Radiative transfer models in the internet-accessible information-computational system “Atmospheric radiation”

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Codes for modeling of the shortwave atmospheric radiative transfer

RAPRAD [Kato et al], RRTM_SW [Clough et al,], MODTRAN4.9 [Anderson et al,], SMARTS[Gueymard C.], SBDART[Ricchiazzi et al], SBMOD [Yang et al]

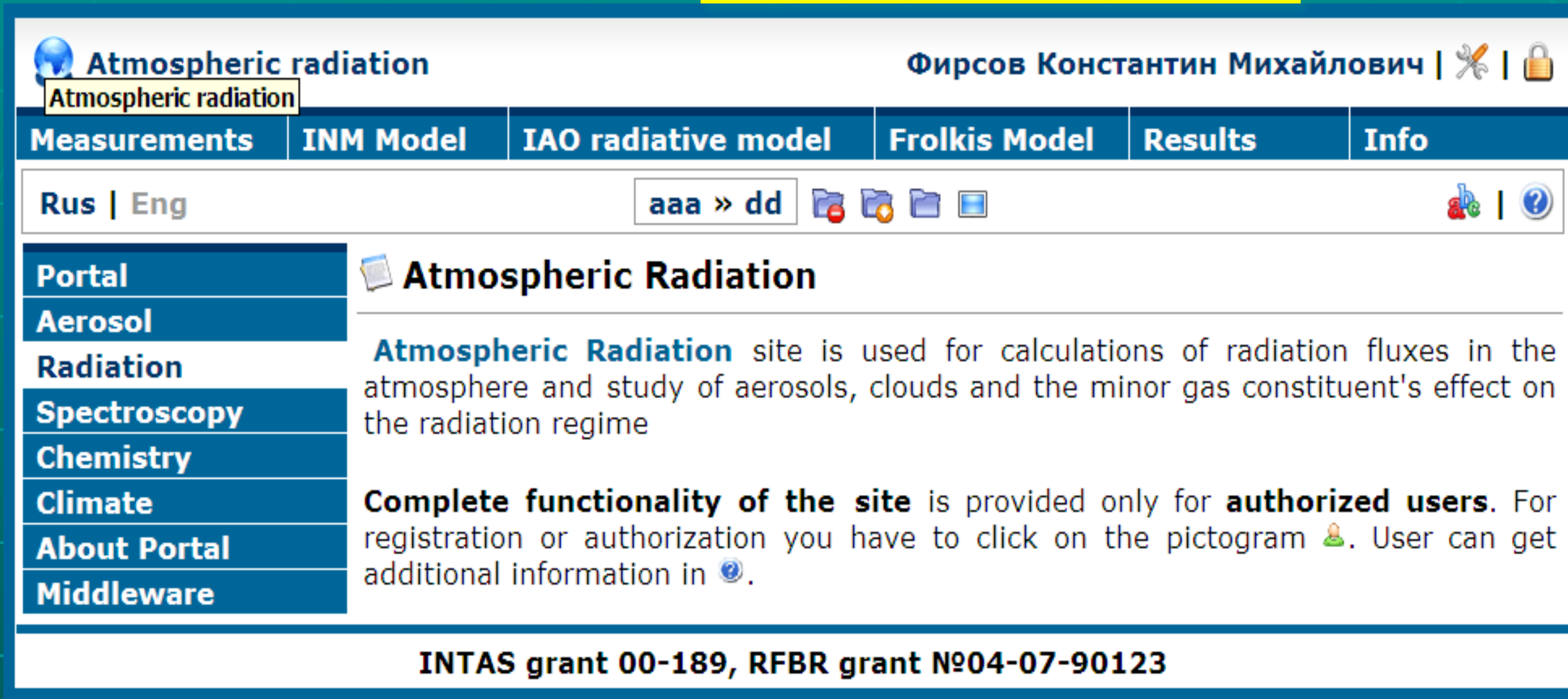
Max. difference between calculated downward SW fluxes >19 W/m^2

[Michalsky J.J., Anderson G.P., Barnard J et al.// J. Geophys. Res. 2006. V. 111.]

