CM SAF cloud, surface albedo and surface radiation products from AVHRR 1982-2009

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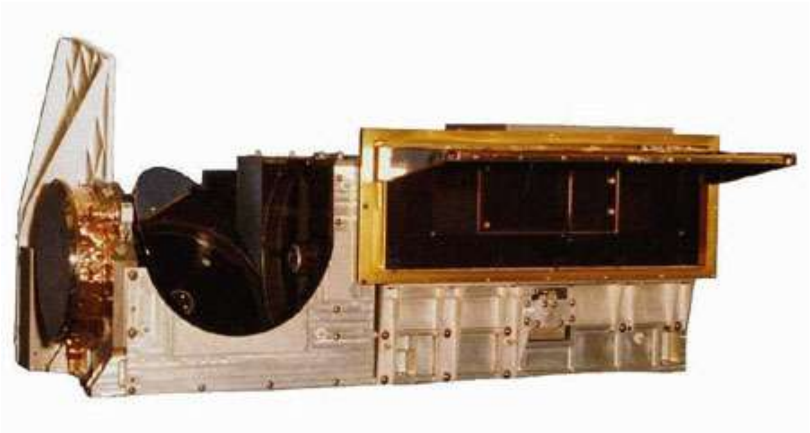
Outline:

- **The historical global AVHRR dataset** *(Karl-Göran)*
  - sensor, satellites, resolution and radiance calibration
- **Description of CLARA cloud products** *(Karl-Göran)*
- **Description of CLARA surface albedo products** *(Aku)*
- **Description of CLARA surface radiation products** *(Aku)*
- **Outlook (CLARA-A2)** *(Aku)*

The historical AVHRR data set

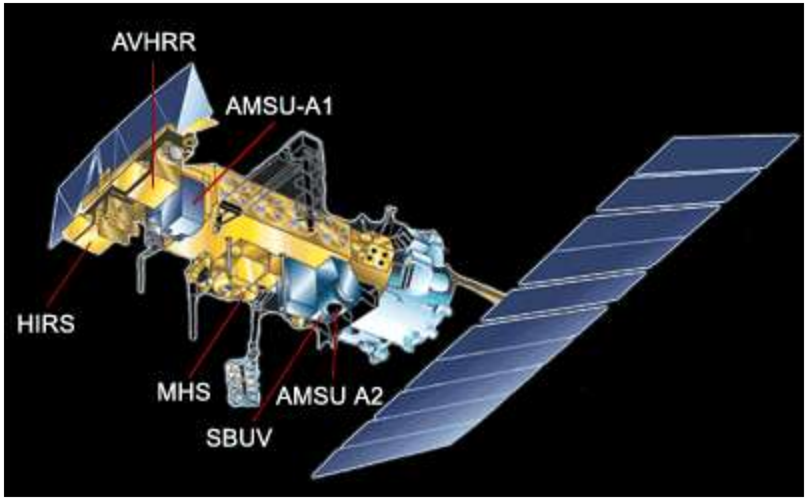
The Advanced Very High Resolution Radiometer – AVHRR



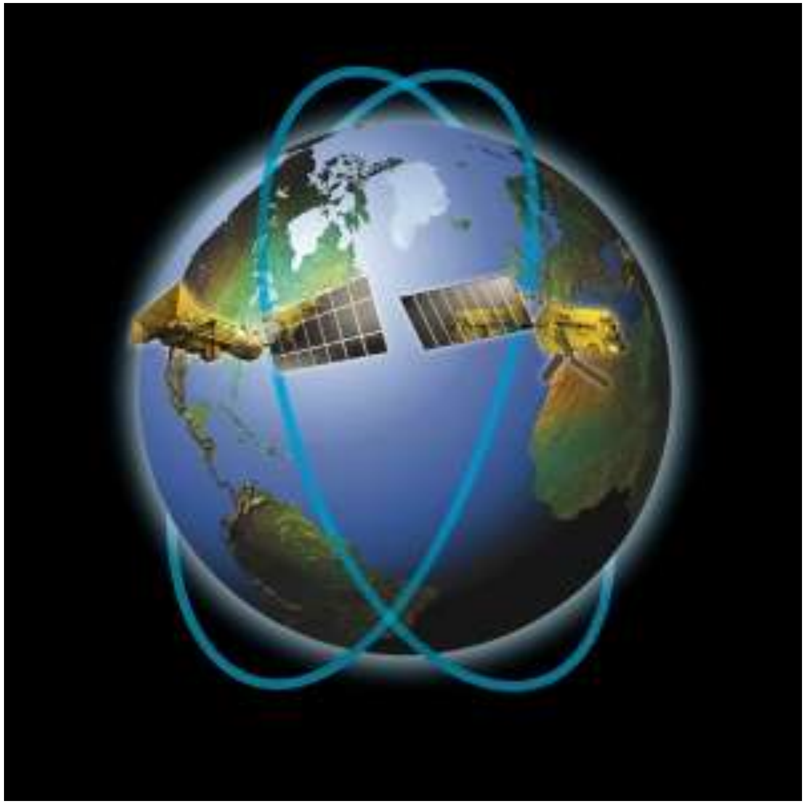
Channel Number	Wavelength (micrometers) AVHRR/1 NOAA-6,8,10	Wavelength (micrometers) AVHRR/2 NOAA-7,9,11,12,14	Wavelength (micrometers) AVHRR/3 NOAA-15,16,17,18 NOAA-19, Metop-A
1	0.58-0.68	0.58-0.68	0.58-0.68
2	0.725-1.10	0.725-1.10	0.725-1.10
3A	-	-	1.58-1.64
3B	3.55-3.93	3.55-3.93	3.55-3.93
4	10.50-11.50	10.50-11.50	10.50-11.50
5	Channel 4 repeated	11.5-12.5	11.5-12.5

The historical AVHRR data set

AVHRR is carried by polar orbiting NOAA and Metop satellites



NOAA satellite and its payload



Orbit configuration of NOAA and Metop satellites

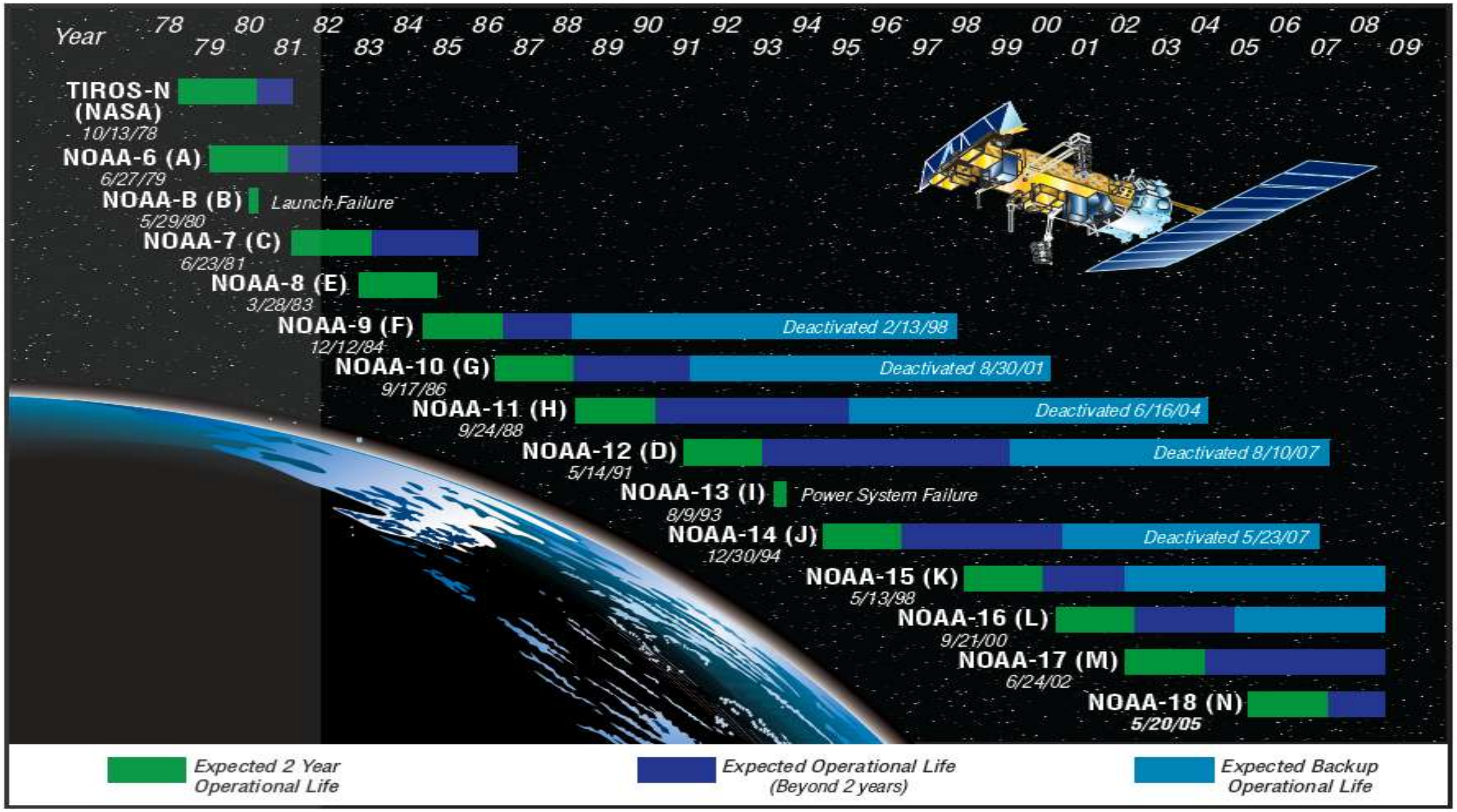
- *Operating in sun-synchronous orbits for two orbit constellations 6 hours apart*

- *NOAA observations at fix local solar times (7:30/17:30 and 13:30/01:30)*

- *Metop observations at 10:00/22:00*

The historical AVHRR data set

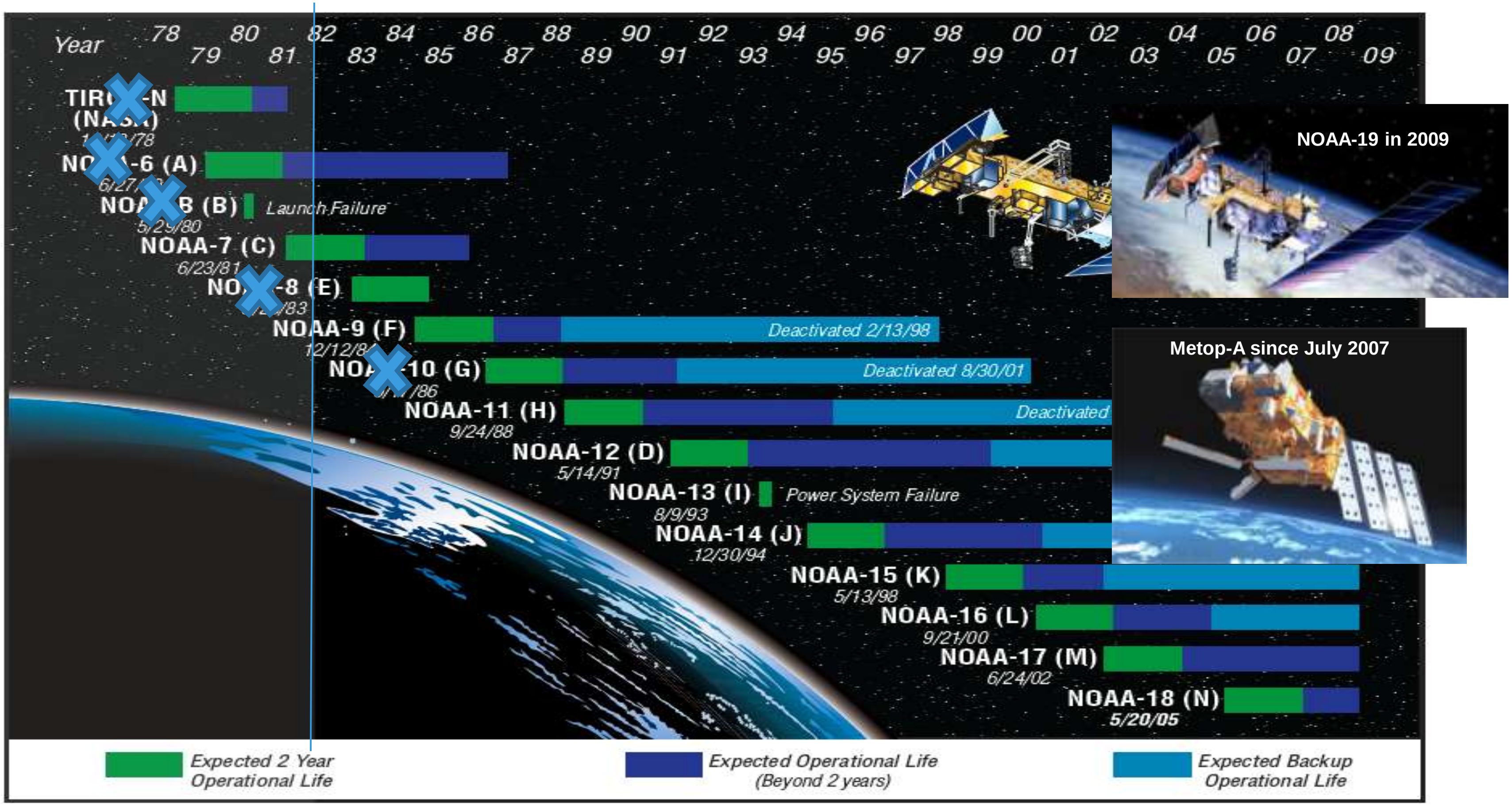
All NOAA satellites used in the CM SAF CLARA dataset 1982-2009



