shown are an artifact of the difference between times of prediction and observation, as well as averaging period differences.

Our last example relates to situations where there is controlled burning to reduce fuel loading. The Australian Bureau of Meteorology provides forecasts twice a day for 18 prescribed sites in Western Australia. The fire authority responsible for the burning wants to avoid smoke impacting on populated areas. In Figure 8, we show the example of the 18 trajectories initiated at 0300 UTC on 10 November 1997. Note in the upper left-hand panel that two trajectories almost coincide, but one continues on to the northwest and the other curves around towards the city of Perth. There is a time difference when their geographical positions coincide that leads to the later divergence of the trajectories. Comparing the two trajectories near the centre of the upper right-hand side and the lower right-hand side panels, it is observed that although they start at nearly the same place, one travels over the city and the other to the west of the city. In the upper two panels, it is seen that those trajectories that start north of the city travel eastward while all of the others travel north or northwestward. These samples illustrate the non-linearity and chaotic nature of atmospheric flow.

CONCLUSION

In this paper, we have reviewed the current status of ATMs suitable for regional scale modelling and prediction of particulate pollution arising from large-scale forest fire events. We believe that through the RSMCs and the ICAO volcanic ash centres, there currently exists a global infrastructure capable of undertaking smoke modelling in real time, and these centres should be an initial focus of WHO's effort in this area. Additional modelling capabilities and experience exist in various regional centres, for example in Brazil, South Africa and Singapore. Whilst there is always room for improvement, current ATMs utilizing NWP inputs are well advanced in terms of their meteorology. However, the required level of information on emission rates from forest fires (in particular) and smoke deposition rates for input to the ATMs is lacking. This is an area that must be quickly addressed if a global capability to issue forest fire smoke predictions, which give suitable guidance to health authorities and emergency management planners, is to be rapidly achieved.

We recommend that WHO and ICAO collaborate with WMO to coordinate the modelling effort to forecast the extent and concentrations of smoke from large-scale fires likely to last for periods of several weeks. This would include satellite measurements, surface and aircraft monitoring, in addition to the modelling, in order to be able to initialize, calibrate and verify the models. In South East Asia, the programme to address ASEAN Regional Trans-boundary Smoke (PARTS) under the auspices of WMO is already beginning to develop an integrated approach. It would be helpful if a data set suitable for initialization, calibration and verification of models were collected and made available to the modelling community. Preliminary efforts to develop such a data set have begun [through the WMO Commission for Atmospheric Science (CAS)], but financial support is now required. In their meeting early in 1998, CAS emphasised the importance of the coordinating role of WMO in emergency response activities.

REFERENCES

1. Mosca S, Graziani G, Klug W, Bellasio R, Bianconi R. ATMES II- evaluation of long-range dispersion models using 1st ETEX release data. European Commission, Ispra, 1997.

2. Klug W, Graziani G, Grippa G, Pierce D, Tassone C (eds). Evaluation of long-range atmospheric transport models using environmental radioactivity data from the Chernobyl accident: the ATMES Report, Elsevier Applied Science, London, 1992.

3. WMO Workshop on Regional Transboundary Smoke and Haze in South East Asia, Singapore 2-5 June 1998, Executive Summary. World Meteorological Organisation, Geneva, 1998.

4. Jean M. Atmospheric transport modelling: overview. WMO EER Training Seminar, 6-10 October 1997, Montreal, Canada, 1997.

5. World Meteorological Organisation. World Weather Watch Programme 1995: WWW Technical Progress Report on the Global Data-Processing System. GDPS TP Report Series No.5, 1996, WMO/TD-No.744, World Meteorological Organisation, Geneva.

6. World Meteorological Organisation. World Weather Watch Programme 1997: WWW Technical Progress Report on the Global Data-Processing System. GDPS TP Report Series No. 7, 1998, WMO/TD-No.896, World Meteorological Organisation, Geneva.

7. Pudykiewicz J. Simulation of the Chernobyl dispersion with a 3-D hemispheric tracer model. Tellus 1989; 41B: 391-412.

8. Bompay F. Description of the atmospheric transport model used by Meteo-France during the ATMES phase of ETEX. In Mosca S, Graziani G, Klug W, Bellasio R, Bianconi R (eds). ATMES II-Evaluation of Long-range Dispersion Models using 1st ETEX Release Data, Volume 2: Models description. European Commission, Ispra, 1997.

9. Maryon RH, Smith FB, Conway BJ, Goddard DM. The U. K. nuclear accident model. Progress in Nuclear Energy, 1991; 26: 85-104.

10. Draxler RR, Hess GD. An overview of the HYSPLIT_4 modelling system for trajectories, dispersion and deposition. Australian Meteorological Magazine, 1998; 47: 295-308.

