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# The Australian Aerosol and Climate Research Program: A proposal

*CAWCR Technical Report No. 003*

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## Important Disclaimer

# Contents

## Acknowledgement

This proposal was written by Melita Keywood, John Gras and Leon Rotstayn with comment by Al Gabric, Ian Galbally, Paul Holper, Martin Cope, Peter May, Imogen Jubb, Ross Mitchell, Christian Jakob and Michael Manton, as an outcome of the “Something in the Air Climate and Aerosol Workshop” held in Canberra on 18-19 August 2008.

The proposal has been circulated amongst the participants of the workshop, and comments have been incorporated where appropriate. We believe this document represents the views of the workshop participants who comprise a significant portion of the Australian aerosol research community.

## Executive Summary

This document sets out the rationale and design of an Australian Aerosol and Climate Research Program (AACRP). An AACRP should be considered an essential component of a properly integrated Australian climate research program. The major rationale of an AACRP is to understand and quantify the role of aerosol in climate change – with particular emphasis on aerosol specific to the Australian region and/or impacts in the Australian region.

The successive IPCC assessments, including the most recent (IPCC 2007) have identified the significant (net negative) contribution by aerosol to global climate forcing, with this forcing being highly uncertain. Reduction of the uncertainty in the aerosol forcing estimate is required to correspondingly improve projections of future climate.

The review of "Future Climate Change Research and Observations…learning from the IPCC Fourth Assessment report" WMO (2008) identified "better quantification of radiative forcing due to aerosols –cloud interactions" as an "**urgent need"**. The review also identified the "**critical need"** to improve the understanding of the processes (e.g., aerosol transport, convective processes, cloud formation and dissipation) leading to this forcing, (and) represent them reliably in climate models leading to this forcing."

From an Australian regional perspective there are a number of other specific needs that result from our unique geographic location in the relatively clean southern hemisphere, our unique position of being the driest continent and our unique physical environment and ecosystems. These needs include an understanding of the dynamical teleconnections of aerosol in other global regions and their impact on Australian regional climate. Because such teleconnections depend in part on indirect aerosol effects, their representation in models is critically dependent upon the representation of cloud processes and aerosol-cloud interaction. There is a specific need to understand the potential feedbacks of these teleconnections and climate change in general on Australian regional aerosols such as dust emissions, bushfire emissions, Southern Ocean natural aerosol production, terrestrial biogenic aerosol and aerosol precursor emissions, transport and removal processes. Australian regional aerosols may in turn exert important effects on Australian climate (Rotstayn et al., 2008a,b).

An AACRP would have the following priorities:

- A short- to medium-term program of coupled atmosphere-ocean GCM simulations to explore the effects of aerosol forcing on Australian climate and rainfall, and GCM sensitivity studies intended to provide useful information on how to target future field programs.
- An immediate- to long-term program that targets specific regionally important aerosol processes that will use all modelling and observational tools including comprehensive aerosol and aerosol precursor experiments and models with detailed chemical schemes such as chemical transport models.
- An immediate- to long-term program to investigate how regionally important aerosols are interacting with clouds, e.g. run one or more large international experiments looking at aerosol-cloud-precipitation down wind of Australian cities, in the tropics, or over the Southern Ocean.
- A long-term program of ensuring that regionally important aerosol and cloud processes are accurately represented in ACCESS. This will include key observational verification studies.

# 1. Introduction

This documents sets out the rationale and design of an Australian Aerosol and Climate Research Program (AACRP). This proposal is a result of the recent review paper on the possible impacts of anthropogenic and natural aerosols on Australian climate (Rotstayn et al., 2008a) and the outcome of a workshop on aerosols and climate change (Something in the Air, 2008) held in Canberra on 18 and 19 August 2008. The review paper and a summary of the workshop proceedings are attached as appendices to this proposal.

# 2. Rationale

An AACRP should be considered an essential component of a properly integrated Australian climate research program. The major objective of an AARCP is to understand and quantify the role of aerosol in climate change – with particular emphasis on aerosol specific to the Australian region and/or impacts in the Australian region.

We expect this research to span a range of temporal and spatial scales and the net outcome to be a reduction in the uncertainty of future climate projections. We also expect that the maximum benefit is likely to accrue through targeted studies that improve our understanding of atmospheric processes represented in models of the earth-climate system. These will include studies that robustly challenge model process parameterisations and descriptions of the current and past state of the atmosphere, and studies of processes that are either absent or poorly represented in existing models but that could significantly impact climate projections.

# 3. The Scientific Issue

The successive IPCC assessments, including the most recent (IPCC 2007) have identified the significant (net negative) contribution by aerosol to global climate forcing. Within this aerosol component, both direct and indirect effects have been identified as significant, and globally, indirect effects through aerosol modification of cloud properties are estimated to contribute around 60% of the aerosol forcing (-0.7 W $m^{-2}$ or 75% of forcing due to $CO_2$ increase since pre-industrial times). Both effects carry large uncertainties (e.g. -0.3 to -1.8 W $m^{-2}$ for the indirect effect) that propagate directly into an unacceptably large uncertainty in modelled climate forcing by all anthropogenic constituents. Due to this large uncertainty in anthropogenic climate forcing, it is not possible to use the observed temperature record to constrain estimates of the earth's climate sensitivity. Reduction of these uncertainties is required to improve estimates of future climate change. Unlike long-lived radiatively important gases, aerosols have short atmospheric lifetimes and are highly spatially inhomogeneous. In general, any radiative effects associated with aerosols have been thought to occur relatively close to their source areas. Climate modelling suggests that induced dynamic effects in both atmosphere and ocean may propagate far more widely than previously understood, even inter-hemispherically. The CSIRO global climate model (GCM) has featured prominently in these studies (Rotstayn et al., 2000; Rotstayn and Lohmann, 2002; Cai et al., 2006; Cai et al., 2007; Cai and Cowen, 2007; Rotstayn et al., 2007; Rotstayn et al., 2008b). These dynamical changes in turn may have extremely important consequences on local climate and atmospheric processes well removed from the aerosol source areas.

The review of "Future Climate Change Research and Observations…learning from the IPCC Fourth Assessment report" WMO (2008) [secn 4.4], specifically identified "better quantification of radiative forcing due to aerosols–cloud interactions" as an "**urgent need"**. This review also identified the "**critical need"** to improve the understanding of the processes (e.g., aerosol transport, convective processes, cloud formation and dissipation) leading to this forcing, (and) represent them reliably in climate models leading to this forcing."

The major reasons for the identified shortcomings in material for IPCC AR4 were:

- Lack of understanding of fundamental processes
- Insufficient model parameterisations
- Lack of observations and data quality,

(WMO 2008, p22)

## 4. Specific Australian Needs

From an Australian regional perspective there are a number of other specific needs that stem from our unique location in the relatively unpolluted Southern Hemisphere, our unique position of being the driest continent and our unique physical environment and ecosystems.

These needs include an urgent requirement to better understand dynamical teleconnections of aerosol in other global regions and consequent impacts on regional atmospheric processes. Specifically, we need a much better understanding of the sensitivity of the Australian climate to aerosol emission in the Northern Hemisphere, including (but not limited to) south and east Asia. There is evidence that these teleconnections may significantly influence the dynamical processes across the Southern Hemisphere (including Australia) and the Indo-Pacific warming structure, with consequences for weather and precipitation.

These teleconnections, and climate change in general, have a significant potential to influence regional aerosol processes including dust emissions, bushfire emissions, Southern Ocean natural aerosol production, terrestrial biogenic aerosol and aerosol precursor emissions, transport and removal processes. Australian regional aerosol processes may in turn exert important effects on Australian climate (Rotstayn et al., 2008a,b).

In summary, there is an urgent need to better understand and quantify the unique Australian aerosol and particularly its radiative and cloud nucleating properties as well as aerosol-cloud interactions in the Australian context.

## 5. Possible Program to Address These Needs

A program of research activities that will address the specific Australian needs outlined above is described below. Short term is 0-3 years, medium term is 3-6 years and long term is 6-10 years.

- Short- to medium-term program of GCM sensitivity studies, e.g. does the observed increase in Australian dust in the last few years exert a climatically significant effect on atmospheric circulation? Sensitivity studies may provide useful information regarding how to target future field programs.
- Short- to medium-term program involving the verification and improvement of the initial aerosol scheme in ACCESS, using high-resolution models and new sets of local observations e.g. marine, biogenic and smoke components. This should also include the treatment of aerosol-cloud interactions.

