Atmos. Chem. Phys. Discuss., 7, S15–S22, 2007
www.atmos-chem-phys-discuss.net/7/S15/2007/

Atmospheric
Chemistry
and Physics
Discussions

Interactive comment on “Inverse modelling-based reconstruction of the Chernobyl source term available for long-range transport” *by* X. Davoine and M. Bocquet

J. Pudykiewicz (Referee)

Janusz.Pudykiewicz@ec.gc.ca

Received and published: 19 January 2007

The paper on the application of inverse methods for evaluation of the release of radioactivity from the Chernobyl accident is both interesting and quite relevant to practical application. My comments are quite minor and they are intended to improve the clarity of the presentation and possibly to suggest some ideas for the future work.

1. Formulation of the method

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

When introducing the basic methodology of the source reconstruction I would like to suggest to define clearly the specific structure of the algorithm. In particular it could be helpful to state explicitly that the problem consist essentially in minimization of

$$\mathcal{L} = \sum_{\sigma,\epsilon)} p(\sigma,\epsilon) \ln \frac{p(\sigma,\epsilon)}{\nu(\sigma,\epsilon)} + \beta^T \left\{ \mu - \sum_{\sigma,\epsilon)} p(\sigma,\epsilon)(H\sigma + \epsilon) \right\}$$

(with all notations the same as those used in the original paper published by the second author in the QJRMS). Based on my understanding of the original paper from QJRMS, the theory behind the methodology proposed by the authors is quite elegant and it is worthwhile to show this. It would be also helpful to comment in few sentences on the relation of the proposed methodology to other ill posed inverse problems in physics and engineering (for example image deconvolution).

2. Scale analysis of the continuity equation

The issue of the basic physical approximation used in the manuscript requires some additional clarification. On page 4 we read: "*We have checked this is a numerically valid approximation for accidental releases*". This should be corrected; the fact that $divV = 0$ is not the property of a release but the property of a specific flow system.

Let us us examine the validity of this approximation. It is true that large variations of density are observed mainly in vertical and, subsequently, at the scale considered by the authors, we can introduce the following decomposition:

$$\rho(x,y,z,t) = \rho_0(z) + \rho'(x,y,z,t),$$

where ρ_0 is the height dependent basic state and ρ' is the deviation. After substitution of this decomposition to the continuity equation, we obtain:

$$\frac{1}{\rho_0}\left[\frac{\partial \rho'}{\partial t} + V\nabla\rho'\right] + \frac{w}{\rho_0}\frac{d\rho_0}{dt} + \nabla V = 0.$$

On the basis of scale analysis, we can neglect the term in square brackets and our continuity equation has following form:

$$\nabla V + w\frac{d}{dz}\ln\rho_0 = 0.$$

It is quite clear that even after performing the scale analysis of the continuity equation and neglecting terms which are small in the context of the problem discussed by the authors, we can assume $\nabla V = 0$ only in situations with negligible vertical motions. For the majority of actual atmospheric flows on the scale considered by the authors, the assumption $\nabla V = 0$ is not acceptable and it leads to significant errors particularly in the frontal zones which are quite critical in the transport of radioactivity.

3. Wet scavenging of radioactive particles

The problem of wet scavenging is very complex because the radioactivity is transported both in the gas phase and on aerosol particles of different sizes. Ideally, the model should consider both the radioactive particles and gases. In most of meteorological applications one single “bulk” phase was considered which in most cases was a mixture of radioactive gases and particles. This situation lead obviously to some problems in parameterization of scavenging. Very often the problems with parameterization of wet removal were avoided in the long range transport models by assuming that transport of radioactivity takes place almost exclusively on fine particles with radius of the order of 1 $\mu\mathrm{m}$. Such fine particles are not removed by below-cloud scavenging by rain and therefore some type of parameterization of in cloud or “nucleation scavenging” should be used (the Belot scavenging scheme is not applicable for fine particles).

