Atmospheric Dry Deposition in JULES

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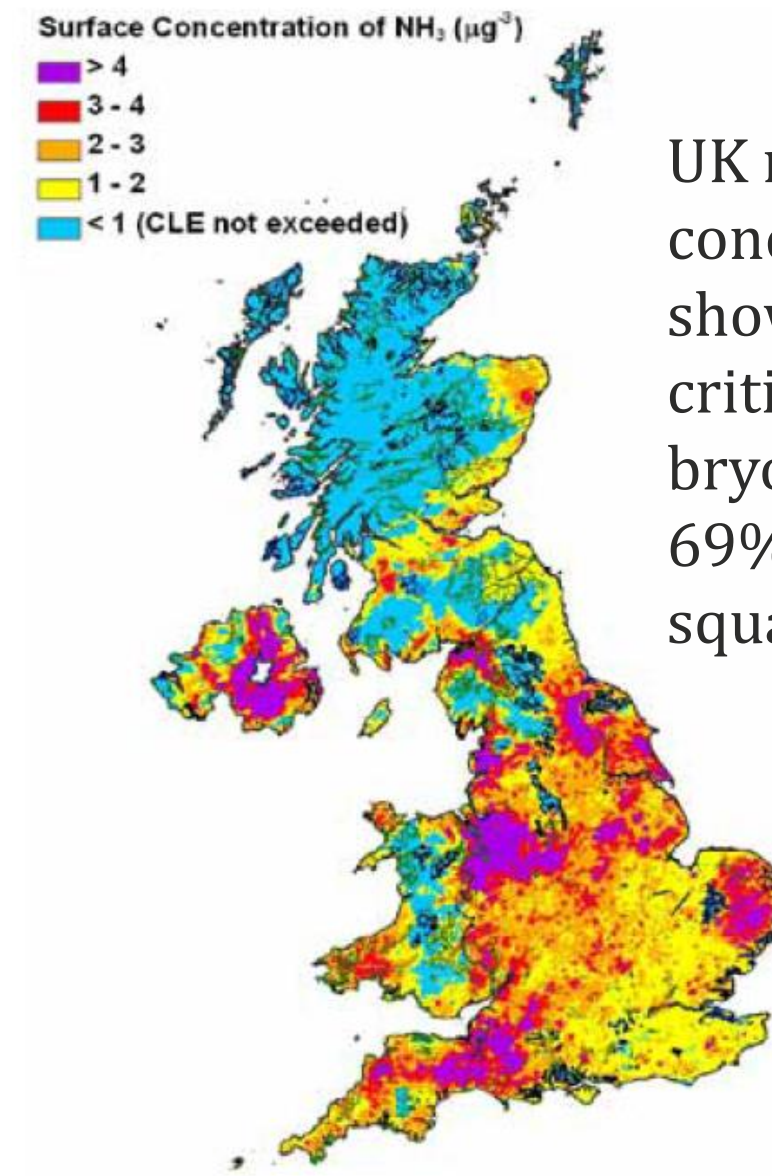
Background

- **Surface exchange fluxes**
  - In UM-coupled configuration, JULES calculates the surface exchange fluxes of energy, water and carbon between the atmosphere and all surface components - land, oceans and cryosphere
  - Aim to extend to surface exchange of atmospheric trace gases and aerosols i.e. net flux of deposition/uptake and emissions/releases
  - Initial work on dry deposition of trace gases

- **Also address issues with current UKCA dry deposition scheme**
  - Science and code need updating
  - UKCA has restrictions on surface tile configurations - allowed configurations:
    5 pft/9tile, 9pft/13-tile, 13pft/17 tile and 13pft/27 tile (UKESM1.1)
  - Significant coding needed to add new surface tile configuration, e.g. UKESM2 with dynamic ice sheet module will use 10 elevated rock tiles

