The ESA GlobAlbedo project for mapping the Earth's land surface albedo for 15 years (1995-2010) from European sensors: Role of 10 years of MODIS

Jan-Peter Muller, Gerardo López, Neville Shane,
Mullard Space Science Laboratory, UCL
P.Lewis, Matt Disney, UCL Geography
Jürgen Fischer, Luis Guanter, Freie Universität Berlin
Pete North, Andreas Heckel, Swansea University
Uwe Krämer, Carsten Brockmann, Brockmann Consult
Simon Pinnock, ESA ESRIN

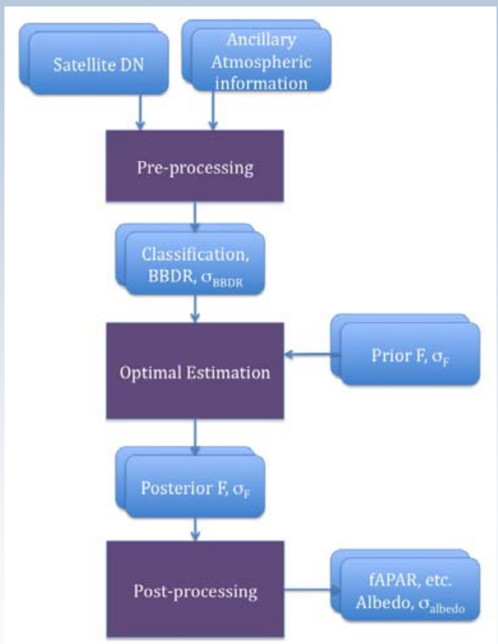
•*With contributions from Crystal Schaaf (BU) and Gabriela Schaapman-Strub (University of Zürich)*

Overall Aims

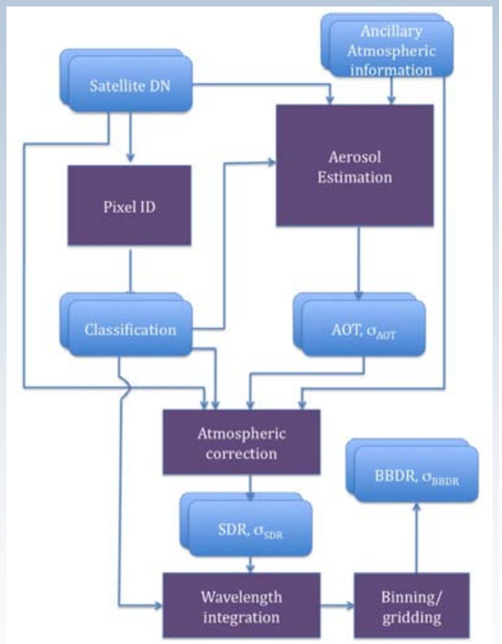
- Production of a 15 year record (1995-2010) of Land Surface BroadBand Albedo (BBA) from European space assets to provide an independent capability to generate this Essential Climate Variable
- Input data will consists of level 1b (radiometrically calibrated, satellite projection)
  - ATSR2 (6/1995-12/2008), MERIS and AATSR (6/2002-12/2010)
  - VGT (24.3.98-31.1.03) and VGT2 (1.2.03-12/2010)
- An estimated uncertainty (variance-covariance matrix) is produced for each output pixel using an optimal estimation framework
- Validation of final albedo products as well as intermediate products (e.g. cloud masks, aerosol retrievals, narrow-to-broadband)
- GlobAlbedo products will be freely available via ftp, http and an OGC-compliant webGIS

Product Processing and Validation

- Subset of GlobAlbedo products validated
- Focus on Pixel ID AOT SDR N-to-BB Albedo
- Validation performed by relevant producer with support from PI
- Russian Albedo validation performed by G. Schaapman-Strub



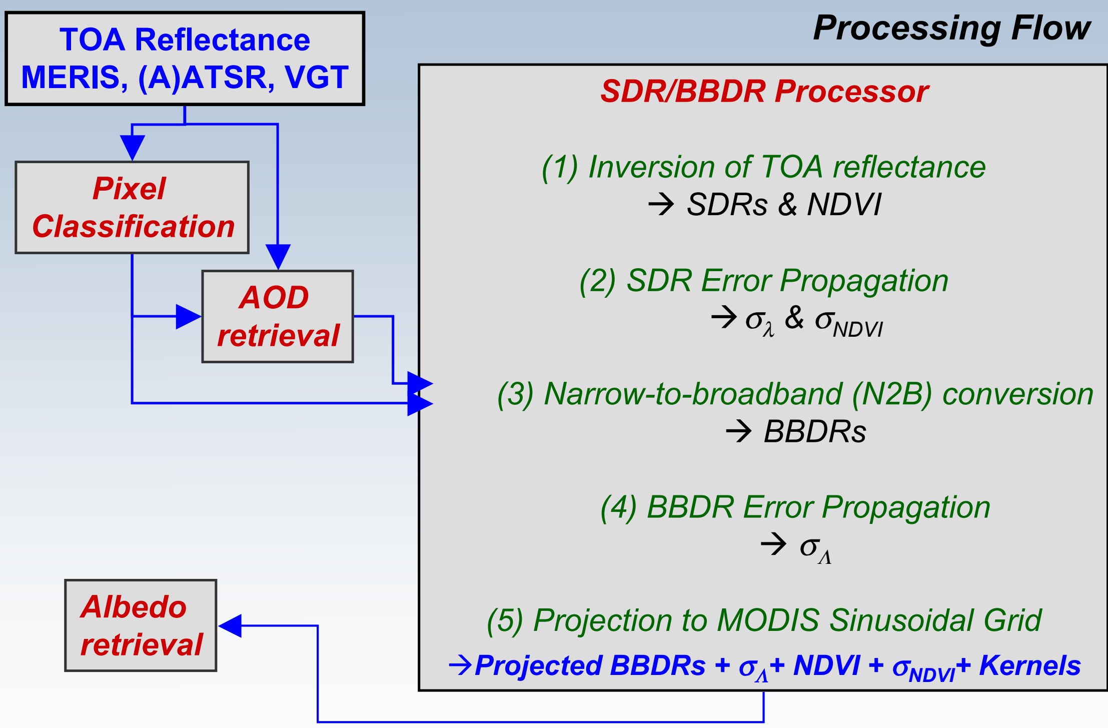
Overall GlobAlbedo processing chain



GlobAlbedo product flowchart

www.GlobAlbedo.org

Processing Flow



BRDF TILE product (not currently distributed)

