# Deposition: Linking the Land Surface and Atmospheric Composition


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# Content and Acknowledgements

## Content

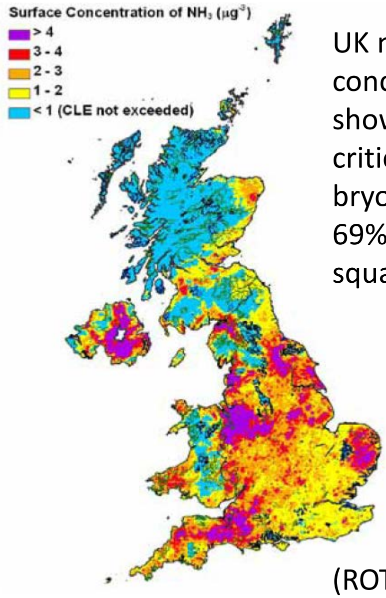
1. Atmospheric Deposition: Background
2. Atmospheric Deposition in the UKCA
3. Future directions

## Acknowledgements


- David Stevenson
- Catherine Hardacre
- Oliver Wild
- ACITES Dry Deposition Working Group

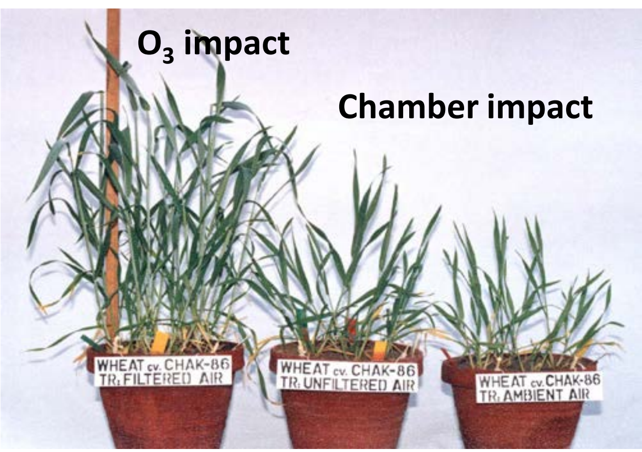
# Relevance of Atmospheric Deposition

- 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)



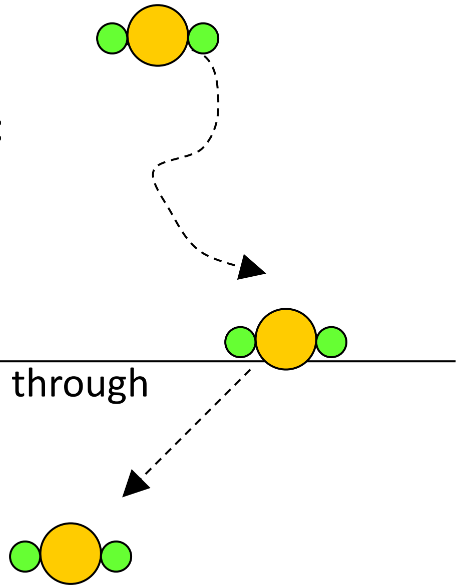

**$O_3$ injury to wheat, Pakistan (courtesy of A. Wahid)**

- 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*

# Modelling dry deposition processes

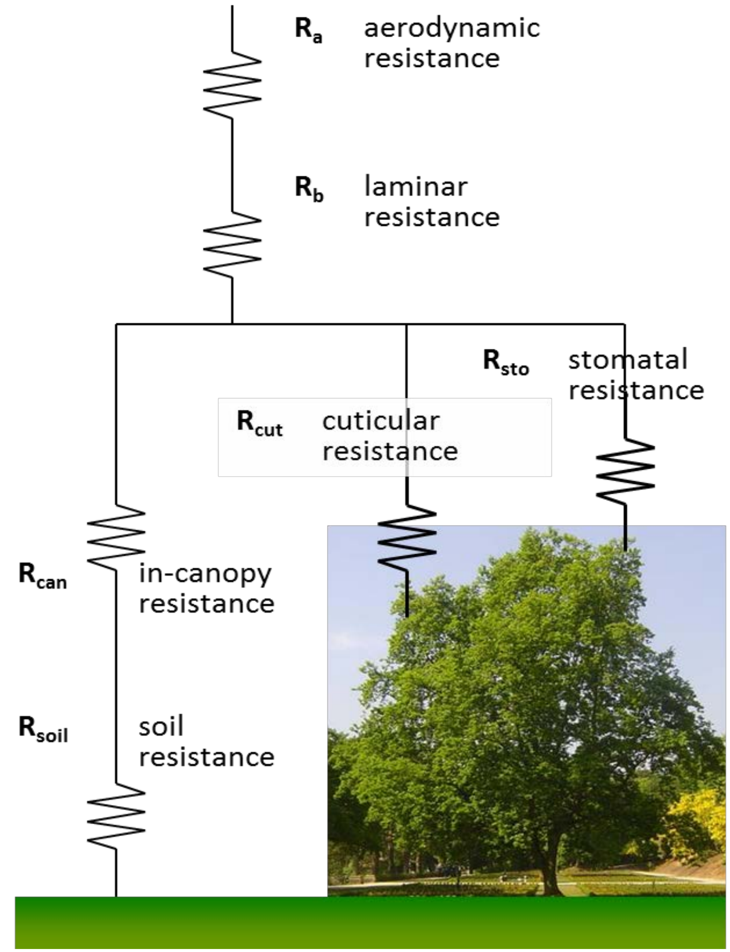
1. **Turbulent transport** through atmosphere

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

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Following slides focus on ozone but generally applicable ……….

