Regulation ecosystem services of European plain forest landscapes assessment based on remote sensing data

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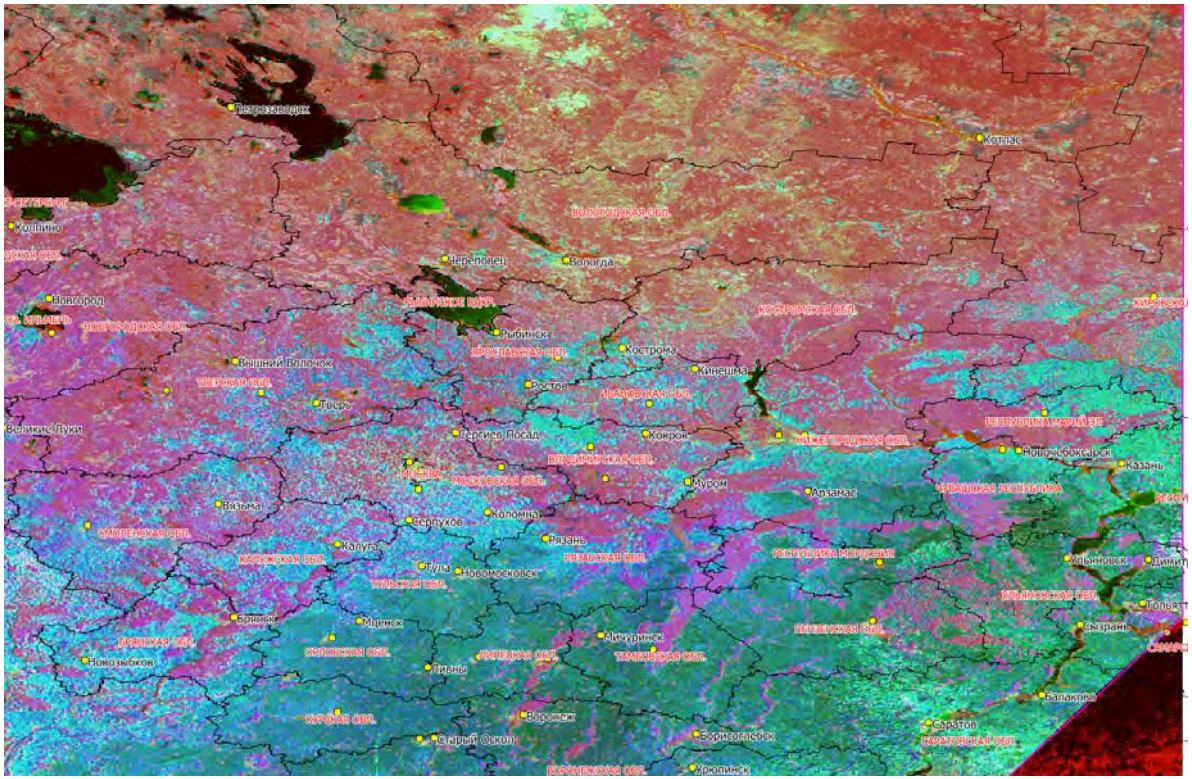
Introduction:

A fundamental problem within the concept of ecosystem services is the socio-economic assessment of supportive and regulatory services, designed to directly link the basic physical and geographical conditions with socio-economic activity.

Purpose:

Advancing of the multispectral remote sensing data analysis based on the thermodynamic approach to assess regulating ecosystem services in medium scale



Approach

Regulation services:
Relation between relief, climate and supporting services of land cover measured by remote sensing.

Measured supporting services:
-NDVI
-Albedo
-Absorbed solar radiation components (evapotranspiration costs, energy accumulation)
-Parameters of land cover structure (entropy, information, resilience (q-parameter by Tsallis)

Data and materials - climate

WorldClim Version2

WorldClim version 2 has average monthly climate data for minimum, mean, and maximum temperature and for precipitation for 1970-2000.

You can download the variables for different spatial resolutions, from 30 seconds (~1 km^2) to 10 minutes (~340 km^2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).

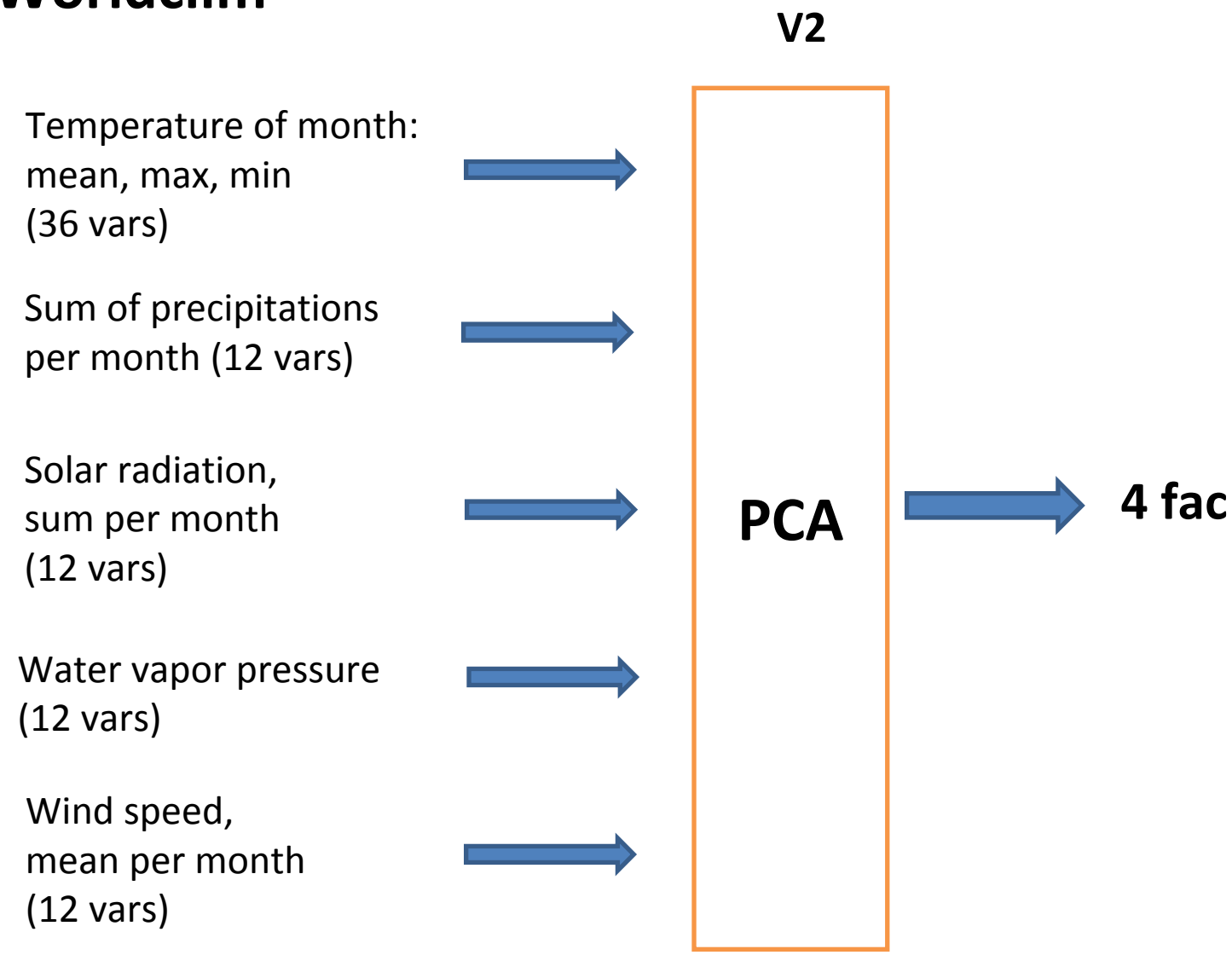
variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavg 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (kJ m^{-2} day^{-1})	srad 10m	srad 5m	srad 2.5m	srad 30s
wind speed (m s^{-1})	wind 10m	wind 5m	wind 2.5m	wind 30s
water vapor pressure (kPa)	vapr 10m	vapr 5m	vapr 2.5m	vapr 30s

Data and materials – remote sensing data

MODIS Terra, MOD09A1 one day, 500x500m per pixel

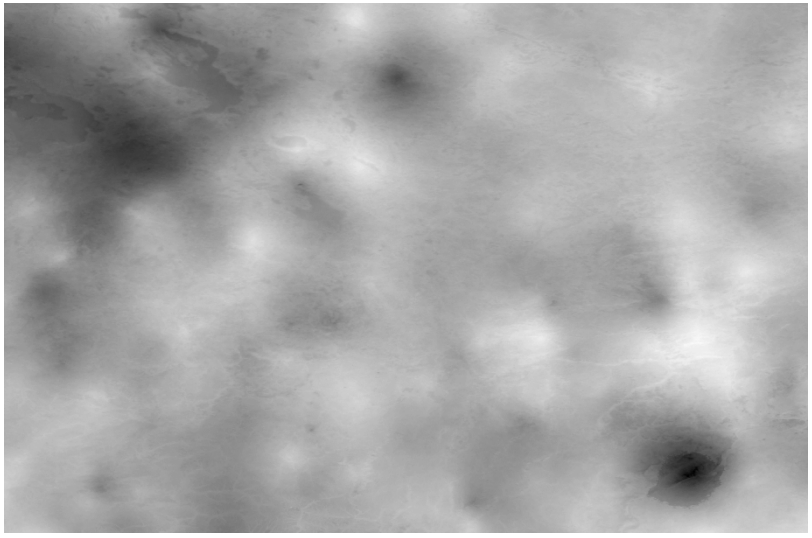
Year	Month	Day	Sun elevation	DOY
2002	May	1.05	41	121
		9.05	39	129
	June	18.06	34	169
		26.06	37	177
		4.07	36	185
	July	20.07	39	201
		28.07	40	209
	August	29.08	56	241
2003	May	1.05	41	121
		9.05	40	129
		25.05	37	145
	July	20.07	39	201
		28.07	40	209
2016	May	8.05	41	129
	July	27.07	42	209
	August	4.08	43	217
2017	May	1.05	42	121
		17.05	38	137
	April	10.04	36	161
	August	13.08	45	225

Data processing: Worldclim

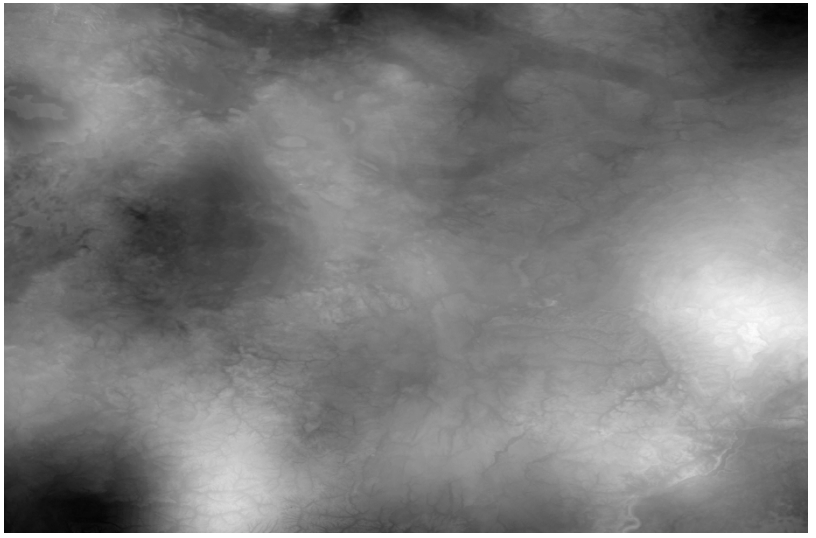


Fac 1 – Warm period precipitations decrease

Fac 2 – Temp and radiation increment

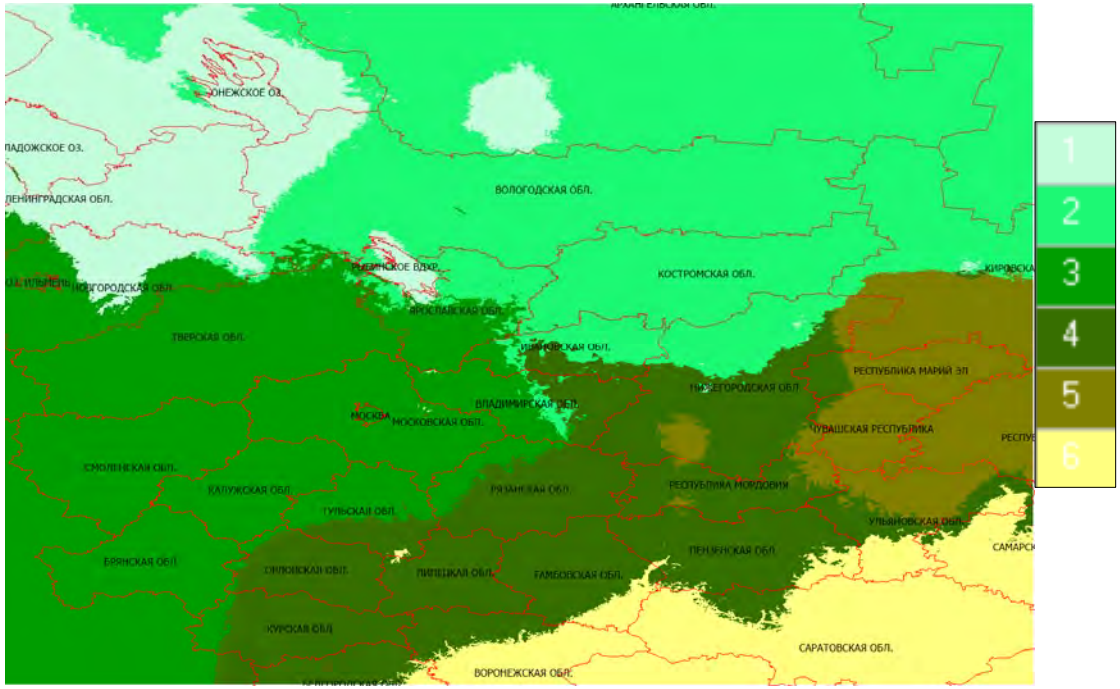


Fac 3 – Warm period precipitations increment



Fac 4 – Wind speed increment

Climatic zoning by factors



Atlantic-arctic zone:

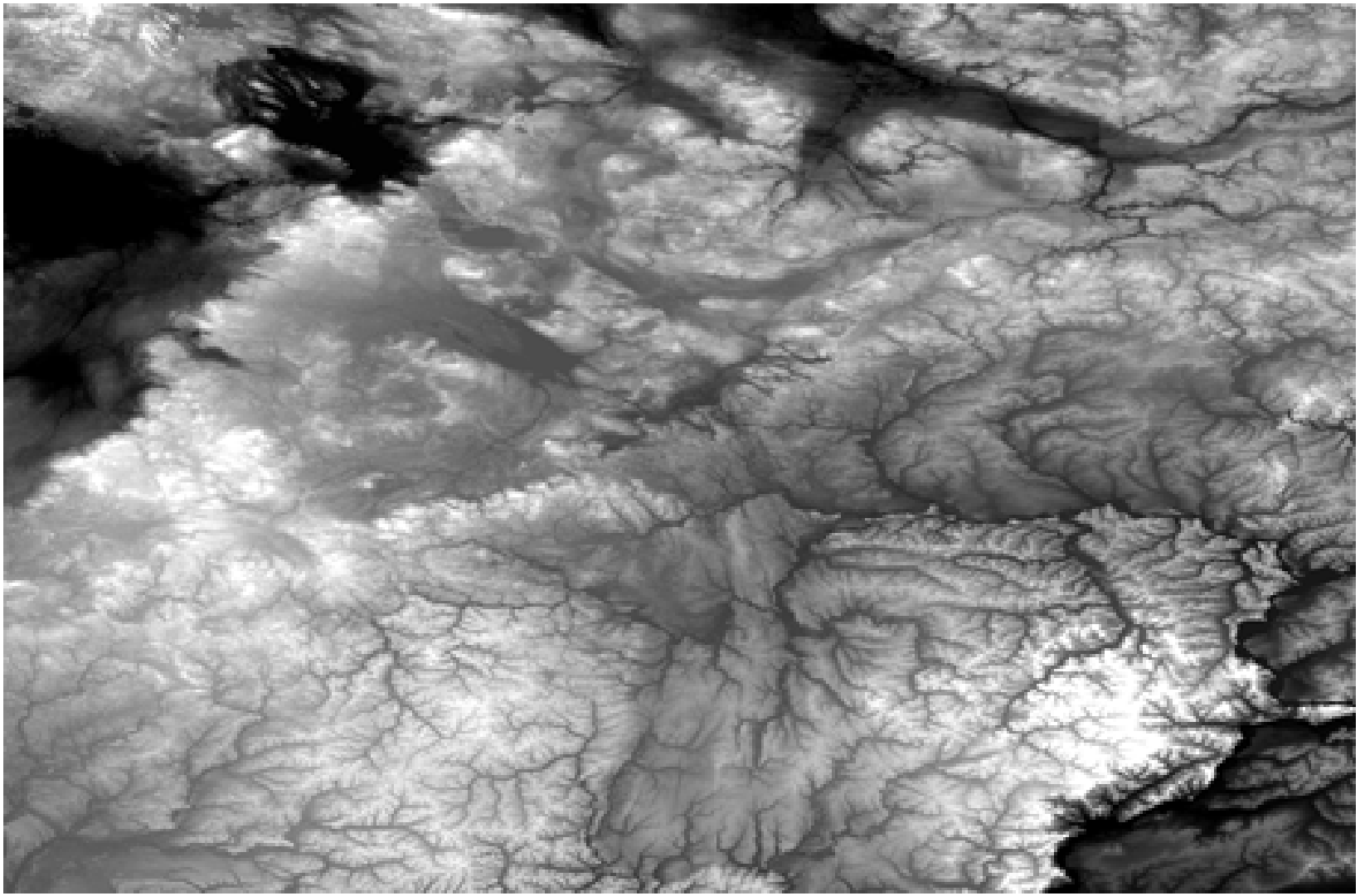
1. Baltic, moist, warm
2. Cis-Urals, dry, cold

Atlantic-continenal

3. European (Western, wet)
4. European (Eastern, dry)
5. European (Cis-Urals, cold)
6. European (Steppe, dry)

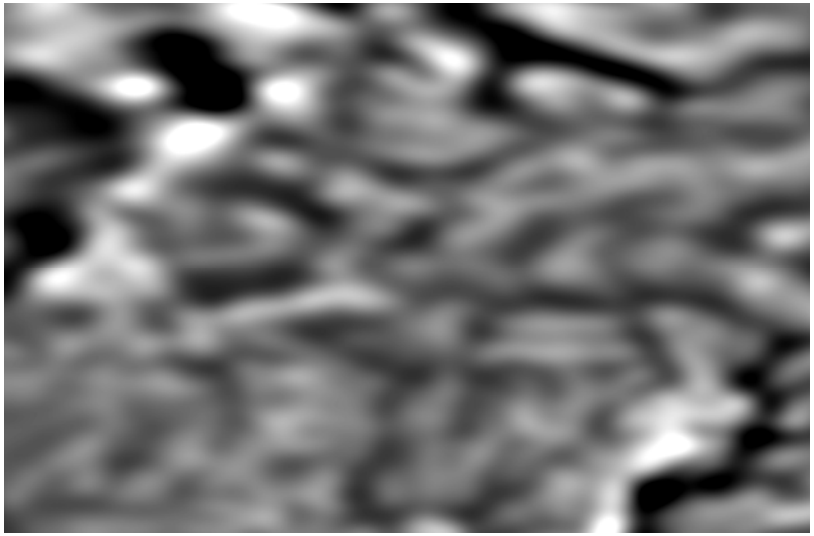
N	Mean year temp.	Annual precipitation	Temperature oC			Pec, mm	Radiation, sum	VAP	Wind
			Mean	MIN	MAX				
			JANUARY						
1	2.78	658.63	-10.50	-15.83	-5.17	41.16	1005.44	0.22	2.92
2	1.94	596.91	-12.81	-18.28	-7.34	35.80	1149.58	0.19	3.25
3	4.86	631.81	-8.28	-13.56	-3.00	38.70	1970.70	0.27	3.40
4	4.93	560.46	-9.96	-15.86	-4.06	36.56	2364.06	0.22	3.90
5	3.38	525.18	-12.40	-18.17	-6.63	31.24	1972.03	0.19	4.05
6	5.73	471.36	-10.02	-16.46	-3.58	37.30	2913.52	0.21	4.05
			JUNE						
1			13.88	8.55	19.21	64.75	19777.17	1.10	2.73
2			14.48	9.01	19.95	67.88	19823.12	1.11	2.80
3			16.12	10.84	21.40	75.55	20218.13	1.28	2.60
4			17.49	11.59	23.39	63.28	20581.38	1.27	3.00
5			16.97	11.20	22.73	64.46	20897.34	1.21	3.24
6			19.60	13.16	26.04	52.15	21229.05	1.29	3.28

Data and materials – relief
DEM G-TOPO

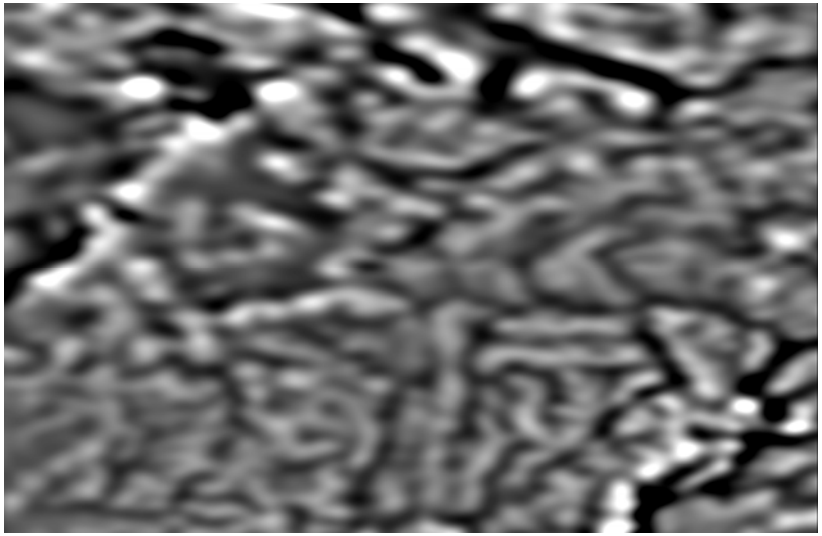


Relief processing:
Hierarchical organization analysis

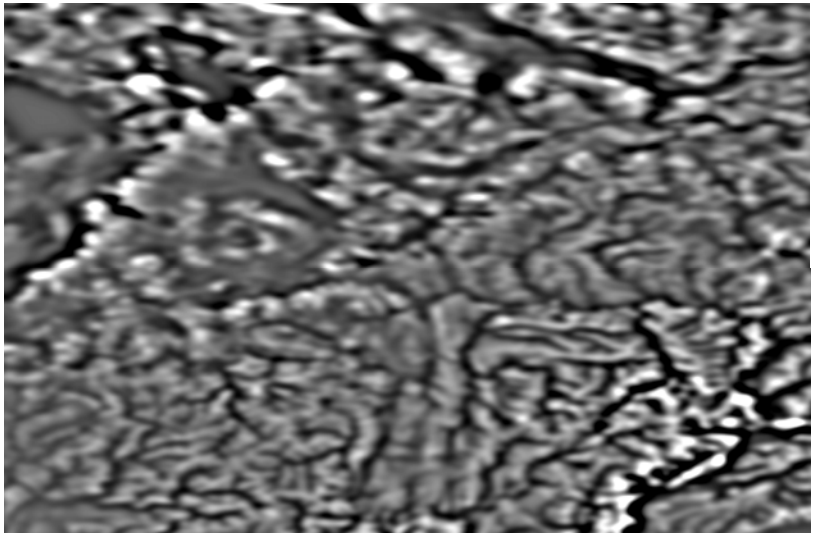
120-330 km



50-120 km

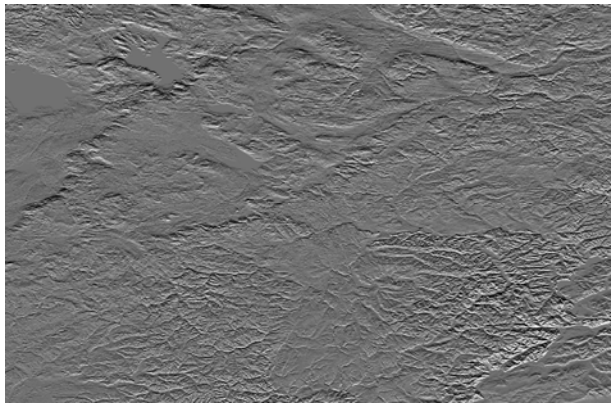


30-50 km

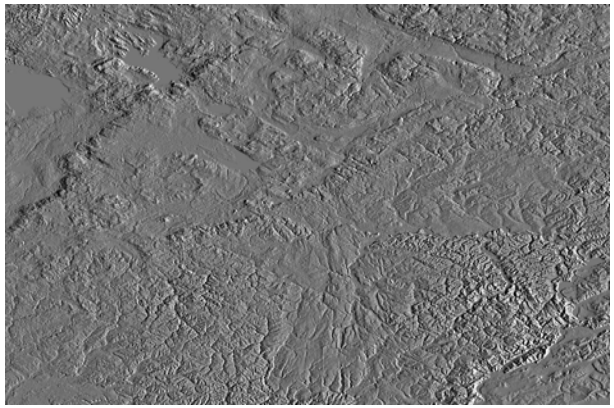


15-30 km

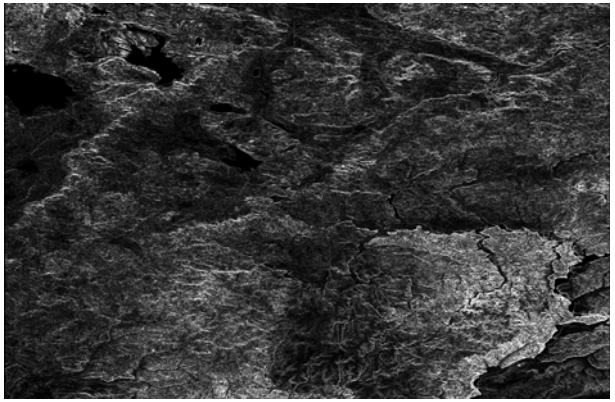
Relief processing:
Morphometrical characteristics for each hierarchical level