- 9 kernels [isotropic, geometric, volumetric] x [VIS, NIR, SW]
- 45 layers from 9 x 9 error variance/covariance matrix per pixel
- Pixel classification (land or water), Relative entropy (impact of priors), SZA
- Nsamples and Mdays used in BRDF retrieval from accumulator arrays
- 59 band product with each layer of 32-bit floating point arrays (324.09 MB)

Albedo TILE product (distributed)

- 6 albedos [DHR, BHR] x [VIS, NIR, SW]
- 6 standard errors for [DHR, BHR] for [VIS, NIR, BBA] derived from error variance/covariance matrix per pixel
- Pixel classification (water or land [snow or no-snow depending on Mdays]), Relative entropy (impact of priors), posteriori entropy
- Nsamples and Mdays used in BRDF retrieval from accumulator arrays
- 17-band product with each layer of 32-bit floating point arrays (93.37MB)

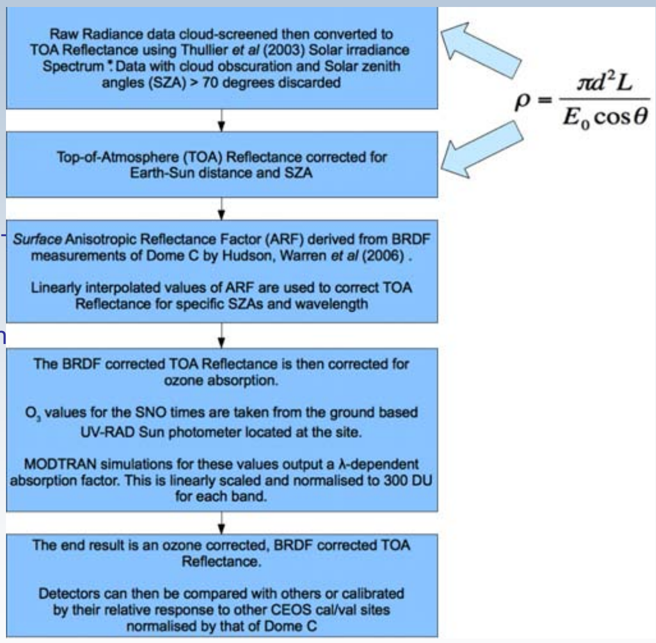
Sensor intercalibration

Jan-Peter Muller, Dale Potts*, Neville Shane

* PhD supported by NERC and NPL

Sensor intercalibration over DOME-C

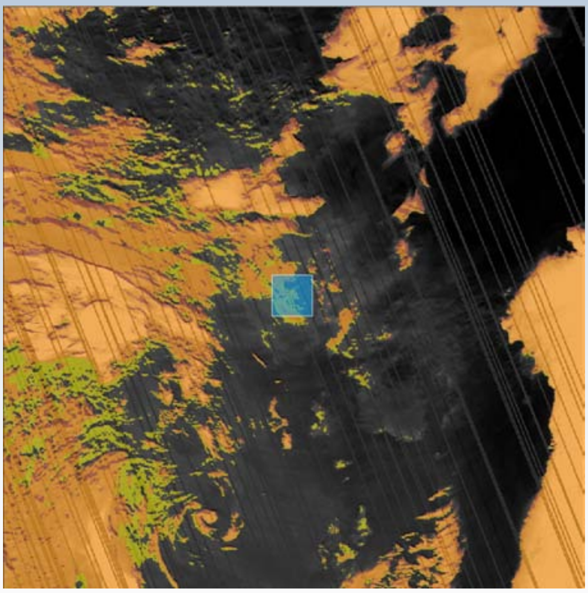
- CNES have used the DOME-C in Antarctica for calibrating VEGETATION since 1998
- Cao et al (CJRS Special Issue) developed a GEOSS QA4EO-compliant scheme for inter-comparison of sensor such as MODIS vs MERIS
- Smith et al., RALspace report no. PO-RP-RAL-AT-0599 (2009) applied similar to MERIS-AATSR-MODIS
- Potts et al (ESA Bergen 2010) have applied an updated approach to MERIS-AATSR-VEGETATION
- BRDF and O3 corrections applied as O3 can change values by >30% from one day to the next



Thuillier et al., (2003), Solar Physics, 214(1): 1-22
Hudson, Warren et al., (2006). JGR, 111, D18106

Cloud masking DOME-C observations

- Challenging problem to detect cloud over snow/ice
- VEGETATION has dead pixels in their 1.6µm CCD which makes it even more challenging as this channel is very helpful usually in distinguishing snow/ice from cloud
- GlobAlbedo PixelID applied with tweaked parameters (yellow area) and compared against cloud mask supplied with product (orange)
- Assessments performed only for cloud-free pixels in a 25 x 25km area centred on the ground tower site at DOME-C
- Results look reasonable for all input scenes although there may still be spill-over from



Final intersensor calibration results

AATSR vs MERIS	AATSR Report PO-RP-RAL-AT-0599 intercomparison results (page 32 and 33)				
RAL (2002-2008)	Ratio AATSR/MERIS	StdDev	Offset	Slope	Number of data points
550/560nm band	1.0374	0.0152	0.6956	1.0176	Unspecified
660/665nm band	1.0288	0.0108	0.4993	1.0152	Unspecified
870/865nm band	1.0369	0.0079	0.6179	1.0198	Unspecified

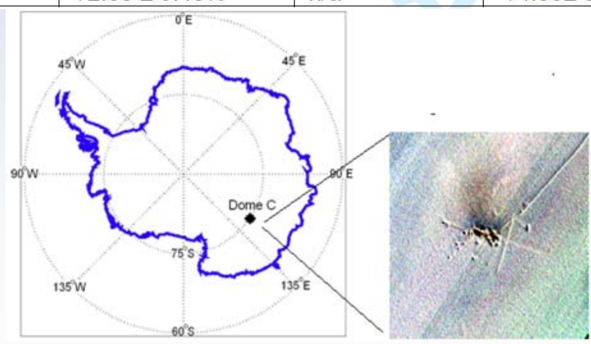
Dec09+Jan10 results	Best fit coefficients of bandwidth and ARF corrected, normalised TOA reflectance AFTER ozone correction					
AATSR vs MERIS	Ratio AATSR/MERIS	StdDev	Offset	Slope	R-squared	Number of data points
550/560nm band	1.025273127	0.0072287	-0.169	1.2189	0.7585	15
660/665nm band	1.009335959	0.0099814	0.0726	0.93	0.4636	15
870/865nm band	1.026507198	0.0072884	-0.023	1.0523	0.8741	15

