Abstract Title: A Ground Flash Fraction Retrieval Algorithm for GLM

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ABSTRACT

A Bayesian inversion method is introduced for retrieving the fraction of ground flashes in a set of N lightning observed by a satellite lightning imager (such as the Geostationary Lightning Mapper, GLM). An "exponential model" is applied as a physically reasonable constraint to describe the measured lightning optical parameter distributions. Population statistics (i.e., the mean and variance) are invoked to add additional constraints to the retrieval process. The Maximum A Posteriori (MAP) solution is employed. The approach is tested by performing simulated retrievals, and retrieval error statistics are provided. The approach is feasible for $N > 2000$, and retrieval errors decrease as N is increased.

A Ground Flash Fraction Retrieval Algorithm for GLM

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1. INTRODUCTION

A constrained mixed exponential distribution model and a Bayesian inversion method are introduced for retrieving the fraction of ground flashes in a set of flashes observed by the future Geostationary Lightning Mapper (GLM); the method can also be applied to low Earth orbiting lightning imagers. The approach is tested by performing simulated retrievals, and retrieval error statistics are provided.

2. DISTRIBUTIONS OF A LIGHTNING OPTICAL PARAMETER (SHIFTED MGA)

Figure 1 shows the ground and cloud flash distributions of $y \equiv x - 64\ km^2$ (where x = the Maximum Group Area, MGA, in a flash). These data were derived from an analysis of 5 years of OTD data (Koshak, 2010), and discussed in Koshak and Solakiewicz (2010). The red analytic curve in each plot is an exponential distribution with a mean equivalent to the data average shown in the upper right corner of the plot.

