Princess Sirindhorn Neutron Monitor and Leader Fraction

Time delay histograms

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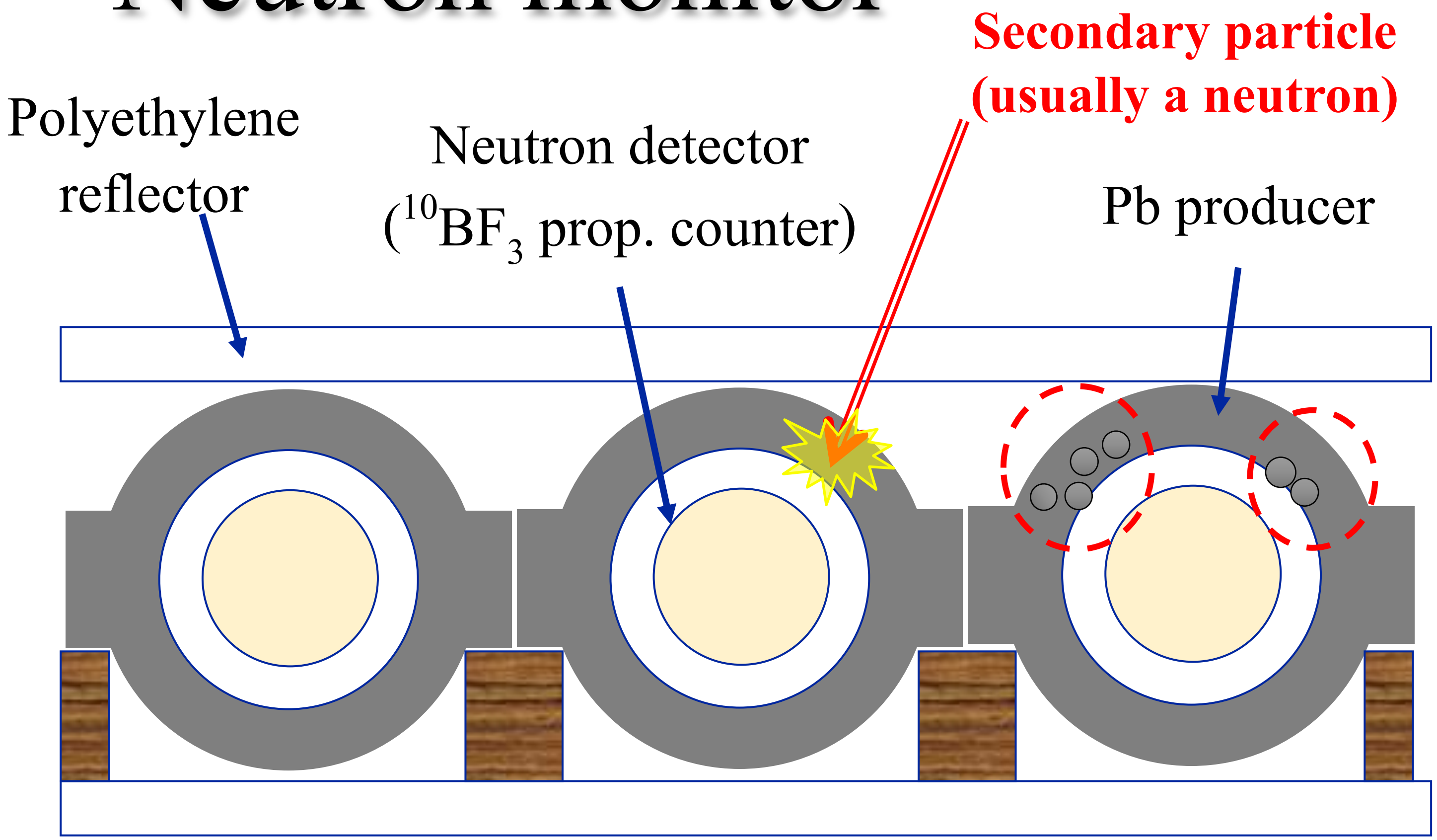
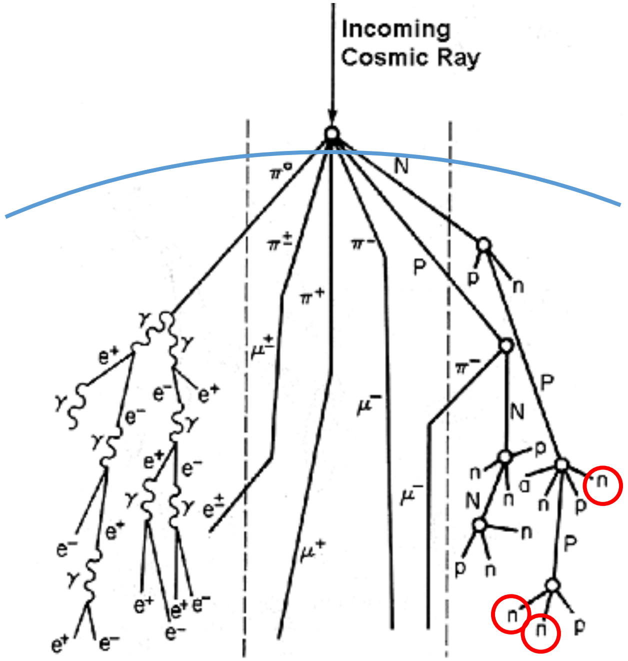
มหาวิทยาลัยเทคโนโลยีราชมงคลธัญบุรี

Neutron monitor





More energetic primary
More energetic secondary

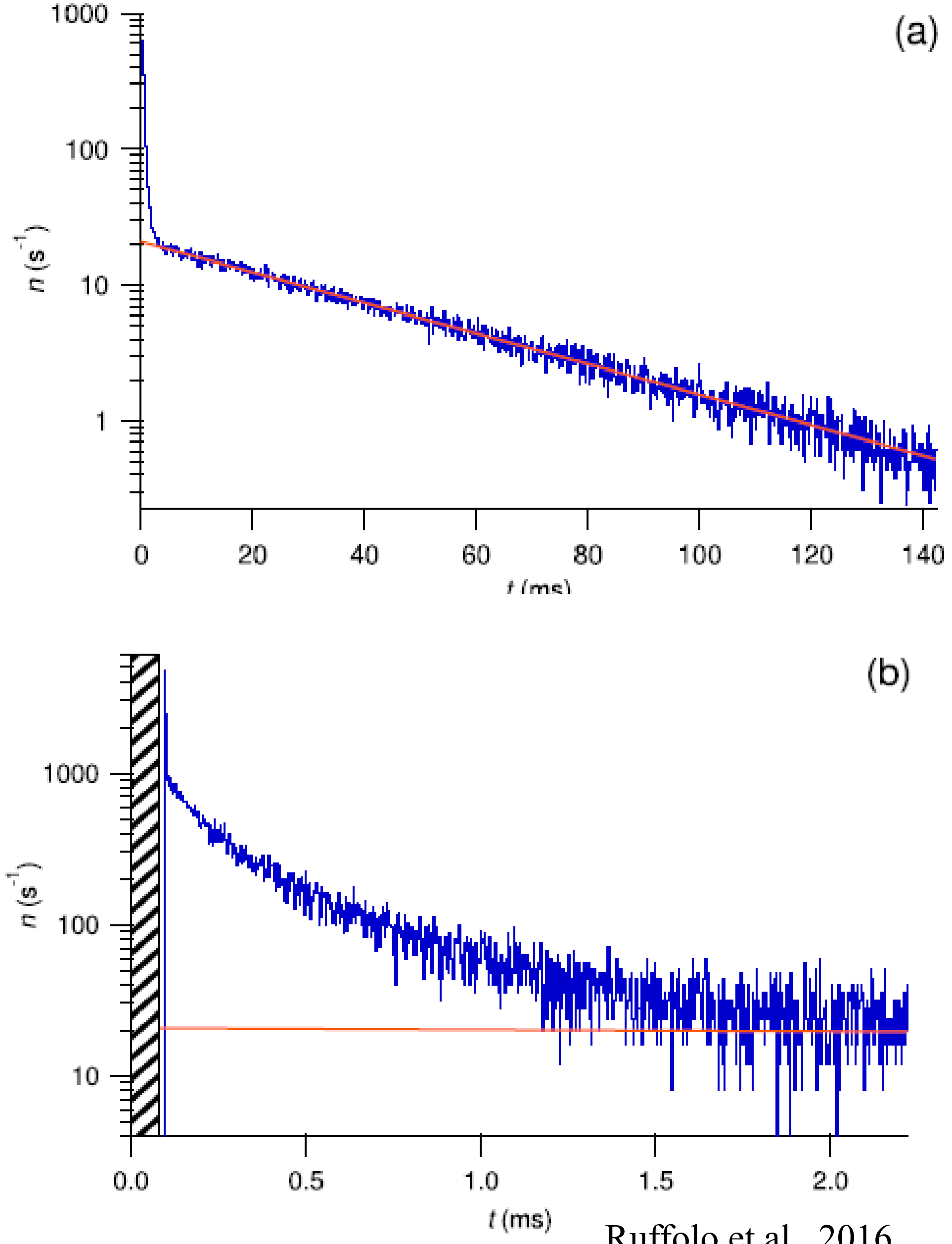
More neutrons in monitor

Higher multiplicity

Time-delay histograms

- Electronics record time delay, interval of time between one count to the next count.
- We statistically calculate the leader fraction from histograms of time delay, related to cosmic ray spectral index.
- Amplitude of exponential tail (red) indicates rate of "leaders" arriving by chance, not "following" in temporal association with preceding count.

