LONG-TERM CHANGES IN SOLAR SHORTWAVE IRRADIANCE DUE TO DIFFERENT SOURCES ACCORDING TO MEASUREMENTS AND RECONSTRUCTION MODEL IN NORTHERN EURASIA

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GOALS

- Development of method for the reconstruction the long-term variability of solar shortwave irradiance (SR)
- Detailed testing the method against long-term measurements of Moscow State University Meteorological Observatory (MO MSU) since 1968
- Evaluation of the rate of different geophysical factors influence on SR variations
- Reconstruction and analysis of SR variability for Northern Eurasia

MODEL RECONSTRUCTION OF SOLAR SHORTWAVE IRRADIANCE

$$V_i = \frac{\sum_j (W_j(h)\ (v\_aer_{i,j}(\tau_a, P_{cf}, A) + v\_cq_{i,j}(CQ_A) + v\_tcld_{i,j}(\tau_c, P_{ov}))}{\sum_j W_j(h)}$$

v_aer	**SR variability due to aerosol**
τ_a	AOT (aerosol optical thickness)
P_{cf}	Occurrences of clear sky conditions
A	Surface albedo

v_cq	**SR variability due to cloud amount**
CQ_A	Effective cloud amount transmission with account of the surface albedo influence [A]

v_tcld	**SR variability due to cloud optical thickness**
τ_c	Cloud optical thickness
P_{ov}	Occurrences of overcast cloud conditions

$W(h)$ – weights function
h – solar angle
i – year index
j – month index

based on (Chubarova, 2008)

Effective cloud amount transmission

$$CQ_A = \frac{CQ_{A=0}}{(1 - A(\mathbf{C} - \mathbf{D}\, CQ_{A=0}))}$$

$$CQ_{A=0} = \sum_{Nl=0}^{10} \{[P(Nl) - P(Nl, N_{10})] \times CQ_{A=0}(Nl) + P(Nl, N_{10}) \times CQ_{A=0}(Nl) \times CQ_{up}\}$$

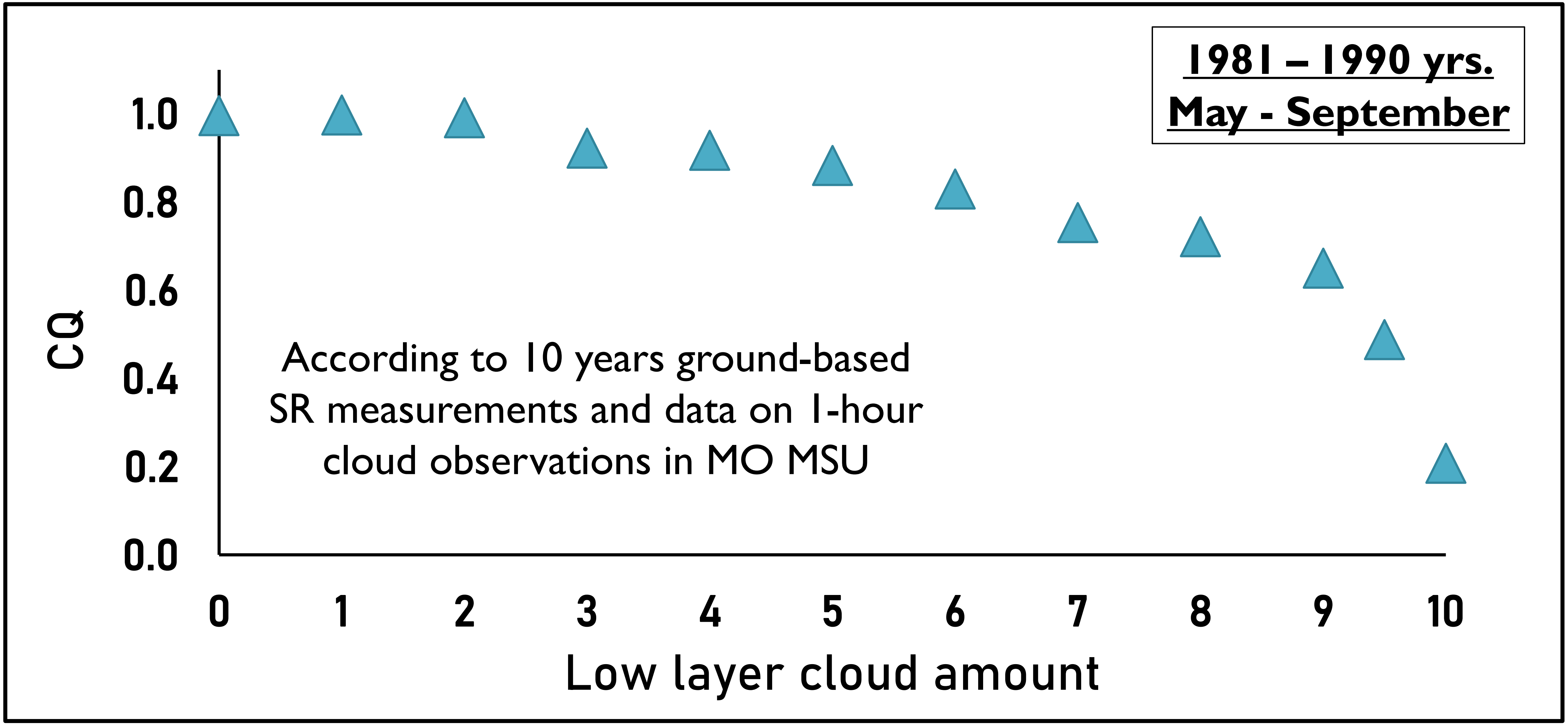
$CQ_{A=0}$	Cloud amount transmission without influence of surface albedo
! $CQ_{A=0}(Nl)$	SR transmission by low layer cloudiness
$P(Nl)$	Frequency of low layer cloud amount (Nl) with different amounts of total cloudiness
$P(Nl, N_{10})$	Frequency when total cloud amount is equal N=10 (overcast conditions) with different amount of low layer clouds
CQ_{up}	Mean SR transmission by overcast upper layer cloudiness (CQup = 0.923)

