EO-derived surface albedo time series

Nektarios Chrysoulakis
FORTH
N. Plastira 100, Vassilika Vouton, 70013, Heraklion
zedd2@iacm.forth.gr
http://rslab.gr

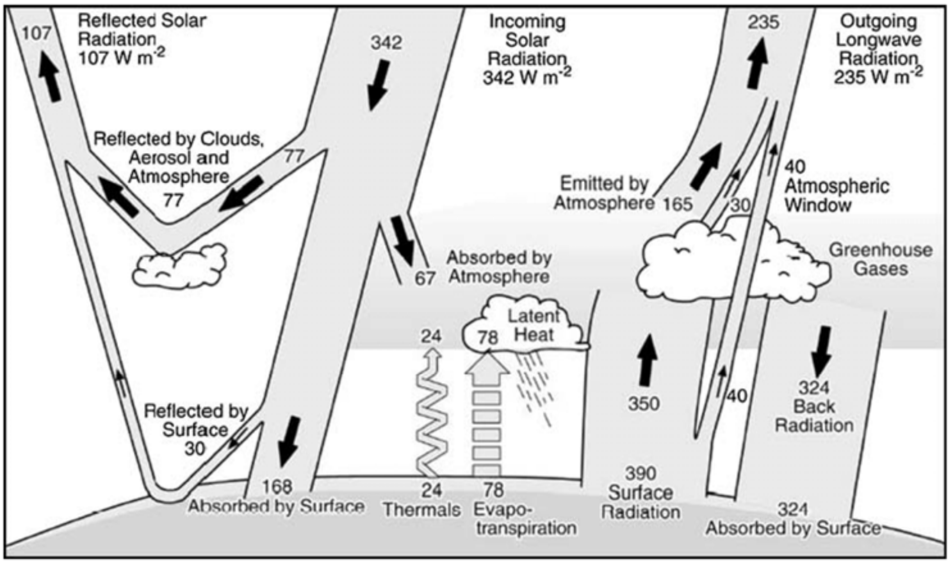
Outline

- Introduction
- LSA Estimation
- Local and Fine Scale LSA
- Global LSA
- Global Albedo Products
- Albedo Web-service
- Concluding Remarks

Introduction

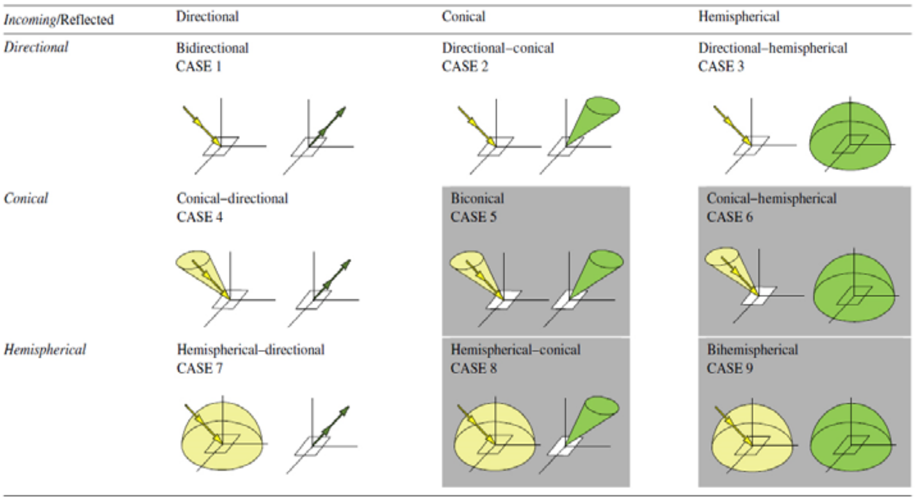
- **Land Surface Albedo (LSA)** is a key climatic variable for the study of the planetary energy budget and the partition of energy between the atmosphere and the Earth's surface.
- Factors affecting LSA spatio-temporal variations include **solar illumination**, **seasonal phenomena** (precipitation, vegetation phenology), **human induced changes** (crops, urbanization), and **abrupt changes** (e.g. forest fires).
- A continuous global LSA monitoring is only feasible using **EO** and big data analysis techniques.

Introduction



(Kiehl and Trenberth 1997)

Introduction

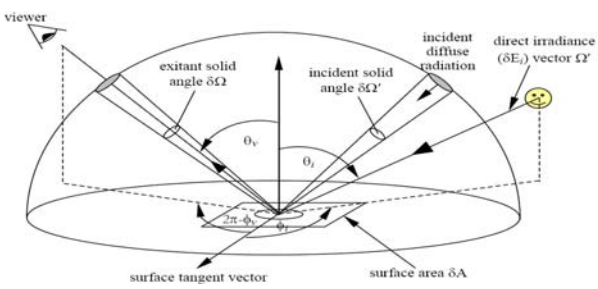


Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1	Directional–conical CASE 2	Directional–hemispherical CASE 3
Conical	Conical–directional CASE 4	Biconical CASE 5	Conical–hemispherical CASE 6
Hemispherical	Hemispherical–directional CASE 7	Hemispherical–conical CASE 8	Bihemispherical CASE 9

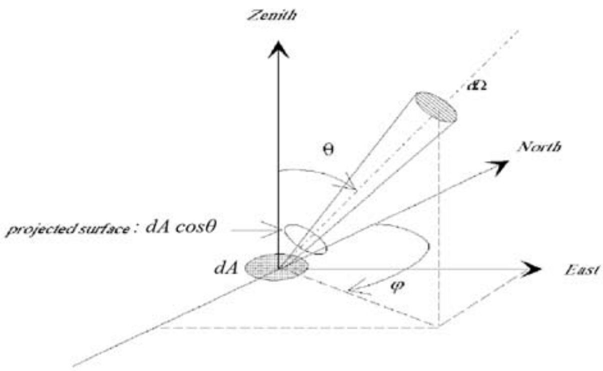
(Schaepman-Strub et al. 2006)

Introduction

- To retrieve LSA from satellite observations:
  - ✓ Compute the incoming narrowband TOA radiances.
  - ✓ Atmospherically correct to derive narrowband surface radiances.
  - ✓ Correct the anisotropic reflection by the surface.
  - ✓ Calculate narrowband LSAs.
  - ✓ Convert the narrowband LSAs to broadband LSA.



Introduction

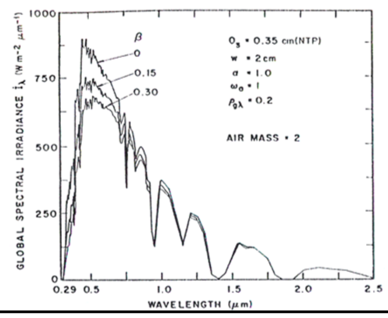


- Intensity (radiance): $L_\lambda = \dfrac{dE_\lambda}{\cos\theta \, d\Omega dt dA d\lambda}$
- Flux (irradiance): $dF_\lambda = L_\lambda \cos\theta \, d\Omega$

LSA Estimation

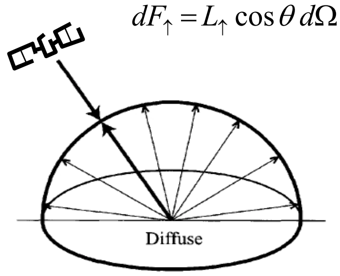
$$a_{[\lambda_1,\lambda_2]} := \frac{F^{\uparrow}_{[\lambda_1,\lambda_2]}}{F^{\downarrow}_{[\lambda_1,\lambda_2]}} = \frac{\int_{\lambda_1}^{\lambda_2}\int_{2\pi} L^{\uparrow}(\lambda,\theta_{out},\phi_{out})\cos\theta_{out} d\Omega_{out} d\lambda}{\int_{\lambda_1}^{\lambda_2}\int_{2\pi} L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in} d\Omega_{in} d\lambda}$$

$$F_{\downarrow} = F_n cos\theta_s + F_d$$



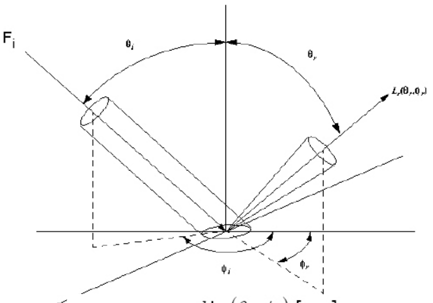
$$F_{\uparrow} = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_{\uparrow}\cos\theta\sin\theta \, d\theta d\phi = \pi L_{\uparrow}$$

$$dF_{\uparrow} = L_{\uparrow}\cos\theta \, d\Omega$$



LSA Estimation

- BRDF: $f_r(\Omega_i, \Omega_r)$



$$f_r\ (\Omega_i, \Omega_r) = \frac{d\,I_r(\theta_r, \phi_r)}{d\,F_i(\theta_i, \phi_i)}\ [sr^{-1}]$$

I [W m^{-2} sr^{-1}]	Radiance
F [W m^{-2}]	Irradiance

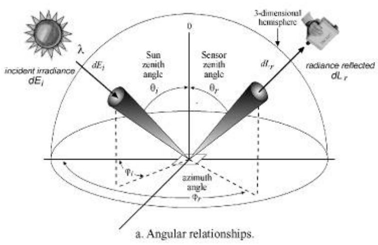
$$f_r = f_r\left(\lambda, \theta_{out}, \phi_{out}, \theta_{in}, \phi_{in}\right)$$

$$R\left(\lambda, \theta_{out}, \phi_{out}, \theta_{in}, \phi_{in}\right) = \frac{dI\left(\lambda, \theta_{out}, \phi_{out}, \theta_{in}, \phi_{in}\right)}{dI^{ideal}\left(\lambda, \theta_{in}, \phi_{in}\right)}$$

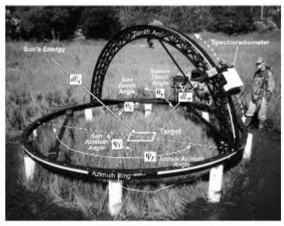
- BRF: is given by the ratio of the reflected radiant flux from a surface area dA to the reflected radiant flux from an ideal and diffuse surface of the same area dA under identical view geometry and single direction illumination.

$$R = \pi\ f_r$$

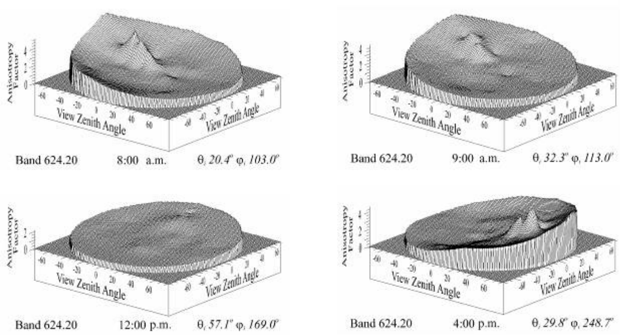
LSA Estimation



a. Angular relationships.



b. Sandmeier Field Goniometer.



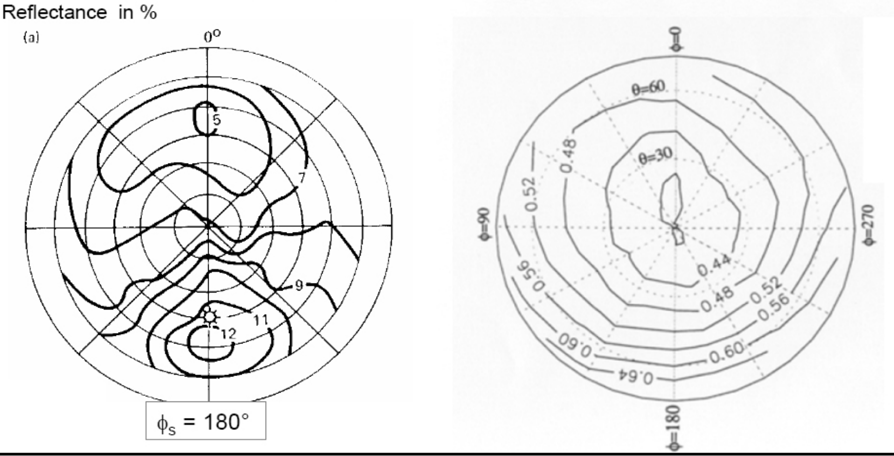
LSA Estimation

Polar diagrams of directional reflectance.

