AIRS Point Spread Function Reconstruction using AIRS and MODIS Data

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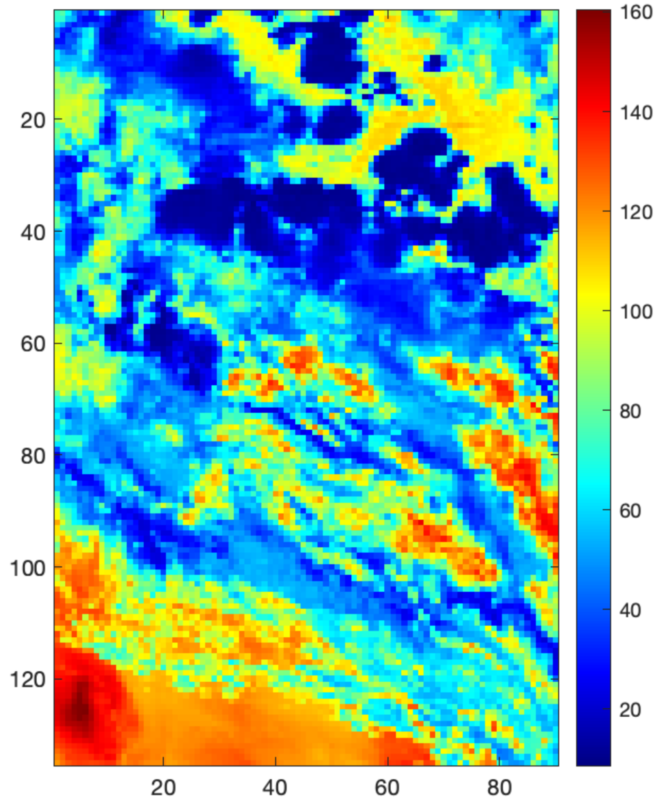
Motivation and Approach

- The purpose of this effort is to use MODIS data to refine our knowledge of post-launch AIRS point spread functions (PSFs), including suspected changes over the mission.
- Deriving mathematical optimization formulation for reconstruction of AIRS spatial response functions from AIRS and MODIS data.

AIRS Data

- AIRS spatial response is different for each of 2378 channels and 90 scan angles.
- Channels range from 3.7 μm to 15.4 μm
- Spatial resolution is 13.5 km
- Granule is 90 scan angles by 135 scans
  - 240 granules per day
- Match AIRS and MODIS radiances.
- Resample MODIS radiances onto AIRS PSF grid
  - AIRS PSFs are 39x39 pixels, 0.04 degrees / pixel
  - Each AIRS footprint corresponds to 40x40 MODIS pixels
  - MODIS channel 31 used with 1 km resolution



AIRS granule
Channel 776 (913.4 cm^{-1}), window channel

Minimization Problem

We want to reconstruct a point spread function K_i by solving the following minimization problem:

$$\min_{K_i} E(K_i) = \min_{K_i} \left|\left| L'_{AIRS,i,sc}(K_i) - L'_{MODIS,i,sc} \right|\right|_2^2$$

Approaches Investigated

- Different types of regularization constraints on the reconstruction:
  - Constraint on magnitude of reconstruction
  - Constraint on L^2-norm of the gradient of reconstruction (Tikhonov regularization)

  $\Rightarrow$ No regularization was required.
- Log barrier soft positivity constraint on the reconstruction
- Different types of optimization algorithms:
  - Regular (L^2) Gradient Descent
  - Sobolev (H^1) Gradient Descent
- Different initial conditions:

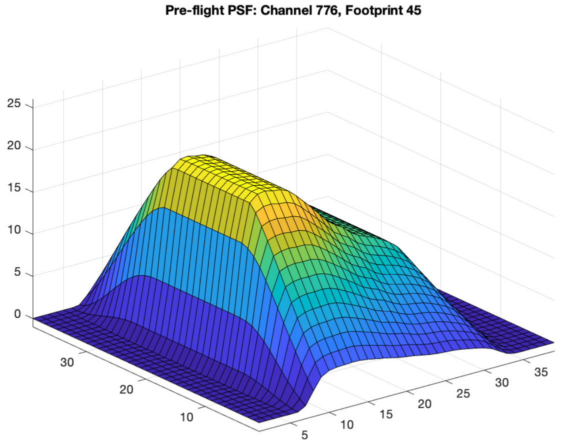
  $\Rightarrow$ The methodology is not sensitive to the choice of initial conditions.

