Curriculum Vitae for Richard Kleeman

1 Education

- Bachelor of Science (Honours) in Theoretical Physics from the Australian National University. Awarded in 1980.
- Doctor of Philosophy in Mathematical Physics from Adelaide University. Awarded in 1986. Doctoral dissertation was on quantum field theory. Supervisor was Prof. H.S. Green foundation professor of mathematical physics at Adelaide University.

2 Employment History

- Full Professor of Mathematics (tenured) Courant Institute of Mathematical Sciences, NYU from September 2004 to present.
- Associate Professor of Mathematics (tenured) Courant Institute of Mathematical Sciences, NYU from September 1999 to September 2004.
- Principal Research Scientist in the Oceanography Group of the Bureau of Meteorology Research Center 1999.
- Senior Research Scientist in the Climate Group of the Bureau of Meteorology Research Center 1995-1999.
- Senior Professional Officer (Class C) in the Climate Group of the Bureau of Meteorology Research Center between 1991 and 1994.
- Science (Grade 2) in the Climate Group of the Bureau of Meteorology Research Center between 1988 and 1991.
- CSIRO Postdoctoral Fellow at the Division of Atmospheric Research during 1986 and 1987.

3 Refereed Publications

1. Kleeman R., 1981, “On representations of a generalized method of field quantization”; Journal of Aust. Math. Soc. (Ser. B); Vol 23 pp52-63.

2. Kleeman R., 1983, “Aspects of modular quantization”; Journal of Math. Phys.; Vol 24 pp166-172.

3. Kleeman R., 1985, “Commutation factors on generalized Lie Algebras”; Journal of Math. Phys.; Vol 26 pp2405-2412.

4. Kleeman R. 1987, “Observables in modular field theory”; Journal of Aust. Math. Soc. (Ser. B); Vol. 29 pp221-248.

5. Kleeman R., J.S. Frederiksen and R.C. Bell, 1988 “Statistical Dynamics of Quasi-Geostrophic Flows” in “Computational Techniques and Applications: CTAC-87” ed by Noye and Fletcher (North Holland).

6. Kleeman R.,1989 “A Modeling Study of the Effect of the Andes on the Summertime Circulation of Tropical South America”; Journ., Atmos. Sci.; Vol. 46, pp3344-3362.

7. Kleeman R.,1991 “A Simple Model of The Atmospheric Response to ENSO Sea Surface Temperature Anomalies”; Journ., Atmos. Sci,; Vol 48, pp3-18.

8. Kleeman R., M. Latif and M. Flügel,1992 “A Hybrid Coupled Tropical Atmosphere Ocean Model: Sensitivities and Hindcast Skill”; Max Planck Institut fur Meteorologie Report No. 76 (January 1992).

9. Kleeman R., 1993 “On the dependence of hindcast skill on ocean thermodynamics in a coupled ocean-atmosphere model”; J. Clim.; Vol 6, pp2012-2033.

10. Power S.B. and R. Kleeman, 1993 “Multiple Equilibria in a Global General Circulation Model”; J. Phys. Oceanogr.; Vol 23, pp1670-1681.

11. Kleeman R., B.J. McAvaney and R.C. Balgovind, 1994, “An analysis of the Interannual Heat flux Response in an Atmospheric General Circulation Model in the Tropical Pacific”, J. Geophys. Res. (Atmospheres); Vol 99, pp5539-5550.

12. Power S.B. and R. Kleeman, 1994 “Surface Heat Flux Parameterization and the Response of Ocean General Circulation Models to High Latitude Freshening” Tellus A; Vol 46, pp86-95.

13. Kleeman R. and S.B. Power, 1994, “Limits to predictability in a coupled ocean-atmosphere model due to atmospheric noise”, Tellus A Vol 46, pp529-540.

14. Power S.B., A.M. Moore, N.R. Smith, D.A. Post and R.Kleeman, 1994 “On the Stability of North Atlantic Deep Water Formation in a Global Ocean Circulation Model” J. Phys. Oceanogr.; Vol 24, pp904-916.

15. Kleeman R. and S.B. Power, 1995, “A simple atmospheric model of heat flux for ocean model studies”, J. Phys. Oceanogr. Vol 25, pp92-105.