(a) Gras, 50% ground cover (b) Firn snow (*θ ... Off nadir angle*)

$\Delta\lambda$ 0.58-0.68 μm; Sun $\theta_i = 45°$ $\phi_i = 180°$ $\Delta\lambda$ 0.80-0.90 μm ; $\theta_i = 50°$ $\phi_i = 0°$

Reflectance in %



LSA Estimation

- The **spectral albedo** is defined as the ratio between the hemispherical integrals of the up-welling (reflected) spectral radiance and the down-welling spectral radiance weighted by the cosine of the angle between the respective reference direction and the surface normal:

$$a(\lambda) := \frac{\int_{2\pi} L^{\uparrow}(\lambda,\theta_{out},\phi_{out})\cos\theta_{out}\,d\Omega_{out}}{\int_{2\pi} L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\,d\Omega_{in}}$$

BRDF

$$L^{\uparrow}(\lambda,\theta_{out},\phi_{out}) = \frac{1}{\pi}\int_{2\pi} R(\lambda,\theta_{out},\phi_{out},\theta_{in},\phi_{in})L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\,d\Omega_{in}$$

$$a(\lambda) = \frac{\frac{1}{\pi}\int_{2\pi}\int_{2\pi} R(\lambda,\theta_{out},\phi_{out},\theta_{in},\phi_{in})L^{\downarrow}(\lambda,\theta_{in},\phi_{in})\cos\theta_{in}\cos\theta_{out}\,d\Omega_{in}\,d\Omega_{out}}{F^{\downarrow}(\lambda)}$$

- **α(λ) is not a true surface property** but rather a characteristic of the coupled surface-atmosphere system.

LSA Estimation

- Considering only direct radiation, thus a beam from a specific direction (θ_{dh}, ϕ_{dh}): $F^{\downarrow}(\lambda) = F_0(\lambda)\cos\theta_{dh}$

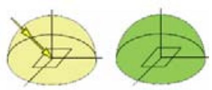
$$L^{\uparrow}(\lambda, \theta_{out}, \phi_{out}; \theta_{dh}, \phi_{dh}) = \frac{1}{\pi} R(\lambda, \theta_{out}, \phi_{out}, \theta_{dh}, \phi_{dh}) F_0(\lambda)\cos\theta_{dh}$$

- In this case we obtain the spectral directional hemispherical ("**black-sky**") albedo :

$$a^{dh}(\lambda; \theta_{dh}, \phi_{dh}) = \frac{1}{\pi} \int_{2\pi} R(\lambda, \theta_{out}, \phi_{out}, \theta_{dh}, \phi_{dh}) \cos\theta_{out} d\Omega_{out}$$

- On the other hand, for completely diffuse illumination:

$$L^{\downarrow}(\lambda, \theta_{in}, \phi_{in}) = L_0(\lambda) \qquad F^{\downarrow}(\lambda) = \pi L_0(\lambda)$$



- In this case we obtain the bi-hemispherical (“**white-sky**”) albedo:

$$a^{bh}(\lambda) = \frac{1}{\pi} \int_{2\pi} a^{dh}(\lambda; \theta_{in}, \phi_{in}) \cos\theta_{in} d\Omega_{in}$$

LSA Estimation

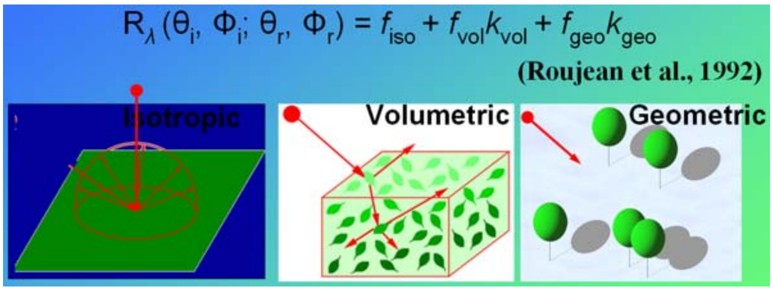
- The quantities $\alpha^{dh}(\lambda;\theta_{dh},\phi_{dh})$ and $a^{bh}(\lambda)$ are **true surface properties** and correspond to the limiting cases of point source and completely diffuse illumination .
- To obtain an approximation of the albedo for ambient illumination conditions (“**blue-sky**”), it is suggested to linearly combine the $a^{bh}(\lambda)$ for isotropic diffuse illumination conditions and the $\alpha^{dh}(\lambda;\theta_{dh},\phi_{dh})$ as:

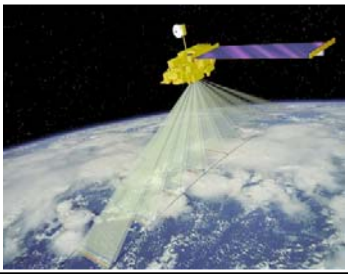
$$a(\lambda) = [1 - f_{diffuse}(\lambda)] a^{dh}(\lambda; \theta_s, \phi_s) + f_{diffuse}(\lambda) a^{bh}(\lambda)$$

- where $f_{diffuse}$ denotes the fraction of diffuse radiation and is a function of **Aerosol Optical Thickness (AOT)**.
- Therefore, to estimate spectral albedo, the parameters $\alpha^{dh}(\lambda;\theta_{dh},\phi_{dh})$, $a^{bh}(\lambda)$ και $f_{diffuse}$ should be estimated, or in practice, **BRDF** and **AOT**.

LSA Estimation

- Semi-empirical models:





Schaaf et al. 2002

LSA Estimation

$$R(\theta_{in}, \varphi_{in}, \theta_{out}, \varphi_{out}, \lambda) = f_{iso}(\lambda) + f_{vol}(\lambda) K_{vol}(\theta_{in}, \varphi_{in}, \theta_{out}, \varphi_{out}) + f_{geo}(\lambda) K_{geo}(\theta_{in}, \varphi_{in}, \theta_{out}, \varphi_{out})$$

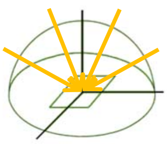
$$\alpha_{bs}(\theta, \lambda) = f_{iso}(\lambda)(g_{0iso} + g_{1iso}\theta^2 + g_{2iso}\theta^3) + f_{vol}(\lambda)(g_{0vol} + g_{1vol}\theta^2 + g_{2vol}\theta^3) + f_{geo}(\lambda)(g_{0geo} + g_{1geo}\theta^2 + g_{2geo}\theta^3)$$

MODIS

Term g_{jk} for kernel k	k = Isotropic	k = RossThick	k = LiSparse-R
g_{0k} (term 1)	1.0	−0.007574	−1.284909
g_{0k} (term θ^2)	0.0	−0.070987	−0.166314
g_{0k} (term θ^3)	0.0	0.307588	0.041840
White-sky	1.0	0.189184	−1.377622

α_{bs} : average of all SZAs

α_{ws} : independent of θ



Schaaf et al. 2002

LSA Estimation

$$LSA(\theta,\lambda) = \{1 - f_{diffuse}(\theta, AOT(\lambda))\} a_{bs}(\theta,\lambda) + f_{diffuse}(\theta, \mathrm{AOT}(\lambda)) a_{ws}(\lambda)$$

$$f_{diffuse}(\theta, \mathrm{AOT}(\lambda))$$

AEROSOL OPTICAL DEPTH (0 - 0.98)

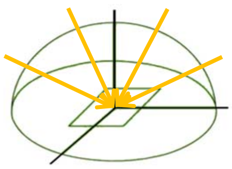
SOLAR ZENITH ANGLE (0 - 89°)	0	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.22	0.24	0.26	0.28	0.3	0.32
0	0.068	0.08	0.09	0.101	0.112	0.122	0.132	0.142	0.152	0.161	0.171	0.18	0.189	0.198	0.207	0.215	0.224
1	0.068	0.08	0.09	0.101	0.112	0.122	0.132	0.142	0.152	0.161	0.171	0.18	0.189	0.198	0.207	0.215	0.224
2	0.068	0.08	0.09	0.101	0.112	0.122	0.132	0.142	0.152	0.161	0.171	0.18	0.189	0.198	0.207	0.215	0.224
3	0.068	0.08	0.091	0.101	0.112	0.122	0.132	0.142	0.152	0.161	0.171	0.18	0.189	0.198	0.207	0.216	0.224
4	0.068	0.08	0.091	0.101	0.112	0.122	0.132	0.142	0.152	0.162	0.171	0.18	0.189	0.198	0.207	0.216	0.224
5	0.069	0.08	0.091	0.101	0.112	0.122	0.132	0.142	0.152	0.162	0.171	0.18	0.19	0.198	0.207	0.216	0.224
6	0.069	0.08	0.091	0.102	0.112	0.122	0.133	0.143	0.152	0.162	0.171	0.181	0.19	0.199	0.208	0.216	0.225
7	0.069	0.08	0.091	0.102	0.112	0.123	0.133	0.143	0.152	0.162	0.172	0.181	0.19	0.199	0.208	0.216	0.225
8	0.069	0.08	0.091	0.102	0.112	0.123	0.133	0.143	0.153	0.162	0.172	0.181	0.19	0.199	0.208	0.217	0.225
9	0.069	0.08	0.091	0.102	0.113	0.123	0.133	0.143	0.153	0.163	0.172	0.181	0.191	0.2	0.208	0.217	0.226
10	0.069	0.08	0.091	0.102	0.113	0.123	0.133	0.143	0.153	0.163	0.172	0.182	0.191	0.2	0.209	0.218	0.226
11	0.069	0.081	0.092	0.102	0.113	0.123	0.134	0.144	0.154	0.163	0.173	0.182	0.191	0.2	0.209	0.218	0.227
12	0.069	0.081	0.092	0.103	0.113	0.124	0.134	0.144	0.154	0.164	0.173	0.183	0.192	0.201	0.21	0.219	0.227
13	0.07	0.081	0.092	0.103	0.114	0.124	0.134	0.145	0.154	0.164	0.174	0.183	0.192	0.201	0.21	0.219	0.228
14	0.07	0.081	0.092	0.103	0.114	0.124	0.135	0.145	0.155	0.165	0.174	0.184	0.193	0.202	0.211	0.22	0.228
15	0.07	0.081	0.093	0.104	0.114	0.125	0.135	0.145	0.155	0.165	0.175	0.184	0.193	0.203	0.212	0.22	0.229
16	0.07	0.082	0.093	0.104	0.115	0.125	0.136	0.146	0.156	0.166	0.175	0.185	0.194	0.203	0.212	0.221	0.23
17	0.07	0.082	0.093	0.104	0.115	0.126	0.136	0.146	0.156	0.166	0.176	0.185	0.195	0.204	0.213	0.222	0.23
18	0.071	0.082	0.094	0.105	0.116	0.126	0.137	0.147	0.157	0.167	0.177	0.186	0.195	0.205	0.214	0.223	0.231
19	0.071	0.083	0.094	0.105	0.116	0.127	0.137	0.147	0.158	0.168	0.177	0.187	0.196	0.205	0.214	0.223	0.232
20	0.071	0.083	0.094	0.106	0.117	0.127	0.138	0.148	0.158	0.168	0.178	0.188	0.197	0.206	0.215	0.224	0.233
21	0.072	0.083	0.095	0.106	0.117	0.128	0.138	0.149	0.159	0.169	0.179	0.188	0.198	0.207	0.216	0.225	0.234
22	0.072	0.084	0.095	0.107	0.118	0.128	0.139	0.149	0.16	0.17	0.18	0.189	0.199	0.208	0.217	0.226	0.235
23	0.072	0.084	0.096	0.107	0.118	0.129	0.14	0.15	0.16	0.171	0.18	0.19	0.2	0.209	0.218	0.227	0.236
24	0.073	0.085	0.096	0.108	0.119	0.13	0.14	0.151	0.161	0.171	0.181	0.191	0.201	0.21	0.219	0.228	0.237
25	0.073	0.085	0.097	0.108	0.119	0.13	0.141	0.152	0.162	0.172	0.182	0.192	0.202	0.211	0.22	0.23	0.239
26	0.074	0.086	0.097	0.109	0.12	0.131	0.142	0.153	0.163	0.173	0.183	0.193	0.203	0.212	0.222	0.231	0.24
27	0.074	0.086	0.098	0.109	0.121	0.132	0.143	0.154	0.164	0.174	0.184	0.194	0.204	0.214	0.223	0.232	0.241
28	0.074	0.087	0.099	0.11	0.122	0.133	0.144	0.154	0.165	0.175	0.186	0.195	0.205	0.215	0.224	0.234	0.243
29	0.075	0.087	0.099	0.111	0.122	0.134	0.145	0.155	0.166	0.177	0.187	0.197	0.207	0.216	0.226	0.235	0.244
30	0.075	0.088	0.1	0.112	0.123	0.135	0.146	0.157	0.167	0.178	0.188	0.198	0.208	0.218	0.227	0.236	0.246
31	0.076	0.088	0.101	0.112	0.124	0.136	0.147	0.158	0.168	0.179	0.189	0.199	0.209	0.219	0.229	0.238	0.247
32	0.077	0.089	0.101	0.113	0.125	0.136	0.148	0.159	0.17	0.18	0.191	0.201	0.211	0.221	0.23	0.24	0.249
33	0.077	0.09	0.102	0.114	0.126	0.138	0.149	0.16	0.171	0.182	0.192	0.202	0.212	0.222	0.232	0.241	0.251
34	0.078	0.09	0.103	0.115	0.127	0.139	0.15	0.161	0.172	0.183	0.193	0.204	0.214	0.224	0.234	0.243	0.253
35	0.078	0.091	0.104	0.116	0.128	0.14	0.151	0.163	0.174	0.184	0.195	0.205	0.216	0.226	0.236	0.245	0.255

