13th Fire and Forest Meteorology Conference. Lorne, Australia 1996.

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

Alan Wain[1], Nigel Tapper[1], Martin Hooper[2] and Joanne VanderZalm[2]

[1]*Environmental Climatology Group, Monash University, Clayton 3168, Australia*
E-mail: alanwain@arts.monash.edu.au
[2]*Gippsland Centre for Environmental Science, Monash University, Churchill 3842, Australia*

Abstract. Regional haze originating mainly from biomass burning is not a recent phenomenon in South East Asia. In the 1920's Dutch colonial meteorologists remarked on the regional haze over the Indonesian archipelago and suggested that aerosols of Australian origin were possible contributors to the degraded air quality. However, in the period since 1980 interactions of inter-annual climate variability (mainly related to El Nino-Southern Oscillation (ENSO) events) and escalating human pressure on South East Asia's tropical forest resources have led to an unprecedented amount of wildfire activity. Correspondingly, there have been a number of very serious regional haze episodes that have drawn attention to the role of biomass burning in South East Asia, particularly in the drought years of 1982-83, 1987, 1991-92 and 1994. Concern has also been expressed about the impacts of these large but little understood fires on human health and safety, and on the regional and global atmosphere and climate.

In any detailed understanding of regional biomass burning it is critically important to understand the processes of atmospheric transport of products of burning so that interactions between source and impact areas can be properly evaluated. Large scale atmospheric trajectory-dispersion models can be a particularly useful tool in investigating such interactions. After a brief description of the techniques, this paper outlines three distinct ways that this approach can be used to better understand biomass burning and its impacts in the region. First, progress in the development of a seasonal climatology of contemporary transport patterns, and year-to-year variability of transport for the Maritime Continent region, is reported. As well as illustrating preferred transport directions, this approach allows possible emission source and sink areas to be linked in a climatological sense. Second, a number of case studies from major fire events of the 1990's are used to show the clear atmospheric linkages that exist between degraded air quality in a number of Southeast Asian cities and large-scale forest fires that occur in remote parts of the region. Finally, using results from an aerosol sampling program in northern Australia, the combination of trajectory modelling and chemical analyses is shown to be a powerful tool for determination of the place of origin and nature of the source of the particulate aerosol produced.

Introduction

The 'maritime continent' can be geographically defined as the area of warm ocean and islands to the north of Australia that is one of three important areas of tropical convection around the globe (Ramage 1968). The Maritime Continent region plays a pivotal role in the general circulation of the global atmosphere, largely because of the vast quantities of sensible and latent heat released during tropical convection in the region (Sturman and Tapper, 1996). This energy drives the meridional (Hadley) and zonal equatorial (Walker) circulation cells which are seen as vital components of the so-called "global heat engine". Because of the region's role in global circulation systems as well as the deep tropical convection, there is considerable potential for the transport of the products of biomass burning.

At the core of the Maritime Continent is the South East Asian region which is the focus for SEAFIRE, the Southeast Asia Fire Research Experiment (see SEAFIRE home page http://tooms.arts.monash.edu/~seafire/).

Episodes of regional haze originating from biomass burning in the region have probably occurred intermittently for thousands of years. Certainly, in the 1920's Dutch colonial meteorologists remarked on the regional haze over the Indonesian archipelago and suggested that aerosols of Australian origin were possible contributors to the degraded air quality. Recent work has shown the likelihood of such transport between Australia and Southeast Asia (Wain et al., forthcoming). However, there is also no doubt that a significant proportion of the haze is generated within the region from a variety of activities that involve biomass burning as well as from urban-industrial activities. In the period since 1980 interactions of inter-annual climate variability (mainly related to El

Niño-Southern Oscillation (ENSO) events) and escalating human pressure on South East Asia's tropical forest resources have led to an unprecedented amount of wildfire activity (Goldammer, 1990). Correspondingly, there have been a number of very serious regional haze episodes that have drawn global attention to the role of biomass burning in Southeast Asia, particularly in the drought years of 1982-83, 1987, 1991-92 and 1994 (Tapper, 1995).

Trajectory-dispersion modelling is a particularly useful approach in developing a better understanding of the regional haze problems of the maritime continent region. This paper briefly outlines some preliminary aspects of this work.

Atmospheric Trajectory Modelling for SEAFIRE

Preamble and Model Description

Large scale atmospheric trajectory-dispersion models can be a particularlyuseful tool in evaluating the interactions between smoke particulate source areas and impact areas. Such models show the vertical and horizontal motion of air parcels over a specified time from a designated point.

The main trajectory model currently being used in this study is Version 4 of the NOAA pYSPLIT model, coupled with the Australian Bureau of Meteorology's tropical assimilation and prognosis scheme (TAPS). (The trajectories produced for the case study were produced using HYSPLIT version 3 (Draxler 1993)).

The model is being validated with the Bureau of Meteorology Research Centre (BMRC) trajectory model (Mills & Powers 1990) and other physical observations, such as air pollution records and satellite images. The work is being done with the close collaboration and cooperation of the Australian Bureau of Meteorology.

There are a number of ways that trajectory modelling can be of use in SEAFIRE:

- in developing a seasonal climatology of contemporary transport patterns, and year-to-year variability in transport,
- in investigating particular case studies to show linkages between particulate source areas (fires) and degraded air quality in major SEA urban areas
- to confirm source areas for particulate measured at regional aerosol sampling stations

Briefly, the climatology involves running more than 100,000 individual 10-day trajectories from approximately 80 grid points across the South East Asian region. It is using archived data for the period 1991-1996 to show typical monthly transport patterns and year-to-year variability in transport patterns (eg ENSO and Anti-ENSO patterns). As well as the climatology, a number of case studies of individual events are planned.

The Major Haze Event of 1994 in SEA

The most recent severe ASEAN haze event occurred over the period August-October 1994. During the peak of the haze episode between 10 September and 15 October visibilities were reduced to less than 10 km (some days < 2km) over large areas of Borneo and Peninsular Malaysia, including Singapore (Tussin 1995). This had negative implications for both health and the economy of the areas affected (Hassan et.al. 1995).

While local sources cannot be discounted entirely, much of the blame for this episode has been placed on wildfires burning in Borneo (Sarawak and Kalimantan) and Sumatra. 1994 was the last year of a persistent ENSO-related drought in the region.

We have produced daily trajectories for the period 15 September - 20 October, both forward from areas where fires were observed, and backward from some of the main regional population centres

Areas where fires occurred included Palangkaraya and Pangkalan Bun in Indonesian Kalimantan, and Palembang and Pakanbaru in Sumatra (Nurhayati pers comm). These four locations are used as source points for forward trajectories in this case study.

A composite of forward trajectories (all 3-day trajectories starting at 950 hPa ~ 500 m above the surface) from Palangkaraya shows that most trajectories remain over Borneo, particularly early in the period. However, about 30% move westward, eventually reaching Malaysia and Sumatra.

Figure 1 shows two families of trajectories emanating from Pangkalan Bun, one set comprising about 50% of the total moving northwest over Singapore and the Malaysian Peninsular, and the other set recurving in mon-

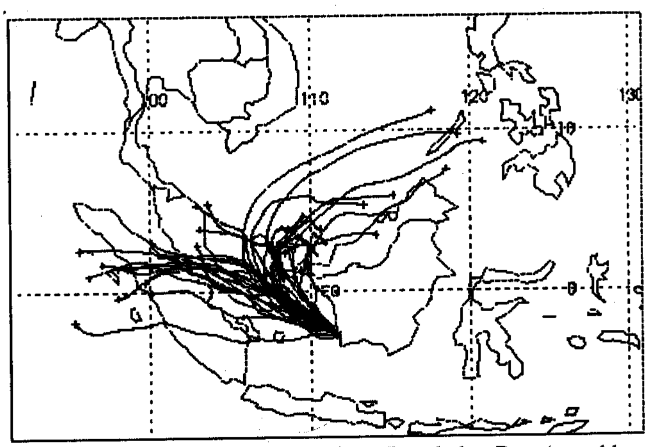

Figure 1. Forward trajectories from Pangkalan Bun (monthly composite)

soon flow toward the Philippines. It would appear that smoke entrained above this location had a significant impact on the observed severely degraded air quality of Singapore and southern Peninsula Malaysia.

By comparison, according to trajectories from the burning regions of Sumatra, smoke from these fires would have contributed little to the major haze problems of Singapore and Peninsular Malaysia at that time

Backward trajectories from Singapore confirm some of what we have already seen in figure 1.

Air reaching Singapore during the study period comes primarily from the SE, consistent with the trade wind circulation at this time. ~ 50% of trajectories pass over Kalimantan during their 3 day track, indicating that the probability of fires from this area contributing to haze in Singapore is high.

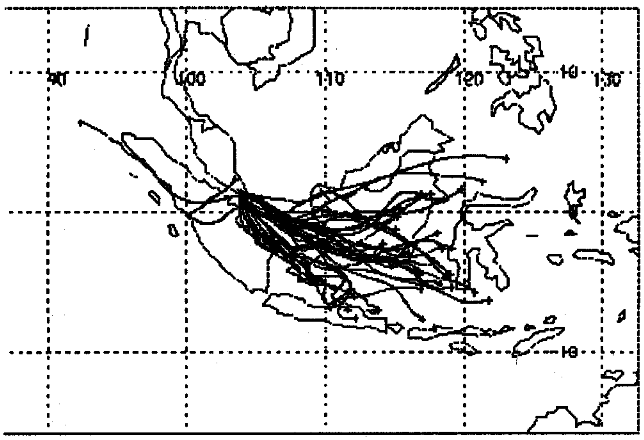

Figure 2. Backward trajectories from Singapore (monthly composite)

In contrast to the Singapore situation, the composite of back trajectories from Jakarta (not shown) shows that any air quality problems in that city during September-October 1994 could not have originated in the Kalimantan fires. Almost all trajectories originate in the SE quadrant. Although the 3 day trajectories do not extend this far, possible sources of aerosol in that direction are fires burning in north western Australia (This has been confirmed in later 5 day runs made using HYSPLIT 4).

Finally, trajectory modelling in conjunction with detailed chemical analyses is a powerful tool in the determination of the place of origin and nature of the source of particulate samples obtained around the region.

Interpretation of Particulate Samples

In collaboration with others, Monash University is currently operating a number of regional air quality sampling stations around the maritime continent region.

Let's just concern ourselves with some of the results from the Jabiru station, located within the Kakadu National Park of the Northern Territory. Up to ~10% of the Territory area burns every year (Beringer, Packham and Tapper 1995), and in Kakadu, burning is more in line with traditional burning regimes of ~35% of the area each year, so there is an abundance of products of biomass burning to sample. In the region of Kakadu, much of the burning is of savanna woodland, while further south in the Territory, it is mainly the extensive savanna grasslands that burn (Beringer, Packham and Tapper 1995).

Table 1 lists days in Jabiru in 1995 which had relatively high particulate loadings. The sampler is a Stacked Filter Unit that collects two size fractions 'fine' < 2 microns and 'coarse' 2-10 microns. Looking at all samples, about 40% of fine material is pyrogenic aerosol (mainly black carbon, and non sea salt and non crustal potassium). The coarse fraction mainly comprises sea salt (40%) and mineral dust (30%). So broadly it can be stated that high levels of fine particulate tend to be associated with fire activity and high levels of coarse material are associated with sea salt and crustal dust.

Table 1. Samples with high particulate loadings collected at Jabiru, Northern Territory, 1995.

Date	Fine Particulate Matter (μg/m^3)	Fine Black Carbon (μg/m^3)	Coarse Particulate Matter (μg/m^3)	Coarse Black Carbon (μg/m^3)
30 June, 1995	14.0	2.6	11.8	0.3
18 July, 1995	12.3	1.5	8.2	0.2
17 Aug., 1995	21.3	5.1	6.8	0.8
28 Sept., 1995	12.6	1.7	15.0	0.2
22 Oct., 1995	10.1	1.2	35.7	1.1
28 Oct., 1995	16.7	3.1	5.9	0.4

At the moment we are trying to get fire location data from the Bushfires Council of the Northern Territory so that we can tie these high particulate days to particular fires using the trajectory model. However, backward trajectories show that air reaching Jabiru on August 17(highest fine level) had passed over Arnhem Land and Western Queensland, both potential sources of biomass burning particulate.

References

Abdul Malik B Tussin. 1995. Thick Haze in Malaysia in the 90's presented at the International Symposium of Climate and Life in Asia-Pacific (ISCLAP). April 1995.

Beringer J., D. Packham, N. Tapper. 1995. Biomass Burning and Resulting Emissions in the Northern Territory, Australia International Journal of Wildland Fire 5(4) 229-235.

Draxler, R.R. 1992. Hybrid Single-Particle Lagrangian Integrated Trajectories (HY-SPLIT): Version 3.0 — User's Guide and Model Description NOAA Technical Memorandum ERL ARL-195 Air Resources Laboratory Silver Spring Maryland.

Goldammer, J.G. 1990. Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Ecological Studies 84, Springer-Verlag, Berlin.

Hassan, M.H., A.Z. Abidin, M.K. Yusoff, A.W. Ghazali, A. Muda, and M.P. Zakaria. 1995. Damage Costs of the 1991 and 1994 Haze Episodes presented at the International Symposium of Climate and Life in Asia-Pacific (ISCLAP) April 1995.

Mills G.A., and P.E. Powers. 1990. Trajectory Output from Operational RASP Forecasts -additional forecast guidance BMRC 23p.

Sturman, A.P. and N.J. Tapper. 1996. The Weather and Climate of Australia and New Zealand. Oxford University Press, Melbourne.

Tapper, N.J. 1995. ASEAN Haze. p43-44 in Paehlke, R. (ed.) Conservation and Environmentalism: An Encyclopedia. Garland Publishing, New York.

Wain, A., N. Tapper, G. Mills and J. McBride. A trajectory climatology for the Australian region. For submission to Journal of Meteorology and Atmospheric Physics.