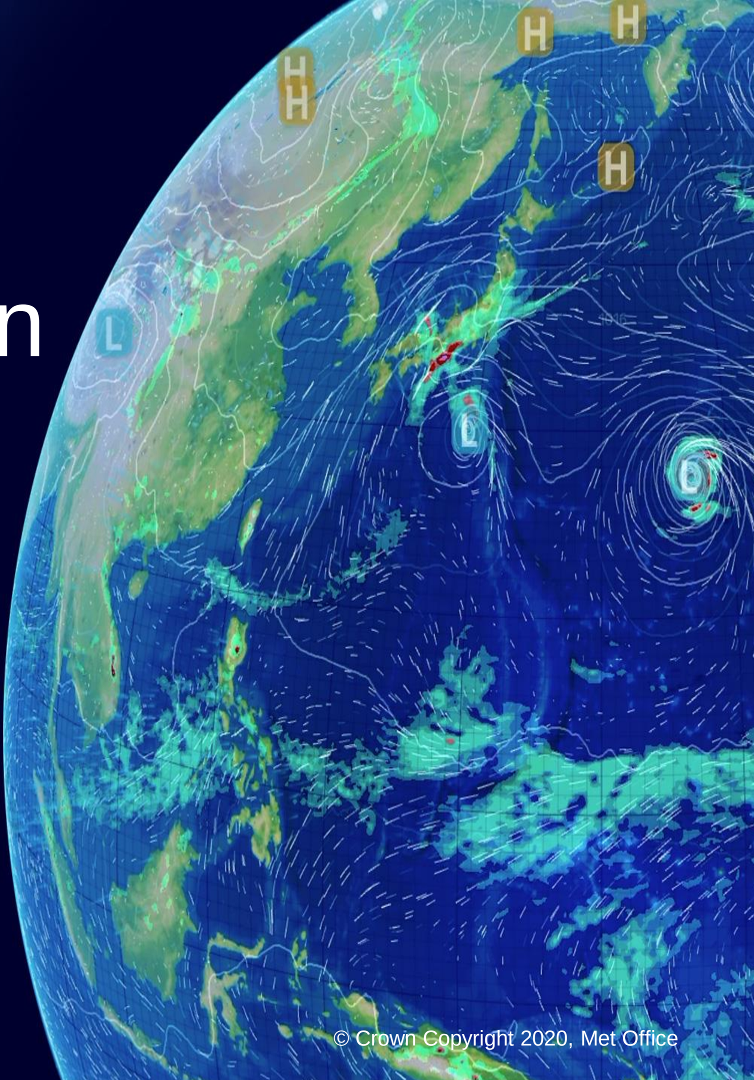
Met Office

Modelling dry deposition in an operational Lagrangian model

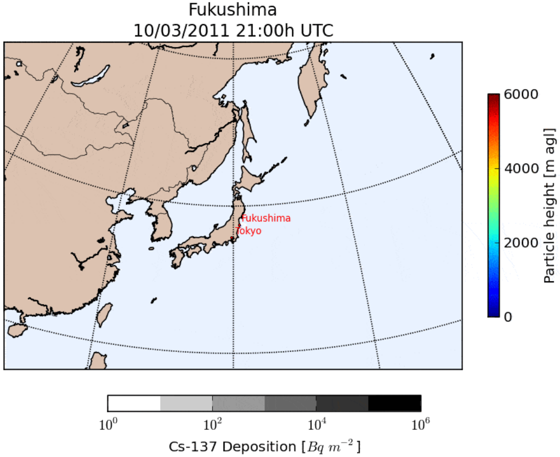
Helen Webster



Met Office

Predicts the atmospheric transport **and deposition to the ground surface** of airborne substances

