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Utilization of radar-based precipitation estimates in hydrological models in the Czech Republic

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Abstract. The precipitation in the region of the Czech Republic is monitored using radar estimates and telemetric raingauges. The radar estimates are adjusted by mean field bias and combined with the available raingauges and the raingauge-radar combined estimates are utilized as an alternative source of data for hydrological modelling which still relies mainly on raingauge data. A hydrological rainfall-runoff model named Hydrog is optionally using the merged radar-raingauge precipitation estimate in form of mean areal precipitation calculated for Thiessen's polygons which are determined according to raingauge locations. Some experiments on a chosen catchment have been conducted using also areal distribution of precipitation according to the subcatchments of different mean size. The modelling calculation leads to the conclusion that in the case of the chosen catchments the radar can well serve as a source of precipitation data for hydrological modelling. The usefulness of radar data varies according to the prevalent precipitation type: In stratiform precipitation the relative importance of radar data is not so pronounced and is comparable with the performance when using only raingauges, but in convective heavy rainfalls the radar data are highly beneficial. The performance of the hydrological model in convective situation improves especially when the subcatchments are of small size. According to the conducted experimental calculations, best performance has been achieved with the lowest size of subcatchment being equal 60 km^2.

1 Background

Areal quantitative precipitation estimation (QPE) is traditionally made by raingauge "point" measurements and subsequent computations using interpolation, kriging, Thiessen's polygons etc (e.g. Gilman, 1964). Weather radar offers another possibility to provide 'direct' QPE but until recently this option was not used too much. Among the reasons which caused not-so-widespread use of the radar QPE were (i) rather limited availability of the weather-radar-based QPE, (ii) errors of the radar-based QPE, (iii) lack of experience with radar data. The Czech Hydrometeorological Institute (CHMI) modernized its weather radar network during the last decade of the 20th century, which resulted in fully digitized data processing with the option to control all the volume reflectivity and Doppler wind data. It allowed much better data processing for the quantitative precipitation estimation (Kráčmar et al., 1999; Novák and Kráčmar, 2001).

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The Czech Hydrometeorological Institute has in 2003 put into operation a QPE system that consists of original radar precipitation estimate, a mean field bias (MFB) – adjusted radar estimate, raingauge-only (interpolation) estimate and a combination, called "merge" (see Šálek et al., 2004; Šálek, 2000). Conceptually, the merged estimate is a linear combination of radar precipitation estimate and raingauge measurements in a way that minimizes the expected error variance.

The aim of this multisensor QPE system, highly inspired by Fulton et al. (1998) and Seo (1998), is to provide users with most accurate precipitation estimate along with information about the performance of the particular measurement system. Moreover, areal QPE for particular areas (catchments and/or Thiessens' polygons) are calculated and also used as a precipitation input into hydrological models.

2 Radar-raingauge merged data for hydrological modelling

Since 2003 the hourly combined (merged) QPE has been used as a precipitation input into the hydrological model Hydrog that is used for several catchments in the eastern part of the Czech Republic (see Fig. 1). Since the optional use of either the raingauge data or the combined estimates (easy "switch" from gauge data to merged data) had to be ensured, the merged QPE is being calculated for the areas of Thiessen's polygons which were designed according to the

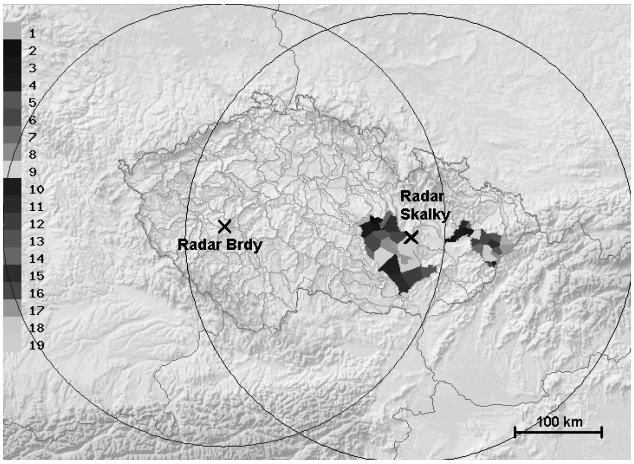

Fig. 1. Areas of the Thiessen's polygons for which the areal precipitation estimates are computed (in the eastern part of the Czech Republic), along with the radar sites and the maximum range of the CHMI radars. The polygons southwest of the radar Skalky are used for Svratka and Svitava catchments, the polygons to the east of the radar Skalky are utilized for Bečva catchment.