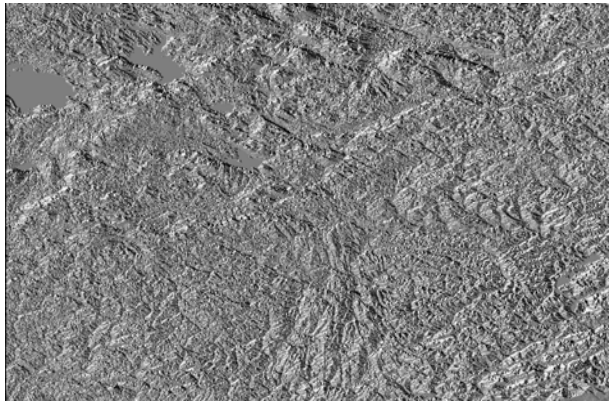
luminous intensity - south



luminous intensity - east

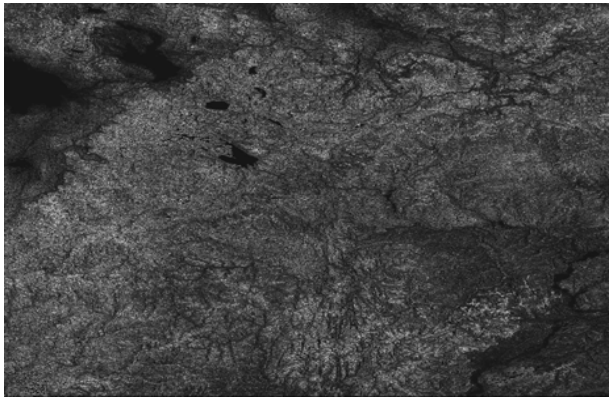


curvature



slope

plan convexity



profile convexity

Supporting services

based on remote sensing date– transformation energy in land cover – energetic characteristics

BALANCE OF ABSORBED SOLAR RADIATION: $R = Ex + DU$

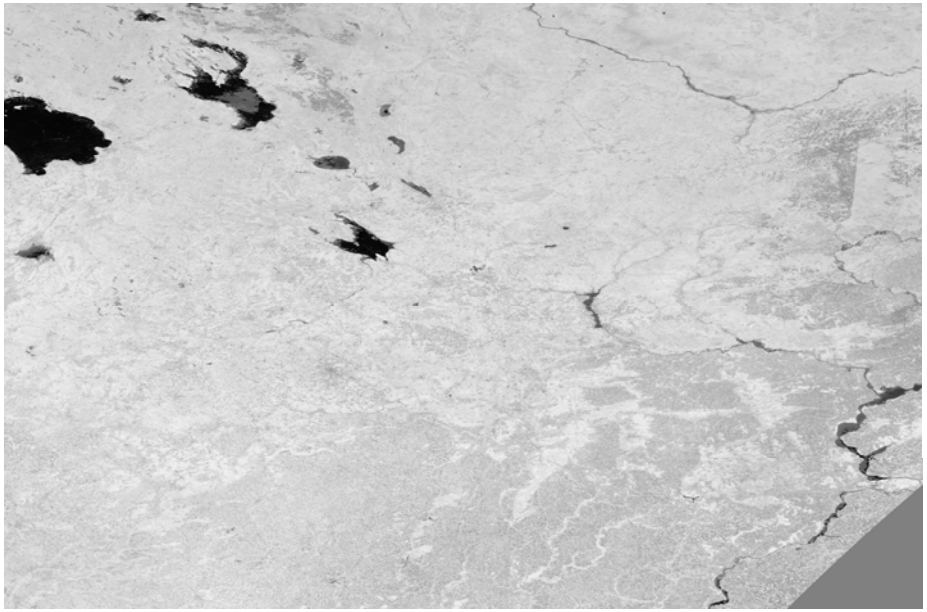
- **EX – Exergy of absorbed solar radiation, wt/m^2**
- **DU - Internal energy increment, wt/m^2**

- **K - Information increment by Kullback, nit**
- **S - Entropy of output solar radiation, nit**
- **q-parameter, Tsallis – measure of ecosustems concurrence**
- **NDVI**

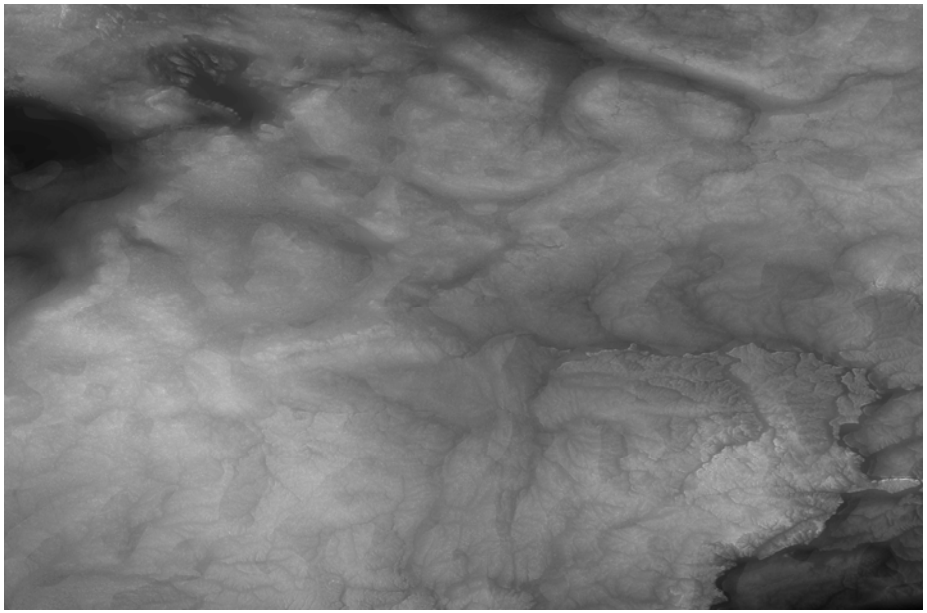
Regulating services of relief: Contribution of morphometrically characteristics to supporting services

Variable	Terms			
	9 May 2002	17 May 2017	28 July 2002	27 July 2016
Albedo	18	12	14	6
NDVI	20	17	14	15
Exergy (evapotranspiration)	23	17	18	10
Internal energy increment	25	19	20	15
q-parameter	24	20	11	14
Entropy	14	11	7	9
Information	15	13	7	9

