1997 ANNUAL REPORT FOR ONR MARINE METEOROLOGY PROGRAM

FUNDING MANAGER: DR. ROBERT F. ABBEY JR. (PROGRAM NO. N00014-94-1-0556).

I. Header Information

A. Name: Professor Lance M. Leslie

B. Title of Grant: Predictability of Tropical Cyclones: Theoretical and Practical Aspects

C. Address: School of Mathematics, University of New South Wales, Sydney, Australia 2052

D. E- Mail: L.Leslie@unsw.edu.au

E. Tel: 61-2-9385-3307
Fax: 61-2-9385-1071

II. Narrative Documentation

A. The long term goals of this program remain largely unchanged, namely to define, and attempt to approach in practice, the limits to predictability of tropical cyclones, beginning with track forecasting and later extending the work to intensity and structure.

B. The scientific objectives of the effort are to apply the techniques of non-linear systems analysis to estimating the so-called "intrinsic" limits to predictability for (i) tropical cyclone mean forecast position errors in the first instance, and (ii) to tropical cyclone intensity and intensity change in the second part of the program. The intrinsic limits are to be compared with the results being obtained in practice and the size of the disparity represents the gains in predictive skill that are still achievable. It is of fundamental importance to have some idea of how large the gap is between that being obtained and the ultimately achievable in order to justify the continued allocation of resources to the various problems. Additionally, it is worthwhile recognizing that the critical problem of landfalling tropical cyclones is now capable of being addressed with the new data sources and improved models now available.

C. The approach to the task has been to extend the work of the previous program (1994-1995), which used a "perfect model - perfect ensemble" technique to estimate the inherent predictability limit and compared that limit with results obtained in practice, for the Australian region and the northwest Pacific, out to 72 hours ahead. A barotropic model was used in that study, together with a new data assimilation scheme developed jointly with Oregon State University. In the present program, the barotropic work was completed by extending it to other basins. Results were similar to those already obtained. All work is presently being carried out with a new model developed at UNSW in collaboration with NCEP, Washington, DC and using data obtained from NRL-Monterey, UW-Madison and the Australian Bureau of Meteorology. The focus thus far has been on the Atlantic and Australian region basins, especially the very active 1995 and 1996 Atlantic basin seasons. Increased attention also is now being paid to the eastern Pacific as it is of great interest to the US Navy. The data used has been of much higher quality than that hitherto available, and this fact is reflected in the results section, below.

D. The proposal is nearing the end of the first year of its term and the tasks completed are as follows:
(i) work with the barotropic model on four hurricane basins has been completed. Essentially identical results were obtained for every basin.
(ii) attention has now turned exclusively to a baroclinic model and the entire set of calculations is being repeated for each basin, together with additional work on the Atlantic basin seasons of 1995 and 1996.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1997		**00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Predictability of Tropical Cyclones: Theoretical and Practical Aspects	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of New South Wales,School of Mathematics,Sydney, Australia 2052,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

(iii) the data assimilation scheme developed with Andrew bennett of OSU also has been extended to a baroclinic model, and can be relocated anywhere on the globe. A series of experiments has been carried out with TCM-90 data and published using this approach. NRL-Monterey have expressed interest in the procedure.
(iv) very high quality data sets have been obtained from NRL-Monterey,UW-Madison and the Australian Bureau of Meteorology and are being used routinely in the PI's data assimilation scheme.

E. Results
As mentioned above, the barotropic work was completed by extending it to other basins, including the Atlantic and Indian Ocean basins. Results were almost identical with the previous estimates of a gap between practical and inherent predictability limits of between 40 to 50 per cent. Over the second half of the program, a new, high resolution, baroclinic model has been used and to date has been applied to the Atlantic and Australian region basins and in great detail to a number of selected "difficult" storms. The other major development has been the availability in real time and research mode of high spatial and temporal resolution satellite wind vectors from GOES-8 and GMS-5. Water vapor and scatterometer winds also are being ingested into the assimilation system. The combination of improved data, a superior data assimilation scheme, and the new model has reduced the difference between the practical and inherent predictability limits by 10 per cent to between 30 and 40 per cent. Moreover, the difficult storms were those that were most dramatically improved, as has been reported on in journal articles and will be reported on further in upcoming conferences.

F. Impact for science/systems applications
By far the most significant impact in the program to date continues to be the large reduction of mean position errors in tropical cyclone track prediction by the order of 10 per cent. This reduction has come from three main sources: improved data coverage with up to 1000 additional, high quality satellite derived wind vectors for each 24 hours of data assimilation; the development of the 4-D variational data assimilation scheme; and the use of the new very high resolution limited area model. As far as the PI is aware, no other data assimilation system is operating on an hourly data ingestion, and much of the impact has come from this high temporal resolution assimilation of high quality data.

G. Transitions: the new data assimilation and prediction system is now run routinely at the Sydney office of the Bureau of Meteorology, and is being tested in real-time during the next Australian region tropical cyclone season (October 1997 - April 1998), jointly with Dr. John LeMarshall of the Australian Bureau of Meteorology. The system was tested during the Atlantic season of 1997 but as there was only one hurricane no conclusions can be drawn. The PI is planning to visit NRL-Monterey early in 1998 to test the system again, jointly with UW-Madison in the 1998 season.

H. Relationship to other projects: there is some overlap with the program of Prof. Johnny Chan of the City University of Hong Kong. The link is the use of a model developed at UNSW and a visit by Kevin Cheung to UNSW funded by a China-Australia agreement. There is no collaborative work at this stage, but that might change in the future.

III. Statistical Information

A. List of publications: a total of 24 publications were accepted/published in peer-reviewed journals in 1997. One of these was a Special Issue of the journal Meteorology and Atmospheric Physics, edited by Dr. Naomi Surgi of the National Hurricane center, Miami and myself. A further 4 are in preparation, including two book chapters, and 2 WMO reports. The full list of publications can be found at the end of this report.

B. Number/names of graduate students: Mr. Kwok Aune Tan (Data assimilation, modeling); Miss Lu Hua (Modeling, air-sea interaction), Mr Qi Lixin. One female, and 2 minority students.

C. Post-docs: Dr. Matthew England. Air-sea interaction. Funded by Australian Research Council for period Jan 1 1997 to December 31, 1998.

D. Patents: Nil

E. Oral presentations: During 1997, a total of about 25 oral presentations have been made, including:
3 presentations, AMOS Conference, Melbourne, February 1997
2 presentation, the 22nd AMS Conference on Hurricanes and Tropical Meteorology, Fort Collins, May 19-23, 1997
1 presentation, UCLA, May 26, 1997
2 presentations, IAMAS/IAPSO meeting, Melbourne, July 1-9, 1997
Invited Lecture, Macquarie University, August 13, 1997
4 presentations, Chinese Academy of Sciences, Beijing, August 18-22, 1997
2 presentations, WMO COMPARE workshop, Deutshe Wetterdienst, Offenbach, Germany, October, 1997
Address to Graduating Science Class on Tropical Meteorology, October 1997.

F. Service on committees: A number of committees were served on during 1997, including:
AMS Committee for the Meisenger Award, 1997
COMPARE Committee (WMO), 1996 ->. TCM-90 case chosen for the next COMPARE experiment.
Convenor and member of organizing committee, AMOS Conference, Sydney, February, 1997.
Organizing Committee for next CITAC (Conference on Information Technology and Advanced Computation), Adelaide, September,1997.

G. Honors/Awards: One major honor was achieved during 1997, namely, the PI was elected as an Academician in the Eurasian Academy of Science in a ceremony in Beijing on August 19, 1997. The Academy is relatively new and has formed out of the old Russian academy of Science. Its head office will be located in Bonn, Germany.

