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Dedication

Professor Ionel Michael Navon who recently turned 65 years young is currently Faculty Professor in the School of Computational Science and Department of Mathematics at Florida State University (FSU). He has played an active part in many fields of research during the last few decades. His distinguished achievements in the domain of variational data assimilation have contributed to development in this field of endeavor.

His contributions in this field are due in no small part to his having the opportunity to collaborate with outstanding colleagues and pioneers in the field and young doctoral and post-doctoral collaborators at stages when the field of data assimilation was at its active development phase.

Early in his career he worked at Council of Scientific and Industrial Research, South Africa, and worked on a project on the impact of GARP data sets DST-5 and DST-6 (1976–1981) on predictability degradation in the southern hemisphere supported by NASA/GSFC and coordinated by E. Kalnay related to direct insertion of data into prediction models.

He got attracted to variational methods in meteorology [1] and during a sabbatical year 1982–1983 at NASA/GSFC, he worked on augmented Lagrangian methods directly related to mathematical aspects of data assimilation [2].

Having met in 1981 with a pioneer of optimal control and variational data assimilation in meteorology, F.X. Le Dimet, he presented an early review of "Variational and Optimization Methods in Meteorology", at the International Symposium on Variational Methods in Geosciences, held at the University of Oklahoma, Norman, OK, 1985 [3–4] and a conference at ICIAM 1987 Paris with Beny Neta [5].

A close collaboration with F.X. Le Dimet led to an early comprehensive review of data assimilation [6].

Close collaboration with the group of J. O'Brien in the field of variational methods led to a number of pioneering research articles on optimization in meteorology and oceanography [7–9].

Work with F.X. Le Dimet and X. Zou led to publication of seminal papers in the field of variational data assimilation (VDA) such as [10–14]. This resulted from collaboration with J. Derber a pioneer in data assimilation and J. Sela at National Meteorological Center (NMC). Work with Z. Wang *et al.* [15] led to early paper on second-order adjoint method while work with Zou and Le Dimet [12] constituted early contribution to adjoint parameter estimation. With M. Ramamurthy, the use of direct variational methods was applied to initialization of monsoon over a limited area domain [16].

With Zou, D.G. Cacuci, and others, he worked on generalized adjoint sensitivity theory applied to block onset in climatological models, [17].

Collaboration with staff members at NASA/GSFC such as R. Bates and Y. Li on application of VDA to NASA multilevel semi-implicit semi-Lagrangian (SLSI) General Circulation Model (GCM) model led to [18,19] on first adjoint models of SLSI.

Work related to optimization algorithms for VDA and rate of convergence of variational data assimilation as well as choice of efficient minimization algorithms was done with Zou, [20], T-N

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methods and second-order adjoint by Wang [21]. A nice summary of this work was published in a book chapter [22]. A technical report on adjoint sensitivity analysis was written with Le Dimet and Ngodock [23].

Application of data assimilation to finite-element models with K. Zhu and X. Zou [24], boundary control in limited area models with J. Zou [25], novel Hessian preconditioning with NASA GCM with W. Yang and P. Courtier [26].

Initial work on the adjoint of the radiation package of the NCEP spectral GCM was carried out with J. Zou [27]. Documentation of work on adjoint of NASA GEOS GCM was done with Yang [28] and Yang, *et al.* [29] while work on the ARPS University of Oklahoma was done with Z. Wang *et al.* [30]. A survey of practical and theoretical aspects of adjoint parameter estimation and identifiability in meteorology and oceanography is in [31]. During that year Navon was elected Fellow of the American Meteorological Society in view of his contribution and services to the AMS society as editor of *Monthly Weather Review*.