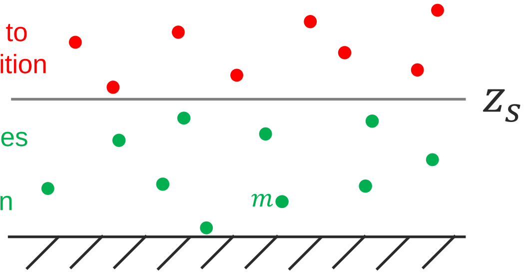
- Offline Lagrangian model
  - Eulerian sub-model
- Used operationally
- Developed following 1986 Chernobyl accident
  - Now has a wide range of atmospheric dispersion applications
    - Gases & particles… and even insects



Dry deposition parameterisation

- Uses the concept of a deposition velocity v_d
- Flux of material to ground is proportional to concentration
  - $F = v_d C$
- Dry deposition
  - $\Delta m = m\left[1 - \exp\left(-\frac{v_d}{z_s} f \Delta t\right)\right]$
    - $0 \leq f \leq 1$, fraction of timestep $z \leq z_s$

- All Lagrangian particles below the deposition height z_s dry deposit
  - Default z_s - boundary layer height



Does not contribute to dry deposition

Contributes to dry deposition

Deposition velocities

Increasing complexity

User specified

- Simple
- v_d fixed
- Specie dependent
- Based on literature reported deposition values

Resistance analogy

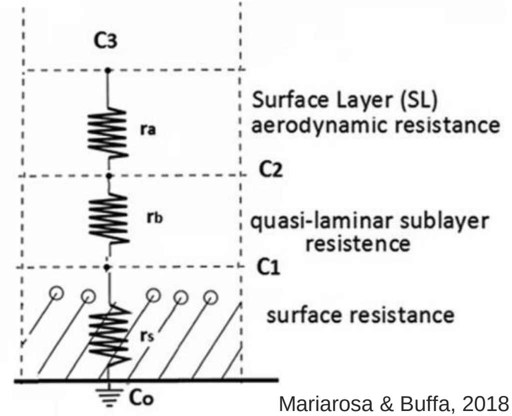
- $v_d = \frac{1}{R_a + R_b + R_c}$
- Meteorological dependency
- Fixed specie-dependent surface resistance

Land use dependent scheme

- Resistance analogy
- Varying surface resistance dependent on land-surface
- Selected species

Resistance analogy

- Aerodynamic resistance depends on stability and roughness length



Mariarosa & Buffa, 2018

$$R_a = \frac{1}{ku_*}\left[\ln\left(\frac{z_r + z_0}{z_0}\right) - \Phi\right],$$

where

$$\Phi = \begin{cases} 2\ln\left(\frac{1+\left(1-16\left(\frac{z_r+z_0}{L}\right)\right)^{1/2}}{1+\left(1-16\frac{z_0}{L}\right)^{1/2}}\right), & \text{unstable,} \\ -5\frac{z_r}{L}, & \text{stable } \frac{z_r+z_0}{L} < 1, \\ -\frac{5}{L}(L-z_0) - 5\ln\left(\frac{z_r+z_0}{L}\right), & \text{stable } \frac{z_0}{L} < 1 \leq \frac{z_r+z_0}{L}, \\ -5\ln\left(\frac{z_r+z_0}{z_0}\right), & \text{stable } \frac{z_0}{L} \geq 1. \end{cases}$$