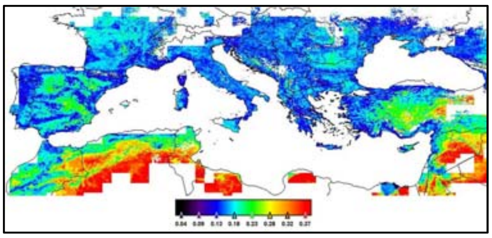
Schaaf et al. 2002

LSA Estimation

$$LSA(\theta,\lambda) = \{1 - f_{diffuse}(\theta, AOT(\lambda))\} a_{bs}(\theta,\lambda) + f_{diffuse}(\theta, \mathrm{AOT}(\lambda)) a_{ws}(\lambda)$$

Average for all SZAs

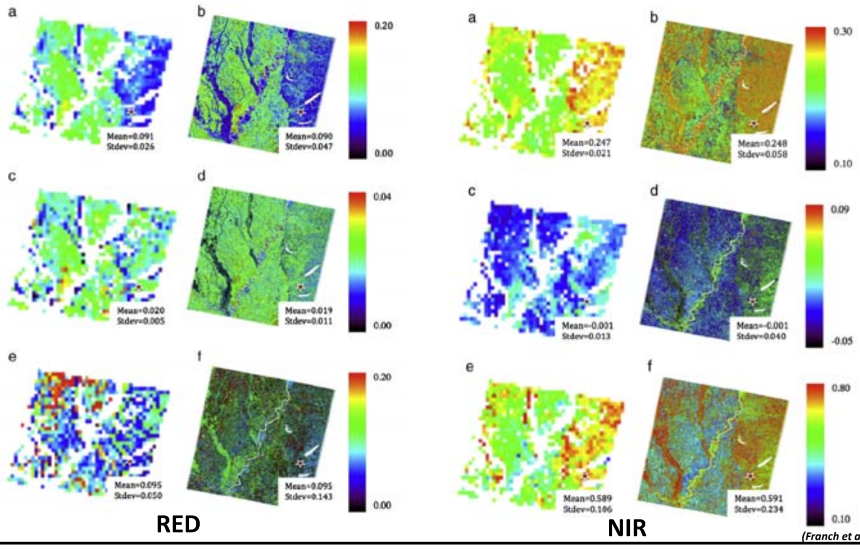




(Benas & Chrysoulakis 2015)

Local and Fine Scale LSA

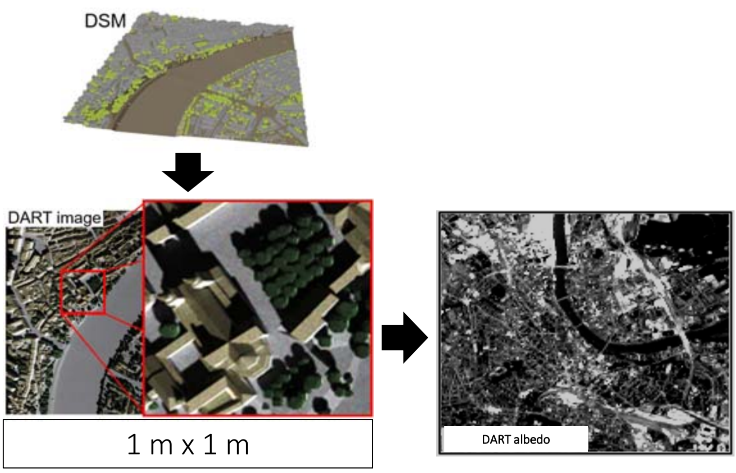
- Extension to Landsat: k_0 (a, b), k_1 (c, d) and k_2 (e, f) results:



(Franch et al. 2014)

Local and Fine Scale LSA

- DART-based simulation of BRDF

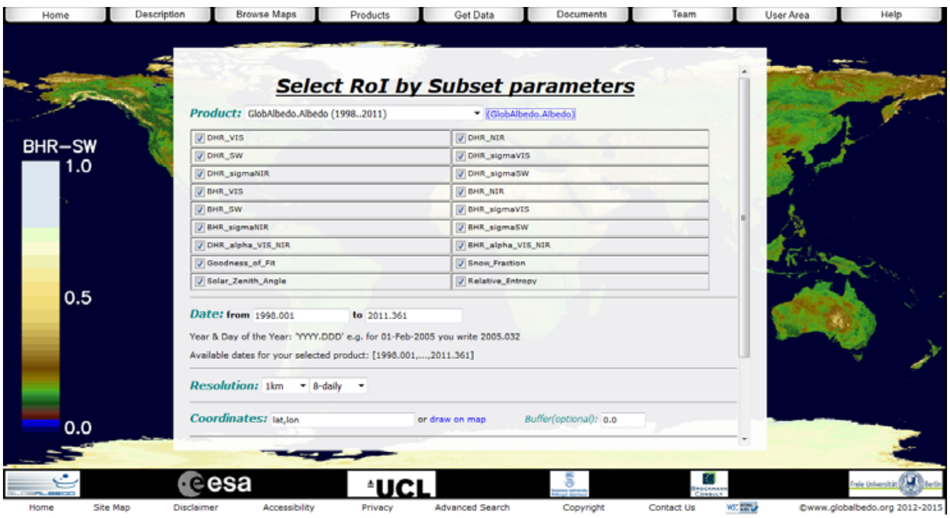


(Gastellau-Etchegorry et al. 2015)

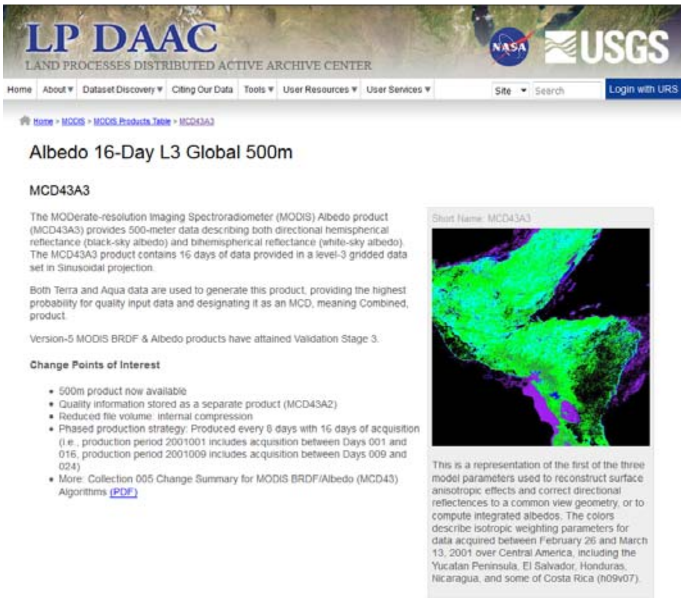
Global LSA

- The only example of albedo retrieval from **multisource data** is the MCD43 series of albedo products, which combines the data from Terra/MODIS and Aqua/MODIS.
- Although use of multisource data helps to improve the spatial/temporal resolution of albedo projects, the problem of **band discrepancy between different sensors** has not been solved.
- **Available Global Products**:
  - ✓ MODIS Albedo Product
  - ✓ POLDER Albedo Product
  - ✓ MERIS Albedo Product (**GLOBALBEDO Project**)
  - ✓ VEGETATION Albedo Product
  - ✓ METEOSAT - MSG Albedo Product

Global LSA

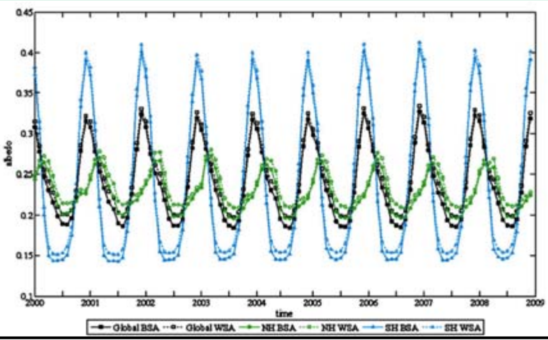


Global LSA



Global LSA

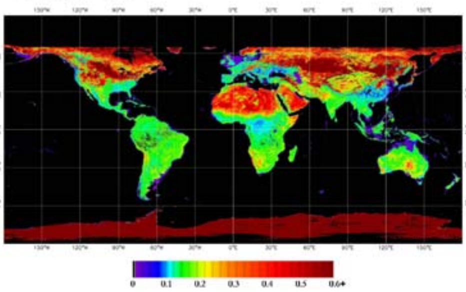
Area	Type of albedo	Yearly average of albedo	Seasonal albedo: Spring	Summer	Autumn	Winter
Northern Hemisphere	BSA	0.225±0.002	0.251±0.003	0.202±0.003	0.209±0.003	0.243±0.003
	WSA	0.235±0.001	0.262±0.003	0.216±0.003	0.217±0.003	0.248±0.003
Southern Hemisphere	BSA	0.255±0.004	0.174±0.004	0.148±0.002	0.268±0.008	0.361±0.004
	WSA	0.264±0.004	0.184±0.004	0.157±0.002	0.277±0.008	0.37±0.004
Global	BSA	0.235±0.001	0.231±0.002	0.19±0.002	0.233±0.003	0.302±0.002
	WSA	0.235±0.001	0.242±0.002	0.203±0.002	0.242±0.003	0.309±0.002



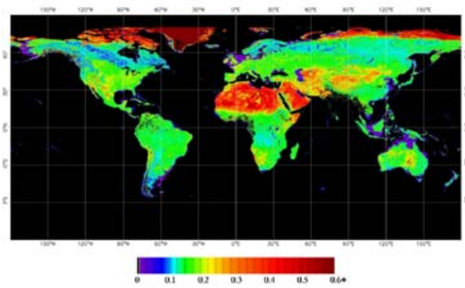
(Zhang et al. 2012)