Regulating services of relief: contribution to NDVI – 20%
9 May 2002



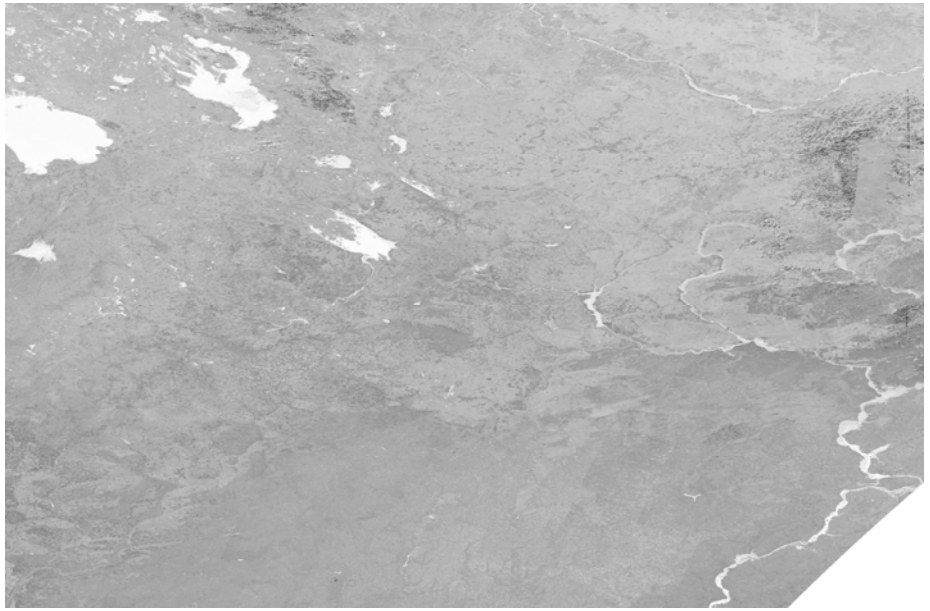
NDVI



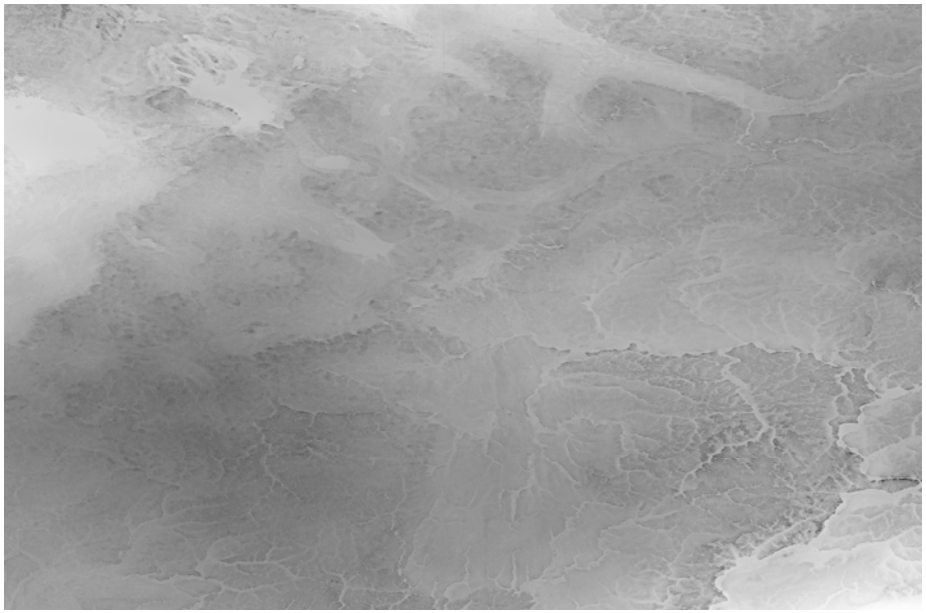
predicted NDVI by relief

residuals

Regulating services of relief: contribution to exergy – 23%
9 May 2002



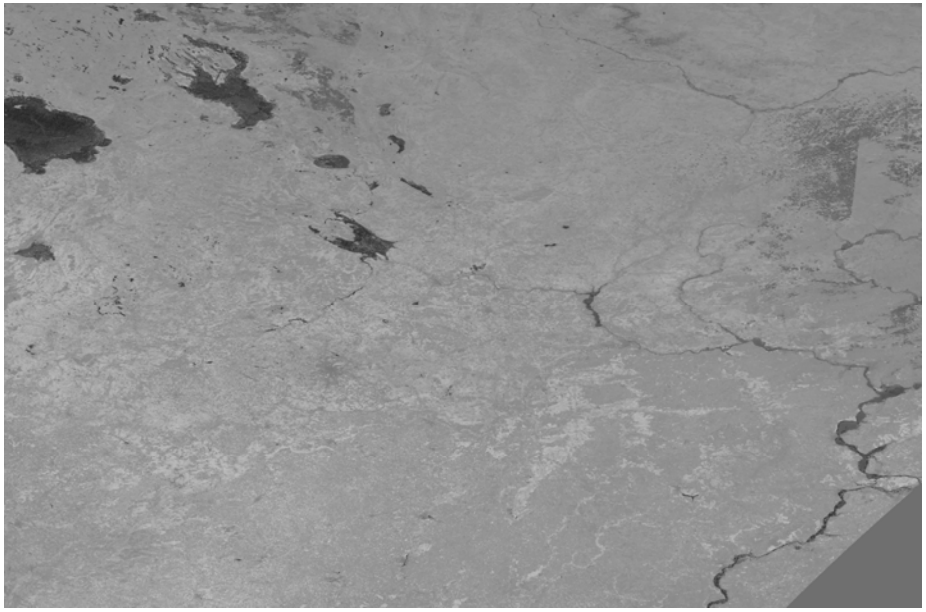
exergy



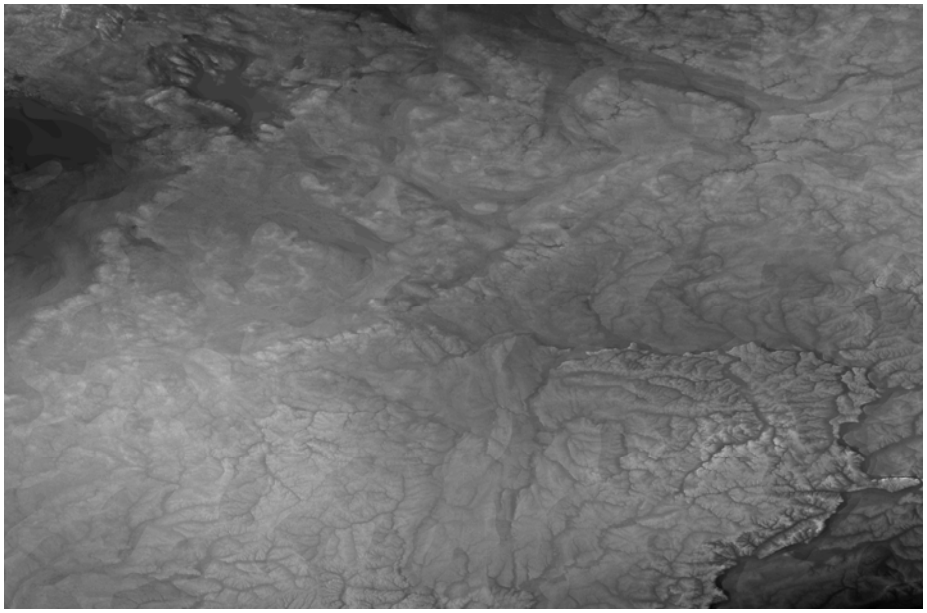
predicted exergy by relief

residuals

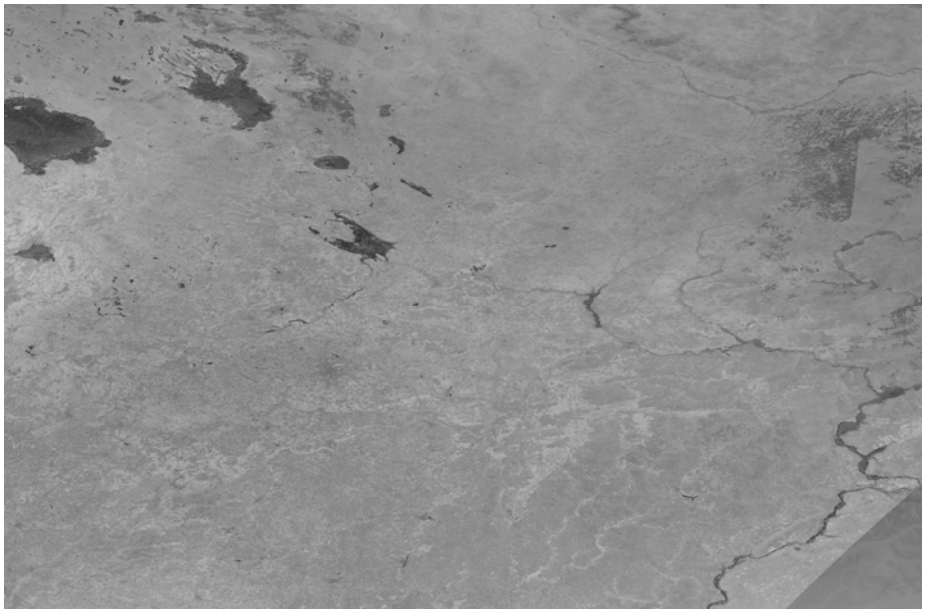
Regulating services of relief: contribution to q-parameter – 24% 9 May 2002



q

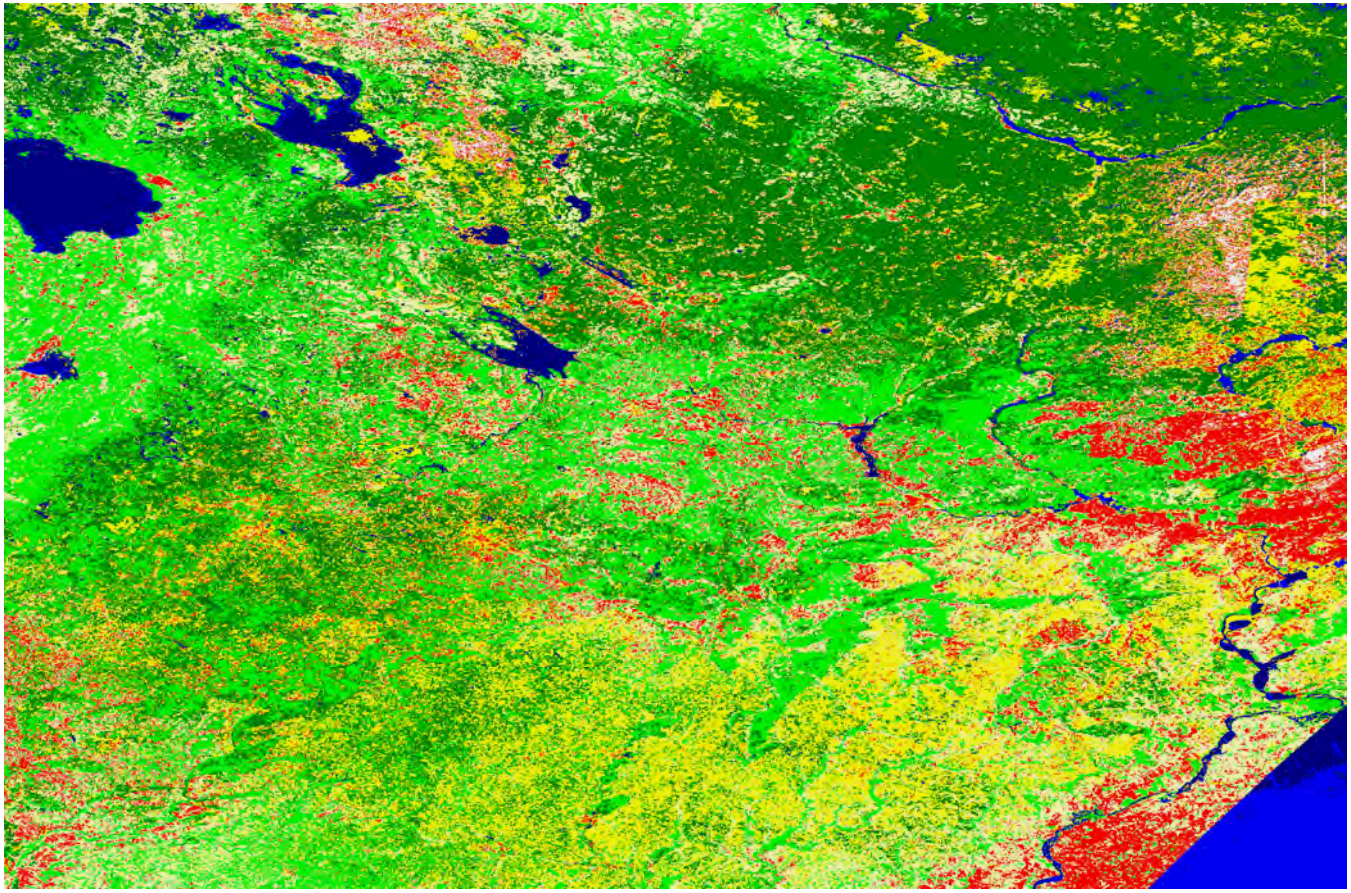


predicted q by relief



residuals

Land cover of territory
(classification based on MODIS data, 2002)



Clouds
1 Croplands
Dry meadows
3 Meadows
4 Mixed forests
5 Coniferous forests
6 Shallows
7 Water

Regulating services
for climate: contribution of energetic characteristics

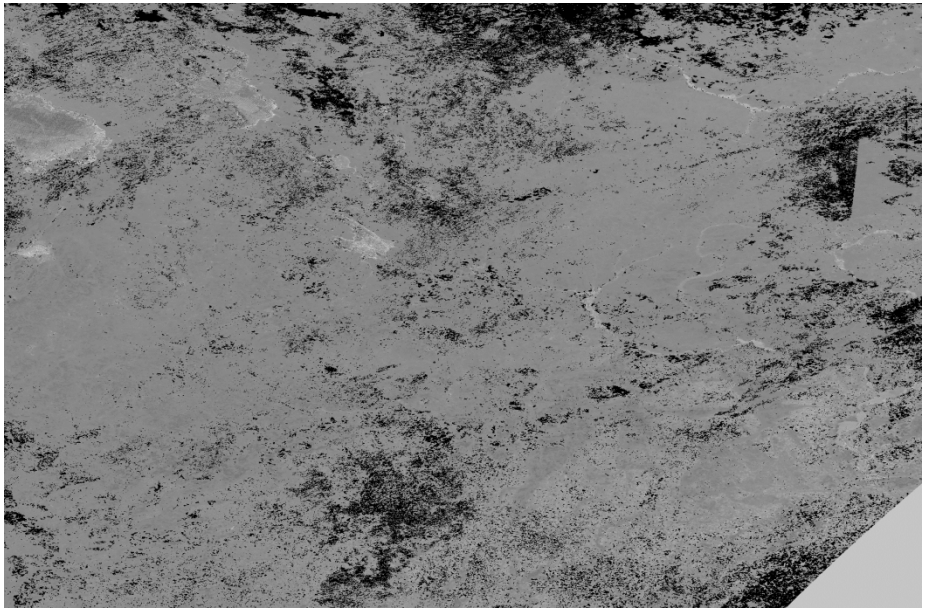
Factors of climatical varibles	9 May 2002	17 May 2017	28 July 2002 r.	28 July 2016
Fac 1. Summer precepitations (-)	36	21	33	21
Fac 2. Temperature, radiation, water vapor pressure (+)	37	30	23	30
Fac 3. Winter precipitatons (-)	9	8	8	8
Fac 4. Wind speed (+)	9	9	5	9
Factors for varibles				
Fac 1. Temp of warm period	41	38	45	38
Fac 2. Temp of cold period	30	15	9	15
Fac 1. Winter prec.	7	4	6	4
Fac 2. Summer prec.	34	22	25	22
Fac 3. Authumn prec.	36	35	39	35
Fac 1. Radiation, winter	38	37	34	37
Fac 2 Radiation, summer	26	16	17	16
Fac 1. Vapor pres. summer	18	8	3	8
Fac 2. Vapor pres. winter	35	37	30	37
Fac 1. Wind speed, winter	31	34	26	34
Fac 2. Wind speed, summer	20	10	13	10

