Relazione Scientifica – Scientific Report

Titolo del programma: Assessing Raman Water Vapor Lidar Calibration Variabilily for the ISAC-CNR RMR lidar and its relation to NDACC objectives.

Proponente/Fruitore: Dr. G.L.Liberti. ISAC-CNR.

The main scientific objective of the visit at NASA-GSFC (23/10-12/11/2010), supported by the CNR's Short Term Mobility 2010 program, was to discuss with Dr. David Whiteman the relevant issues for the processing of Water Vapour (WV) Raman lidar data in order to produce water vapour profiles for the International Network for the Detection of Atmospheric Composition Change (NDACC, http://ndacc-lidar.org/index.php?id=45/Raman+water+vapour.htm) NDACC database where both the NASA GSFC (http://ramanlidar.gsfc.nasa.gov/) and the Rome Tor Vergata CNR (http://lidar.ifa.rm.cnr.it/) Raman lidars are expected to submit results from their observations in a consistent way.

All the relevant steps in the processing were discussed during the visit including:

- Calibration against radiosonde and associated uncertainties
- Background estimation and subtraction
- Dead-time correction and use of analogic channel information
- Molecular extinction correction
- Temporal and vertical filtering
- Temperature correction
- Aerosols extinction correction
- Correction for absorbing gases
- Correction for contamination due to elastically backscattered signal.

As a result of the discussions and the exchange of information with Dr. Whiteman and his group including collaborators at Howard University in Beltsville, a first version of a fully automated processing chain was designed and applied to a set of more than 160 sessions from 2003 to date.
Lidar data from the Rayleigh-Mie-Raman system (Congeduti et al. 1999) in Tor Vergata (41.88°N, 12.68°E, 107 m ASL) were originally processed at CNR-ISAC with a set of tools that required a large amount of supervision particularly in the process of calibration and merging to select the best criteria. Processing a large amount of observations, such as required when testing a new part of the inversion algorithm or modifying a parameter, requires a large amount of experienced operator time and therefore is not suitable for routine operations.
Such tools remain a valid instrument to investigate in detail case studies or to tune single parts of the retrieval algorithms however, within the framework of routine observations with a standard setup of the instrument, it was necessary to have some automatic procedure that would reduce the amount of manpower to process and easily allow the reprocessing of the whole set in case of an update of the algorithm.
Some results from this first set of profiles produced is reported in the following pages as plots whose content is described below.

Obviously this first version of the processing chain, that is fully automated, needs refinements and some sort of post processing quality control that is expected to be the result of continuing the collaboration between the 2 research groups.
Current efforts are in the quality control, the validation of different options in the single processing steps, and in the optimization of the filtering technique in order to maintain a sufficiently large SNR without losing temporal and vertical information.

As soon as the processed profiles will be quality controlled and their error budget properly documented, the observations will be submitted to the NDACC archive.

Despite the fact that the results are still preliminary, a few comments, and relevant definition of actions can already be obtained from a visual inspection of the produced plots and are shortly given in the following.

Radiosonde quality. It seems that there a few cases for which the quality of the radiosonde is questionable. For example a few sessions (e.g. **030911**_____, **050427**_____, **060526**_____) shows a sort of periodic structure in the mixing ratio profile probably due to the switch from one humidity sensor to the other one that is done in the RS92. Spotting and fixing automatically such problem is quite difficult (e.g. which one of the sensors is right if any?) probably the best solution is in the post-processing. In this preliminary analysis we do not apply any correction to upper tropospheric humidity measurements, this should not be a very important issue for calibration, because the maximum height range that would be considered for the calibration would be 6-9 km, but it becomes important to apply the state of the art corrections to the RS92 to evaluate the quality of the Raman profiles in the upper troposphere and the impact of any correction we apply to observations to minimize the observed wet bias.

Calibration. Calibration is performed using the automatic procedure described in Dionisi et al (2010). In some cases (**041108**_____) the profile used for the calibration is too distant in time from any of the lidar profiles. Although a maximum allowed time delay lidar-radiosonde is already included in the calibration procedure, this was computed on an average estimation of temporal variability. For some cases this time window seems to be too large. A possible solution for this as well as for other problems in the calibration should be a post-processing analysis of the output of the calibration fit. If difference with the previous values are too large or the fit is relatively poor then reject the single session calibration value and use an average one. Figure 1 shows for the set of sessions processed the time series of calibration coefficients for the upper channel (upper panel), the lower channel (middle panel) and the ratio between calibration coefficient for the upper and the correspondent for the lower channel. Apart for evident outliers whose origin is currently under investigation the plots show clusters of values that should in principle correspond to homogeneous set up of the instrument. For example for the upper channel, the high voltage applied to the photomultiplier of the WV channel was modified during the period 1/10/2007-27/4/2008 (values within the blue rectangle in figure 1). Apparently, this change, operated to decrease the large background signal observed in this channel, lowered the detection efficiency, as confirmed by the increase both in value and variability of the calibration constant.

Upper troposphere wet bias. It is evident in most of the cases that an upper tropospheric wet bias exists as shown by the behaviour of the green line in the central panel. A solution for the wet bias should be developed and applied as first priority. A possible explanation for the observed wet bias, having excluded from the analyses of the vertical behaviour as well as of the entity other possible factors (e.g. background), is the contamination of the relatively low Raman signal from the 355 nm elastically backscattered signal. Given the ratio between elastic and Raman backscatter cross section, even a small portion of elastically backscattered signal would contribute to the WV Raman one inducing a wet bias becoming particularly evident in the upper troposphere because of the relatively low amount of water vapour in the upper troposphere. The system design is such that all the UV (<440 nm) signals are transmitted in the same optical fibres and separated at the end, there are 2 possible independent candidate mechanisms (or even their combination) that would produce such disturbance:

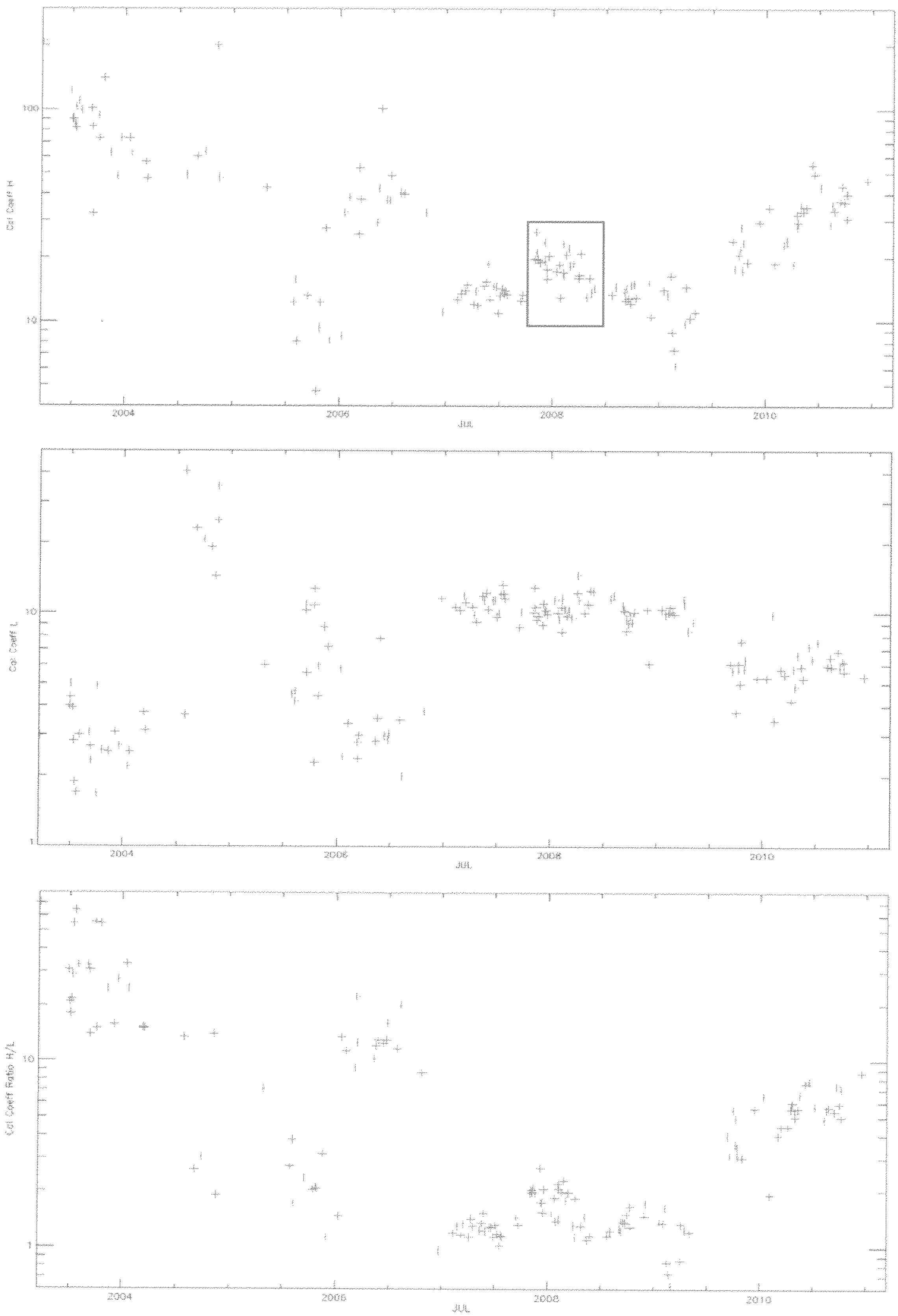


Figure 1 Time series of calibration coefficients for the upper channel (upper panel), the lower channel (middle panel) and the ratio between calibration coefficient for the upper and the correspondent for the lower channel. *See text for the discussion of data within the blue rectangle.*

- Interferential Filter (IF) not correctly blocking the elastically backscattered 355 nm radiation. This hypotheses seems to be at least partly supported by the improvement when changing the IF's in summer 2009 (see below).
- Fluorescence 'somewhere' (likely in the optical fibers) that produces a signal at the Raman wavelength.

Figure 2 show the WV profile in the atmospheric region were a minimum is expected to occur (4-7 ppmv) in water vapour. The figure is obtained using the calibrated sessions reported in the appendix.

- black symbols are retrieved mixing ratios (in ppmv) with vertical sampling of 75 m but integrated over the whole session (typically 3-4 hours) and vertically up to 1 km thick layer.
- orange line is the average profile obtained from the average of all black symbols.
- grey line is the average profile obtained from the average of 2007-2008 profiles.
- the pink + symbols are the average summer values for midlatitude as estimated from the figures of a paper on MLS observations (Van Thien et al. 2010).
- the colored lines are the seasonal and total (see legend) average profiles of mixing ratio as obtained from the radiosounding without applying any correction to the original data.
- The light grey band include the interval 5-7 ppm (this range should likely be a bit larger, it depends on how much of the distribution you want this statement to pertain to) that is expected at the tropopause.

NB. Only retrieved mixing ratio values with a SNR≥5 have been plotted and used in the statistics. This simple a-posteriori test on the SNR seems to filter out quite efficiently unrealistic values, however, see also below, still in some cases low quality observations may pass this filter requiring the development of an a-priori quality control. The grey curve is the average profile obtained using only observations between 2007-2008 period for which we have good confidence on the performances of the system.

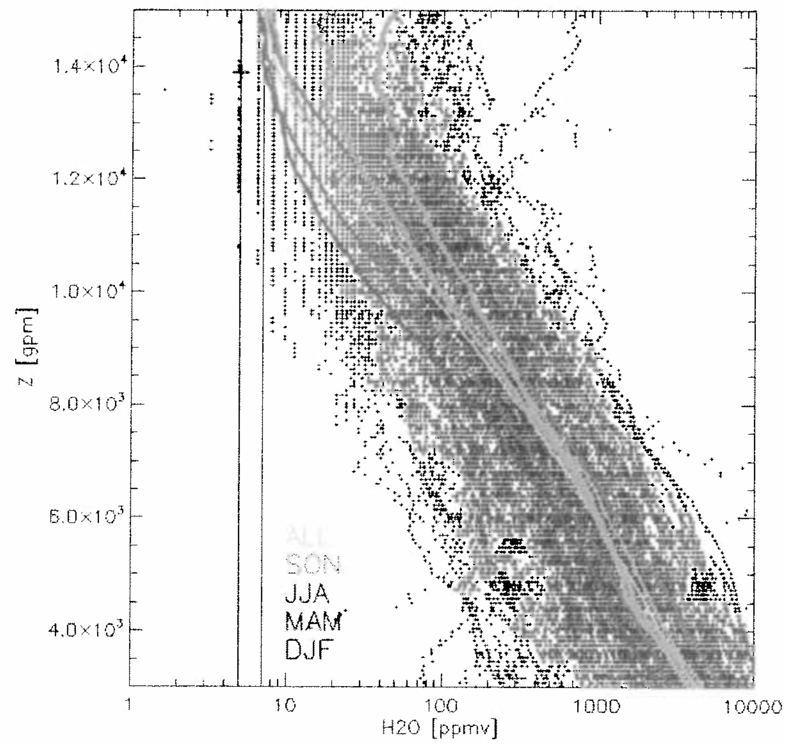


Figure 2. Water vapour profiles in the Upper Troposphere. See text for explanation.

If we consider, for the 2007-2008 period a wet bias of about 10 ppm, to the reference 5-7 ppm, this corresponds to a mixing ratio of 0.006 g/kg. Assuming an average calibration value of 10 and an average count value, in the N2 channel of 70, the wet bias corresponds to a WV count value of about 0.04. Considering that the average count value in the elastic 532 channel in that region of the atmosphere is about 200 and assuming the effect is simply proportional to the elastically scattered signal then a correction coefficient should be of the order of 10^{-4}.

Automatic Quality Control (QC) of the raw data. The current procedure does not apply any a-priori QC of the raw data having confidence that the a-posteriori analyses of the SNR would be able to eliminate low quality observations. However it appears than in few cases (e.g. **050427**_____) low quality raw data are responsible for low quality processed profiles. The origin and the possibility to automatically discriminate low quality raw data need to be investigated at the same time than a post processing procedure to eliminate low quality processed profiles.

Cloud contamination. The current version does not apply any test for cloud contamination however in some cases (e.g. **060310**_____) the effect of cloud contamination is evident. A flag on cloud contaminated observation should be added based on the analyses of the observed elastically backscattered signal at 532 nm.

Figure 3 shows an example of information available from a measurement session processed with the *dynamic integration approach*. The dynamic integration approach consists in a compromise between having meaningful measurements (i.e. with a SNR above a given threshold) and maintaining original 75 m – 1 minute sampling to keep the unique information available from lidar derived WV profiles on temporal and vertical variability. With this approach each single bin is processed at the original sampling rate then if the SNR is below the given threshold (5 in the reported case) the measurements are integrated within a 2D boxcar progressively and *anisotropically* up to reach a SNR larger than a given threshold (5 and 10 in the two examples reported). A maximum integration on the vertical of 1 km (i.e. 13 vertical bins) is allowed. The panels show from up left to low right:

- Mixing ratio [g/kg] where the merging between lower and upper channels is obtained by selecting, below 6 km, the observation for the channel with the higher SNR. Above 6 km the profile is given by the upper channel. The colour scale corresponds to the first column in the legend in the lower right corner. Each column refers to one panel from top left to low right.
- Mixing ratio [g/kg] for the bins where the lower channel was selected. The colour scale is dynamically adjusted on the basis of min and max value.
- Absolute value of the relative difference [%] between single profiles and session averaged one. Values below 10% are black. This panel should somehow contain the information on temporal variability.
- SNR. The white line is the average profile.
- Total number of valid bins used in the integration. The white line is the average profile.
- Maximum time range used in the integration (NB this may not refer to the same vertical level). The white line is the average profile.
- Maximum vertical range used in the integration (NB this may not refer to the same single acquisition time profile). The white continuous line is the average profile the dashed one is the square root value of the total number of bins used in the integration (both curves are multiplied by the same scaling factor to make them visible).

The examples reported in Figure 3 shows the behaviour of the dynamic integration. For example the relatively dry structure observed at about 4 km need a signal integration to reach the SNR threshold, while in this case up to 8 km there is no need for integration if the minimum required SNR threshold is 5.

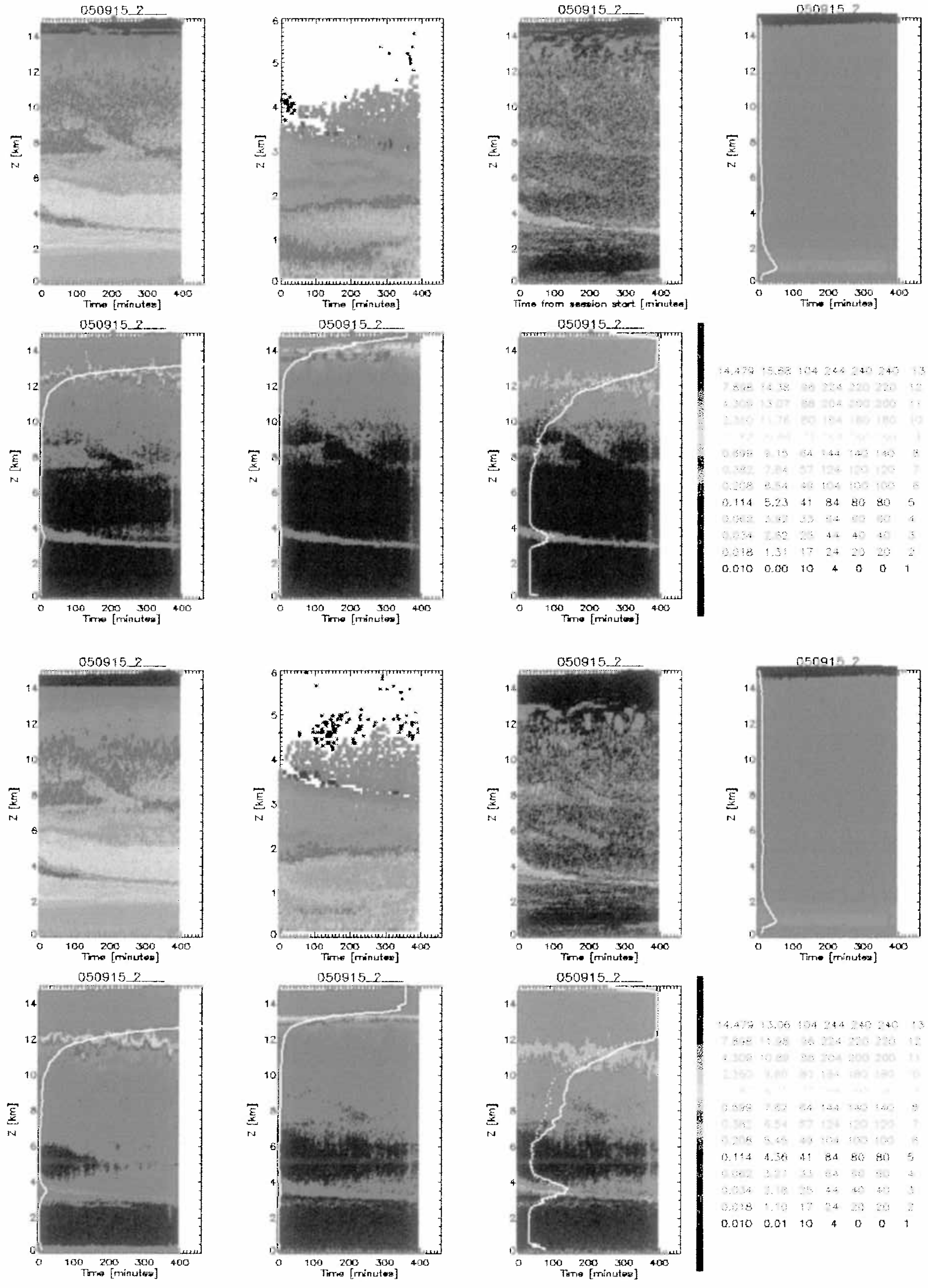


Figure 3. Examples of time series of WV mixing ratio profiles obtained with the dynamic integration approach during a measurement session. Upper panel SNR≥5 lower panel SNR≥10 (see text for explanation of single panel content)

Figure 4 shows profiles of statistics obtained from the subset of sessions processed with the dynamic integration approach with a minimum SNR threshold of 5. The panels show from up left to low right:

- total number of bins having a SNR≥5 (i.e. the bins used in the reported statistics)
- average WV mixing ratio profile;
- average SNR profile;
- average # of single 75 m- 1' bins used in the integration;
- average maximum integration time interval
- average maximum vertical integration interval and (blue line) ratio between the square root of the total number of bins and the maximum vertical integration interval. This latter curve contains information on the anisotropy of the integration. As expected the ratio is larger than one that means that integration is performed preferentially in time.

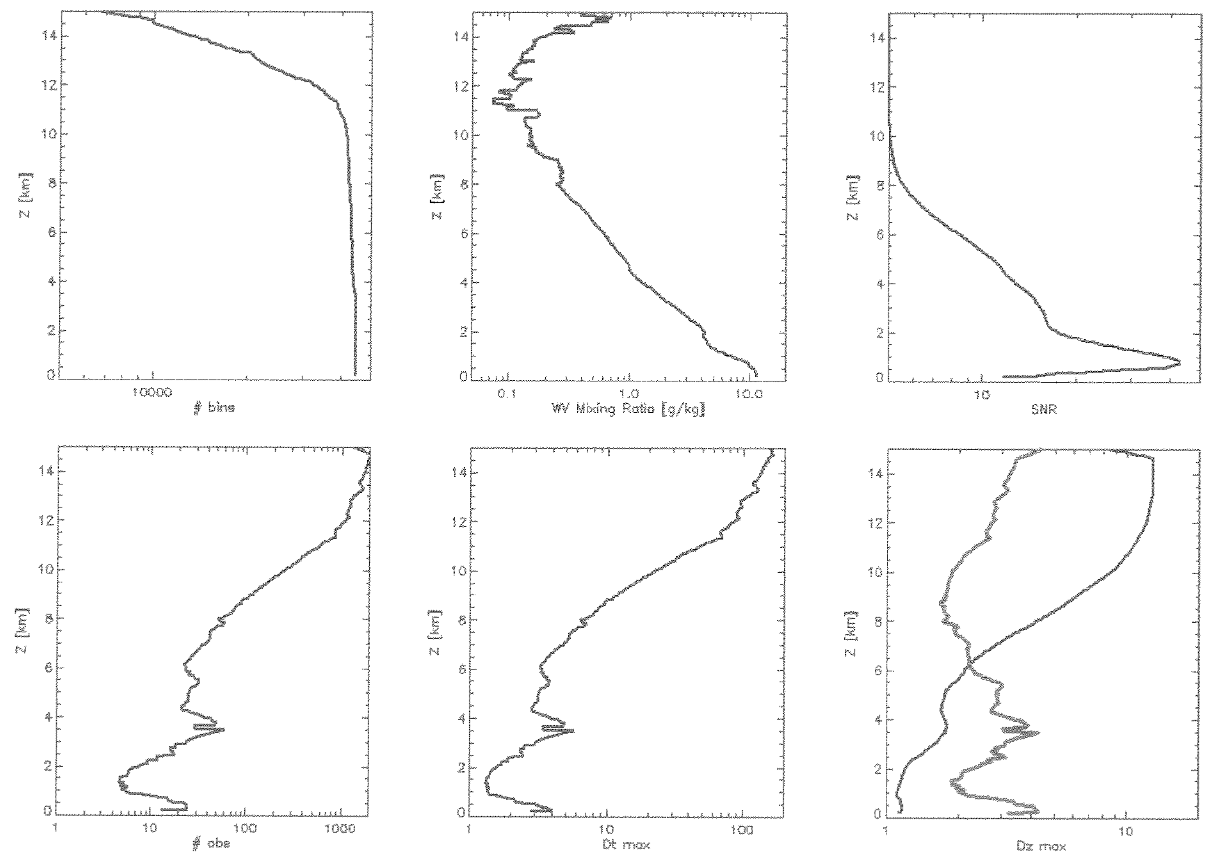


Figure 4. Profiles of statistics obtained from the subset of sessions processed with the dynamic integration approach with a minimum SNR threshold of 5. See text for explanation.

References

- Congeduti, F., F. Marenco, P. Baldetti, E. Vincenti, The multiple mirror lidar "9-eyes", *J. Opt. A: Pure Appl. Opt.*, 1, 185-191, 1999.
- Dionisi,D., F.Congeduti, G.L.Liberti, and F.Cardillo, 2010. Calibration of a multichannel water vapor Raman lidar through noncollocated operational soundings: optimization and characterization of accuracy and variability. *J. Atmos. Oceanic Tech.* 27, 1, 108-121.
- Van Thien, L., W.A. Gallus, M.A. Olsen, N.Livesey, 2010: Comparison of Aura MLS Water Vapor Measurements with GFS and NAM Analyses in the Upper Troposphere–Lower Stratosphere. *J. Atmos. Oceanic Technol.*, **27**, 274–289.

Appendix 1. Examples of processed profiles

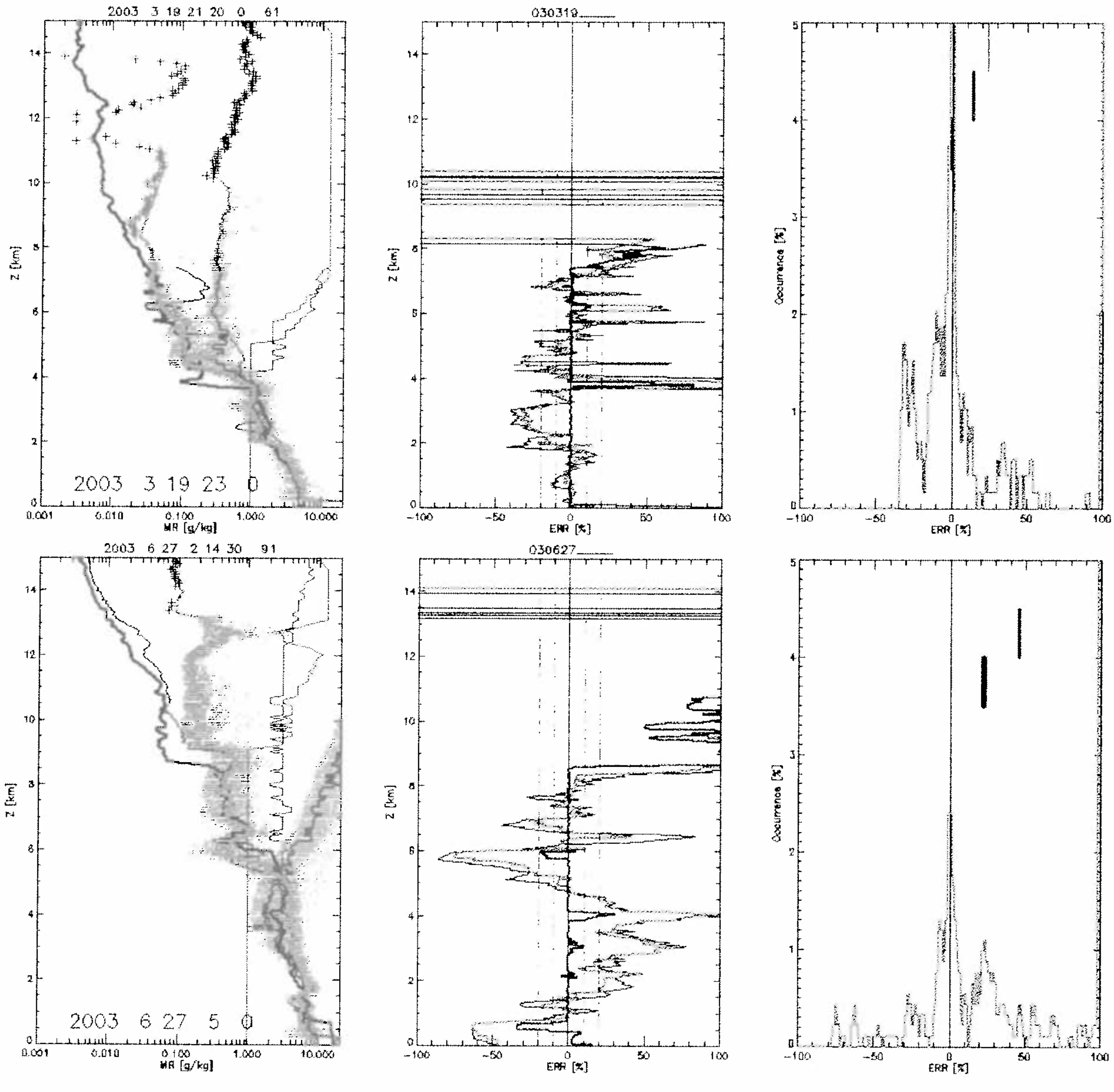
Description of the figures
For each session a set of 3 panels is reported.

