Met Office

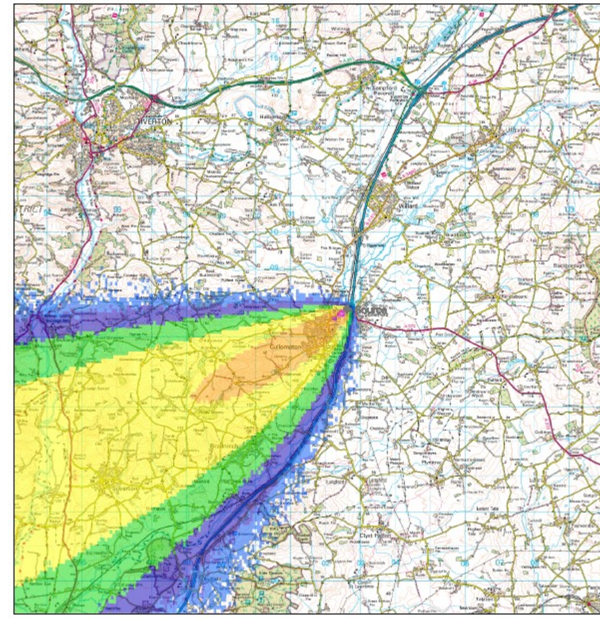
Dry deposition modelling in a Lagrangian dispersion model

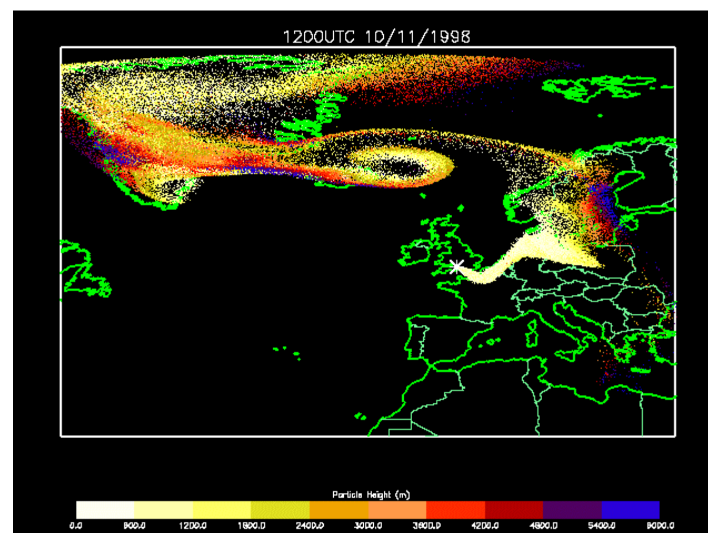
HARMO12, Croatia, October 2008

Helen Webster

Lagrangian dispersion model

- NAME (Numerical Atmospheric-dispersion Modelling Environment)
  - Uses NWP 3-d flow fields or single site observations
  - Loss processes: radioactive decay, wet & dry deposition, chemical transformations
  - Wide range of applications
    - Emergency response: chemical, biological and nuclear
    - Air quality: forecasts and episode analysis
    - Disease spread (foot and mouth; bluetongue)
    - Identifying source locations and strengths
    - Volcanic ash
    - Dust forecasts
    - Policy support





Dry Deposition modelling

Met Office

- Applied on a particle basis
- Uses the concept of a deposition velocity (v_d)
- Deposition flux ∝ concentration
- All particles within the boundary layer subject to dry deposition
  - Common modelling technique in Lagrangian models
  - Appropriate if pollutant well mixed within boundary layer
  - Relatively smooth deposition fields

