Photographic High-Dynamic-Range Scalar Visualization—Supplemental Material

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Abstract—This supplemental material contains contents that are left out from the paper for conciseness. Specifically, details of the tone-mapping operator evaluations are explained, including the full set of tone-mapped images used in evaluations of tone-mapping operators, and details of selected distortion images. Next, the fully documented expert evaluation is reported.

Index Terms—Photographic, tone mapping, glare, high dynamic range visualization, 2D diagrams.

1 Tone-mapped Images for Evaluations

This section reports on the details of the evaluation of tone-mapping operators which is discussed in Section 3.1 of the paper. The evaluation was performed using three representative HDR datasets: Hurricane Isabel 2D scatter plot (Isabel TvP), world flight routes (World Flights), and parallel coordinates of hurricane Isabel (Isabel parallel coordinates). These datasets are chosen because they are typical representatives of HDR data containing different types of features: Isabel TvP contains only dots; Isabel parallel coordinates contain curves and high-value area of curve crossings; the world flights data is a less abstract geospatial data containing both dots and curves.

Our systematic evaluation considers 14 popular tone-mapping operators: linear, gamma 1/2.2 (gamma), logarithmic (log), Ash02 [1], Pat00 [2], Man06 [3], Man08 [4], Mai11 [5], Fer11 [6], Fat02 [7], Dra03 [8], Dur02 [9], Rei02 [10], and Rei05 [11]. The tone-mapping operators are chosen to be evaluated as they are well-accepted techniques and have been implemented in the state-of-the-art HDR processing toolkit [12].

All tone-mapped LDR images used in the tone-mapping operator evaluation are shown in Figure 1. Names of tone-mapping techniques are shown in the first column; results of the World Flight data, Hurricane Isabel Parallel Coordinates, and Isabel TvP are listed in the second through fourth columns respectively.

The mean values of distortions of evaluated tone-mapping operators on each dataset and the average across all datasets are summarized in Table 1 in ascending order.

TABLE 1
Mean distortion metric of tone-mapping operators in our evaluation.

TMO	IsabelTvP	World Flights	IsabelPC	Averaged
Man08 [4]	0.483	0.372	0.698	0.517
Man06 [3]	0.541	0.796	0.558	0.632
Mai11 [5]	0.532	0.610	1.076	0.739
Ash02 [1]	0.749	1.653	0.731	1.044
Rei05 [11]	0.650	0.685	1.850	1.062
log	0.756	0.954	1.604	1.105
Dur02 [9]	0.803	1.211	1.632	1.216
Fat02 [7]	0.802	1.350	1.645	1.266
Fer11 [6]	1.267	1.666	1.681	1.538
Dra03 [8]	1.280	1.838	1.590	1.570
Pat00 [2]	1.339	1.684	1.696	1.573
Rei02 [10]	1.259	1.792	1.781	1.610
gamma	1.564	1.801	1.962	1.775
linear	2.580	2.663	2.626	2.623

The top three best performers (Man08 [4], Man06 [3], and Mai11 [5]) have much lower scores than other tone-mapping operators, indicating that they generate fewer distortions in general. Since Mai11 [5] is the only global tone-mapping operator within the top three, we pick it as our choice for global HDR visualization. A further examination on the distributions of distortions in tone-mapped images made us choose Man06 [3] over Man08 [4] as Man06 [3] yields lower errors in regions of important features than Man08 [4].

Detailed distortion images of individual channels comparing the top three tone-mapping operators: [4], [3], and [5] are shown in Figure 2. The top three best performers (Man08 [4], Man06 [3], and Mai11 [5]) have much lower scores than other tone-mapping operators indicating that they generate fewer distortions in general. Therefore, we focus on these three tone-mapping operators and further examine the distribution of distortions in tone-mapped images generated by them. Figure 2 shows the case of the World Flight data where the distortion of Man08 [4] is significantly lower than the other two tone-mapping operators. The distortion maps are generated using [13], where green indicates loss of visible contrast, red for reversal of visible contrast, and blue for amplification of invisible contrast. By examining the distortion maps, it can be seen that the loss of contrast in Man08 [4] and Mai11 [5] occur particularly in high-value regions of the map, i.e., East Asia, Europe,

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and North America, making it difficult to recognize details in these regions; whereas the same type of distortion in Man06 [3] occurs in regions of lower values and of smaller distortion values. Although Man06 [3] yields higher error values in larger areas than the other tone-mapping operators for contrast reversal and amplification, these errors occur on regions of lower-value, and the features in those regions can still be seen in the tone-mapped image. These findings can be verified by examining the actual tone-mapped images (Figure 1).

2 Expert User Evaluation

We evaluate our visualization tool that implements the proposed method with a study of visualization experts.

2.1 Study Design

We used a usability study design with a think-aloud approach and questionnaires. After an introduction to the proposed method, participants were shown with three static examples to get familiar with our visualization, and then they were asked to explore the New York taxi data with our visualization tool while the observer watched, listened, and talked to participants.

We instructed the participants to interact with the visualization tool, for example, exploring glares with the "magic lens", trying different lens modes, switching the glares on-and-off, changing the threshold for glaring, or choosing between different color maps, to gain insights into the data. The observer was responsible to answer any questions asked by participants. To record the feedback from participants, we audio recorded the conversations between participants and the observer and later processed these records into transcripts. The participants were asked to fill out a questionnaire after the task. The questionnaire is comprised of seven Likert-scale questions to get a quantitative, subjective evaluation. A pilot study with one subject was carried out to adapt the usability study process.

2.2 Participants and Study Procedure

There were 5 participants (1 female, 4 males) who all have a normal color vision and visual acuity. All of them are experienced visualization experts with experiences in the area from 3 years to 10 years. They were from the SCI Institute, and were not involved in the research for this paper except as participants of the user study and the participation was voluntary. The full study was conducted in the SCI institute's lab isolated from outside distractions. The stimuli were presented on a 28-inch LED display with a resolution of 3840×2160 pixels. We first introduced the visualization method with three examples: the New York taxi, Wine Quality parallel coordinates, and the hand CT scan; then, the interaction techniques were introduced. After that, they were asked to explore the New York taxi data, and then fill out the questionnaire. The live demo session of the study was audio recorded to get feedback. The typical length of the study was around 30 min.

2.3 Feedback from Participants

After the study, we documented transcripts of audio recordings and marked useful comments from each participant, and identified comments made by several participants. We found some common preferences from participants as follows.

First, they found that glares effectively draw their attention to high valued areas and make the visualization memorable: "I like the glaring part. Even without the visualization, you can something remember where they are", "I like the glare one. At least they are more memorable", "With the glares you know where to look for. They caught people's attention", "It's nice to have halos [glares] to highlight densely clustered particles", and "And yours [our method] correctly identified high-density areas, and so once I've had trust in it I would look at different areas [than in the traditional method] for high density. Like the fact that this is stronger than here is really helpful."

Second, the participants liked interactive techniques that reveal the underlying image under glares: "Lens tool is to see the underlying structures around the glare, which makes sense. To explore the localities using glares then with the lens are a really useful tool" and "Having something that you can hover over to see details in the lower level is super valuable."

Third, they found the global-and-local tone-mapped images useful and not confusing: "It's clear that you could see that you have a large absolute value [outside the lens], and here you could see a large relative value [inside the lens]. It's easy to understand [that the colors inside and outside of the lens are not comparable]", and "we perceive [contrast] locally, and we should take advantage of it."

2.4 Results of the Questionnaire

For the questionnaire, we asked participants to rate the following seven statements after interacting with the visualization tool:

1. Rate the insights gained for 2D aggregated data using the proposed method.
2. Revealing the image and bright pixels under glares with the lens improves understandings of data.
3. Lens for local contrast enhancement improves understandings of data.
4. Switching glares on-and-off improves understandings of data.
5. Rate how misleading the glares are.
6. Rate how misleading the local tone mapping operator with lens is.
7. Rate the aesthetic aspect of the method.

Also, we asked participants to leave their comments after these questions. For each question, we used a Likert scale from 1 (not at all/strongly disagree) to 5 (excellent/strongly agree).

We summarized the mean responses of the questionnaire in Table 2. By further averaging scores based on the grouping of statements: 4.4 is rated for insights gained of data with the new method (Statement 1), 4.7 for effectiveness of interaction methods (Statements 2–4), and 2.3 for how misleading the new method is (Statements 5–6).

TABLE 2
Mean Responses of the Questionnaire

Statements	Likert Scale (range: 1–5)
Rate insights gained with our method	4.4
The reveal and bright pixels modes improve data understandings	4.8
Switching glares improves data understandings.	4.6
The contrast lens provides additional info of data.	4.6
Rate how misleading the information introduced by glares is.	2.2
Rate how misleading the contrast lens is.	2.4
Rate the aesthetic of the method.	4.4

High agreements are achieved for the first five statements within participants, where rating differences between them are no more than one scale. One participant rated the sixth statement with a 4 argued that the approach could be misleading for quantitative interpretation: “The fact that the color map domain changes is misleading, but with a separate, labeled (with data values) local color map would make me pick ‘not at all’.” He made further comments on the quantitative aspect of the approach: “The only critic is that I don’t know how these numbers play out as I know what the log scale is.” This problem is resolved after value range bars are drawn on color maps.

They also made remarks on their data exploration experience. One said that “you may think they (the glares) are only points, and with the lens, you can see that they are clusters”. Another commented: ”That (the usefulness of the glare switch) depends on the flow of interactions—how often you use it, how many glares in the data, and also the size of screens. Also, it depends on the strains or stress of the user. But I think it’s totally fine for the case you showed.”

Overall, participants agreed that the proposed method was able to improve insights gained from the dataset, and was effective for qualitative analysis of the dataset. They agreed that the glares steered their attention to interact with the high-value regions.

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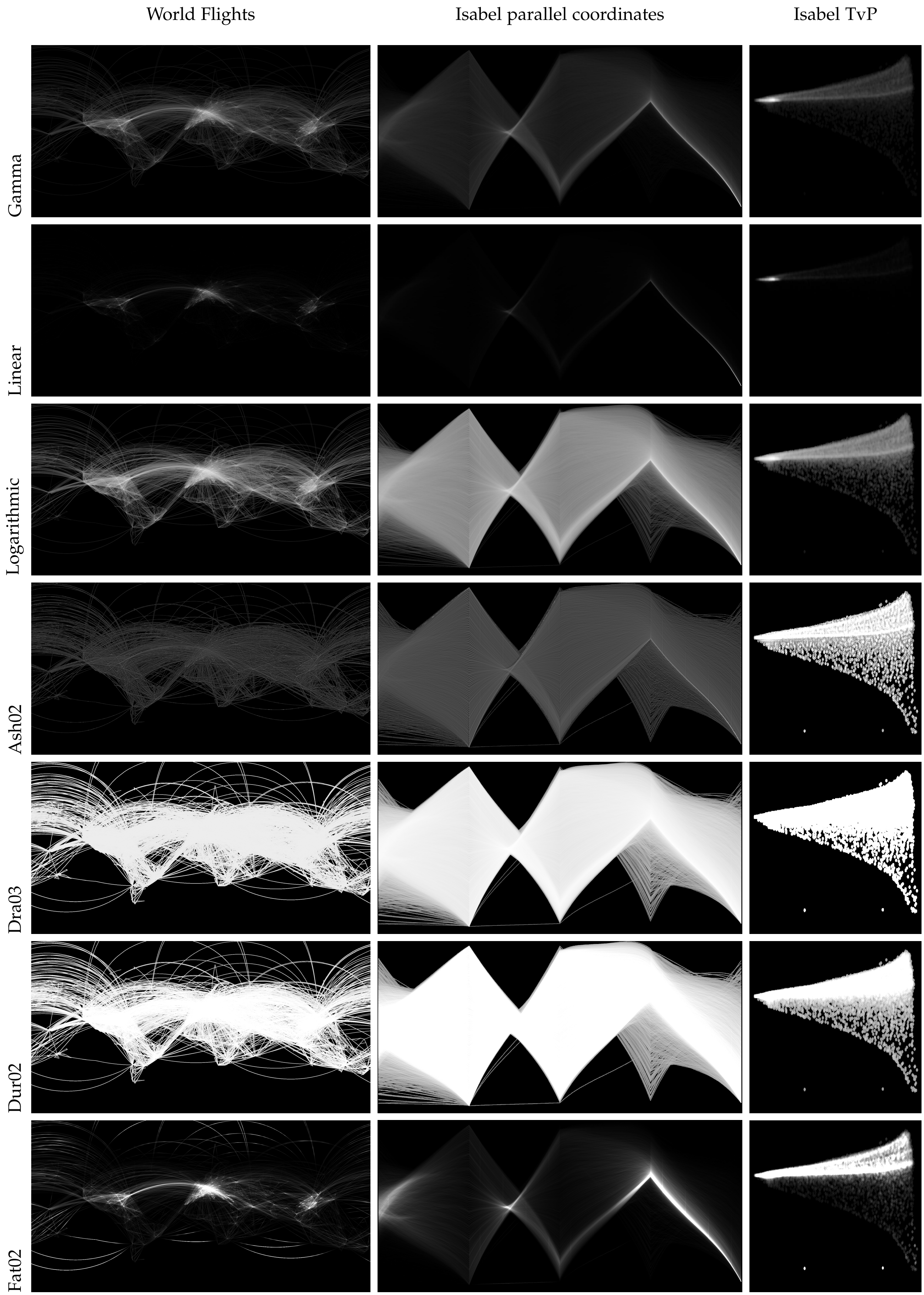

Fig. 1. Tone-mapped images used in our evaluation: World flights (first row), Isabel parallel coordinates (second row), and the scatterplot of Hurricane Isabel TvP data (third row)

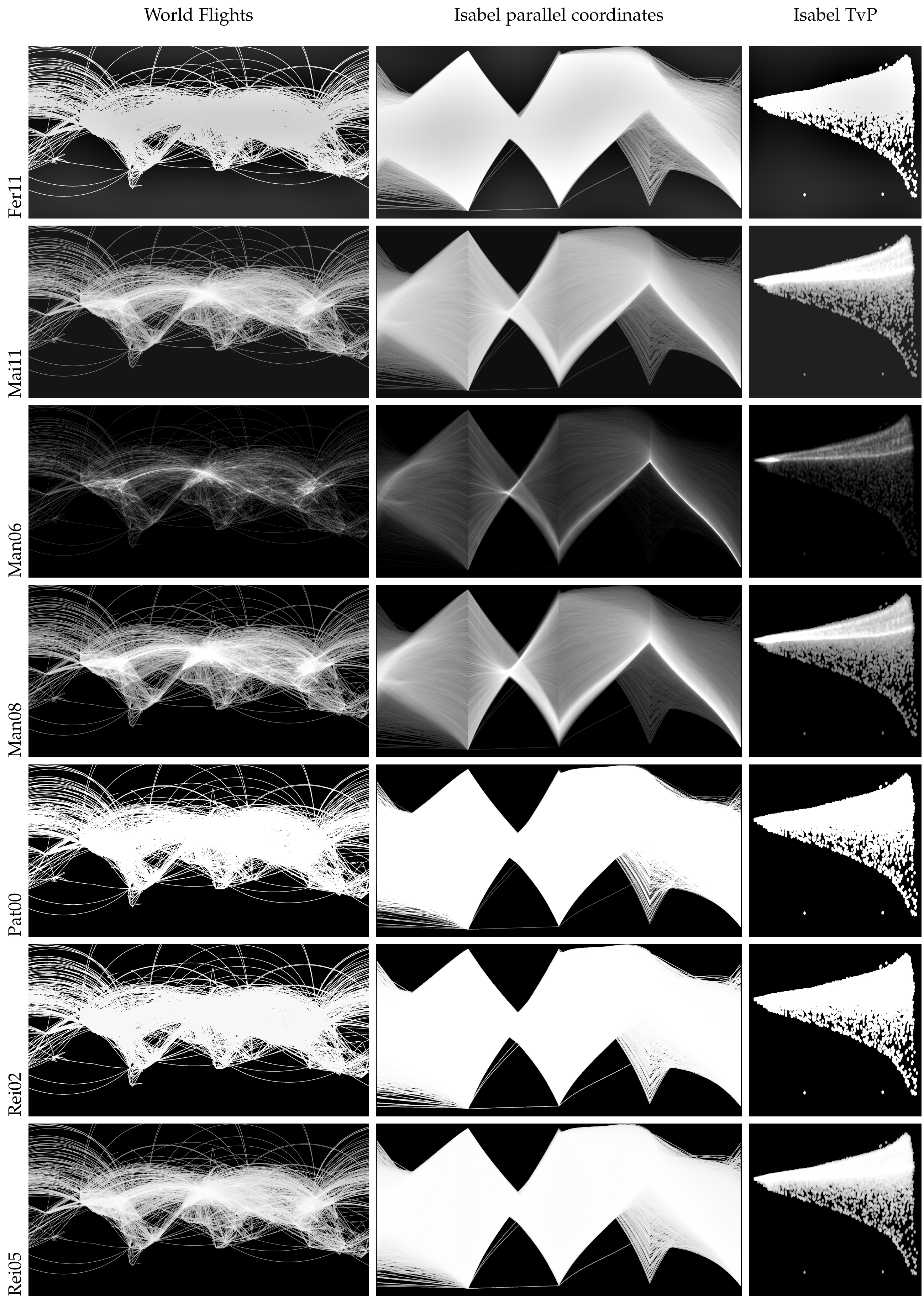

Fig. 1. Continued figure from previous page.

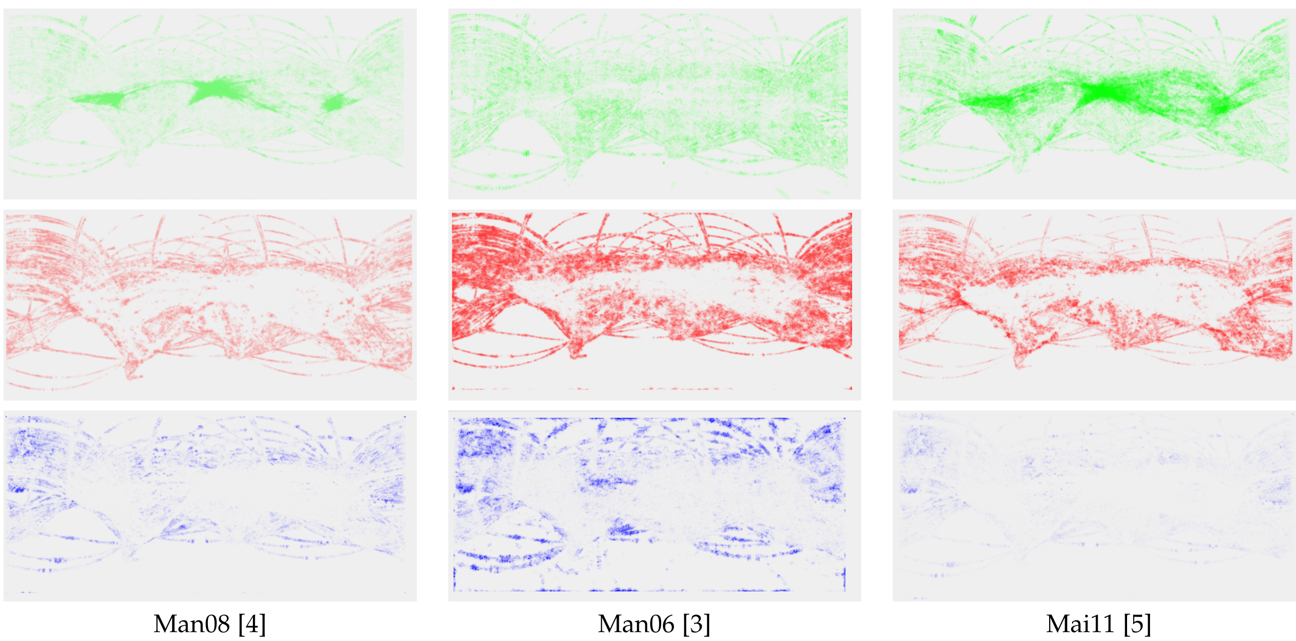

Fig. 2. Distortion maps of the top three tone-mapping operators in our evaluation.