Climate regulation service: contribution of energetic characteristics to climate

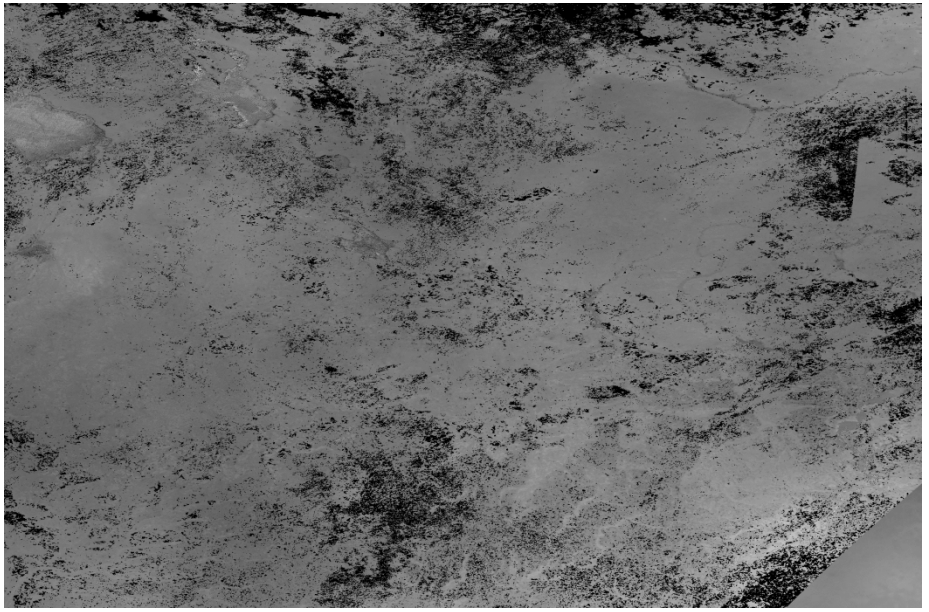
Factor 1. Warm period precipitations, 36%

9 May 2002

Factor 1



predicted



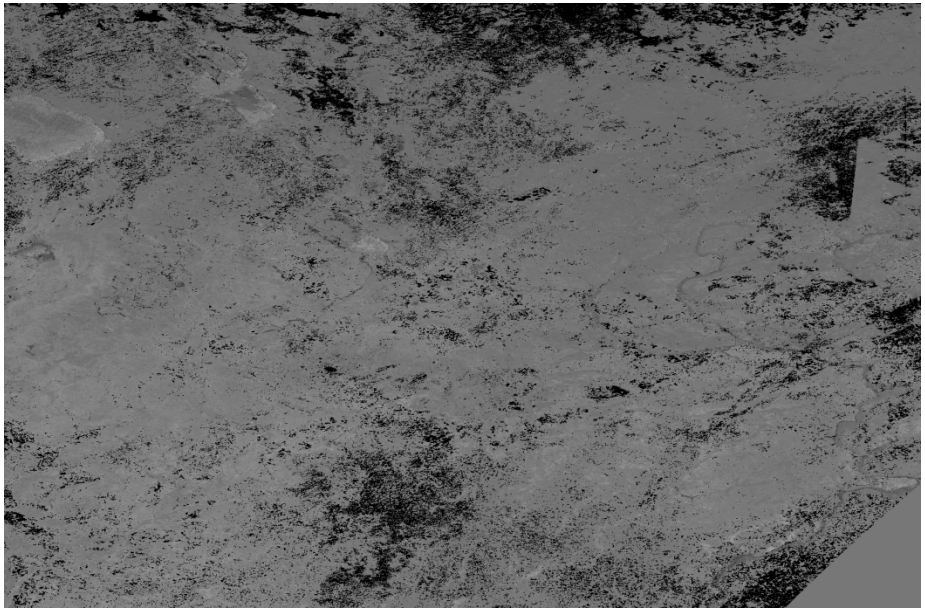
residuals

Climate regulation service: contribution of energetic characteristics to climate

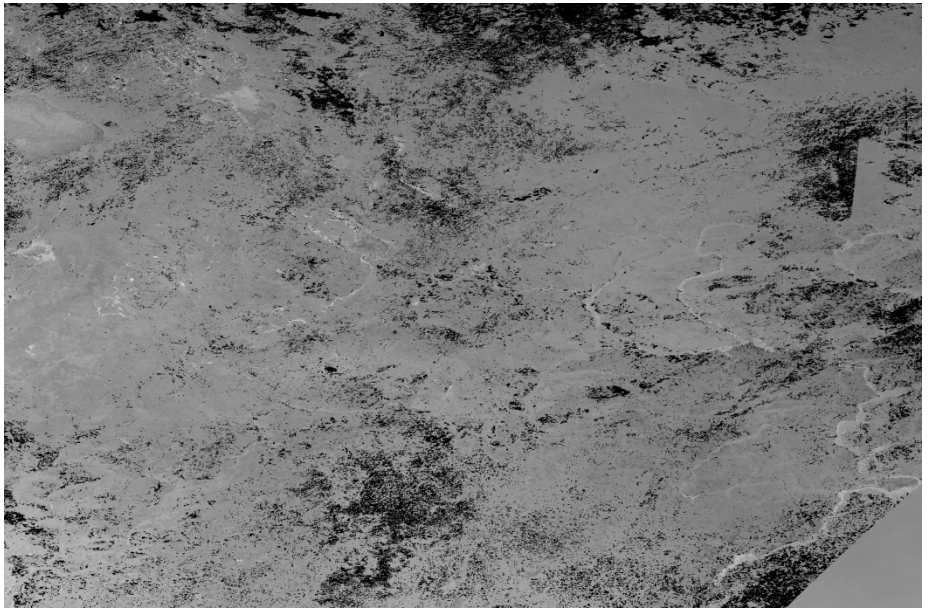
Factor 2. Temperature, radiation, 37%

9 may 2002

Factor 2



predicted

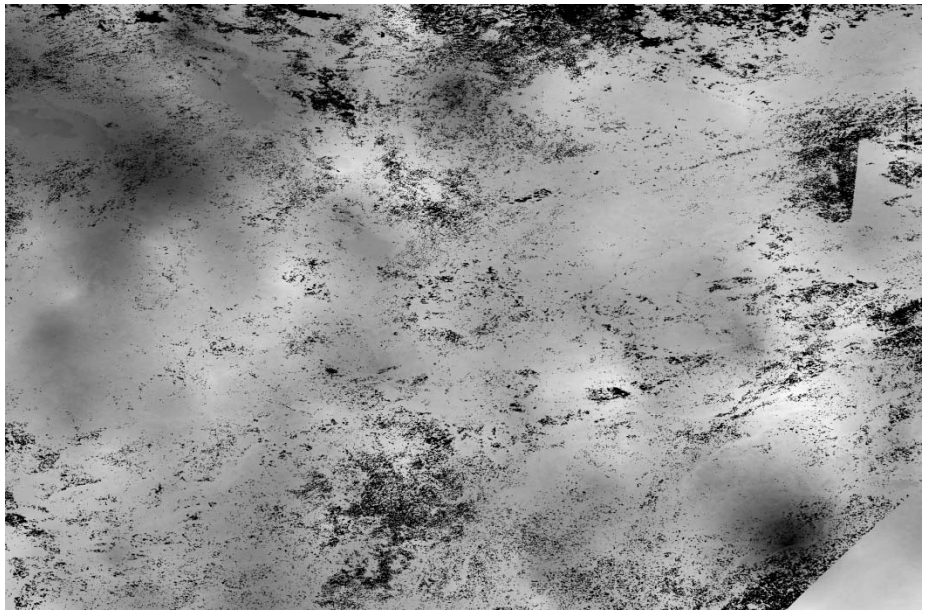


residuals

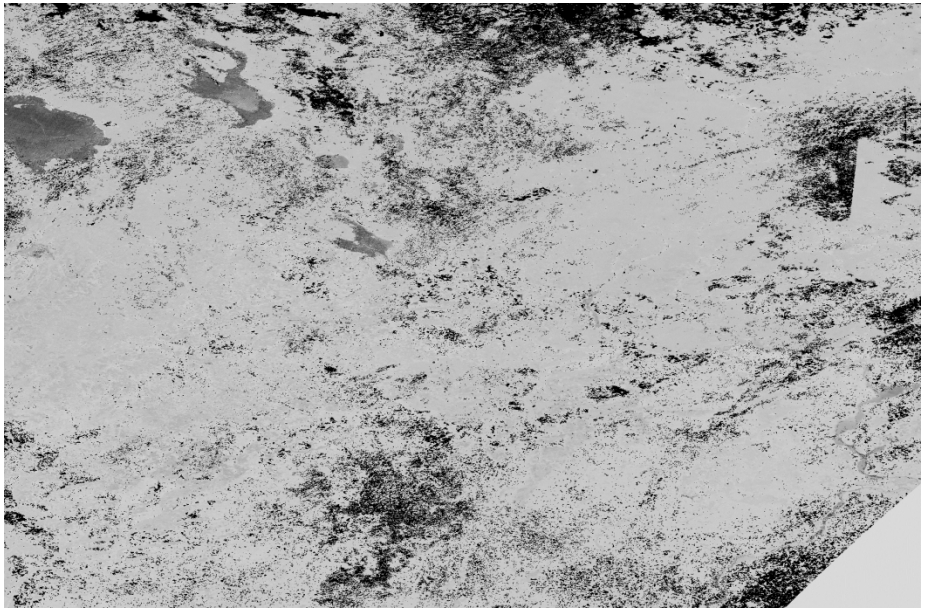
Climate regulation service: contribution of energetic characteristics to climate