Courtesy of Andrew Heidinger, NOAA

The historical AVHRR data set

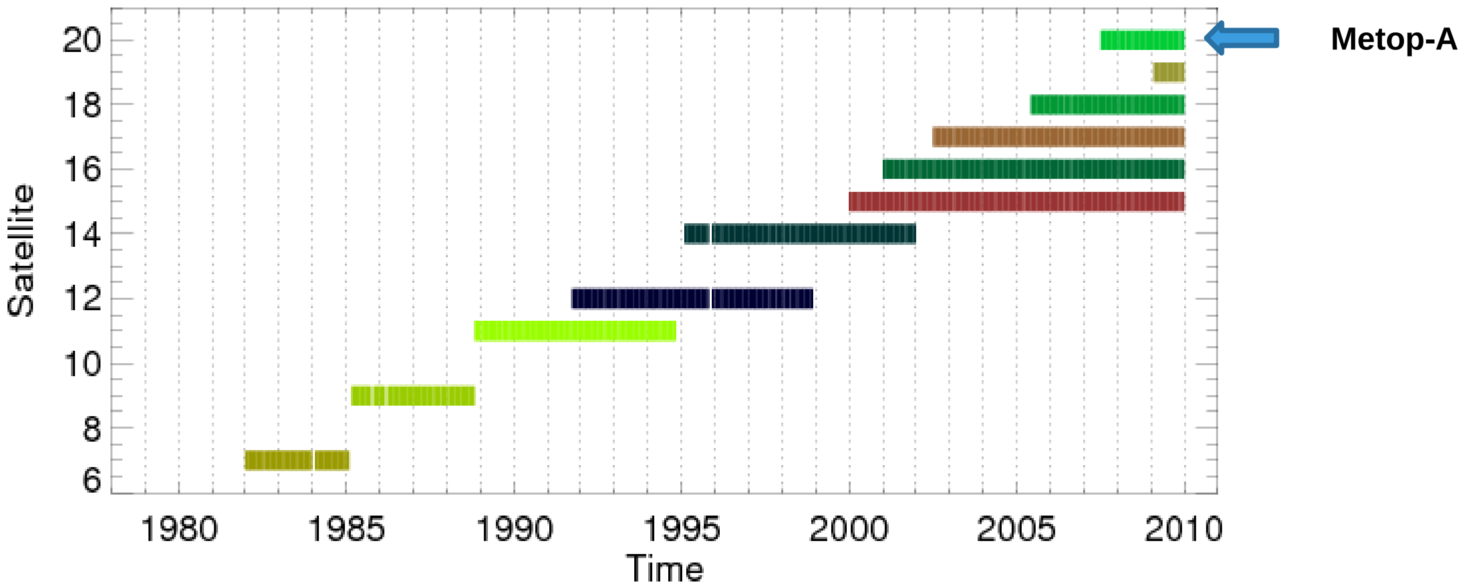
All NOAA satellites used in the CM SAF CLARA dataset 1982-2009



Courtesy of Andrew Heidinger, NOAA

The historical AVHRR data set

All NOAA satellites used in the CM SAF CLARA dataset 1982-2009
- Available time periods for each satellite



Note: Often referred to as the **GAC dataset =** Global Area Coverage AVHRR data provided in a reduced resolution of 4 km

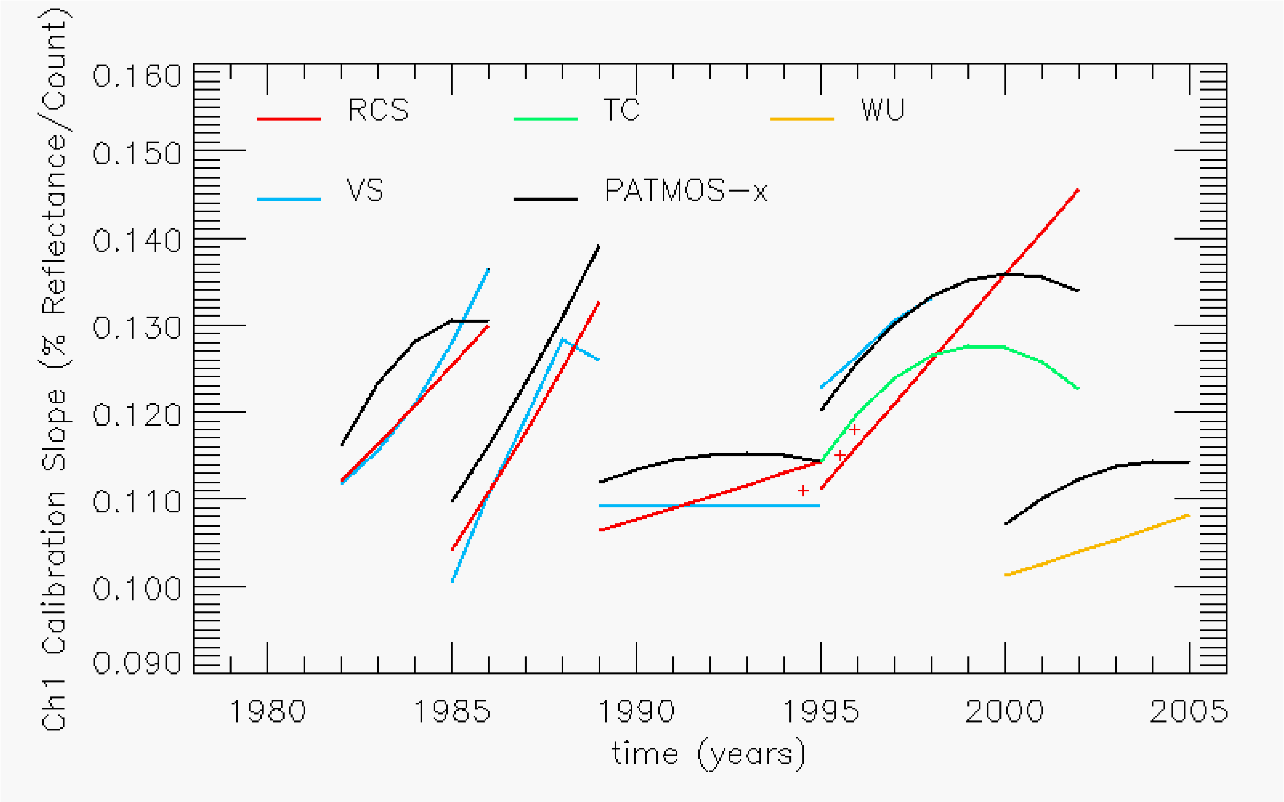
CLARA = CM SAF c**L**ouds, **A**lbedo and **RA**diation dataset

All CLARA products delivered in netCDF format in August 2012

The historical AVHRR data set

Definition of a consistent radiance dataset *(Fundamental Climate Data Record – FCDR)*

CM SAF relies on PATMOS-x FCDR *(Heidinger et al., IJRS, 2010)*



Example of time dependent corrections of calibration constants in AVHRR channel 1 (PATMOS-x black curve) – derived from MODIS and surface site comparisons

CLARA Cloud products

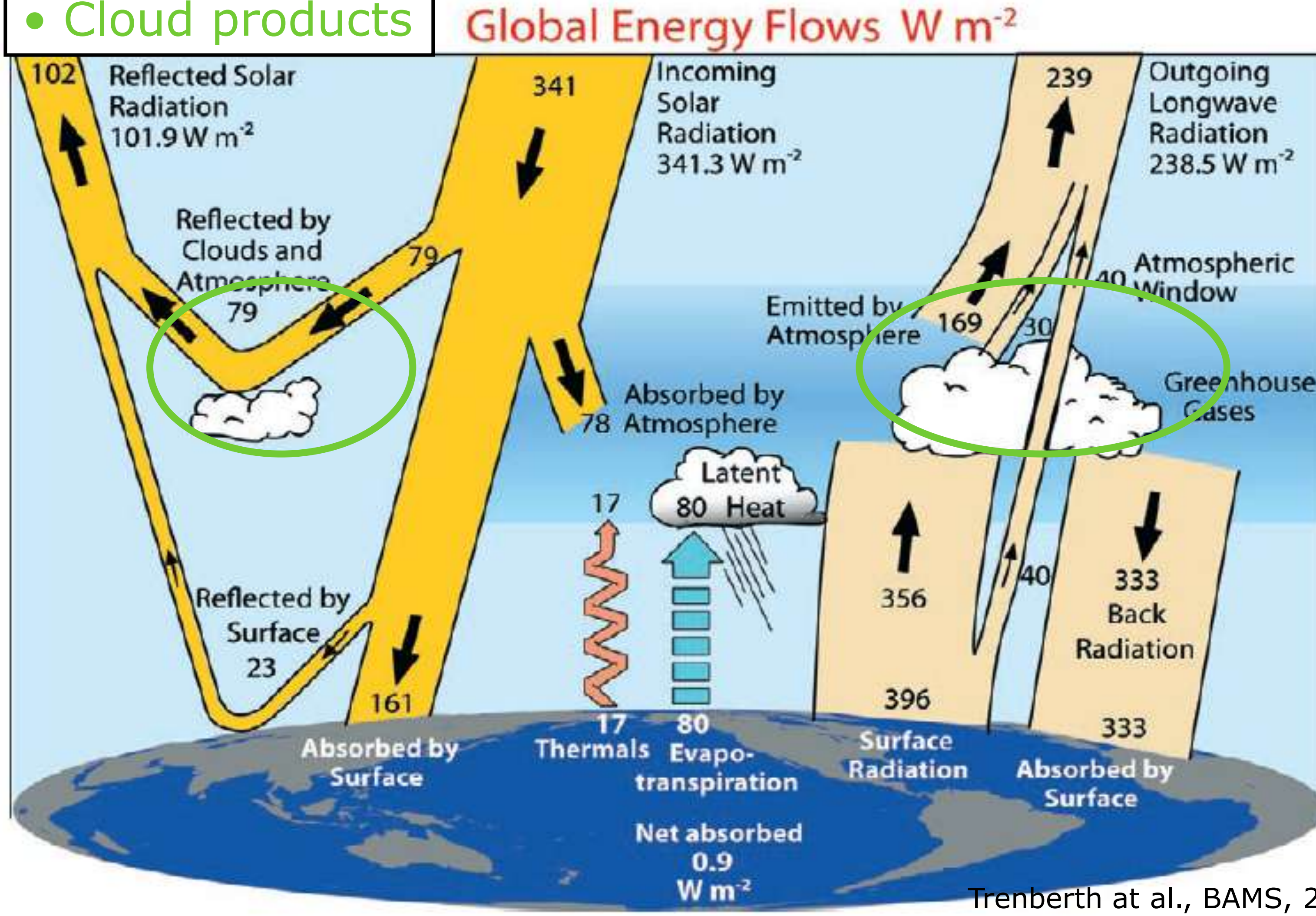
- **Cloud Fractional Cover (CFC)**
- **Cloud Top Level (CTO)**
- **Cloud Optical Thickness (COT)**
- **Cloud Phase (CPH)**
- **Liquid Water Path (LWP)**
- **Ice Water Path (IWP)**
- **Joint Cloud Property Histogram (JCH)**

Algorithm documents and user manuals online! www.cmsaf.eu

Karlsson, K.-G., Riihelä, A., Müller, R., Meirink, J. F., Sedlar, J., Stengel, M., Lockhoff, M., Trentmann, J., Kaspar, F., Hollmann, R., and Wolters, E.: CLARA-A1: a cloud, albedo, and radiation dataset from 28 yr of global AVHRR data, Atmos. Chem. Phys., 13, 5351-5367, doi:10.5194/acp-13-5351-2013, 2013

