Joint Weather & Climate Research Programme – a partnership in weather and climate research

Atmospheric Dry Deposition in JULES

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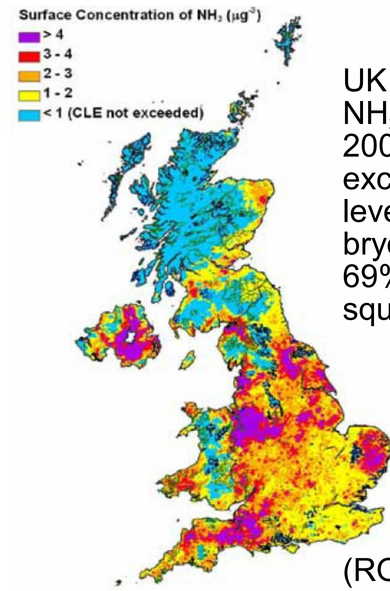
JULES Annual Meeting
22nd-23rd July 2019

National Centre for Atmospheric Science · National Oceanography Centre · Centre for Ecology & Hydrology · National Centre for Earth Observation · PML Plymouth Marine Laboratory · British Antarctic Survey

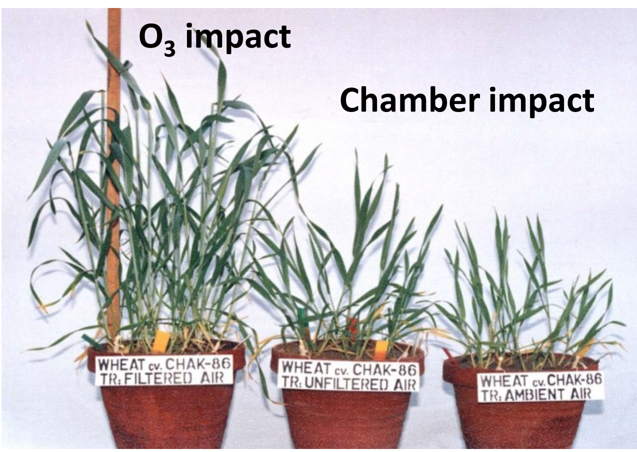
Atmospheric dry deposition

- 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)

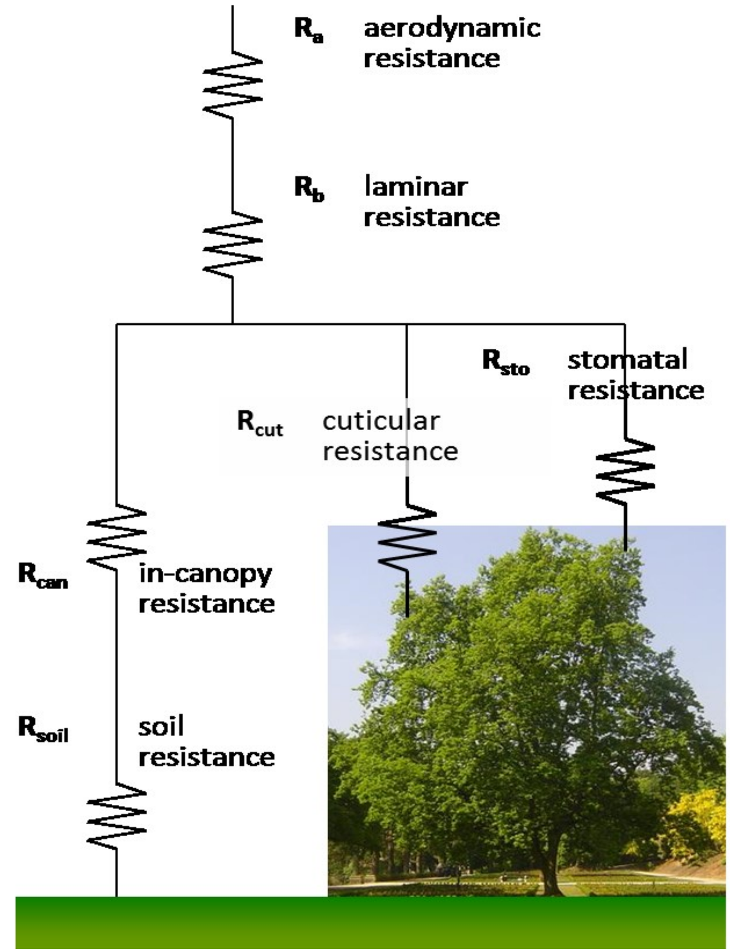
- Policy-relevant implications for air quality, crop yields, etc.
  - *Critical loads for acid deposition and eutrophication*
  - *Ozone exposure and effects on human health and vegetation*
  - *Particulate matter (aerosol) and impact on human health*