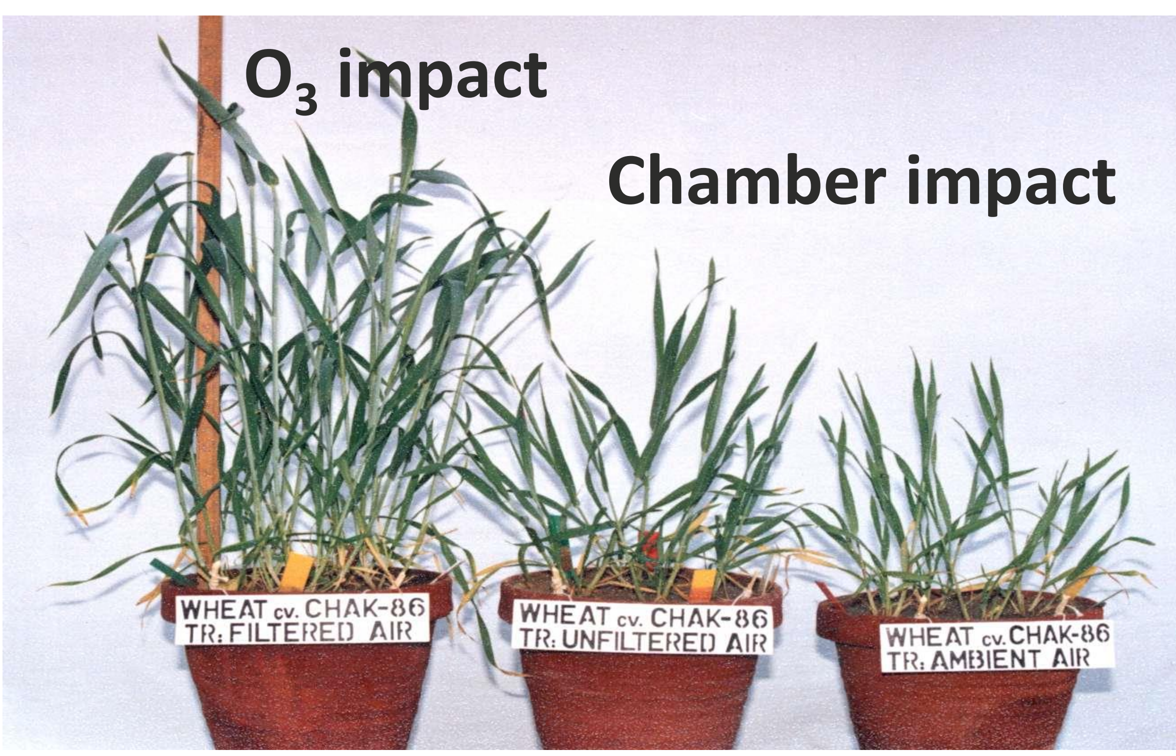
Atmospheric dry deposition

- 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)



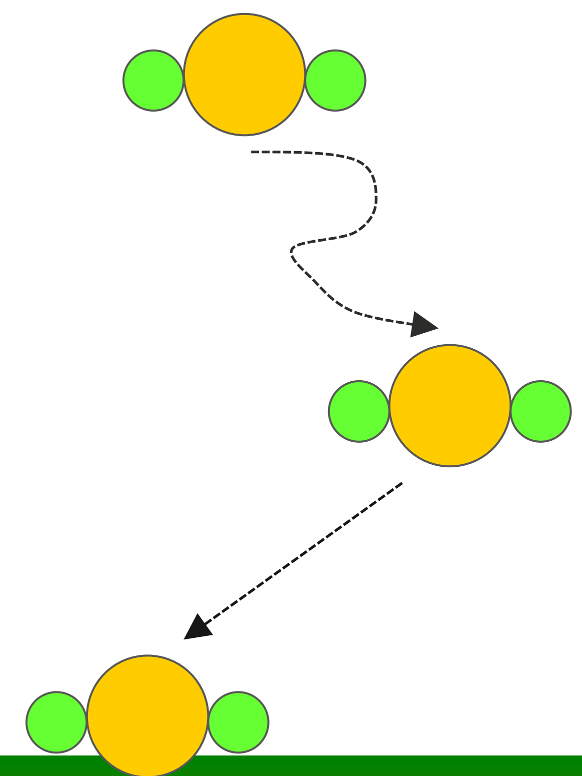
O_3 injury to wheat, Pakistan (courtesy of A. Wahid)

- 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*

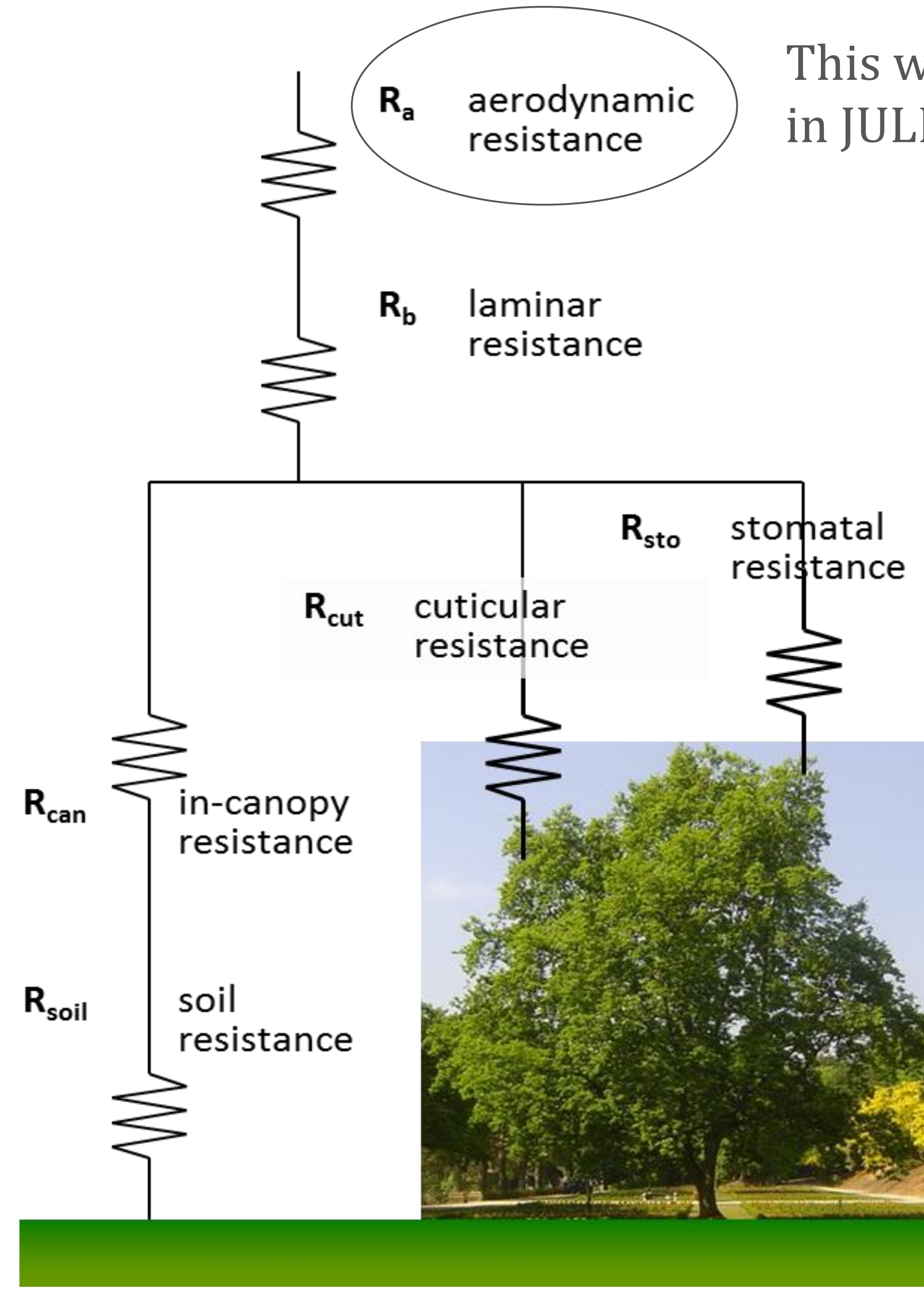
Modelling dry deposition processes

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.)



