The Excel spreadsheet

Step-by-step calculation of spectra from HITRAN

Conversion to transmittance

Multiplication of transmittance with the Planck function

Integration of the Planck function and transmittance products

Determination of transmittance of the atmosphere

Columns of the spreadsheet

The starting point is the HITRAN data, which have been converted in Lorentzian lines from 0 to 2400 cm^{-1} with a spacing of 0.1 cm^{-1}. The columns across the top are

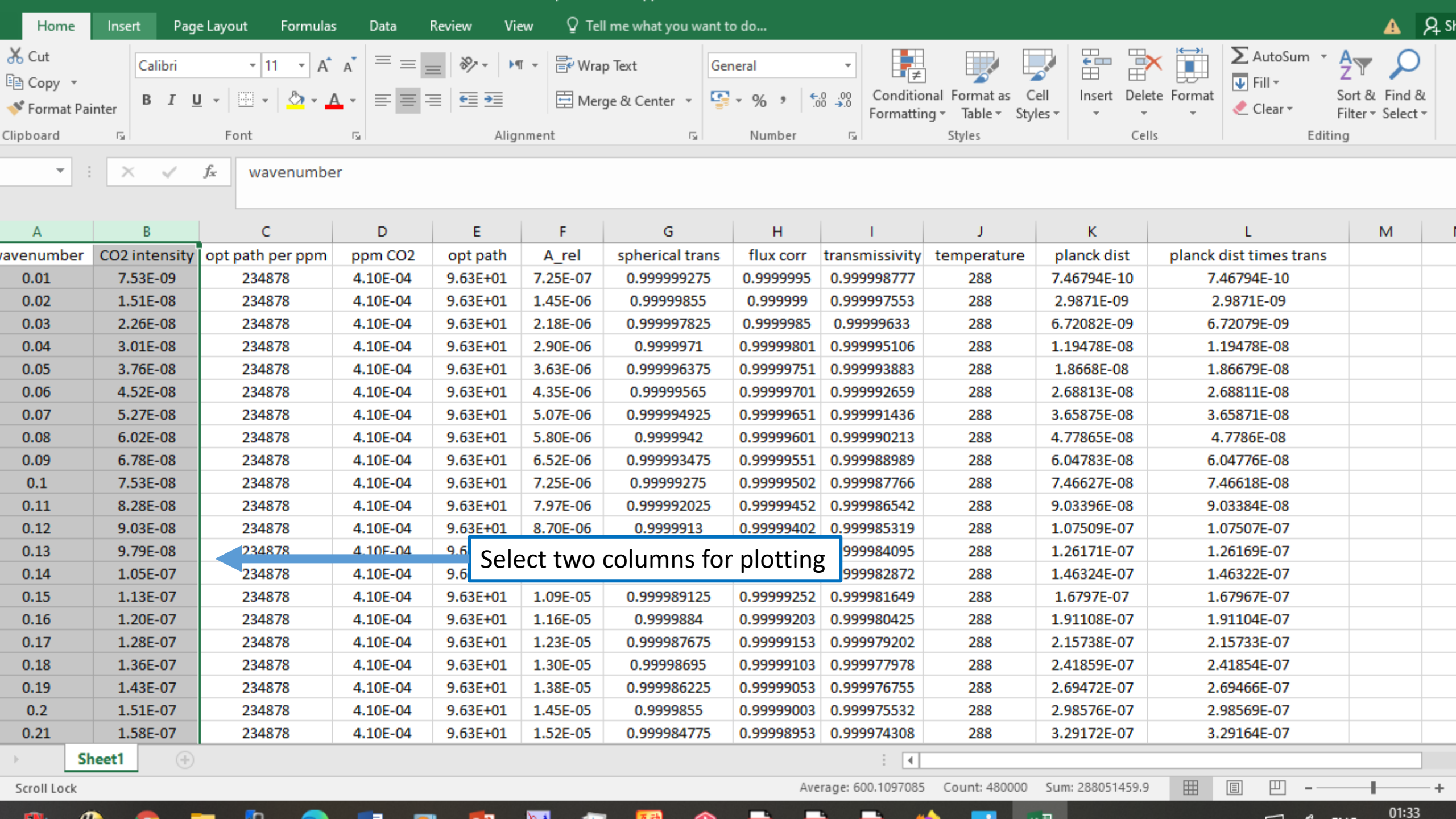
A. wavenumber
B. CO2 intensity
C. cross-sectional density up to TOA (per ppm of CO2) [constant]
D. ppm CO2 [constant]
E. cross-sectional density (the product of C. and D.)
F. A_rel the absorbance to base e (the product of B. and E.)
G. spherical points source transmittance (=exp{-A_rel})
H. flux correction (=[exp{-A_rel*1.245} + exp{-A_rel*0.13}]/2)
I. transmittance (the product of G. and H.)
J. Temperature [constant]
K. Planck distribution using wavenumber in A. and temperature in J.)
L. Plank disttributions times CO2 transmittance (product of I. and K.)

Results of the spreadsheet

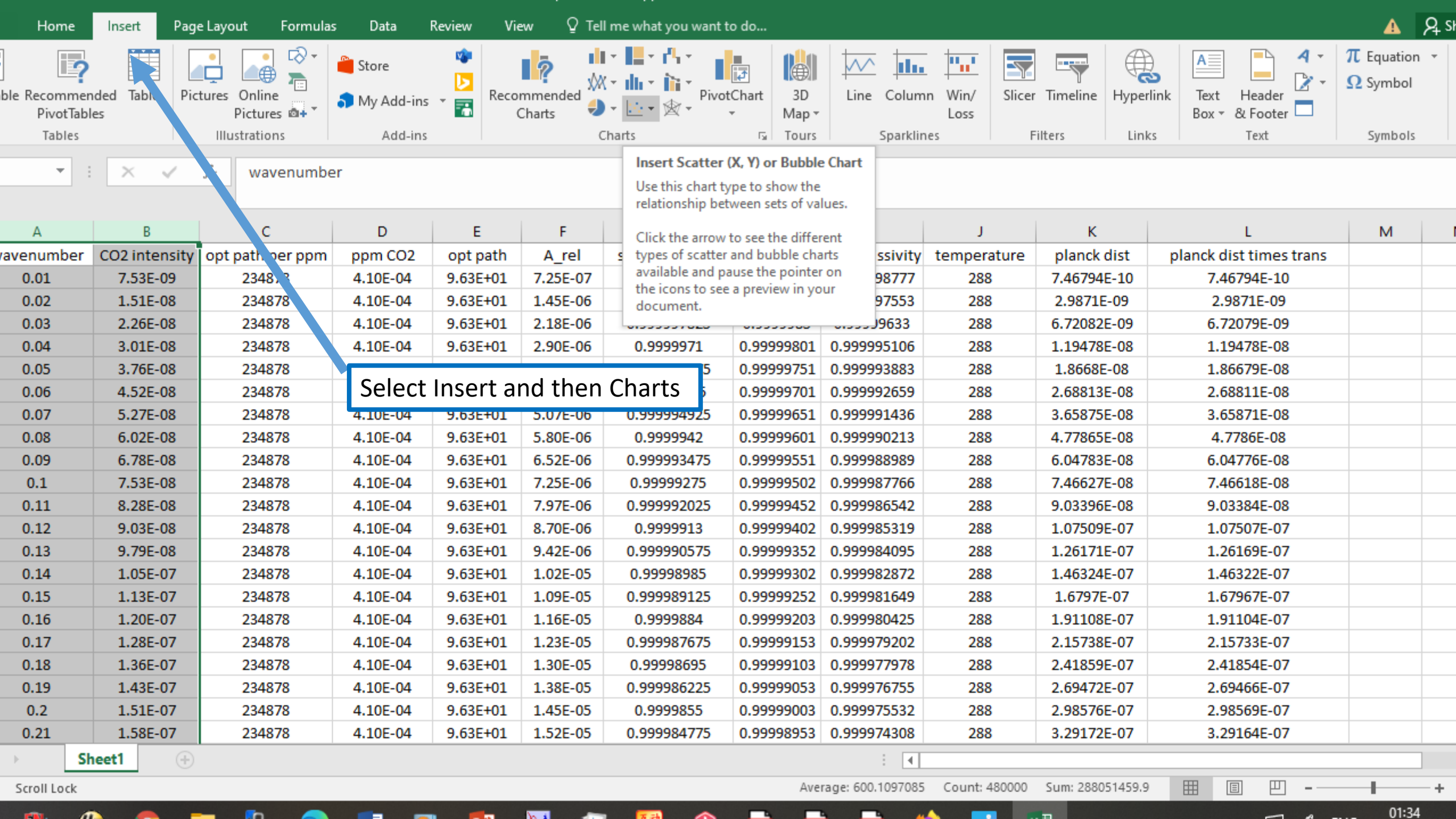
The integrated (summed) values of the Planck distribution and Planck distribution times the transmissivity of CO_2 are given in column M. Note that the summed values need to be divided by 100 since the increment of each point is 0.01 cm^{-1} but the spectral flux units are per cm^{-1}. Since the sum is over 240,000 points it is quite accurate and we do not need to use the trapezoid rule.

In this example, the temperature is 288 K and the integrated flux at the surface of the earth is 391.2 W/m^2. For the Planck curve with CO_2 absorption the integrated flux is 286.4 W/m^2. Thus, the total transmissivity is 0.7322 for this example, which only contains CO_2.

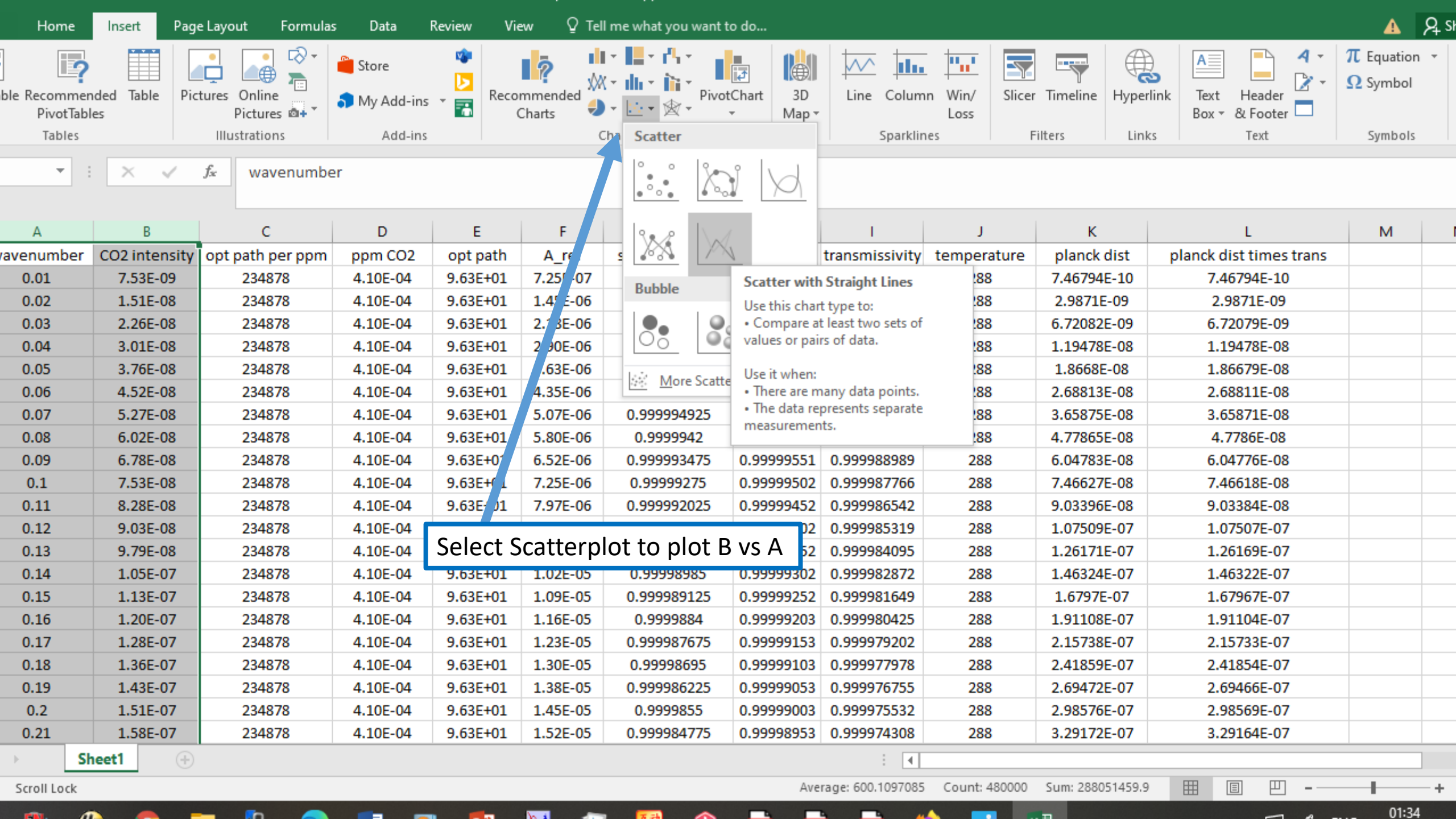
The layout and plotting (using the Excel scatter plot function are shown in the following slides).