CLARA Cloud products

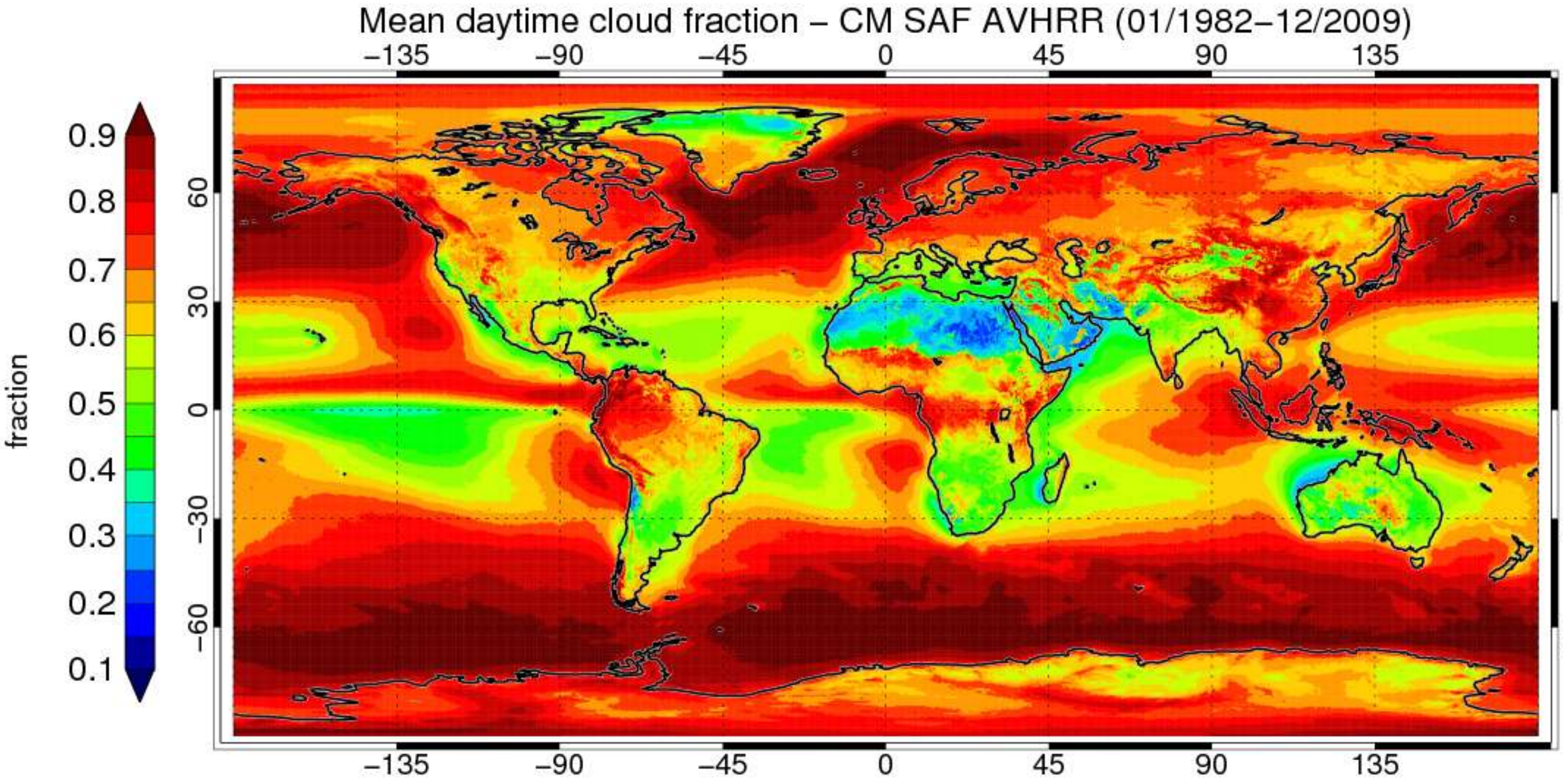
- Cloud products



Trenberth at al., BAMS, 2009

Cloud product composition and options

Spatial grid 1: - Global latitude-longitude grid with 0.25 degree resolution



CLARA Cloud products

Cloud product composition and options

Spatial grid 2: - Two Polar grids with 25 km resolution

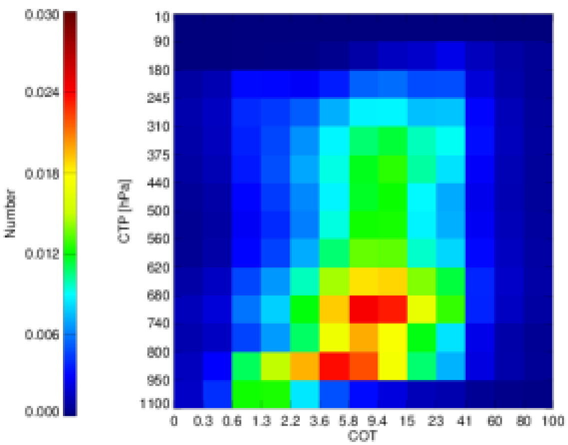
(illustrated later for surface albedo products)

CLARA Cloud products

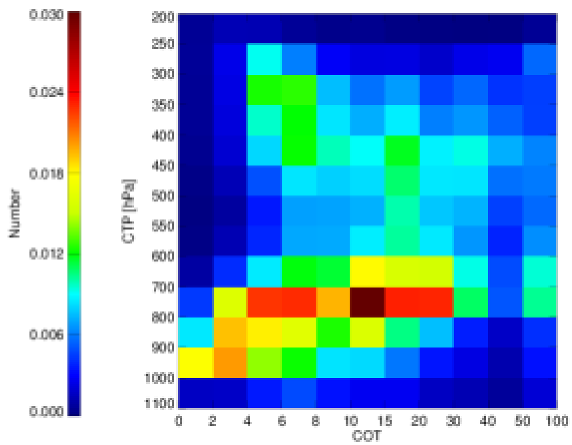
Cloud product composition and options

Spatial grid 3: - Joint histograms defined in 1 degree grid resolution

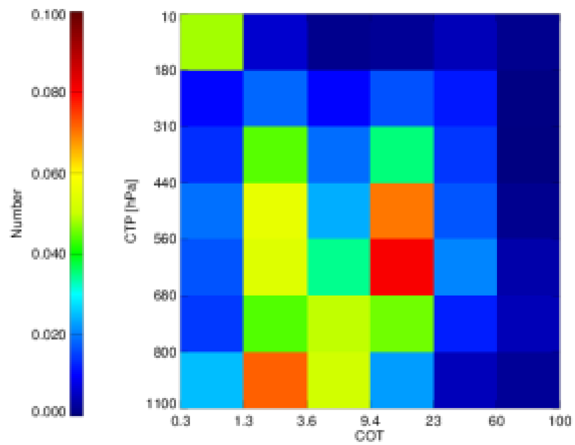
CM SAF



MODIS



ISCCP



Example of JCHs for March 2007 based on all global grid points and for all clouds

- Observe that results can be compiled for user-defined subsets of grid points (regions)!

Cloud product composition and options

Temporal options:

- Products including all data (all orbits) means that averages have been composed with a latitude-dependent temporal resolution *(normally 4 observations per day at the equator increasing up to 28 observations per day at the pole)*

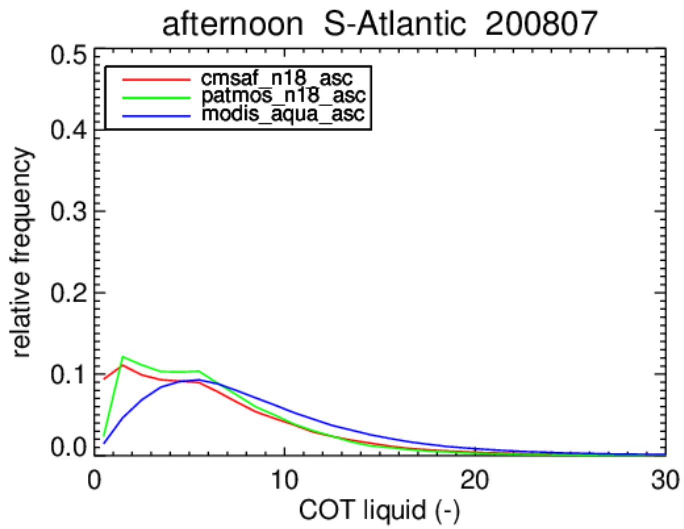
- Sub-setting the dataset is possible, e.g. select results from

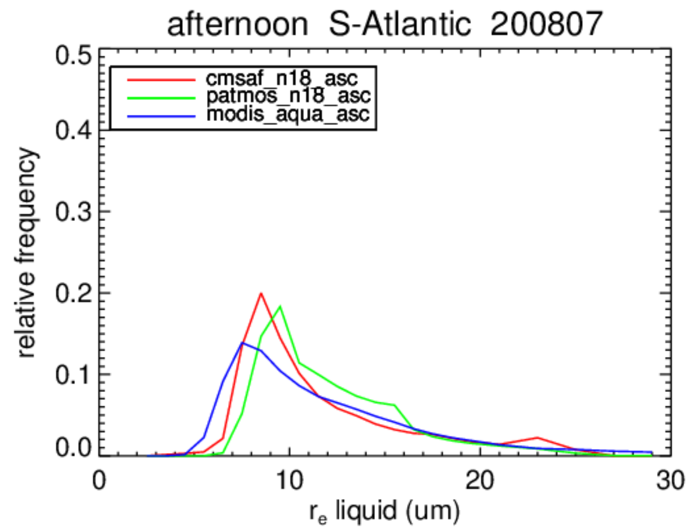
    - Individual satellites
    - Only daytime results (solar zenith angles below 80 degrees)
    - Only night-time results (solar zenith angles above 95 degrees)

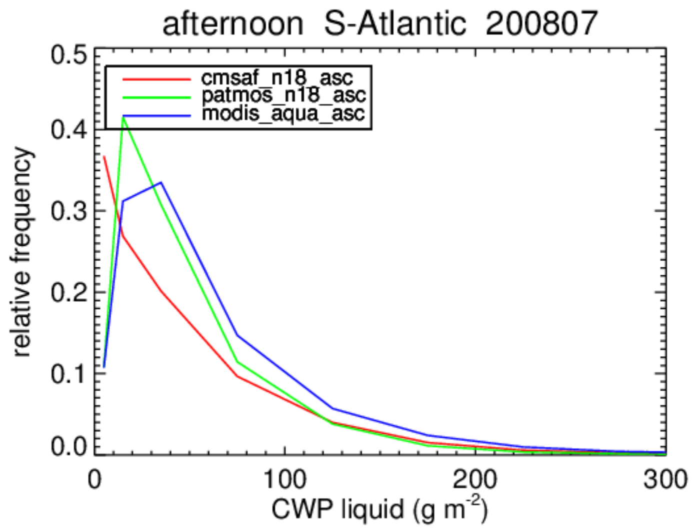
Metadata and auxiliary datasets:

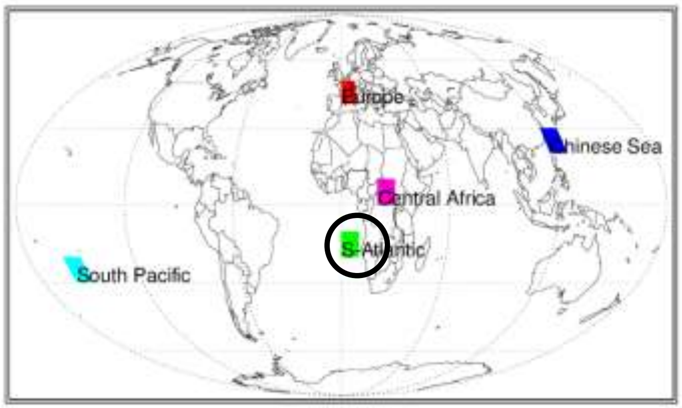
- Products include additional information about e.g. statistical distributions, uncertainties and background information (e.g., topography and land mask)

CLARA evaluation: South Atlantic – liquid water clouds









CLARA evaluation: Summary of results

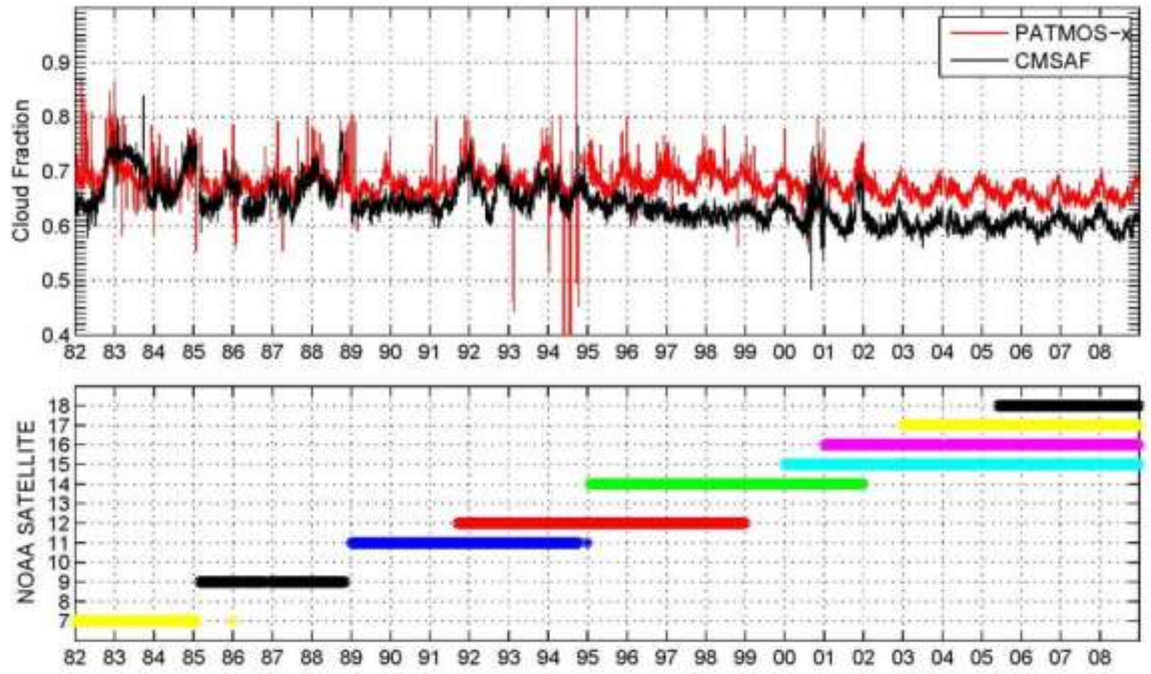
Accuracy requirements are target CM SAF requirements

Product		Accuracy requirement (Mean error or Bias))	Achieved accuracies
Cloud Fractional Cover	(CFC)	10 % (absolute)	3.6 % (SYNOP) -10 % (CALIPSO) -4.1 % (PATMOS-x) -10 % to -20 % (MODIS) 0 % to -12 % (ISCCP)
Cloud Top Height Cloud Top Pressure	(CTH) (CTP)	1200 m 110 hPa	-2661 m (CALIPSO) -20 to 60 hPa (PATMOS-X) -40 to -50 hPa (MODIS) -20 to 60 hPa (ISCCP)
Cloud Optical Thickness	(COT)	15 %	3-20 % (PATMOS-x) -5 % to -10 % (MODIS) 50-60 % (ISCCP)
Cloud Phase	(CPH)	5 % (absolute)	7-15 % (PATMOS-x) 3-20 % (MODIS) 12-15 % (ISCCP)
Liquid Water Path	(LWP)	15 %	+15 % to -26 % (UWisc) 0-30 % (PATMOS-x) 15 % (MODIS) 30-50 % (ISCCP)
Ice Water Path	(IWP)	25 %	0 % to -120 % (PATMOS-x) 0 % to -80 % (MODIS) 30-50 % (ISCCP)
Joint Cloud Histogram	(JCH)	n/a	n/a

Achieved accuracies given for independent datasets (black) and other satellite-based datasets (blue)

CLARA Cloud products

CLARA usage: Warning on global trend analysis



Decreasing trend in global cloud fraction mainly a result of changed observation frequency (more observations in the last ten years in morning and evening when cloud detection is more problematic)

- Daytime-only and night-time only results show no trend!