This was already in JULES

- Many atmospheric chemical transport models, including UK chemistry-climate and Earth System models, use a "Wesely-resistance" approach

- Atmospheric dry deposition in UKCA and now JULES

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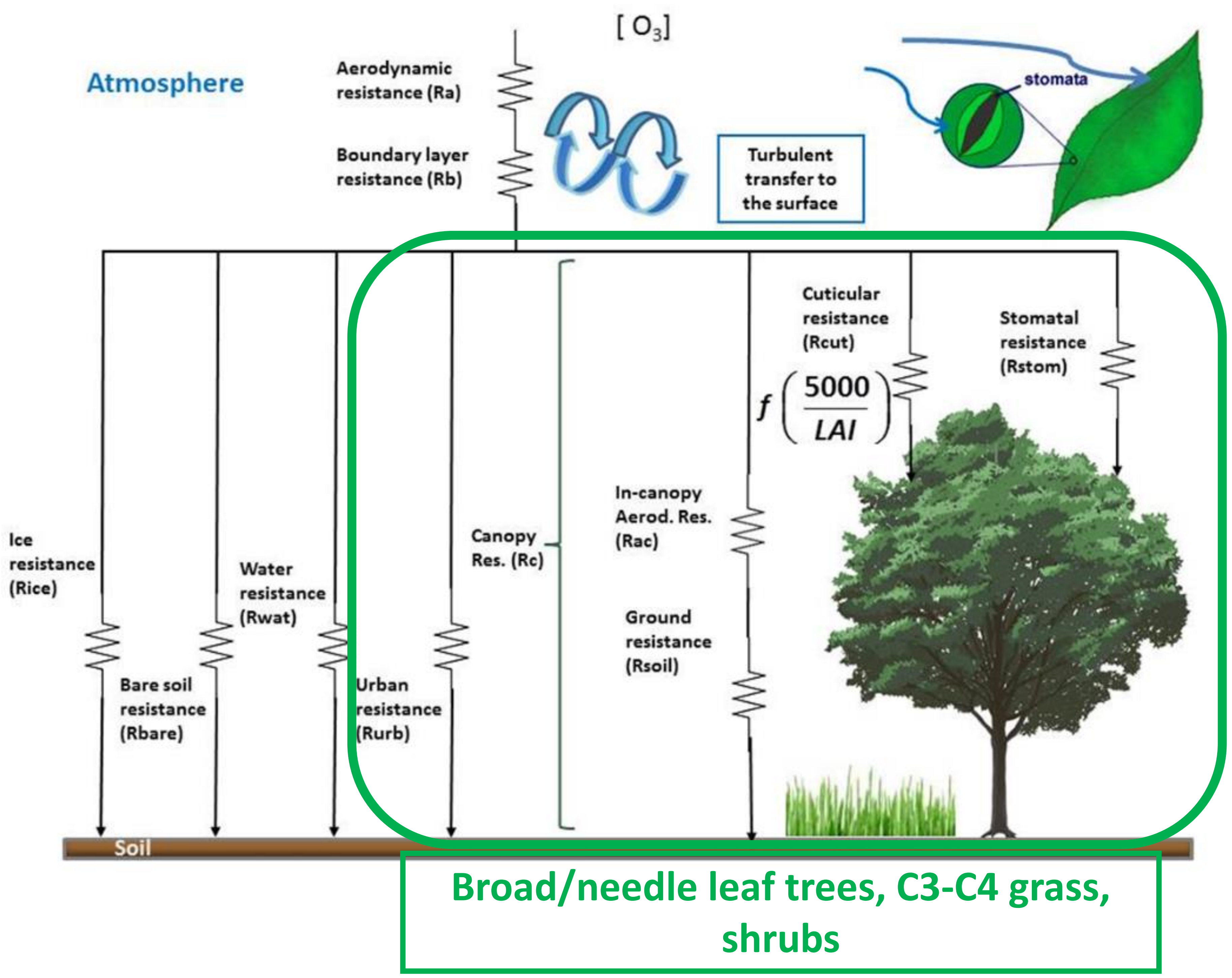
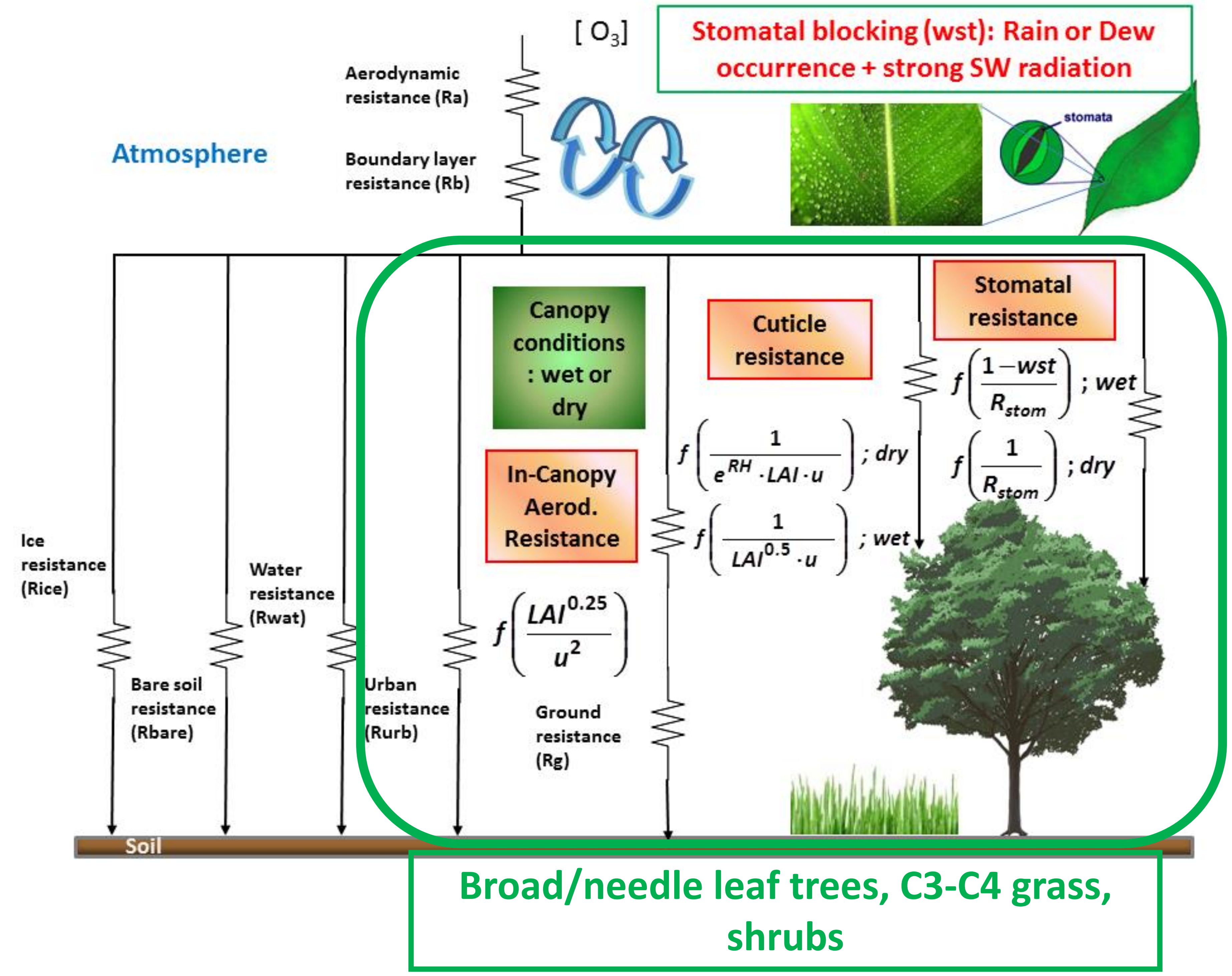
Dry deposition schemes in the UKCA model

Current scheme in UKCA (UKESM)



- Wesely (1989) scheme for gas-phase species
- Deposition of aerosol species based on roughness length and the use of prescribed deposition velocities. Also sedimentation.
- Need to mirror pft order/description used in JULES

HadGEM3 branch (F. Centoni)
JULES branch (G Hayman)



- Implementation of Zhang et al. scheme (Atmos. Chem. Phys. 2003) for O_3
- Allows for stomatal blocking when wet, which reduces stomatal uptake.

JULES with Atmospheric Deposition: options

- There are three deposition options:
  - l_deposition = false: Use the existing UKCA-based deposition routines in UM-coupled JULES applications. For JULES standalone, this switches off the deposition science and no deposition output is produced.
  - l_deposition = true and dry_dep_model= 1: JULES-based implementation of the current interactive dry deposition routines in the UKCA, including (a) the restriction on the number of surface tile configurations and the ordering of the pfts and non-vegetated surfaces, and (b) the deposition parameters are hard-wired in the code.
  - l_deposition = true and dry_dep_model= 2: This uses a JULES-based implementation of the current interactive dry deposition routines, which removes the restrictions on the surface tile configuration and the ordering of the surface types. Deposition parameters for the different deposited chemical species and surface tile configuration are input through namelists.
- For standalone JULES, Deposition routines called from 'surf_couple_extra'
- For UM-coupled JULES, Deposition routines called from UKCA routine 'ukca_chemistry_ctl'

Current position

- JULES with atmospheric deposition in the JULES, UM and UKCA code trunks from UM vn13.1 release (October 2022)

- Testing for the release indicated equivalence of the UKCA and JULES-based deposition routines ("bit" comparability)

- Recent work for UKESM2 identified a minor coding error in the JULES-based deposition routines, controlled by a deposition switch used in UKESM2

- Tickets for UM vn13.4 release (JULES #1332, UKCA #31 and UM #7351)

  a. To correct coding error in the JULES-based deposition routines
  b. To implement science changes made to the UKCA deposition routines since the UM vn13.1 release
  c. ~~Correct UKCA calculation of the surface tile fractions for deposition (ukca_ddepctl), which has the implicit assumption that the last surface type is ice:~~

```
IF (seaice_frac(i,k) > 0.0) THEN
  gsf(i,k,lake) = (1.0 - seaice_frac(i,k)) * seafrac
  gsf(i,k,ntype) = gsf(i,k,ntype) + seaice_frac(i,k) * seafrac
END IF
```

- After discussion with UKESM-UM-UKCA code owners/managers, reversed (c) to maintain output for existing UKESM1 and UKESM1.1 configurations