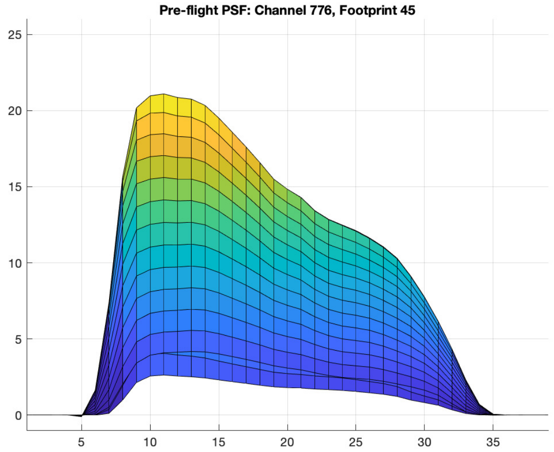
Latest Investigations

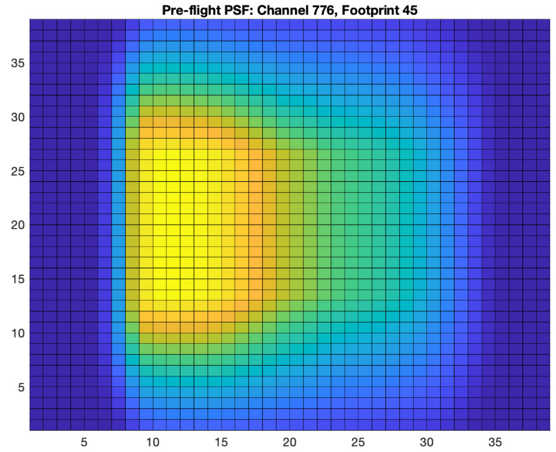
- Examined full days of data for each of the three days:
  - Data collected right after the launch:
    - March 1, 2003
    - March 2, 2003
  - Data collected at the middle of the mission:
    - March 1, 2014
- Used 235 to 239 granules for each of these days.
- Data over oceans were considered for deriving PSFs.

