Five decades in Science and Mathematics: Celebrating the Career of prof. Ionel Michael Navon

Inverse Problems and Data Assimilation minisymposium
SIAM CSE 2015, Salt Lake City, Utah
Ionel Michael Navon  
Florida State University

- After five decades in science and mathematics, Professor Ionel Michael Navon is retiring.
- Fields of interest: applied mathematics, physics, computational math, meteorology, geophysics, astrology.
- Publications: 5 Books and co-authored more than 250 scientific articles.
- Navon has always been a scholar, a researcher, an investigator and has spent his life and career in learning and scholarship.
- Along the way, he has worked for universities, meteorological institutes, and science and space powerhouses around the world.
- He has collaborated and created global alliances.
A bit of history

- Navon is a native of Romania, and lived there with his family until 1950. Following World War II, the political climate changed and became unfavorable for them, as Russian influence gave rise to imposed communism.

- Concerned for their security; Navon’s father moved the family to Israel.

- Between the ages of 10 and 14 he had to learn Hebrew. “I didn’t know a word of Hebrew, but I learned it in a few months”.

- He finished elementary school, and went to high school at the age of 14, in Paris, France. The family sent him there where his father’s sister lived, to get a better education there. “So I had to learn French within few a months”.

- After high school, he tried to go to university, but he couldn’t pursue his studies since being an Israeli citizen he was called to serve 2 and 1/2 years in the army.
After being discharged from the army, he studied for and received the B.S. in Mathematics and Physics (Hebrew Univ. of Jerusalem, 1967)
Soon after graduation, Michael married, and completed his M.S. diploma in Meteorology (Hebrew Univ. of Jerusalem, 1971)
Michael received his Ph.D. in Applied Mathematics (University of the Witwatersrand, Johannesburg, South Africa, 1979)
Michael joined FSU in 1985 and immediately started to make an impact.
Michael is one of the most influential leaders in the field of variational data assimilation.

Web of Science Report (1st page)
Michael’s work has defined and shaped the field of variational data assimilation.
Michael published five books

2005
(over 450 citations)

2013
Conjugate-Gradient Methods for Large-Scale Minimization in Meteorology

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ABSTRACT

During the last few years new meteorological variational analysis methods have evolved, requiring large-scale minimization of a nonlinear objective function described in terms of discrete variables. The conjugate-gradient method was found to represent a good compromise in convergence rates and computer memory requirements between simpler and more complex methods of nonlinear optimization. In this study different available conjugate-gradient algorithms are presented with the aim of assessing their use in large-scale typical minimization problems in meteorology. Computational efficiency and accuracy are our principal criteria.

Four different conjugate-gradient methods, representative of up-to-date available scientific software, were compared by applying them to two different meteorological problems of interest using criteria of computational economy and accuracy. Conclusions are presented as to the adequacy of the different conjugate-gradient algorithms for large-scale minimization problems in different meteorological applications.
Objective Analysis of Pseudostress over the Indian Ocean
Using a Direct-Minimization Approach

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ABSTRACT

A variational approach is used to develop an objective analysis technique which produces monthly average 1-deg pseudostress vector fields over the Indian Ocean. A cost functional is constructed which consists of five terms, each expressing a lack of fit to prescribed conditions. The first expresses the proximity to the input (first-guess) field. The second deals with the closeness of fit to the climatological value for that month. The third is a measure of data roughness, and the fourth and fifth are kinematic constraints on agreement of the curl and divergence of the results to the curl and divergence of the climatology. Each term also has a coefficient (weight) which determines how closely the minimization fits each lack of fit. These weights are determined by comparing the results using various weight combinations to an independent subjective analysis of the same dataset. The cost functional is minimized using the conjugate-gradient method.

Results from various weight combinations are presented for the months of January and July 1984 and the results examined in terms of these selections. Quantitative and qualitative comparisons to the subjective analysis are made to find which weight combination provides the best results. It was found that the weight on the second term balances the influence of the original (first-guess) field and climatology. The smoothing term weight determines how wide an area deviations of the first guess from climatology is affected. The weights on the kinematic terms are fine-tuning parameters.
The Second Order Adjoint Analysis: Theory and Applications

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Received January 30, 1992
Revised May 26, 1992

Summary

The adjoint method application in variational data assimilation provides a way of obtaining the exact gradient of the cost function $J$ with respect to the control variables. Additional information may be obtained by using second order information. This paper presents a second order adjoint model (SOA) for a shallow-water equation model on a limited-area domain. One integration of such a model yields a value of the Hessian (the matrix of second partial derivatives, $V^2J$) multiplied by a vector or a column of the Hessian of the cost function with respect to the initial conditions. The SOA model was then used to conduct a sensitivity analysis of the cost function with respect to distributed observations and to study the evolution of the condition number (the ratio of the largest to smallest eigenvalues) of the Hessian during the course of the minimization. The condition number is strongly related to the convergence rate of the minimization. It is proved that the Hessian is positive definite during the process of the minimization, which in turn proves the uniqueness of the optimal solution for the test problem.