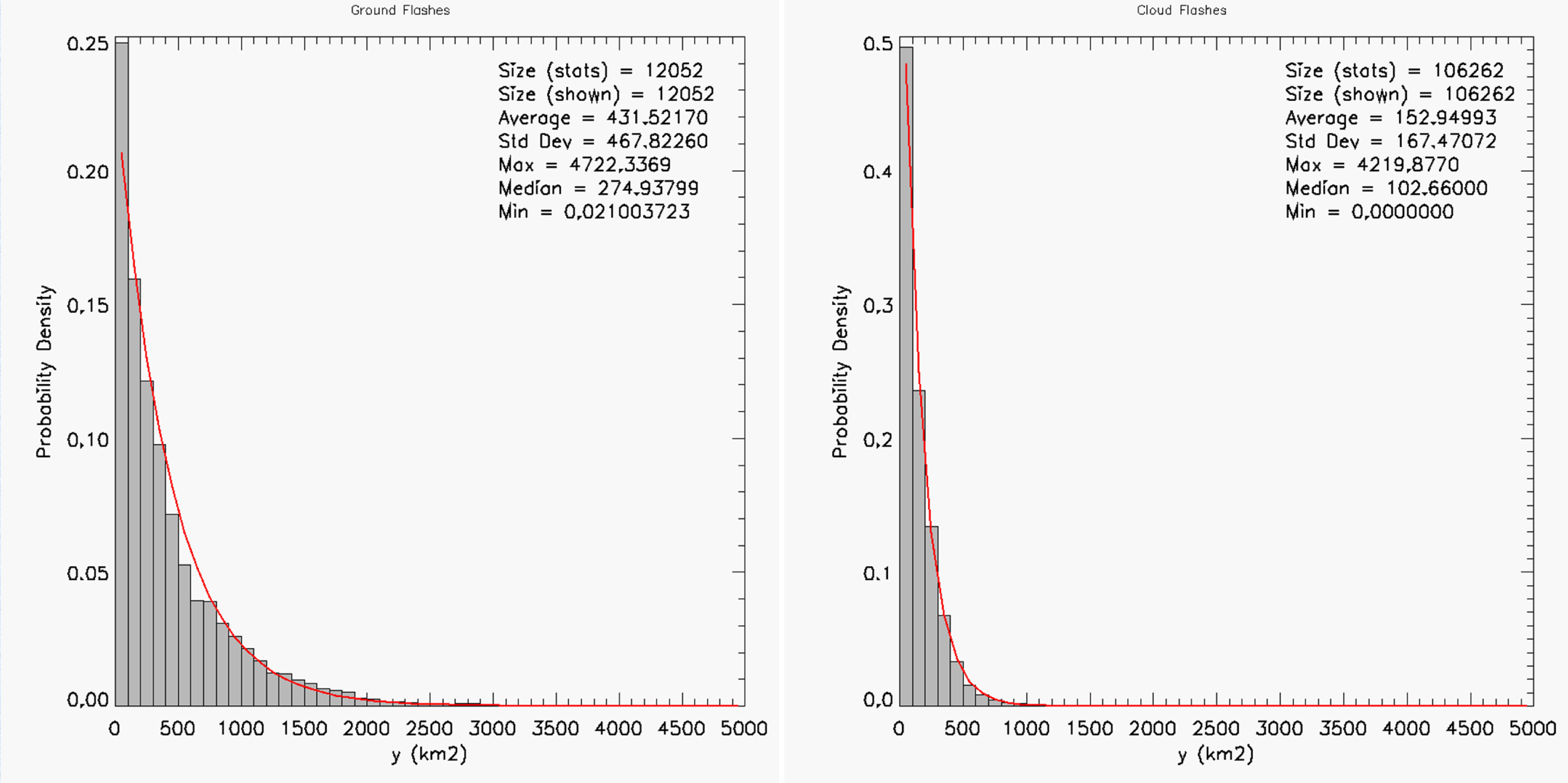


Figure 1. Distributions of the (shifted) MGA variable, *y*.

3. RETRIEVAL METHOD

For a mixture of ground and cloud flashes, one can consider a superposition of exponential distributions. This gives, in general, the following *Mixed Exponential Distribution Model*, and *Bayesian Inversion* scheme:

Mixed Exponential Distribution Model

Basic Definitions:

x = Maximum Group Area (MGA) in a flash

$y = x - 64km^2$ (Shifted MGA)

N_g = # Ground flashes in lat/lon bin of interest

N = # Flashes in lat/lon bin of interest

$\alpha = N_g / N$ (Ground flash fraction)

μ_g = Population mean y for ground flashes (in lat/lon bin of interest)

μ_c = Population mean y for cloud flashes (in lat/lon bin of interest)

Distribution of MGA modeled as a Mixed Exponential Distribution:

$$p(y) = \alpha p_g(y) + (1-\alpha)p_c(y) = \frac{\alpha}{\mu_g} e^{-y/\mu_g} + \frac{(1-\alpha)}{\mu_c} e^{-y/\mu_c}, \quad y \geq 0 \quad .$$

Population Means of y:

$$\mu_g \equiv \int_0^\infty y p_g(y) dy, \quad \mu_c \equiv \int_0^\infty y p_c(y) dy \ .$$

Require that:

$$\mu_g > \mu_c$$

Bayesian Inversion

Bayes' Law:

$$P(\alpha, \mu_g, \mu_c | \mathbf{y}) = \frac{P(\mathbf{y} | \alpha, \mu_g, \mu_c) P(\alpha, \mu_g, \mu_c)}{P(\mathbf{y})} \ ,$$

Find parameters $\mathbf{v} = (\alpha, \mu_g, \mu_c)$ that maximize the probability on LHS.

This means one maximizes the following :

$$S(\mathbf{v}) \equiv \ln\left[P(\mathbf{y}|\mathbf{v})P(\mathbf{v})\right] = \ln\prod_{i=1}^{m} p(y_i|\mathbf{v}) + \ln P(\mathbf{v}) = \sum_{i=1}^{m} \ln\left[\frac{\alpha}{\mu_g} e^{-y_i/\mu_g} + \frac{(1-\alpha)}{\mu_c} e^{-y_i/\mu_c}\right] + \ln P(\mathbf{v}),$$

Formally :

$$\frac{\partial S(\mathbf{v})}{\partial \mathbf{v}} = \mathbf{0} \quad \Rightarrow \quad \mathbf{v} = \text{"Maximum A Posteriori (MAP) Solution"}$$

Practically :

Use Broyden-Fletcher-Goldfarb-Shannon variant of Davidon-Fletcher-Powell numerical method to minimize $-S(\mathbf{v})$. Also, $P(\mathbf{v})$ is simplified by assuming model parameter independence, with $P(\alpha)$ uniform, and $P(\mu_g)$ & $P(\mu_c)$ both normal distributions.

4. GROUND FLASH FRACTION RETRIEVAL ERRORS FROM SIMULATIONS

To test the retrieval method, lightning sources were simulated; the known ground flash fraction was compared to the retrieved value. A few examples of retrieval errors are shown in **Figure 2** for *N*=2000.

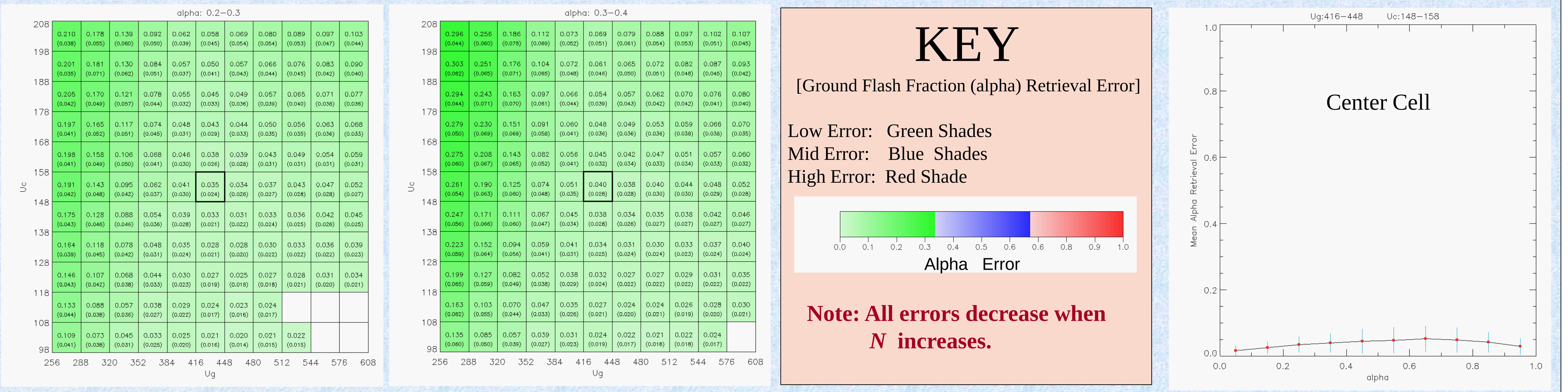
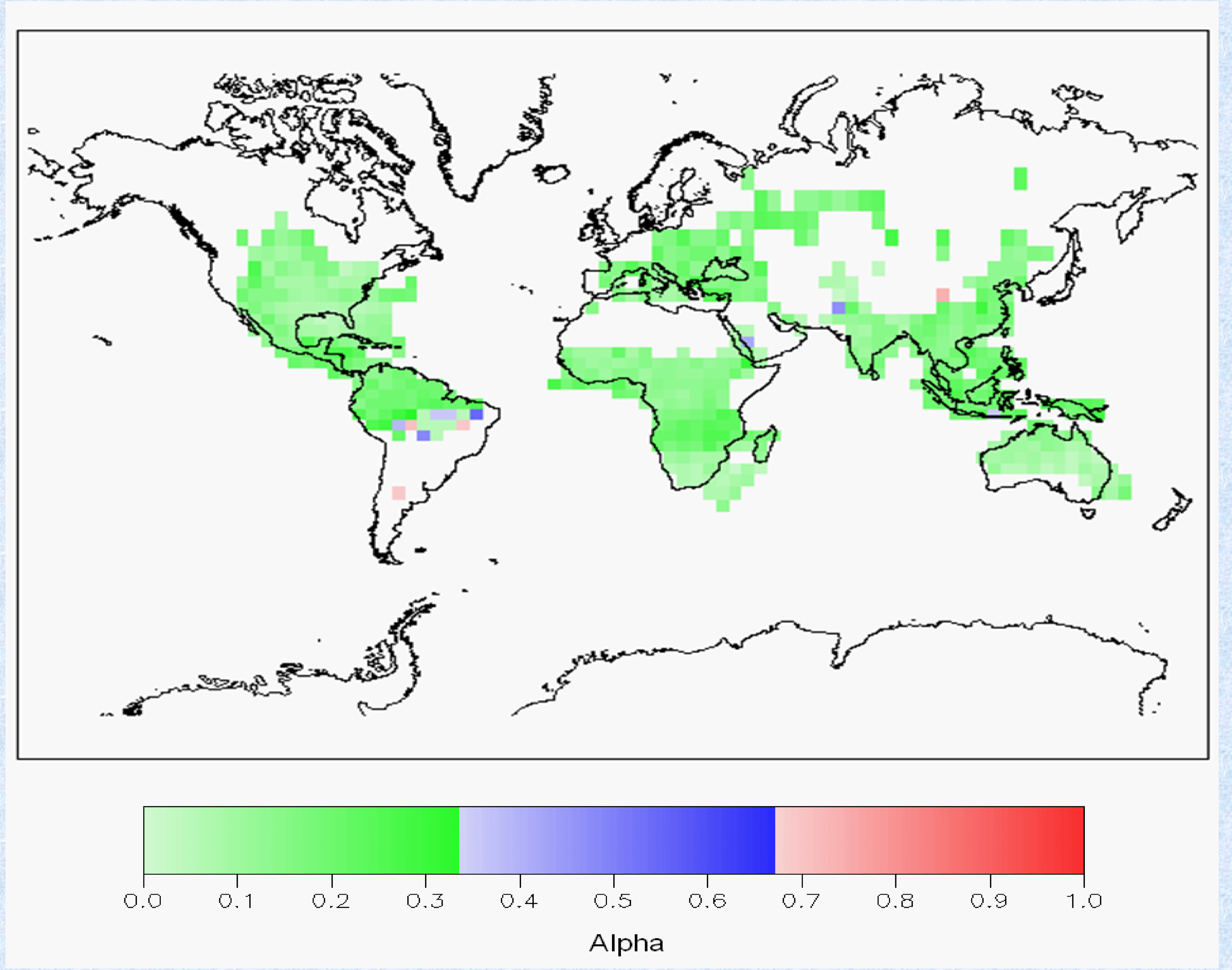