According to the model simulations:

C = 0.1

D = 0.7

SR TRANSMISSION ON LOW LAYER CLOUD AMOUNT



SR SENSIBILITY TO INTERANNUAL AEROSOL OPTICAL THICKNESS VARIATIONS

$$v\_aer_{i,j} = P_{cf\,i,j}\left[\left(\frac{\tau_{a_{i,j}}}{\tau_{a,mean_i}}\right)^{a \sin h^2 - b \sin h - c} - 1\right]$$

v_aer	SR variations due to variations in AOT
i	year index
j	month index
h	solar angle
τ_a	AOT at 550 nm
P_{cf}	occurrences of clear sky conditions
$\tau_{a,\,mean}$	mean AOT at 550 nm in the month, weighted on the full period
a, b, c	empirical coefficients according to the model simulations

SR SENSIBILITY TO INTERANNUAL CLOUD OPTICAL THICKNESS VARIATIONS IN OVERCAST CONDITIONS

$$v\_tcld_{i,j} = P_{ov_{i,j}} \left(\frac{CQ_{ov,mean_j} - CQ_{ov,i,j}}{CQ_{ov,mean_j}} \right)$$

v_tcld	SR variations due to variations in cloud optical thickness
i	year index
j	month index
CQ_{ov}	cloud transmission in overcast condition
P_{ov}	occurrences of overcast cloud conditions
$CQ_{ov,mean}$	mean cloud transmission in overcast condition in the month, weighted on the full period

TESTING
THE RECONSTRUCTION MODEL

Testing parameters:

Period: 1968-2016 yrs.

Time of year: May-September

Data:

1-hour ground-based SR measurements in MO MSU since 1968

Yanishevsky's
pyranometer and actinometer

Model input parameters:

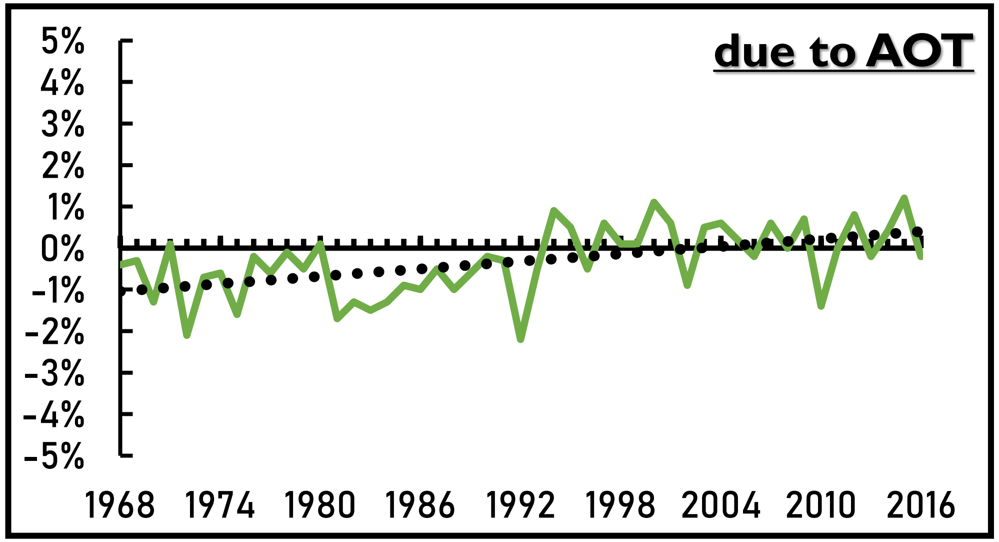
Cloudiness:

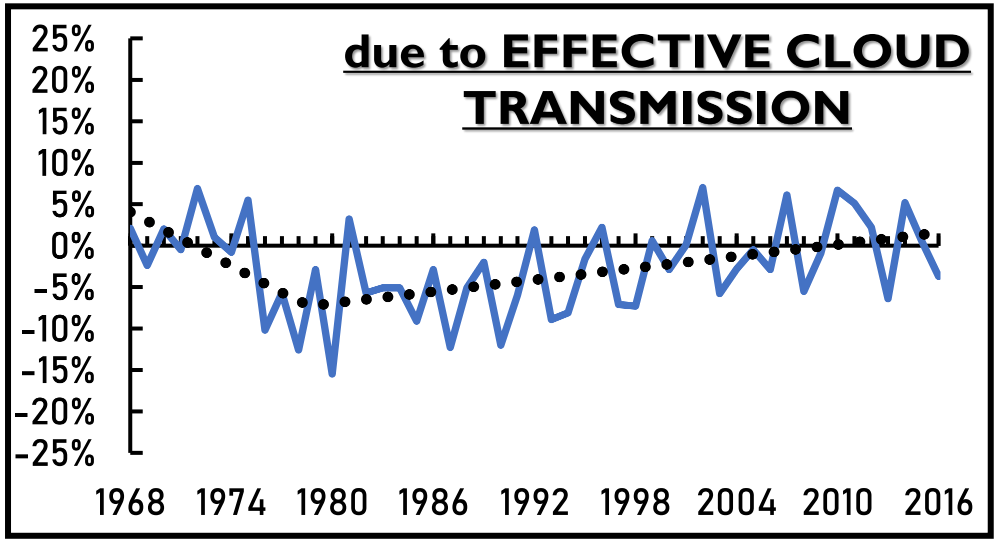
- 1-hour cloud observations in MO MSU

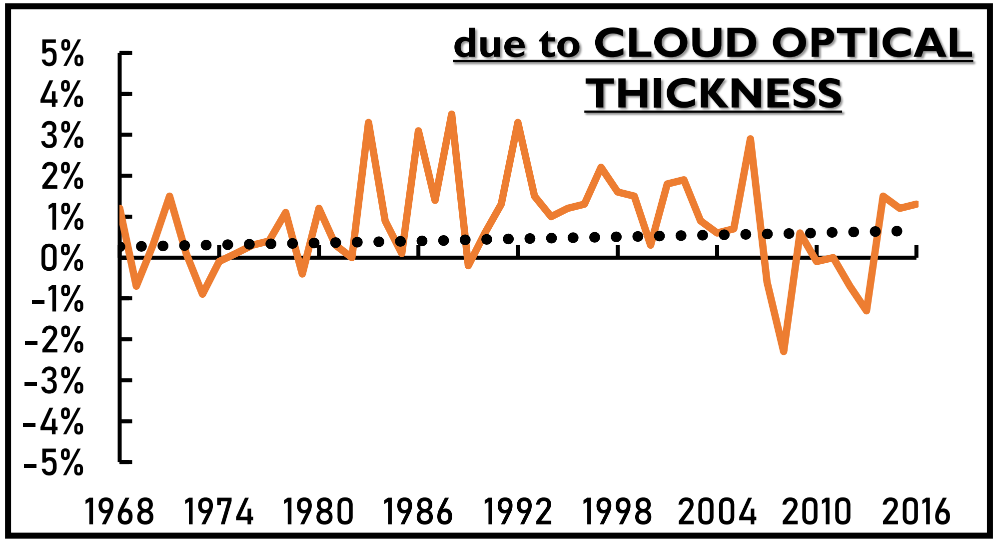
Aerosol:

- until 2002 – AOT at 550 nm was calculated using direct shortwave irradiance and water vapor content (Tarasova and Yarkho, 1991) from MO MSU's data base
- since 2002 – AOT measurements in MO MSU by photometer CIMEL CE 318-2

THE CONTRIBUTION OF VARIOUS FACTORS IN SR VARIATIONS

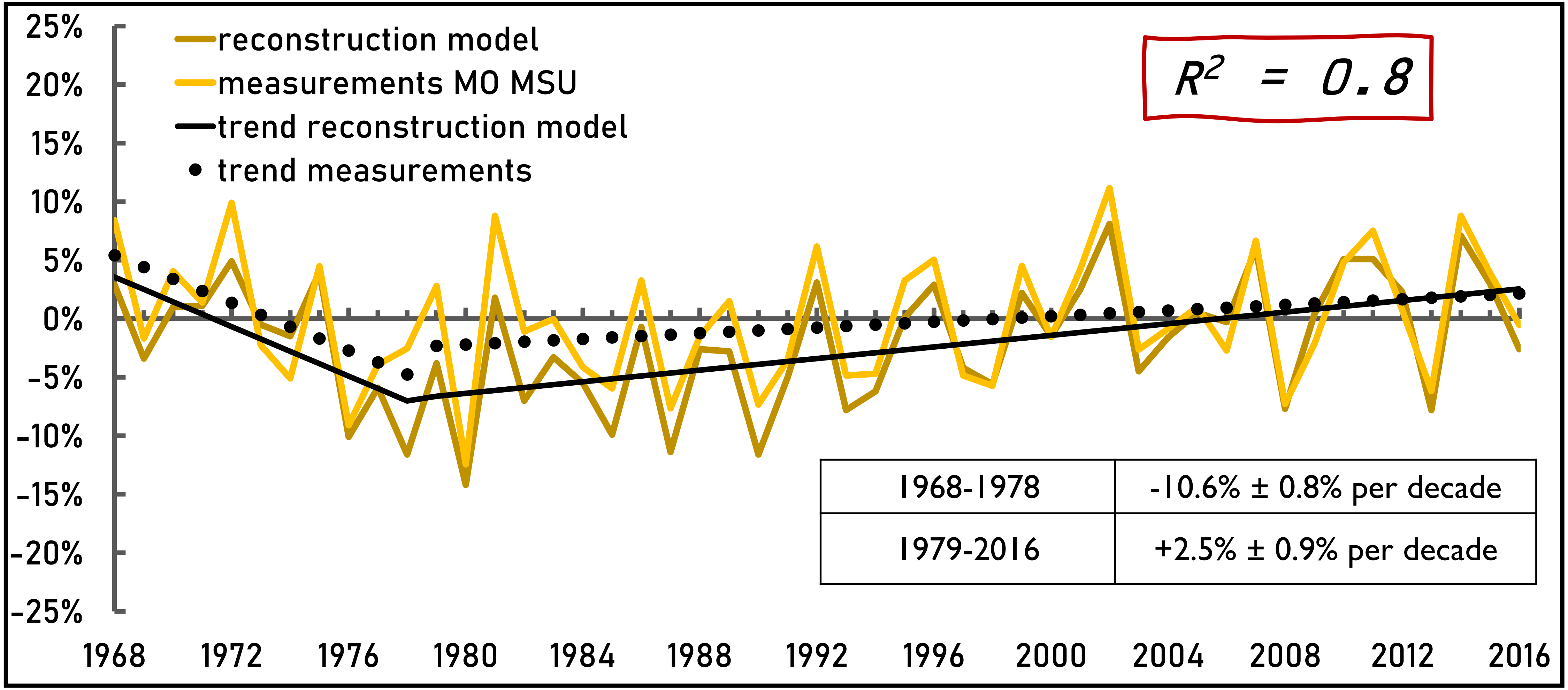






SR variations due to AOT	1979-2016	+0.4% ± 0.1% per decade
due to cloud optical thickness	1979-2016	-0.3% ± 0.2% per decade (not significant trend)
due to effective cloud transmission	1968-1978	-10.8% ± 0.8% per decade
	1979-2016	+2.4% ± 0.9% per decade

RELATIVE CHANGES IN SHORTWAVE RADIATION DUE TO THE MEASUREMENTS AND RECONSTRUCTION MODEL IN MOSCOW



RECONSTRUCTION OF SR VARIABILITY IN NORTHERN EURASIA

WARM PERIOD (MAY-SEPTEMBER)

INPUT DATA

CLOUDINESS OBSERVATION

	Russia	Other stations
Data Archive	RIHMI-WDC	ISD (Integrated Surface Hourly Data Base) by NOAA NCEI (National Centers for Environmental Information)
Web Site	http://meteo.ru/	https://www.ncdc.noaa.gov/isd
Time Resolution	3 hour	3 hour