11. Crutzen PJ, Heidt LE, Kranec JP, Pollock WH, Seiler W. Biomass burning as a source of the atmospheric gases CO, H_2, N_2O, NO, CH_3Cl, and COS. Nature 1979; 282: 253-56.

12. Levine J S (ed). Biomass Burning and Global Change (in 2 volumes), MIT Press, Cambridge, Mass, 1996.

13. Ward DE. Factors influencing the emissions of gases and particulate matter from biomass burning. In Goldammer JG (ed). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges, 1990.

14. Crutzen PJ, Andreae MO. Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science, 1990; 250: 1669-78.

15. Levine JS. Biomass burning and the production of greenhouse gases. In Zepp RG (ed). Climate-Biosphere Interaction: Biogenic Emissions and Environmental Effects of Climate Change, John Wiley and Sons, Inc. 1994.

16. Fearnside PM, Leal N Jr, Fernandes FM. Rainforest burning and the global carbon budget: biomass combustion efficiency and charcoal formation in the Brazilian Amazon. Journal of Geophysical Research, 1993; 98: 16733-43.

17. Carvalho JA, Santos JM, Santos JC, Leitav MM. A tropical rainforest clearing experiment by biomass burning in the Manaus region. Atmospheric Environment, 1995; 27, 2301-9.

18. Hobbs PV, Reid JS, Herring JA et al. Particle and trace-gas measurements in the smoke from prescribed burns of forest products in the Pacific Northwest. In: Levine JS (ed). Biomass Burning and Global Change, MIT Press, 1996.

19. Kaufman YI, Remer LA, Ottmar RD et al. Relationship between remotely sensed fire intensity and rate of emission of smoke: SCAR-C Experiment. In Levine JS (ed). Biomass Burning and Global Change, MIT Press, 1996.

20. Wain A, Tapper NJ, Hooper M, Vander ZJ. Movement of products of biomass burning around the Maritime Continent Region: the use of atmospheric trajectory models to establish sources, impact areas and a regional transport climatology. Proceedings of the 13th International Conference on Fire and Forest Meteorology, Lorne, Australia, October 1996. International Association of Wildland Fire, 1998.