L = "leader fraction" (inverse multiplicity)



Ruffolo et al., 2016

Time-delay histograms

- We calculate the leader fraction from histograms of time delay.
- Time-delay is the interval of time between one count and the next count.
- For the chance coincidences only, at rate α

$$n(t) = \alpha e^{-\alpha(t-t_d)}$$

- Let $R(t)$ be the survival probability of no new counts in one counter tube over the time delay t.
- The dead time t_d is the time when electronics would not record time delays.
- R_n the survival probability that no new neutrons from nuclear interactions of the same cosmic ray arrive within time delay t. Then ..

$$n(t) = -\frac{dR}{dt} = \left(\alpha R_n - \frac{dR_n}{dt}\right)e^{\alpha(t-t_d)}$$

$R(t_d) = 1$ and at time $t > 5$ ms then …

$\frac{dR_n}{dt} = 0$ and $R_n(\infty) = L$

$$n(t) = \alpha L e^{-\alpha(t-t_d)}$$

We can fit the exponential tail of the distribution to measure L.

Ruffolo et al., 2016

Extraction of Leader Fraction

We use the fitting exponential tail parameters to calculate *L.*

$$L = \frac{1 - e^{-\alpha \mathrm{t_o}}}{\alpha e^{\alpha t_d}}$$

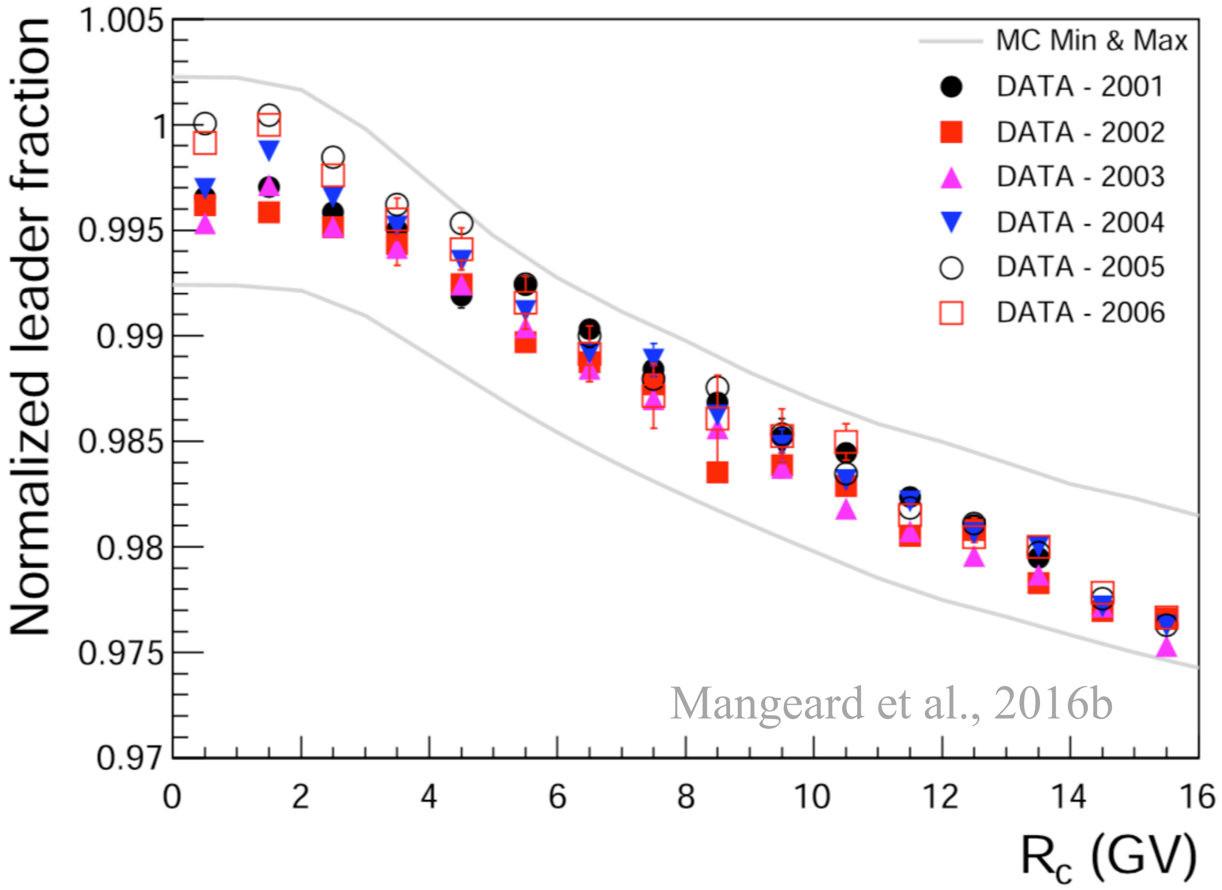
where $t_o = 142$ ms is when time delay was recorded modulo. This affected to the 600- and 700-series firmware.

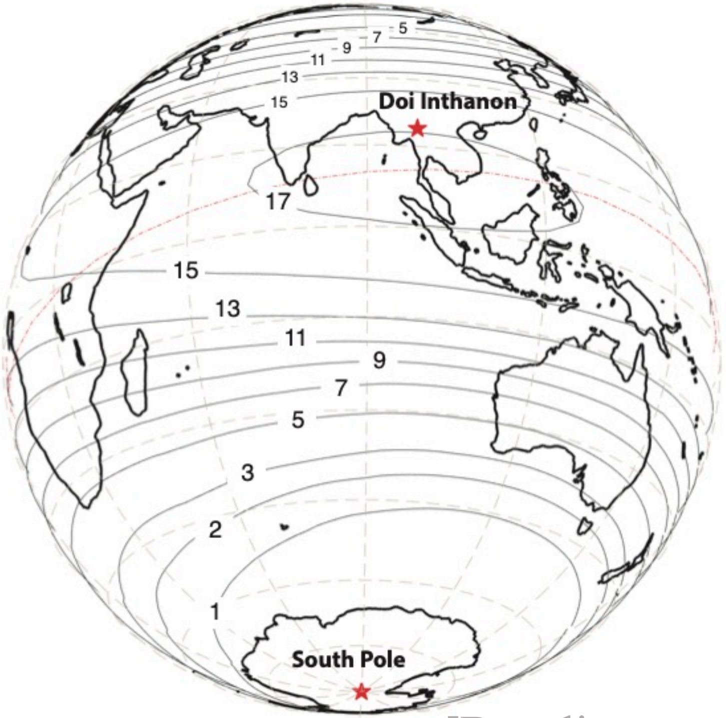
For 800-series firmware, a count was excluded from the histogram when time delay was larger than t_o

$$L = \frac{A}{\alpha e^{\alpha t_d}}$$

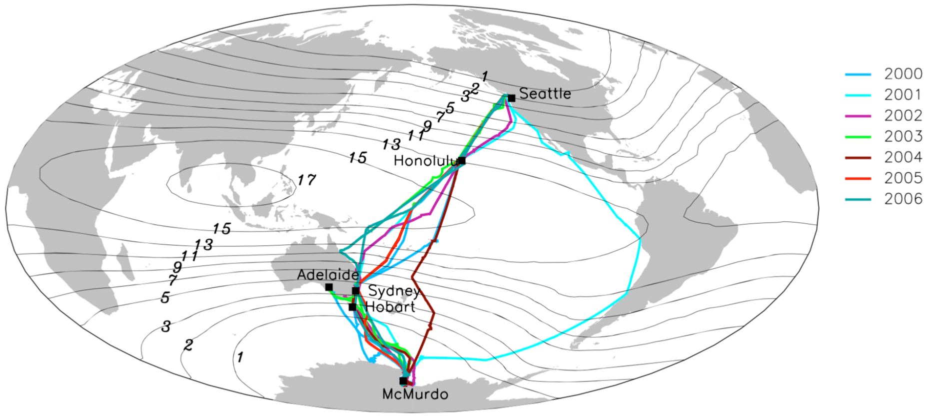
Leader fraction & cosmic ray spectrum …

... from a ship-borne latitude surveys 2000 - 2007



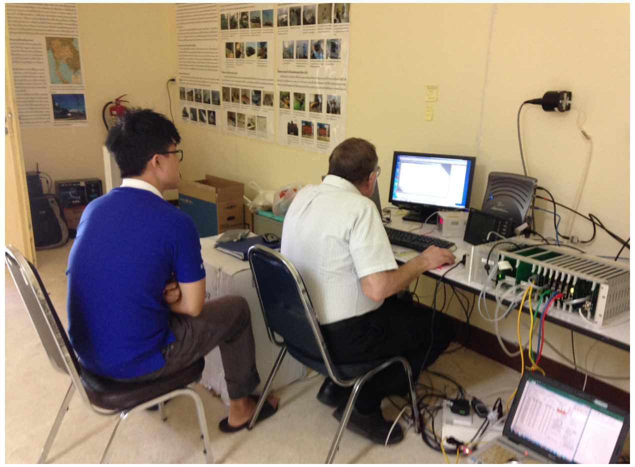


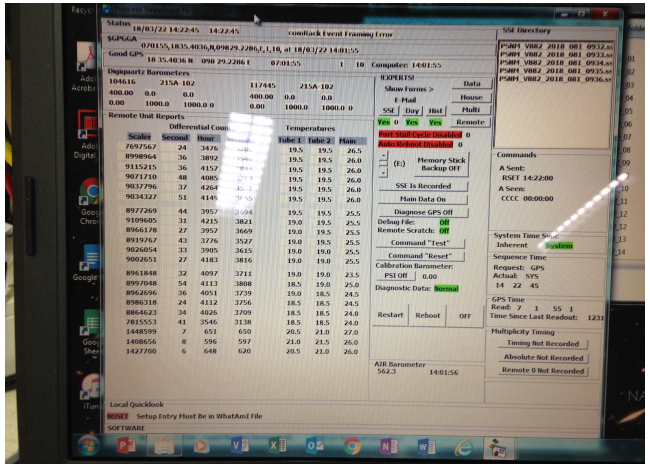
[Banglieng et al., 2020]