Global LSA

MODIS Broadband White-Sky Albedo (0.3-5.0mm)
January 2001



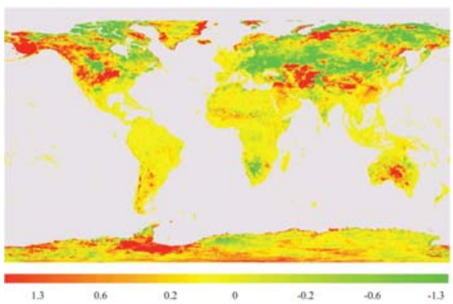
MODIS Broadband White-Sky Albedo (0.3-5.0mm)
June 2001



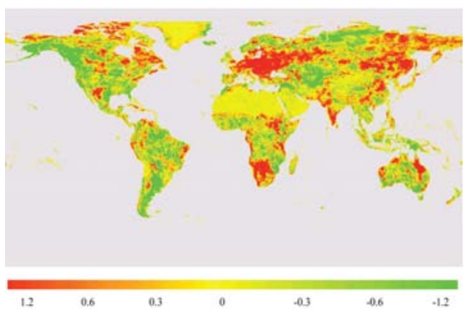
(Liang et al. 2012)

Global LSA

WSA

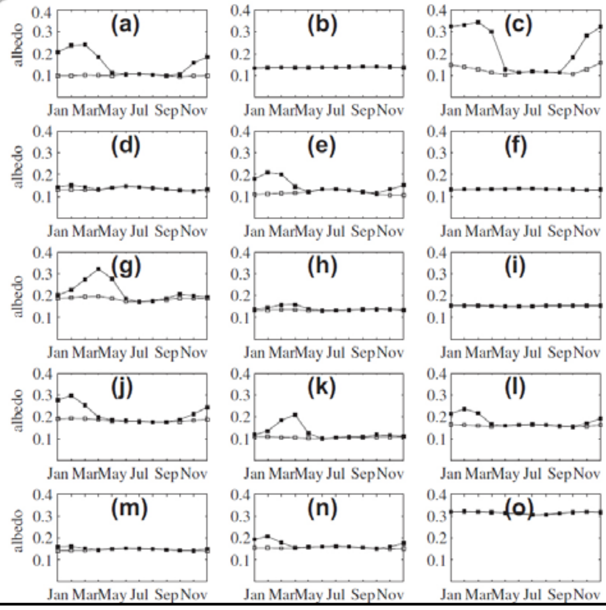


NDVI



(Zhang et al. 2012)

Global LSA



(a) Evergreen Needleleaf forest, (b) Evergreen Broadleaf forest, (c) Deciduous Needleleaf forest, (d) Deciduous Broadleaf forest, (e) Mixed forest, (f) Closed shrublands, (g) Open shrublands, (h) Woody savannas, (i) Savannas, (j) Grasslands, (k) Permanent wetlands, (l) Croplands, (m) Urban and built-up, (n) Cropland/Natural vegetation mosaic, (o) Barren or sparsely vegetated.

(Liang et al. 2012)

Global LSA

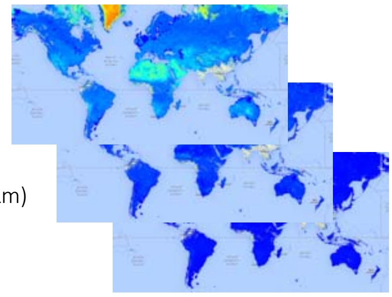
Product name	Product category	Classes of Grids	Spatial resolution	Temporal resolution
MOD/MYD/MCD43A3	Albedo	Tile	500 m	16 d
MOD/MYD/MCD43B3	Albedo	Tile	1000 m	16 d
MOD/MYD/MCD43C3	Albedo	CMG	5600 m	16 d
MOD/MYD/MCD43A1	BRDF-Albedo Model Parameters	Tile	500 m	16 d
MOD/MYD/MCD43B1	BRDF-Albedo Model Parameters	Tile	1000 m	16 d
MOD/MYD/MCD43C1	BF-Albedo Model Parameters	CMG	5600 m	16 d
MOD/MYD/MCD43A2	BRDF-Albedo Quality	Tile	500 m	16 d
MOD/MYD/MCD43B2	BRDF-Albedo Quality	Tile	1000 m	16 d
MOD/MYD/MCD43C2	BRDF-Albedo Snow-free Quality	Tile	5600 m	16 d
MOD/MYD/MCD43A4	Nadir BRDF-Adjusted Reflectance	Tile	500 m	16 d
MOD/MYD/MCD43B4	F-Adjusted Reflectance	Tile	1000 m	16 d
MOD/MYD/MCD43C4	Nadir BRDF-Adjusted Reflectance	CMG	5600 m	16 d

*Tile and CMG represent two grids based on different projections of the MODIS products. Tile presents a method that uses a sinusoidal projection grid to divide the Earth's surface into 36*18 publishing units, and CMG (Climate Modeling Grid) presents globally equal-longitude-latitude grids (0.05°, 1°, etc.).*

Global LSA

Level 3 Albedo Model Parameters MCD43A1

- Combined Terra and Aqua data products
- 8–day temporal average
- 500 m × 500 m spatial resolution
- Include f_{iso}, f_{vol}, f_{geo}, on a pixel basis
  - at 7 wavelengths
  - and 3 broad bands (shortwave: 0.3 - 5.0 μm)
- Product Quality parameters are available (MCD43A2)



Level 3 AOT Product (MOD08)

- Available separately from Terra and Aqua
- monthly temporal average
- 1° × 1° spatial resolution
- Average Terra/Aqua AOT computed and interpolated

(Mitraka et al. 2016)

Global LSA

BRDF-Albedo Model Parameters 16-Day L3 Global 500m

The MODerate-resolution Imaging Spectroradiometer (MODIS) BRDF/Albedo Model Parameters product (MCD43A1) contains datasets providing users with weighting parameters for the models used to derive the Albedo and BRDF products (MCD43A3 and MCD43A4). The models support the spatial relationship and parameter characterization best describing the differences in radiation due to the scattering (anisotropy) of each pixel, relying on multi-date, atmospherically corrected, cloud-cleared input data measured over 16-day periods. Both Terra and Aqua data are used in the generation of this product, providing the highest probability for quality input data and designating it as an MCD, meaning Combined, product.

Version-5 MODIS/Terra+Aqua BRDF/Albedo products are Validated Stage 1, meaning that accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts. Although there may be later improved versions, these data are ready for use in scientific publications.

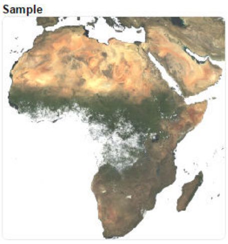
Data availability (time)
Feb 18, 2000 - Feb 2, 2016

Provider
USGS LPDAAC

Tags
modis, mcd43a1, 16day, global, usgs, albedo, brdf, reflectance

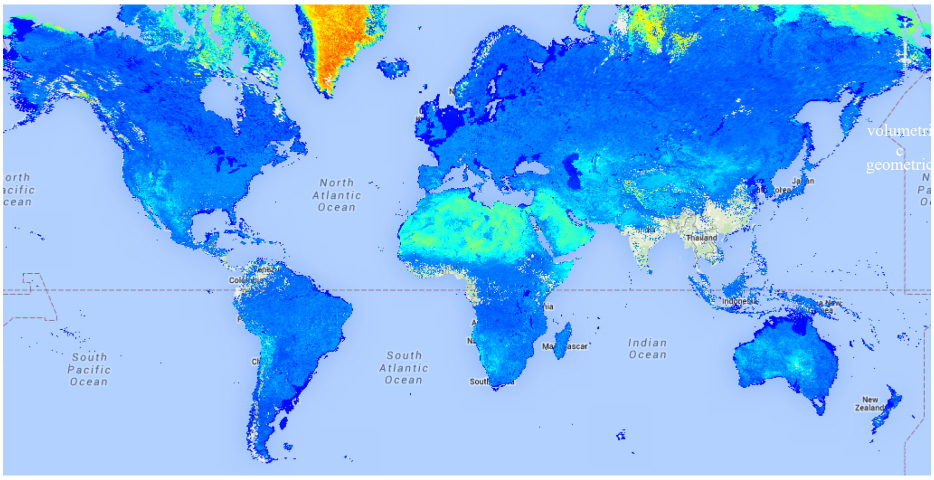
ImageCollection ID
MODIS/MCD43A1

Sample



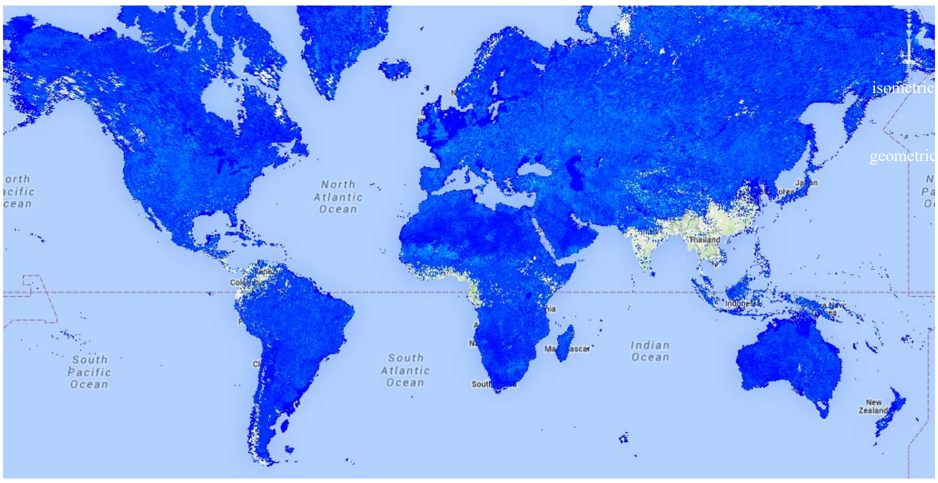
Global LSA

- Isotropic



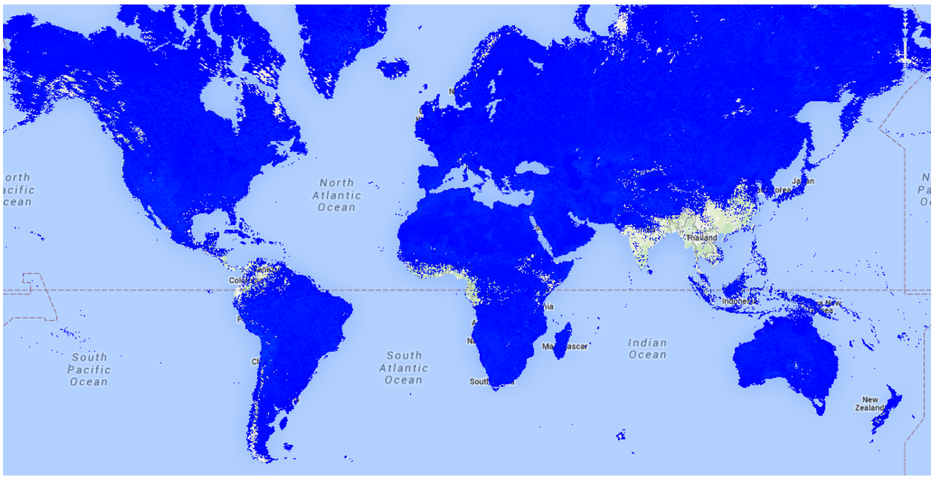
Global LSA

- Volumetric



Global LSA

- Geometric



Global LSA

MCD43A2 BRDF-Albedo Quality 16-Day Global 500m

The MODerate-resolution Imaging Spectroradiometer (MODIS) BRDF/Albedo Quality product (MCD43A2) describes the overall condition of the other BRDF and Albedo products. The MCD43A2 product contains 16 days of data at 500 meter spatial resolution provided in a level-3 gridded data set in Sinusoidal projection, and includes albedo quality, snow conditions, ancillary information, and inversion information. Both Terra and Aqua data are used in the generation of this product, providing the highest probability for quality input data and designating it as an MCD, meaning Combined, product.

