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Analytic clear-sky index fluctuation correlation model

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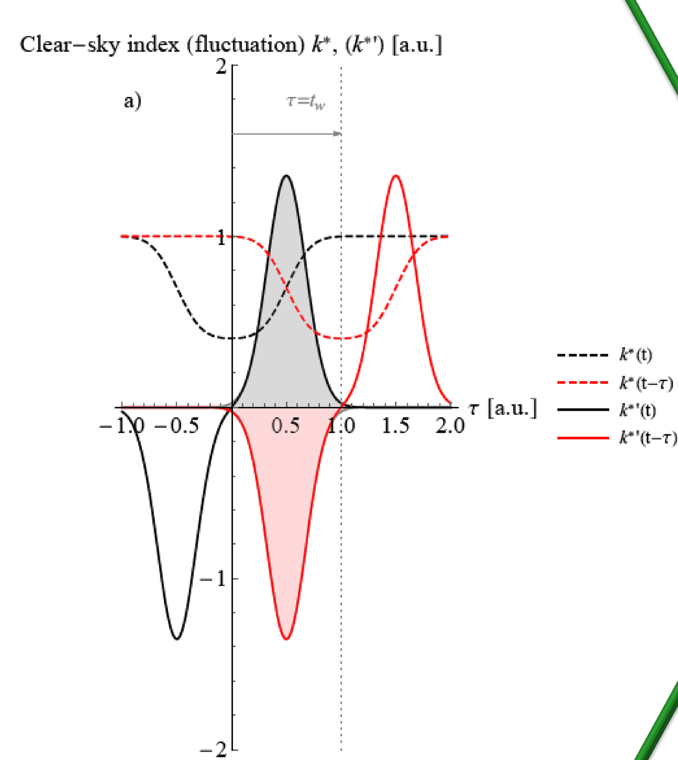
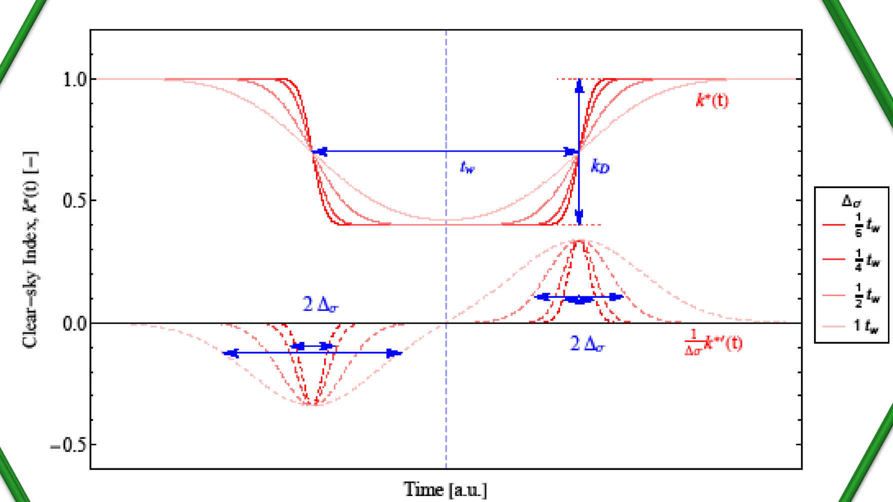
Set-up

Bottom-up calculation of lagged **cross-correlation** versus time between PV-systems due to multiple quasi-statically moving clouds, based on [1].

Sigmoid-shaped parametrization **of** clear-sky index k_t^* time series of clouds, with **Gaussian** first derivative.