[Mangeard et al., 2016b]

Field trip Doi Inthanon March 19-23, 2018





Neutron Time-delay Observation at Doi Inthanon

Normalization period	Start date	End date	Cadence	Firmware series	Software Version
1a	2007 Dec 9	2009 Jun 28	Daily	600 (18)	-
1b	2009 Jun 29	2011 Jan 15	Hourly	600 (18)	-
2	2011 Jan 15	2014 Feb 8	Hourly	700 (18)	-
3	2014 Feb 8	2014 Jun 11	Hourly	700 (17)	-
4a	2014 Jun 11	2014 Dec 6	Daily	800 (18)	Before 8.46
4b	2014 Dec 7	2015 Mar 3	Hourly	800 (18)	8.46, 8.47
5	2015 Mar 3	2015 May 30	Hourly	800 (18)	8.50
6a	2015 May 31	2016 May 17	Hourly	600 (6), 800 (12)	8.50-8.82
6b	2016 May 18	2016 Jun 30	Hourly	600 (6), 800 (12)	8.82
7	2016 Jun 30	2017 Jun 12	Hourly	800 (18)	8.82
8	2017 Jun 12	2017 Aug 3	Hourly	600 (6), 700 (6), 800 (6)	8.91-8.93
9	2017 Aug 3	2018 Apr 19	Hourly	800 (18)	8.93 - 8.124

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	A	B	C	D	E	F	G	H	I	J
1	From:	LandBase								
2	To:	Cosray								
3	Subject:	C:\LandBase\Histograms\SP_H19_01_01_01.HIS								
4										
5	Note:	These	data	are	from	SPCosRay01	(RP	180420)		
6	Program:	Land	Monitor	Version	8.126	Modified	at:	Wilson	Roadl	4/4/18
7	Hour	Pressure	Average:	514.2						
8	HHK000:	4589	2066	1298	-11.96	11.84	4.98	-11.5	-11	-1
9	HHK100:	8706	2066	1306	-11.98	11.87	5.02	-13	-12.5	-2
10	HHK200:	19969	2064	1298	-11.82	11.82	4.98	-11	-11	-1
11	HHK300:	52522	23209	1298	-11.96	11.87	4.99	20.5	21	27.5
12	HHK301:	30681	8422	1289	-11.9	11.82	4.98	21	21	27.5
13	HHK302:	52516	64978	1298	-11.93	11.87	4.96	20.5	21	27
14	HHK303:	30681	6042	1289	-11.9	11.84	4.99	21	21	27
15	HHK304:	30681	4335	1298	-11.93	11.84	4.98	21	21	27.5
16	HHK305:	50949	31042	1314	-11.93	11.82	5.03	22.5	22.5	28
17	HHK400:	30674	32640	1314	-11.79	11.76	5.01	20.5	21.5	26.5
18	HHK401:	52526	17955	1289	-12.01	11.93	4.94	21.5	21	27
19	HHK402:	30681	13016	1298	-11.96	11.93	4.98	21.5	21	27
20	HHK403:	52526	15275	1289	-11.84	11.73	4.99	21.5	21	27
21	HHK404:	52516	63707	1289	-11.93	11.73	4.99	21.5	21	27
22	HHK405:	49565	25109	1289	-11.98	11.84	4.96	22.5	23	29
23										

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
24	Event	Histograms:																				
25	CHANNEL	UPHA000	SPHA000	UPHA100	SPHA100	UPHA200	SPHA200	UPHA300	SPHA300	UPHA301	SPHA301	UPHA302	SPHA302	UPHA303	SPHA303	UPHA304	SPHA304	UPHA305	SPHA305	UPHA400	SPHA400	UPHA401
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27	0	2199	0	2168	0	1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
28	1	543	0	566	0	590	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	
29	2	397	0	444	0	407	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	
30	3	361	0	395	0	347	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
31	4	317	0	372	0	360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	5	384	0	366	0	358	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
33	6	415	0	403	0	457	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
34	7	621	0	615	0	752	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
35	8	531	0	594	0	619	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	
36	9	529	0	545	0	654	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	
37	10	500	222	595	107	628	472	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
38	11	233	1199	261	862	232	1963	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
39	12	190	2915	208	2386	175	3736	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
40	13	159	4380	160	4149	158	4682	0	0	0	0	1	0	0	0	0	0	0	0	2	0	
41	14	150	4864	141	4779	159	4775	0	0	0	0	0	0	0	0	0	0	1	0	0	0	