Table 1. Characteristics of the Svitava river catchment (discharge characteristics are influenced by reservoirs).

Catchment area	1118 km^2
Final profile (altitude)	Bílovice (218 m a. s. l.)
Highest altitude	586 m a. s. l.
Average annual precipitation 1931–1980	649 mm
Discharge Q_{355d} (from 1931–1980 data)	1.52 m^3
Discharge Q_{30d} (from 1931–1980 data)	11 m^3
Discharge Q_{100y} (from 1931–2003 data)	179 m^3

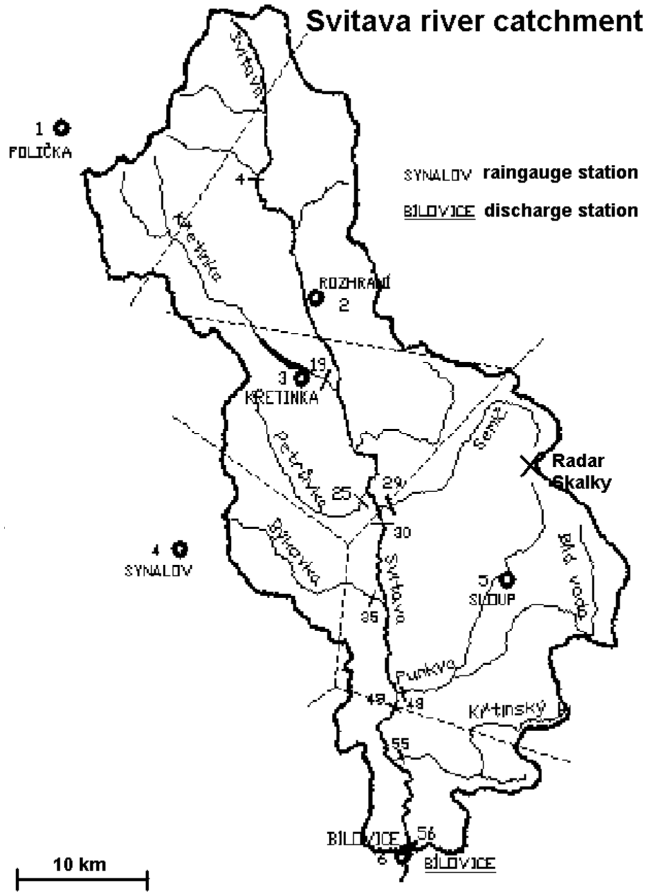

Fig. 2. The Svitava river catchment with the used raingauge stations and the main discharge station. The Thiessen's polygon pertinent to the raingauge stations are hinted by hashed lines.

installed/planned raingauges. Then it is relatively easy to change the data input without too serious intervention in the modelling system. Moreover, since the radar (or combined) estimate is available very quickly, it offers an opportunity to run the hydrological models promptly after significant precipitation is detected, without the necessity to wait until all the raingauge data are collected.

The performance of the model runs with the various inputs (raingauge, radar, combinations) was tested for Svitava river catchment that is located nearby the Skalky radar (from 0 to approx. 50 km far from the radar site).

3 Hydrological modelling on the Svitava river using merged precipitation data

3.1 The description of the Svitava catchment and the model Hydrog

The characteristics of the Svitava river catchment (see also Fig. 2) are in Table 1. The Svitava river flows in an almost southerly direction and the catchment has an elongated shape. Water reservoirs within the catchment are Letovice on the Křetínka River (11.6 mil. m^3) and Boskovice on the river Bělá (7.3 mil. m^3). The catchment water balance is influenced by a permanent take-off of around 1 m^3 s^{-1} by a so called Březová watermain that serves for the city of Brno.

The discharge at various profiles of the Svitava river catchment is being modelled by model Hydrog. The model is designed for the simulation and operational forecasts of water runoff with the ability to take into account the artificial outflow from chosen reservoirs. The immediate state of the system supposes either simply stabilized flow of water in the river network or it is possible to estimate it by simulation from the preceding period. In this case it comes back in time to the time point, when it is possible to suppose stabilised flow. In chosen gauging stations where the discharge is measured, it is then possible to make correction of the calculated values by the measured ones. Then the calculation of the forecasted discharge follows.