16. Power S.B., R.Kleeman, R.A. Coleman and B.J. McAvaney, 1995 “Modeling the surface heat flux response to long-lived SST anomalies in the North Atlantic”, J. Clim. Vol 8, pp2161-2180.

17. Kleeman R., 1994 “Forecasts of Tropical Pacific SST Using a Low Order Coupled Ocean-Atmosphere Dynamical Model”, in NOAA Experimental Long-Lead Forecast Bulletin (since June 1994).

18. Kleeman R., A.M. Moore and N.R. Smith, 1995 “Assimilation of subsurface thermal data into an intermediate tropical coupled ocean-atmosphere model”, Mon. Weath. Rev. Vol 123, pp3103-3113.

19. Power S.B., F. Tseitkin, M. Dix, R. Kleeman, R. Colman and D. Holland, 1995 “Stochastic Variability at the Air-Sea Interface on Decadal Time-scales”, Geophys. Rev. Lett. Vol 22 pp2593-2596.

20. Moore A. M. and R. Kleeman, 1996, “The Dynamics of Error Growth and Predictability in a Coupled Model of ENSO”, Q. J. R. Met. Soc. Vol 122, pp1405-1446.

21. Kleeman R., R. Colman, N.R. Smith and S.B. Power, 1996, “A recent change in the mean state of the Pacific ocean: Observational evidence, atmospheric and oceanic responses”, J. Geophys. Res. (Oceans), Vol 101, pp20483-20499

22. Kleeman R. and A.M. Moore, 1997, "A theory for the limitation of ENSO predictability due to stochastic atmospheric transients", Journal of Atmos. Sci., Vol 54, pp753-767.

23. Latif M., R. Kleeman and C. Eckert, 1997, "An investigation of Tropical Climate Variability 1949-1994: An attempt to Understand the Anomalous 1990s.", J. Clim., Vol 10, pp2221-2239.

24. Moore A. M. and R. Kleeman, 1997, "The Singular Vectors of a Coupled Ocean-Atmosphere Model of ENSO, Part I: Thermodynamics, Energetics and Error Growth", Q. J. R. Met. Soc., Vol 123, pp953-981.

25. Moore A. M. and R. Kleeman, 1997, "The Singular Vectors of a Coupled Ocean-Atmosphere Model of ENSO, Part II: Sensitivity studies and dynamical interpretation", Q. J. R. Met. Soc., Vol 123 pp983-1006.

26. Walsh K. and R. Kleeman, 1997: "Predicting Atlantic tropical cyclone numbers and Australian rainfall using north Pacific sea surface temperatures", Geophys. Res. Lett., Vol 24 pp3249-3252.

27. Moore A.M. and R. Kleeman, 1998: "Skill Assessment for ENSO using Ensemble Prediction", Q. J. R. Met. Soc., Vol 124, pp557-584.

28. Latif M., D. Anderson, T. Barnett, M. Cane, R. Kleeman, A. Leetma, J. O'Brien, A. Rosati and E. Schneider, 1998: "TOGA Review Paper: Predictability and Prediction", J. Geophys. Res. (Oceans) Vol 103 pp14,375-14,393.

29. Kleeman R. and A.M. Moore, 1999: "A new method for determining the reliability of dynamical ENSO predictions", Mon. Weath. Rev., Vol 127, pp 694-705.

30. Kleeman R. and S.B. Power, 1999: "Modulation of ENSO variability on Decadal and Longer Timescales" , in "El Nino and the Southern Oscillation, Multiscale Variability and its impacts on Natural Ecosystems and Society", eds. H.F. Diaz and V. Markgraf, Cambridge University Press.

31. Moore A.M. and R. Kleeman, 1999: "Stochastic Forcing of ENSO by the intraseasonal oscillation", J. Clim., Vol 12, 1199-1220.

32. Kleeman R., G. Wang and S. Jewson, 2001, "Surface flux response to interannual tropical Pacific sea surface temperature variability in AMIP models", Climate Dynamics, Vol. 17, 627-641.

33. Kleeman R., N.H. Naik and M.A. Cane, 2000: "On the meridional location of the Pacific Ocean subtropical gyre", J. Phys. Oceanogr., Vol 30, 1988-2000.

