POlarimeter Definition EXperiment (PODEX) Level 1 comparisons

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PODEX: 3 polarimeters on the ER-2

AirMSPI: Airborne Multiangle SpectroPolarimetric Imager (JPL)

PACS: Passive Aerosol and Cloud Suite (UMBC/GSFC)

RSP: Research Scanning Polarimeter (GISS)

Start with the basics:
how does instrument radiometry compare?

- Help better understand retrieved product comparison
- Help differentiate algorithm vs measurement differences
- Help understand our instrument charactistics – Do they act as we expect?
- Optimal estimation algorithms need accurate measurement uncertainties

We don't have absolute measurements - no instrument is 'right' or 'wrong'. We can only tell if instruments agree as expected.

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~~**PACS:** Passive Aerosol and Cloud Suite (UMBC/GSFC)~~

RSP: Research Scanning Polarimeter (GISS)

PACS data are not available for comparison yet…

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Instrument reflectance & polarization comparison

- Geolocation and wing flex
- Pixel to pixel matchup
- Comparison scenes
- Instrument uncertainty models
- Results
- Recommendations for future efforts

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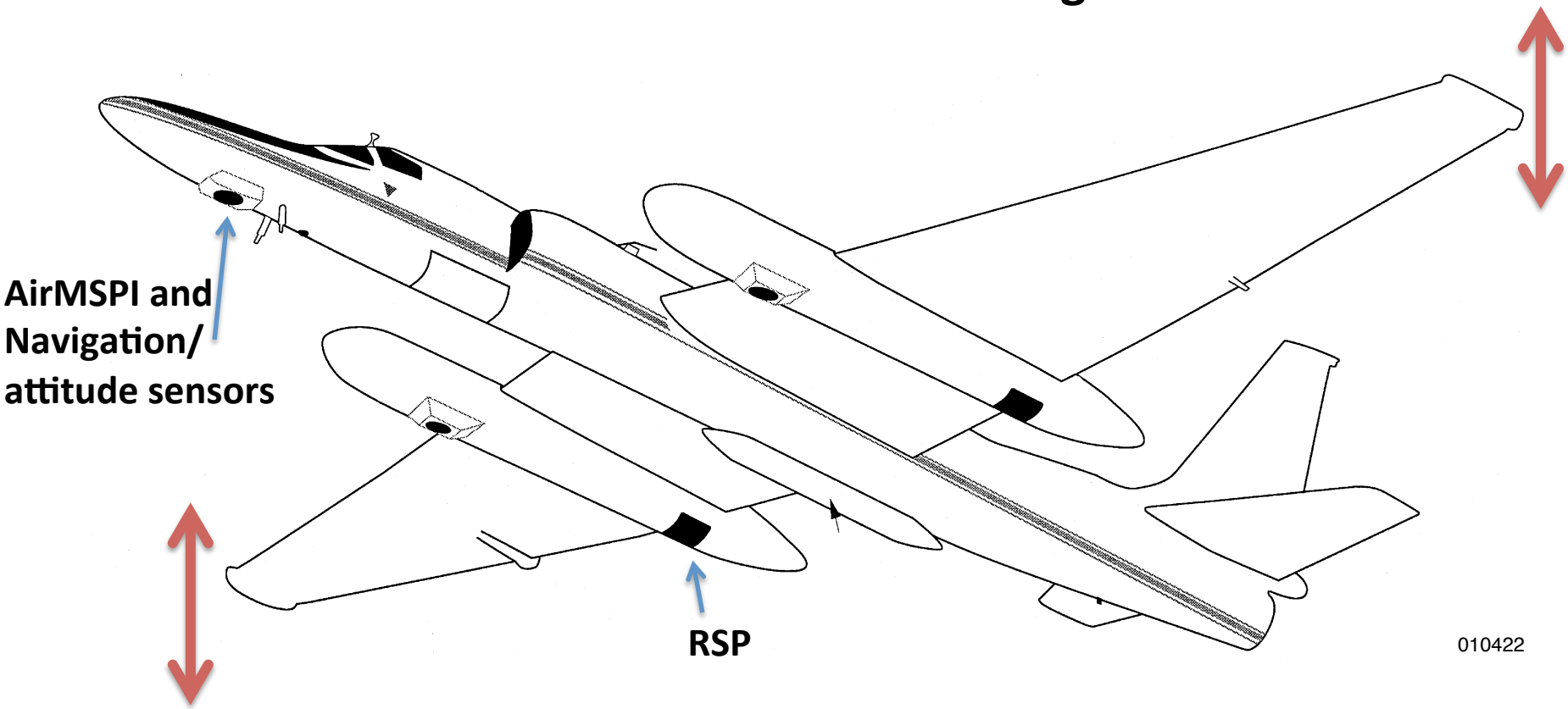
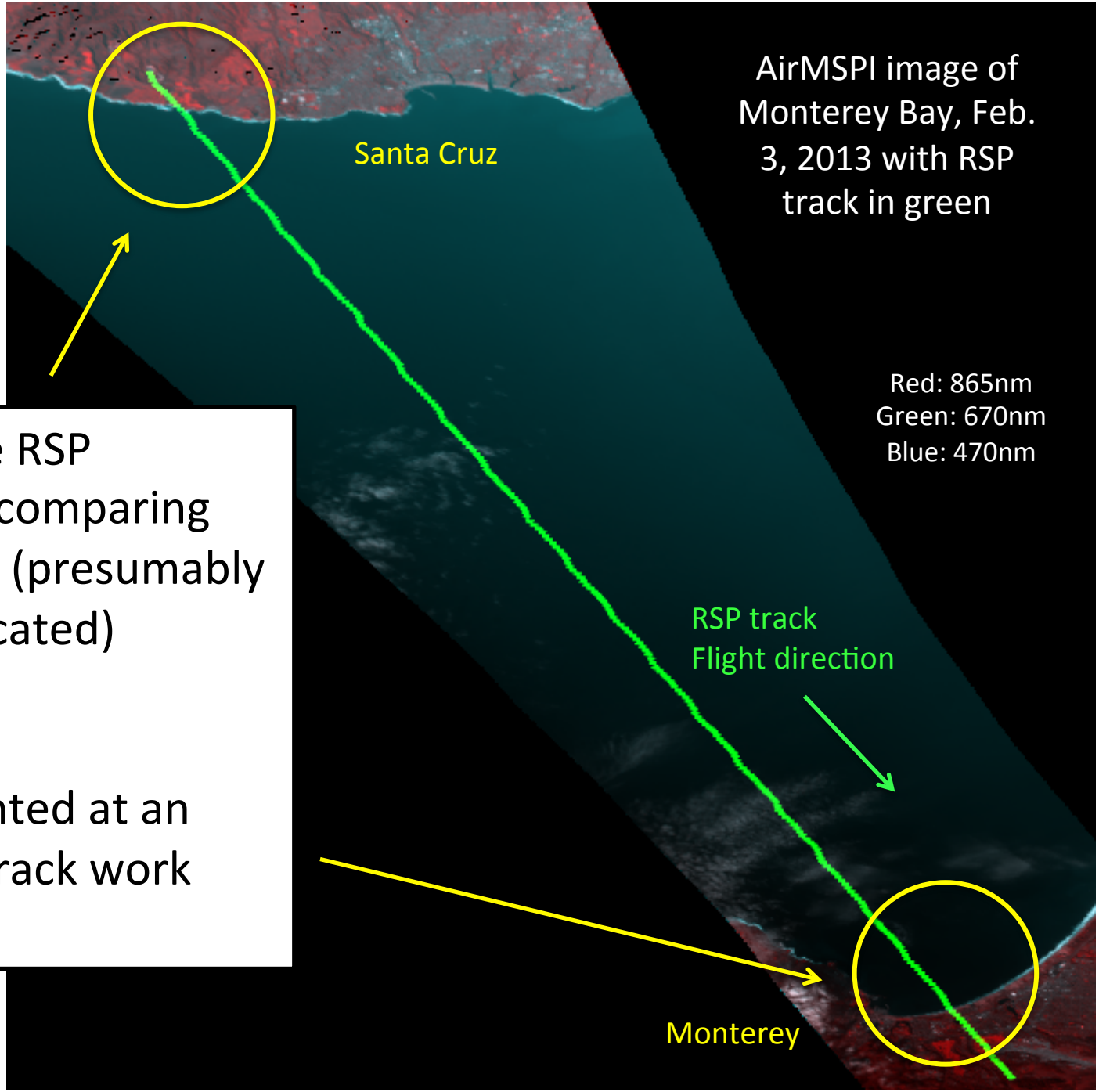
Wing ‘flex’ may roll the RSP observations from attitude measurements in the fuselage



Wing ‘flex’ varies with fuel load and payload.

1˚ of pointing error at ER-2 cruising altitude is 350m on the ground

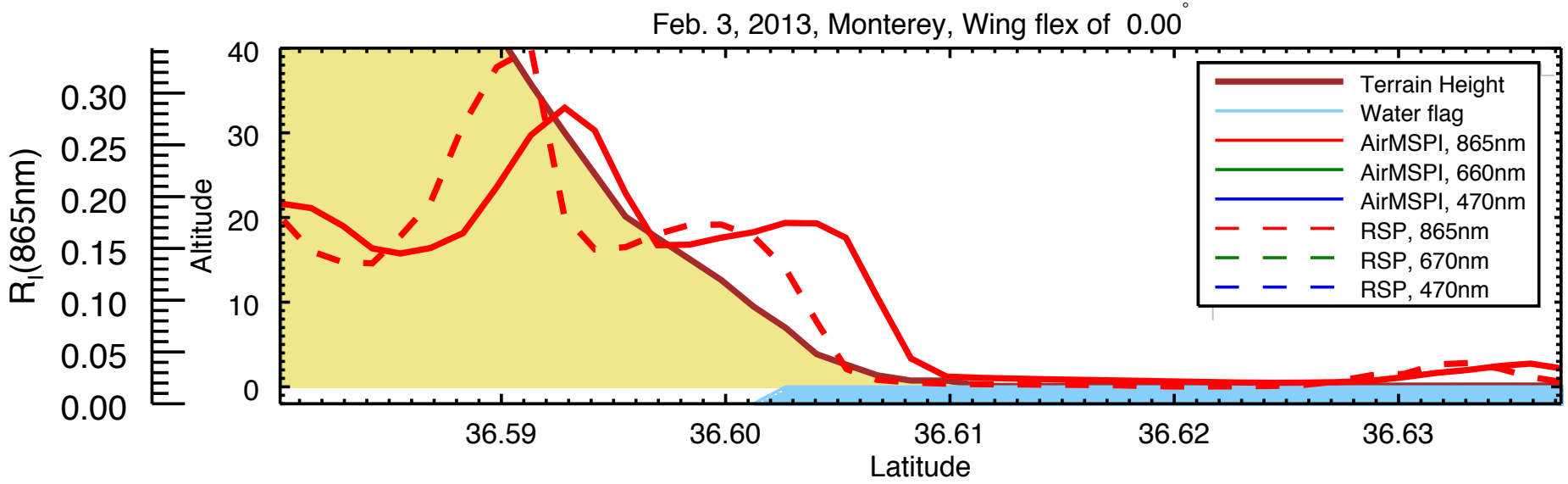
(Attitude sensors were placed in wing pod for SEAC4RS)



We can test the RSP geolocation by comparing observations to (presumably correctly geolocated) AirMSPI data.

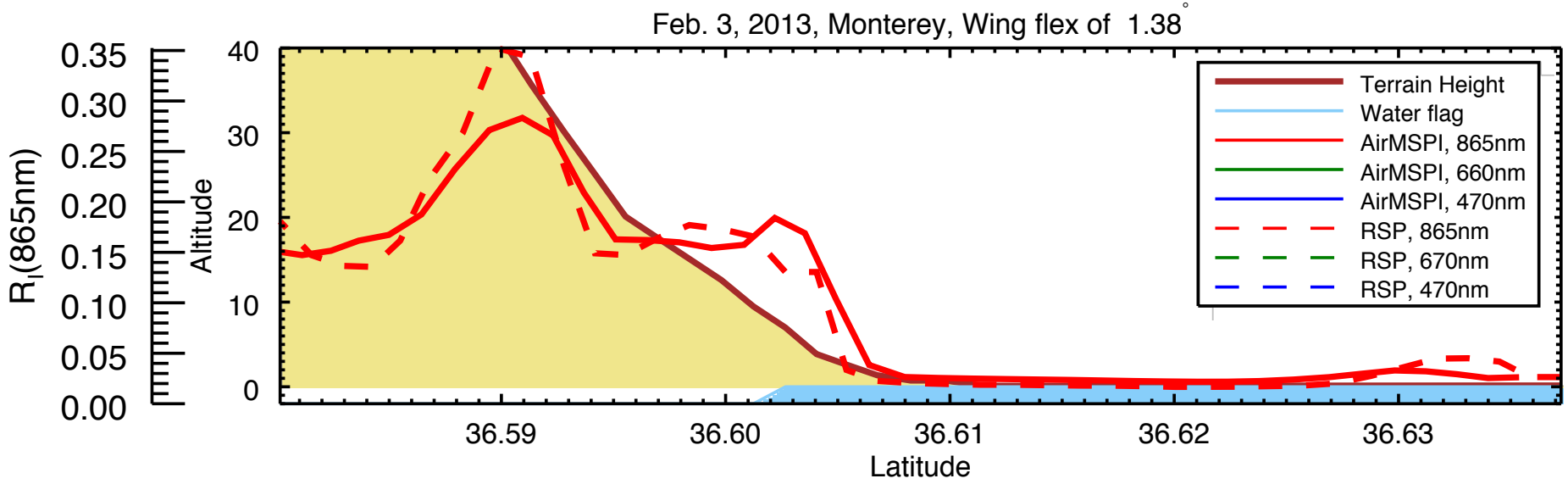
Coastlines oriented at an angle to flight track work well for this

Uncorrected for wing flex:



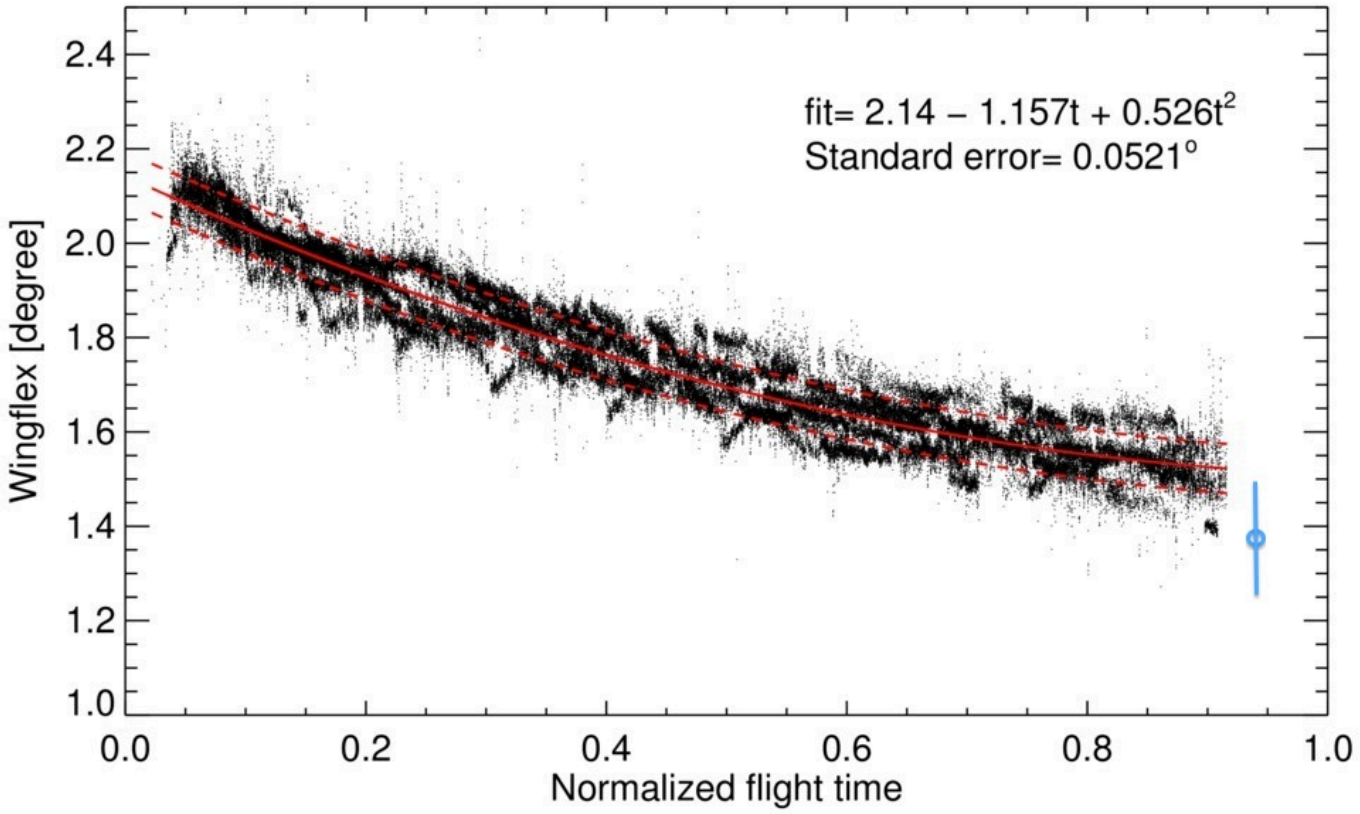
Corrected for wing flex of 1.38°:

(positive means counter-clockwise for the pilot)



SEAC4RS wing flex parameterization

Bastiaan van Diedenhoven, Rose Dominguez used the eMAS IMU files to determine a flight time based wing flex parameterization



We assume this also applies for PODEX…

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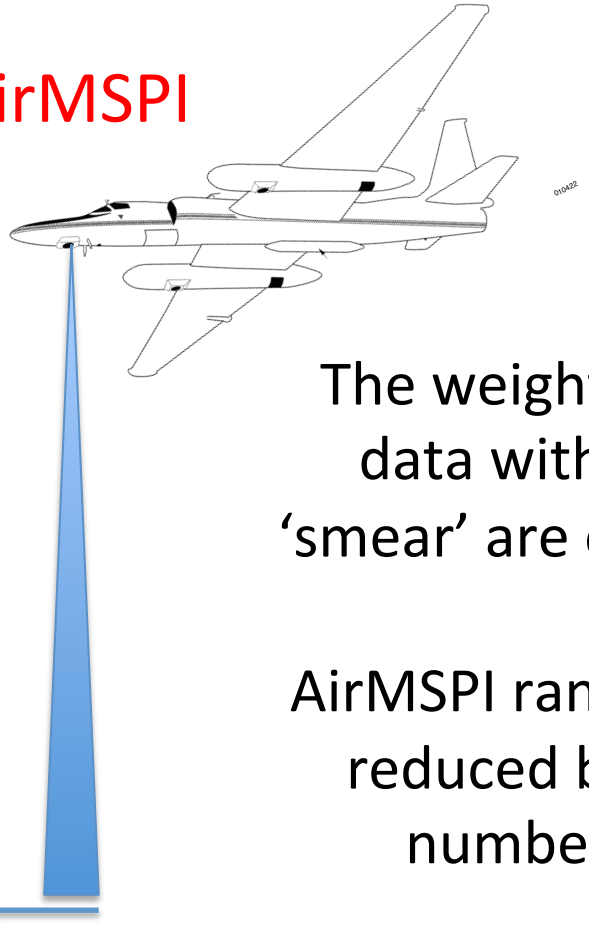
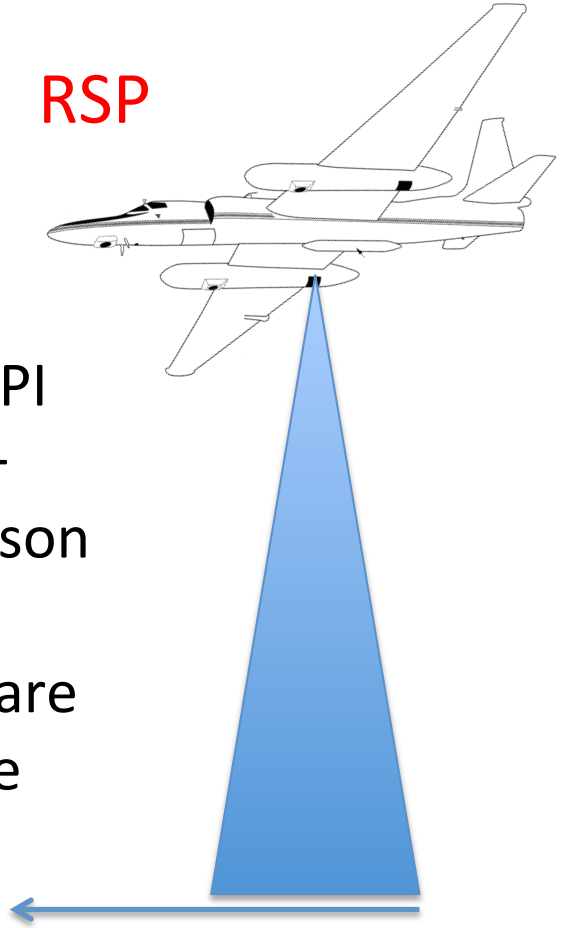
Pixel to pixel matchup

Spatial scale considerations

AirMSPI



RSP



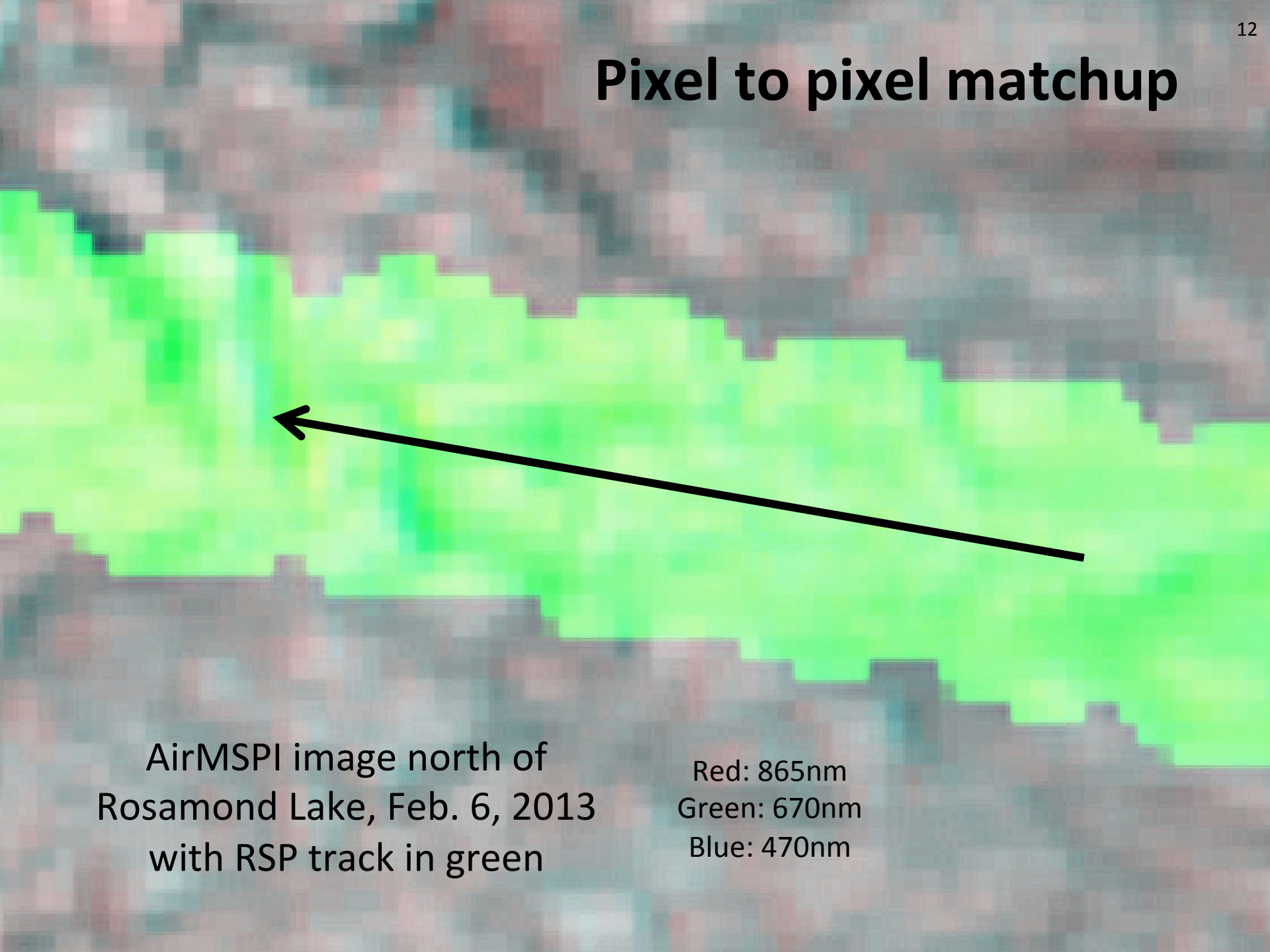
The weighted mean of all AirMSPI data within the RSP footprint + 'smear' are extracted for comparison

AirMSPI random error estimates are reduced by $1/\sqrt{n}$, where n is the number of original samples

7m nadir footprint, 9m along track 'smear'

277m nadir footprint, 277m along track 'smear'

Pixel to pixel matchup

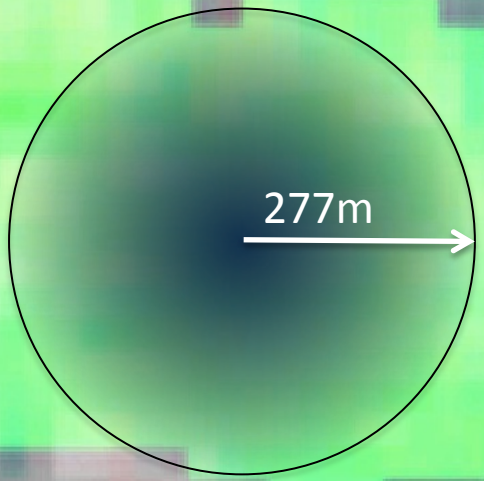


AirMSPI image north of Rosamond Lake, Feb. 6, 2013 with RSP track in green

Red: 865nm
Green: 670nm
Blue: 470nm

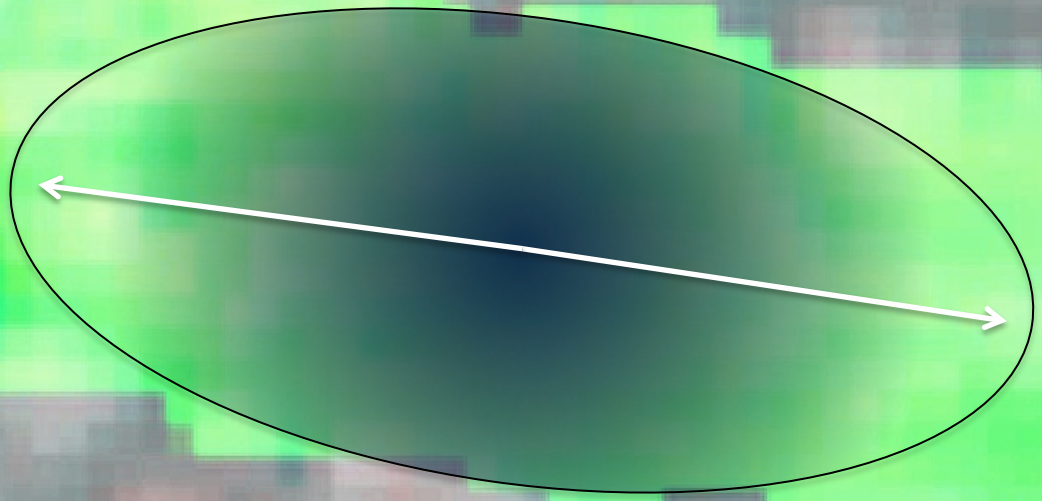
Pixel to pixel matchup

For each RSP location, create a center weighted mask for the AirMSPI image



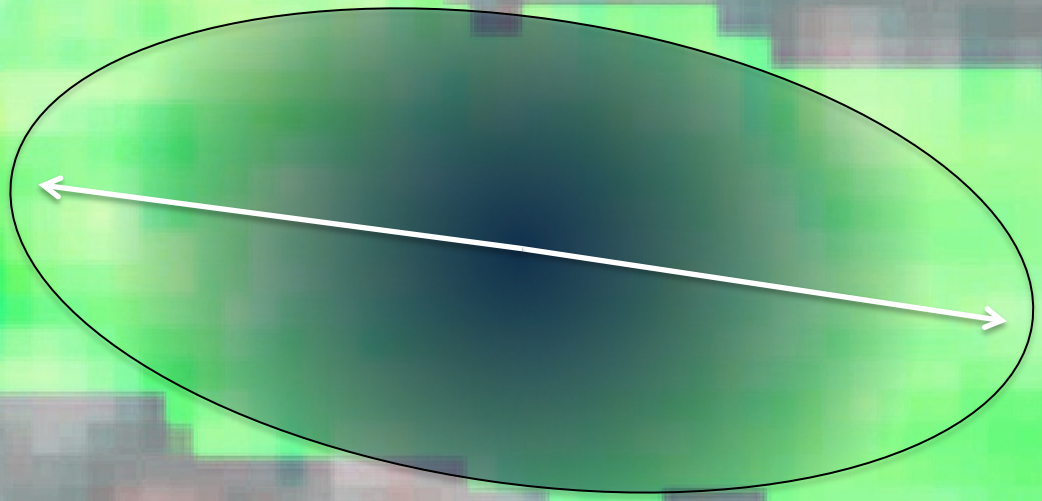
Pixel to pixel matchup

‘smear’ in the along track direction



Pixel to pixel matchup

‘smear’ in the along track direction



Update and apply this mask for all RSP pixels for comparison (also account for data quality)

AirMSPI nadir views, closest match for RSP viewing geometry

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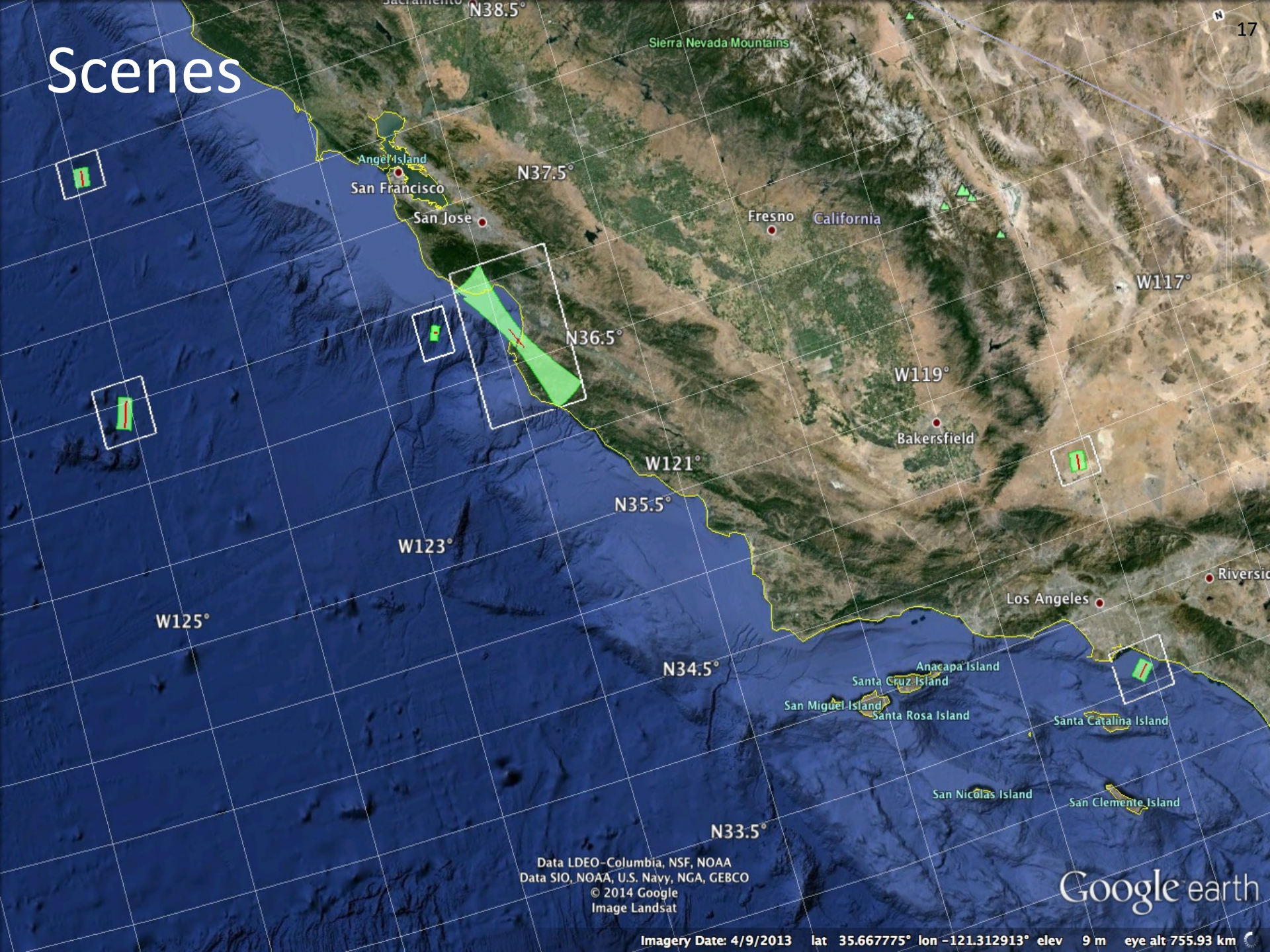
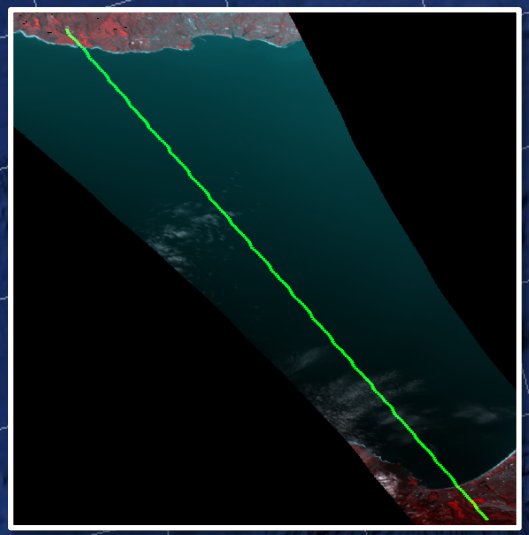
Scenes

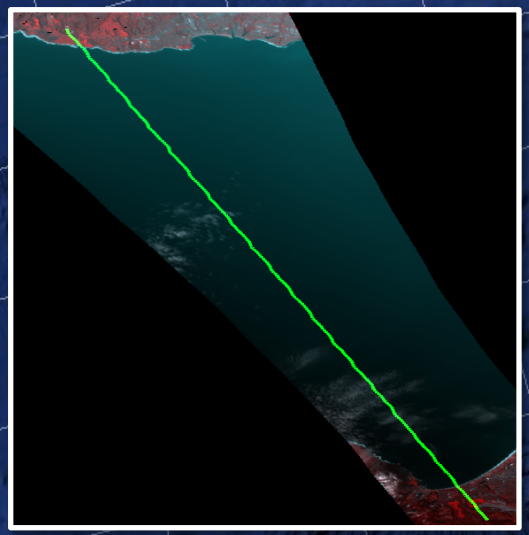

N38.5°
Sierra Nevada Mountains
Angel Island
San Francisco
N37.5°
San Jose
Fresno
California
W117°
N36.5°
W119°
Bakersfield
W121°
N35.5°
W123°
Riversid
Los Angeles
W125°
N34.5°
Anacapa Island
Santa Cruz Island
San Miguel Island
Santa Rosa Island
Santa Catalina Island
San Nicolas Island
San Clemente Island
N33.5°
Data LDEO-Columbia, NSF, NOAA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2014 Google
Image Landsat
Google earth
Imagery Date: 4/9/2013 lat 35.667775° lon -121.312913° elev 9 m eye alt 755.93 km

Scenes



Monterey Bay
Feb 3, 2013
Clear images of bay
Low reflectance
Moderate / high polarization

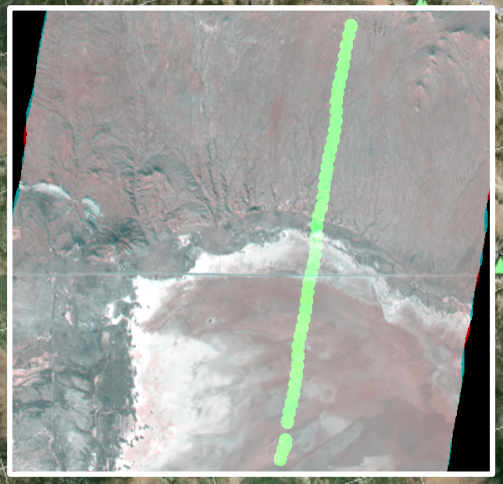
Scenes



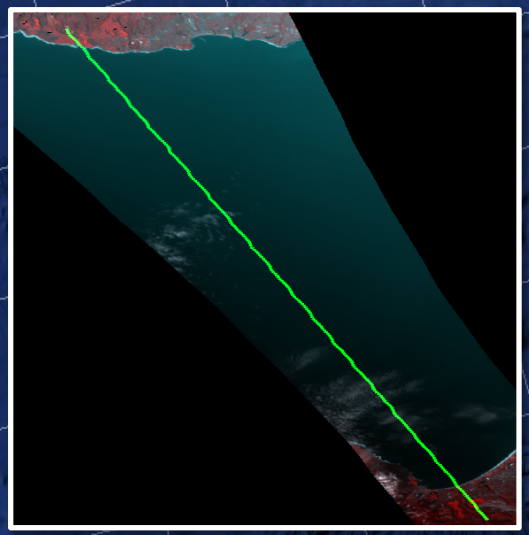
Monterey Bay
Feb 3, 2013
Clear images of bay
Low reflectance
Moderate / high polarization

Huntington Beach
Feb 6, 2013
Clear images of bay
Low ref., high pol.,
with more aerosols
AERONET site

Scenes



Rosamond
Jan 31, 2013
Dry lake bed
high ref., high pol.,
Ground MSPI data



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Feb 3, 2013
Clear images of bay
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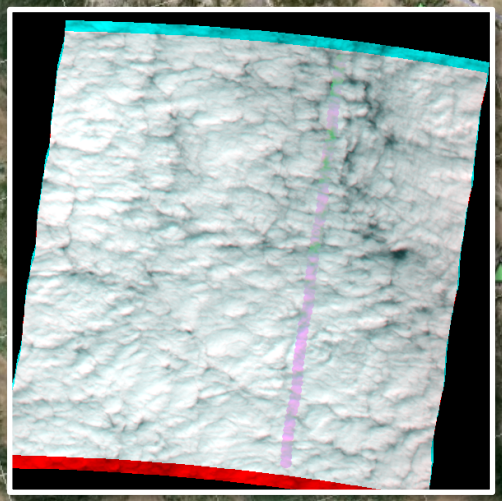
Moderate / high polarization

Huntington Beach
Feb 6, 2013
Clear images of bay
Low ref., high pol.,
with more aerosols
AERONET site

Scenes

Marine stratocumulus
Feb 3, 2013
high ref., low pol.



Rosamond
Jan 31, 2013
Dry lake bed
high ref., high pol.,
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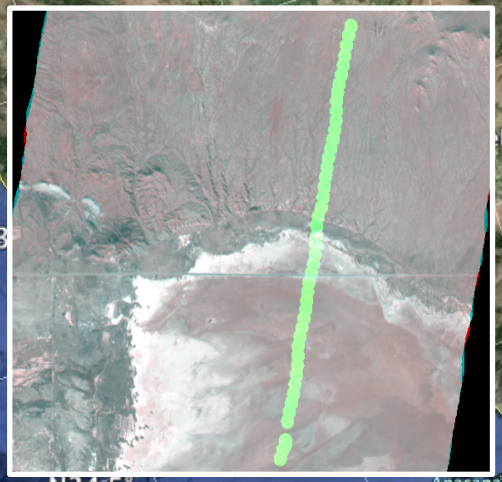

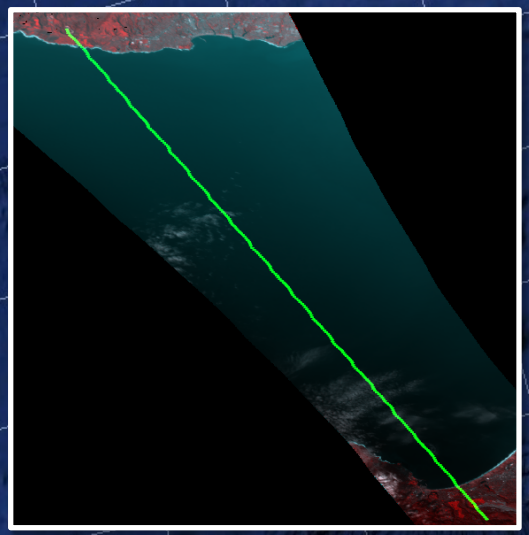

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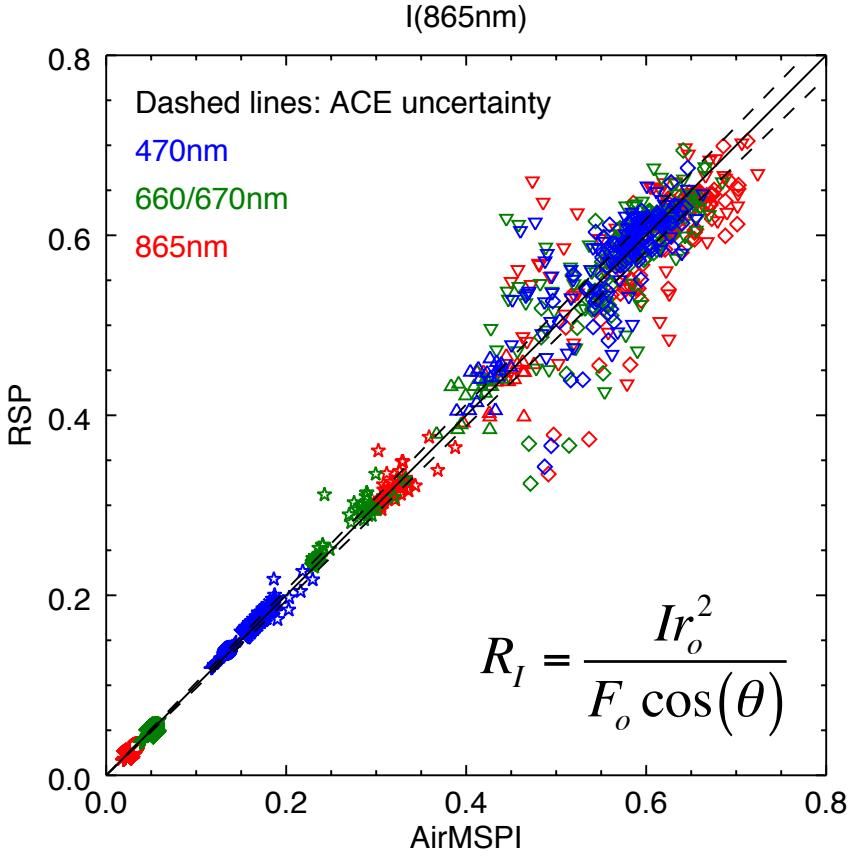
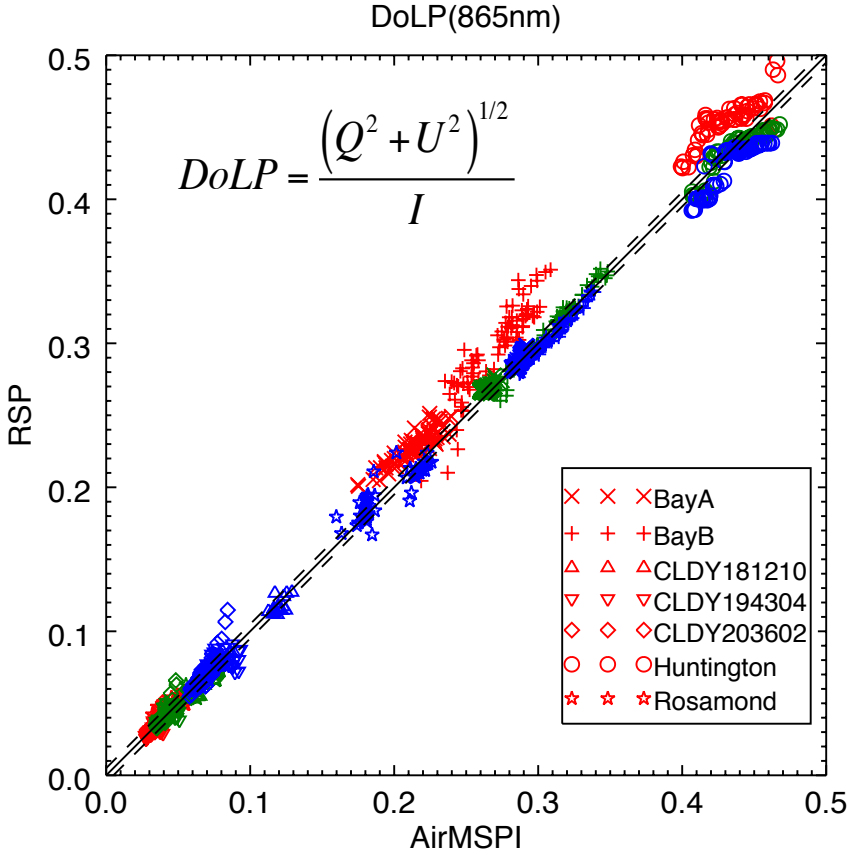
AERONET site

Direct comparison

R_I: Reflectance

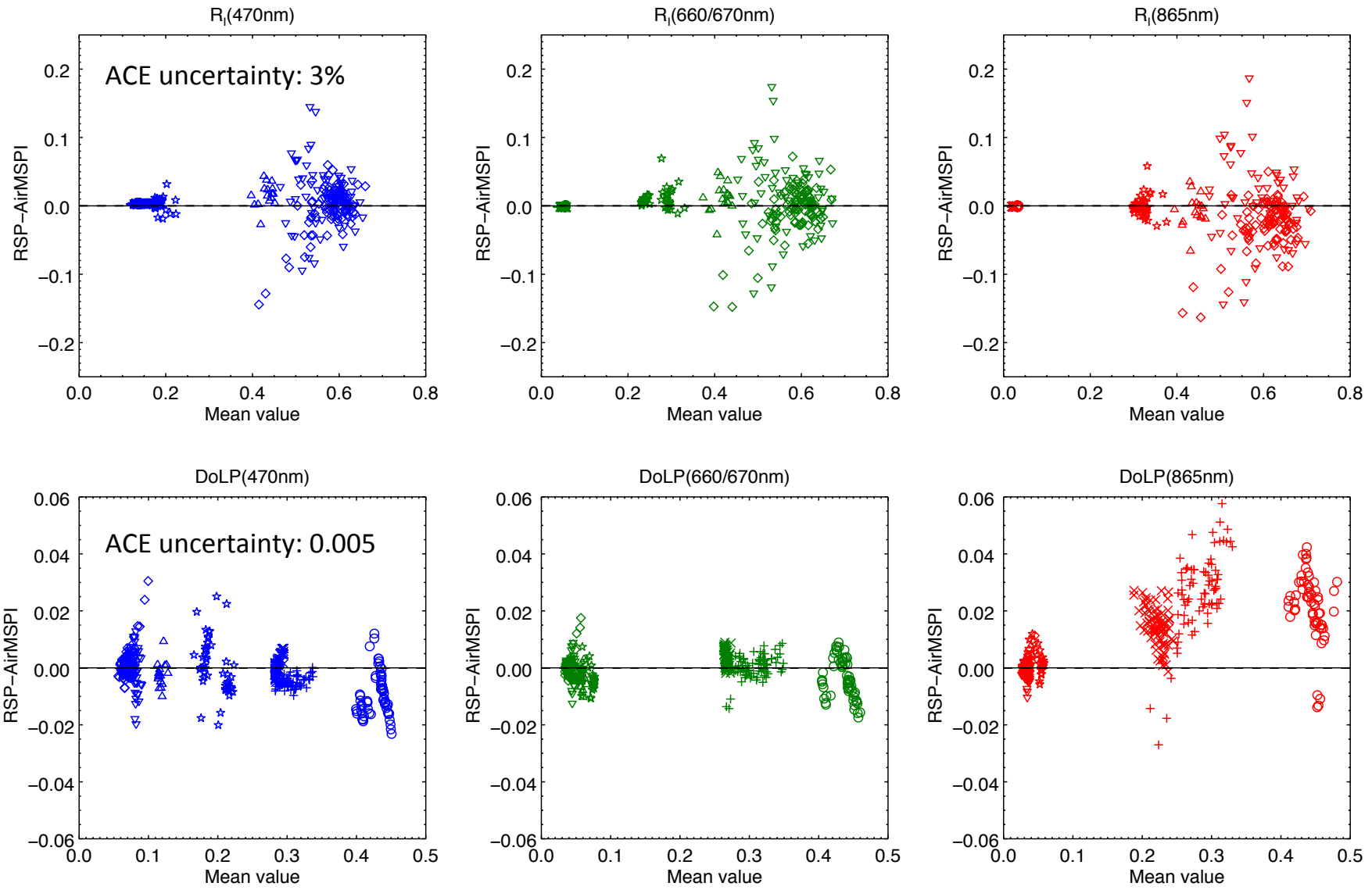


DoLP: Degree of Linear Polarization

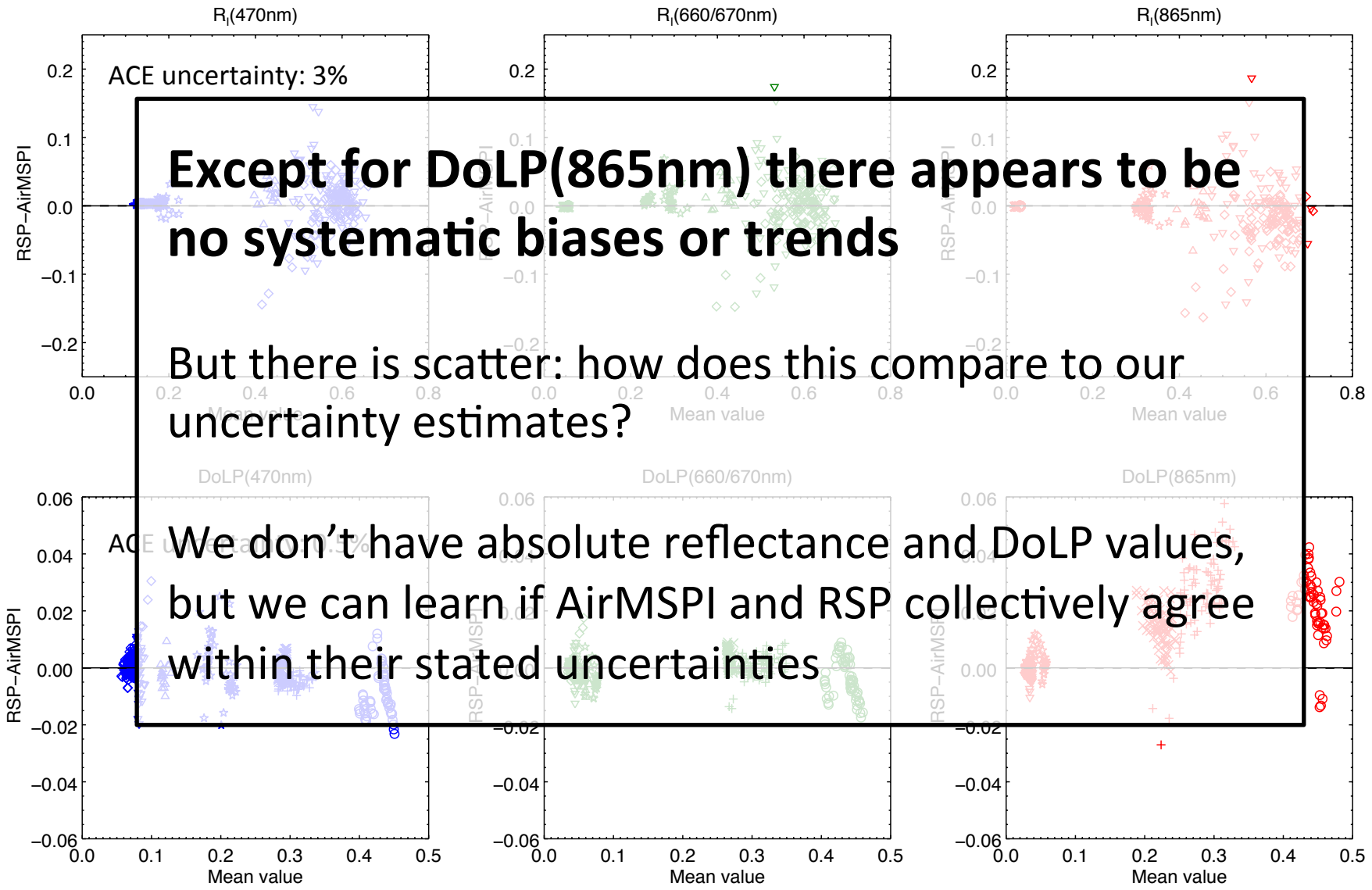


r_o – solar distance in AU; θ – Solar Zenith Angle; F_o – Solar constant.

Direct comparison



Direct comparison



Except for DoLP(865nm) there appears to be no systematic biases or trends

But there is scatter: how does this compare to our uncertainty estimates?

We don't have absolute reflectance and DoLP values, but we can learn if AirMSPI and RSP collectively agree within their stated uncertainties

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Instrument uncertainty

(models are complicated and fully described in appendix)

AirMSPI

$$\sigma^2_{R_I} = f(R_I)$$

$$\sigma^2_{DoLP} = f(R_I)$$

RSP

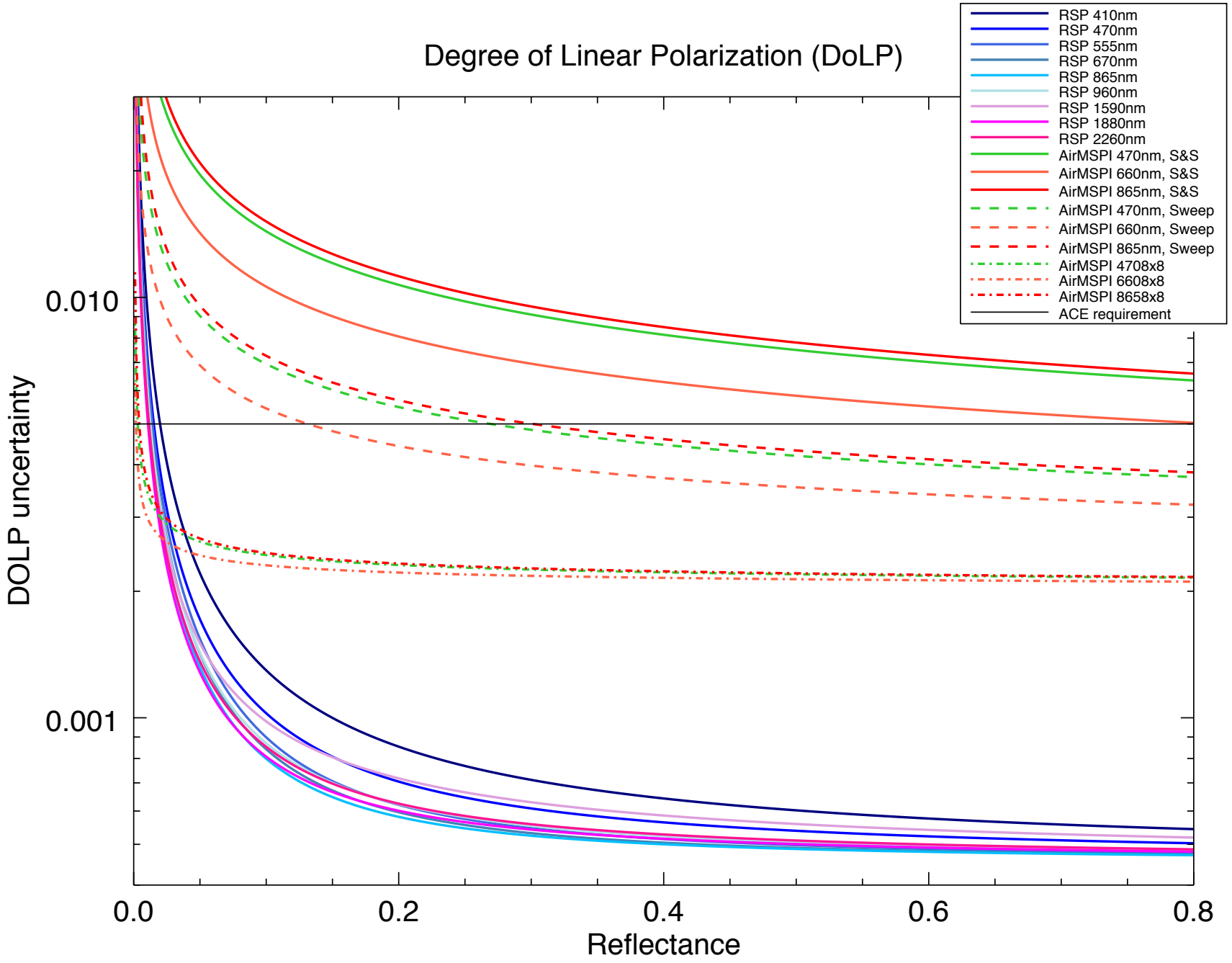
$$\sigma^2_{R_I} = f(R_I, DoLP)$$

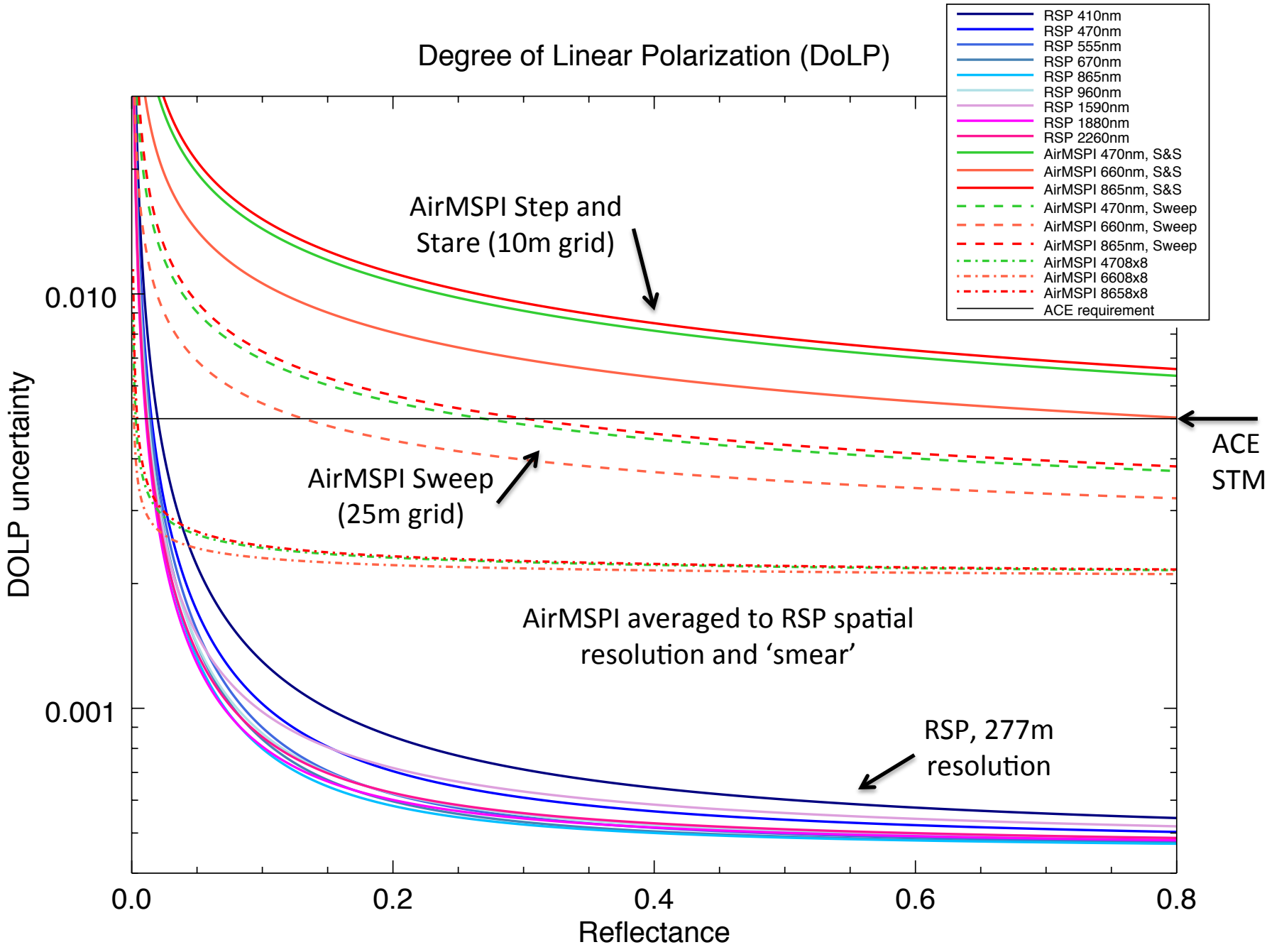
$$\sigma^2_{DoLP} = f(R_I, DoLP, \chi)$$

Adjustment for pixel averaging is addressed by multiplying by

$$\frac{1}{\sqrt{n}}$$

(this is relevant for high spatial resolution AirMSPI)


Degree of Linear Polarization (DoLP)
RSP 410nm
RSP 470nm
RSP 555nm
RSP 670nm
RSP 865nm
RSP 960nm
RSP 1590nm
RSP 1880nm
RSP 2260nm
AirMSPI 470nm, S&S
AirMSPI 660nm, S&S
AirMSPI 865nm, S&S
AirMSPI 470nm, Sweep
AirMSPI 660nm, Sweep
AirMSPI 865nm, Sweep
AirMSPI 4708x8
AirMSPI 6608x8
AirMSPI 8658x8
ACE requirement
DOLP uncertainty
0.010
0.001
0.0
0.2
0.4
0.6
0.8
Reflectance


Degree of Linear Polarization (DoLP)
RSP 410nm
RSP 470nm
RSP 555nm
RSP 670nm
RSP 865nm
RSP 960nm
RSP 1590nm
RSP 1880nm
RSP 2260nm
AirMSPI 470nm, S&S
AirMSPI 660nm, S&S
AirMSPI 865nm, S&S
AirMSPI 470nm, Sweep
AirMSPI 660nm, Sweep
AirMSPI 865nm, Sweep
AirMSPI 4708x8
AirMSPI 6608x8
AirMSPI 8658x8
ACE requirement
AirMSPI Step and Stare (10m grid)
AirMSPI Sweep (25m grid)
ACE STM
AirMSPI averaged to RSP spatial resolution and 'smear'
RSP, 277m resolution
DOLP uncertainty
0.010
0.001
0.0
0.2
0.4
0.6
0.8
Reflectance

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Normalize difference by uncertainty

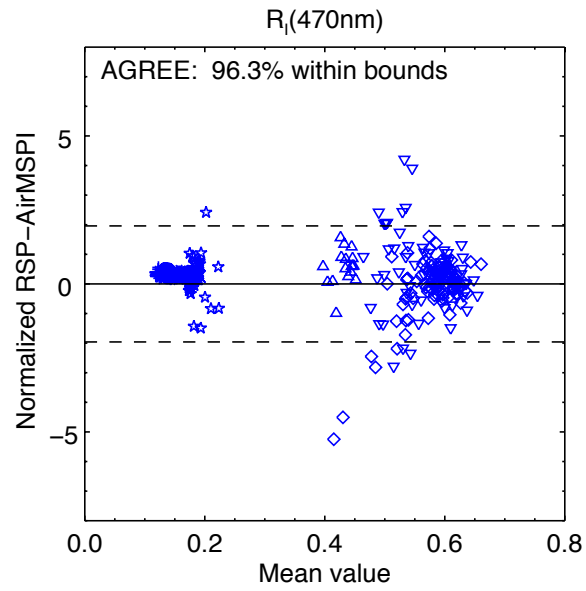
We put results into an uncertainty context…

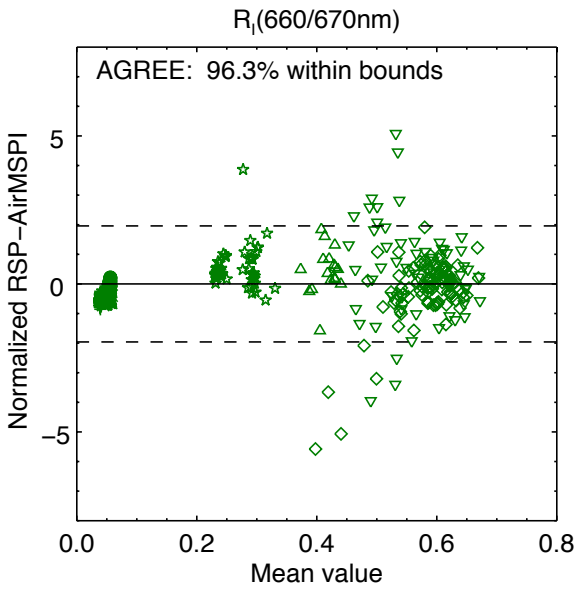
$$Difference = \frac{RSP - AirMSPI}{\sigma_{RSP} + \sigma_{AirMSPI}}$$

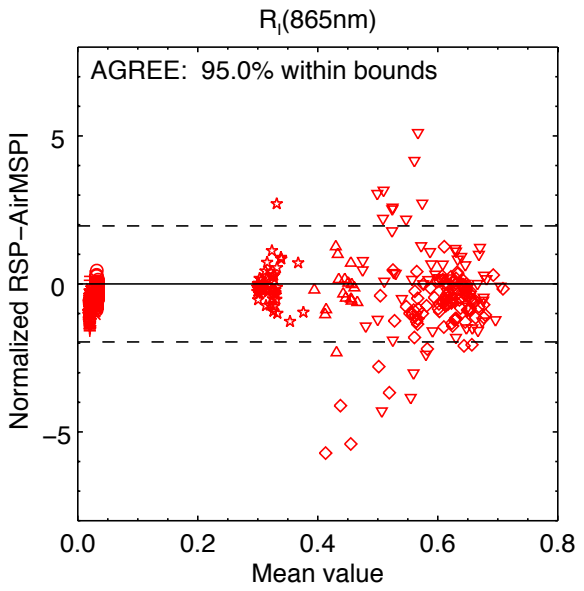
…so that differences are expressed in terms of measurement uncertainty

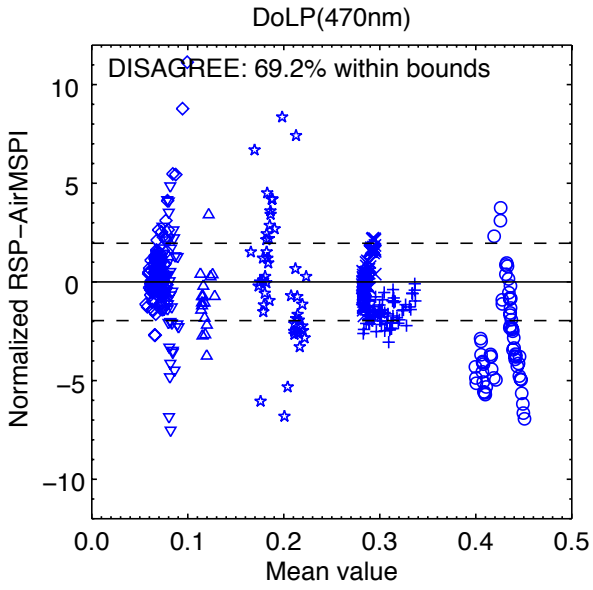
"1" means a pair of measurements are different by 1 sigma RSP + 1 sigma AirMSPI

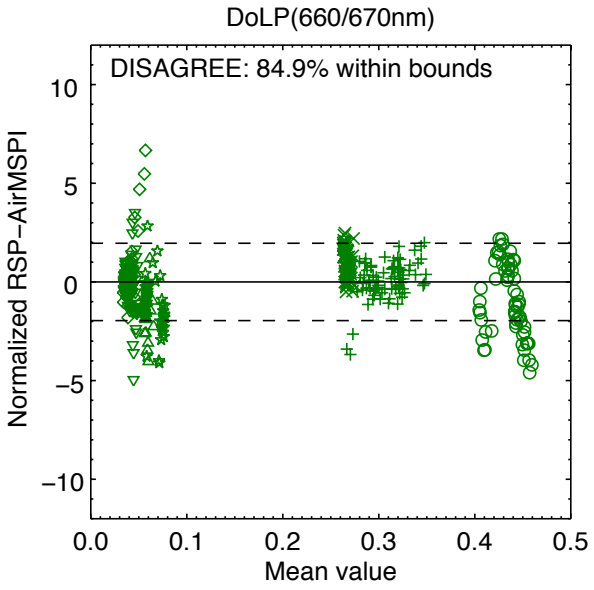
Comparison normalized by uncertainty

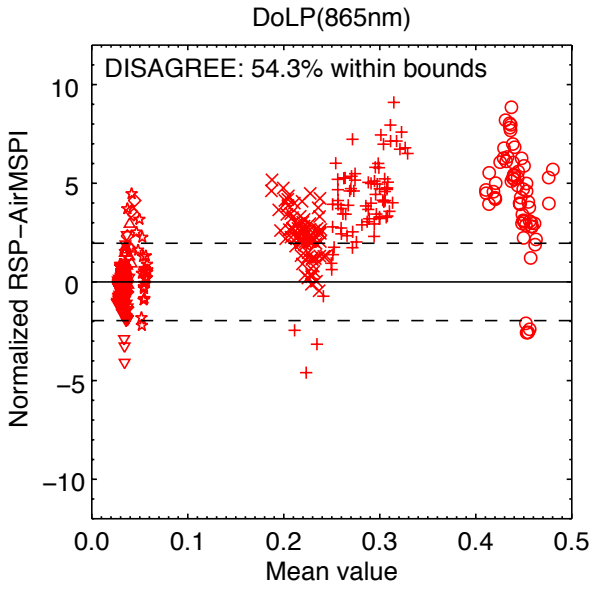




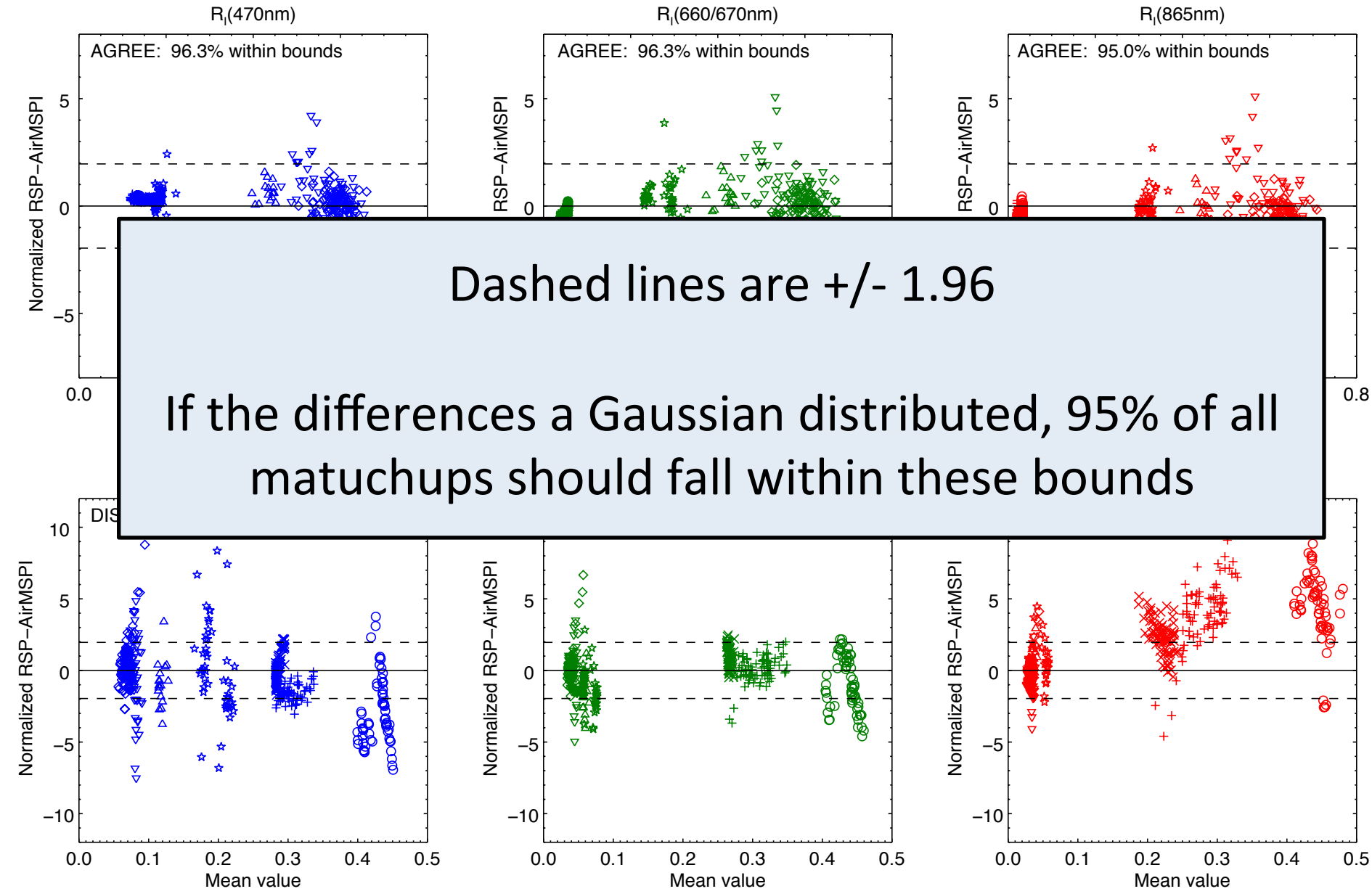




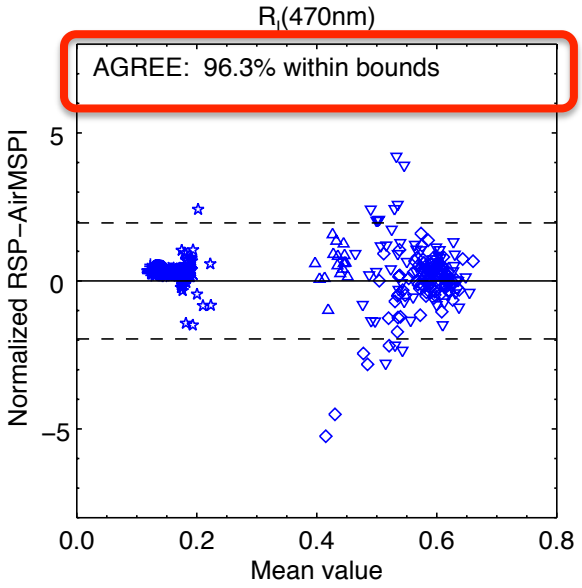


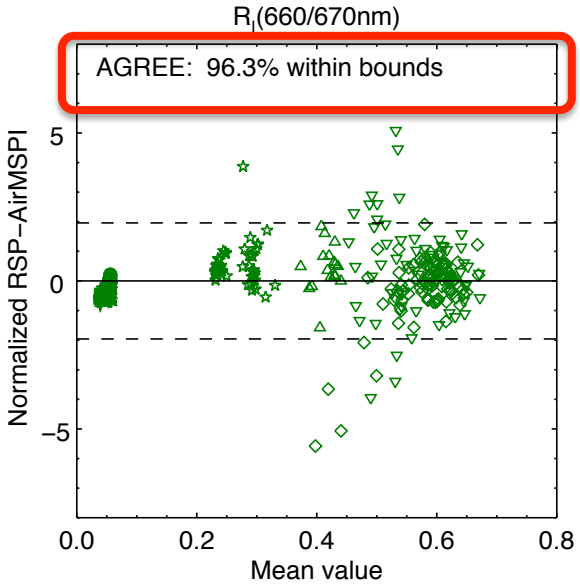


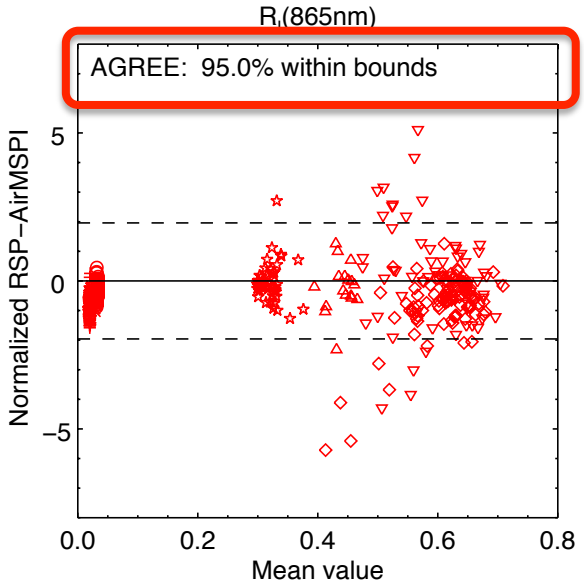
Comparison normalized by uncertainty

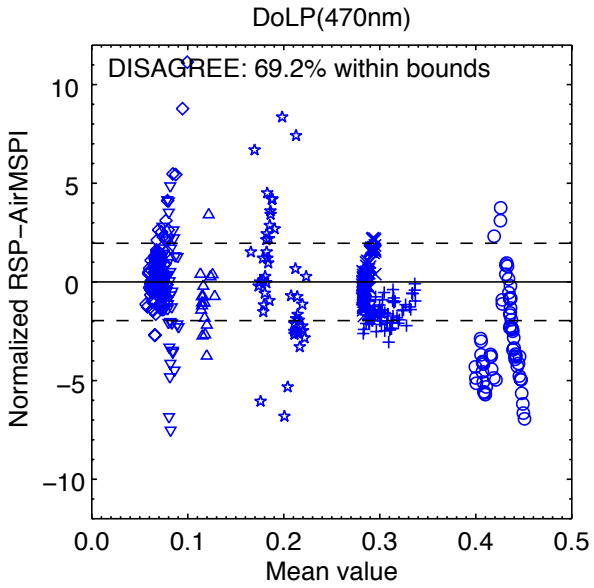


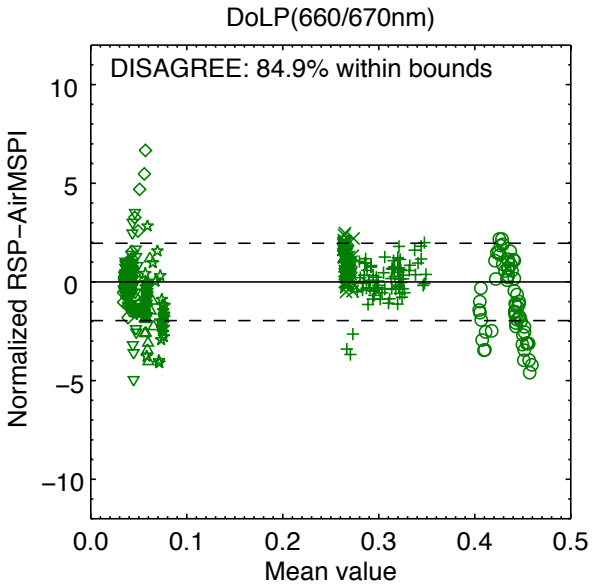
Reflectances agree as expected…

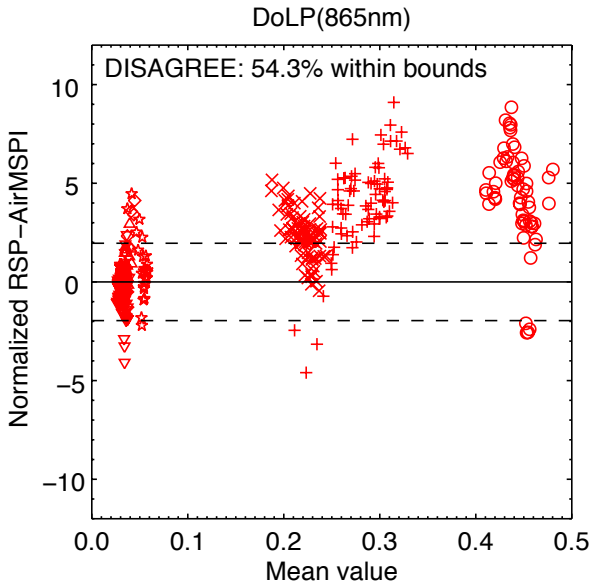




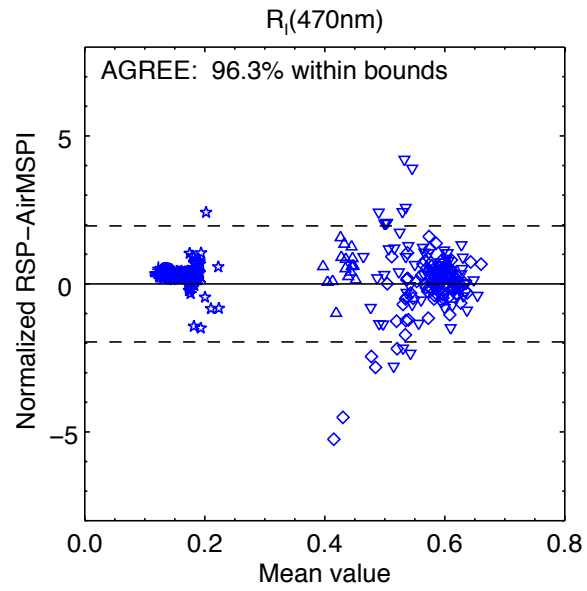


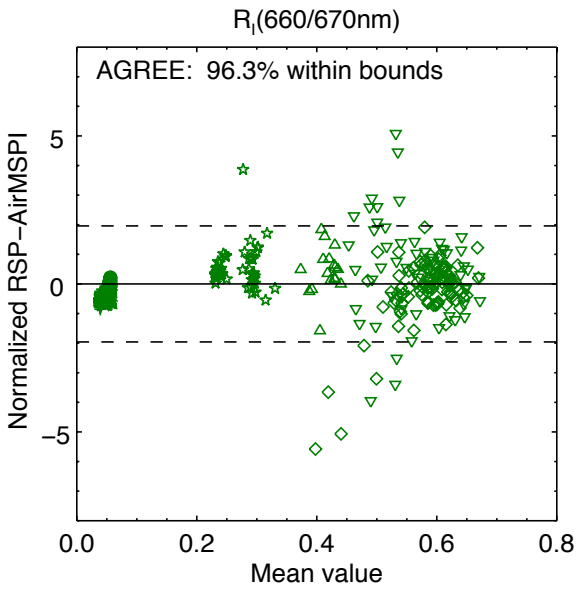


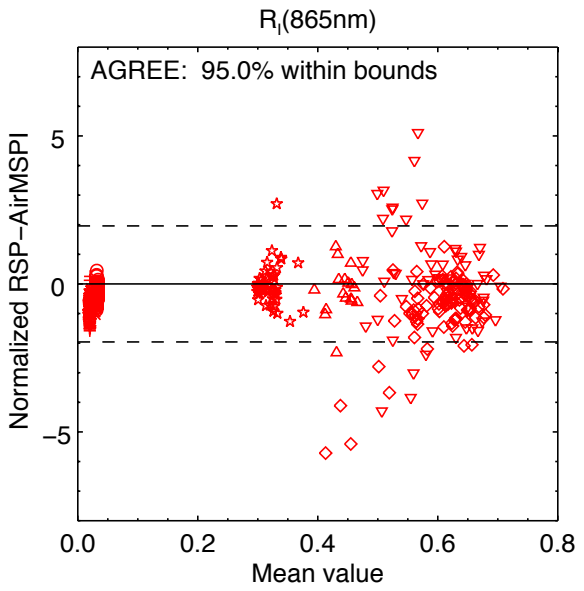


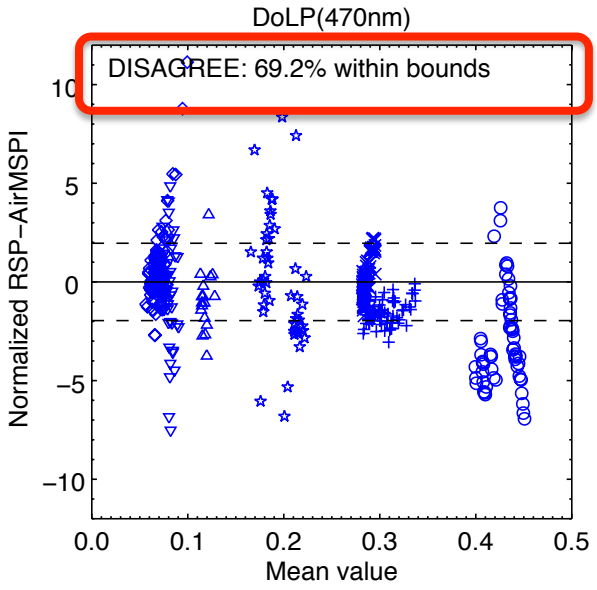


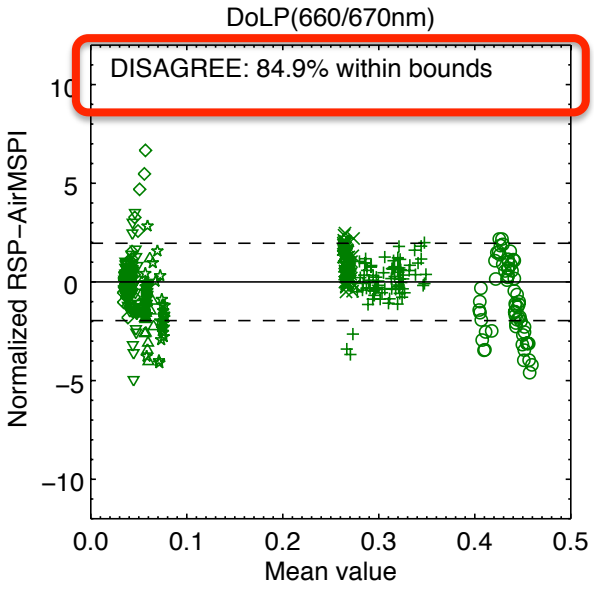
DoLP does not agree as expected

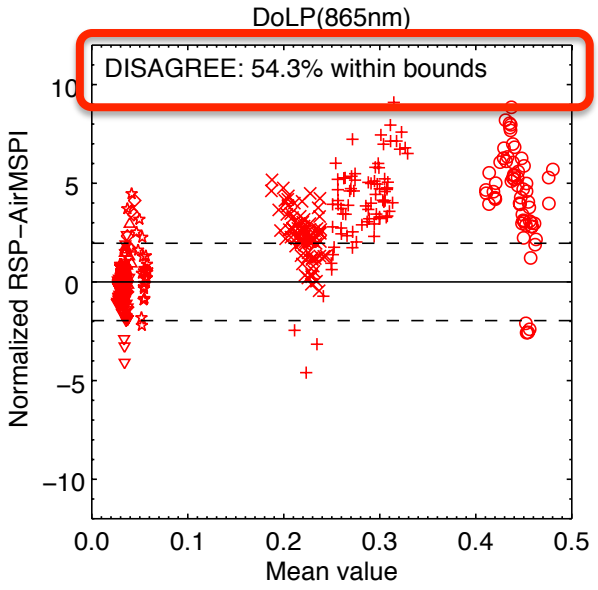




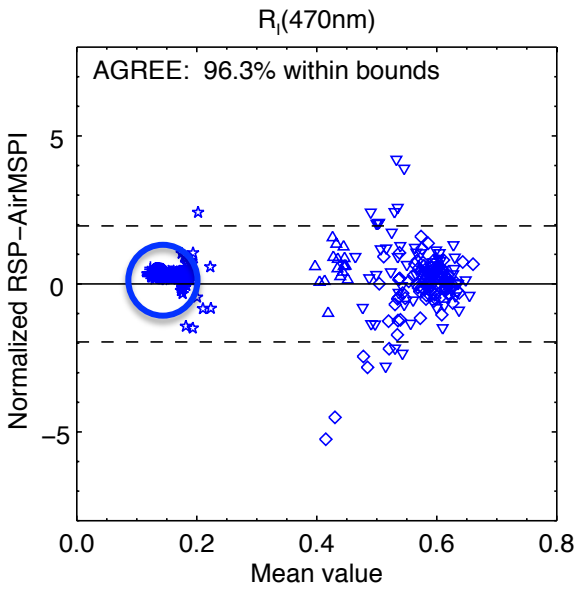


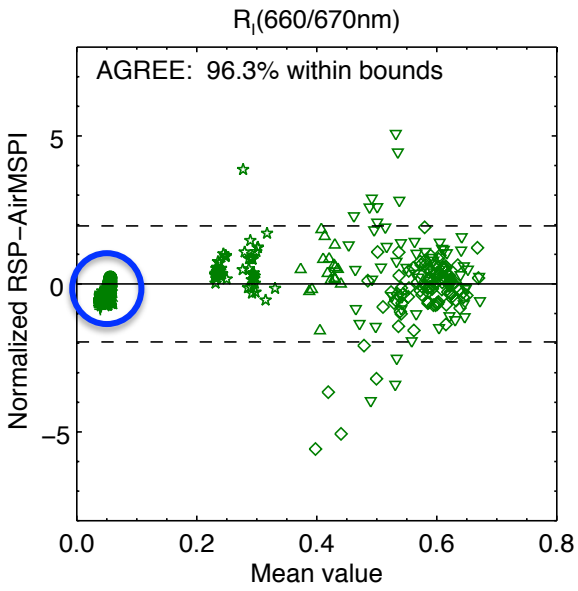


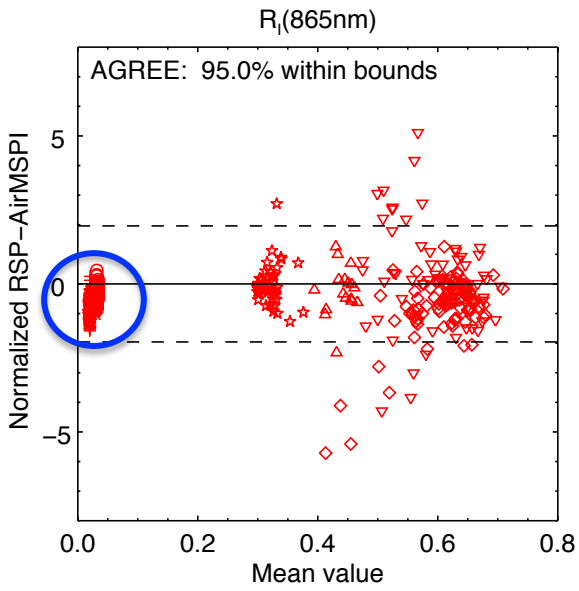


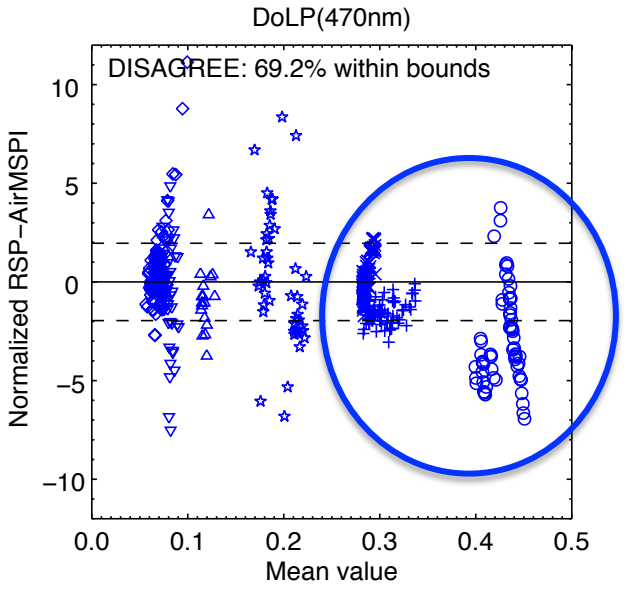


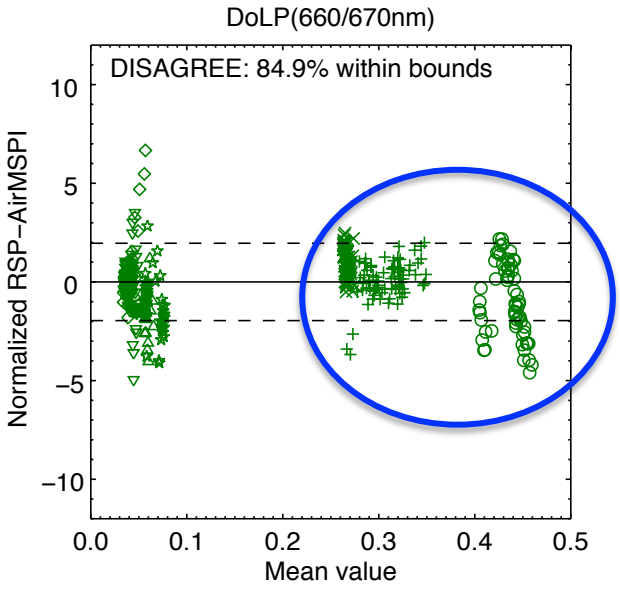
Water

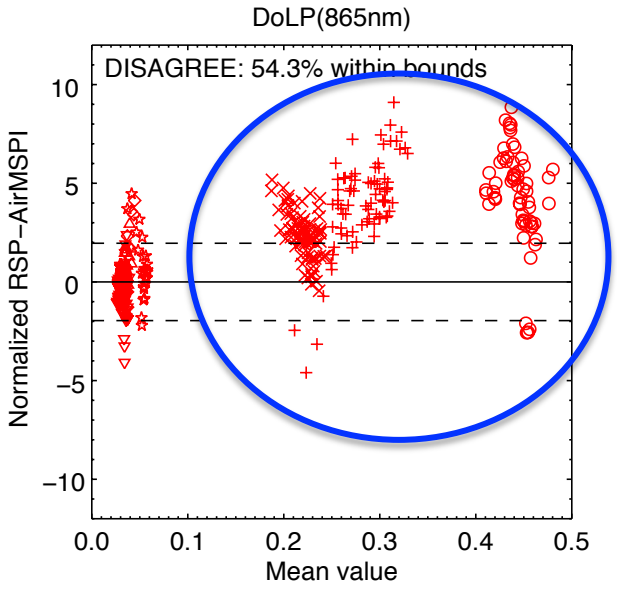

R_l(470nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value


R_l(660/670nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value

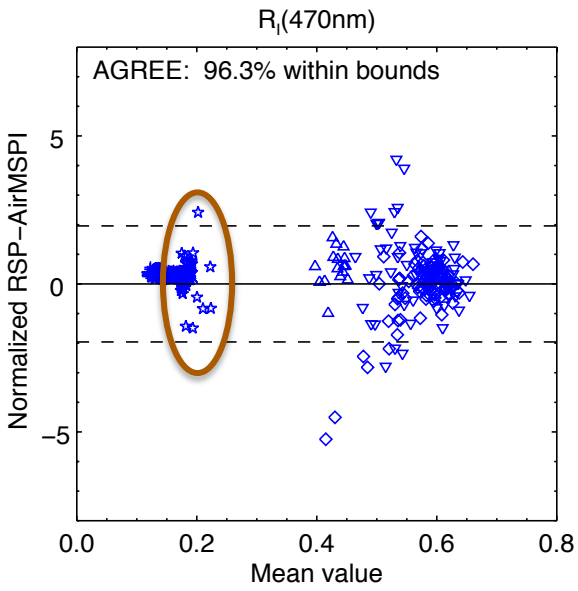

R_l(865nm)
AGREE: 95.0% within bounds
Normalized RSP−AirMSPI
Mean value

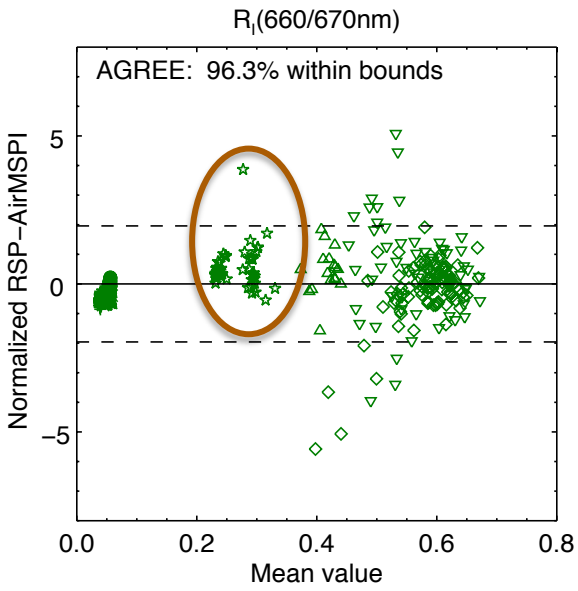

DoLP(470nm)
DISAGREE: 69.2% within bounds
Normalized RSP−AirMSPI
Mean value

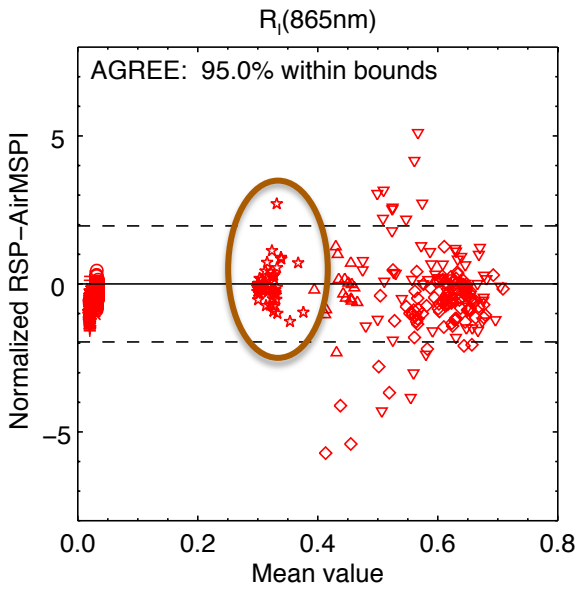

DoLP(660/670nm)
DISAGREE: 84.9% within bounds
Normalized RSP−AirMSPI
Mean value

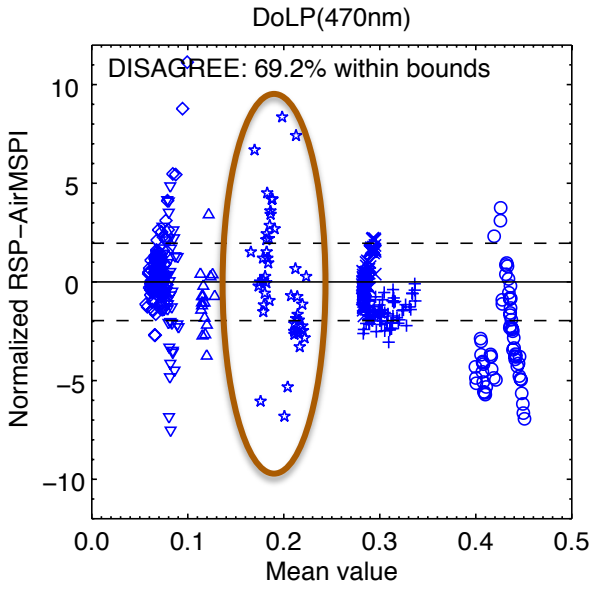

DoLP(865nm)
DISAGREE: 54.3% within bounds
Normalized RSP−AirMSPI
Mean value

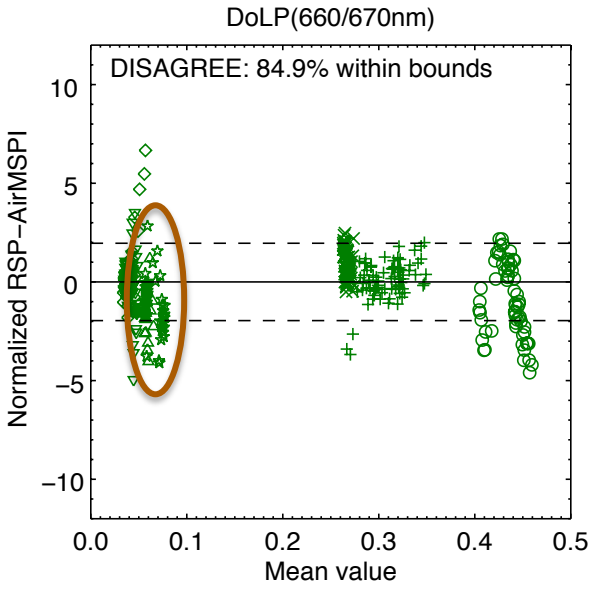
Land

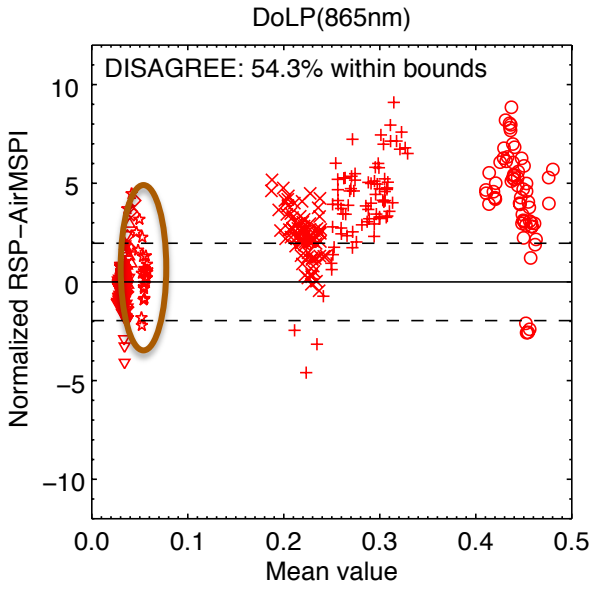

R_l(470nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value


R_l(660/670nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value

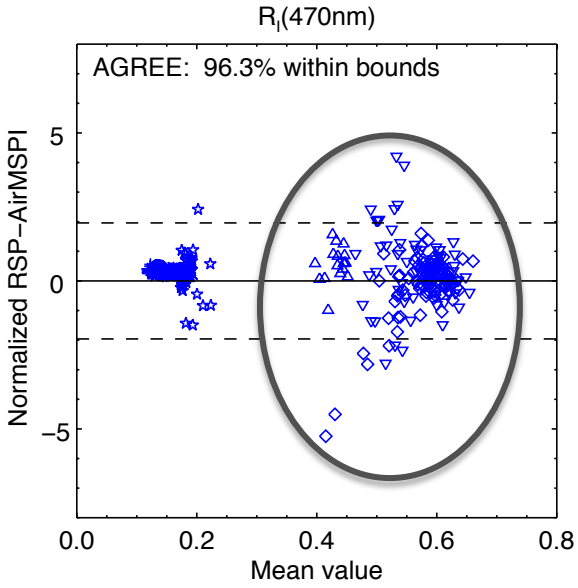

R_l(865nm)
AGREE: 95.0% within bounds
Normalized RSP−AirMSPI
Mean value

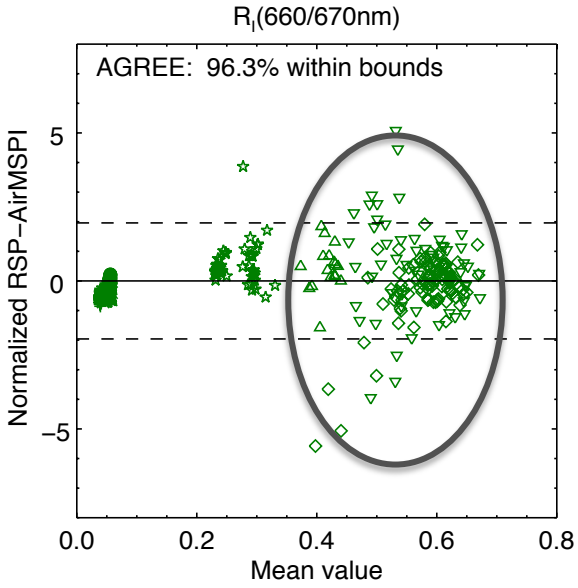

DoLP(470nm)
DISAGREE: 69.2% within bounds
Normalized RSP−AirMSPI
Mean value

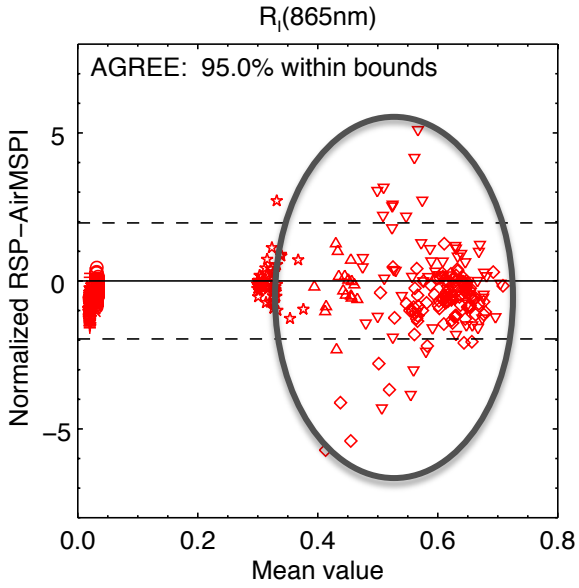

DoLP(660/670nm)
DISAGREE: 84.9% within bounds
Normalized RSP−AirMSPI
Mean value

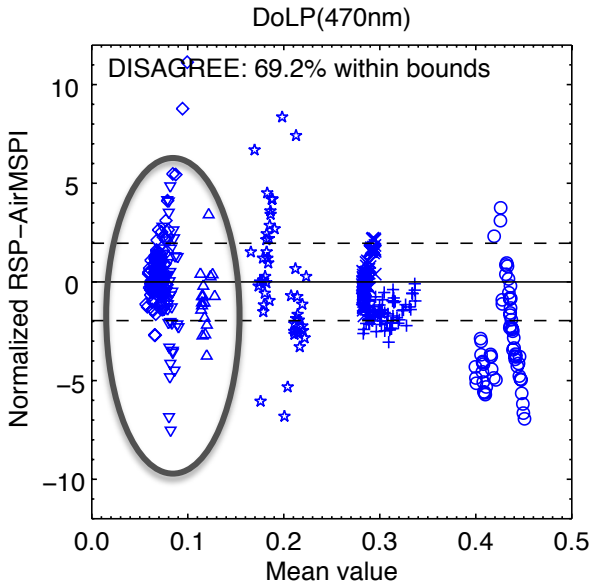

DoLP(865nm)
DISAGREE: 54.3% within bounds
Normalized RSP−AirMSPI
Mean value

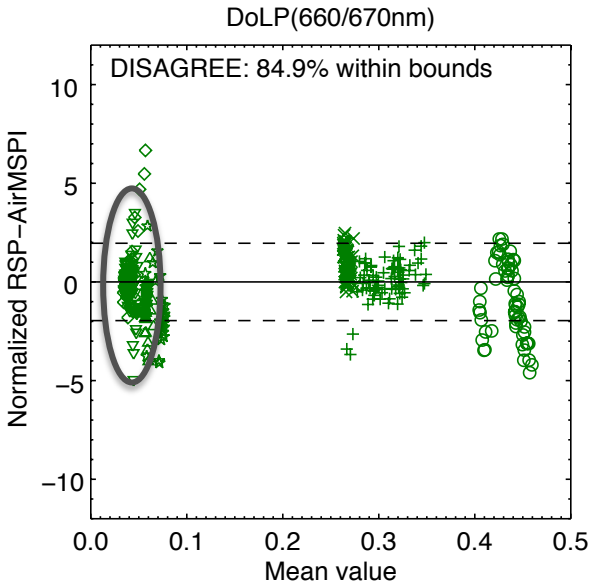
Cloud

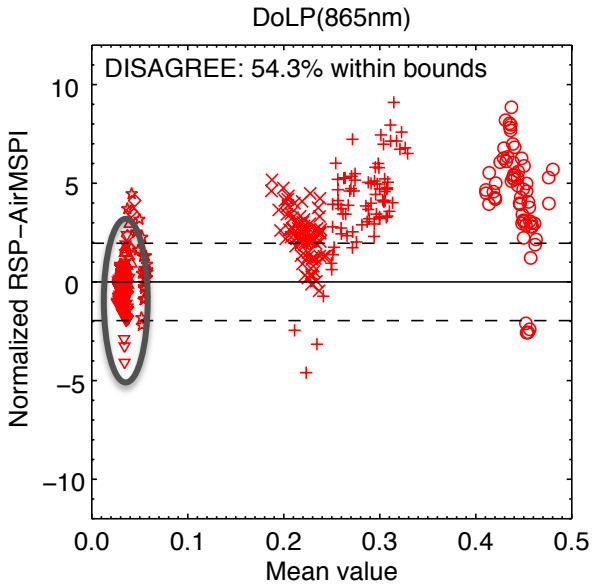

R_I(470nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value


R_I(660/670nm)
AGREE: 96.3% within bounds
Normalized RSP−AirMSPI
Mean value


R_I(865nm)
AGREE: 95.0% within bounds
Normalized RSP−AirMSPI
Mean value


DoLP(470nm)
DISAGREE: 69.2% within bounds
Normalized RSP−AirMSPI
Mean value


DoLP(660/670nm)
DISAGREE: 84.9% within bounds
Normalized RSP−AirMSPI
Mean value


DoLP(865nm)
DISAGREE: 54.3% within bounds
Normalized RSP−AirMSPI
Mean value

This comparison

CAN NOT

Indicate which instrument is ‘right’ – only that they disagree (for DoLP) greater than their uncertainty estimates

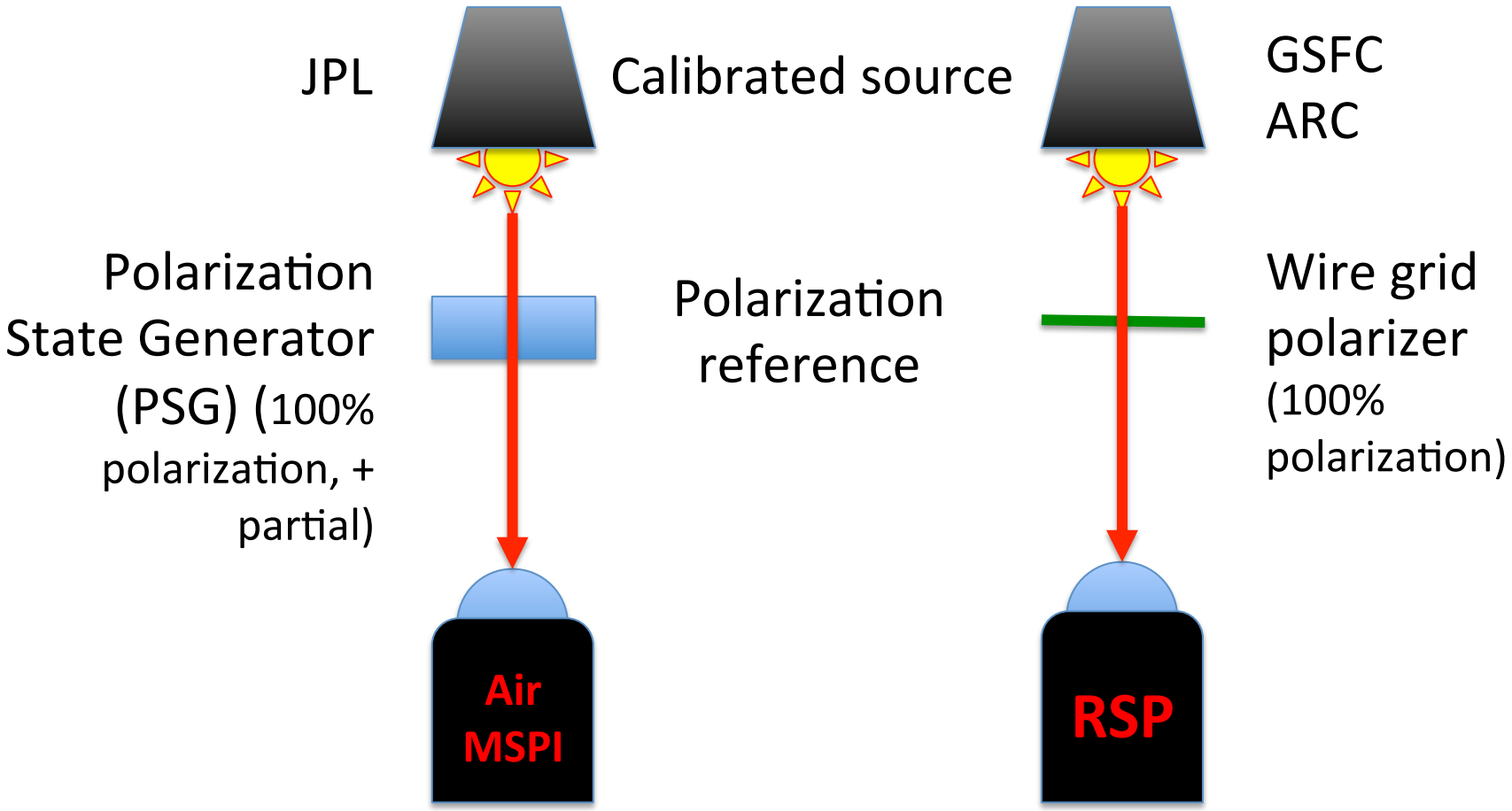
Instrument reflectance & polarization comparison

- Geolocation and wing flex
- Pixel to pixel matchup
- Comparison scenes
- Instrument uncertainty models
- Results
- **Recommendations for future efforts**

Continued analysis

- Incorporate PACS!
- Post-PODEX field campaigns:
  - SEAC4RS (AirMSPI + RSP)
  - HyspIRI (AirMSPI and sometimes RSP?)
  - For continued monitoring – how can we ensure that polarimeters are regularly deployed together?
- Suggestions of scenes and scene types?

Calibration technique



Diner, D. J., Davis, A., Hancock, B., Geier, S., Rheingans, B., Jovanovic, V., Bull, M., Rider, D. M., Chipman, R. A., Mahler, A. B., and others, 2010: First results from a dual photoelastic-modulator-based polarimetric camera. *Appl. Opt.*, 49 (15), 2929--2946.

Cairns, B., Russell, E.E., and Travis, L.D., 1999: Research Scanning Polarimeter: Calibration and Ground-based Measurements. *Proc. SPIE*.

Calibration

Should we be performing calibration comparisons?

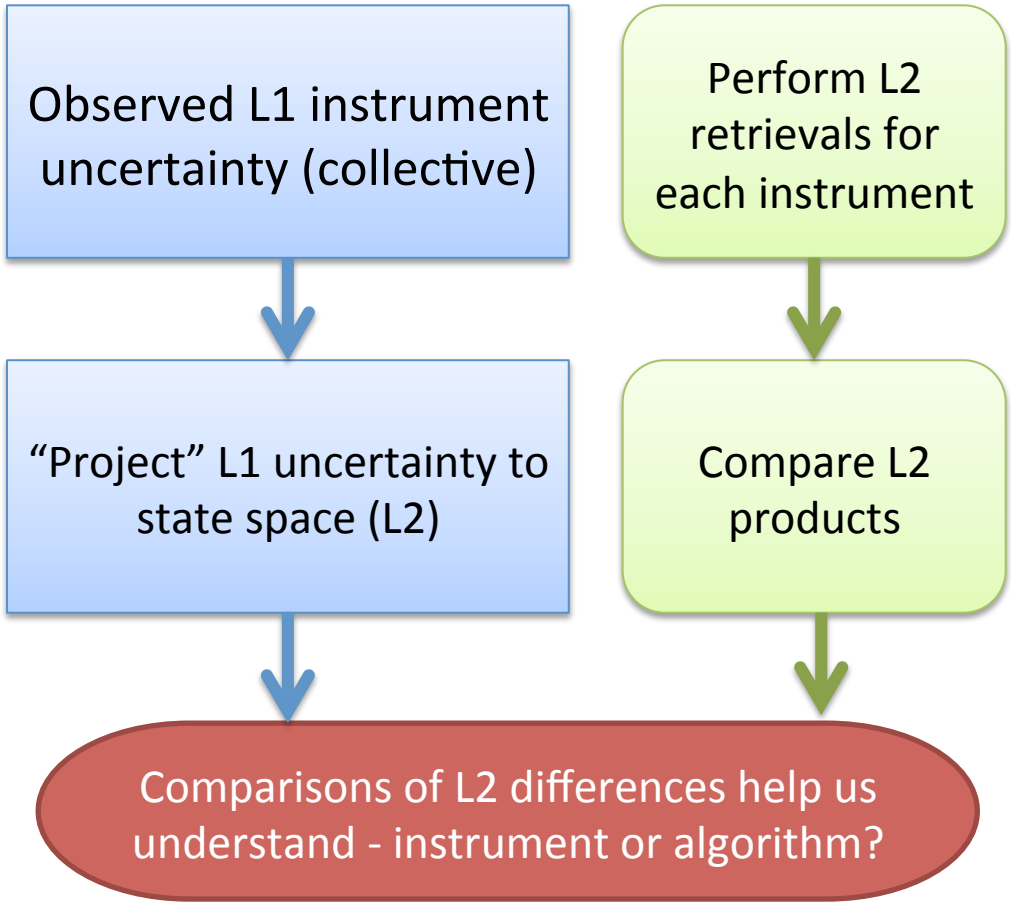
If so, what to we need to consider that is polarization specific?

Should we consider viewing angle dependence?

Can we unify the instrument uncertainty models? Are we accounting for the same sources of uncertainty in an appropriate way?

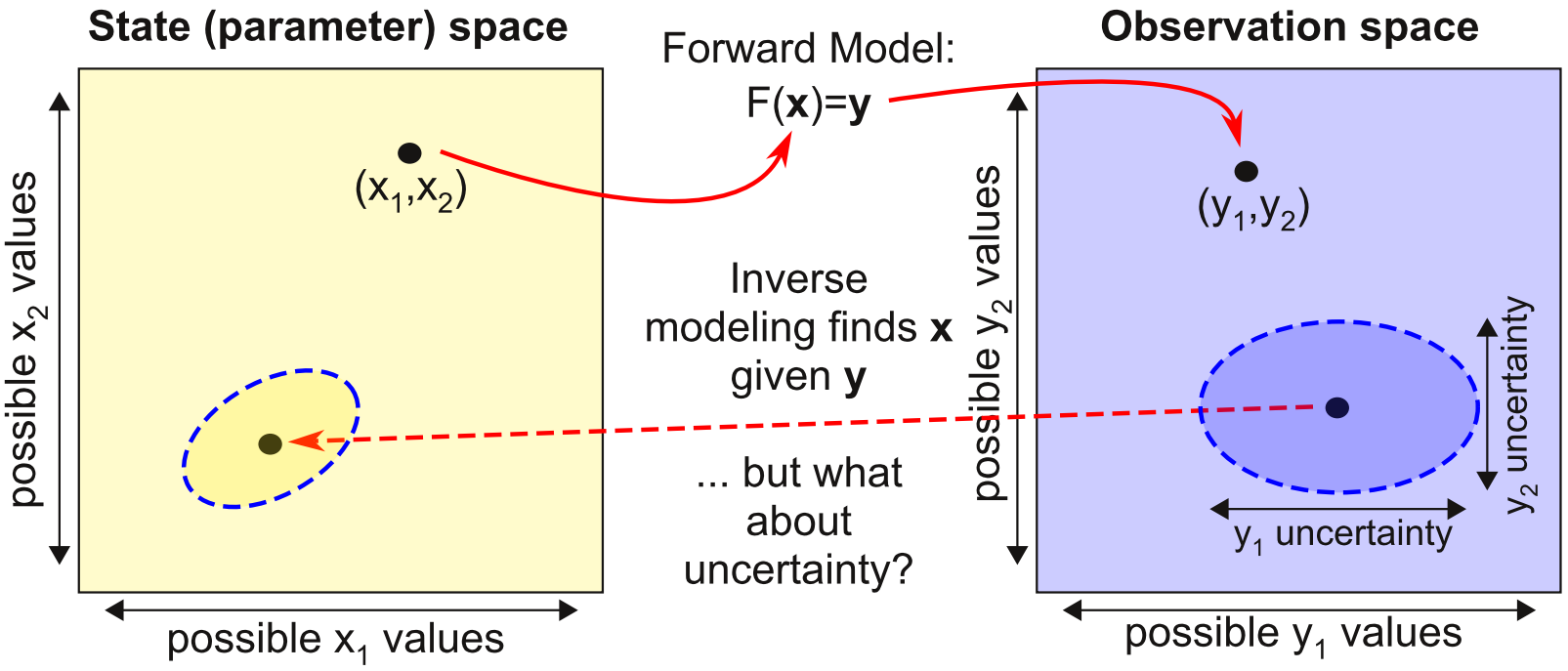
Moving from Level 1 to Level 2

- Perform Level 2 (parameter) retrievals on comparison scenes
- Compare differences in above to information content / error propagation analysis



Goal: understand if differences are due primarily to radiometry or algorithms?

"Error propagation"



Analysis of fine-mode aerosol retrieval capabilities by different passive remote sensing instrument designs

Kirk Knobelspiesse,[1,2,*] Brian Cairns,[1] Michael Mishchenko,[1] Jacek Chowdhary,[3,1] Kostas Tsigaridis,[3,1] Bastiaan van Diedenhoven,[3,1] William Martin,[3,1] Matteo Ottaviani,[1,4] and Mikhail Alexandrov[3,1]

[1]*NASA Goddard Institute for Space Studies, 2880 Broadway, New York, New York 10025, USA*
[2]*NASA Postdoctoral Program fellow, USA*
[3]*Columbia University, 2880 Broadway, New York, New York 10025, USA*
[4]*Stevens Institute of Technology, Hoboken, New Jersey, USA*
**kirk.knobelspiesse@nasa.gov*

Knobelspiesse, K., Cairns, B., Mishchenko, M., Chowdhary, J., Tsigaridis, K., van Diedenhoven, B., Martin, W., Ottaviani, M., and Alexandrov, M., 2012: Analysis of fine-mode aerosol retrieval capabilities by different passive remote sensing instrument designs. *Opt. Express*, 20 (19), 21457-21484.

Conclusions

- Wing flex: use SEAC4RS parameterization, coastline matching.
- Comparisons of AirMSPI and RSP reflectances agree within uncertainties.
- Comparisons of AirMSPI and RSP DoLP do not agree within uncertainties. 865nm is worst, 660/670nm is best.
- Results DO NOT indicate which instrument is 'right'.
- Results call for a discussion of polarimetric calibration techniques, and possible cross-calibration.
- Results call for unified ways of describing instrument uncertainty
- **This will be much better with PACS!!!**

Thank You

Results, file locations, uncertainty model can be found here (starting in July):

http://geo.arc.nasa.gov/sgg/ACEPWG/

Shameless Fall AGU session plug:

Advanced remote sensing techniques and innovative retrieval approaches for characterization of aerosol and cloud properties

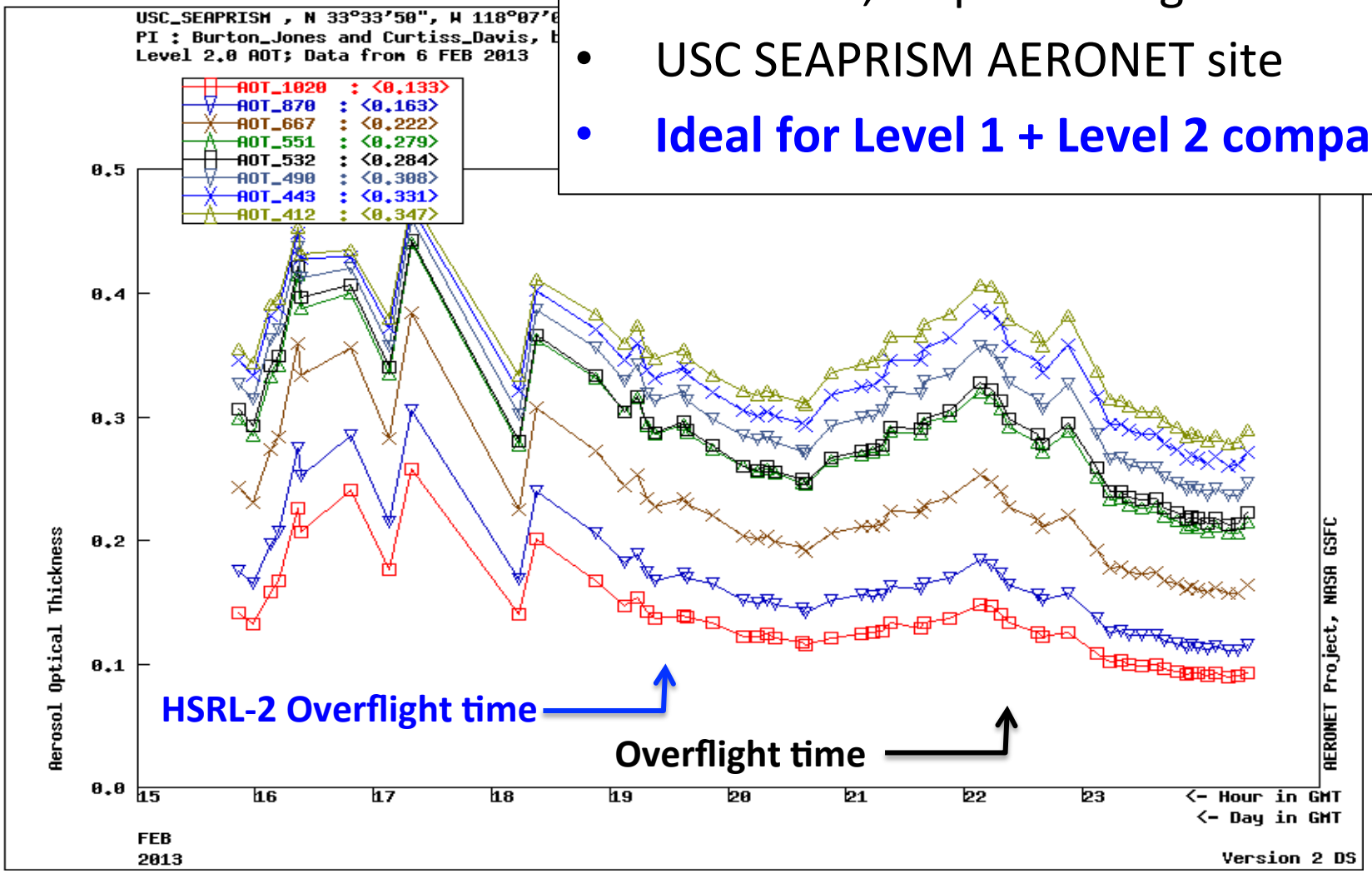
Bastiaan van Diedenhoven, Olga Kalashnikova, Kirk Knobelspiesse

Abstracts due August 6th

Huntington Beach scene

Feb. 6 Huntington Beach image:

- no clouds, LA pollution gradient
- USC SEAPRISM AERONET site
- **Ideal for Level 1 + Level 2 comparison**



Backup slides

RSP uncertainty model

$$\sigma_{R_I}^2 = \left(\frac{r^2 \sigma'_{floor}}{\mu_s} \right)^2 + \frac{a' R_I r^2}{2\mu_s} + \frac{\sigma_{\ln K}^2 R_P^2}{16} + \sigma_{\alpha_c}^2 R_I^2$$

$$\sigma_{DoLP}^2 = 4\left(1 + \frac{DoLP^2}{2}\right)\left(\frac{r^2 \sigma'_{floor}}{\mu_s R_I}\right) + 2\left(1 - \frac{DoLP^2}{2}\right)\frac{a' r^2}{\mu_s R_I}$$

$$+ \frac{\sigma_{\ln K}^2}{2}\left[1 - DoLP^2 + \frac{DoLP^4}{2}\left(1 - \frac{\sin^2 4\chi}{2}\right)\right] + \sigma_{\ln \alpha}^2 DoLP^2$$

r	solar distance in AU
σ'_{floor}	detector noise floor
μ_s	cosine of Solar Zenith Angle
a’	shot noise parameter
σ_{lnK}	relative gain coefficient characterization uncertainty
$\sigma_{\alpha c}$	absolute radiometric characterization uncertainty
σ_{lna}	Polarimetric calibration uncertainty

AirMSPI uncertainty Model

$$SNR = \frac{S}{\left(1.25S + r^2 f\right)^{1/2}}$$

$$S = \frac{1.408x10^{18}\,\xi\eta\Lambda}{\lambda^4 e^{\left(\frac{2489.7}{\lambda}-1\right)}}$$

$$\sigma_{R_I}^2 = R_I^2\left(\sigma_{Rcal}^2 + SNR^{-2}\right)$$

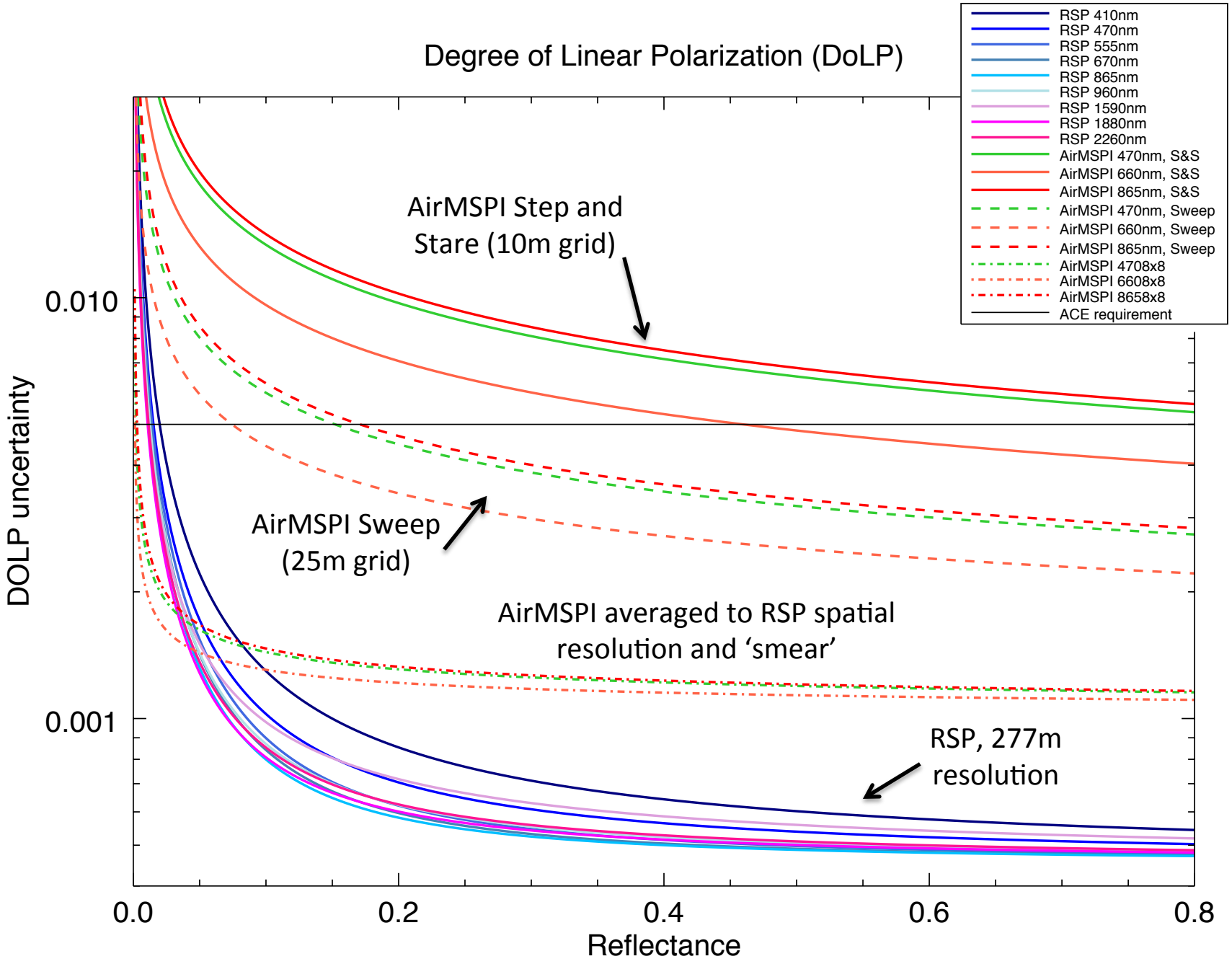
$$\sigma_{DoLP}^2 = \sigma_{PolCal}^2 + s^2 SNR^{-2}$$

SNR	signal to noise ratio
S	signal in electrons
r	read noise (9 electrons)
f	# subframes / image (23)
ξ	optical throughput
η	detector quantum efficiency
Λ	bandpass
λ	band center wavelength
σ	Radiometric calib. uncertainty
σ	Polarimetric calib. uncertainty

Diner, D.J., A. Davis, B. Hancock, G. Gutt, R.A. Chipman, and B. Cairns (2007). Dual-photoelastic-modulator-based polarimetric imaging concept for aerosol remote sensing. *Appl. Opt*. **46**, 8428-8445.

Diner, D.J., F. Xu, M.J. Garay, J.V. Martonchik, B.E. Rheingans, S. Geier, A. Davis, B.R. Hancock, V.M. Jovanovic, M.A. Bull, K. Capraro, R.A. Chipman, and S.C. McClain (2013). The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI): a new tool for aerosol and cloud remote sensing": *AMT* **6**, 2007-2025.

If AirMSPI calibration uncertainty is 0.001, not 0.002…


Degree of Linear Polarization (DoLP)
RSP 410nm
RSP 470nm
RSP 555nm
RSP 670nm
RSP 865nm
RSP 960nm
RSP 1590nm
RSP 1880nm
RSP 2260nm
AirMSPI 470nm, S&S
AirMSPI 660nm, S&S
AirMSPI 865nm, S&S
AirMSPI 470nm, Sweep
AirMSPI 660nm, Sweep
AirMSPI 865nm, Sweep
AirMSPI 4708x8
AirMSPI 6608x8
AirMSPI 8658x8
ACE requirement
AirMSPI Step and Stare (10m grid)
AirMSPI Sweep (25m grid)
AirMSPI averaged to RSP spatial resolution and 'smear'
RSP, 277m resolution
DOLP uncertainty
0.010
0.001
0.0
0.2
0.4
0.6
0.8
Reflectance

Comparison normalized by uncertainty