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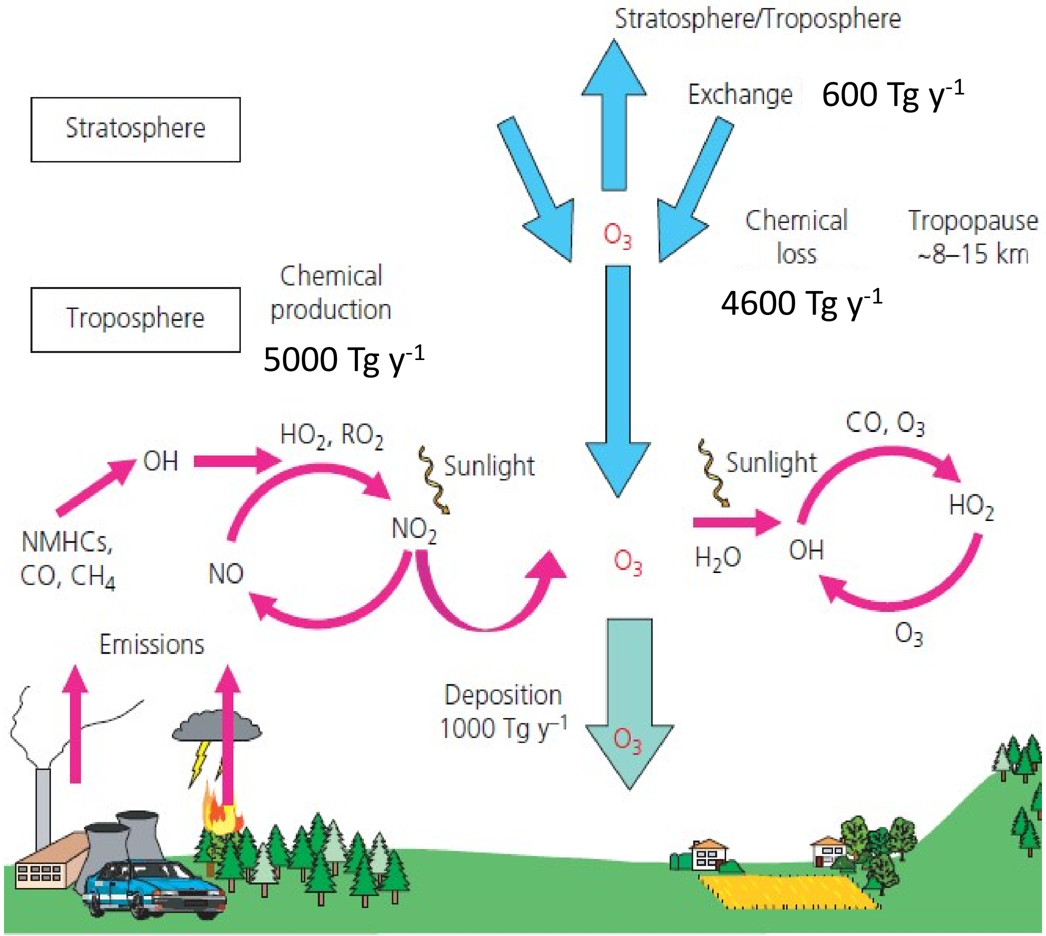
# Deposition: major contributor to uncertainty in global $O_3$ budget




*Stevenson et al 2006; Royal Society, 2008*

Burden: 340 Tg
Lifetime: 22 days

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

| Model | Deposition Scheme[a] | Land Cover Classes[b] | Annual global $O_3$ deposition / Tg $yr^{-1}$ |
|---|---|---|---|
| CAMCHEM-3311m13 | Wesely | 17 | 861 |
| CAMCHEM-3514 | Wesely | 17 | 818 |
| CHASER-v03 | Wesely | | 939 |
| FRSGC/UCI-v01 | Wesely | 9 | 943 |
| GEMAQ-EC | Wesely | 15 | 878 |
| GEOSChem-v07 | Wesely | 11 | 913 |
| GISS-PUCCINI-modelA | Wesely | 8 | 975 |
| GISS-PUCCINI-modelEaer | Wesely | 8 | 1112 |
| GISS-PUCCINI-modelE | Wesely | 8 | 1179 |
| GMI-v02f | Wesely | | 819 |
| INCA-vSSz | Wesely | 11 | 1256 |
| LLNL-IMPACT-T5a | Wesely | 13 | 1000 |
| MOZARTGFDL-v2 | Wesely | 11 | 997 |
| STOC-HadAM3-v01 | Wesely | 9 | 1095 |
| STOCHEM-v02 | Wesely | 9 | 834 |
| TM5-JRC-cy2-ipcc-v1 | Wesely | 4 | 844 |
| ULAQ-v02 | Prescribed[c] | | 1116 |
| UM-CAM-v01 | Prescribed[c] | 5 | 1023 |
| Average ($\pm 1\sigma$) | | | $978 \pm 127$ |
| Average seasonal amplitude[d] | | | $38 \pm 8$ |
| Average monthly range[e] | | | $38 \pm 6$ |

*Hardacre et al. 2015*

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# $O_3$ deposition to different land-cover types

