FACTOR SEPARATION IN THE ATMOSPHERE

Applications and Future Prospects

Modeling atmospheric processes in order to forecast the weather or future climate change is an extremely complex and computationally intensive undertaking. One of the main difficulties is that there are a huge number of factors that need to be taken into account, some of which are still poorly understood. The Alpert–Stein Factor Separation (FS) Methodology is a computational procedure that helps deal with these nonlinear factors. Pinhas Alpert was the main pioneer of the FS method in meteorology, and in recent years many scientists have applied this methodology to a range of modeling problems, including paleoclimatology, limnology, regional climate change, rainfall analysis, cloud modeling, pollution, crop growth, and other forecasting applications. This book is the first to describe the fundamentals of the method, and to bring together its many applications in the atmospheric sciences, with chapters from many of the leading atmospheric modeling teams around the world. The main audience is researchers and graduate students using the FS method, but it is also of interest to advanced students, researchers, and professionals across the atmospheric sciences.

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FACTOR SEPARATION IN THE ATMOSPHERE

Applications and Future Prospects

Edited by

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Foreword

The Factor Separation method, pioneered in the now classic Stein and Alpert (1993) and Alpert et al. (1995) papers, provides a powerful, much-needed tool to assess both linear and nonlinear relationships among weather and climate forcings and feedbacks. As summarized in Chapter 1 of the book:

The FS method provides the methodology to distinguish between the pure influence of each and every factor as well as their mutual influence or synergies, which come into play when several factors, at least two, are “switched on” together. The understanding of which factor, or what combination of factors is most significant for the final result, is often very interesting in atmospheric studies. Discovering the most dominant factors in a specific problem can guide us to the important physical mechanisms and also to potential improvements in the model formulations.

Before this analysis procedure was introduced, numerical models usually performed sensitivity studies by turning on one forcing at a time, and used these results to decide what are the most important factors affecting a particular model simulation. However, we now recognize that such a linear type of analysis is incomplete and can even lead to the incorrect answer, as is illustrated in several chapters in this book.

This book provides a range of examples that illustrate the power of this analysis methodology for a range of spatial and temporal scales. The next step, besides applying the Alpert–Stein Factor Separation Methodology to additional atmospheric studies, should be to broaden it to include other geophysical disciplines.

Roger A. Pielke Sr.
Preface

This book is the result of almost two decades of research initiated in 1991 by an idea that sensitivity studies in the atmosphere were not being performed in the proper manner. My Ph.D. student Uri Stein was simulating the effects of two central factors on the rainfall over the Eastern Mediterranean with the Mesoscale Model MM4: Mediterranean Sea fluxes and topography. I called Uri, on a Friday in 1991, suggesting that the three simulations he was performing were not enough to capture the potential synergy or interaction between these two factors and that an additional simulation should be performed. Consequently, we developed the Factor Separation Methodology that allows for the separation of four potential contributions in our two-factor problem and $2^2$ simulations for any $n$-factor problem. This separation included specifically the double synergy term which is the net result of interaction between the two factors. As I had expected, we found immediately that the synergy term plays a central role in the atmosphere, one that is often larger than the net contribution of any singular factor’s contribution.

When our paper was submitted in 1992 to the *Journal of Atmospheric Sciences*, I did not know what to expect. It seemed to me that the method was so basic that I could not believe we were the first to apply it in atmospheric sciences. However, our extensive literature search did not show any similar publications.

We were thrilled when the paper was accepted for publication, and I began to talk about it in a lecture series at several well-known institutions including the University of Oklahoma, where the lecture was attended by Doug Lilly and the late Tzvi Gal-Chen. I also spoke at CSU where the lecture was attended by Roger A. Pielke Sr. and Bill Cotton, and I presented the idea at the following four conferences over the years 1992–3:

- the International Workshop on Mediterranean Cyclone Studies, Trieste, Italy, 1992
- the Mesoscale Modeling Workshop, El-Paso, Texas, 1992
- the Yale Mintz Memorial Symposium, Jerusalem, Israel, 1992
On all these occasions, the response was enthusiastic, which served to strengthen our faith in the great potential of our new methodology. I wish to particularly mention the outstandingly strong words of support from senior meteorologists including T. T. Warner (PSU, at that time), Don Johnson (Wisconsin), R. P. Pearce (Reading), D. Lilly (University of Oklahoma), R. A. Pielke Sr. (CSU), B. Cotton (CSU) A. Berger (Louvain-la-Neuve), T. N. Krishnamurti (FSU, Tallahassee University), T. Gal-Chen (University of Oklahoma) and late J. Neumann (Hebrew University, Jerusalem).

