A Demonstration of Real time, Model driven Reflectance Retrieval for AVIRIS-NG Imagery

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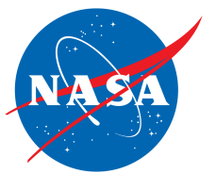
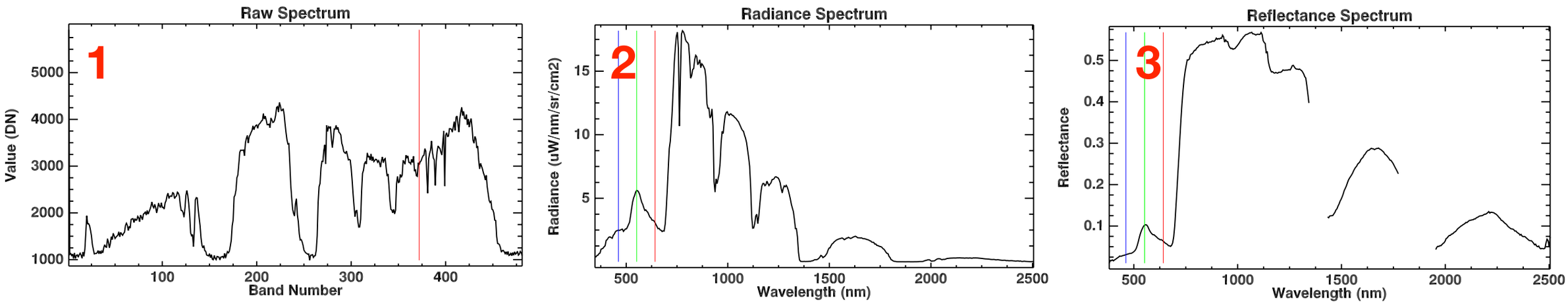


Goal: fast and accurate model-based atmospheric correction

- To retrieve surface reflectance: necessary to correct for atmospheric absorption and scattering effects



- Model-based (ATREM [Gao et al., 1993], FLAASH [Cooley et al., 2002])
  - Accurate Computationally expensive
- Empirical (QUAC [Bernstein et al., 2004], ELM [Conel et al., 1985])
  - Fast Strong assumptions / Require ground spectra (ELM)
- **This work:** demonstrates model-based atmospheric correction at sensor acquisition rates of 500Mb/s

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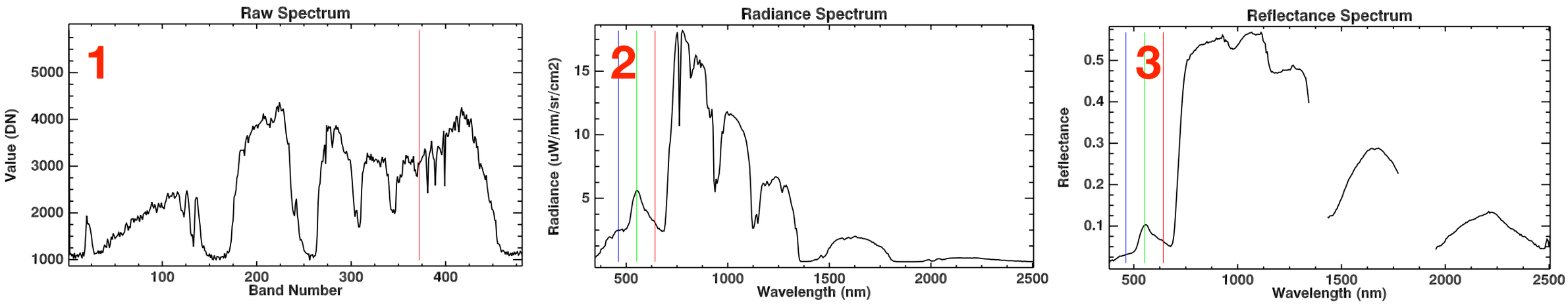

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Motivation: Onboard Analysis

- Modern spectrometers generate data volumes approaching 1Gb/s
- Storage / communications bandwidth limits duty cycles for UAV or exploration applications
- Reflectance imagery available at the sensor enables autonomous applications:
  - Smart downlink prioritization
  - Rapid response to science targets
  - Summary product generation / ROI compression
  - ...

ATREM-based Radiative Transfer Approach

$$\text{TOA reflectance } \rho = \frac{\overbrace{\pi L}^{\text{Radiance}}}{\underbrace{F \cos(\theta)}_{\text{Solar flux}}}$$

[Gao and Goetz., 1990]

ATREM-based Radiative Transfer Approach

$$\text{TOA reflectance } \rho = \frac{\overbrace{\pi L}^{\text{Radiance}}}{\underbrace{F \cos(\theta)}_{\text{Solar flux}}} = \underbrace{T_g}_{\substack{\text{Atmospheric} \\ \text{transmittance}}} \left[\overbrace{r_a}^{\substack{\text{Path} \\ \text{reflectance}}} + \overbrace{\frac{r_s T_d T_u}{1 - s r_s}}^{\substack{\text{Surface} \\ \text{reflectance}}} \right]$$

$\{T_u,\ T_d,\ T_g\}$ = {upward, downward, gaseous} transmittance

s = spherical albedo

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$$\text{Surface reflectance } r_s = \frac{\rho/T_g - r_a}{T_d T_u + s(\rho/T_g - r_a)}$$

[Gao and Goetz., 1990]

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[Gao and Goetz., 1990]

Our approach: precompute LUT of scattering and transmission terms

ATREM-based Radiative Transfer Approach

Scattering and transmission terms depend on:

- *Imaging geometry*: aircraft altitude + solar zenith angle
- *Atmospheric state*: surface pressure elevation + H_2O absorption path

Precompute 4 Dimensional LUT (designed for operating range of Twin Otter):

- Aircraft altitude: {.25, .5, ..., 5}km
- Solar zenith angle: {0, 4, ..., 88}deg
- Surface pressure elevation: {0, 1, ..., 4}km
- H_2O path: {0, ..., 5}cm (60 paths, log spacing)

Scattering terms: 6S code [Vermote et al., 1997]

Transmission terms:
- Absorption cross-sections from HITRAN2012 database [Rothman et al., 2013]
- Coefficients from Oxford Reference Forward Model [Dudhia, 2012]

LUT generation time: ~6k CPU hours on JPL supercomputer cluster

AVIRIS Next Generation (AVIRIS-NG) + Interface

"Designed to exceed AVIRIS-Classic in the spectral, spatial, radiometric and uniformity domains." **http://airbornescience.jpl.nasa.gov/**