**Fluxes**

Absolute

Normalised

by area

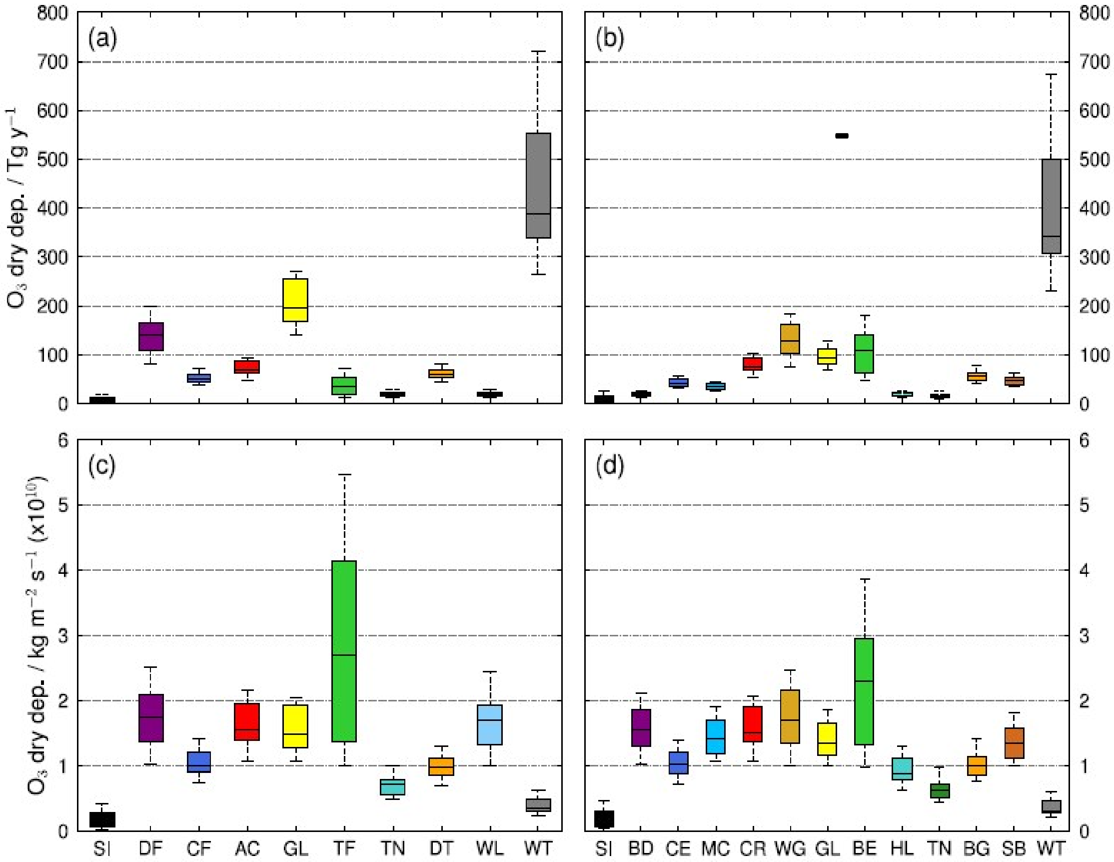



**Figure 4.** Normalised $O_3$ dry deposition partitioned to land cover classes using the OW11 **(a, c)** and GCLF **(b, d)** LCCs respectively. Upper panels show the contribution of each LCC to the annual global $O_3$ dry deposition flux, and lower panels show the average flux to each LCC. The box and whiskers for each land class represent the median, quartiles and 10th/90th percentiles.

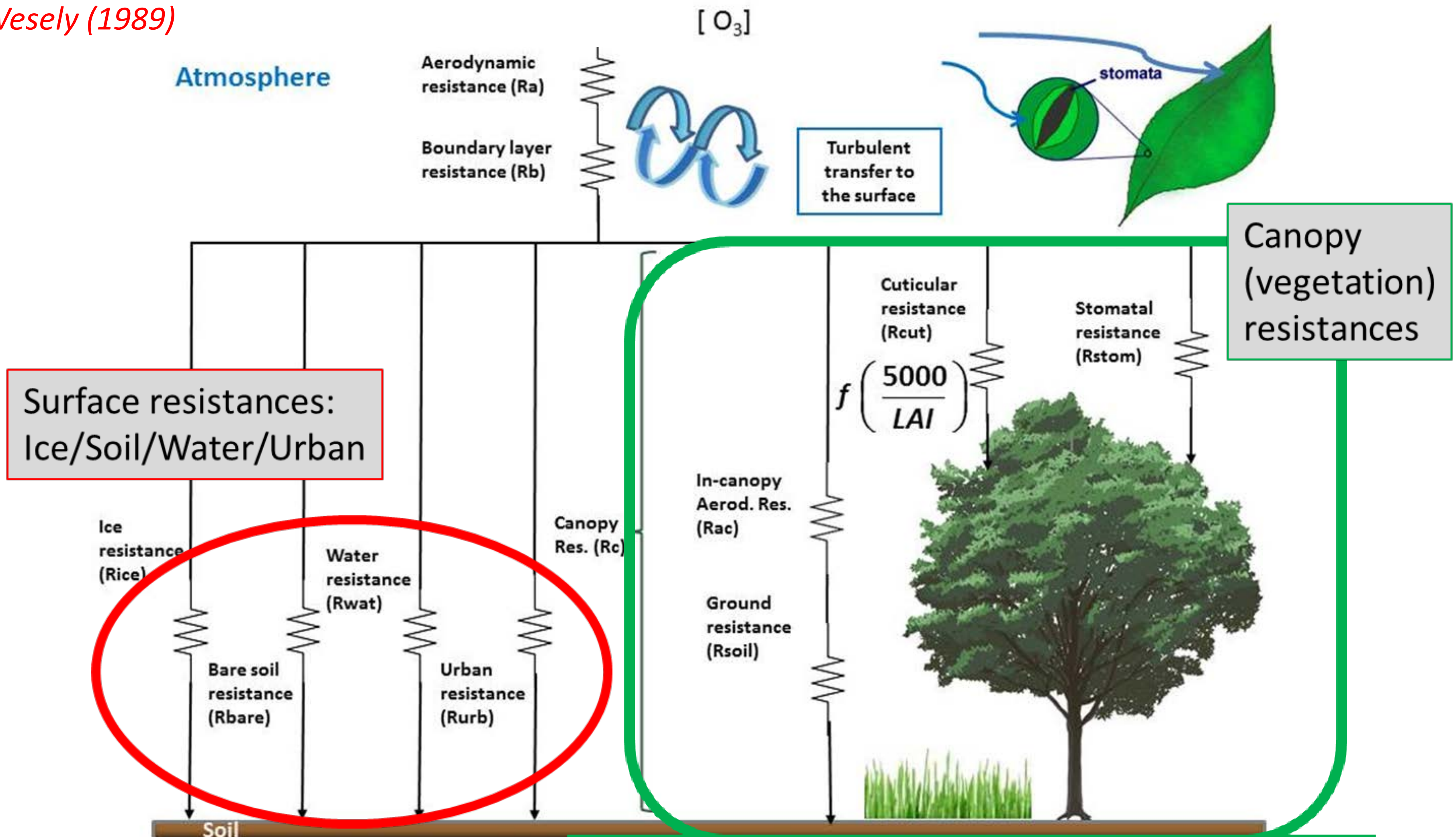
**Olson Land Cover Classes:**

**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**

*Analysis of HTAP model runs (Hardacre et al., 2015)*

# UKCA Dry Deposition Schemes

*Wesely (1989)*




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

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*$R_c$ parameters from land surface module - JULES*
*F Centoni has identified 2 bugs*

