Wet Deposition in UKCA (UM 8.4)

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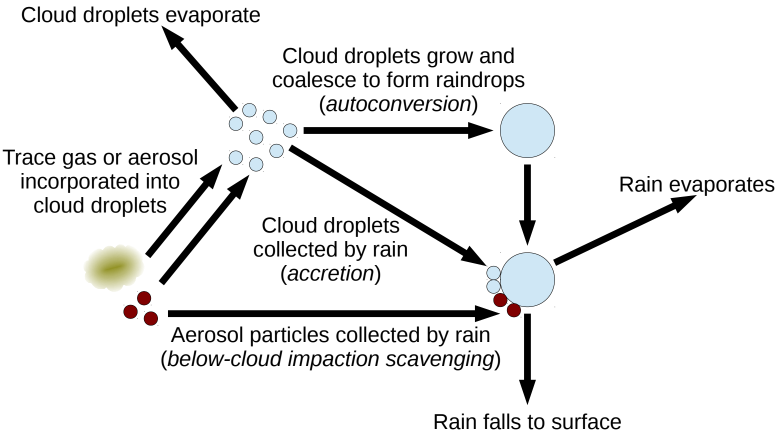
Outline

Introduction

- Wet deposition, by which trace gases and aerosols are removed from the atmosphere by precipitation and deposited at the surface, is one of the major sink processes for soluble compounds in the atmosphere.

- It dominates over dry deposition for soluble trace gases and for all but the coarsest sea-salt and dust aerosols.

Overview


Cloud droplets evaporate
Cloud droplets grow and coalesce to form raindrops (*autoconversion*)
Trace gas or aerosol incorporated into cloud droplets
Rain evaporates
Cloud droplets collected by rain (*accretion*)
Aerosol particles collected by rain (*below-cloud impaction scavenging*)
Rain falls to surface

Wet deposition of gas-phase chemicals

- Equilibrium between gas phase and solute in cloud droplets (Henry's law).
- Removal of solute represented as a first-order loss rate proportional to rain rate and fed into solver.
- Formulation based on Giannakopoulos et al. (1999).

Henry's law

- Concentration of dissolved gas is proportional to its partial pressure (with a temperature-dependent coefficient).

$$H_{\text{eff}} = \underbrace{k_{298\text{ K}}}_{\text{Coefficient at 298 K}} e^{-\overbrace{\frac{\Delta H}{R}}^{\text{Temperature dependence parameter}}\left(\frac{1}{T} - \frac{1}{298\text{ K}}\right)} \tag{1}$$

- Multiplied by a factor $1 + k_{\text{aq}}/H^+$ to account for dissociation in the aqueous phase, where k_{aq} has a similar temperature-dependent form.
- Applying Henry's law gives the fraction of a trace gas which is dissolved in cloud water.

Linkage to cloud and precip. variables

- Removal rate of the dissolved trace gas is proportional to the diagnosed rain rate on each level, via an emiprical scavenging coefficient.
- Coarse temperature-based limits on scavenging in polar regions (no scavenging by ice or snow).
- No account is taken of the fractional removal rate of cloud liquid water or the cloud and rain fractions.
- Convective scavenging is carried out seperately from convective transport, and thus acts on the post-convection environment rather than the rising plume.

Implementation

- Implemented in `UKCA_WDEPRT`.
- Configuration in `UKCA_CHEM_`<*scheme*> (e.g. `UKCA_CHEM_STRATTROP`)
- Hand-edit to set total number of species subject to wet deposition (`JPDW`).

Configuration: selecting species

In `UKCA_CHEM_<scheme>` (e.g. `UKCA_CHEM_STRATTROP`):

- Count of species subject to wet deposition, e.g.:

```
INTEGER, PARAMETER, PUBLIC :: nwet_st_aer = 34
```

- Switch to enable wet deposition for a given species, e.g.:

```
TYPE(CHCH_T), PUBLIC :: chch_defs_strattrop_aer(1:87)=(/ &
...
chch_t(3,'O3   ', 1,'TR   ','Ox   ', 1, 1, 0),          &
chch_t(4,'N    ', 1,'TR   ','NOx  ', 0, 0, 0),          &
...
  /)
```

Configuration: Henry's law coefficients

- Henry's law coefficients, e.g.:

```
REAL :: henry_defs_strattrop_aer(1:6,1:nwet_st_aer)=RESHAPE((/
!    1  O3
 0.1130E-01, 0.2300E+04,  0.0000E+00, 0.0000E+00,  0.0000E+00, 0.0000E+00,&
...
!   12  HCl
 0.1900E+02, 0.6000E+03,  0.1000E+05, 0.0000E+00,  0.0000E+00, 0.0000E+00,&
...
!    6  H2O2
 0.8300E+05, 0.7400E+04,  0.2400E-11,-0.3730E+04,  0.0000E+00, 0.0000E+00,&
...
!   31  SO2
 0.1230E+01, 0.3020E+04,  0.1230E-01, 0.2010E+04,  0.6000E-07, 0.1120E+04,&
...
  /)
!   k_298       -DH/R        k_298       -DH/R        k_298       -DH/R
! Main values for H_eff      Values for k_aq          Values for k_aq
!                           (1st dissociation)       (2nd dissociation)
```