The computation is being made on a schematised catchment, where the real catchment is replaced by an oriented evaluated graph. It consists of stream sections, areas "suspended" onto them, surface reservoirs and an underground reservoir. During the course of the rainfall-runoff process,

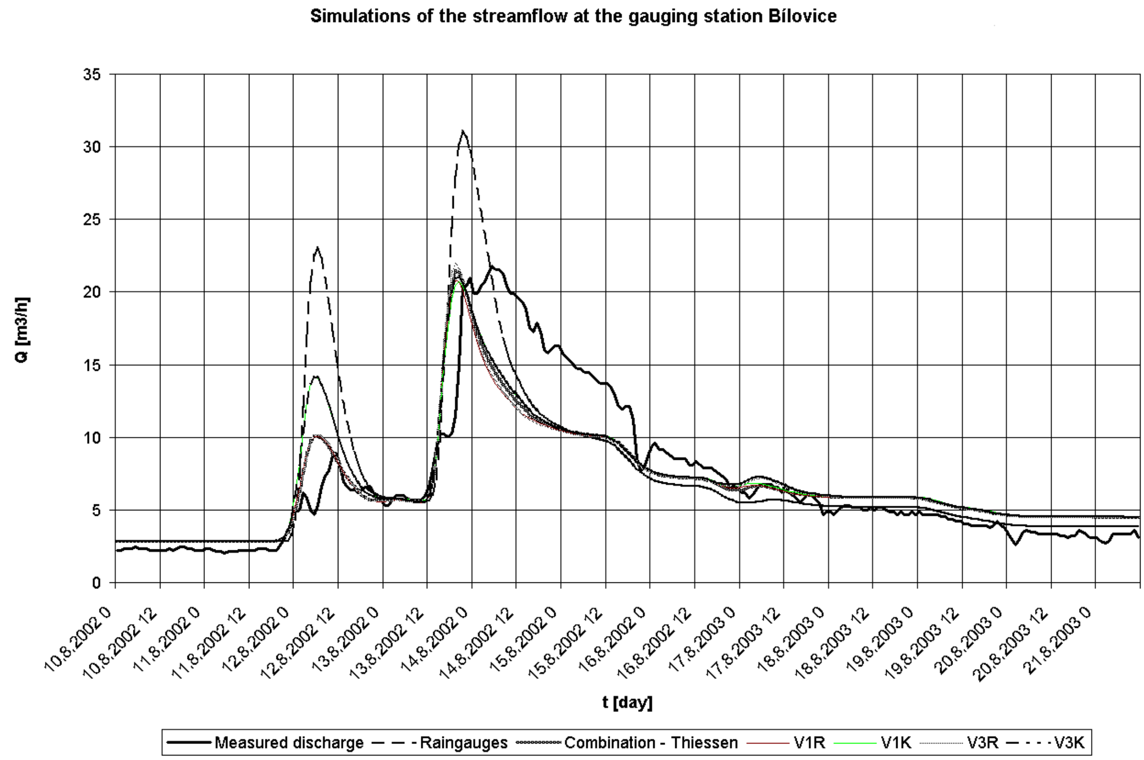

Fig. 3. Simulation of the discharge at the river gauge Bílovice in August 2002. The V1R, V1K, V3R and V3K are abbreviations for Variant 1 using adjusted radar, Variant 1 using (radar-raingauge) combination, Variant 3 using adjusted radar and Variant 3 using combination. The 'variants' denote the decomposition of the basin into subcatchments of different size (V1 – 108 km^2, V3 – 59 km^2) for which the areal QPE are computed.

the rain fallen on the catchment virtually flows through such a graph. During this process, two kinds of routing are considered: hydrological and hydraulic.

During hydrological routing hydrological losses are gradually subtracted from the total intensity of the rainfall falling on the areas - the model respects these losses by a universal loss curve, in which the loss of infiltrations dominates in relation to the rainfall sum in the preceding week. During the hydraulic routing the simulation of areal runoff takes place on the areas of the graph and concentrated runoff on the stream channels, reservoir routing down to the gauging stations of the catchment.

3.2 The results of simulation of significant runoff events

Since the use of the radar-raingauge combined precipitation data in the hydrological models started only in 2002, there have been only a few episodes available, for which the model Hydrog utilizing the various (gauge, radar and merged) estimates was tested. All the analyses were performed as simulations on archived discharge values and precipitation data. It has to be noted that the hourly merged radar-raingauge areal estimates for the Thiessen's polygons were computed without the dedicated raingauge (telemetric tipping-bucket gauges) measurements whose positions are depicted at the Fig. 2. Nowadays the radar-raingauge merged estimate counts with all these data (if they are available) but the aim of the test was to simulate the effect of missing raingauge data when only a few raingauge reading from the main meteorological network were available. The raingauge data that were present in the merged analyses were located outside the Svitava catchment (the nearest one is 3 km southeast of radar Skalky at the edge of the catchment).

In addition to the merged estimates, the model Hydrog was experimentally run with the areal precipitation using only MFB-adjusted radar estimate. Besides the Thiessen's polygons, we tested the model performance with the precipitation field that were decomposed according to the subcatchments of different size (on average 108, 80 and 59 km^2), which were called V1, V2 and V3, respectively (V1 referring to "Variant 1", V2 to "Variant 2" etc.).

3.2.1 Widespread heavy precipitation in August 2002

Significant increase of streamflow took place in August 2002 when the Svitava river basin was partly hit by widespread heavy precipitation that caused disastrous floods mainly in western part of the Czech Republic (in the river basins of Vltava/Moldau and Labe/Elbe). During the test the model parameters were kept constant to default values. The results of the model runs for river-gauging station Bílovice are depicted at the Fig. 3 and Table 2, from which it can be deduced that the radar influences beneficially the result for peak discharge, but the contribution varies according to the method

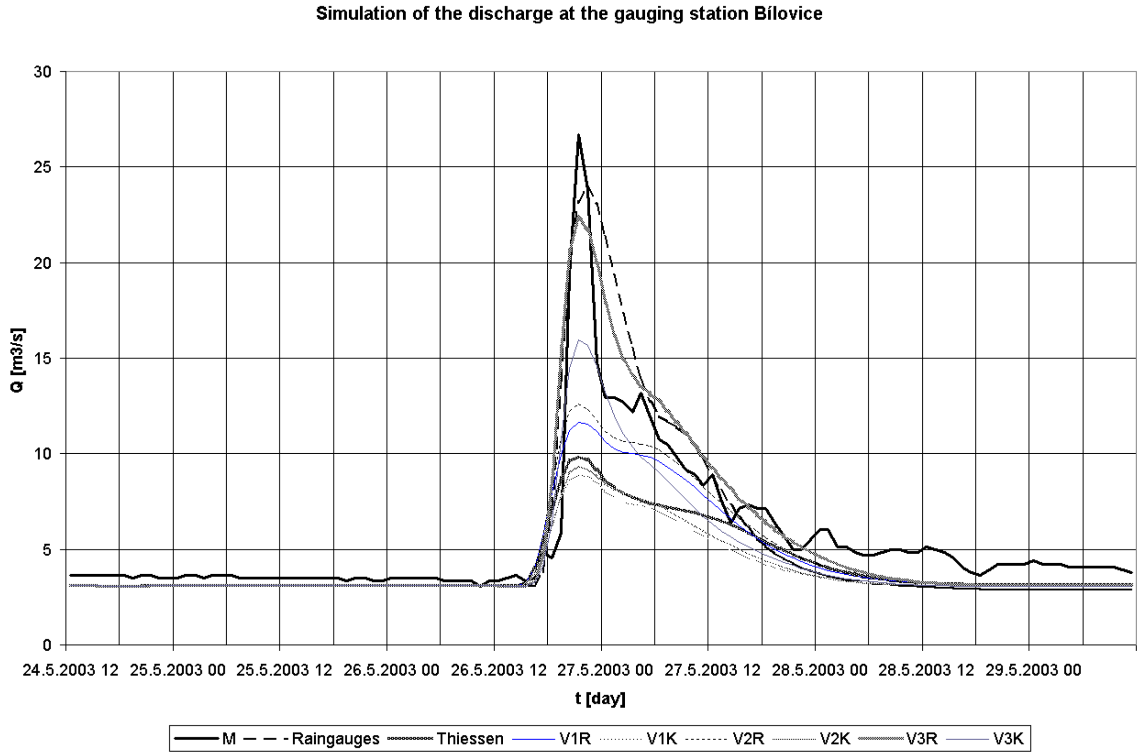

Fig. 4. Simulation of the discharge at the river gauge Bílovice in May 2003. The V1R, V1K, V2R, V2K, V3R and V3K are abbreviations for Variant 1 using adjusted radar, Variant 1 using (radar-raingauge) combination, Variant 2 using adjusted radar, Variant 2 using combination, Variant 3 using adjusted radar and Variant 3 using combination. The 'variants' denote the decomposition of the basin into subcatchments of different size (V1 – 108 km^2, V2 – 80 km^2, V3 – 59 km^2) for which the areal QPE are computed. "M" denotes "Measured discharge".

and the particular river gauge. However, the raingauge-based simulation predicted better the volume of the wave.

3.2.2 Flash flood on 26 May 2003

A flash flood took place on 26 May 2003 in the afternoon in the area of Sloup village (see Fig. 2, south of radar Skalky) and significantly increased streamflow was observed also at the river gauge Bílovice. The flash flood was caused by an intense convective storm which affected very limited area (170 km^2 received the precipitation over 50 mm/day and only 5 km^2 were hit by the rainfall exceeding 70 mm with a maximum precipitation measured by a raingauge was of 90 mm/day). The rainfall lasted only two hours. From the modelling point of view, it was noticeable that part of the heavy precipitation hit the raingauge Sloup. Interestingly enough, the raingauge-based model run was very successful compared to the run when using the combined radar-raingauge precipitation estimates calculated for the Thiessen's polygons (see Fig. 4 and Table 3). However, the reason was quite obvious - the particular Thiessen's polygon pertinent to the raingauge station Sloup is one of the largest ones and the limited-area (yet heavy) precipitation, well captured by radar, was averaged on the whole polygon area, resulting in severe underestimation of the runoff. The model runs, which were performed on the smaller subcatchments, were improving the model results according to decreasing size of the subcatchments; the best results (yet a little worse than the raingauge-only simulation if peak discharge is considered) were achieved by the highest resolution (V3); the adjusted radar-only estimate was even better than the combination of adjusted radar with reduced network of raingauges.

Concerning the interesting fact that the best performance was achieved by using of the dedicated network of raingauges, it has to be stressed that the measured precipitation reached the 'optimal' value in this case by mere accident; if the raingauge had been located a few kilometers far from its actual position, the measured rainfall depth would have been very different, which would have resulted in the corresponding error of the polygon-based areal QPE and the consequent error of the modelled discharge.

4 Final remarks

According to the preliminary results presented above, the combined radar-raingauge-based QPE can be well used in hydrological modelling, provided careful maintenance of the radar and scrutiny of the radar performance and of the raingauges is ensured. On average, the radar-raingauge combined estimate is the best QPE available for the modelling but the contribution of the radar depends significantly on the precipitation processes and the decomposition of the catchment.

Table 2. Root mean square error and correlation coefficients of the simulated and measured discharge at the river gauges Rozhraní, Letovice and Bílovice in August 2002 (see also the Figs. 2 and 3; the Letovice gauge is nearby Křetínka station but note that is heavily influenced by the reservoir).

Variant	Root mean square error			Correlation coefficient		
	Rozhraní	Letovice	Bílovice	Rozhraní	Letovice	Bílovice
Raingauges (only)	0.84	1.55	4.51	0.14	0.97	0.69
Merged – Thiessen	0.62	1.21	**2.99**	0.69	**0.98**	**0.83**
V1 – adj. radar	0.67	1.28	3.08	0.57	**0.98**	0.82
V1 – merged	0.55	**1.07**	3.12	0.71	**0.98**	0.80
V3 – adj. radar	0.66	1.27	3.16	0.58	**0.98**	0.80
V3 – merged	**0.54**	**1.07**	3.15	**0.74**	**0.98**	0.79

Table 3. Root mean square error and correlation coefficients of the simulated and measured discharge at the river gauges Rozhraní, Letovice and Bílovice in May 2003 (see also the Figs. 2 and 4; the Letovice gauge is nearby Křetínka station but note that is heavily influenced by the reservoir).