SP_H19_01_01_01

100%

	305	SMPS305	UMPS400	SMPS400	UMPS401	SMPS401	UMPS402	SMPS402	UMPS403	SMPS403	UMPS404	SMPS404	UMPS405	SMPS405	UMPL000	SMPL000	UMPL100	SMPL100	UMPL200	SMPL200	UMPL300	SMPL300
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28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10448	29514	10751	30059	10478	29411	0	0
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34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	5614	9	5599	16	5316	0	0
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37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	4081	18	4164	10	3835	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	3759	12	3704	11	3533	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3463	6	3533	18	3306	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3240	15	3379	6	3125	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3216	7	3330	10	3129	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	3185	6	3158	13	2972	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3012	12	3064	8	2917	0	0
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52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	2634	8	2693	6	2440	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2606	8	2655	7	2510	0	0
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59	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	2511	10	2498	5	2396	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2285	6	2395	4	2281	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	1	13	2384	3	2415	6	2334	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2195	4	2303	6	2245	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	2241	11	2395	5	2312	0	0
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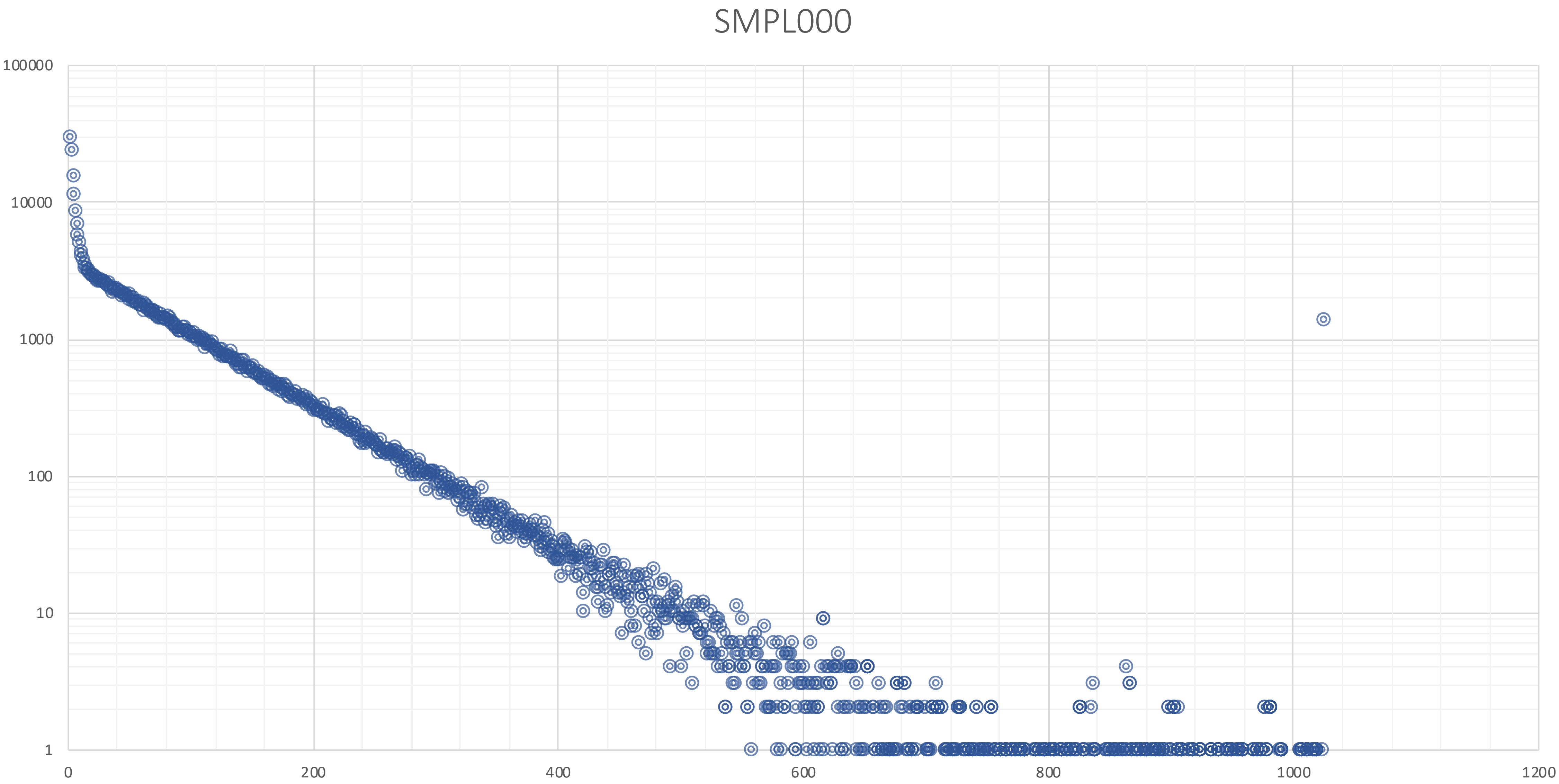
SMPL000
100000
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1
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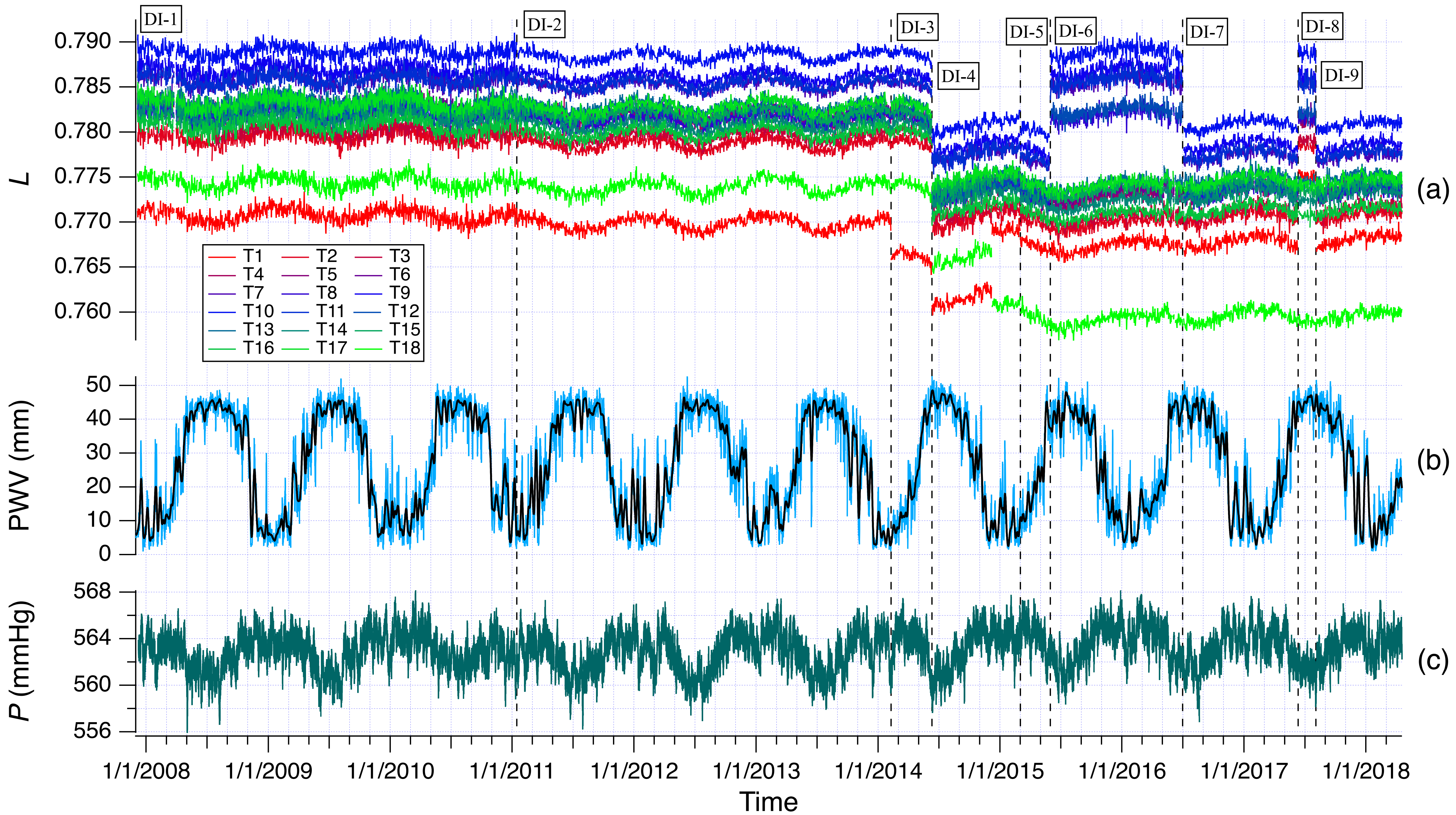
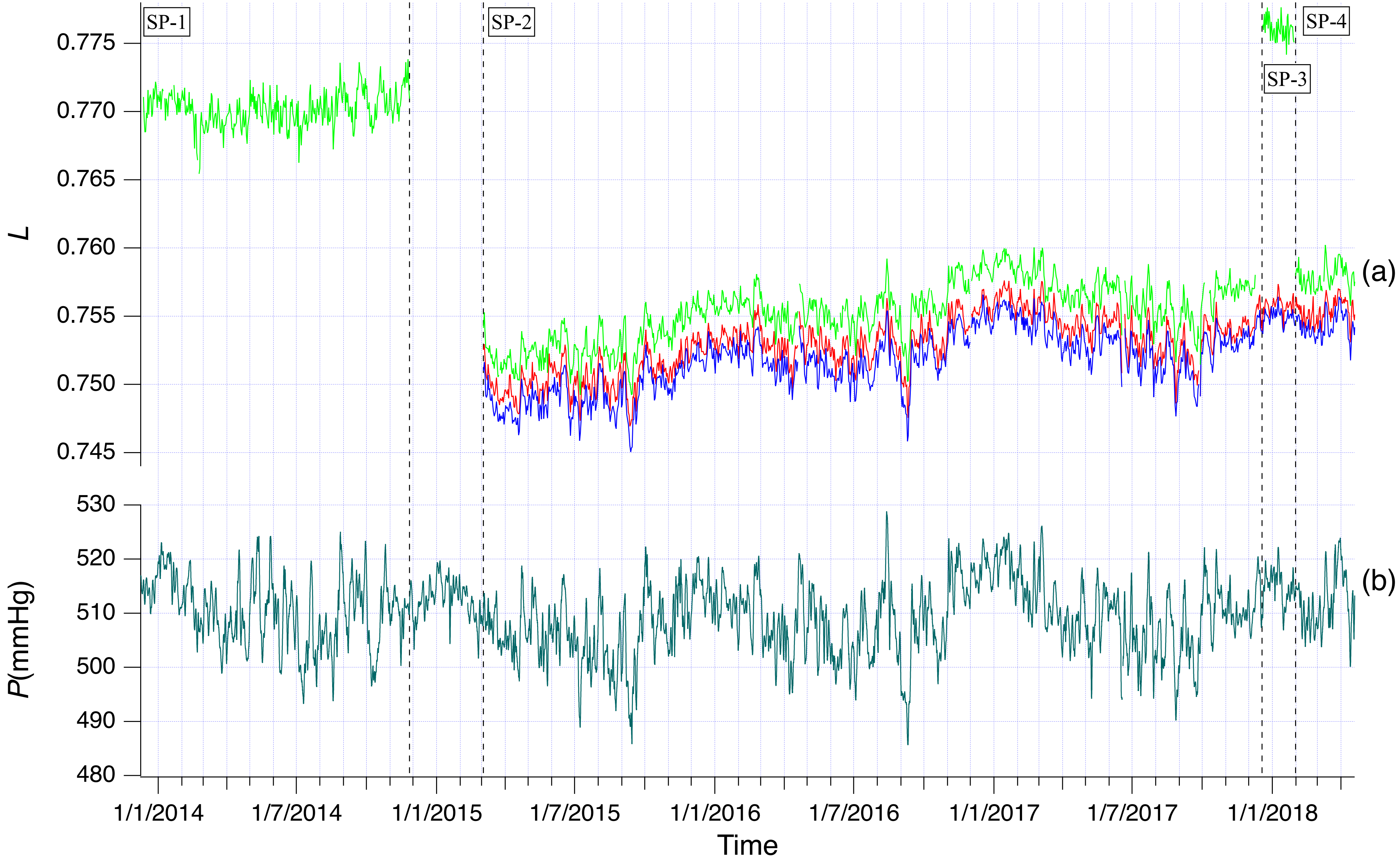
200
400
600
800
1000
1200