MERIS vs VGT	Mean ratio VGT/MERIS	StdDev	Offset	Slope	R-squared	Number of data points
442 vs 450 nm band	1.012482984	0.0397508	1.395	-0.4961	0.5801	8
665 vs 645 nm band	0.95342094	0.0067775	-0.0835	1.0447	0.471	8
865 vs 835 nm band	0.970944006	0.0083773	0.3891	0.5376	0.4385	8

AATSR vs VGT	Mean ratio VGT/AATSR	StdDev	Offset	Slope	R-squared	Number of data points
660 vs 645 nm band	0.947402892	0.0077898	0.3805	0.5341	0.7431	8
870 vs 840 nm band	0.945720049	0.0085332	0.4086	0.5025	0.4745	8
1600 vs 1665 nm band	1.134511487	0.0790827	0.0226	0.977	0.9189	8

How do MERIS & AATSR compare to MODIS

		MODIS 0.64 μm (ρ= 86.73% +/- 1.49% @60 sza)		MODIS 0.86 μm (ρ= 85.48% +/- 1.44% @60 sza)	
	@SZA	Observed Bias	Theoretical Bias	Observed Bias	Theoretical Bias
OrbView/SeaWiFS	59°	-2.74% ±1.32%	1.95%	-2.09% ±1.57%	-1.46%
METOP-A/AVHRR	62°	-8.74% ±1.60%	-0.43%	-10.14% ±1.58%	-8.21%
Envisat/MERIS	62°	0.74% ±2.28%	0.66%	-1.22% ±2.28%	0.20%
ENVISAT/AATSR	62°	1.76% ±2.83%	1.07%	-1.90 ± 2.92%	0.43%
Landsat 7/ETM+	60°	1.03% ±0.52%	1.17%	1.35% ±1.24%	-3.22%
EO-1/Hyperion	60°	+2.63 ± 0.48%	n/a	+4.35± 0.18%	n/a



Processing: Innovations in Albedo retrieval

Prof. P. Lewis, UCL

Prior knowledge constraint

- Regularisation is form of prior knowledge constraint
  - Yesterday, likely to be same as today, with given tolerance
- MODIS backup algorithm, another example
  - Assume knowledge of BRDF shape
  - But sharp transition – not within optimal estimation framework
- Geiger et al. (2008) (MSG)
  - Weak (constant) prior to condition solution
- **GlobAlbedo:**
  - Dynamic (per 8-day time period), spatial prior
    - To condition solution in case of weak sampling
    - To 'gap fill'

$$\left[\sum_{i=0}^{N} K'^T C_{O\,i}^{-1} K' + C_p^{-1}\right] F_t = \left[\sum_{i=0}^{N} K'^T C_{O\,i}^{-1} R + C_p^{-1} K_p\right]$$

$$J_{p\,t} = \left(F_t - F_{p\,t}\right)^T C_{p\,t}^{-1}\left(F_t - F_{p\,t}\right)$$

Rationale

- Prior allows solution even when sampling weak (or non-existent)
  - Obviate need for backup algorithm
- Part of Optimal estimation framework
  - Can estimate uncertainty
  - Can estimate impact of new observations
    - Relative entropy
- Prior here is MODIS climatology:
  - Based on 500m BRDFs
  - But need uncertainty
    - Conservative estimate

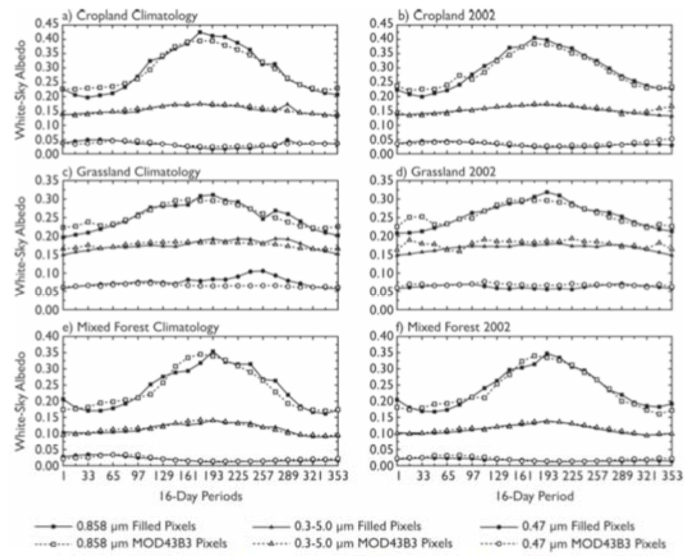


FIG. 9. As in Fig. 8, but for each 16-day period over the 50°–40°N latitude belt.

three ecosystem classes: (a), (b) cropland, (c), (d) grassland, and (e), (f) mixed forest from (left) the 5-yr aggregate climatology and (right) the 2002 single-year albedo data.

www.GlobAlbedo.org

Priors and treatment of Snow

- Impact of snow great
  - Develop 2 priors (snow/no snow)
  - Each associated with different inputs (snow/no snow)
  - N.B. in future could use distance from prior to aid cloud/snow retrievals
- Snow can have strong fwd scattering peak
  - Can claim kernels not appropriate
  - But no suitable replacement model available
    - Attempts e.g.:
      - Klein and Stroeve, 2002; Stroeve and Nolin, 2002; Liang et al., 2005
  - Separation of snow/no snow allows route for possible replacement of snow model

Generation of priors

- Input: MODIS Collection V005 BRDF-Albedo model parameters product
  - MCD43A1, MCD43A2 at 500m*
- Same kernel models as used here
- Estimate climatology and uncertainty in parameters
  - Uncertainty to include actual variation: conservative
- Product has no uncertainty info, but 4 QA states
  - Apply weighting to QA states: *relative* uncertainty $W_{c0} = \frac{1}{\sigma_{QAc0,k}}$

Code	Meaning
0	best quality, full inversion (WoDs, RMSE majority good)
1	good quality, full inversion
2	Magnitude inversion (numobs >=7)
3	Magnitude inversion (numobs >=3&<7)
4	Fill value

* *Thanks to Dave Obler and Robert Wolfe for supply of data on USB2 disks*

www.GlobAlbedo.org

Generation of priors

- Mean: $\bar{f}_k(i,j) = \frac{1}{N_{(i,j)}} \sum_{c=0}^{c=3} \sum_{yQAc} W_{c0} f_{QAc,k}(i,j)$ $\qquad N_{(i,j)} = \sum_{c=0}^{c=3} \sum_{yQAc} W_{c0}$

