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Correct atmospheric optics modelling: Theory and Experiment

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Objectives:

1. Constructing the simple optical model of homogeneous atmosphere
2. Solution of the direct problem of atmospheric optics with operative varying optical parameters for elucidating the interaction between key atmospheric parameters and radiative characteristics
3. The solution of the direct problem is calculation of radiation characteristics (radiant heat. radiation balance at the tropopause level)
4. Comparison with the results of airborne measurements

Optical parameters

- Optical thickness of the clear atmosphere :

$$\tau = \tau_{a.sc} + \tau_{a.ab} + \tau_{R} + \tau_{m.ab} \ .$$

$\tau_{a.sc}$ – the optical thickness of aerosol scattering.

$\tau_{a.ab}$ - the optical thickness of aerosol absorption.

τ_{R}- the optical thickness of molecular scattering.

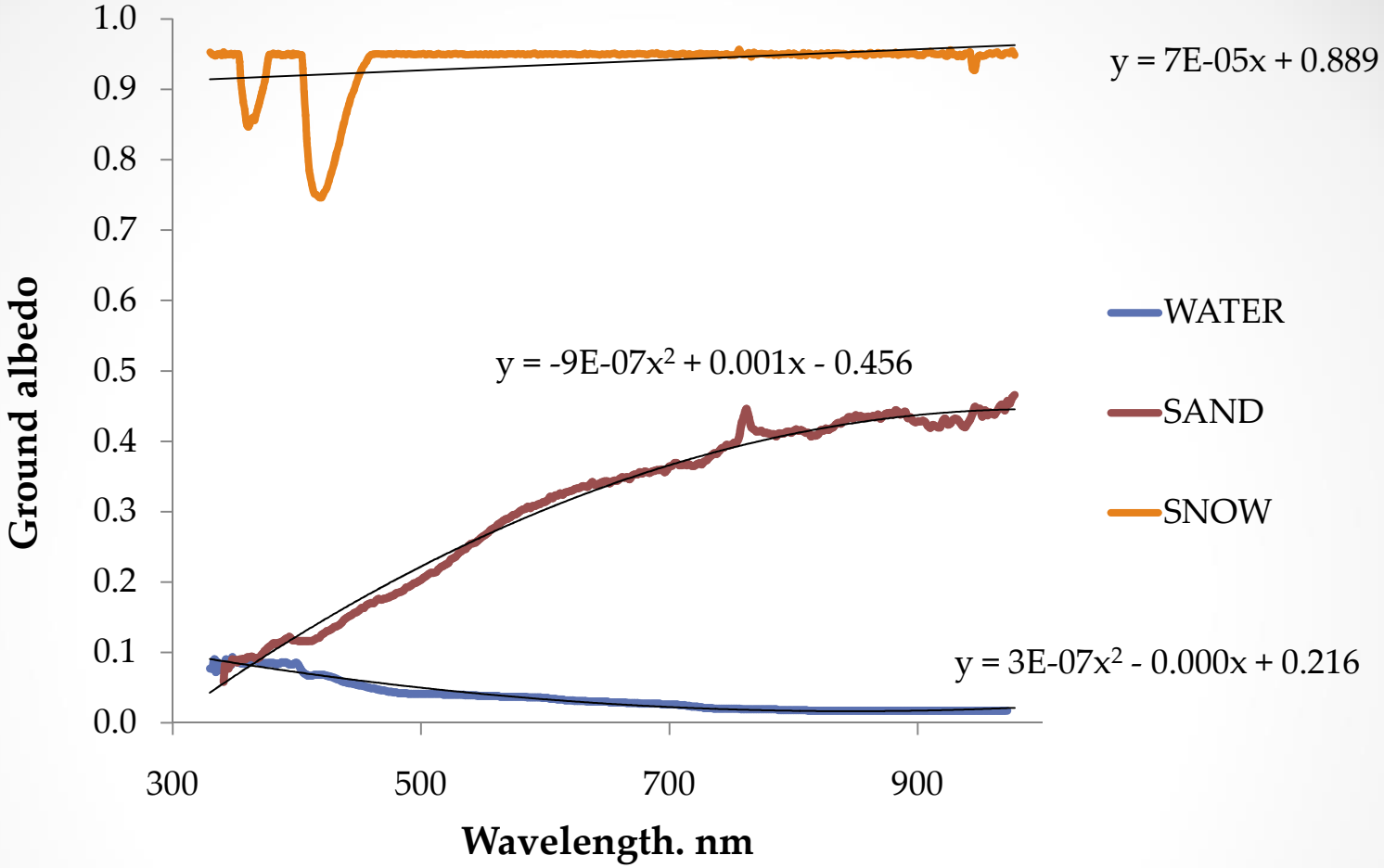
$\tau_{m.ab}$ - the optical thickness of molecular absorption;

- Cloud optical thickness τ_0
- Single scattering albedo: for clear atmosphere

$$\omega = (\tau_{a.sc} + \tau_R)/\tau \quad ;$$

- For cloudy atmosphere $\omega = (\tau_0 + \tau_{a.sc} + \tau_R)/(\tau + \tau_0)$;
- The phase function asymmetry parameter:

  g=0.0 for clear atmosphere and g=0.85 for cloud atmosphere;
- The ground albedo A_s

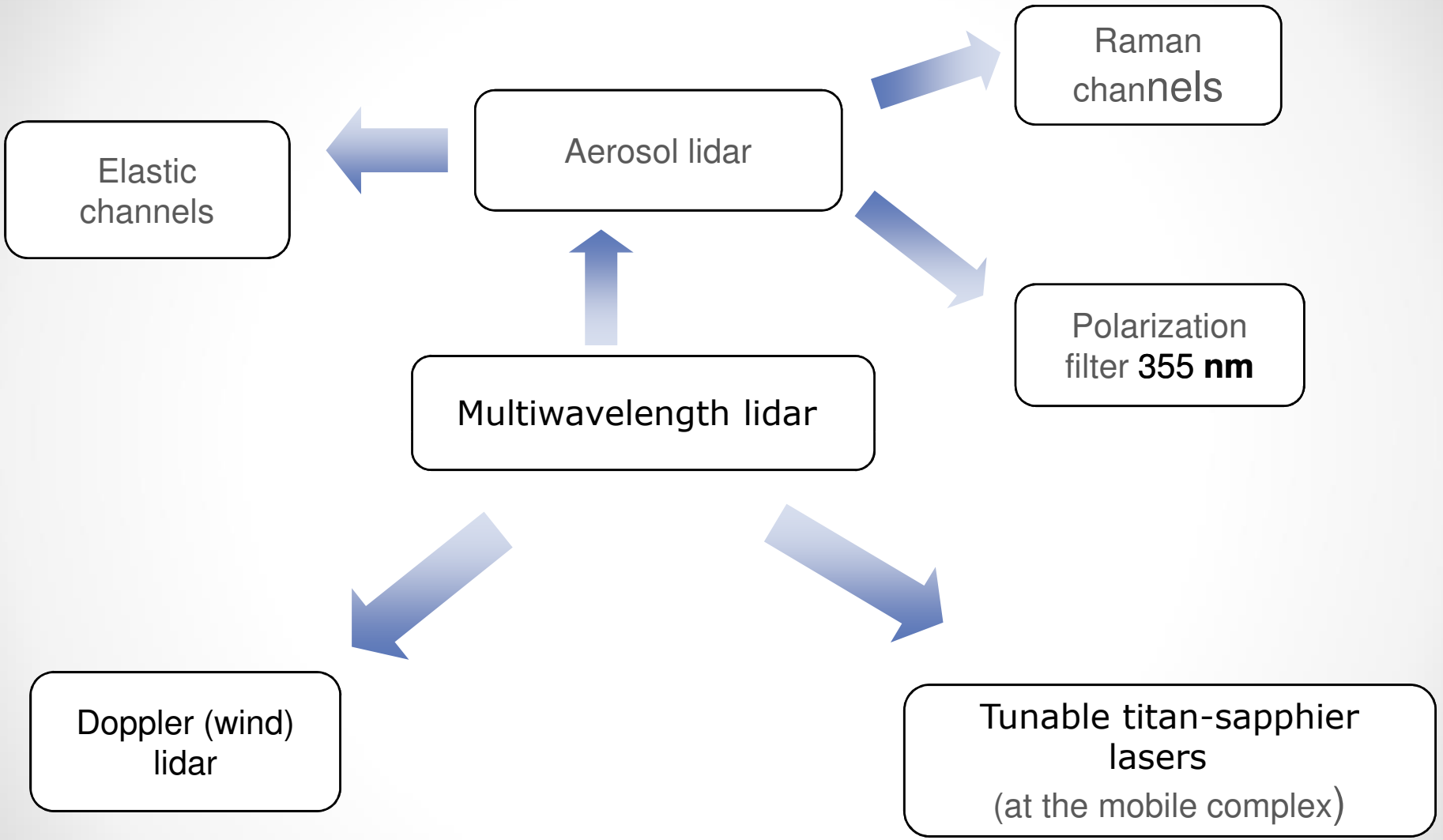


Spectral dependence of the ground albedo of different surfaces from observational data processing

(C.A. Varotsos. I.N. Melnikova. A.P. Cracknell. C. Tzanis. A.V. Vasilyev. New spectral functions of the near-ground albedo derived from aircraft diffraction spectrometer observations. Atmospheric Chemistry and Physics. v. 13. pp. 16211-16245)

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Data of the SPSU RC lidar is used for aerosol optical thickness modelling



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Stationary lidar system:

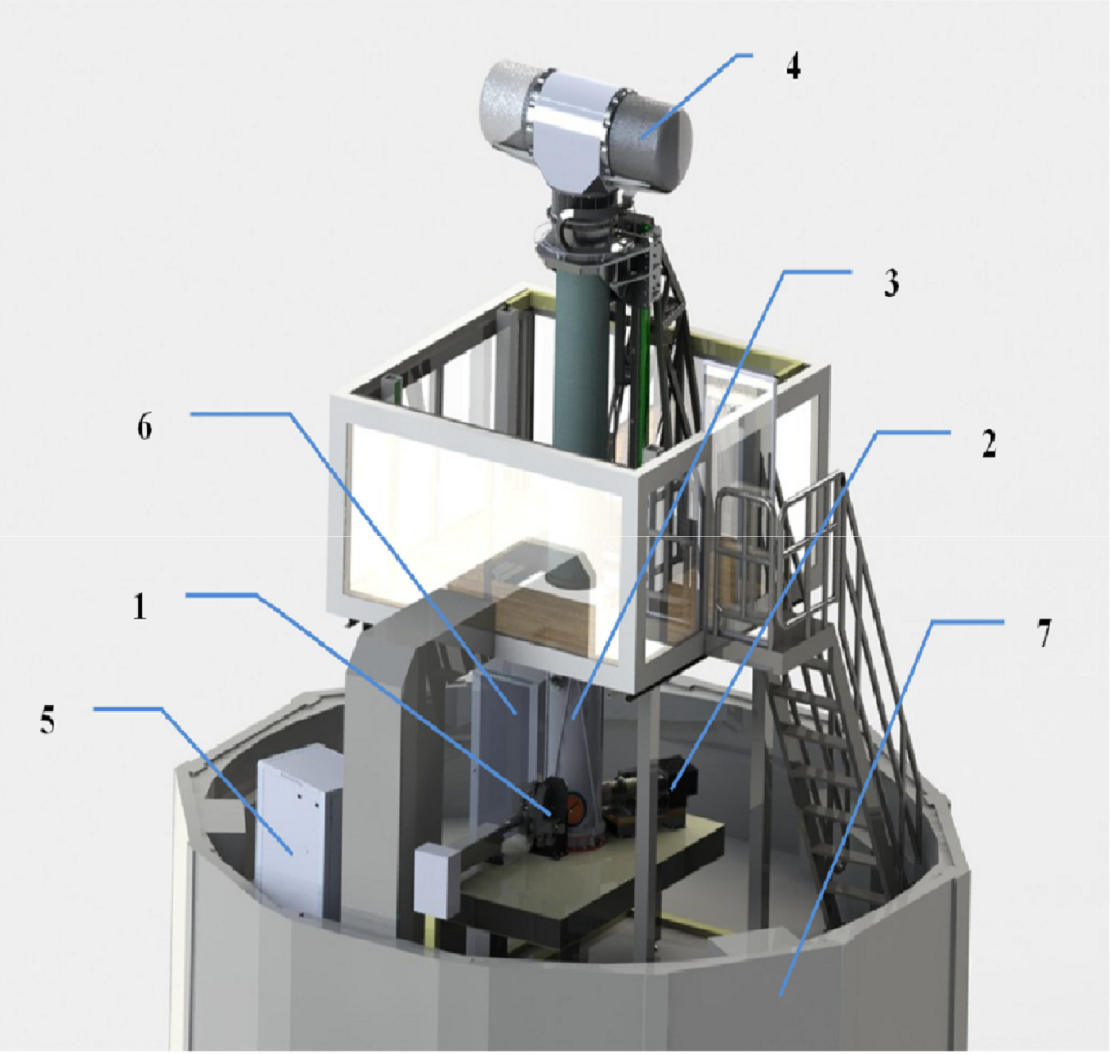
- A Doppler lidar for measuring the wind speed and direction up to 12 km height

- An aerosol lidar for measuring the atmospheric aerosol parameters up to 25 km height

1. Provide regular monitoring the dynamics of an atmospheric pollution above the big city center.

2. Retrieving atmospheric dust parameters: size, extinction coefficient, backscattering coefficient, real and imagine parts of the refractive index, and content

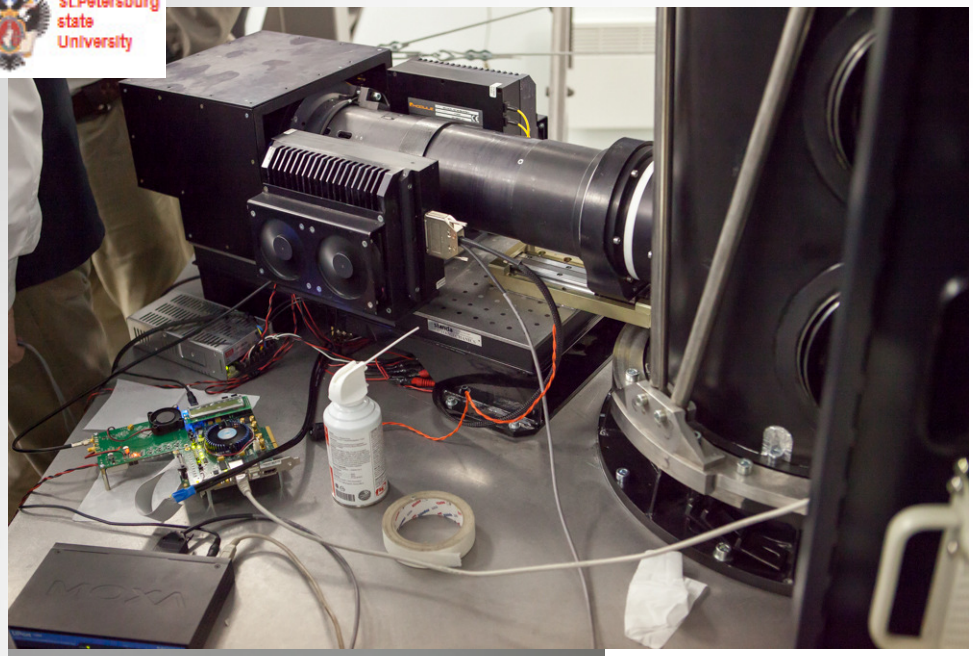
Stationary lidar system

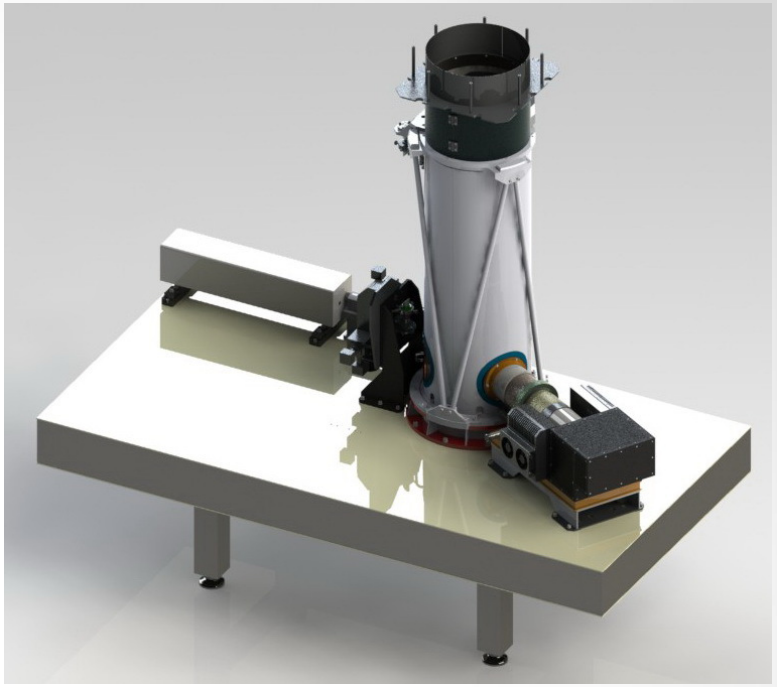


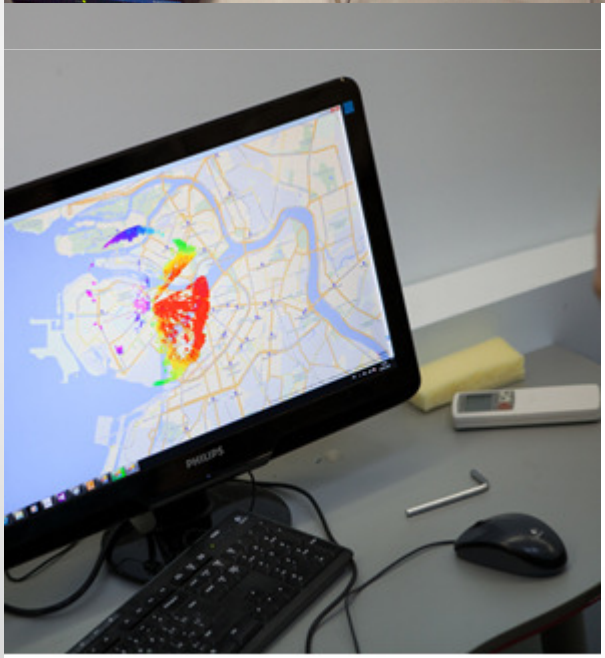
Structure of the complex:

1 – aerosol lidar, 2 – Doppler lidar, 3 – receiving-transmitting telescope, 4 – two-axis scanner, 5 – server rack, 6 – equipment rack, 7 – SPbSU tower.

