Verification of the Hydrological Cycle in the EURAD Model

A contribution to subproject EUMAC

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Introduction

This study aims at verifying the European Acid Deposition (EURAD) model [1,2] with real data. Water is the best-documented trace constituent. The present verification will be done by comparing the modelled with the diagnosed hydrological cycle. The hydrological cycle is represented by the sub-gridscale fluxes of rain, moisture and heat. These fluxes are output quantities of our diagnostic model DIAMOD [3]. DIAMOD operates on a horizontal/vertical/time scale of 100 km/100 hPa/12 h. Results from the MM4 module of the EURAD model are interpolated to this standard grid. The comparison will be done for one day during the Chernobyl event (wet EUMAC case) [4].

Theory

The budget equation for atmospheric moisture in the diagnostic ('D'IAMOD) and prognostic ('E'URAD) version reads as follows [5].

$$\underbrace{L\frac{\partial q}{\partial t} + L\nabla \cdot qV + L\frac{\partial q\omega}{\partial p}}_{[b_q]^D} + \underbrace{\left[L\frac{\partial \overline{q'\omega'}}{\partial p}\right]^D + \left[gL\frac{\partial \overline{P}}{\partial p}\right]^D}_{[s_q]^D} + imb_q = 0 \qquad (1)$$

$$\underbrace{L\frac{\partial q}{\partial t} + \frac{L}{p^*}\left(q\frac{\partial p^*}{\partial t} + D_q - F_H q\right)}_{[b_q]^E} \underbrace{-\frac{L}{p^*}(V_{qf} + F_V q) - \frac{L}{p^*}(D_q + bgM_t N_m(\sigma))}_{\left[L\frac{\partial \overline{q'\omega'}}{\partial p}\right]^E \qquad \left[gL\frac{\partial \overline{P}}{\partial p}\right]^E} = 0 \qquad (2)$$

$$[s_q]^E$$

with:

$D_q = m^2\nabla \cdot \frac{p^* qV}{m} + \frac{\partial p^* q\dot{\sigma}}{\partial \sigma}$

The meaning of most symbols is standard. Terms without overbar are gridscale, fluxes with overbar are sub-gridscale. $\bar{P}$ is the vertical precipitation flux. b_q denotes the gridscale budget, s_q denotes the sub-gridscale signal. The column imbalance imb_q allows an objective separation between signal and error in DIAMOD. The terms $bgM_tN_m(\sigma)$ and $V_{qf}(\sigma)$ are parts of the KUO scheme, F_H and F_V are diffusion operators in the EURAD model [1]. In the case of no convection $[s_q]^E$ reduces to $F_V q$.

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DIAMOD mean=101 Wm^{-2}, rms=245 Wm^{-2} EURAD mean=63 Wm^{-2}, rms=175 Wm^{-2}

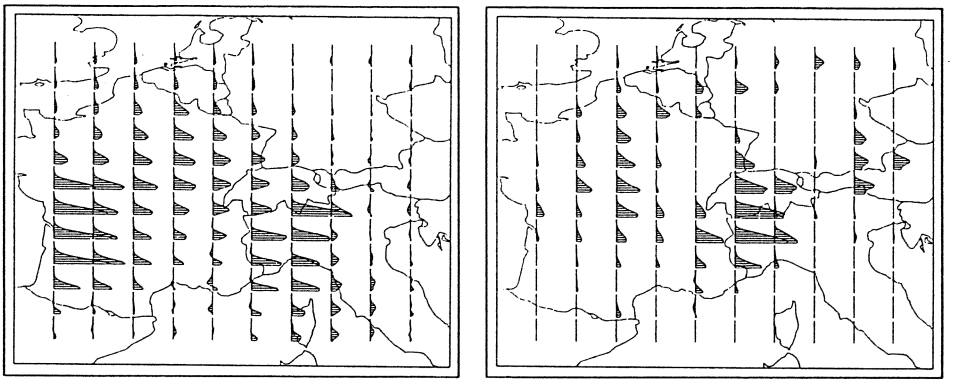


Figure 1. Vertical profiles of diagnosed (left) versus parameterized (right) sub-gridscale rain flux *r(p)* as defined in eq. (3), in units Wm^{-2} for the Chernobyl event, 26th April 1986, 00.00 UTC. Each vertical profile from top of atmosphere (p_t = 0) down to surface pressure (p_s = 1000 *hPa*) is representative for one geographic location. Magnitude of fluxes: spacing between two columns = 1000 Wm^{-2}, positive fluxes downward.

The goal of this study is quantitatively to compare the individual components of the budget equations. This is done in terms of the following sub-gridscale fluxes [6]:

$$\begin{aligned} r(p) &= L\bar{P} && \ldots \text{ rain flux} \\ f(p) &= \frac{1}{g} L\overline{Q'\omega'} && \ldots \text{ moisture flux} \\ w(p) &= \frac{1}{g} c_p \overline{T'\omega'} && \ldots \text{ heat flux} \end{aligned} \tag{3}$$

Eq. (1) is solved in DIAMOD by coupling it with the heat equation (not discussed here), the equivalent is done in EURAD with eq. (2).