A	B	C	D	E	F	G	H	I	J	K	L	M
avenumber	CO2 intensity	opt path per ppm	ppm CO2	opt path	A_rel	spherical trans	flux corr	transmissivity	temperature	planck dist	planck dist times trans	
0.01	7.53E-09	234878	4.10E-04	9.63E+01	7.25E-07	0.999999275	0.9999995	0.999998777	288	7.46794E-10	7.46794E-10	
0.02	1.51E-08	234878	4.10E-04	9.63E+01	1.45E-06	0.99999855	0.999999	0.999997553	288	2.9871E-09	2.9871E-09	
0.03	2.26E-08	234878	4.10E-04	9.63E+01	2.18E-06	0.999997825	0.9999985	0.99999633	288	6.72082E-09	6.72079E-09	
0.04	3.01E-08	234878	4.10E-04	9.63E+01	2.90E-06	0.9999971	0.99999801	0.999995106	288	1.19478E-08	1.19478E-08	
0.05	3.76E-08	234878	4.10E-04	9.63E+01	3.63E-06	0.999996375	0.99999751	0.999993883	288	1.8668E-08	1.86679E-08	
0.06	4.52E-08	234878	4.10E-04	9.63E+01	4.35E-06	0.99999565	0.99999701	0.999992659	288	2.68813E-08	2.68811E-08	
0.07	5.27E-08	234878	4.10E-04	9.63E+01	5.07E-06	0.999994925	0.99999651	0.999991436	288	3.65875E-08	3.65871E-08	
0.08	6.02E-08	234878	4.10E-04	9.63E+01	5.80E-06	0.9999942	0.99999601	0.999990213	288	4.77865E-08	4.7786E-08	
0.09	6.78E-08	234878	4.10E-04	9.63E+01	6.52E-06	0.999993475	0.99999551	0.999988989	288	6.04783E-08	6.04776E-08	
0.1	7.53E-08	234878	4.10E-04	9.63E+01	7.25E-06	0.99999275	0.99999502	0.999987766	288	7.46627E-08	7.46618E-08	
0.11	8.28E-08	234878	4.10E-04	9.63E+01	7.97E-06	0.999992025	0.99999452	0.999986542	288	9.03396E-08	9.03384E-08	
0.12	9.03E-08	234878	4.10E-04	9.63E+01	8.70E-06	0.9999913	0.99999402	0.999985319	288	1.07509E-07	1.07507E-07	
0.13	9.79E-08	234878	4.10E-04	9.6				999984095	288	1.26171E-07	1.26169E-07	
0.14	1.05E-07	234878	4.10E-04	9.6				999982872	288	1.46324E-07	1.46322E-07	
0.15	1.13E-07	234878	4.10E-04	9.63E+01	1.09E-05	0.999989125	0.99999252	0.999981649	288	1.6797E-07	1.67967E-07	
0.16	1.20E-07	234878	4.10E-04	9.63E+01	1.16E-05	0.9999884	0.99999203	0.999980425	288	1.91108E-07	1.91104E-07	
0.17	1.28E-07	234878	4.10E-04	9.63E+01	1.23E-05	0.999987675	0.99999153	0.999979202	288	2.15738E-07	2.15733E-07	
0.18	1.36E-07	234878	4.10E-04	9.63E+01	1.30E-05	0.99998695	0.99999103	0.999977978	288	2.41859E-07	2.41854E-07	
0.19	1.43E-07	234878	4.10E-04	9.63E+01	1.38E-05	0.999986225	0.99999053	0.999976755	288	2.69472E-07	2.69466E-07	
0.2	1.51E-07	234878	4.10E-04	9.63E+01	1.45E-05	0.9999855	0.99999003	0.999975532	288	2.98576E-07	2.98569E-07	
0.21	1.58E-07	234878	4.10E-04	9.63E+01	1.52E-05	0.999984775	0.99998953	0.999974308	288	3.29172E-07	3.29164E-07	



A	B	C	D	E	F			J	K	L	M
wavenumber	CO2 intensity	opt path per ppm	ppm CO2	opt path	A_rel	s	ssivity	temperature	planck dist	planck dist times trans	
0.01	7.53E-09	2348	4.10E-04	9.63E+01	7.25E-07		98777	288	7.46794E-10	7.46794E-10	
0.02	1.51E-08	234878	4.10E-04	9.63E+01	1.45E-06		97553	288	2.9871E-09	2.9871E-09	
0.03	2.26E-08	234878	4.10E-04	9.63E+01	2.18E-06		9633	288	6.72082E-09	6.72079E-09	
0.04	3.01E-08	234878	4.10E-04	9.63E+01	2.90E-06	0.9999971	0.99999801	0.999995106	288	1.19478E-08	1.19478E-08
0.05	3.76E-08	234878				5	0.99999751	0.999993883	288	1.8668E-08	1.86679E-08
0.06	4.52E-08	234878				5	0.99999701	0.999992659	288	2.68813E-08	2.68811E-08
0.07	5.27E-08	234878	4.10E-04	9.63E+01	5.07E-06	0.999994925	0.99999651	0.999991436	288	3.65875E-08	3.65871E-08
0.08	6.02E-08	234878	4.10E-04	9.63E+01	5.80E-06	0.9999942	0.99999601	0.999990213	288	4.77865E-08	4.7786E-08
0.09	6.78E-08	234878	4.10E-04	9.63E+01	6.52E-06	0.999993475	0.99999551	0.999988989	288	6.04783E-08	6.04776E-08
0.1	7.53E-08	234878	4.10E-04	9.63E+01	7.25E-06	0.99999275	0.99999502	0.999987766	288	7.46627E-08	7.46618E-08
0.11	8.28E-08	234878	4.10E-04	9.63E+01	7.97E-06	0.999992025	0.99999452	0.999986542	288	9.03396E-08	9.03384E-08
0.12	9.03E-08	234878	4.10E-04	9.63E+01	8.70E-06	0.9999913	0.99999402	0.999985319	288	1.07509E-07	1.07507E-07
0.13	9.79E-08	234878	4.10E-04	9.63E+01	9.42E-06	0.999990575	0.99999352	0.999984095	288	1.26171E-07	1.26169E-07
0.14	1.05E-07	234878	4.10E-04	9.63E+01	1.02E-05	0.99998985	0.99999302	0.999982872	288	1.46324E-07	1.46322E-07
0.15	1.13E-07	234878	4.10E-04	9.63E+01	1.09E-05	0.999989125	0.99999252	0.999981649	288	1.6797E-07	1.67967E-07
0.16	1.20E-07	234878	4.10E-04	9.63E+01	1.16E-05	0.9999884	0.99999203	0.999980425	288	1.91108E-07	1.91104E-07
0.17	1.28E-07	234878	4.10E-04	9.63E+01	1.23E-05	0.999987675	0.99999153	0.999979202	288	2.15738E-07	2.15733E-07
0.18	1.36E-07	234878	4.10E-04	9.63E+01	1.30E-05	0.99998695	0.99999103	0.999977978	288	2.41859E-07	2.41854E-07
0.19	1.43E-07	234878	4.10E-04	9.63E+01	1.38E-05	0.999986225	0.99999053	0.999976755	288	2.69472E-07	2.69466E-07
0.2	1.51E-07	234878	4.10E-04	9.63E+01	1.45E-05	0.9999855	0.99999003	0.999975532	288	2.98576E-07	2.98569E-07
0.21	1.58E-07	234878	4.10E-04	9.63E+01	1.52E-05	0.999984775	0.99998953	0.999974308	288	3.29172E-07	3.29164E-07



A	B	C	D	E	F			I	J	K	L	M
wavenumber	CO2 intensity	opt path per ppm	ppm CO2	opt path	A_re			transmissivity	temperature	planck dist	planck dist times trans	
0.01	7.53E-09	234878	4.10E-04	9.63E+01	7.25E-07				288	7.46794E-10	7.46794E-10	
0.02	1.51E-08	234878	4.10E-04	9.63E+01	1.45E-06				288	2.9871E-09	2.9871E-09	
0.03	2.26E-08	234878	4.10E-04	9.63E+01	2.18E-06				288	6.72082E-09	6.72079E-09	
0.04	3.01E-08	234878	4.10E-04	9.63E+01	2.90E-06				288	1.19478E-08	1.19478E-08	
0.05	3.76E-08	234878	4.10E-04	9.63E+01	3.63E-06				288	1.8668E-08	1.86679E-08	
0.06	4.52E-08	234878	4.10E-04	9.63E+01	4.35E-06				288	2.68813E-08	2.68811E-08	
0.07	5.27E-08	234878	4.10E-04	9.63E+01	5.07E-06	0.999994925			288	3.65875E-08	3.65871E-08	
0.08	6.02E-08	234878	4.10E-04	9.63E+01	5.80E-06	0.9999942			288	4.77865E-08	4.7786E-08	
0.09	6.78E-08	234878	4.10E-04	9.63E+01	6.52E-06	0.999993475	0.99999551	0.999988989	288	6.04783E-08	6.04776E-08	
0.1	7.53E-08	234878	4.10E-04	9.63E+01	7.25E-06	0.99999275	0.99999502	0.999987766	288	7.46627E-08	7.46618E-08	
0.11	8.28E-08	234878	4.10E-04	9.63E+01	7.97E-06	0.999992025	0.99999452	0.999986542	288	9.03396E-08	9.03384E-08	
0.12	9.03E-08	234878	4.10E-04	9.63E+01	8.70E-06	0.9999913	0.99999402	0.999985319	288	1.07509E-07	1.07507E-07	
0.13	9.79E-08	234878	4.10E-04	9.63E+01	9.42E-06	0.999990575	0.99999352	0.999984095	288	1.26171E-07	1.26169E-07	
0.14	1.05E-07	234878	4.10E-04	9.63E+01	1.02E-05	0.99998985	0.99999302	0.999982872	288	1.46324E-07	1.46322E-07	
0.15	1.13E-07	234878	4.10E-04	9.63E+01	1.09E-05	0.999989125	0.99999252	0.999981649	288	1.6797E-07	1.67967E-07	
0.16	1.20E-07	234878	4.10E-04	9.63E+01	1.16E-05	0.9999884	0.99999203	0.999980425	288	1.91108E-07	1.91104E-07	
0.17	1.28E-07	234878	4.10E-04	9.63E+01	1.23E-05	0.999987675	0.99999153	0.999979202	288	2.15738E-07	2.15733E-07	
0.18	1.36E-07	234878	4.10E-04	9.63E+01	1.30E-05	0.99998695	0.99999103	0.999977978	288	2.41859E-07	2.41854E-07	
0.19	1.43E-07	234878	4.10E-04	9.63E+01	1.38E-05	0.999986225	0.99999053	0.999976755	288	2.69472E-07	2.69466E-07	
0.2	1.51E-07	234878	4.10E-04	9.63E+01	1.45E-05	0.9999855	0.99999003	0.999975532	288	2.98576E-07	2.98569E-07	
0.21	1.58E-07	234878	4.10E-04	9.63E+01	1.52E-05	0.999984775	0.99998953	0.999974308	288	3.29172E-07	3.29164E-07	

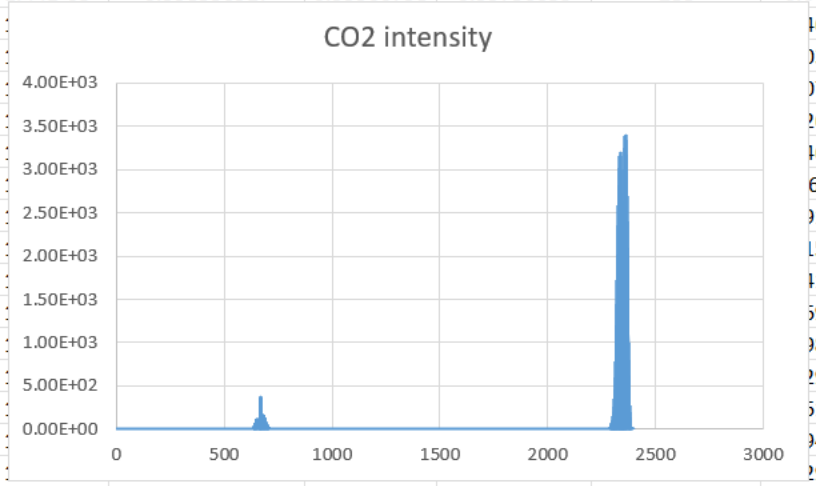
Column B

[redacted] Page Layout Formulas Data Review View Automate Help ChemOffice

Comments Share

A2 0.01

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	0.01	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557154	0.99900814	0.997566728	288	7.46794E-10	7.44977E-10		
3	0.02	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557124	0.99900812	0.997566679	288	2.9871E-09	2.97983E-09		
4	0.03	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557095	0.9990081	0.997566629	288	6.72082E-09	6.70446E-09	Flux (W/m^2)	
5	0.04	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557065	0.99900808	0.997566579	288	1.19478E-08	1.19187E-08	391.1931453	
6	0.05	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557036	0.99900806	0.997566529	288	1.8668E-08	1.86226E-08	Ground	
7	0.06	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557006	0.99900804	0.997566479	288	2.68813E-08	2.68158E-08	304.5329103	
8	0.07	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556977	0.99900802	0.997566429	288	3.65875E-08	3.64984E-08	TOA	
9	0.08	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556947	0.999008	0.99756638	288	4.77865E-08	4.76702E-08	0.778472	
10	0.09	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556917	0.99900798	0.99756633	288	6.04783E-08	6.03311E-08	CO2 Transmittance	
11	0.1	1.46E-05	234972	4.20E-04	9.87E+01						46627E-08	7.4481E-08	0.8	
12	0.11	1.46E-05	234972	4.20E-04	9.87E+01						03396E-08	9.01198E-08	H2O Trans (Assumed)	
13	0.12	1.46E-05	234972	4.20E-04	9.87E+01						07509E-07	1.07247E-07	287.0495924	
14	0.13	1.46E-05	234972	4.20E-04	9.87E+01						26171E-07	1.25863E-07	T_ground	
15	0.14	1.46E-05	234972	4.20E-04	9.87E+01						46324E-07	1.45968E-07		
16	0.15	1.46E-05	234972	4.20E-04	9.87E+01						6797E-07	1.67561E-07		
17	0.16	1.46E-05	234972	4.20E-04	9.87E+01						91108E-07	1.90643E-07		
18	0.17	1.46E-05	234972	4.20E-04	9.87E+01						15738E-07	2.15212E-07		
19	0.18	1.46E-05	234972	4.20E-04	9.87E+01						41859E-07	2.4127E-07		
20	0.19	1.46E-05	234972	4.20E-04	9.87E+01						69472E-07	2.68816E-07		
21	0.2	1.46E-05	234972	4.20E-04	9.87E+01						98576E-07	2.9785E-07		
22	0.21	1.46E-05	234972	4.20E-04	9.87E+01						29172E-07	3.28371E-07		
23	0.22	1.46E-05	234972	4.20E-04	9.87E+01						51259E-07	3.6038E-07		
24	0.23	1.46E-05	234972	4.20E-04	9.87E+01						94838E-07	3.93877E-07		
25	0.24	1.46E-05	234972	4.20E-04	9.87E+01						29907E-07	4.28861E-07		
26	0.25	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556464	0.99900767	0.997565566	288	4.66468E-07	4.65332E-07		
27	0.26	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556435	0.99900765	0.997565516	288	5.04519E-07	5.0329E-07		
28	0.27	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556405	0.99900763	0.997565466	288	5.44061E-07	5.42736E-07		
29	0.28	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556375	0.99900761	0.997565416	288	5.85093E-07	5.83669E-07		
30	0.29	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556356	0.99900759	0.997565383	288	6.27616E-07	6.26088E-07		
31	0.3	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556326	0.99900757	0.997565333	288	6.7163E-07	6.69994E-07		
32	0.31	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556297	0.99900755	0.997565283	288	7.17133E-07	7.15387E-07		
33	0.32	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556267	0.99900753	0.997565234	288	7.64127E-07	7.62267E-07		
34	0.33	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556238	0.99900751	0.997565184	288	8.12611E-07	8.10632E-07		



