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BOOK REVIEW
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# Book Review: Weather, Macroweather, and the Climate: Our Random Yet Predictable Atmosphere

*Tommaso Alberti**

*INAF–Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy*

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**A Book Review on**

**Weather, Macroweather, and the Climate: Our Random Yet Predictable Atmosphere**

Shaun Lovejoy (Oxford: Oxford University Press), 2019, 352 Pages, ISBN: 9780190864217

The large amount of observational data and the massive development of computer resources achieved during the last century have strongly influenced the whole geoscience community, fostering the development of new theoretical and numerical approaches for modeling and forecasting processes in geosciences (Donner and Barbosa, 2008). Although several and significant advances have been made in this direction, today, this remains one of the most important challenges (Lovejoy and Schertzer, 2013). Indeed, increasing the amount of data increases complexity and increasing complexity of numerical modeling increases the corresponding errors. In today's world, data is "big," artificial intelligence increasingly trumps human know-how, and modeling often requires the largest supercomputers. Increasingly, one attempts to model as many structures and interactions as computer technology will permit, focusing on numerical mimickery rather than on understanding (Alberti et al. , 2019). Alternative approaches are based on the existence of higher level statistical laws arising from the collective behavior of myriads of structures. The atmosphere has long been a proving ground for both approaches requiring concepts that have developed over the last forty years in the field of non-linear geophysics (Lucarini et al. , 2014).

The book "Weather, Macroweather, and the Climate: Our Random Yet Predictable Atmosphere" by Lovejoy (2019a) excellently places a really beautiful and instructive discussion about some key points: random vs. deterministic, turbulence, scales, (fractional) dimensions, weather vs. macroweather vs. climate, providing a new understanding of the atmosphere. Lovejoy's main objective is to explain as simply as possible how to understand the atmospheric variability across scales, from millimeters to the size of the planet, from milliseconds to billions of years, by providing a complete review of open problems in atmospheric and climate research, and the attempts that have been made to describe and forecast the behavior of this complex system. The reader will travel through scales to discover atmospheric processes, to detect the difference between weather and climate, and to finally be able in answering how really complex is our environment, what are the current capabilities of forecasting the weather, and why today we are living in an unprecedented warming epoch. The author raises three fundamental points:

***Edited and reviewed by:***
*Roxy Mathew Koll,*
*Indian Institute of Tropical Meteorology (IITM), India*

****Correspondence:***
*Tommaso Alberti*
*tommaso.alberti@inaf.it*

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1. The fundamental role of scale symmetries—scaling laws—in quantifying scale-dependent variability, sources, and mechanisms.
2. How phenomenological descriptions and models can help to derive the main statistical relationships between scales as simply as possible. These models are higher level in the same sense that thermodynamic laws are at a higher level than statistical mechanical ones: they are mutually compatible and the appropriate laws are chosen depending on the application. In atmospheric science, high level turbulent laws are (postulated) to be compatible with the deterministic continuum mechanics laws used in standard numerical weather and climate models. While a phenomena—such as a cloud—may appear complex when viewed deterministically, the corresponding statistical scaling laws may turn to be simple so that "complex does not (necessary) imply complicated."
3. The application of these ideas to the atmosphere requires new notions of scale, of size, allowing us to quantify "how big is bigger than small and how small is smaller than big." The author masterfully discusses these aspects by using two well-connected ideas: one is the Richardson cascade, e.g., a phenomenologically based mechanism (Richardson, 1922), and the other pioneered in turbulence by Kolmogorov (1941) is the scaling, e.g., a mathematical description in terms of scaling laws.

1. The turbulence pioneers viewed a turbulent flow as an ensemble of "eddies" of different sizes defining the characteristic lengths of the different dynamical regimes and processes. The unstable large eddies break up creating smaller eddies and transferring kinetic energy from large to small scales until reaching a sufficiently small (and typical) length scale where energy is dissipated into internal energy by viscous effects.
2. Mathematically writing this formulation and assuming that the statistics of the small scales has a universal character for a sufficiently high Reynolds number, Kolmogorov proposed his eponymous turbulence law according to which the statistics of velocity fluctuations are scaling.
3. Although scaling laws had been proposed starting in the 1920's, when *in situ* (and later remote) data started to be collected some discrepancies appeared. One problem was that the original theories were isotropic and the atmosphere is stratified in the vertical, it is like a thin onion skin surrounding the earth. Isotropic theories could therefore only apply over relatively small ranges of scale, if only to handle atmospheric stratification, anisotropic generalizations were needed.
4. Following Kolmogorov (1941)—the classical turbulence laws assumed weak (quasi-Gaussian) variability characterized by a single exponent, but the variability is on the contrary very high—it is "intermittent" and it turned out that a continuous spectrum of exponents is needed. Whereas, a system with single scaling exponent can be handled with the concept of fractality (1970's) (Mandelbrot, 1977), the continuous spectrum of exponents requires multifractality (1980's).

Fractals significantly influenced the research by Shaun Lovejoy who is recognized as a pioneer of multifractal dynamics and modeling in hydrology, climate, and weather. This work has led to a new class of comprehensive stochastic, rather than deterministic, models, also awarded the 2019 Lewis Fry Richardson medal by the European Geosciences Union (https://www.egu.eu/awards-medals/lewis-fryrichardson/2019/shaun-lovejoy/). This book, firstly recognizing that Richardson himself also pioneered the development of both deterministic numerical weather predictions as well as the statistical scaling "4/3 law" of turbulent diffusion, shows that the two apparently divergent approaches are in fact compatible. While deterministic weather forecasting attempts to mechanistically account for as many structures and interactions as possible, the 4/3 and other statistical laws exploit the idea of scaling to statistically account for the collective behavior of structures of widely different sizes which jointly act to give rise to the atmospheric variability across scales. Richardson not only pioneered statistical turbulence laws, he also was the first to propose (deterministic) numerical weather prediction and Lovejoy's book recounts how computers made it possible to test the predictions of strongly non-linear models against real world phenomena, with weather prediction transitioning from an art-form to a quantitative science. Lovejoy masterfully describes how to finally reunite Richardson's deterministic and statistical (stochastic) strands, showing that the deterministic weather models respect the stochastic scaling laws very well. The book summarizes four decades of work attempting to understand, quantify, and model atmospheric variability, clearly demonstrating that standard ways of dealing with it are inadequate. Using scaling, it shows how atmospheric variability across scales can be interpreted and divided into three different regimes: the weather, representing the fast component of the system, the climate, associated with the slow variability (in the current epoch, mostly anthropogenic in origin), and a new intermediate regime, "macroweather." This third regime clarifies the distinction between the weather and climate and can be exploited for accurate stochastic atmospheric modeling and forecasting on monthly, seasonal and inter-annual timescales. Its skill originates in the long-term memory processes characterizing the ocean-atmosphere coupling that can be modeled with the help of the Fractional Energy Balance Equation (Lovejoy, 2019b). Through the book, Lovejoy well poses questions and provides their answers to "what is climate," "how big is a cloud" (this also fascinated Richardson in the 1920s), and also provides evidence of statistical and multifractal similarities between Earth and Mars. In conclusion, through this book the reader will be fascinated in discovering a different point of view of understanding data and modeling physical systems as simple as possible. It is therefore a must for anyone having interests in nonlinear geosciences and should be used for both pedagogical and research purposes due to its easy of understanding and readability, being characterized by 20 "boxes" with more in depth information as well as footnotes helping readers who want more information.

## AUTHOR CONTRIBUTIONS

TA wrote the manuscript and approved the submitted version.

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