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

$$\Delta m = m\left[1 - \exp\left(-\frac{v_d}{h}\Delta t\right)\right]$$

Δm = change in mass
m = mass
h = boundary layer depth
Δt = model time-step

Issues

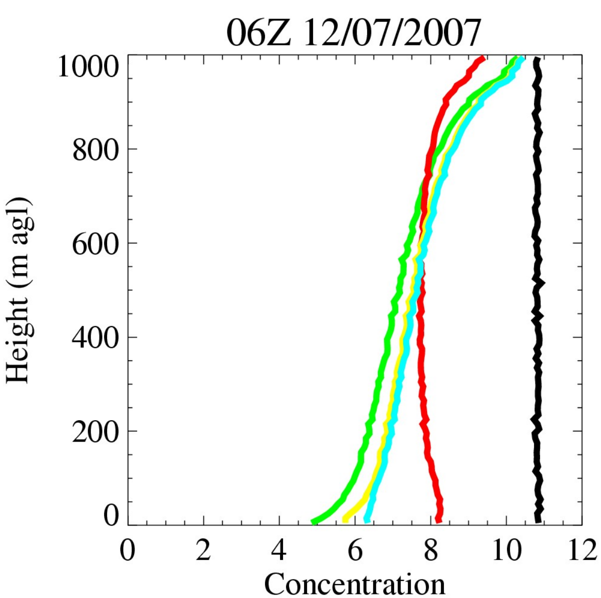
- Pollutant not well mixed
  - e.g. near source
- Introduce deposition height (z_s)
  - Height below which particles are subject to dry deposition
  - User defined variable
  - Well suited to a wide range of problems

$$\Delta m = m\left[1 - \exp\left(-\frac{v_d}{z_s}\Delta t\right)\right]$$

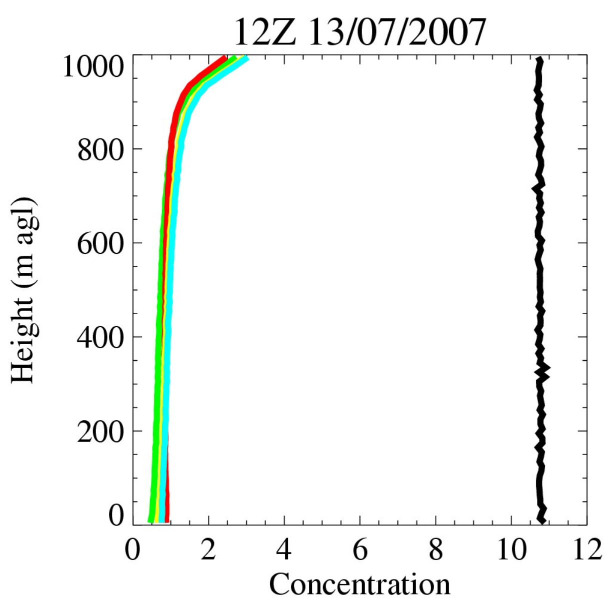
Inhomogeneous turbulence scheme

- Small time-step
- Velocity memory
- Turbulence parameters which vary with height
- Particles reflected at ground

6 hours



36 hours



z_s = 1000m (red)

z_s = 100m (blue)

z_s = 30m (yellow)

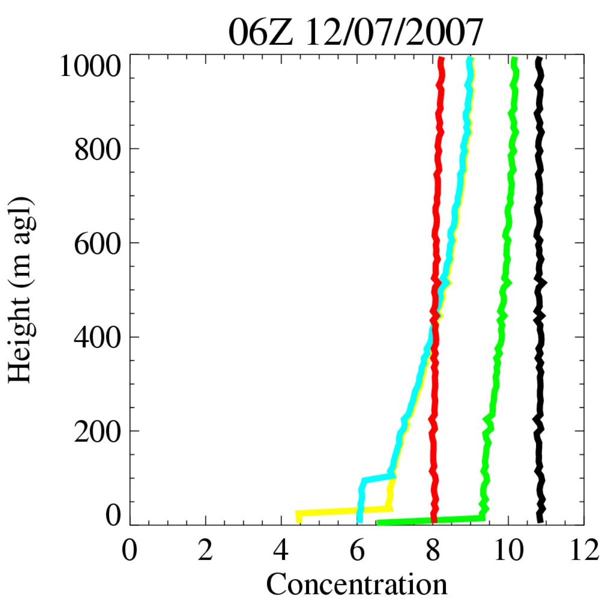
z_s = 3m (green)

Non-depositing (black)