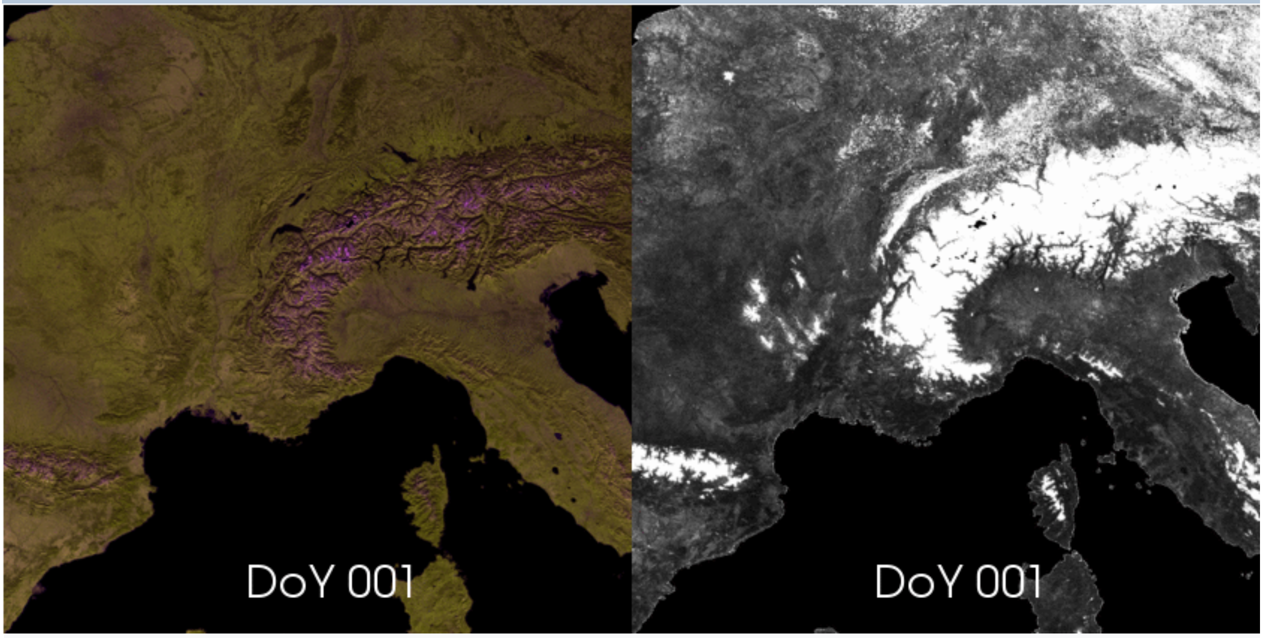
- Standard error (incl. small number bias correction):

$$\sigma_{1,2}^2 = \frac{\sum_{i=1}^{i=n} w_{QAi} \sum_{i=1}^{i=n} \left[w_{QAi} (x_{1,i} - \bar{x}_1)(x_{2,i} - \bar{x}_2) \right]}{\left(\sum_{i=1}^{i=n} w_{QAi} \right)^2 - \sum_{i=1}^{i=n} w_{QAi}^2}$$

$$s_{1,2}^2 = \sigma_{1,2}^2 \Big/ \sum_{i=1}^{i=n} w_{QAi}$$

- Examined temporal-weighting of priors:
  - Very similar to a weighting of climatology priors

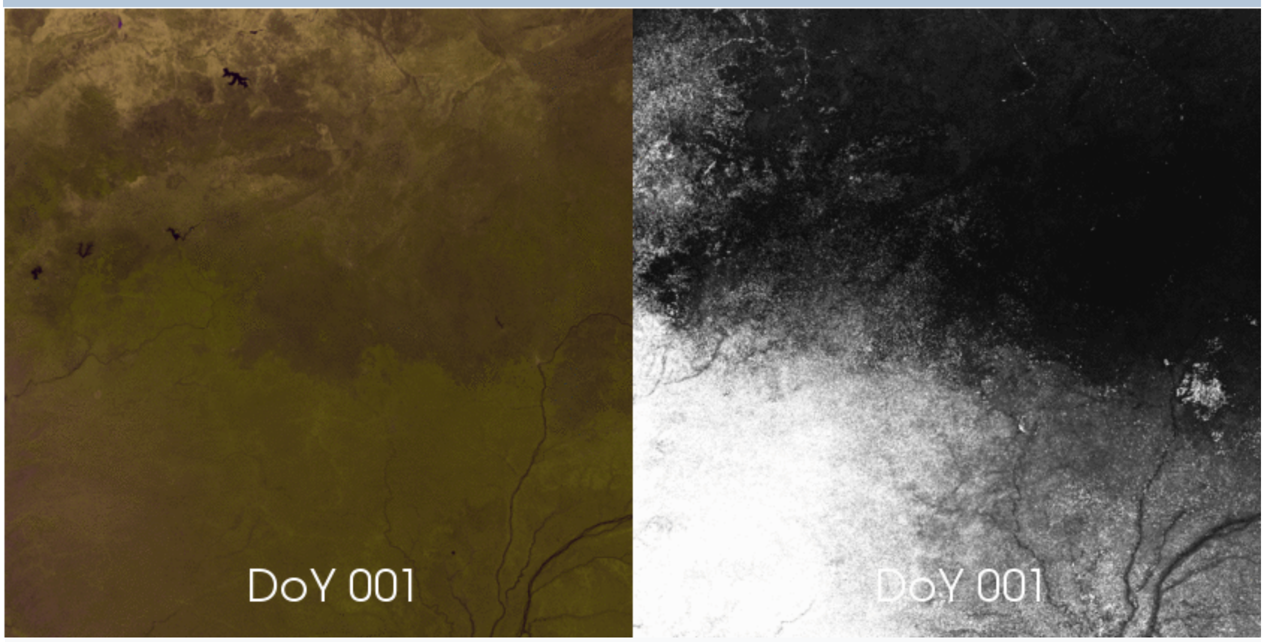
MODIS - Prior



MODIS-derived prior for tile h18v04 for 2005 – FCC SW f0, NIR f0, VIS f0 (RGB) and standard error model parameter f0 VIS, image scaled 0:0.25

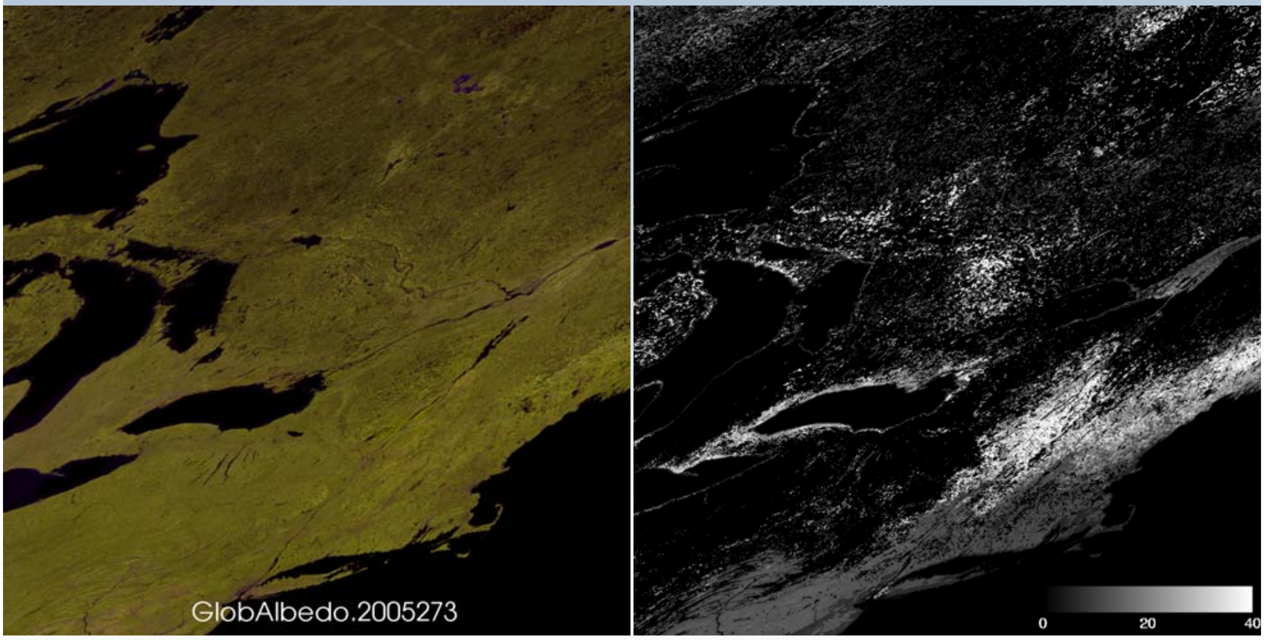
www.GlobAlbedo.org

MODIS - Prior



MODIS-derived prior for tile h19v08 for 2005 – FCC SW f0, NIR f0, VIS f0 (RGB) and standard error model parameter f0 VIS, image scaled 0:0.25

Relative Entropy - assessment of impact of MODIS on GlobAlbedo



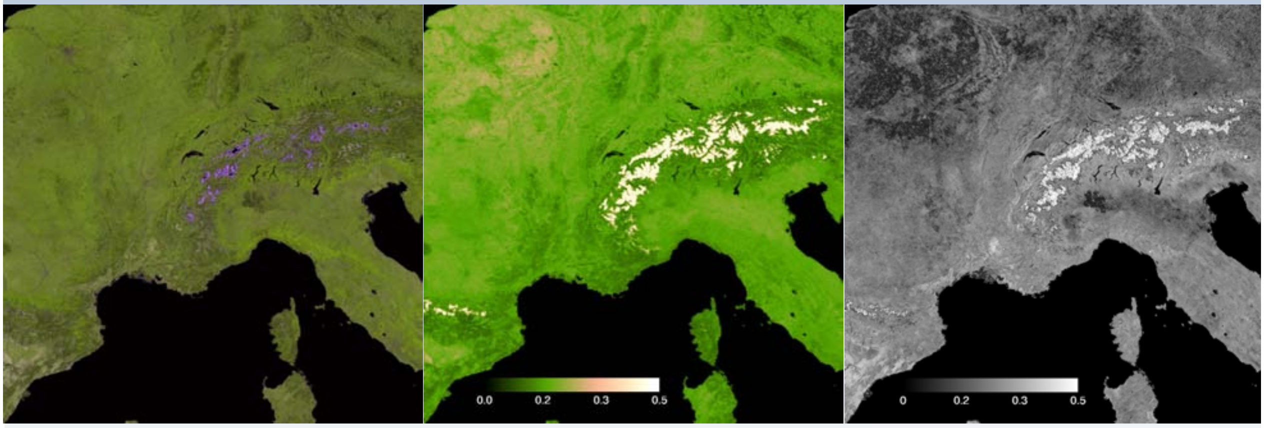
f_0 SW,NIR,VIS (RGB)

www.GlobAlbedo.org

2005 Prototype Products

Gerardo Lopez & Jan-Peter Muller, UCL-MSSL

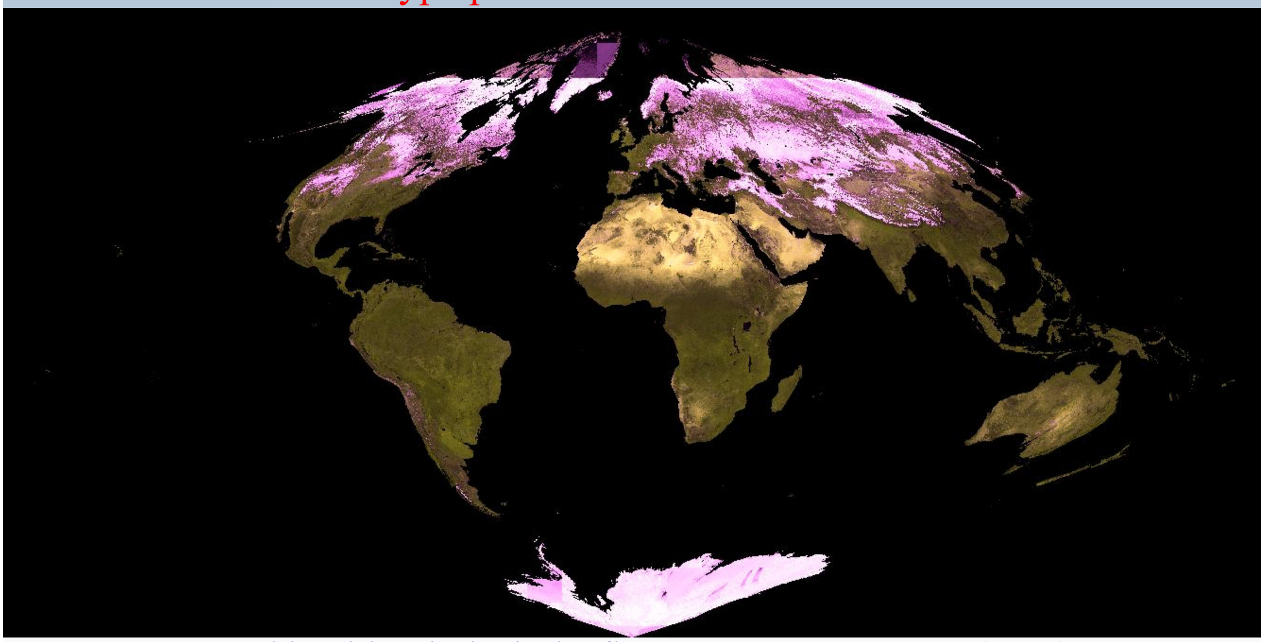
2005 Prototype products:
BRDF/Albedo examples for tile h18v04 (Europe) – DoY 153