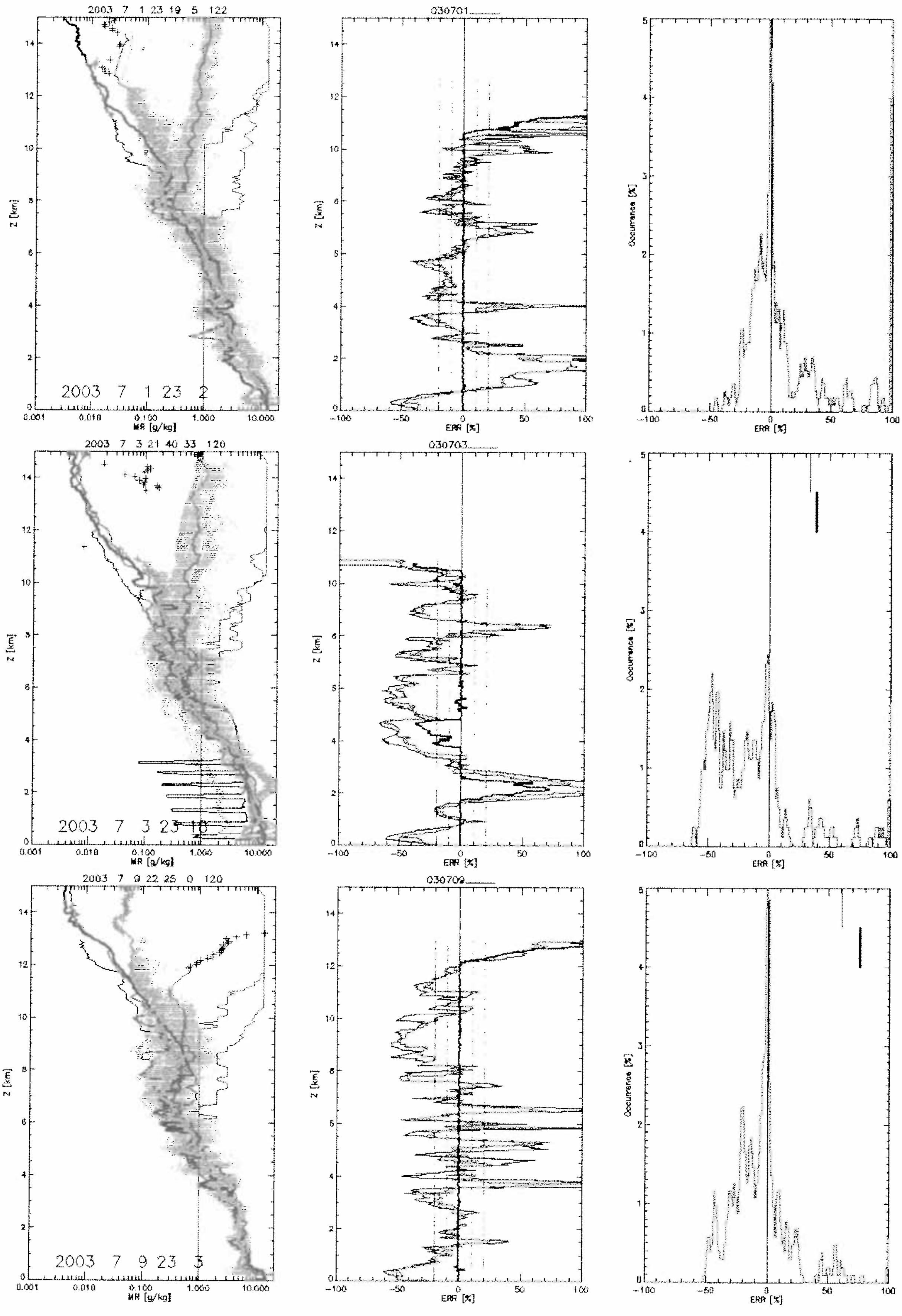
The **left panel** contains the mixing ratio profiles.
The *title* of the panel contains the starting time (YY MM DD HH MN SS) of the Raman measurement session and (last number) the number of single 1' profiles acquired during the session.
The black thick line corresponds to the profile from the radiosonde data closest in time with the average (0.5*(timestart-timestop)) session time (starting time of the launch reported in the bottom of the figure). This sounding is very likely the one used to compute the calibration constant.
Other radiosonde profiles (max 2) may be plotted as thinner black lines if their time is within 6 hours from any of the Raman session profiles. This additional information, when available, is useful to have an idea of variability of water vapour during and in the time around the session.
All radiosonde data are from the RS92 data (with no additional correction) launched from the close site of Pratica di Mare (22 km). If no black lines are reported there were radiosonde observations available within 6 hours from any of the time of the profiles.
Session integrated water vapour mixing profiles for the low (blue line) and the upper (red line) channel and the corresponding merged one (grey line). Note that the grey line covers one of the two profiles according with the merging criteria. The merged profile represents the final product that should be archived.
The session integrated profiles are obtained integrating temporally over the whole session and vertically only if the resulting SNR at the 75 m original sampling is lower than 5. The vertical integration is performed dynamically using a vertical box growing with a step of 2 (i.e. giving boxcars of 5,9,13) and selecting progressively within the box the more homogeneous bin (NB there contiguity is not required). A maximum of 1 km (13 vertical bins) vertical integration is allowed. Larger integration intervals were expected to produce not useful information. The boxcar is moved to maintain the original 75 m vertical sampling. The number of vertical bins used in the integration is reported with the thin blue and red lines (range1-13). Profiles are plotted as thick lines if the SNR≥10. Thin line if SNR≥5. Plus signs are reported for the levels for which the SNR<5. For the grey line it is thick if SNR≥10 and dashed if SNR≥5.
Merging is obtained, below 6 km, by selecting the profile value with the highest associated SNR.
Pink and green dots corresponds to *dynamically integrated* single profiles for the low and upper channel respectively. Dynamically integrated profiles are obtained by maintaining the original 75 m – 1 minute sampling but integrating within a 2D boxcar progressively and *anisotropically* up to reach a SNR≥5. Only bins with SNR above 5 are plotted.

The **center panel** reports the relative difference [%] against the closest in time radiosonde profile (the thick black line in the left panel).
The title is the name of the session in the raw data archive.
Note that for the majority of the cases, but not for all, this corresponds to the profile used to calibrate. The thin black line is the difference, at the radiosonde sampling (about 30 m) between the radiosonde value and the Raman derived value, in the merged profile, of the bin corresponding to the level of the radiosonde taking into account of the different elevation of the stations. The grey lines is obtained searching for each radiosonde value the value in the merging profile with the lowest absolute value of the relative difference within +/- 2 vertical bins from the geometrically correspondent one (the one used for the thin black line). For each level the vertical shift is reported as red dots.

The green line is the composite profile of relative difference obtained by searching within any of the dynamically integrated profiles and within +/- 2 vertical bins the minimum absolute relative difference.
Please note that we are comparing profiles with different temporal and vertical samplings and the rationale for such comparison is to spot large and/or systematic errors. For example the green line, because of the calibration procedure is expected to be, at least within a limited vertical range, close to 0 difference.

The **right panel** is the histogram of distribution of the relative difference profile (grey line) of the central panel. The three blue vertical segments represents the average value of the relative difference for 0-5 km (thick line), 0-10 km (medium line), 0-15 km (thin line).
Again this plot should help to find large and/or systematic errors but also give us an idea of the expected error if ones compares a radiosonde with a profile obtained integrating over a large amount of time.





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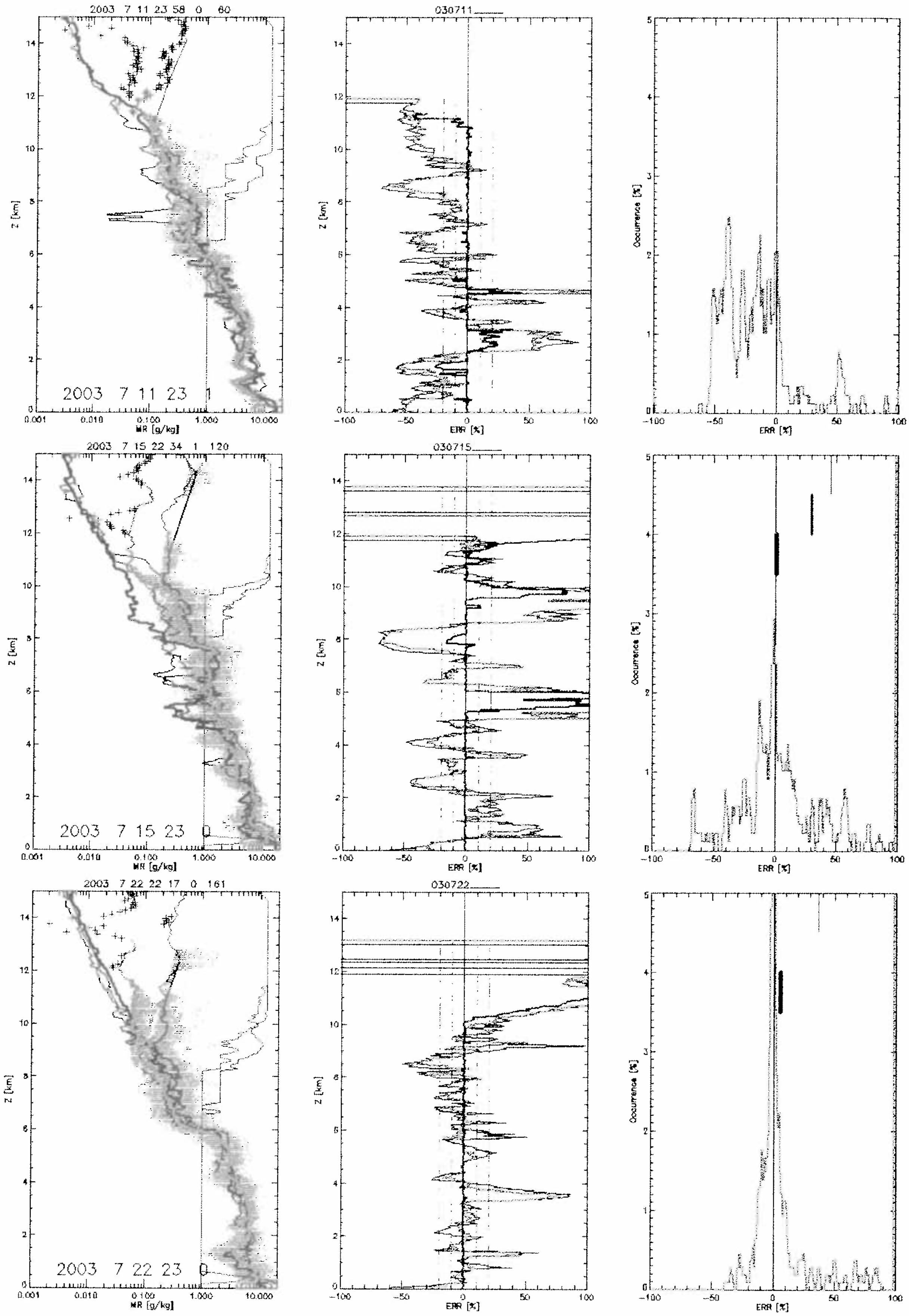
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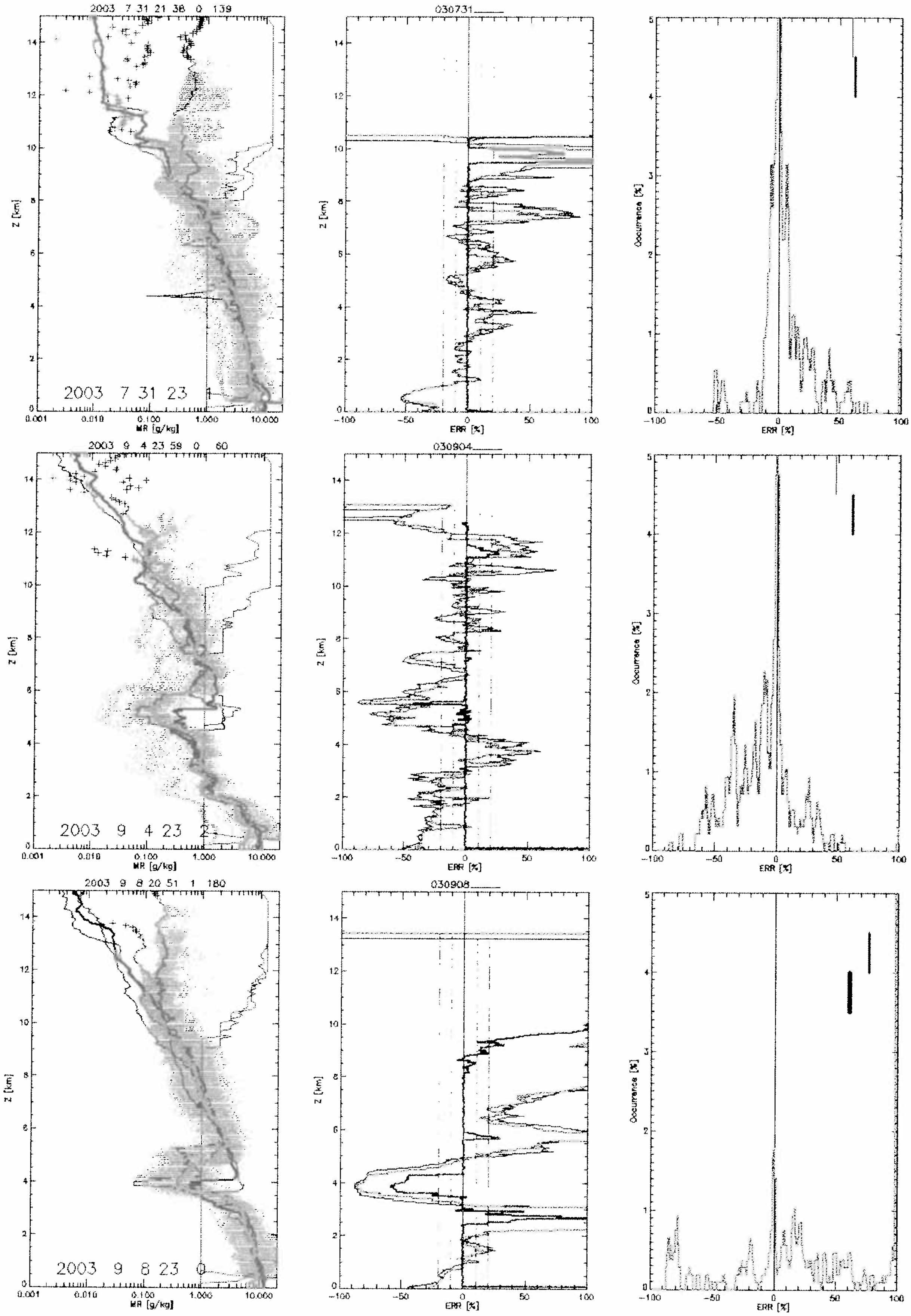
Occurrence [%]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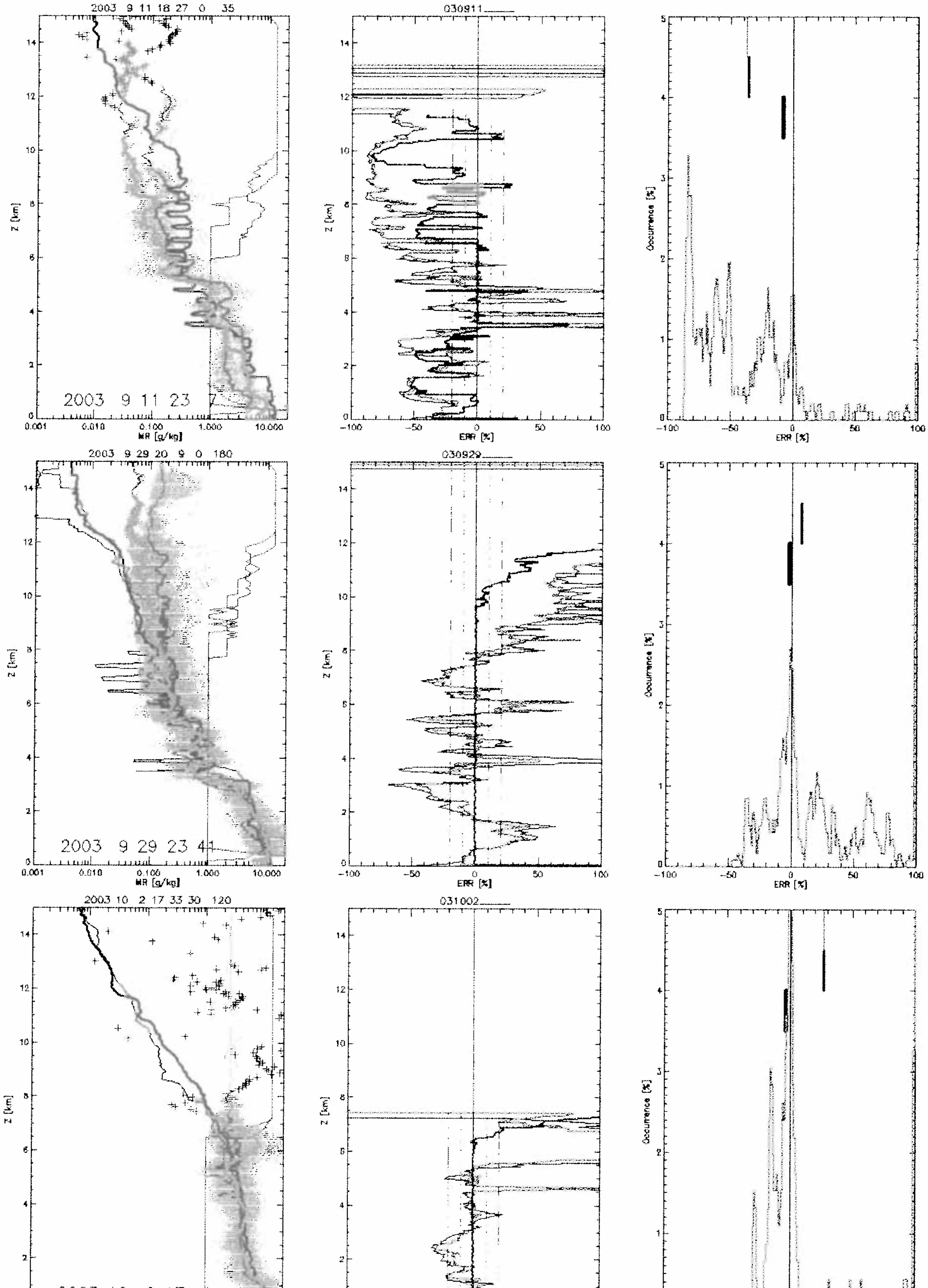
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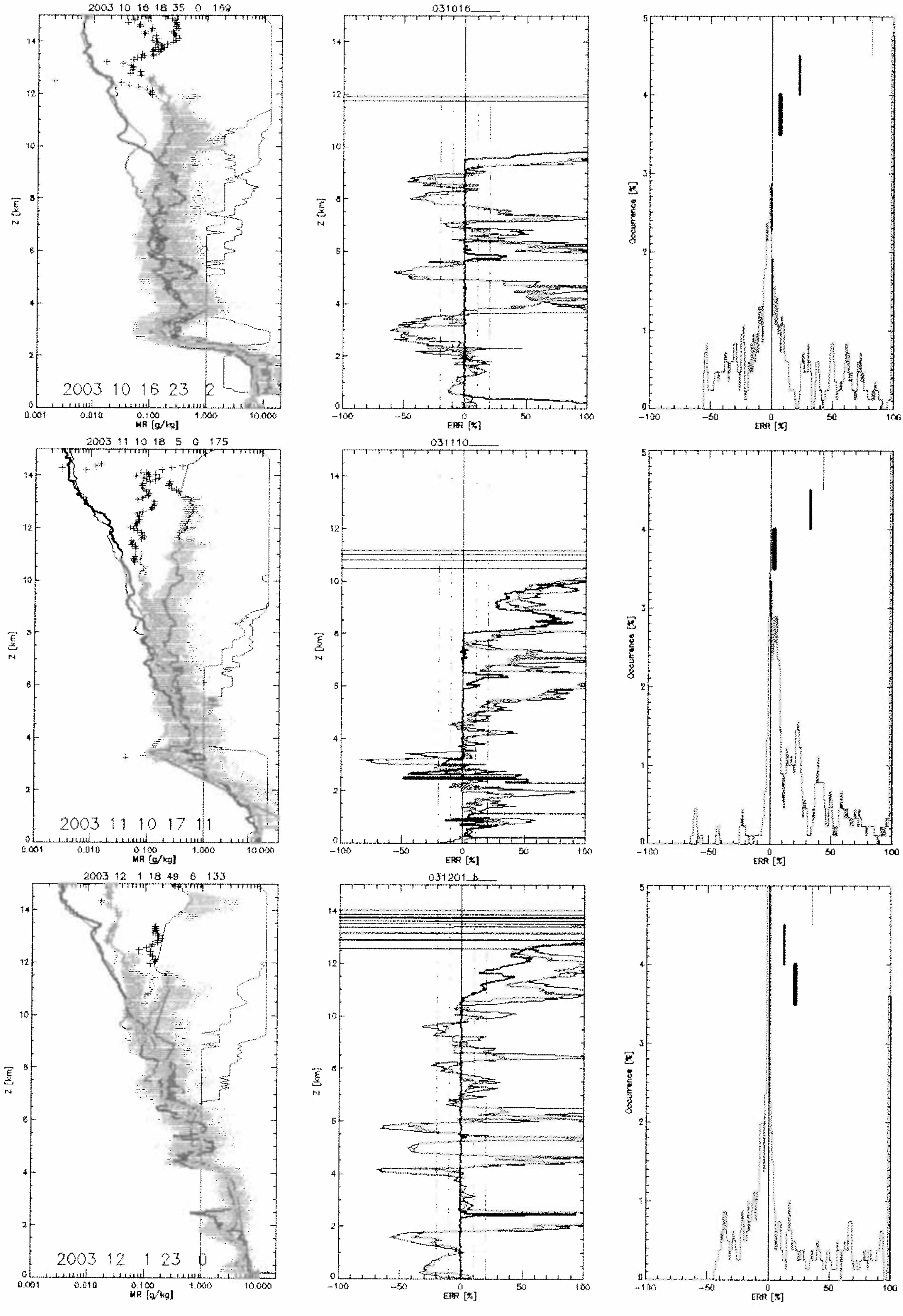
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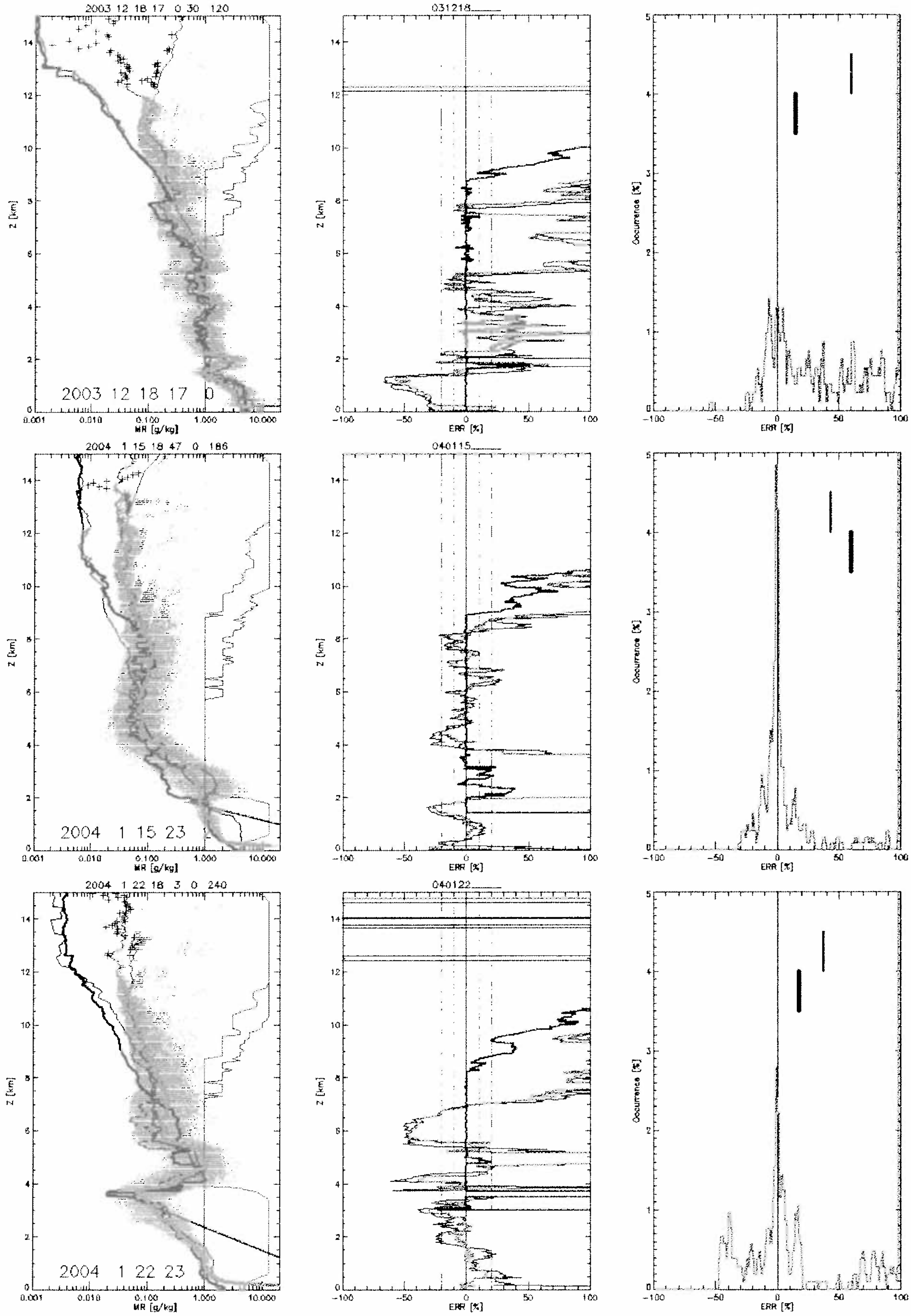

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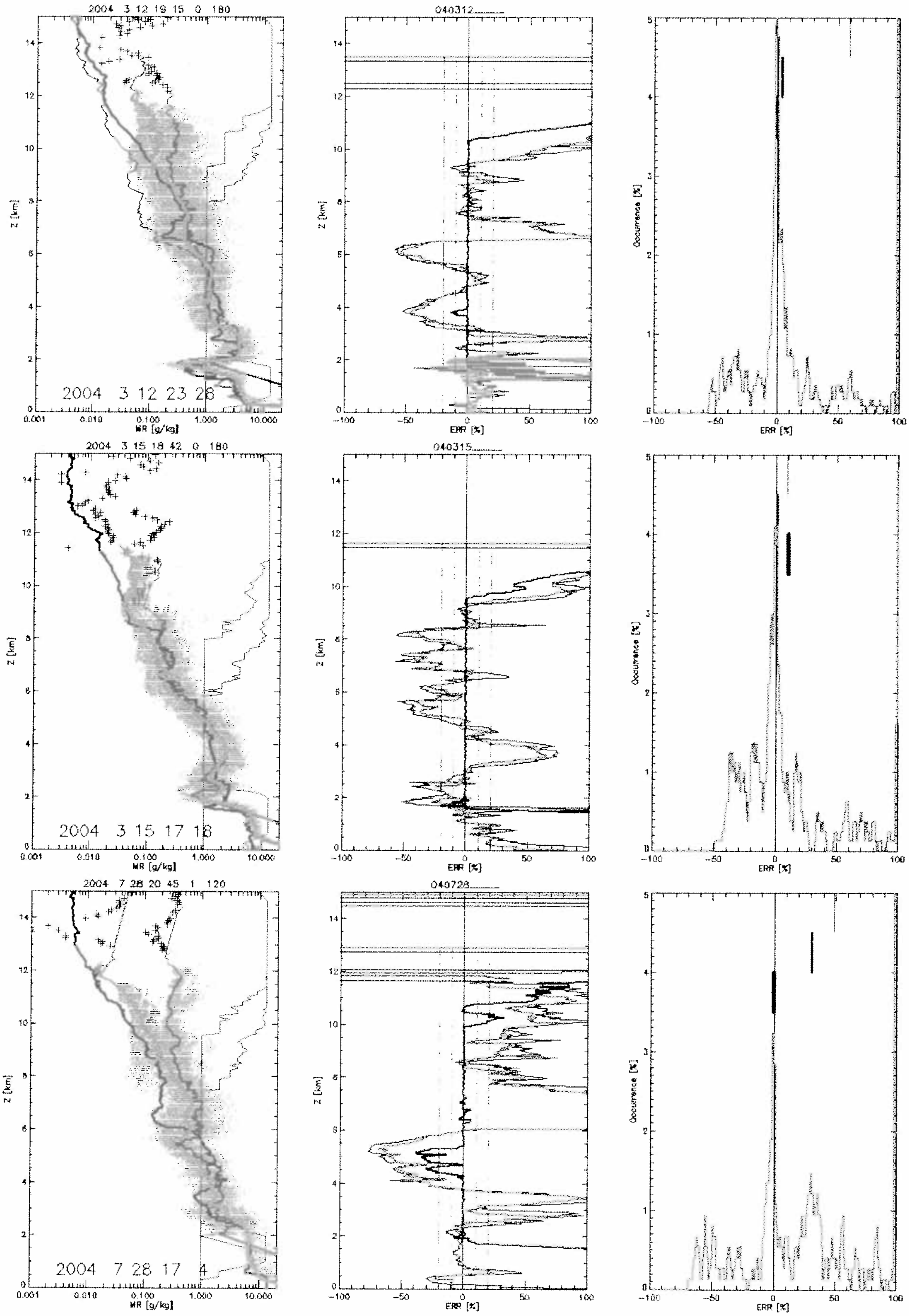
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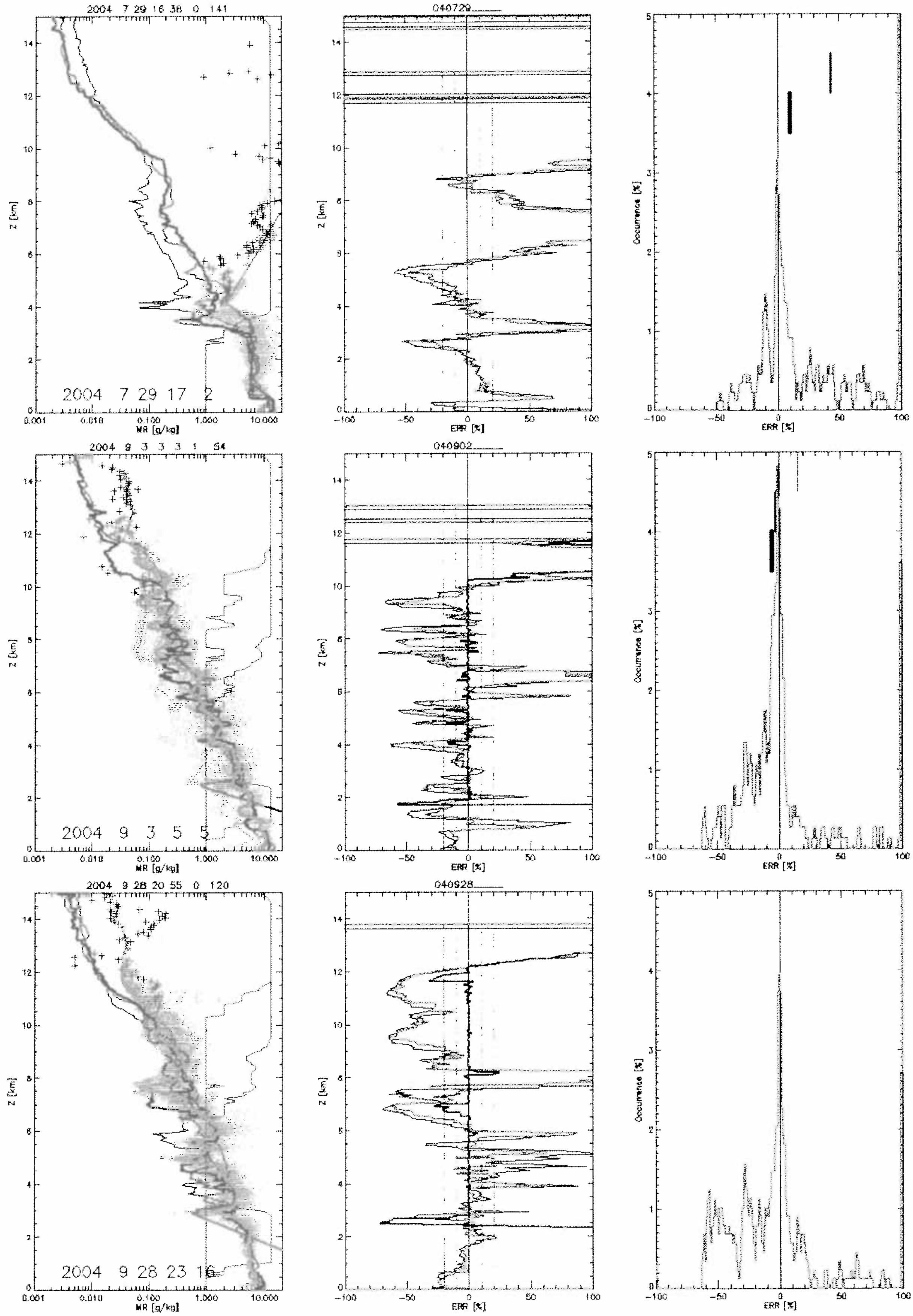
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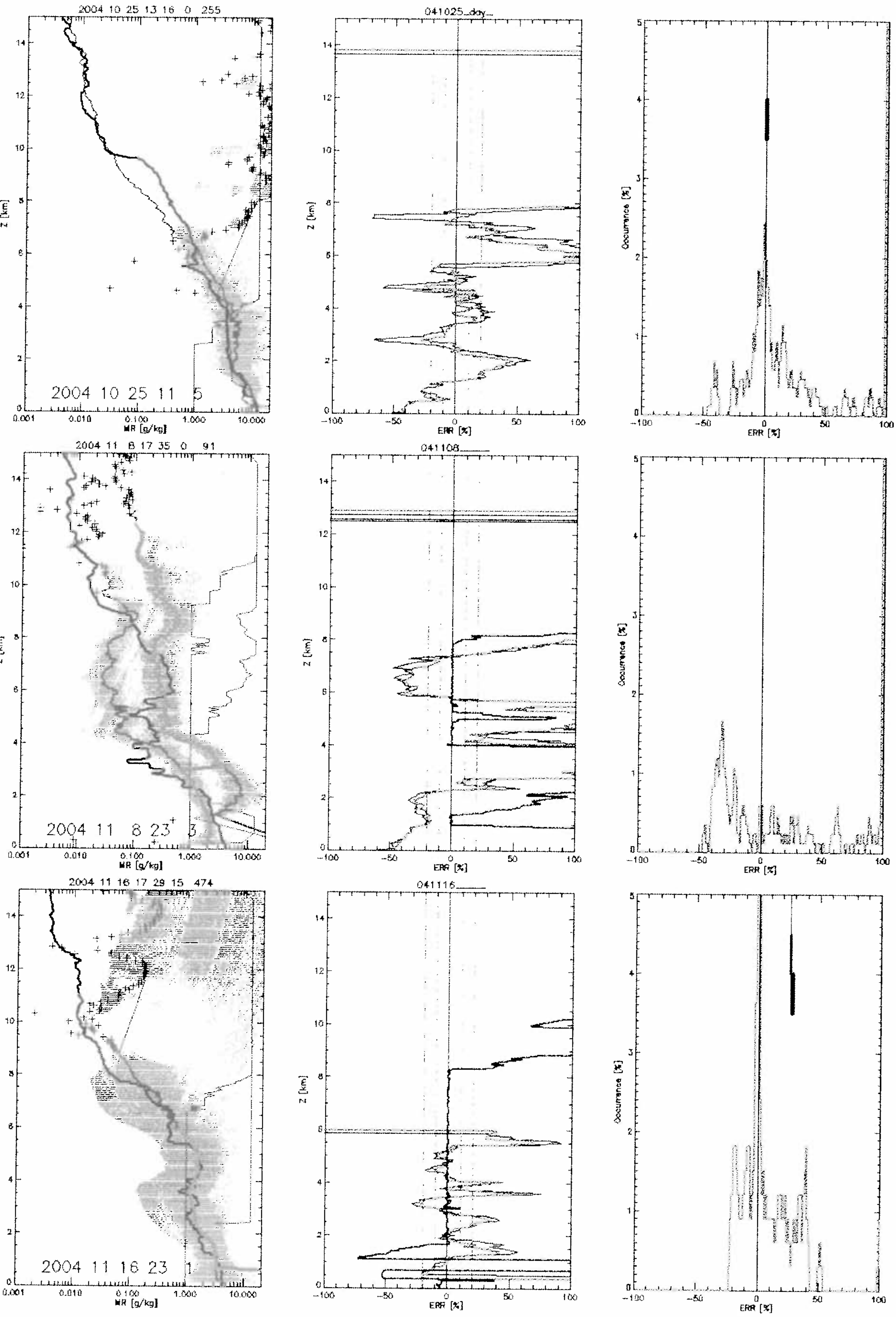

