POSTDOCTORAL FELLOWSHIP

From Weather to Markets: Analyzing Climate Variability and its Financial Implications

EconophysiX Lab (Ecole Polytechnique and Capital Fund Management)

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This research project examines two interconnected topics: (i) the evolving statistical patterns of climate variables beyond mean temperature, with notably a focus on thermal convection and micrometeorology, and (ii) the potential financial consequences on equities, commodities, and futures markets.

Understanding Climate Variability and Its Predictability

Our principal aim will be to analyze shifts in meteorological statistics, extending beyond traditional metrics like mean global temperature [1] and the frequency of extreme weather events [2, 3]. Instead, it will investigate changes in climate variability, skewness, and higher-order moments for temperature and other climate-related variables (such as precipitation, humidity, and wind patterns). Additionally, the evolving predictability of these variables will be assessed using advanced time series analysis techniques [4]. By leveraging comprehensive datasets, including those from the Copernicus project, this research aims to identify significant trends and spatial patterns in key climate parameters, such as precipitation [5, 6] and wind dynamics [7]. A particular attention will be given to small scale atmospheric phenomena (see below). This will provide valuable insights into how climate variability is evolving across both time and space.

We will then explore the implications of shifting climate statistics on financial markets, with a particular focus on stocks and commodities. Prior research [8] has highlighted inefficiencies in market pricing concerning climate risks, suggesting that environmental risks are often systematically underpriced in equity markets. The research will investigate sector-specific vulnerabilities, particularly in agriculture and energy, and explore how climate risk hedging affects asset valuations and investor behavior. Furthermore, it will analyze cross-asset implications, emphasizing the relationships between climate variability and stock returns [9].

Focus on Micrometeorology and Thermal Convection

In order to gain altitude in the atmosphere, birds, glider pilots, and paragliders exploit updrafts, or *thermals* [10–13]. These columns of rising air result from the solar heating of the ground surface, which in turn warms the air in contact with it and initiates atmospheric convection. Early experiments and models in the 1960s [14–17] helped sketch out the structure, periodicity, flow nature, and vorticity of thermals (Fig. 1a). Later, airborne measurements [18, 19] and numerical simulations [20] refined our understanding of their physical characteristics (e.g., their size or shear exchange with the surrounding air [21–23]) and integrated thermal convection into weather models [24, 25]. However, many questions remain, particularly due to the very sparse presence of atmospheric probes. How far apart are the thermal columns from each other? What is the regularity of their spatio-temporal structure? What is the influence of the season, time of day, cloud cover, or the topography and nature of the soil that generates them?

Answering these questions is likely of fundamental importance if we are to improve our understanding of weather variability at larger scales. It is a common observation among free-flight pilots that the nature of thermal activity has changed significantly over the past 10-20 years. Small-scale thermal activity has become much stronger, which could provide valuable insights into broader atmospheric dynamics. Here we want to use free-flight vehicles (paragliders and hang gliders) and sailplanes as atmospheric probes to address the questions above. Pilots carry instruments known as *altivario GPS*, which provide 3D GPS coordinates (Fig. 1b) as well as velocities and accelerations, for hundreds of thousands of flights worldwide. These large datasets are mostly available online for free. Figure 1c shows all the tracks recorded by the Coupe Fédérale de Distance (CFD) in the Annecy region during 2018 and 2019. These data notably show that in the mountains, glider pilots primarily exploit ridges, where thermal activity is most powerful. Figure 1d shows the empirical probability distributions of speeds and curvature radii for the entire French territory. As expected, horizontal speeds and curvature radii are lower when the ascent rate is positive—indicating that thermals are "spiraled" at low speed to optimize their use. These preliminary descriptive statistics are very promising regarding the quality of the data. In fact, coupling these data with satellite information about soil nature, relief, or the Copernicus weather data mentioned above, provides an exceptional playground for tackling these problems using modern statistical tools. Focusing on a highly frequented region should allow for accurate reconstruction of the air mass movements, enabling a fine characterization of the flow within and around thermals (Fig. 1e).