SURFACE ALBEDO

Data Archive	ERA-Interim (Monthly means)
Period	1979-2017
Time Resolution	Monthly average
Spatial Resolution	0.5°

AEROSOL MEASUREMENTS

Instrument	MODIS
Product	Deep Blue + Dark Target AOT at 550 nm
Bias (land)	Deep Blue - [± (0.03 + 20%)] Dark Target - [± (0.05 + 15%)]
Satellite	Terra + Aqua
Period	from 2000 to 2003 – Terra since 2003 – Aqua
Time Resolution	Monthly average
Spatial Resolution	1°
Web Site	http://disc.sci.gsfc.nasa.gov/giovanni/

STATIONS SELECTION FOR SR VARIABILITY RETRIEVAL

REQUIREMENTS

FOR GROUND-BASED MEASUREMENTS:

- ✓ Long-term ground-based SR measurements until 2017 (not less 30 years)
- ✓ No data break for more than 2-3 years

FOR INPUT PARAMETERS:

- ✓ Availability of cloud observations corresponding to the period of shortwave radiation measurements

SELECTED

41
SITES

GROUND-BASED MEASUREMENTS

Long-term ground-based SR measurements:

- **WRDC**
  [World Radiation Data Centre] (Wild et al., 2005)
- **GEBA**
  [Global Energy Balance Archive] (Wild et al., 2017)

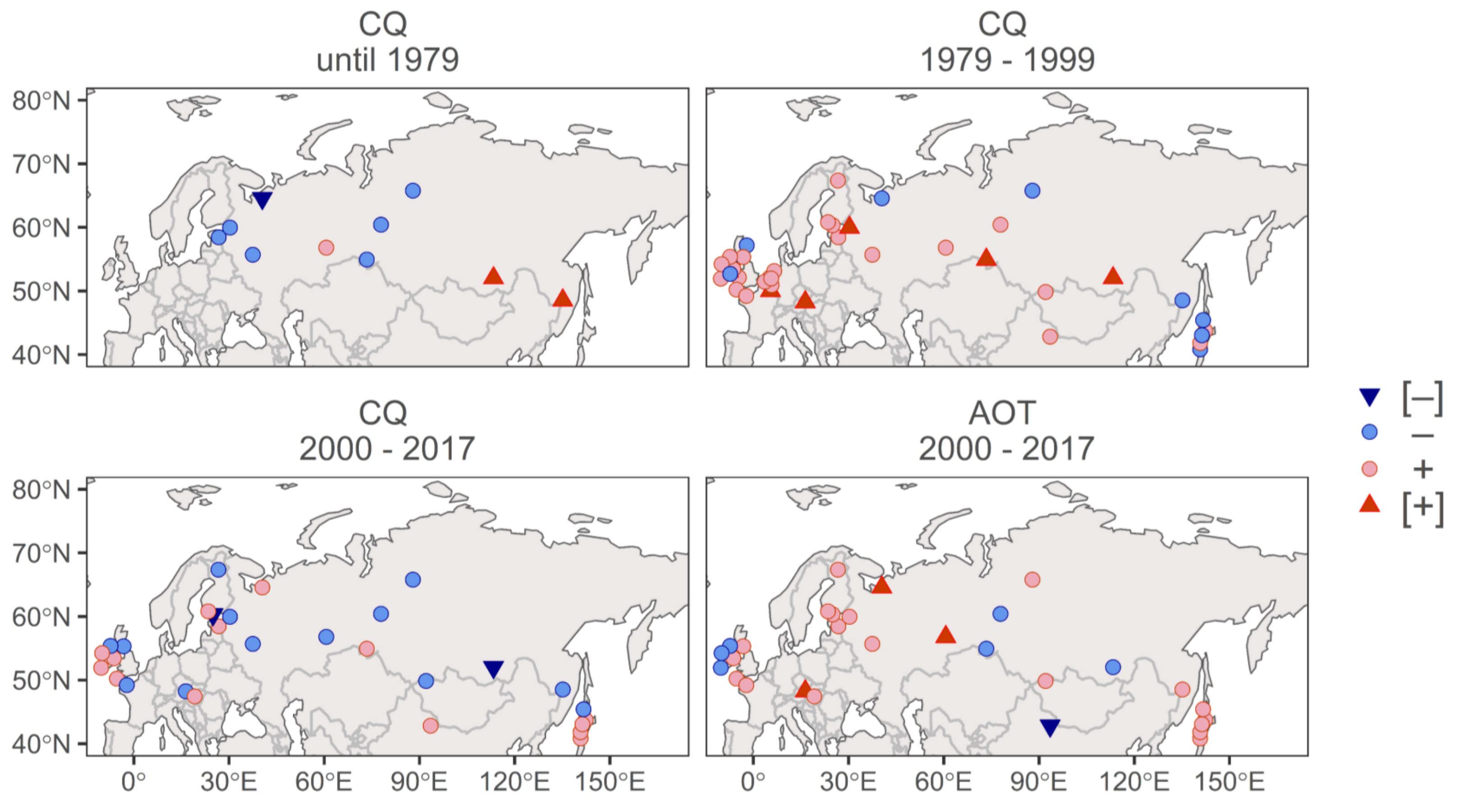
PERIODS TO ANALYZE LONG-TERM CHANGES IN SR DUE TO DIFFERENT FACTORS IN NORTHERN EURASIA UNTIL 2017

Periods	Reason
until 1979 yr.	global dimming
1979-1999 yrs.	global brightening
2000-2017 yrs.	• Changing in SR trends after 2000 (Wild, 2012) • Aerosol database since 2000

POSITIVE AND NEGATIVE SR TRENDS DUE TO EFFECTIVE CLOUD AMOUNT TRANSMISSION (CQ) AND AEROSOL OPTICAL THICKNESS (AOT) IN NORTHERN EURASIA

+ ***positive*** **trend per decade**

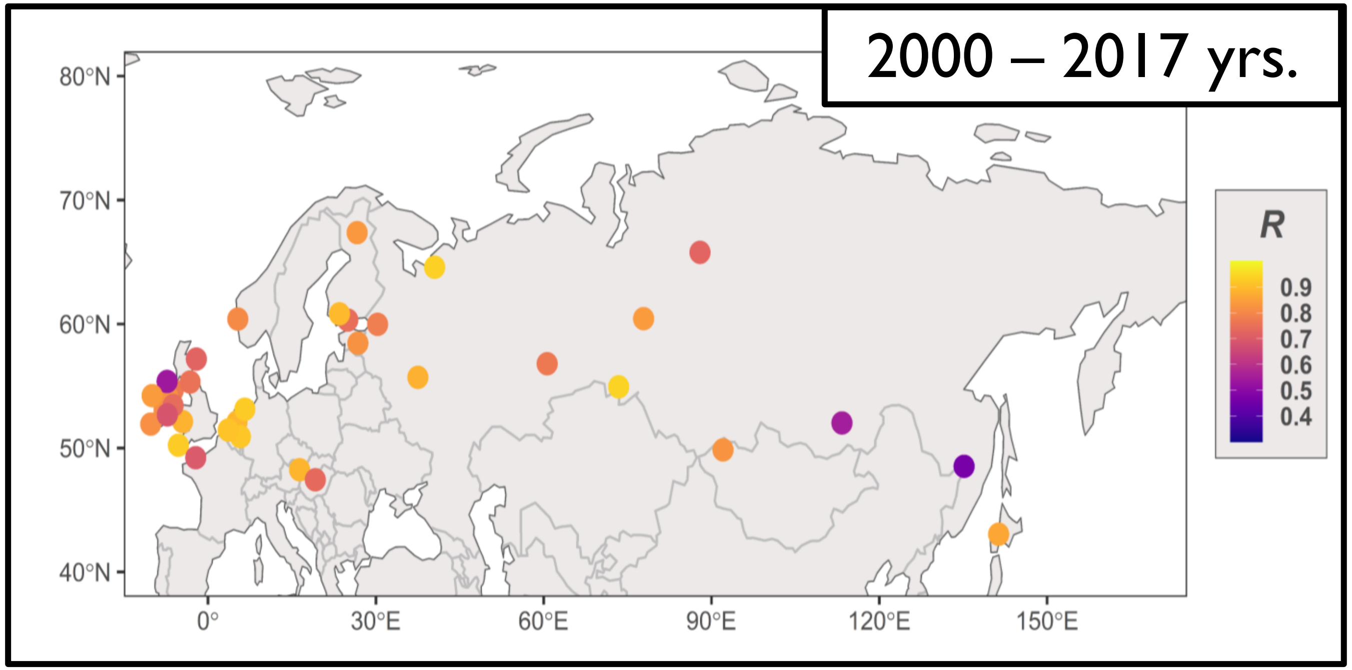
— ***negative*** **trend per decade**



Statistically significant trends were indicated by TRIANGLE icons

ASSESSMENT OF THE CONTRIBUTION OF CLOUDINESS AND AEROSOL IN SR VARIATIONS

Site	Country	lat	lon	R (CQ_A & SR)	R (CQ_A + AOT & SR)
Valentia obs.	IE	51.93	-10.25	0.88	0.89
Belmullet	IE	54.23	-10	0.68	0.69
Malin	IE	55.37	-7.33	0.53	0.52
Dublin	IE	53.43	-6.25	0.72	0.73
Camborne	GB	50.22	-5.32	0.96	0.97
Eskdalemuir	GB	55.32	-3.2	0.86	0.86
Vienna	AT	48.25	16.37	0.94	0.94
Budapest	HU	47.43	19.18	0.99	0.99
Jokioinen	FI	60.82	23.5	0.81	0.75
Helsinki	FI	60.32	24.97	0.86	0.90
Sodankyla	FI	67.37	26.65	0.87	0.88
Toravere	EE	58.45	26.78	0.89	0.90
Moscow	RU	55.7	37.5	0.90	0.92
Ekaterinburg	RU	56.8	60.63	0.89	0.89
Omsk	RU	54.93	73.4	0.93	0.95
Ulaangom	MN	49.85	92.07	0.97	0.98
Chita	RU	52.02	113.33	0.70	0.67
Hakodate	JP	41.82	140.75	0.69	0.68
Aomori	JP	40.82	140.77	0.93	0.95
Sapporo	JP	43.05	141.33	0.96	0.96
Wakkanai	JP	45.42	141.68	0.77	0.79
Asahikawa	JP	43.75	142.37	0.72	0.73



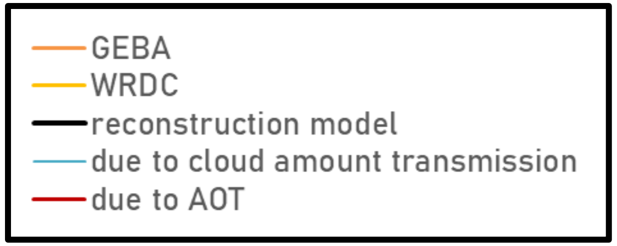
Correlation coefficient between SR variations obtained from measurement data (GEBA and WRDC) and from the reconstruction model due to effective cloud amount transmission