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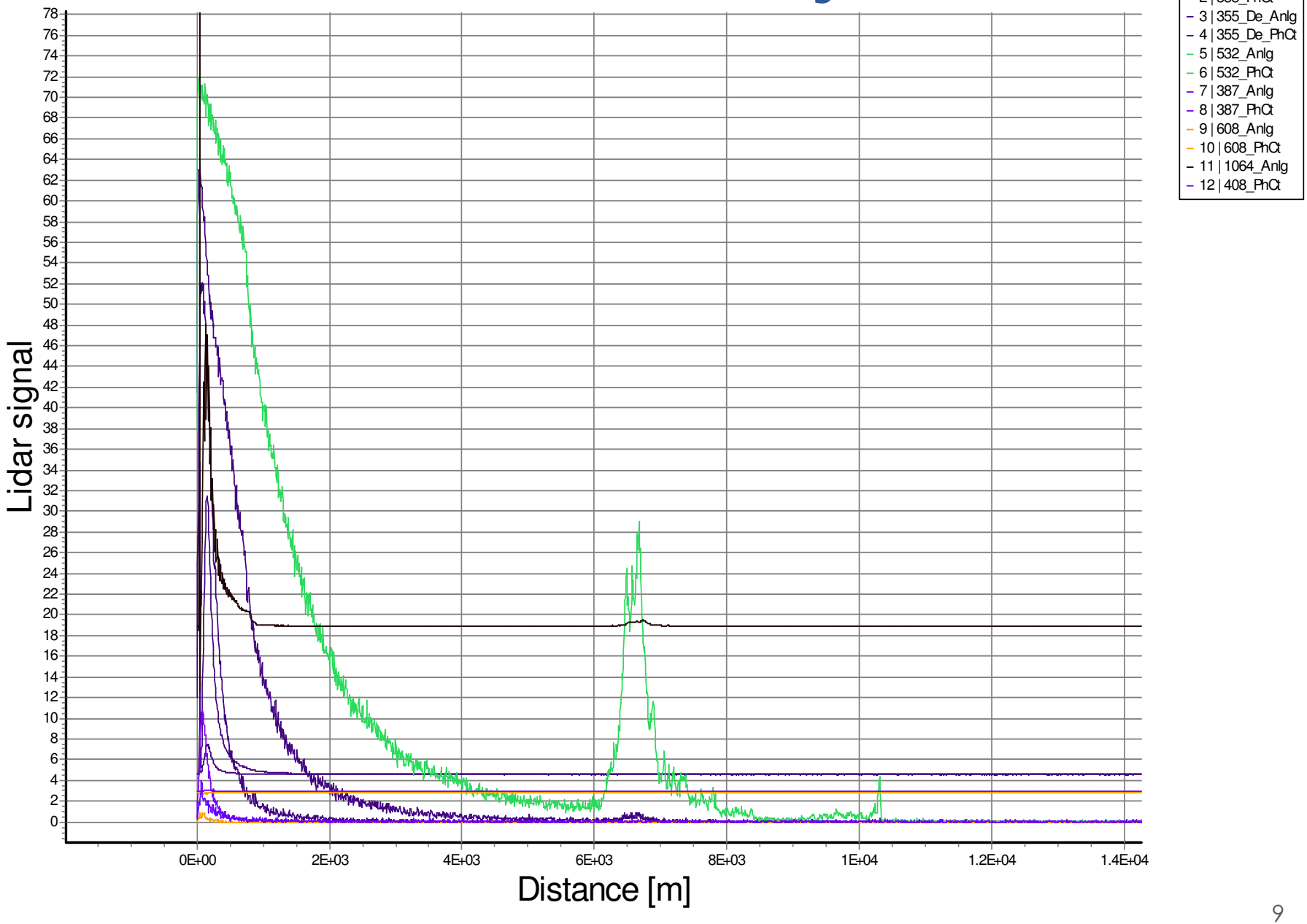


Aerosol lidar
1064 nm - 400 mJ
532 nm - 160 mJ
355 nm - 100 mJ

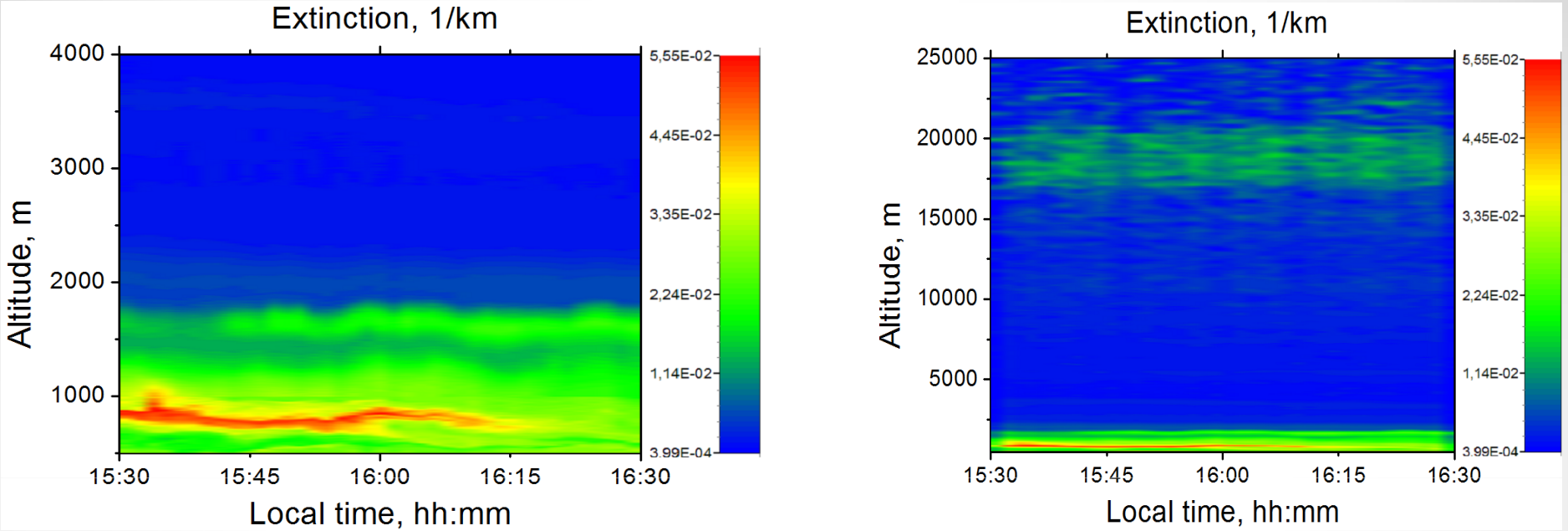
Doppler *(wind)* **lidar** for wind velocity and direction profile
Pulse repetition rate 10kHz

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Screenshot of the received Lidar signal 31.10.2013



Lidar sounding above St. Petersburg city



The extinction coefficient above St. Petersburg 25 March 2013.

The vertical profile till 4 km and 25 km during 1 hour **λ=532 nm**

The maximum of **hat pollution** at 0.7 km, disappeared during 45 min (15:30 - 16:15) $\alpha(z)$~0.056km^{-1}

The stratosphere aerosol–**Yunge layer** at 17-22km $\alpha(z)$~0.015km^{-1}

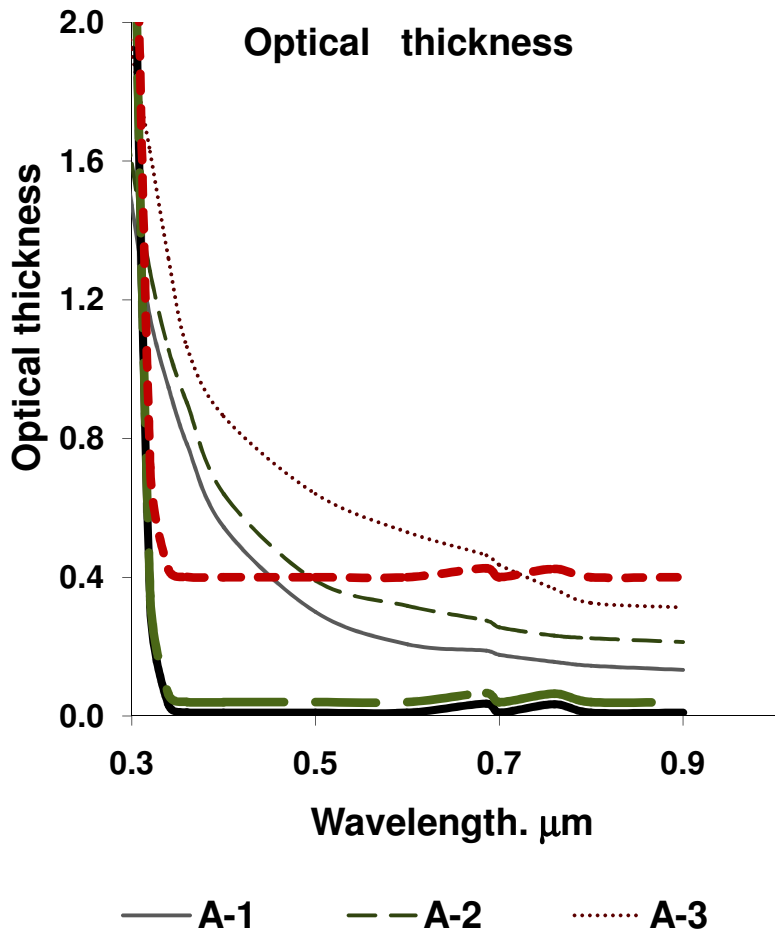
Total optical thickness is **τ = 0.0735**

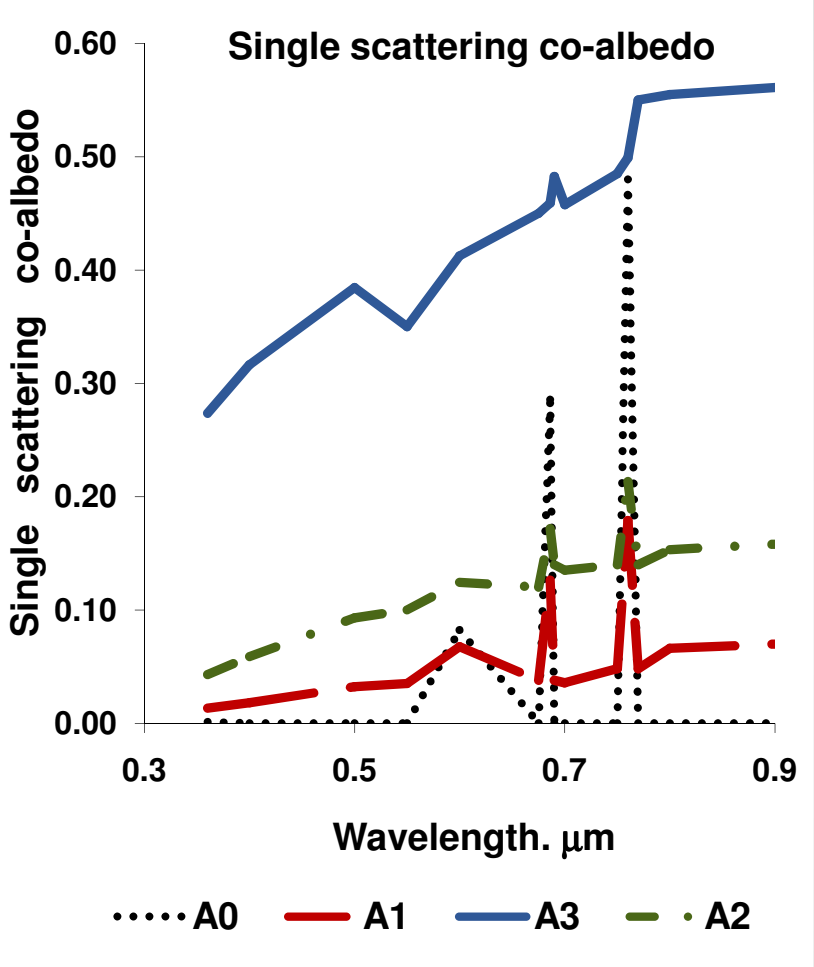
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VALUES OF OPTICAL PARAMETERS OF THE CLEAR ATMOSPHERE

	λ. μm	0.30	0.40	0.50	0.60	0.70	0.80	0.90
Mol scatt	$\tau_{Rel\ (z=0)}$	1.222	0.364	0.14	0.067	0.036	0.021	0.013
Aer 0	$\tau_{a\ scatt}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$\tau_{a\ abs}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aer I	$\tau_{a\ scatt}$	0.25	0.18	0.16	0.14	0.13	0.12	0.12
	$\tau_{a\ abs}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Aer III	$\tau_{a\ scatt}$	0.7	0.5	0.5	0.5	0.4	0.3	0.3
	$\tau_{a\ abs}$	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0	ω_0	0.26184	1.0	1.0	0.91781	1.0	1.0	1.0
I		0.29876	0.98195	0.96774	0.93243	0.94318	0.93378	0.93007
III		0.33328	0.68354	0.61539	0.58757	0.52153	0.44522	0.43899
0	τ	4.667	0.364	0.14	0.072	0.036	0.021	0.013
I		4.927	0.554	0.310	0.222	0.176	0.151	0.143
III								

Clear atmosphere



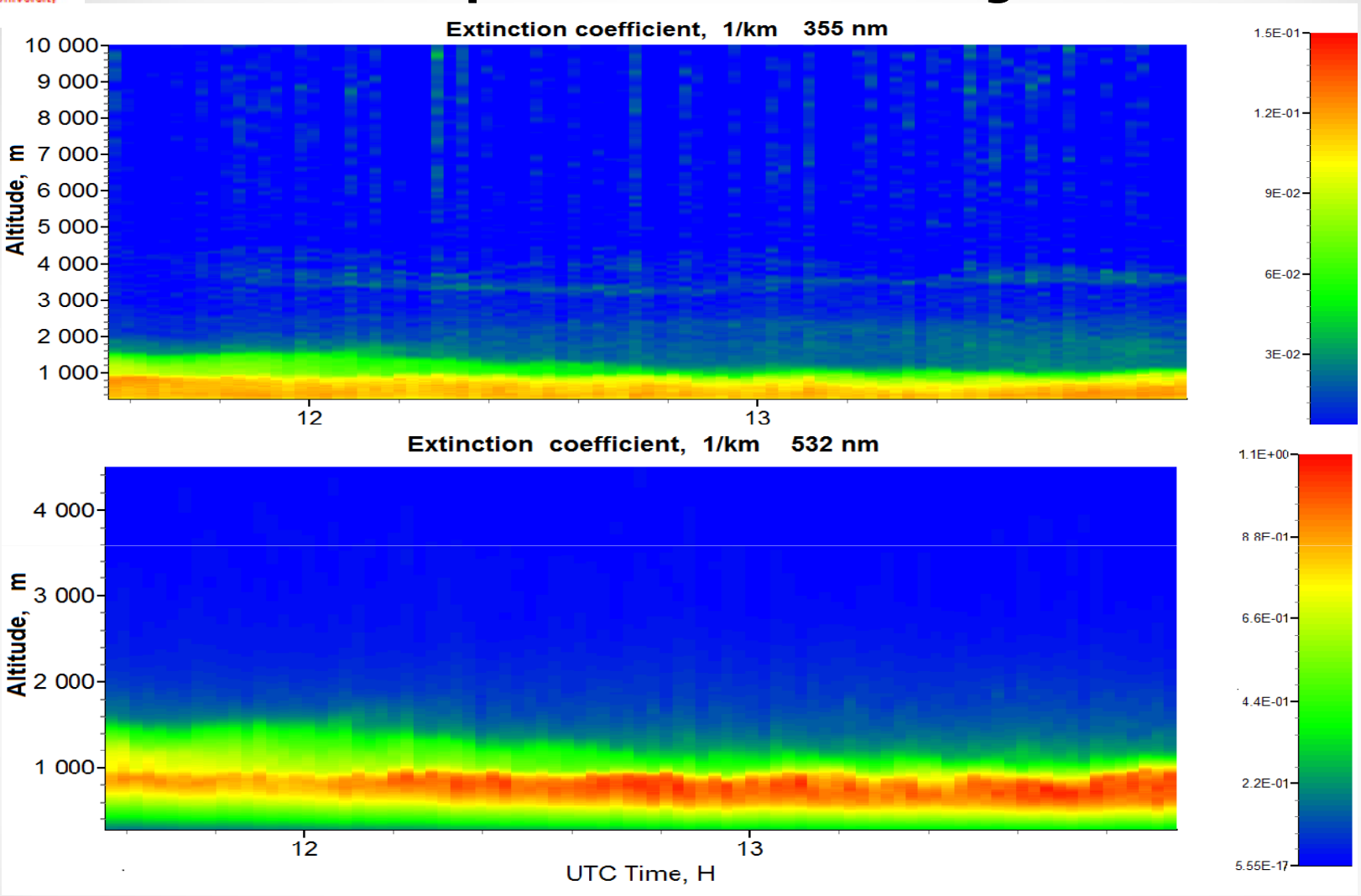


Thin lines –optical thickness of scattering

Thick lines –optical thickness of absorption

Spectral dependence of the single scattering co-albedo for 4 aerosol models

Clear atmosphere. Lidar sounding



Dynamics of the variation of aerosol extinction from lidar observation in SPSU (Donchenko V.K.. Samulenkov D.A.. Melnikova I.N.. Boreysho A.S.. Chugreev A.V. Laser systems of the St.Petersburg State University Resources Center. Possibilities. Problems Statement and the First Results. The contemporary problems of the Earth remote sensing form the Space. Moscow. 2013. Том 10. № 3. p 122-134)

