WHY GEOENGINEERING AND CLIMATE DON'T GO TOGETHER

ANASTASIOS A. TSONIS
Department of Mathematical Sciences, University of Wisconsin-Milwaukee
Milwaukee, WI, USA

This paper is an extension of my letter to the Editor in the journal *Physics Today*, which was recently accepted for publication. The scientists who want to geoengineer climate propose to throw material in the atmosphere that will make the clouds whiter, meaning that their albedo (the amount of radiation they reflect back into space) will increase, thereabout cooling the planet. They propose this in order to stop the, observed in the last century or so, overall positive trend in global temperature, some of which is attributed to human activity. In addition, they have devised a "plan" to dissipate hurricanes, claiming that this way they are going to save lives. Unfortunately, these people want to solve a problem by introducing other problems potentially more dangerous than global warming. Let me explain.

I believe that geoengineers are removed from scientific reality. They ignore the fact that the climate system and its components (clouds, hurricanes, etc.) are highly nonlinear and thus very sensitive to the initial conditions and unstable to changes in the parameters. Such systems are by nature unpredictable. Nevertheless, one could study changes in these systems, in a probabilistic way, when some parameters are changed or when we introduce a fluctuation, *if their formulation is known exactly*. And here lies the whole problem with geoengineering. The formulation of the climate system is only approximately known. Every climate scientist will tell you that the models used in climate prediction and climate projections into the future are not perfect. Many aspects of the climate system are not only poorly understood but they are not represented in the models in a rigorous way simply because their physics is not yet completely known. A prime example is clouds. Cloud microphysics is represented in the models by linear parameterizations. This means that the actual physics and equations describing cloud development and cloud interactions with climate are approximated with linear equations derived from observations. In a highly nonlinear climate system, linearizing processes makes the models imperfect. And there are plenty of those linearizations in the climate models: clouds, heat fluxes between the oceans and the atmosphere, interaction between climate and ecosystems, to mention a few. Simply, climate models are imperfect and they differ between them (Steinhaeuser and Tsonis, 2013; see Figure 1). It is thus not surprising that all CO_2 forced climate simulations starting in the year 2000 missed the leveling off of mean global temperature in the first 12 years of the 21st century. An alarming failure as they all predicted the monotonic increase in the interval 1980-2000 to continue all the way in the 21st century.

In a highly complex system, such as the climate system, changes in its parameters change the dynamics. As such, if clouds are made "whiter" changes in precipitation patterns will most likely occur. Even the geoengineers acknowledge that they don't know how precipitation will be affected. But when precipitation is affected, the atmosphere is affected. What will happen to climate then? Nobody knows. The same can be said about dissipating hurricanes. Hurricanes are the product of self-organization in climate. As every physicist knows self-organization is a far-from-equilibrium process where energy is