Version-5 MODIS/Terra+Aqua BRDF/Albedo products are Validated Stage 1, meaning that accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts. Although there may be later improved versions, these data are ready for use in scientific publications.

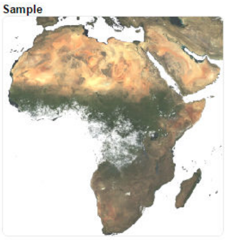
Data availability (time)
Feb 18, 2000 - Feb 2, 2016

Provider
USGS LPDAAC

Tags
modis, mcd43a2, 16day, global, usgs, albedo, quality, brdf, reflectance

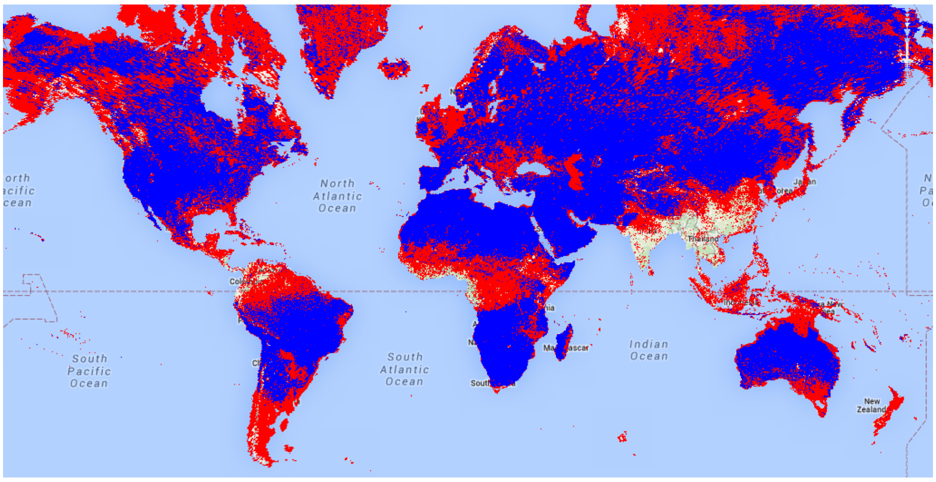
ImageCollection ID
MODIS/MCD43A2

Sample



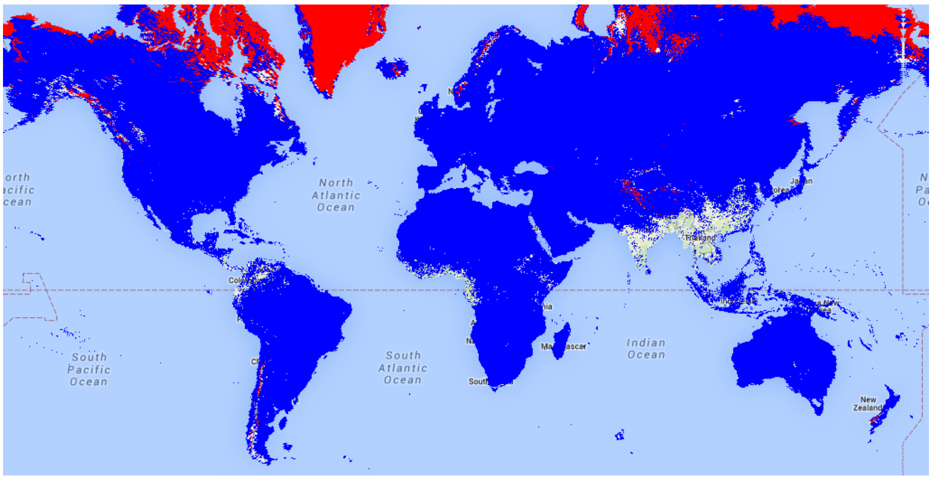
Global LSA

- Albedo Quality



Global LSA

- Snow Cover



Global LSA

MOD08_M3 Atmosphere Monthly Global Product

MOD08_M3 is a level-3 MODIS gridded atmosphere monthly global product. It contains monthly 1 x 1 degree grid average values of atmospheric parameters related to atmospheric aerosol particle properties, total ozone burden, atmospheric water vapor, cloud optical and physical properties, and atmospheric stability indices. This product also provides standard deviations, quality assurance weighted means and other statistically derived quantities for each parameter.

Statistics are computed over a 1 degree equal-angle lat-lon grid that spans a (calendar) monthly interval.

See CDL specification at http://modis-atmos.gsfc.nasa.gov/_specs/MOD08_M3.CDL.fs

Data availability (time)
Mar 1, 2000 - Jan 1, 2016

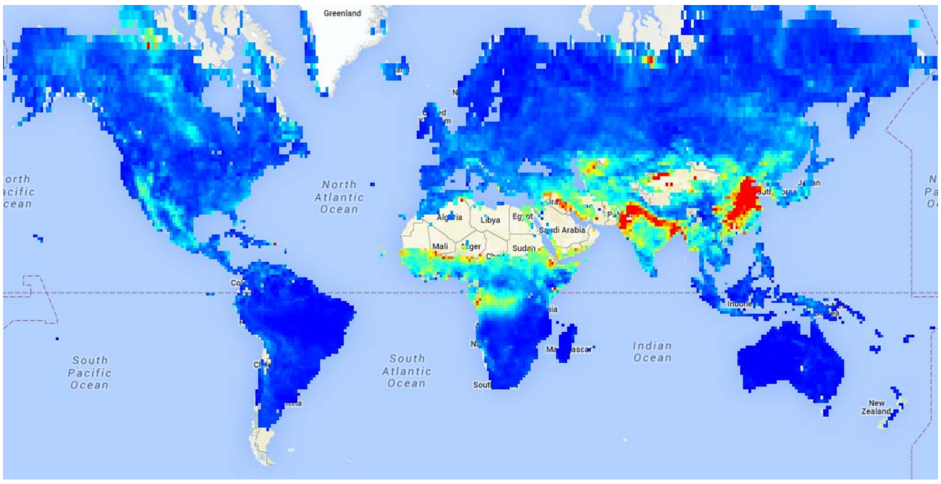
Provider
NASA GSFC

Tags
modis, mod08, mod08_m3, monthly, global, terra, atmosphere, temperature, geophysical

ImageCollection ID
MODIS/MOD08_M3_051

Global LSA

- AOT



Global LSA

Loop over 24 solar zenith angles within a day

×

~3,200,000,000 pixels for the globe

×

~45 8-day products per year

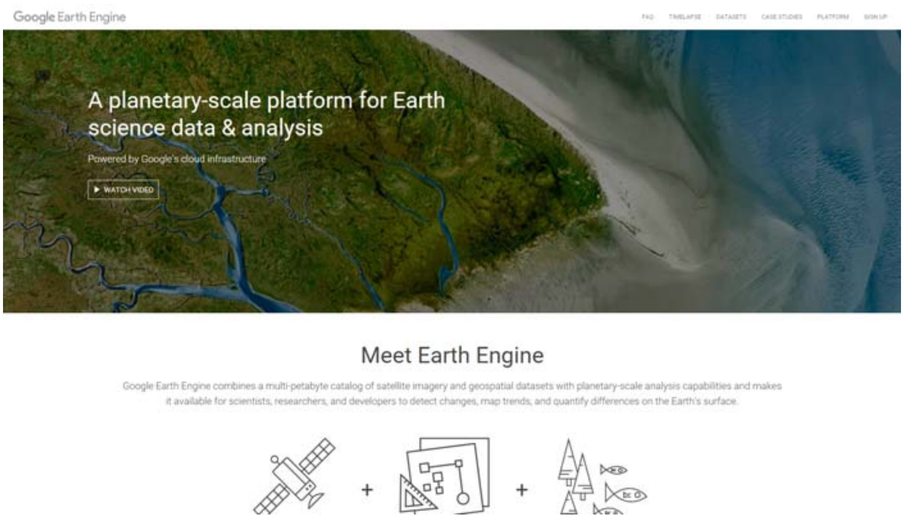
×

15 years

=

IMPOSSIBLE (?)

Global LSA



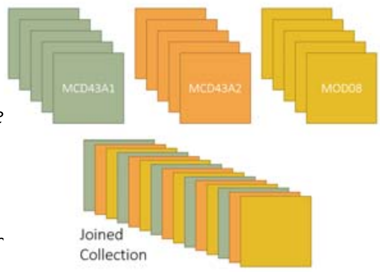
https://earthengine.google.com

Global LSA

- GEE is a platform for **petabyte-scale** scientific analysis and visualization of geospatial datasets.
- GEE stores satellite imagery, organizes it, and makes it available for the first time for global-scale data mining.
- The **public data archive** includes historical earth imagery going back more than forty years, and new imagery is collected every day.
- GEE provides **APIs** in JavaScript and Python, as well as other tools, to enable the analysis of large datasets.

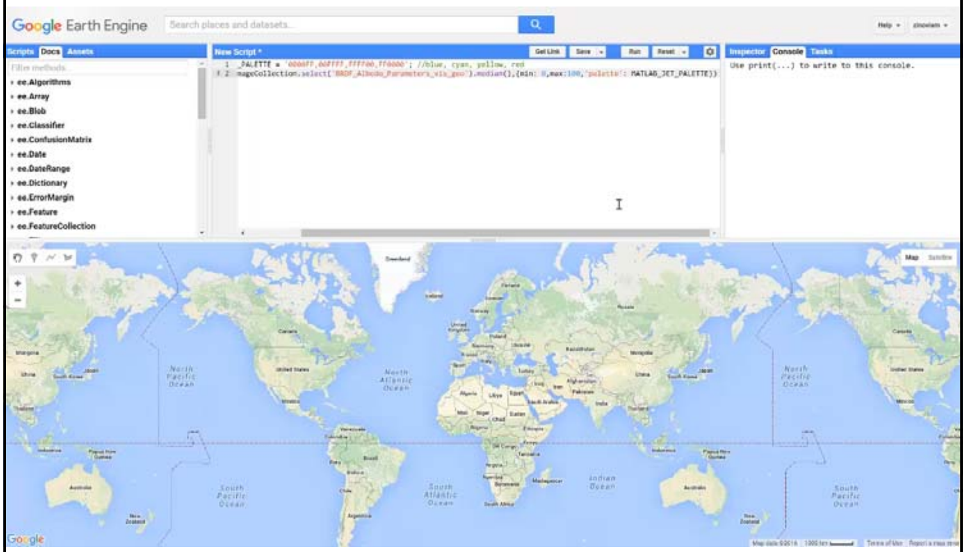
Global LSA

- GEE works with *Image Collections.*
- Computations are not performed in a pixel level, but rather created for an imaged and *mappe*d in parallel to an *Image Collection.*
- Information on the *isotropic reflectance fraction, the volume scattering fraction and the geometrical structure of the surface* are taken from MCD43A1 product.
- Information on the albedo quality is taken from MCD43A2 product.
- Information on the Aerosol Optical Depth is taken from MOD08 product.
- Information for the different collections is *joined* in a single collection.