Direct relation of (auto-) correlation function and shape parameters





1-cloud Sigmoid shape clouds, Gaussian derivatives

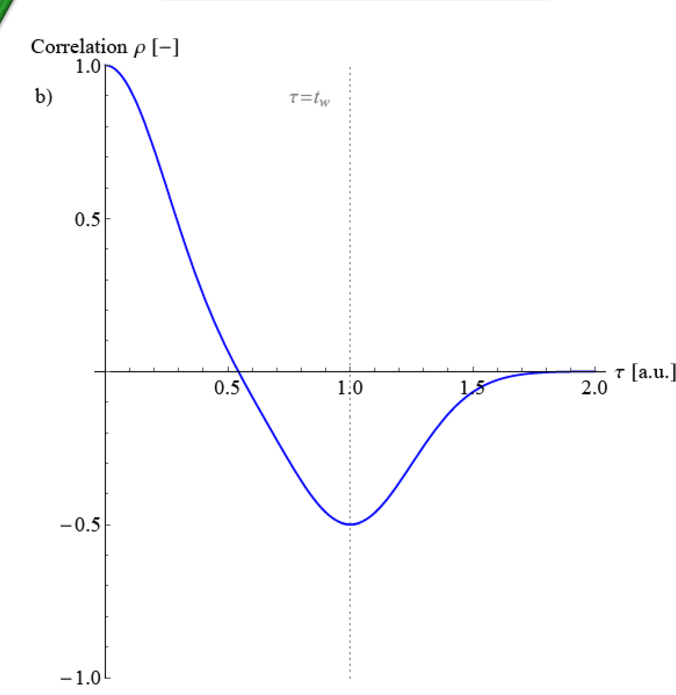
$$k^*(t) = k_D^*\left[\frac{1}{2}\left[\mathrm{Erf}\left(\frac{t-\frac{t_w}{2}}{\Delta_\sigma}\right)+\mathrm{Erfc}\left(\frac{t+\frac{t_w}{2}}{\Delta_\sigma}\right)+1\right]-1\right]+1$$

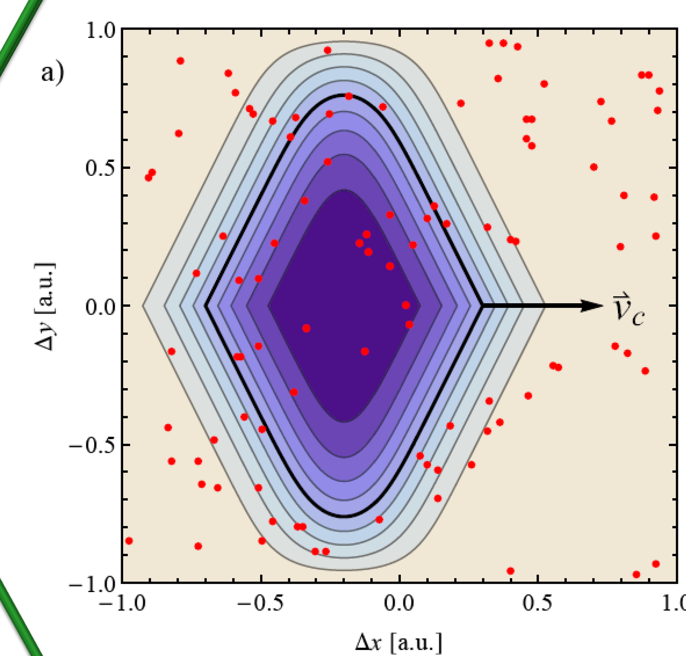
$$k^{*\prime}(t) = \frac{k_D^*}{\sqrt{\pi}\Delta_\sigma}\left[\mathrm{Exp}\left(-\left[\frac{t-\frac{t_w}{2}}{\Delta_\sigma}\right]^2\right)-\mathrm{Exp}\left(-\left[\frac{t+\frac{t_w}{2}}{\Delta_\sigma}\right]^2\right)\right]$$

$$\rho(\tau) \equiv \frac{\int_{-\infty}^{\infty}(k^{*\prime}(t)k^{*\prime}(t-\tau))\,dt}{\sqrt{\int_{-\infty}^{\infty}k^{*\prime}(t)^2dt}\sqrt{\int_{-\infty}^{\infty}k^{*\prime}(t)^2dt}} = \frac{\int_{-\infty}^{\infty}k^{*\prime}(t)k^{*\prime}(t-\tau)dt}{\int_{-\infty}^{\infty}k^{*\prime}(t)k^{*\prime}(t-0)dt} \equiv \frac{(k^{*\prime}\star k^{*\prime})(\tau)}{(k^{*\prime}\star k^{*\prime})(0)}$$