BRDF isotropic parameter: SW, NIR, VIS (R,G,B) | BHR SW | BHR SW SD

www.GlobAlbedo.org

2005 Prototype products: Global 50km SIN BHR



Monthly Bi-hemispherical reflectance - SW, NIR, VIS (RGB)

Validation - Albedo Prototype products

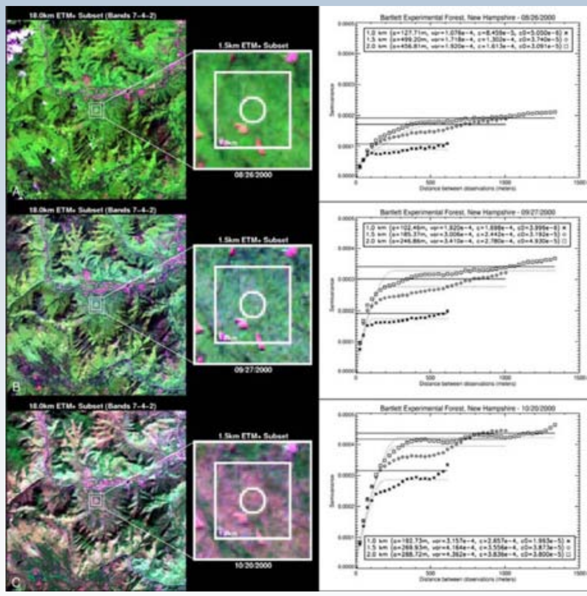
Jan-Peter Muller, Gerardo López, Neville Shane

Albedo validation

- Focusing on 3 aspects
  - Intercomparison of Blue-Sky Albedo with tower albedometer measurements for representative sites which are homogeneous at 1-3km scale (Roman et al., 2009)
  - Assessment of BroadBand Albedo (VIS, NIR, SW) at the global scale on monthly time-steps with MISR and MODIS
  - Assessment of GlobAlbedo with MCD43
- Tower albedometer data obtained from C. Schaaf of Boston University who has processed such data for a wide variety of North American sites. Dr Schaaf is in charge of MODIS albedo validation and Co-Chair of CEOS-WGCV-LPV task on albedo as well as a consultant on GlobAlbedo
- Intercomparison with University of Amsterdam tower sites in Siberia performed by Gabriela Schaapman-Strub (University of Zurich)
- These data were processed to obtain averages over 11-13h Local Time along with Direct-to-Diffuse (SURFRAD) or MODIS 1º x 1º look-up of AOD, Cloud Fraction and Snow cover.

Assessment of blue-sky broadband albedo

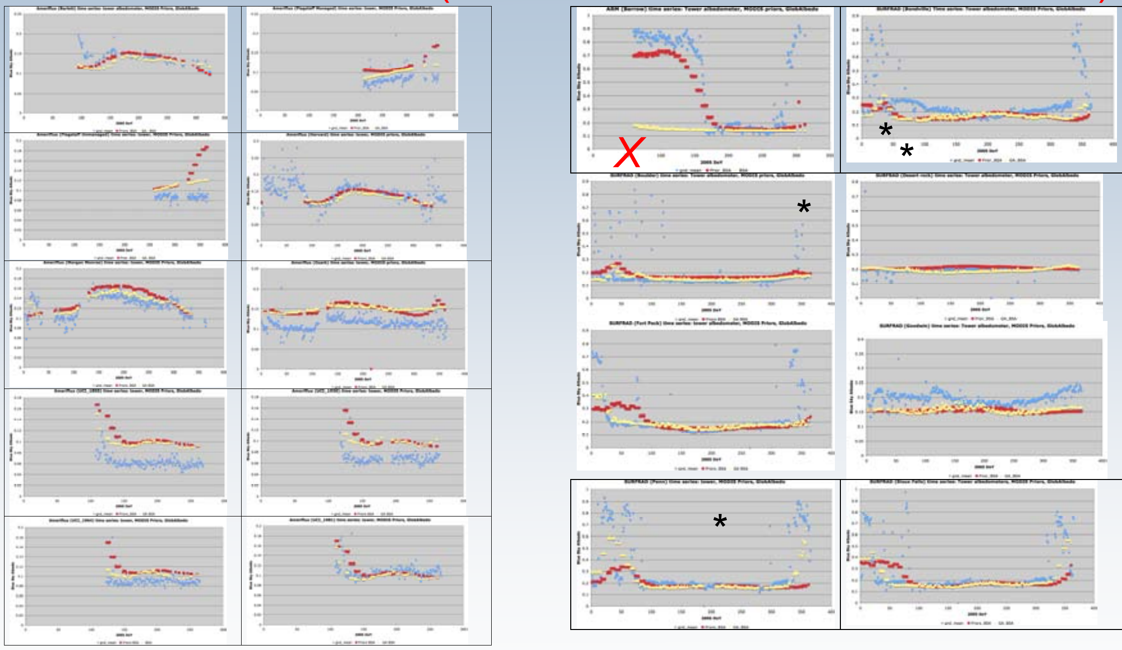
- For worldwide test sites where tower-based albedo values have been acquired, spatial geostatistics (semi-variance) have been employed by Boston University to assess the homogeneity of the site
- 20 ARM, 16 AmeriFLUX, 13 CRN and 7 SURFRAD sites have been processed to date
- For homogeneous sites, BU provided blue-sky tower albedometer values from the sites for leaf-on and leaf-off conditions
- Where sites coincide with BSRN/SURFRAD, direct-to-diffuse measurements obtained, elsewhere AODs taken from MODIS 0.5 degree climatology



Roman et al., RSE (2009)

North American test sites (12 Ameriflux, 1 ARM, 7 SURFRAD)