Modelling dry deposition processes

1. **Turbulent transport** through atmosphere

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

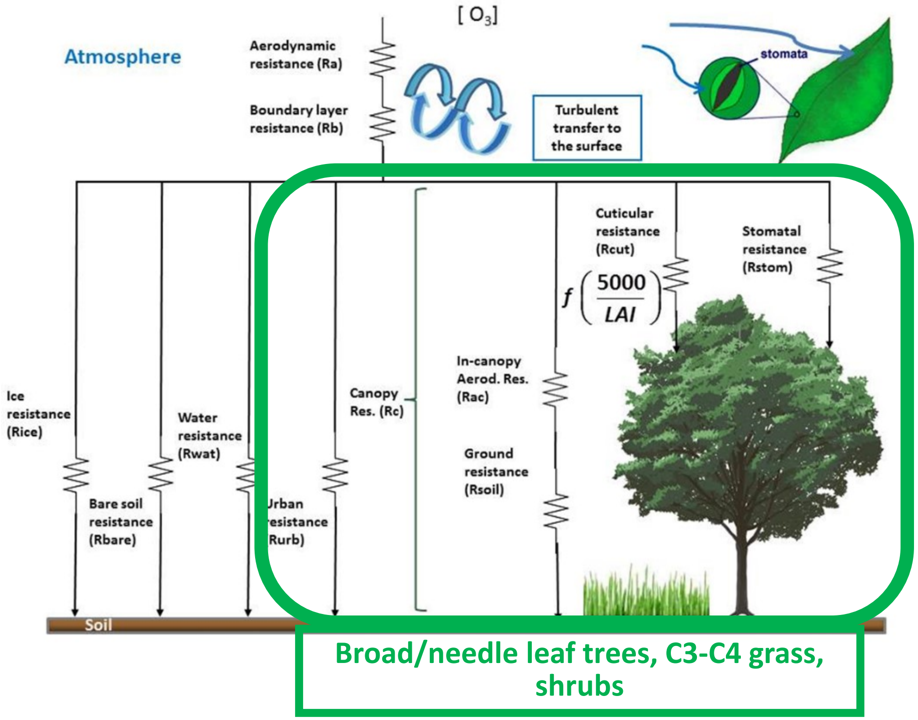
3. **Uptake** on surface by adsorption, followed by dissolution or reaction (depends on surface type: vegetation, soil, water, light, etc.)