Uncorrected leader fraction at PSNM, Thailand



Uncorrected leader fraction at South Pole



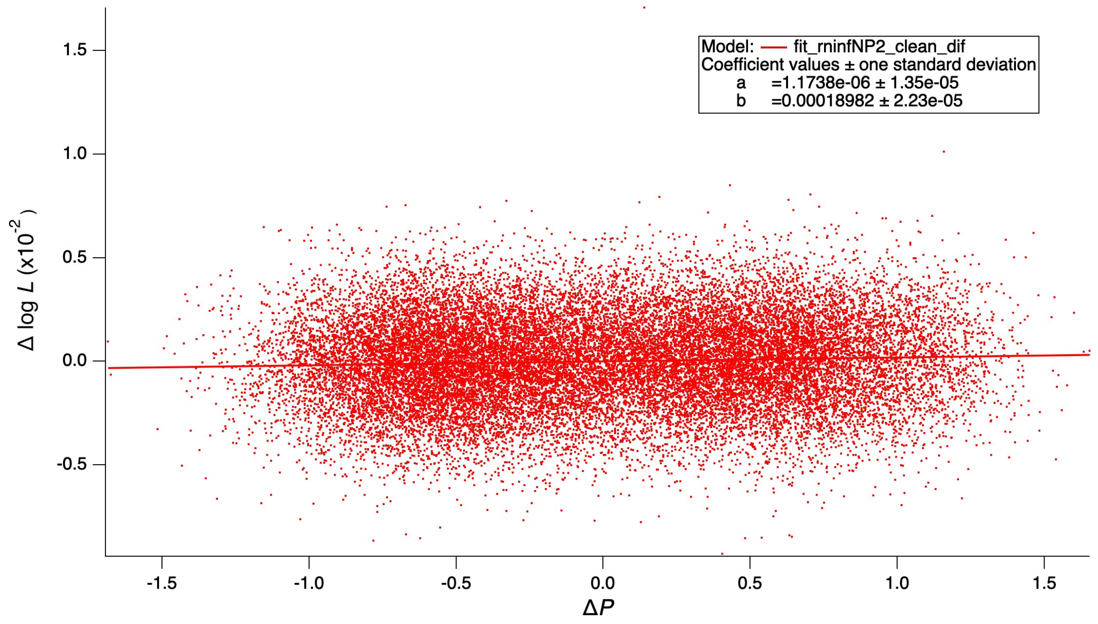
Atmospheric pressure correction

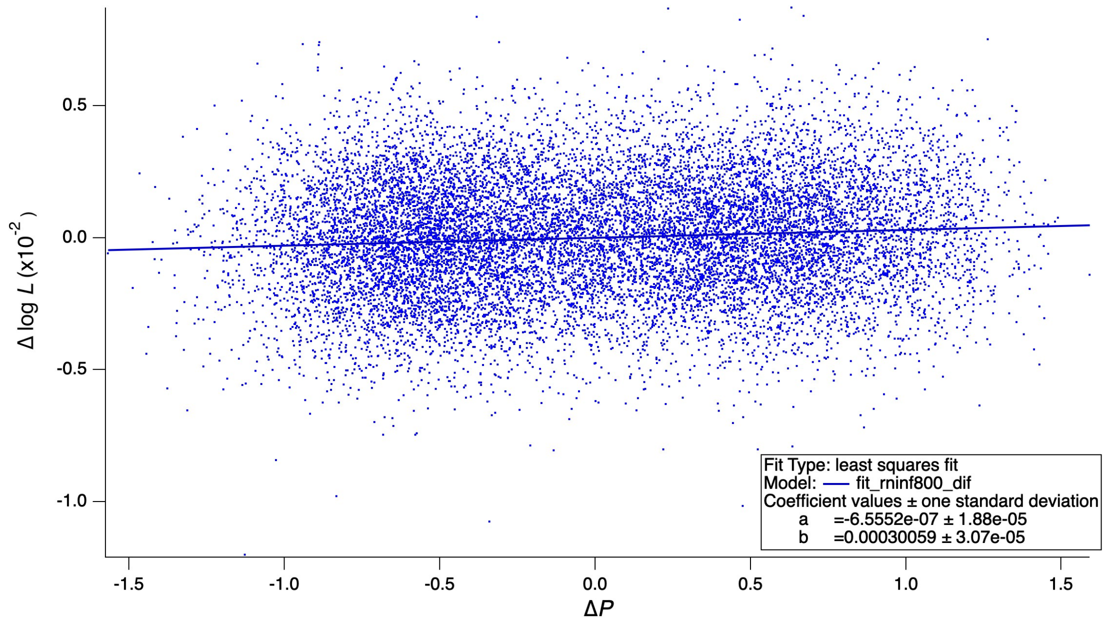
To remove the effect of the atmospheric depth, we fit vs. with a linear model.

The parameter b of that linear fit was defined as a coefficient of pressure correction.

$$L_{\text{Pcorr}} = L_{\text{Uncorr}} \exp[-b(P - P_0)]$$

P_0=563 mmHg is the reference pressure at Doi Inthanon.





Water vapor correction

Water vapor pressure: E_w

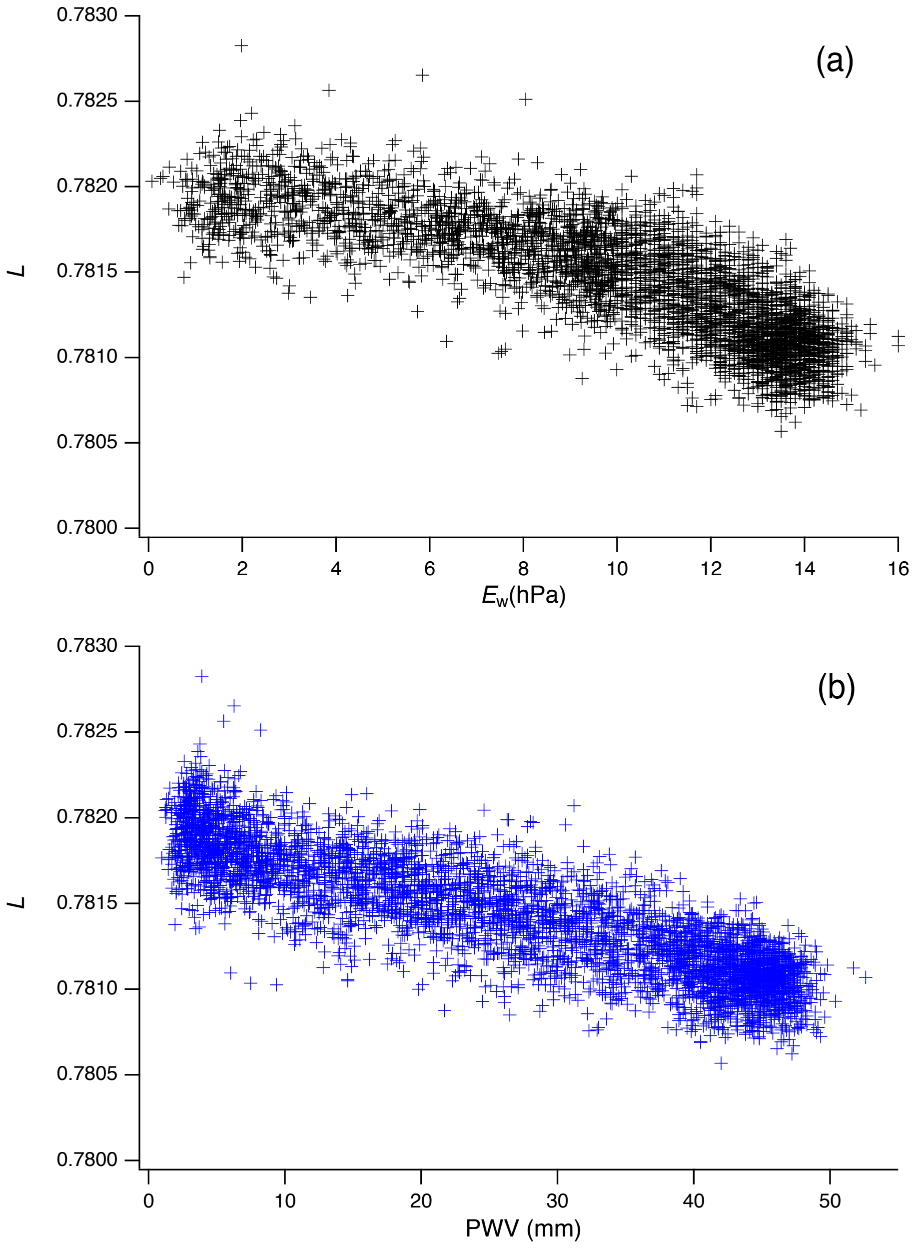
$$E_w = (6.113\ \text{hPa})\frac{RH}{100}\exp\left(\frac{17.62T}{T + 243.12}\right)$$