Namelist generator

The JULES atmospheric deposition namelists comprise

- jules_deposition
- A set of duplicate ‘jules_deposition_species’ namelists, one for each trace gas that is deposited in the atmospheric chemical mechanism
- ‘jules_deposition_species_specific’ namelist, with deposition parameters used by only one trace gas
- Some namelist entries have a dependence on surface type

Namelist generator (*) developed to produce the set of namelists for

- the atmospheric chemistry mechanism
- the surface tile configuration
- the settings of the deposition switches

(*) https://code.metoffice.gov.uk/trac/utils/browser/dry_deposition_namelist_generator

```
[namelist:jules_deposition]
dry_dep_model=2
dzl_const=50.0
l_deposition=.true.
l_deposition_flux=.false.
l_deposition_gc_corr=.false.
l_fix_drydep_so2_water=.false.
l_fix_improve_drydep=.false.
l_fix_ukca_h2dd_x=.false.
l_ukca_ddep_lev1=.false.
l_ukca_ddepo3_ocean=.false.
l_ukca_dry_dep_so2wet=.false.
l_ukca_emsdrvn_ch4=.false.
ndry_dep_species=42
tundra_s_limit=0.866

[namelist:jules_deposition_species(1)]
!!dd_ice_coeff_io=-13.57,6841.9,-857410.6
dep_species_name_io='O3'
dep_species_rmm_io=48.0
diffusion_coeff_io=1.400000e-05
diffusion_corr_io=1.6
r_tundra_io=800.0
rsurf_std_io=307.7,285.7,280.4,232.6,233.5,355.0,355.0,355.0,309
.3,309.3,309.3,324.3,392.2,444.4,2000.0,645.2,2000.0,2000.0,2000
.0,2000.0,2000.0,2000.0,2000.0,2000.0,2000.0,2000.0,2000.0

[namelist:jules_deposition_species_specific]
ch4_mml_io=1.008e5
ch4_scaling_io=15.0
ch4dd_tundra_io=-4.757e-6,4.0288e-3,-1.13592,106.636
ch4_up_flux_io=39.5,39.5,39.5,50.0,50.0,30.0,30.0,30.0,37.0,37.0
,37.0,27.5,27.5,1.00e+30,1.00e+30,30.0,1.00e+30,1.00e+30,1.00e+3
0,1.00e+30,1.00e+30,1.00e+30,1.00e+30,1.00e+30,1.00e+30,1.00e+30
,1.00e+30
cuticle_o3_io=5000.0
h2dd_c_io=19.7,19.7,19.7,19.7,19.7,17.7,17.7,17.7,1.235,1.235,1.
235,1.0,1.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
0.0
h2dd_m_io=-41.9,-41.9,-41.9,-41.9,-41.9,-41.4,-41.4,-41.4,-
0.472,-0.472,-
0.472,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.
0,0.0
h2dd_q_io=0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.27,0.27,0.27,0.0,0.0
,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
r_wet_soil_o3_io=500.0
```

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JULES Atmospheric Deposition in UKESM1.1

- UKESM1.1 AMIP runs

  - u-cy714 (“control”): UKCA-based deposition routines (l_deposition = false switched off), with UM, JULES and UKCA trunks at UM vn13.3

  - u-cy733: JULES-based deposition routines (l_deposition = true and dry_dep_model =2), with UM and UKCA trunks at UM vn13.3 and JULES branch JULES_vn7.3_atmospheric_deposition_fix@r26213, correcting the misplaced bracket.

  - u-cy738: UKCA-based deposition routines (l_deposition = false switched off), with UM and JULES trunk at UM13.3 with UKCA branch um13.3_JULES_atmospheric_deposition_fix@r1987, changing ntype to ice. This is equivalent to suite u-cy733.

  - u-cy739: Uses JULES-based deposition routines (l_deposition = true and dry_dep_model =2), using UM and UKCA trunks at UM13.3 with an alternative JULES branch JULES_vn7.3_atmospheric_deposition_test@r26214, correcting the misplaced bracket and reverting to the “UKCA” logic for the calculation of the deposition surface tile fractions (i.e. ice changed back to ntype). This is equivalent to the control run, suite u-cy714.