- Resolution:
  - Spectral: 380-2500nm at 5nm
  - Spatial: 0.5m / pixel or finer
- Dedicated FPGA interface:
  - Handles high-speed Camera Link protocol (500Mb/s)
  - Associates frames with co-mounted GPS / INU position stream

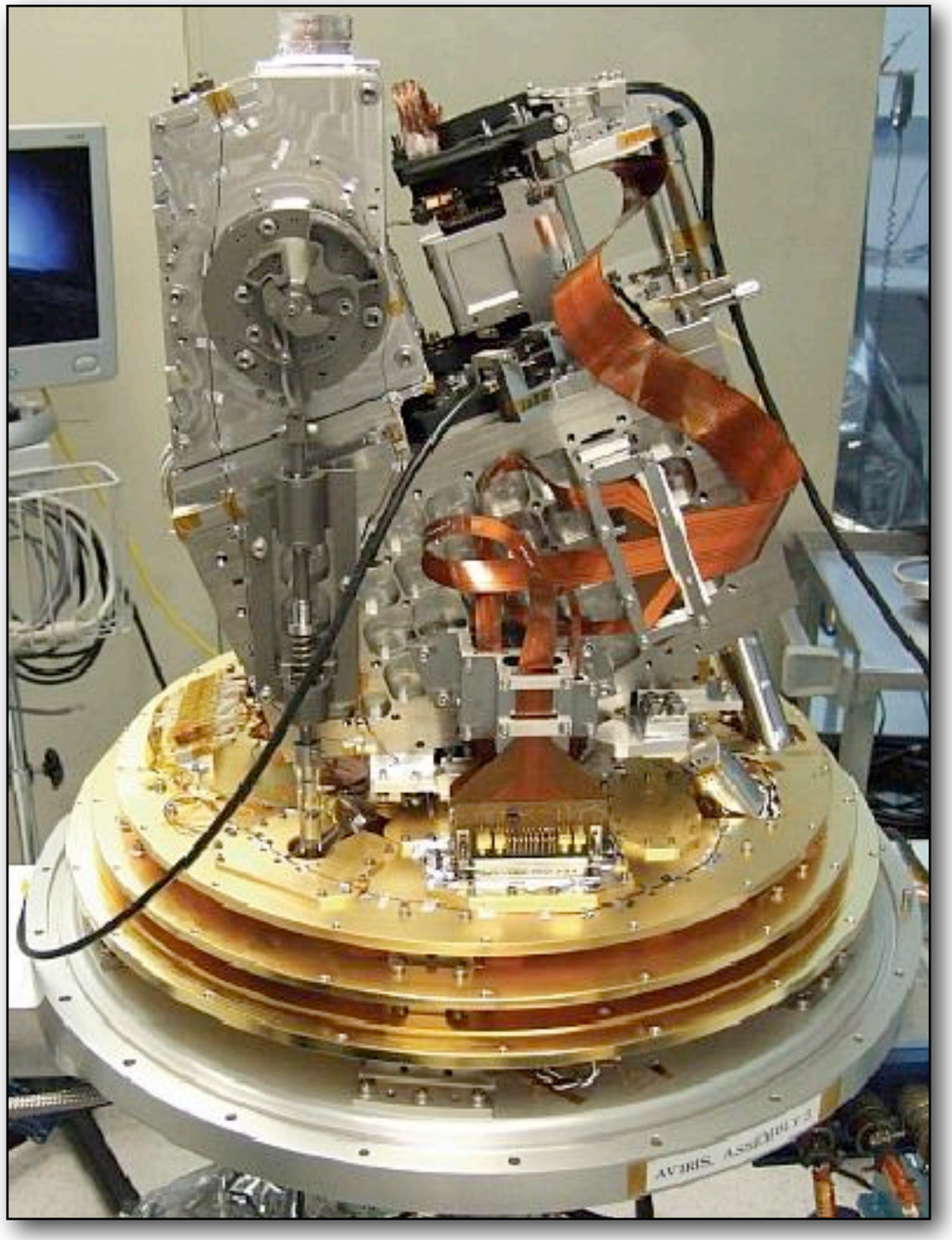
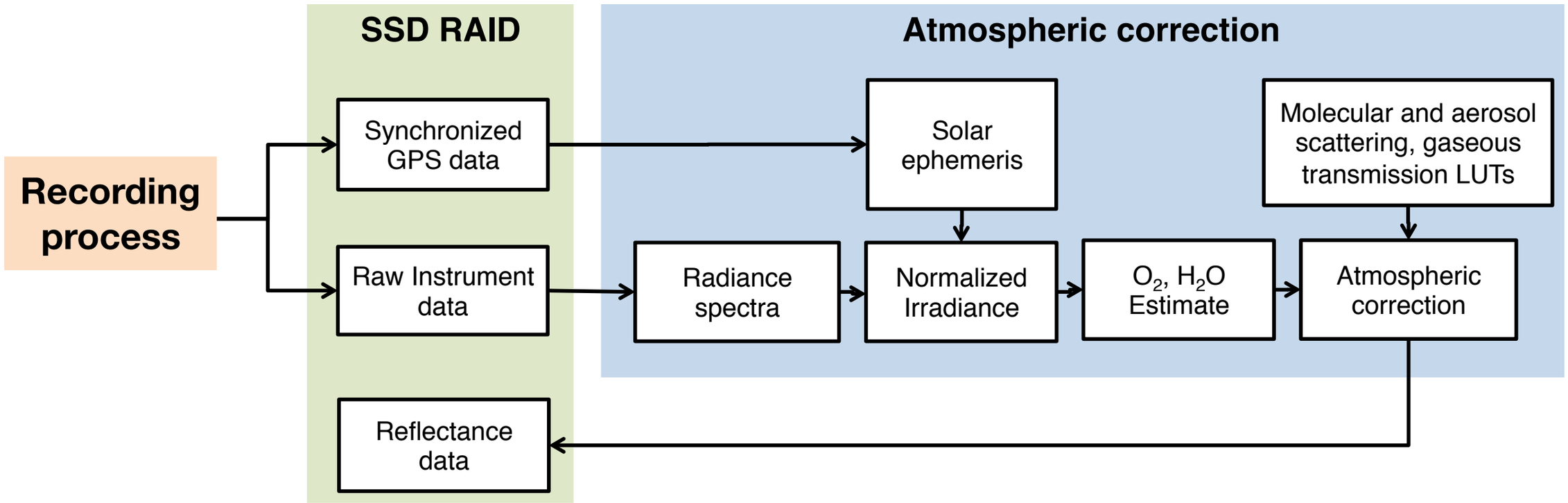


Image credit: http://airbornescience.jpl.nasa.gov/instruments/avirisng

Architecture and Data Flow

Watchdog process (Python) monitors SSD for new imagery, activates atmospheric correction routine (C), displays reflectance spectra as they are generated