- Short- to medium-term program of coupled atmosphere-ocean GCM simulations to explore the effects of different aerosol forcing components on Australian climate, especially rainfall. This exploration should include the uncertainty in indirect aerosol effects, and the uncertainty in past and future emissions in Asia and elsewhere.
- Immediate- to long-term program that targets specific regionally important aerosol processes that will use all modelling and observational tools including models with detailed chemical schemes such as chemical transport models.
- Immediate- to long-term program to investigate how regionally important aerosols are interacting with clouds e.g. run one or more large international experiments that investigate aerosol-cloud-precipitation down wind of Australian cities, in the tropics, over the Southern Ocean and other marine sources to the east of Australia (where much of Australia's cities and agriculture is located).
- Immediate- to long-term program to enhance use of remotely sensed aerosol data and integration with in-situ aerosol observation. This program may involve data handling development and will help fill the free-atmosphere data void.
- Long-term program of ensuring that regionally important aerosol processes are accurately represented in ACCESS. This will include verification studies.
- Long-term program combining climate models with observations to ensure that feedbacks are being adequately captured.
- Immediate- to long-term program to continue accurate incorporation of climate change science in projections for assessing impacts through downscaling, e.g. for air quality managers and mitigation strategies.

In addition, an AACRP would maintain and develop long term observational programs that will determine whether models are accurately capturing regional processes and climate change effects. The observational program will be representative of different climate and ecological regimes (e.g. Cape Grim, Northern Australia Tropical Station, AERONET, ARM) and will incorporate all aspects of aerosol chemistry and microphysics. In addition, the AACRP should include the observation of more difficult issues such as ice nuclei and free tropospheric aerosol composition by adopting above-ground platforms such as blimps, balloons and manned and unmanned aircraft. The AACRP should also be supported by complementary research efforts in related areas, such as atmospheric moist processes (clouds, convection and boundary layer) and ocean biogeochemistry.

## 6. Strategies

The following approaches and activities will be important components of the AACRP:

- Genuine national effort with inter-institutional collaboration.
- International expertise and collaboration.
- The funding of larger projects proposed by collaborating organisations
- Establishment of a mechanism (such as a panel of scientific experts including international members) for prioritising research activities that bring together representative observational, modelling and management.
- Platform for airborne measurements – Australian capability is now seriously depleted. In the absence of a real national facility (manned/unmanned aircraft) most airborne work will need to be done collaboratively with overseas groups, but would require levering funds.
- Recognition of the synergies with air pollution management and planning.

- Recognition of the synergies with other areas of climate research (e.g., atmospheric moist processes, atmosphere-ocean dynamics and ocean biogeochemistry).
- Increased dialogue between modellers and observational scientists.

# 7. How an AACRP will address Australian Government Policy

The international climate research community has clearly identified the urgent need for further research on aerosols, incorporating both observations and modelling activities to reduce uncertainty in future climate projections. A well defined aerosol research strategy needs to be part of any future climate research program supporting the Australian Government's Climate Change Policy of adapting to climate change, mitigating climate change and helping to shape a global solution.

**Adaptation and Mitigation**: The *Fourth Assessment Report* projects an increase of between 1.1 and 6.4 °C in the globally averaged surface temperature over the period 1990 to 2100. About half of the uncertainty in this projection arises from uncertainty about future greenhouse gas emissions and about half from uncertainties in global climate models. A significant fraction of the uncertainty in the climate models arises from the uncertainty associated with understanding and effectively parameterising aerosol processes. Before we can adapt and mitigate effectively, reduced uncertainty in climate projections is required. The actions we take for a 1.1 °C change in global temperature are likely to be significantly different from those we take for a 6.4 °C change in temperature as will the associated economic costs. In addition, climate modelling suggests that recent and future Australian rainfall trends are substantially affected by aerosol changes. Adaptation studies need to be supported by a better understanding of the drivers and likely future direction of regional rainfall changes, and this requires a better understanding of aerosol-climate interactions. In the short to medium term, the CSIRO GCM provides an attractive tool for modelling studies that require a coupled atmosphere-ocean GCM. In the longer term, the new Australian community climate model (ACCESS) will replace the CSIRO GCM as the preferred model.

**Contributing to a global solution:** Australia will continue to contribute to the future IPCC assessments. Including well-researched aerosol schemes in ACCESS and developing observational records that underpin comprehensive model-observation comparisons will assist in reducing uncertainties associated with predictions. Australia already plays a significant role in international aerosol observational programs, including WMO Global Atmospheric Watch (GAW) and NASA's Aerosol Robotic Network (AERONET). Since 1976 the Australian Government funded Baseline Air Pollution station at Cape Grim has contributed data on Southern Hemispheric background composition, including aerosol properties, as well as contributing to the development of GAW. This work is expected to continue through the WMO GAW IGACO initiative to develop integrated data sets comprising in-situ measurements such as Cape Grim and other regionally important sites with remotely sensed atmospheric properties that will form the basis for consistent global data for model assimilation and testing.