CLARA Cloud products

Strengths:

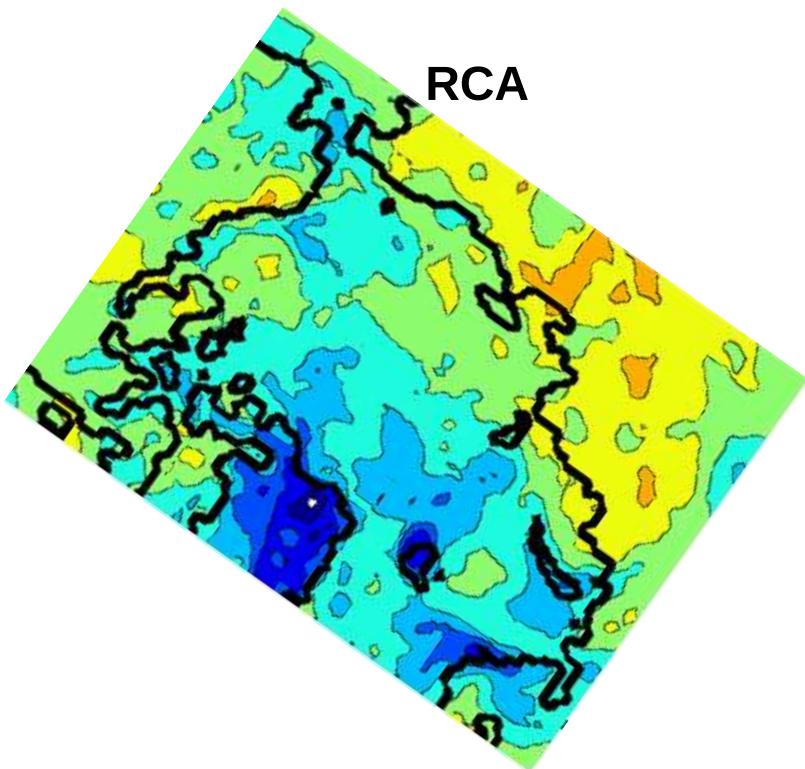
- Global coverage of seven different cloud properties for the longest time record available from satellites
- Best observational coverage over Polar Regions (high quality observations in the Polar summer)
- Rigorously evaluated products – using both independent and other satellite based datasets
- Best quality found for mid- and high latitudes and over all oceans

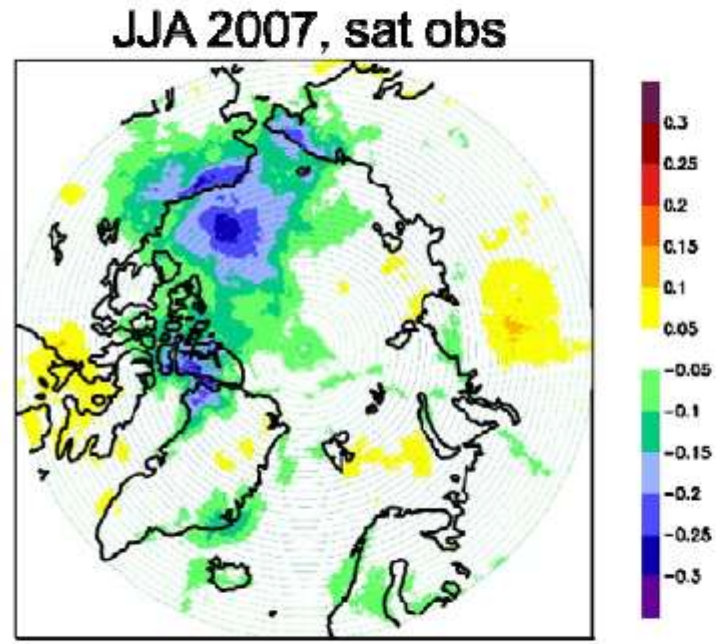
Weaknesses

- Latitude-dependent time sampling (two observations per day and satellite at the Equator increasing to 14 at the Poles)
- Some products relying on reflected solar radiation – only daytime!
- Global trend analyses not possible yet
  - Limited coverage in the first part of the period
  - Cloud amounts underestimated over Polar regions in Polar winter
  - Daytime cloud amounts overestimated over subtropical land areas

Example of application

SMHI Rossby Centre climate simulation (RCA model) of mean cloud cover anomaly (JJA 2007 – relative to 30 years average) over the Arctic region compared to CLARA-A1 anomaly (28 years)





Conclusion: Climate models still not able to simulate Arctic cloudiness properly – one reason for problems to simulate ice extent

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CLARA surface radiation products: Algorithms and applications

Aku Riihelä

FMI

CM SAF 2013 workshop

Online event, 2.10.2013

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CLARA surface radiation products

- **Solar surface irradiance (SIS)**
- **Surface downwelling longwave (SDL)**
- **Surface upwelling longwave (SOL)**
- **Surface albedo (SAL)**
- **Cloud radiative effect shortwave (CFS)**
- **Cloud radiative effect longwave (CFL)**
- **Surface net shortwave (SNS)**
- **Surface net longwave (SNL)**
- **Surface radiation budget (SRB)**

Algorithm documents and user manuals online! www.cmsaf.eu

Karlsson, K.-G., Riihelä, A., Müller, R., Meirink, J. F., Sedlar, J., Stengel, M., Lockhoff, M., Trentmann, J., Kaspar, F., Hollmann, R., and Wolters, E.: CLARA-A1: a cloud, albedo, and radiation dataset from 28 yr of global AVHRR data, Atmos. Chem. Phys., 13, 5351-5367, doi:10.5194/acp-13-5351-2013, 2013

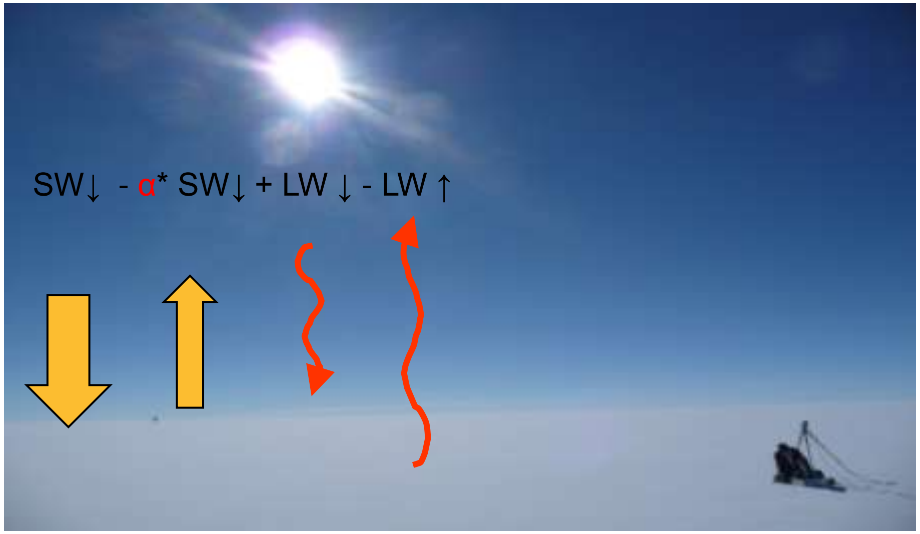
Surface albedo

Radiation budget at surface:

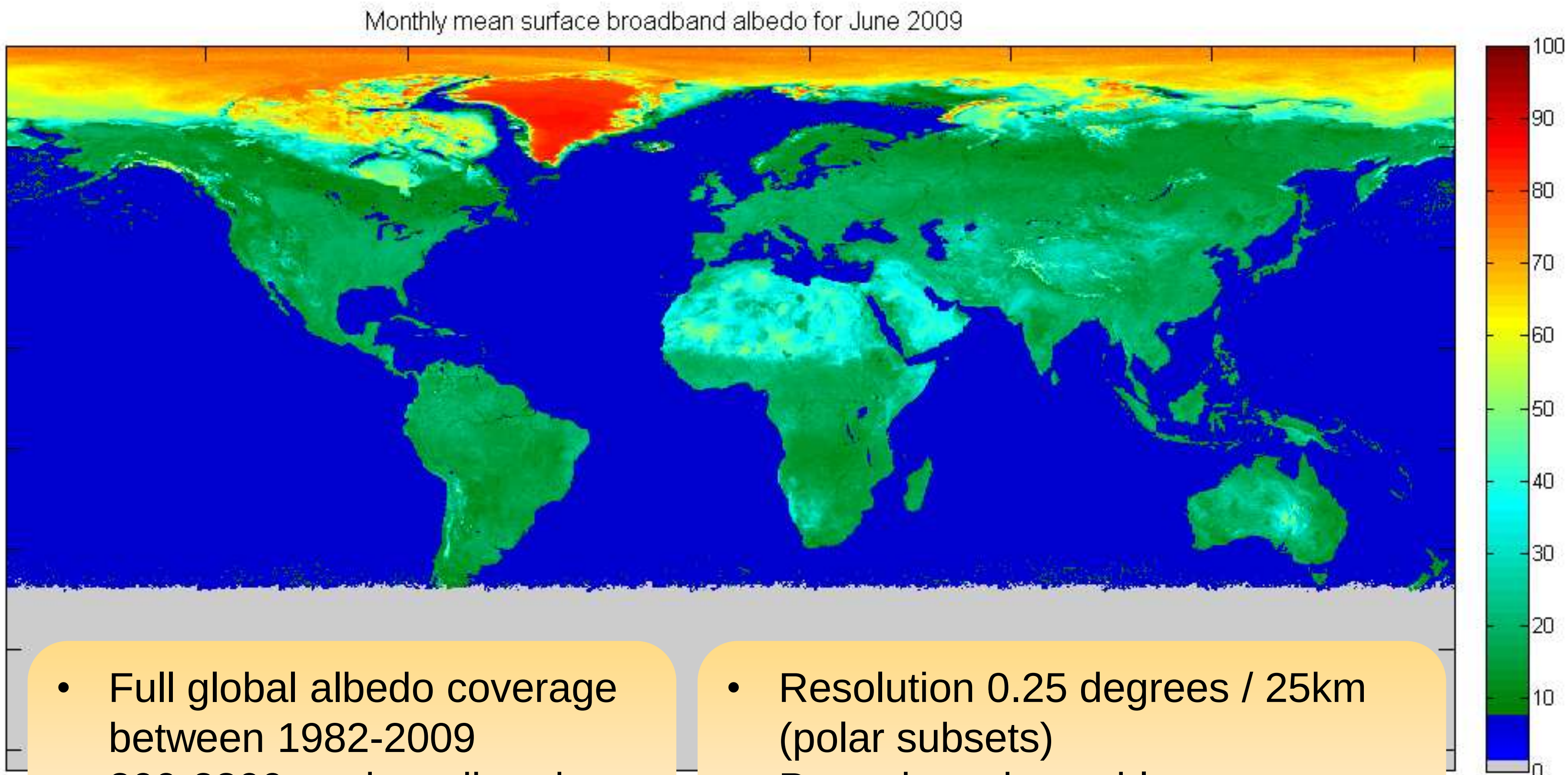
E_{net} = SW↓ – α * SW↓ + LW ↓ - LW↑

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

Image courtesy of NSIDC



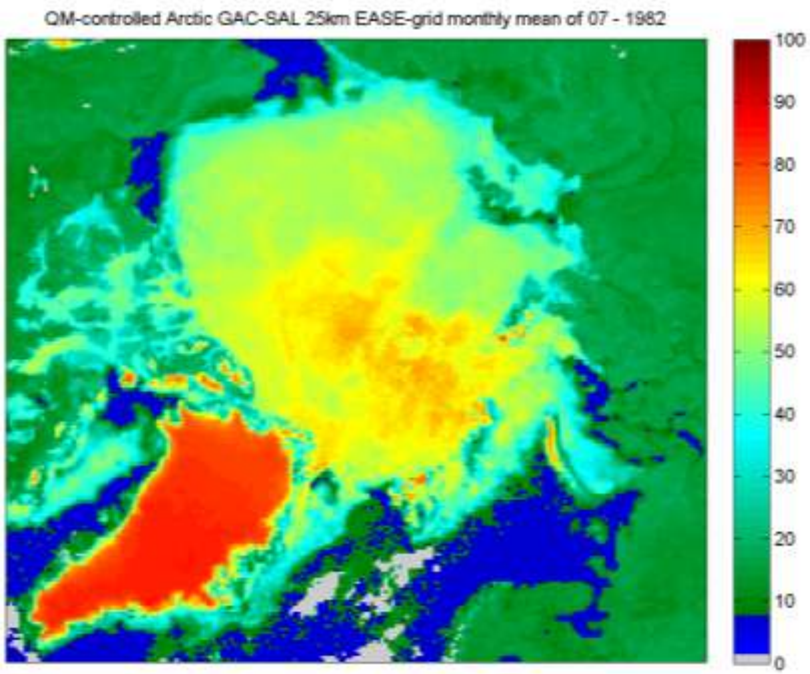
The CLARA-A1-SAL (AVHRR release 1)

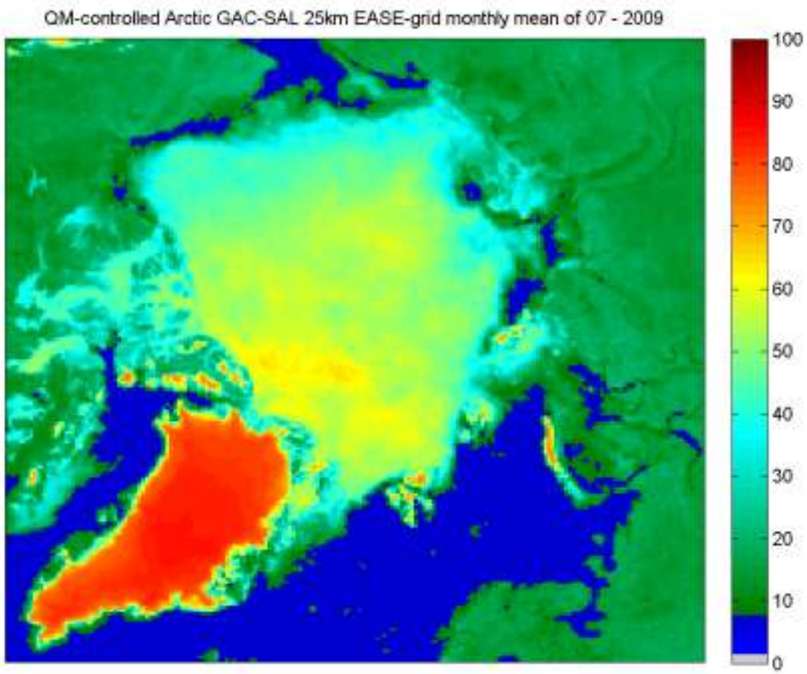


- Full global albedo coverage between 1982-2009
- 300-2800 nm broadband
- Black-sky albedo (BSA)

