Characterization of EO-1 Hyperion in Pseudo Invariant Calibration Sites (PICS)

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EO-1 Science Team

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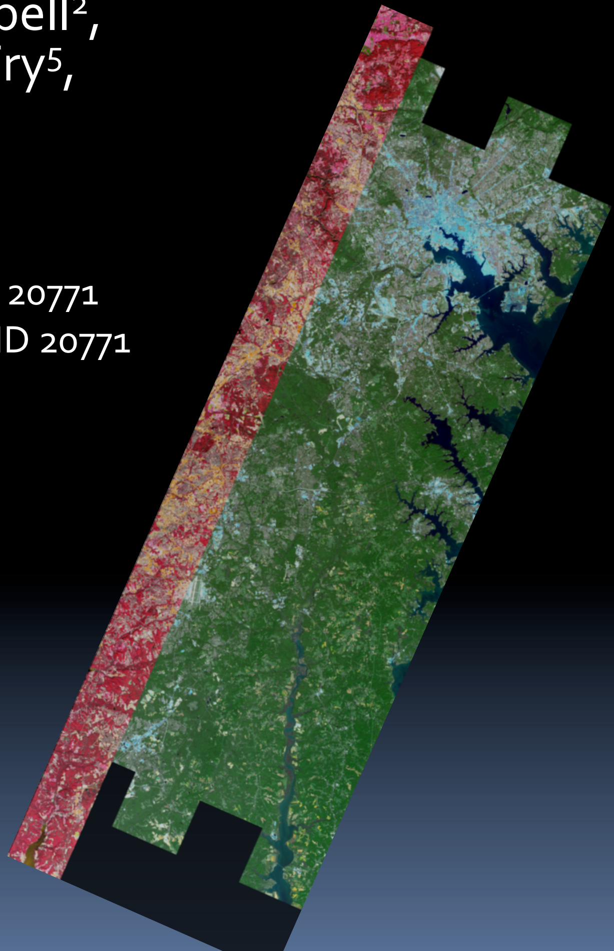
6/01/2016



Hyperion (red) overlay on ALI Image (green), Oct 2012 Baltimore, MD

Introduction

Objectives/Questions

1. Can high-resolution commercial data be used to understand sub 30m pixel variability in Hyperion data?

2. How stable is Hyperion through time : a) with atmospherically corrected land surface reflectance from 3 correction approaches; and with b) TOA for the full time series?

3. Can Hyperion be used to cross calibrate a virtual constellation for land surface imaging?

Study Area

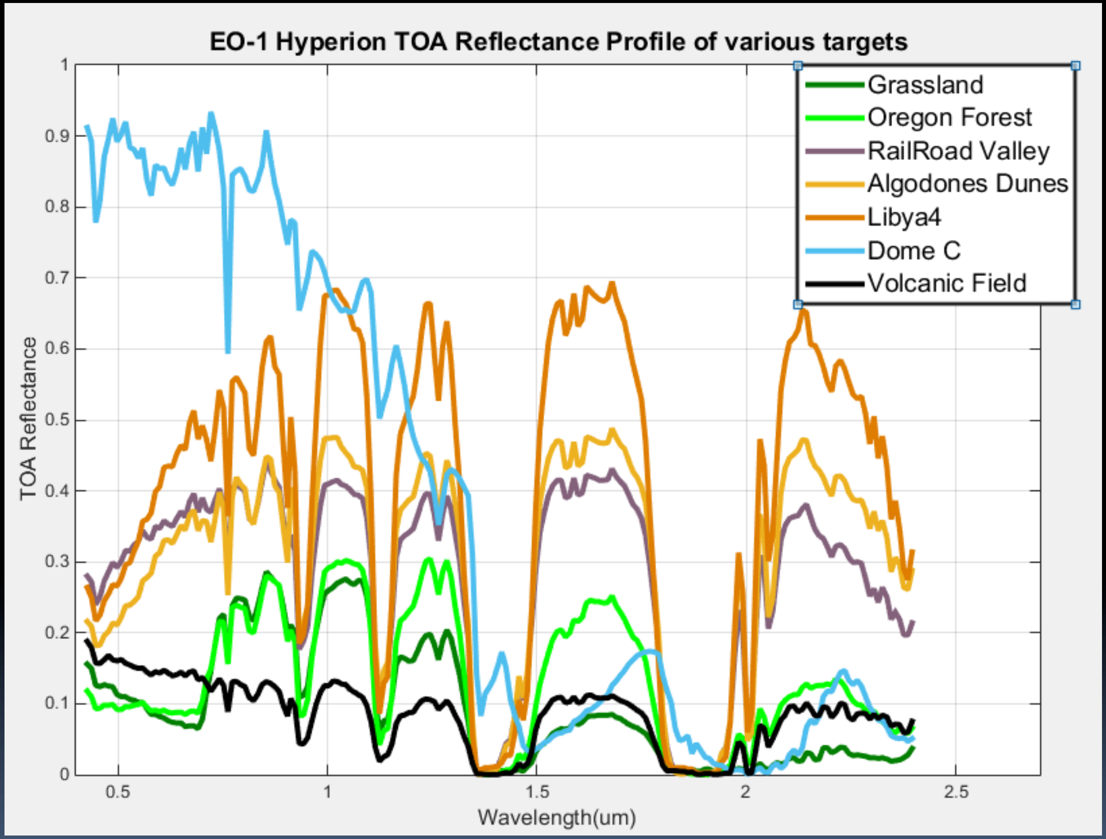
- CEOS – core validation sites
  - Hyperion data has been routinely collected in the Libyan desert (Libya-4)
  - Other studies have used this site to monitor sensor degradation and cross-calibrate measurements
  - Landsat ETM+, MSS, SRTM, MODIS, EO-1

Chander et al. 2010 RSE

Why PICS?

From:
On-orbit calibration: Use of psuedo invariant calibraiton sites (PICS), vicarious campaigns, and global averaging

- Hyperion acquisitions over different land cover types have been collected and evaluated.
  - Bright Deserts PICS (Libya 4, Algodones Dunes)
  - Medium Bright Playa PICS (RVPN)
  - Vegetation (Oregon Forest, SDSU test vegetation site)
  - Snow (Dome C)
  - Dark PICS (Volcanic field in Libya)



Prior Moderate Resolution Studies of Libya-4 PICS

Chander et al. 2010 RSE

- TOA reflectance from MODIS 2000-2008 (161 scenes) and Landsat 7 1999-2008 (86 scenes)

  both < 0.479% yr^{-1} from all bands
- MODIS within image standard deviation < 1.4%, Landsat 7 < 2.2%

Choi et al. 2013 JARS

- Hyperion within Libya-4 study area TOA reflectance < 5%
- Hyperion spectrally stable TOA reflectance < 0.625% yr^{-1} from all bands 2004 - 2012

Prior studies have not a) investigated co-registered and atmospherically corrected Hyperion data for a long-time series in Libya-4 CEOS validation site; and b) investigated the full TOA time-series with precession.
Does more information exist about the quality of Hyperion data?

Part 1

Neigh, C.S.R., McCorkel, J., & Middleton, E.M. (2015). Quantifying Libya-4 Surface Reflectance Heterogeneity With WorldView-1, 2 and EO-1 Hyperion. *IEEE Geoscience and Remote Sensing Letters, 12, 2277-2281*

Part 2

Neigh, C.S.R., McCorkel, J., Campbell, P.K.E., Ong, L., Ly, V., Landis, D., & Middleton, E. (2016). Monitoring orbital precession of EO-1 Hyperion with three atmospheric correction models in the Libya-4 PICS. *IEEE Geoscience and Remote Sensing Letters, under review*

Part 3

TOA time-series

IEEE

GEOSCIENCE AND REMOTE SENSING LETTERS

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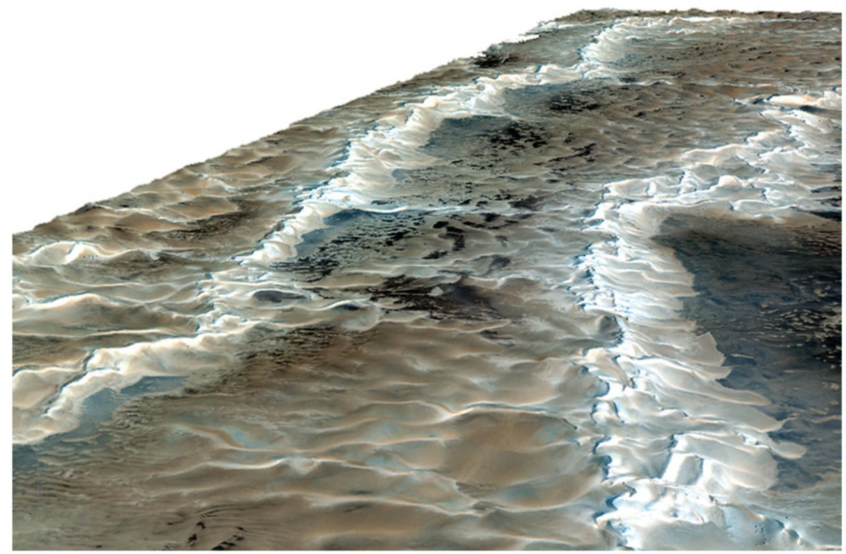
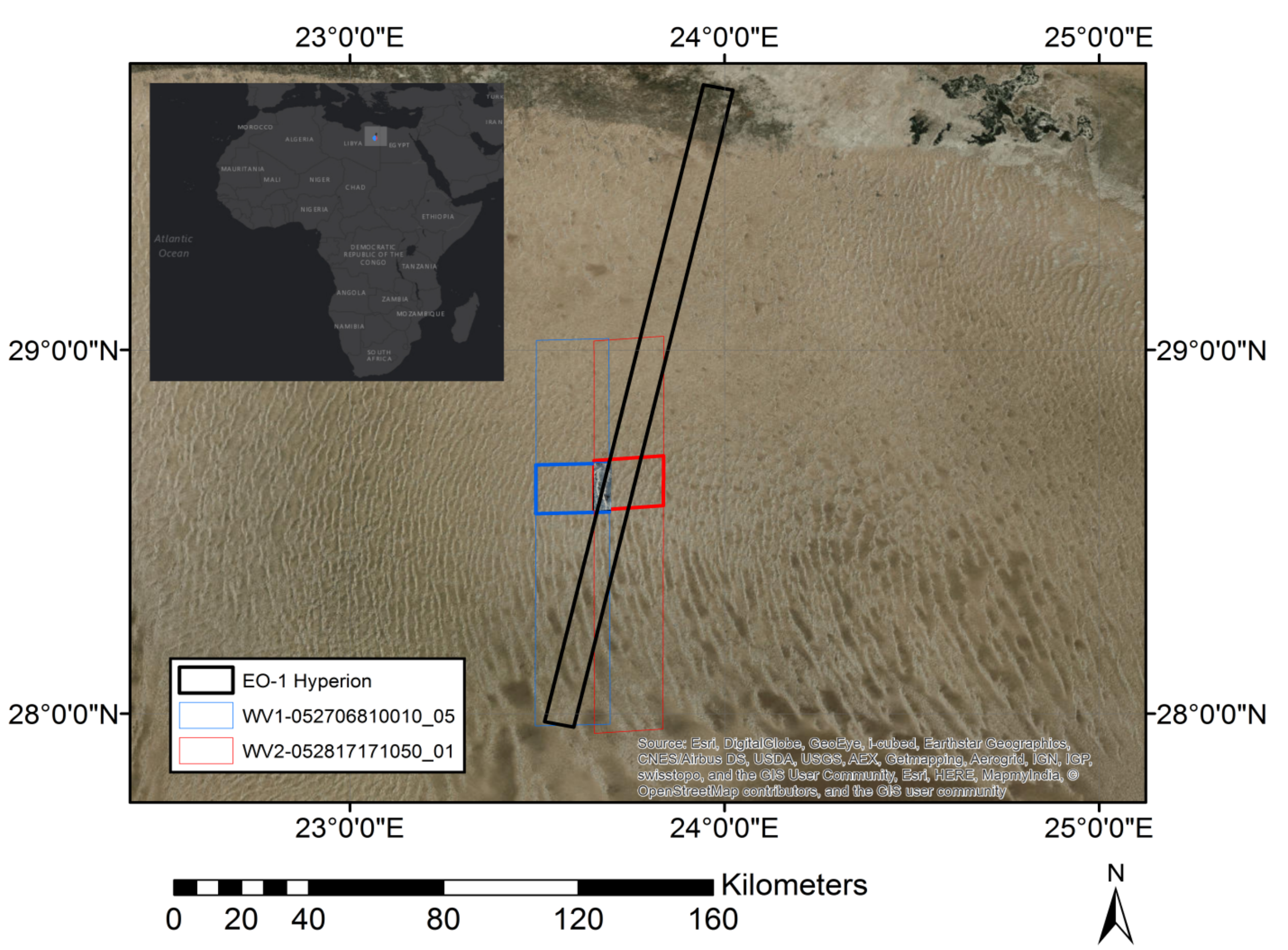


Example in true color of a 3-D subset of WorldView-2 with a linear stretch applied and with a vertical 2× exaggeration factor.