Figure 2. Mean ground flash fraction (alpha) retrieval errors as a function of the known population mean values of MGA (2 left plots); the true alpha range is given at top of each plot. The standard deviations about the mean are shown in parentheses within each cell. Variation of retrieval error is also shown as a function of entire true alpha range (right-most plot).

5. GLOBAL RETRIEVAL OF GROUND FLASH FRACTION (FROM OTD DATA; Figure 3)

The ability to retrieve ground flash fraction has important benefits to the atmospheric chemistry community. For example, using the method to partition the existing OTD/LIS satellite global lightning climatology into separate ground and cloud flash climatologies would improve estimates of global lightning nitrogen oxides (NOx) production; this in turn would improve both regional air quality and global chemistry/climate model predictions. A first attempt is made here to retrieve the ground flash fraction on a global scale using just OTD data.



For the 562 4x4 degree lat/lon bins shown to the left (each bin has N ≥2000), the following stats were obtained:

Mean Alpha = 0.151
Std Dev. Of Alpha = 0.081
Max Alpha = 0.739
Min Alpha = 0.019

Figure 3. Ground flash fraction on a global scale using Optical Transient Detector (OTD) data.

6. REFERENCES

- Koshak, W. J., 2010: Optical Characteristics of OTD Flashes and the Implications for Flash-Type Discrimination, accepted in JTECH, May 2010.
- Koshak, W. J., R. J. Solakiewicz, 2010: Retrieving the Fraction of Ground Flashes from Satellite Lightning Imager Data Using CONUS-Based Optical Statistics, accepted pending revisions JTECH, May 2010.