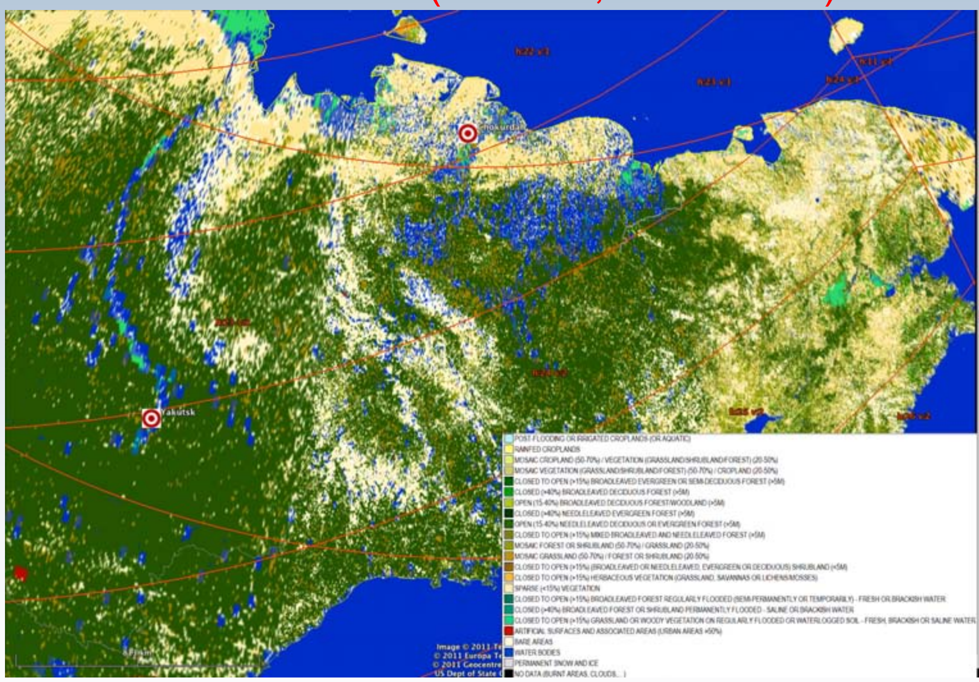
North American test sites (12 Ameriflux, 1 ARM, 7 SURFRAD)



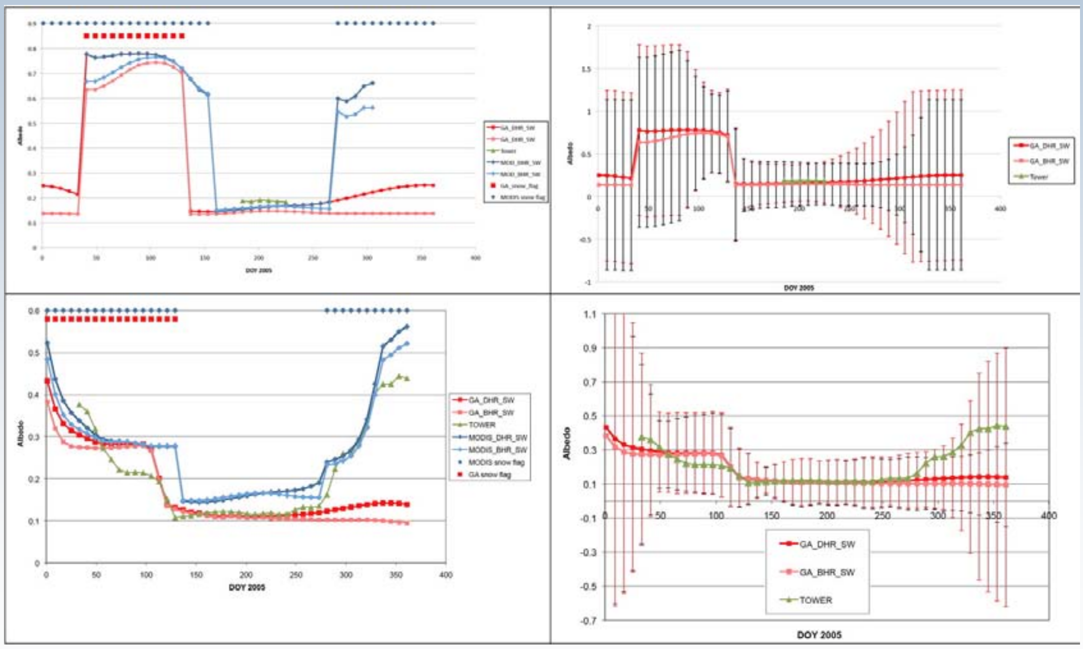
Tower albedometer MODIS Prior GlobAlbedo *Poor snow albedos, X missing DEM value

www.GlobAlbedo.org

Russian test sites (Yakursk, Chokurdah)



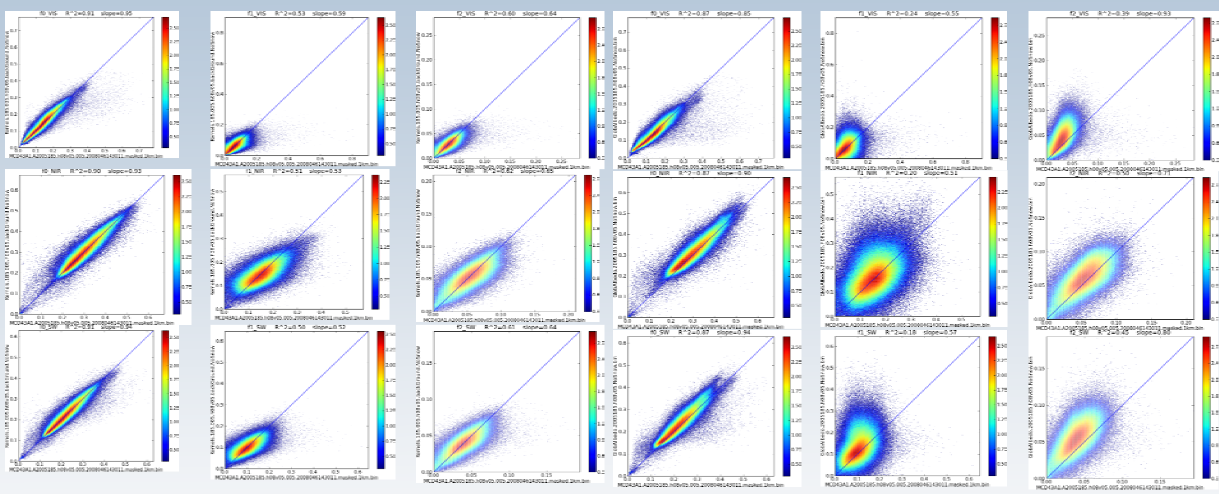
Russian test sites (Yakursk, Chokurdah) Results provided by Gabriela Schaapman-Strub (U of Zurich)