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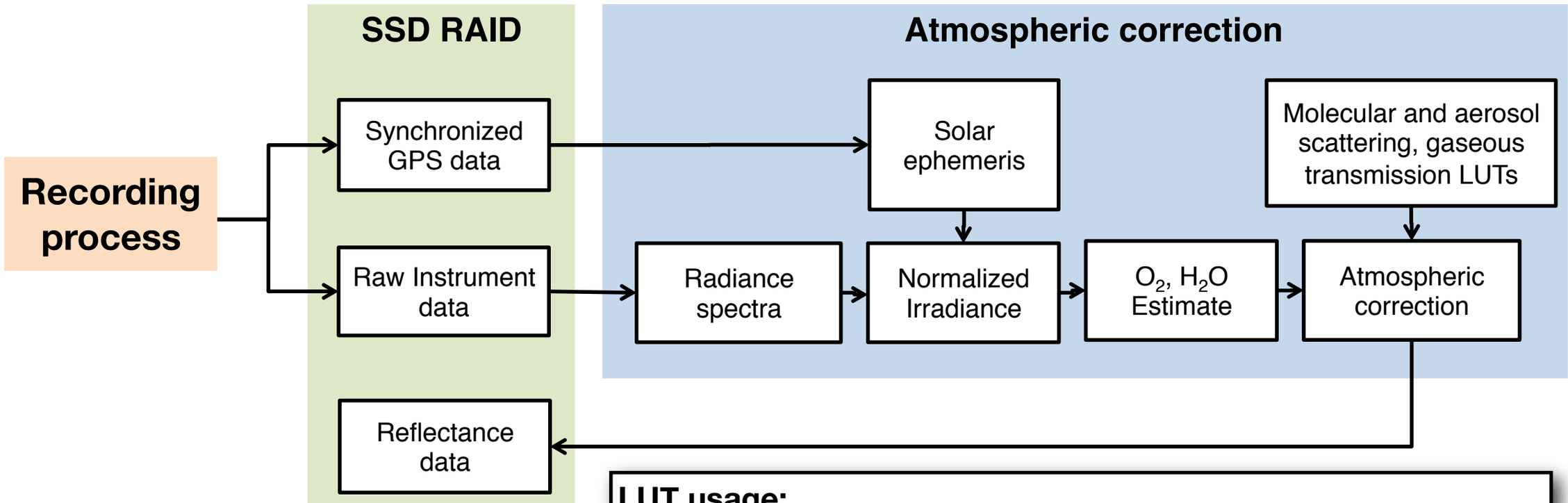


LUT usage:

- Locate nearest aircraft elevation + solar zenith angle in LUT
- Estimate O_2, H_2O via Continuum-Interpolated Band Ratio (CIBR)
  - Pressure elevation estimated from 760nm oxygen-A band
  - Water vapor estimated from 940 and 1140 nm CIBR averages
- Bilinear interpolation along pressure elevation, water vapor axes

Demonstration on AVIRIS-NG Imagery

- Tested real time system onboard Twin Otter over two regions: San Joaquin Valley (SJV) and UC-Riverside (UCR)
- Successfully processed 31/31 flightlines at the sensor acquisition rate of 500Mb/s
- **First demonstration of real time, model-based atmospheric correction of hyperspectral imagery onboard an aircraft**

Above: real time system in action onboard the Twin Otter

Capture Time (UTC)	Location	Zenith	Altitude (m)	#Lines
11 June 2014 19:50:45	SJV	13.4	4186	39103
11 June 2014 20:01:36	SJV	13.3	4107	32259
11 June 2014 20:14:48	SJV	13.9	4179	24906
11 June 2014 20:21:57	SJV	14.4	4131	23407
11 June 2014 20:38:06	SJV	16.3	4657	33765
11 June 2014 20:46:31	SJV	17.3	4625	35751
11 June 2014 21:18:22	SJV	22.0	2577	42210
11 June 2014 21:29:13	SJV	23.9	2479	32604
11 June 2014 23:00:35	SJV	42.1	1620	16656
12 June 2014 19:57:14	UCR	10.9	2384	26778
12 June 2014 20:02:45	UCR	11.1	2378	17973
12 June 2014 20:06:43	UCR	11.4	2375	20700
12 June 2014 20:12:43	UCR	11.9	2363	12840
12 June 2014 20:16:48	UCR	12.3	2393	14091
12 June 2014 20:20:47	UCR	12.7	2320	17934
12 June 2014 20:29:43	UCR	13.9	1247	14043
12 June 2014 20:33:47	UCR	14.5	1257	13023
12 June 2014 20:37:30	UCR	15.0	1230	12727
12 June 2014 20:41:11	UCR	15.6	1260	11937
12 June 2014 20:44:38	UCR	16.2	1236	13489
12 June 2014 20:48:58	UCR	16.9	1251	15109
12 June 2014 20:54:35	UCR	17.8	1227	12612
12 June 2014 20:59:37	UCR	18.5	2376	33297
12 June 2014 21:11:54	UCR	20.6	2557	19576
12 June 2014 21:17:16	UCR	21.6	2531	17608
12 June 2014 21:21:59	UCR	22.5	2543	22644
12 June 2014 21:28:10	UCR	23.8	2552	9414
12 June 2014 21:31:42	UCR	24.4	2525	17169
12 June 2014 21:38:58	UCR	26.0	2046	20322
12 June 2014 21:53:42	UCR	28.5	2065	17034
12 June 2014 21:59:31	UCR	29.7	2018	16245

Validation Data and Algorithms

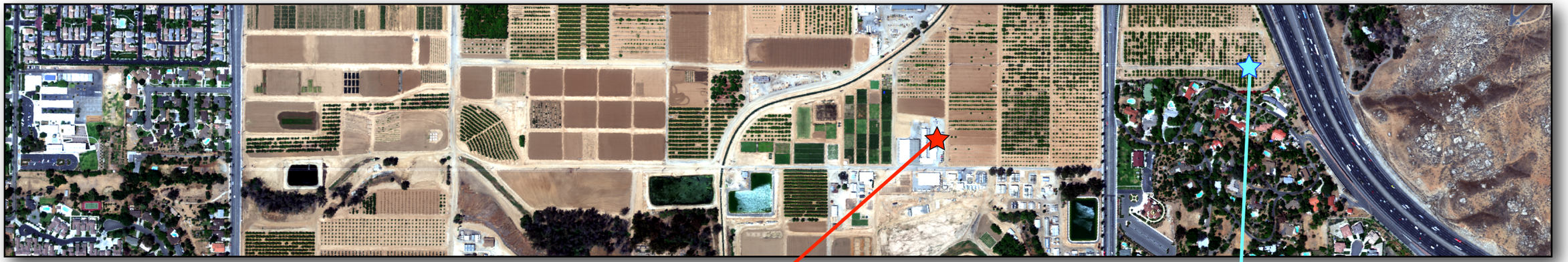
Validation data:

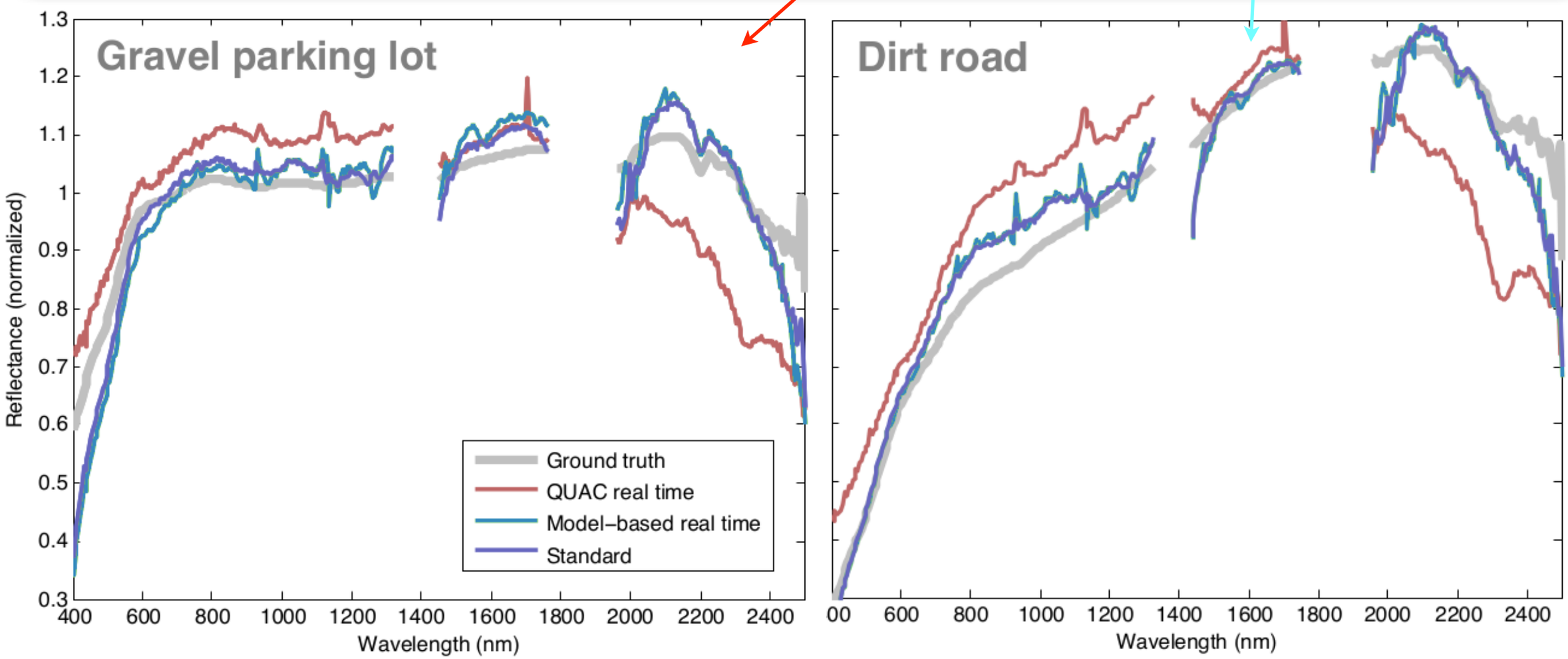
- Flightlines:
  - UCR (6/12/14, 20:16:48): urban area, orchards
  - SJV (6/11/14, 20:21:57): chaparral vegetation, bare terrain
- ASD field spectra of UCR area from summer 2013

Algorithm comparisons:

- QUAC [Bernstein et al, 2004]
  - Empirical approach: assumes linear model, estimates baseline + offset using in-scene pixels, CPUtime = minutes
  - Applied to TOA reflectances without filtering bright / sharp features
    - Exclude pixels where QUAC output outside [0,1] range (<1% of all pixels)
- AVIRIS-NG Standard Science Pipeline
  - ATREM-based ground processing pipeline, CPUtime = hours

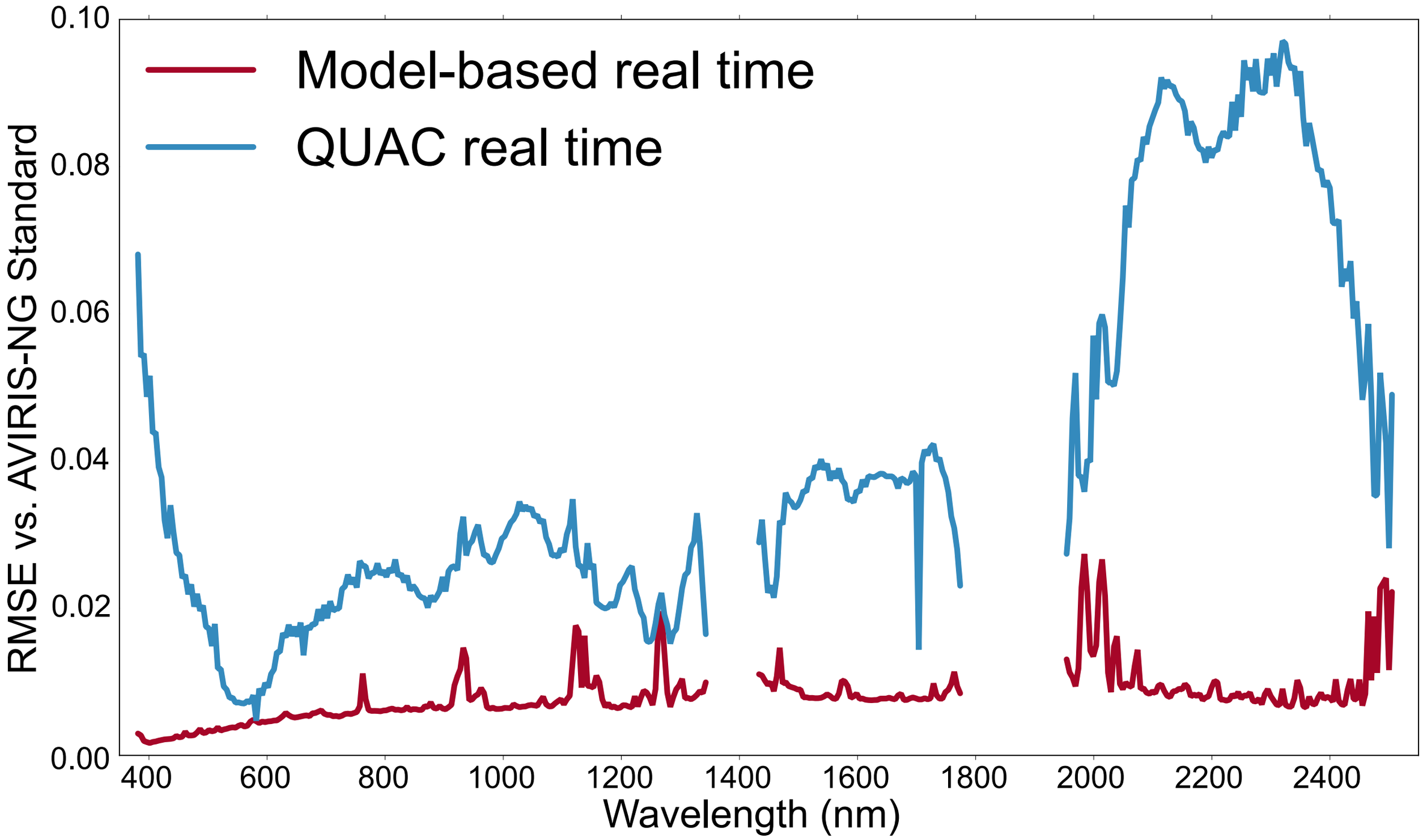
UCR Flightline Comparisons:
ASD Field Spectra, QUAC, AVIRIS-NG Standard