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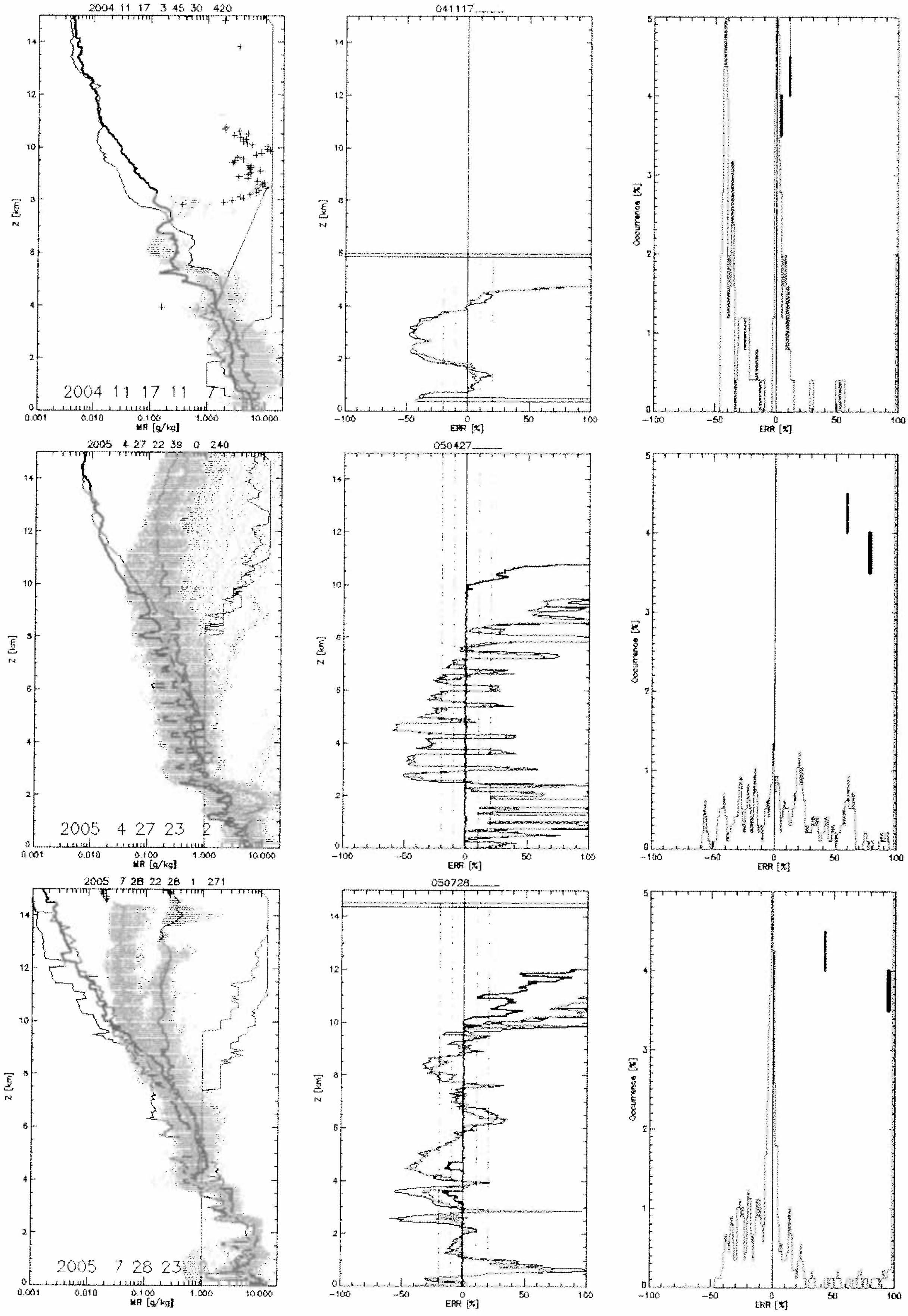
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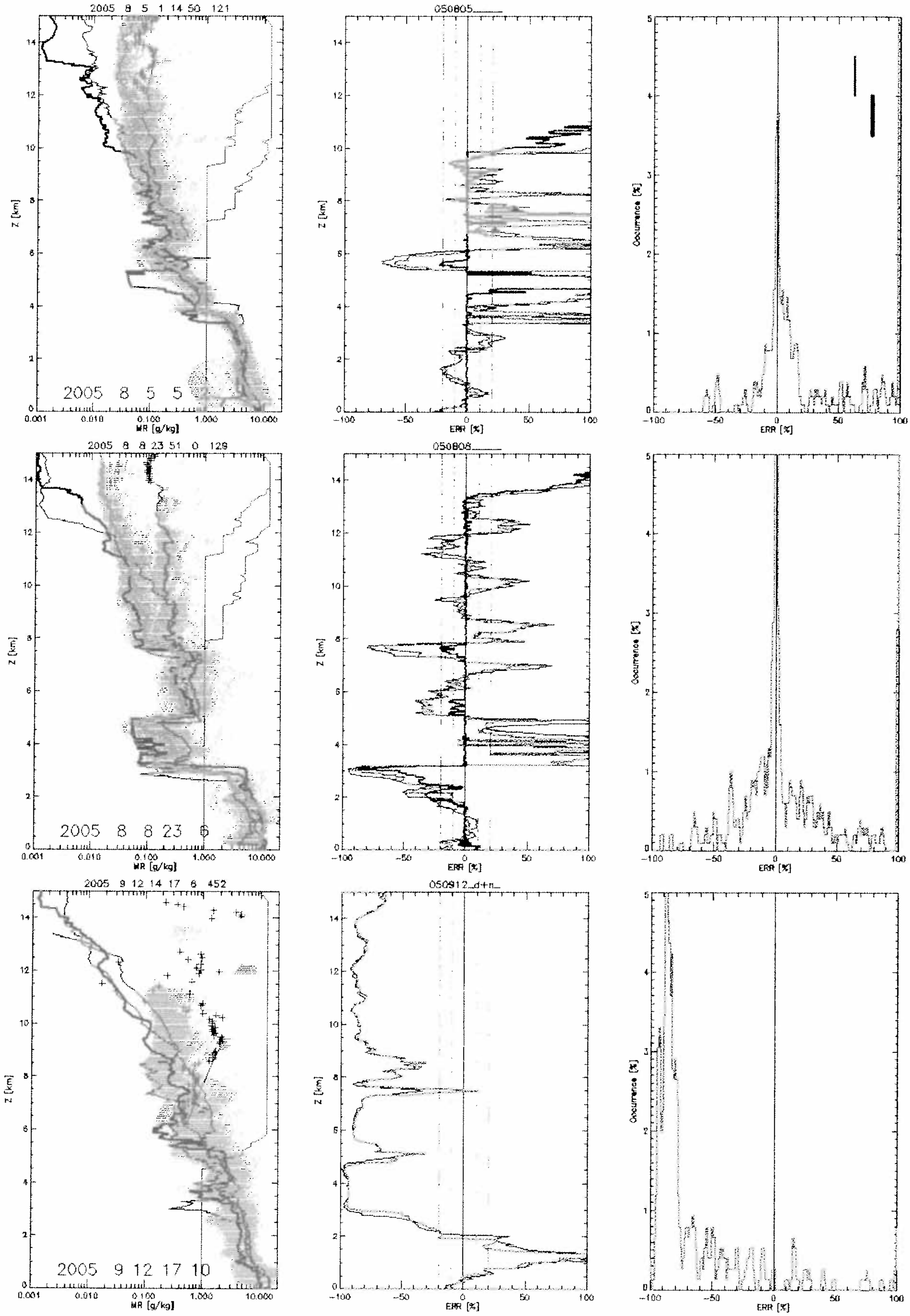
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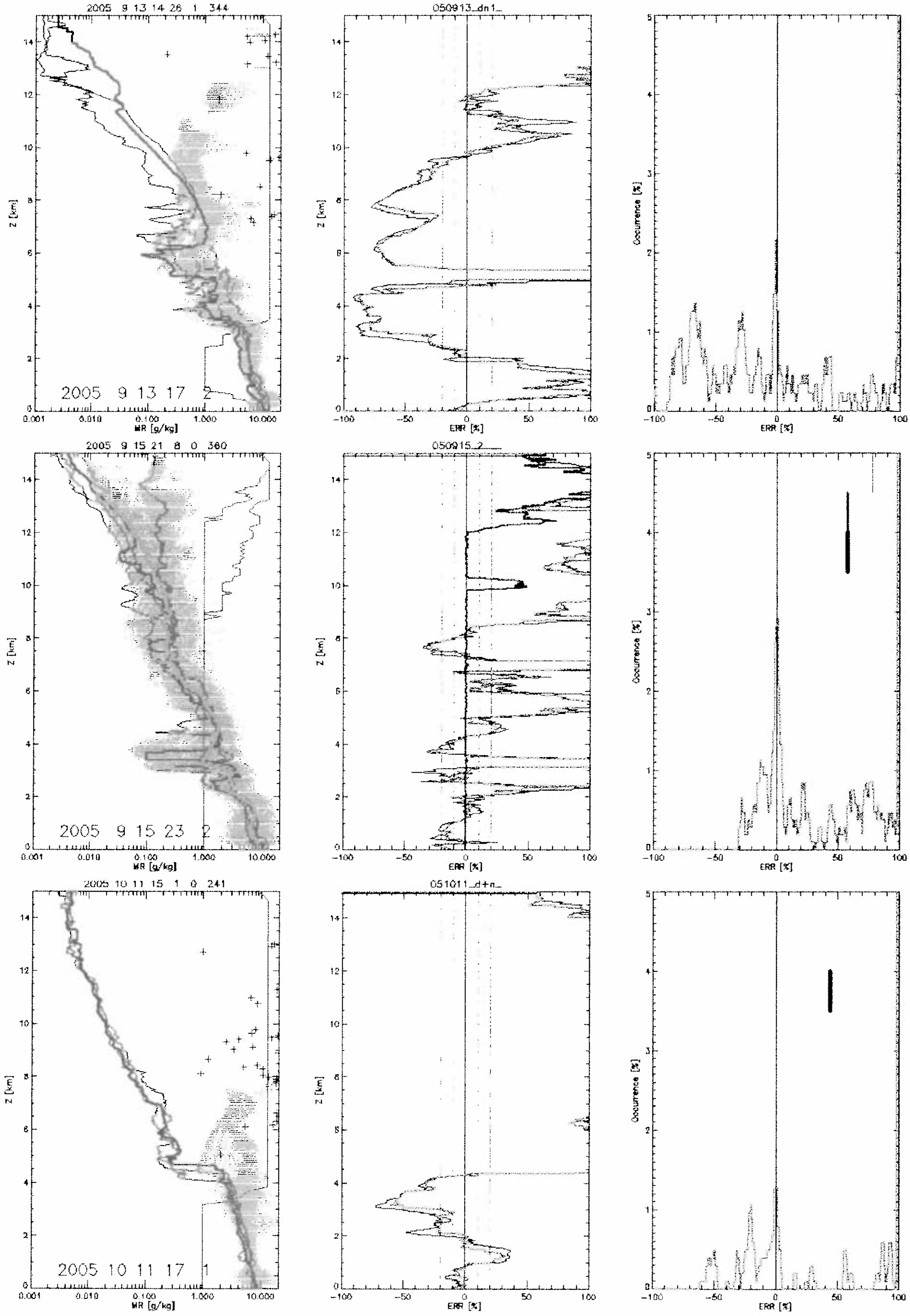
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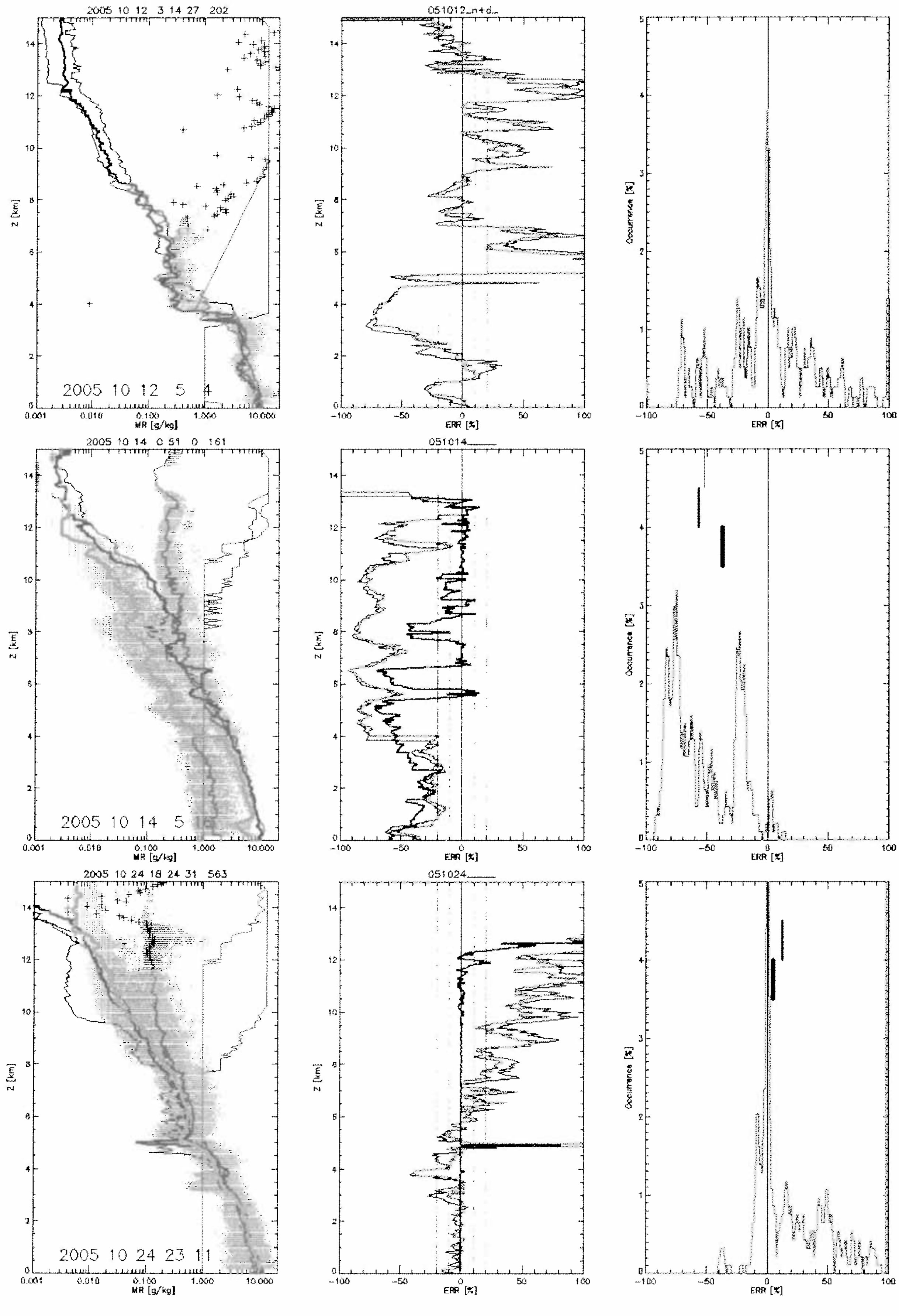
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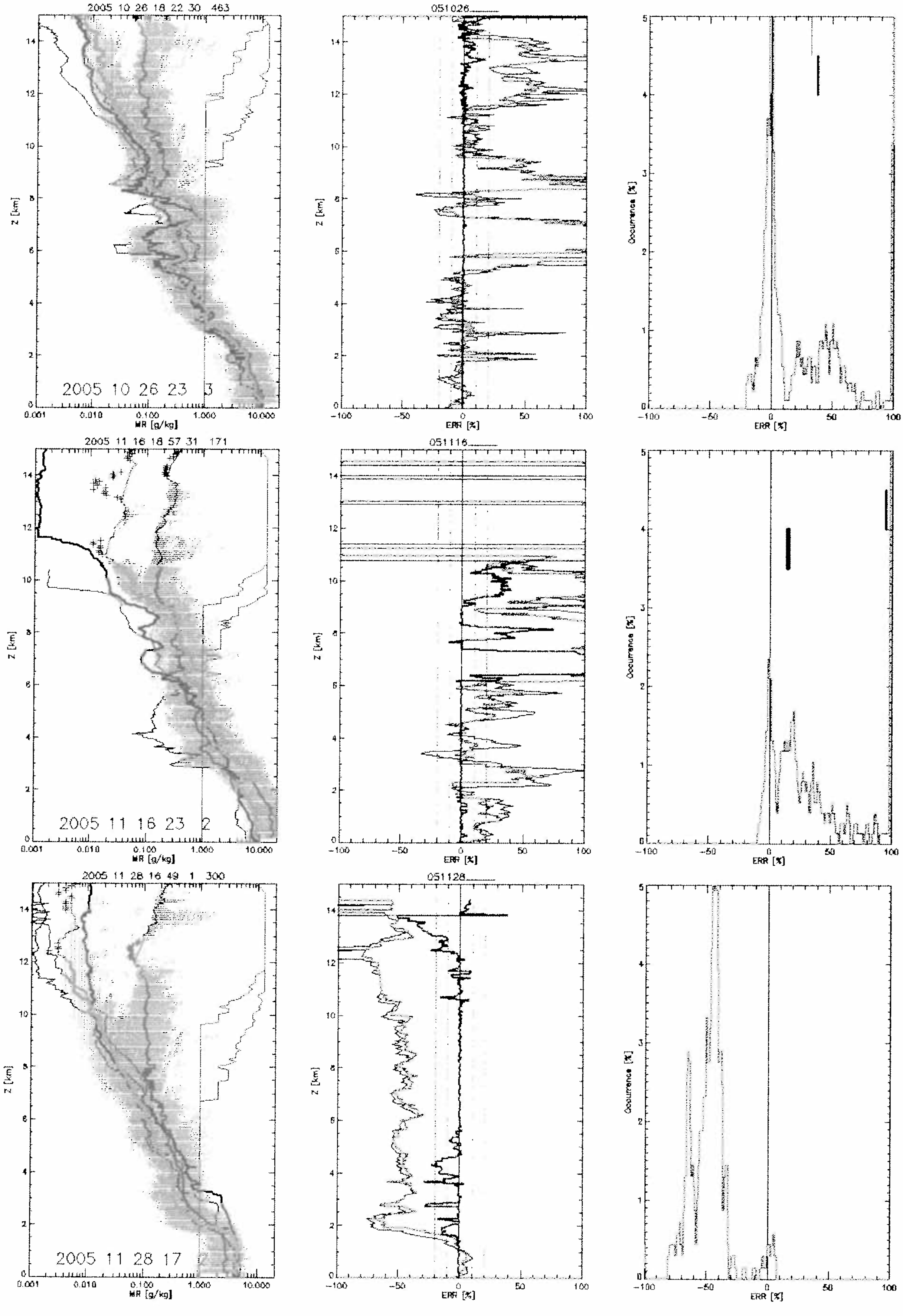
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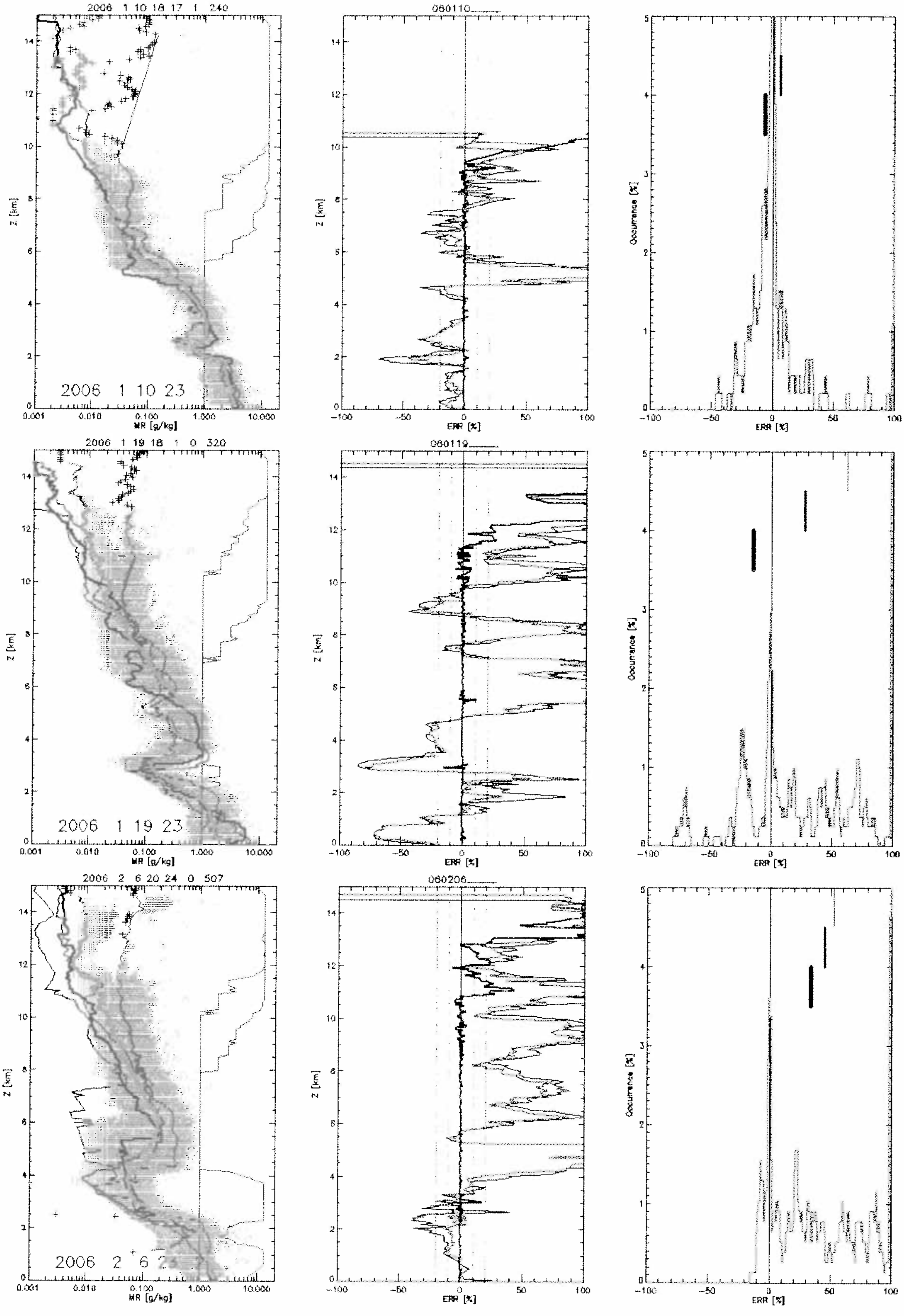
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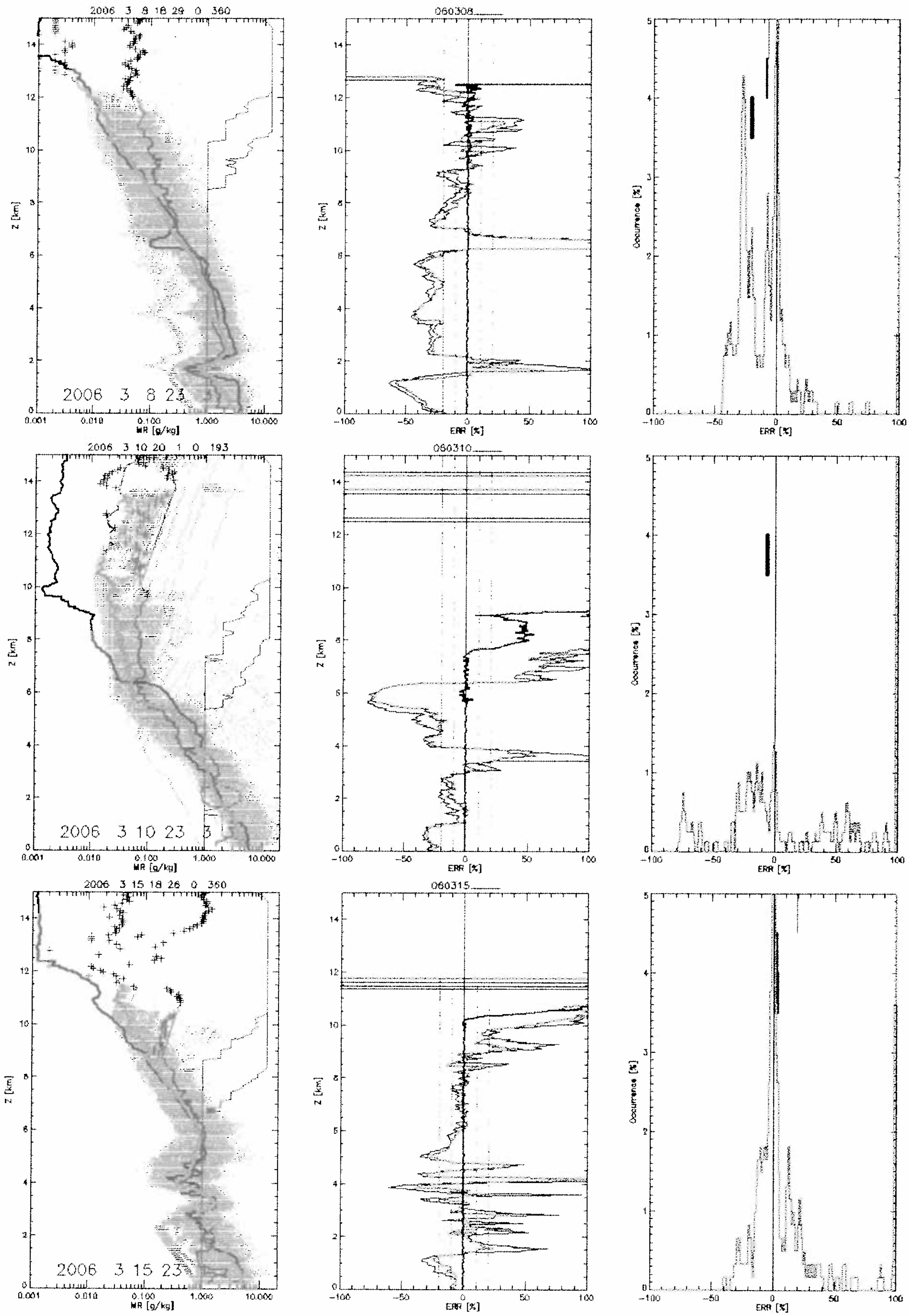
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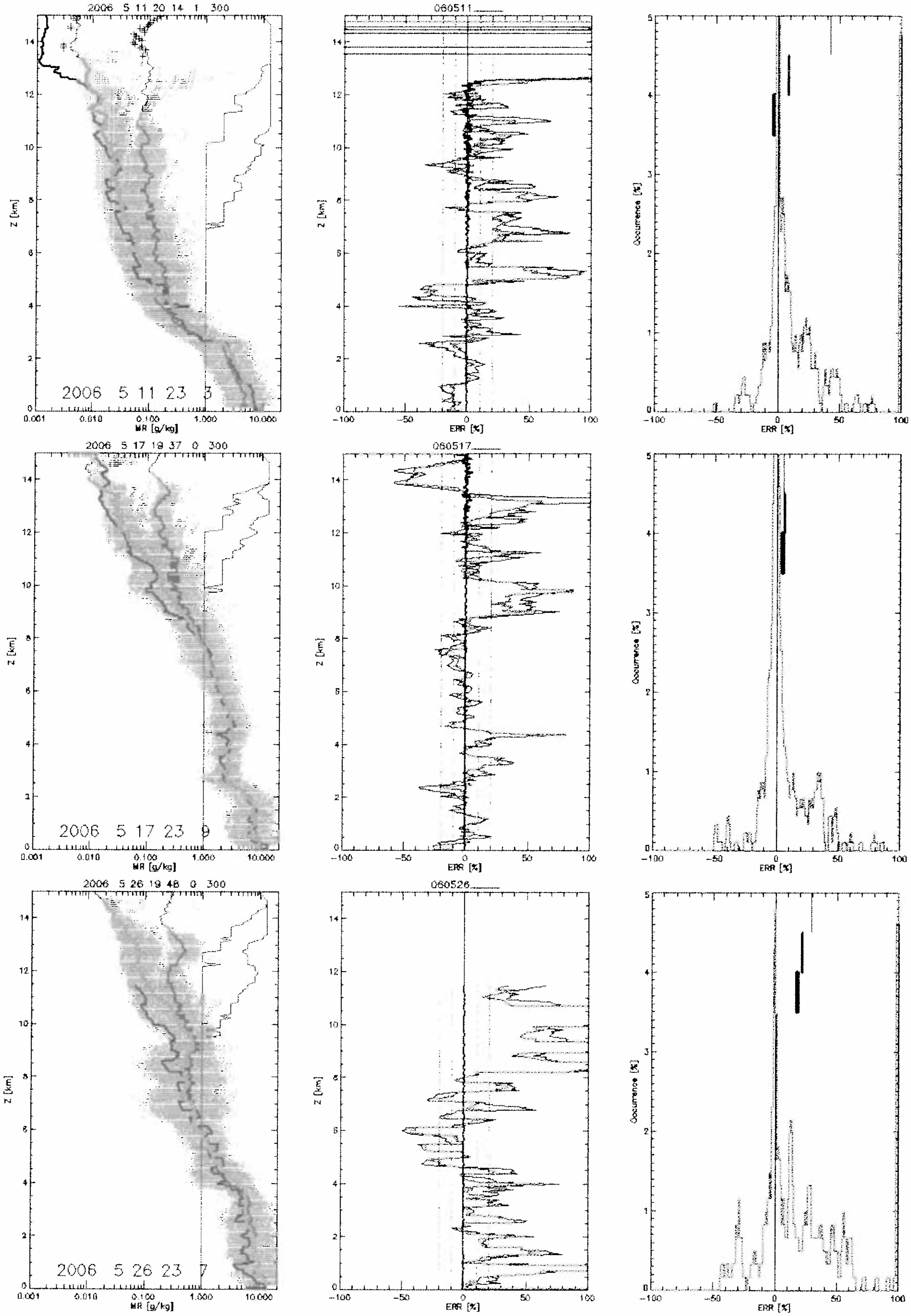
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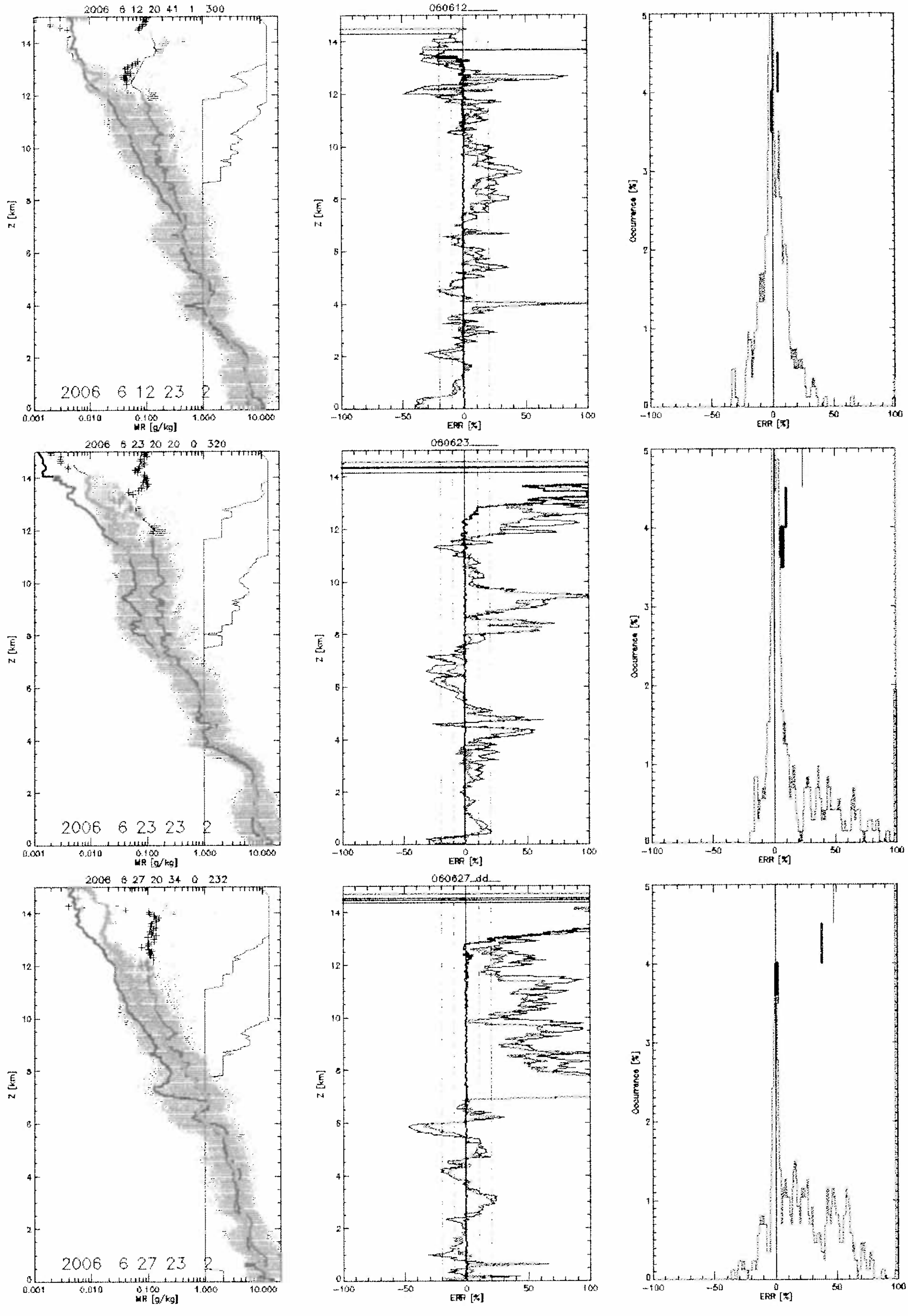
2006 6 12 20 41 1 300
2006 6 12 23 2
060612
2006 6 23 20 20 0 320
2006 6 23 23 2
060623
2006 6 27 20 34 0 232
2006 6 27 23 2
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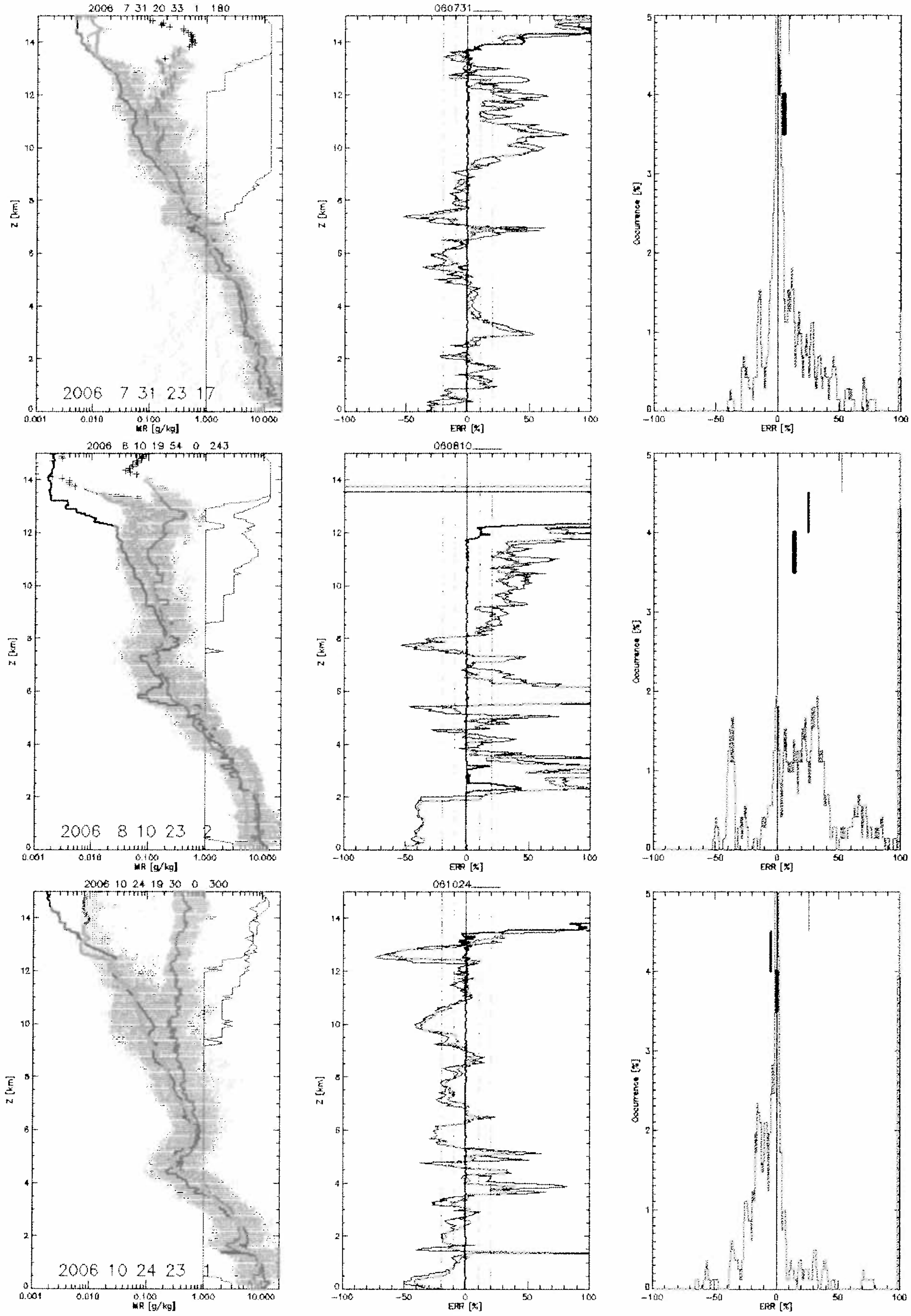
ERR [%]
Occurrence [%]