Channel 776 (913.4 cm^{-1}), Footprint 45

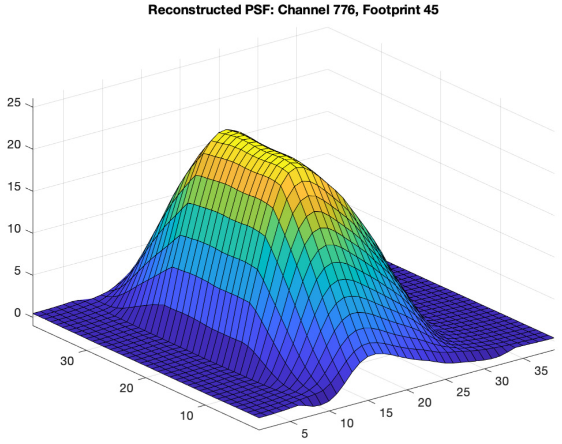
Pre-flight PSF

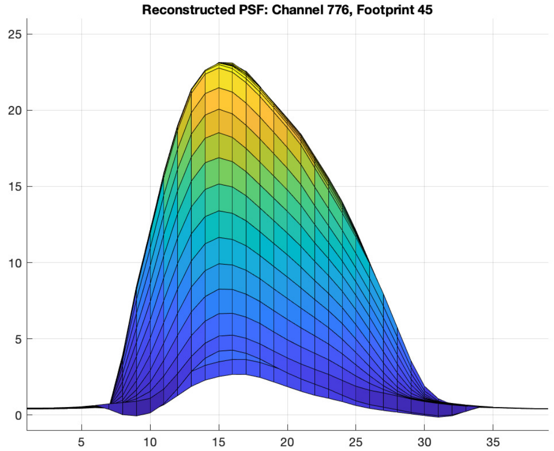


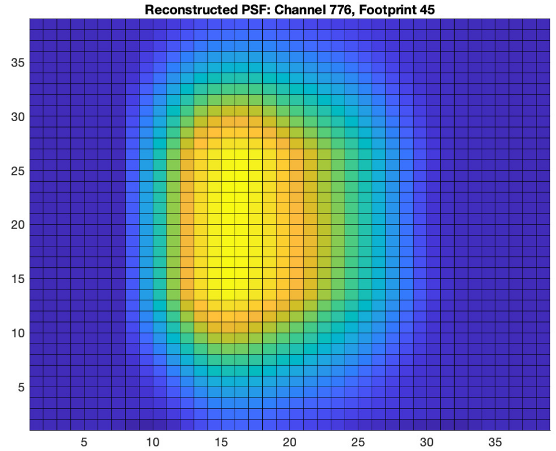




Reconstructed PSF

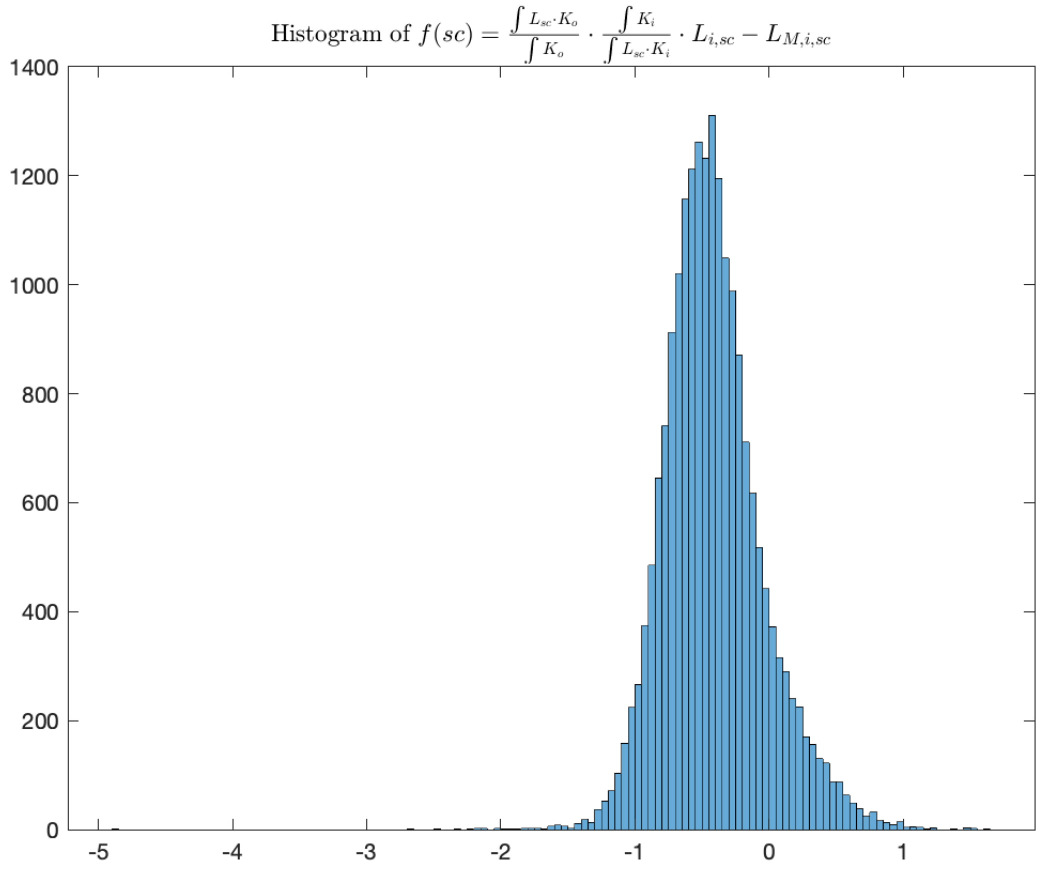


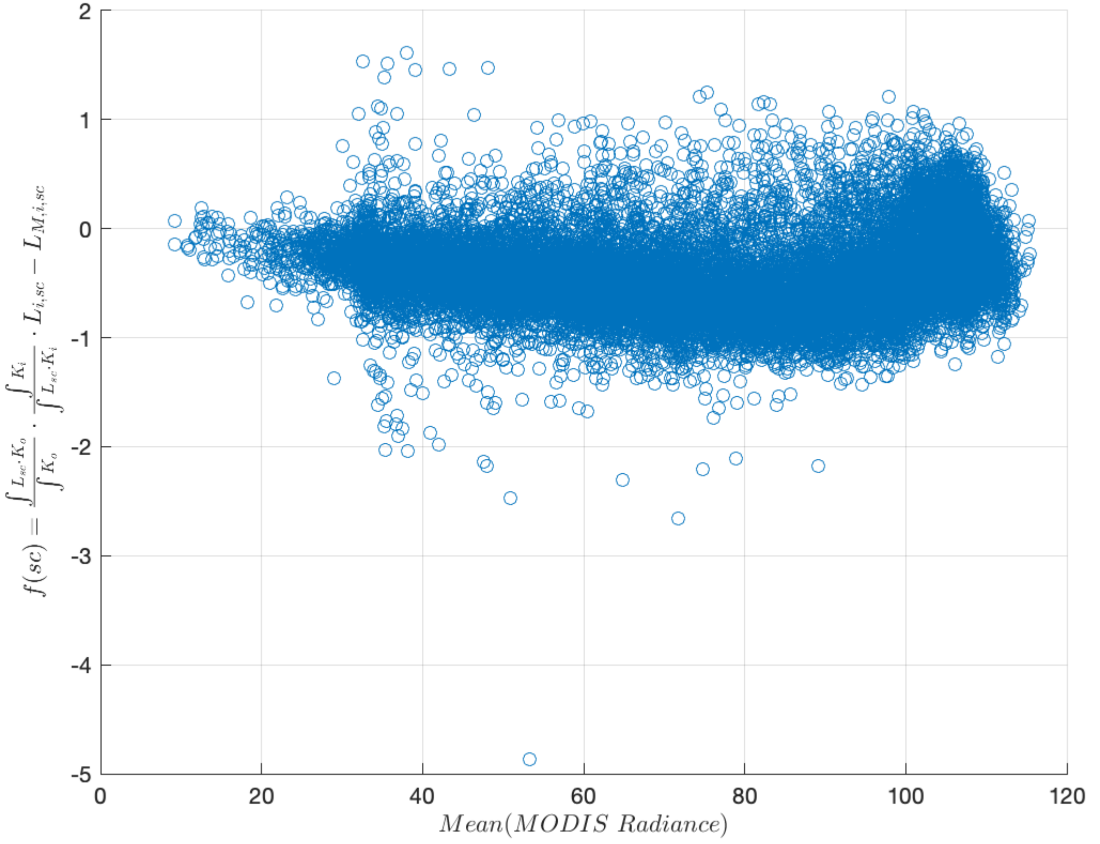




Using data from March 1, 2014

Residuals: PSF Reconstruction for Channel 776, Footprint 45





How does PSF trained on one day's data agree with the data for a different day?