Chokurdah

Yakursk

GlobAlbedo BRDF comparison with Priors & MCD43 for h08v05

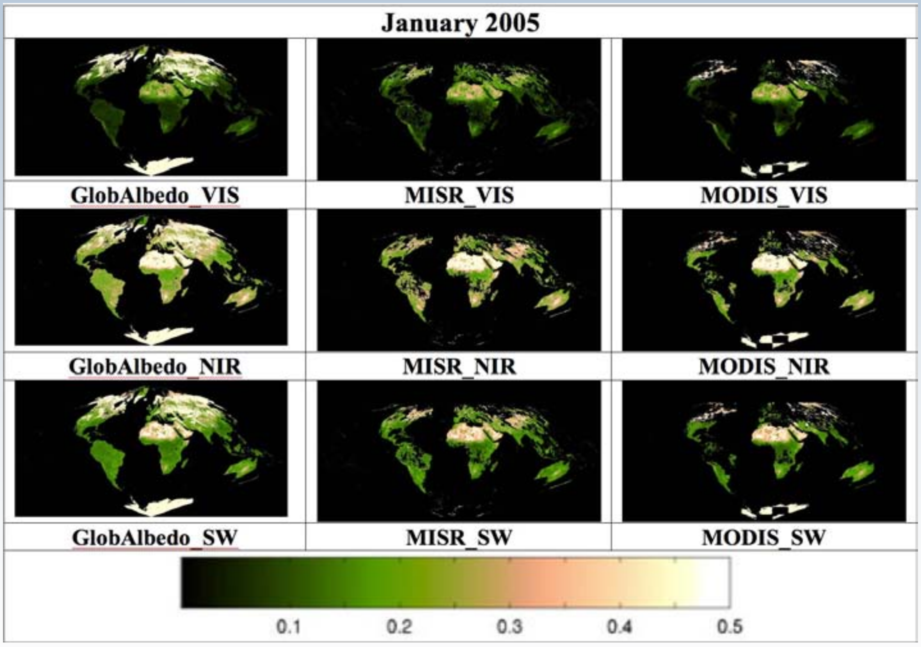


fo *f1* *f2* *fo* *f1* *f2*

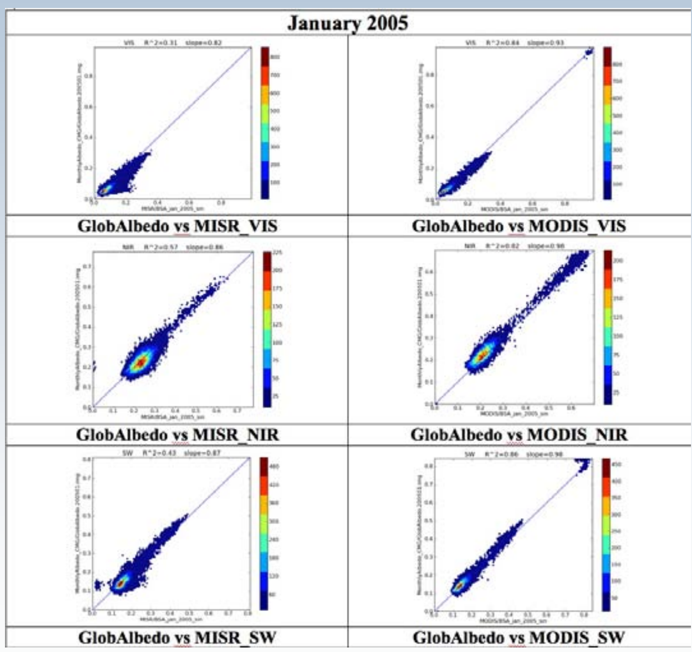
Prior vs MCD43 of BRDF parameters

GlobAlbedo vs MCD43 of BRDF parameters

Global 50km albedo (DHR) inter-comparison datasets

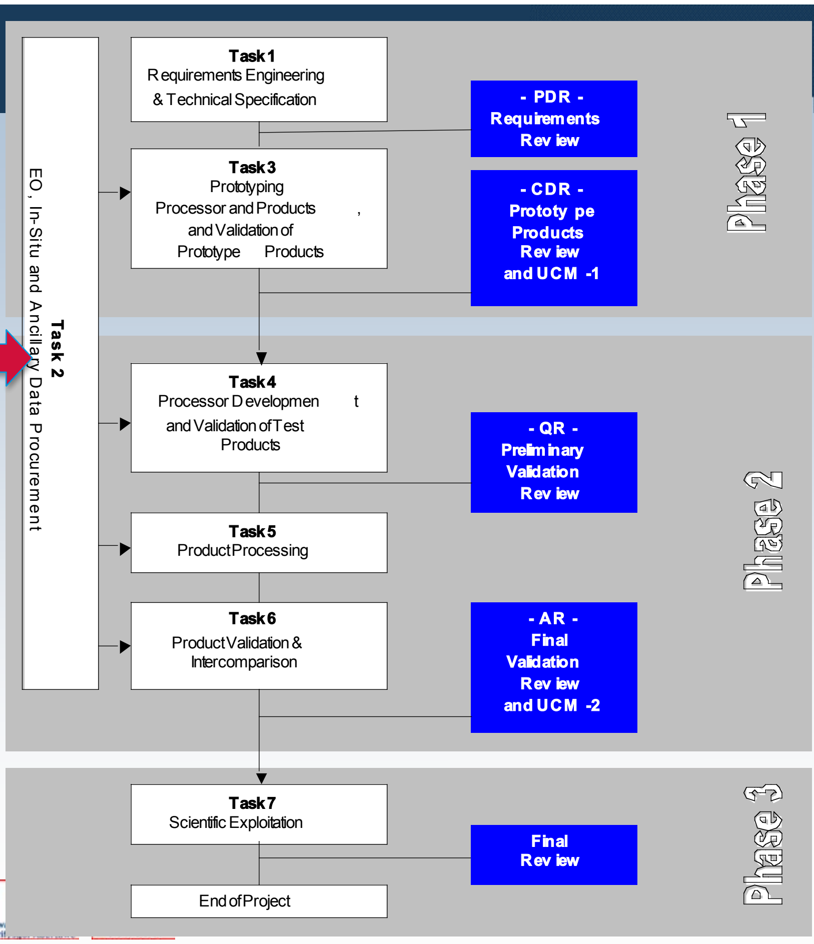


Global 50km Albedo (DHR) inter-comparisons



What next?

- MODIS prior to be extended back to 1995 using LTDR and forward using MODIS (3/10-3/11)
- 15 year processing to start in 7/11 and due to be completed by 10/11
- Validation datasets need to be established for global BSRN sites for entire time period
- Inter-comparisons with MISR, POLDER, METEOSAT Land-SAF
- ECMWF, Météo-France, MPI Hamburg testing impact of uncertainties on NWP forecasts



Freie Universität Berlin