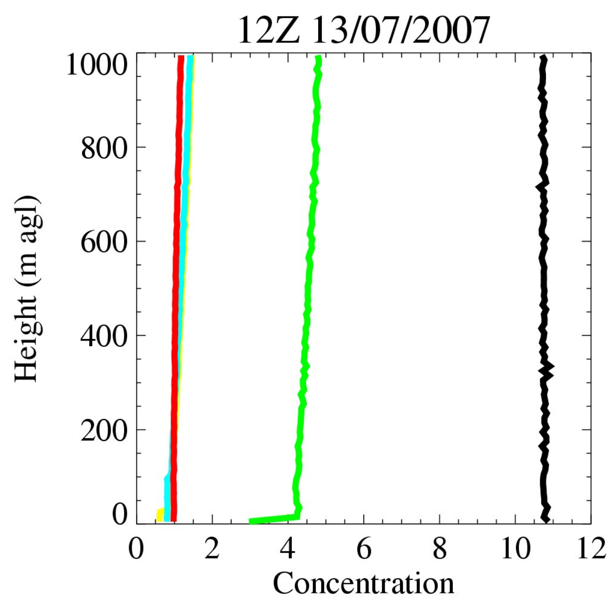
Homogeneous turbulence scheme

- Larger time-step
- No velocity memory
- Reflection at ground
- Cheaper scheme for long(er) range studies
- Turbulence parameters constant with height
- Entrainment scheme at boundary layer top

6 hours



36 hours



z_s = 1000m (red)

z_s = 100m (blue)

z_s = 30m (yellow)

z_s = 3m (green)

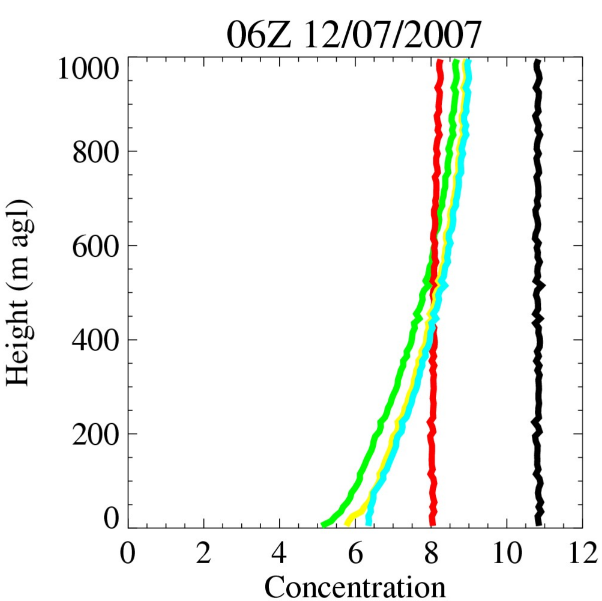
Non-depositing (black)

Homogeneous turbulence scheme

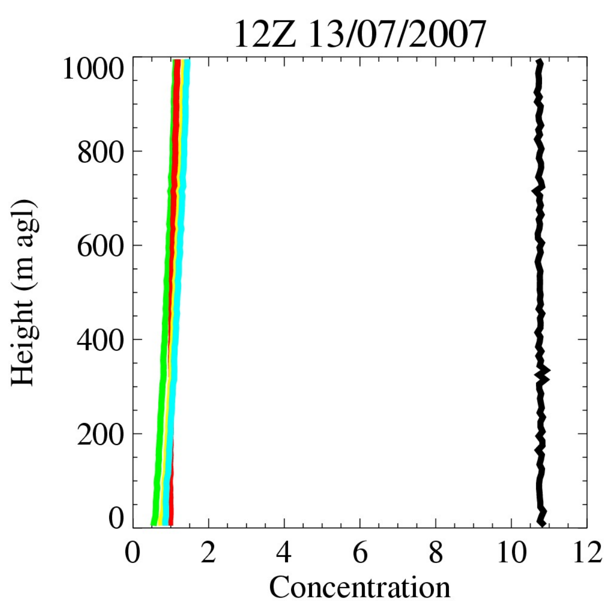
- Introduce *f* – fraction of model time-step below deposition height

$$\Delta m = m\left[1 - \exp\left(-\frac{v_d}{z_s} f \Delta t\right)\right]$$

6 hours



36 hours



z_s = 1000m (red)

z_s = 100m (blue)

z_s = 30m (yellow)

z_s = 3m (green)