2006 7 31 20 33 1 180
2006 7 31 23 17
060731
2006 8 10 19 54 0 243
2006 8 10 23 2
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2006 10 24 19 30 0 300
2006 10 24 23 1
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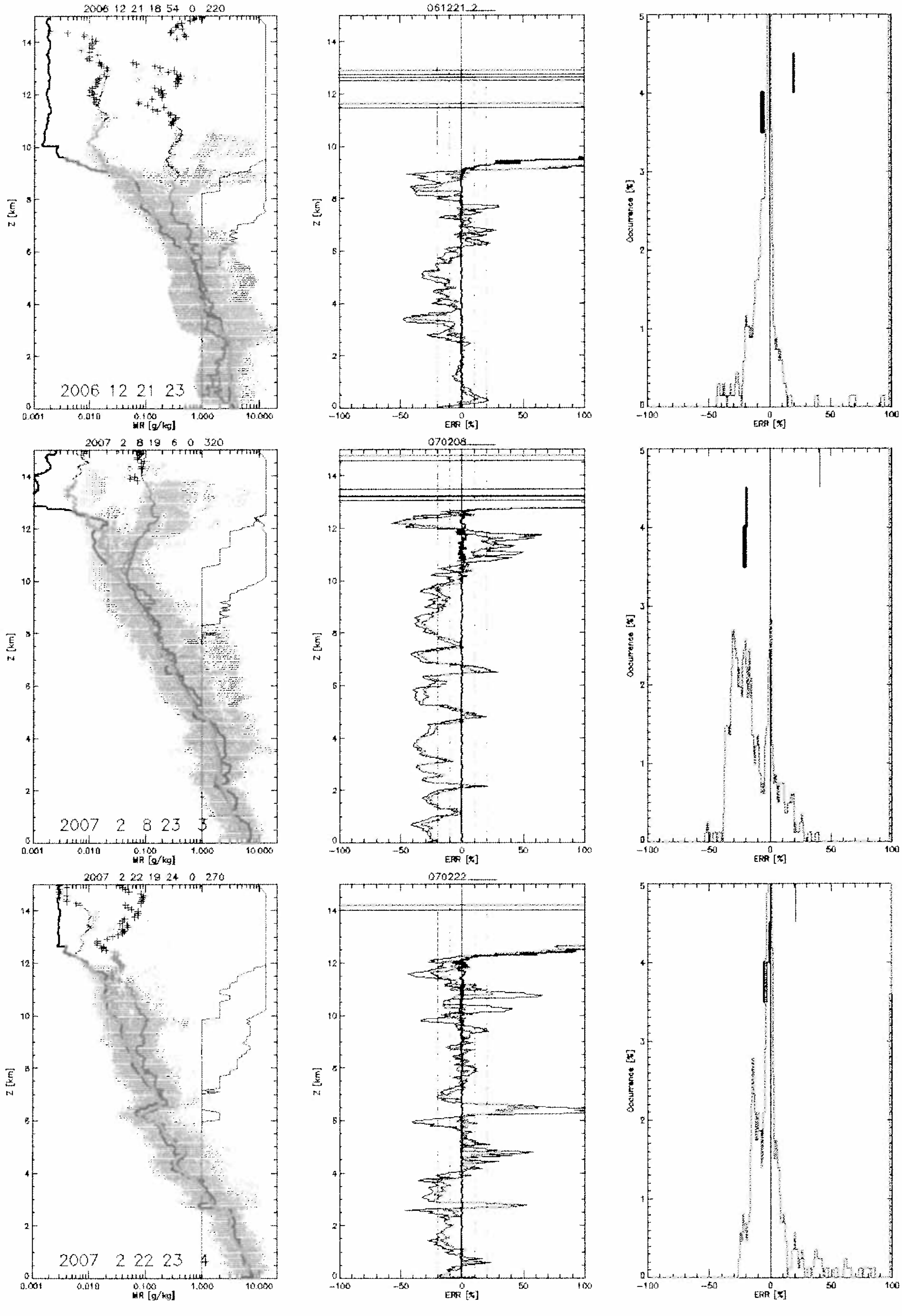

2006 12 21 18 54 0 220
2006 12 21 23
061221_2
2007 2 8 19 6 0 320
2007 2 8 23 3
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2007 2 22 19 24 0 270
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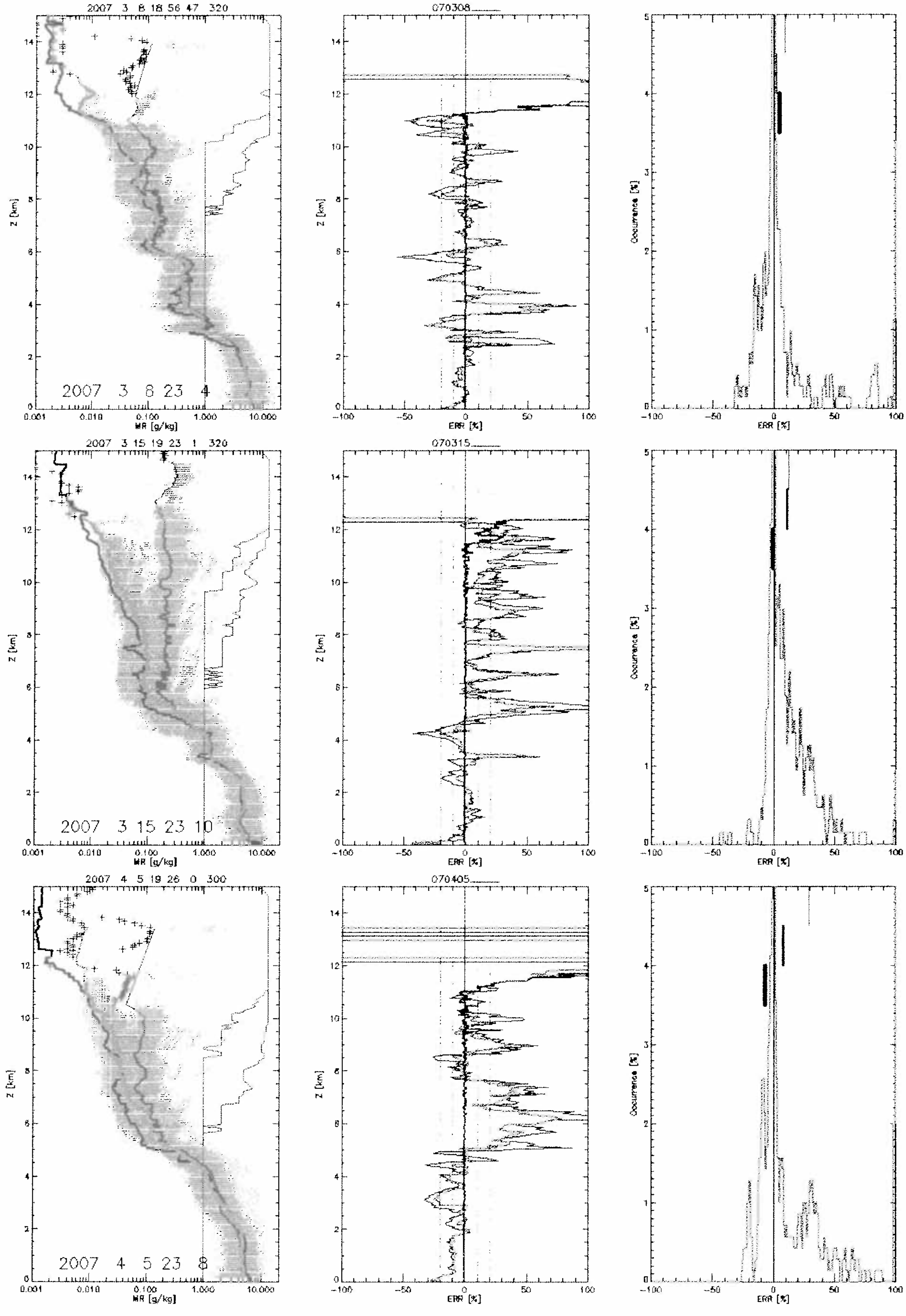
Occurrence [%]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2007 3 8 23 4
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MR [g/kg]
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Occurrence [%]
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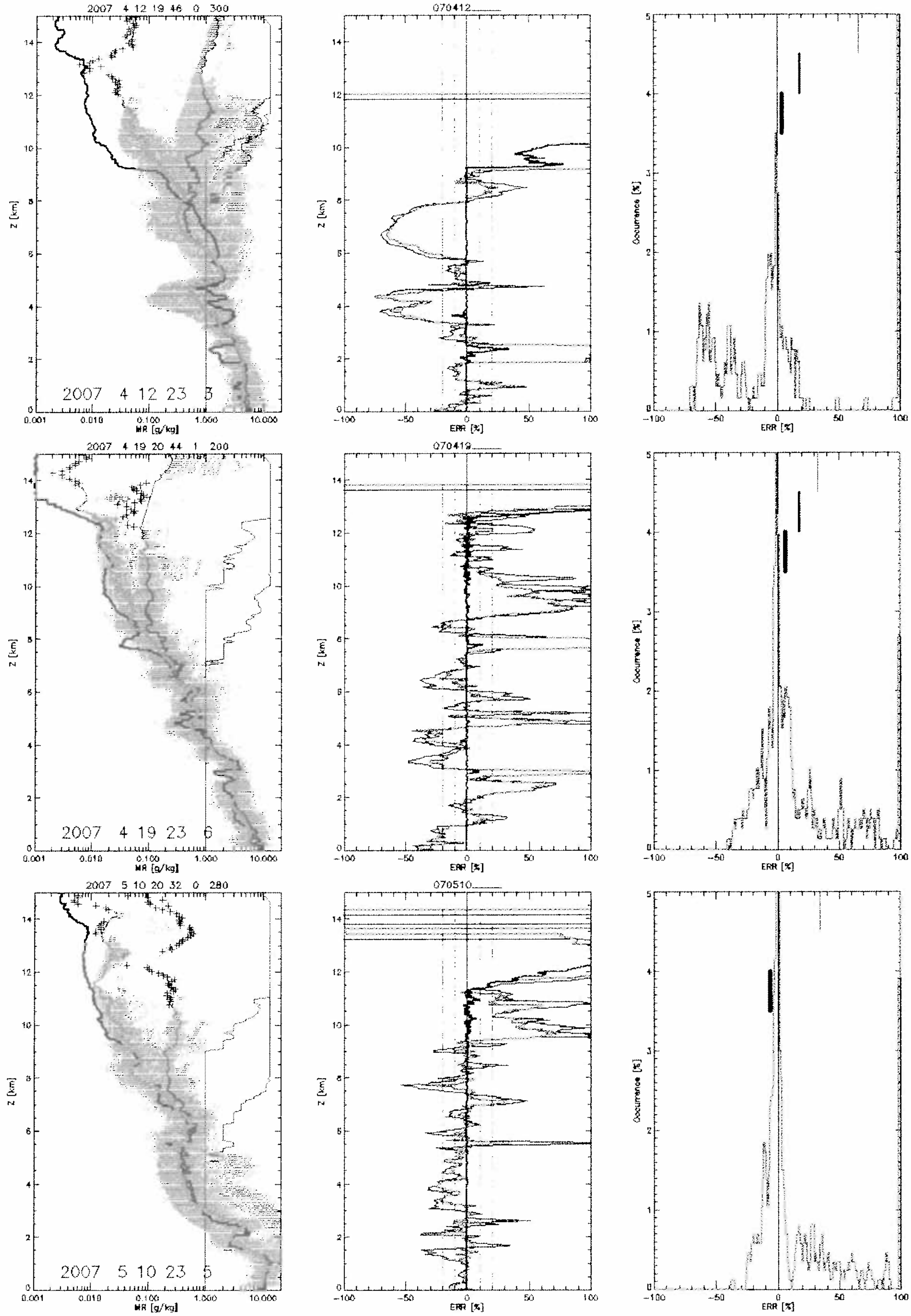
2007 4 12 19 46 0 300
070412
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2007 4 19 20 44 1 200
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2007 4 19 23 6
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2007 5 10 23 5
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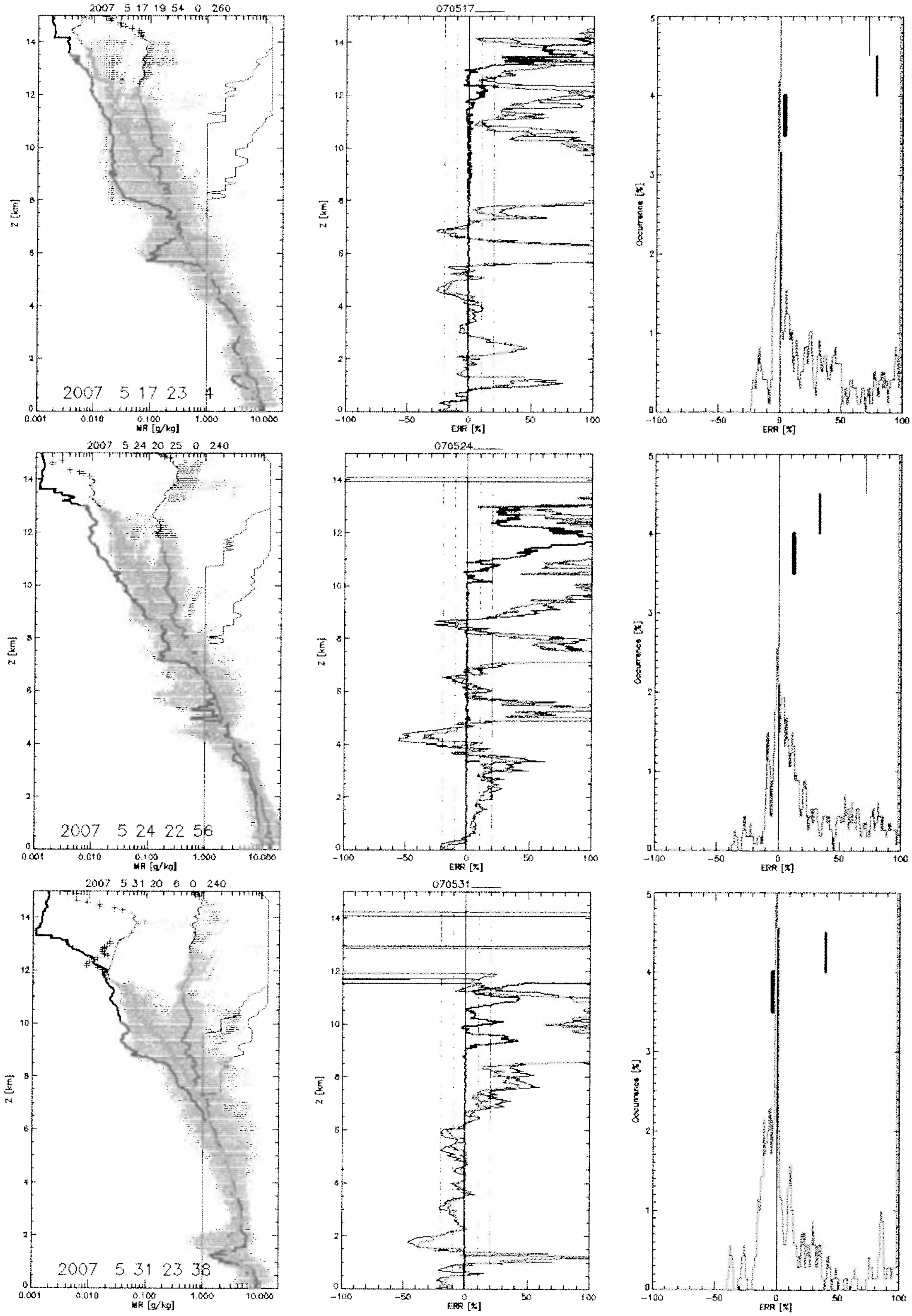
MR [g/kg]
ERR [%]
Occurrence [%]