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# Something in the Air 2008-Summary

The "Something in the Air Climate and Aerosol Workshop" was held in Canberra between 18-19 August 2008 and was attended by more than 60 participants. These included aerosol and climate researchers, students and climate policy makers. The aim of the workshop was to share information on current aerosol-climate issues and to articulate ideas on how aerosol research in Australia can be used to improve climate change projections, and understand and manage climate change adaptation and mitigation.

The two-day meeting covered several themes including

- the influence of aerosols on climate both globally and in Australia,
- aerosol sources, physical and chemical processes relevant to Australia,
- the progression from observations to process modelling to regional and global climate

The keynote address by Professor Joyce Penner of the University of Michigan presented the climatic effects of aerosol from an international perspective. This was followed by a further scene-setting presentation on why aerosols matter for Australian climate change. The aerosol sources and processes addressed at the meeting included emissions from bushfires, the characterisation of Australian continental aerosol, interaction between cloud microphysics and aerosols, Southern Ocean aerosol and biogenic aerosol. Some of the large-scale effects of aerosols on climate presented included the effect of Australian dust on climate, the impact of Australian dust storms on regional ocean biogeochemistry and the pan-oceanic impacts of aerosol forcing on Southern Hemisphere climate change. Two presentations focused on experiences with merging observations with models.

Each of these 30-minute presentations was followed by 15 minutes of discussion, and the workshop ended with a meeting summary and planning session.

The outcomes of this final session are presented below.

## General Observations

- Aerosol radiative forcing due to direct and indirect effects are one of the largest source of uncertainty for future climate projections
- This meeting has highlighted a range of aerosol and related cloud processes and feedbacks on the climate system that are not currently well captured in global climate models
- An Australian aerosol research program should be one component in an integrated Australian climate research program
    - Cannot be carried out in isolation
    - The major rationale of an aerosol research program should be to assess aerosols and their effects on a range of scales, temporal and spatial and to reduce uncertainty in our climate projections

## Why carry out aerosol research in Australia

- The Southern Hemisphere has less land mass and more ocean area than the Northern Hemisphere so that circulation patterns (atmospheric and oceanic) differ.
- The Southern Hemisphere has different sources (e.g terrestrial emissions of isoprene and marine emissions of biogenic sulfur are amongst the worlds' largest) but fewer, and more localised, anthropogenic sources of aerosol.

- There is little direct inter-hemispheric transport of tropospheric aerosol. This means that anthropogenic perturbations to aerosol are overall smaller that in the NH and consequently Southern Hemisphere aerosol is more sensitive to change than the aerosol in the Northern Hemisphere.
- This is particularly significant for precipitation in Australia. Australia's dry climate (low rainfall and high temperature) means that sensitivity to change in climate is potentially more significant.
- To have control of our own model development e.g. running relevant sensitivity tests

## Current and future modelling

- ACCESS is the main earth system model that will be developed/used in Australia over the next decade
- An Australian aerosol research program needs to be closely aligned with and informed by ACCESS
    - Define processes studies
    - Incorporate into different modelling scales
    - Improving the dialogue between the observational and modelling communities
- UKCA will need to be verified and refined for Australia using finer resolution models
- For the time being, CSIRO Mk3.5A will continue to provide the best platform for exploring the climate response, because it will be some time before ACCESS is available as a fully coupled modelling system
- Should put in place projects that do some aerosol work in ACCESS

## Nationally co-ordinated measurement program

- Inform and verify models of different scales
- Improved physico-chemical characterisation of climatically important aerosol
- Improved quantification of aerosol and aerosol precursor sources
- Improved understanding of the physico-chemical processes that maintain climatically important atmospheric aerosol over Australia
- Contribution to globally-integrated and climate-scale aerosol data sets (both in situ and remotely sensed) ensuring Australia's unique regional conditions are represented.
- Suggestion for a program to capture lost data
- Suggestion to piggy-back aerosol measurements onto existing programs e.g. TERN-NCRIS, FluxNet, BoM etc.