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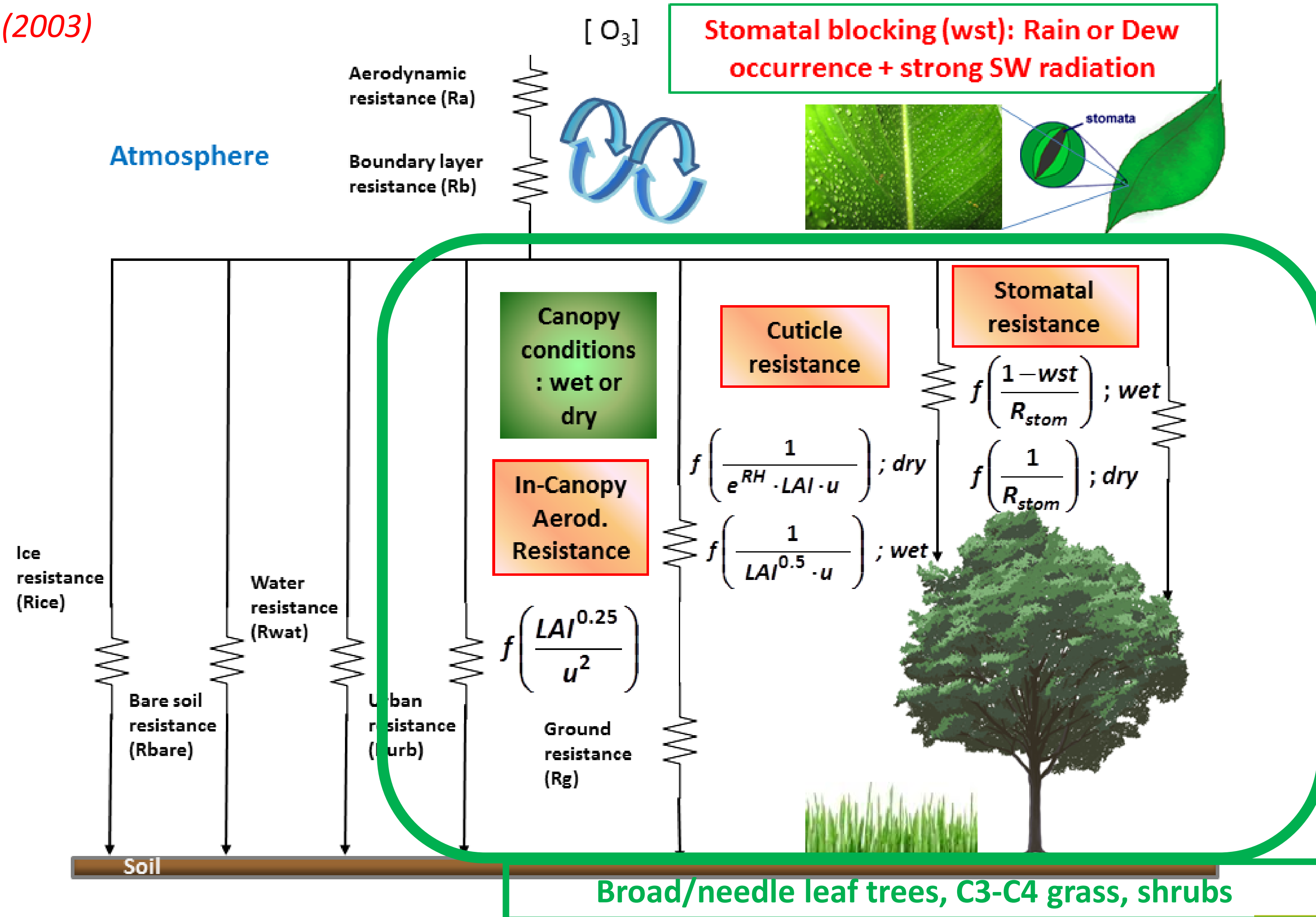
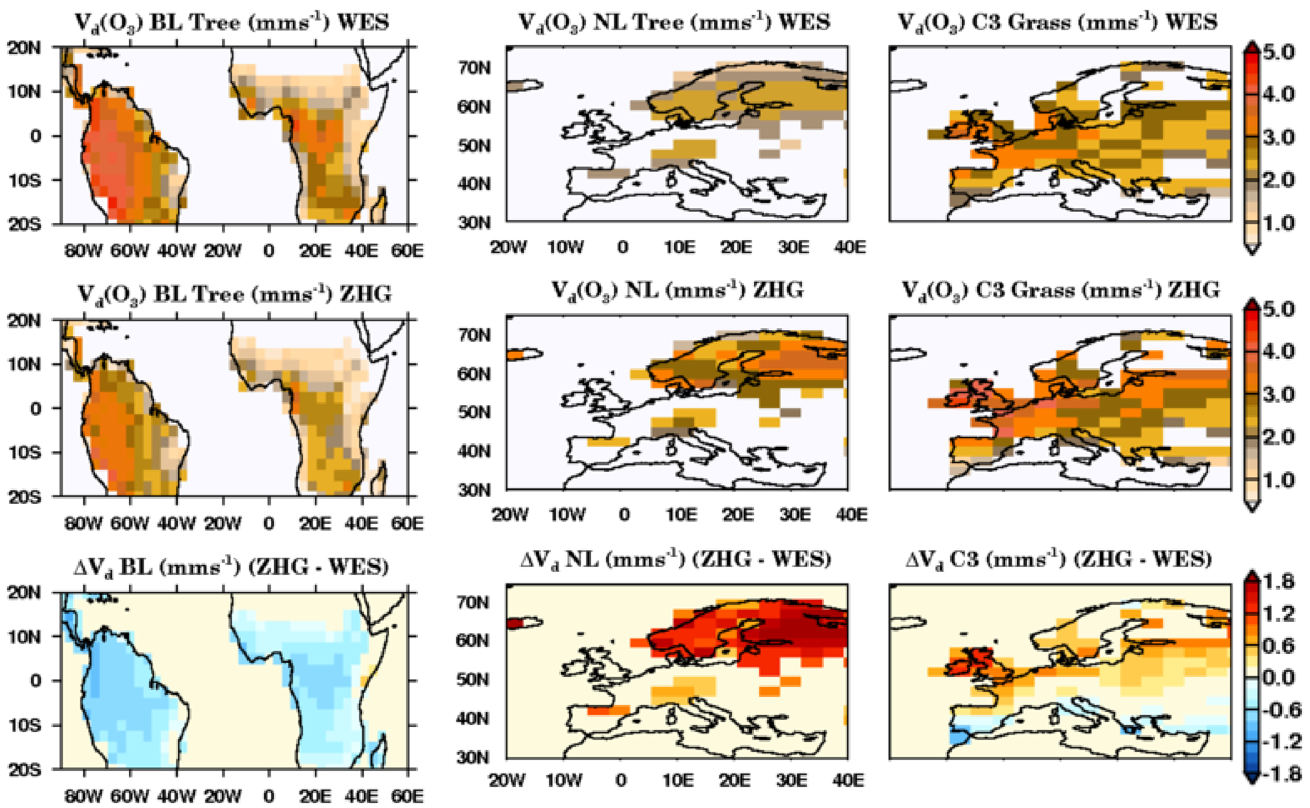
# UKCA Dry Deposition Schemes

