Improved Solar Reference Spectrum

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Abstract. An empirical solar linelist has been developed containing over 40,000 lines covering the 600-25000 cm^{-1} region. This linelist, together with a subroutine that encodes a simple solar lineshape basis function, can be used to generate high-resolution solar pseudo-transmittance spectra, to support analysis of remote sensing observations of the earth using sunlight.

Input Spectra

Fitted 29 different high-res FTS spectra:

- ATMOS Shuttle: 600-4800 cm^{-1}
- MkIV balloon: 650 5650 cm^{-1}
- DU balloon: 12900-13200 cm^{-1}
- Kitt Peak: 3800-25000 cm^{-1}
- Park Falls: 3900-15000 cm^{-1}

Instrument	Spectrum	Altitude (km)	SZA (deg.)	MOPD (cm)	FOVO (rads)	NU_s (cm^{-1})	NU_f (cm^{-1})	ΔV (cm^{-1})
MkIV	1992_258.600	39.16	36.4	64.5	.0040	625	5700	0.007533
MkIV	2011_267.600	39.44	37.5	56.8	.0040	625	5700	0.007533
ATMOS	1985_sl3.1	329.5	00.0	48.9	.0014	450	1500	0.007533
ATMOS	1985_sl3.2	329.5	00.0	48.9	.0010	950	2000	0.007533
ATMOS	1985_sl3.3	329.5	00.0	48.9	.0010	1350	3800	0.007533
ATMOS	1985_sl3.4	293.7	00.0	48.9	.0010	2650	4850	0.005022
ATMOS	1994_at3.f09	316.6	00.0	48.9	.0020	450	2800	0.007533
ATMOS	1994_at3.f12	293.7	00.0	47.0	.0040	450	1500	0.007533
ATMOS	1994_at3.f03	329.5	00.0	48.9	.0010	1350	3800	0.007533
ATMOS	1994_at3.f04	293.7	00.0	48.9	.0028	2650	4850	0.005022
Denver U	20000707.794	33.3	79.4	20.0	.0050	12930	13250	0.015066
Kitt Peak	901218R0.003	2.09	81.6	35.0	.0000	3800	8900	0.009477
Kitt Peak	901218R0.006	2.09	55.7	35.0	.0000	3800	8900	0.009477
Kitt Peak	810509R0.004	2.09	14.6	35.0	.0000	4000	9000	0.009477
Kitt Peak	810509R0.005	2.09	70.4	35.0	.0000	4000	9000	0.009477
Kitt Peak	830627R0.003	2.09	72.1	34.1	.0000	8000	14200	0.007327
Kitt Peak	830627R0.004	2.09	11.6	34.1	.0000	8000	14200	0.007327
Kitt Peak	790401R0.008	2.09	35.4	18.3	.0000	12000	18600	0.018152
Kitt Peak	830619R0.003	2.09	66.7	7.5	.0000	12500	25000	0.025078
Kitt Peak	830619R0.005	2.09	86.9	7.5	.0000	12500	25000	0.025078
Kitt Peak	820928R0.001	2.09	34.1	78.3	.0092	3000	6000	0.006075
Kitt Peak	830619R0.001	2.09	14.2	17.1	.0092	12000	19200	0.019440
Kitt Peak	830620R0.010	2.09	15.7	13.0	.0092	8600	24400	0.025515
Kitt Peak	830621R0.023	2.09	9.5	11.7	.0092	8400	24400	0.025515
Kitt Peak	830805R0.005	2.09	20.9	6.0	.0092	4000	14000	0.014459
Kitt Peak	850408R0.001	2.09	25.4	51.0	.0092	4700	7800	0.004070
Kitt Peak	871014R0.011	2.09	42.2	26.3	.0092	8800	14000	0.014216
Kitt Peak	881026R0.010	2.09	76.4	17.0	.0092	4100	14500	0.014665
Park Falls	20050308	0.44	53.4	45.0	.0024	4000	15000	0.007533

Spectra listed above used to derive solar linelist

List include both disk-center (ATMOS, MkIV, DU, KP) and disk-integrated (KP).

Approach is to fit all spectra simultaneously, using an accurate LBL model of the telluric gas absorption spectrum (GFIT). Spectra include low- and high-SZA, allowing attribution of missing absorptions: telluric or solar.