IEEE

Methods: Part 1 & 2

Data Overlap



Path 181 row 40 WRS2

High Resolution (temporally sparse):
WorldView-1 42 cm pan
WorldView-2 46 cm pan 1.8 m MSI

Moderate Resolution (temporally dense):
Landsat-8 30 m(FLAASH)
Hyperion 30 m (FLAASH)

Issues not accounted for or not completely mediated:

1. Resampling
2. BRDF, seasonal & off nadir viewing
3. Co-registration sub 30 m pixel
4. Instrument spectral degradation

Among others…

Longitudinal Dunes in Calanscio Sand Sea (Libya-4)

Uploaded on September 20, 2011

by Gabor MERKL

Camera: Canon EOS 350D DIGITAL
Taken on 2006/03/30 05:55:08
Exposure: 0.006s (1/180)
Focal Length: 22.00mm
F/Stop: f/11.000
ISO Speed: ISO100
Exposure Bias: 0.00 EV
No flash

28° 0' 49.68" N 23° 46' 27.89" E
http://www.panoramio.com/photo/59315749

138 m elevation

Methods: Hyperion Image Processing

Data Selection

- May - Sept
- < 10° Off Nadir
- 400+ images filtered to 35
- 2004 - 2015

Atmospheric Correction

- Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) – no polishing
- Atmospheric REMoval program (ATREM)
- Atmospheric CORrection Now (ACORN)

Co-Registration

- >20 tie points per image < 0.6 RMSE to Landsat 8 L1T
- Cloudy images and bad pixels removed with Coef . Var. > 0.5
- Subset to 159 x 458 pixels
  - Center lower portion of strip within Libya-4 (Chander et al. 2010 RSE) CEOS core validation site.
  - Corresponds to WV-1 and WV-2 overlapping area.

Convolution

- 8-Bands
- Co-registered to WV-2

Methods: WorldView Image Processing

Data Selection

- Nearest coincident date to the Hyperion time-series with WorldView-1 and WorldView-2
- Hyperion 8/9/2012
- WorldView-1 and WorldView-2 both 8/12/2012

Atmospheric Correction

- WV-2 8 Band FLAASH
- Viewing geometry included
- No water vapor or aerosol correction

Digital Terrain Model

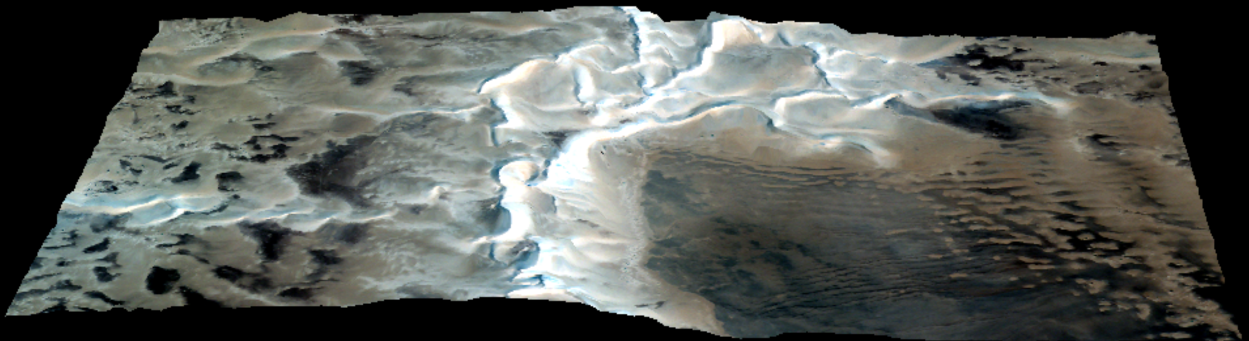
- ENVI DEM extraction module
- WorldView-1 and WorldView-2 Pan Bands 50 cm (cross track stereo)
- > 50 tie points, no ground control points
- RMSE < 3.5 m relative to RPCs
- 2 m resolution

Neigh et al. 2015, IEEE GSRL

3D Surface View of Subset Area

Hyperion True Color Convolved 8/09/12
Red 630-690 nm
Green 510-580 nm
Blue 450-510 nm
Cubic Convolution 2m

WorldView-2 True Color 8/12/12
Red Band 5 630-690nm
Green Band 3 510-580nm
Blue Band 2 450-510 nm
2m



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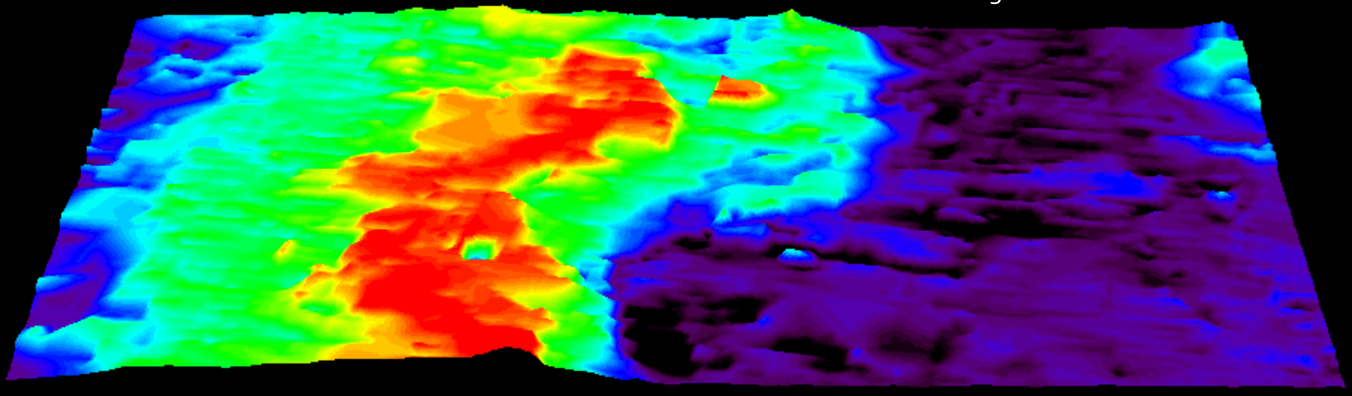
WorldView-2 – WorldView-1
Digital Terrain Model
2m



Neigh et al. 2015, IEEE GSRL

Results Part 1: Sub 30m Cross Calibration

1. Can high-resolution commercial data be used to understand sub 30m pixel variability in Hyperion data?

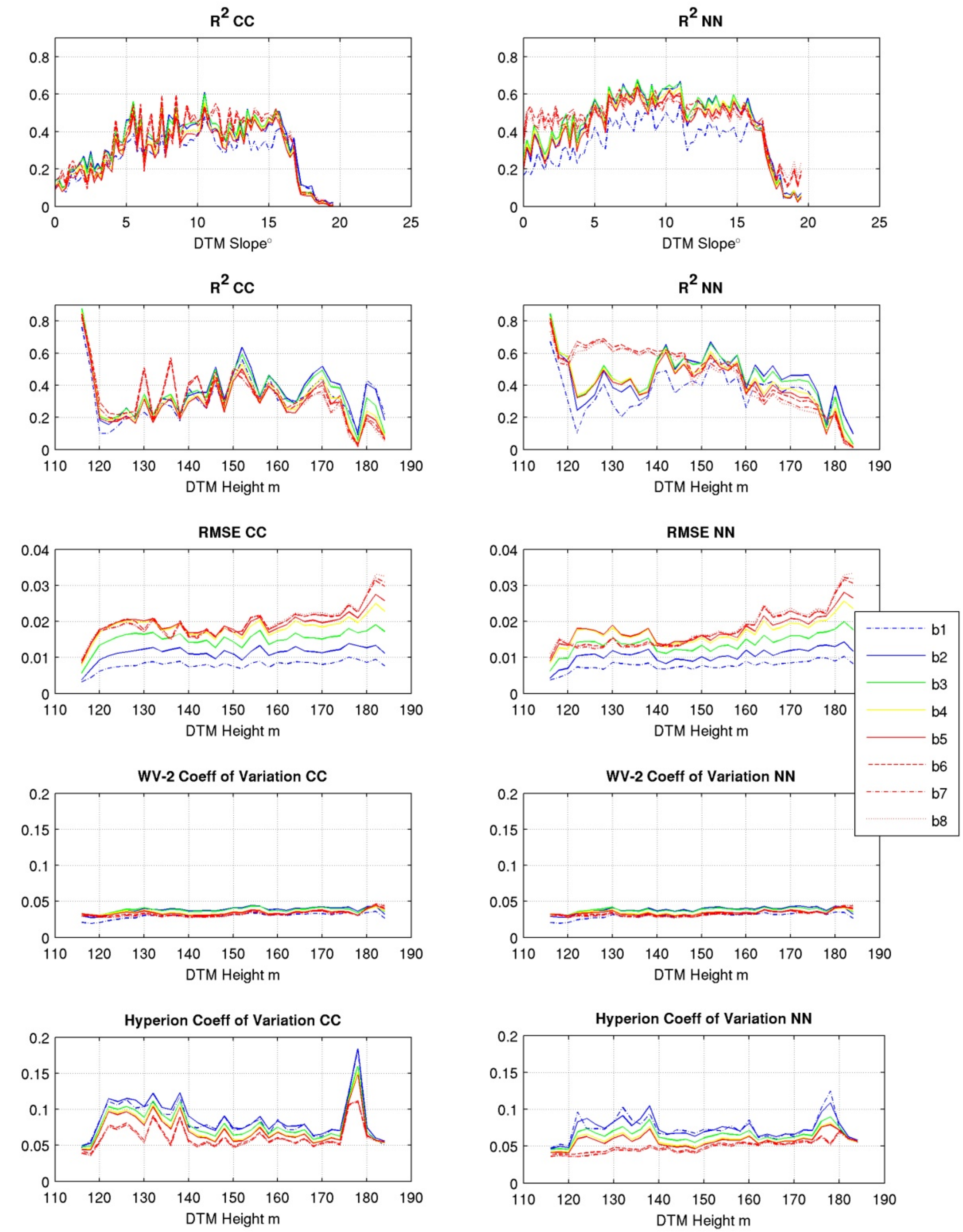
Results Part 1:

Terrain Impacts Cross Calibration in Libya-4 at sub 30m resolution

1. Elevation and slope have a strong influence on WV-2 band agreement with Hyperion data, ranging from low agreement at dune tops ($R^2 < 0.05$) to higher agreement in sand flats ($R^2 > 0.6, P < 0.001$). RMSEs increase with height as well.