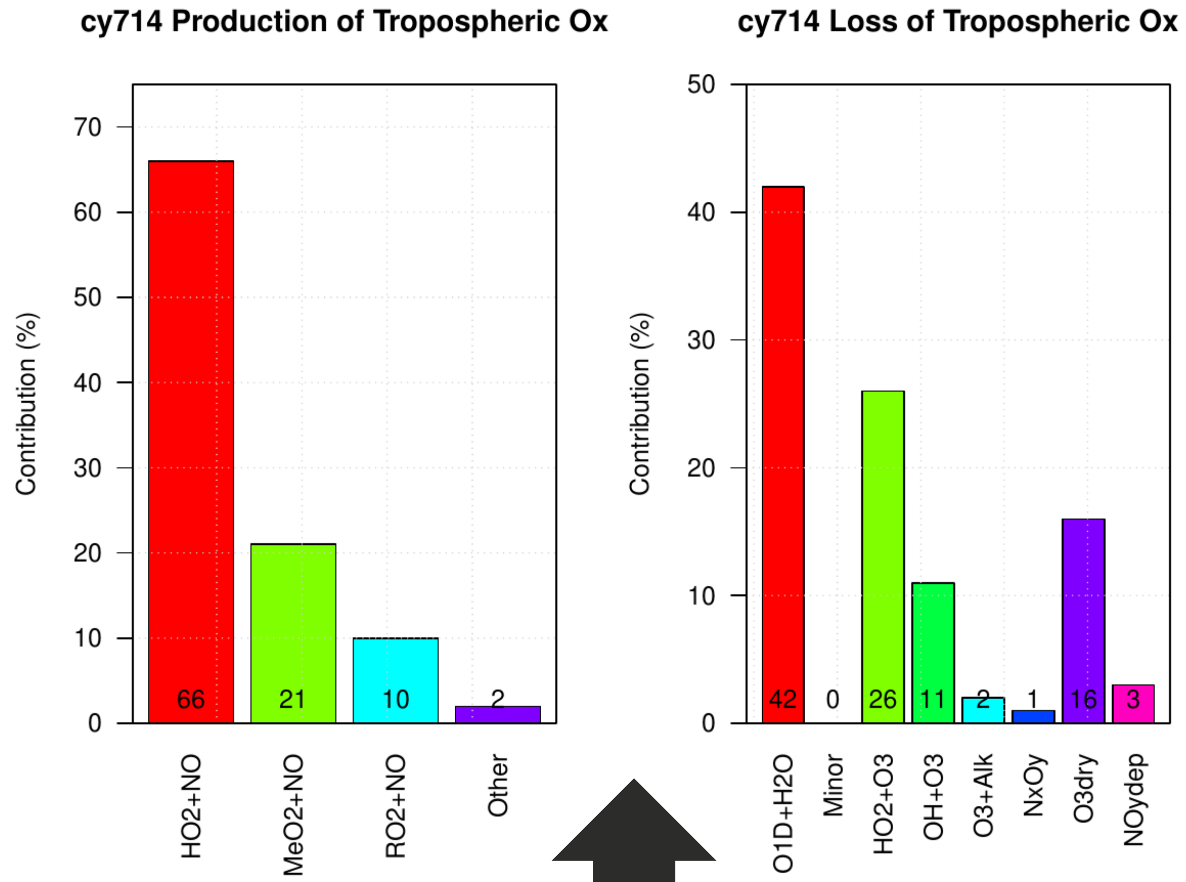
UKESM1.1: Tropospheric Oxidant budget

UKCA-based deposition routines

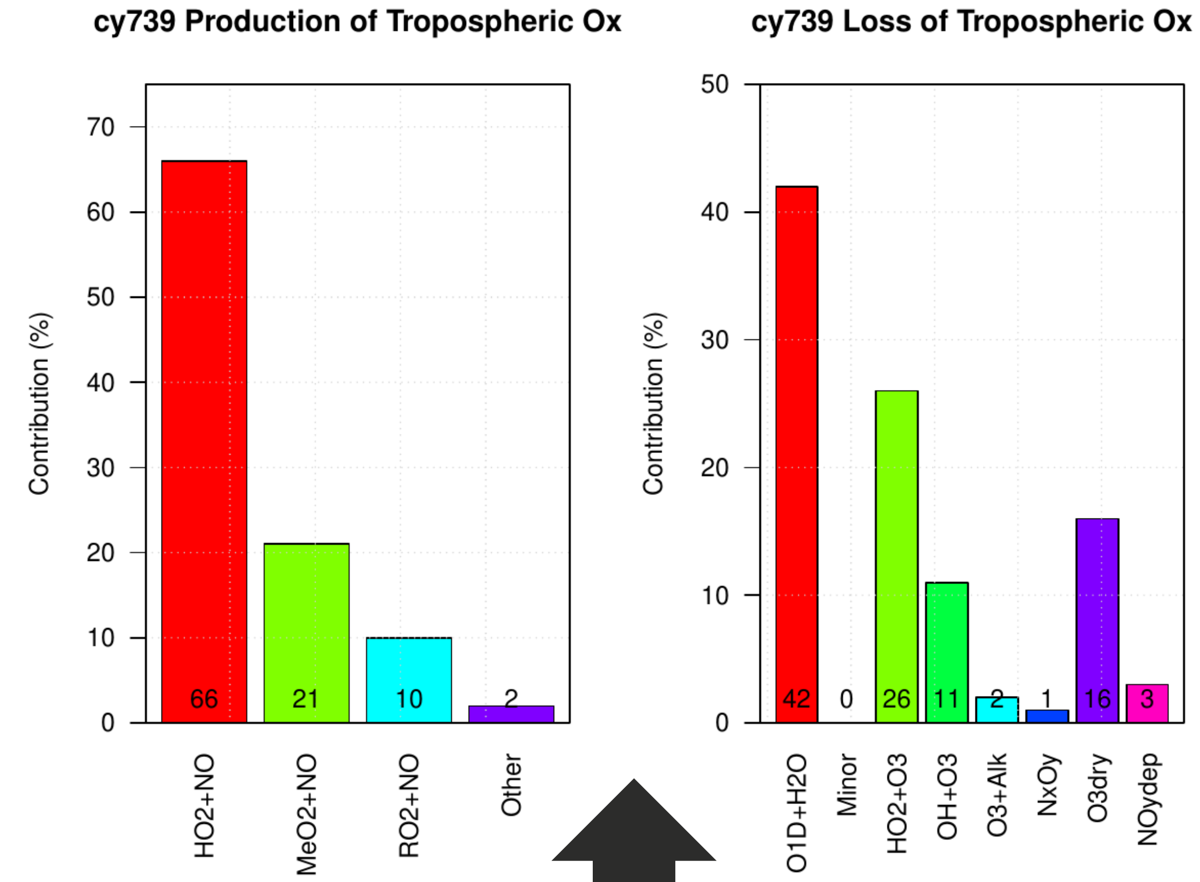
Control (UM, JULES & UKCA trunks)