Sheet1 +

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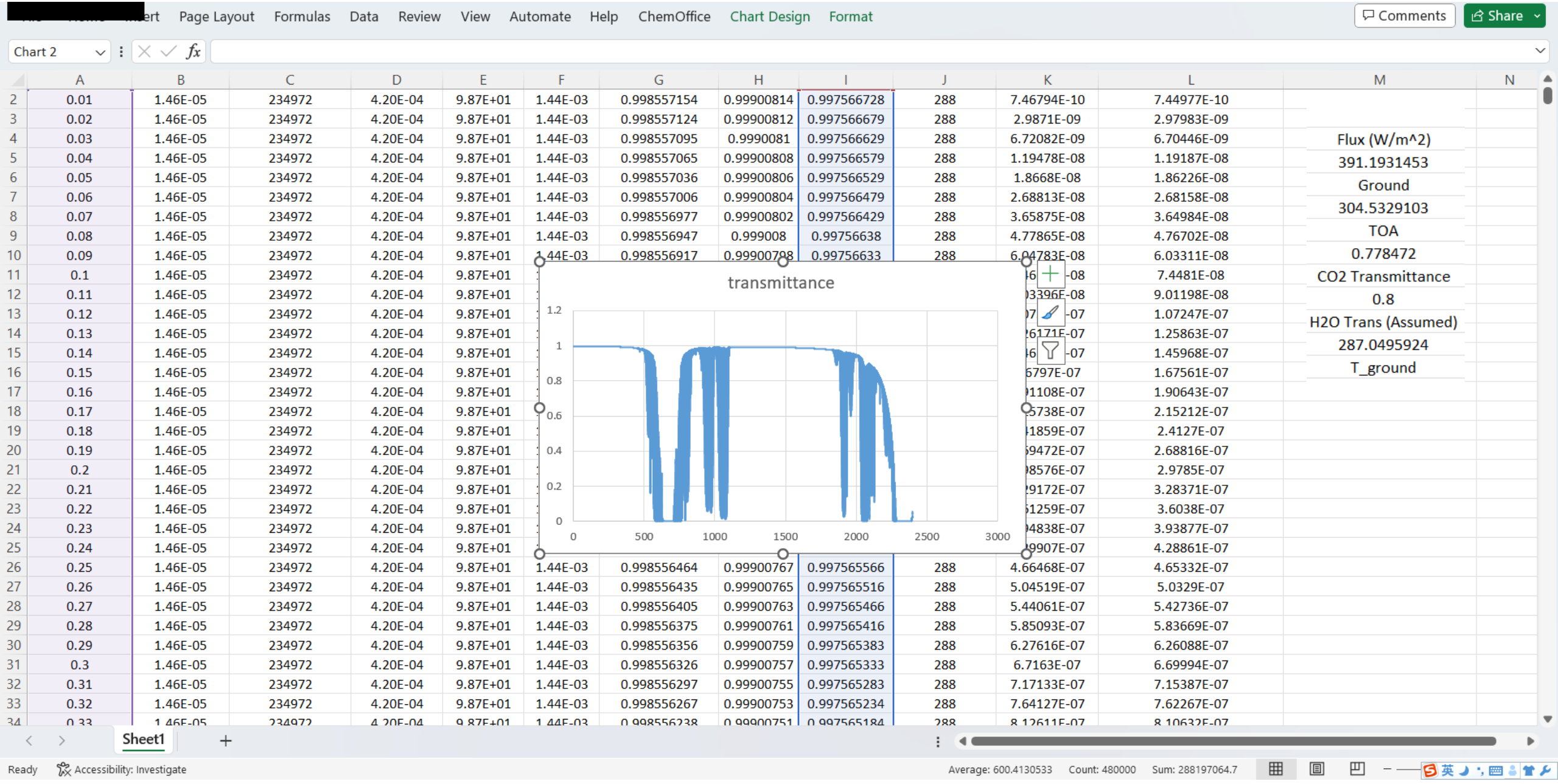
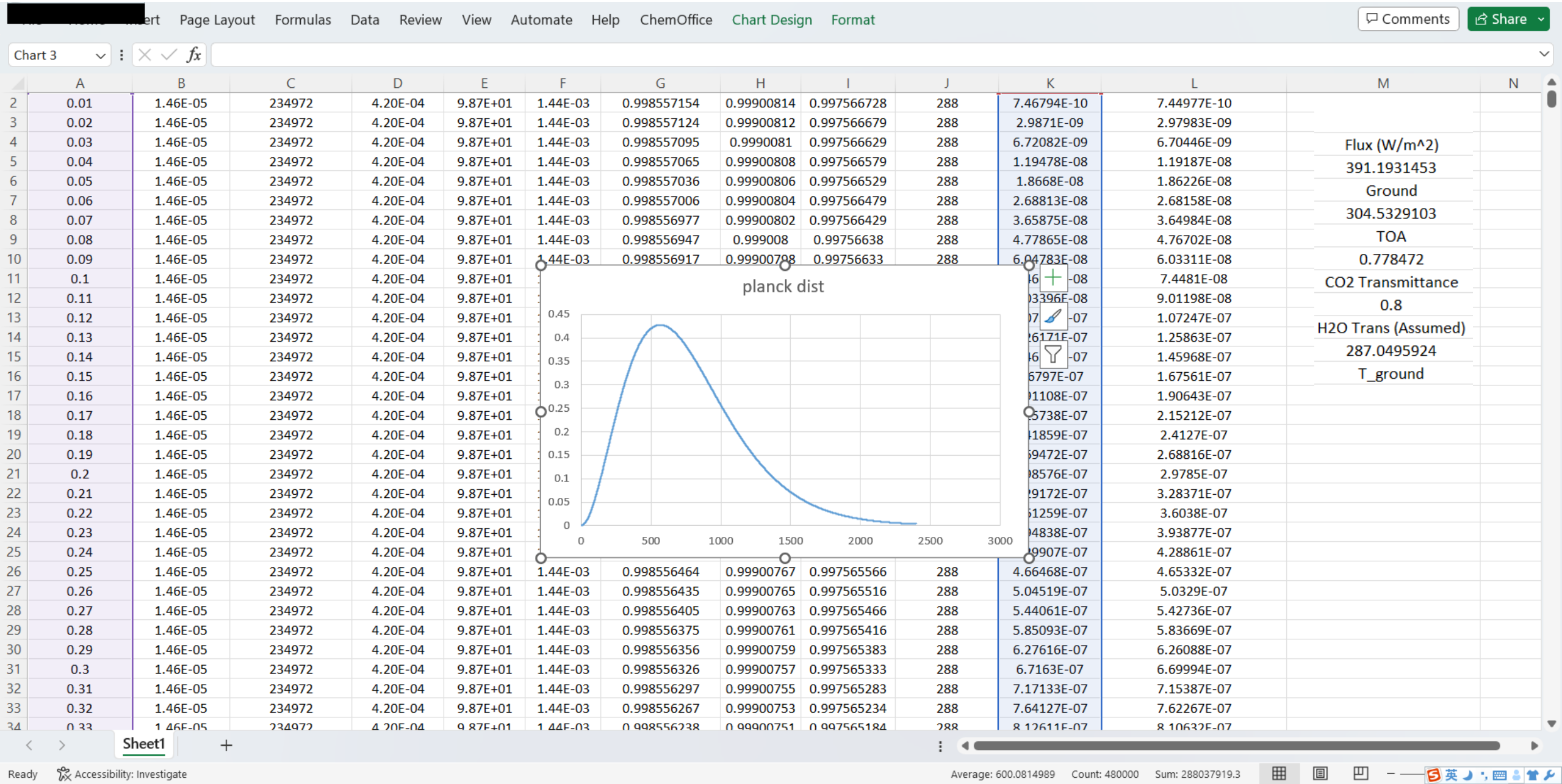
Column I