34. Krishna Kumar K., R. Kleeman, M.A. Cane and B. Rajagopalan, 1999, "Epochal changes in Indian Monsoon-ENSO Precursors", Geophys. Res. Lett., Vol 26, pp75-78.

35. Moore A.M. and R. Kleeman, 1999, "The Non-Normal Nature of El Nino and Intraseasonal Variability", J. Clim., Vol 12, 2965-2982.

36. Kleeman R., J.P. McCreary and B.A. Klinger, 1999, "A mechanism for the decadal variation of ENSO", Geophys. Res. Lett., Vol 26, p1743.

37. Kessler W.S. and R. Kleeman, 2000: "Rectification of the Madden-Julian Oscillation into the ENSO cycle.", J.Clim., Vol 13, 3560-3575.

38. Nicholls, N., C. Frederiksen, and R. Kleeman, 2000: "Operational experience with climate model predictions". Chapter 8 in: Applications of seasonal climate forecasting in agricultural and natural ecosystems. The Australian experience, Hammer,G.L, Nicholls,N., and Mitchell,C. (eds.), Kluwer, 482 pp.

39. Moore A.M. and R. Kleeman, 2001: "The Differences between the optimal perturbations of coupled models of ENSO", J. Clim. Vol 14, 138-163.

40. Wang G., R.Kleeman, N.R.Smith and F.Tseitkin, 2002: "Seasonal predictions with a BMRC coupled global ocean-atmosphere model"; Mon. Weath. Rev. Vol 130, 975-991.

41. Kleeman R., 2002: "Measuring dynamical prediction utility using relative entropy", Journ. Atmos. Sci. Vol 59, 2057-2072.

42. Keenlyside N. and R. Kleeman, 2002: "On the annual cycle of the zonal currents in the equatorial Pacific", J. Geophys. Res (Oceans) Vol 107 (August) doi:10.1029/2000JC000711.

43. Klinger B.A., J.P. McCreary and R. Kleeman, 2002: "The relationship between oscillating subtropical wind and equatorial temperature", J. Phys. Oceanogr. Vol. 32, 1507-1521.

44. Tang Y. and R. Kleeman, 2002: "A new strategy for assimilating SST data for ENSO predictions", Geophys. Res. Lett., Vol 29 (September) doi: 10.1029/2002GL014860.

45. Kleeman R., A. J. Majda and I. Timofeyev, 2002: "Quantifying predictability in a model with statistical features of the atmosphere", Proceedings of the National Academy of Science, Vol 99, 15291-15296.

46. A. J. Majda, R. Kleeman, and D. Cai. A framework of predictability through relative entropy. Meth. Appl. Anal., 9:425-444, 2002.

47. R-H Zhang, S.E. Zebiak, R. Kleeman, and N. Keenlyside. A new intermediate coupled model for El Nino simulation and prediction. Geophys. Res. Lett., 30:2012, 2003.

48. J. Zavala-Garay, A.M. Moore, C. L. Perez, and R. Kleeman. The response of a coupled model of ENSO to observed estimates of stochastic forcing. J. Clim., 16:2827-2842, 2003.

49. Y. Tang, R. Kleeman, A. M. Moore, A. Weaver, and J. Vialard. The use of ocean reanalysis products to initialize ENSO predictions. Geo. Res. Lett., 30:1694, 2003. doi:10.1029/2003GL017664.

50. A. Solomon, J. P. McCreary, R. Kleeman, and B. A. Klinger. Interannual and decadal variability in a coupled ocean-atmosphere model of the Pacific region. J. Clim., 16:383-405, 2003.

51. A. M. Moore, J. Vialard, A. Weaver, D. L. T. Anderson, R. Kleeman, and J. R. Johnson. The role of atmospheric dynamics and nonnormality in controlling optimal perturbation growth in coupled models of ENSO. J. Clim., 16:951-968, 2003.

52. R. Kleeman, Y. Tang, and A. M. Moore. The calculation of climatically relevant singular vectors in the presence of weather noise as applied to the ENSO problem. J. Atmos Sci, 60:2856-2868, 2003.