2. WV-2 observations at 2 m are more homogenous (Coefficient of Variation (CV) = standard deviation/mean CV < 5%) compared to convolved 2-m NN Hyperion (CV < 15%).

3. Good agreement exists between Hyperion data convolved to WV-2 bands when resampled with the NN method within specific sub-portions of the Libya-4 PICS ($R^2 > 0.7$).



Neigh et al. 2015, IEEE GSRL

Results Part 2: Hyperion Median Trends

2. How stable is Hyperion through time with atmospherically corrected land surface reflectance from 3 correction approaches?

Atmospheric Correction Models

All models follow the same radiative transfer model (Gao and Goetz, 1990), though each model uses a slightly different version and FLAASH adds a term to account for adjacency effects (Adler-Golden et al., 1999).

FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes)

FLAASH is a MODTRAN4-based atmospheric correction software package developed by the Air Force Phillips Laboratory, Hanscom AFB and Spectral Sciences, Inc (SSI) (Adler-Golden et al., 1999). It provides accurate, physics-based derivation of apparent surface reflectance through derivation of atmospheric properties such as surface albedo, surface altitude, water vapor column, aerosol and cloud optical depths, surface and atmospheric temperatures

ATREM (Atmosphere Removal Program)

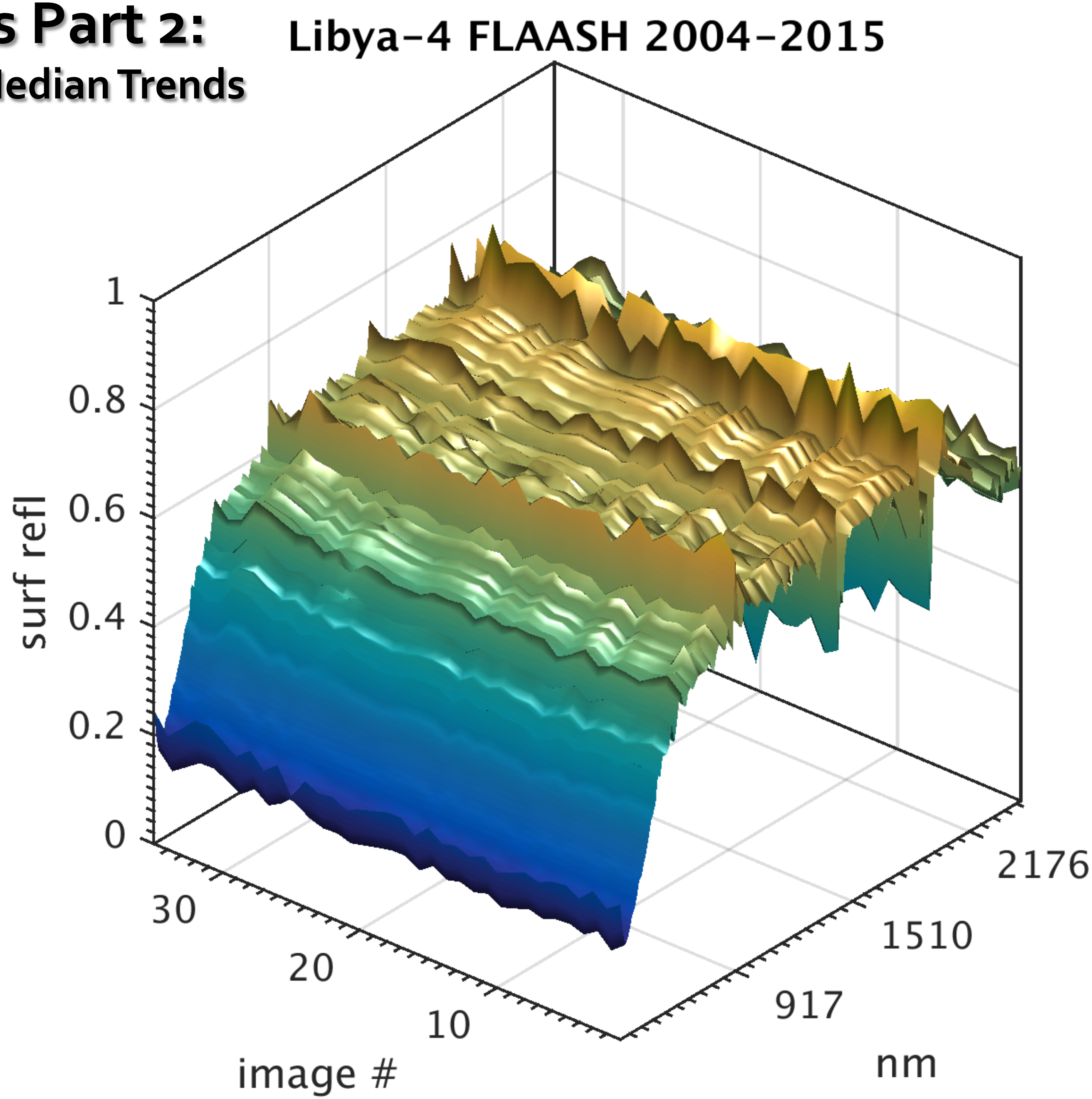
ATREM retrieves scaled surface reflectance from hyperspectral data using a radiative transfer model (Gao and Goetz, 1990; Gao et al., 1993; CSES, 1999). First the solar zenith angle is derived based on the acquisition time, date, and geographic location. Atmospheric transmittance spectra are derived for each of seven atmospheric gases. A water vapor "lookup table" is created by generating modeled spectra for various water vapor concentrations, again using the Malkmus narrow band model and estimating the 0.94 and/or 1.13 micrometer water vapor band depths for each spectrum. Band depths are determined using a ratio of the band center to the two band shoulders. Water vapor is then estimated for each pixel by determining the band depth and comparing to the modeled band depths in the lookup table. The output of this procedure is an image showing the spatial distribution of various water vapor concentrations for each pixel. Atmospheric scattering is modeled using the "6S" radiative transfer code (Tanre et al., 1986).

ACORN (Atmospheric CORrection Now)

ACORN is a commercially-available, enhanced atmospheric model-based software that uses licensed MODTRAN4 technology (Berk et al, 1999) to produce high quality surface reflectance without ground measurements. ACORN uses look-up-tables calculated with the MODTRAN4 radiative transfer code to model atmospheric gas absorption as well as molecular and aerosol scattering effects, converting the calibrated sensor radiance measurements to apparent surface reflectance (AIG, 2001).

Neigh et al. 2016, IEEE GSRL under review

Results Part 2:
Hyperion Median Trends



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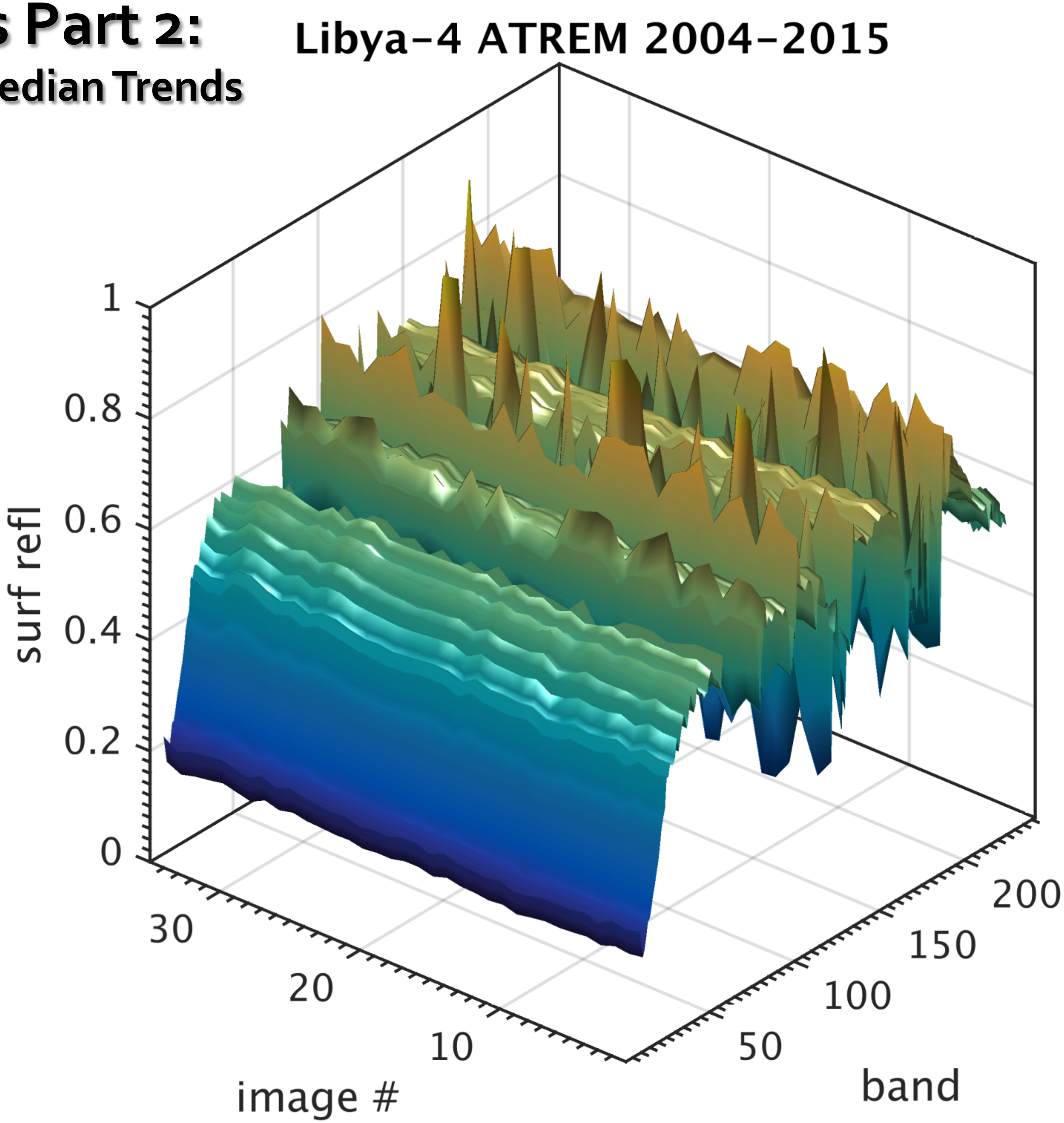
Results Part 2:
Hyperion Median Trends