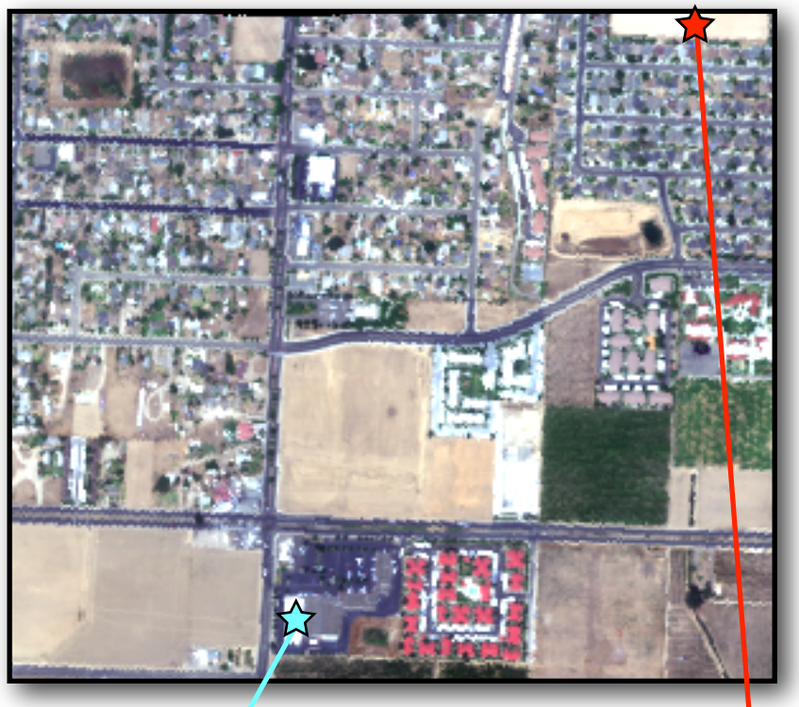


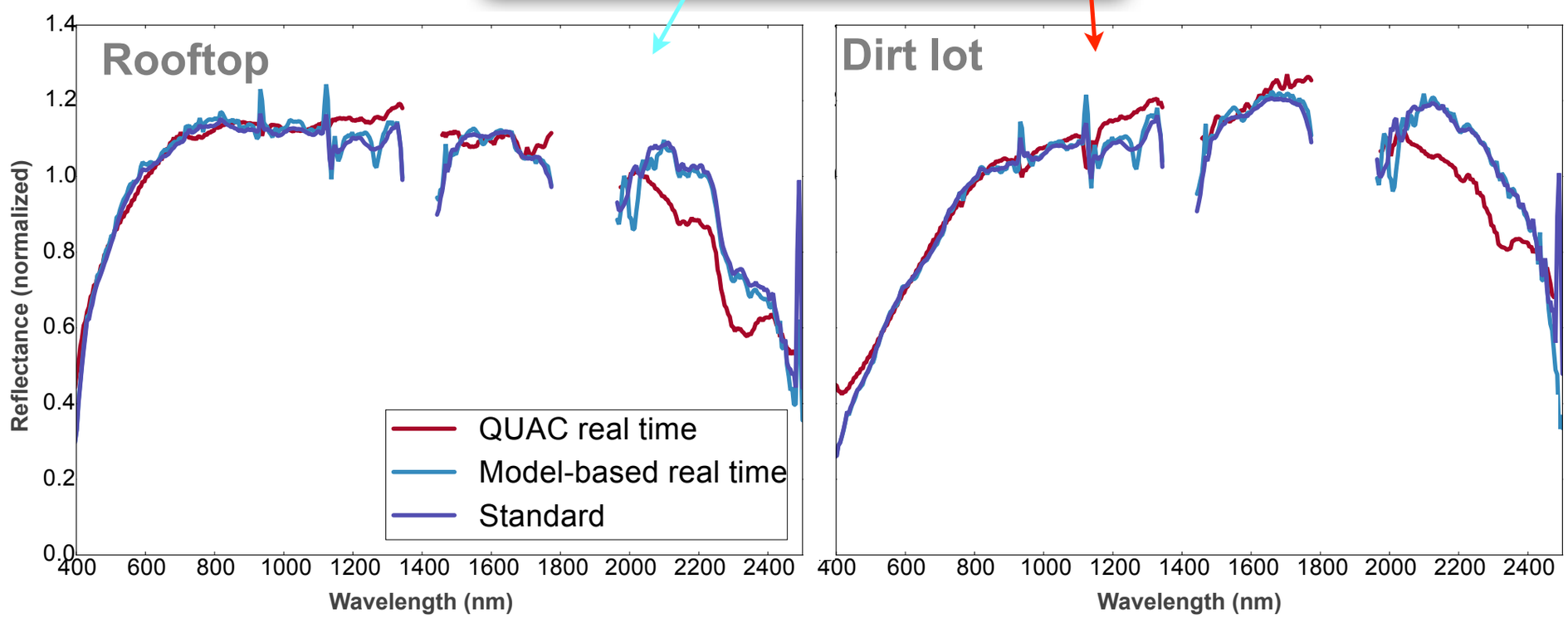
Real time Reflectance Retrieval for AVIRIS-NG Imagery