53. J. Zavala-Garay, A.M. Moore, and R. Kleeman. Influence of stochastic forcing on ENSO prediction. J. Geophys. Res. (Oceans), 109:C11007, 2004.

54. M.K. Tippett, R. Kleeman, and Y. Tang. Measuring the potential utility of seasonal climate predictions. Geophys. Res. Lett., 31:L22201, 2004. doi 10.1029/2004GL020673.

55. Y. Tang, R. Kleeman, A.M. Moore, A. Weaver, and J. Vialard. A simple initialization scheme for an oceanic general circulation model for ENSO prediction. J. Geophys. Res. (Oceans), 109:C05014, 2004. doi:10.1029/2003JC002159.

56. Y. Tang, R. Kleeman, and A.M. Moore. SST assimilation experiments in a tropical Pacific Ocean model. J. Phys. Oceanogr., 34:623-642, 2004.

57. Y. Tang, R. Kleeman, and A.M. Moore. A simple method for estimating variations in the predictability of ENSO. Geophy. Res. Lett., 31:L17205, 2004. doi: 10.1029/2004GL020673.

58. R-H Zhang, S.E. Zebiak, R. Kleeman, and N. Keenlyside. Retrospective El Nino hindcasts/forecasts using an improved intermediate coupled model. Mon. Weath. Rev., 133:2777-2802, 2005.

59. R-H Zhang, R. Kleeman, S.E. Zebiak, S. Raynaud, and N. Keenlyside. An empirical parameterization of subsurface entrainment temperature for improved SST anomaly simulations in an intermediate ocean model. J. Clim., 18:350-371, 2005.

60. J. Zavala-Garay, C. Zhang, A.M. Moore, and R. Kleeman. On the linear response of ENSO to the Madden Julian Oscillation. J. Clim., 18:2441-2459, 2005.

61. Y. Tang, R. Kleeman, and A.M. Moore. On the reliability of ENSO dynamical predictions. J. Atmos Sci, 62:1770-1791, 2005.

62. S. Raynaud, P. Yiou, R. Kleeman, and S. Speich. Using MSSA to determine explicitly the oscillatory dynamics of weakly nonlinear climate systems. Nonlin. Proc. Geophys., 12:807-815, 2005.

63. S. Raynaud and R. Kleeman. The pseudo-equatorial mode of interannual variability in an intermediate complexity model of the Tropical Atlantic. J. Clim., 2005. Submitted.

64. C. L. Perez, A.M. Moore, J. Zavala-Garay, and R. Kleeman. A Comparison of the Influence of Additive and Multiplicative Stochastic Forcing on a Coupled Model of ENSO. J. Clim., 18(23):5066-5085, 2005.

65. X. S. Liang and R. Kleeman. Information transfer between dynamical system components. Phys. Rev. Lett., 95(24):244101, 2005.

66. R. Kleeman and A. J. Majda. Predictability in a model of geostrophic turbulence. J. Atmos Sci, 62:2864-2879, 2005.

67. R. Abramov, A.J. Majda, and R. Kleeman. Information theory and predictability for low frequency variability. J. Atmos Sci, 62:65-87, 2005.

68. Y. Tang, R. Kleeman, and S. Miller. ENSO predictability of a fully coupled GCM model using singular vector analysis. J. Clim., 19:3361-3377, 2006.

69. A.M. Moore, J. Zavala-Garay, Y. Tang, R. Kleeman, A. Weaver, J. Vialard, K. Sahami, D. L. T. Anderson, and M. Fisher. Optimal forcing patterns for coupled models of ENSO. J. Clim., 19:4683-4699, 2006.

70. X. S. Liang and R. Kleeman. A rigorous formalism of information transfer between dynamical system components II. Continuous flow. Physica D., 227:173-182, 2007.

71. X. S. Liang and R. Kleeman. A rigorous formalism of information transfer between dynamical system components I. Discrete maps. Physica D., 231:1-9, 2007.

72. R. Kleeman. Information flow in ensemble weather predictions. J. Atmos Sci., 64(3):1005-1016, 2007.

73. R. Kleeman. Statistical predictability in the atmosphere and other dynamical systems. Physica D, 230:65-71, 2007.

74. Y. Tang, R. Kleeman, and A.M. Moore. Comparison of Information-based Measures of Forecast Uncertainty in Ensemble ENSO Prediction. J. Clim., 21:230-247, 2008.

75. R. Kleeman. Limits, variability and general behaviour of statistical predictability of the mid-latitude atmosphere. J. Atmos Sci, 65:263-275, 2008.

76. R. Kleeman. Stochastic theories for the irregularity of ENSO. Phil. Trans. Roy. Soc. A., 2008 366:2509-2524; doi:10.1098/rsta.2008.0048.

77. R. Kleeman. Stochastic theories for the irregularity of ENSO. Chapter 10 in “Stochastic Physics and Climate Modelling”. Edited by T. Palmer and P. Williams, Cambridge University Press, Cambridge, 2010.

78. R. Kleeman. Information theory and dynamical system predictability. Entropy, 13:612-649, 2011.

79. R. Kleeman. Spectral analysis of multi-dimensional stochastic geophysical models with an application to decadal ENSO variability. J. Atmos. Sci., 68(1):13-25, 2011.

80. M. Gehne and R. Kleeman. Spectral analysis of tropical atmospheric dynamical variables using a linear shallow water modal decomposition. J. Atmos. Sci., 69(7):2300-2316, 2012.

81. M. Gehne, R. Kleeman, and K.E. Trenberth. Irregularity and decadal variation in ENSO: A simplified model based on Principal Oscillation Patterns. Clim. Dyn., 43(12):3327–3350, 2014.

82. R. Kleeman and B.E. Turkington. A nonequilibrium statistical model of spectrally truncated Burgers-Hopf dynamics. Comm. Pure Appl. Math., 67(12):1905–1946, 2014. arXiv:1206.6545.

83. R. Kleeman. A path integral formalism for non-equilibrium Hamiltonian statistical systems. J. Stat. Phys., 158(6):1271–1297, 2015. DOI 10.1007/s10955-014-1149-x, arXiv:1307.1102.

84. R. Kleeman. A path integral formalism for the closure of autonomous statistical systems. Physica Scripta, 2015. (submitted). arXiv:1503.04325.

85. R. Kleeman. An efficient numerical implementation of a path integral method for the closure of non-equilibrium statistical systems. In preparation for submission to J. Stat. Phys., 2015.

86. G. Chavez and R. Kleeman. A perturbative method for the calculation of entropic functionals and maximum entropy densities in the case of weakly non-Gaussian densities. In preparation for submission to J. Tim. Ser. Anal., 2015.

4 Some Research Highlights

4.1 Predictability of El Nino

Predictability of this phenomenon is of great societal importance. Useful dynamical predictability has been established in the past 20 years. The paper

- Kleeman R: On the dependence of hindcast skill on ocean thermodynamics in a coupled ocean-atmosphere model"; J. Clim.; Vol 6, pp2012-2033.

established that this predictability was related to the presence in prediction models of a coupled mode of variability known as the delayed action oscillator.

The cause of the irregularity of El Nino and the effect of this on climate predictability were clarified in

- Kleeman R. and S.B. Power, 1994, "Limits to predictability in a coupled ocean-atmosphere model due to atmospheric noise", Tellus A Vol 46, pp529-540.
- Kleeman R. and A.M. Moore, 1997, "A theory for the limitation of ENSO predictability due to stochastic atmospheric transients", Journal of Atmos. Sci., Vol 54, pp753-767.
- Moore A.M. and R. Kleeman, 1999: "Stochastic Forcing of ENSO by the intraseasonal oscillation", J. Clim., Vol 12, 1199-1220.

The nature of variations in the extent of climate predictability were investigated in

- Moore A.M. and R. Kleeman, 1998: "Skill Assessment for ENSO using Ensemble Prediction", Q. J. R. Met. Soc., Vol 124, pp557-584.
- Kleeman R. and A.M. Moore, 1999: "A new method for determining the reliability of dynamical ENSO predictions", Mon. Weath. Rev., Vol 127, pp 694-705.

An authoritative review paper on the general topic was coauthored in

- Latif M., D. Anderson, T. Barnett, M. Cane, R. Kleeman, A. Leetma, J. O'Brien, A. Rosati and E. Schneider, 1998: "TOGA Review Paper: Predictability and Prediction", J. Geophys. Res. (Oceans) Vol 103 pp14,375-14,393.

4.2 Stochastic paradigm for ENSO irregularity

The irregularity of ENSO is well known and implies an important limitation on predictability. There exist presently two plausible mechanisms for this one of which was pioneered and thoroughly explored by this author and coworkers. This involved the stochastic forcing of the coupled atmosphere ocean system by atmospheric transients such as the Madden Julian Oscillation. One of the first papers to seriously explore this mechanism in a realistic model was described in

1. Kleeman R. and S.B. Power, 1994, "Limits to predictability in a coupled ocean-atmosphere model due to atmospheric noise", Tellus A Vol 46, pp529-540.

This was taken further and thoroughly investigated in the two papers

1. Kleeman R. and A.M. Moore, 1997, "A theory for the limitation of ENSO predictability due to stochastic atmospheric transients", Journal of Atmos. Sci., Vol 54, pp753-767.
2. Moore A.M. and R. Kleeman, 1999: "Stochastic Forcing of ENSO by the intraseasonal oscillation", J. Clim., Vol 12, 1199-1220.

Both of these papers have been highly influential in the further development of the stochastic paradigm of ENSO. A series of further papers by the author and co-workers has made a major contribution to the elaboration of this paradigm. Examples include:

1. Kessler W.S. and R. Kleeman, 2000: "Rectification of the Madden-Julian Oscillation into the ENSO cycle.", J.Clim., Vol 13, 3560-3575.

2. J. Zavala-Garay, A.M. Moore, and R. Kleeman. Influence of stochastic forcing on ENSO prediction. J. Geophys. Res. (Oceans), 109:C11007, 2004.

3. C. L. Perez, A.M. Moore, J. Zavala-Garay, and R. Kleeman. A Comparison of the Influence of Additive and Multiplicative Stochastic Forcing on a Coupled Model of ENSO. J. Clim., 18(23):5066-5085, 2005.

The author was recently asked to write a review paper on this subject for Philisophical Transactions of the Royal Society:

1. R. Kleeman. Stochastic theories for the irregularity of ENSO. Phil. Trans. Roy. Soc. A., 2008 366:2509-2524; doi:10.1098/rsta.2008.0048.

This also appeared in 2009 in a Cambridge University monograph on stochastic climate modeling:

1. R. Kleeman. Stochastic theories for the irregularity of ENSO. Chapter 10 in "Stochastic Physics and Climate Modelling". Edited by T. Palmer and P. Williams, Cambridge University Press, Cambridge, 2010.

4.3 Decadal Climate Variability

In the late 1990s extensive investigation of this subject commenced in the literature. Some of the first papers on the nature of Pacific decadal variability were

- Kleeman R., R. Colman, N.R. Smith and S.B. Power, 1996, "A recent change in the mean state of the Pacific ocean: Observational evidence, atmospheric and oceanic responses", J. Geophys. Res. (Oceans), Vol 101, pp20483-20499

- Latif M., R. Kleeman and C. Eckert, 1997, "An investigation of Tropical Climate Variability 1949-1994: An attempt to Understand the Anomalous 1990s.", J. Clim., Vol 10, pp2221-2239.

Several mechanisms for this variability were proposed at this time. The following paper has a mechanism for which observational corroboration has recently been found by McPhaden and Zhang (published in Nature):

- Kleeman R., J.P. McCreary and B.A. Klinger, 1999, "A mechanism for the decadal variation of ENSO", Geophys. Res. Lett., Vol 26, p1743.

An alternative mechanism for the decadal variability involving stochastic forcing of the climate system was proposed in

- Kleeman R. and S.B. Power, 1999: "Modulation of ENSO variability on Decadal and Longer Timescales" , in "El Nino and the Southern Oscillation, Multiscale Variability and its impacts on Natural Ecosystems and Society", eds. H.F. Diaz and V. Markgraf, Cambridge University Press.

4.4 Theoretical Predictability Studies

The nature of predictability in dynamical systems and what causes it to vary from one forecast to another has received much theoretical development in the atmospheric and oceanographic literature. A new general theoretical framework using information theory was proposed in

- Kleeman R., 2002: "Measuring dynamical prediction utility using relative entropy", Journ. Atmos. Sci. Vol 59, 2057-2072.

This work was motivated by practical climate prediction (see section 4.1 above) and has important applications in atmospheric and climate prediction as well. These were explored in

1. Kleeman R., A. J. Majda and I. Timofeyev, 2002: "Quantifying predictability in a model with statistical features of the atmosphere", Proceedings of the National Academy of Science, Vol 99, 15291-15296.

2. R. Kleeman and A. J. Majda. Predictability in a model of geostrophic turbulence. J. Atmos Sci, 62:2864-2879, 2005.

3. R. Kleeman. Statistical predictability in the atmosphere and other dynamical systems. Physica D, 230:65-71, 2007.

4. R. Kleeman. Limits, variability and general behaviour of statistical predictability of the mid-latitude atmosphere. J. Atmos Sci, 65:263-275, 2008.

A review article of this field which has as its basis information theory was recently published in the leading mathematical physics journal Entropy:

1. R. Kleeman. Information theory and dynamical system predictability. Entropy, 13:612-649, 2011.

4.5 Information flow

A major cause of prediction error is the transmission of errors in the initial conditions (analysis) of predictions through to prediction time. This flow of uncertainty amounts to an information flow in the sense of Shannon. The author and co-workers have developed a new rigorous theoretical framework for understanding this flow in the three papers

1. X. S. Liang and R. Kleeman. Information transfer between dynamical system components. Phys. Rev. Lett., 95(24):244101, 2005.
2. X. S. Liang and R. Kleeman. A rigorous formalism of information transfer between dynamical system components II. Continuous flow. Physica D., 227:173-182, 2007.
3. X. S. Liang and R. Kleeman. A rigorous formalism of information transfer between dynamical system components I. Discrete maps. Physica D., 231:1-9, 2007.

and has also explored the use of information flow in determining the optimal observing network for defining initial conditions for prediction:

1. R. Kleeman. Information flow in ensemble weather predictions. J. Atmos Sci., 64(3):1005-1016, 2007.

4.6 Non-equilibrium statistical systems

The key perspective developed in the theoretical predictability work discussed above was that statistical predictability is equivalent to the degree of disequilibrium within a statistical system. Consequently non-equilibrium statistical mechanics is very much relevant to understanding predictability within dynamical systems. It is also crucial for understanding how unresolved scales of motion within a geophysical numerical model influence the resolved scales. Important theoretical insights into this fundamental subject have recently been uncovered and published in the applied mathematical and mathematical physics literature:

1. R. Kleeman and B.E. Turkington. A nonequilibrium statistical model of spectrally truncated Burgers-Hopf dynamics. Comm. Pure Appl. Math., 67(12):1905–1946, 2014. arXiv:1206.6545.

2. R. Kleeman. A path integral formalism for non-equilibrium Hamiltonian statistical systems. J. Stat. Phys., 158(6):1271–1297, 2015. DOI 10.1007/s10955-014-1149-x, arXiv:1307.1102.

3. R. Kleeman. A path integral formalism for the closure of autonomous statistical systems. Physica Scripta, 2015. (submitted). arXiv:1503.04325.

5 Reviewing

Around 2000 reviews completed for J. Atmos. Sci., J. Phys. Oceanogr., Geophys. Res. Lett., J. Clim., J. Geophys. Res., Tellus, Proc. Roy. Met. Soc., Physica D, Nonlinearity, J. Stat. Phys. and Mon. Weath. Rev. Service on 6 research proposal panels (NSF and NOAA) occured between 1999 and the present.

6 Grant awards

Between 1999 and the present a large number of awards have been made to the author by funding agencies within the US. These include NSF, NOAA and NASA. Over 3 million dollars have been awarded to NYU with the author as investigator in this time period. The list includes

- Principal Investigator, NSF grant to study the predictability of ENSO (1998-2001). Grant value around $400K.
- Co-investigator, NOAA OGP grant to study decadal variability in the Pacific ocean (1997-2000). Grant value around $600K.
- Principal Investigator, NSF grant to develop reliability measures for climate predictions (2001-2003). Grant value $300K.
- Principal Investigator, NOAA grant to study the variability and potential predictability of the tropical Atlantic climate (2001-2003). Grant value $300K

- Principal Investigator, NASA grant to study the predictability of the NSIPP coupled atmosphere ocean system (2001-2005). Grant value $480K.