ASSESSMENT OF THE CONTRIBUTION OF CLOUDINESS AND AEROSOL IN SR VARIATIONS

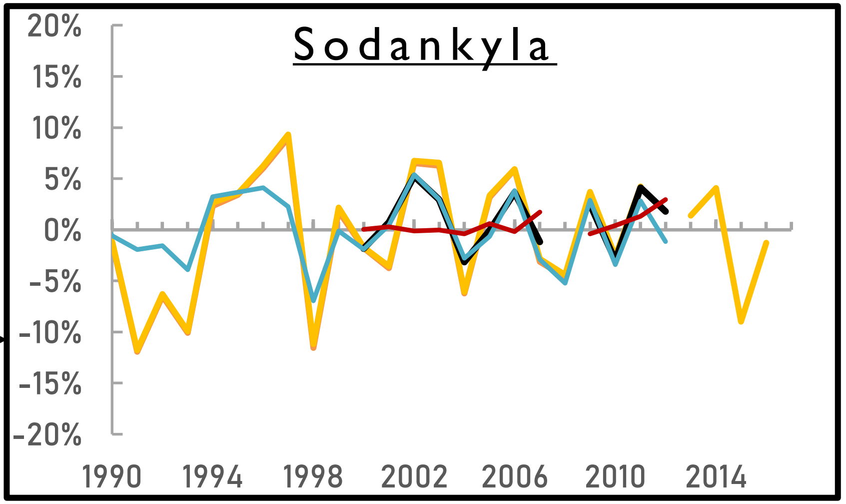
Variations:

- due to **effective cloud amount transmission** declare **81%** of variations SR
- due to **AOT** declare **19%** of variations SR

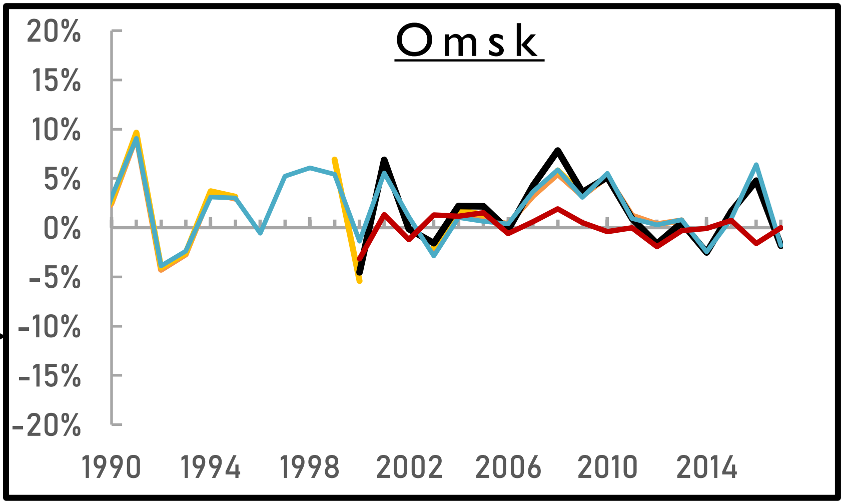
Why SR variations due to AOT should be accounted?



May changed the general tendency of SR variations (see 2012 yr.)



May significantly strengthen SR variations (see 2001 yr.)



RESULTS

- The reconstruction model for shortwave solar irradiance was developed and tested against long-term measurements of Moscow State University Meteorological Observatory (MO MSU) since 1968 with R^2 equal 0,8. It was detected that cloud amount and aerosol optical thickness have the most significant influence on solar irradiance trends. The analysis of SR trends has detected a significant decline in SR of -10.6% per decade until 1979 yr., which was changed then to significant growth of 2.5% per decade.
- Using the SR model reconstruction the regional characteristics of SR trends due to different sources were obtained for Northern Eurasia.
- For most stations in Northern Eurasia the contribution of the cloud factor prevails, with the exception of the Asian region and the North of Europe, where there is an increase in the aerosol factor.
- On the most sites in European part of the Northern Eurasia an increasing trend in SR since 1979 was indicated explained by decrease in effective cloud transmission. In the last 20 years the trend of increasing cloud transmission has weakened and changed trend sign in the North of Europe and in some Asian regions. At the same time, at most European sites, SR growing due to a decrease in the aerosol optical thickness has been continuing.
- In the future, it is planned to include the cold period in the analysis.

COMMENTS

QUESTIONS

SUGGESTIONS

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