UCR Flightline:
Per-band RMSE vs. AVIRIS-NG Standard



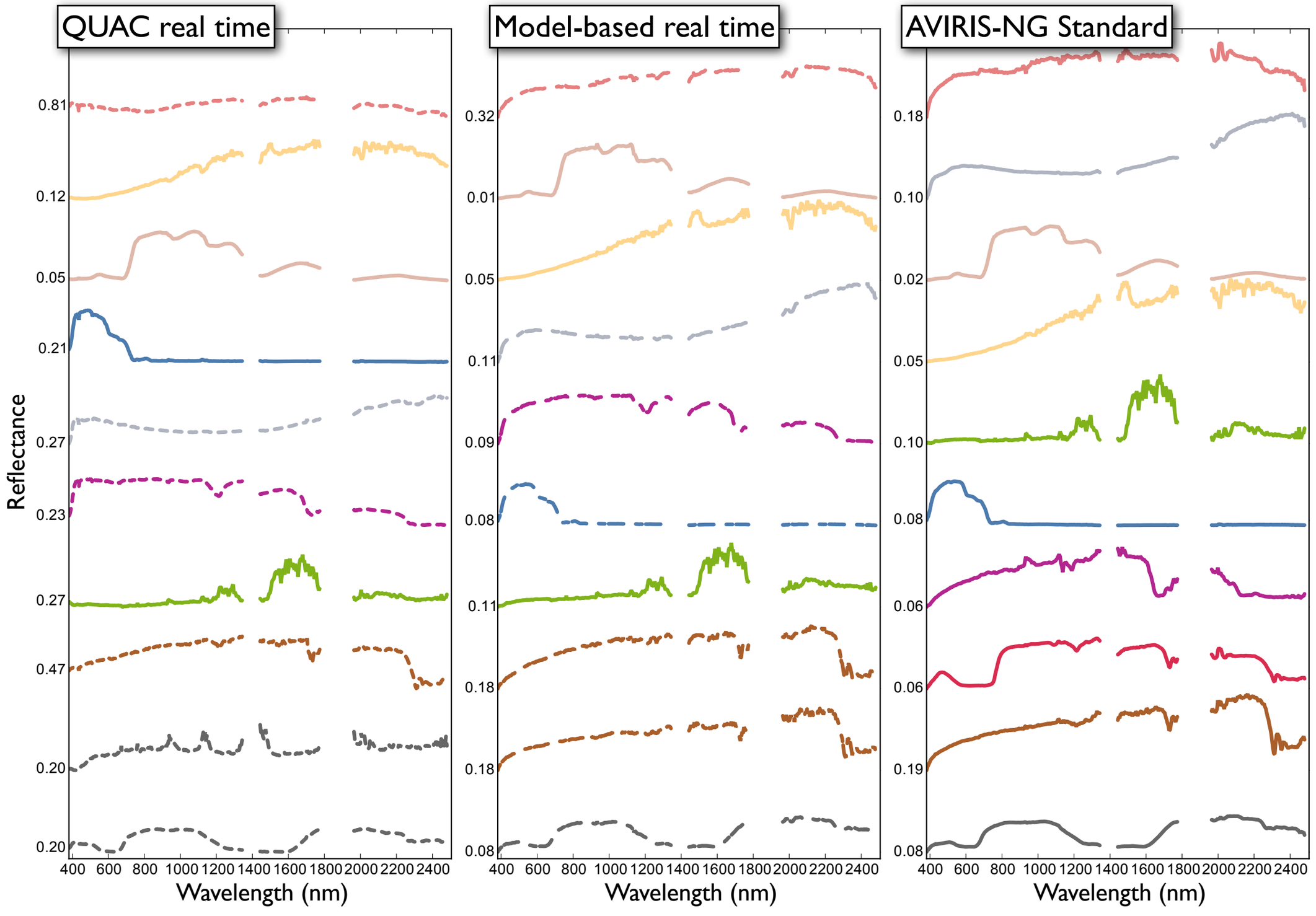
SJV Flightline Comparisons: QUAC, AVIRIS-NG Standard