Numerical results show that the sensitivity of the response increases with time and that the sensitivity to the geopotential field is larger by an order of magnitude than that to the $u$ and $v$ components of the velocity field. Experiments using data from an ECMWF analysis of the First Global Geophysical Experiment (FGGE) show that the cost function $J$ is more sensitive to observations at points where meteorologically intensive events occur. Using the second order adjoint shows that most changes in the value of the condition number of the Hessian occur during the first few iterations of the minimization and are strongly correlated to major large-scale changes in the reconstructed initial conditions fields.

1. Introduction

The complete description of the initial atmospheric state in a numerical weather prediction method constitutes an important issue. The four-dimensional variational data assimilation (VDA) method offers a promising way to achieve such a description of the atmosphere. It consists of finding the assimilating model solution which minimizes a properly chosen objective function measuring the distance between model solution and available observations distributed in space and time. The control variables are either the initial conditions or the initial conditions plus the boundary conditions. The boundary conditions have to be specified so that the problem is well posed in the sense of Hadamard. In most of the unconstrained minimization algorithms associated with the VDA approach, the gradient of the objective function with respect to the control variables plays an essential role. This gradient is obtained through one direct integration of the model equations followed by a backwards integration in time of the linear adjoint system of the direct model.
1992: Michael demonstrates that 4D-Var can be used with real life NWP models

Variational Data Assimilation with an Adiabatic Version of the NMC Spectral Model*

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(Manuscript received 29 July 1991, in final form 10 October 1991)

ABSTRACT

Variational four-dimensional (4D) data assimilation is performed using an adiabatic version of the National Meteorological Center (NMC) baroclinic spectral primitive equation model with operationally analyzed fields as well as simulated datasets. Two limited-memory quasi-Newton minimization techniques were used to iteratively find the minimum of a cost function, with the NMC forecast as a constraint. The cost function consists of a weighted square sum of the differences between the model forecast and observations over a time interval. In all the experiments described in this paper, observations are available for all degrees of freedom of the model. The derivation of the adjoint of the discretized adiabatic NMC spectral model is presented. The creation of this adjoint model allows the gradient of the cost function with respect to the initial conditions to be computed using a single backward-in-time integration of the adjoint equations.

As an initial evaluation of the variational data-assimilation procedure, an assimilation system with a low-resolution version of the NMC spectral model was tested using fields from a Rossby–Haurwitz-wave solution as observations. The results were encouraging, with a significant reduction in the magnitudes of both the cost function and the norm of its gradient during the minimization process. In particular, the high-frequency noise exhibited in the rms of the divergence field, produced by random perturbation in the initial conditions, is largely eliminated after the variational data assimilation.

The performance of the assimilation scheme was examined in a more realistic configuration using the adiabatic NMC spectral model truncated at T40. Both operationally analyzed observations, consisting of vorticity, divergence, temperature, surface pressure and moisture fields (distributed at two time levels separated by a 6-h time interval), and model-generated data were variationally assimilated. The effect of the number of observation fields in time on the convergence rate of the minimization and the impacts due to the inclusion of the horizontal diffusion and the surface drag in the model and its adjoint on the convergence rate and the accuracy of the retrieval are addressed.
NUMERICAL EXPERIENCE WITH LIMITED-MEMORY QUASI-NEWTON AND TRUNCATED NEWTON METHODS*

X. ZOU†, I. M. NAVON‡, M. BERGER§, K. H. PHUA¶,
T. SCHLICK‖, AND F. X. LE DIMET**


Key words. limited-memory quasi-Newton methods, truncated Newton methods, synthetic cluster functions, large-scale unconstrained minimization
Michael at NATO Advanced Research Workshop, les Houches, France, 1993
Practical and theoretical aspects of adjoint parameter estimation and identifiability in meteorology and oceanography

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Abstract

The present paper has two aims. One is to survey briefly the state of the art of parameter estimation in meteorology and oceanography in view of applications of 4-D variational data assimilation techniques to inverse parameter estimation problems, which bear promise of serious positive impact on improving model prediction. The other aim is to present crucial aspects of identifiability and stability essential for validating results of optimal parameter estimation and which have not been addressed so far in either the meteorological or the oceanographic literature.