Spectroscopic databanks of absorption lines of the atmospheric gases

1. **HITRAN** [http://cfa-www.harvard.edu/hitran/]
2. **GEISA** [Jacquinet-Husson et al.]
3. **BT2** (H_2O lines) [Barber R.J., Tennyson J., et al]
4. **PS** (H_2O lines) [H. Partridge and D.W. Schwenke]

Internet-accessible system «Atmospheric Radiation» in the IAO site: http://atrad.atmos.iao.ru/



Servers:

- **Institute of Atmospheric Optics SB RAS (Tomsk)** http://atrad.atmos.iao.ru
- **Ural State University (Ekaterinburg)** http://atmos.physics.usu.ru
- **Volgograd State University (Volgograd)**
- http://atmos.volsu.ru

Longwave radiative transfer

$$F^{\uparrow}(z) = \int_0^{\infty} \pi B_\nu(z_0) T_\nu^f(z,z_0)\,d\nu + \int_0^{\infty}\int_0^{z} \pi B_\nu(z') \frac{dT_\nu^f(z,z')}{dz'}\,dz'\,d\nu$$

$$F^{\downarrow}(z) = \int_0^{\infty}\int_z^{\infty} \pi B_\nu(z') \frac{dT_\nu^f(z,z')}{dz'}\,dz'\,d\nu$$

$$\tau(z,z') = \int_z^{z'} K\big(\nu, p(h), \mathrm{t}(h)\big)\rho(h)\,dh$$

F(z) – radiative flux at the altitude *z;* *τ(ν,z,z')*- optical depth at wavenumber ν ; *ρ (h)* – gas concentration; p(h) -pressure, t(h)- temperature, μ- zenith angle cosinus

Shortwave radiative transfer

$$\mu \frac{\partial I(\tau,\mu,\varphi)}{\partial \tau} = I(\tau,\mu,\varphi) - \varpi(\tau)/4\pi \int_0^{2\pi} d\varphi' \int_0^{1} d\mu' f(\tau,\mu,\varphi,\mu',\varphi') I(\tau,\mu',\varphi')$$