(Mitraka et al. 2016)

Global LSA



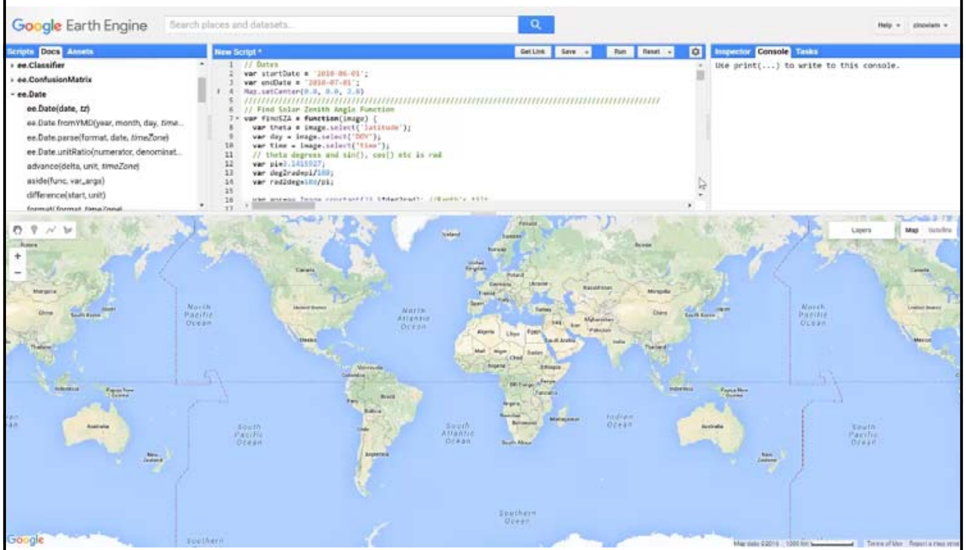
(Mitraka et al. 2016)

Global LSA

- A function *calculateAlbedo* has been developed to estimate the blue-sky albedo for an image.
- The *calculateAlbedo* function estimates for one image
  - ✓ the WSA as a function of f_{iso}, f_{vol}, f_{geo}
  - ✓ the BSA for individual SZA (hourly basis) as a function of f_{iso}, f_{vol}, f_{geo}
  - ✓ the Blue-sky Albedo in hourly basis, as a function of WSA and BSA, accounting for the diffuse radiation ($f_{diffuse}$) using AOT.
  - ✓ the mean daily Blue-sky Albedo corresponding to all solar zenith angles.
- The *calculateAlbedo* is then mapped to the entire Image Collection for the whole 15-year MODIS products

(Mitraka et al. 2016)

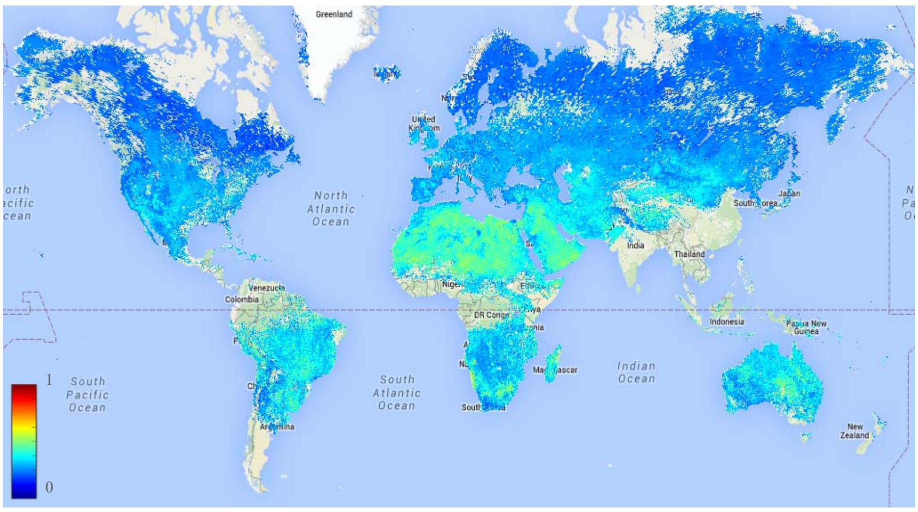
Global LSA



(Mitraka et al. 2016)

Global LSA

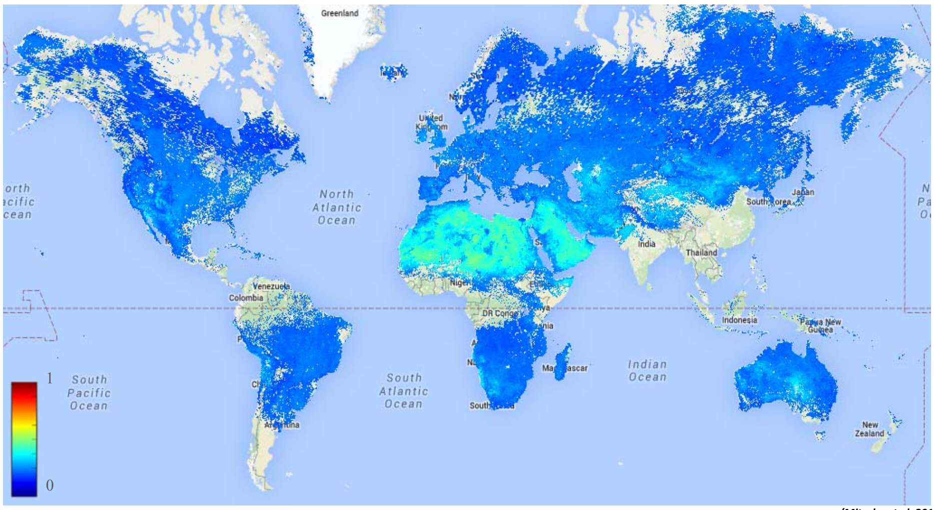
- BSA example for June 2010



(Mitraka et al. 2016)

Global LSA

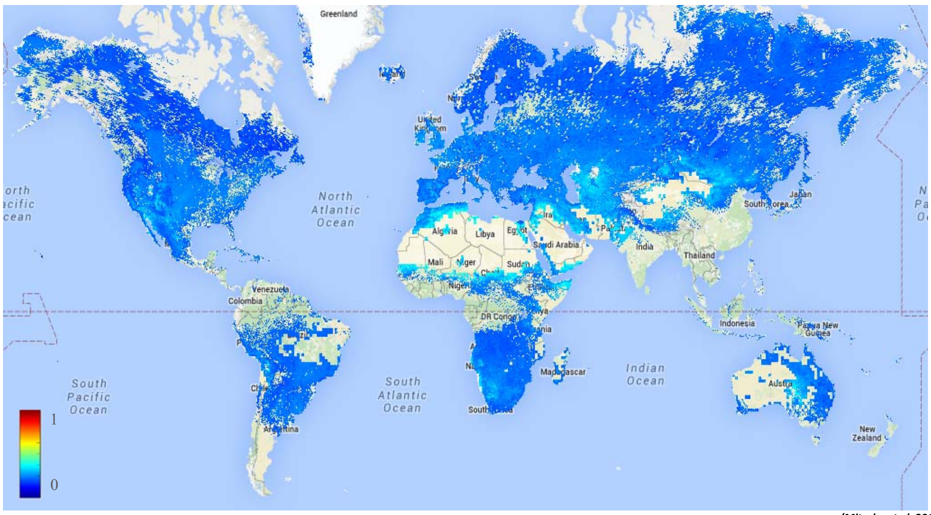
- WSA example for June 2010



(Mitraka et al. 2016)

Global LSA

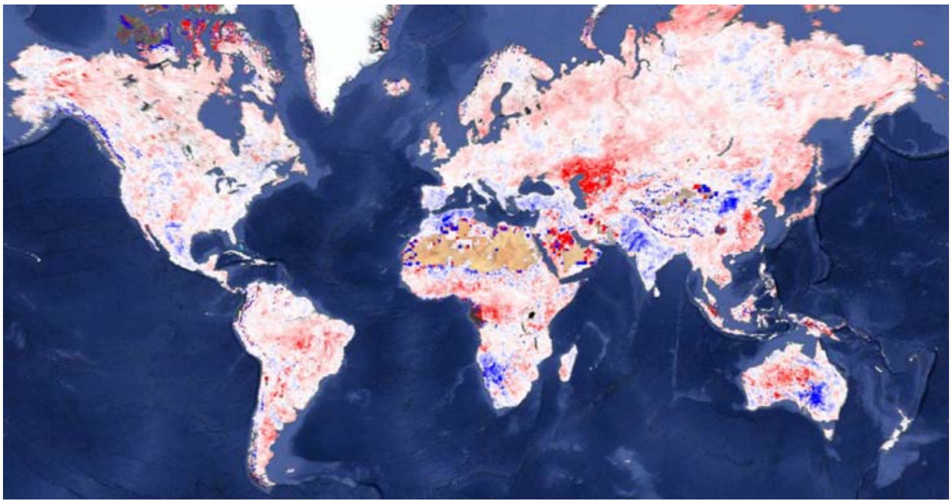
- Blue-sky Albedo, example for June 2010



(Mitraka et al. 2016)

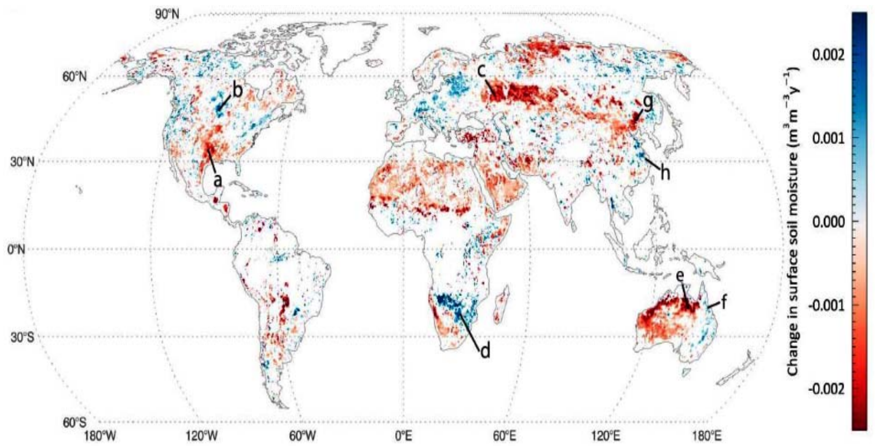
Global LSA

- Global Blue-sky Albedo Trends 2000 - 2015



Global LSA

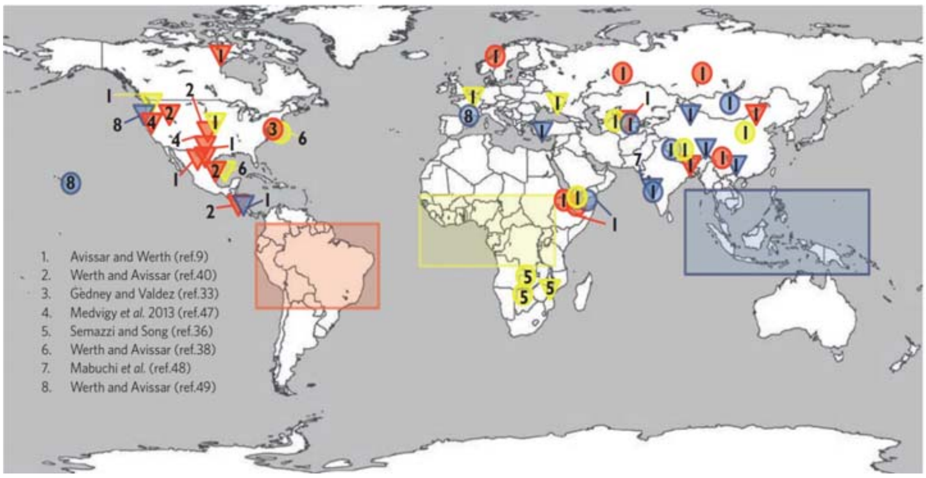
- Changes in Soil Moisture over the period 1988 - 2010



(Dorigo et al. 2012)