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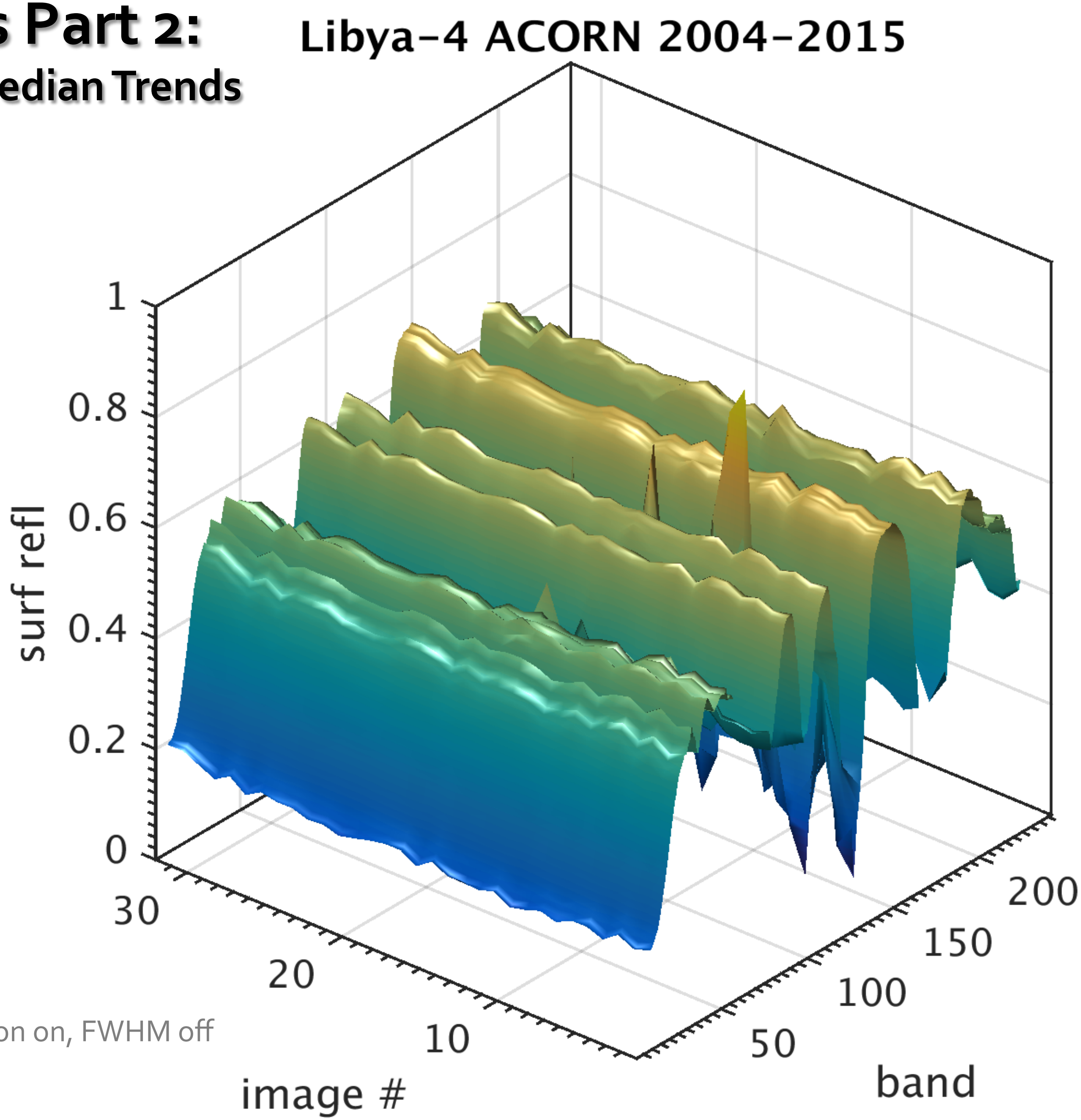
Results Part 2:
Hyperion Median Trends



Artifact suppression on, FWHM off

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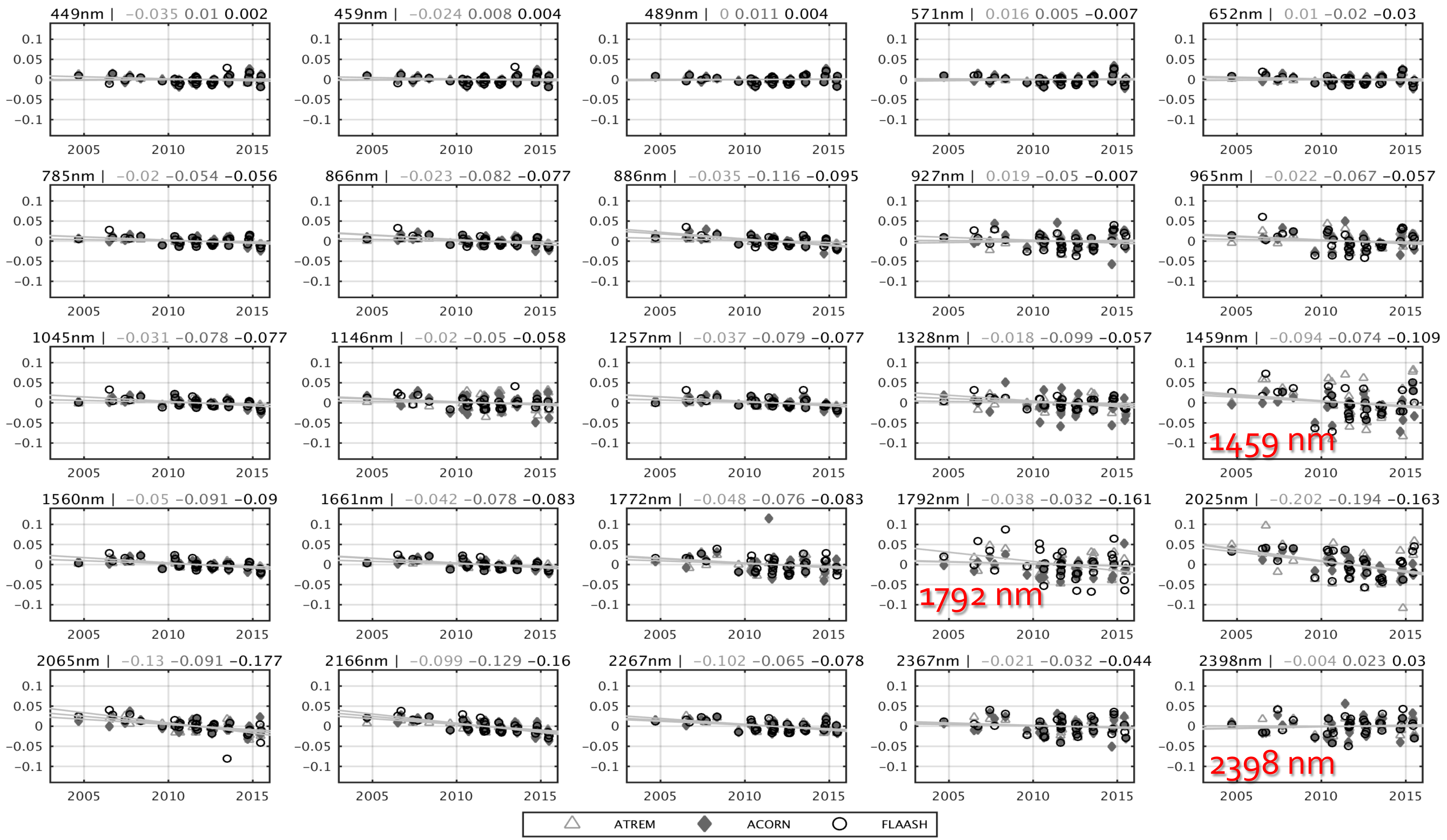
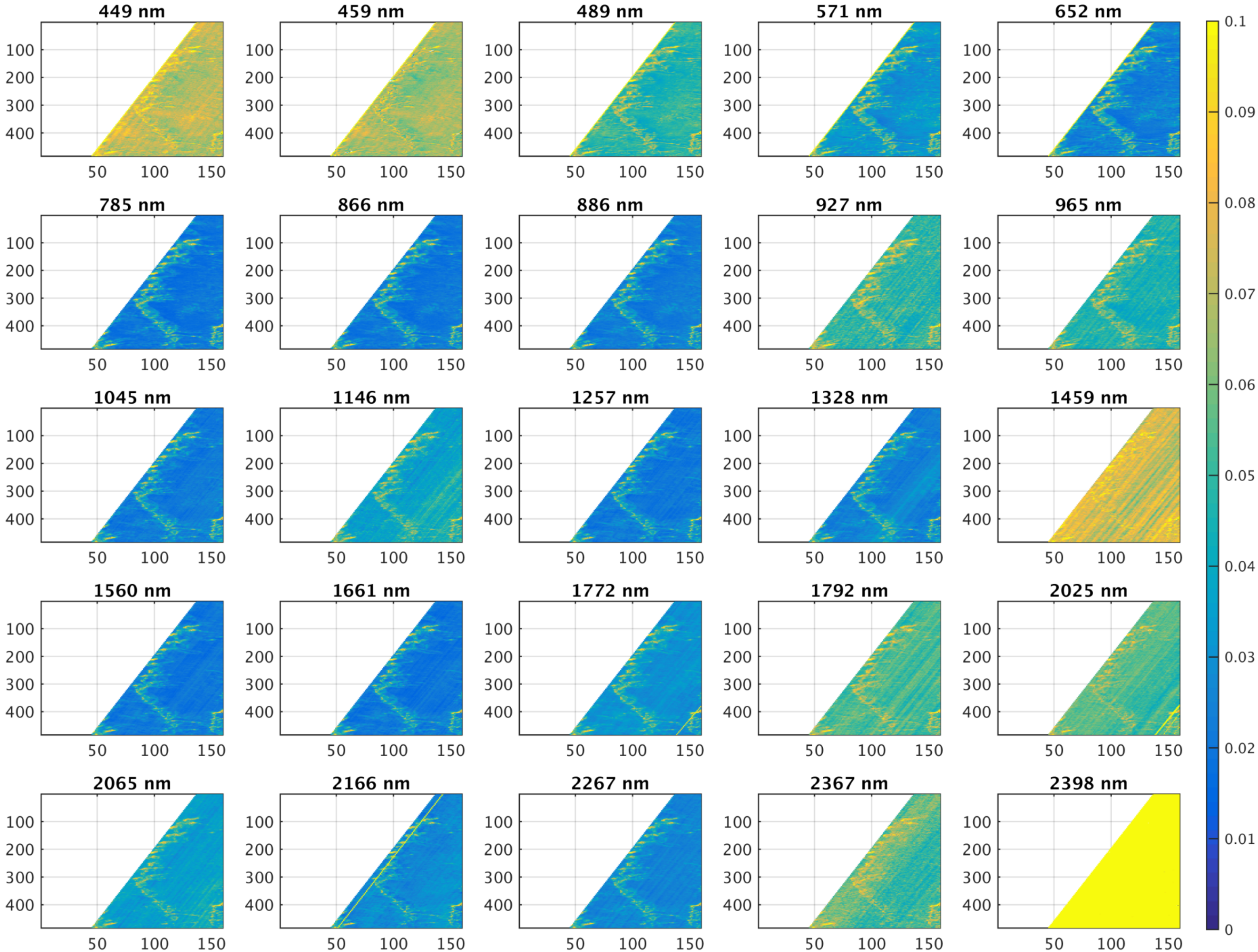
Results Part 2: Hyperion Median Trends (25 Bands)

From 2004-2015 maximum change for specific models: Visible < 5.3%, NIR < 7.6%, SWIR < 8.9%



