Real time spectra and wavelength correlation maps: new insights into octave-spanning supercontinuum generation and rogue waves

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Real time measurements of fluctuations during nonlinear pulse propagation in optical fibers present significant challenges, yet there is clearly much insight to be obtained in explicitly measuring shot-to-shot variation in pulse characteristics. This is especially the case in optical supercontinuum (SC) generation, where many different processes contribute to the spectral broadening, and isolating particular physical effects can be difficult or impossible using time-averaged measurements [1]. In this context, however, the recent development of dispersive-time stretching for real time spectral measurements represents a major development, providing new insights into effects of modulation instability (MI) and rogue wave generation [2], and the statistical analysis of low power SC generation around 1.5 μm [3]. However, results to date have been limited to low SC bandwidths of only around 200 nm, and the statistical data extracted from experiments has been only partially analyzed.

In this paper, we report two significant advances in this field of study (i) the use of dispersive time stretching for real time measurements of a high power Ti:Sapphire generated SC spanning 550-1100 nm, and (ii) the use of a wavelength correlation map to directly reveal the physics of different processes contributing to the SC.

Fig. 1(a) shows the spectral measurements obtained. The SC was generated in 12 cm of photonic crystal fiber (790 nm zero dispersion) pumped by 5 kW peak power 200 fs pulses at 810 nm. We show the average OSA spectrum (black curve) and 1000 shot-to-shot spectra (gray curves) using time-stretching in 100 m of specially-designed normally-dispersive fiber. The real time spectra show significant fluctuations and we highlight the rare appearance of extreme frequency shifting rogue solitons (RS). The mean of the real-time measurements (red curve) is in excellent agreement with the average OSA spectrum, confirming our measurement fidelity.

This experimental data can be analyzed using wavelength correlation coefficient mapping which shows the noise interdependence between different wavelengths in the SC, and thus reveals a link to particular physical processes [3]. The power of this technique is readily illustrated: For example, Fig. 1(b) shows the calculated correlation coefficient over the full SC bandwidth [4], revealing how the SC soliton edge (λ_{SOL}~ 1060 nm) and the dispersive wave edge (λ_{DW} ~ 650 nm) are anti-correlated ($\rho < 0$) due to the physics of soliton-DW energy transfer. In addition, Fig. 1(c) shows detail around the pump, with positive and negative correlation zones indicating wavelength jitter from noise effects (e.g MI) feeding back to the pump during propagation. This ability to directly identify correlated regions of the SC in the presence of noise is a major advance in our ability to study the nonlinear dynamics of SC generation and nonlinear pulse propagation, and our results suggest that it become a standard diagnostic tool in ultrafast nonlinear optics.

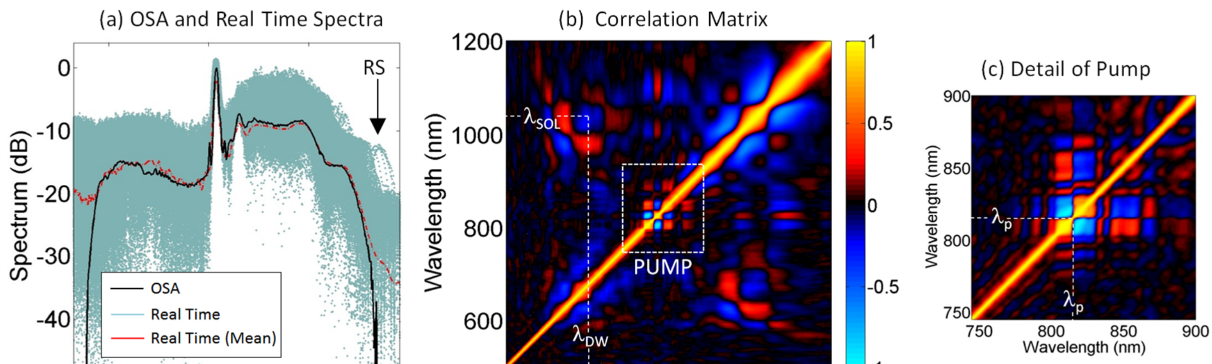

Fig 1. Experimental results: (a) OSA and real-time spectra; (b) and (c) Wavelength correlations. Positive correlation ($\rho>0$) implies that the intensities at λ_1 and λ_2 increase or decrease together while negative (anti) correlation ($\rho<0$) indicates that as the intensity at one wavelength increases, that at the other wavelength decreases and vice-versa.

References

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[4] We use the standard definition $\rho(\lambda_1,\lambda_2) = \mathrm{cov}(I_1,I_2)/\sigma_1\sigma_2$ where: $I_1 = I(\lambda_1)$, $I_2 = I(\lambda_2)$; cov is covariance; $\sigma_{1,2}$ is standard deviation at λ_1,λ_2.

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