JULES and Atmospheric Deposition

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ACITES Dry Deposition Working Group

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Content

1. Deposition: Background and current status
2. ACITES Dry Deposition Working Group
3. Future directions and open forum

Acknowledgements

• Federico Centoni
• David Stevenson
• Oliver Wild (and Catherine Hardacre)
Relevance of Atmospheric Deposition

- Important atmospheric process
  - Governs atmospheric abundance of many compounds (e.g., $O_3$, $H_2O_2$, $HNO_3$, $SO_2$, $NH_3$, aerosol, ...)
- Important process for the biosphere
  - Governs input of key nutrients/oxidants to vegetation
- Links atmosphere and biosphere
  - Contributes to climate and Earth system feedbacks

UK map of modelled $NH_3$ concentrations for 2003 showing exceedance of critical levels for sensitive bryophyte and lichen in 69% of the 1-km grid squares (ROTAP, 2012)

- Policy-relevant implications for air quality, crop yields, etc.
  - Critical loads for acid deposition and eutrophication
  - Ozone exposure and effects on human health and vegetation
  - Particulate matter (aerosol) and impact on human health

- See talk and poster by Feung

$O_3$ injury to wheat, Pakistan (courtesy of A. Wahid)
Modelling dry deposition processes

1. **Turbulent transport** through atmosphere

2. **Molecular diffusion** through laminar sub-layer

3. **Uptake** on surface by adsorption, followed by dissolution or reaction (depends on surface type: vegetation, soil, water, light, etc.)

Most atmospheric chemical transport models use a “Wesely-resistance” approach:

- $R_a$: aerodynamic resistance
- $R_b$: laminar resistance
- $R_{cut}$: cuticular resistance
- $R_{can}$: in-canopy resistance
- $R_{soil}$: soil resistance
- $R_{sto}$: stomatal resistance

Following slides focus on ozone but generally applicable ..........
Deposition: major contributor to uncertainty in global $O_3$ budget

Dry deposition is one of the main source of intermodel variability in surface $O_3$ predictions

Stevenson et al 2006; Royal Society, 2008

Hardacre et al. 2015
O$_3$ deposition to different land-cover types

Fluxes

Absolute

Normalised by area

Olson Land Cover Classes:
SI: Snow/Ice
DF: Deciduous Forest
CF: Coniferous Forest
AC: Agricultural Land, Crops
GL: Grass Land
TF: Tropical Forest
TN: Tundra
DT: Desert
WL: Wetland
WT: Water

Figure 4. Normalised O$_3$ dry deposition partitioned to land cover classes using the OW11 (a, c) and GCLF (b, d) LCCs respectively. Upper panels show the contribution of each LCC to the annual global O$_3$ dry deposition flux, and lower panels show the average flux to each LCC. The box and whiskers for each land class represent the median, quartiles and 10th/90th percentiles.

Analysis of HTAP model runs (Hardacre et al., 2015)
See also poster by Oliver Wild
UKCA Dry Deposition Schemes

Wesely (1989) and Zhang et al. (2003)

Surface resistances: Ice/Soil/Water/Urban

Broad/needle leaf trees, C3-C4 grass, shrubs

Canopy (vegetation) resistances
Canopy uptake differences

Amazon grid, Ozone – January (2000)

**Zhang Scheme:** Stomatal blocking effect when rain or dew in presence of strong SW radiation

\[ f \left( RH, u_*, LAI \right) \]

\[ f \left( \frac{1 - wst}{R_{stom}} \right) \]

\[ wst = \text{fraction of blocked stomata} \]

**Wesely Scheme**

**In-Canopy Conductance Terms (mm s\(^{-1}\))**

**Canopy Conductance Terms (mm s\(^{-1}\))**

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Courtesy of F Centoni (CEH/Edinburgh)
Scheme change effect on simulated \(O_3\)

Total \(O_3\) dry deposition = 1005 Tg yr\(^{-1}\)

\(\Delta O_3\) dry deposition = -5%

\(O_3\) dry deposition = 36 ppb

\(\Delta [O_3]\) land = -1.3%

Courtesy of F Centoni (CEH/Edinburgh)
Looking to the future

There will be more coupling between land surface and atmospheric chemistry/composition, in both directions.

Courtesy of G Folberth (Met Office)
Until recently, no representation of soil nitrogen and effects on plants

No layering of soil carbon

At present, JULES uses RothC.

Developments

Dynamic vegetation

Energy, water, photosynthesis

Soil C

C for growth

Plant uptake of N

Soil C and N

Energy, water, photosynthesis

Dynamic vegetation

C for growth

Courtesy of D Clark (CEH)
Plant processes are not part of ECOSSE (in JULES).

- Preliminary results suggest good agreement for soil NO emissions but N$_2$O emissions currently too high.
Dry Deposition working group

- Dry deposition working group formed as part of the NERC ACITES* project
- Currently involves:
  - O Wild (and C Hardacre, U. Lancaster)
  - G Folberth, F O’Connor, C Ordonez (Met Office)
  - G Hayman, E Nemitz, F Centoni (CEH)
  - L Emberson (SEI, York)
  - D Stevenson (U. Edinburgh)
  - M Val Martin (U. Sheffield)
- Informal meetings held at JULES (2013) and ACITES (2014, 2015) events
- Strategy (short) paper produced
- New members welcome

(*) ACITES = Atmospheric Chemistry in the Earth System
https://www.ncas.ac.uk/index.php/en/acites-news
ACITES Dry Deposition working group

- Co-ordinate efforts in linking the atmosphere with the land surface via dry deposition fluxes

- Aims/Actions
  - Outline the role and importance of dry deposition in the Earth system
  - Assess the current state of dry deposition in the major ESMs and identify any shortcomings
  - Adopt a similar approach to the Master Chemical Mechanism, including the creation of a “gold standard” (benchmark) model of dry deposition
  - Develop a plan with key milestones for the next 5-10 years
  - Develop links with international groups
Modelling dry deposition: How do we formulate models?

Over 30 minute model timestep, whole BL ‘sees’ the surface ....

But all deposited gases must pass through lowest layer .....
Issues and open forum (1)

➢ **Science**
  - Sensitivity to stomatal vs non-stomatal partitioning (and effects on crops/radiative forcing)
  - Behaviour during extreme events (e.g. heatwaves)
  - Implications for past as well as future trends

➢ **Considerations**
  - Need/desire to update dry-deposition scheme in UKCA
  - Ensure consistency between UKCA and JULES
  - Development of ‘offline’ version of UKCA

  - JULES will increasingly require atmospheric ‘deposition’ inputs
  - Single or multi-layer schemes (for UKCA deposition, in-canopy chemistry)
Gather community opinion on how deposition should be handled in future

- H₂O, energy, carbon exchange already in JULES. Addition of chemical species an extension?

- Should JULES provide deposition parameters (e.g., \( r_c \)) as current or calculate deposition velocities (pft/species dependent) or mass fluxes (requires species concentrations)?

- Single or multi-layer capability

- ‘MCM approach’ to test/benchmark new science or more sophisticated process-based schemes being developed e.g., in EU ECLAIRE project, with traceable simplification for use in chemical transport and Earth System models

- Resourcing

- Any feedback/views/comments to Garry Hayman (CEH, garr@ceh.ac.uk)