In most Vis bands < 0.24% yr^{-1}, most other bands <0.4% yr^{-1}

FLAASH CV


449 nm
459 nm
489 nm
571 nm
652 nm
785 nm
866 nm
886 nm
927 nm
965 nm
1045 nm
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1257 nm
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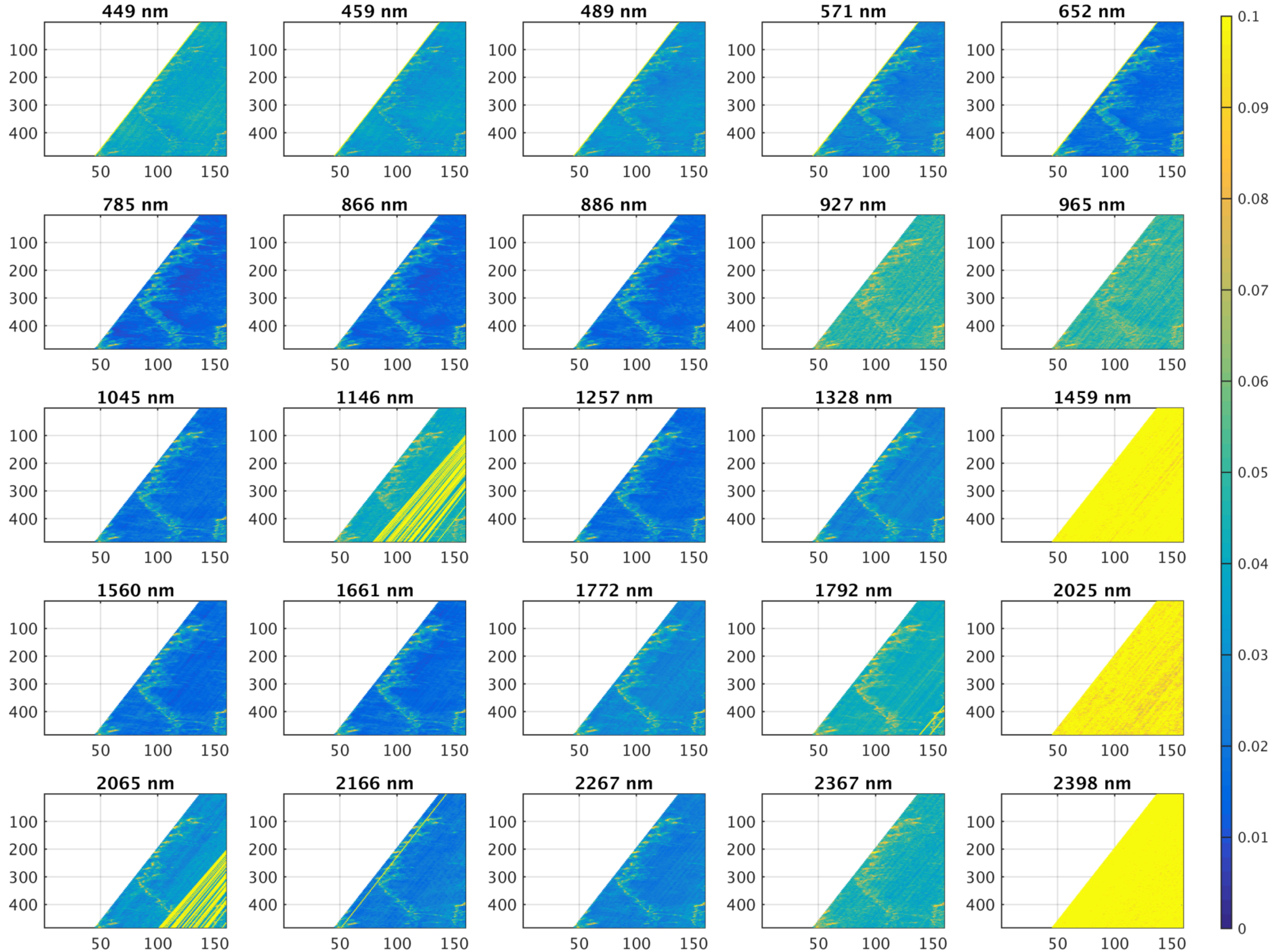
1459 nm
1560 nm
1661 nm
1772 nm
1792 nm
2025 nm
2065 nm
2166 nm
2267 nm
2367 nm
2398 nm
100
200
300
400
50
100
150
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

ATREM CV



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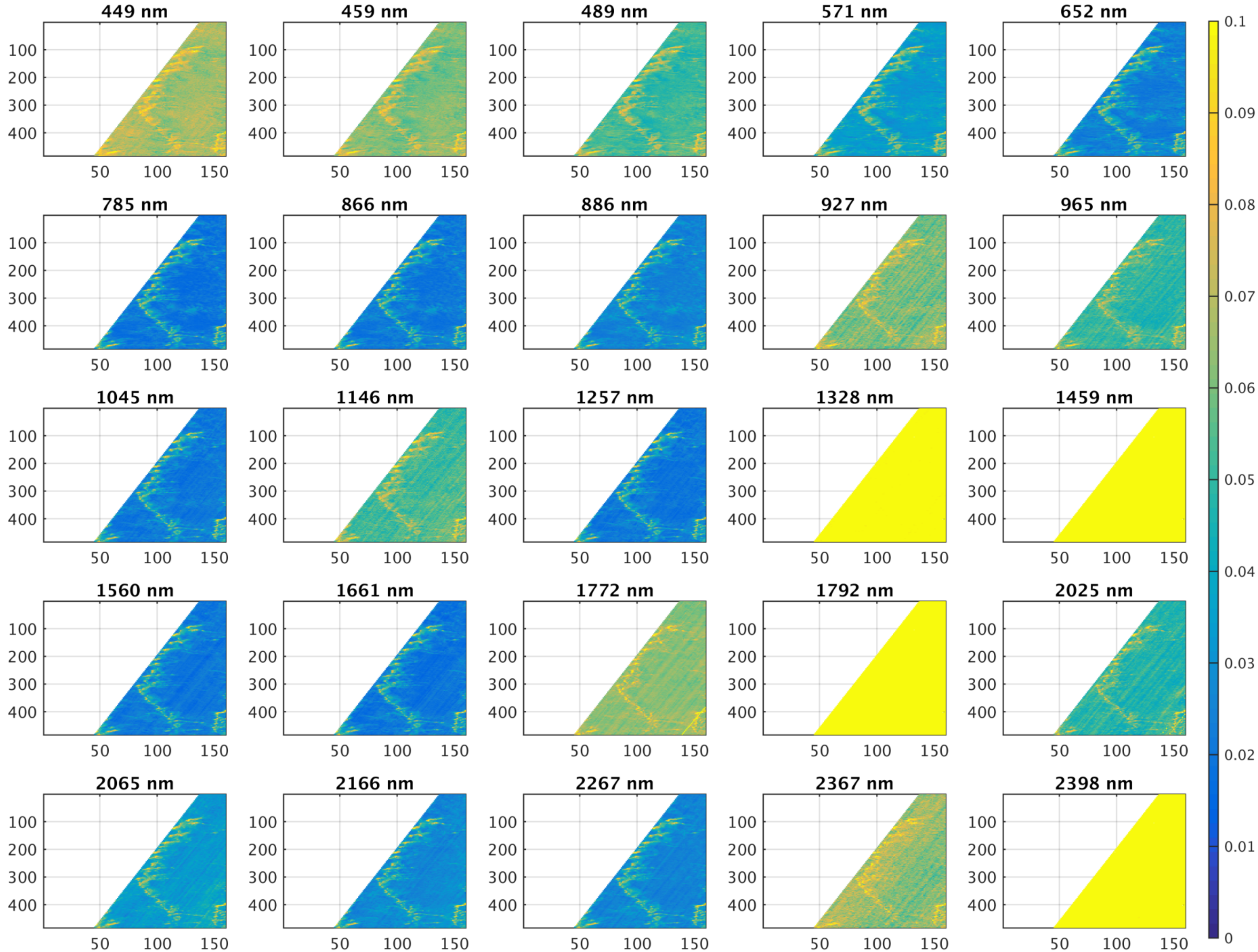
1560 nm
1661 nm
1772 nm
1792 nm
2025 nm
2065 nm
2166 nm
2267 nm
2367 nm
2398 nm
100 200 300 400
50 100 150
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1

ACORN CV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2367 nm
2398 nm
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

Results Part 2: Hyperion Surface Reflectance Uncertainty

Do the dunes increase uncertainty between atmospheric correction models?

Temporal uncertainty by pixel calculated as:
Coefficient of Variation (CV) = standard deviation/mean

Combined Uncertainty = $\sqrt{FLAASH_{CV}^2 + ATREM_{CV}^2 + ACORN_{CV}^2}$

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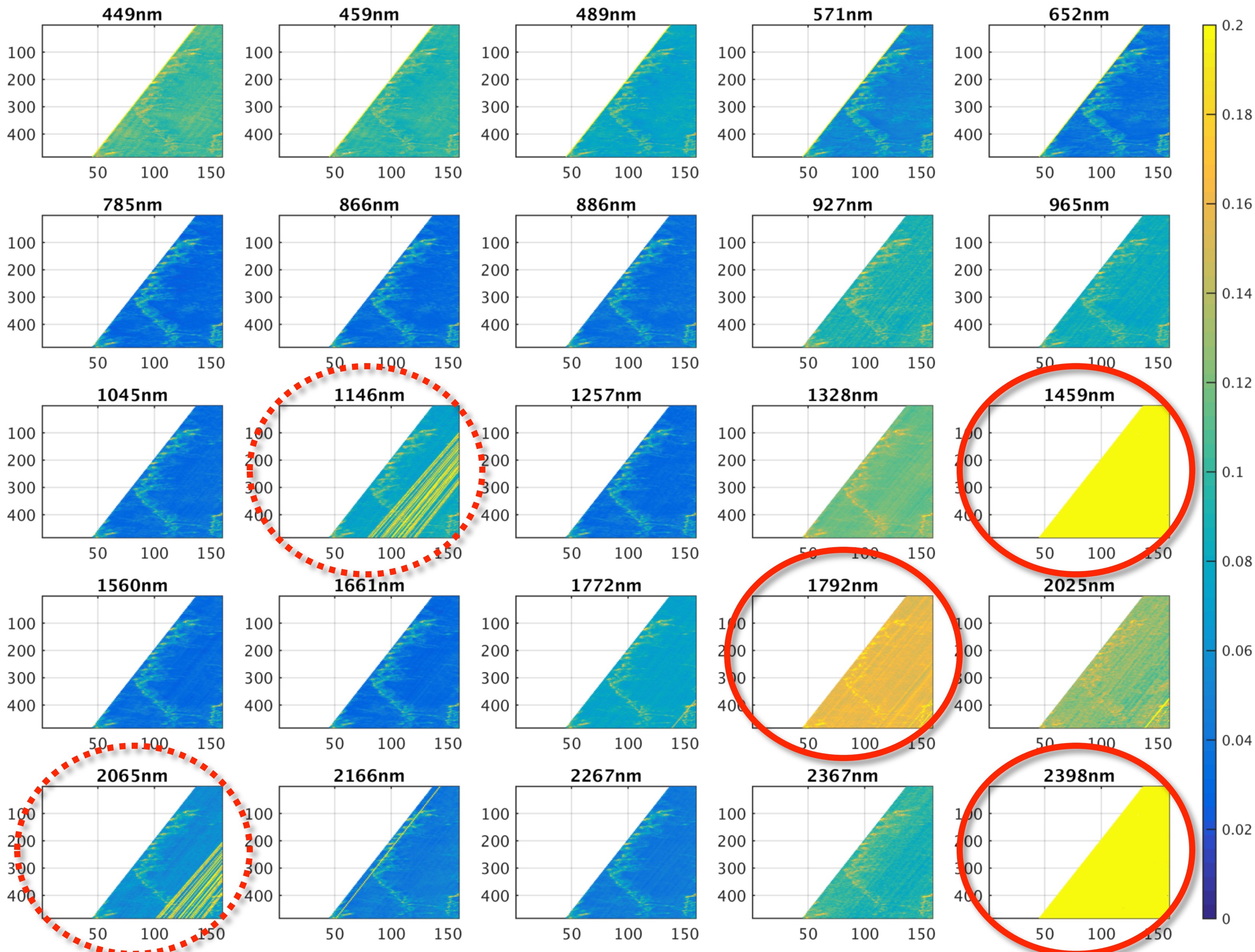
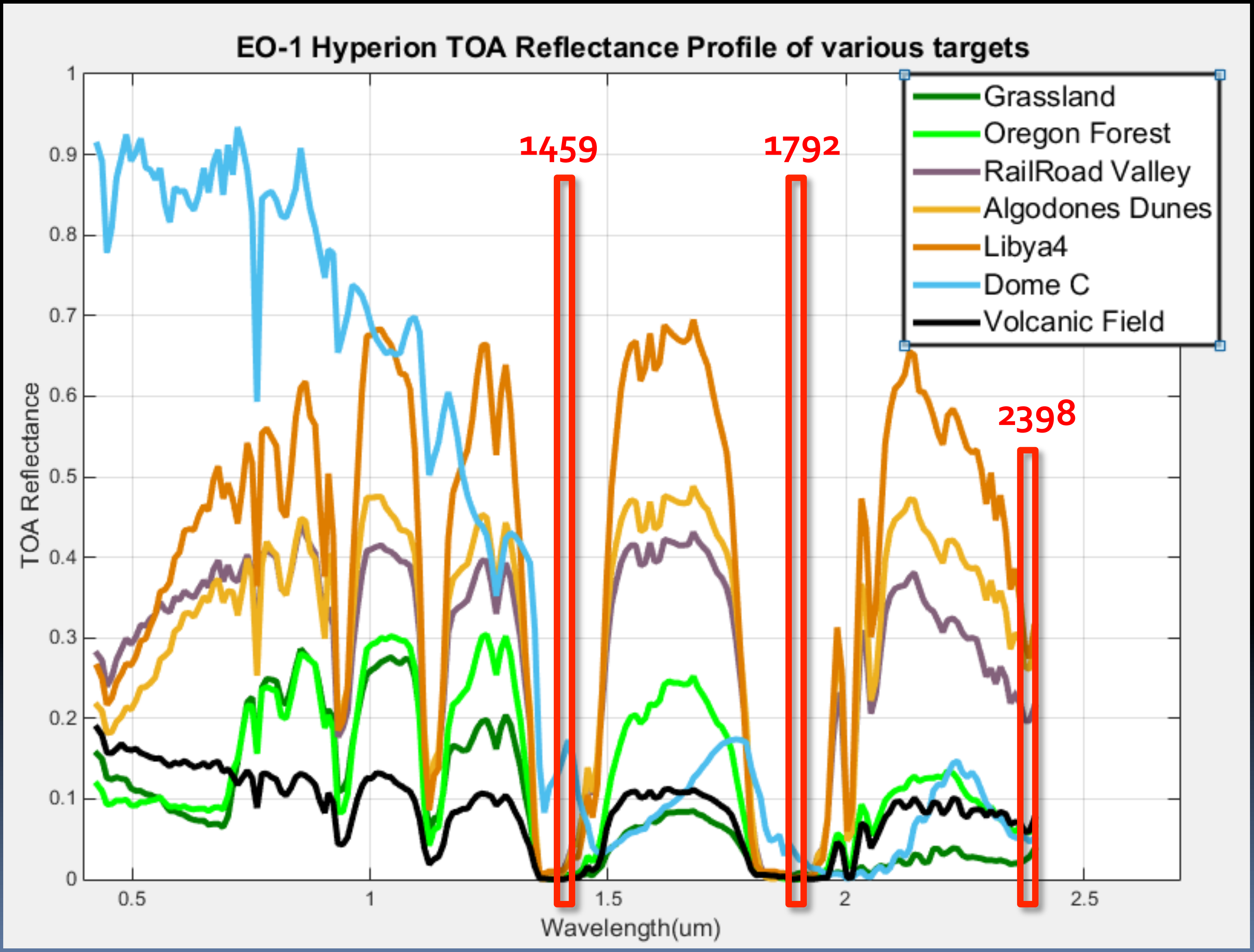
Combined CV Maps (FLAASH, ATREM & ACORN)