2007 5 17 19 54 0 260
2007 5 17 23 4
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MR [g/kg]
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Occurrence [%]
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2007 5 31 23 38
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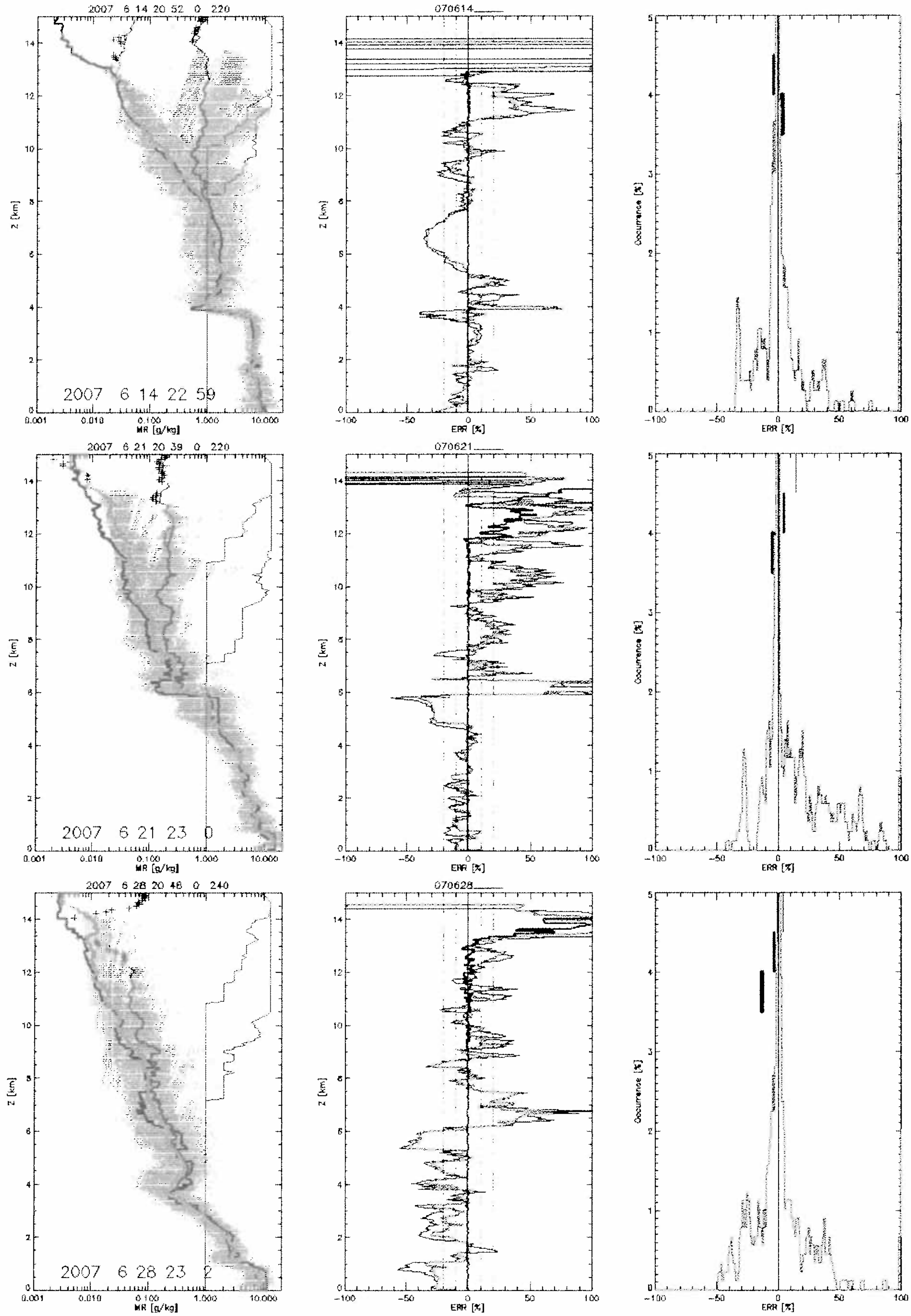
2007 6 14 20 52 0 220
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2007 6 21 23 0
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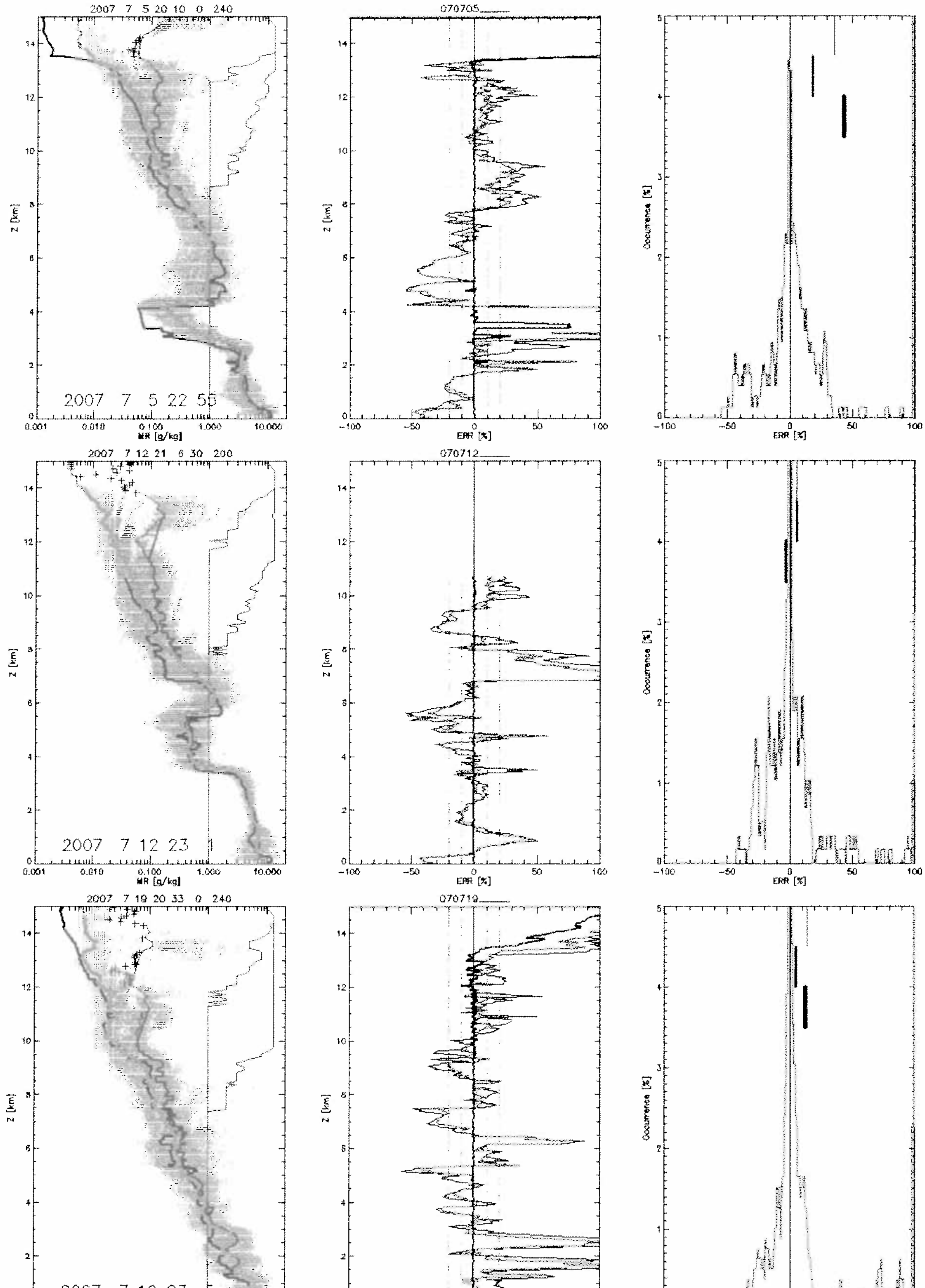
ERR [%]
Occurrence [%]


2007 7 5 20 10 0 240
2007 7 5 22 55
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2007 7 12 21 6 30 200
2007 7 12 23 1
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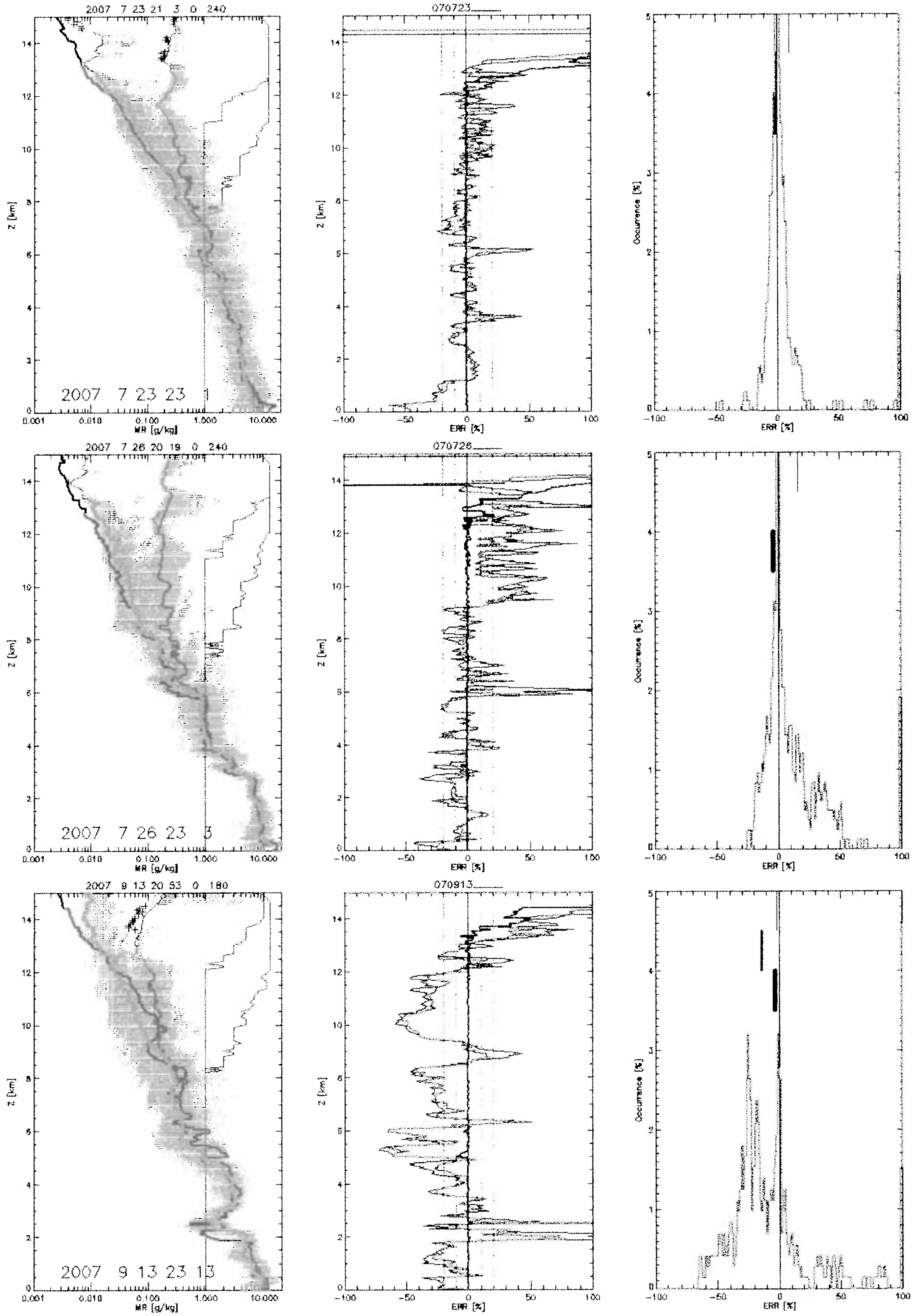
MR [g/kg]
ERR [%]
Occurrence [%]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Occurrence [%]
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2007 9 13 23 13
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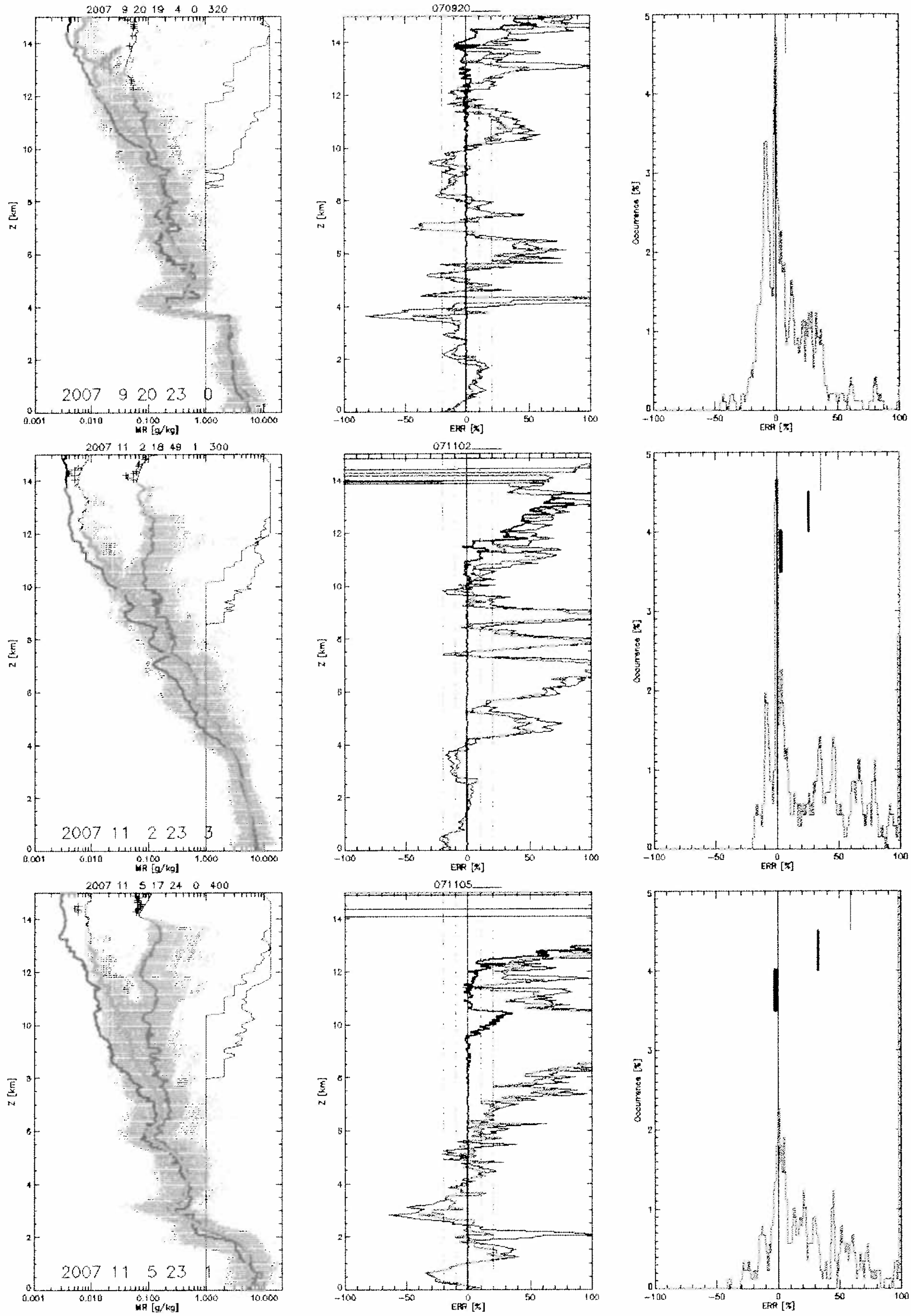

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Z [km]
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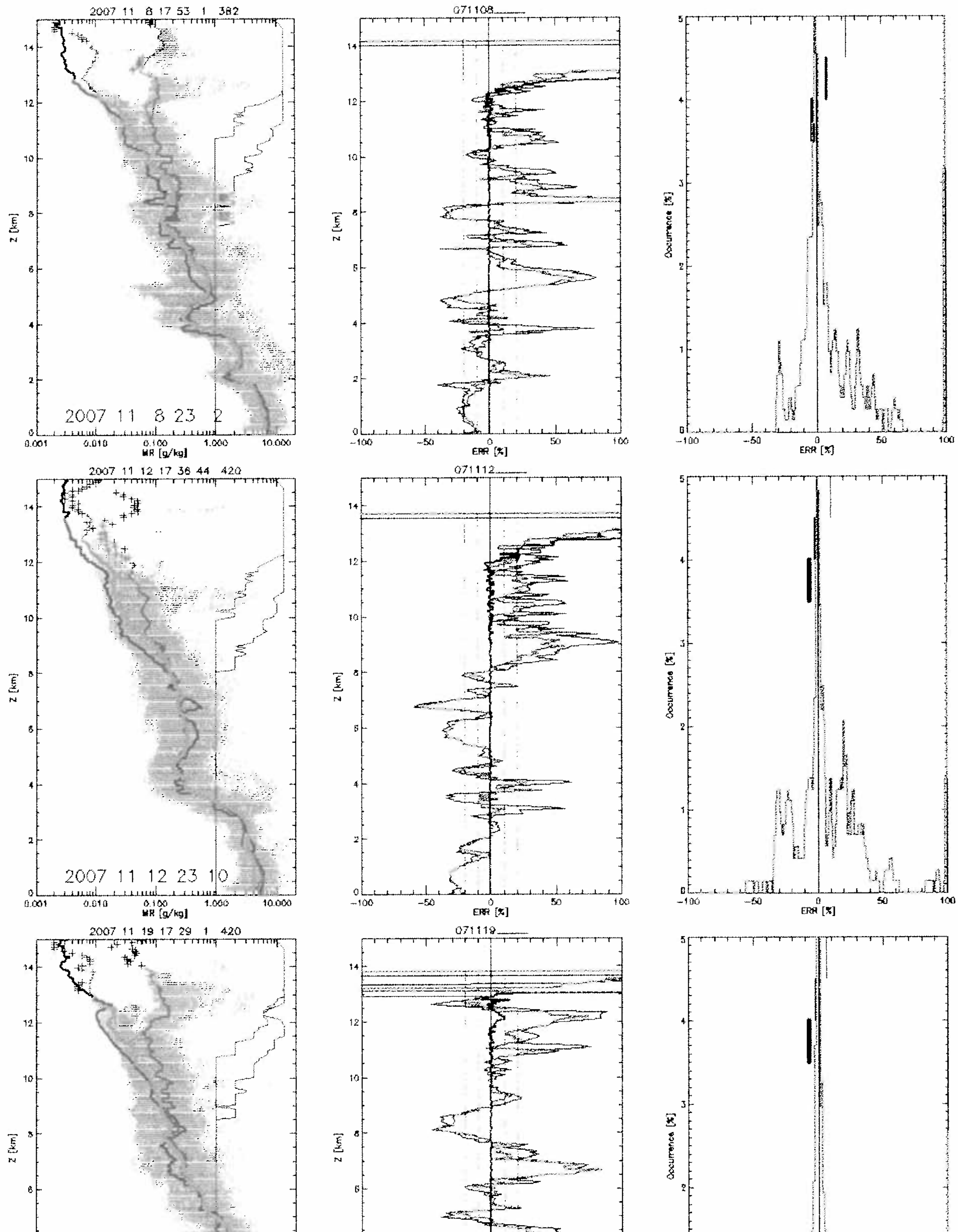
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2007 11 12 17 36 44 420
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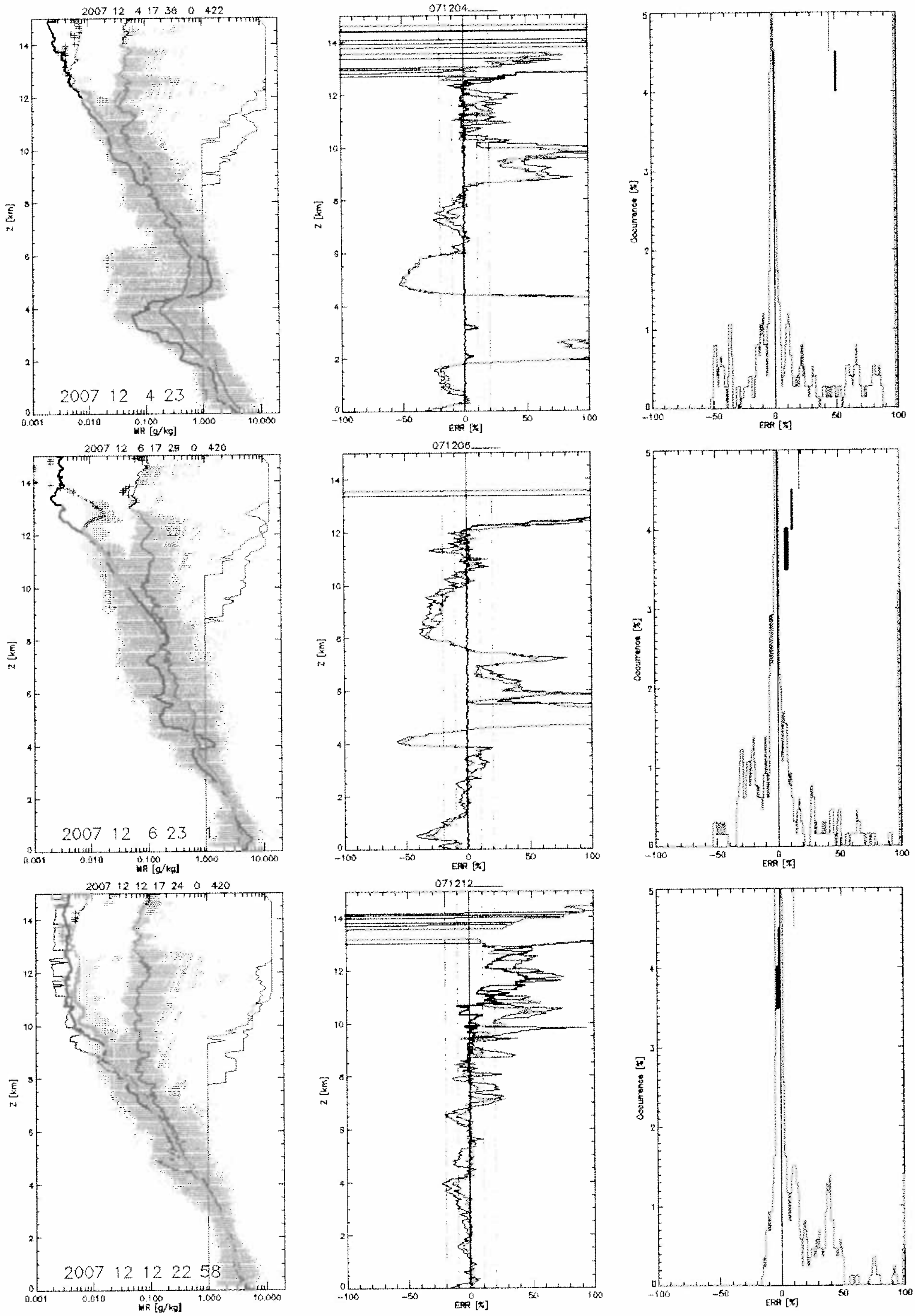
MR [g/kg]
ERR [%]
Occurrence [%]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MR [g/kg]
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ERR [%]
Occurrence [%]
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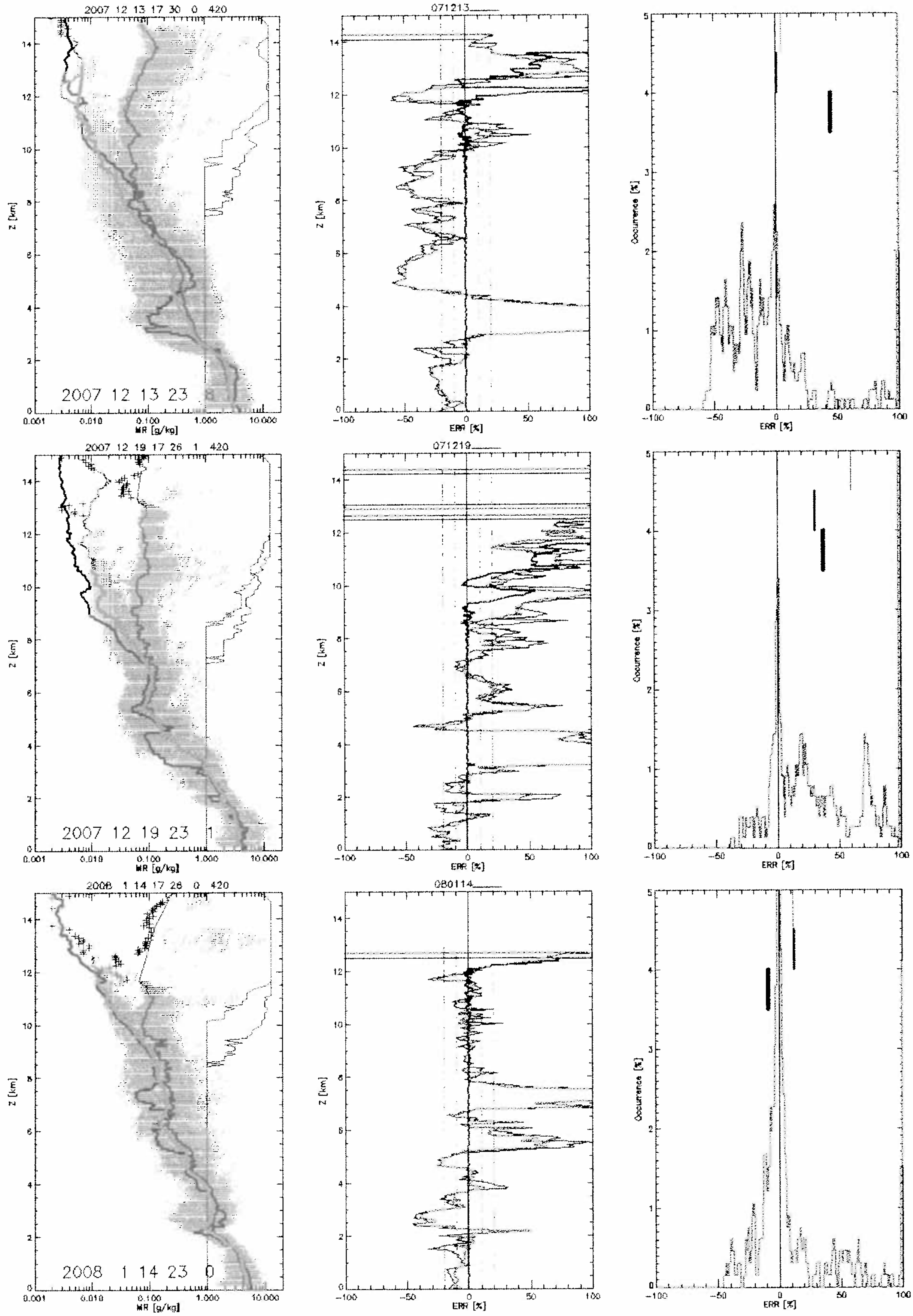
071206
2007 12 12 17 24 0 420
2007 12 12 22 58
071212



2007 12 13 17 30 0 420
071213
2007 12 13 23 8
2007 12 19 17 26 1 420
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2007 12 19 23 1
2008 1 14 17 26 0 420
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2008 1 14 23 0
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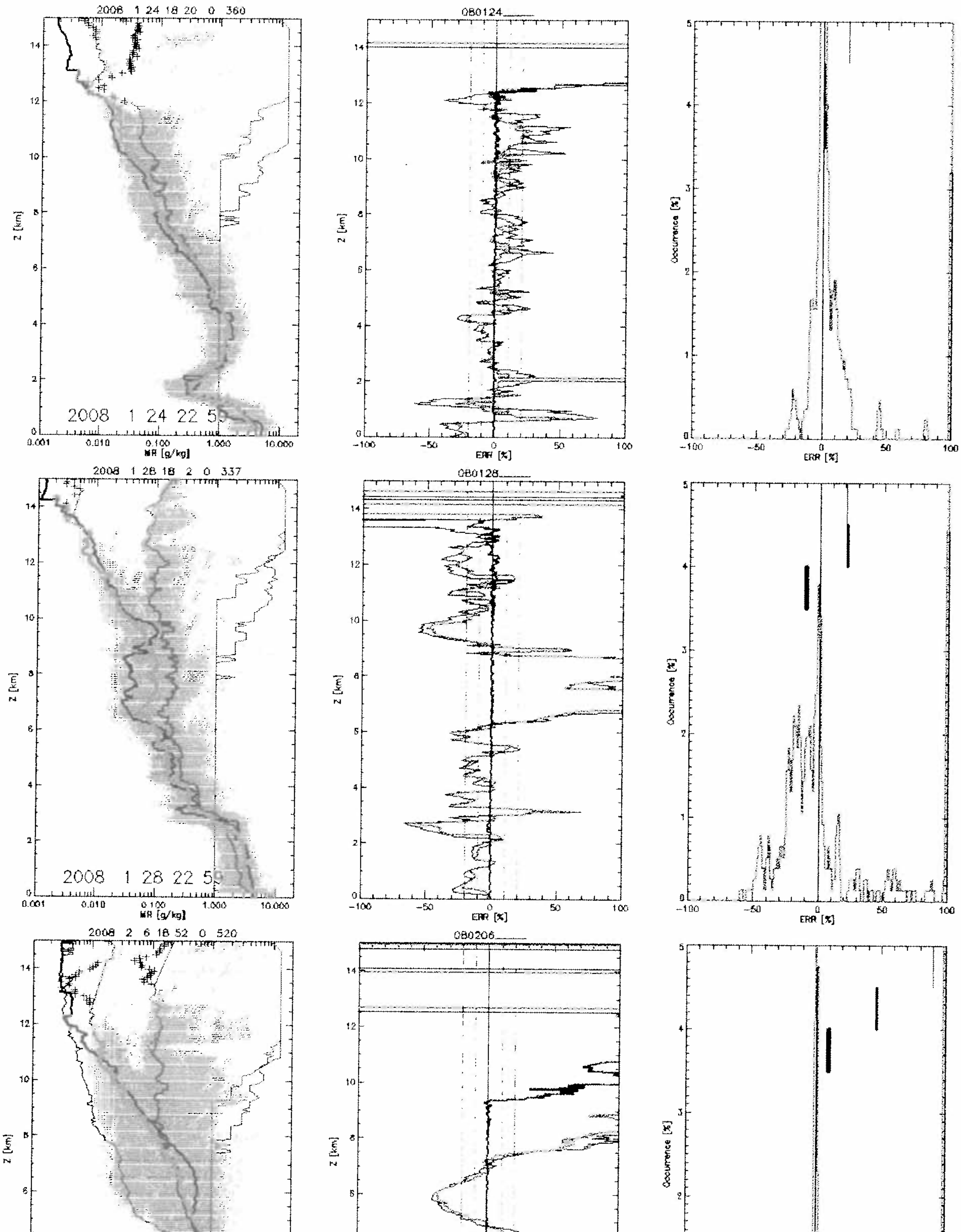
MR [g/kg]
ERR [%]
Occurrence [%]


2008 1 24 18 20 0 360
080124
2008 1 28 18 2 0 337
080128
2008 2 6 18 52 0 520
080206
2008 2 6 23 4
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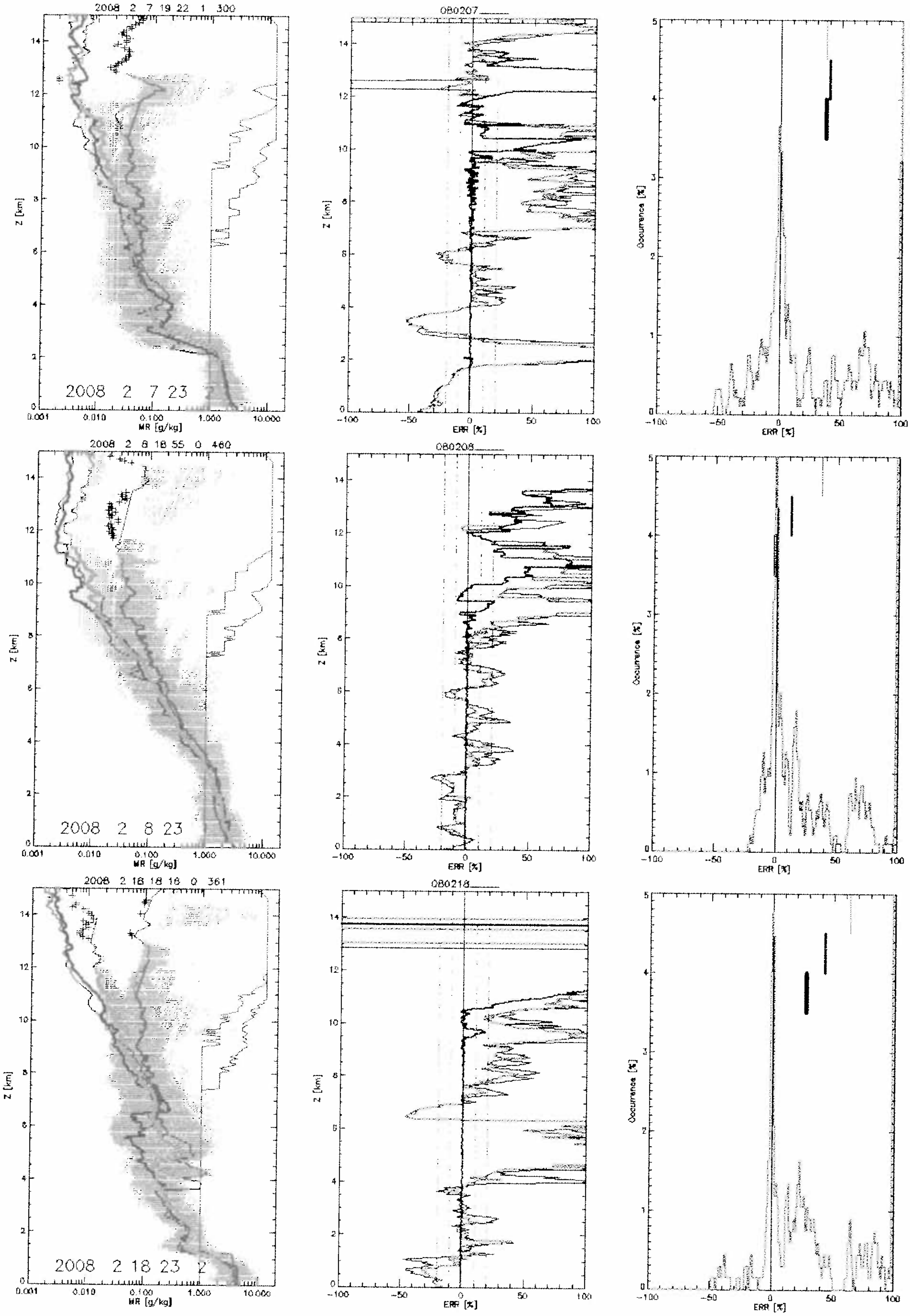
MR [g/kg]
ERR [%]
Occurrence [%]