- Resolution 0.25 degrees / 25km (polar subsets)
- Pentads and monthly means
- Based on a radiance FCDR

The CLARA-A1-SAL (AVHRR release 1)





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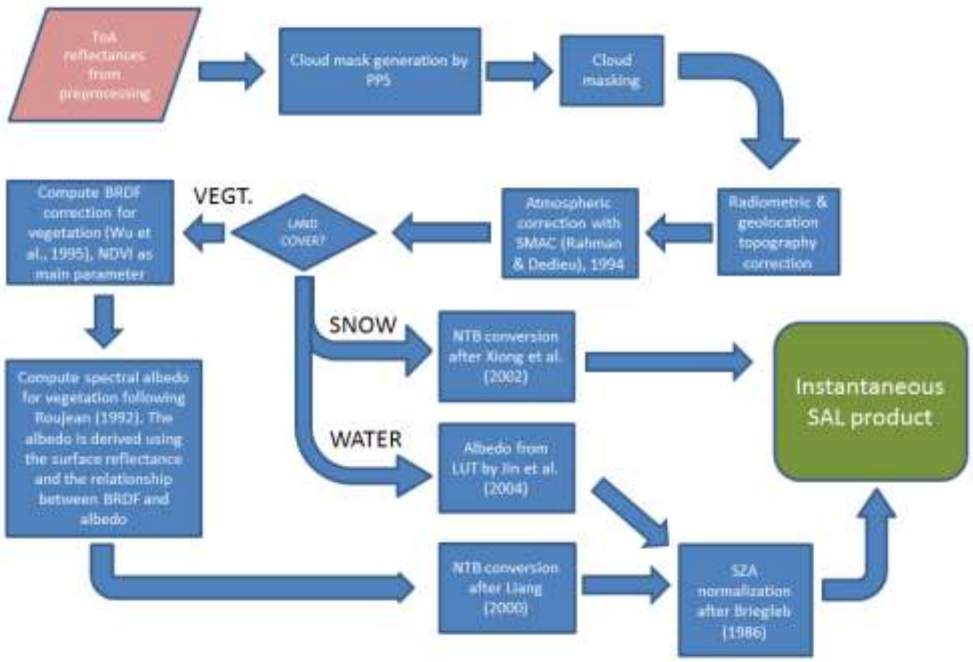
Algorithm introduction

(don’t worry, it will be brief)

The SAL algorithm

- A shortwave black-sky surface albedo product
- 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



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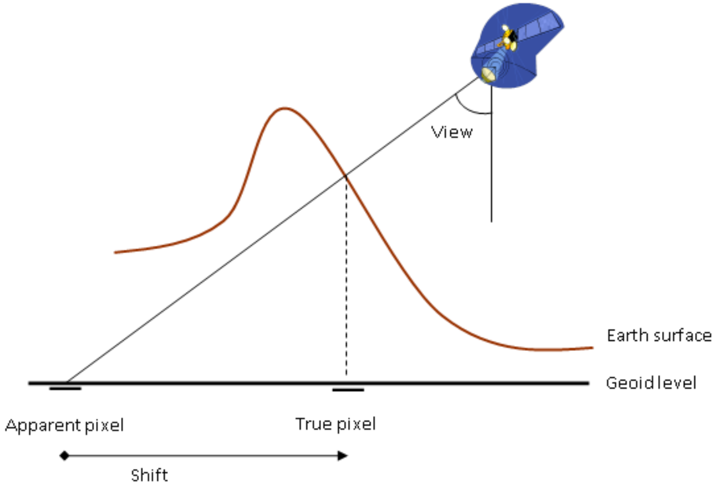
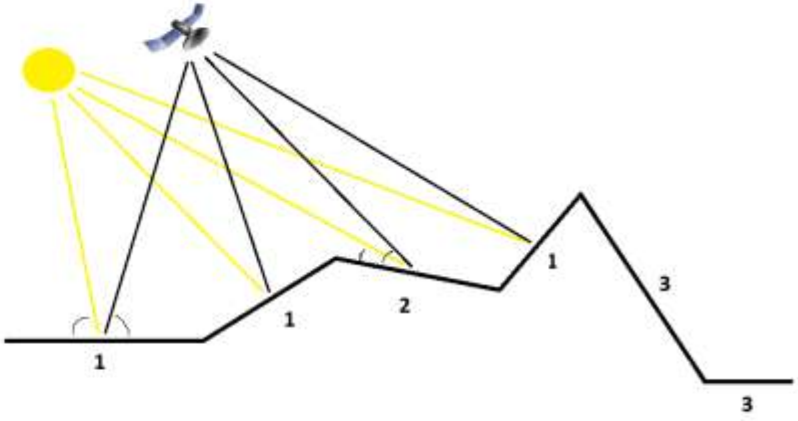
0. Topography correction



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 (path radiance) need to be removed from the observed TOA reflectances to generate direct-illumination-only surface reflectances for black-sky albedo computation.

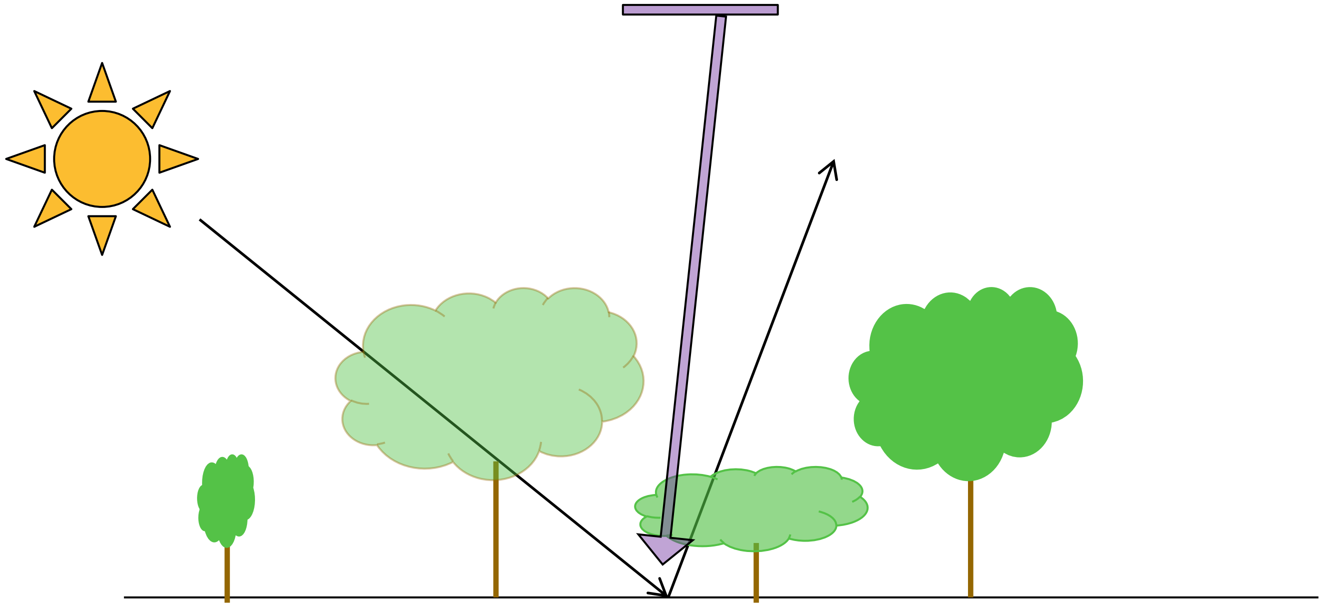
- The Simplified Model for Atmospheric Correction (SMAC) is our algorithm of choice for this operation [Rahman & Dedieu, 1994].

- Inputs
  - TOA reflectances in the visible and near-infrared imager bands
  - Aerosol Optical Depth (AOD) content of the atmosphere, <u>currently constant at 0.1</u>
  - Total ozone column (O3), currently constant at 0.35 (atm cm)
  - Total column water vapour content, from ECMWF ERA-Interim reanalysis (g/cm^2)
  - Surface pressure, from ECMWF ERA-Interim

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”:

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



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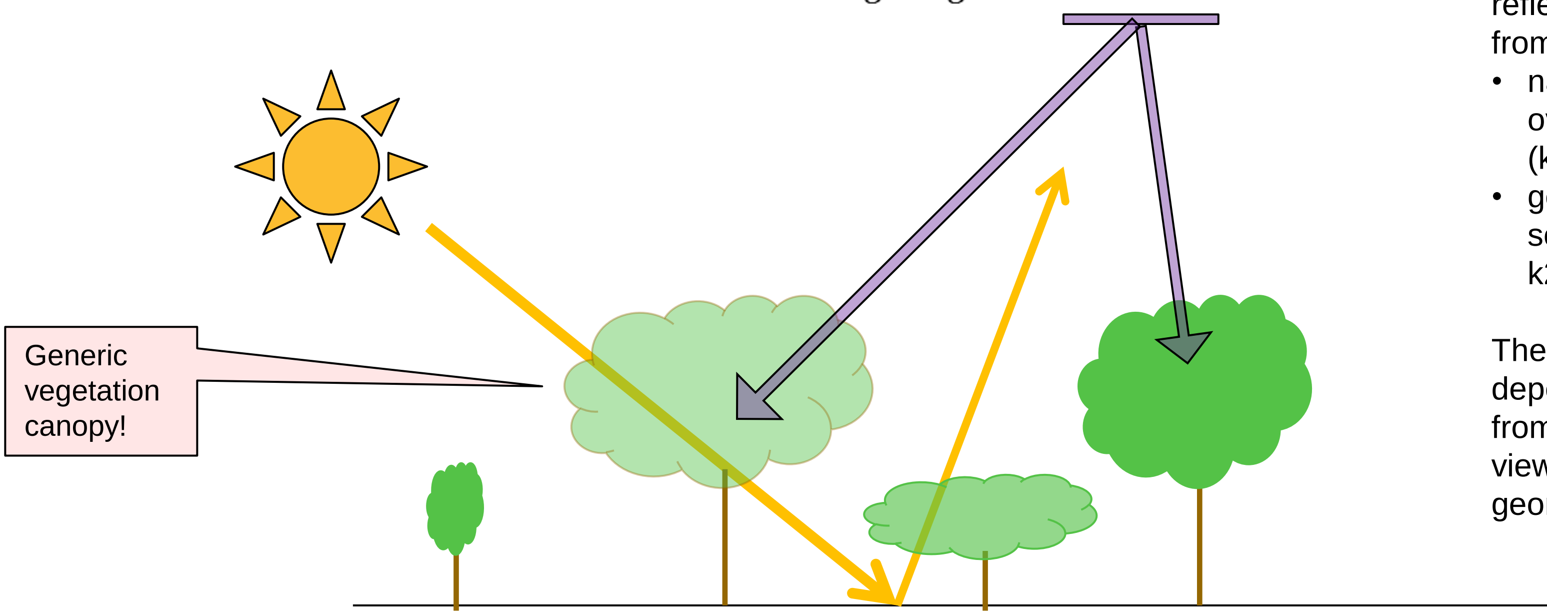


k terms describe the reflectance contributions from:

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

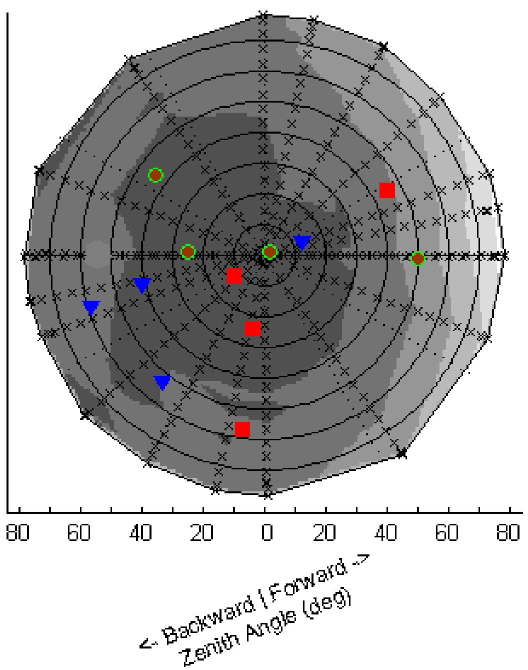
The *f* terms describe the dependency of the model from the viewing/illumination geometry of the scene.

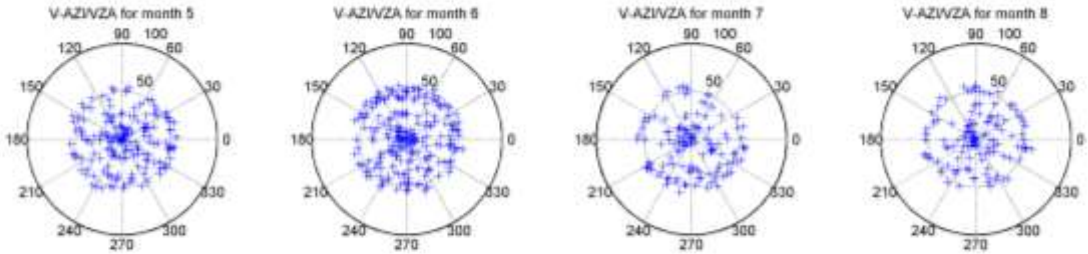
2.5. Anisotropy sampling of snow

- 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: Do not apply a model, in stead 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)!