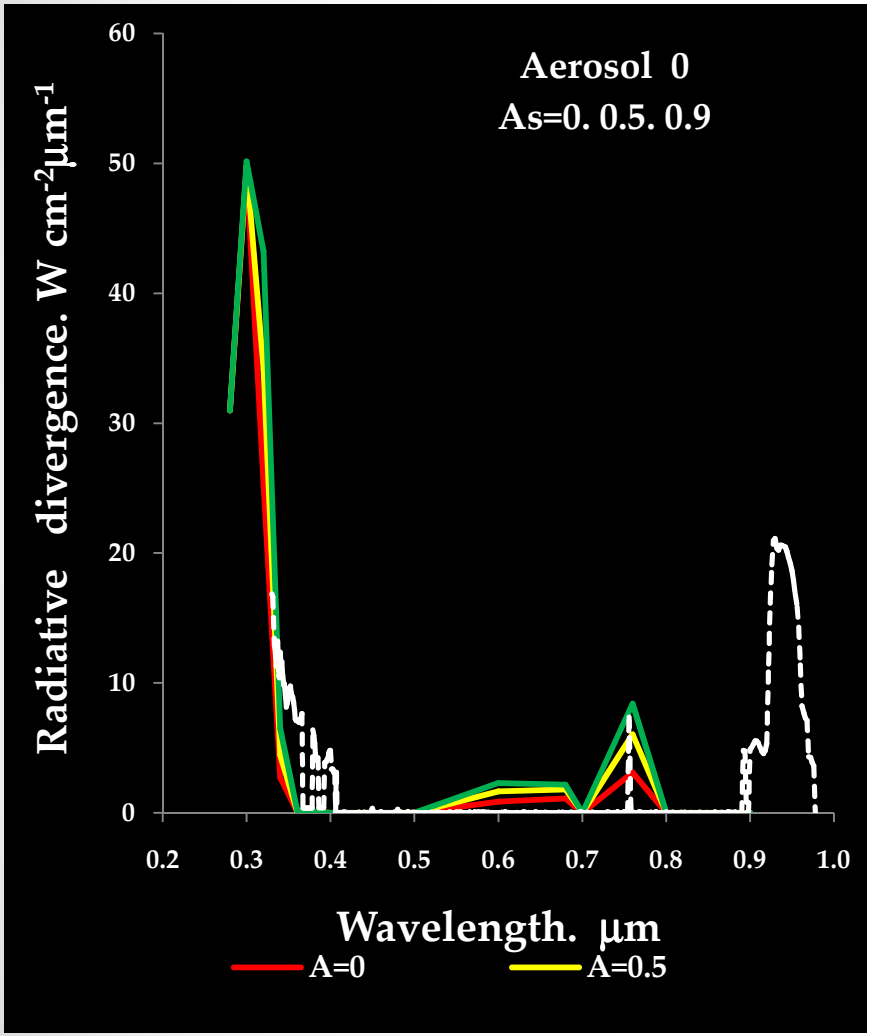
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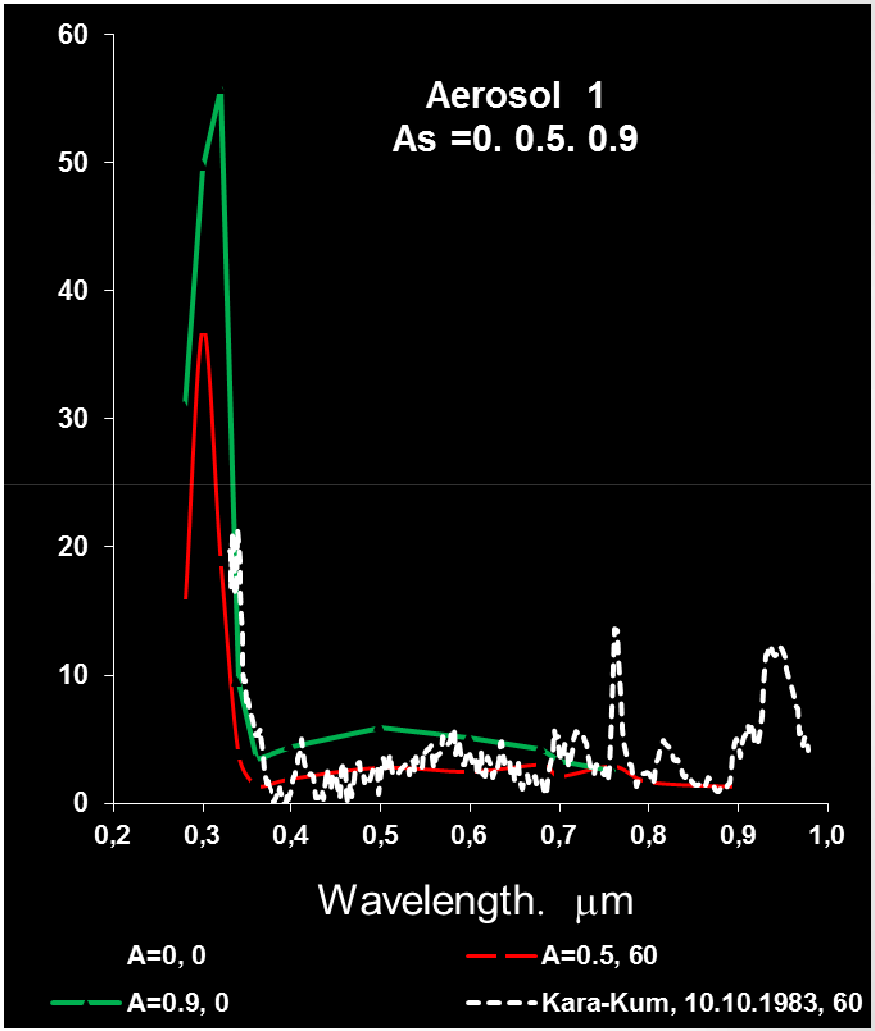
Experimental values of the aerosol optical thickness in St.Petersburg and suburbs

Wavelength. nm Experiment	355	532	700
St. Petersburg city. Lidar sounding	0.136	0.842	
The Ladoga Lake Airborne observations	0.01	0.06	0.15
Peterhoff city. Ground observations	0.03	0.07	0.09

Calculation of radiative characteristics

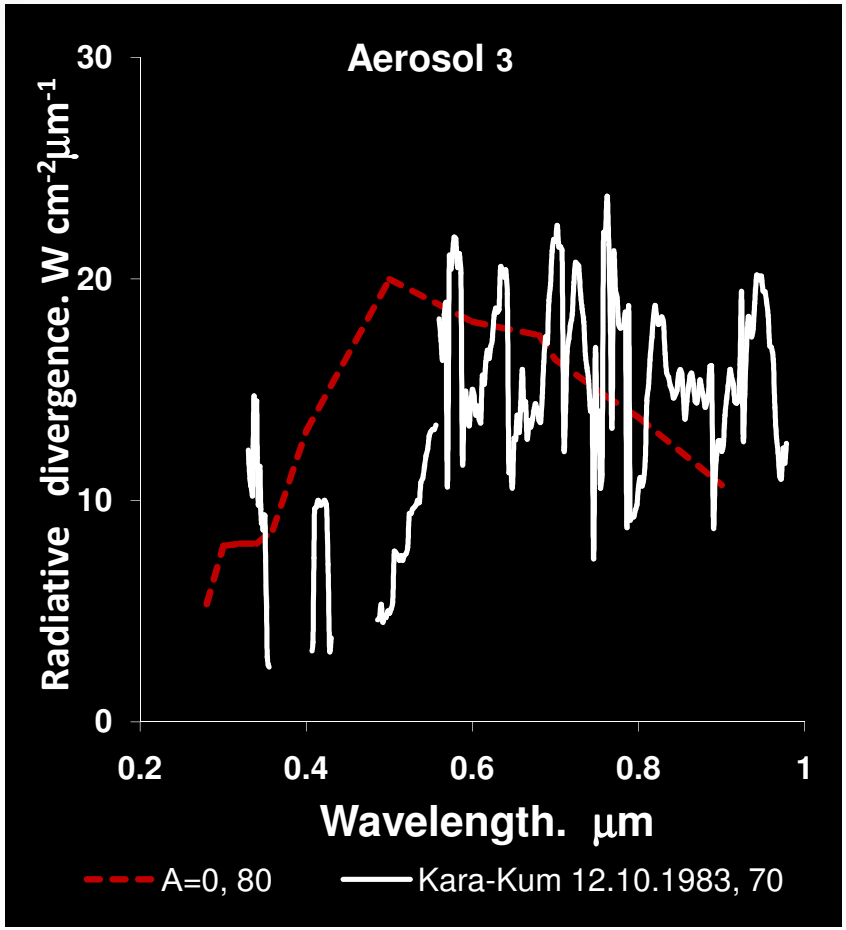
Clear atmosphere. Radiative divergence





Simulation and airborne observation of radiative divergence for models of Aerosol 0 and 1

Clear atmosphere. Radiative divergence (continuation)



Simulation (Aerosol 3) and airborne observation of radiative divergence after the sand storm (Melnikova I.. Vasilyev A. Short-wave solar radiation in the Earth atmosphere. Calculation. Observation. Interpretation. Springer-Verlag. Heidelberg. 2004. 350 p.)

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- CLOUD 1

τ_0= 5 and 10 for all wavelength. added to the scattering optical thickness of the clear atmosphere

- CLOUD 2 2-layer atmosphere :

cloud 1 (in layer 0-1 km) + clear layer above the cloud

The partly scattered light falls to cloud top and cloud spherical albedo is assumed as ground albedo for above - cloud layer

- CLOUD 3

$\tau_0(\lambda)$ - Spectral dependent optical thickness

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OPTICAL PARAMETERS OF THE CLOUD-1 MODEL

	λ. μm	0.30	0.4	0.5	0.6	0.7	0.8	0.9
0	τ_Σ (τ_0=10)	14.667	10.364	10.140	10.117	10.036	10.021	10.013
I		14.927	10.554	10.310	10.287	10.176	10.151	10.143
II	CLOUD 1	15.078	10.680	10.430	10.427	10.296	10.261	10.253
III		15.767	11.264	11.040	11.037	10.836	10.721	10.713
0	ω_0 (τ_0=10)	0.76512	1	1	0.99605	1	1	1
I		0.76854	0.99905	0.99903	0.99222	0.99902	0.99902	0.99901
II	CLOUD 1	0.76887	0.99626	0.99617	0.98945	0.99612	0.99610	0.99610
III		0.75614	0.96449	0.96377	0.95742	0.96309	0.96269	0.96266
0	τ_Σ (τ_0=5)	9.667	5.364	5.140	5.117	5.036	5.021	5.013
I		9.927	5.554	5.310	5.287	5.176	5.151	5.143
II	CLOUD 1	10.078	5.680	5.430	5.427	5.296	5.261	5.253
III		10.767	6.264	6.040	6.037	5.836	5.721	5.713
0	ω_0 (τ_0=5)	0.64363	1	1	0.99218	1	1	1
I		0.65196	0.99820	0.99812	0.98487	0.99807	0.99806	0.99806
II	CLOUD 1	0.65420	0.99296	0.99263	0.97973	0.99245	0.99240	0.99240
III		0.64289	0.93614	0.93378	0.92215	0.93146	0.93008	0.93008

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OPTICAL PARAMETERS IN THE CLEAR ABOVE-CLOUD LAYER ($P_{Z=1KM}$)