JULES-based deposition routines

UKCA surface tile fractions



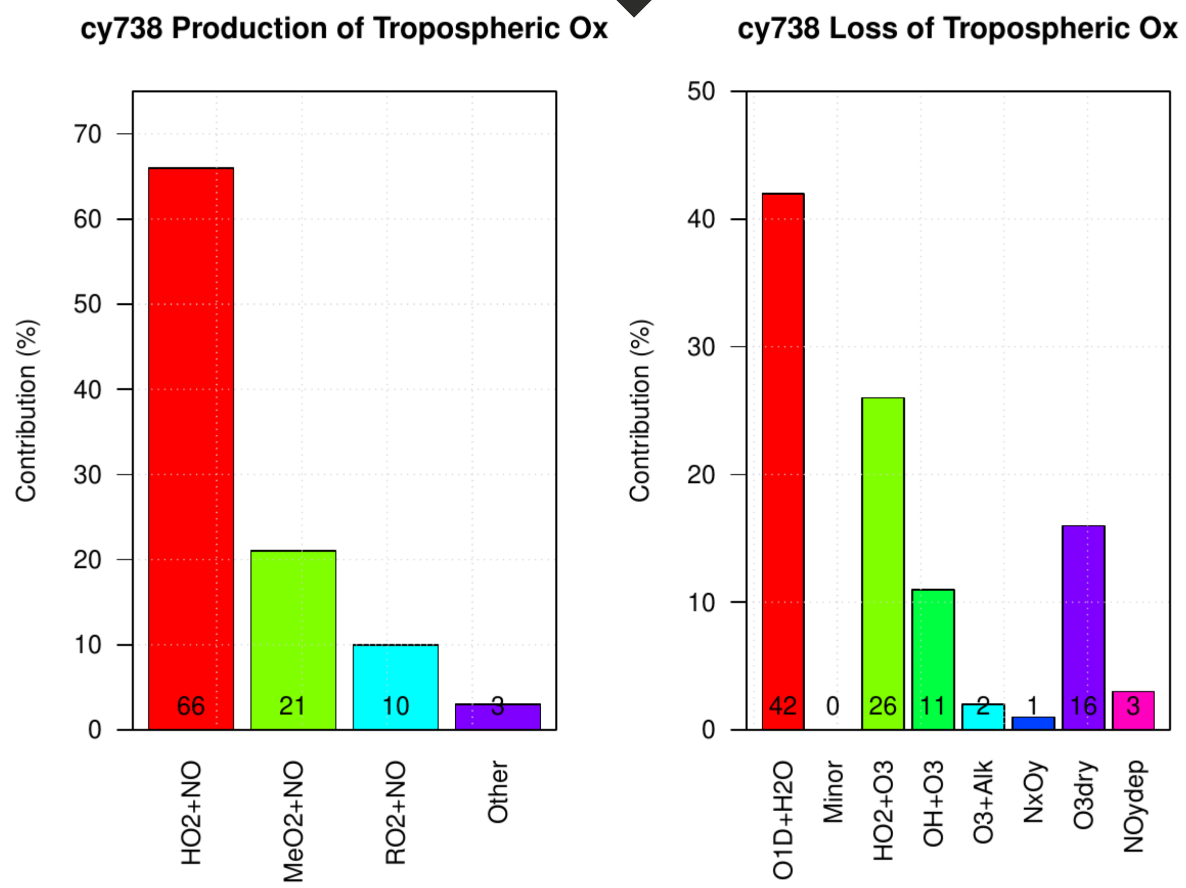
BIT COMPARE



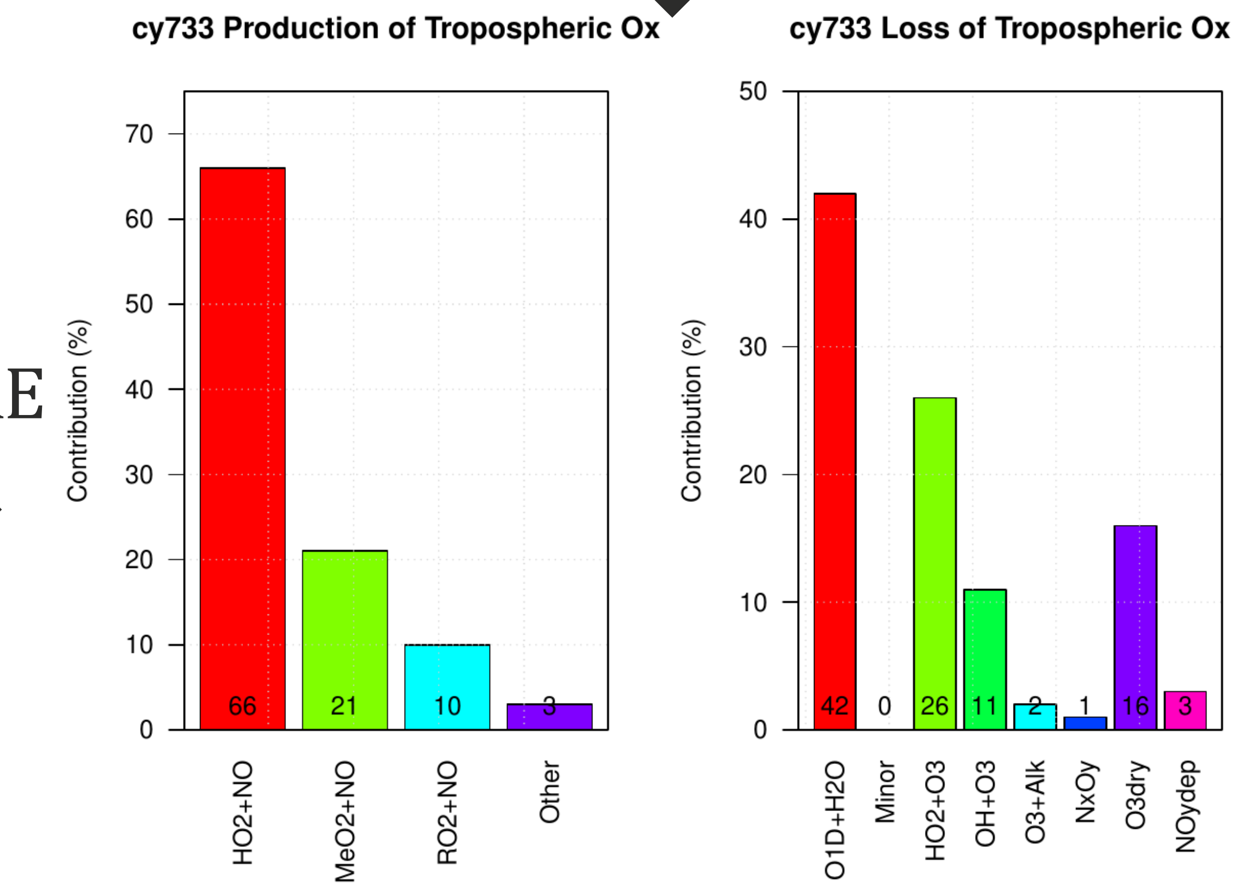
DIFFER

DIFFER

JULES surface tile fractions



BIT COMPARE



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UKESM1.1: hydroxyl radical

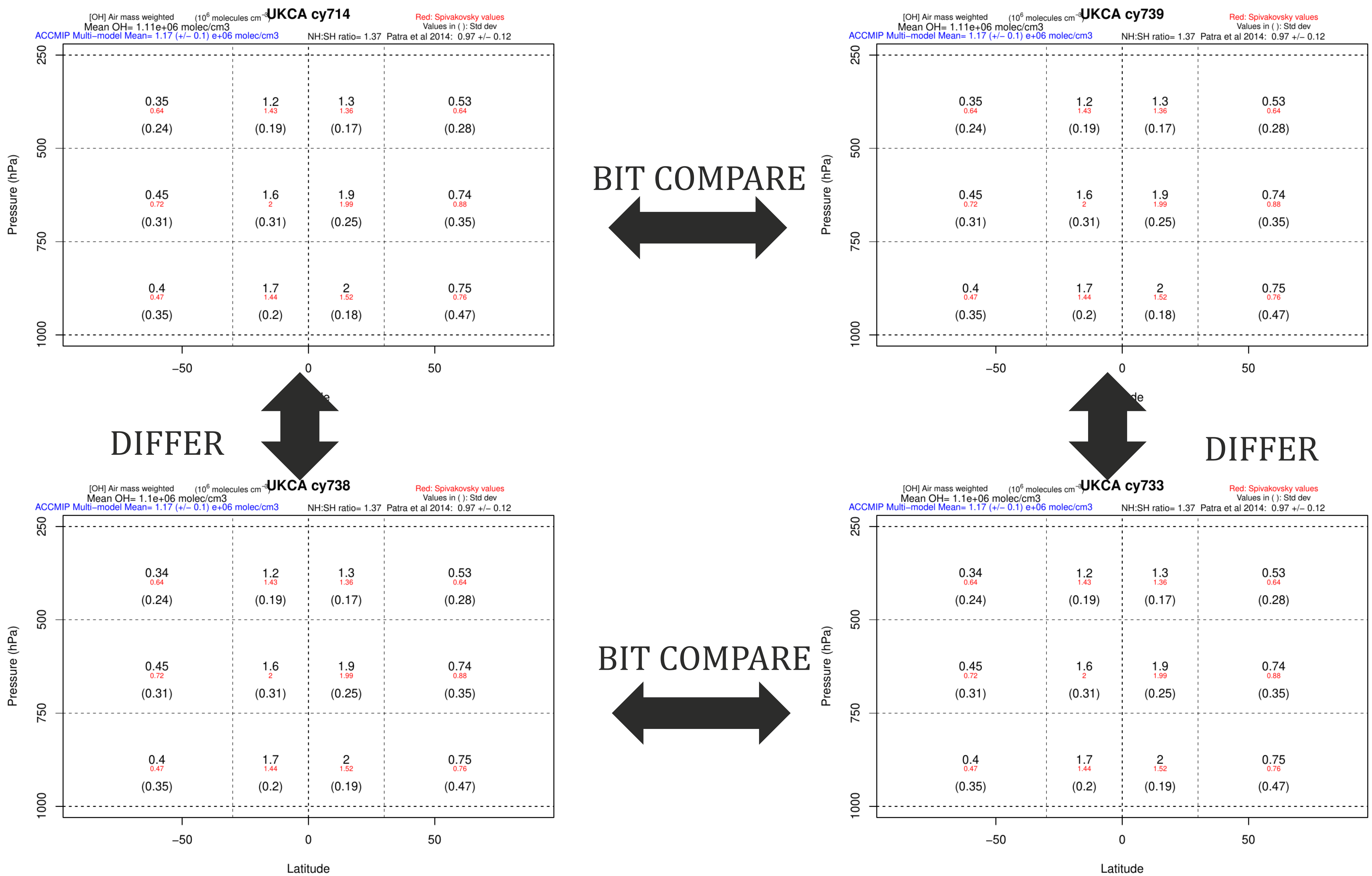
UKCA-based deposition routines

Control (UM, JULES & UKCA trunks)

JULES-based deposition routines

UKCA surface tile fractions

JULES surface tile fractions



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Future work, wishlist & activities

- UKESM2
  - Use JULES-based deposition routines for current 13pft/27 surface tile configuration
  - Create namelists for surface configuration using elevated rock (13pft/37 surface tiles)
- Code development
  - How to maintain alignment of the JULES and UKCA-based deposition routines
  - Address outstanding issues from development of JULES-based deposition
  - Implement Zhang deposition scheme (currently on a branch)
  - Aerosol deposition
- Convene a meeting of those working on deposition in the UK (modelling and observation)