Global LSA

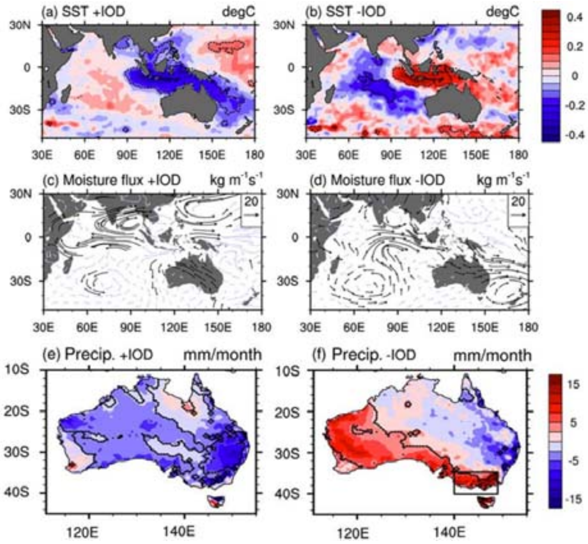
- Extratropical effects on precipitation due to deforestation in tropics



(Lawrence & Vandecar 2104)

Global LSA

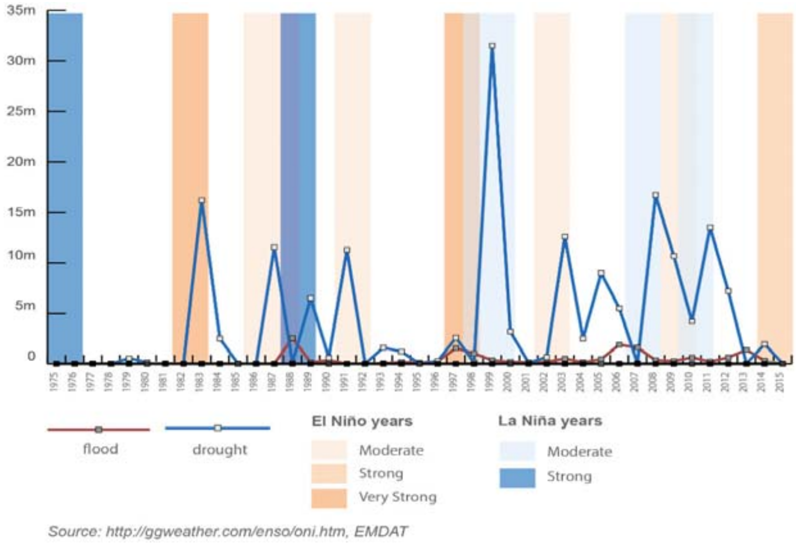
- Southeast Australia's droughts



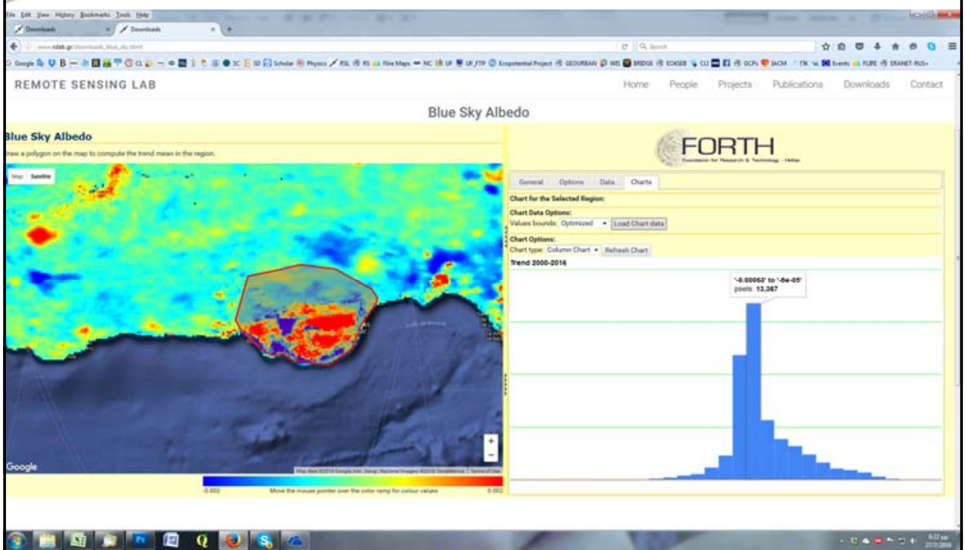
(Ummenhoferet al. 2009)