$$I = \sum_{i=1}^{N} C_i I_i$$

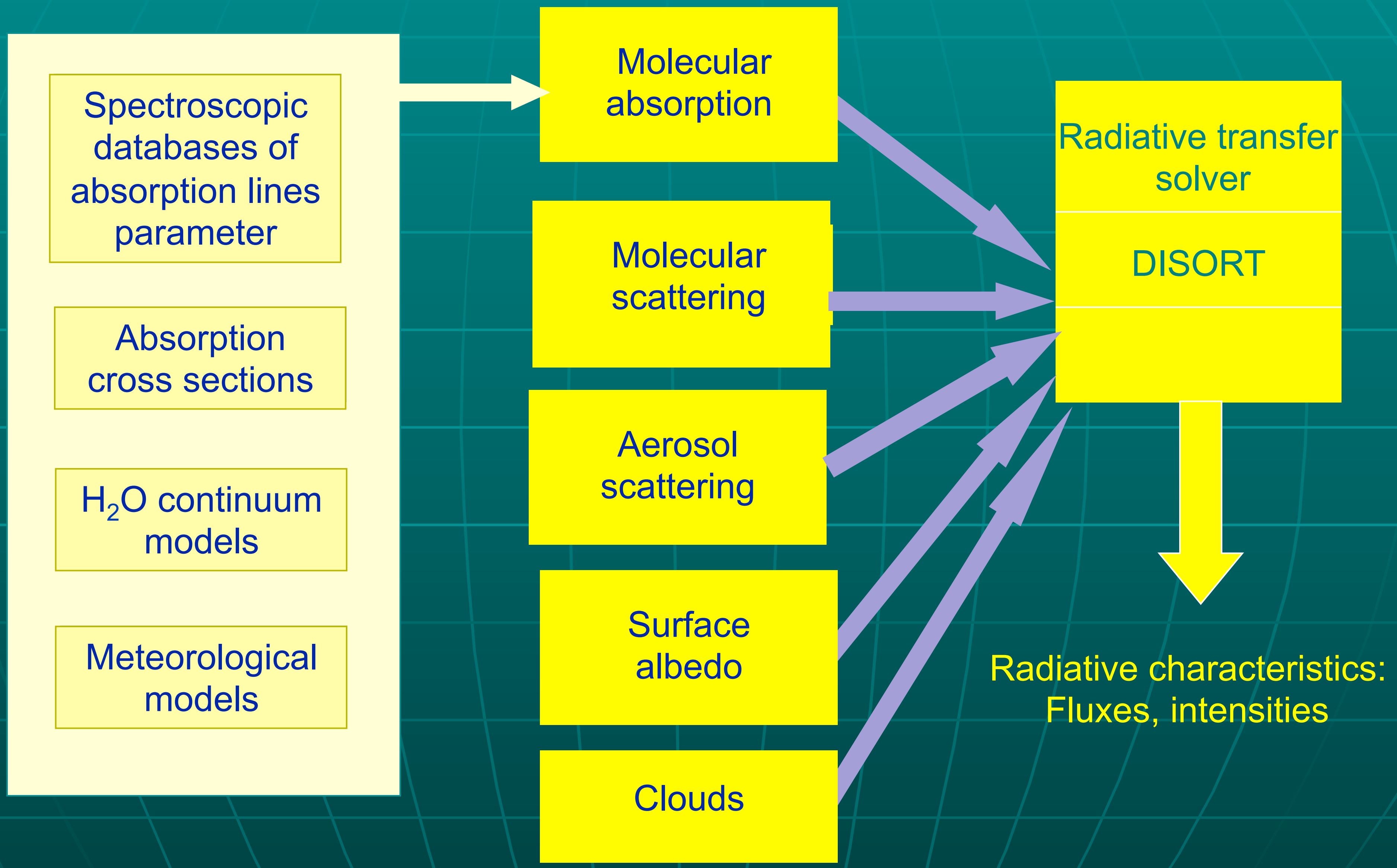
Frolkis Model

- two stream approximation for 17 spectral intervals in 4,43-1000 mkm (10-2260 cm^{-1}) spectral region
- aerosols and H_2O, CO_2, O_3, CH_4 ,N_2O, O_2 absorption
- 3-parametric approximation of Curtis-Godson for atmospheric pressure and temperature inhomogeneity

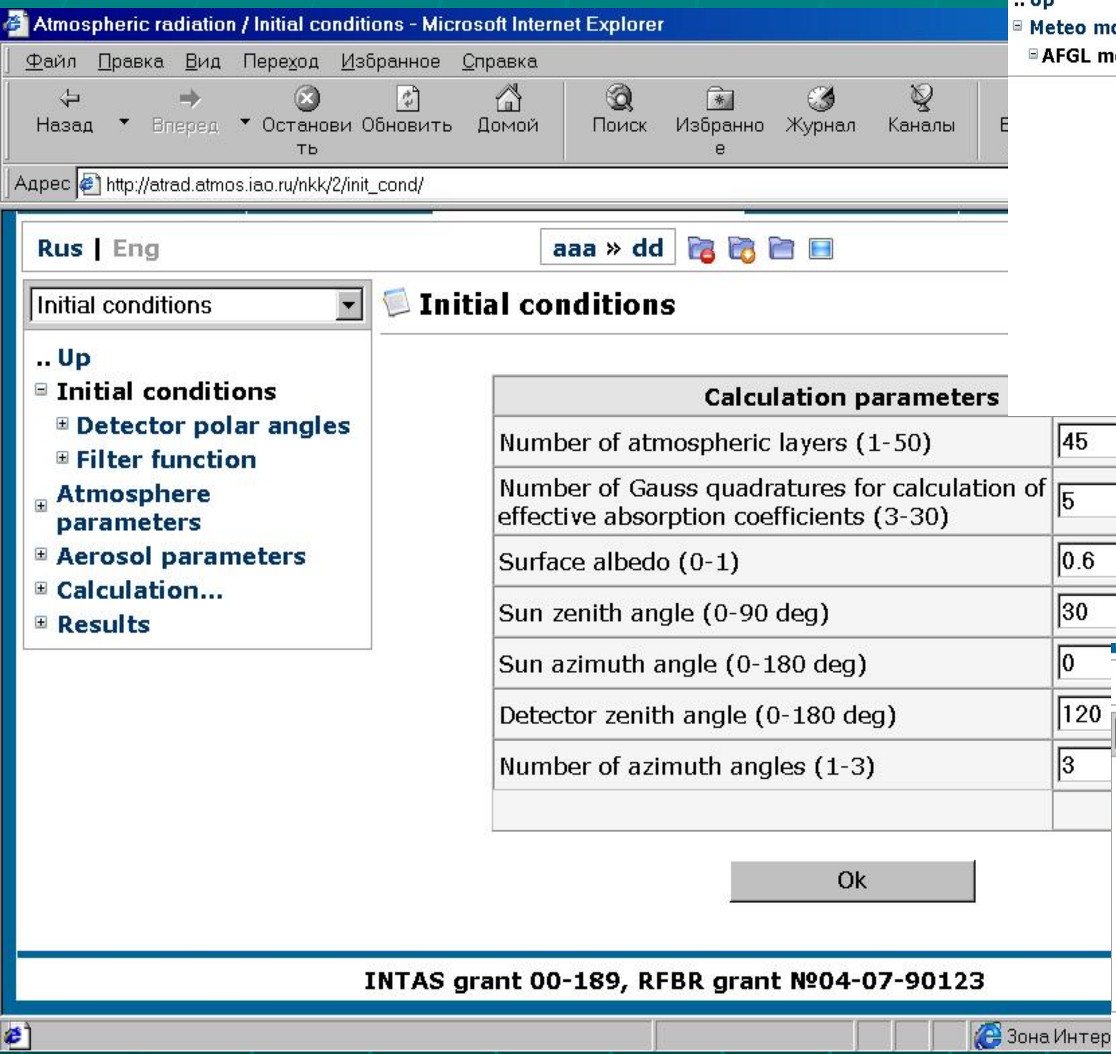
INM Model

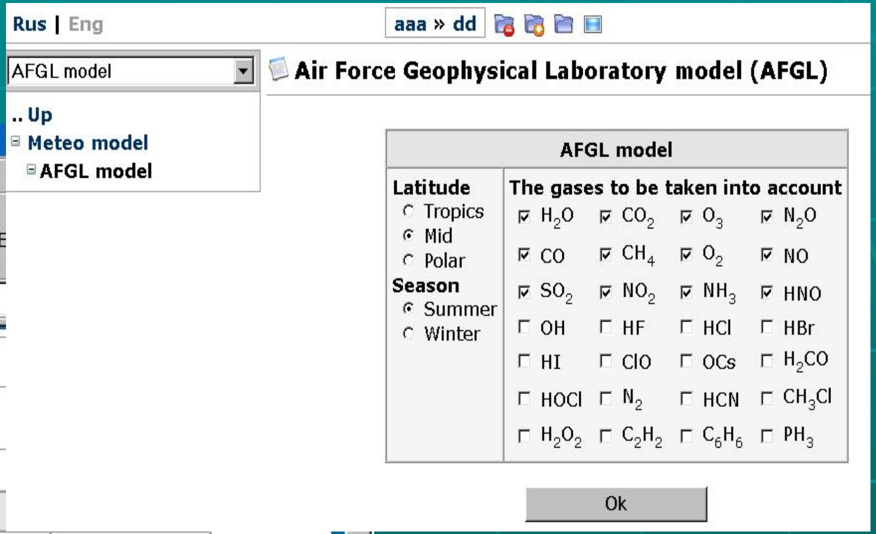
- H_2O, CO_2, O_3, CH_4, N_2O, O_2 absorption, aerosol, clouds
- Longwave (thermal) spectrum is divided into 10 spectral bands
- shortwave (solar) spectrum – 18 bands
- height of the upper boundary layer - 50 km,
- the number of the atmosphere vertical levels -20-30
- Parameterization of H_2O, CO_2 absorption by k-distribution method,
- ozone by 2-parametric approximation of Curtis-Godson

