

Preface

Data Assimilation is a set of mathematical techniques allowing us to use all the information available within a time frame. This includes observational data, any a priori information we may have and a deterministic or stochastic model describing our system, and encapsulating our theoretical understanding. The mathematical basis is the estimation theory or theory of the inverse problem that is an organized set of mathematical techniques for obtaining useful information about the physical world on the basis of observation.

In a conventional problem one would use a set of known prior parameters to predict the state of the physical system. This approach is usually called a “forward problem.” In the “inverse problem” one attempts to use available observation of the state of the system to estimate poorly known parameters of the state itself. In both these cases Data Assimilation can be treated as a Bayesian system. The Bayesian theorem or the law of inverse probability allows us to combine a priori information about the parameters with the information contained into observations to guide the statistical inference process.

The reason why the Data Assimilation is so effective is that it seeks to produce an analysis that fits a set of observations taken over a time frame (not just the observations made at one instant in time). This is subject to the strong constraint that the evolution of the analyzed quantities is governed by a deterministic model describing the given observation.

Due to its flexibility Data Assimilation has been applied to several fields, from the numerical weather prediction, where it was first developed, to planetary climate analysis up to the evolution of biological cells.

One begins with a forecast model, often called background. In order to make useful predictions the background must be updated frequently with noisy and sparse measurements. This procedure updates the background in light of the new observation to produce an analysis, which, under suitable assumptions is the maximum estimate of the model state vector. Later, the model is restarted from analysis and produces a new background forecast.

Data Assimilation and model forecasts can be combined into an observing system simulation experiment in order to quantify the effect of changes in the observation accuracy, type, location, and frequency on the accuracy of the numerical forecast.

The method is prone to severe limitations, because eventually the forecasted parameters diverge from the true values. The optimal procedures would combine the most exhaustive theoretical and observational knowledge taking into account the errors of observation and those due to the model.

The aim of this book is to give an in-depth and complete overview in the frame of the SpringerBrief short book concept, to construct Data Assimilation in different and emerging fields from environment to biology, as outlined in the Applications chapter.

The book serves both teachers and college students and other interested parties providing the algorithms and formulas to manage the Data Assimilation wherever a dynamic system is present.

In writing this book I have followed the history of the data assimilation evolution. The first chapter gives a wide overview of the data assimilation steps starting from Gauss' first methods to the most recent as those developed under the Monte Carlo methods. The second chapter treats the representation of the physical system as an ontological basis of the problem. The third chapter deals with the classical Kalman filter, while the fourth chapter deals with the advanced methods based on recursive Bayesian Estimation. A special chapter, the fifth, deals with the possible applications, from the first Lorenz model, passing through the biology and medicine up to planetary assimilation, mainly on Mars. The earthquake application, where the model is highly nonlinear and the error is non-Gaussian, is also reported in order to offer another point of view to the reader.

The book endeavors to give a concise contribution to understanding the data assimilation and related methodologies. The mathematical concepts and related algorithms are fully presented, especially for those facing this theme for the first time.

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