2008 2 7 19 22 1 300
2008 2 7 23
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MR [g/kg]
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Occurrence [%]
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2008 2 8 23
080208
2008 2 18 18 16 0 361
2008 2 18 23 2
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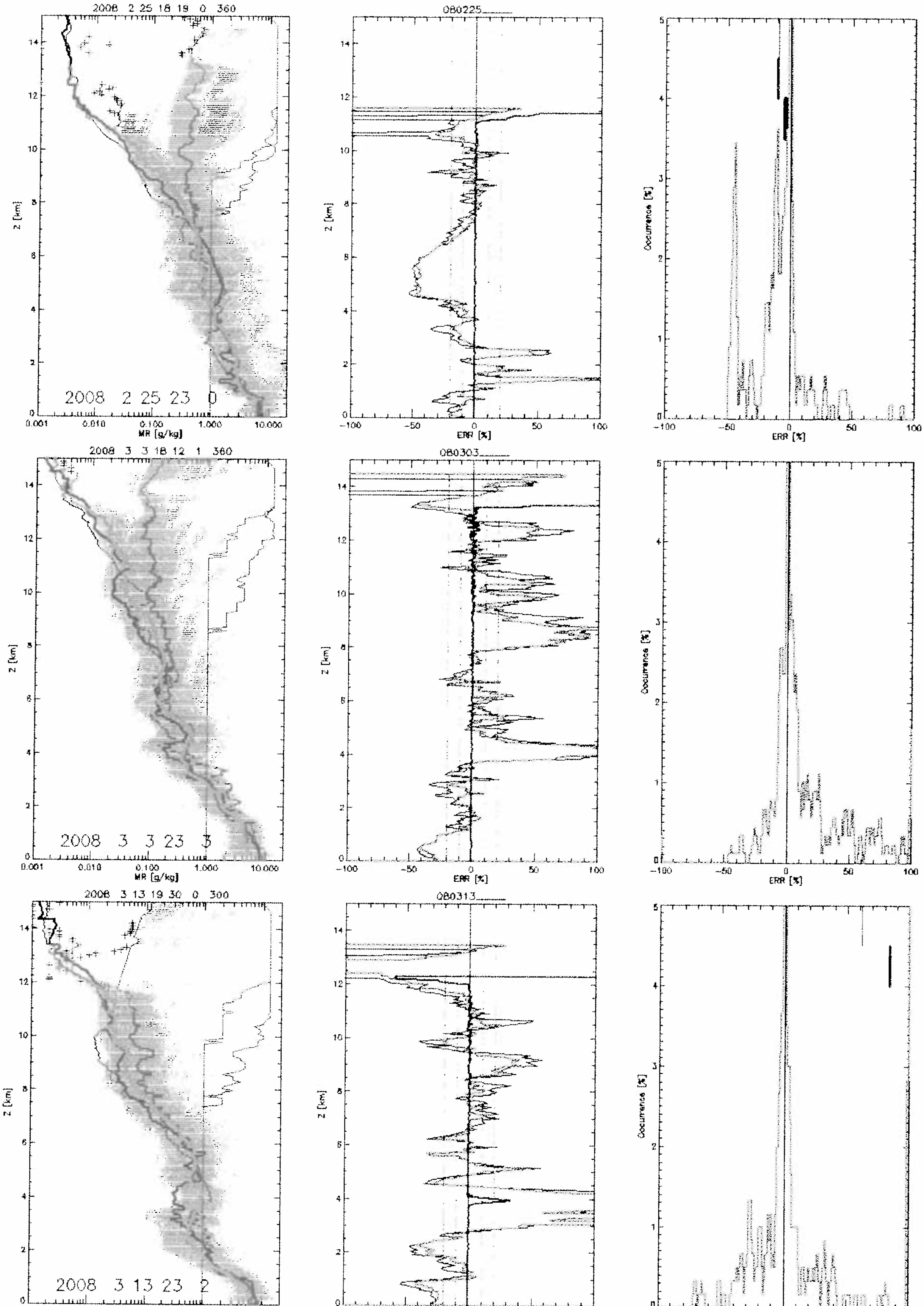
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MR [g/kg]
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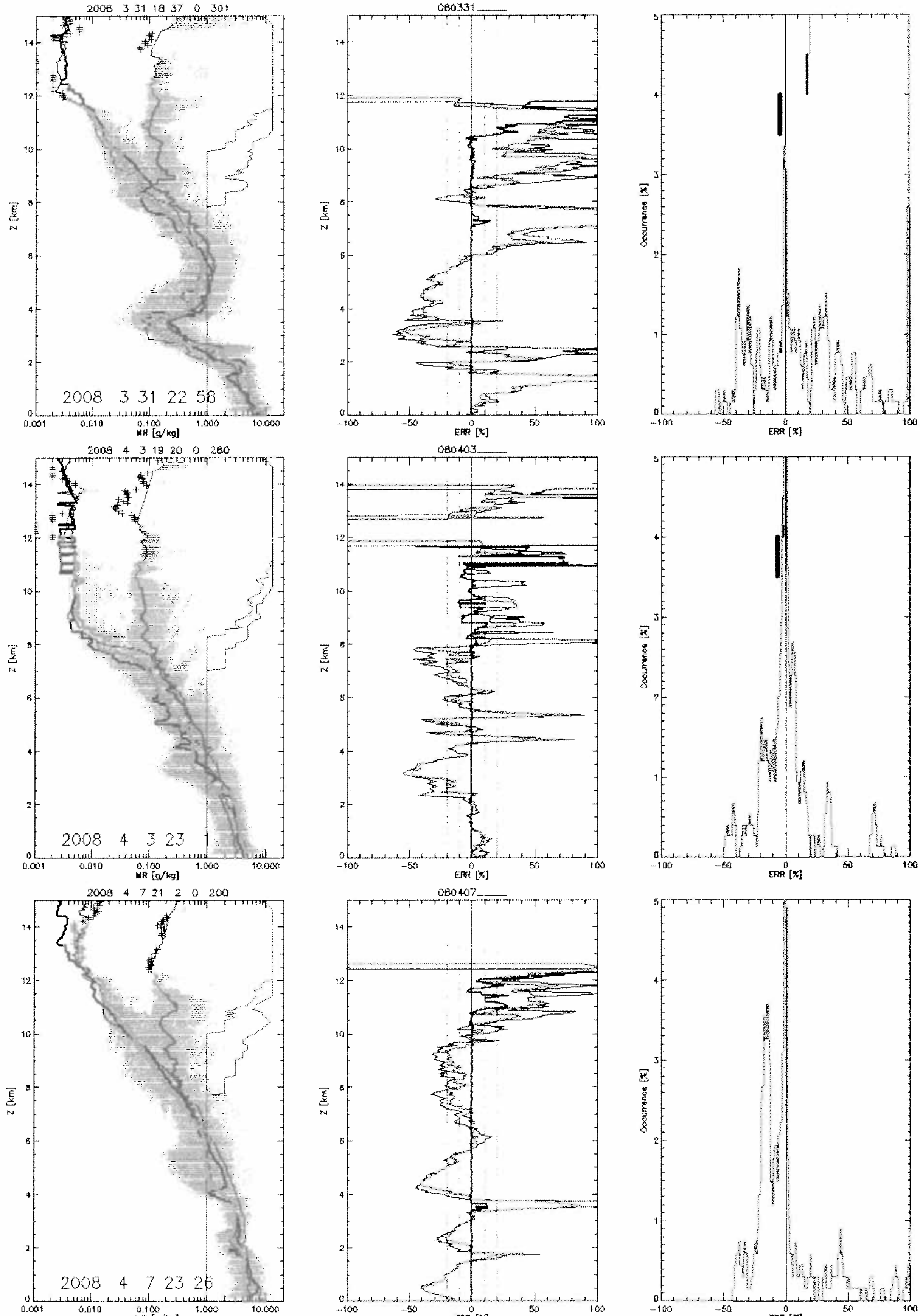
2008 3 31 18 37 0 301
2008 3 31 22 58
080331
2008 4 3 19 20 0 280
2008 4 3 23 1
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2008 4 7 21 2 0 200
2008 4 7 23 26
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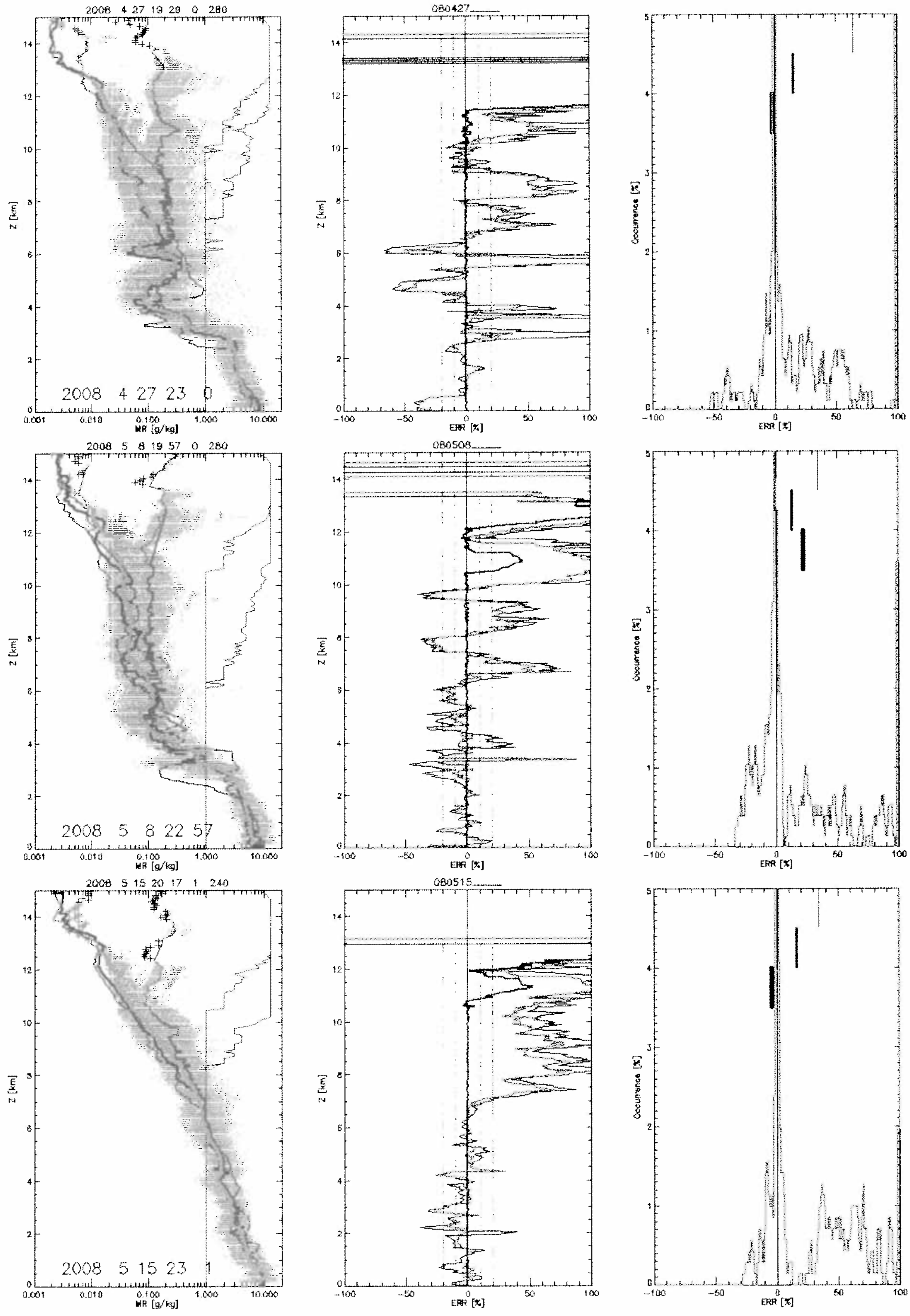
MR [g/kg]
ERR [%]
Occurrence [%]



2008 4 27 19 28 0 280
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2008 4 27 23 0
2008 5 8 19 57 0 280
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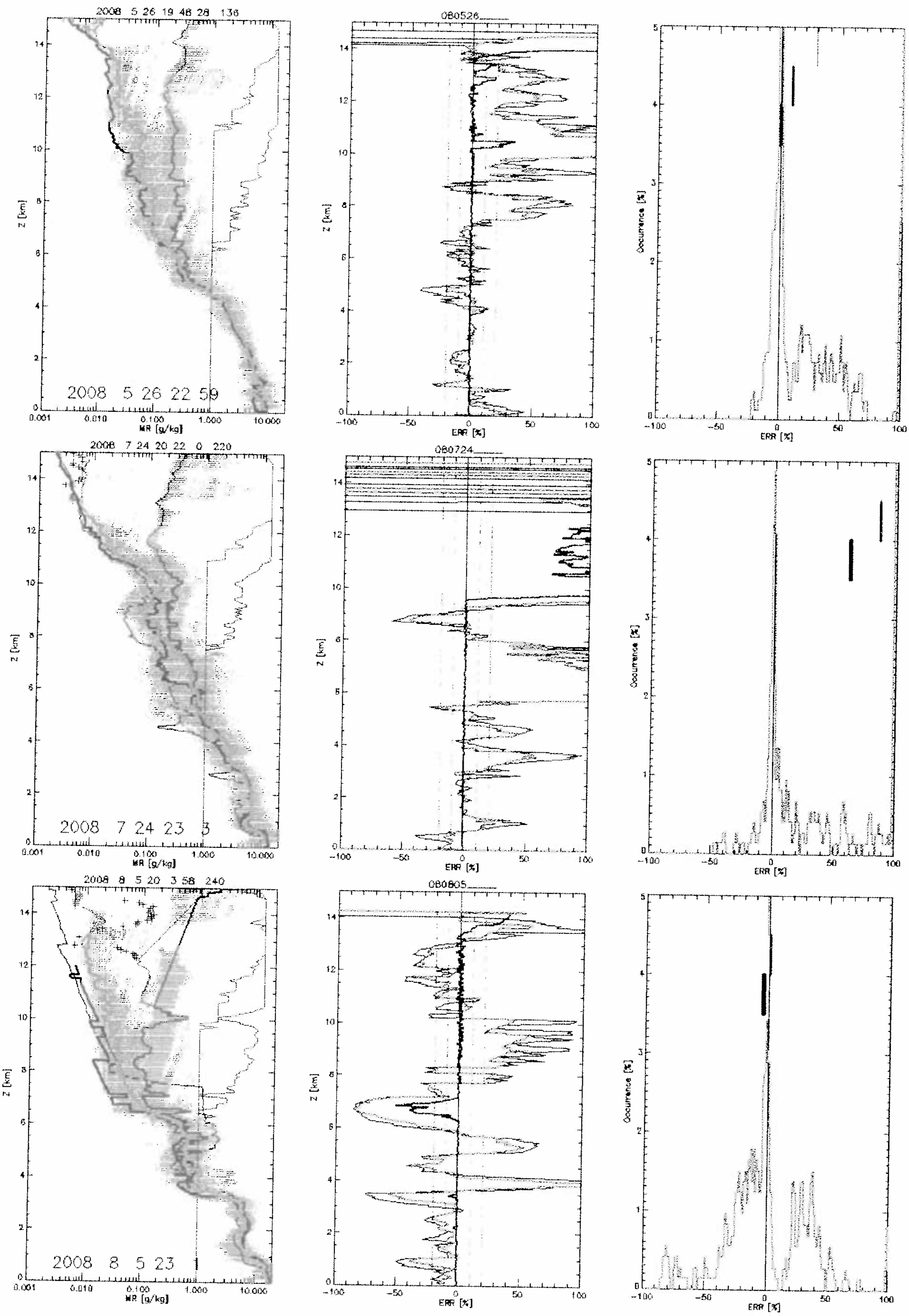
MR [g/kg]
ERR [%]
Occurrence [%]


2008 5 26 19 48 28 136
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2008 7 24 23 3
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2008 8 5 20 3 58 240
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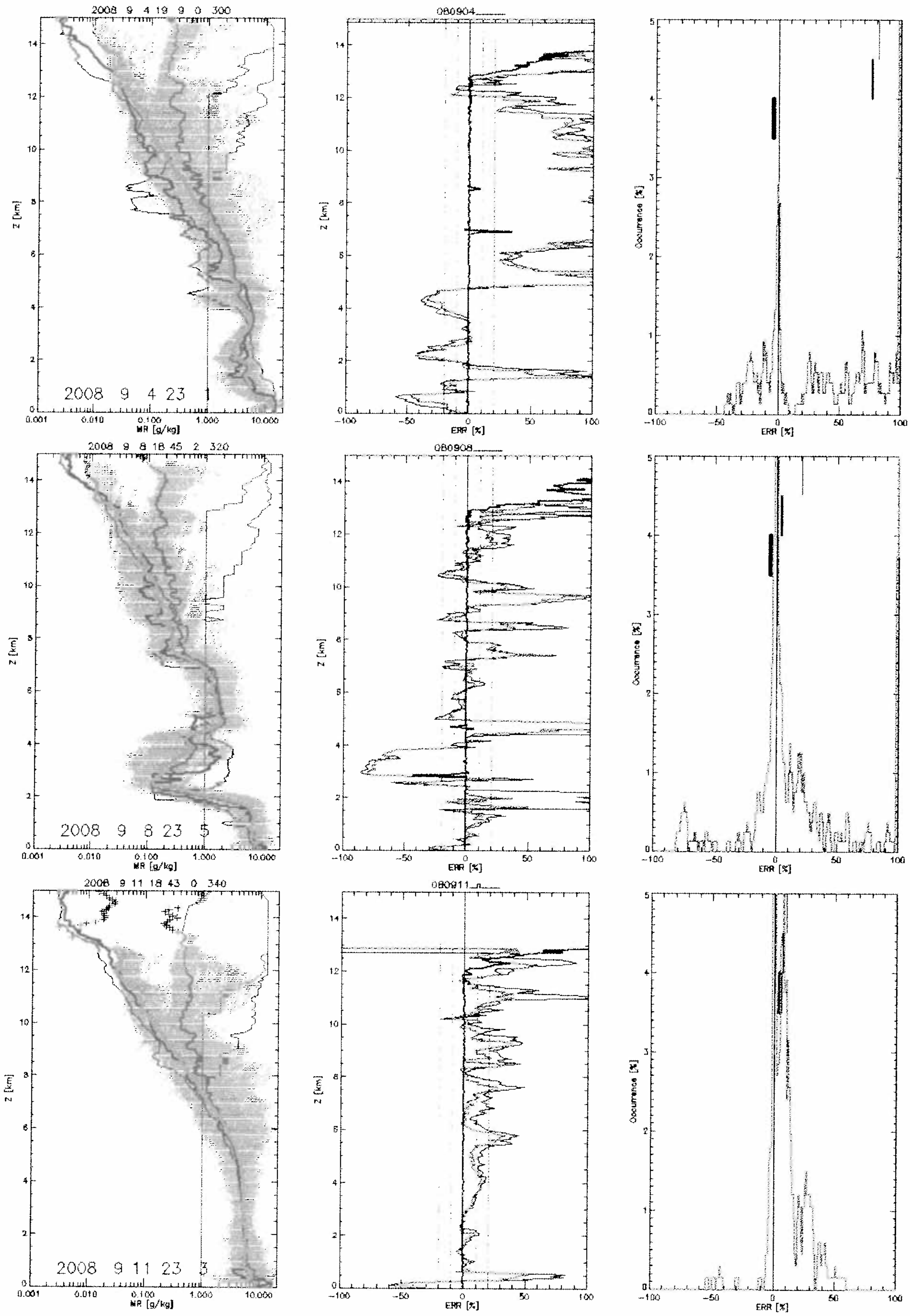
2008 9 4 19 9 0 300
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2008 9 4 23 1
2008 9 8 18 45 2 320
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2008 9 8 23 5
2008 9 11 18 43 0 340
080911
2008 9 11 23 3
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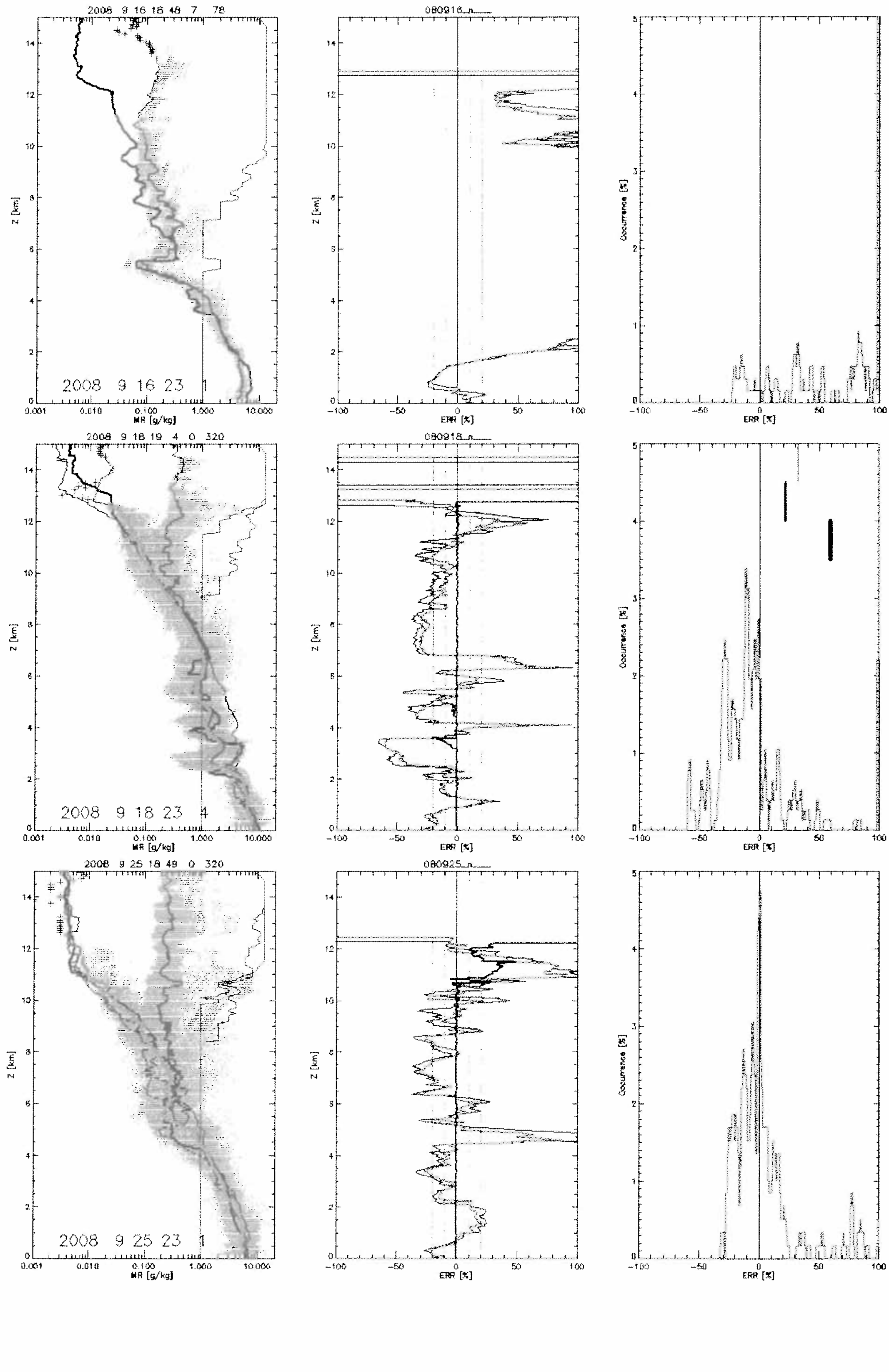
MR [g/kg]
ERR [%]
Occurrence [%]



2008 9 16 18 48 7 78
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2008 9 16 23 1
2008 9 18 19 4 0 320
080918_n
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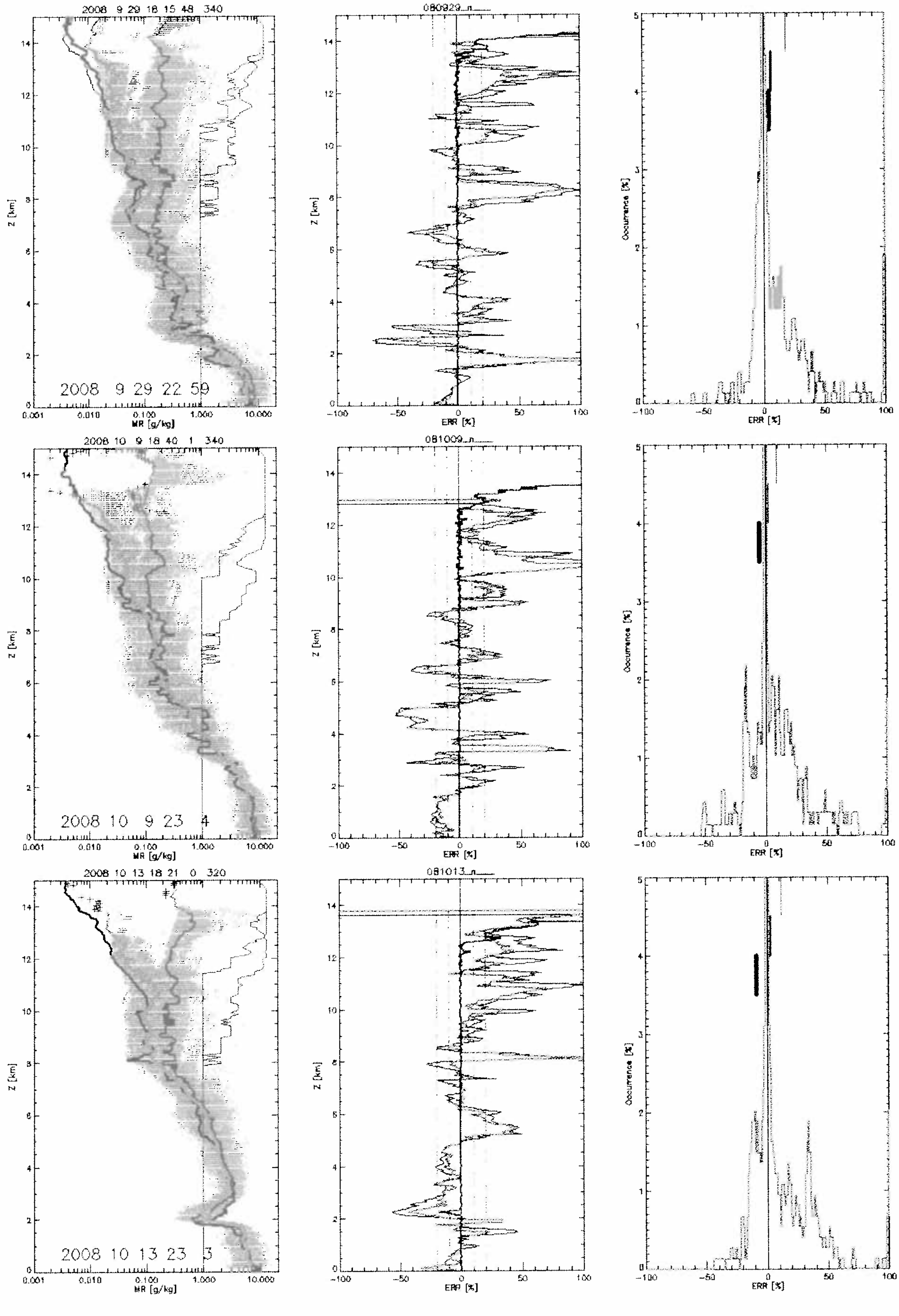
MR [g/kg]
ERR [%]
Occurrence [%]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2008 9 29 22 59
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MR [g/kg]
080929_n
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2008 10 9 23 4
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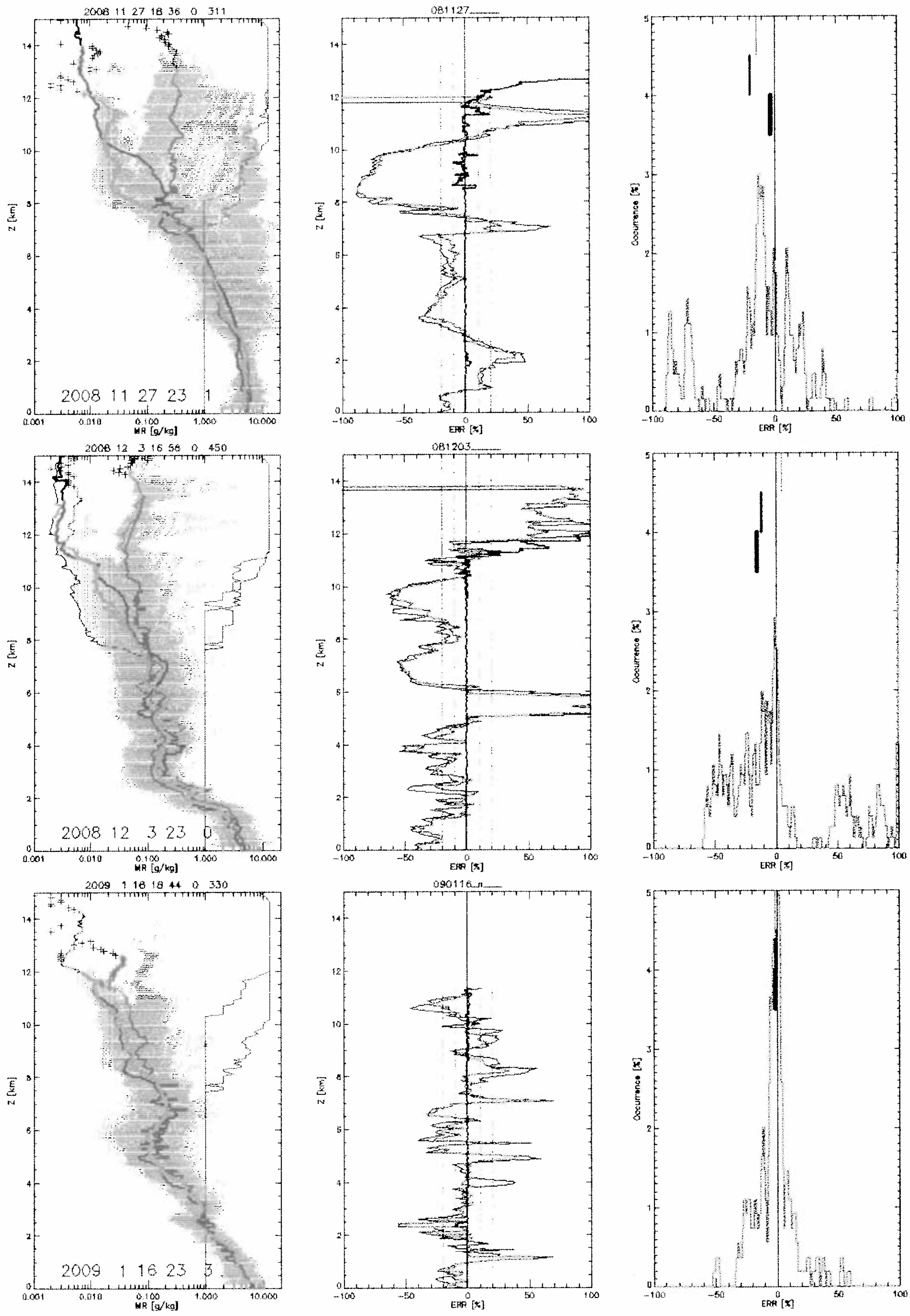
2008 10 13 23 3
081013_n