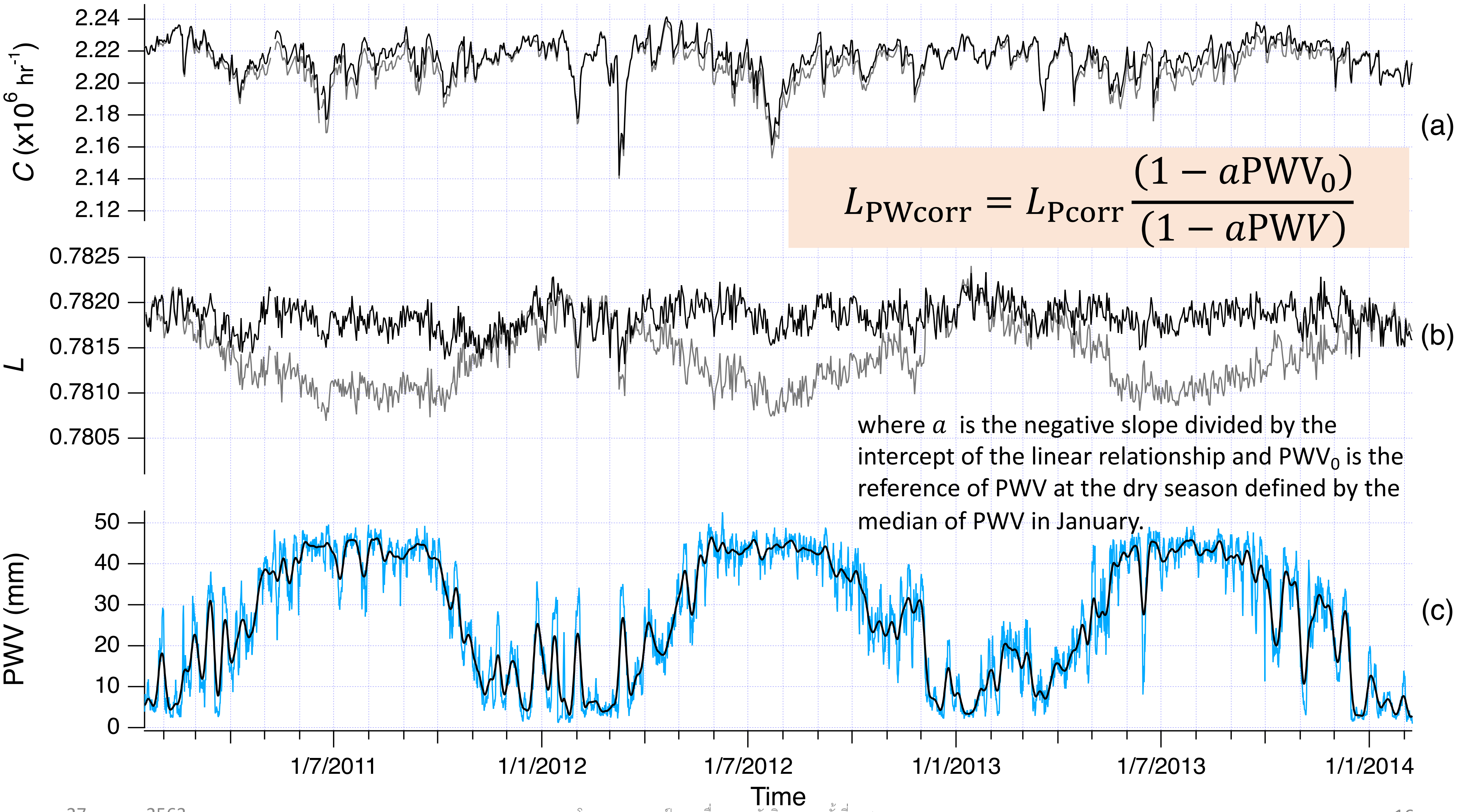
Precipitable water vapor: PWV

The vertical integral of the absolute vapor mass density which yields the column water per m^2

$$\text{IWV} = \int_0^P \frac{q}{g}\,dP \quad \Rightarrow \quad \text{PWV} = \frac{\text{IWV}}{\rho_w}$$