Real time Reflectance Retrieval for AVIRIS-NG Imagery

UCR SMACC [Gruninger et al., 2004] Endmembers

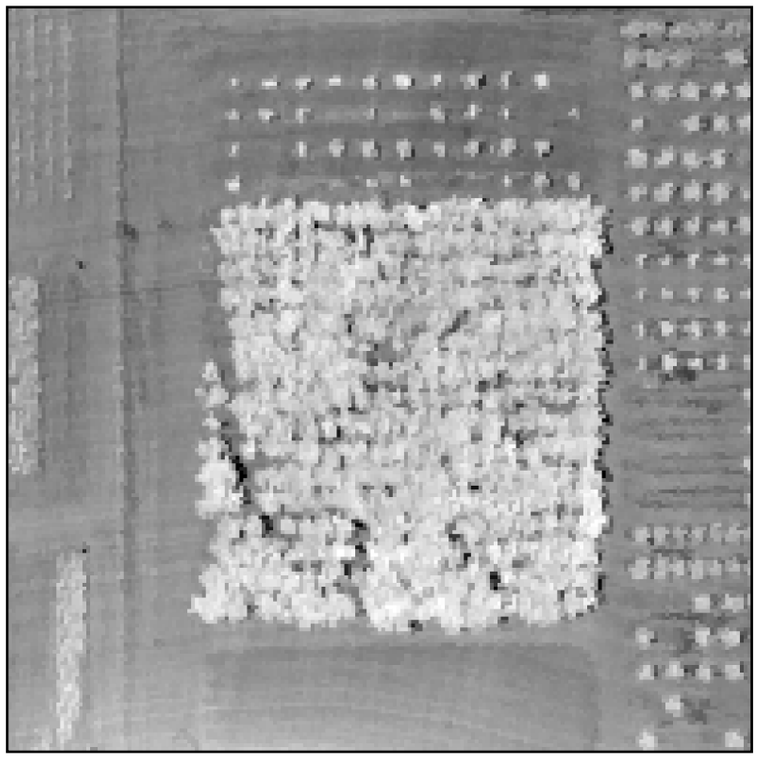


Real time Reflectance Retrieval for AVIRIS-NG Imagery

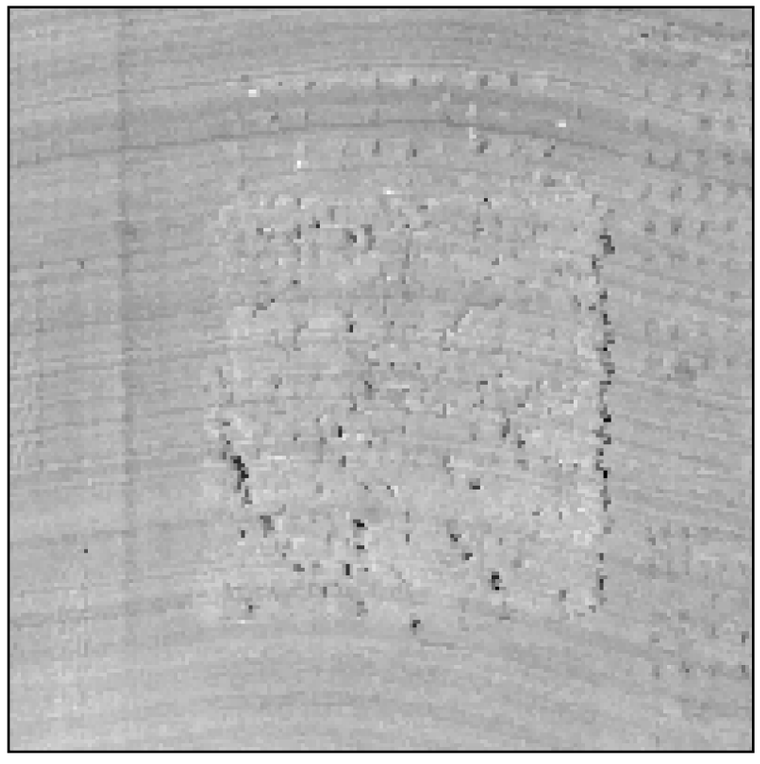
H_2O Retrievals: Correlation with NDWI [Gao, 1996]
CIBR vs. 3-Phase, NDVI>0.0

False-color Composite

Model-based Real time (CIBR)



AVIRIS-NG Standard (3-Phase)



Correlation (H_2O retrieval, NDWI)
Model-based: 0.72852
AVIRIS-NG Standard: 0.22520

Summary and Future Work

- We demonstrated model-based atmospheric correction at sensor acquisition rates of 500Mb/s
- Real time execution possible by shifting radiative transfer computations offline
- Successful in-flight runs on AVIRIS-NG platform
- Next steps:
  - Preparing TGRS paper:
    “Real time Reflectance Retrieval for AVIRIS-NG Imagery”
  - Real time orthorectification

Acknowledgments

- Sarah Lundeen, Scott Nolte and the AVIRIS-NG team
- Glenn Sellar, John Morgan, Mark Helmlinger and Erika Podest for collecting the UCR field spectra
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Fin

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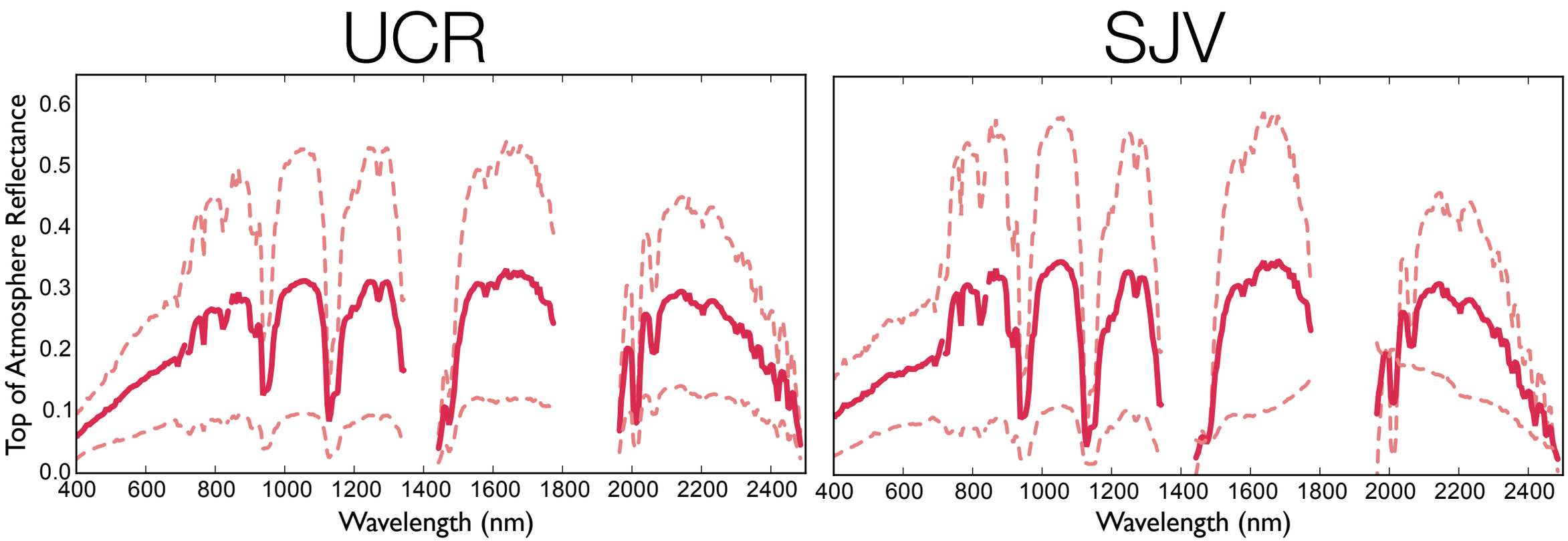
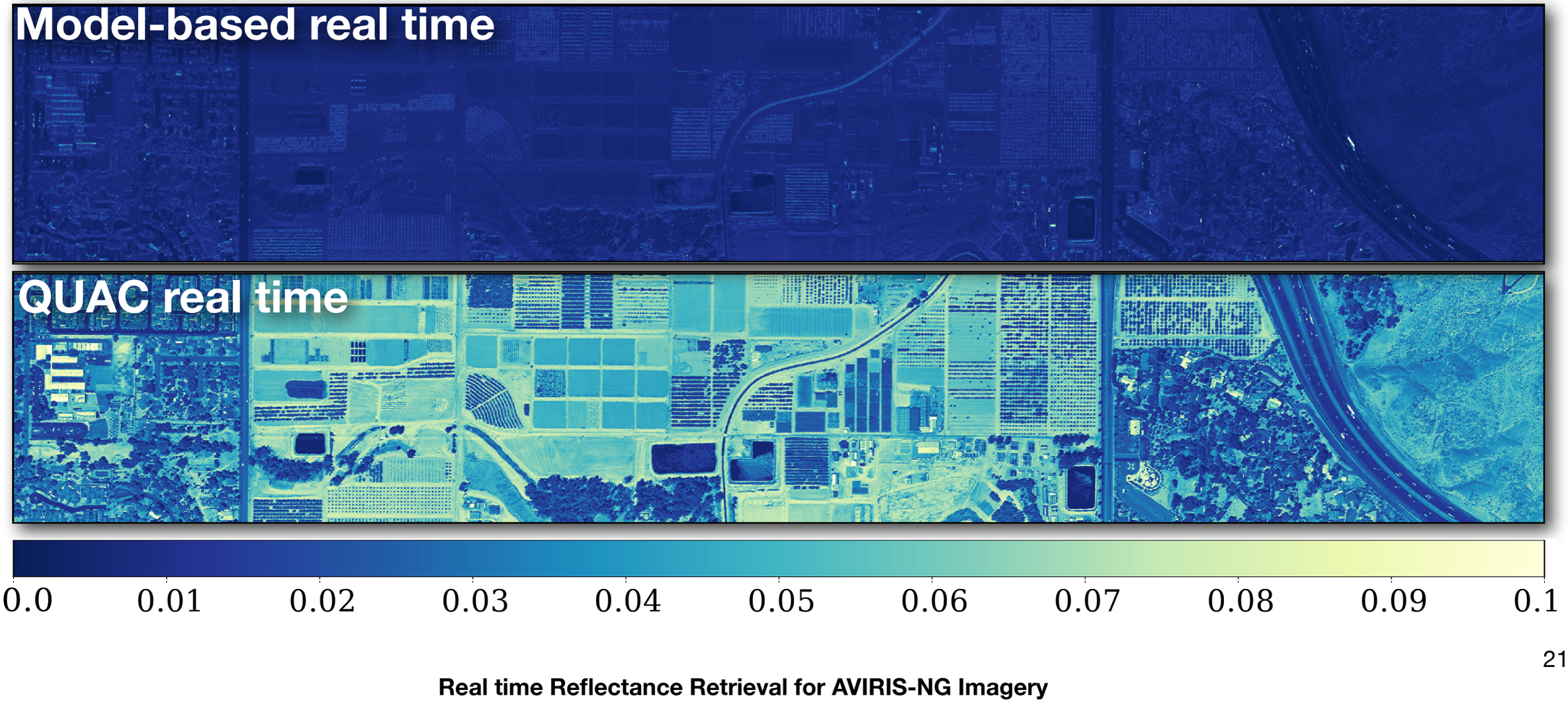
Per-band Mean/Std. Dev. of TOA Reflectances