Sub-gridscale fluxes

The fluxes are calculated on a 32 × 32 × 10 box array covering Europe. Input data used in DIAMOD are the uninitialized ECMWF analyses. The rms-value of imb_q is 33 Wm^{-2}. The EURAD fluxes are obtained by averaging the last 12 hours (centered at 26th April 1986, 00.00 UTC) of an 18 hour forecast. In this study only a part covering France, Switzerland, Germany and northern Italy is considered.

Fig. 1 shows the rain flux *r(p)*. While the precipitation patterns of DIAMOD and EURAD compare reasonably well over Switzerland and northern Italy, the EURAD fluxes are too small in the rest of the domain. Note that only KUO columns produce rain in EURAD.

Fig. 2 shows the moisture flux *f(p)*. It is everywhere upward. *f(p)* is of the order of 100 Wm^{-2} in DIAMOD. The EURAD equivalent is one order of magnitude smaller.

When it comes to the heat flux (Fig. 3), equivalent remarks apply. There is no con-

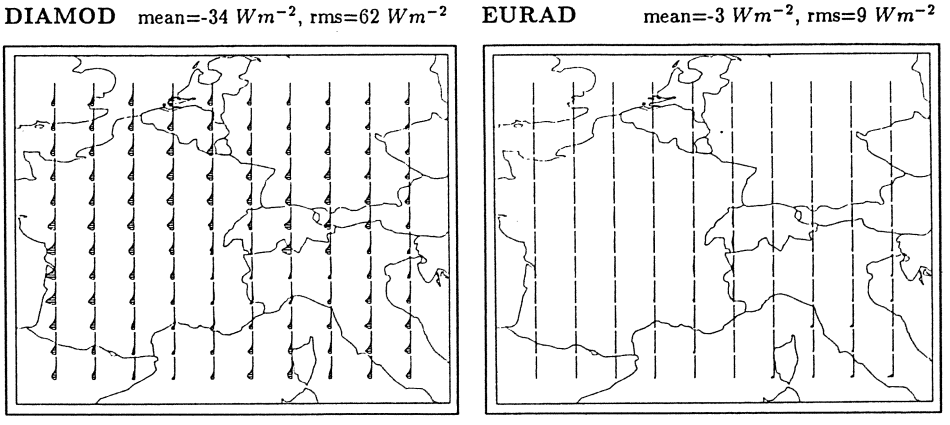


Figure 2. Vertical profiles of sub-gridscale moisture flux *f(p)*. Everything else same as in Figure 1.

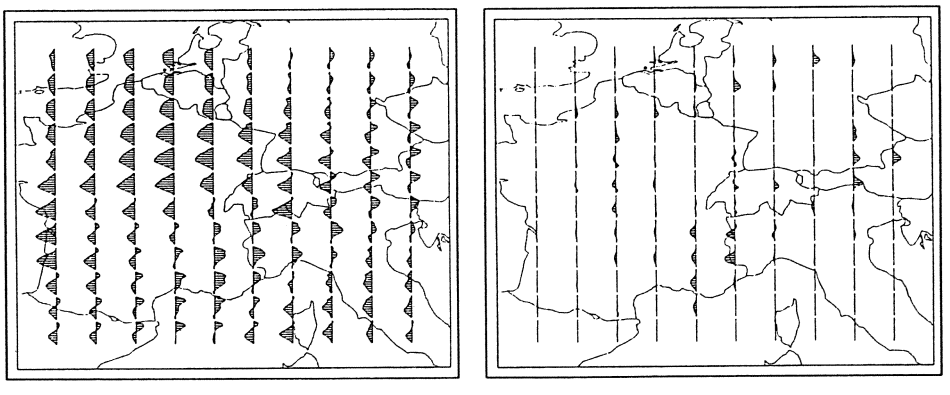


Figure 3. Vertical profiles of sub-gridscale heat flux *w(p)*. Everything else same as in Figure 1.

vection in non-KUO columns. Modelled convection in KUO columns is much weaker than diagnosed. In summary, there is virtually no similarity between the panels.

Discussion

In this study we have presented a comparison between diagnosed (DIAMOD) and modelled (EURAD) heat budgets over Europe. The difference in our approach to the more traditional one [7] is that we verify not only at the earth's surface but in the free atmosphere as well. The comparison has been done for the *wet* EUMAC case; it has revealed pronounced differences between the sub-gridscale vertical heat fluxes in the two representations. We claim that DIAMOD comes closer to reality since it uses observed free atmosphere tendencies plus surface while EURAD does not. In this sense we consider DIAMOD the control background of the EURAD model. The following results emerge:

- Diagnosed fluxes are always active, whereas modelled fluxes are restricted to KUO columns.
- All sub-gridscale EURAD fluxes are considerably smaller than the equivalent DIAMOD fluxes.

We offer the following conclusions:
- The main reason for the differences must be in the EURAD parameterization.
- Conversely, uncertainties of the DIAMOD results are largely due to data errors (*e.g.*, of the vertical velocity field).

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