- Co-investigator, NSF grant to investigate the predictability of a hierarchy of coupled models (2002-2004). Grant value $100K.

- Principal Investigator, NSF grant: Collaborative research of Mathematics in the Geosciences award (2003-2005). Grant value $680K.

- Principal Investigator, NSF grant: Collaborative research of Mathematics in the Geosciences award (2005-2008). Grant value $150K

- Principal Investigator, NSF grant: Mid-latitude atmospheric predictability (2005-2008). Grant value $300K

- Principal investigator, NSF grant: Mid-latitude weather predictability and tropical convection coherency (2009-2011). $300K.

7 Citations

In June 2013 a search of the ISI Citation Index revealed that the publications in section 3 has been cited 2662 times in the refereed literature. The rate of citation is displayed for the past 20 years:

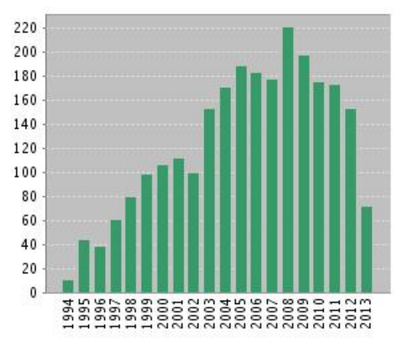

Figure 1: Kleeman citation rate in recent years. The figures for 2013 are through May.

8 Administration

Director of the Center for Atmosphere Ocean Science NYU, 2000-2005 and 2011-2012. This unit is located within the Mathematics Department at NYU (the Courant Institute houses Mathematics and Computer Science at NYU). It was a major new initiative for NYU and during my term as Director it rapidly expanded both in terms of faculty as well as postdoctoral fellows and external funding. In consultation with the Director of the Courant Institute and the Dean of Science at NYU, I was responsible for developing a new graduate program; hiring world class faculty and shaping the Center as a unique interdisciplinary unit. The Mathematics Department at NYU is widely regarded as amongst the strongest in the US in applied mathematics and the Center has leveraged this reputation to build a Meteorology and Oceanography Center in which applied mathematics is making a substantial contribution. Graduate students from this program are highly qualified mathematically and are in high demand nationally.

9 International Committee Membership

CLIVAR Working Group on Seasonal to Interannual Prediction. This panel includes representatives of major international groups active in the area of climate prediction. Membership 1999-2004.

10 Postdoctoral and Graduate Supervision

Noel Keenlyside (Phd granted, 2001, Monash), Ryan Walker, Oleksii Mostovyi, Minoru Kadota (Phd granted 2008), Maria Gehne (Phd granted 2012) and Seth Cottrell (Math Phd student).

Steven Jewson, Youmin Tang, Stephane Raynaud and X. San Liang (postdoctoral fellows).

11 Educational Activities

Developed and delivered NYU graduate and undergraduate courses on (among others):

1. Tropical atmosphere-ocean interaction. Lecture notes and cirriculum available at http://www.math.nyu.edu/faculty/kleeman/Syllabus.htm
2. Climate dynamics. Lecture notes and cirriculum available at http://www.math.nyu.edu/faculty/kleeman/syllabus33.html
   Book in preparation.
3. Theoretical Meteorology. Cirriculum available at http://www.math.nyu.edu/faculty/kleeman/syllabus2.htm
4. Atmospheric Dynamics. Cirriculum available at http://www.math.nyu.edu/faculty/kleeman/syllabus2.html
5. Information theory and predictability Cirriculum available at http://www.math.nyu.edu/faculty/kleeman/syllabusinfo.html
6. Linear algebra (undergraduate and graduate). Lecture notes and cirriculum available at http://www.math.nyu.edu/faculty/kleeman/syllabus3.htm
7. Multivariate Calculus.
8. Physical Oceanography.
9. Statistical Physics.
10. Basic Probability