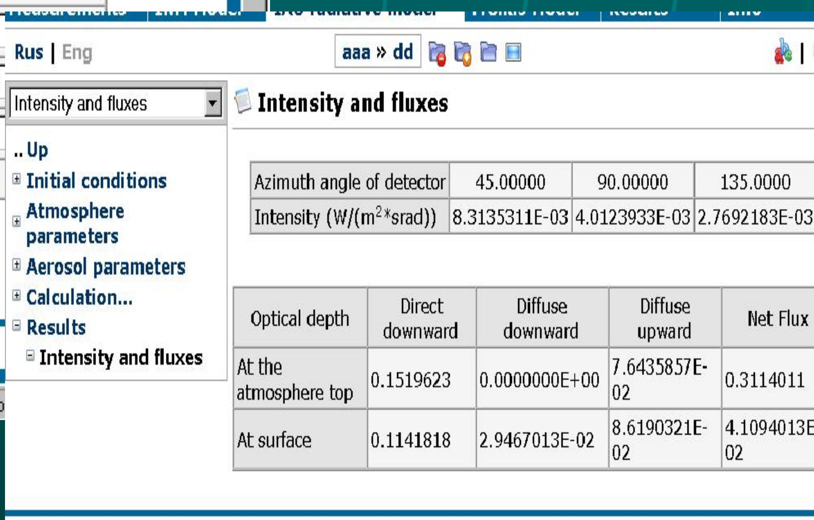
IAO radiative model in the internet system «Atmospheric Radiation»



Interface of the Internet-accessible system «Atmospheric Radiation»







Spectroscopic databases of absorption lines parameters

Spectral interval, cm^{-1}	Number of H_2O (16) lines in the databank			
	BT2	PS	HITRAN 2004	HITRAN 2008
9000-10000	20825195	10675	554	613
10000-11000	17774321	18654	2742	2540
11000-12000	15010019	10862	711	1151
12000-13000	12588904	12866	1031	1614
13000-14000	10480937	15622	1720	1903
14000-15000	8588504	12284	1528	1244
15000-16000	6977227	12835	1516	1647
16000-17000	5606762	11689	1118	1248
17000-18000	4423476	12502	1061	1160
18000-19000	3430768	11053	712	757
19000-20000	2613454	9647	704	767
9000-20000	**108319567**	**138689**	**13397**	**14644**

HITRAN Database Format

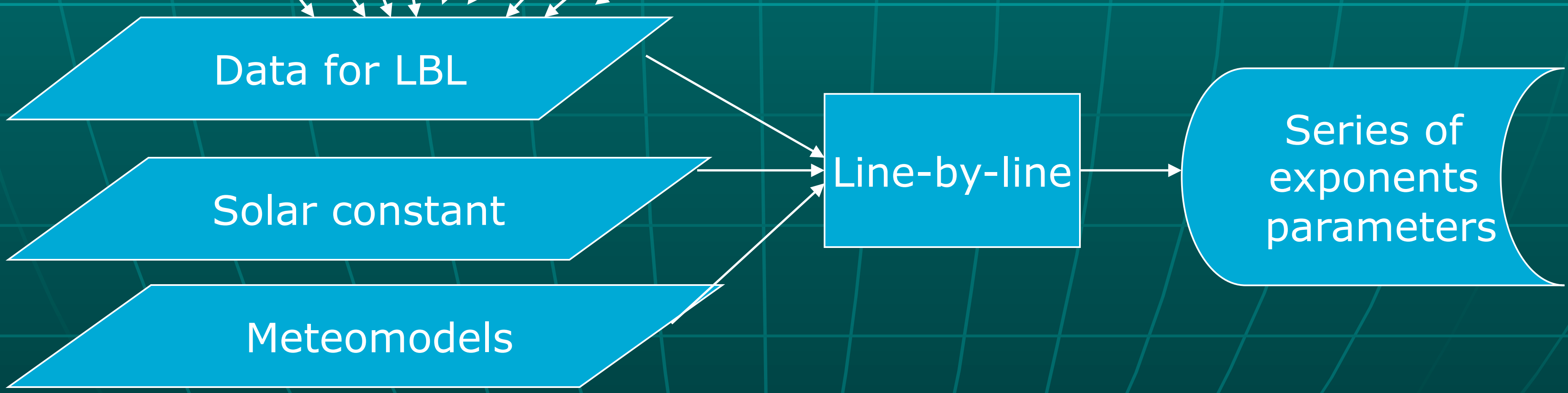
Format for HITRAN Parameters, 1986 though 2001