With Z. Li, he published [32] "Sensitivity analysis of outgoing radiation at the top of the atmosphere in the NCEP/MRF model", while with Y. Zhu, then Ph.D. student at FSU he wrote a paper [33] "FSU-GSM forecast error sensitivity to initial conditions: Application to Indian summer monsoon". With Y. Yang and R. Todling (NASA/GMAO) he wrote a documentation of the multi-tasked tangent linear and adjoint models of the adiabatic version of the NASA GEOS-2 GCM [34], with Y. Zhu [35] he addressed the issue of impact of key parameters estimation on the performance of the FSU spectral model using the full physics adjoint, and with Y. Yang *et al.* [36] studied the sensitivity to large scale environmental fields of the relaxed Arakawa-Schubert parameterization in the NASA GEOS-1 GCM. With Z. Li and A. Barcilon [37], we studied block onset using adjoint sensitivity perturbations.

Issues of incremental 4D-Var were addressed with Z. Li *et al.* [38], while with Zhang *et al.* [39] he addressed issue of the use of nondifferentiable optimization in 4D-Var. The optimality of 4D-Var and its relationship with the Kalman filter and Kalman smoother, was investigated with Li [40], while Zou *et al.* [41] completed a research on the 4D-Var data assimilation with a diabatic version of the NCEP global spectral model.

A comprehensive review on second order adjoint information in data assimilation was written with Le Dimet and Daescu [42].

With Alekseev he co-wrote "Analysis of an ill-posed problem using multiscale resolution and second order adjoint techniques" [43]. With then doctoral student C. Homescu he co-wrote a paper [44] on numerical and theoretical considerations for adjoint sensitivity calculation of discontinuous flow while with Z. Liu an MPI parallel version of the adjoint of the FSU global spectral model was developed [45].

Adjoint methods extended to fluid flow served as the background of a paper co-written with Z. Li, M.Y. Hussaini, and F.X. Le Dimet entitled "Optimal control of cylinder wakes via suction and blowing" [46].

A fixed-lag Kalman smoother was employed for the "GEOS retrospective data assimilation system: The 6 hour lag case" paper written in collaboration with Y. Zhu, R. Todling , J. Guoy, S.E. Cohn and Y. Yang, then a postdoctoral researcher at FSU [47].

A paper entitled "New methodology for optimal control of shocked flow using the Sod shock tube problem model for optimal control of flow with discontinuities in the framework of the 1-D Riemann problem of the Euler equations" was co-written with then doctoral student C. Homescu [48]. "Calculation of uncertainty propagation using adjoint equations" was co-written with Alekseev [49] while "An analysis of a hybrid optimization method for variational data assimilation" was published with Daescu [50].

A novel approach to "Adaptive observations in the context of 4D-Var data assimilation" was co-written with Daescu [51] while "Documentation of the TLM and adjoint of the TLM and adjoint models of the Lin-Rood spherical shallow water finite volume model" was developed with a doctoral student Akella [52].

A paper on the initialization of ensemble data assimilation was co-written with M. Zupanski, S. Fletcher, B. Uzunoglu, R.P. Heikes, D.A. Randall, and T.D. Ringler [53] along with a study on the impact of the background error on incomplete observations for 4D-Var data assimilation with the FSU GSM, co-written with Daescu and Z. Liu [54].

Use of adjoint method for goal oriented methods was addressed in papers with Alekseev one on *a-posteriori* pointwise error estimation using adjoint temperature and Lagrange remainder [55,56], while the other addressed adjoint correction and bounding of error using Lagrange form of truncation term [57]. In collaboration with Z. Li and M.Y. Hussaini "Analysis of the singular vectors of the full-physics Florida State University global spectral model" was written [58]. "A comparative study of the performance of high resolution advection schemes in the context of data assimilation" was co-written with doctoral student Akella [59]. A POD reduced order approach to four-dimensional variational data assimilation using proper orthogonal decomposition paper was co-written with Y. Cao, J. Zhu and Z. Luo [60].

Finally, a study of forecast errors in variational data assimilation using high-resolution advection schemes of the Lin-Rood finite volume shallow water model was written with doctoral student Akella [61].

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