- Repeatability: Examine data from consecutive days (March 1 & 2, 2003).
- Change: Compare data collected right after the launch (2003) with data collected at the middle of the mission (2014).

Channel 776 (913.4 cm^{-1}), Footprint 45

Residuals

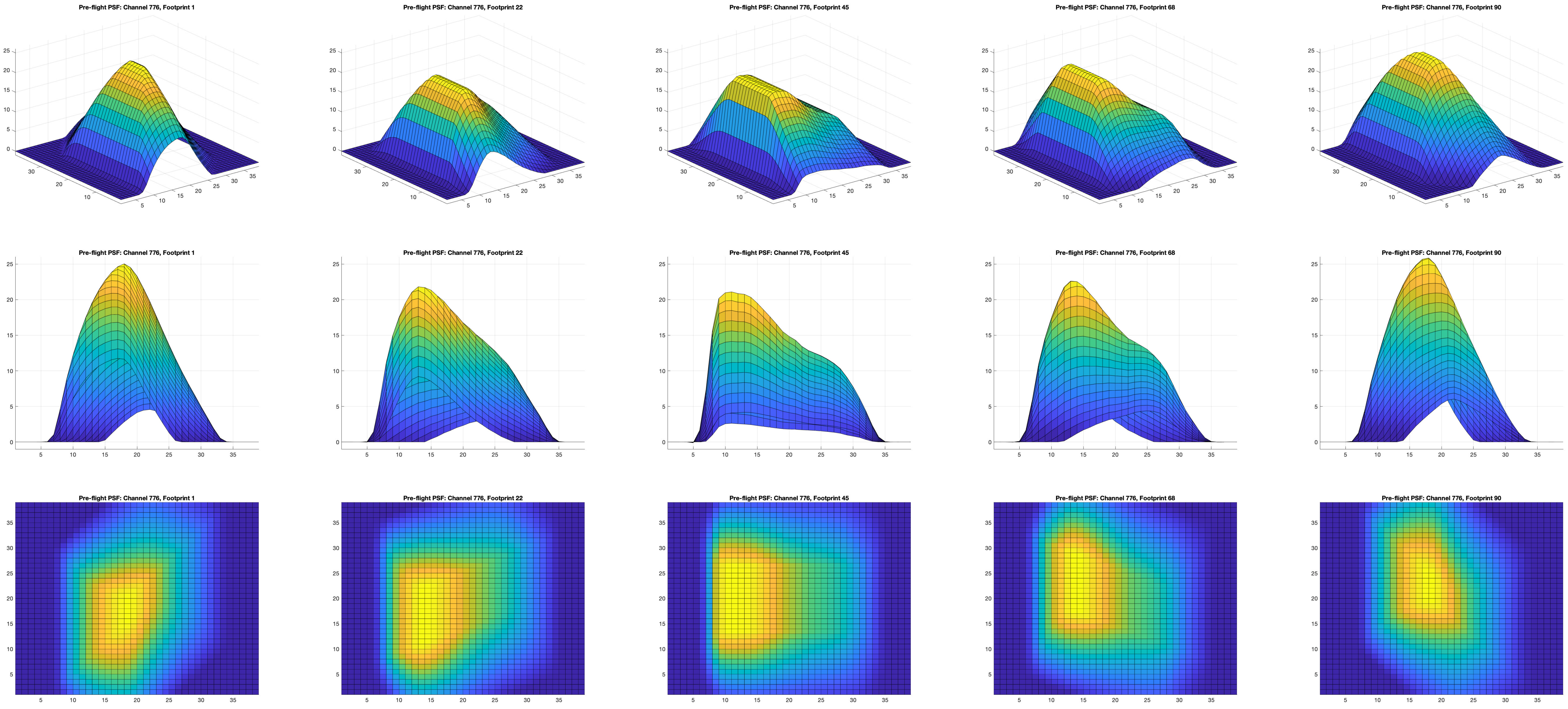
train \ test	2003.03.01	2003.03.02	2014.03.01
Pre-flight PSF	0.5960	0.5862	0.5251
2003.03.01	0.3091	0.3182	0.3082
2003.03.02	0.3092	0.3167	0.3071
2014.03.01	0.3158	0.3237	0.3102

Observations:

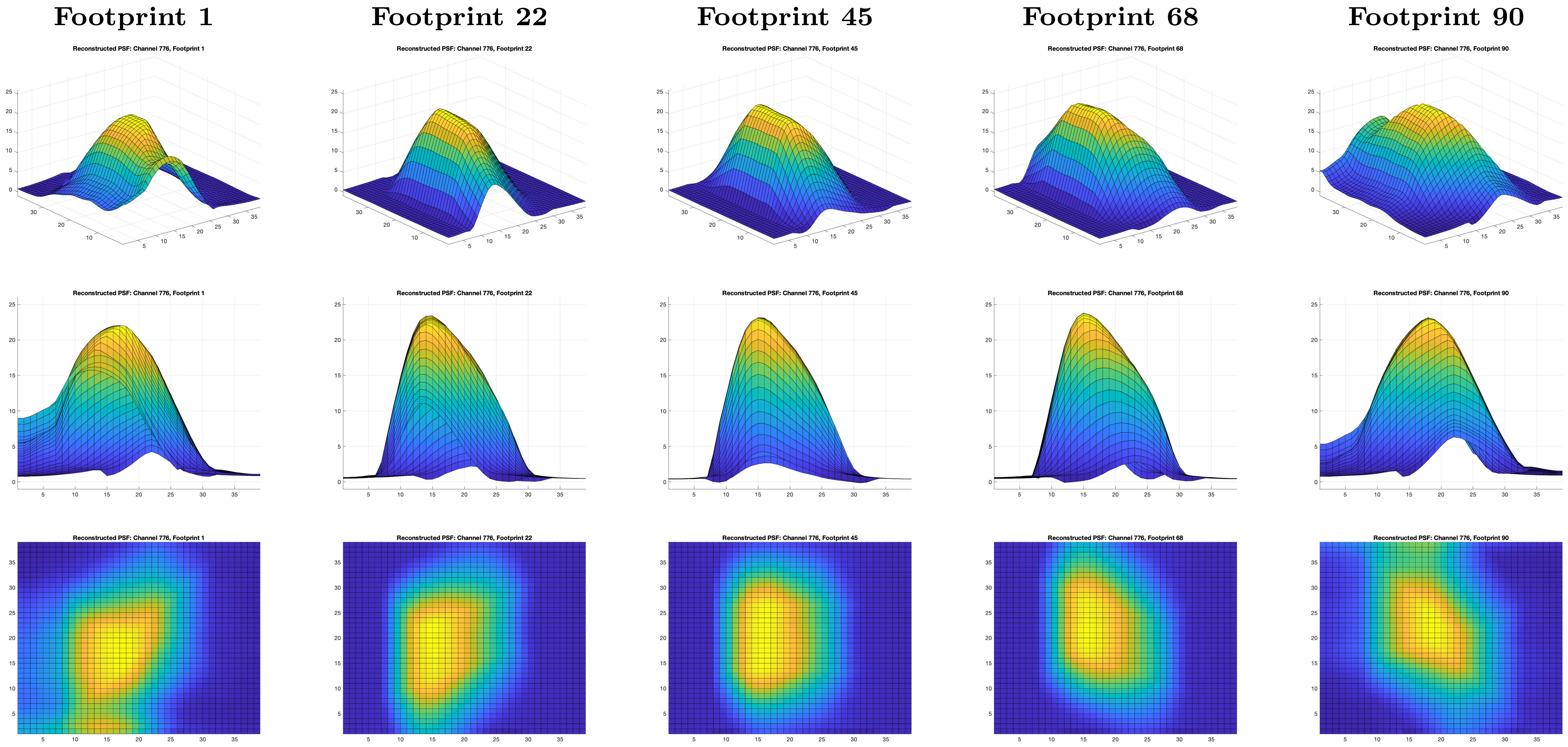
- Data from different dates agree much better with PSFs computed from any other date than it does with pre-flight PSFs.
- The 2014 data has somewhat higher residuals, suggesting some sort of degradation if we see similar effects over many channels.

Pre-flight PSFs for channel 776 (913.4 cm^{-1})