- QUAC assumes std. dev. ~constant for all wavelengths
- RMSE greatest for bands where std. diverges (<600 & >2000nm)

UCR Flightline:
Per-pixel RMSE vs. AVIRIS-NG Standard



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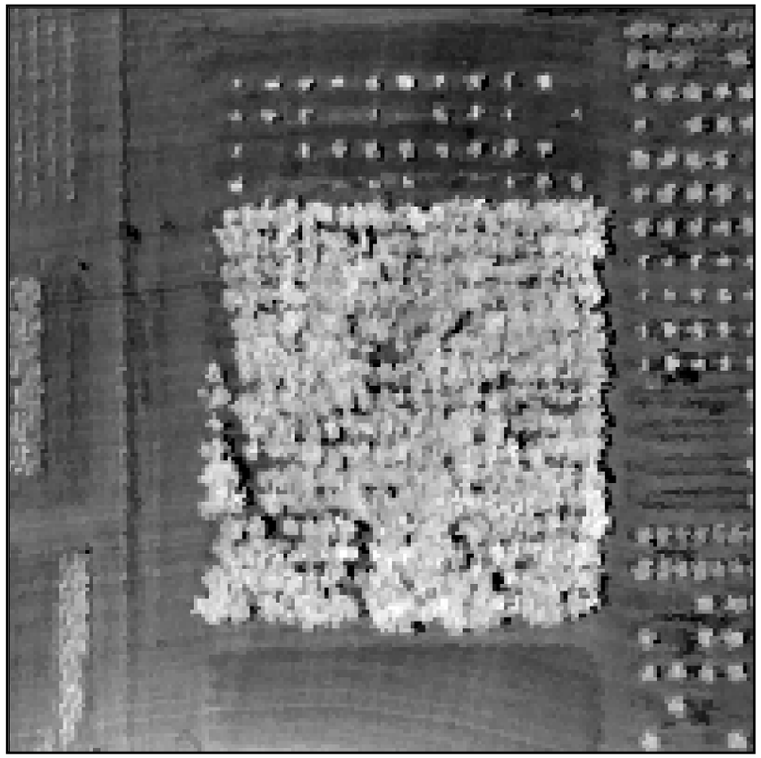
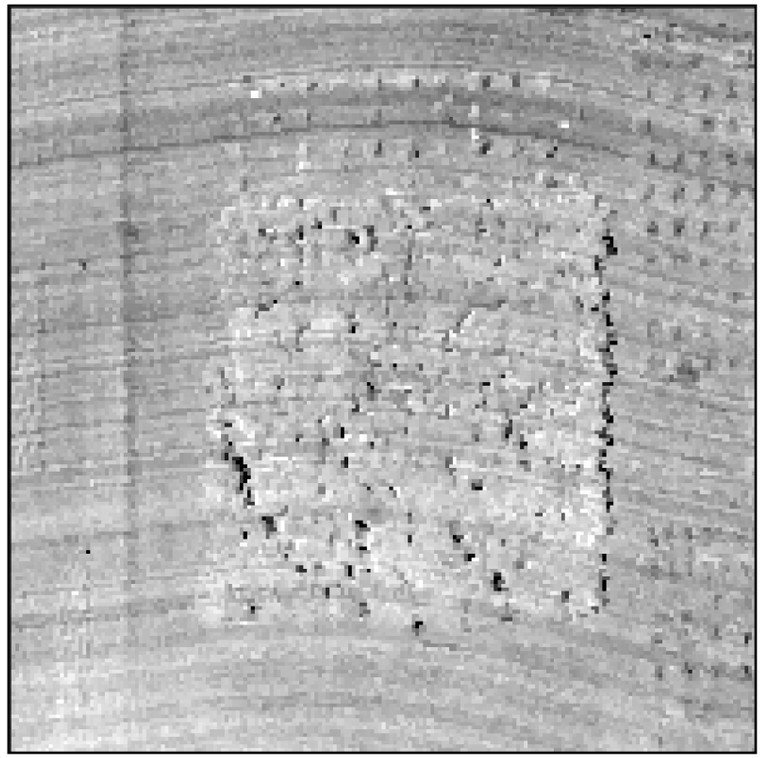
H_2O Retrievals: Correlation with NDWI [Gao, 1996]
CIBR vs. 3-Phase, NDVI>0.75

False-color Composite

Model-based Real time (CIBR)



AVIRIS-NG Standard (3-Phase)



Correlation (H_2O retrieval, NDWI)
Model-based: 0.67026
AVIRIS-NG Standard: 0.07954