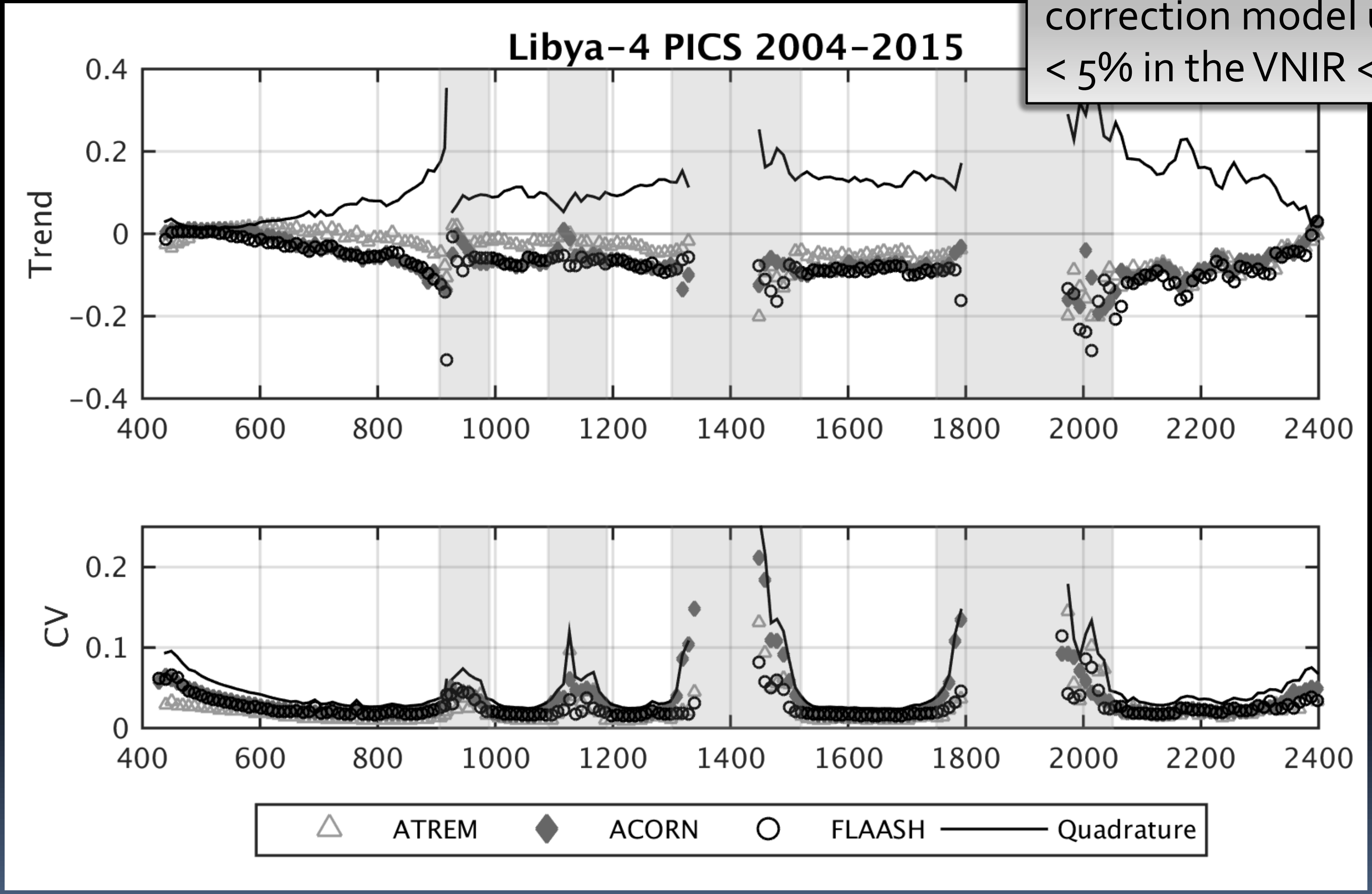
Combined CV > 20%

Spectral Signature Impact on Cross Calibration



Trends and CV for 172 Bands

Hyperion is stable in most bands, independent of atmospheric correction model used:
< 5% in the VNIR < 10% in the SWIR



Means of 172 calibrated Hyperion bands from 35 images, for 3 atmospheric correction models, from 2004 to 2015: (top row) least squares fit linear trend in surface reflectance; (2nd row) coefficient of variation (CV). The quadrature (combined uncertainty) is calculated as the square root of the sum of squares. Grey area indicates atmospheric absorption bands.

Neigh et al. 2016, IEEE GSRL under review

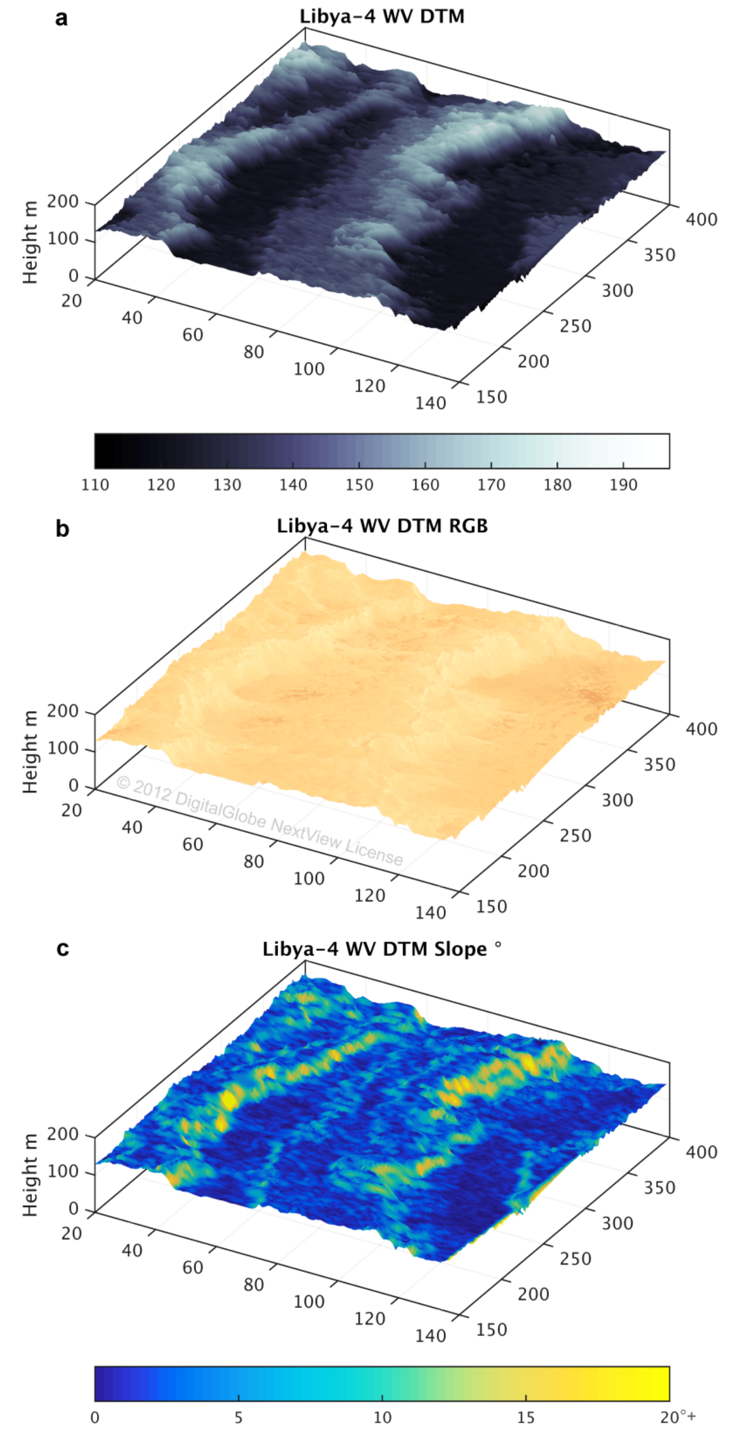
25

3D subsets of the study area

(a) WorldView-1 and 2 derived digital terrain model (DTM);

(b) WorldView-2 true color red, green and blue image linear stretched and draped on the DTM © 2012 DigitalGlobe NextView License.;

(c) Slope estimates from DTM draped on DTM.