Footprint 1 | Footprint 22 | Footprint 45 | Footprint 68 | Footprint 90



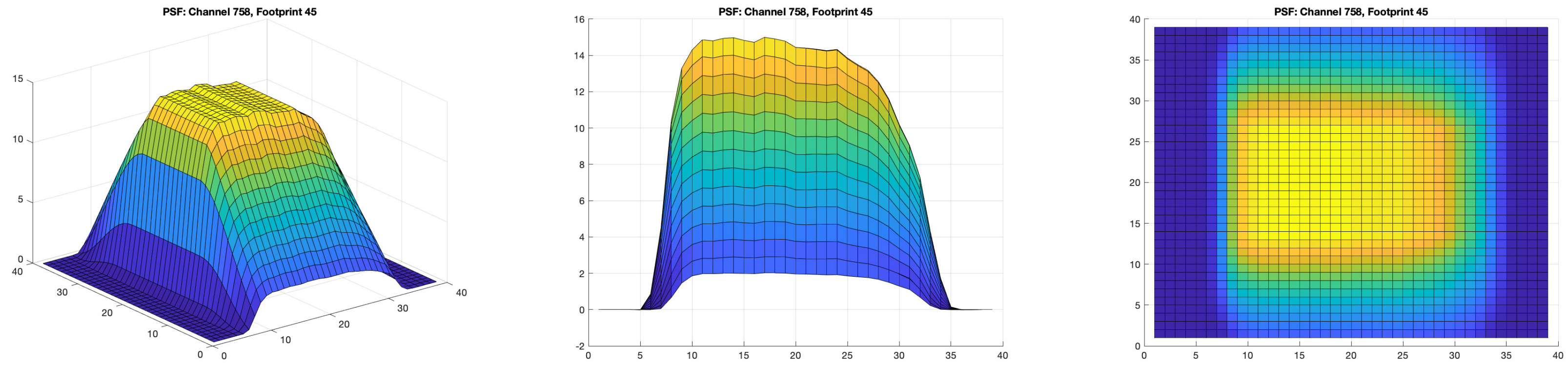
Reconstructed PSFs for channel 776 (913.4 cm^{-1}) based on March 1, 2014 data



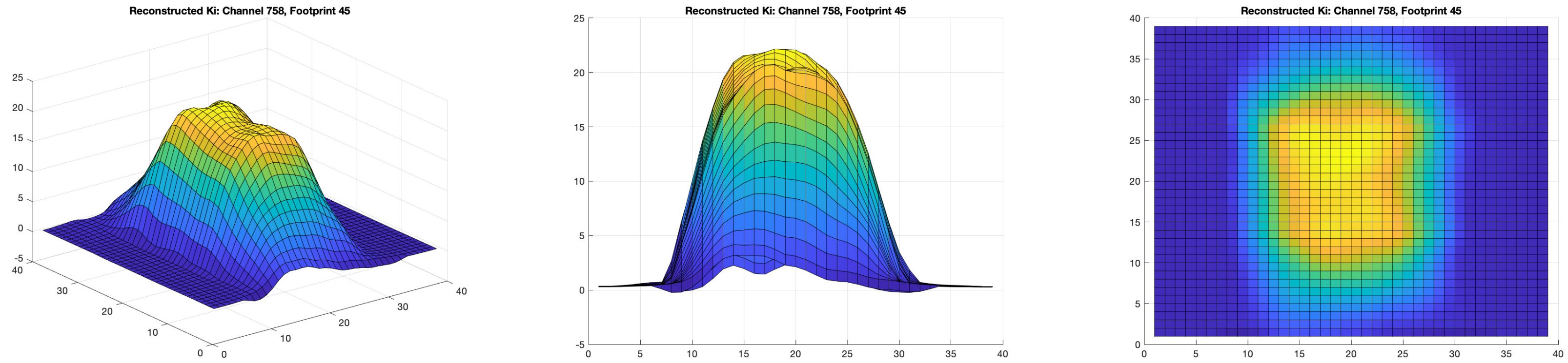
Channel 758 (900.0 cm^{-1}), Footprint 45

- Examine a similar window channel, now the problem module of M-08.
- As with the 913.4 cm^{-1} channel, the reconstructed PSFs are much narrower in the X dimension.