Factor 3. Cold period precipitations, 9%

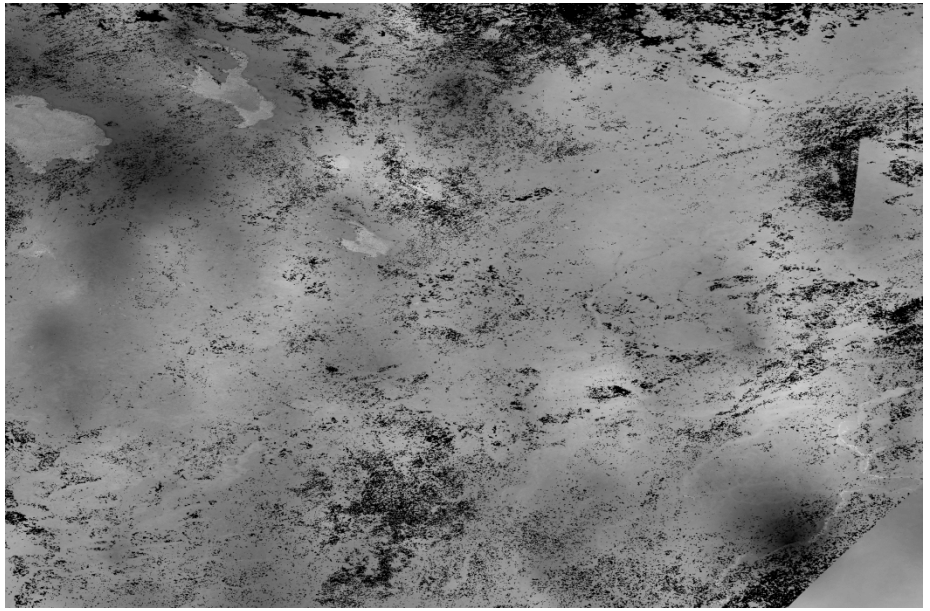
9 May 2002



Factor 3

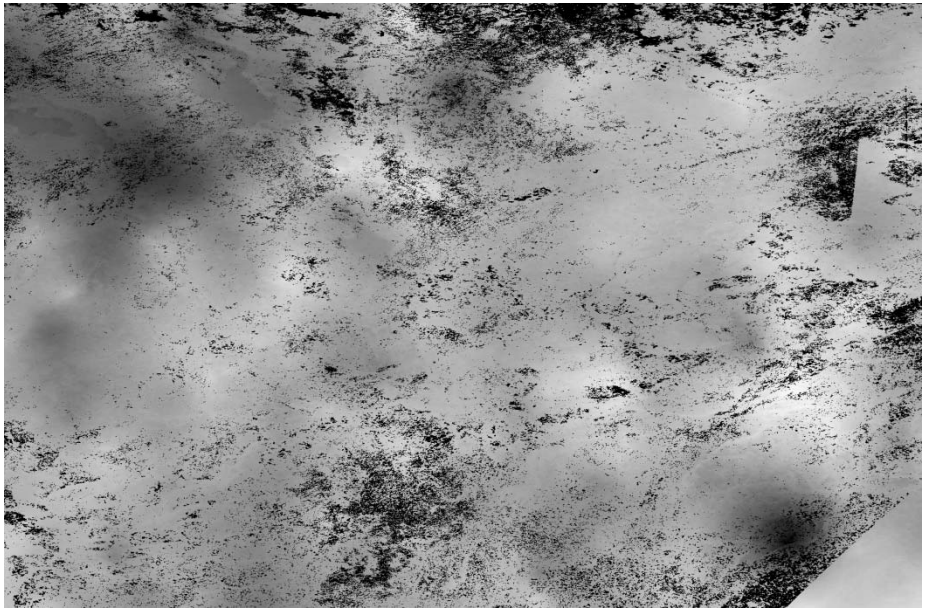


predicted

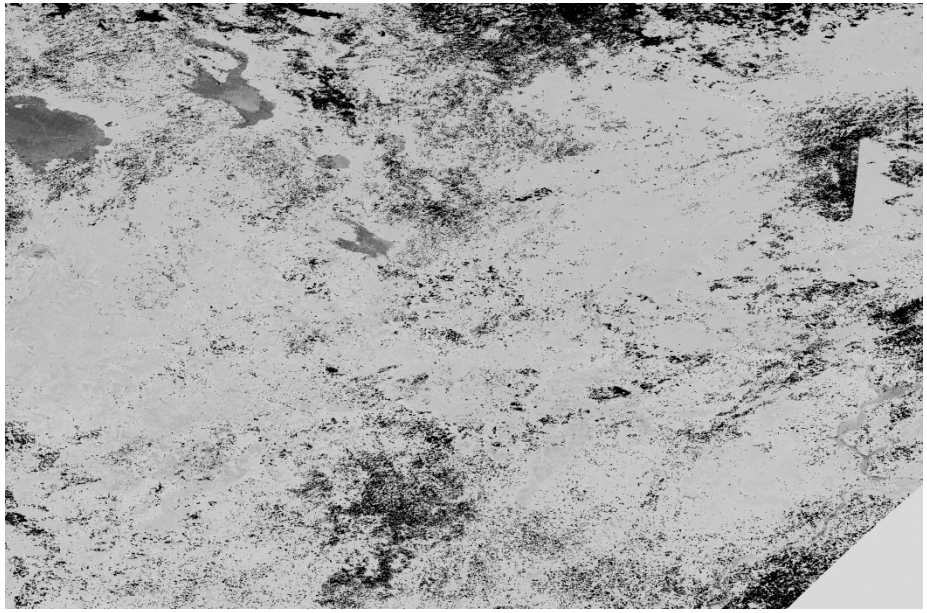


residuals

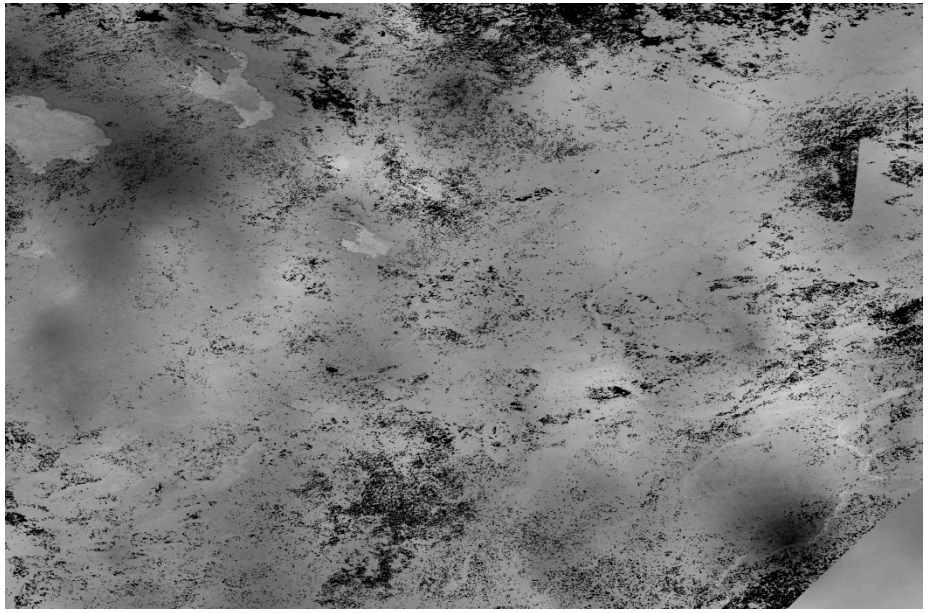
Climate regulation service: contribution of energetic characteristics to climate
Factor 4. Wind speed, 9%
9 May 2002



Factor 3



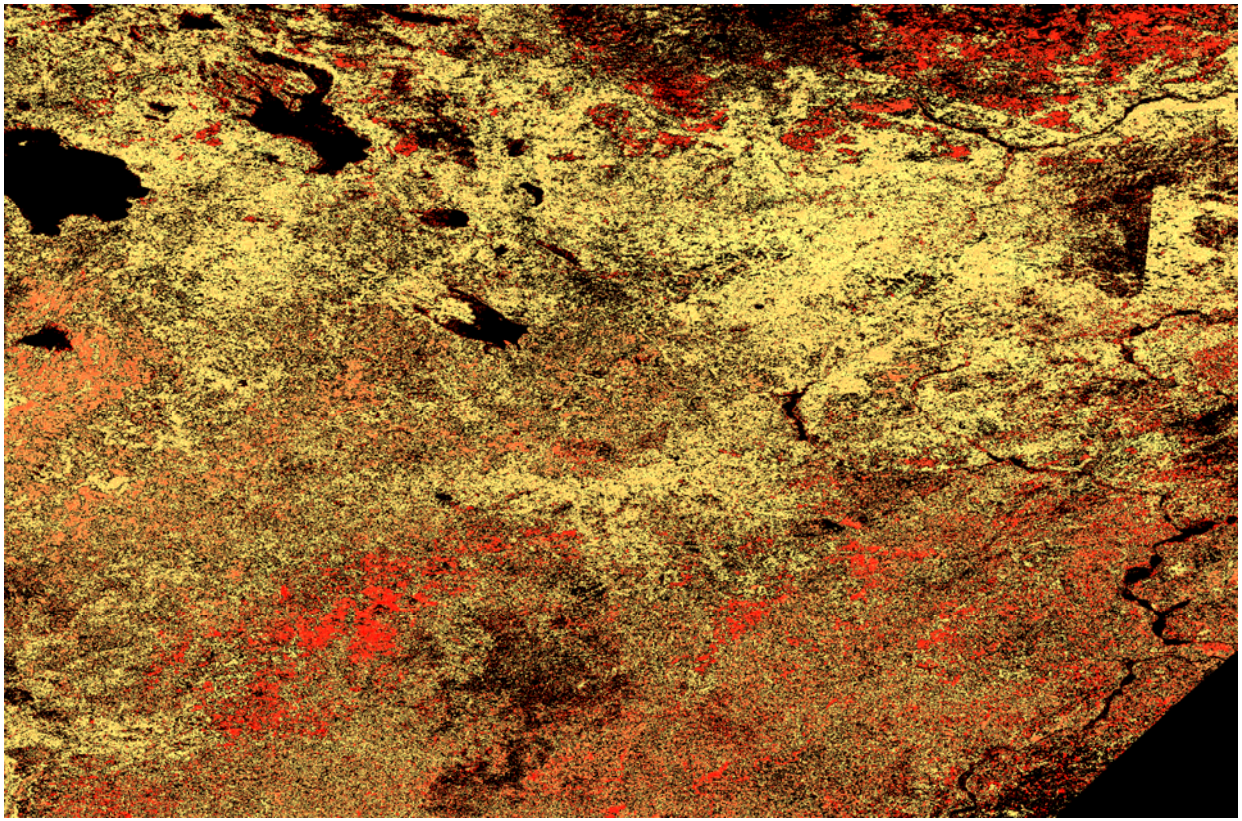
predicted



residuals

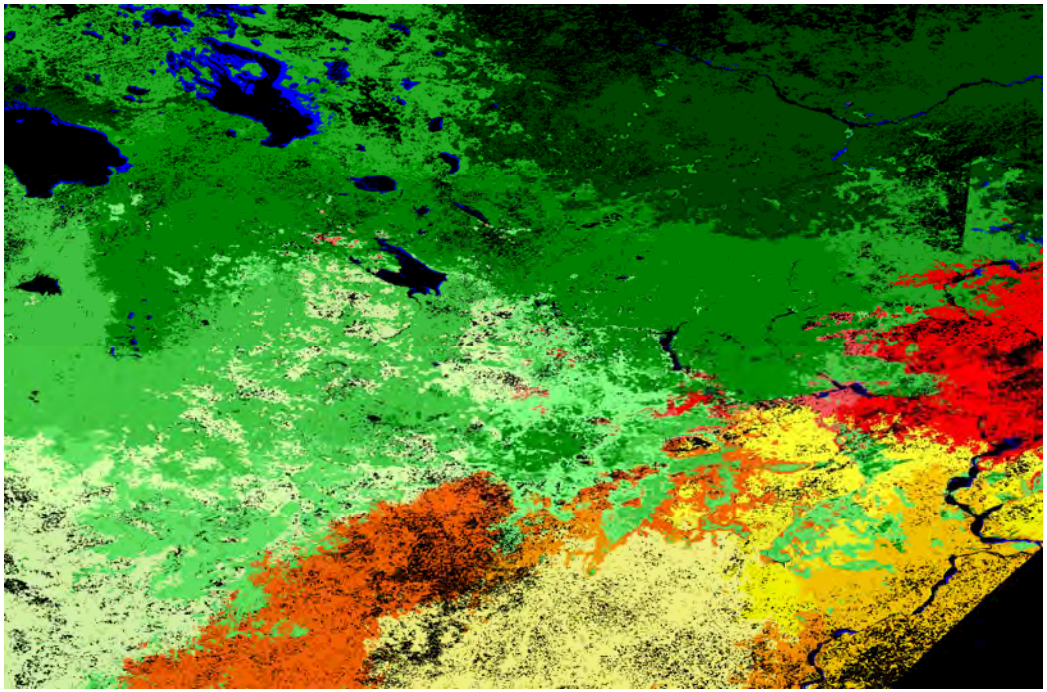
Dynamic of regulation services

Classification of difference between climatically factors predicted by energetic variables at 2017 and 2002



min max

Non-equilibrium climate and land cover: Discrimination of land cover types (2002) by climatic factors