## Balance between observations and modelling

- Application of existing models and observations to better identify and understand the effects of aerosols (from local to global scales)
- Development and verification of improved regional parameterisations of aerosol sources, properties and processes in existing and developing climate and earth system models
- Assessment of the regional impacts of aerosol within Australia, for example impacts of changing aerosol on rainfall, regional effects of bushfire smoke, regional marine biogeochemistry

## What was missing from the workshop program?

Issues identified as potentially important in a national aerosol-climate program but not being sufficiently addressed in the current workshop included:

- Stratospheric aerosol (including volcanic aerosol) – but can probably only be addressed comprehensively with international collaboration

- Ice nuclei – on ongoing issue that also probably requires international collaboration
- Interaction of biogenic aerosol and anthropogenic aerosol
- Recognition of the synergy between air quality and climate aerosols
- Global model assimilations
- Recognition of the synergy between an aerosol-climate program and improved parameterisations of other atmospheric processes (e.g., convection, clouds and boundary layer)

## Aerosol-climate program

The main outcome from the workshop will be a separate report outlining the rationale, needs and suggested content for an Australian aerosol-climate program.

**Something in the Air – Aerosols and Climate Change**
**18-19 August 2008**
**Rydges Lakeside Canberra**
**Day 1, 18 August**

| | | |
|---|---|---|
| **09.30** | **Registration and morning tea** | |
| | | |
| Facilitator | Mr Paul Holper, CSIRO | |
| 10:00 | Introduction and objectives of the meeting | Dr Greg Ayers, Chief, CSIRO Marine & Atmospheric Research |
| 10:10 | Aerosols and climate: an international perspective | Prof. Joyce Penner, University of Michigan |
| 10.50 | Discussion | |
| 11:10 | Why aerosols matter for Australian climate change | Dr Leon Rotstayn, CAWCR – CSIRO |
| 11.50 | Discussion | |
| | | |
| **12:10** | **Lunch** | |
| | | |
| Facilitator | Ms Ashley Fuller, Department of Climate Change | |
| | **Sources/Processes** | |
| 13:10 | Aerosol emission from bushfires: characterisation, distribution and accounting | Dr Mick Meyer, CAWCR – CSIRO |
| 13.40 | Discussion | |
| 13.55 | Characterisation of Australian continental aerosol | Dr Ross Mitchell, CAWCR – CSIRO |
| 14.25 | Discussion | |
| 14.40 | Interactions between cloud microphysics and aerosol particles. | Dr Justin Peters, Bureau of Meteorology |
| 15.10 | Discussion | |
| | | |
| **15:25** | **Afternoon tea** | |
| | | |
| Facilitator | Ms Imogen Jubb, Australian Climate Change Science Program | |
| | **Sources/Processes** | |
| 15.45 | Southern Ocean aerosol | Dr John Gras, CAWCR – CSIRO |
| 16.15 | Discussion | |
| 16.30 | Biogenic aerosol | Dr Melita Keywood, CAWCR – CSIRO |
| 17.00 | Discussion | |
| 17.15 | Close | |
| | | |
| 18.30 | Dinner - The Chairman & Yip<br>108 Bunda St Canberra City 2601 ACT | |

**Something in the Air – Aerosols and Climate Change**
**18-19 August 2008**
**Rydges Lakeside Canberra**
**Day 2, 19August**

| | | |
|---|---|---|
| Facilitator | Dr Steve Siems. Monash University | |
| | **Large-scale Effects** | |
| 9:00 | Australian dust and climate change: more questions than answers | Prof. Grant McTainsh, Griffith University |
| 9.30 | Discussion | |
| 9.45 | Australian dust storms in 2002-03 and their impact on regional ocean biogeochemistry | A/Prof. Al Gabric, Griffith University |
| 10.15 | Discussion | |
| 10.30 | Pan-oceanic impacts of aerosol forcing and Southern Hemisphere climate change | Dr Wenju Cai, CAWCR - CSIRO |
| 11.00 | Discussion | |
| | | |
| **11:15** | **Morning tea** | |
| | | |
| Facilitator | Mr Anthony Swirepik, Department of Climate Change | |
| | **Observations to Models** | |
| 11:45 | Improving clouds in climate models through process studies: Lessons from the GEWEX Cloud System Study | Prof. Christian Jakob, Monash University |
| 12.15 | Discussion | |
| 12.30 | Primary and secondary aerosols: linking observations and modelling | Dr Martin Cope, CACWR – CSIRO |
| 13.00 | Discussion | |
| | | |
| **13:15** | **Lunch** | |
| | | |
| 14:15 | Meeting Summary and plans | Dr Melita Keywood, CAWCR – CSIRO |
| 15.00 | Close | |

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