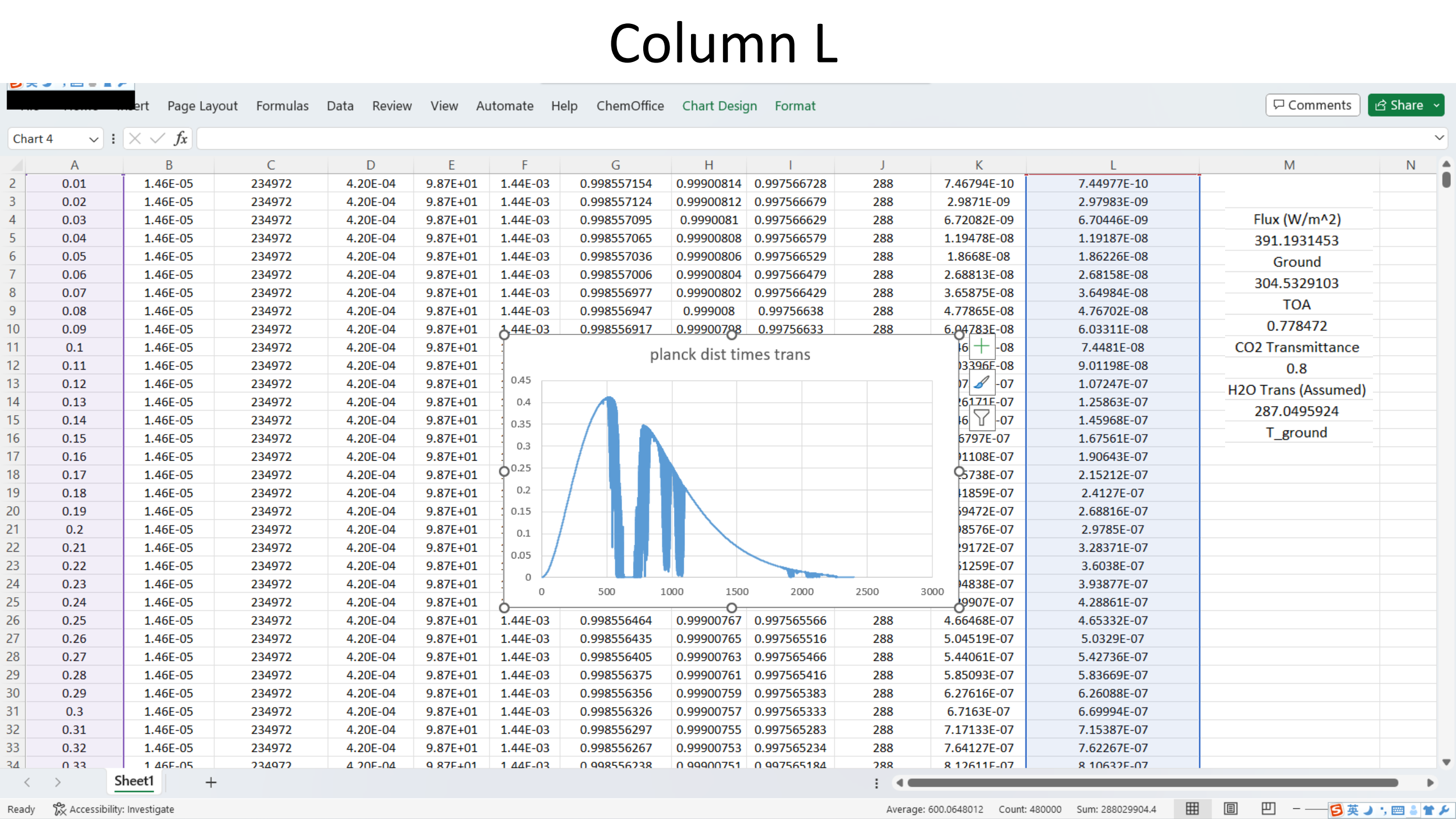
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	0.01	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557154	0.99900814	0.997566728	288	7.46794E-10	7.44977E-10		
3	0.02	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557124	0.99900812	0.997566679	288	2.9871E-09	2.97983E-09		
4	0.03	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557095	0.9990081	0.997566629	288	6.72082E-09	6.70446E-09		
5	0.04	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557065	0.99900808	0.997566579	288	1.19478E-08	1.19187E-08		
6	0.05	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557036	0.99900806	0.997566529	288	1.8668E-08	1.86226E-08		
7	0.06	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557006	0.99900804	0.997566479	288	2.68813E-08	2.68158E-08		
8	0.07	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556977	0.99900802	0.997566429	288	3.65875E-08	3.64984E-08		
9	0.08	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556947	0.999008	0.99756638	288	4.77865E-08	4.76702E-08		
10	0.09	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556917	0.99900798	0.99756633	288	6.04783E-08	6.03311E-08		
11	0.1	1.46E-05	234972	4.20E-04	9.87E+01						46	7.4481E-08		
12	0.11	1.46E-05	234972	4.20E-04	9.87E+01						03396E-08	9.01198E-08		
13	0.12	1.46E-05	234972	4.20E-04	9.87E+01						07 -07	1.07247E-07		
14	0.13	1.46E-05	234972	4.20E-04	9.87E+01						26171E-07	1.25863E-07		
15	0.14	1.46E-05	234972	4.20E-04	9.87E+01						46 -07	1.45968E-07		
16	0.15	1.46E-05	234972	4.20E-04	9.87E+01						6797E-07	1.67561E-07		
17	0.16	1.46E-05	234972	4.20E-04	9.87E+01						91108E-07	1.90643E-07		
18	0.17	1.46E-05	234972	4.20E-04	9.87E+01						5738E-07	2.15212E-07		
19	0.18	1.46E-05	234972	4.20E-04	9.87E+01						41859E-07	2.4127E-07		
20	0.19	1.46E-05	234972	4.20E-04	9.87E+01						59472E-07	2.68816E-07		
21	0.2	1.46E-05	234972	4.20E-04	9.87E+01						98576E-07	2.9785E-07		
22	0.21	1.46E-05	234972	4.20E-04	9.87E+01						29172E-07	3.28371E-07		
23	0.22	1.46E-05	234972	4.20E-04	9.87E+01						51259E-07	3.6038E-07		
24	0.23	1.46E-05	234972	4.20E-04	9.87E+01						94838E-07	3.93877E-07		
25	0.24	1.46E-05	234972	4.20E-04	9.87E+01						39907E-07	4.28861E-07		
26	0.25	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556464	0.99900767	0.997565566	288	4.66468E-07	4.65332E-07		
27	0.26	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556435	0.99900765	0.997565516	288	5.04519E-07	5.0329E-07		
28	0.27	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556405	0.99900763	0.997565466	288	5.44061E-07	5.42736E-07		
29	0.28	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556375	0.99900761	0.997565416	288	5.85093E-07	5.83669E-07		
30	0.29	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556356	0.99900759	0.997565383	288	6.27616E-07	6.26088E-07		
31	0.3	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556326	0.99900757	0.997565333	288	6.7163E-07	6.69994E-07		
32	0.31	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556297	0.99900755	0.997565283	288	7.17133E-07	7.15387E-07		
33	0.32	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556267	0.99900753	0.997565234	288	7.64127E-07	7.62267E-07		
34	0.33	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556238	0.99900751	0.997565184	288	8.12611E-07	8.10632E-07		

Column K



	A	B	C	D	E	F	G	H	I	J	K	L
2	0.01	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557154	0.99900814	0.997566728	288	7.46794E-10	7.44977E-10
3	0.02	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557124	0.99900812	0.997566679	288	2.9871E-09	2.97983E-09
4	0.03	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557095	0.9990081	0.997566629	288	6.72082E-09	6.70446E-09
5	0.04	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557065	0.99900808	0.997566579	288	1.19478E-08	1.19187E-08
6	0.05	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557036	0.99900806	0.997566529	288	1.8668E-08	1.86226E-08
7	0.06	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557006	0.99900804	0.997566479	288	2.68813E-08	2.68158E-08
8	0.07	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556977	0.99900802	0.997566429	288	3.65875E-08	3.64984E-08
9	0.08	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556947	0.999008	0.99756638	288	4.77865E-08	4.76702E-08
10	0.09	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556917	0.99900798	0.99756633	288	6.04783E-08	6.03311E-08
11	0.1	1.46E-05	234972	4.20E-04	9.87E+01						46 -08	7.4481E-08
12	0.11	1.46E-05	234972	4.20E-04	9.87E+01						03396E-08	9.01198E-08
13	0.12	1.46E-05	234972	4.20E-04	9.87E+01						07 -07	1.07247E-07
14	0.13	1.46E-05	234972	4.20E-04	9.87E+01						26171E-07	1.25863E-07
15	0.14	1.46E-05	234972	4.20E-04	9.87E+01						46 -07	1.45968E-07
16	0.15	1.46E-05	234972	4.20E-04	9.87E+01						6797E-07	1.67561E-07
17	0.16	1.46E-05	234972	4.20E-04	9.87E+01						91108E-07	1.90643E-07
18	0.17	1.46E-05	234972	4.20E-04	9.87E+01						5738E-07	2.15212E-07
19	0.18	1.46E-05	234972	4.20E-04	9.87E+01						41859E-07	2.4127E-07
20	0.19	1.46E-05	234972	4.20E-04	9.87E+01						59472E-07	2.68816E-07
21	0.2	1.46E-05	234972	4.20E-04	9.87E+01						08576E-07	2.9785E-07
22	0.21	1.46E-05	234972	4.20E-04	9.87E+01						29172E-07	3.28371E-07
23	0.22	1.46E-05	234972	4.20E-04	9.87E+01						51259E-07	3.6038E-07
24	0.23	1.46E-05	234972	4.20E-04	9.87E+01						94838E-07	3.93877E-07
25	0.24	1.46E-05	234972	4.20E-04	9.87E+01						99907E-07	4.28861E-07
26	0.25	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556464	0.99900767	0.997565566	288	4.66468E-07	4.65332E-07
27	0.26	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556435	0.99900765	0.997565516	288	5.04519E-07	5.0329E-07
28	0.27	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556405	0.99900763	0.997565466	288	5.44061E-07	5.42736E-07
29	0.28	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556375	0.99900761	0.997565416	288	5.85093E-07	5.83669E-07
30	0.29	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556356	0.99900759	0.997565383	288	6.27616E-07	6.26088E-07
31	0.3	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556326	0.99900757	0.997565333	288	6.7163E-07	6.69994E-07
32	0.31	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556297	0.99900755	0.997565283	288	7.17133E-07	7.15387E-07
33	0.32	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556267	0.99900753	0.997565234	288	7.64127E-07	7.62267E-07
34	0.33	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556238	0.99900751	0.997565184	288	8.12611E-07	8.10632E-07

