Lorenz's View on the Predictability Limit of the Atmosphere

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To determine whether (or not) the intrinsic predictability limit of the atmosphere is two weeks and whether (or not) Lorenz's approaches support this limit, this entry discusses the following topics: **(A)**. The Lorenz 1963 model qualitatively revealed the essence of a finite predictability within a chaotic system such as the atmosphere. However, the Lorenz 1963 model did not determine a precise limit for atmospheric predictability. **(B)**. In the 1960s, using real-world models, the two-week predictability limit was originally estimated based on a doubling time of five days. The finding was documented by Charney et al. in 1966 and has become a consensus. Throughout this entry, Major Point A and B are used as respective references for these topics. A literature review and an analysis suggested that the Lorenz 1963 model qualitatively revealed a finite predictability, and that findings of the Lorenz 1969 model with a saturation assumption supported the idea of the two-week predictability limit, which, in the 1960s, was estimated based on a doubling time of five days obtained using real-world models. However, the theoretical Lorenz 1963 and 1969 models have limitations, such as a lack of certain processes and assumptions, and, therefore, cannot represent an intrinsic predictability limit of the atmosphere. This entry suggests an optimistic view for searching for a predictability limit using different approaches and is supported by recent promising simulations that go beyond two weeks.

Lorenz models predictability limit doubling time intrinsic predictability

Is the predictability limit of the atmosphere two weeks? Has a physical foundation been robustly established and verified for such a (theoretical) predictability limit? The concept of predictability can be defined as the ability to make predictions (Thompson 1957 [1]), and can be further broken down into intrinsic predictability, which is determined by flow itself; and practical predictability, which is influenced by mathematical techniques such as models and data assimilation systems (Lorenz 1963a [2]) The above definitions are consistent with the following in Lorenz (1982 [3]): "*The instability of the atmosphere places an upper bound on the predictability of instantaneous weather patterns. The skill with which current operational forecasting procedures are observed to perform determines a lower bound*." Therefore, the question becomes whether (or not) the intrinsic predictability of the atmosphere is limited to two weeks and if the upper limit of predictability for most advanced models is also two weeks. These questions have been raised for more than five decades (e.g., Lorenz 1963b [4]; Charney et al., 1966 [5]). However, as implicitly suggested by the title of Lorenz (1996, 2006 [6][7]) "Predictability—A problem partly solved", the predictability problem remains partly unsolved, according to Lorenz, who is known for his contributions to chaos theory. To provide a baseline for future researchers continuing to tackle this partially solved problem using theoretical and/or real-world models, this study presents a brief overview of the current understanding of finite predictability (e.g., Lorenz 1963b [4]; 1993 [8]; Charney et al., 1966 [5]; Reeves 2014 [9]), as well as major features of the Lorenz 1969 model (e.g., Lorenz 1969 [10]; Lilly 1972 [11]), which is often considered to be a major tool for illustrating the two-week predictability limit.

Past studies regarding the complexities of the atmosphere have yielded numerous, different approaches for studying atmospheric predictability as well as dynamics. Major theory-based concepts, including chaos (e.g., Lorenz 1963b [4]), (baroclinic) instability and waves (Tribbia and Baumhefner, 2004 [12]; Lorenz 1984a [13]), and turbulence (Lilly 1972 [11]; Leith 1971 [14]; Leith and Kraichnan 1972 [15]; Lorenz 1969 [10]), have been applied in order to understand atmospheric predictability. For example, in the 1960s, the Lorenz 1963 model (Lorenz 1963b [4]) was proposed in order to rediscover the sensitive dependence of solutions on initial conditions (SDICs), later known as chaos (Li and Yorke, 1975 [16]). Although the Lorenz 1963 model and generalized Lorenz models with many modes have been used to demonstrate a finite intrinsic predictability for the atmosphere (e.g., Lorenz 1993 [8]; Shen 2014, 2019 [17][18]; Shen et al., 2021, 2022a, b [19][20][21] and references therein), as discussed below, they have not been used to quantitatively determine an upper limit for predictability (Reeves, 2014 [9]). This fact is not well known.

On the other hand, the meteorology community has cited Lorenz’s 1969 model (Lorenz 1969 [10]) and follow-up studies by Lilly (Lilly 1972, 1973, 1990 [11][22][23]; Rotunno and Snyder 2008 [24]; Palmer et al., 2014 [25]; Durran and Gingrich 2014 [26]; Lloveras et al., 2022 [27]) for providing answers to the question of the intrinsic predictability limit being two weeks. Therefore, as of 2023, the following statement is implicitly or explicitly accepted by the meteorology community:

The intrinsic predictability limit of two weeks was reported in Lorenz (1969) [10].

As discussed later in Section 2, the content of the above statement is not supported by a review of studies, including Lorenz (1993 [8]) and Reeves (2014 [9]). As such, the above statement is referred to as the “hypothesis for the intrinsic predictability limit”. In fact, as we discuss in the text below, the above statement is not accurate and will be revised.

An idealized model or concept may effectively and qualitatively reveal the fundamental dynamics, and the mechanism, for a targeted phenomenon. On the other hand, Turing (1952 [28]) reminded us that an idealized model is *“a simplification and an idealization, and consequently a falsification*”. This paper argues that inconsistencies between idealized models and new results from different approaches may indicate a need to revisit a model’s realism and assumptions to improve our understanding of concepts. Previous, promising 30-day simulations (Shen et. al., 2010, 2011 [29][30]) provided such a motivation for revisiting the validity of the two-week predictability limit, which is presumably supported by Lorenz’s studies (e.g., Lorenz 1969 [10]).

The paper is organized to present Lorenz’s perspective on predictability limits and major features of the Lorenz 1969 model and is followed by a review and analysis of relevant studies.

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