where $q = \frac{E_w}{p}$

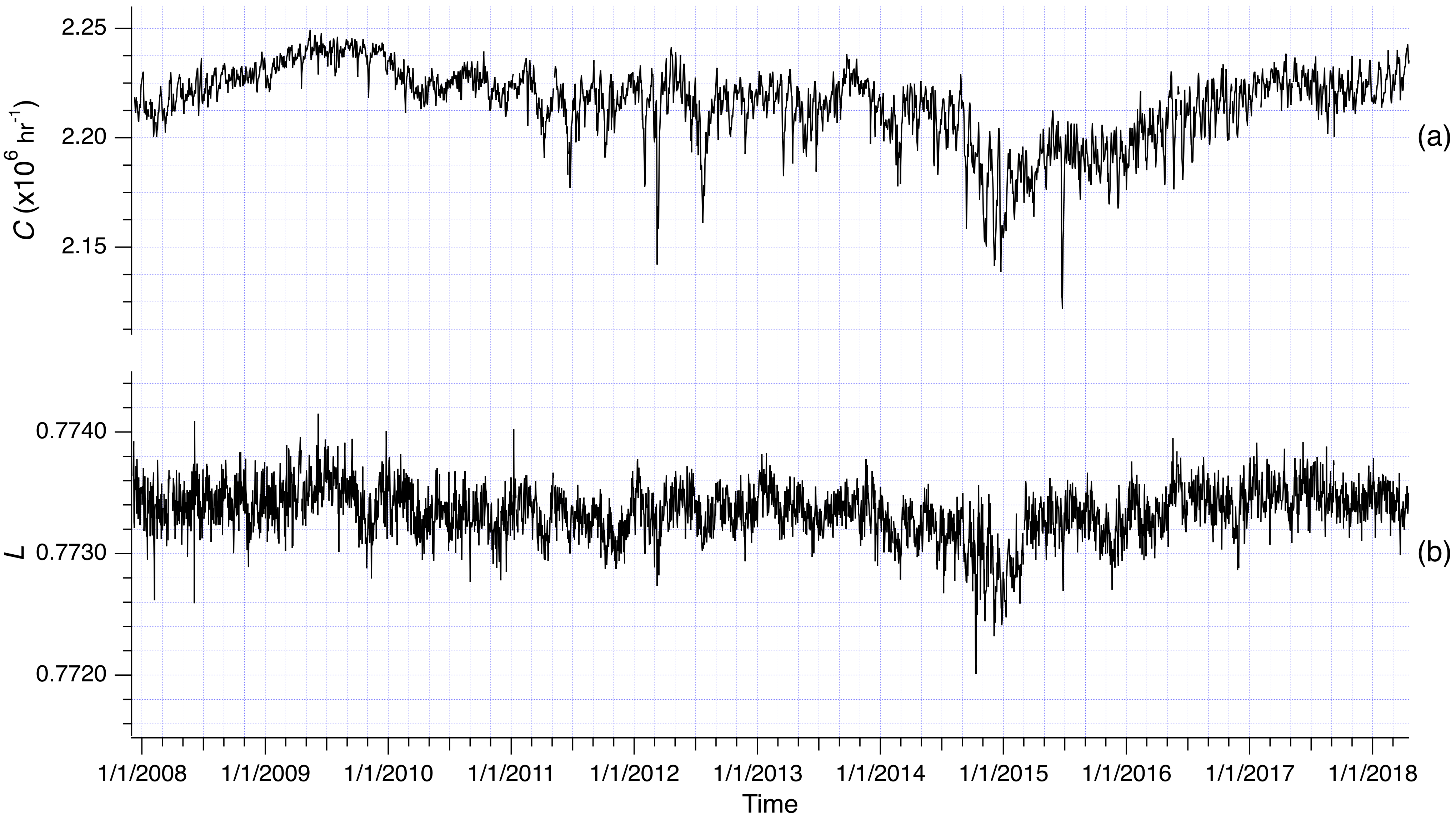




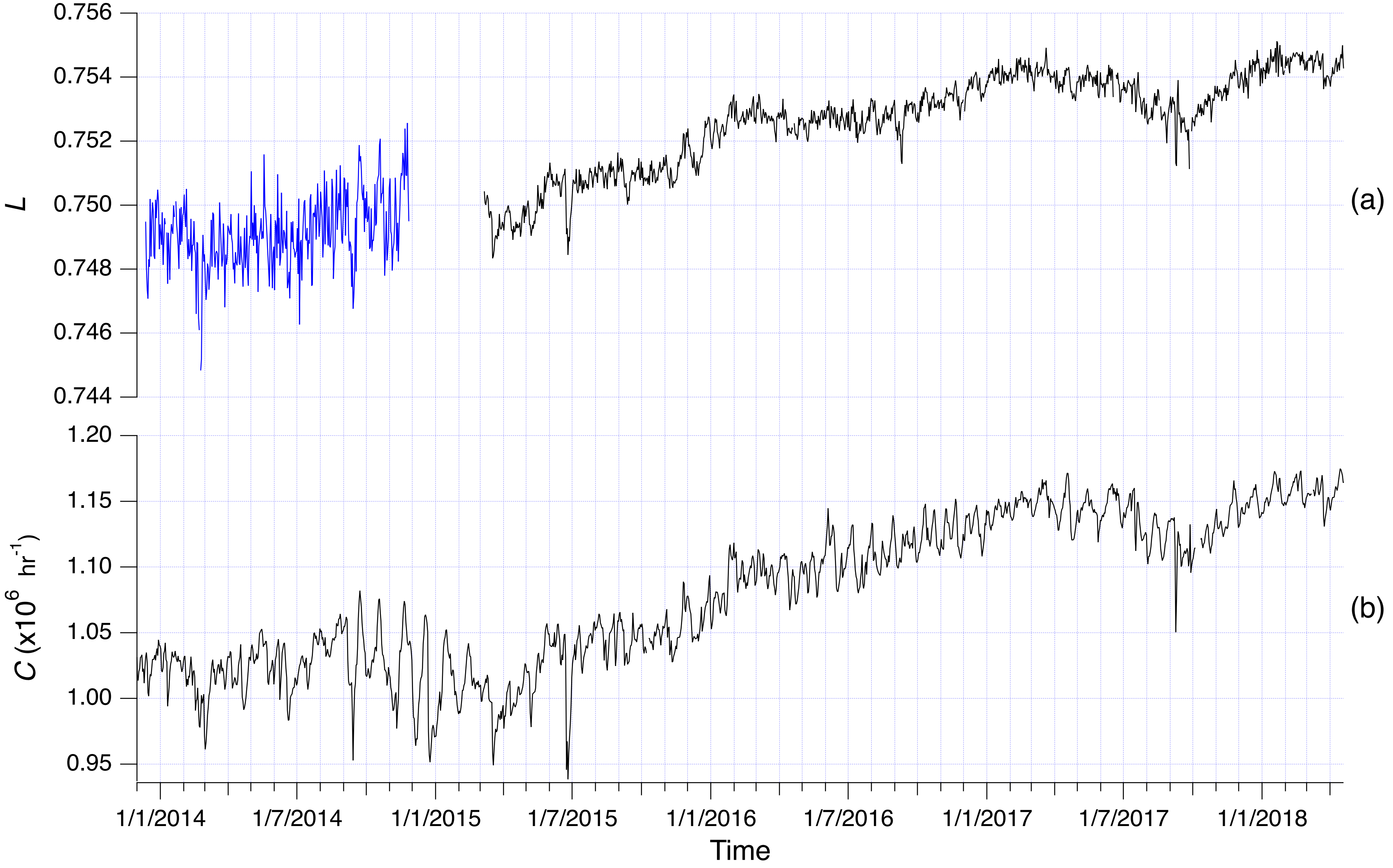
$$L_{\mathrm{PWcorr}} = L_{\mathrm{Pcorr}} \frac{(1 - a\mathrm{PWV}_0)}{(1 - a\mathrm{PW}V)}$$

where a is the negative slope divided by the intercept of the linear relationship and PWV_0 is the reference of PWV at the dry season defined by the median of PWV in January.

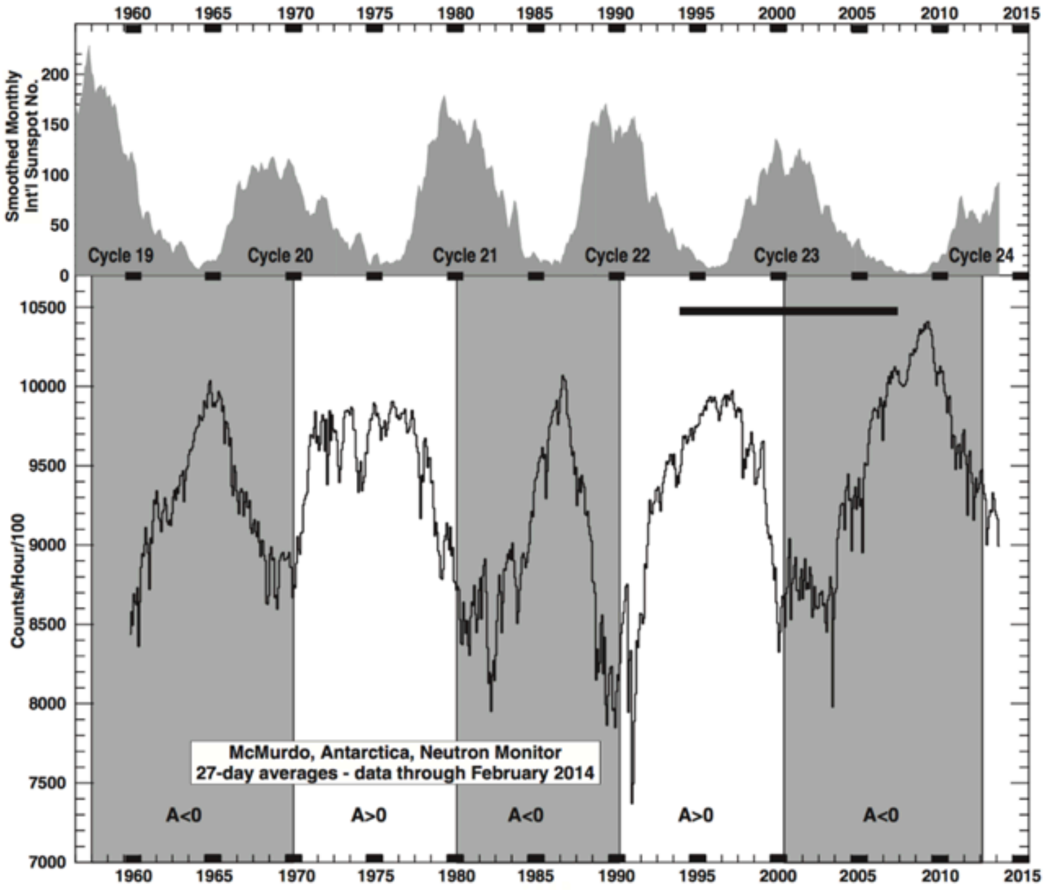
Leader fraction *L* and count rate *C* at Doi Inthanon