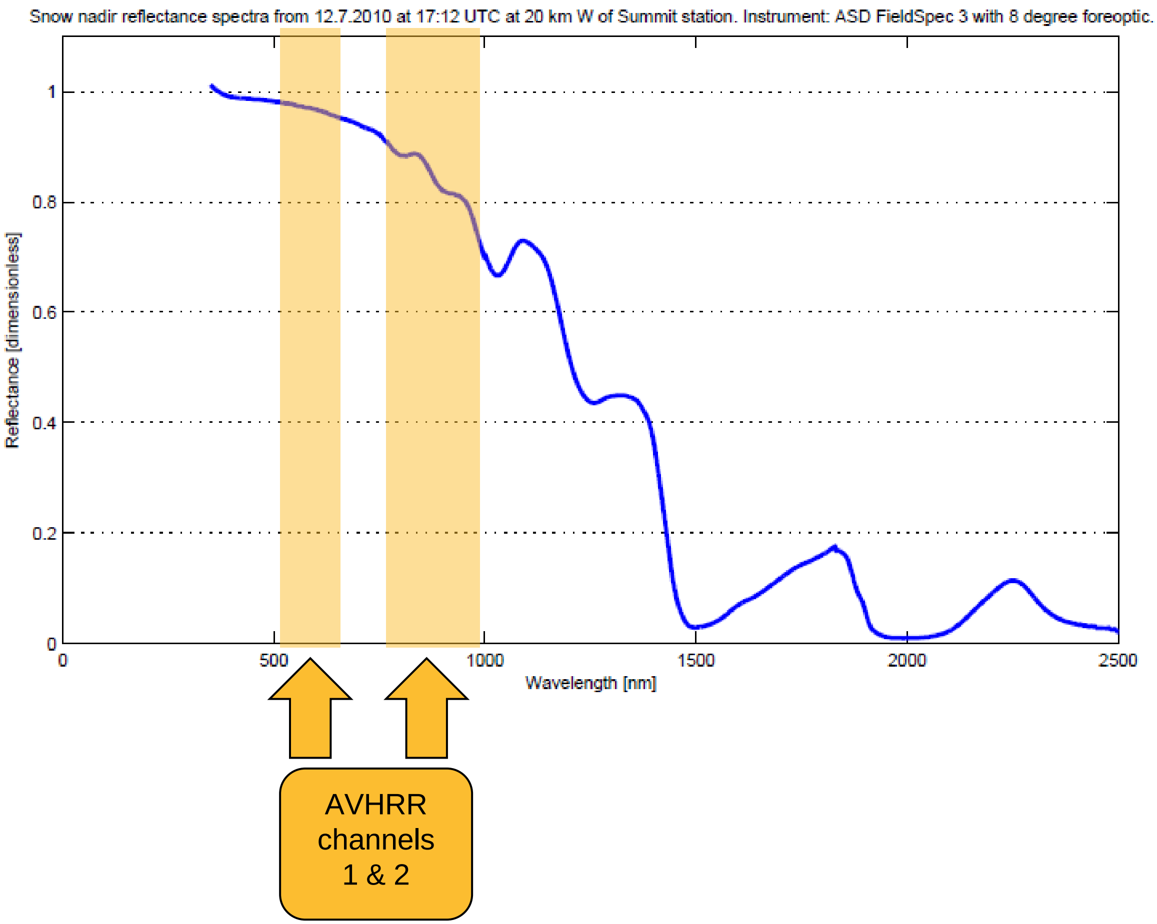




Reflectance sampling distribution at Summit Camp, Greenland Ice Sheet, summer 2005. Radial distance shows viewing zenith angles, azimuthal angles as shown.

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!



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

Vegetation-AVHRR:
Liang (2000)

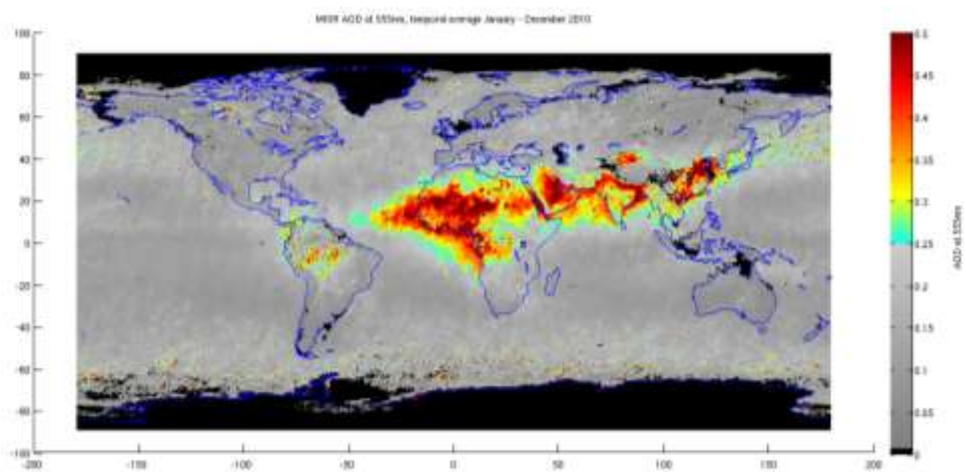
Vegetation-SEVIRI:
Van Leeuwen & Roujean (2002)

Snow:
Xiong et al. (2002)

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

Limitations of the algorithm

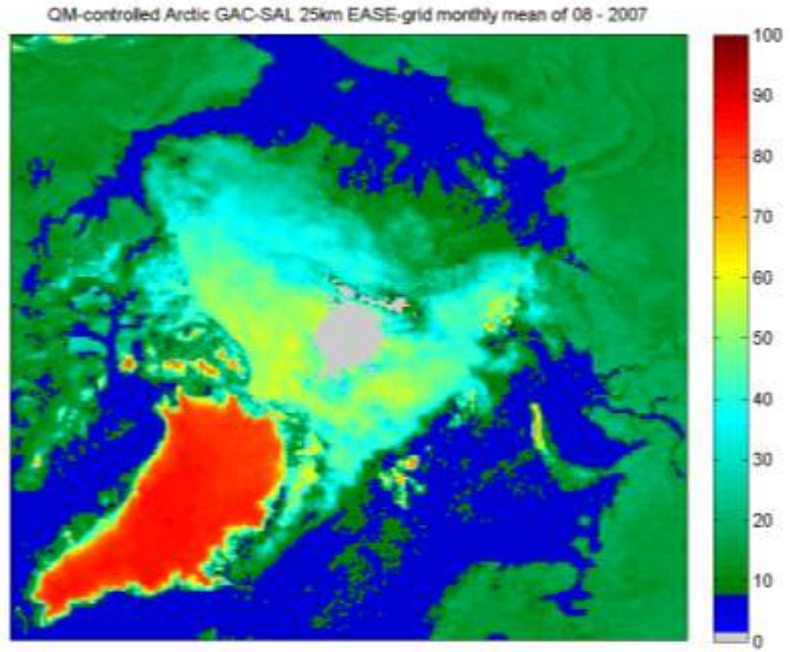
1. Sun Zenith Angle of the scene has to be less than 70 degrees and the Viewing Zenith Angle (of the satellite) less than 60 degrees
    - Retrievals would be unreliable outside these bounds
2. Cloud masking errors do occur sporadically
    - Cloud reflectance propagates into an albedo ”retrieval”
3. 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

When all is said and done…

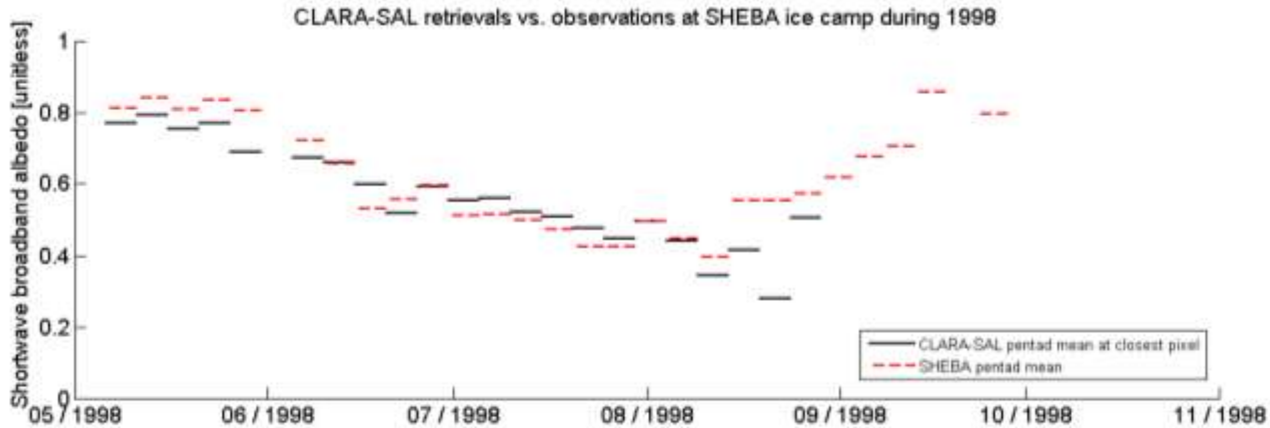
- We have retrieved a broadband black-sky surface albedo for a satellite image*
- The instantaneous images are then projected into a common map grid and averaged over a pentad/week/month to create the product we distribute to You, the user.

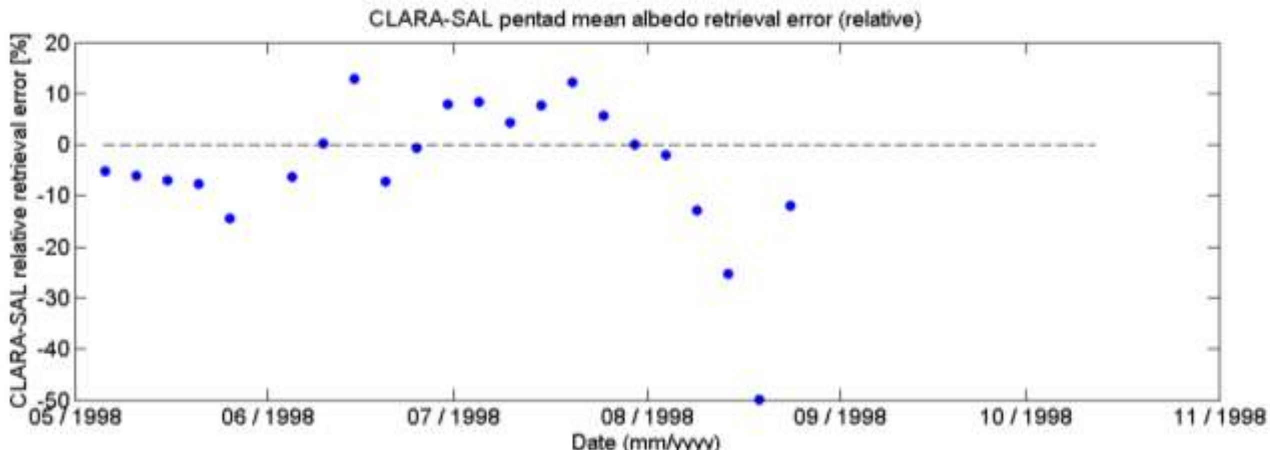


* Multiple images required for a robust snow albedo retrieval

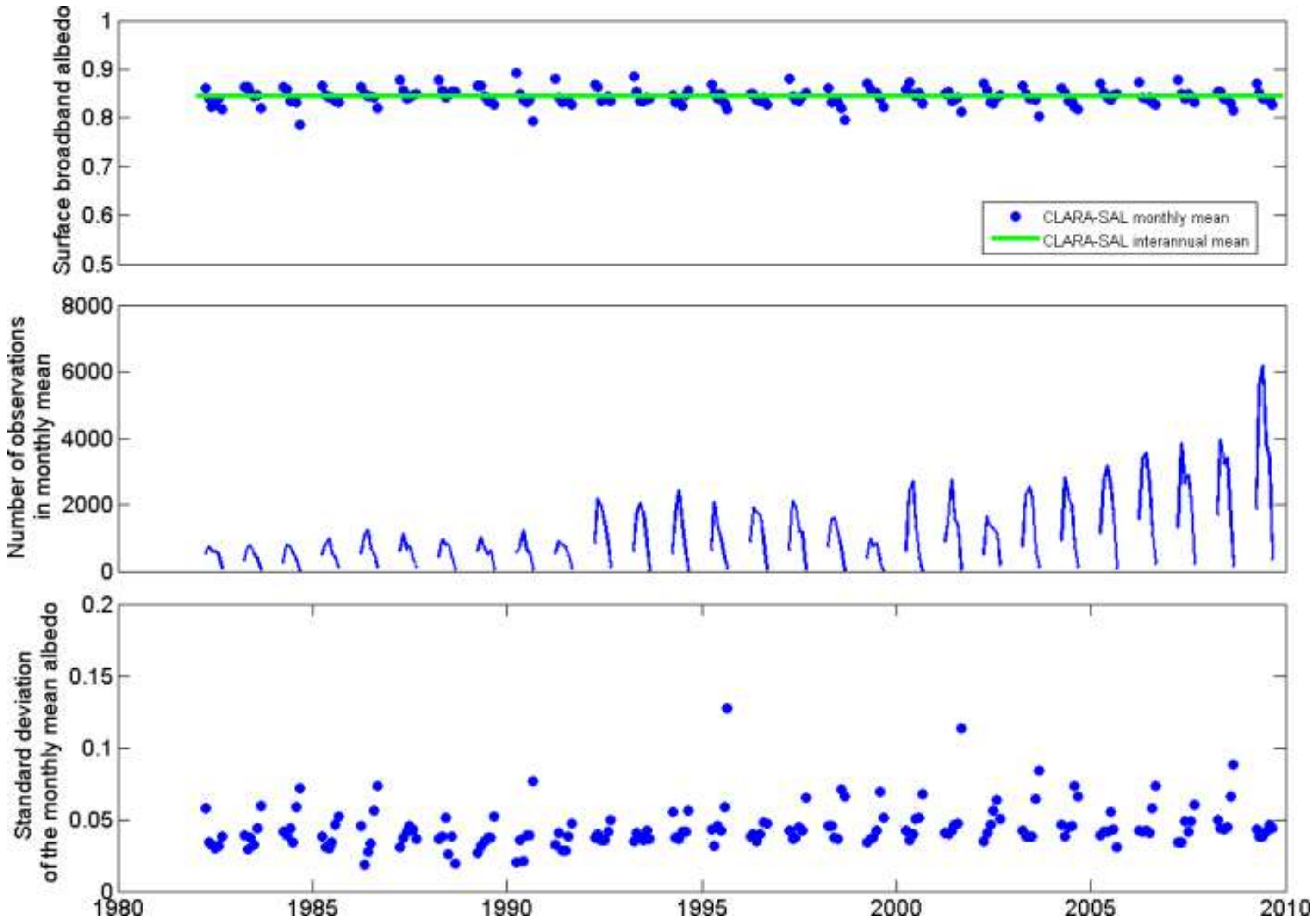
Validation of CLARA-A1-SAL over sea ice

- **Comparisons to SHEBA (and Tara) campaign albedo data**
- **Good accuracy overall (10-15% relative)**
- **Late-summer retrievals challenging**