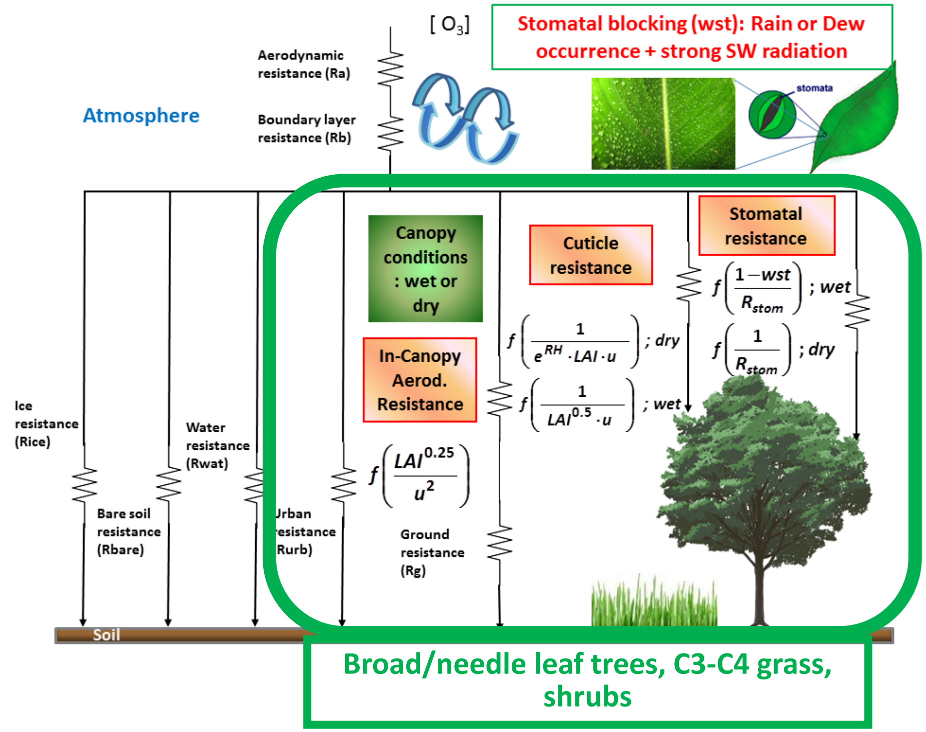
- Many atmospheric chemical transport models, including UK chemistry-climate and Earth System models, use a "Wesely-resistance" approach
- Atmospheric dry deposition currently in UKCA

Dry deposition schemes in the UKCA model

Current scheme in UKCA (UKESM)



HadGEM3 branch
F. Centoni (CEH & U. Edinburgh)



- 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

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

Dry Deposition in UKESM:

Future Requirements

- Consistency between UKCA (Gas and Aerosols) and JULES as more land surface types added
- Deposition to other surfaces, e.g., ocean and cryosphere
- Move towards more process-based dry deposition schemes, especially for aerosol species
- Shift towards 'bidirectional surface exchange' schemes: deposition, (re-)emission and PBL mixing

Designing a new framework for modelling dry deposition

- Community consultation and workshop held in 2016/2017
- Where should dry deposition 'live'? – JULES~~, UKCA or new interface module~~
- UKCA to provide surface concentrations with deposition fluxes returned
- In principle, UKCA will not need to know 'details' of surface

Status at last JULES annual meeting (September 2018)

➢ Code development

- JULES vn5.0 - Branch with atmospheric deposition: https://code.metoffice.gov.uk/trac/jules/browser/main/branches/dev/garryhayman/JULES_vn5.0_with_atmospheric_deposition
- Recoded UKCA gas-phase dry deposition routines (from UM vn10.9, October 2017)
- 12 new files added (existing and Zhang O_3 schemes as options) and 16 existing files edited

➢ Model runs and testing

- Runs with standalone JULES Atmospheric Deposition branch (vn 5.0) at single sites
- Created offline ‘test’ model to compare outputs from JULES and UKCA deposition routines driven with the same values of the calling variables (taken from the standalone JULES runs)
- Confirmed resistance and deposition velocity terms were the same within platform/compiler precision (except where differences expected)
- Identified ‘bug’ in existing UKCA surface resistance routine: parts of code hardwired to 5-pft configuration. Now corrected by Alan Hewitt: https://code.metoffice.gov.uk/trac/um/browser/main/branches/dev/alanjhewitt/vn11.1_fix_npft