Global LSA

- Floods and Drafts in Eastern Africa

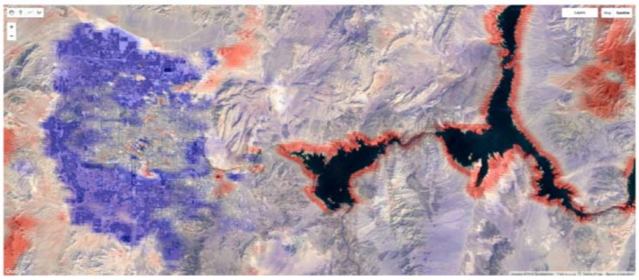


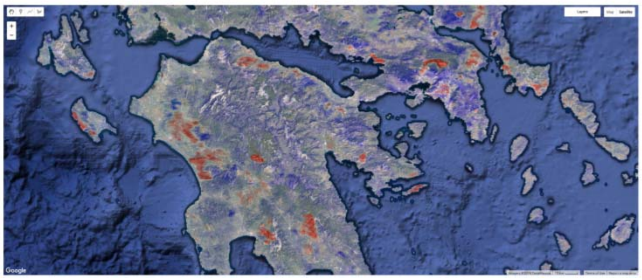
Albedo Web-service



http://rslab.gr

Albedo Web-service





Albedo Web-service

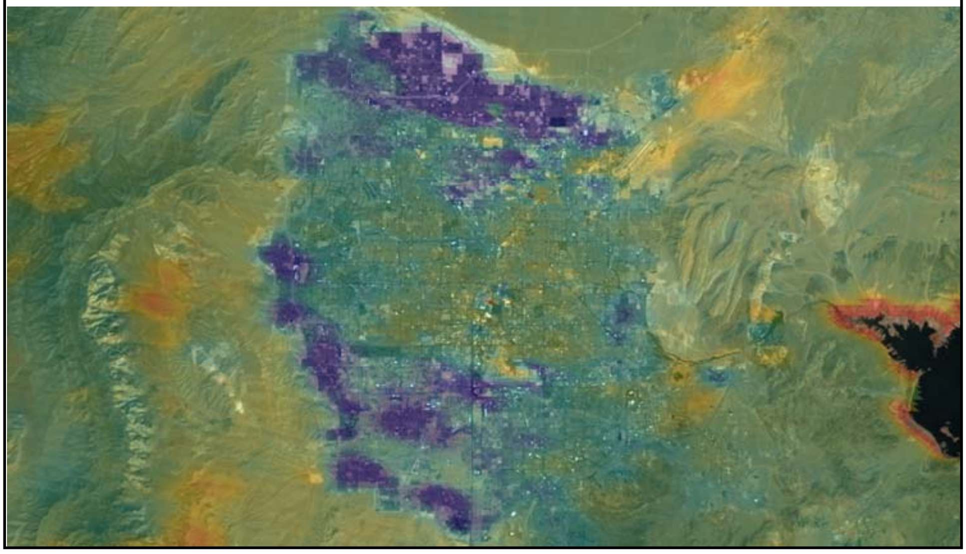
- Urbanization: Las Vegas 2000

Albedo Web-service

- Urbanization: Las Vegas 2015

Albedo Web-service

- Urbanization: Las Vegas Albedo Trend



Albedo Web-service

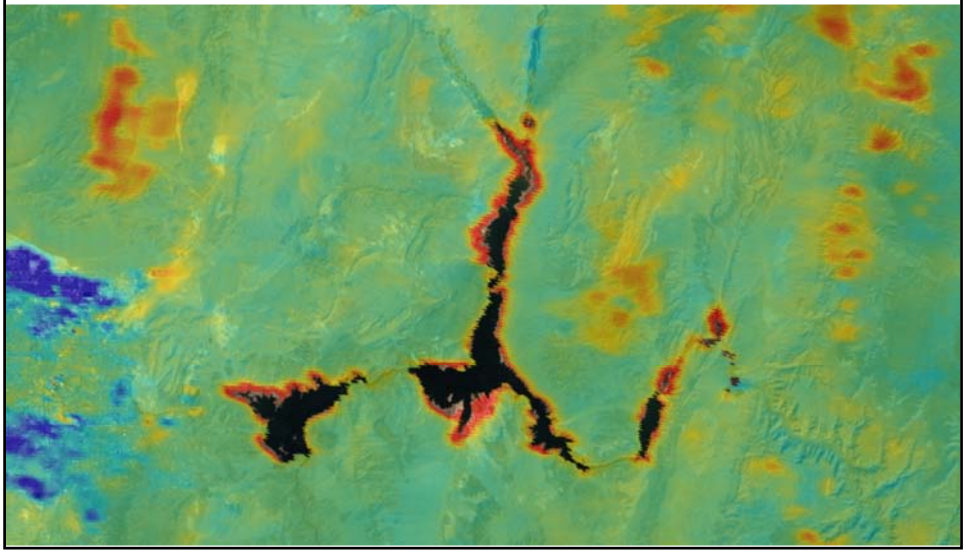
- Drainage: Colorado River 2000

Albedo Web-service

- Drainage: Colorado River 2015

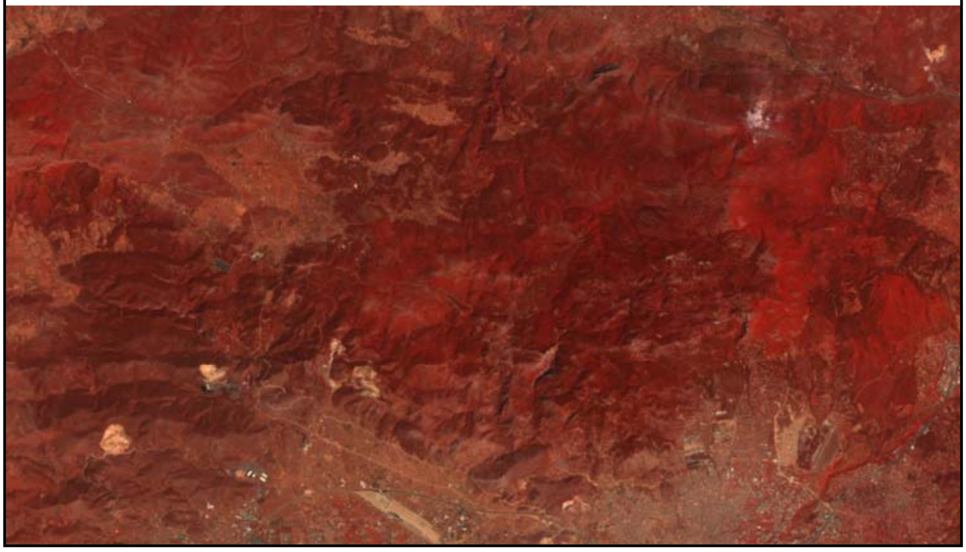
Albedo Web-service

- Drainage: Colorado River Albedo Trend



Albedo Web-service

- Forest fires: Athens 2000

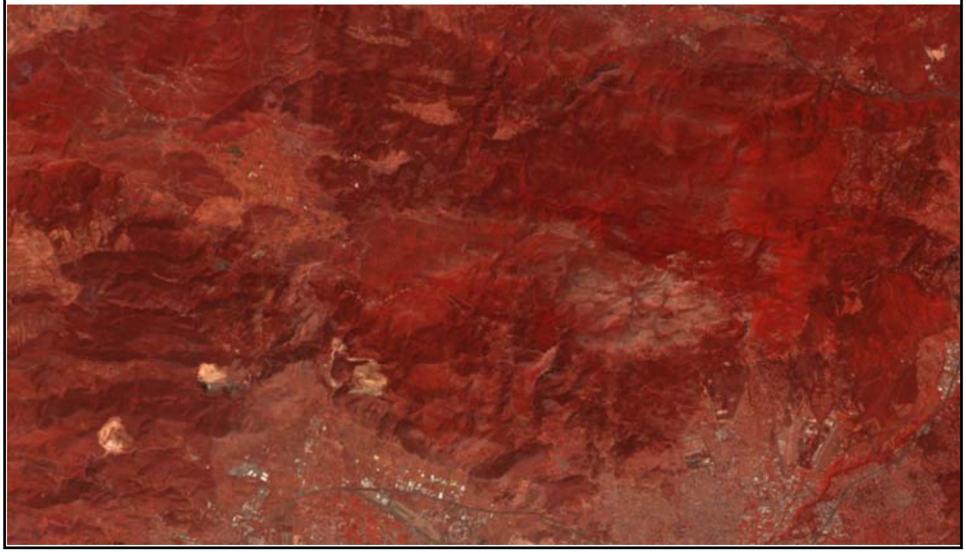


Albedo Web-service

- Forest fires: Athens 2007

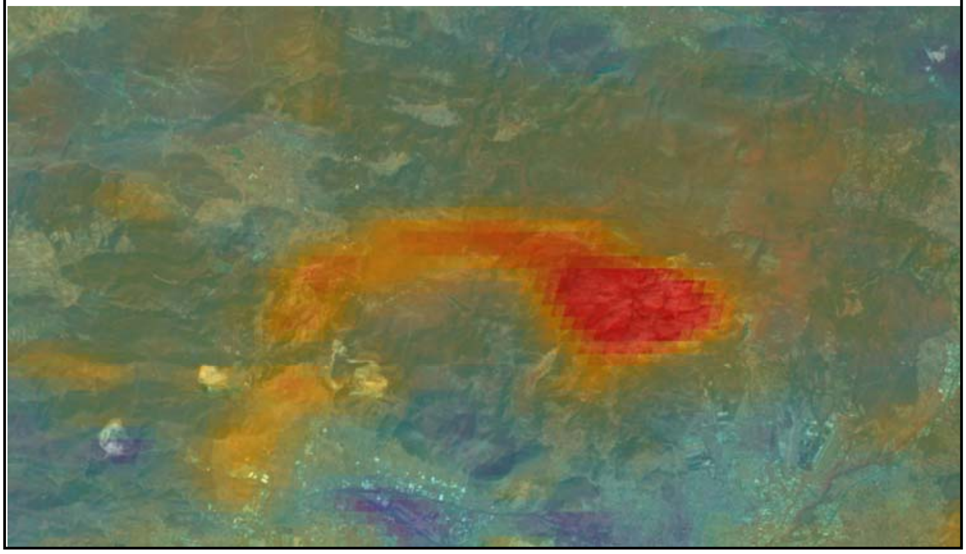
Albedo Web-service

- Forest fires: Athens 2015

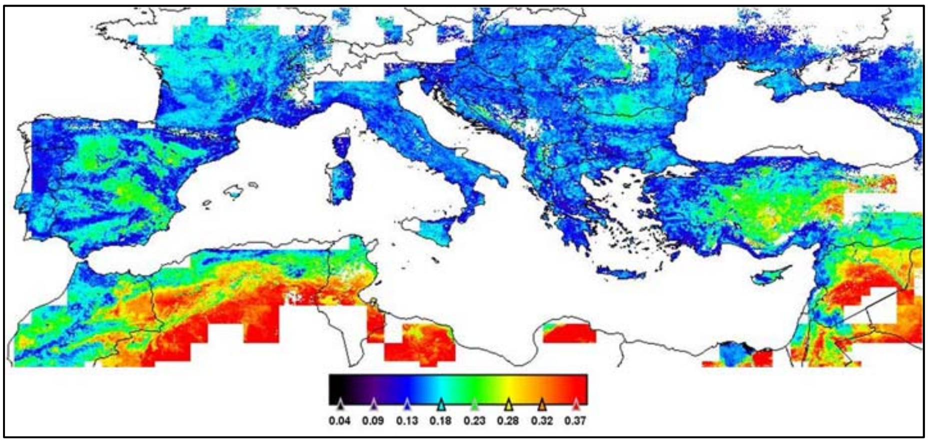


Albedo Web-service

- Forest fires: Athens Albedo Trend



Albedo Web-service



(Benas & Chrysoulakis 2015)

Albedo Web-service

Type number	Land Cover Type	Average LSA (±1σ)
0	Water	-
1	Evergreen Needleleaf forest	0.12 ± 0.03
2	Evergreen Broadleaf forest	0.14 ± 0.02
3	Deciduous Needleleaf forest	0.11 ± 0.04
4	Deciduous Broadleaf forest	0.14 ± 0.01
5	Mixed forest	0.13 ± 0.02
6	Closed shrublands	0.12 ± 0.02
7	Open shrublands	0.22 ± 0.05
8	Woody savannas	0.14 ± 0.02
9	Savannas	0.15 ± 0.02
10	Grasslands	0.21 ± 0.06
11	Permanent wetlands	0.09 ± 0.03
12	Croplands	0.18 ± 0.03
13	Urban and built-up	0.16 ± 0.03
14	Cropland/Natural vegetation mosaic	0.16 ± 0.02
15	Snow and ice	-
16	Barren or sparsely vegetated	0.33 ± 0.06

(Benas & Chrysoulakis 2015)

Albedo Web-service

0	Water
1	Evergreen Needleleaf fores
2	Evergreen Broadleaf forest
3	Deciduous Needleleaf fore
4	Deciduous Broadleaf forest
5	Mixed forest
6	Closed shrublands
7	Open shrublands
8	Woody savannas
9	Savannas
10	Grasslands
11	Permanent wetlands
12	Croplands
13	Urban and built-up
14	Cropland/Natural vegetatio
15	Snow and ice
16	Barren or sparsely vegetate

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.6 (9.5)	-	-	-	1.7 (8.1)	-	-	11.0 (11.2)	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-									
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-4.7 (4.0)	-4.1 (4.0)	-	-	-	-	-	-	-	-	-0.5 (7.2)	-	-
5	-1.6 (8.5)	-	-	-	-1.3 (6.6)	-	-	-1.0 (8.6)	-5.8 (7.3)	-	-	-1.3 (7.4)	-	-0.7 (7.1)	-	-
6	-4.5 (7.8)	-	-	-	-	-4.8 (6.6)	-2.4 (8.5)	-3.2 (7.7)	0.5 (8.9)	-	-	-	-	-	-	-
7	-	-	-	-	-	-9.3 (6.1)	-8.1 (7.6)	-9.4 (4.7)	-8.2 (3.8)	-8.1 (6.2)	-	-6.6 (6.1)	-	-7.2 (6.0)	-	-6.0 (11.3)
8	-5.9 (7.3)	-	-	-	-3.8 (6.3)	-5.3 (7.7)	-3.0 (11.2)	-5.3 (5.9)	-6.0 (7.0)	-1.4 (12.4)	-	-3.2 (7.9)	-	-3.6 (5.4)	-	-
9	-11.9 (17.0)									4.9 (7.9)	-	-6.3 (5.8)	-	-5.3 (4.6)	-	-
10	-	-	-	-	-5.5 (8.8)	-	-8.6 (7.3)	-7.2 (6.0)	-8.3 (3.9)	-6.4 (5.6)	-	-6.3 (5.3)	-	-5.1 (5.6)	-	-5.2 (10.3)
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-6.4 (6.5)	-11.6 (12.3)	1.5 (9.3)	-7.0 (5.4)	-7.8 (4.6)	-5. (5.						13.6 (14.5)
13							-	-	-	-	-	-	-3.1 (7.0)	-	-	-
14	-	-	-	-	-4.4 (5.0)	-	-6.2 (19.8)	-4.9 (5.9)	-6.5 (3.5)	-4.6 (8.7)	-	-3.9 (6.6)	-	-3.3 (4.8)	-	-
15								-	-	-	-					
16	-	-	-	-	-	-	-10.3 (7.2)	-	-	-9.2 (6.7)	-	-16.2 (11.8)	-	-	-	-5.2 (7.6)

Evergreen needleleaf forest → Woody savanna

Savanna → Evergreen needleleaf forest

Croplands → Barren land

Croplands → Closed shrublands

Barren land → Open shrublands

Barren land → Croplands

(Benas & Chrysoulakis 2015)

Albedo Web-service

0	Water
1	Evergreen Needleleaf fores
2	Evergreen Broadleaf forest
3	Deciduous Needleleaf fore
4	Deciduous Broadleaf forest
5	Mixed forest
6	Closed shrublands
7	Open shrublands
8	Woody savannas
9	Savannas
10	Grasslands
11	Permanent wetlands
12	Croplands
13	Urban and built-up
14	Cropland/Natural vegetatio
15	Snow and ice
16	Barren or sparsely vegetate

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.6 (9.5)	-	-	-	1.7 (8.1)	-	-	11.0 (11.2)	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-4.7 (4.0)	-4.1 (4.0)	-	-	-	-	-	-	-	-	-0.5 (7.2)	-	-
5	-1.6 (8.5)	-	-	-	-1.3 (6.6)	-	-	-1.0 (8.6)	-5.8 (7.3)	-	-	-1.3 (7.4)	-	-0.7 (7.1)	-	-
6	-4.5 (7.8)	-	-	-	-	-4.8 (6.6)	-2.4 (8.5)	-3.2 (7.7)	0.5 (8.9)	-	-	-	-	-	-	-
7	-	-	-	-	-	-9.3 (6.1)	-8.1 (7.6)	-9.4 (4.7)	-8.2 (3.8)	-8.1 (6.2)	-	-6.6 (6.1)	-	-7.2 (6.0)	-	-6.0 (11.3)
8	-5.9 (7.3)	-	-	-	-3.8 (6.3)	-5.3 (7.7)	-3.0 (11.2)	-5.3 (5.9)	-6.0 (7.0)	-1.4 (12.4)	-	-3.2 (7.9)	-	-3.6 (5.4)	-	-
9	-11.9 (17.0)	-	-	-	-5.8 (7.8)	-8.0 (8.8)	-3.3 (8.6)	-6.4 (5.3)	-7.2 (4.5)	-4.9 (7.9)	-	-6.3 (5.8)	-	-5.3 (4.6)	-	-
10	-	-	-	-	-5.5 (8.8)	-	-8.6 (7.3)	-7.2 (6.0)	-8.3 (3.9)	-6.4 (5.6)	-	-6.3 (5.3)	-	-5.1 (5.6)	-	-5.2 (10.3)
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-6.4 (6.5)	-11.6 (12.3)	1.5 (9.3)	-7.0 (5.4)	-7.8 (4.6)	-5.9 (5.3)	-	-3.6 (7.0)	-	-5.0 (4.9)	-	13.6 (14.5)
13	-	-	-	-	-	-	-	-	-	-	-	-	-3.1 (7.0)	-	-	-
14	-	-	-	-	-4.4 (5.0)	-	-6.2 (19.8)	-4.9 (5.9)	-6.5 (3.5)	-4.6 (8.7)	-	-3.9 (6.6)	-	-3.3 (4.8)	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
											-	-16.2 (11.8)	-	-	-	-5.2 (7.6)

Decreasing LSA not caused by LC changes

Concluding Remarks

- LSA trends are **consistent with SM trends**, as well as with previous studies found that **snow cover in the Northern Hemisphere has decreased**.
- The strong spatial consistency of LSA and SM trends suggests that **decreasing SM supply in the Southern Hemisphere is the main mechanism contributing to increase in LSA trend**.
- **LULC** change has **an important role locally**, but is apparently too geographically confined to govern the global LSA.

Concluding Remarks

- Whether the changing in global radiation balance, as a result of the change in LSA, is representative of natural climate variability, or reflects a more permanent characteristic of the land surface is **a key question for Earth System Science**.
- It is therefore obvious the importance of the **use of disaggregated LSA datasets as inputs in Earth System Science models** for regional and global scale simulations of the behaviour of the climate system.

Thank you!

Nektarios Chrysoulakis

FORTH/IACM
N. Plastira 100, Vassilika Vouton,
70013, Heraklion
zedd2@iacm.forth.gr

http://rslab.gr