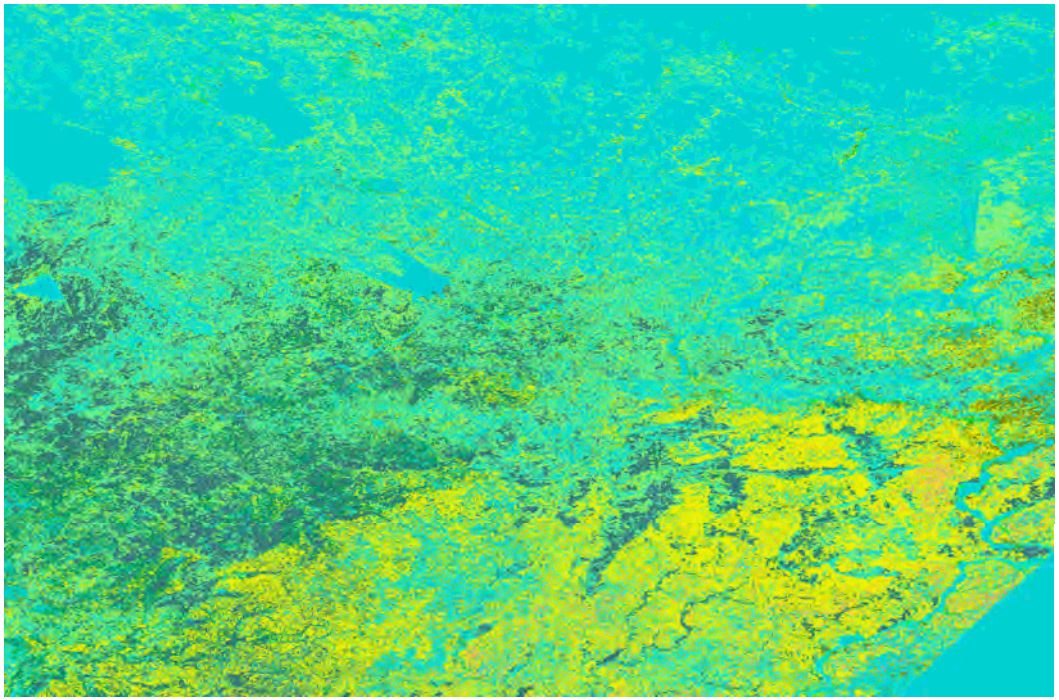
Total determination - 28%

measure of non-equilibrium

0 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	66.9	2.5	13.1	14.3	1.4	.0	.4	.2	.2	.0	.0	.2	.1	.0	.1	.6
2	32.1	16.6	7.8	21.0	4.0	.4	2.6	1.6	.5	.1	.2	3.4	1.4	.3	1.1	7.0
3	13.2	1.4	46.6	11.4	17.7	1.7	3.3	2.1	.5	.0	.0	.1	.4	.1	.2	1.2
4	22.6	1.9	23.5	31.1	6.6	1.0	3.3	1.6	2.5	.3	.2	1.0	.5	.7	.3	2.9
5	.7	.3	22.3	1.2	44.2	10.5	6.7	8.1	1.6	.2	.1	.4	.9	1.2	.3	1.2
6	.0	.1	2.0	.0	20.5	29.5	4.1	22.9	4.0	.9	.6	2.3	1.5	10.4	.5	.7
7	1.9	.5	18.8	5.0	18.6	6.1	9.3	12.4	7.4	1.3	.7	2.4	1.9	9.9	.7	3.0
8	.1	.1	5.1	.3	16.6	12.3	5.8	38.6	2.6	1.7	.4	1.0	1.2	11.6	1.0	1.6
9	1.0	.1	.3	.3	.3	.5	1.0	.8	49.6	9.1	5.0	11.3	4.0	15.5	.1	1.2
10	.2	.1	.6	.4	.3	2.6	1.6	4.9	9.0	22.9	3.5	19.8	4.2	16.4	.8	12.7
11	0.0	.0	.0	.0	.0	.1	.6	.1	48.8	13.5	7.8	17.9	3.6	6.5	.0	1.1
12	.0	.0	.1	.0	.1	1.9	.9	4.0	5.9	23.6	5.8	31.2	3.7	18.8	.3	3.7
13	8.0	.6	5.2	6.7	1.3	.9	3.0	1.2	28.9	6.6	3.2	11.9	4.8	11.6	.5	5.5
14	1.8	.1	5.9	3.9	1.9	5.9	5.4	10.6	9.9	8.5	2.1	4.9	4.0	30.3	1.2	3.8
15	1.0	.4	9.4	4.2	10.3	5.4	7.8	27.7	1.7	4.1	.4	1.9	1.4	3.6	4.6	16.2
16	2.3	.6	6.8	5.0	5.8	2.9	6.7	13.1	2.9	5.6	.7	6.1	2.1	3.1	3.0	33.4

Non-equilibrium climate and land cover:
Discrimination of climate types by energetic characteristics



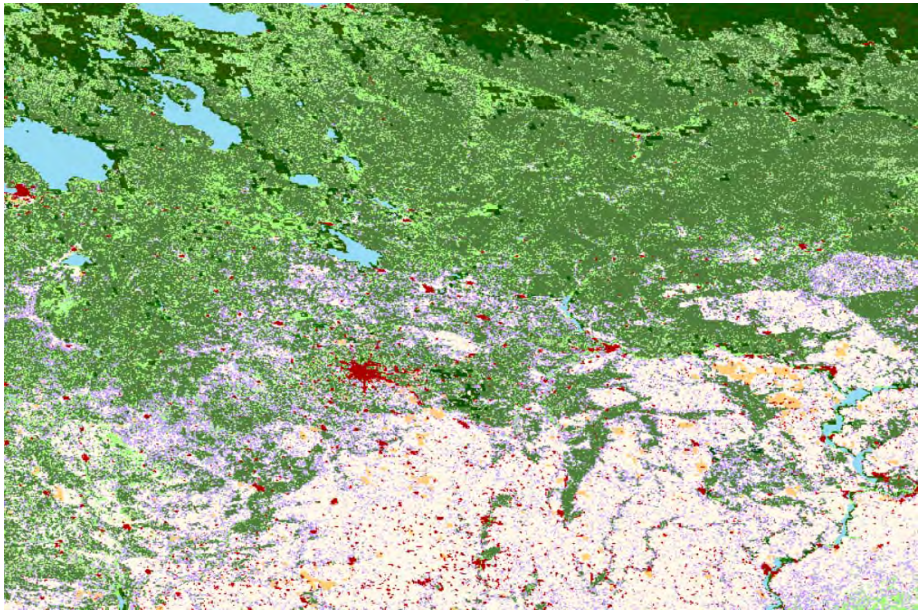
Total determination - 28%

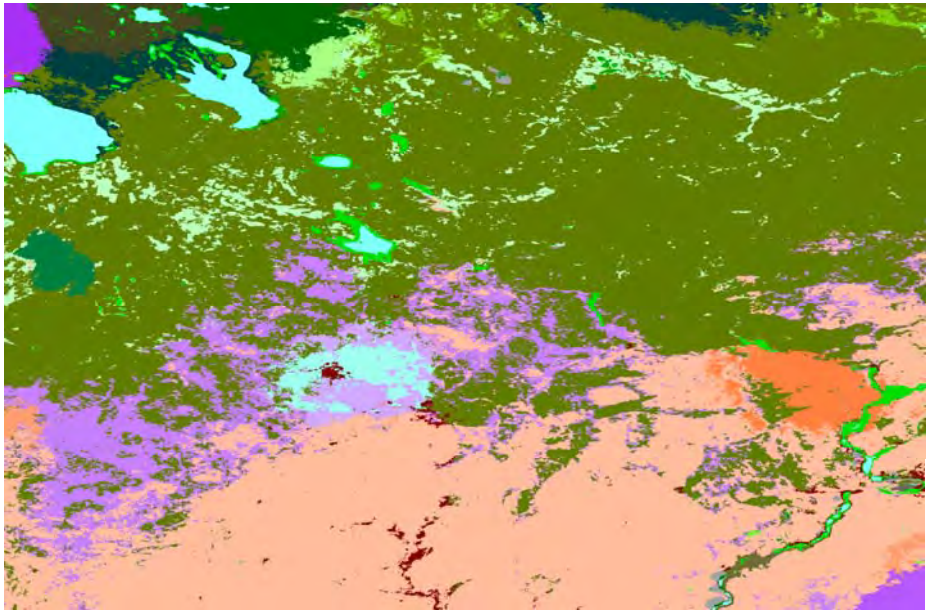
measure of non-equilibrium

0 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	22.9	2.0	13.0	31.1	7.0	1.6	9.2	.7	.0	.5	2.9	4.5	.1	.4	.6	3.5
1	5.5	10.6	26.2	34.5	2.6	1.5	1.9	.3	.0	.3	4.5	8.5	.3	.4	.6	2.3
2	1.1	9.0	53.3	13.5	.1	1.0	.1	.1	0.0	.2	3.2	13.3	1.0	1.3	1.8	1.1
3	.9	4.0	20.5	36.4	5.5	4.4	6.9	.4	.0	1.3	7.2	9.8	.5	.8	.9	.6
4	.1	.7	1.3	14.2	13.1	24.9	29.3	2.2	.4	2.3	4.6	6.1	.0	.3	.3	.1
5	.0	.1	.2	4.8	5.2	42.3	17.7	3.6	4.3	8.8	4.7	5.7	.1	1.5	1.1	.0
6	.2	.5	1.1	7.8	7.9	20.7	44.0	3.8	.9	2.8	2.4	6.8	.0	.3	.3	.4
7	.2	.5	.9	6.3	7.8	29.9	31.6	4.2	.7	3.2	3.3	9.2	.1	.8	1.0	.4
8	.0	.2	.3	.9	1.3	15.7	24.6	2.6	13.6	22.7	1.3	2.1	.1	4.5	9.7	.4
9	.2	.3	1.2	7.1	4.3	9.2	15.5	1.2	2.8	13.3	8.0	5.9	.3	12.8	17.9	.2
10	.7	1.7	5.5	12.1	4.5	7.6	7.1	.6	.2	3.5	13.2	21.0	.6	13.8	7.0	.9
11	1.7	.9	2.7	10.6	3.9	6.9	5.1	.6	.1	1.0	10.0	40.2	.5	10.1	5.0	.7
12	1.0	1.2	2.5	.6	.9	6.2	10.2	1.6	.7	3.7	9.4	14.1	1.5	39.2	5.9	1.3
13	.8	.9	1.4	3.6	2.5	3.9	6.0	1.2	1.0	7.4	9.4	8.3	.7	40.8	11.4	.8
14	.8	.6	1.5	1.4	1.5	4.9	8.9	1.8	1.7	8.1	8.0	4.9	.7	22.8	30.7	1.7
15	.2	.1	.1	.1	.1	.9	1.4	.7	.2	.8	3.7	10.7	.3	12.9	2.3	65.5

Land use and ecosystem services





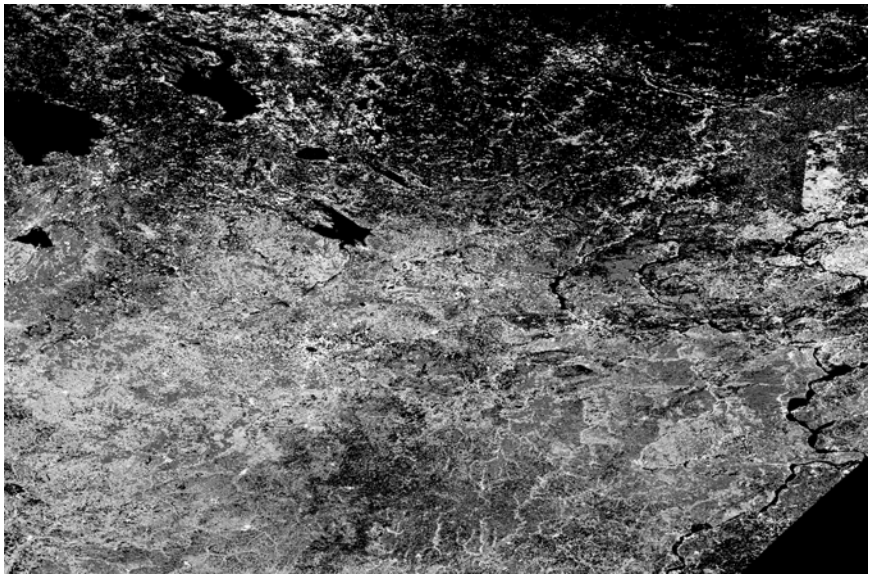
Global Land System map V2 (1x1 km) from L. Kehoe, A. Romero-Muñoz, E. Polaina, L. Estes, H. Kreft, T. Kuemmerle Biodiversity at risk under future cropland expansion and intensification. 2017.

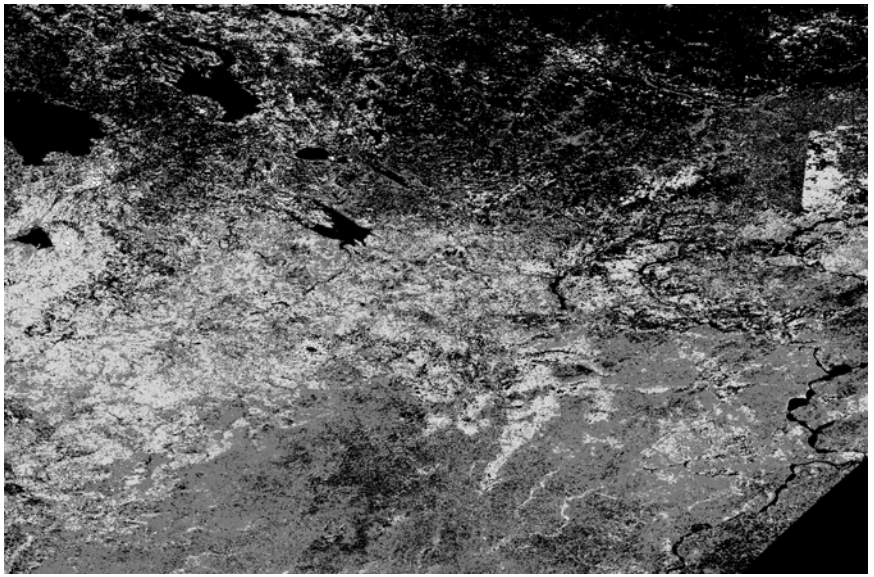
- Cropland; extensive, few livestock
- Cropland; extensive, bovines, goats _sheep
- Cropland; extensive, pigs _poultry
- Cropland; medium intensive, few livestock
- Cropland; medium intensive, bovines, goats _sheep
- Cropland; medium intensive, pigs _poultry
- Cropland; intensive, few livestock
- Cropland; intensive, bovines, goats _sheep
- Cropland; intensive, pigs _poultry
- Mosaic cropland and forest; pigs _poultry
- Mosaic cropland (ext) and forest; few livestock
- Mosaic cropland (med, int.) and forest; few livestock
- Mosaic cropland (int) and forest; few livestock
- Dense forest
- Forest, few livestock
- Forest, pigs _poultry
- Mosaic grassland and forest
- Mosaic, grassland and bare
- Grassland, natural
- Grassland, few livestock
- Grassland, bovines, goats _sheep
- Bare
- Bare, few livestock
- Peri-urban _villages
- Urban
- Dense forest_CS
- Forest, few livestock_CS
- Forest, pigs _poultry_CS
- Mosaic grassland and forest_CS
- Mosaic grassland and bare_CS
- Grassland, natural_CS
- Grassland, few livestock_CS
- Grassland, bovines, goats _sheep_CS