Progress since September 2018

- Further code development
  - ✓ Flexible on pft configuration and order
  - ✓ Replaced lookup tables in code to assign surface resistance parameters to pft and species with parameter values passed via namelist, which will avoid code change if add/change pft
  - ✓ Code added to input surface tracer concentrations as prescribed data (dimensions: time, tracer=ndep_species, land)
  - ✓ Boundary-layer height variable defined in JULES (zh) but fixed at 1 km in standalone version (needed to convert deposition velocities to deposition fluxes). Now prescribed data.
  - ✓ # of boundary layer levels (bl_levels, set in deposition namelist) and separation of boundary layer levels (dzl, fixed values for code development). dzl now prescribed data.
  - ✓ JULES deposition metadata added

- Code into trunk for JULES vn5.5 release (Doug Clark)
  - Upgraded to JULES vn5.4 (March 2019): https://code.metoffice.gov.uk/trac/jules/browser/main/branches/dev/garryhayman/JULES_vn5.4_atmospheric_deposition
  - Branch with atmospheric deposition – set-up and I/O (ticket 662): https://code.metoffice.gov.uk/trac/jules/browser/main/branches/dev/douglasclark/r14931_vn5.4_dry_deposition

Deposition namelists: JULES vn5.5

JULES vn5.5: u-bk878

```
&jules_deposition
l_deposition=.false.
/
```

JULES vn5.5 – full namelist

```
&jules_deposition
dzl_const=20.0
dry_dep_model=1
l_deposition=.true.
l_deposition_flux=.true.
l_ukca_ddep_lev1=.true.
ndry_dep_species=6
tundra_s_limit=0.866
/
```

Parameter meaning:

- l_deposition is the master switch for atmospheric dry deposition in JULES
- dzl_const is a constant value for the separation of the boundary layer levels (in m)
- dry_dep_model = 1 (current implementation in UM-UKCA); = 2 (current UKCA implementation in JULES); = 3 (Zhang O_3 scheme)
- l_deposition_fluxes is a switch to use calculate deposition fluxes (requires surface species concentrations)
- l_ukca_ddep_lev1 is UKCA switch to calculate boundary-layer separation used in calculation of deposition velocities (true – use separation of bottom level, dzl(:,:,1); false – effectively use height of BL)
- ndry_dep_species is the number of deposited species. Needed to define size of new "species" dimension (in init_model_grid.inc, which is called before init_jules_deposition)
- tundra_s_limit is the sine of the latitude of the southern limit of the NH tundra

Deposition namelists: JULES vn5.5

JULES vn5.5 – full namelist

```
&jules_deposition_species
cuticle_o3_io=5000.0
dep_species_name_io='O3'
diffusion_coeff_io=X.X
diffusion_corr_io=1.6
rsurf_std_io=200.0,200.0,200.0,200.0,400.0,800.0,2200.0,800.0,2500.0
r_wet_soil_o3_io=500.0

&jules_deposition_species
dep_species_name_io='NO2'
diffusion_coeff_io=X.X
diffusion_corr_io=1.6
rsurf_std_io=225.0,225.0,400.0,400.0,600.0,1200.0,2600.0,1200.0,3500.0

[namelist:jules_depparm_species(4)]
dep_species_name_io='SO2'
diffusion_coeff_io=X.X
diffusion_corr_io=1.9
dd_ice_coeff_io=0.0001,0.003308,0.1637
rsurf_io=100.0,100.0,150.0,350.0,400.0,400.0,10.0,700.0,1.00E+30

&jules_deposition_species
ch4_scaling_io=15.0
ch4_up_flux_io=39.5,50.0,30.0,37.0,27.5,0.0,0.0,27.5,0.0
ch4dd_tundra_io=-4.757e-6,4.0288e-3,-1.13592,106.636
dep_species_name_io='CH4'
diffusion_coeff_io=X.X
rsurf_std_io=9*1.00E+30

&jules_deposition_species
dep_species_name_io='H2'
diffusion_coeff_io=X.X
h2dd_c_io=19.70,19.70,17.70,1.235,1.0,0.0,0.0,17.70,0.0
h2dd_m_io=-41.90,-41.90,-41.39,-0.472,0.0,0.0,0.0,-41.39,0.0
h2dd_q_io=0.0,0.0,0.0,0.27,5*0.0
rsurf_std_io=1.00E+30,1.00E+30,4550.0,6*1.00E+30
```