Pre-flight PSF

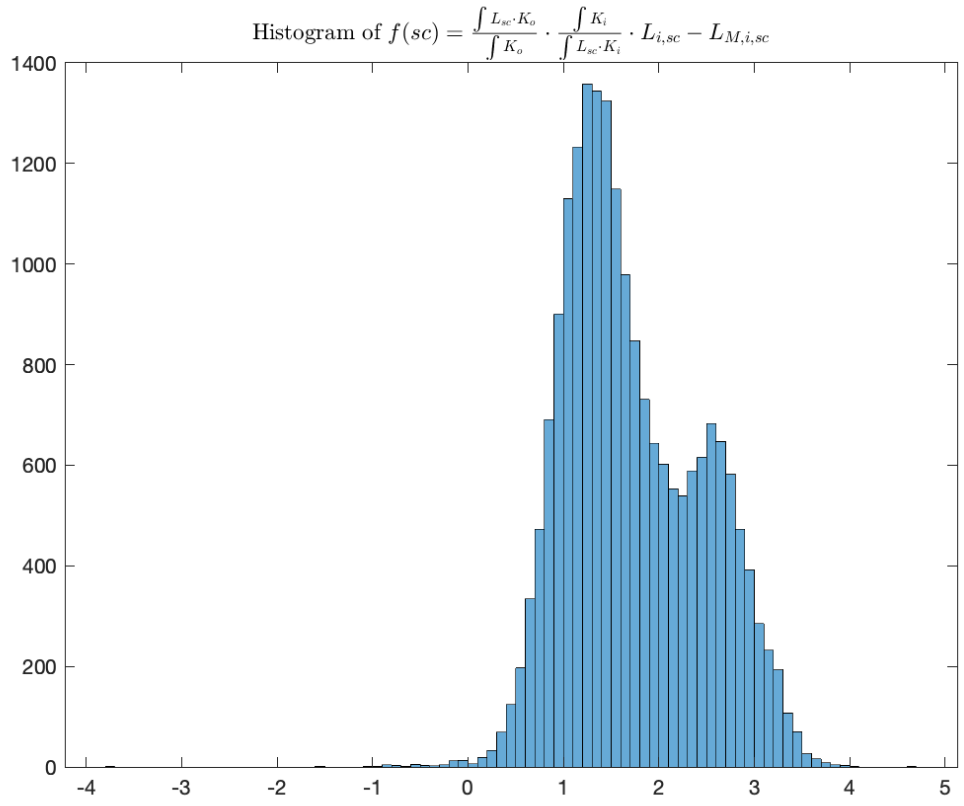


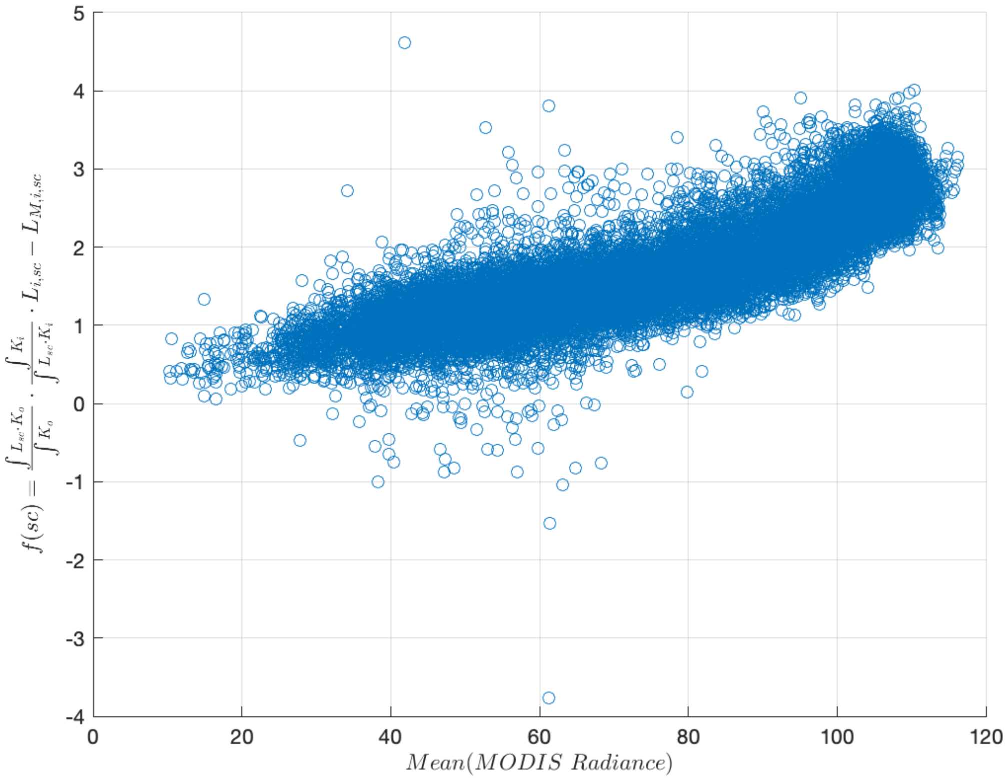
Reconstructed PSF



Using data from March 1, 2014

Residuals: PSF Reconstruction for Channel 758, Footprint 45





- M-08 is already known to have a bias with scene temperature, and now we see it when we compare it to MODIS.
- Residuals are much larger for the M-08 channel, especially at higher scene brightness. This might suggest some stray signal that can't be accounted for by 40x40 MODIS pixels – perhaps out-of-band or out-of-area.

How does PSF trained on one day's data agree with the data for a different day?

Channel 758 (900.0 cm^{-1}), Footprint 45

Residuals

train \ test	2003.03.01	2003.03.02	2014.03.01
Pre-flight PSF	3.7407	3.5915	3.7845
2003.03.01	3.4131	3.2919	3.4909
2003.03.02	3.4178	3.2831	3.4861
2014.03.01	3.4368	3.3067	3.4674

Observations:

- Residuals are much higher for 900.0 cm^{-1} compared to 913.4 cm^{-1} channel, but we still improve over pre-flight PSF.
- 2014 is again worse than 2003, supporting the idea of degradation.

Discussions of Results

- Approach is successful:
  - Generates PSF with smaller residuals compared to pre-flight PSF.
- Soft positivity constraint on reconstruction:
  - Does not prevent negative values on edges of PSF (similar to pre-flight PSF).
- Sidelobes at ends of scan (footprints 1 and 90) – future investigation.
- The narrowing we saw at nadir and the nodes at the ends of the scan. Re-check the MODIS indexing.
- M-08 A/B currently does not perform as well as channel 776.
- The new PSFs may have time dependence.
- The new reconstructed PSFs should be a big help to analyses using AIRS and MODIS data together.