Non-depositing (black)

Gravitational settling of heavy particles

- Previous approach:
  - Conducted separately to ambient mean velocity and turbulence advection
  - Uses concept of a sedimentation velocity (w_{sed})
  - Particles below ground sedimented out
  - Total dry deposition = dry deposition + sedimentation
  - Potential computational noise issues

$$\frac{dz}{dt} = -w_{sed}$$

Modifications to gravitational settling

- Include sedimentation velocity in deposition velocity (Underwood)
- Damp sedimentation velocity below z_s
- Simultaneous advection of sedimentation, ambient mean velocity and turbulence
- Fraction of model time-step, f, appropriate

$$v_d = \frac{w_{sed}}{1 - \exp\left(-\frac{w_{sed}}{v'_d}\right)}$$

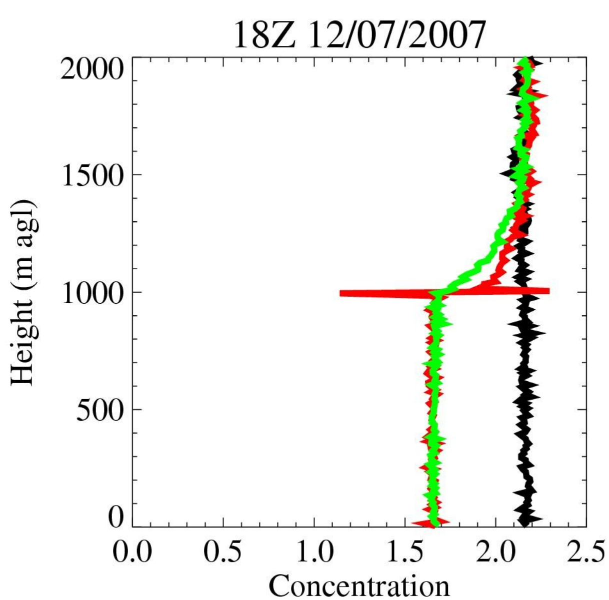
$$v'_d = \frac{1}{R_a + R_b + R_c}$$

$$\frac{\mathrm{d}z}{\mathrm{d}t} = \begin{cases} w_a + w' - w_{sed}, & z \geq z_s \\ w_a + w' - w_{sed}\dfrac{z}{z_s}, & z < z_s \end{cases}$$

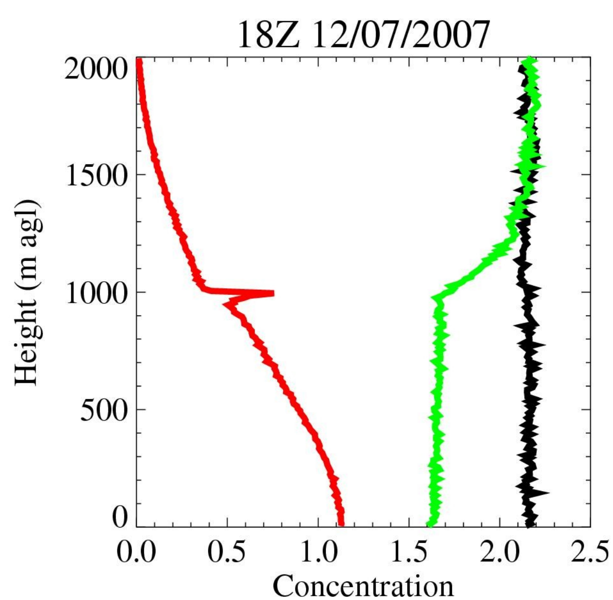
Homogeneous scheme

- Entrainment scheme
  - Discontinuity in turbulence parameters at boundary layer top
  - particles reflected or transmitted with given probability

Small particles



Large particles



Non-depositing (black)

Depositing (green)

Sedimenting & depositing (red)