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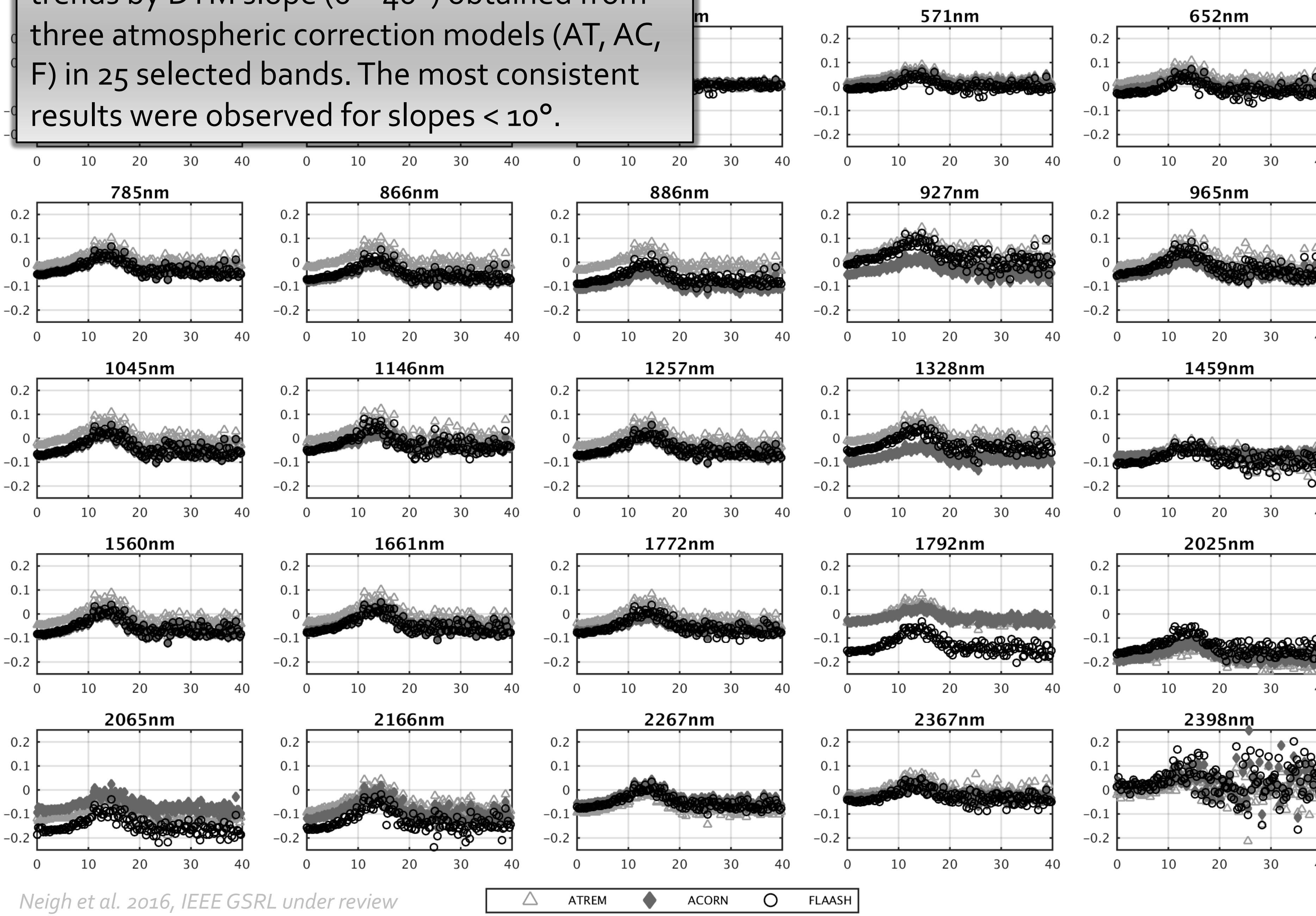
The VSWIR surface reflectance anomaly trends by DTM slope (0 – 40°) obtained from three atmospheric correction models (AT, AC, F) in 25 selected bands. The most consistent results were observed for slopes < 10°.



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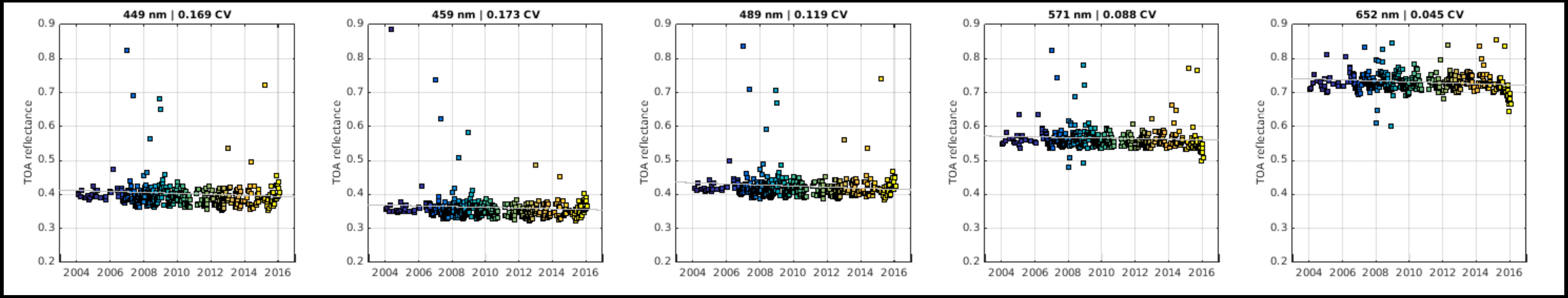
Preliminary Results Part 3: Hyperion TOA PICS Trends

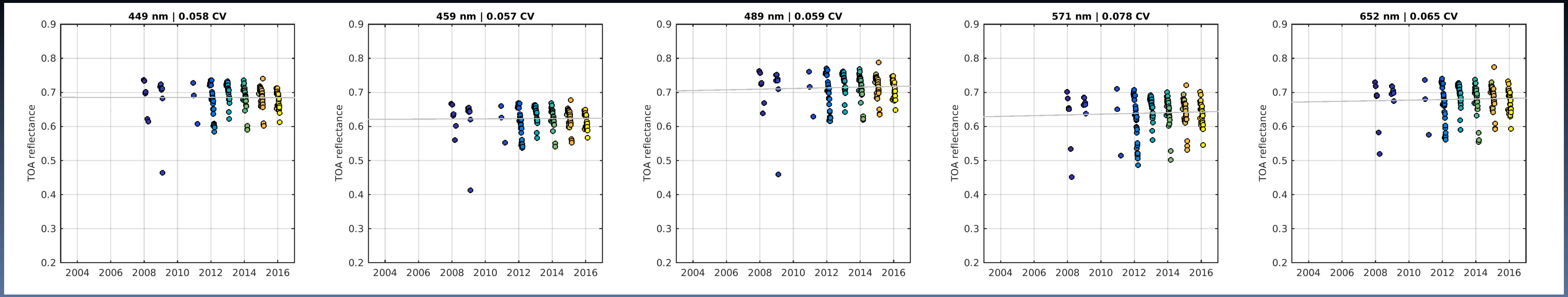
3. How stable is Hyperion through time in L1GST TOA reflectance with all image acquisitions?

Preliminary Results Part 3: Hyperion PICS TOA Trends

Libya-4   394 images - median value of overlapping area



Dome C   190 images - median value of overlapping area



Summary

- Hyperion is very stable through time.
  - In most Vis bands < 0.24% yr^{-1}, most other bands <0.4% yr^{-1} compared to other TOA reflectance studies >0.675% yr^{-1}
- FLAASH vs. ATREM vs. ACORN
  - Consistent in Vis and variable in NIR and SWIR
  - Bands impacted more by atmospheric absorption have more variance between approaches
- Libya-4 CEOS site exhibits variability from 30m to 2m that can be quantified with a high resolution digital terrain model
  - Variation in dune topography impacts BRDF and observed reflectance
  - Difficult to distinguish between sensor/product differences and actual resolution differences
- Is a virtual constellation possible with spaceborne spectrometer measurements?
  - We provide enhanced estimates of instrument stability useful for cross calibration studies from 30-m to 2-m resolution. FLAASH reflectance between convolved Hyperion and WorldView-2 are reasonably good in homogenous areas (CV <2%).

    (R2 > 0.64-0.77, p-val < 0.001)

    Low correlation heterogeneous areas (CV 5-7%).

    (R2 <0.19-0.24, p-val < 0.001)
  - Libya-4 heterogeneity should be considered when convolving and or cross-calibrating data at high resolution or efforts should be made to minimize site conditions that introduce errors.
- Future work
  - TOA analysis for the entire time-series L1GST for Libya-4 & Dome C analyzing impacts of orbital precession.

Thank You

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Neigh C.S.R., McCorkel J., Campbell P., Ong L., Ly V., Landis D., Fry S., and Middleton E. (2016) Monitoring ortbital precession of EO-1 Hyperion with three atmospheric correction models in the Libya-4 PICS *IEEE Geoscience and Remote Sensing Letters, under review.*

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Neigh C.S.R., Masek J., and Nickeson J. (2013) High Resolution Satellite Data Open to Government Scientists. *AGU EOS Transactions* 94 (13), 121-123.

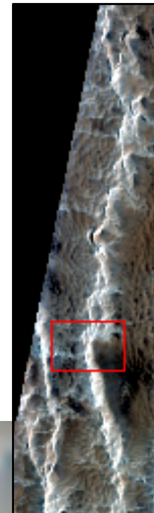
Subset example of Hyperion vs. WorldView-2

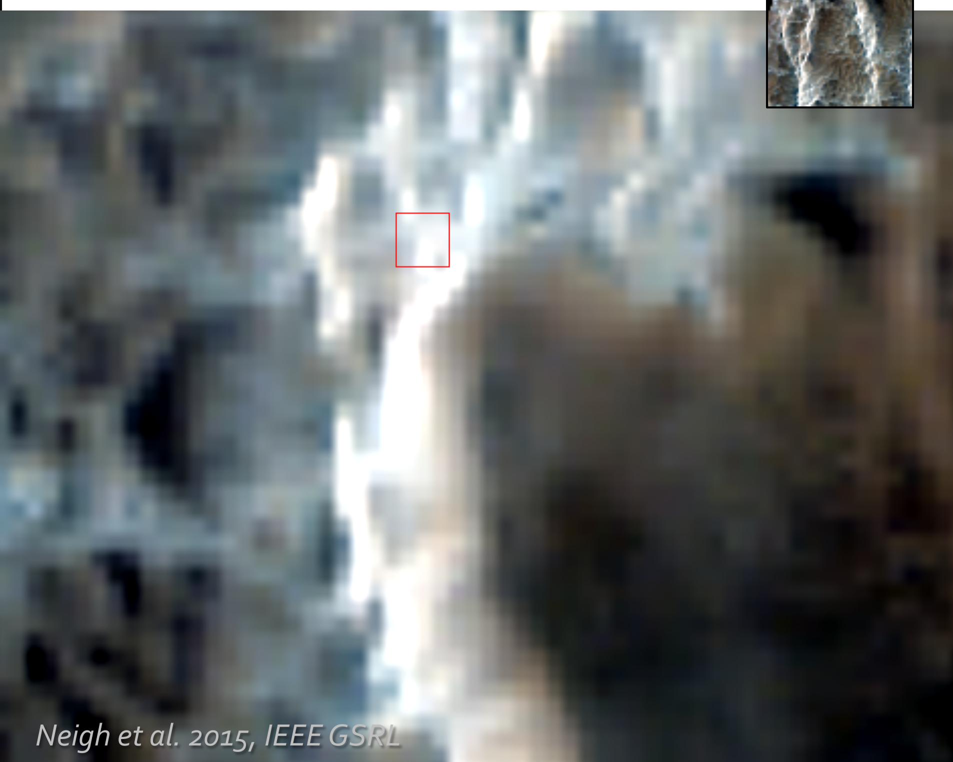
Linear stretch applied to enhance image visualization , Hyperion co-registered to WV-2