2008 11 27 18 36 0 311
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MR [g/kg]
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2008 12 3 16 56 0 450
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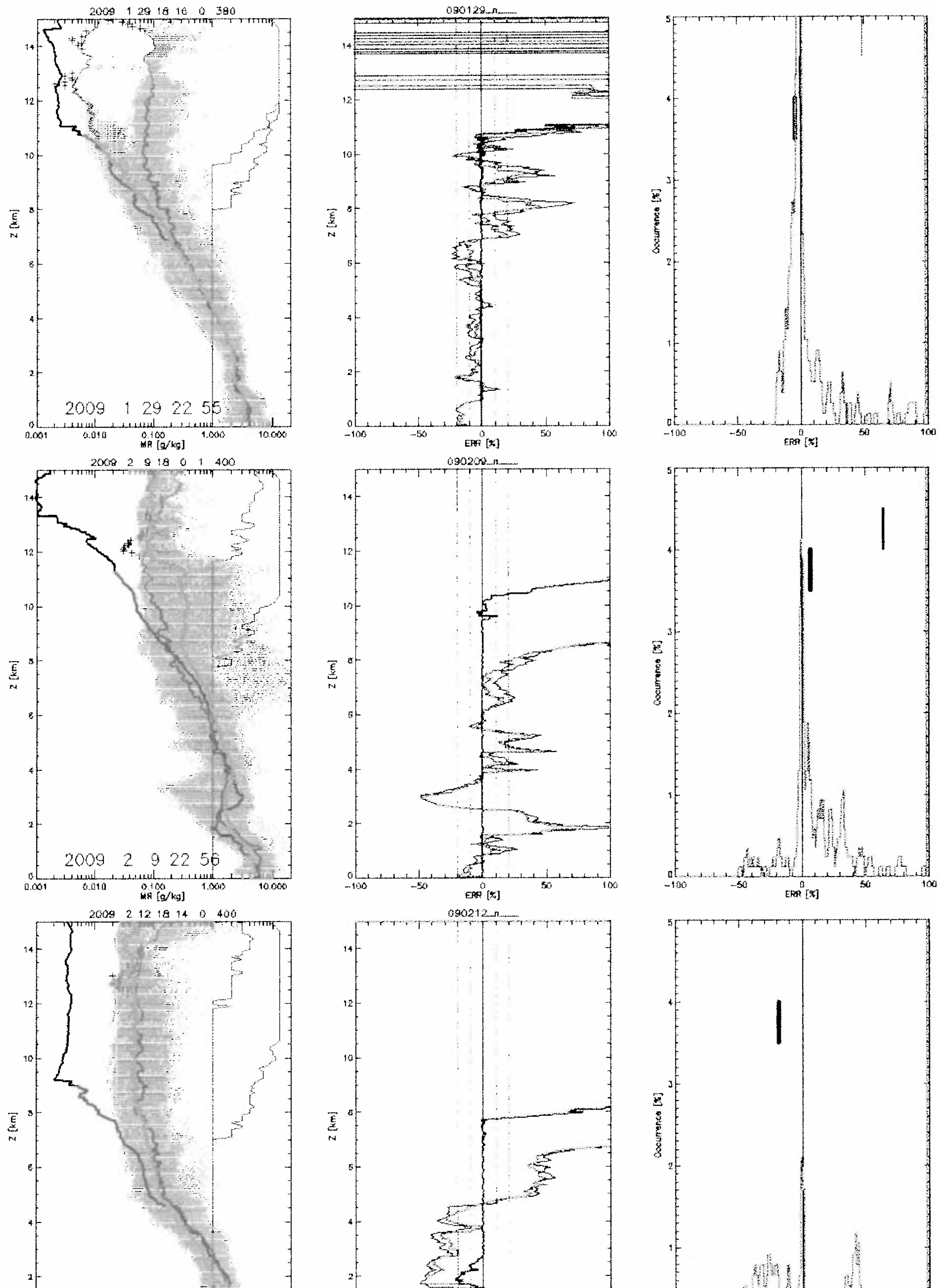
2009 1 29 18 16 0 380
2009 1 29 22 55
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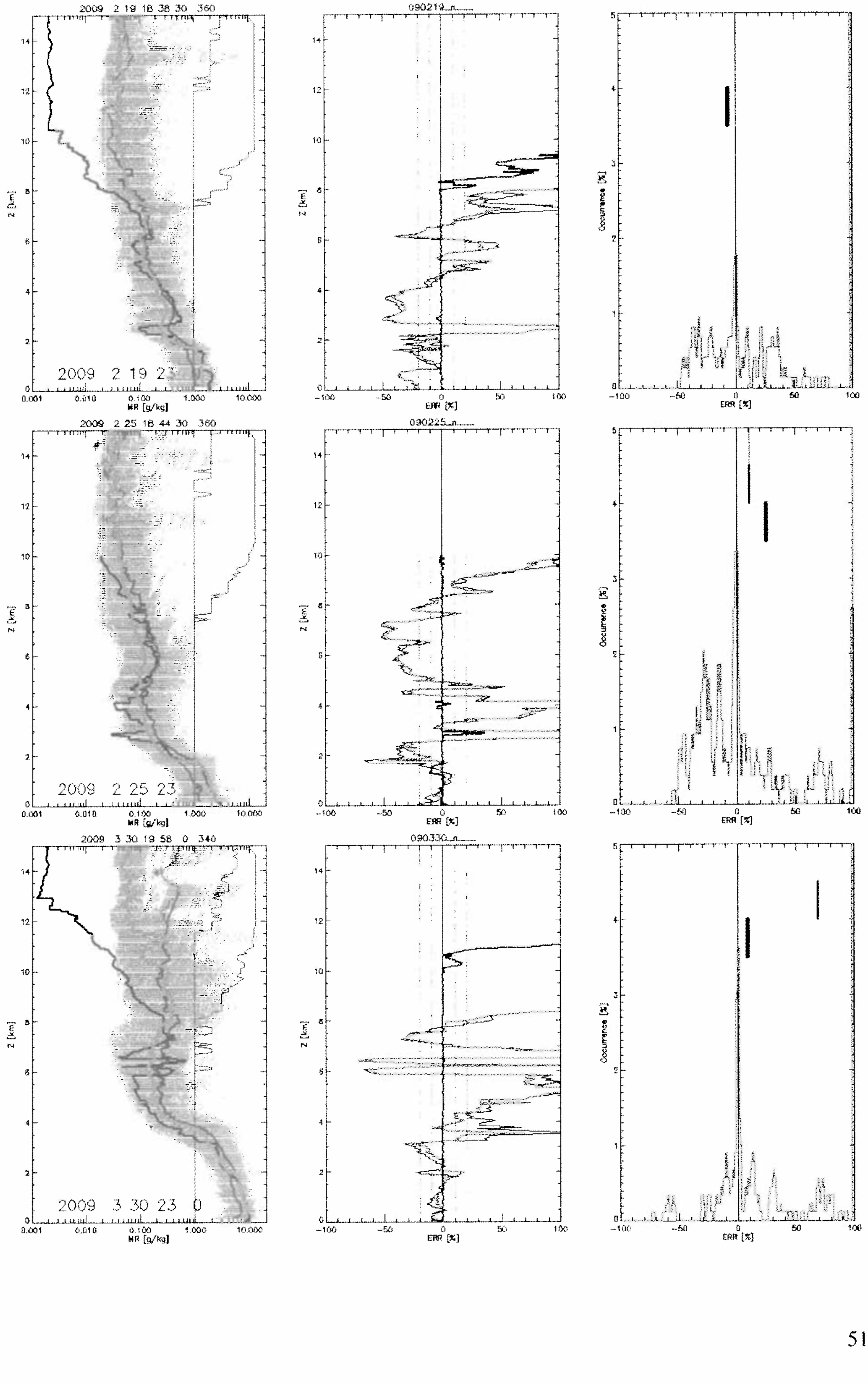
090212_n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ERR [%]
Occurrence [%]
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2009 2 25 23
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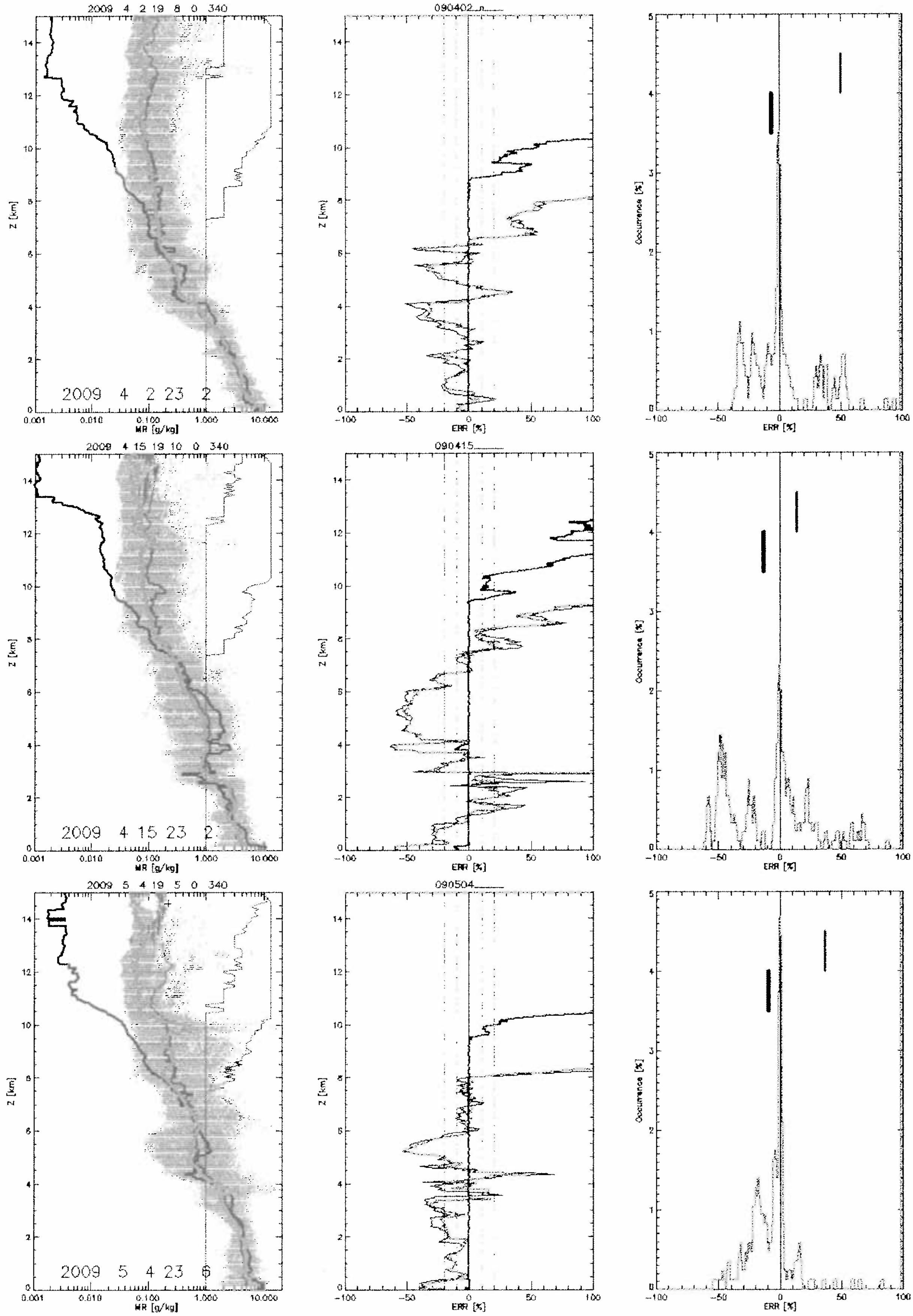
2009 3 30 23 0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2009 4 2 23 2
2009 4 15 19 10 0 340
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2009 4 15 23 2
2009 5 4 19 5 0 340
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2009 5 4 23 6
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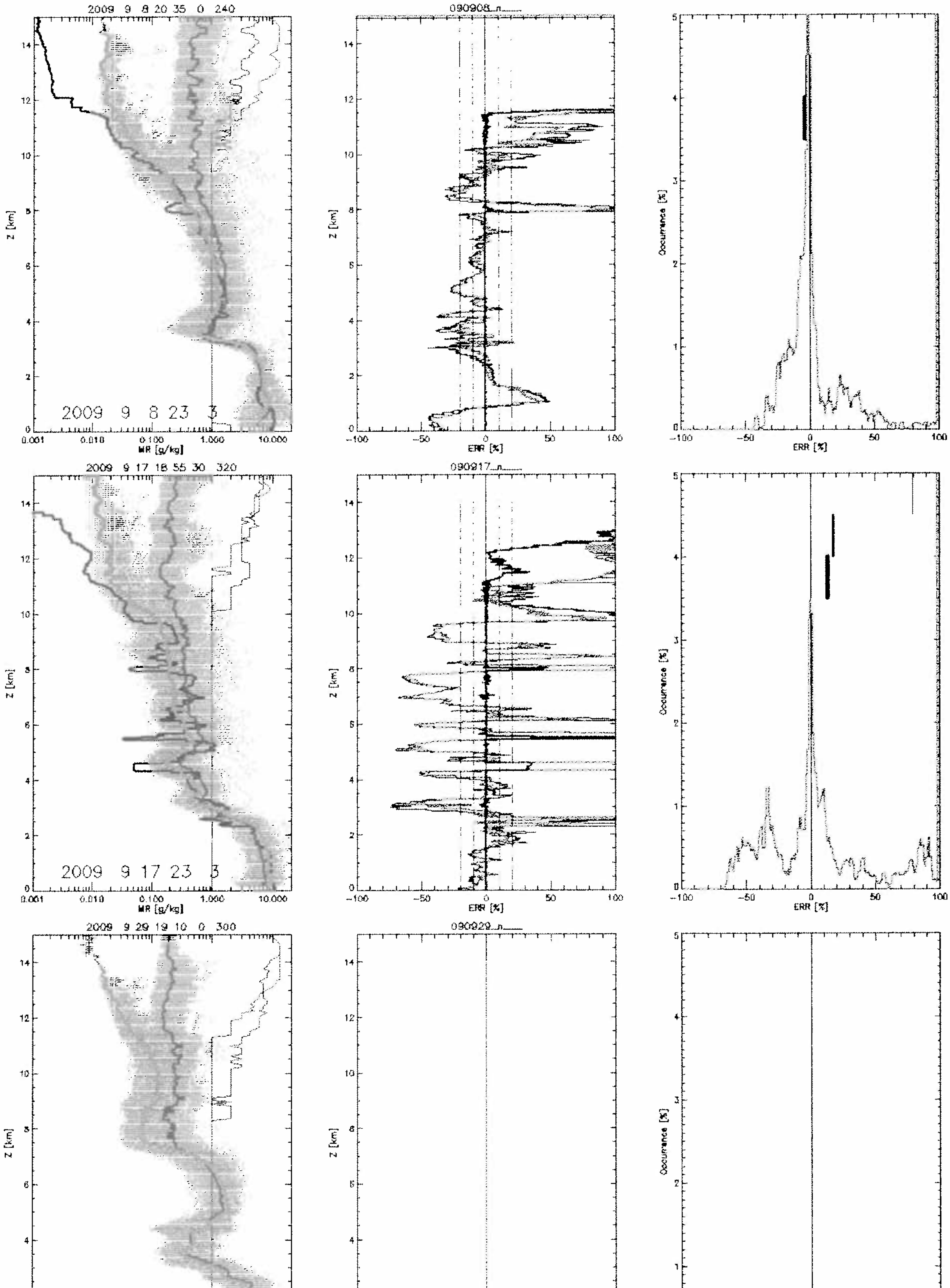
MR [g/kg]
ERR [%]
Occurrence [%]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Occurrence [%]
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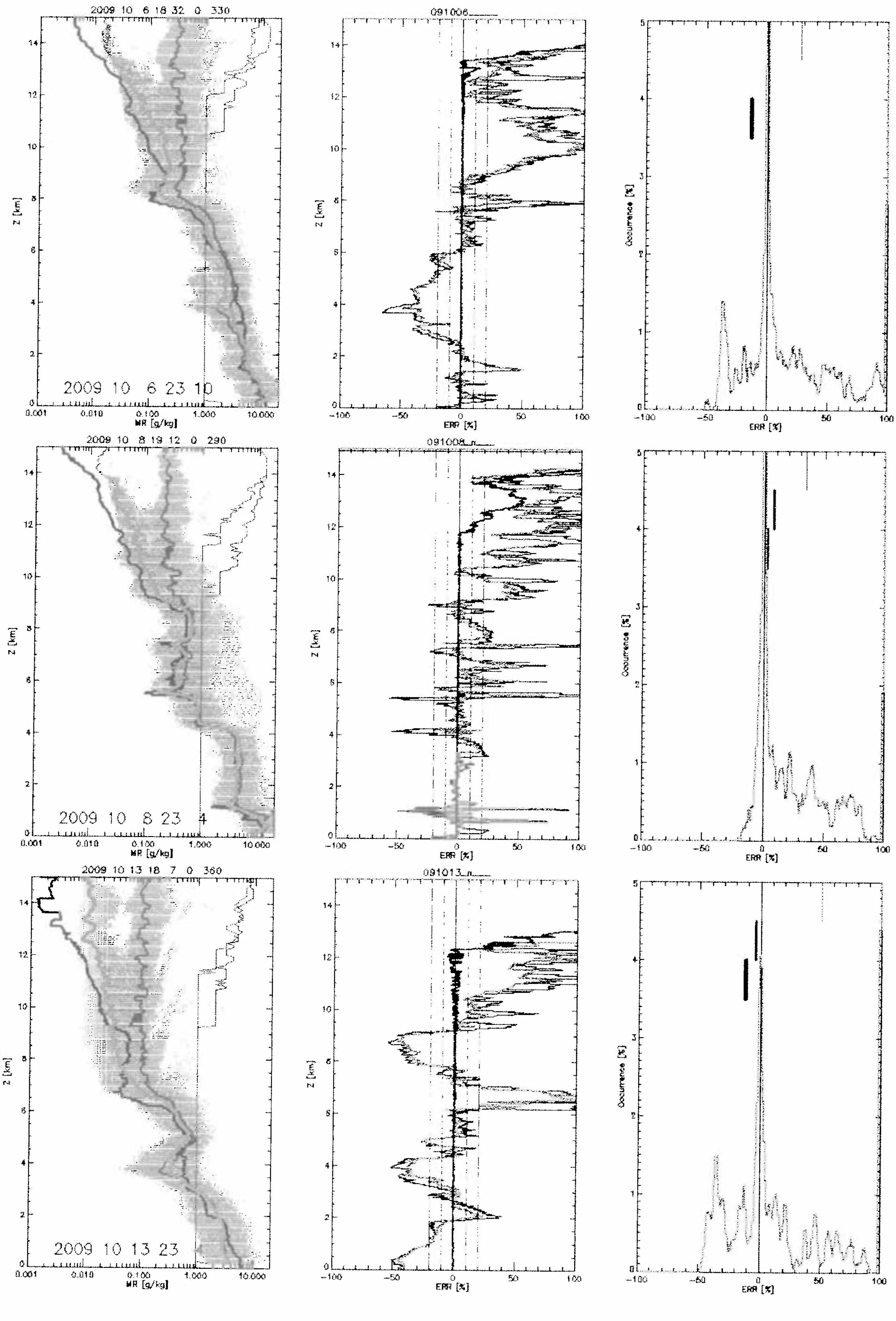
090929_n


2009 10 6 18 32 0 330
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MR [g/kg]
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Occurrence [%]
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2009 10 8 23 4
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2009 10 13 18 7 0 360
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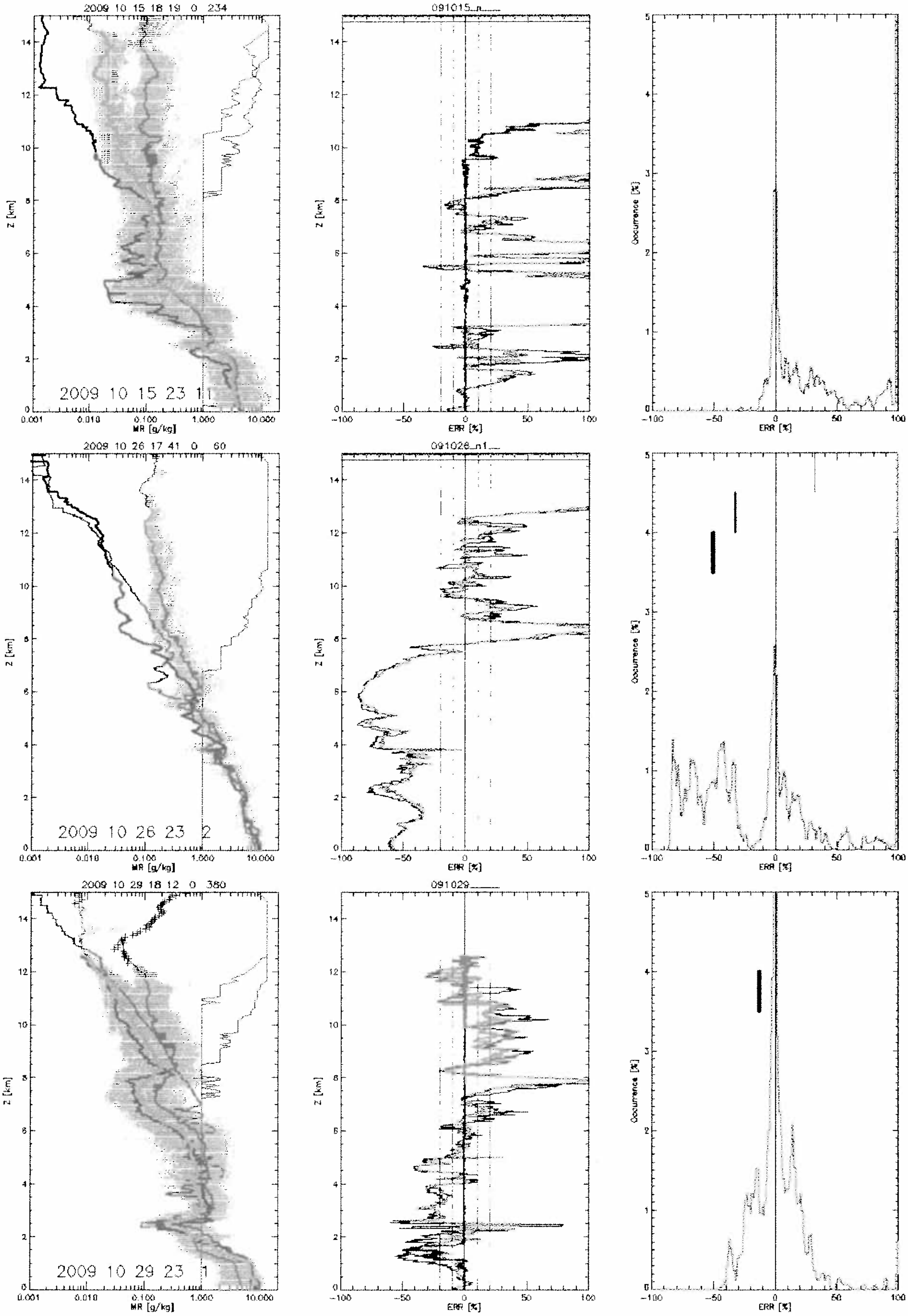
091013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2009 10 26 23 2
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2009 10 29 23 1
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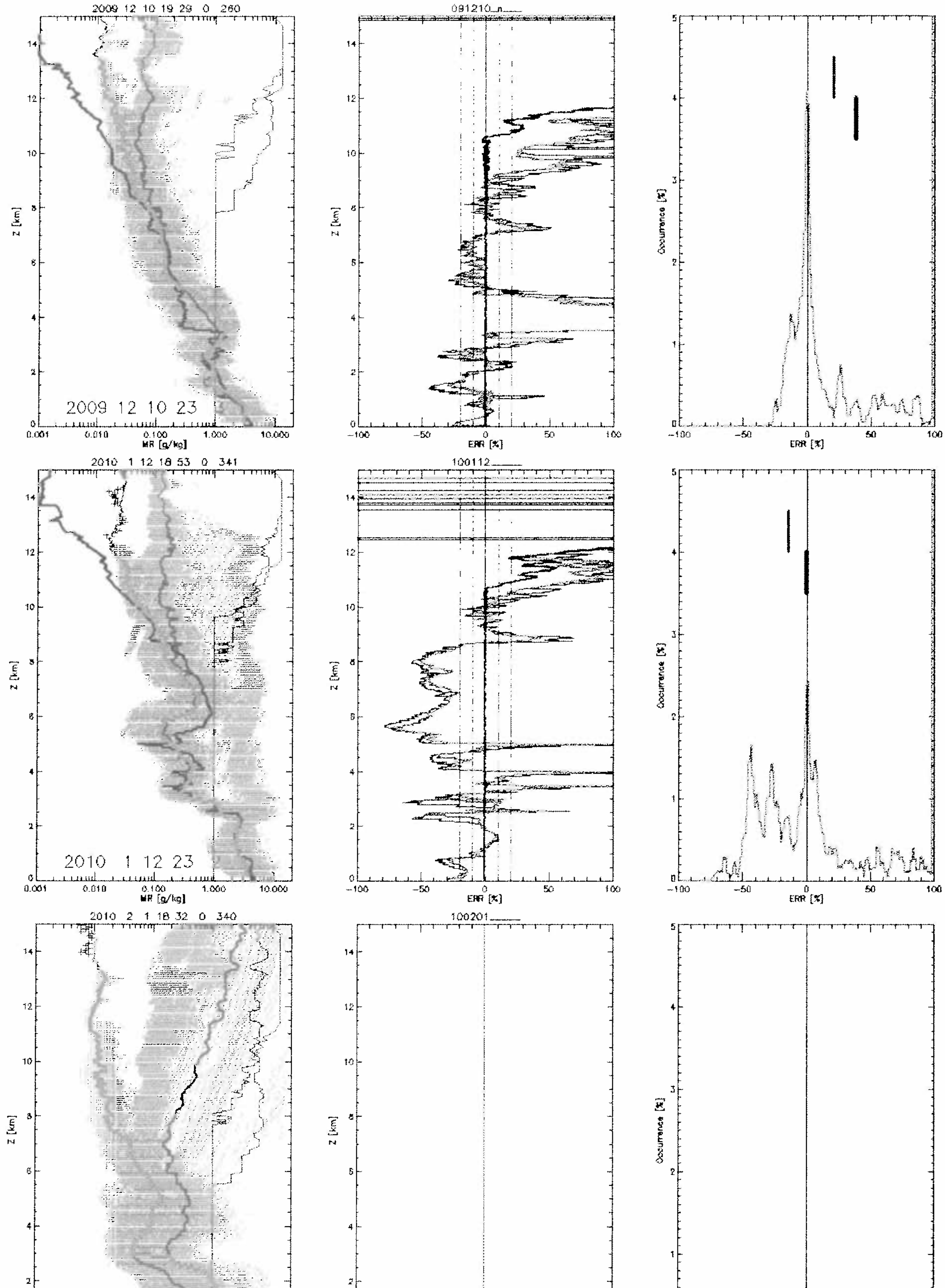
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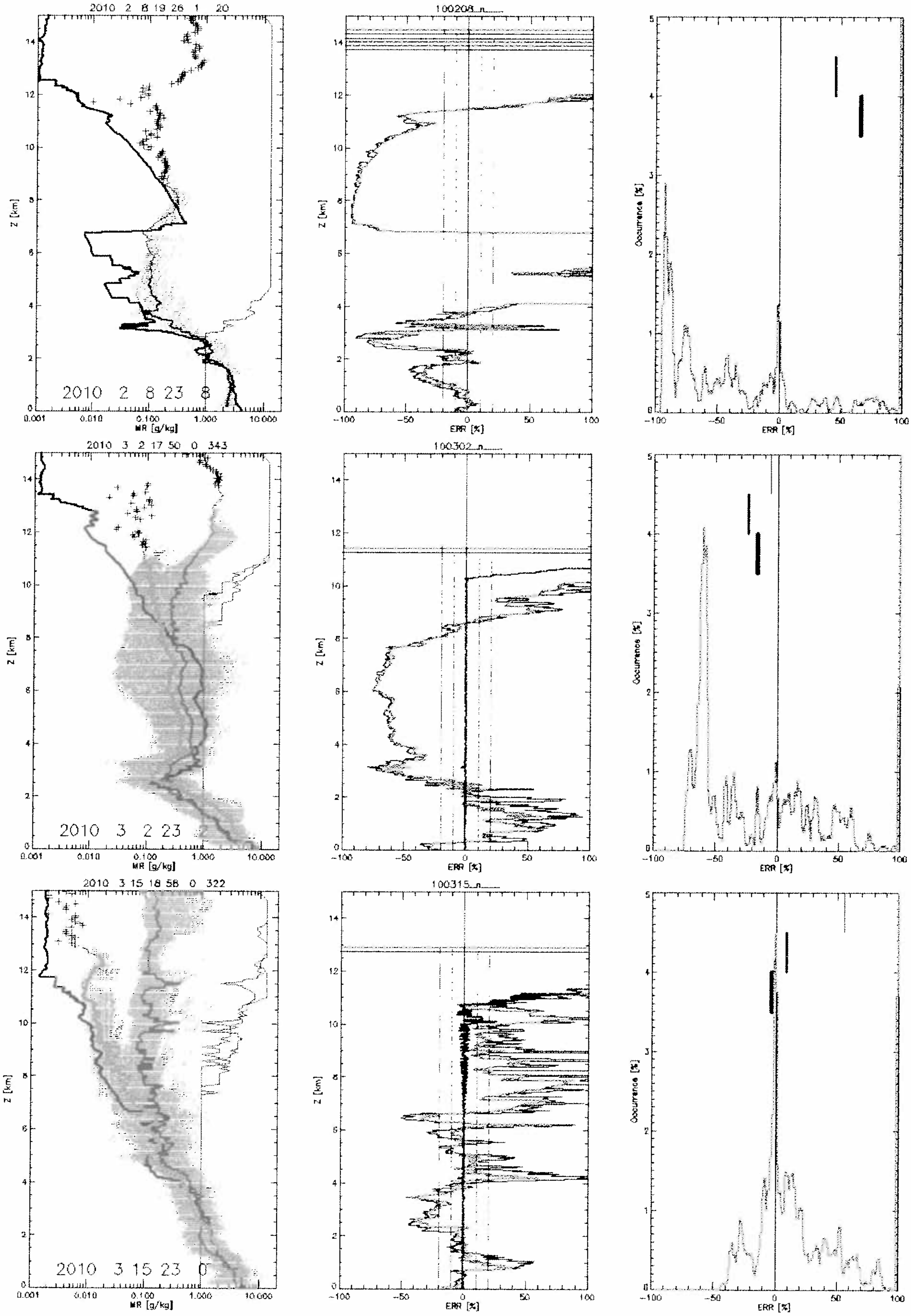
MR [g/kg]
ERR [%]
Occurrence [%]