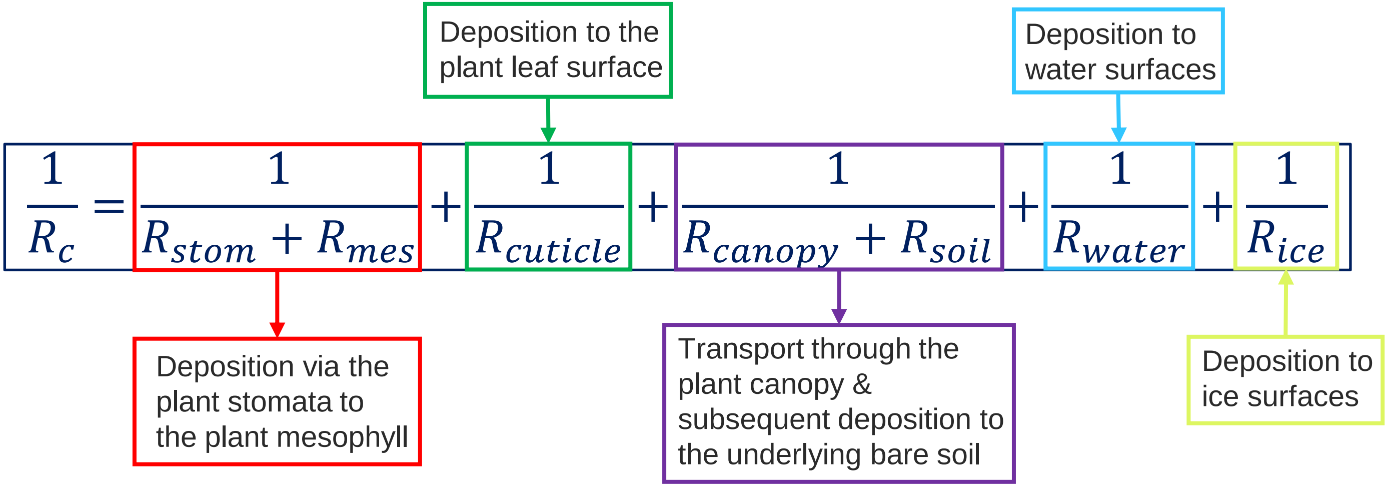
$$v_d = \frac{1}{R_a + R_b + R_c}$$

- Laminar resistance depends on friction velocity
  - $R_b = \frac{1}{8u_*}$

Meteorological dependency

Land-use dependent scheme

- Uptake at the ground is strongly dependent on the land-surface type & properties



$$\frac{1}{R_c} = \boxed{\frac{1}{R_{stom} + R_{mes}}} + \boxed{\frac{1}{R_{cuticle}}} + \boxed{\frac{1}{R_{canopy} + R_{soil}}} + \boxed{\frac{1}{R_{water}}} + \boxed{\frac{1}{R_{ice}}}$$

Deposition to the plant leaf surface

Deposition to water surfaces

Deposition via the plant stomata to the plant mesophyll

Transport through the plant canopy & subsequent deposition to the underlying bare soil

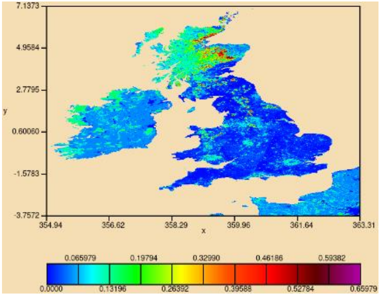
Deposition to ice surfaces

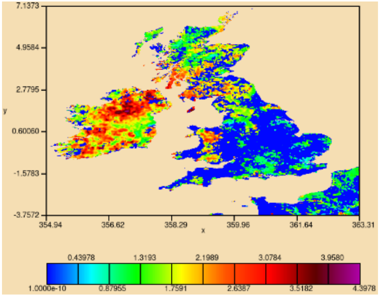
STOCHEM parameterisations

ozone, nitric oxide, nitrogen dioxide, nitric acid, PAN, hydrogen peroxide, methane, carbon monoxide, hydrogen, formaldehyde, sulphur dioxide, ammonia

- Requires additional surface and plant information
  - e.g., stomatal conductance, leaf area index
    - Ancillaries: fixed (e.g., land use) or monthly (e.g., LAI)
    - NWP data: varying with time (e.g., stomatal conductance)

Shrubs





LAI

STOCHEM parameterisations

ozone, nitric oxide, nitrogen dioxide, nitric acid, PAN, hydrogen peroxide, methane, carbon monoxide, hydrogen, formaldehyde, sulphur dioxide, ammonia

- Deposition to vegetation occurs mainly via the stomata
- Mesophyllic resistance is **not** negligible

$$\frac{1}{R_c} = \frac{1}{R_{stom} + R_{mes}} + \frac{1}{R_s} = \frac{g_c}{2.4} + \frac{1}{R_s}$$