H. Percentage of funds to other organizations: Aside from overheads of 17.5% charged by UNSW, nil.

Peer-reviewed journal articles 1997:

Leslie, LM and Surgi, N (Special Editors) (1997) Tropical Cyclones, **Meteorology and Atmospheric Physics**. In final preparation.

Leslie, LM, Abbey, RF, and Holland, GJ, 1997: Tropical cyclone track predictability. **Meteorology and Atmospheric Physics** (Accepted).

Buckley, B.W. and Leslie LM, 1997: A numerical study of a tropical cyclone undergoing extr-tropical transition, **Meteorology and Atmospheric Physics** (Accepted).

Leslie, LM and Dietachmayer, GS (1997) Comparing schemes for integrating the Euler equations, **Monthly Weather Review**, **125**, In press

Leslie, LM and Purser, RJ (1997) A new class of generalised Lorenz numerical integration schemes, **Monthly Weather Review**, **125**, 1261-1276.

Leslie, LM and Purser, RJ (1997) A new semi - Lagrangian semi - implicit NWP model for operations and

research: Formulation and performance in single and multi - processor computing environments, **Atmosphere - Ocean**, **31,** In press

Leslie, LM, Abbey, R.F. and Holland, G.J. (1997) Hurricanes: Are there simple linear invariants hidden within these complex non-linear dynamical systems? **Phys. Rev. Lett.** (In Press).

Batt, KL and Leslie LM, 1997: Verification of output from a very high resolution numerical weather prediction model. Meteorological Applications (In Press).

Le Marshall, JL, Leslie, LM and Bennett, AF (1996) Tropical cyclone Beti - An example of the benefits of assimilating hourly satellite wind data, **Australian Meteorological Magazine,**

Leslie, LM and Fraedrich, K (1997) A new general circulation model: Formulation and preliminary results, **Climate Dynamics, 13**, pp. 35 - 43.

Shao, Y and Leslie, LM (1997) Wind erosion prediction over the Australian continent, **Journal of Geophysical Research**, In press

Leslie, LM and Morison RP (1997) Ensemble prediction experiments with Tropical Cyclone Bobby. **Aust. Meteor. Mag.**, In Press.

Shao, Y and Leslie, LM (1997) Prediction of soil moisture over the Australian continent, **Meteorology and Atmospheric Physics**, **63,** 195-216.

LeMarshall, JL and Leslie, LM (1997) The importance of direct read-out satellite observations in sub-synoptic scale meteorology, **Advances in Space Research**, **19**, 413-422.

Leslie, LM and LeMarshall, JL (1997) The generation and assimilation of cloud drift winds in numerical weather prediction, **Journal of the Meteorological Society of Japan**, **75**, 273-285.

Schubert, S and Leslie, LM (1997) Combining dynamical and statistical models for local weather forecasting, **Weather and Forecasting**, **12**, In press

Leslie, LM and Speer, MS (1997) Atmospheric particulate transport modelling in a controlled burn event, **Meteorological Applications**, In press

Speer, MS and Leslie, LM (1997) Real - time prediction of heavy rainfall over the coast of Southeast Australia, **Meteorological Applications**, **4**, In press

Speer, MS and Leslie, LM (1997) Ensemble forecasting of a rainfall event over New South Wales, **Australian Meteorological Magazine**, **46,** 75-78.

Speers, MS and Leslie, LM (1997) Climatology of coastal ridging over NSW, **International Journal of Climatology**, **17**, 831-845.

Leslie, LM and Morison, PR (1997) Prediction of Atlantic hurricanes in the 1995 season, **Monthly Weather Review**, **125**, In press

Leslie, LM and Speer, MS, 1997: Short-range ensemble forecasting of Australian east coast cyclogenesis. Wea. And Forecasting, **12**, In Press.

Bennett, AF, Chua, BS and Leslie, LM (1996 and 1997) Generalised inversion of a global numerical weather prediction model (Parts I and II), **Meteorology and Atmospheric Physics, 60**, 165 - 178, and **Meteorology and Atmospheric Physics** (In Press)**.**