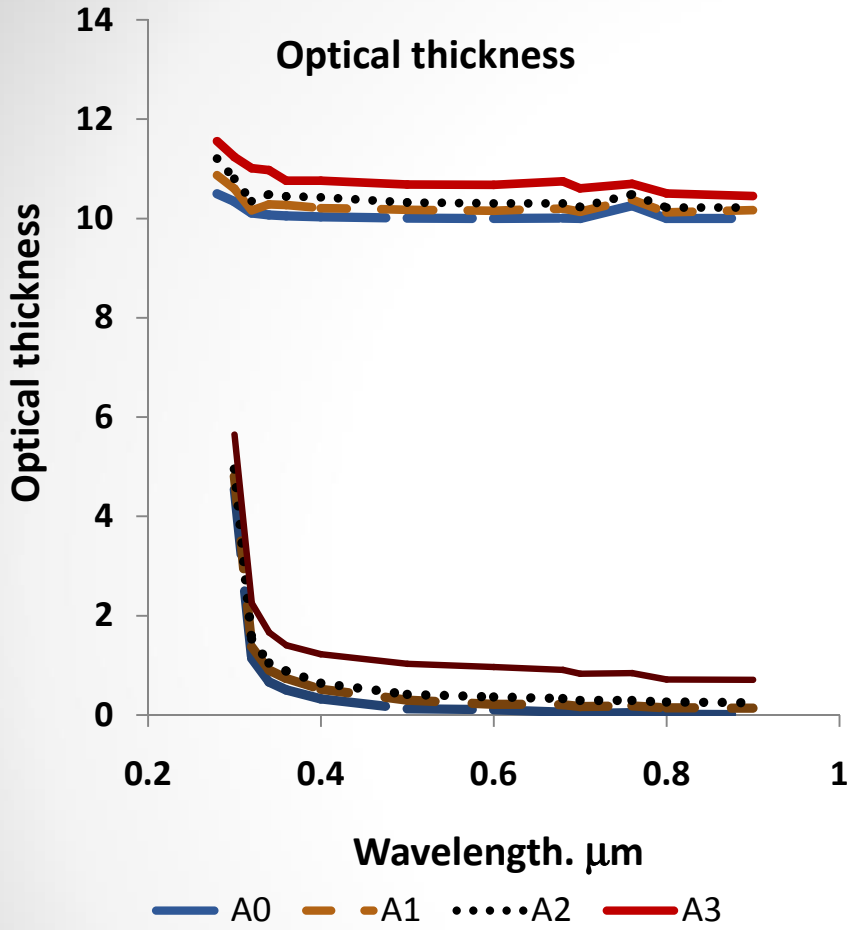
	λ, μm	0.30	0.4	0.5	0.6	0.7	0.8	0.9
0	τ_Σ	4.545	0.328	0.13	0.110	0.032	0.019	0.012
I		4.805	0.518	0.300	0.215	0.172	0.149	0.142
II		4.956	0.644	0.420	0.365	0.292	0.259	0.252
III		5.645	1.228	1.030	0.965	0.832	0.719	0.712
0	ω_0	0.24202	1	1	0.54546	1	1	1
I		0.28097	0.98070	0.96667	0.93023	0.94186	0.93289	0.92958
II		0.29681	0.93789	0.90476	0.84932	0.86301	0.84556	0.84127
III		0.31887	0.67427	0.61165	0.58031	0.51923	0.44367	0.43820

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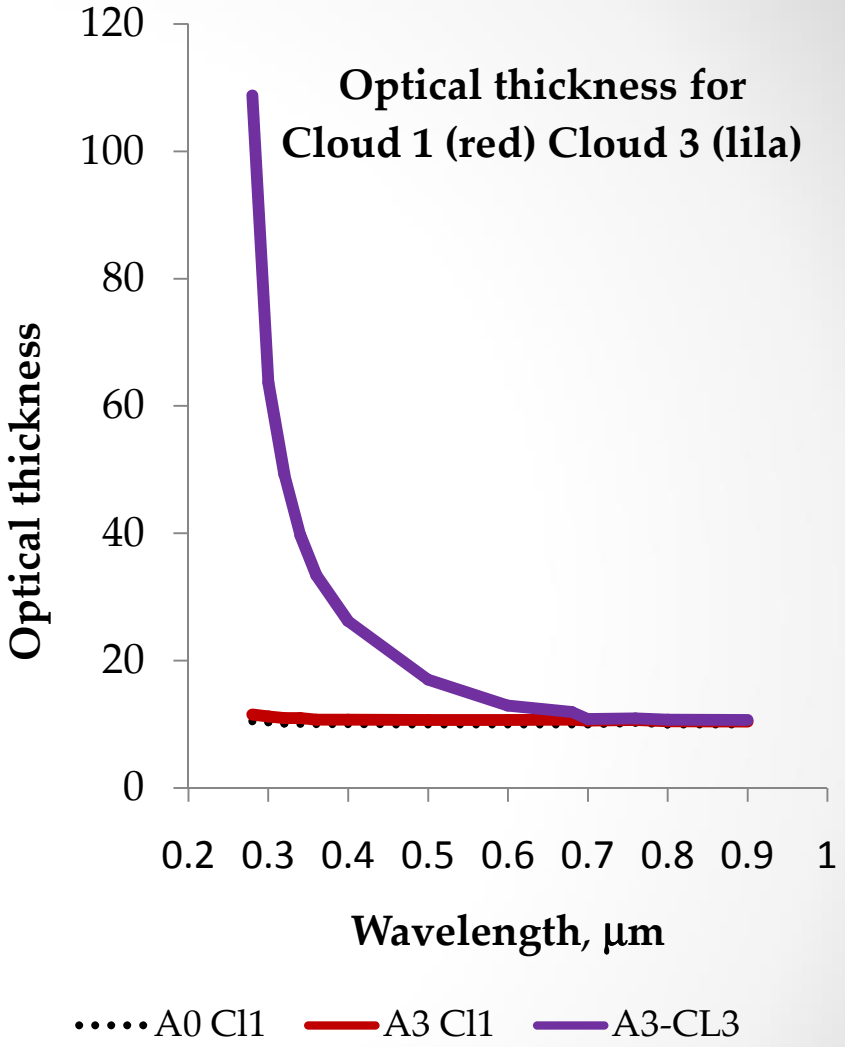
OPTICAL PARAMETERS OF THE CLOUD-3 MODEL

	λ, μm	0.30	0.40	0.50	0.60	0.70	0.80	0.90
τ_{scatt}	τ_0	58	25	16	12	10	10	10
Rel scatt	$\tau_{(z>0)}$	1.222	0.364	0.140	0.067	0.036	0.021	0.013
0	τ_Σ	62.667	25.364	16.140	12.072	10.036	10.021	10.013
I		62.805	25.518	16.300	12.210	10.172	10.149	10.142
II		62.956	25.644	16.420	12.350	10.292	10.259	10.252
III		63.645	26.228	17.030	12.96	10.832	10.719	10.712
0	ω_0	0.945027	1	1	0.99959	1	1	1
I		0.944988	0.999608	0.99939	0.99918	0.99902	0.99902	0.99901
II		0.944644	0.998440	0.99756	0.99676	0.99611	0.99610	0.99610
III		0.939590	0.984749	0.97651	0.96914	0.96307	0.96268	0.96266

Cloudy atmosphere

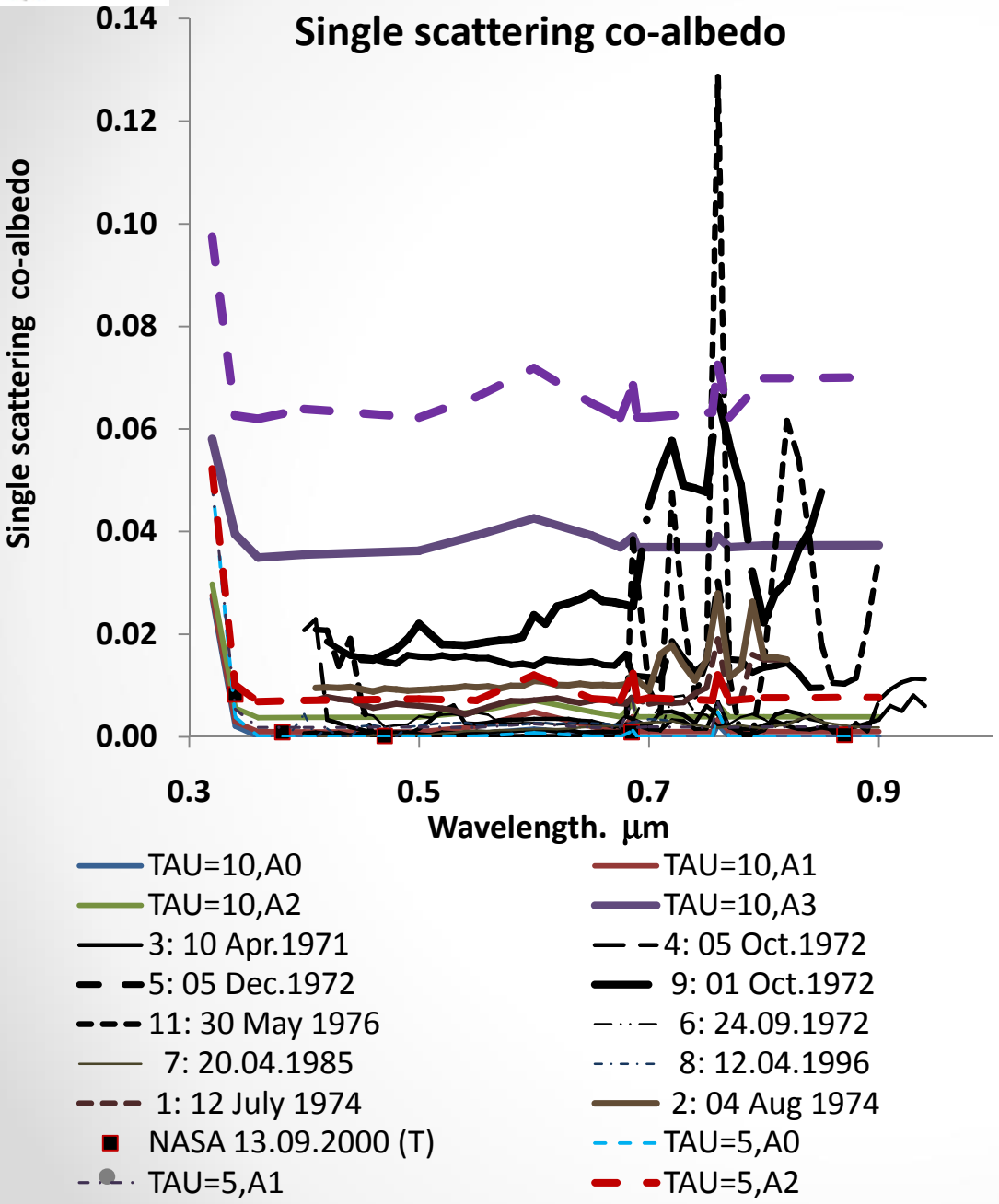


Optical thickness of Cloud-1 model (τ_0=10) (upper group of curves) and above-cloud atmosphere (lower group of curves) for 4 Aerosol models