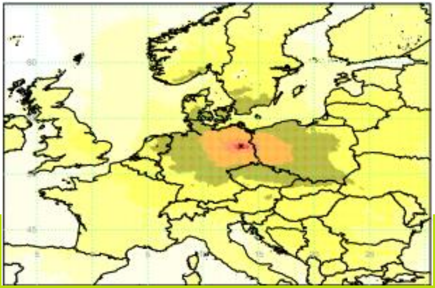
g_c - Stomatal conductance

R_s

Land-surface index	Land-surface type	Standard surface resistance (s m^{-1})
1	Broadleaf trees	225
2	Needleleaf trees	225
3	C3 (temperate) grass	400
4	C4 (tropical) grass	400
5	Shrubs	600 (steppe), 1200 (tundra)
6	Urban	1200
7	Inland water	2600
8	Bare soil	1200 (steppe and tundra)
9	Land-ice	3500

Table 3: Standard surface resistances for nitrogen dioxide

land-sea effect: less deposition over water than over land



STOCHEM parameterisations

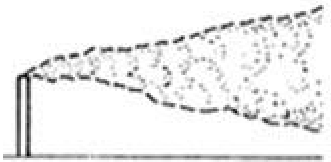
ozone, nitric oxide, nitrogen dioxide, nitric acid, PAN, hydrogen peroxide, methane, carbon monoxide, hydrogen, formaldehyde, sulphur dioxide, ammonia

- Deposits to vegetation via the stomata and the cuticle
- The dry deposition rate depends on the wetness of the leaf surface
- The cuticular resistance parameterisation has a dependence on surface temperature (T_s) and canopy water (cw)

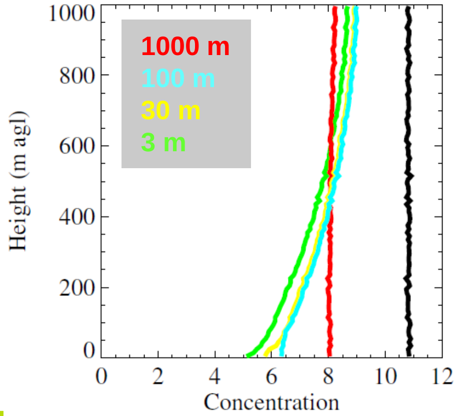
$$\boxed{\frac{1}{R_c} = \frac{1}{R_{stom}} + \frac{1}{R_{cuticle}} + \frac{1}{R_s} = \frac{g_c}{0.97} + \frac{1}{R_{cuticle}} + \frac{1}{10}}$$

$$R_{cuticle} = \begin{cases} 1000.0, & T_s < 268\text{ K} \\ 200.0, & 268\text{ K} \le T_s \le 272\text{ K} \\ 10.0, & T_s > 272\text{ K} \;\&\; cw > 0.25\text{ mm} \\ 5.0 \log\left[T_s - 271.15\right] \exp\left[\dfrac{100.0 - rh}{12.0}\right], & T_s > 272\text{ K} \;\&\; cw \le 0.25\text{ mm} \end{cases}$$

Near-source modelling

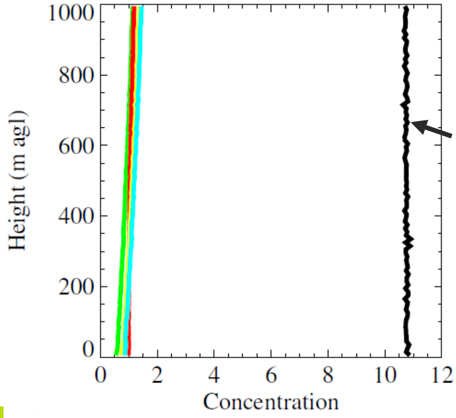


- Material is not well mixed within the boundary layer
- User option to specify a lower deposition height z_s
  - Noisy deposition fields (fewer Lagrangian particles)
  - Increased run-time (more Lagrangian particles required)



