WHY GEOENGINEERING AND CLIMATE DON'T GO TOGETHER

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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 not conserved but it flows between the organizing system and its environment. If this flow is interrupted, how will the ocean and atmosphere react? And if this is attempted on a global scale how is climate going to react?

Nobody knows with high confidence the answer to these questions. And while models can give you an answer, they are not reliable enough to justify messing with climate. To me it is not surprising that model prediction on hurricane tracks and intensity in a global warming scenario is presented in the interval 2070-2100. Sixty years into the future! In other words un-verifiable in our lifetime. Why don't they present predictions in the next 10 years where we can at least verify something? The answer is simple. They don't trust the models. In 2005 (the Katrina year), we had 28 hurricanes making landfall in the U.S. A big deal was made about the effect of global warming in hurricane activity and intensity. Since then the U.S. has experienced very "quiet" hurricane seasons.

I would not have a problem with geoengineering if we knew very well the physics and dynamics of the climate system. We have a good idea of the large-scale flow of ocean currents but detail measurements are not available. We know the basic physics in cloud formation and its thermodynamics. But we do not fully understand or represent detailed cloud microphysics. We don't understand the complex connections between climate and ecosystems. And with complex nonlinear systems details are important. So, why don't we make an effort to first improve our understanding of our climate system and its components before we try to operate on it? We can engineer a car or a plane because we know the underlying physics of flight, combustion, motion, and we understand the role of every component. Can geoengineers say the same about climate?

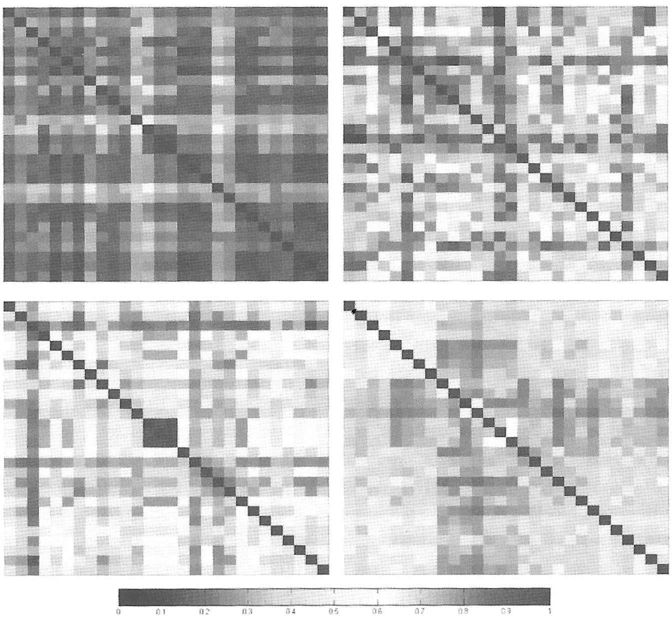
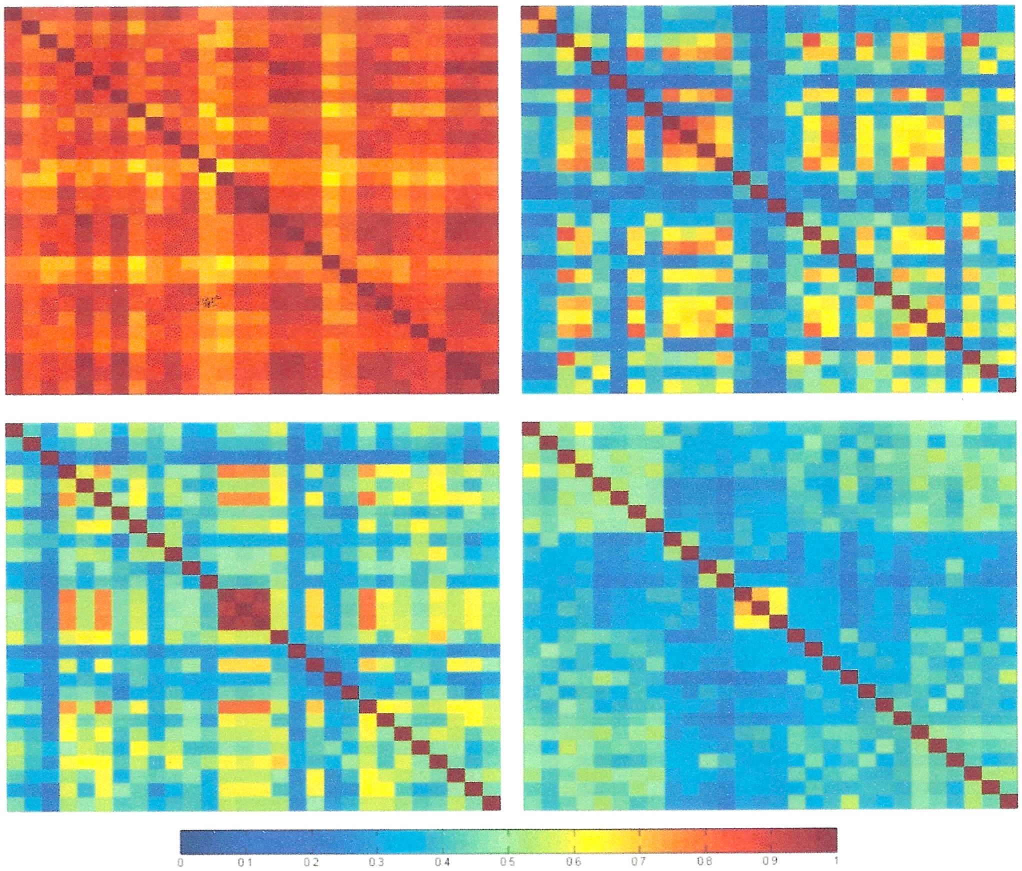


Fig. 1: We considered 28 model runs from 23 different climate models. For each run we considered four fields: (A) the 500 hPa field, (B) the Sea Level Pressure (SLP) field, (C) the Surface Air Temperature (SAT), and (D) the precipitation field. For each run and each field we constructed the network and delineated its communities. We then estimated the Adjusted Rand Index (ARI) between a model run and all other available model runs The top left panel corresponds to the 500 hPa field, the top right to the SLP field, the bottom left to the SAT field, and the bottom right to the precipitation field. The top row is the comparison of run 1 with all other runs and the bottom row is the comparison of run 28 with all other runs. The ARI between a run with itself is equal to one (red diagonal). This figure indicates that with the exception of the 500 hPa field, the models don't agree well with each other especially for the temperature and precipitation fields.

REFERENCES

1. K. Steinhaeuser and A.A. Tsonis (2013) "A climate model intercomparison at the dynamics level." *Climate Dynamics*. DOI 10.1007/s00382-013-1761-5.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