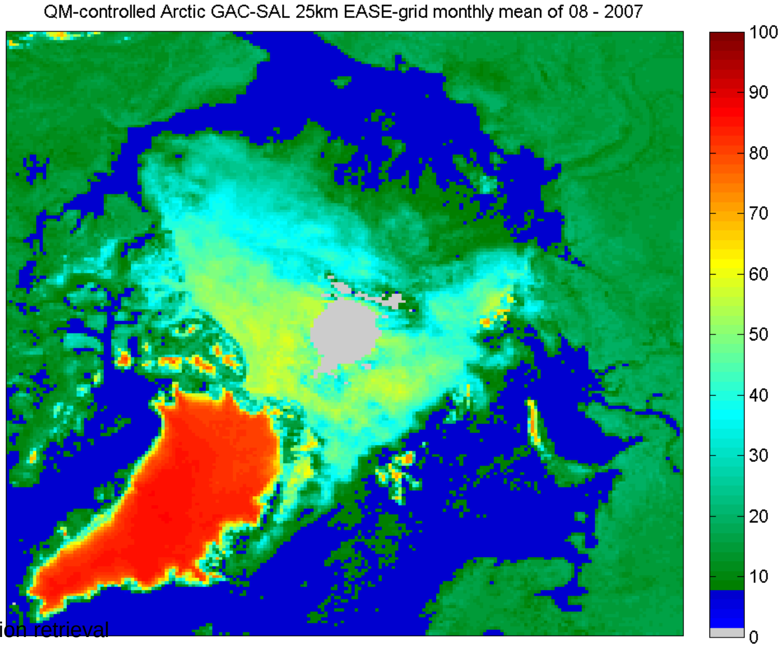
Vegetation-SEVIRI:
Van Leeuwen & Roujean (2002)

Snow:
Xiong et al. (2002)

Water (LUT-based):
Jin et al. (2004)

When all is said and done…

- We have retrieved a broadband black-sky surface albedo for a satellite image*
- The instantaneous images are then projected into a common map grid and averaged over a pentad/week/month to create the product we distribute to You, the user.

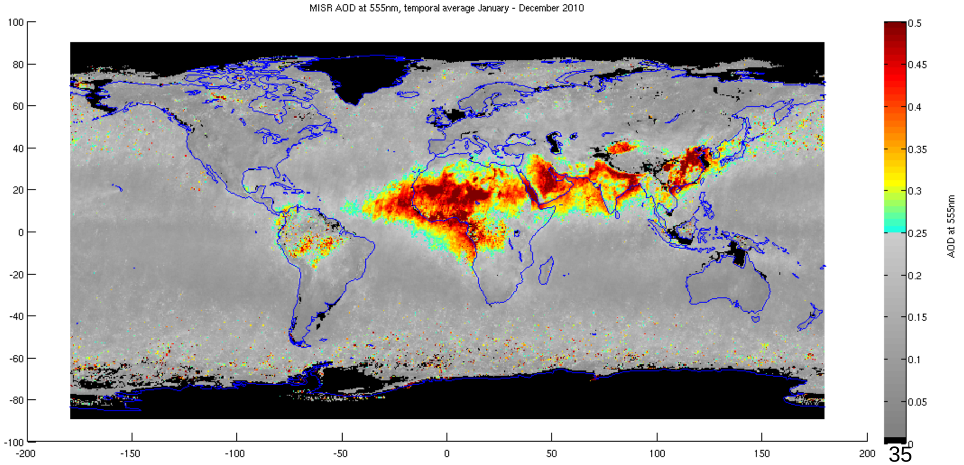


* Multiple images required for a robust snow albedo retrieval

Limitations of the algorithm

1. Sun Zenith Angle of the scene has to be less than 70 degrees and the Viewing Zenith Angle (of the satellite) less than 60 degrees
    - Retrievals would be unreliable outside these bounds
2. Cloud masking errors do occur sporadically
    - Cloud reflectance propagates into an albedo ”retrieval”
3. Aerosols and O3 concentrations currently constant in retrievals
    - Increased uncertainty over areas where AOD is high (see figure below)
    - O3 effect is much smaller than the aerosol effect
4. Coarse resolution (15 km^2, 0.25 degrees, 25 km$^{2)}$ may not allow for accurate small-scale studies

Problems using SAL?
You can contact me at
aku.riihela@fmi.fi



Thanks for tuning in!