Parameter	Molecule number	Isotopologue number	Transition frequency (cm^{-1})	Line Intensity	$\|R\|^2$	Air-broadened width	Self-broadened width	lower-state Energy	Temperature dependence (of air width)	Pressure shift	upper vibrational quanta	lower vibrational quanta	upper local quanta	lower local quanta	Error codes	Reference codes
Field Length	2	1	12	10	10	5	5	10	4	8	3	3	9	9	3	6

New Format for HITRAN Parameters, Editions after 2001

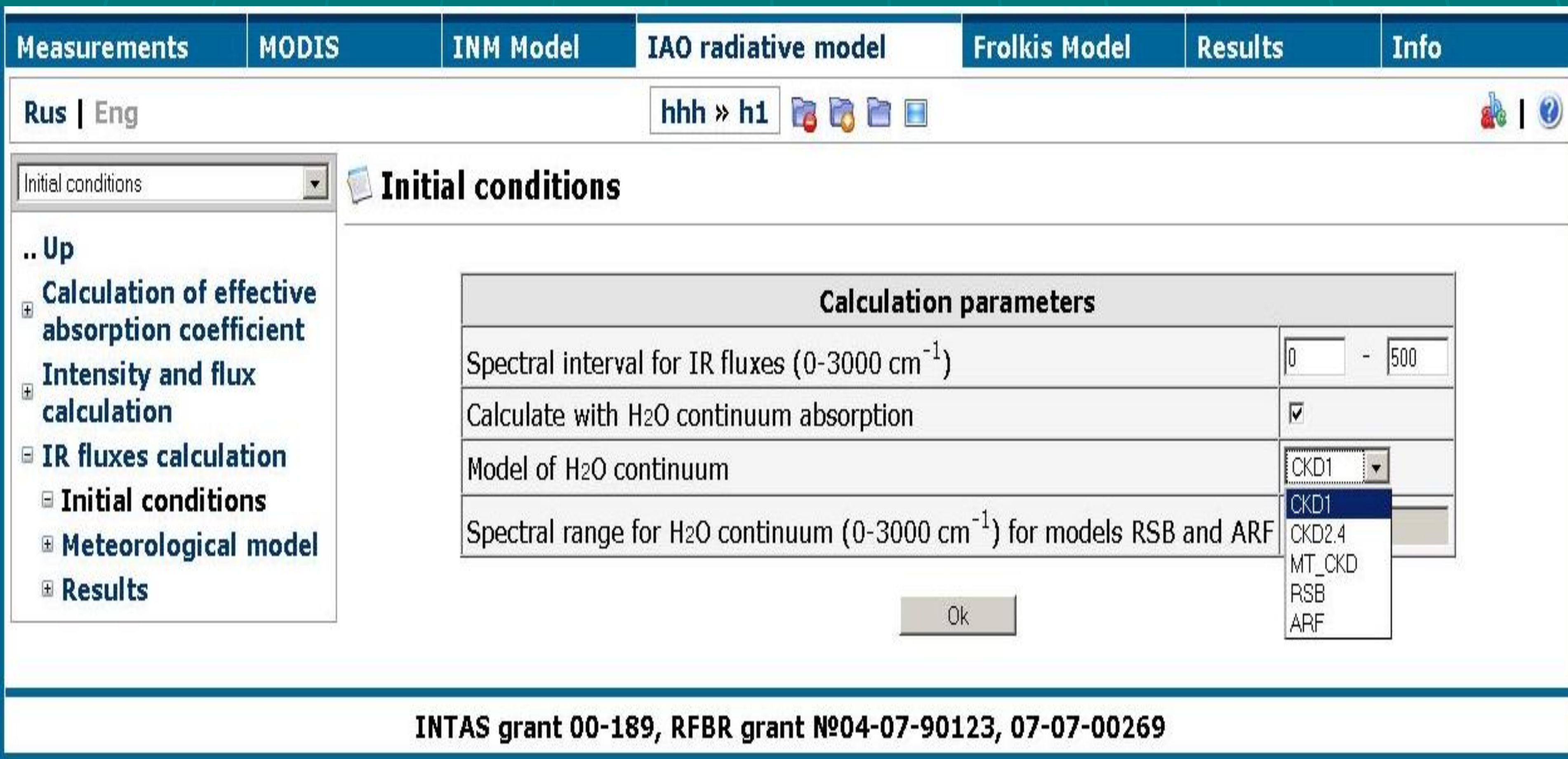
Parameter	Molecule number	Isotopologue number	Transition frequency (cm^{-1})	Line Intensity	Einstein-A coefficient	Air-broadened width	Self-broadened width	lower-state Energy	Temperature dependence (of air width)	Pressure shift	upper vibrational quanta	lower vibrational quanta	upper local quanta	lower local quanta	Error codes	Reference codes	Flag for line-mixing	upper statistical weight	lower statistical weight
Field Length	2	1	12	10	10	5	5	10	4	8	15	15	15	15	6	12	1	7	7
FORTRAN descriptor	I2	I1	F12.6	1PE10.3	E10.3	0PF5.4	F5.4	1PF10.4	0PF4.2	F8.6	A15	A15	A15	A15	6I1	6I2	A1	F7.1	F7.1