Hand-edit

- Unfortunately, the count of species subject to wet deposition is also included in a namelist, as well as directly in the source code, and these values must be kept in sync.
- If the value in the source code is changed, the one in the namelist can be updated via a hand-edit:

set_jpdw_<*NN*>.ed

```
ed CNTLATM <<\EOF
/JPDW/c
 JPDW = <NN>,
.
wq
EOF
```

Wet deposition of aerosol particles

Aerosol particles can be removed by precipitation in three ways:

nucleation scavenging
: where aerosol particles act as cloud condensation nuclei (CCN) for droplets which then form rain;

in-cloud impaction scavenging
: where aerosol particles are collected by impaction with cloud droplets which then form rain (not included in the model);

below-cloud impaction scavenging
: where aerosol particles are collected by impaction with falling precipitation.

Nucleation scavenging

- Aerosol particles are incorporated into cloud droplets when they act as CCN (*activation*).

- The scavenging schemes use a simplified approach, rather than using the diagnostics from the activation scheme.

Nucleation scavenging (large-scale): activation

- Based on Spracklen et al. (2005), soluble particles larger than a fixed critical wet radius are assumed to act as CCN. This radius is set in `UKCA_SCAVENGING_MOD`:

```
! radius cutoff for activation
REAL, PARAMETER :: nscavact = 103.0e-9
```

- All of the coarse mode, none of the nucleation mode, and the upper end of the Atiken and accumulation modes.
- This gives the fraction of number and mass in each mode (in the cloudy fraction of the grid box) which are dissolved and thus susceptible to wet deposition.
- There is an alternative option in the UMUI to use the fixed scavenging ratios from ECHAM5–HAM (Stier et al., 2005).

Nucleation scavenging (large-scale): removal

- These are then removed at the same fractional rate as the cloud water itself is removed as precipitation, based on diagnostics from the large-scale precip. scheme (UMDP 26).
- Removal of cloud water is the sum of autoconversion (PRAUT), accretion by rain (PRACW) and riming by ice/snow (PIACW/PSACW).
- These are added together in `UKCA_AERO_CTL` before being passed to the scavenging routine (`UKCA_RAINOUT`).

Nucleation scavenging (large-scale): caveats

- No more than 90% by number of a given mode may be removed in a timestep.
- For very low liquid water contents, a fixed removal timescale is applied instead.
- Below 258 K, all particles in the insoluble modes are also susceptible to wet deposition (but by rain only – there is no actual treatment of ice nucleation scavenging yet).

Nucleation scavenging (convective): outline

- Based on Kipling et al. (2013), this operates from within the convection scheme (UMDP 27), removing aerosol as the tracers are transported within the convective updraught.
- All of the soluble accumulation and coarse modes, none of the nucleation mode and a configurable fraction (default 50%) of the soluble Aitken mode considered to be dissolved.
- This aerosol is removed at the same fractional rate as condensate is converted to precipitation within the convective plume.

Nuc. scavenging (convective): implementation

- Implemented as `UKCA_PLUME_SCAV` in UKCA_SCAVENGING_MOD.
- Called from `CONVEC2` at each level within the body of the convection scheme, using in-plume variables, rather than from anywhere within `UKCA_MAIN1` (which sees only the end-of-timestep environment).
- Usual UKCA/GLOMAP-mode variables therefore not available, and logic is required to identify the number and mass tracers from the combined UM tracers array.

Nuc. scavenging (convective): implementation (2)

- UKCA_SCAV_INIT sets up the mappings required to identify the tracers, and is called from UKCA_INIT.
- UKCA_CALC_AQUEOUS calculates the fraction of each tracer which is susceptible to wet deposition.
- UKCA_PLUME_SCAV calls this and calculates the rate at which each tracer is removed from the plume at this level.
- Note that diagnostics for convective removal rates are currently missing.

Below-cloud impaction scavenging: rain

- This follows Slinn (1984), based on a 2D look-up table of scavenging efficiencies for different aerosol and raindrop sizes.
- Aerosol modes are treated as monodisperse at their geometric-mean wet radius.
- Raindrops are divided into 7 bins assuming a Marshll–Palmer distribution.

Below-cloud impaction scavenging: snow

- This is implemented as a power law for each mode following Wang et al. (2011), where the fraction removed from each mode m is:

$$k_m = \overbrace{a_m}^{\text{prescribed coefficient and exponent for each mode}} \underbrace{P}_{\text{total (LS+conv.) snowfall rate}}{}^{\overbrace{b_m}}$$

Below-cloud impaction scavenging: implementation

- Code for both rain and snow is in `UKCA_IMPC_SCAV`.
- Look-up table for rain is in `UKCA_MODE_SETUP`.
- Large-scale and convective precip. are handled similarly, except that they are assumed to apply over 100% and 30% of the grid-box respectively (the large-scale rain fraction diagnostic is not used).

A final note on branches

- A number of the features described were not yet in the UM trunk at 8.4, although they are in the `vn8.4_UKCA` package branch.
- The description in the 8.4 version of UMDP 84 describes the trunk rather than the branch, so you may be better referring to the 9.2 version in this instance.

References

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