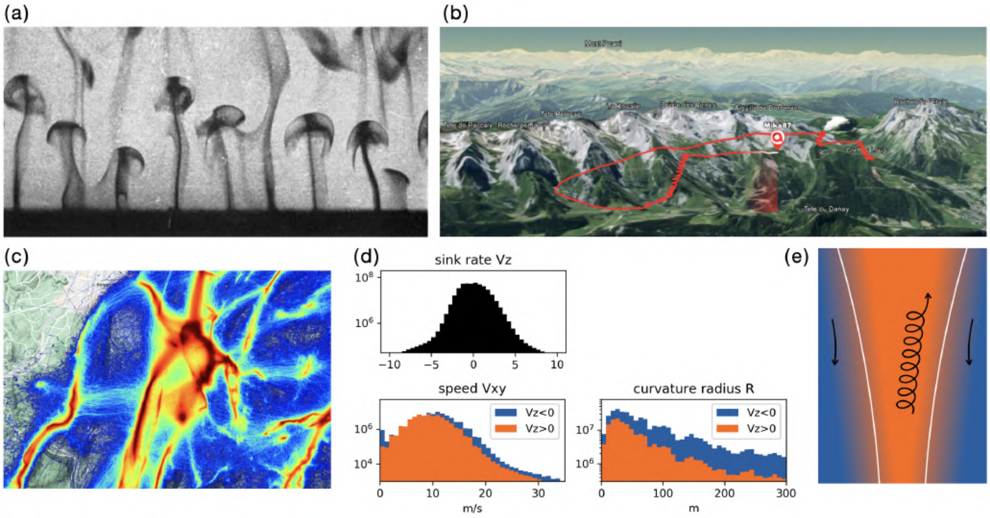

Figure 1: (a) Visualization of thermals above a heated plate [17]. (b) 3D GPS track of a paragliding flight (June 12, 2021, Aravis mountain range). (c) Top-down view of a large number of GPS tracks in the Annecy region. (d) Descriptive statistics (v_z, v_{xy}, and curvature radius) for the same data. (e) Stylized representation of the mean field $\langle v_z(x,y)\rangle$ derived from GPS tracks.

Candidate Profile

The candidate will work with a large, globally comprehensive dataset spanning several decades. Success in this role requires the ability to efficiently handle and interpret vast amounts of data, as well as strong analytical skills. Proficiency in Python, a strong background in statistical and time series analysis, experience with data-driven projects, and the ability to manipulate large datasets are advised.

References

[1] J. Hansen *et al.*, Proceedings of the National Academy of Sciences (2012).
[2] D. Coumou and S. Rahmstorf, Nature Climate Change (2012).
[3] J. P. Kossin *et al.*, Proceedings of the National Academy of Sciences (2020).
[4] J. A. Screen and C. Deser, Nature Climate Change (2019).
[5] K. E. Trenberth, Climate Research (2011).
[6] G. Myhre *et al.*, Scientific Reports (2019).
[7] G. Zappa *et al.*, Environmental Research Letters (2020).
[8] H. Hong, F. W. Li, and J. Xu, Journal of Econometrics (2019).
[9] W. Kang and K. G. Rouwenhorst, Journal of Financial Economics (2020).
[10] H. Weimerskirch, O. Chastel, C. Barbraud, and O. Tostain, Nature **421**, 333 (2003).
[11] H. J. Williams, E. Shepard, M. D. Holton, P. Alarcón, and R. Wilson, PNAS **117**, 17884 (2020).
[12] Y. Leshem and Y. Yom-Tov, Ibis **138**, 667 (1996).
[13] H. Weimerskirch, C. Bishop, T. Jeanniard-du Dot, A. Prudor, and G. Sachs, Science **353**, 74 (2016).
[14] B. Woodward, Quarterly Journal of the Royal Meteorological Society **85**, 144 (1959).
[15] A. Townsend, Journal of Fluid Mechanics **3**, 361 (1958).
[16] J. Turner, Annual Review of Fluid Mechanics **1**, 29 (1969).
[17] E. Sparrow, R. Husar, and R. Goldstein, Journal of Fluid Mechanics **41**, 793 (1970).
[18] D. Konovalov, Technical Soaring **29**, 121 (1970).
[19] D. Lenschow and P. Stephens, Boundary-Layer Meteorology **19**, 509 (1980).
[20] A. M. Blyth, S. G. Lasher-Trapp, and W. A. Cooper, J. of the Royal Meteorological Society **131**, 1171 (2005).
[21] D. Hernandez-Deckers and S. C. Sherwood, Journal of the Atmospheric Sciences **73**, 4117 (2016).
[22] D. Lecoanet and N. Jeevanjee, Journal of the Atmospheric Sciences **76**, 3785 (2019).
[23] J. M. Peters, W. Hannah, and H. Morrison, Journal of the Atmospheric Sciences **76**, 1645 (2019).
[24] J. Pergaud, V. Masson, S. Malardel, and F. Couvreux, Boundary-layer meteorology **132**, 83 (2009).
[25] S. C. Sherwood, D. Hernández-Deckers, M. Colin, and F. Robinson, J. of Atm. Sciences **70**, 2426 (2013).