*Zhang (2003)*



# An alternative non-stomatal deposition approach in UM-UKCA model: effects on $O_3$ deposition velocity




- <u>Zhang et al. 2003 dry dep. scheme</u> led to significant spatially distributed changes and latitudinal gradients of $O_3$ $V_d$ especially in the NH.
- Large differences of $O_3$ $V_d$ mainly driven by changes of non-stomatal conductance terms both in space and in time.
- Non-stomatal fraction of total $O_3$ deposition increased in the NH, considerably during the cooler season and in spring (up to 70% over Needle leaf forests; up to 60% over C3 grass).

"Revising ozone dry deposition in the UKCA model and implementing an alternative non-stomatal deposition approach", Centoni F., Stevenson D., Fowler D., et al. 2016a, in prep.

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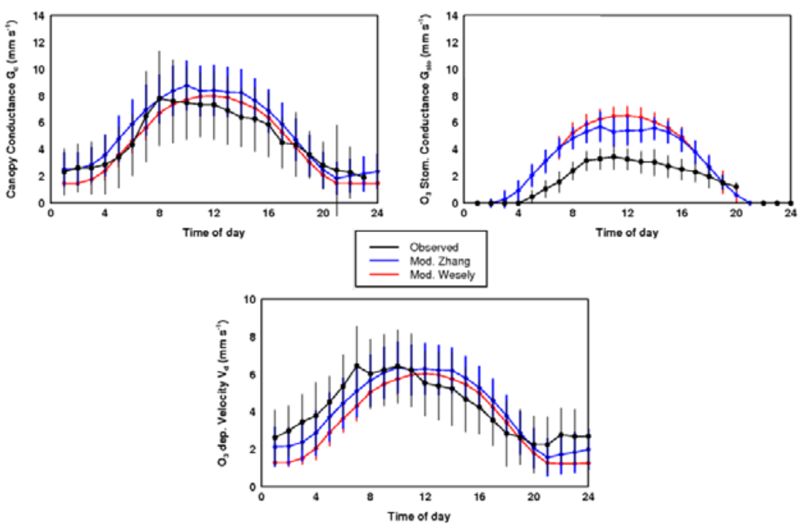
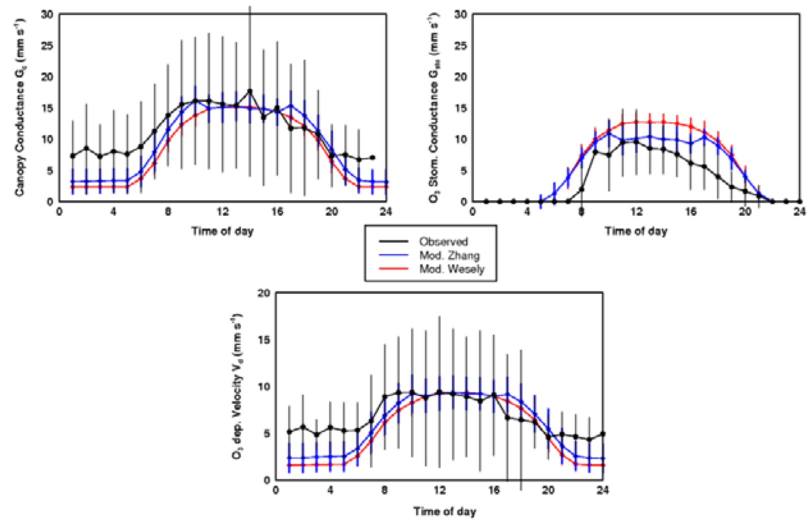
# Evaluating $O_3$ deposition velocity in the UKCA model: preliminary results

- Good ability to capture diurnal variation at selected sites

**Easter Bush, SE Scotland, (55N 3W)**
**Grassland, Spring 2002**




**Hyytiala, Finland, (61N 24E)**
**Coniferous forest, Summer 2002**




**"Evaluation of ozone dry deposition velocity terms in the UM-UKCA model",**
**Centoni F., Fowler D., Nemitz E., Stevenson D. et al. 2016b, in prep.**

- Less good where plants experience water stress (e.g., in the Mediterranean basin)

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# UKCA Dry Deposition

| Model Name | Formula |
|---|---|
| O3 | $O_3$ |
| NO | NO |
| NO2 | $NO_2$ |
| NO3 | $NO_3$ |
| N2O5 | $N_2O_5$ |
| HONO2 | $HNO_3$ |
| HONO | HONO |
| ISON | |
| H2SO4 | $H_2SO_4$ |
| H2O2 | $H_2O_2$ |
| H2 | $H_2$ |
| CH3OOH | $CH_3OOH$ |
| HACET | |
| ROOH | Other organic peroxides |
| PAN | Peroxy Acetyl Nitrates |
| PPAN | |
| MPAN | |
| CO | CO |
| CH4 | $CH_4$ |
| NH3 | $NH_3$ |
| | |
| SO2 | $SO_2$ |
| DMSO | |
| MSA | |
| OnitU | |
| SEC_ORG | Any other secondary organics |
| ORGNIT | Organic nitrogen |

- Different approaches for gas-phase and aerosol components
- Gas-phase species: Use resistance approach (Wesely/Zhang)
- Aerosol species: Use roughness length to infer a surface type and then use a prescribed velocity

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# ÉCLAIRE: Surface Exchange Model (ESX)

## Motivation:

- Growing evidence that a lot of chemistry happens within and near canopies - large gradients in concentration, radiation, T, RH
- Subgrid process, not treated by current single-layer approaches
  - Exception: global modelling of NO-$NO_2$-$O_3$ chemistry in canopies by Ganzeveld et al. in two-layer approach

## Approach:

- ÉCLAIRE is developing a new multi-layer exchange/transport/chemistry module (ESX)
- Complex 1-D stand-alone model (many layers; different chemistry schemes; explicity/parameterised leaf surface chemistry; different in-canopy transport schemes; compensation points)
- Designed to be modular, simplifiable and consistent with EMEP CTM
- Simplify as much as required for CTM (ESM?), verified against complex model in off-line mode (off-line tests required to establish minimum number of layers etc.)
- Use the stand-alone model to re-analyse/assimilate field flux data with multi-layer concept
- Community model; freely available; backed by international community (see workshop background documents at **https://colloque.inra.fr/cost_eclaire**)

# Future Developments

- 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

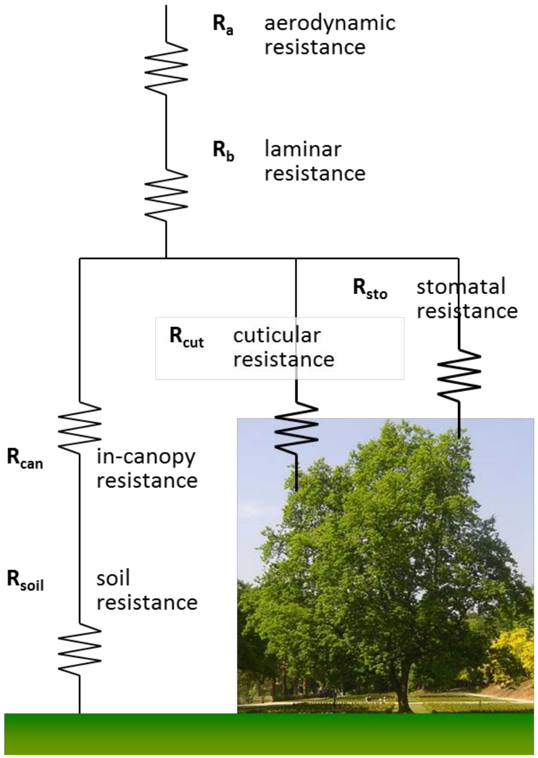
- Considerations
  - Need/desire to update dry-deposition scheme in UKCA
  - Consistent treatment of gas and aerosol species

  - Consistency between UKCA and JULES, e.g., as more pft's added to JULES
  - Should JULES provide deposition parameters (e.g., $r_c$) as current or calculate deposition velocities (pft/species dependent) or mass fluxes (requires species concentrations)?
  - With addition of N-cycle, JULES will increasingly require atmospheric 'deposition' inputs

  - Extension to other species – exchange rather than uptake
  - Single or multi-layer schemes (for UKCA deposition, in-canopy chemistry)
  - Implications for development of 'offline' version of UKCA

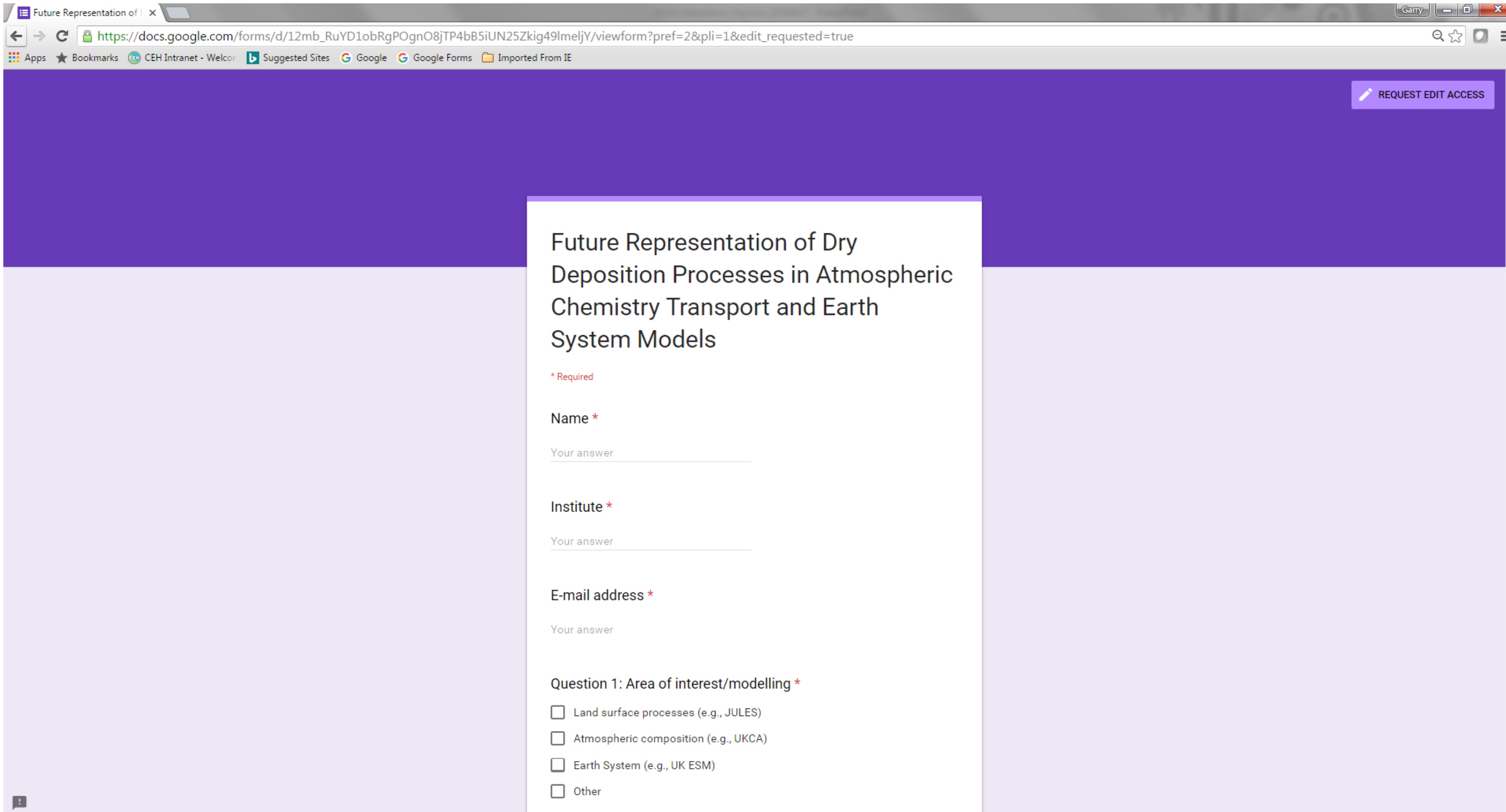
# Dry Deposition: Future Developments

- Dry deposition working group formed as part of the NERC ACITES* project
- Informal meetings held at JULES (2013) and ACITES (2014, 2015) events
- New members welcome
- Subgroup created to consider future ESM developments:
  - G Hayman, E Nemitz (CEH)
  - O Wild (U. Lancaster)
  - G Folberth, F O'Connor, A Hewitt, A Wilshire, J Mulcahy (Met Office)
  - L Emberson (SEI, York)
  - D Stevenson (U. Edinburgh)
  - L Abraham (U. Cambridge)




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

# Community Consultation: https://goo.gl/vfQuFU

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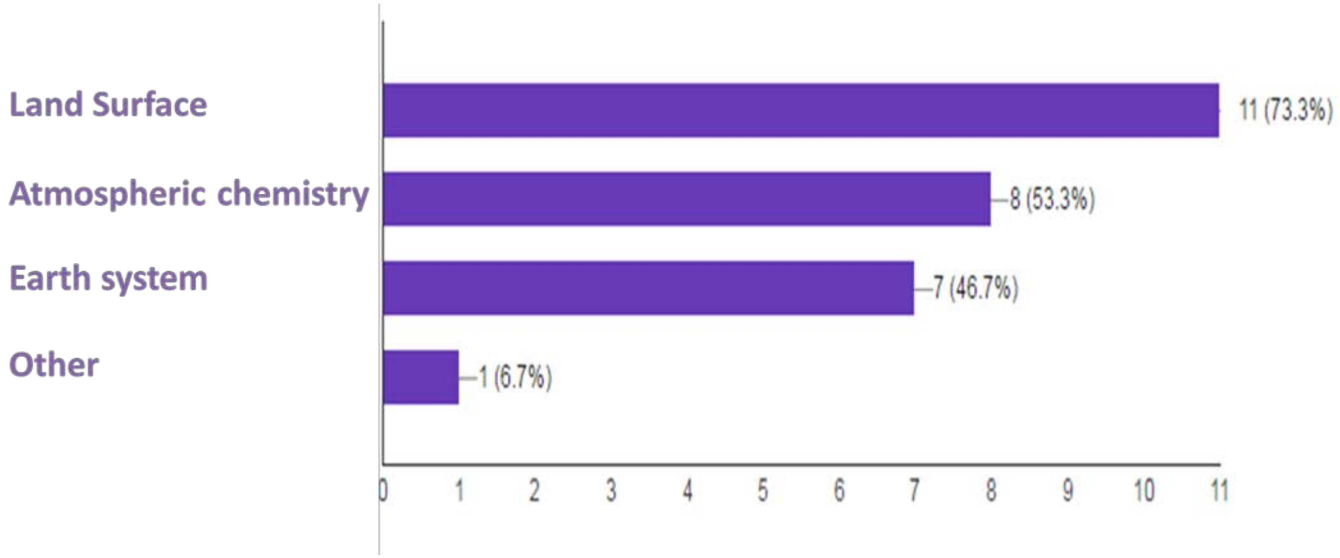
# Consultation: Key points