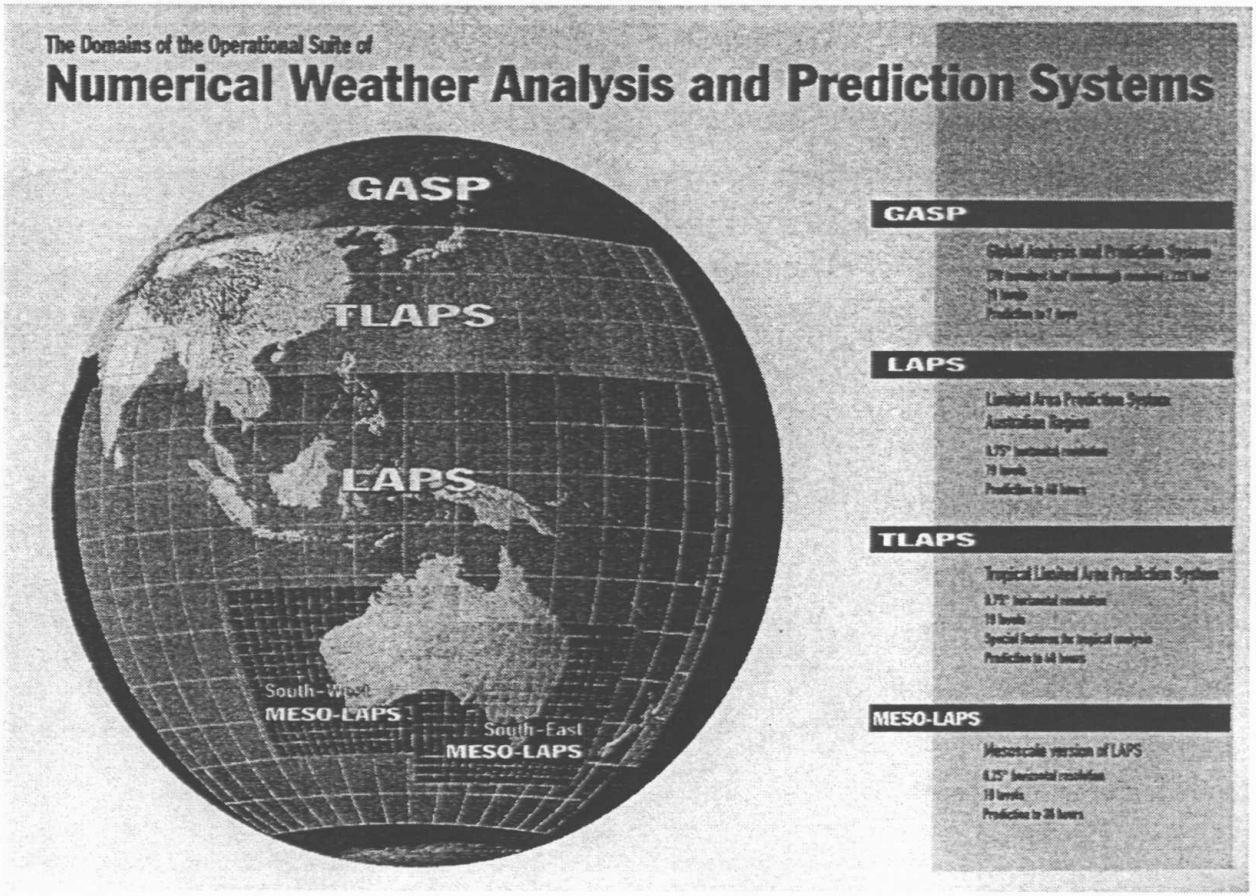

Figure 1. Australian Bureau of Meteorology Numerical Meteorological Products (NWP), September 1998

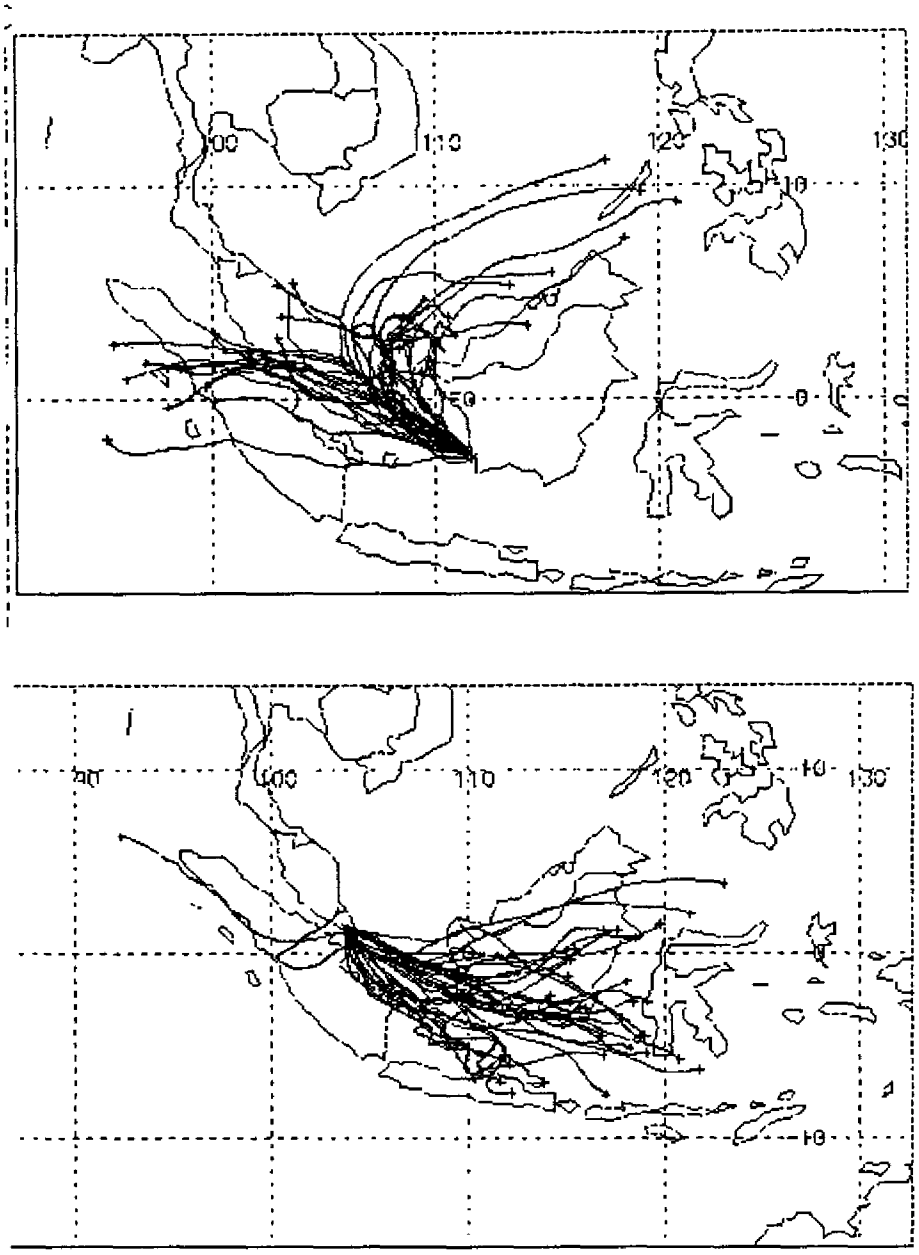

Figure 2. Daily trajectories for the period 10 September-15 October 1994. (a) A composite of 3-day forward trajectories, startingat 950 hPa (500m) Above Pangkalan Bun, Kalimantan. (b) A composite of 3-day backward Trajectories ending at 950 hPa (500m) above Singapore. HYSPLIT_3 Trajectory dispersion model running on Bureau of Meterology TAPS data (20).