Leader fraction *L* and count rate *C* at South Pole

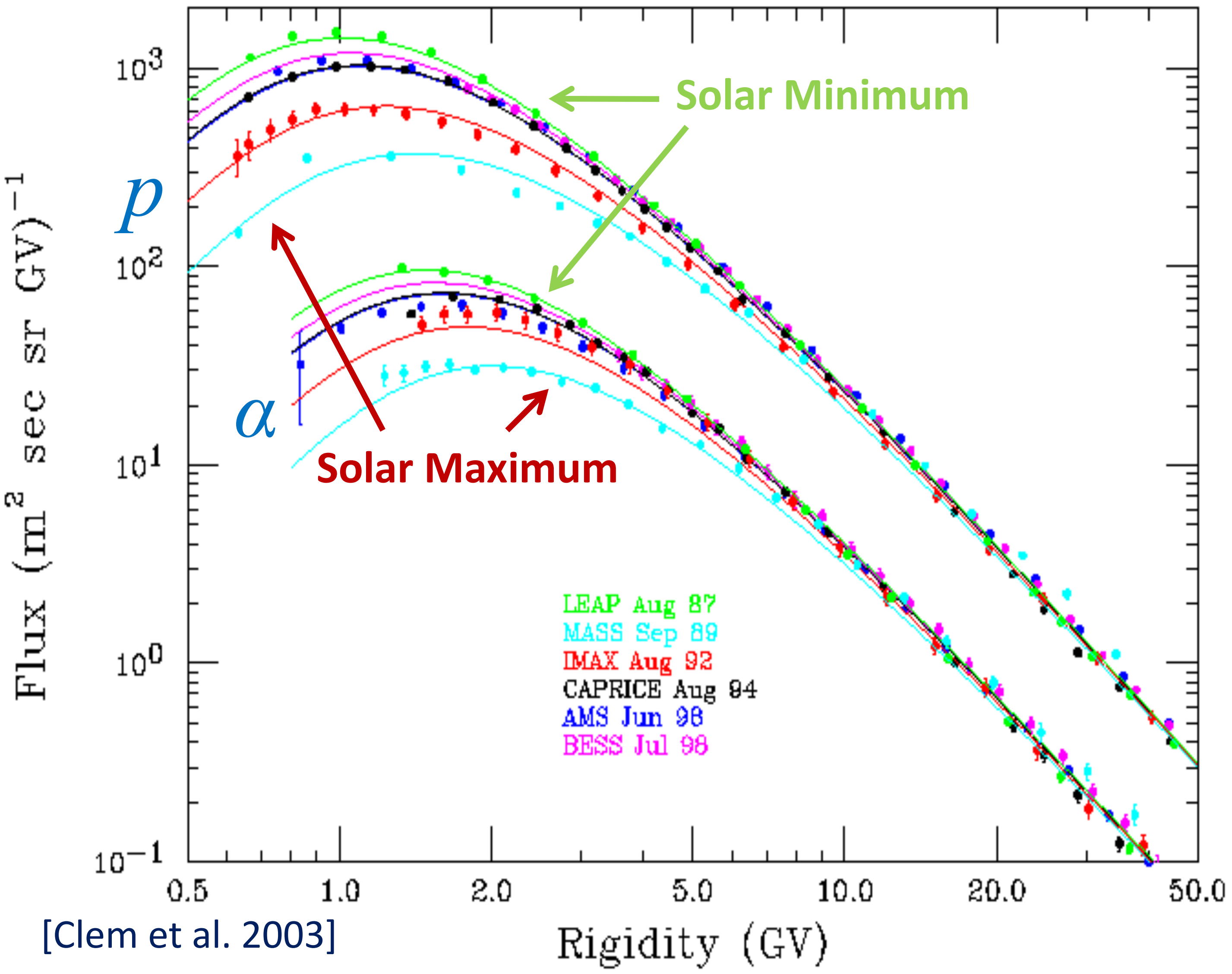


Solar modulation



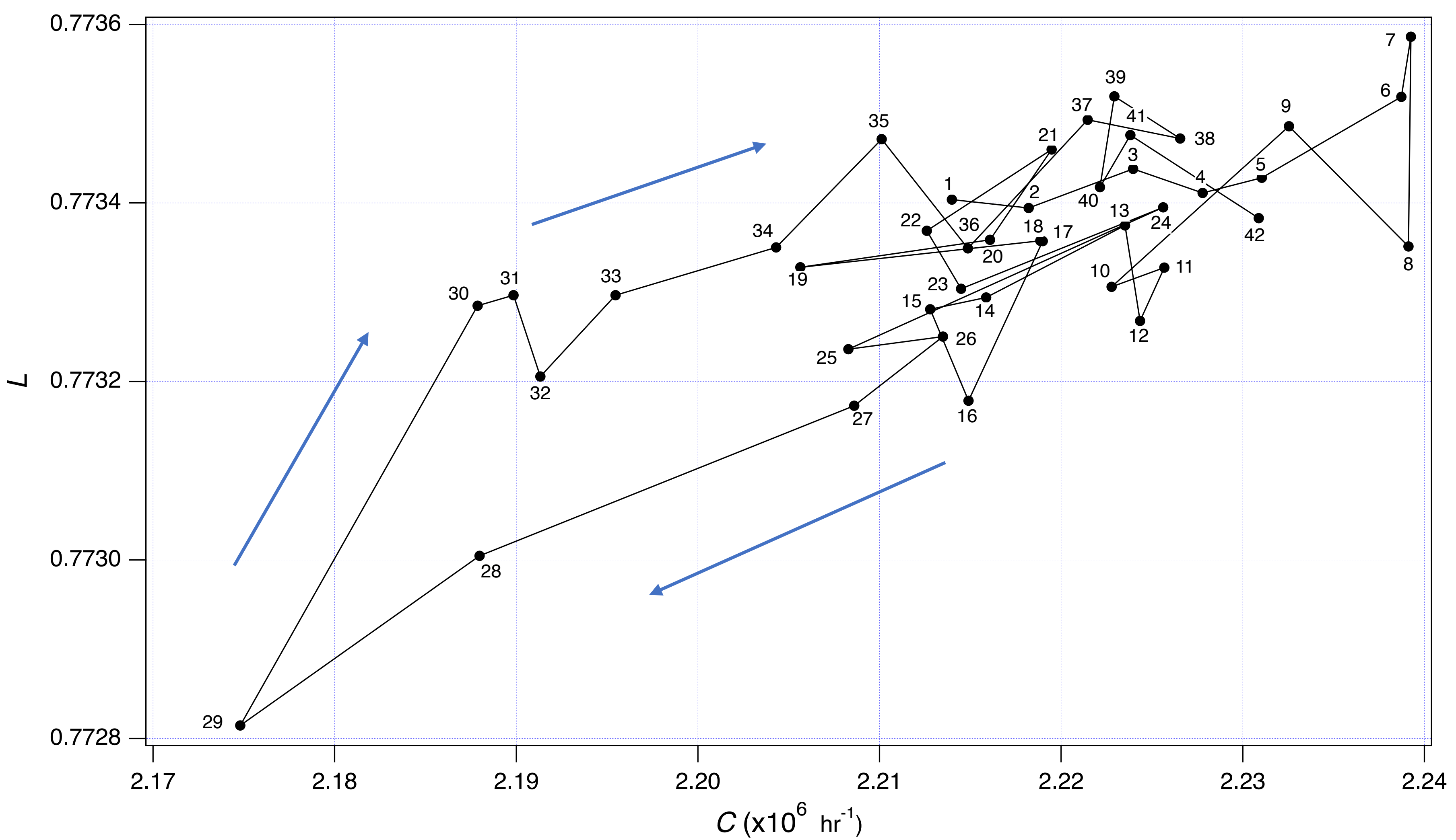
[Nuntiyakul et al., 2014]

The energy (or rigidity) spectrum of galactic cosmic rays varies with the solar cycle.

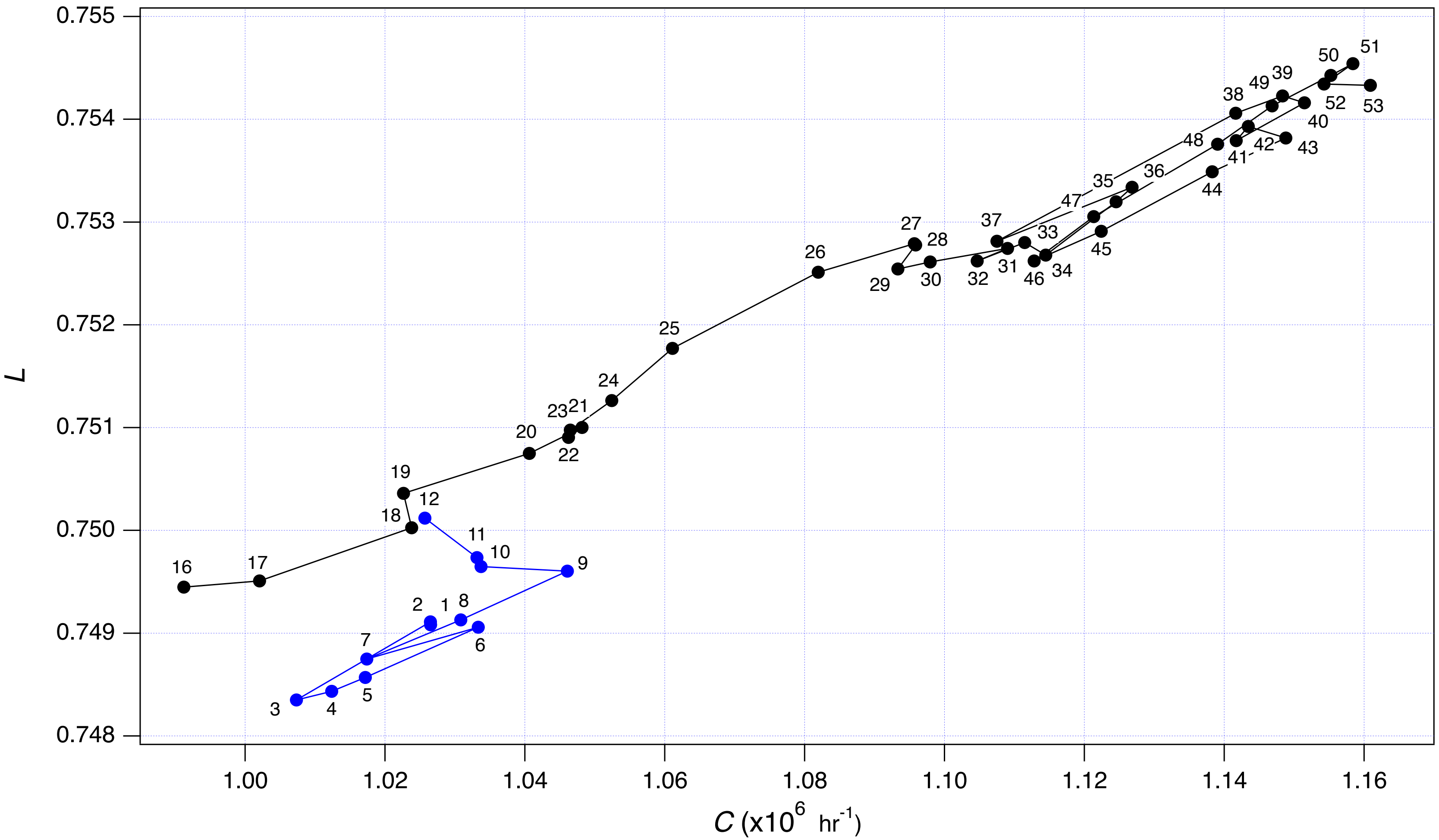


[Clem et al. 2003]

Three month averages of *L* vs. *C*, PSNM



Monthly averages of *L* vs. *C*, South Pole NM



References

- Mangeard, P.-S., Ruffolo, D., Saiz, A., Nuntiyakul, W., Bieber, J., Clem, J., et al. (2016). Dependence of the neutron monitor count rate and time delay distribution on the rigidity spectrum of primary cosmic rays. Journal of Geophysics Research, 121, 11620–11636.
- Nuntiyakul, W., Evenson, P., Ruffolo, D., Saiz, A., Bieber, J., Clem, J., et al. (2014). Latitude survey investigation of galactic cosmic ray solar mod- ulation during 19942007. Astrophysical Journal, 795.
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