Stability of CLARA-SAL over (a small area of) the Greenland Ice Sheet

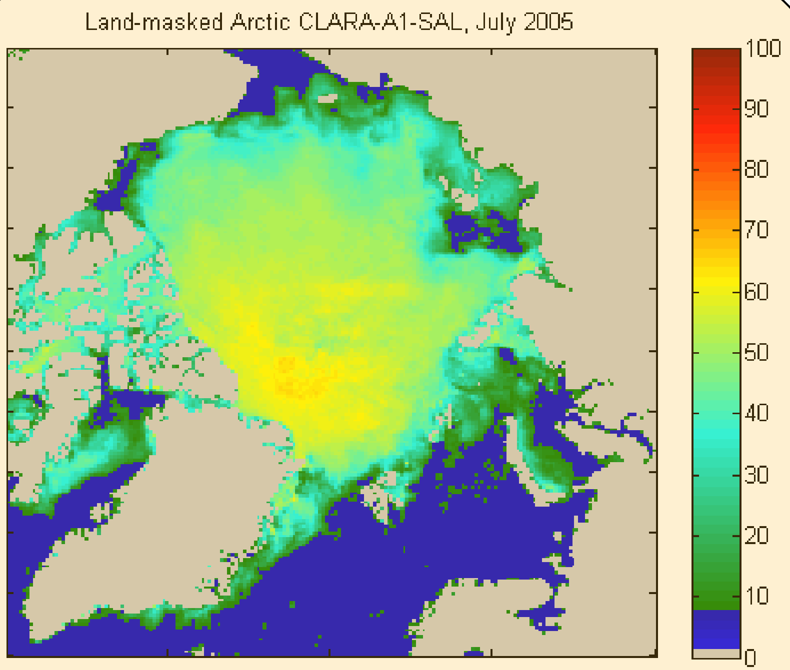


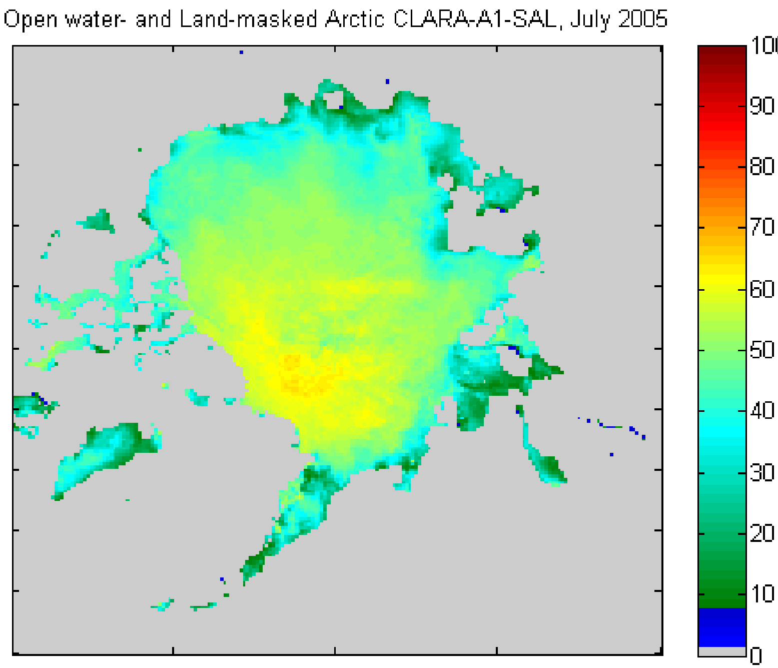
28-year mean α: 0.844
Max deviation 6.8% (relative)

So what can you do with it?

Some example applications of CLARA-A1-SAL

Analysis of CLARA-A1-SAL for Arctic sea ice albedo trends





1) Mask all land areas from the data (GSHHS)

2) Mask all areas outside of recorded sea ice extent (NSIDC Sea Ice Index*)

* Fetterer, Florence. 2002. *Sea Ice Index*. [monthly means, 1982-2009]. Boulder, Colorado USA: National Snow and Ice Data Center.

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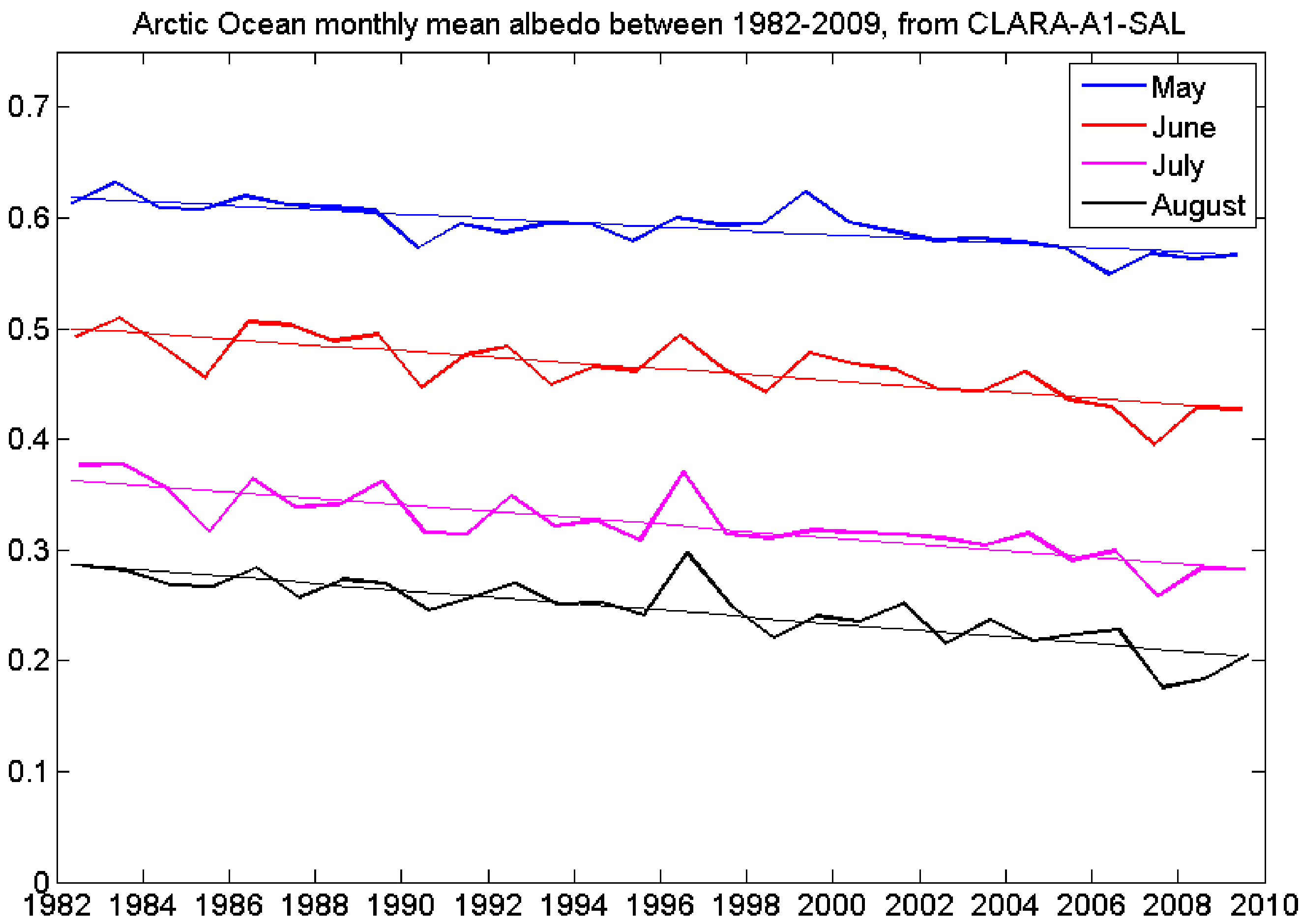
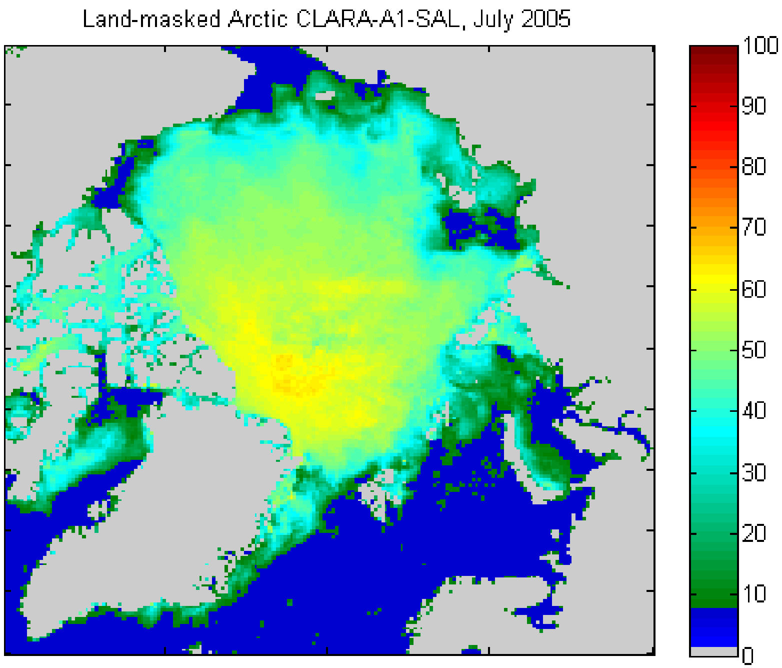
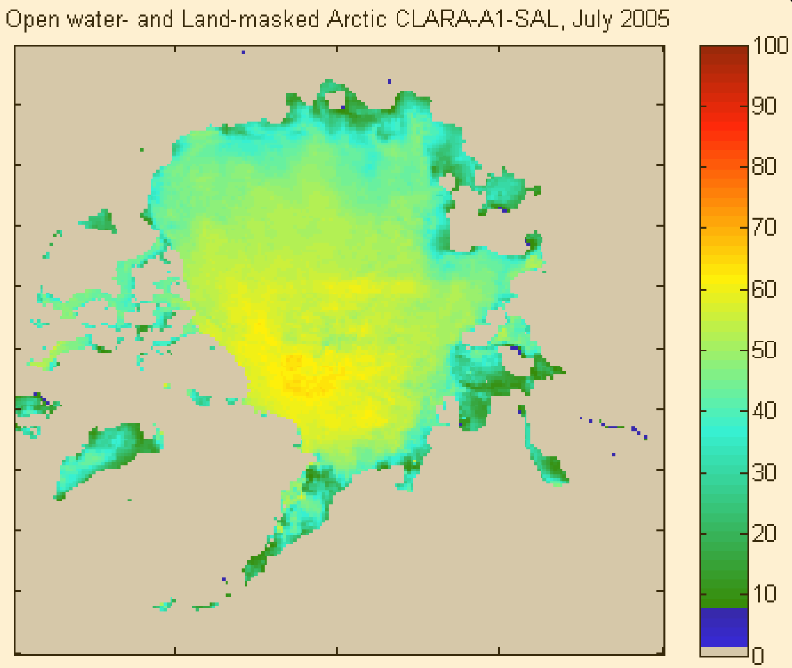
Trends in land-masked data…



Extracting trends for sea ice zone only



1) Mask all land areas from the data (GSHHS)



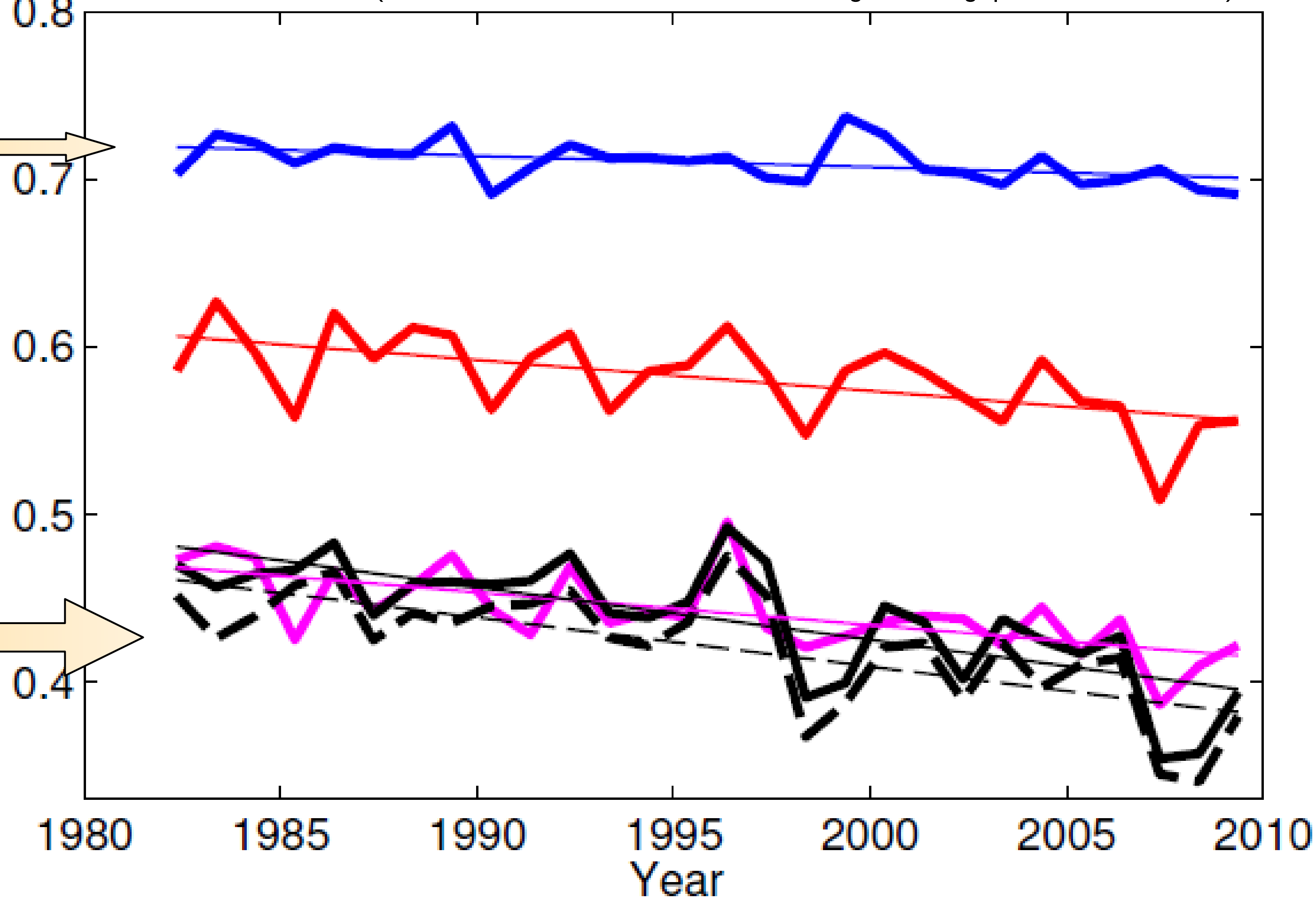
2) Mask all areas outside of recorded sea ice extent (NSIDC Sea Ice Index*)

* Fetterer, Florence. 2002. *Sea Ice Index*. [monthly means, 1982-2009]. Boulder, Colorado USA: National Snow and Ice Data Center.