Variant	Root mean square error			Correlation coefficient		
	Rozhraní	Letovice	Bílovice	Rozhraní	Letovice	Bílovice
Raingauges (only)	**0.180**	**0.103**	2.677	−0.142	**0.840**	0.914
Merged – Thiessen	1.398	1.312	3.980	0.774	0.377	0.844
V1 – adj. Radar	1.311	1.207	3.301	0.654	0.324	0.845
V1 – merged	0.564	0.549	4.392	0.450	0.367	0.860
V2 – adj. Radar	0.989	1.175	3.066	0.660	0.300	0.848
V2 – merged	0.381	0.607	4.218	0.554	0.379	0.866
V3 – adj. Radar	1.690	1.460	**2.221**	**0.785**	0.395	0.918
V3 – merged	0.725	0.651	2.608	0.687	0.423	**0.923**

In the widespread (stratiform) precipitation the decomposition is not so important and the radar contribution is rather modest. In convective precipitation the radar QPE is very important but its performance depends significantly on the decomposition of the river basin. However, the decomposition has its obvious lower limit that is determined by the average size of the storm cells (approx. $10\,\mathrm{km}^2$); if smaller area are used, then negative effects of up- and downdrafts on the radar-based QPE are likely to be more significant.

The use of radar-based (or radar-influenced) QPE in the Czech Hydrometeorological Institute for the hydrological modelling is not limited only to the procedure described above; the adjusted hourly QPE from the radar are used also for calibration of the hydrological model Aqualog. The utilization of the combined QPE in the hydrological modelling is intended to increase in the following years.

The radar is no longer considered as a competitor to raingauges but as a complementary tool for the precipitation estimation. The radar-based QPE is important especially by his ability to provide a prompt overview, or, in other words, the "first guess" of the precipitation. The radar information is valuable especially in highly variable convective precipitation while in some stratiform rainfall with pronounced bright band effect or strong orographic enhancement the radar-based QPE may be too erroneous. The user must be trained to be able to assess the performance of the radar precipitation measurement and then to assign some estimate of reliability to the scenario which the hydrological model computes.

The radar-based QPE is only a part of the whole information package which is needed for the successful utilization of the hydrological model in streamflow forecasting. The combined QPE is followed by the quantitative precipitation forecasts of the numerical weather prediction model ALADIN and the model run can be updated by the rivergauge measurements. Although the influence of the radar-influenced QPE is therefore limited, from the preliminary results it can be stated that it does improve the whole hydrometeorological information system.

References

Gilman, Ch. S.: Rainfall, in Chou, V. T. (Ed.), 1964, Handbook of Applied Hydrology, McGraw-Hill, USA, 1964.

Fulton, R., Breidenbach, J., Seo., D.-J., Miller., D., and O'Bannon., T.: The WSR-88D rainfall algorithm, Wea. Forecasting, 13, 377–395, 1998.

Kráčmar, J., Joss, J., Novák, P., Havránek, P., and Šálek, M.: First Steps Towards Quantitative Usage of Data from Weather Radar

Network, in Final Seminar of COST 75: "Advanced Weather Radar Systems" – Locarno, 23.–27.3.1998, European Commission, Luxembourg, 91–101, 1999.

Novák, P. and Kráčmar, J.: Vertical Reflectivity Profles in the Czech Weather Radar Network , 30th International AMS Conference on Radar Meteorology, 19–24 July 2001, Munich, Germany, poster presentation, http://www.chmi.cz/meteo/rad/pub/ams_rad2001/index.html, 2001.

Seo., D.-J.: Real-time estimation of rainfall fields using radar rainfall and rain gage data, J. Hydrol., 208, 37–52, 1998.

Šálek, M.: The radar and raingauge merge precipitation estimate of daily rainfall – first results in the Czech Republic, Phys. and Chem. of the Earth, 25, 2000, 977–979, 2000.

Šálek, M., Novák, P., and Seo, D.-J.: Operational application of combined radar and raingauges precipitation estimation at the CHMI, in Proceedings of ERAD 2004, ERAD publication series, 2, this volume, 2004.