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Catherine E. Scott

The Biogeochemical Impacts of Forests and the Implications for Climate Change Mitigation

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The Biogeochemical Impacts of Forests and the Implications for Climate Change Mitigation

Doctoral Thesis accepted by
the University of Leeds, UK

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Supervisor's Foreword

Forests and vegetation emit biogenic volatile organic compounds (BVOCs) into the atmosphere which, once oxidised, can partition into the particle phase, forming secondary organic aerosol (SOA). This thesis reports a unique and comprehensive analysis of the impact of BVOC emissions on atmospheric aerosol and climate. A state-of-the-art global aerosol microphysics model is used to make the first detailed assessment of the impact of BVOC emissions on aerosol microphysical properties, improving our understanding of the role of these emissions in controlling the Earth's climate.

Laboratory experiments, ambient atmospheric observations and model simulations are combined to provide new evidence that the oxidation products of BVOCs participate in the first steps of particle formation. This finding means that BVOCs have a larger impact on climate than previously thought, with the global radiative effect of biogenic SOA estimated to be half the net anthropogenic radiative forcing of climate. The thesis also reports on the implications for the climate impact of forests. Accounting for the climate impacts of SOA, alongside the carbon cycle and surface albedo effects that have been studied in previous work, increases the total warming effect of global deforestation by 21 %. The thesis suggests that deforestation warms climate more than previously thought.

Leeds, UK, June 2014 | Dr. Dominick Spracklen

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Contents

Abbreviations and Acronyms

AIE	Aerosol Indirect Effect
AOGCM	Atmosphere–Ocean General Circulation Model
BHN	Binary Homogeneous Nucleation
BLN	Boundary Layer Nucleation
BVOC	Biogenic Volatile Organic Compound
CCN	Cloud Condensation Nuclei
CDNC	Cloud Droplet Number Concentration
CLM	Community Land Model
CO_2e	Carbon Dioxide Equivalent
DRE	Direct Radiative Effect
ECS	Equilibrium Climate Sensitivity
E–S	Edwards–Slingo Radiative Transfer Model
ESM	Earth System Model
FAO	Food and Agriculture Organisation of the United Nations
GCM	General Circulation Model
GFED	Global Fire Emissions Database
GHG	Greenhouse Gas
GLOMAP	Global Model of Aerosol Processes
IPCC	Intergovernmental Panel on Climate Change
LW	Longwave
MEGAN	Model of Emissions of Gases and Aerosol from Nature
ppbv	Parts per billion by volume
pptv	Parts per trillion by volume
RCP	Representative Concentration Pathway
RE	Radiative Effect
RF	Radiative Forcing
SMPS	Scanning Mobility Particle Sizer
SOA	Secondary Organic Aerosol
SRES	Special Report on Emission Scenarios
SS	Supersaturation
SS_{max}	Maximum Supersaturation

SW	Shortwave
TOA	Top of the Atmosphere
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1
Introduction

Vegetation emits biogenic volatile organic compounds (BVOCs) into the atmosphere which, once oxidised, may partition into the particle-phase forming secondary organic aerosol (SOA). In this thesis, the climatic impacts of biogenic SOA are quantified, using a detailed global aerosol microphysics model, and the sensitivity of these radiative effects to the representation of various atmospheric processes is examined.

The radiative effects of biogenic SOA have implications for the climatic impact of forests and any changes to their distribution. In this thesis, simple deforestation scenarios are used to quantify the radiative effects of potential changes to the magnitude and distribution of biogenic SOA production.

1.1 The Climate System

The energy balance of the Earth system is governed by fluxes of incoming and outgoing radiation. Shortwave (SW) solar radiation reaching the Earth system is either reflected or absorbed, as dictated by the nature of the surface and composition of the atmosphere. Figure 1.1 depicts the estimated global average energy flows within the Earth system and indicates that the atmosphere exerts considerable control over how much incoming radiation reaches the surface.

Almost half of the incoming solar radiation is absorbed at the Earth's surface and re-emitted at longer wavelengths (LW); the Earth system behaves almost as a black body with a total emissive power (σT^4) proportional to the fourth power of its temperature, T, where σ is the Stefan-Boltzmann constant. In its equilibrium state, the amount of energy entering the Earth system is equal to that which leaves. If LW radiation is prevented from leaving, the system shifts in order to maintain the required outgoing flux, with an increase in emissive temperature. As such, changes to atmospheric composition, levels of incoming SW radiation, and

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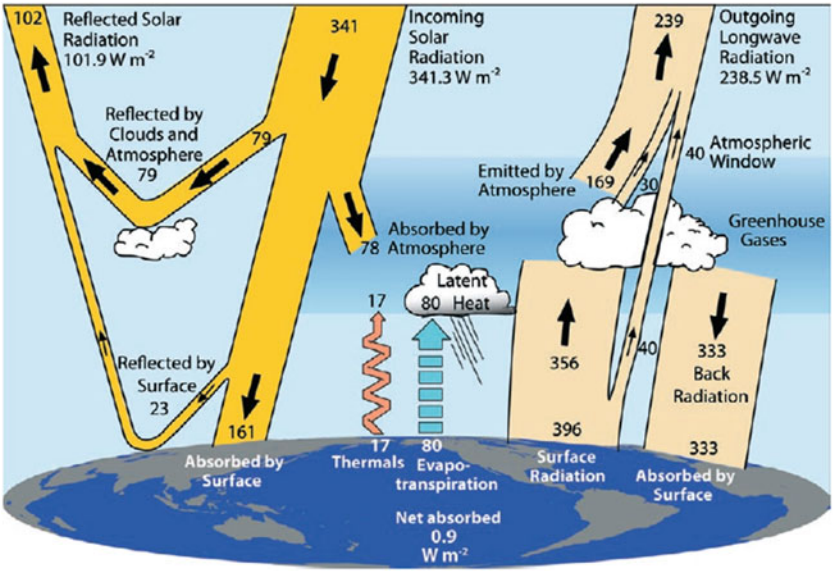

Fig. 1.1 Schematic of the estimated global average energy budget (values in W m^{-2}) for March 2000 to May 2004; reproduced from Trenberth et al. [225]

properties of the Earth's surface that initiate a radiative imbalance, can alter the temperature.

A radiative forcing (RF) may be assigned to physical factors on the basis of their ability to perturb the Earth's radiative balance, over a given time period. The RF is most commonly defined as the net change in radiative flux (i.e. downwards minus upwards) at the tropopause, after allowing for stratospheric temperatures to readjust to radiative equilibrium but with surface and tropospheric temperatures and state held fixed at their unperturbed values [58, 82, 189]. As the surface and troposphere are strongly coupled by convective heat transfer, there is a direct relationship between the RF across the tropopause and the global mean equilibrium temperature change at the Earth's surface (ΔT_s), such that $\Delta T_s = \lambda$ RF [189], where λ represents the *climate sensitivity parameter* (in K W^{-1} m^2). However, the relationship between RF and transient climate change is not straightforward, and consideration must be given to the temporal and spatial variability of the forcing agent.

1.2 Forests and Their Impact on the Climate

Approximately 31 % of the Earth's land area (4.03 billion hectares) is presently covered by forest (Fig. 1.2); one third of this being undisturbed primary forest [55]. More than half of the world's current forest cover lies within just five countries: The Russian Federation, Brazil, Canada, the United States of America and China [55].