Calculation of effective absorption coefficients



H_2O continuum models

- -RSB (Robertc et al, 1976)
- -ARF (Arefiev, 1990)
- -CKD1 (Clough et al, 1989)
- -CKD2.4 (Mlawer et al, 1998)
- -MTCKD (Clough et al, 2003, 2007)



Longwave fluxes on different atmospheric heights with H_2O, CO_2, O_3, N_2O, CH_4 absorption and different H_2O continuum models in 0-3000 cm^{-1} spectral region. MLS

Z, км	H_2O continuum models				
	CKD2.4	RSB	ARF	CKD1	MT_CKD
	Upward fluxes, W/m^2				
5	347.342	348.581	348.918	346.753	347.160
10	298.688	301.030	301.590	297.269	298.465
90	281.265	284.035	284.603	279.814	281.173
	Downward fluxes, W/m^2				
0	350.505	349.317	348.573	350.110	350.918
5	161.377	155.689	155.331	164.078	162.105
10	53.193	50.888	50.867	54.305	52.776

Difference 4-5 W/m^2 (downward fluxes)

Algorithm to calculate the broadband atmospheric radiative transfer (IAO radiative model)

$$I_{\Delta\lambda} = \sum_{i=1}^{N} C_i Q_i$$

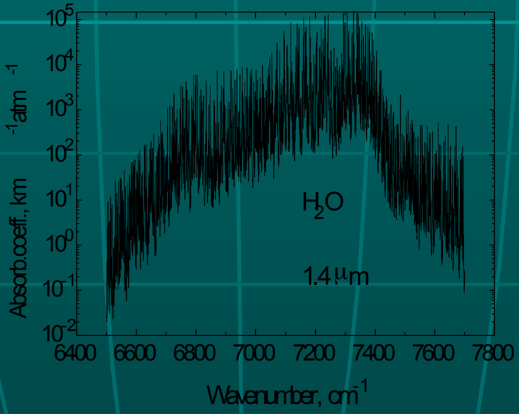
Q_i is the monochromatic radiative characteristic (brightness, flux) at the cumulative wavelength g_i ($i=1,\ldots,N$; N~5-10)

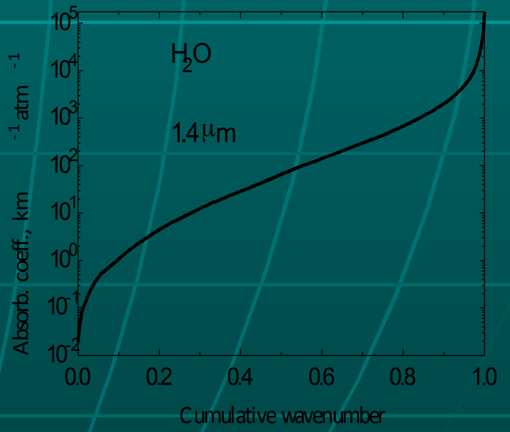
Calculation stages:

1. Altitude profile of absorption coefficients $K(\lambda,h)$ by line-by-line method from HITRAN with high resolution;
2. Effective absorption coefficients $K(g_i,h)$ at the cumulative wavelengths g_i taking into account Sun radiation $S(\lambda)$ and filter function $F(\lambda)$

$$g(k,h) = \int_{\lambda_1}^{\lambda_2} F(\lambda)S(\lambda)U(\lambda)d\lambda$$

$$U(\lambda) = \begin{cases} 1, & K(\lambda,h) < k \\ 0, & K(\lambda,h) > k \end{cases}$$