As noted by Yeh (1986, Water Resour. Res. 22, 95–108) in the context of ground water flow parameter estimation the inverse or parameter estimation problem is often ill-posed and beset by instability and nonuniqueness, particularly if one seeks parameters distributed in space-time domain. This approach will allow one to assess and rigorously validate results of parameter estimation, i.e. do they indeed represent a real identification of physical model parameters or just compensate model errors? A brief survey of other approaches for solving the problem of optimal parameter estimation in meteorology and oceanography is finally presented. © 1997 Elsevier Science B.V.
2001: Michael establishes fundamental equivalence properties between 4D-Var and KF

Optimality of variational data assimilation and its relationship with the Kalman filter and smoother

By ZHIJIN LI and I. M. NAVON*
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(Received 23 June 1999; revised 25 August 2000)

SUMMARY

The known properties of equivalence between four-dimensional variational (4D-Var) data assimilation and the Kalman filter as well as the fixed-interval Kalman smoother point to particular optimal properties of 4D-Var. In the linear context, the 4D-Var solution is optimal, not only with respect to the model trajectory segment over the assimilation time interval, but also with respect to any model state at a single observation time level; in the batch processing (cycling 4D-Var) method, the information in 4D-Var is fully transferred from one batch to the next by the background term; 4D-Var allows the processing of observations in subsets, while the final solution is optimal as all observations are processed simultaneously. These properties hold even for models that are imperfect, as well as not invertible. Various properties of equivalence of 4D-Var to the Kalman filter and smoother result from these optimality properties of 4D-Var. Further, we show that the fixed-lag Kalman smoother may also be constructed in an optimal way using a multiple batch-processing 4D-Var approach. While error covariances are crucial for the equivalence, practical techniques for evaluating error covariances in the framework of cycling 4D-Var are discussed.

KEYWORDS: Data assimilation Kalman filter Kalman smoother Optimality
2002: Michael starts the “modern age” of widely accepted SOA use in DA
A reduced-order approach to four-dimensional variational data assimilation using proper orthogonal decomposition

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SUMMARY

Four-dimensional variational data assimilation (4DVAR) is a powerful tool for data assimilation in meteorology and oceanography. However, a major hurdle in use of 4DVAR for realistic general circulation models is the dimension of the control space (generally equal to the size of the model state variable and typically of order 10⁷–10⁸) and the high computational cost in computing the cost function and its gradient that require integration model and its adjoint model.

In this paper, we propose a 4DVAR approach based on proper orthogonal decomposition (POD). POD is an efficient way to carry out reduced order modelling by identifying the few most energetic modes in a sequence of snapshots from a time-dependent system, and providing a means of obtaining a low-dimensional description of the system’s dynamics. The POD-based 4DVAR not only reduces the dimension of control space, but also reduces the size of dynamical model, both in dramatic ways. The novelty of our approach also consists in the inclusion of adaptability, applied when in the process of iterative control the new control variables depart significantly from the ones on which the POD model was based upon. In addition, these approaches also allow to conveniently constructing the adjoint model.

The proposed POD-based 4DVAR methods are tested and demonstrated using a reduced gravity wave ocean model in Pacific domain in the context of identical twin data assimilation experiments. A comparison with data assimilation experiments in the full model space shows that with an appropriate selection of the basis functions the optimization in the POD space is able to provide accurate results at a reduced computational cost. The POD-based 4DVAR methods have the potential to approximate the performance of full order 4DVAR with less than 1/100 computer time of the full order 4DVAR. The HFTN (Hessian-free truncated-Newton) algorithm benefits most from the order reduction (see (Int. J. Numer Meth. Fluids, in press)) since computational savings are achieved both in the outer and inner iterations of this method.

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Comparison of optimized Dynamic Mode Decomposition vs POD for the shallow water equations model reduction with large-time-step observations

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SUMMARY

We propose a framework for dynamic mode decomposition of 2D flows, when numerical or experimental data snapshots are captured with large time steps. Such problems originate for instance from meteorology, when a large time step acts like a filter in obtaining the significant Koopman modes, therefore the classic dynamic mode decomposition method is not effective. This study is motivated by the need to further clarify the connection between Koopman modes and POD dynamic modes. We apply dynamic mode decomposition (DMD) and proper orthogonal decomposition (POD) to derive reduced-order models of Shallow Water Equations (SWE). A new algorithm for extracting the dominant Koopman modes of the flow field and a new criterion of selecting the optimal Koopman modes are proposed. A quantitative comparison of the spatial modes computed from the two decompositions is performed and a rigorous error analysis for the ROM models obtained by the classic POD and the optimized DMD is presented.

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Fellow of the American Meteorological Society, 1998
Honorary Member of Romanian Academy of Science, 2013
(1998, with prof. Ying Hwa Kuo)
Florida State University
Tallahassee, Florida
In Recognition of Meritorious Service to the University,
And on Recommendation of the Faculty of the
College of Arts & Sciences
Hereby is Designated
I. Michael Navon
Professor Emeritus
Effective on the 30th day of August, 2014

Dean
Sally E. McRorie
Interim Provost and Executive Vice President
President

Professor Emeritus, Florida State, 2014
Let the celebrations begin!