Trends in land & water-masked data…

(dashed and solid black lines indicate original and gap-filled CLARA-SAL)

Sea ice/snow cover albedo resets during the cold winter period → no trend!



Late-summer sea ice albedo decreases, possibly with accelerating speed through the dataset → the remaining August sea ice zone is darker than before!

Riihelä, A., Manninen, T., and Laine, V., 2013: Observed changes in the albedo of the Arctic sea-ice zone for the period 1982–2009, Nature Climate Change, doi:10.1038/nclimate1963

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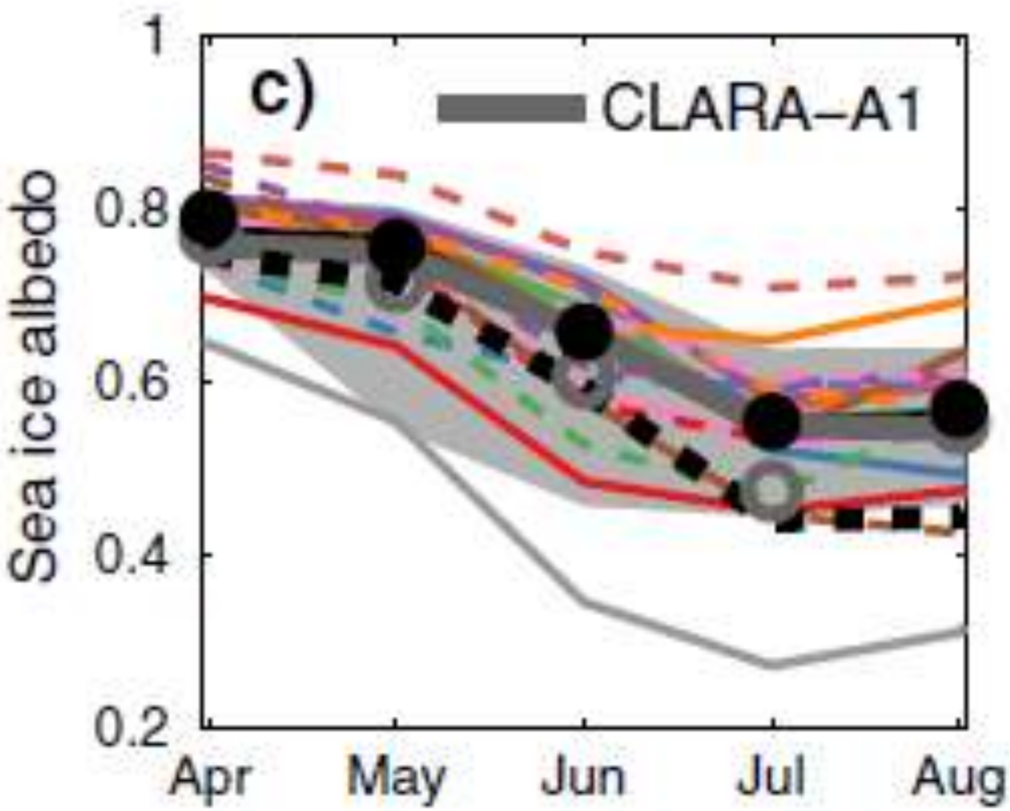
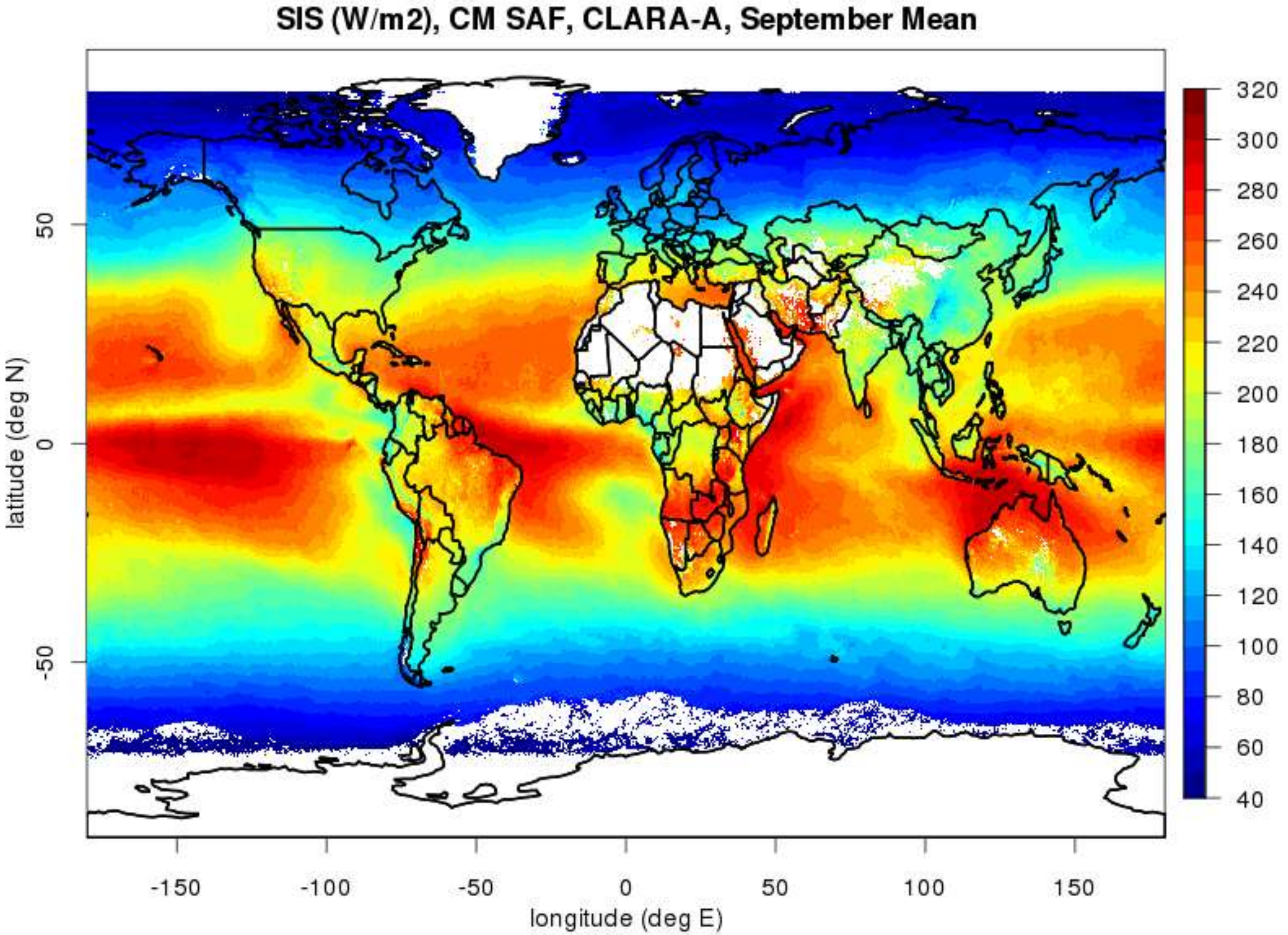
Comparing CLARA-A1-SAL with CMIP5 sea ice albedo parameterizations



CMIP5 ensemble mean of sea ice albedo agrees with CLARA-A1-SAL, but individual models have a wide range of variability

Karlsson, J., and G. Svensson (2013), Consequences of poor representation of Arctic sea-ice albedo and cloud-radiation interactions in the CMIP5 model ensemble, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50768.

CLARA-A1-SIS



Resolution

Spatial: **0.25° x 0.25°**

Temporal: **daily, monthly** means

Coverage

Global, 1982-2009

Accuracy

~10 W/m² for monthly means, ~20 W/m² for daily means based on BSRN surface observations

Stability

Not yet assessed

Availability

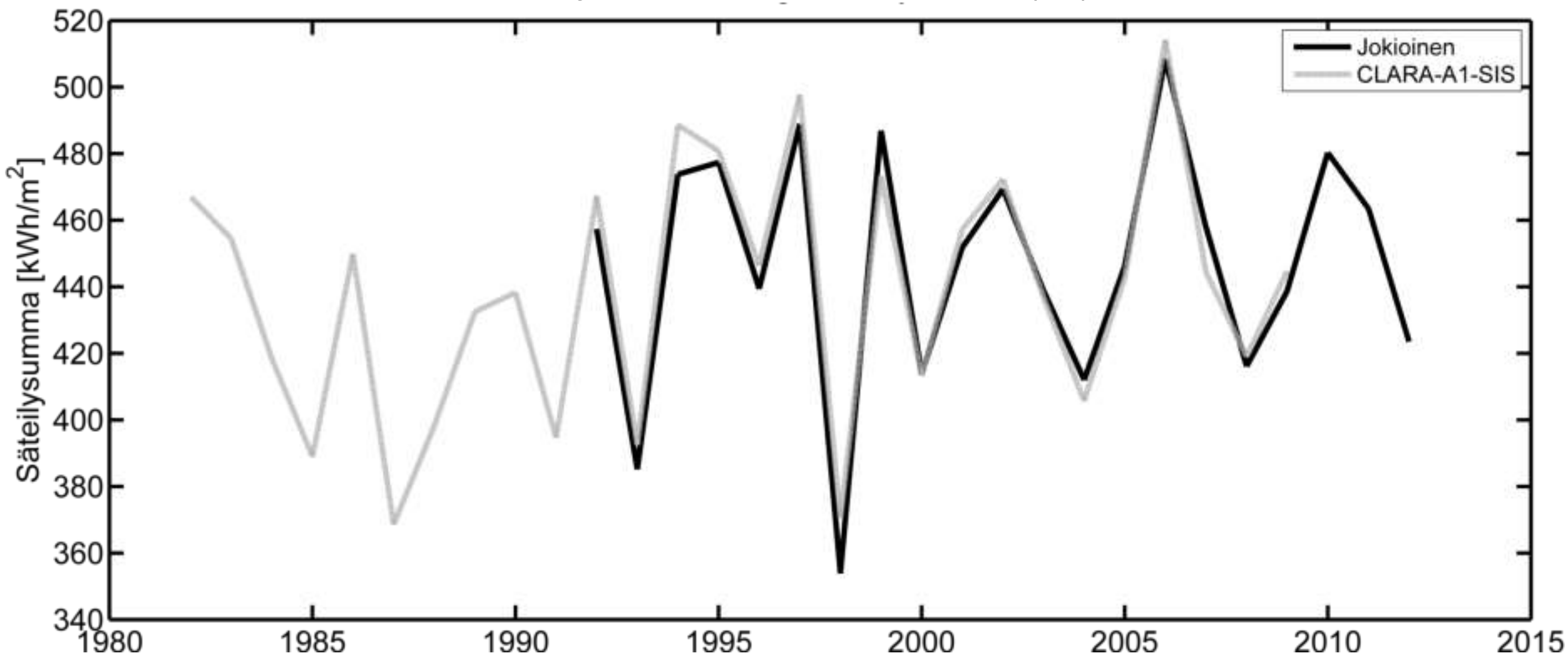
www.cmsaf.eu; **CF-netcdf**-format; freely available without restrictions

Digital Object Identifier (doi)

10.5676/EUM_SAF_CM/CLARA_A/V001

Evaluating solar energy potential based on CLARA-A1-SIS in Finland

Cumulative sum of irradiance at ground level over the summer months (JJA) – in situ versus CLARA-A1-SIS



CLARA - Outlook

CLARA Edition 2 (released 2015):

- Regional cloud detection deficiencies solved or mitigated
- Cloud effective radius new official product
- Enhanced product dataset (Level 2 + Level 2b)
- Improved consistency between products
- SAL improvements in atmospheric correction, sea ice identification and use of a more dynamic land cover dataset.
- Improvement of surface radiation products over bright surfaces and improved corrections for the longwave surface radiation products

CLARA Edition 3 (released 2017):

- Extended back to 1978 (AVHRR/1)
- Methods for correcting effects of orbital drift
- Improved error characterization (e.g. probabilistic cloud mask and modelled uncertainties from OE techniques)

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The end