Optical thickness of Cloud-1 and Cloud 3 models

Cloudy atmosphere (continuation)



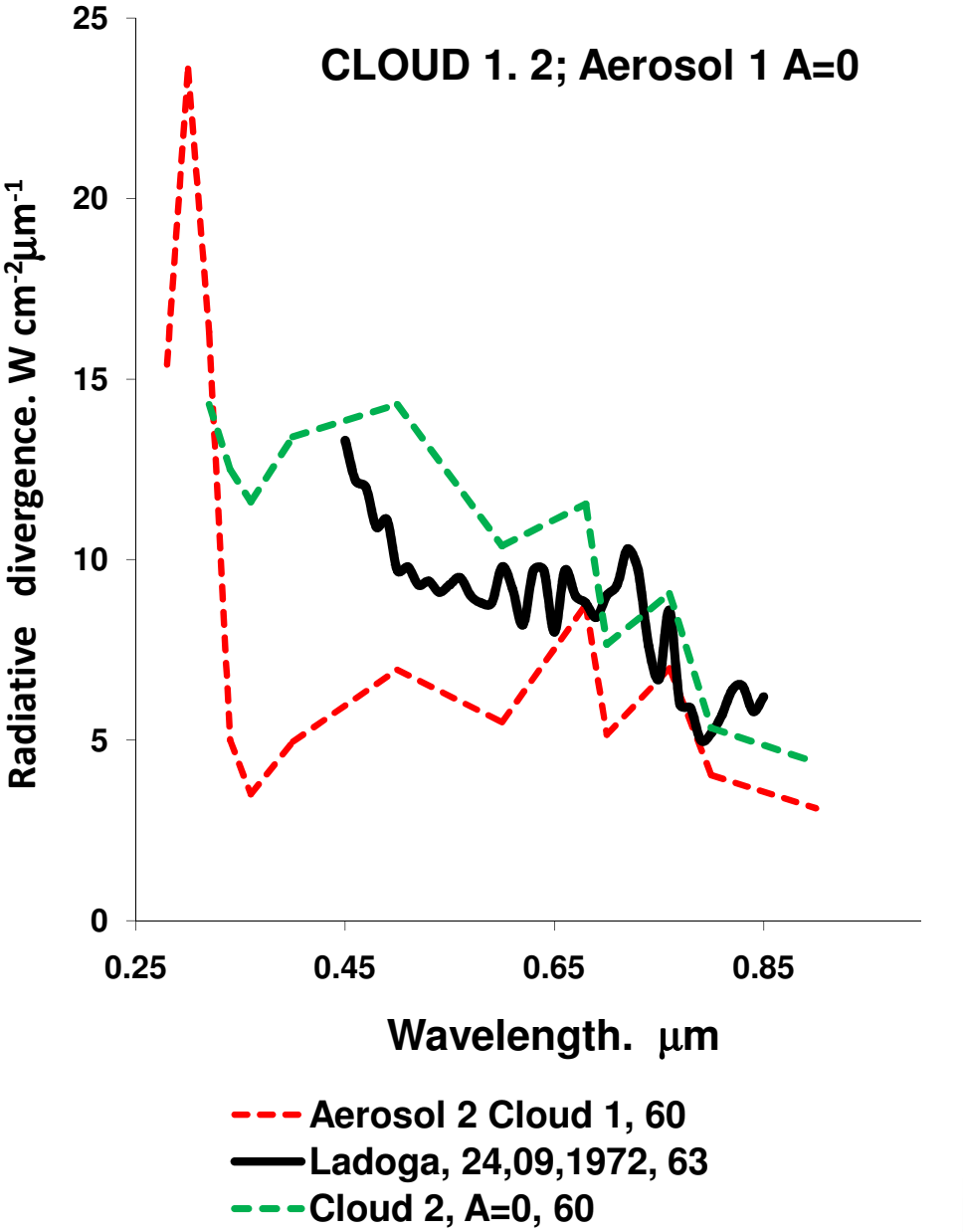
Single scattering co-albedo for 4 aerosol models and Cloud-1 model with optical thickness 5 and 10

and

experimental data from

(Melnikova I. Vasilyev A. Short-wave solar radiation in the Earth atmosphere. Calculation. Observation. Interpretation. Springer-Verlag. Heidelberg. 2004. 350 p.)

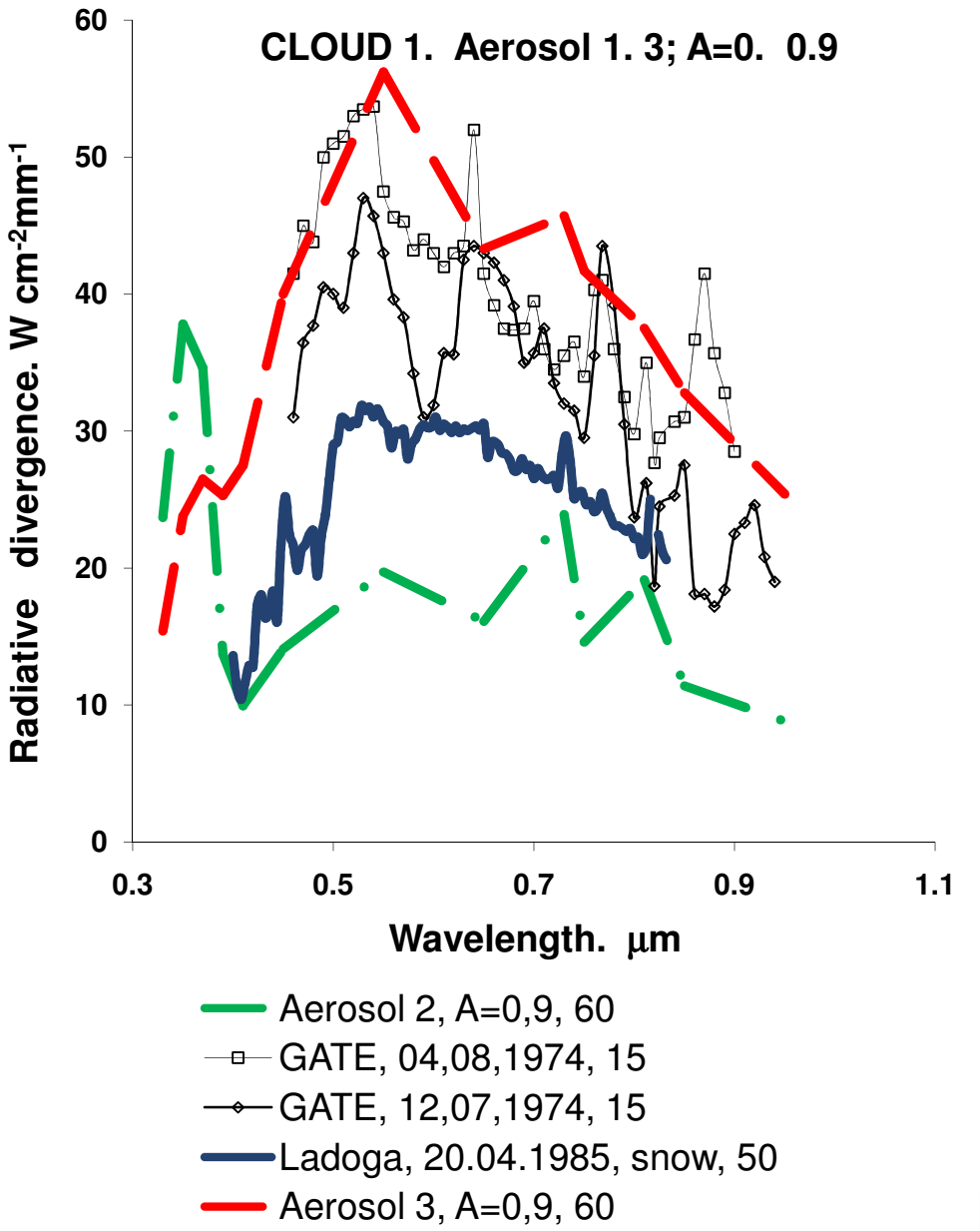
Cloudy atmosphere. Radiative divergence



Simulation for Aerosol 1. Cloud 1 (red) and 2 (green) models and results of airborne observation of the radiative divergence above the Ladoga Lake