Column L



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	0.01	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557154	0.99900814	0.997566728	288	7.46794E-10	7.44977E-10		
3	0.02	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557124	0.99900812	0.997566679	288	2.9871E-09	2.97983E-09		
4	0.03	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557095	0.9990081	0.997566629	288	6.72082E-09	6.70446E-09	Flux (W/m^2)	
5	0.04	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557065	0.99900808	0.997566579	288	1.19478E-08	1.19187E-08	391.1931453	
6	0.05	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557036	0.99900806	0.997566529	288	1.8668E-08	1.86226E-08	Ground	
7	0.06	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998557006	0.99900804	0.997566479	288	2.68813E-08	2.68158E-08	304.5329103	
8	0.07	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556977	0.99900802	0.997566429	288	3.65875E-08	3.64984E-08	TOA	
9	0.08	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556947	0.999008	0.99756638	288	4.77865E-08	4.76702E-08	0.778472	
10	0.09	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556917	0.99900798	0.99756633	288	6.04783E-08	6.03311E-08	CO2 Transmittance	
11	0.1	1.46E-05	234972	4.20E-04	9.87E+01						46	7.4481E-08	0.8	
12	0.11	1.46E-05	234972	4.20E-04	9.87E+01						03396E-08	9.01198E-08		
13	0.12	1.46E-05	234972	4.20E-04	9.87E+01						07 -07	1.07247E-07	H2O Trans (Assumed)	
14	0.13	1.46E-05	234972	4.20E-04	9.87E+01						26171E-07	1.25863E-07	287.0495924	
15	0.14	1.46E-05	234972	4.20E-04	9.87E+01						46 -07	1.45968E-07	T_ground	
16	0.15	1.46E-05	234972	4.20E-04	9.87E+01						6797E-07	1.67561E-07		
17	0.16	1.46E-05	234972	4.20E-04	9.87E+01						91108E-07	1.90643E-07		
18	0.17	1.46E-05	234972	4.20E-04	9.87E+01						5738E-07	2.15212E-07		
19	0.18	1.46E-05	234972	4.20E-04	9.87E+01						41859E-07	2.4127E-07		
20	0.19	1.46E-05	234972	4.20E-04	9.87E+01						59472E-07	2.68816E-07		
21	0.2	1.46E-05	234972	4.20E-04	9.87E+01						08576E-07	2.9785E-07		
22	0.21	1.46E-05	234972	4.20E-04	9.87E+01						29172E-07	3.28371E-07		
23	0.22	1.46E-05	234972	4.20E-04	9.87E+01						51259E-07	3.6038E-07		
24	0.23	1.46E-05	234972	4.20E-04	9.87E+01						94838E-07	3.93877E-07		
25	0.24	1.46E-05	234972	4.20E-04	9.87E+01						99907E-07	4.28861E-07		
26	0.25	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556464	0.99900767	0.997565566	288	4.66468E-07	4.65332E-07		
27	0.26	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556435	0.99900765	0.997565516	288	5.04519E-07	5.0329E-07		
28	0.27	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556405	0.99900763	0.997565466	288	5.44061E-07	5.42736E-07		
29	0.28	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556375	0.99900761	0.997565416	288	5.85093E-07	5.83669E-07		
30	0.29	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556356	0.99900759	0.997565383	288	6.27616E-07	6.26088E-07		
31	0.3	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556326	0.99900757	0.997565333	288	6.7163E-07	6.69994E-07		
32	0.31	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556297	0.99900755	0.997565283	288	7.17133E-07	7.15387E-07		
33	0.32	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556267	0.99900753	0.997565234	288	7.64127E-07	7.62267E-07		
34	0.33	1.46E-05	234972	4.20E-04	9.87E+01	1.44E-03	0.998556238	0.99900751	0.997565184	288	8.12611E-07	8.10632E-07		

Column M

The Column M gives a single integrated result for the transmittance and global transmittance,

If we either sum (as done below using igor for graphical Convenience) or integrate numerically we find that the flux of bare earth must be 391.1 Wm^{-2}. We must keep in mind the geometric factor of 4 since the surface area of a sphere is $4\pi R^2$. The earth emits as a sphere, but absorbs as a disc, with area πR^2. The transmittance at the TOA creates a deficit in the balance that must be filled by the increase in heat and surface radiation of the earth. The temperature of the surface relative to the bare planet is the greenhouse warming. We calculate it to be 32.0 ^oC.

Flux (W/m^2)
391.1931453
Ground
304.5329103
TOA
0.778472
CO2 Transmittance
0.8
H2O Trans (Assumed)
287.0495924
T_ground

Calculation of Temperature vs CO_2 ppm

To use the Excel spread sheet you only need to modify column D. There are 250,000 entries in that column. The Excel method is to select the first cell and change it to the desired values. Then point at the lower right-hand corner of the cell and double click. The value will be propagated through the entire column and the calculations will continue. On the far right the integrated flux of the Planck distribution product with CO_2 transmittance will be used to calculate the global transmittance. The transmittance and surface temperature are given.

Column D can be altered to calculate T_{atm}

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	0.01	0	opt path per ppm	ppm CO2	opt path	A_rel	spherical trans	flux corr	transmittance	temperature	planck dist	planck dist times trans		
2	0.02	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	2.9871E-09	2.9871E-09		
3	0.03	0.00E+00	234972	5.60E-04	[illegible]	0.00E+00	1	1.00E+00	1.00E+00	288	6.72082E-09	6.72082E-09	Flux (W/m^2)	
4	0.04	0.00E+00	234972	5.60E-04	[illegible]	0.00E+00	1	1.00E+00	1.00E+00	288	1.19478E-08	1.19478E-08	391.1931453	
5	0.05	0.00E+00	234972	5.60E-04	1.32E+02	[illegible]	1	1.00E+00	1.00E+00	288	1.8668E-08	1.8668E-08	Ground	
6	0.06	0.00E+00	234972	5.60E-04	1.32E+02	0.00[illegible]	1	1.00E+00	1.00E+00	288	2.68813E-08	2.68813E-08	300.3109885	
7	0.07	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	3.65875E-08	3.65875E-08	TOA	
8	0.08	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	4.77865E-08	4.77865E-08	0.767679578	
9	0.09	0.00E+00	2349									6.04783E-08	CO2 Transmittance	
10	0.1	0.00E+00	2349									7.46627E-08	0.8	
11	0.11	0.00E+00	2349									9.03396E-08	H2O Trans (Assumed)	
12	0.12	0.00E+00	2349									1.07509E-07	288.0531885	
13	0.13	0.00E+00	2349									1.26171E-07	T_ground	
14	0.14	0.00E+00	2349									1.46324E-07		
15	0.15	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	1.6797E-07	1.6797E-07		
16	0.16	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	1.91108E-07	1.91108E-07		
17	0.17	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	2.15738E-07	2.15738E-07		
18	0.18	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	2.41859E-07	2.41859E-07		
19	0.19	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	2.69472E-07	2.69472E-07		
20	0.2	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	2.98576E-07	2.98576E-07		
21	0.21	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	3.29172E-07	3.29172E-07		
22	0.22	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	3.61259E-07	3.61259E-07		
23	0.23	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	3.94838E-07	3.94838E-07		
24	0.24	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	4.29907E-07	4.29907E-07		
25	0.25	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	4.66468E-07	4.66468E-07		
26	0.26	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	5.04519E-07	5.04519E-07		
27	0.27	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	5.44061E-07	5.44061E-07		
28	0.28	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	5.85093E-07	5.85093E-07		
29	0.29	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	6.27616E-07	6.27616E-07		
30	0.3	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	6.7163E-07	6.7163E-07		
31	0.31	0.00E+00	234972	5.60E-04	1.32E+02	0.00E+00	1	1.00E+00	1.00E+00	288	7.17133E-07	7.17133E-07		

After entering a new CO2 value selected the lower right-hand corner and double click. This will fill the entire column and propagate the calculation to column M.

By input of a series of values of CO_2 ppm in column D one can obtain both transmittance and temperature for each value. The spectra above and series of temperatures and transmittances have also been calculated using Python.

One issue is the length of the files. Typical HITRAN files have tens of thousands of spectral transitions and when given broadening and Gaussian or Lorentzian form the files have circa 250,000 points to have a resolution of 0.01 cm^{-1}.

In practice we were unable to implement python scripts for 250,000 points. We used 25,000 points and repeated all above spreadsheet calculations with 25,000 points (and a resolution of 0.1 cm^{-1}. Given a broadening of γ = 0.1 cm^{-1} the resolution is a real concern.

The Python scripts are functional using 25,000 points. By eye the spectra, transmittance and so on appear identical. However, the numerical values of the depends on CO_2 ppm are approximately 50% smaller for the 0.1 cm^{-1} spacing compared to the 0.01 cm^{-1} spacing.

Goal of the spreadsheet is to calculate global transmittance and temperature changes as a function of CO_2 ppm