D. Lilly informed me that he decided immediately to apply our method to a turbulence study he was performing at that time with his student, L. Deng. In fact, Deng and Lilly presented their factor separation study in the same year (1992), even before our paper was published in 1993. Their reference is: L. Deng and D. K. Lilly (1992) Helicity effect on turbulent decay in a rotating frame, 10th Symposium on Turbulence and Diffusion, Portland, OR, pp. 338–341, AMS.

This new application illustrated the relative ease of applying the new methodology to different applications – my presentation in Oklahoma was in May 1992 and their proceeding publication appeared just a few months later.

Meanwhile, we submitted more papers on the method including a study focusing on the mechanisms related to the Genoa cyclogenesis, which analysed four factors and required 16 simulations including one quadruple, four triple, and six double synergies. In 1995 we submitted a paper entitled, ‘Synergism in weather and climate’ by P. Alpert, U. Stein, M. Tsidulko, and B. U. Neeman. In response, we received the following beautiful and most encouraging words from Rainer Bleck, who was one of the referees:

Unless there are difficulties with this method that have yet to come to light and may limit its broad use, the synergistic analysis method developed by Stein and Alpert is likely to become an indispensable tool in our field. After reading this paper, very few investigators trying to isolate the effect of various physical factors on climate and circulation through numerical simulation will be able to argue that they are exempt from using this method.

I cannot think of any aspect in the paper requiring further work; in other words, the paper is essentially ready to be published in J. Climate as is. A few minor editorial suggestions are spelled out in the manuscript which I am returning to the editor.

This is one of the few cases where one waits to hear from the journal editor that the paper has been accepted, so that one can start referencing it in one’s own work, talking about it in class, etc. (Rainer Bleck)

Interestingly, the paper was rejected by the Editor stating that it was not appropriate for that particular journal.
Preface

A few years after our initial efforts on factor separation, I established the Factor Separation Group email list which grew within a year or two to about 50 users all over the world; many of whom can be found in my acknowledgements list below because they have initiated and been part of many interesting discussions and developments over the years. The incorporation of the method into various and diverse atmospheric topics was quick, and some of those works provide the basis for the different applications in the following chapters of the present book.

A few words on the order of the chapters in the book are appropriate here. Following the introduction (Chapter 1) and the mathematical formulation of the method (Chapter 2), some analytical functions are analyzed (Chapter 3) based on the Master Thesis of Tatiana Sholokhman, my co-author of the present book. Following these initial chapters are eleven chapters on various applications with the general order decreasing from the macro-scale to the micro-scale. Therefore, the following chapters and applications are: Paleoclimate (Chapter 4), Mesometeorology (Chapter 5), Regional climate (Chapter 6), Heavy rainfall and Cyclogenesis (Chapter 7), Clouds (Chapter 8), Limnology (Chapter 9), Pollution (Chapter 10), Crop growth (Chapter 11), Sea breeze (Chapter 12) and two different forecasting applications (Chapters 13, 14). Chapter 15 discusses some difficulties and prospects of the methodology, including a comparison to a similar but different method applied mainly in biotechnology experiments. Chapter 14 by T. N. Krishnamurti also suggests and discusses a similar but different method for factor separation. Chapter 16 provides a summary. An important addition at the end is an Appendix, which lists, to the best of our knowledge, all articles and publications employing the Alpert–Stein Factor Separation Methodology at the time of publication. I wish to emphasize that up until the last moment we were informed of new publications using the method that we had not heard about before.

It should be noted that for consistency throughout the chapters of the book we have suggested that the method be referred to as the ‘Alpert–Stein Methodology’ or the ‘Alpert–Stein Factor Separation Methodology’.

Special thanks go to the US–Israel BiNational Science Foundation (BSF) jointly with T. T. Warner (then at PSU), which funded our initial research on cyclogenesis over the Mediterranean that yielded the Factor Separation Methodology. Also, thanks go to the German–Israel Foundation (GIF), which continued the funding to our cyclogenesis study jointly with J. Egger (Munich University).

Cambridge University Press is to be congratulated on carefully bringing the book to its final stage with highly professional foresight and good advice.

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Preface


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