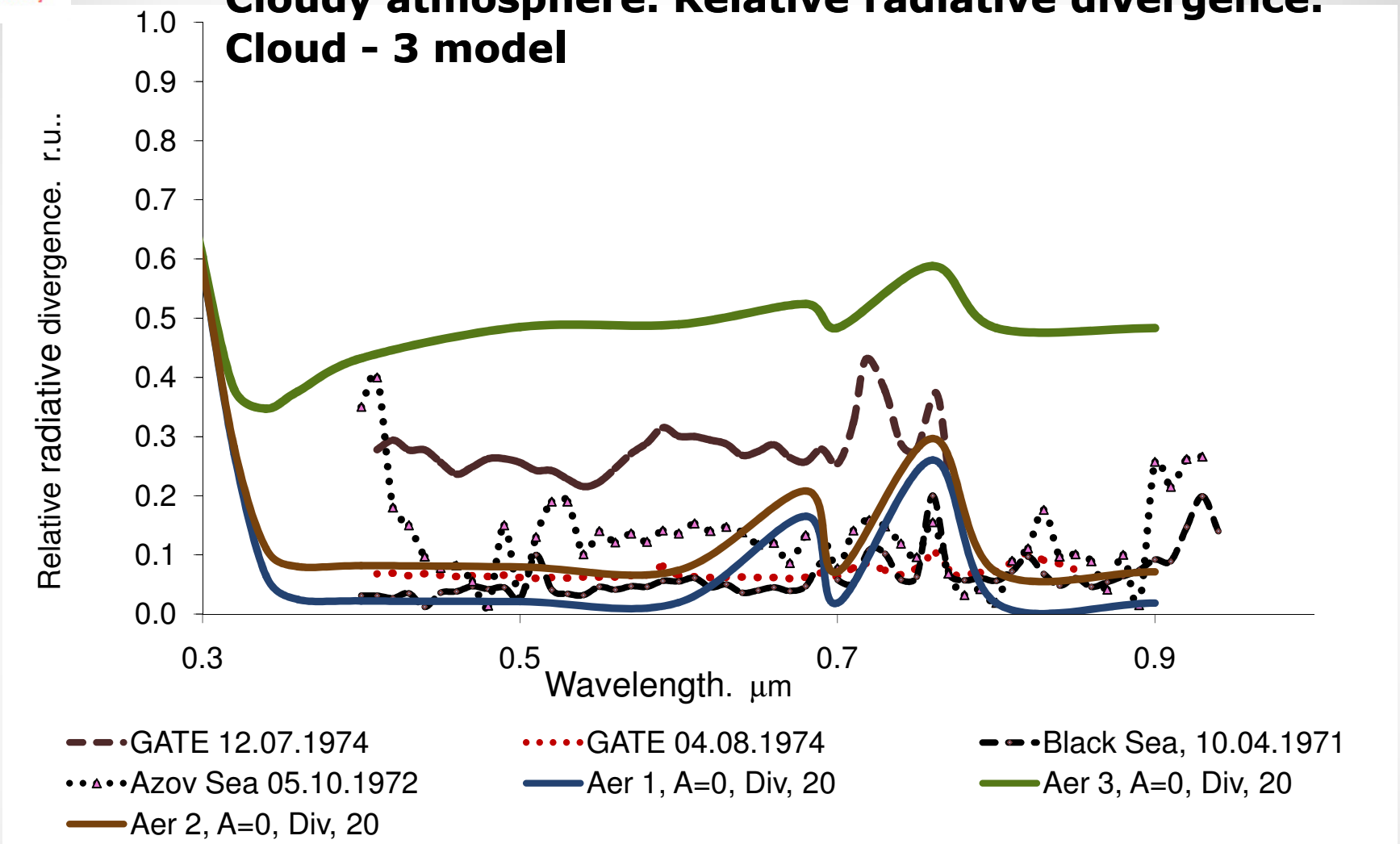
(Melnikova I.. Vasilyev A. Short-wave solar radiation in the Earth atmosphere. Calculation. Observation. Interpretation. Springer-Verlag. Heidelberg. 2004. 350 p.)

Cloudy atmosphere. Radiative divergence (continuation)



Simulation for Aerosol 1 and 3).
Cloud 1 model
and results of
airborne observations of radiative divergence after the sand storm (Sakhara dust) above the Atlantic Ocean and
in clean atmosphere above the Ladoga Lake

(Melnikova I.. Vasilyev A. Short-wave solar radiation in the Earth atmosphere. Calculation Observation. Interpretation. Springer-Verlag. Heidelberg. 2004. 350 p.)



Simulation (Aerosol 1.2 and 3) for Cloud 3 model and airborne observation of relative radiative divergence in cloudy atmosphere

(Melnikova I.. Vasilyev A. Short-wave solar radiation in the Earth atmosphere. Calculation. Observation. Interpretation. Springer-Verlag. Heidelberg. 2004. 350 p.)

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Local instantaneous radiative forcing (variations of the net flux at the troposphere top)

	Clear atmosphere		Cloud 1 (Smoothed cloud)			Cloud 2 (2-layer atmosphere)		
	$(1-F^{\uparrow})$	forsing Aerosol	$(1-F^{\uparrow})$	forsing Aerosol	forsing cloud	$(1-F^{\uparrow})$	forsing Aerosol	forsing cloud
Aer=0	0.761	0.0	0.4843	0.0	-0.2767	0.7743	0.0	+0.0133
W/m²					-50.152			+2.41
Aer=1	0.758	-0.0024	0.4831	-0.0012	-0.2755	0.534	-0.2403	-0.2246
W/m²	6	-0.435		-0.2175	-49.93		-43.55	-40.71
Aer=2	0.768	+0.0065	0.492	+0.0077	-0.2755	0.5804	-0.1949	-0.1835
W/m²		+1.178		+1.396	-49.93		-35.14	-33.26
Aer=3	0.863	0.1021	0.6788	+0.1945	-0.1843	0.8219	+0.0476	-0.0412
W/m²		+18.5		+35.25	-33.40		+8.628	-7.468

$$f_{aeros}=[(1-F^{\uparrow})_{Aer\,0} - (1-F^{\uparrow})]F_0^{\downarrow}$$

$$f_{cloud}= [(1-F^{\uparrow})_{clear} -(1-F^{\uparrow})]F_0^{\downarrow}$$

Estimating the heating rate of the atmospheric layer

in the shortwave range $\left(\frac{dT}{dt}\right)_p = \frac{S_\lambda}{rC_p}\frac{dR}{dz}$

S_λ = 1000 J/(s m^2) - the solar constant in shortwave range (0.3–1.0 μm);

r = 1 kg/m^3 - the air density at the level 800 mb;

C_p = 1005 J/(kg deg) - the specific heat of the dry air in clear atmosphere

C_p = 1952 J/(kg deg) - the specific heat of water vapor at constant pressure;

C_p = 4218 J/(kg deg) - the specific heat of liquid water at 0 °C;

The average value C_p = 2392 J/(kg deg) in clouds.

Model	dT/dt. degree / day			
	CLEAR		CLOUD	
A_S	0	0.9	0	0.9
Aerosol 1	2.7	3.0	2.7	2.9
Aerosol 3	12.3	24.5	5.6	8.3

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CONCLUSIONS:

1.Lidar sounding in the Research Park of SPSU provides the construction of adequate optical models of the atmosphere

2.The simplest optical model provides suitable results of radiative characteristics calculation that shows an acceptable accordance with airborne observation

3.These model allows clearly demonstrate influence of chosen optical parameter on radiative characteristics.

4.The presence of aerosols in the atmosphere greatly affects the optical and radiative properties of clouds

5.Even the simple models confirm that simulation of the atmosphere optical and radiative characteristics should accurate account for atmospheric pollution and correct forecast of global environmental changes

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Research Park (100 MEuros, 2010-2012)

Nanotechnology and Material Science
10 resource centers

Biomedicine and Human Health
6 resource centers



21 resource centers

Ecology and Rational Nature Management
3 resource centers

Information Systems and Technology
2 resource centers

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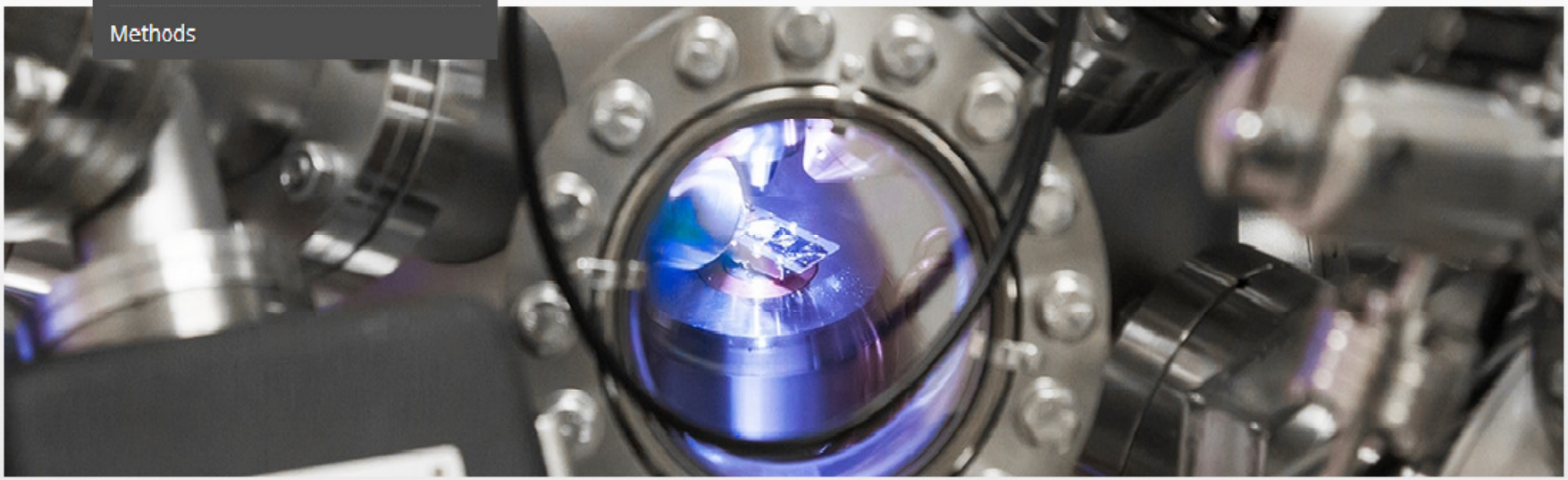
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Thanks for your attention