Solar Model/Linelist

Assumed Solar Line Shape

The solar pseudo transmittance is calculated from the equation

$$T(v) = R(v) + [1-R(v)] \,.\, \mathrm{Exp}[-\Sigma_i\, s_i\, f(v-v_i)]$$

s is line-center absorbance

$f(v-v_0)$ is solar line shape

R is the ratio of Planck functions at the 4200K solar T-minimum (~500 km above the sun's surface), and at the ~5800K surface (τ=1)

$$f(v-v_0) = \mathrm{Exp}[-(v-v_0)^2/\sqrt{\{d^4+w^2.(v-v_0)^2\}}]$$

v_0 is the solar line center frequency (cm^{-1})

w is the 1/e folding width (cm^{-1})

d is the Doppler width (cm^{-1})

Near line center, $(v- v_0)^2 w^2 << d^4$

$$f(v-v_0) = \mathrm{Exp}[-((v- v_0)/d)^2] \quad \text{(Doppler)}$$

In far line wing limit, $(v- v_0)^2 w^2 >> d^4$

$$f(v-v_0) = \mathrm{Exp}[-|v- v_0|/w] \quad \text{(Exponential)}$$

Center-to-Limb Variations

s,w,d are assumed to vary as follows:

$$s = u^2.s_{DI} + (1-u^2).s_{DC}$$
$$w = u^2.w_{DI} + (1-u^2).w_{DC}$$
$$d = u^2.d_{DI} + (1-u^2).d_{DC}$$

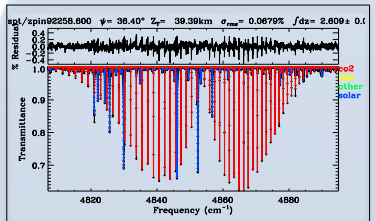
DC subscript represent Disk Center case

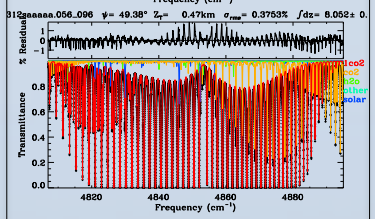
DI subscript represent Disk Integrated case

u is fraction of solar diameter observed

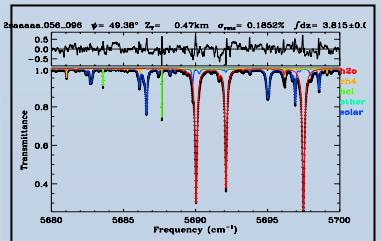
7 parameters per line ($v_0\, s_{DI}\, s_{DC}\, w_{DI}\, w_{DC}\, d_{DI}\, d_{DC}$) are derived and stored in linelist.

Validation of Solar Reference Spectrum





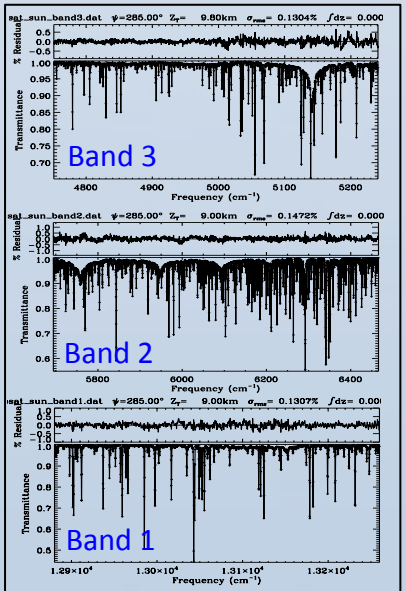
Spectrum from 39 km (top) allows better characterization of solar lines than spectrum from surface (bottom)



Fit to Park Falls TCCON spectrum from March 2009 at SZA = 49° under cold, dry conditions (-12C, 43%).

Instrument	Spectrum	Altitude (km)	SZA (deg.)	MOPD (cm)	FOVO (rads)	NU_s (cm^{-1})	NU_f (cm^{-1})	ΔV (cm^{-1})
MkIV	2014_256	38.76	31.7	56.8	.0040	625	5700	0.007533
Kitt Peak	irradres1920.rev	∞	0.0	40.0	.0092	4800	5200	0.006075
Kitt Peak	irradres1560.rev	∞	0.0	60.0	.0092	5750	6400	0.004070
Kitt Peak	irradthuwn.dat	∞	0.0	25.0	.0092	9991	33365	0.010000
ACE	Hase et al. [2010]	650.0	00.0	25.0	.0013	700	4430	0.005000
GOSAT	sun_band3	675.00	0.0	2.5	.0092	4750	5300	0.199479
GOSAT	sun_band2	675.00	0.0	2.5	.0092	5650	6500	0.199479
GOSAT	sun_band1	675.00	0.0	2.5	.0092	12800	13300	0.199479
SAO	2010_solref	∞	0.0	2.4	.0092	9990	49980	0.100000
Park Falls	20090312	0.44	49.4	45.0	.0024	4000	15000	0.007533

Spectra above used to validate solar linelist



Fits to GOSAT diffuser plate spectra, (disk-integrated) after correcting for earthshine and zero level offset (Band 1).

Summary. Main advantages of this solar reference spectrum:

- Broad spectral coverage at high spectral resolution
- Balloon spectra characterize regions blacked out from ground
- Consistent handling of disk-center and disk-integrated cases

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