Hyperion True Color Convolved
FLAASH
8/9/2012

Red	630-690 nm
Green	510-580 nm
Blue	450-510 nm

Cubic Convolution 2m

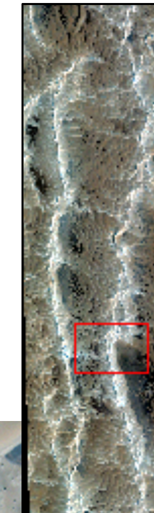


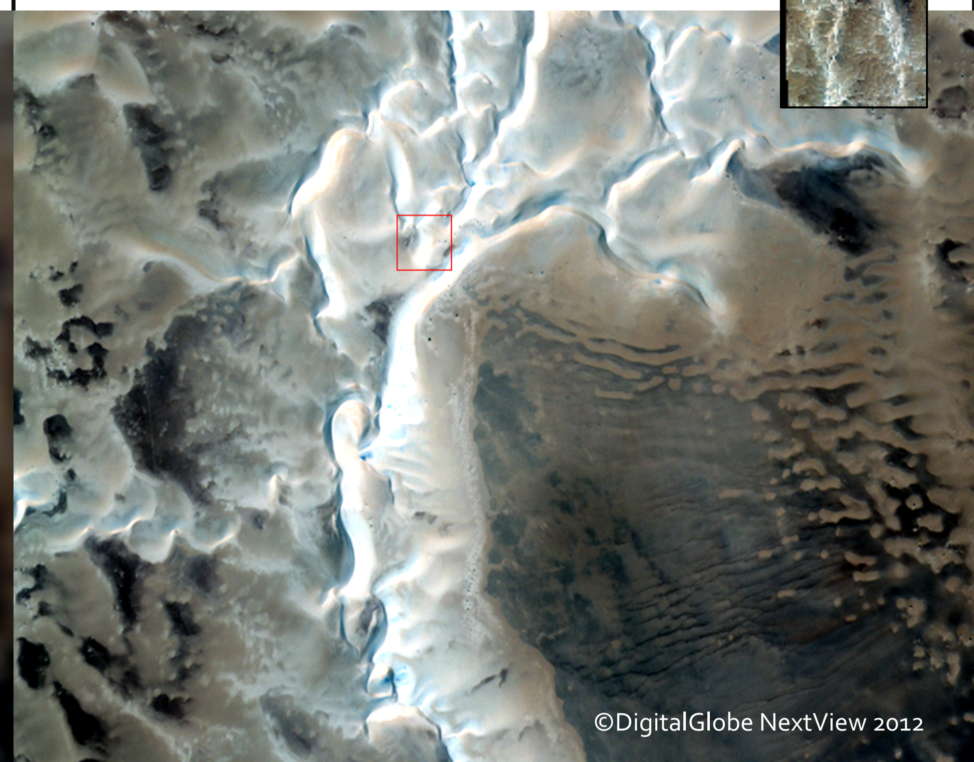


WorldView-2 True Color
FLAASH
8/12/2012

Red	Band 5 630-690 nm
Green	Band 3 510-580 nm
Blue	Band 2 450-510 nm

2m





Why is Hyperion Reflectance CV Greater than WV2?

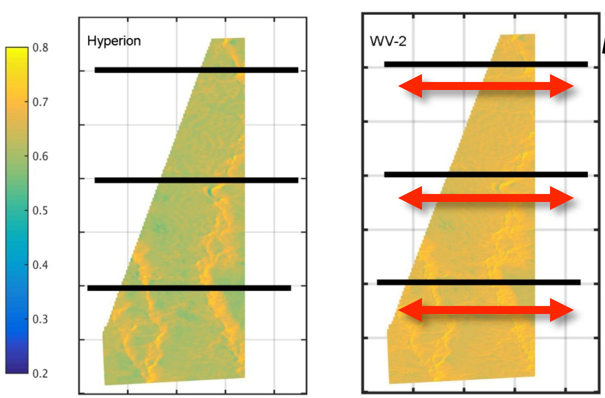
3 Transects (30 m wide) Across the Study Area
CV length of the 3 transects, 8 bands 15 pixels (30 m)

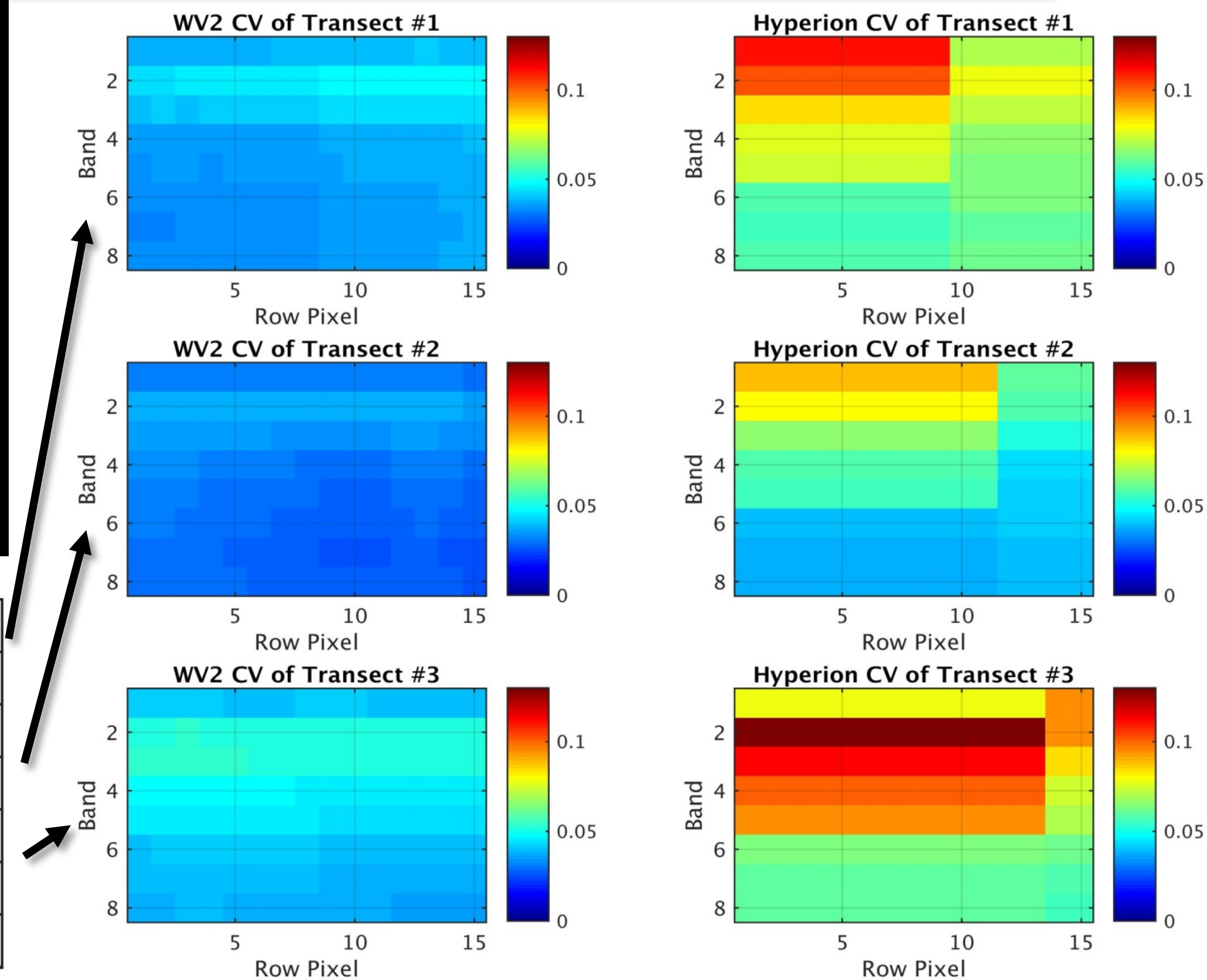
Spatial resolution vs. Radiometric /Detector Precision

In most cases Hyperion has a higher CV on the length of the transect

Due to:

- No radiometric detector correction for Hyperion (stripping — per detector gains, biases, spectral response functions, nonlinearities, noise, etc.)
- SNR for WV2 > Hyperion (bandwidth)





Neigh et al. 2015, IEEE GSRL

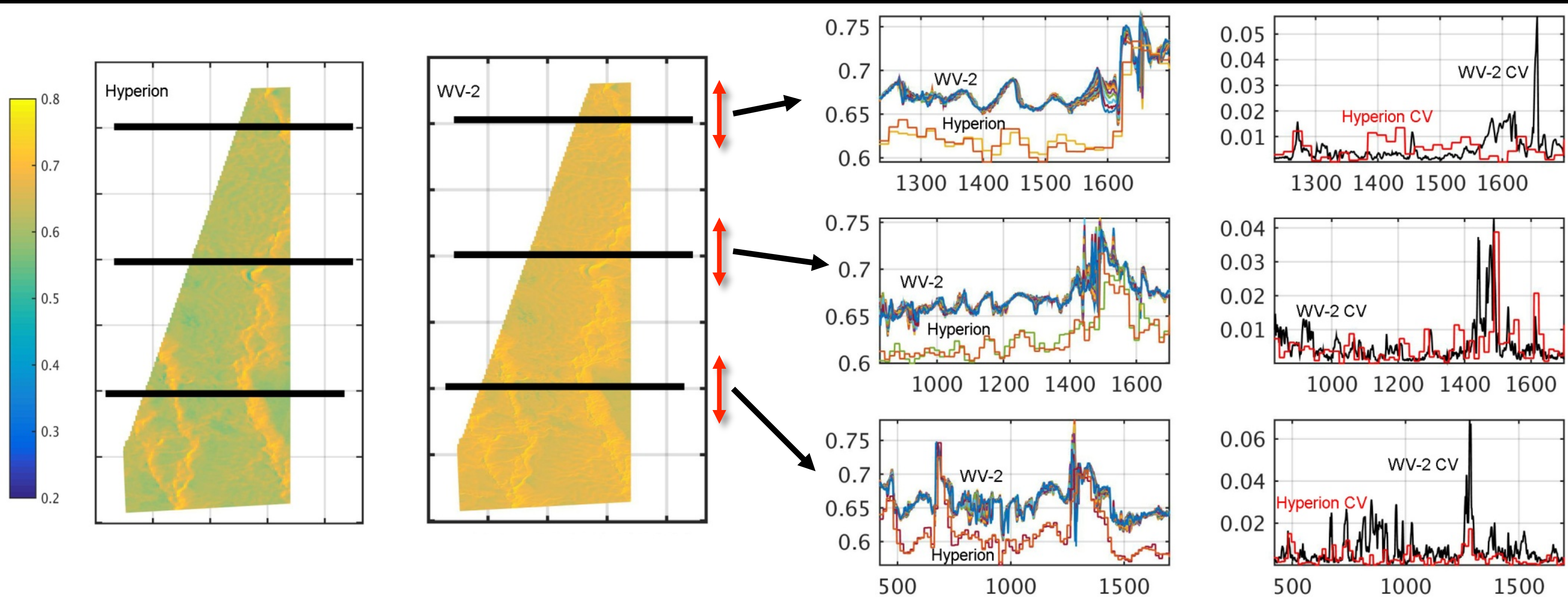
Why is Hyperion Reflectance CV Greater than WV2?

3 Transects (30 m wide) Across the Study Area
Band 8 example

Spatial resolution vs. Radiometric /Detector Precision

In most cases WorldView-2 has a higher CV on the width of the transect

Hyperion **WV-2** **Reflectance** **CV**



Neigh et al. 2015, IEEE GSRL