GAW Report No. 231

Fourth WMO Filter Radiometer Comparison (FRC-IV)

(Davos, Switzerland, 28 September - 16 October 2015)

WEATHER CLIMATE WATER

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Fourth WMO Filter Radiometer Comparison (FRC-IV)

(Davos, Switzerland, 28 September – 16 October 2015)

Prepared by

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at:
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1. INTRODUCTION

Aerosol optical depth (AOD) is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between an observation point and the top of the atmosphere. It is a measure of the integrated columnar aerosol load and the most important parameter for direct radiative forcing studies. AOD is not directly measurable but retrieved from observations of the spectral transmission of the atmosphere. AOD measurements are performed with sun-pointing direct beam instruments, or with simultaneous global and diffuse measurements. The World Meteorological Organization (WMO, 1986) recommends measuring at least at 3 of the following center wavelengths: 368, 412, 500, 675, 778, 862 nm, with a bandwidth of 5 nm. The field-of-view geometry for direct beam radiometers should correspond to the WMO (1986) specifications of a full opening angle of 2.5° and a slope angle of 1°.

Different instruments from different global and national networks, but also independent instrumentation, measure the direct irradiance and the aerosol related attenuation. In 2006, the Commission for Instruments and Methods of Observations (CIMO, 2007) recognized "the need for establishing a primary reference AOD Centre to satisfy the need for traceability of Optical Depth measurements, conducting international intercomparisons, guaranteeing data quality needed in climate studies". It was recommended that the World Optical Depth Research and Calibration Centre (WORCC) at the Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC) be designated the primary WMO Reference Centre for AOD measurements as part of WRC activities (WMO, 2006).

The quality of AOD data from intercomparisons can be evaluated by applying the WMO criteria discussed in WMO Global Atmosphere Watch (GAW) Report No. 162 (WMO, 2005). According to these criteria, the ability to trace the calibration to a primary reference is not currently possible based on physical measurement systems, so the initial form of traceability is based on difference criteria. In this case, an intercomparison or co-location traceability is established if the AOD difference between networks is within specified limits. The definition of these limits depends on the method of measurement used. For finite field-of-view instruments the limit ("U95") is defined as follows for air mass m:

$$U95 < \pm(0.005+0.010/m) \qquad (1)$$

Where the first term of the formula (0.005), accounts for instrumental and algorithmic uncertainties, while the second term represents the uncertainty related to the calibration of each instrument. The latter corresponds to a requirement for the relative uncertainty in the instrument calibration to be less than 1 %.

The Fourth Filter Radiometer Comparison (FRC-IV) was held concurrently with the 12th International Pyrheliometer Comparison (IPC-XII) in Davos, Switzerland. Instrumentation belonging to different AOD global networks were invited. The comparison took place at the premises of PMOD/WRC from 28 September – 16 October 2015. Thirty filter radiometers and spectroradiometers from 12 countries participated in this campaign.

The objective of this campaign was to compare different instruments belonging to different global or national networks in order to quantify the main factors that are responsible for possible deviations. The aim of the whole activity was to initiate action towards homogenization of the AOD measurements on a global scale. The comparison protocol was formulated according to the WMO recommendations. Measurements of each instrument were compared to the WORCC Precision Filter Radiometer (PFR) triad.

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2. SET UP AND MEASUREMENTS

2.1 Location and conditions

PMOD/WRC (46° 49′ N, 9° 51′ E, 1590 m above sea level) is situated at the edge of the small town of Davos in the eastern part of Switzerland. The valley of Davos runs East – West and in autumn the horizon limits solar observations to zenith angles smaller than about 78° (from about 7:15 to 16:15 hours CET). The average sunshine duration in September and October is 173 and 156 hours, respectively, and the average AOD is 0.055 for 500nm.

The FRC-VI comparison lasted for 19 days from 28 September to 16 October 2015. During this period there were five days (28, 29, 30 of September, 1 and 12 of October) with sunshine and only very limited presence of clouds. Measurements from these days have been used for comparing the participating instruments.