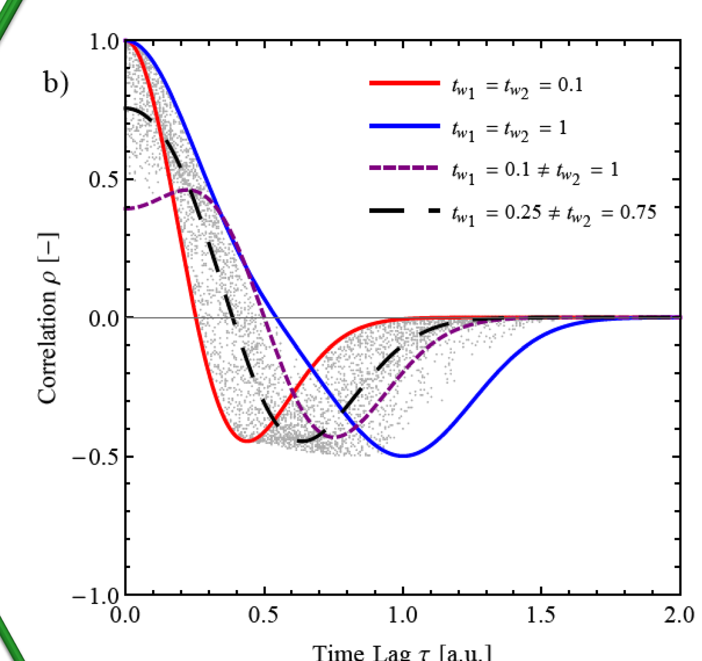
$$\rho(\tau) = \frac{\mathrm{Exp}\left(-\frac{1}{2}\left[\frac{\tau-t_w}{\Delta_\sigma}\right]^2\right)-2\,\mathrm{Exp}\left(-\frac{1}{2}\left[\frac{\tau}{\Delta_\sigma}\right]^2\right)+\mathrm{Exp}\left(-\frac{1}{2}\left[\frac{\tau+t_w}{\Delta_\sigma}\right]^2\right)}{2\left[\mathrm{Exp}\left(-\frac{1}{2}\left[\frac{t_w}{\Delta_\sigma}\right]^2\right)-1\right]}$$

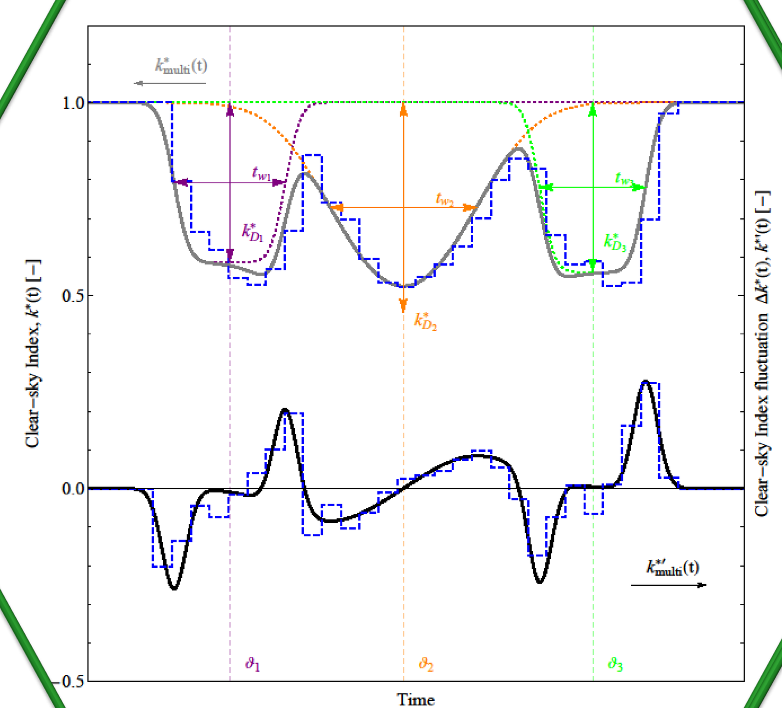
1-cloud *cross*-correlation = lagged *auto*correlation (⋆) evaluated via Fourier-transform