Notes

- Duplicate namelists, one for each tracer
- diffusion_coeff_io – diffusion coefficient for R_b (quasi-laminar resistance), currently calculated in code
- diffusion_corr_io – diffusion correction to stomatal conductance (for O_3, SO_2, NO_2, PAN and NH_3)
- dep_species_name – name of atmospheric tracer.
- rsurf_std_io(ntype) – specifies the standard surface resistance R_c (dimension ntype), which may get modified.
- cuticle_o3_io, h2dd_c_io(ntype), ch4_up_flux_io(ntype) – species-specific terms (e.g., for O_3, H_2 and CH_4)

Evaluation

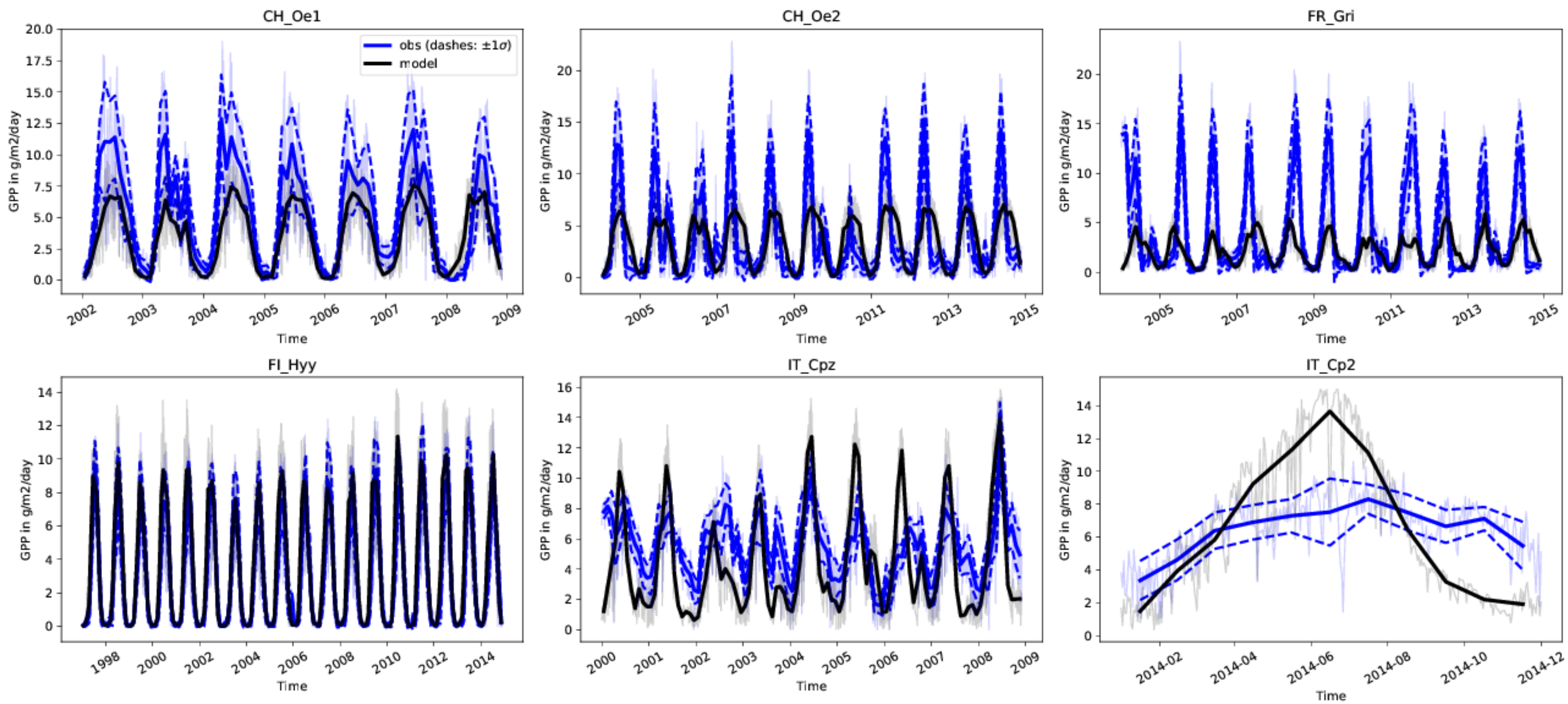
- Adapted JULES FLUXNET suite (u-al752) to use JULES Deposition Branch: u-bc577 (vn5.0) and u-bh191 (vn 5.4)
- Sourcing and collating driving meteorological, ancillary and deposition-related measurements for model evaluation