(a) 6 hours

Well mixed

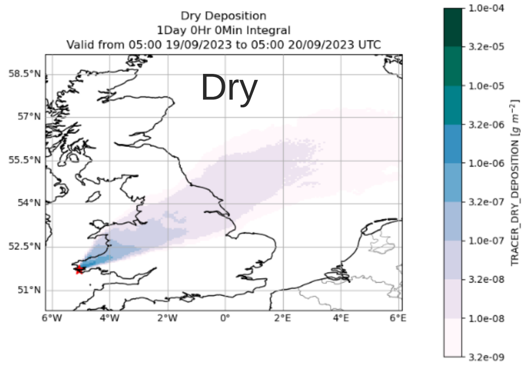


(b) 36 hours

Initial profile / non-depositing specie

Model validation of dry deposition

- Difficult
- Lack of deposition observations
  - Often long-term measurements
  - Total deposition (including wet)
    - For soluble species, wet deposition often dominates
- Often validated indirectly via air concentrations
  - Uncertainties in emissions, transport, dispersion, chemistry, wet deposition, etc.
  - Tracer experiments: Kincaid, ETEX, CAPTEX / ANATEX
  - Events: air quality, fires, volcanic eruptions, radiological incidents, etc.


Dry Deposition
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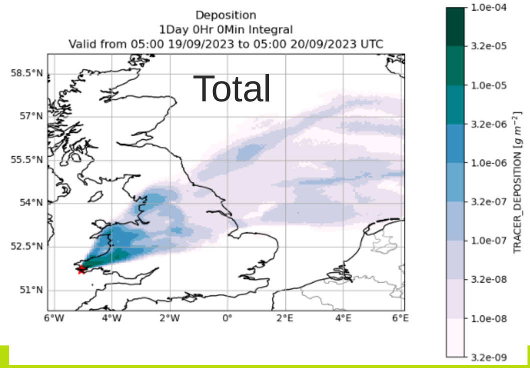
Valid from 05:00 19/09/2023 to 05:00 20/09/2023 UTC


Deposition
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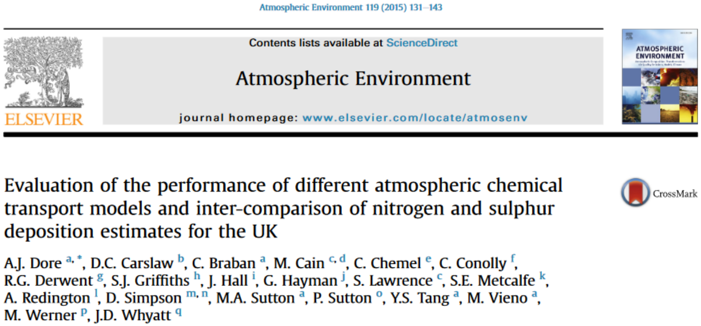
Validation



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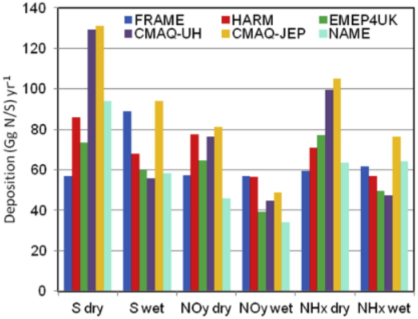
ELSEVIER

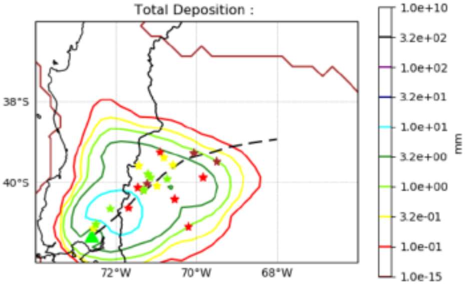
Evaluation of the performance of different atmospheric chemical transport models and inter-comparison of nitrogen and sulphur deposition estimates for the UK

CrossMark

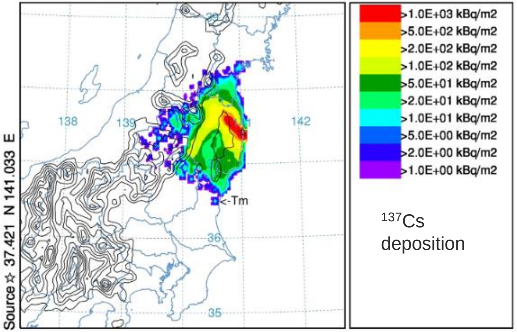
A.J. Dore [a,*], D.C. Carslaw [b], C. Braban [a], M. Cain [c,d], C. Chemel [e], C. Conolly [f], R.G. Derwent [g], S.J. Griffiths [h], J. Hall [i], G. Hayman [j], S. Lawrence [c], S.E. Metcalfe [k], A. Redington [l], D. Simpson [m,n], M.A. Sutton [a], P. Sutton [o], Y.S. Tang [a], M. Vieno [a], M. Werner [p], J.D. Whyatt [q]



2015 Calbuco eruption

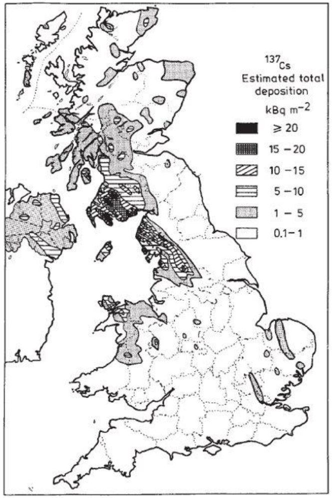


Fukushima



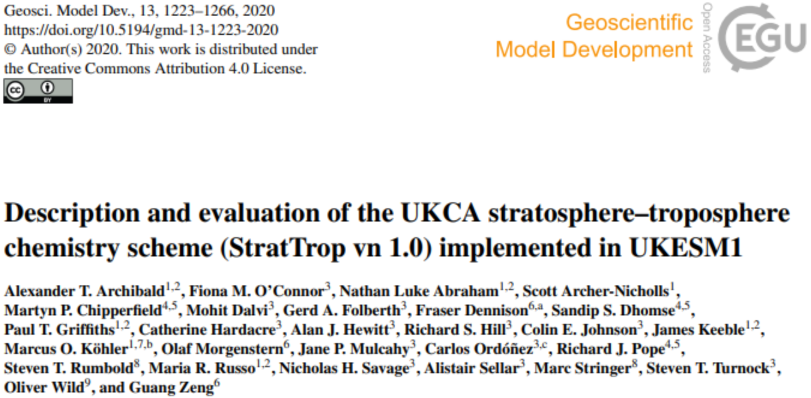
^{137}Cs deposition

Chernobyl



Clark & Smith, 1988

Future work - UKCA



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https://doi.org/10.5194/gmd-13-1223-2020

Geoscientific
Model Development
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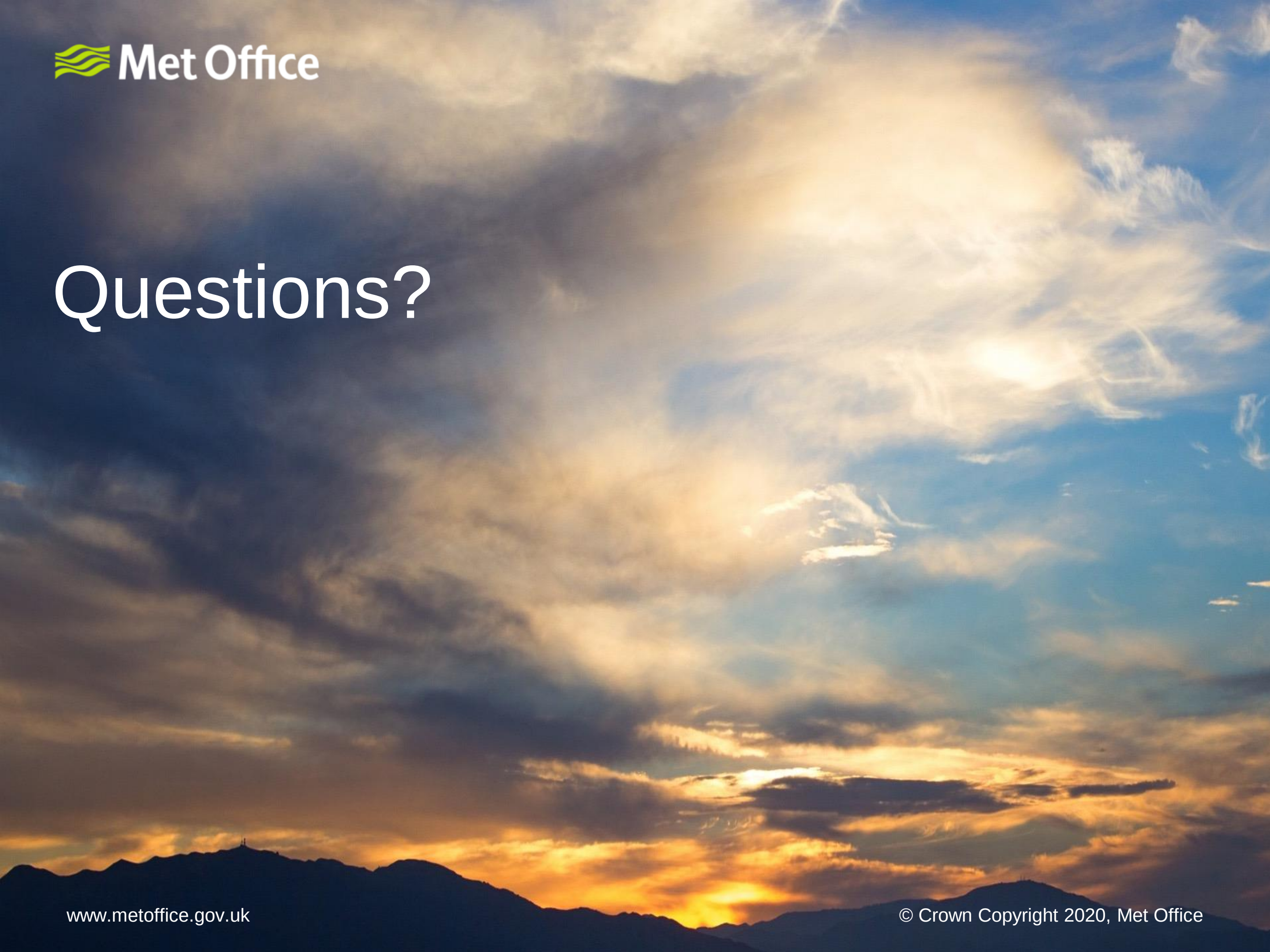
Description and evaluation of the UKCA stratosphere–troposphere chemistry scheme (StratTrop vn 1.0) implemented in UKESM1

Alexander T. Archibald[1,2], Fiona M. O'Connor[3], Nathan Luke Abraham[1,2], Scott Archer-Nicholls[1], Martyn P. Chipperfield[4,5], Mohit Dalvi[3], Gerd A. Folberth[3], Fraser Dennison[6,a], Sandip S. Dhomse[4,5], Paul T. Griffiths[1,2], Catherine Hardacre[3], Alan J. Hewitt[3], Richard S. Hill[3], Colin E. Johnson[3], James Keeble[1,2], Marcus O. Köhler[1,7,b], Olaf Morgenstern[6], Jane P. Mulcahy[3], Carlos Ordóñez[3,c], Richard J. Pope[4,5], Steven T. Rumbold[8], Maria R. Russo[1,2], Nicholas H. Savage[3], Alistair Sellar[3], Marc Stringer[8], Steven T. Turnock[3], Oliver Wild[9], and Guang Zeng[6]

- Implementation of UKCA chemistry scheme into NAME
    - Includes dry deposition scheme
        - Uses resistance analogy
        - Similar to land-use dependent scheme
            - Widely used
            - Frequent updates (e.g., recently SO_2, O_3)



Questions?