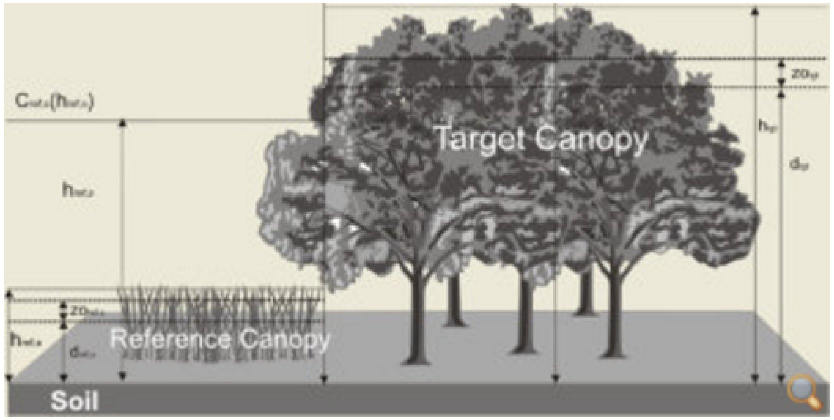

- Deposition module needed in the UKCA for input to oceans (in ESM) and for 'offline' version
- General agreement that land-related aspects should be in JULES
- Flexibility needed to include new chemical species and plant functional types
- Lack of relevant observational data for model development and evaluation; more data needed from tropical regions (with link to $O_3$ vegetation damage)
- Longer term, move away from 'big leaf' approach to canopy exchange modelling (with implications for full multi-layer treatment)

# Code development

- As part of the new UK ESM LTSM project, CEH will develop and test an offline deposition module:
  - Include current UKCA deposition schemes (9 and 13-tile versions)
  - Include scheme used in the EMEP CTM; considered to represent the current state-of-knowledge.

- Compare stomatal conductance with the Deposition of Ozone for Stomatal Exchange (DO3SE) model.

**DO3SE: Deposition of Ozone for Stomatal Exchange**




DO3SE (Deposition of Ozone for Stomatal Exchange) is a dry deposition model designed to estimate the total and stomatal deposition (or flux) of ozone ($O_3$) to selected European land-cover types and plant species.

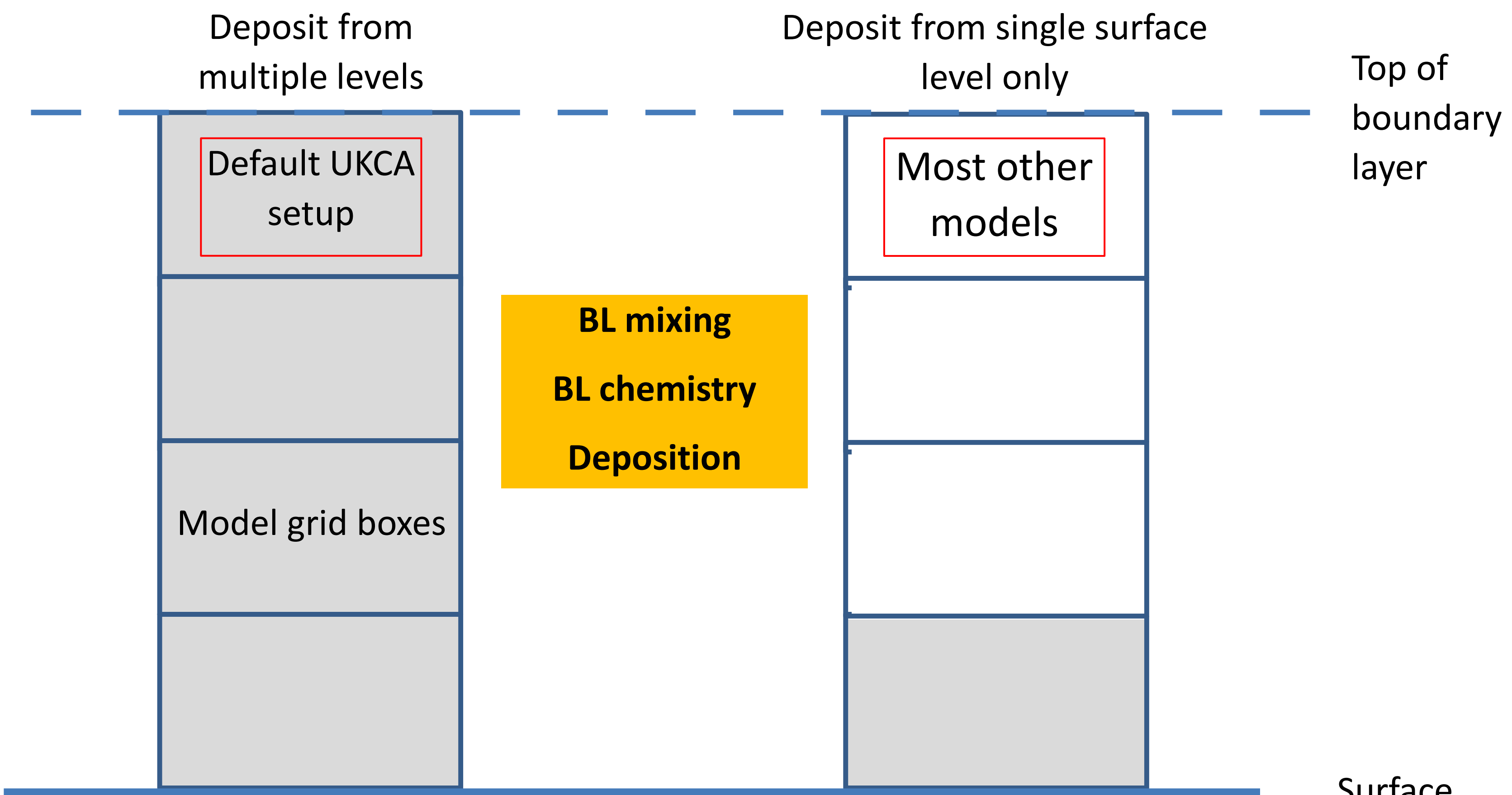
https://www.sei-international.org/do3se

# Advance Notice

**iLEAPS (Integrated Land Ecosystem Atmospheric Processes Study)**

- Future Earth core project
- Canopy Exchange model intercomparison (CANEXMIP)
- Science Conference (Oxford, 2017)

# 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 …..**

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***Both sorts of schemes implemented in UKCA model***