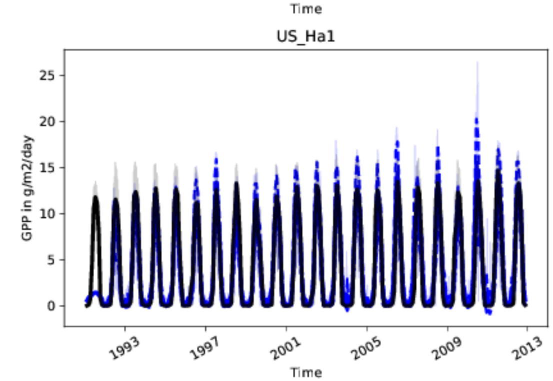
Site	Site biome	Data Availability			Part of JULES FLUXNET Suite
		Met.	Ancillary	Deposition	
Harvard Forest (US)	Deciduous broad-leaf forest	Y	Y	Not Yet	Y
Blodgett Forest (US)	Evergreen needle-leaf forest	Y	Y	Not Yet	Y
Hyytiälä (FI)	Evergreen needle-leaf forest	Y	Y	Y: O_3	Y
Castel Porziano (IT)	Evergreen broad-leaf forest	Y	Y	Y: O_3	Y
Grignon (FR)	Crop	Y	Y	Y: O_3	Y
Oensingen (CH)	Grassland	Y	Y	Y: O_3	Y
Alice Holt (UK)	Broadleaf woodland				
Auchencorth Moss (UK)	Ombrotrophic peatland	Y	Y	Y	
Easter Bush (UK)	Improved grassland	Y	Y	Y	

Assistance of Karina Williams, Eddy Comyn-Platt and Carolina Duran Rojas gratefully acknowledged

FLUXNET output …

FLUXNET suite output: Gross primary productivity





Also, plots of:

- sensible and latent heat fluxes
- soil moisture
- stomatal conductance
- net ecosystem exchange
- ecosystem respiration

Preliminary dry deposition comparison …

FLUXNET suite output:

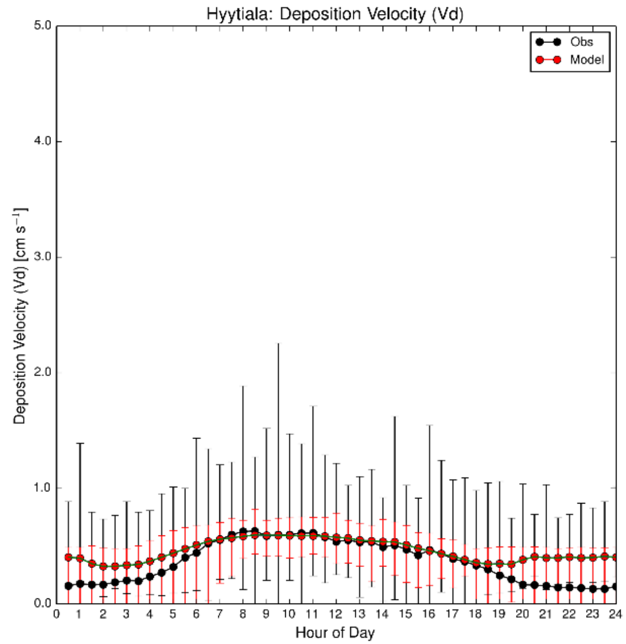
Vegetated surfaces:

$V_d = 1/R_a + 2/R_b + 1/R_c$

Non-vegetated surfaces:

$V_d = 1/R_a + 1/R_b + 1/R_c$

$1/R_c = 1/R_{c\ stomatal} + 1/R_{c\ non\text{-}stomatal}$

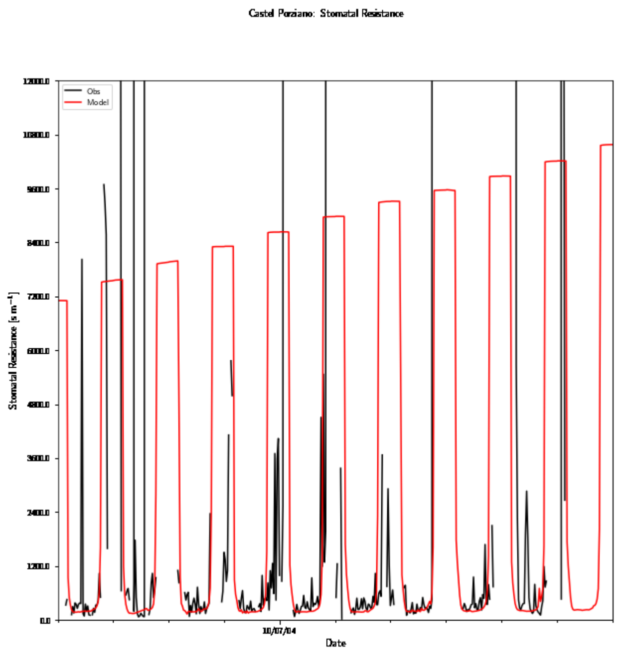


Hyytiälä (Finland)

- Evergreen needle-leaf forest

- O_3 deposition velocity
- Mean (min, max) diurnal cycle, June-August 2003

- Further investigation in progress to understand night-time differences



Castel Porziano (Italy)

- Broad-leaf forest

- O_3 stomatal resistance
- Time-series, July 2004

Relevant related activities

- JULES
  - Eleanor Blyth, Emma Robinson & Sebastian Garrigues: Review of aerodynamic resistance (R_a) schemes
  - Martin Best & Graham Weedon: Revise roughness lengths (which affect friction velocity), following evaluation of JULES friction velocity against FLUXNET observations of momentum flux. Relevant to aerodynamic resistance
- UKESM
  - Becky Oliver & Lina Mercado: Implementation and testing of new photosynthesis scheme, based on Medlyn et al.. Relevant to stomatal conductance
- US Ozone Deposition
  - Presentation at workshop (2017)
  - *Paper on Ozone Deposition*

Current & Future Plans

- Comparison versus observations and other model outputs
  - Site-specific evaluation using modified JULES FLUXNET suites
  - Standalone gridded runs at UK and global scale

- Code development – JULES standalone
  - Add new CEH science from EMEP model (with CEH Edinburgh)
  - Add further deposition code to JULES trunk (with Doug Clark)
  - *Add current UKCA aerosol code – discuss with dry deposition advisory group*

- Code development – coupled to UM
  - Get JULES-UKCA version working for UKESM
  - *Add Ashok Luhar's O_3 deposition scheme to oceans*

Deposition namelists: Development

JULES vn5.4 with atmospheric deposition

```
&jules_deposition
bl_levels=38
dry_dep_model=2
l_deposition=.true.
l_deposition_flux=.true.
l_deposition_print=.true.
l_ukca_ddep_lev1=.true.
ndep_species=6
/
```