3. Solving the radiative transfer equation at each wavelength g_i by DISORT

Longwave fluxes in 0-3000 cm^{-1} spectral region for CCMVAL meteomodel

Meteomodel	*Z*, km	Upward flux , W/m^2			Downward flux , W/m^2		
		LBL [Fomin*]	k-distribution	Difference,%	LBL [Fomin*]	k-distribution	Difference,%
A_1	100	176.8	177.66	-0,486	0	0	0
	0	212.4	212.45	-0,024	140.7	141.82	-0,796
A_2	100	220.7	221.40	-0,317	0	0	0
	0	298.9	299.14	-0,080	214.01	214.67	-0,308
A_3	100	278.9	279.69	-0,283	0	0	0
	0	456.88	456.78	0,022	402.96	404.71	-0,435
B_1	100	176.62	177.44	-0,464	0	0	0
	0	212.47	212.45	0,009	141.20	142.23	-0,729
B_2	100	220.34	221.06	-0,327	0	0	0
	0	298.95	299.14	-0,064	214.48	215.08	-0,280
B_3	100	278.37	279.18	-0,291	0	0	0
	0	456.88	456.78	0,022	403.12	404.85	-0,429

*A*1- *A*3: CO_2 -338 *ppm (1986)*, *B*1- *B*3: CO_2 -380 *ppm* (2005)

*Fomin B.A., Falaleeva V.A. *Atmospheric and Oceanic Optics.* 2009

Difference **<0,5% (upward fluxes)**
<1% (downward fluxes)

A_1, B_1: 80,185° СШ

A_2, B_2: 49,906° СШ

A_3, B_3: 0,56° СШ

Shortwave downward and upward fluxes

MLS, 10000-10500 cm^{-1}, A_s=1, SZA=30^o

Height,km	Upward fluxes, W/m^2			Downward fluxes, W/m^2		
	Monte Carlo, LBL [Fomin]	DISORT, LBL	DISORT, KD	Monte Carlo, LBL [Fomin]	DISORT, LBL	DISORT, KD
Clouds Scl, R_{ef} = 5.4 μm, τ_{cloud} = 2.81; layer 12.4–13 km						
0	23.20	23.01	22.75	23.20	23.01	22.75
1	21.53	21.25	20.95	25.14	24.99	24.81
2	20.79	20.48	20.18	26.81	26.67	26.62
5	20.18	19.86	19.54	29.79	29.61	29.85
10	20.13	19.79	19.47	30.97	30.92	29.93
100	20.47	20.07	19.47	31.44	31.36	31.74
Clouds Cb, R_{ef} = 30 μm, τ_{cloud} = 9.7; layer 1.8–2 km						
0	21.42	21.74	21.51	21.42	21.74	21.51
1	20.02	20.24	19.99	23.14	23.55	23.38
2	20.53	20.68	20.60	26.98	26.91	27.04
5	19.22	19.48	19.31	30.15	29.93	30.38
10	19.10	19.34	19.16	31.38	31.25	30.67
100	19.10	19.34	19.16	31.45	31.36	31.74

Upward fluxes at the atmosphere top, W/m^2

Spectral interval, mkm	line-by-line	k-distribution
0.87-1	20.81	20.56
1-1.1	19.67	19.95
1.28-1.53	3.89	3.88
1.64-2.13	3.56	3.52
1.64-2.13 Cb	7.08	7.36
1.64-2.13 Scl	14.4	14.47

Scattering and absorption by aerosol, cloud and Rayleigh, absorption by all gases
SZA=30^o MLS.

DATA

IAO SB RAS, VolSU

MODIS satellite data of optical characteristics of clouds and aerosol for northern hemisphere

RRC Kurchatov Institute

Optical characteristics of drop clouds and aerosol models.

Benchmark calculations of downward and upward radiation for testing of atmospheric radiative transfer models

ICS

USU

A priori information of vertical profiles of H_2O, HDO, O_3, CH_4, CO_2 and temperature

Thank you for attention!