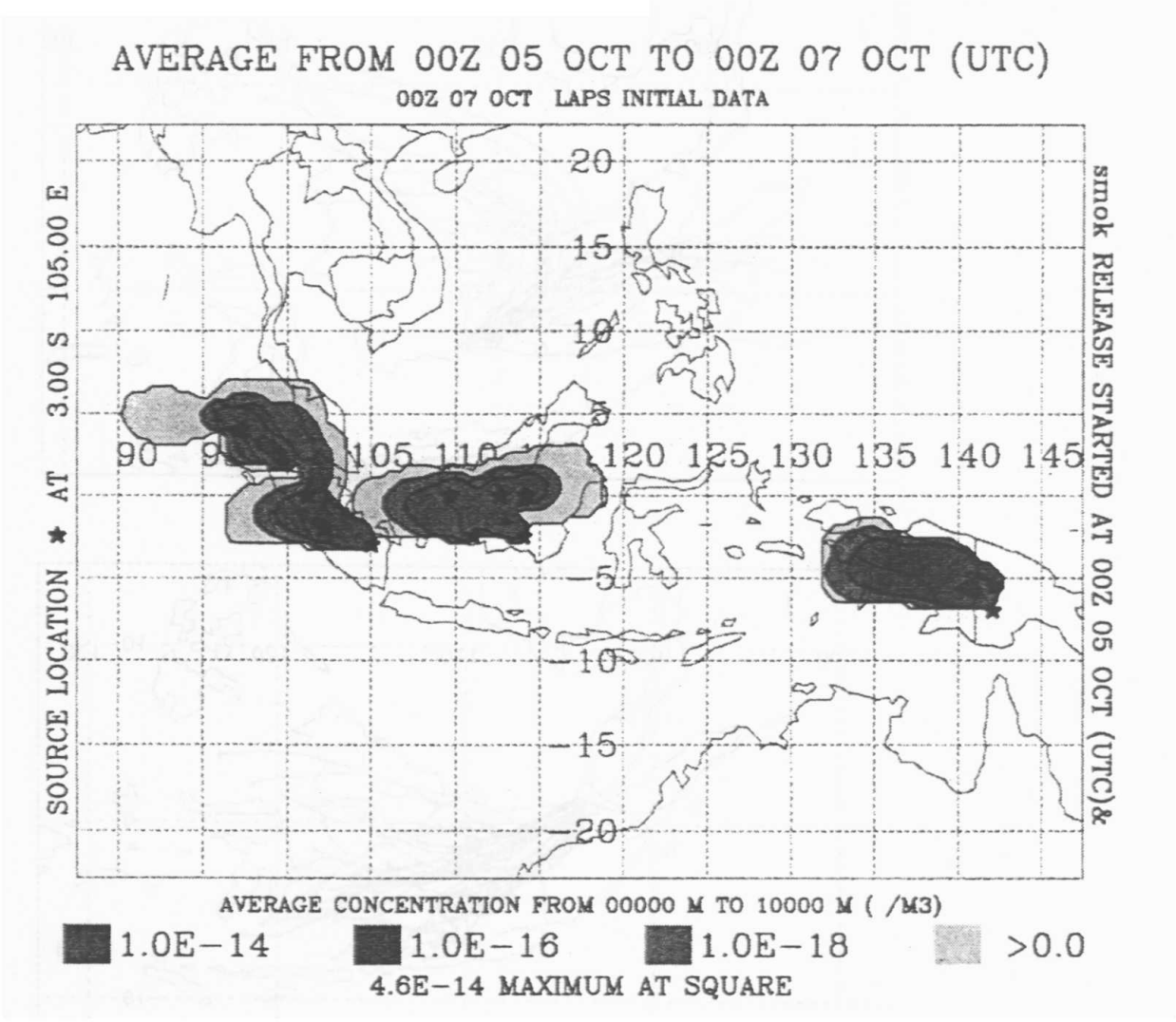

Figure 3. The relative particulate concentrations over South East Asia, 5-7 October 1997. An example of forecasts able to be made with little initialization information. Bureau of Meteorology LAPS data, HYSPLIT_4 trajectory dispersion model.