Future Work

- Reconstruct and examine PSFs for different channels.
  - Starting to investigate M-08 issues.
  - Look at shortwave channels. (Shortwave trends in the radiances).
- Publish a better set of reconstructed PSFs.

Backup Slides

AIRS Radiances

The spatially averaged radiance from AIRS depends on the scene and AIRS spatial response:

$$L_{AIRS,i,sc} = \frac{\sum_{x,y} L_{i,sc}(x,y) K_i(x,y)}{\sum_{x,y} K_i(x,y)},$$

where

$L_{i,sc}$ = scene radiance in channel i at scan sc

K_i = AIRS spatial response function for a given footprint (scan angle)

$L_{AIRS,i,sc}$ = AIRS L1B radiance in channel i at scan sc

AIRS Radiances

The spatially averaged radiance from AIRS depends on the scene and AIRS spatial response:

$$L_{AIRS,i,sc} = \frac{\sum_{x,y} L_{i,sc}(x,y) K_i(x,y)}{\sum_{x,y} K_i(x,y)},$$

Given radiance $L_{AIRS,i,sc}$ captured by AIRS instrument, we can correct it, obtaining $L'_{AIRS,i,sc}$:

$$L'_{AIRS,i,sc} = \frac{\sum_{x,y} L_{sc}(x,y) K_o(x,y)}{\sum_{x,y} K_o(x,y)} \frac{\sum_{x,y} K_i(x,y)}{\sum_{x,y} L_{sc}(x,y) K_i(x,y)} L_{AIRS,i,sc},$$

where

L_{sc} = MODIS scene radiance at scan sc

K_o = average AIRS spatial response function (over all channels)

$L'_{AIRS,i,sc}$ = spatially corrected AIRS radiance in channel i at scan sc

MODIS Radiances

The MODIS averaged radiance $L'_{MODIS,i,sc}$ (to compare with $L'_{AIRS,i,sc}$) must also be weighted by the average AIRS spatial response function:

$$L'_{MODIS,i,sc} = \frac{\sum_{x,y} L_{sc}(x,y) K_o(x,y)}{\sum_{x,y} K_o(x,y)}.$$

Minimization Problem

We want to find K_i by solving the following minimization problem:

$$\min_{K_i} E(K_i) = \min_{K_i} \left|\left|L'_{AIRS,i,sc}(K_i) - L'_{MODIS,i,sc}\right|\right|_2^2$$

We know that the point spread function K_i should be non-negative.

$\Rightarrow$ Introduce ***log barrier*** soft positivity constraint on K_i. The new minimization problem is:

$$\min_{K_i} E(K_i) = \min_{K_i} \left|\left|L'_{AIRS,i,sc}(K_i) - L'_{MODIS,i,sc}\right|\right|_2^2 - \lambda \int \log(K_i)dx$$

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or

$$\min_{K_i} E(K_i) = \min_{K_i} \sum_{sc} \left(\frac{\int L_{sc}(x) K_o(x)}{\int K_o(x)} \cdot \frac{\int K_i dx}{\int L_{sc} \cdot K_i dx} \cdot L_{AIRS,i,sc} - L'_{MODIS,i,sc} \right)^2 - \lambda \int \log(K_i) dx.$$

Euler-Lagrange Equation

Minimization problem:

$$\min_{K_i} E(K_i) = \min_{K_i} \sum_{sc} \left(\frac{\int L_{sc}(x) K_o(x)}{\int K_o(x)} \cdot \frac{\int K_i dx}{\int L_{sc} \cdot K_i dx} \cdot L_{AIRS,i,sc} - L'_{MODIS,i,sc} \right)^2 - \lambda \int \log(K_i) dx.$$

$\Rightarrow$ K_i must solve the following Euler-Lagrange equation:

$$\begin{aligned} \partial_{L^2} E(K_i) &= \sum_{sc} \Bigg(\left[\frac{\int L_{sc}(x) K_o(x)}{\int K_o(x)} \cdot \frac{\int K_i}{\int L_{sc} K_i} \cdot L_{AIRS,i,sc} - L'_{MODIS,i,sc} \right] \\ &\times \frac{\int L_{sc}(x) K_o(x)}{\int K_o(x)} \cdot L_{AIRS,i,sc} \cdot \frac{\int L_{sc} K_i - (\int K_i) L_{sc}}{(\int L_{sc} \cdot K_i)^2} \Bigg) - \lambda \frac{1}{K_i} = 0. \end{aligned}$$

Sobolev Gradient Descent

Advance the Euler-Lagrange equation using Sobolev Gradient Descent:

$$\frac{dK_i}{dt} = -\partial_{H^1} E(K_i) = -(I - \triangle)^{-1} \partial_{L^2} E(K_i),$$

which can be re-written as:

$$(I - \triangle) \frac{dK_i}{dt} = -\partial_{L^2} E(K_i)$$

Acknowledgements

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Thank You!