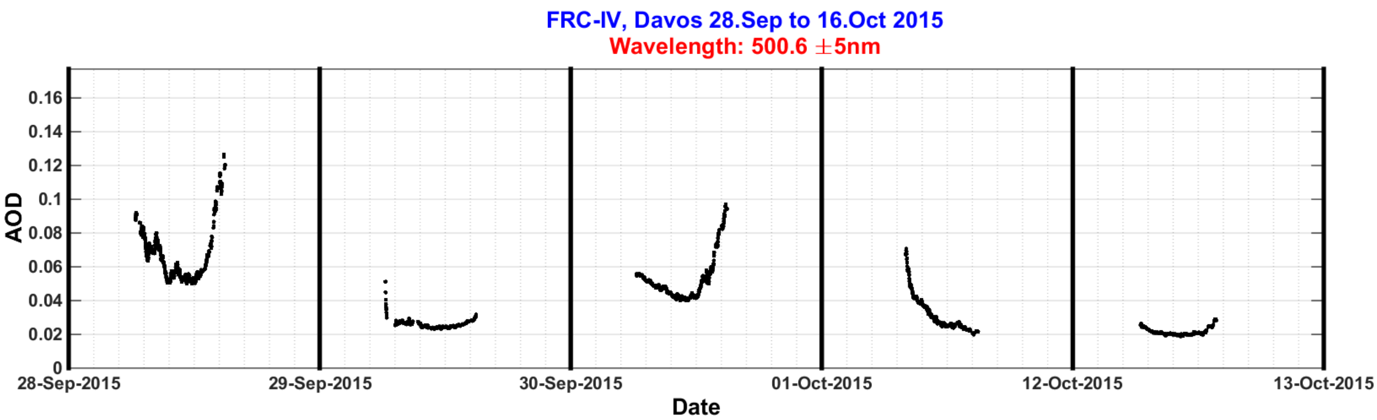

Figure 1. Average AOD at 500nm measured from the WORCC triad. The symbols represent one-minute measurements.

During the five intercomparison days, AOD varied from 0.02 up to 0.12 at 500nm, which can be considered normal values for the area. Figure 1 shows the AOD variability during the intercomparison days as measured from the WORCC triad.

2.2 Instrumentation

Thirty instruments from 12 countries participated in the campaign, representing the most widely used instrument types for AOD retrieval. The participating filter radiometers were either of the direct pointed type, e.g. classic sun-photometers (SPM), including sky-scanning radiometers used in direct sun mode, or hemispherical rotating shadow-band radiometers.

a. Nine (9) instruments were of the PFR type that is used in the GAW AOD network (Wehrli, 2005). The PFR is a classic SPM with 4 independent channels, a field of view (FoV) of ±1.25° and equipped with 3 to 5nm bandwidth interference filters. The detector unit is held at a constant temperature of 20°C by an active Peltier system.
b. Two (2) radiometers were of the Carter-Scott SP02 type (Mitchell and Forgan, 2003), which is similar to the PFR, but has a wider field of view of ±2.5° and no temperature controller.
c. Three (3) Cimel CE318 sun and sky scanning radiometers as used by AERONET (Holben, 1998). These instruments have a narrow field of view of 1.2° and measure the sun with 8 channels sequentially within a few seconds.
d. Four (4) MFRSR rotating shadow band radiometers (Harrison and Michalsky, 1994) with a hemispheric field of view.

e. Three (3) Precision Solar Radiometers (PSR) that are direct sun pointing spectroradiometers able to measure the spectrum from 300 up to 1000nm with the variable step of an average value of 0.7 nm manufactured at PMOD/WRC.
f. Three (3) direct sun pointing POM-2 sky radiometers instruments from Prede Co., Ltd.
g. Four (4) Solar Spectral Irradiance Meters (SSIM) from Cofovo Energy Inc.
h. One (1) Microtops hand held aerosol sun-photometer from Solar light Co.

Details on the instrument types and participating institutes can be found on Table 1. In addition, a summary of basic characteristics of each instrument type is provided in Table 2.

Table 1. List of participants and instrument types

No	*Country*	*Institute*	*Type of radiometer*	*Network*	*Acronym*
1	Switzerland	PMOD/WRC	PFR-N	GAW-PFR	PFR_CH_N06_IZO
2	Switzerland	PMOD/WRC	PFR-N	GAW-PFR	PFR_CH_N21_IZO
3	Switzerland	PMOD/WRC	PFR-N	GAW-PFR	PFR_CH_N24_MLO
4	Switzerland	PMOD/WRC	PFR-N	GAW-PFR, WORCC triad	PFR_CH_N01
5	Switzerland	PMOD/WRC	PFR-N	GAW-PFR, WORCC triad	PFR_CH_N25
6	Switzerland	PMOD/WRC	PFR-N	GAW-PFR, WORCC triad	PFR_CH_N27
7	Sweden	SMHI	PFR-N	GAW-PFR, As. Station	PFR_SE_N35
8	Germany	DWD-MOL	PFR-N	GAW-PFR, As. Station	PFR_DE_N44
9	Switzerland	MeteoSwiss	PFR-N	GAW-PFR	PFR_MS_N11*
10	Switzerland	PMOD/WRC	CIMEL	AERONET	CIM_CH_354
11	Spain -France	Univ. Valladolid - LOA Lille	CIMEL	AERONET-Europe	CIM_ES_627_VLD
12	Spain	AEMET (Izaña Atmos. Res. Cen.)	CIMEL	AERONET	CIM_ES_917_IZO
13	Italy	ARPA Valle d'Aosta	POM-2	SKYNET	POM_IT
14	Germany	DWD-MOL	POM-2	Germany-national	POM_DE
15	Japan	Jap. Met. Agency	POM-2		POM_JP
16	USA	NOAA	SPO2		SPO_US_1
17	Australia	Bureau of Meteorology	SPO2	Australian-national	SPO_AU_1
18	USA	NASA-Langley SSAI	MFRSR		MFR_US_1
19	USA	NOAA	MFRSR	SURFRAD	MFR_US_2
20	USA	NOAA	MFRSR	SURFRAD	MFR_US_3
21	Germany	DWD-MOL	MFRSR	Germany-national	MFR_DE
22	Germany	DWD-MOL	PSR	Germany-national	PSR_004
23	Germany	DWD-MOL	PSR	Germany-national	PSR_007
24	Switzerland	PMOD/WRC	PSR		PSR_007
25	Canada	Cofovo energy Inc	SSIM	commercial	SSM_CA_SN102
26	Canada	Cofovo energy Inc	SSIM	commercial	SSM_CA_SN103
27	Canada	Cofovo energy Inc	SSIM	commercial	SSM_CA_SN112
28	Canada	Cofovo energy Inc	SSIM	commercial	SSM_CA_SN113
29	Greece	NOA	Microtops	Campaign based	MIC_GR
30	S. Arabia	KACARE	POM-2	SKYNET	POM_SA**

**Submitted data for only one day*
***Did not submit data*

Table 2. Summary of basic characteristics of each instrument type

Instrument type	*Measuring wavelengths (nm)*	*Field of view (°)*	*FWHM* (nm)*	*Measurement principle*
PFR-N	368, 412, 500, 863	2.5	3.8-5.4	Sun pointing on tracker
CIMEL	340, 379, 440, 500, 670, 870, 1021	1.2	10	Sun pointing on tracker
MFRSR	415, 500, 615,673, 870, 940	Variable	10	Diffuse and global using shadowband
POM-2	315, 340, 380, 400, 500, 675, 870, 940, 1020, 1627, 2200	1	3 (UV), 10 (VIS) up to 20 (IR)	Sun pointing on tracker
PSR	300-1000, step 0.7	1.5	1.5-6	Sun pointing on tracker
SPO2	368, 412, 502, 675, 778, 812, 862	2.4	5	Sun pointing on tracker
SSIM	6 filters, spectral AOD retrieval	2	5	Sun pointing on tracker
microtops	340, 440, 500, 870, 936	2.5	10	Hand held – tripod

**Full width at half maximum*

2.3 Data acquisition and AOD retrieval

Measurements of solar irradiance were nominally taken each full minute by the participants' data acquisition systems, yielding typically 500 observations per cloudless day. Actual sampling/averaging rates ranged from 15 seconds to 1 minute depending on the instrument. Simultaneous measurements were defined in a timing window of 30 seconds after each minute. The raw measurements were evaluated by each participant according to their preferred algorithms, including cloud-screening, and submitted for comparison.

The set of measurements covered wavelengths between 340 nm and 2200 nm. Channels 368±3nm, 412±3nm, 500±3nm, 865±5nm were defined as the AOD intercomparison wavelengths. The number of instruments that submitted AOD retrievals for each of those wavelengths is summarized in Table 3.

Table 3. Number of instruments that submitted data for each wavelength range

Wavelength	Number of instruments
368±3nm	17
412±3nm	21
500±3nm	29
865±5nm	29

Ångström exponents were derived from optical depths at 865 and 500nm (29 instruments). Atmospheric pressure, precipitable water, relative humidity, and temperature readings (every 10 minutes) from the MeteoSwiss weather station located at the comparison site were provided to all participants. Total ozone column content measured with a double brewer monochromator at PMOD/WRC was available as well. In order to avoid AOD-related discrepancies introduced by uncertainties linked with the above mentioned auxiliary data, all participants used the provided data set. Several of the participating radiometers were calibrated at various sites within a few months prior to the FRC-IV. Their performance during this comparison can be used to estimate the homogeneity of AOD observations across weather services or networks. Details about every instrument’s calibration basics and history can be found in Annex 2a.

2.4 Comparison basics and WORCC triad

During FRC-IV, measurements from participating radiometers were evaluated using a uniform comparison software. FRC-VI was based on AOD results derived from measurements by different algorithms used in the normal operation of the radiometers. Recommendations for a comparison were formulated during the WMO experts workshop on Global surface network for long-term observations of column aerosol optical properties, held in 2004 in Davos (WMO, 2005), which called for:

- More than 1000 data points with AOD at 500nm between 0.04 and 0.20
- A minimum duration of 5 days
- Traceability requiring 95% uncertainty within ±0.005 + 0.01/m optical depths

During FRC-IV, weather conditions allowed for over 1000 measurements on 5 days, permitting the accomplishment of the above-mentioned recommendations. During the campaign, AOD retrieved from data of participating instruments were compared with the WORCC reference PFR triad. Before the start of the campaign, the PFR triad was inter-compared with three PFR instruments that had performed measurements at Izaña, Tenerife, Spain (2 instruments) and Mauna Loa, Hawaii, USA for nearly one year. Using the Langley calibration results of these three instruments, extraterrestrial voltages were determined. During five cloudless days in August - September 2015, the three above mentioned instruments together with the three PFR (triad) were inter-compared. The differences in AOD derived from the three (Izaña and Mauna Loa) instruments were less than 0.5% for all wavelengths. A comparison of their average with the triad PFRs showed that for PFRs N25 and N27, differences were less than 1%, which is the WORCC upper limit for not applying a new calibration for each instrument/wavelength. For PFR N01, discrepancies on three out of four wavelengths ranged from 1.1% to 1.2%. So, for the duration of the intercomparison, the PFR N01 instrument was recalibrated and replaced in the triad by the PFR N24.

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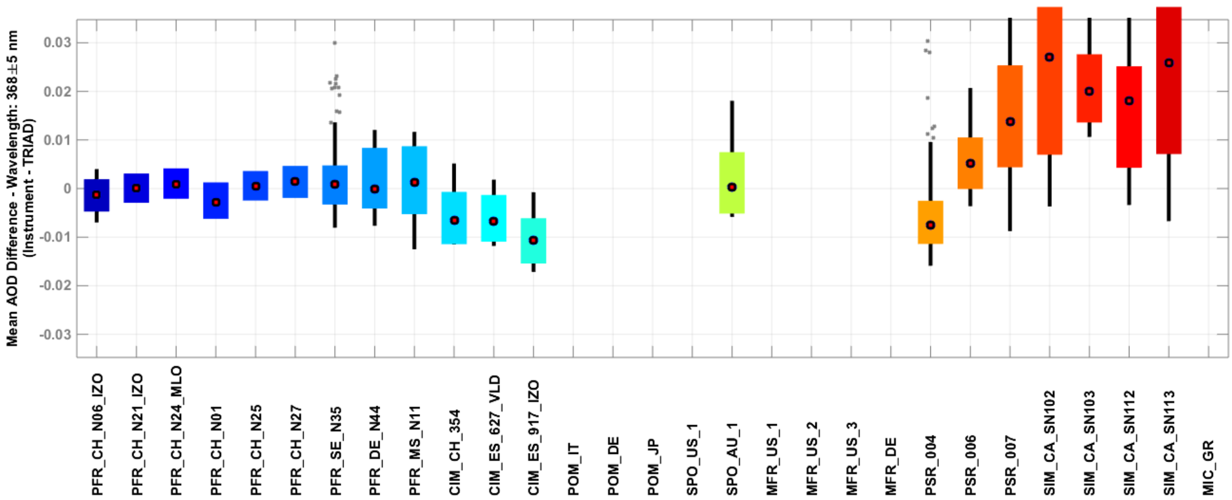
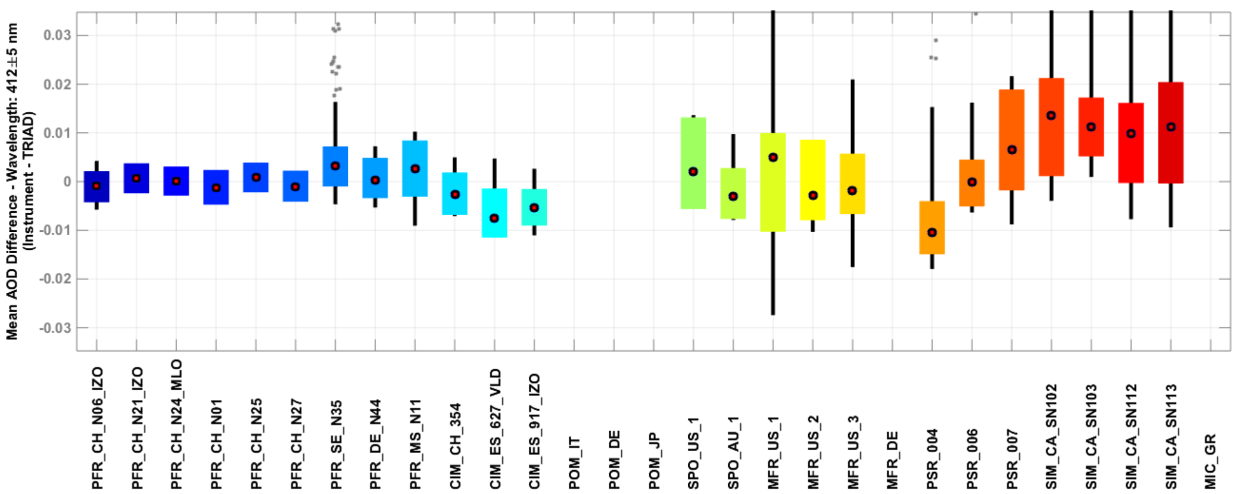
3. RESULTS

3.1 Aerosol Optical Depth comparison

Concerning the AOD results, each minute AOD measurement of each participating instrument was compared with the synchronous measurement that was derived by the mean of the triad PFRs. As mentioned, each participant used their own cloud-screening procedure. Since all measurements were compared with the triad, the number of compared observations has an upper limit related to the number of the cloud-screened triad measurements/minutes per day. The results of the comparison for the four wavelengths are shown in Figures 2a-d.





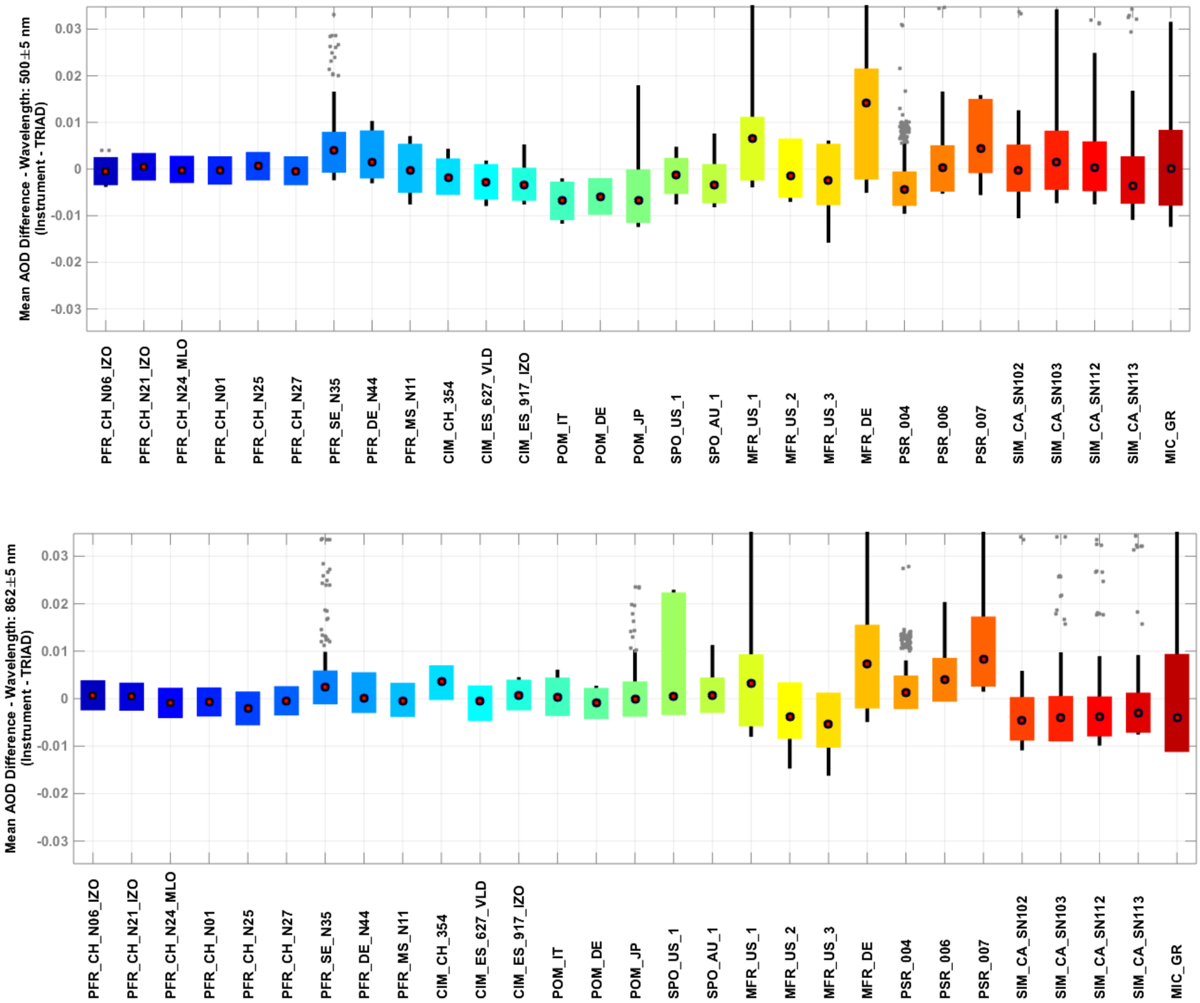


Fig 2a-d: AOD comparison results at 368±3nm (a), 412±3nm (b), 500±3nm (c), 865±5nm (d). The red dots represent the median of the difference of each instrument from the mean of the triad at each wavelength over the five FRC-IV selected days. The colored boxes represent the 10^{th} and 90^{th} percentiles while the black lines represent the minimum and maximum values of the distribution excluding the outliers. Outliers (gray dots) represent values that are outside the 10^{th} and 90^{th} percentiles by 4 times the width of the distribution at 10% level. CIMEL related AOD's for 412 and 368nm have been extrapolated using the CIMEL AOD's at 340, 380 and 440nm and the Ångström exponents derived from these three wavelengths.

Statistics and graphical representations of the performance of each individual instrument for each wavelength can be found in Appendices 2b and 2c, respectively. The number of instruments that performed measurements within the WMO limits criterion for different wavelengths are shown in Figure 3.

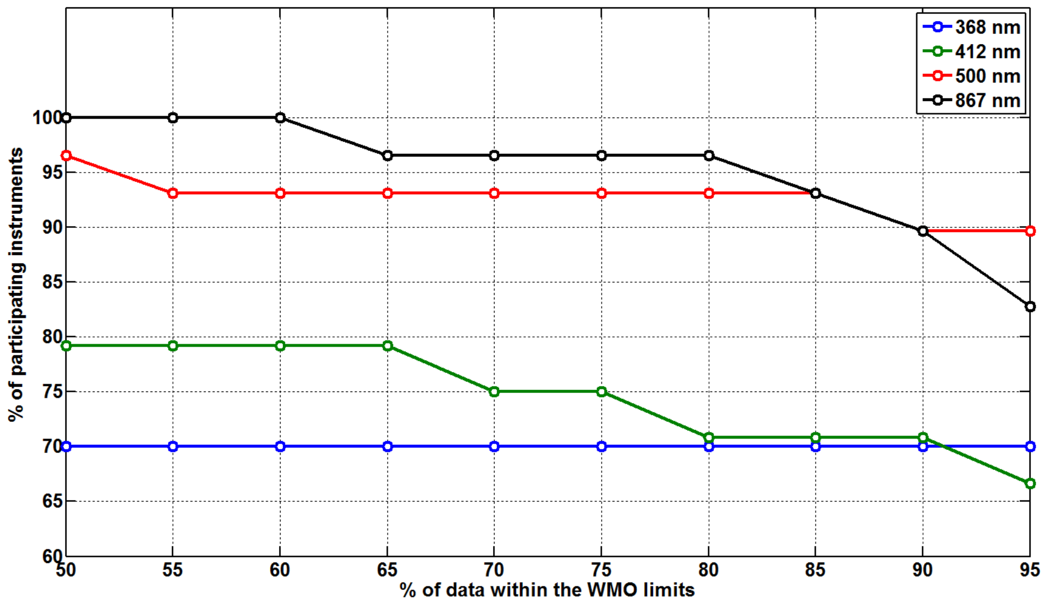


Figure 3. Percentage of instruments that lie within the "0.005 + 0.01/m optical depths" criterion. The horizontal axis shows different percentages of measurements within the criterion ending on 95%, that is the U95 WMO limit.

3.2 Ångström exponents

The Ångström's empirical law $\tau(\lambda) = \beta\ \lambda^{-\alpha}$ is often used to describe the AOD spectral distribution and in modelling of the atmospheric radiative transfer, or for interpolating AOD between disparate wavelengths. The value of the Ångström exponent (AE) is also a qualitative indicator of the aerosol particle size distribution and allows for discrimination between coarse mode aerosols (α<1), typical for dust and sea salt; and fine mode (α>2), associated with pollution and biomass burning. Ångström's law is based on a simplified power law (Junge distribution $dN(r) / d\log(r) = Ar^{-\upsilon}$) for the particle number density distribution, while natural situations are more realistically described by multimodal lognormal distributions, leading to a wavelength dependency of the Ångström exponent. The curvature of the AOD spectrum is often (Eck et al., 1999; O'Neill et al., 2001) accounted for by a second-order polynomial approximation in the form of $\ln \tau(\lambda) = a + b \ln(\lambda) + c (\ln(\lambda))^2$. Cachorro et al. (2001) demonstrated the necessity of defining a standard spectral range where the Ångström parameters should be determined. The use of a standard Ångström exponent derived from AOD observations at the most common wavelengths of 500±3nm and 865±5nm was proposed at the WMO/GAW experts meeting in March 2004, at Davos, Switzerland (WMO, 2005).

Since all participating instruments were able to measure at 500±3nm and 865±5nm, we have averaged the derived minute based AE from each instrument and have compared it with those derived from the WORCC triad (see Figure 4).

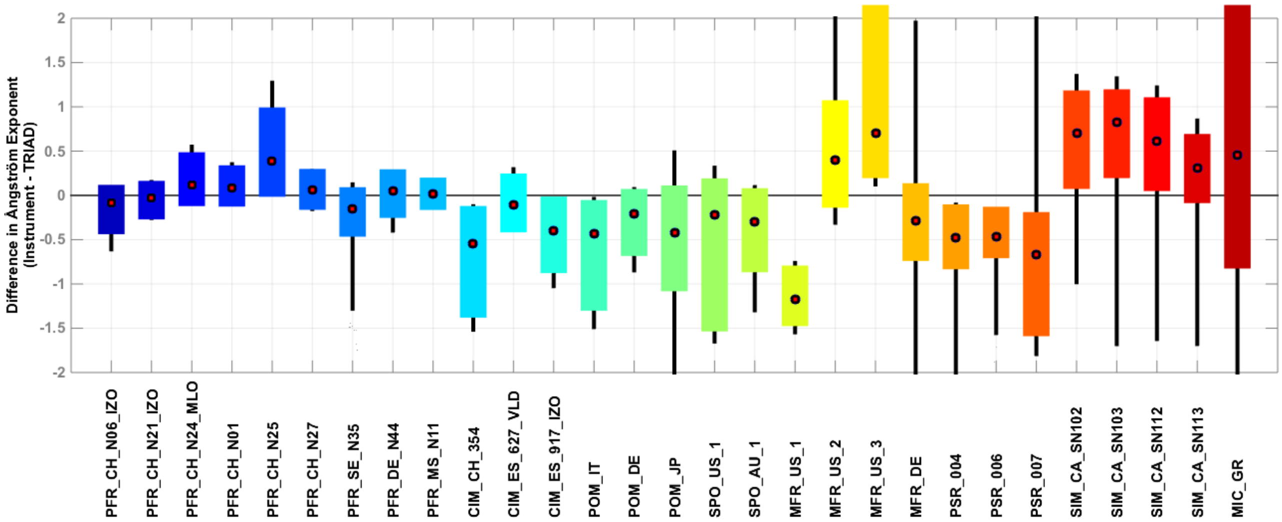


Figure 4. Difference in the Ångström exponent between each instrument and the WORCC triad. The colored boxes represent the 10th and 90th percentiles while the black lines represent the minimum and maximum values of the distribution excluding the outliers. Outliers (gray dots) are considered values that are outside the 10th and 90th percentiles by 4 times the width of the distribution at 10% level.

Detailed histograms of the AE differences of each instrument compared with those calculated with the triad are presented in Annex 2d.

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4. CONCLUSIONS AND RECOMMENDATIONS

A total number of 30 instruments participated in the FRC-IV. The intercomparison fulfilled the WMO recommendations concerning the number of days and measurements performed. Concerning the U95 WMO criterion, 27 and 25 out of 29 instruments for 500 and 862 nm respectively were within the limits while 14 out of 20 and 16 out of 24 achieved it for 368 and 412 nm, respectively. It is estimated that improvements in pointing, homogenization of inputs used on the AOD retrieval algorithm (common set of ozone cross sections, NO_2 optical depth determination, air mass calculation and Rayleigh scattering formulas), improvement in each instrument characterization, and calibration of the radiometers, could all improve the reported agreement.

Concerning the determination of the Ångström Exponent, comparisons under low AOD (AOD<0.1 at 500nm) lead to differences in the order of 0.5 to 1 even when AOD agreement was within the WMO limits. In addition, low AOD values during the campaign did not favor an investigation of uncertainties related to aerosol forward scattering, which is linked to each instrument's measuring field of view.

The results of the FRC-IV, which included a large variety of AOD measuring instrumentation via the participation of reference instruments from AERONET Europe, SKYNET, GAW-PFR, SURFRAD and the Australian aerosol network, could be considered as a starting point for global AOD homogeneity initiatives. The ultimate aim is a unified AOD product to be used for long term aerosol and radiative forcing studies, case studies involving accurate AOD retrievals, and satellite validation related activities.