Revisions to the entrainment scheme

- Follow work of Thomson et al. (1997) for a non-zero mean vertical velocity
- Exit velocity determined by incident velocity
- Equation for exit velocity (transmission or reflection) solved numerically

Transmission

$$\sigma_w(\mathrm{i})\exp\left[-\frac{(w_i+w_{sed})^2}{2\sigma_w^2(\mathrm{i})}\right]-\sigma_w(\mathrm{t})\exp\left[-\frac{(w_t+w_{sed})^2}{2\sigma_w^2(\mathrm{t})}\right]$$

$$+\sqrt{\frac{\pi}{2}}w_{sed}\left[\mathrm{erf}\left(\frac{w_i+w_{sed}}{\sqrt{2}\sigma_w(\mathrm{i})}\right)-\mathrm{erf}\left(\frac{w_t+w_{sed}}{\sqrt{2}\sigma_w(\mathrm{t})}\right)\right]=0$$

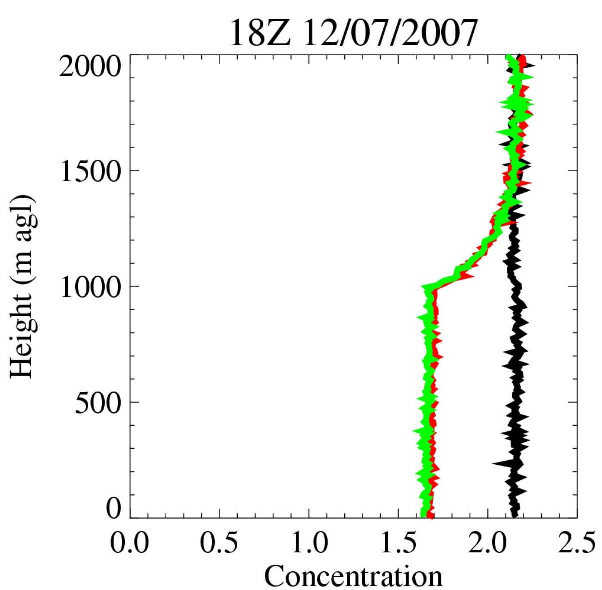
where i = incident and t = transmitted

σ_w^2 = effective velocity variance
= $K / \Delta t$

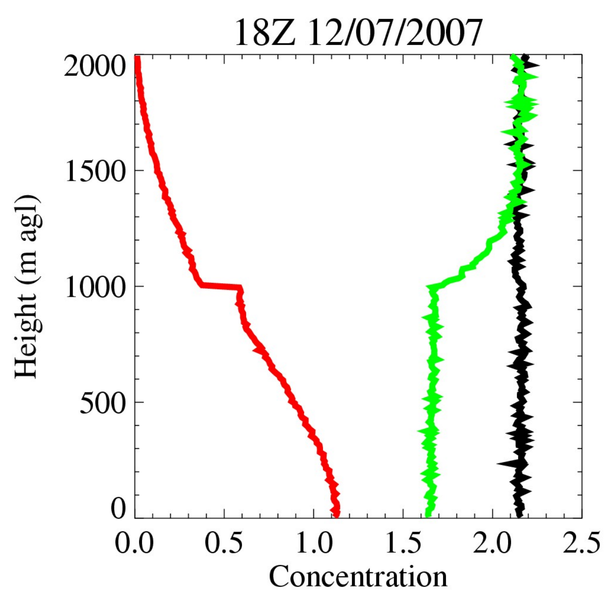
Revised entrainment scheme

- Well behaved
- Increase in cost (~15%) for sedimenting species

Small particles



Large particles



Inert (black)

Depositing (green)

Sedimenting & depositing (red)

Conclusions

- Improved deposition and gravitational settling schemes
  - Simultaneous advection
    - mean ambient velocity, turbulence and sedimentation
  - Entrainment scheme
    - Exit velocity determined by the incident velocity
  - Flexible structure – user defined deposition height
    - Lower deposition height – more particles required?
  - Smoother deposition fields
  - Well behaved
    - Both turbulence schemes
    - Range of deposition heights
  - Manageable increase in cost for sedimenting species