The most evident example of the long-range transport of radioactivity on fine particles was the intercontinental transport of I^{131} from the Chernobyl (Pudykiewicz J. 1989, Simulation of the Chernobyl dispersion with a 3-D hemispheric transport model, Tellus, 41B, pp. 391-412). The scavenging scheme used in the Tellus paper is described by a simple formula of the form:

$$\begin{cases} \Lambda = 0 & U < U_0 \text{ no subgrid-scale cloudiness} \\ \Lambda = \beta\lambda_a & U \geq U_0 \text{ subgrid-scale condensation} \end{cases}$$

where $\beta = (U - U_0)/(U_s - U_0)$ is the cloud cover, U is the relative humidity, U_0 is the grid point value of the relative humidity from which the subgrid–scale condensation can start; following Sundqvist (1976) $U_s = 0.8$ was assumed. λ_a is an empirical parameter; it was assumed that for long range transport of nuclear tracers $\lambda_a = 3.5 \times 10^{-5}$ $[\mathrm{sec}^{-1}]$.

The above relation describes in cloud scavenging of fine particles. In order to make it more useful from the point of view of solving the inverse problem we should generalize it as follows. The rate of change of concentration of fine particles c_a can be estimated as

$$\frac{d\,c_a}{dt} = c_w\,P$$

where $c_w = c_a\,\epsilon/m$ (Junge formula), $0 \leq \epsilon \leq 1$, m is the cloud water mixing ratio, and P is the rate of the release of precipitation. According to Sundqvist, P can be described by a relatively simple relation

$$P = \mathcal{C}_0\,(1 - \exp(-(m/m_r)^2)\,m$$

where $\mathcal{C}_0$ is a time scale of conversion of cloud water to precipitation, m_r is a parameter characterizing the cloud entering into a well developed precipitating state.

After substitution of the expression for P to the equation governing changes of c_a, we obtain the following equation:

$$\frac{d\,c_a}{dt} = c_a\,\epsilon\,\mathcal{C}_0\,(1 - \exp(-(m/m_r)^2)$$

which leads to the following estimate of the wet scavenging coefficient inside clouds:

$$\Lambda_{cl} = \epsilon\,\mathcal{C}_0\,(1 - \exp(-(m/m_r)^2)$$

After considering the fact that clouds are covering only a fraction $0 \le \beta \le 1$ of the grid cell of the model we can estimate the average value of the wet scavenging coefficient as

$$\Lambda = \beta\,\Lambda_{cl} = \beta\,\epsilon\,\mathcal{C}_0\,(1 - \exp(-(m/m_r)^2))$$

If we assume

$$\begin{cases} \epsilon = 0.75 & \text{typical value of the scavenging efficiency} \\ \mathcal{C}_0 = 10^{-4}\mathrm{s}^{-1} & \text{average value for stratiform clouds} \\ m_r = 0.5 \times 10^{-3}\mathrm{g\ kg}^{-1} & \\ m = 0.35 \times 10^{-3} - 0.65 \times 10^{-3}\mathrm{g\ kg}^{-1} & \text{cloud water (mixing ratio)} \\ \beta = (U - U_0)/(U_s - U_0) & \\ U_0 = 0.8 & \end{cases}$$

we can obtain (for $\beta = 1$):

$$\Lambda = 0.29 \times 10^{-4}\beta - 0.61 \times 10^{-4}\beta.$$

The value of Λ used by Pudykiewicz (1989) ($\Lambda = 0.35 \times 10^{-4}$) is within this range.

There is consistent trend to increase the resolution of the models simulating transport of nuclear tracers and improve the description of the source term. This trend will undeniably create the need to use models based on equations describing explicitly the aerosol dynamics.

However, before this is achieved, we can improve the estimate of the wet scavenging of small particles using the relation

$$\Lambda = \epsilon \mathcal{C}_0 \frac{(U - U_0)}{(U_s - U_0)} \left[1 - \exp(-(m/m_r)^2) \right]$$

Considering that cloud water could be either obtained from the meteorological model or diagnosed based on the information from the reanalysis files, the use of this relation should not present any problems. It could be also quite interesting to see how the modified in–cloud scavenging formula will affect the results of inversion (this is not necessary for the present paper but could be useful in the future studies).

4. Other suggestions

1) The problem of dry deposition velocity could be discussed in more detail; what is its impact on the inversion results when compared to the influence of wet scavenging?

2) In evaluation of prior probability distribution I can suggest the use of a simple forced convection model to estimate the effective height of the release based on a modified parcel method.

3) How to address the fact that radioactivity was transported in a gas phase and on particles?

5. Recommendations

The paper is certainly acceptable for the publication after small revisions addressing the above suggestions.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 1, 2007.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper