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Laser Filament Induced Water Condensation

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Abstract. At relative humidities above 70%, femtosecond laser filaments generate aerosol particles and water droplets in the atmosphere. The water vapour condensation and droplet stabilization are assured by soluble species produced in the laser plasma.

1 Introduction

The prevention of damaging weather phenomena like floods, hail and lightning strikes has been a dream of a mankind for centuries, attracting attention to broadly defined local weather-control techniques. On the other hand, human activities have, until now, only caused damages to the Earth, leading to pollution, stratospheric ozone depletion and global warming, so that considerable efforts are now dedicated to discover new technologies for possibly repairing these damages (geo-engineering). If proven successful, these new technologies would ultimately have huge beneficial effects in both human and economic terms through the reductions in human and economic losses in both the developing countries and the industrialized world. Considerable efforts have recently been made with respect to water condensation and rain control, though with conventional techniques, which are neither very efficient nor environmental friendly (rocket seeding with particles of silver iodide or other salts).

Multi TW-class femtosecond lasers recently opened new perspectives in this respect by producing water vapour condensation in the atmosphere with laser-induced plasma filaments [1,2]. Laser filaments are self-sustained light structures of typically 100 um diameter and up to hundreds of meters in length, widely extending the traditional linear diffraction limit [3]. They stem from the dynamic balance between Kerr self-focusing and defocusing by the self-generated plasma and/or negative higher-order Kerr terms [4]. Based on field experiments in various atmospheric conditions, we show that laser filaments can induce water condensation and fast droplet growth up to several µm in diameter in the atmosphere as soon as the relative humidity (RH) exceeds 70%.

2 Results and discussion

Comparing the particle density in the free atmosphere, with and without laser filaments clearly evidences the laser-induced particle formation and growth even far below saturation (Fig. 1a). The most spectacular effect is observed on the nanoparticles class around ~25-300 nm diameter. For example, at 75% RH, the nanoparticle density typically increased by 10^5 cm^{-3} (10 times the background concentration), while 10 μm particles increased by a few cm^{-3} (30% of background). Furthermore, the generated particles are stable. For example, 25-nm-diameter particles have been observed to be stable over at least 20 min, limited by the diffusion out of the measurement chamber.

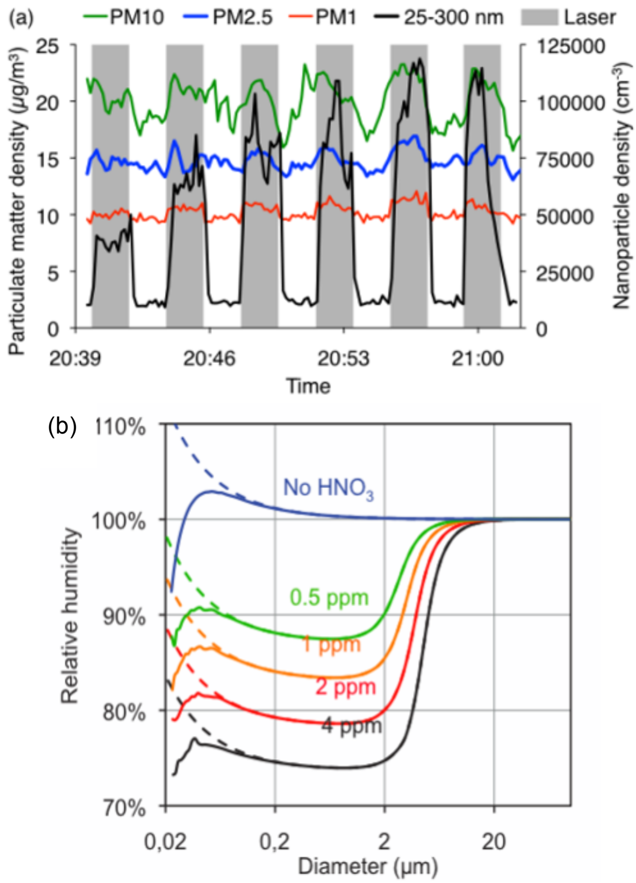

Fig. 1. (a) Typical effect of the laser filaments in sub-saturated (75% RH, 13°C) conditions. PMx stands for Particulate Matter of aerodynamic diameter x µm or less; (b) Köhler plots for a droplet density of 1000 cm^{-3}, at T=279 K and 1013.25 hPa Curves from top to bottom correspond to 0, 0.5, 1, 2, and 4 ppm initial concentration of gaseous HNO_3 [2].

The production of particles over the whole size range is the result of three subsequent regimes. First, the laser assists the nucleation of ~25 nm particles acting as cloud condensation nuclei (CCN). These nuclei subsequently grow if the RH is sufficient to ensure their stability. Finally, once they reach ~500 nm, their subsequent evolution can be described by the diffusion-limited growth model. This scenario requires a highly efficient stabilizing mechanism to prevent the particles from re-evaporating well below 100% RH. A relevant mechanism may be provided by the strong impact of the laser filaments on the local chemical composition of the atmosphere. Typical O_3 and NO_2 concentrations were respectively 200 ppb and 25 ppb in the filament vicinity, expectedly resulting in a HNO_3 concentration in the ppm range.

We performed numerical simulations based on the Köhler theory, in order to test this binary H_2O-HNO_3 condensation model. Fig. 1(b) displays the resulting Köhler plots, i.e. the equilibrium RH over the ternary H_2O–HNO_3 droplet surface, as a function of its diameter, in conditions representative of the laser filaments volume. Water vapour uptake dominates evaporation if the RH is higher than its equilibrium value, i.e. if the droplet is above the curve. This value decreases down to 75% RH for a HNO_3 concentration of 4 ppm, allowing droplets from several tens of nm to a few

μm to grow at RH well below 100% and to shift towards the right of the plot until they reach an ascending branch of the Köhler curve. i.e. at several μm, consistent with the experimental data.

In order to test the scalability of the process, and therefore possible macroscopic effects in the atmosphere, we recently performed experiments at the 100 TW level, in collaboration with Prof. R. Sauerbrey at the Forschungs Zentrum Dresden Rossendorf. The results indicate that the aerosol production scales highly non-linearly (~ I^5) with laser power [5], which appears very promising for large-scale applications.

3 Conculsion

By investigating laser-induced water vapour condensation under various atmospheric conditions, we observed that laser filaments initiate the nucleation of nanoparticles and their growth within a few seconds up to stable micrometric particles, even at RH as low as 70%. Both experimental measurements and simulations show that this process is driven by the formation of 25 nm binary H_2O–HNO_3 particles. These results define the favourable conditions for laser-assisted condensation and provide a theoretical understanding to this phenomenon. As a consequence, they also open the way to applications in the real atmosphere, from remote sounding of the atmosphere to precipitation modulation.

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