2010 2 8 19 26 1 20
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2010 2 8 23 8
2010 3 2 17 50 0 343
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2010 3 15 18 58 0 322
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2010 3 15 23 0
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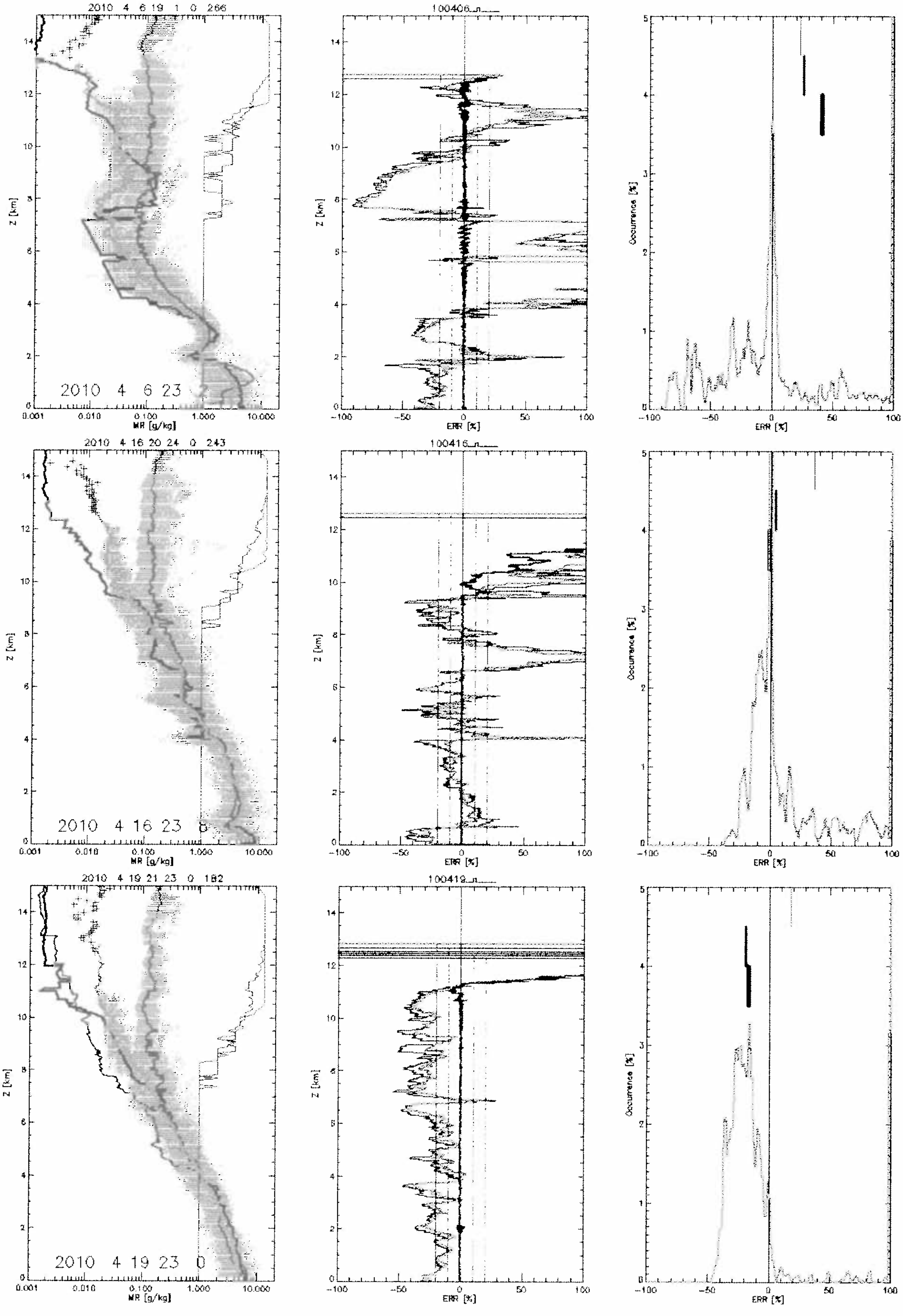
MR [g/kg]
ERR [%]
Occurrence [%]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2010 4 16 20 24 0 243
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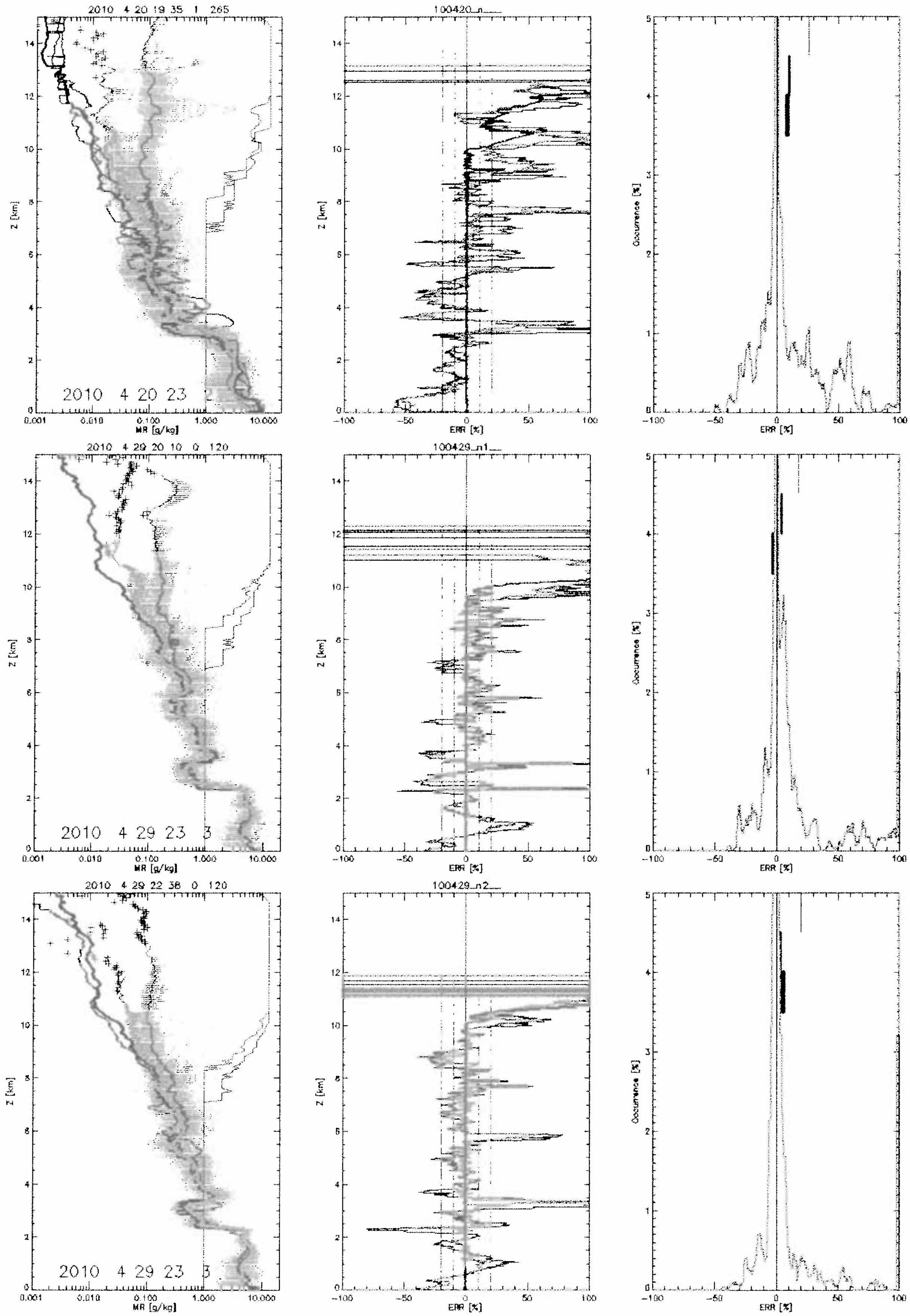
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2010 4 20 23 2
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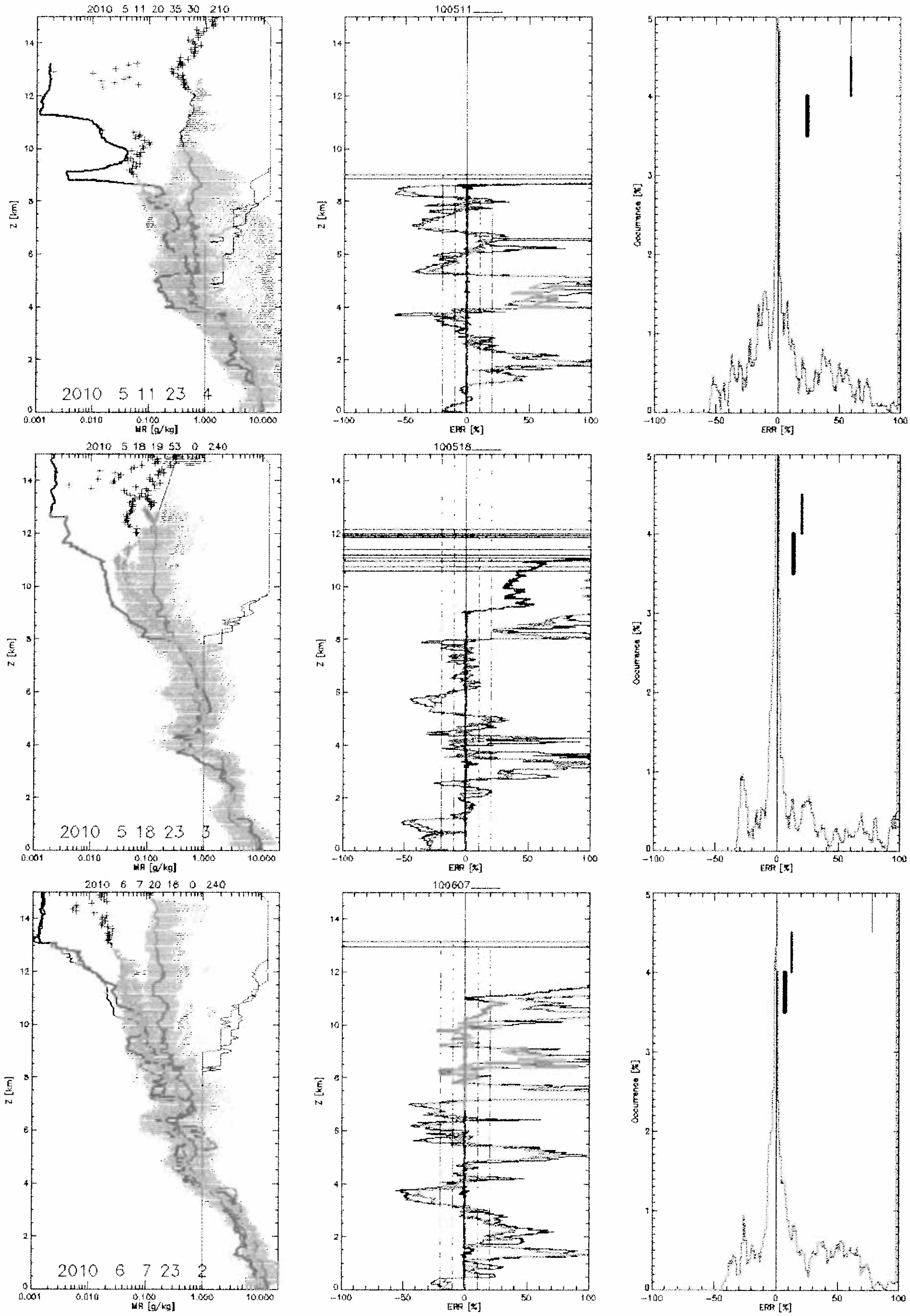
2010 5 11 20 35 30 210
2010 5 11 23 4
100511
2010 5 18 19 53 0 240
2010 5 18 23 3
100518
2010 6 7 20 18 0 240
2010 6 7 23 2
100607
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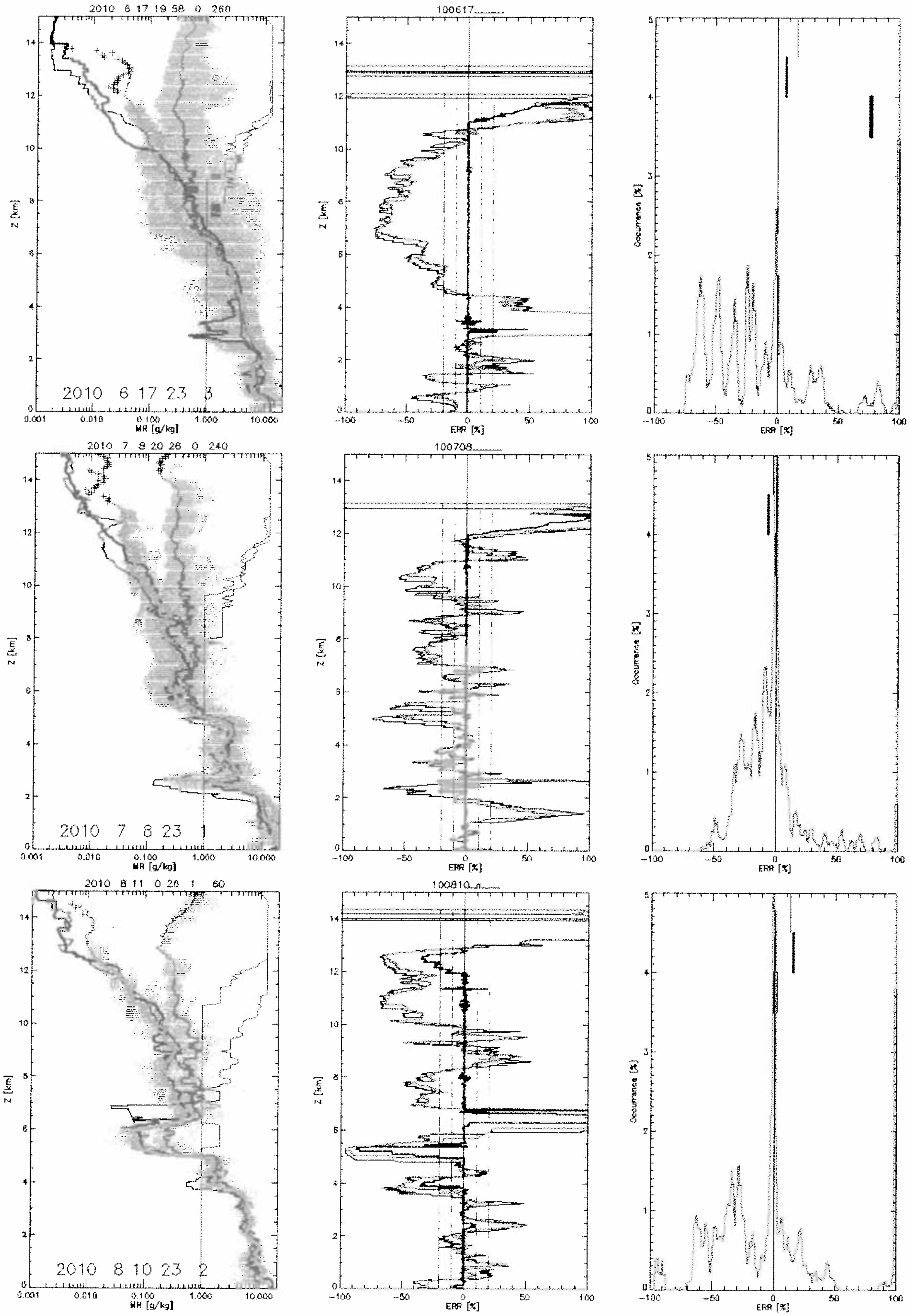
MR [g/kg]
ERR [%]
Occurrence [%]


2010 6 17 19 58 0 260
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2010 6 17 23 3
2010 7 8 20 26 0 240
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2010 7 8 23 1
2010 8 11 0 26 1 60
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2010 8 10 23 2
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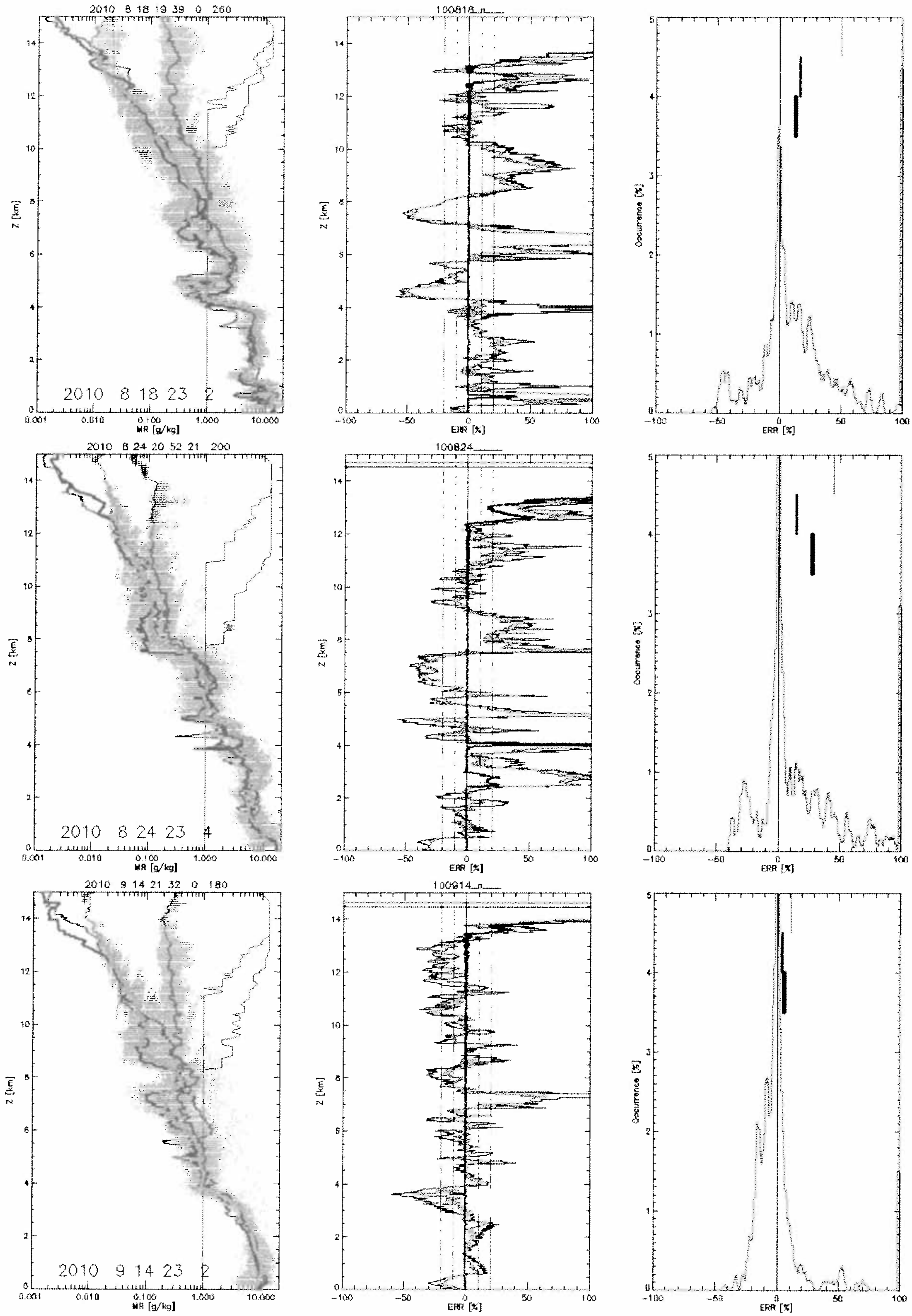
MR [g/kg]
ERR [%]
Occurrence [%]



2010 8 18 19 39 0 260
2010 8 18 23 2
100818_n
2010 8 24 20 52 21 200
2010 8 24 23 4
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2010 9 14 23 2
100914_n
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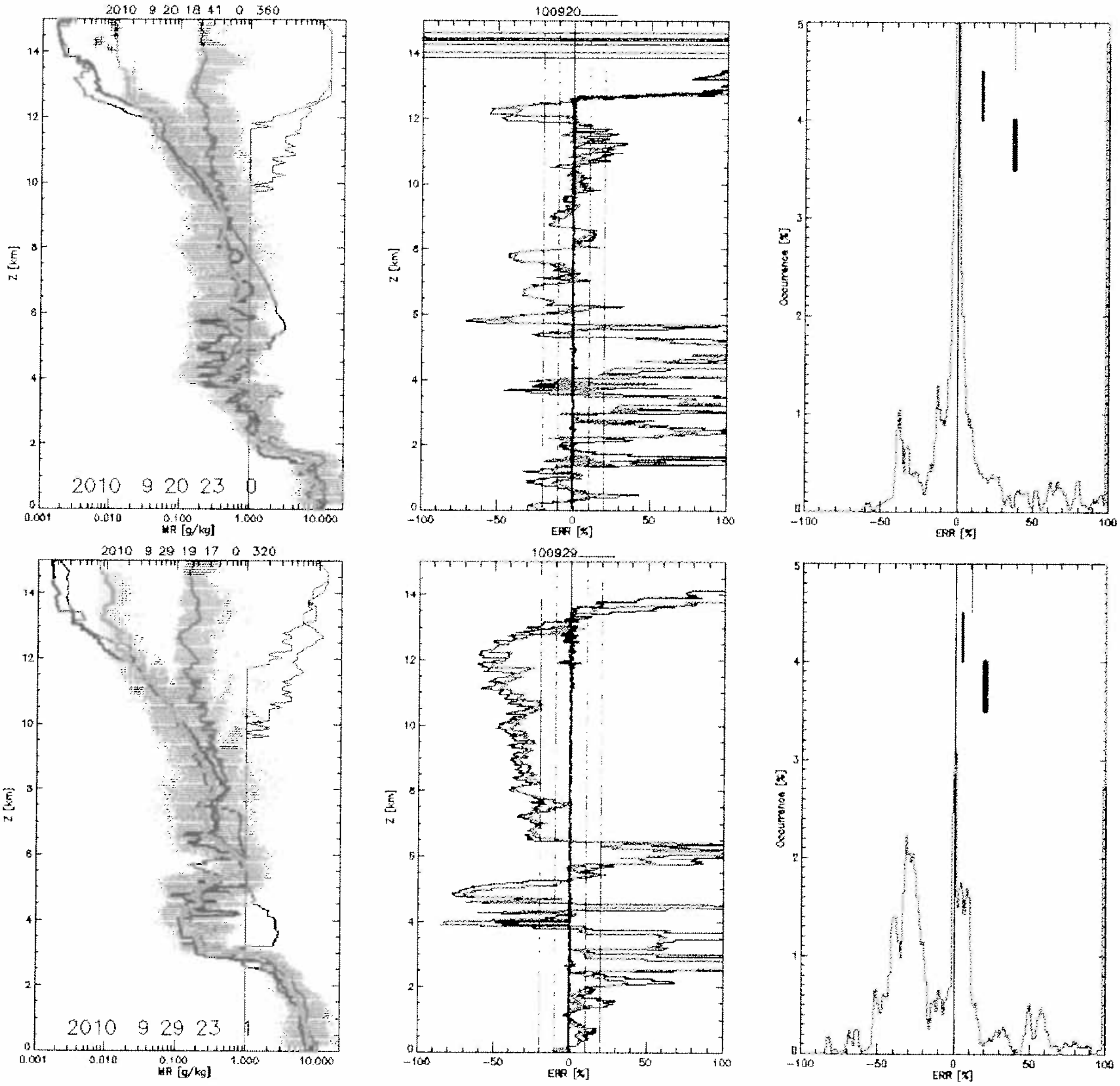
MR [g/kg]
ERR [%]
Occurrence [%]


2010 9 20 18 41 0 360
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2010 9 20 23 0
2010 9 29 19 17 0 320
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2010 9 29 23 1
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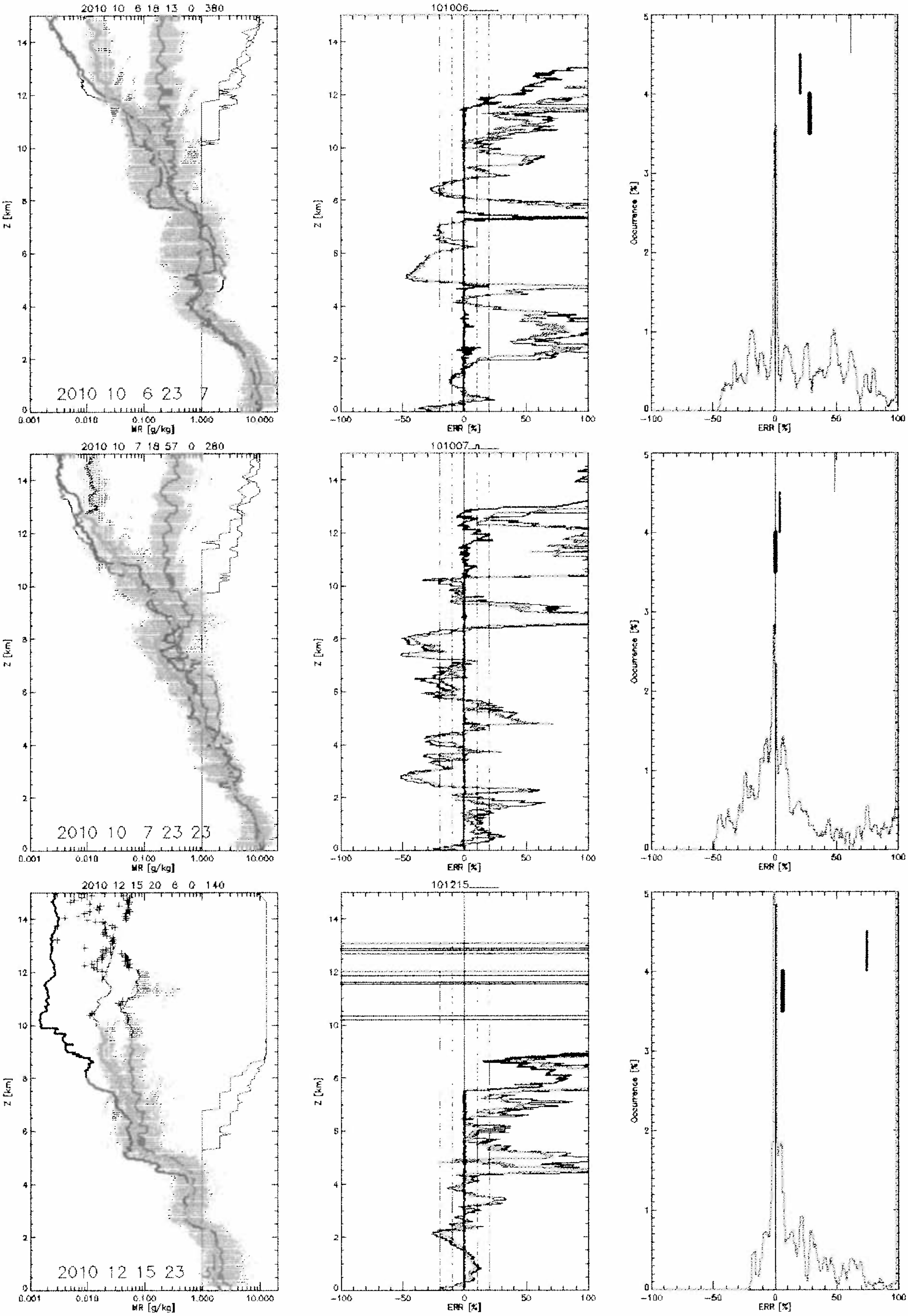
MR [g/kg]
ERR [%]
Occurrence [%]


2010 10 6 18 13 0 380
2010 10 6 23 7
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Occurrence [%]
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2010 10 7 23 23
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2010 12 15 20 6 0 140
2010 12 15 23
101215