Discriminant analysis: land use types from relief characteristics and climate factors - 60%
Best recognition – mosaic cropland and forests

Type		0	1	2	3	7	15	16	17	18	19	20	21	23	24	25	26	27	28	30	31	32	33	36	37	38
0 Unclassified	0	71.4	.4	0.0	.3	.1	.1	.5	0.0	.5	.8	.3	.9	.5	2.0	.9	17.0	.3	.0	.3	1.3	.0	0.0	.2	.3	1.9
1 Cropland ext, few ls	1	.0	78.7	.8	3.6	0.0	1.0	10.3	.3	0.0	.0	0.0	.2	.0	0.0	.0	.1	.2	.0	.4	3.3	0.0	.1	.0	.8	.1
2 Cropland ext, bgs	2	0.0	0.0	90.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 Cropland ext, pp	3	0.0	55.4	.1	##	0.0	8.3	4.6	0.0	0.0	0.0	0.0	.4	.0	0.0	.0	.0	.3	0.0	.3	1.0	0.0	2.2	0.0	.4	.1
7 Cropland int, few ls	7	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	95.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 Mosaic cropland and forest, pp	15	0.0	26.8	.3	9.4	0.0	19.8	15.1	0.0	0.0	0.0	0.0	.4	.0	0.0	.0	.0	.3	0.0	.8	9.7	0.0	16.1	0.0	.8	.2
16 Mosaic cropland ext and open forest, few ls	16	.0	37.5	.7	1.5	0.0	2.7	28.4	1.0	0.0	.1	.0	.2	.0	.0	.0	.2	.2	.1	.7	23.3	.0	.7	.0	2.5	.2
17 Mosaic cropland m. int and open forest, few ls	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 Mosaic cropland int and open forest, few ls	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 Dense forest	19	1.5	.7	0.0	.2	.1	.7	1.2	0.0	2.4	16.6	12.5	.3	.1	6.3	2.1	3.0	.1	0.0	.3	46.7	1.3	.5	.3	2.8	.5
20 Open forest, few ls	20	.6	.4	0.0	.2	.0	.5	1.0	0.0	2.4	9.1	22.1	.5	.0	13.6	2.8	2.6	.0	0.0	.4	32.2	3.9	.2	.4	6.7	.3
21 Open forest, pp	21	3.7	0.0	0.0	1.9	0.0	31.5	3.7	0.0	0.0	0.0	0.0	35.2	0.0	0.0	0.0	1.9	0.0	0.0	0.0	20.4	0.0	1.9	0.0	0.0	0.0
23 Mosaic grassland and bare	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	20.0	50.0	0.0	0.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24 Natural grassland	24	9.6	1.2	0.0	.2	.0	.0	1.6	0.0	.0	2.6	2.5	.3	.9	41.0	3.1	18.1	.3	0.0	.2	10.8	.7	.0	.9	3.0	3.0
25 Grassland, few ls	25	5.1	1.5	0.0	.7	.1	.5	1.8	.4	1.9	5.6	12.3	1.4	.2	10.2	7.6	11.7	.1	0.0	.4	16.9	1.9	.1	.7	18.6	.3
26 Grassland, bgs	26	11.5	3.7	.0	1.3	0.0	.3	7.4	.1	4.3	2.6	.9	4.9	1.7	4.3	4.0	26.4	.9	.3	1.0	14.6	0.0	.5	1.1	7.0	1.1
27 Bare	27	0.0	40.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	40.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0
28 Bare,few ls	28	0.0	21.4	0.0	0.0	0.0	0.0	35.7	7.1	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	7.1	7.1	0.0	14.3	0.0	0.0	0.0	0.0	0.0
30 Urban	30	.0	49.4	.1	3.0	0.0	2.5	9.9	.1	.1	.0	.0	.6	.2	.0	.1	.8	.7	.3	8.6	12.8	.0	7.9	.1	2.4	.3
31 Dense forest_CS	31	.0	2.2	.1	.1	.0	.6	4.7	.0	.5	2.3	.6	.0	.0	.8	.1	.1	.2	.0	.2	82.5	.5	1.3	.6	1.6	.8
32 Open forest, few ls_CS	32	.0	2.5	.1	.1	.0	.4	5.5	.0	1.6	3.3	3.4	.0	.0	2.7	.3	.2	.1	.0	.3	69.2	2.2	.6	1.2	5.4	.7
33 Open forest, pp_CS	33	.4	5.7	.0	.5	0.0	8.2	12.4	0.0	0.0	0.0	0.0	.2	0.0	0.0	.0	.1	0.0	0.0	1.9	33.8	0.0	34.5	0.0	1.5	.4
36 Natural grassland_CS	36	1.9	3.0	.0	.3	.0	.1	4.5	.3	.0	2.9	.5	.1	.3	17.6	2.1	9.3	.4	.1	.9	34.0	.1	.3	4.3	16.3	.6
37 Grassland, few ls_CS	37	.1	5.5	.4	.3	.0	.9	8.9	1.8	.9	1.9	1.7	.0	.0	2.1	1.0	1.2	.1	.0	.2	53.6	1.2	1.1	1.1	14.9	.7
38 Grassland, bgs _CS	38	0.0	0.0	10.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.0

Assessment of non-equilibrium land use types and climate regulating services for landscape cover (climatic factors predicted by energetic characteristics)





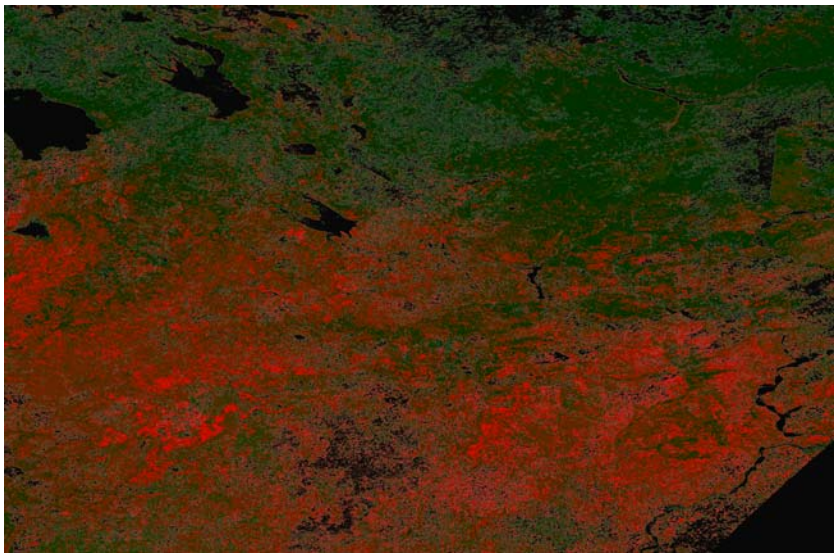
2002

Measure of non-equilibrium: sum of the probabilities of assigning a pixel to land use types by discriminant analysis

0 **1**

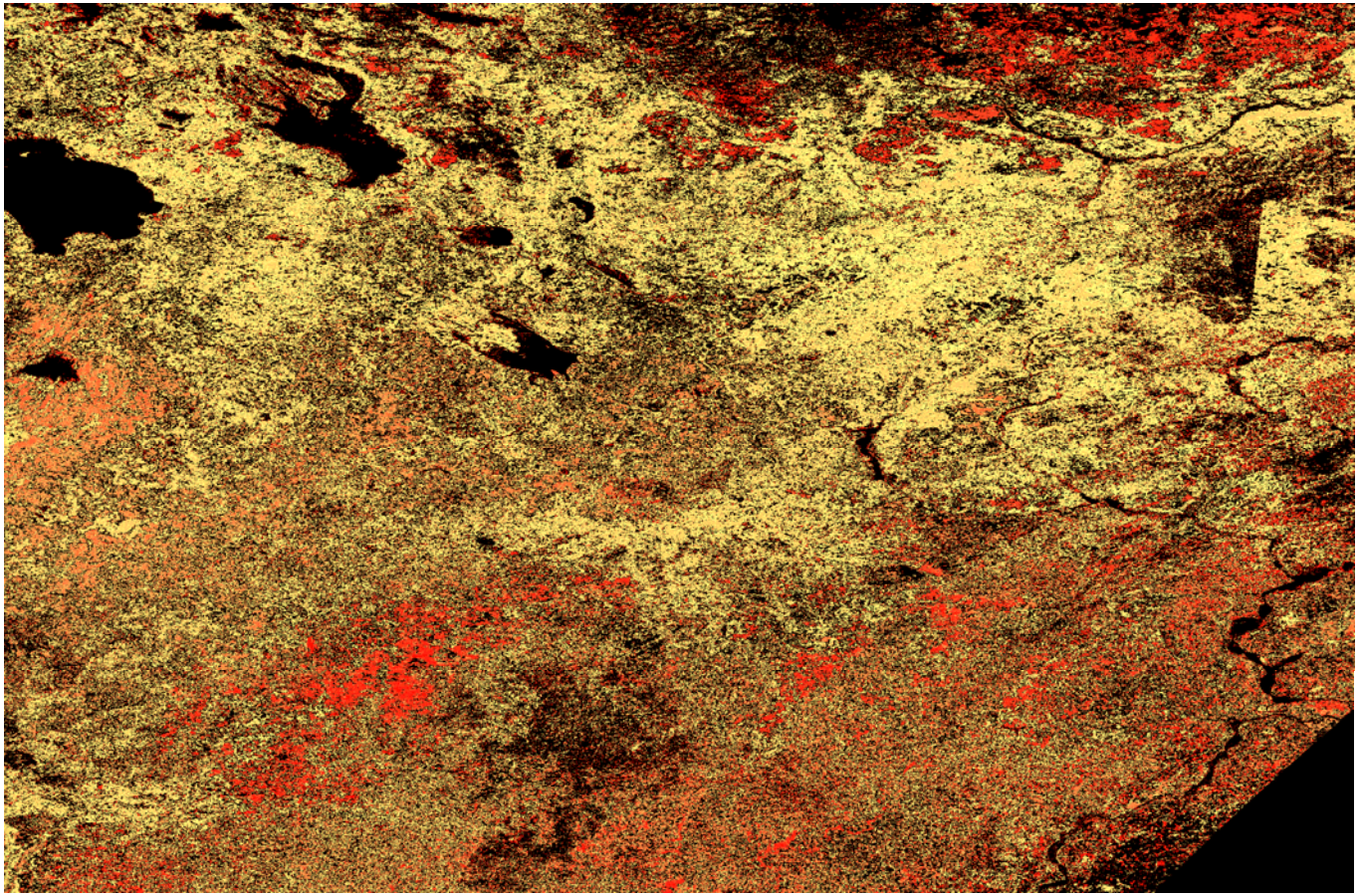
2017

Difference between equilibrium



1	-0.0611
2	-0.0332
3	-0.0214
4	-0.0133
5	-0.0069
6	-0.0018
7	0.0028
8	0.0080
9	0.0133
10	0.0182
11	0.0235
12	0.0294
13	0.0390
14	0.0560
15	0.0934
16	0.1256

Difference between climate regulation service 9 May 2002 and 17 May 2017



min max

Calculation of the relationship between the average annual climate parameters (incoming solar radiation, temperature, precipitation, wind speed, etc.) from databases of different spatial scales and energetic variables, allows quantifying the contribution of different landscapes (active surfaces and their combinations) to the formation of a temperature and precipitation fields.

Analysis of dynamic this relationship, allows to detect regions most sensitive to the changes in land use regime (deforestation?).

Analysis of supporting and regulation ecosystem services will provide quantitative estimates of the contribution of different types of ecosystems to mesoclimate. Analysis of their long-term dynamics will provide an opportunity to assess the impact of land use changing and, in particular, deforestation on regional heat fluxes and fields of precipitation.


THANK YOU
FOR ATTENTION