2D-cloud and Random Virtual Network: transections





N_c-cloud (multi): Linear combination of Cross-correlations

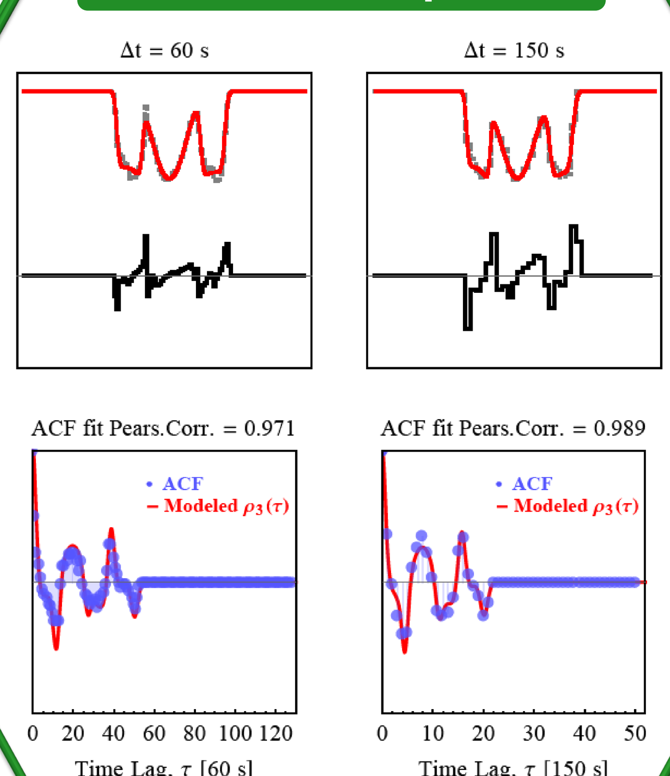
$$\rho_{N_c}(\tau) = \frac{\left(k^{*\prime}_{\mathrm{multi}}\star k^{*\prime}_{\mathrm{multi}}\right)(\tau)}{\left(k^{*\prime}_{\mathrm{multi}}\star k^{*\prime}_{\mathrm{multi}}\right)(0)} = \frac{\sum_{m=1,n=1}^{N_c}(k_m^{*\prime}\star k_n^{*\prime})(\tau)}{\sum_{m=1,n=1}^{N_c}(k_m^{*\prime}\star k_n^{*\prime})(0)}$$

$N_c - 1$ unique parameters for width (t_w), lag (θ), opacity (k_D^*)

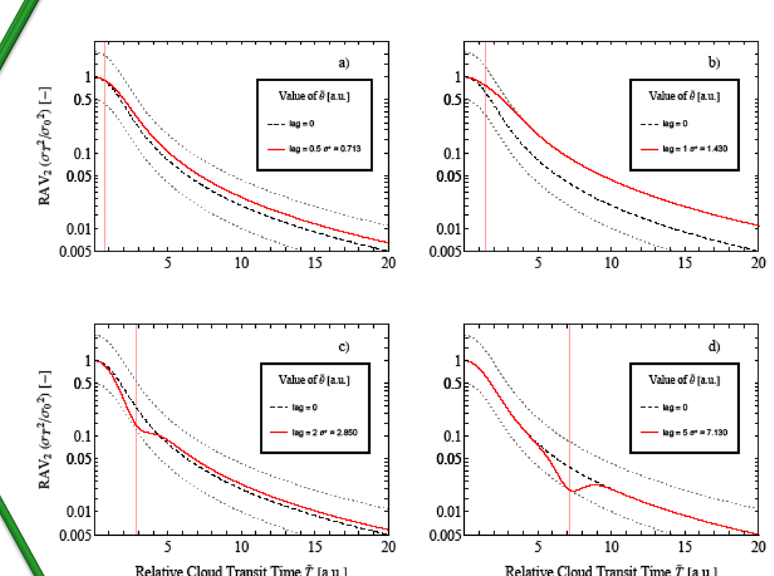
N-cloud (multi): lagged summation

$$k^*_{\mathrm{multi}}(t) = 1 + \sum_{m=1}^{N_c}\left[k_m^*(t-\vartheta_m)-1\right]$$

Numerical Comparison



Relative Aggregate Variability RAV: see [1,2]



$$\frac{\sigma_T^2}{\sigma_0^2} = \frac{2}{T^2}\int_0^T [T-\tau]\rho(\tau)d\tau$$

Key Findings

Generic analytic autocorrelation model for parametrized clouds.

Realistic implementation is **trade-off** between detail and number of parameters.

Flexible implementation for realistic (dynamic) clouds

Parametrization of aggregate **variability** in PV-network

References

[1] B. Elsinga and W.G.J.H.M. van Sark, Sol. Energy (155) 2017, p. 985-1001

[2] J. Widén, Sol. Energy (122) 2015, p.1409–1424