Notes

- l_deposition is the master switch for atmospheric dry deposition in JULES
- bl_levels is number of BL levels
- dry_dep_model = 1 (current implementation in UM-UKCA); = 2 (current UKCA implementation in JULES); = 3 (Zhang O_3 scheme)
- l_deposition_fluxes is a switch to use calculate deposition fluxes (requires surface species concentrations)
- l_deposition_print is a temporary switch to output parameter values
- l_ukca_ddep_lev1 is UKCA switch to calculate boundary-layer separation used in calculation of deposition velocities (true – use separation of bottom level, dzl(:,:,1); false – effectively use height of BL)
- ndry_dep_species is the number of deposited species. Needed to define size of new “species” dimension (in init_model_grid.inc, which is called before init_jules_deposition)

Deposition namelists: Development

```
[namelist:jules_depparm_species(1)]
cuticle_o3=5000.0
dep_species_name_io='O3'
!!rcutd0_zhang_io=6000.0,4000.0,4000.0,4000.0,5000.0,6000.0,0.0,0.0,0.0
!!rcutw0_zhang_io=400.0,200.0,200.0,200.0,300.0,400.0,0.0,0.0,0.0
rsurf_io=200.0,200.0,200.0,200.0,400.0,800.0,2200.0,800.0,2500.0
r_wet_o3=500.0

[namelist:jules_depparm_species(2)]
ch4_mml=1.008e5
ch4_tar_scaling=15.0
ch4_up_flux_io=39.5,50.0,30.0,37.0,27.5,0.0,0.0,27.5,0.0
ch4dd_tun=-4.757e-6,4.0288e-3,-1.13592,106.636
dep_species_name_io='CH4'
!!rcutd0_zhang_io=9*1.00E+30
!!rcutw0_zhang_io=9*1.00E+30
rsurf_io=9*1.00E+30

[namelist:jules_depparm_species(3)]
dep_species_name_io='NO2'
!!rcutd0_zhang_io=9*1.00E+30
!!rcutw0_zhang_io=9*1.00E+30
rsurf_io=225.0,225.0,400.0,400.0,600.0,1200.0,2600.0,1200.0,3500.0

[namelist:jules_depparm_species(4)]
dep_species_name_io='SO2'
!!rcutd0_zhang_io=9*1.00E+30
!!rcutw0_zhang_io=9*1.00E+30
rsurf_io=100.0,100.0,150.0,350.0,400.0,400.0,10.0,700.0,1.00E+30
so2dd_ice=0.0001,0.003308,0.1637

[namelist:jules_depparm_species(5)]
dep_species_name_io='CO'
!!rcutd0_zhang_io=9*1.00E+30
!!rcutw0_zhang_io=9*1.00E+30
rsurf_io=3700.0,7300.0,4550.0,1960.0,4550.0,1.00E+30,1.00E+30,
        =1.00E+30,1.00E+30

[namelist:jules_depparm_species(6)]
dep_species_name_io='H2'
h2dd_c_io=19.70,19.70,17.70,1.235,1.0,0.0,0.0,17.70,0.0
h2dd_m_io=-41.90,-41.90,-41.39,-0.472,0.0,0.0,0.0,-41.39,0.0
h2dd_q_io=0.0,0.0,0.0,0.27,5*0.0
!!rcutd0_zhang_io=9*1.00E+30
!!rcutw0_zhang_io=9*1.00E+30
rsurf_io=1.00E+30,1.00E+30,4550.0,6*1.00E+30
```

<u>Notes</u>

- rsurf_io – specifies the surface resistance (dimension ntype)
- rcutd0_zhang_io & rcutw0_zhang_io – surface resistance parameters (dimension npft) relevant to Zhang deposition scheme. Commented out as not used with dep_model = 2
- Species-specific terms (e.g., for H_2 and CH_4)
- Updated JULES branch and rose suites u-ax608 and u-ax609 (on JASMIN)