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ANNEX 1

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ANNEX 2a

INSTRUMENT CALIBRATIONS REPORT

Instrument	Calibration
PFR_CH_N06_IZO	Langley calibration at the high mountain station at Izaña, Tenerife, January 2015 – August 2015
PFR_CH_N21_IZO	Langley calibration at the high mountain station at Izaña, Tenerife, Spain January 2015 – August 2015
PFR_CH_N24_MLO	Langley calibration at the high mountain station at Mauna Loa, USA, July 2014 – August 2015
PFR_CH_N01	WORCC, PMOD triad, recalibrated
PFR_CH_N25	WORCC, PMOD triad
PFR_CH_N27	WORCC, PMOD triad
PFR_SE_N35	WORCC, PMOD triad 2014-06-10
PFR_DE_N44	WORCC, PMOD triad, recalibrated
PFR_MS_N11	The direct solar irradiance data measured by PFRs at four MeteoSwiss stations within the range 305-1024 nm are calibrated by means of Langley plots at Jungfraujoch (Sphinx) and at Davos (PMOD)
CIM_CH_354	Langley calibration, AERONET
CIM_ES_627_VLD	Langley calibration, AERONET
CIM_ES_917_IZO	Langley calibration, AERONET
POM_IT	Modified Langley method, according to Campanelli et al., 2007
POM_DE	Modified Langley method, according to Campanelli et al., 2007
POM_JP	Calibrated by an outdoor comparison to JMA reference POM-02 at Meteorological Research Institute in Tsukuba, Japan, May 2015 - August 2015. JMA reference POM-02 is calibrated by Langley extrapolations at the high mountain station at Mauna Loa.
SPO_US_1	Michalsky et al., 2001. It uses nearest Langleys (in time) from in situ measurements and determines a robust estimate for V0.
SPO_AU_1	Langley calibration for all wavelengths except 412 from the 3 year record at the field site (Cobar, New South Wales). The Davos IPC days used to apply the general method to get a calibration of the 412 from the 500 nm channel of the SPO2.
MFR_US_1	Fit to a multi-year set of Langley derived Top Of Atmosphere V0 values. Monthly V0 are determined from this fit line and used with each month of incident data to determine the Total Optical Depth.
MFR_US_2	Langley calibration at Boulder, CO and during FRC for August – October, 2015
MFR_US_3	Langley calibration at Boulder, CO and during FRC for August – October, 2015
MFR_DE	Local Langley calibration
PSR_004	Absolute spectral irradiance calibration at PMOD/WORCC laboratory
PSR_006	Absolute spectral irradiance calibration at PMOD/WORCC laboratory
PSR_007	Absolute spectral irradiance calibration at PMOD/WORCC laboratory
SIM_CA_SN102	Absolute spectral irradiance calibration at National Renewable Energy Laboratory SSRL
SIM_CA_SN103	Absolute spectral irradiance calibration at National Renewable Energy Laboratory SSRL
SIM_CA_SN112	Absolute spectral irradiance calibration against SN102
SIM_CA_SN113	Absolute spectral irradiance calibration against SN102
MIC_GR	Intercomparison with a CIMEL instrument, August 2015

ANNEX 2b

COMPARISON STATISTICS FOR EACH INSTRUMENT AND FOR EACH MEASURED WAVELENGTH

Wavelength: 368±3nm

Instrument	Median ±1σ	Percentile [5,95]	Correlation Coefficient	Linear Fit (Slope, Intercept)	Number of Data
PFR_CH_N06_IZO	-0.001 ± 0.001	[-0.003 , -0.001]	1.000	(0.992,-0.001)	1792
PFR_CH_N21_IZO	+0.000 ± 0.000	[-0.001 , +0.001]	1.000	(1.005,-0.000)	1962
PFR_CH_N24_MLO	+0.001 ± 0.000	[+0.000 , +0.002]	1.000	(1.009,0.000)	2011
PFR_CH_N01	-0.003 ± 0.001	[-0.004 , -0.001]	1.000	(1.002,-0.003)	2011
PFR_CH_N25	+0.001 ± 0.000	[-0.000 , +0.001]	1.000	(0.998,0.001)	1993
PFR_CH_N27	+0.002 ± 0.001	[+0.000 , +0.002]	1.000	(1.006,0.001)	2010
PFR_SE_N35	+0.001 ± 0.008	[-0.001 , +0.003]	0.999	(0.988,0.002)	1927
PFR_DE_N44	-0.000 ± 0.003	[-0.002 , +0.007]	0.999	(1.020,-0.001)	1744
PFR_MS_N11	+0.001 ± 0.003	[-0.004 , +0.007]	0.975	(0.995,0.002)	367
CIM_CH_354	-0.006 ± 0.002	[-0.010 , -0.002]	0.998	(1.042,-0.009)	332
CIM_ES_627_VLD	-0.007 ± 0.002	[-0.009 , -0.003]	0.998	(0.998,-0.006)	114
CIM_ES_917_IZO	-0.011 ± 0.002	[-0.013 , -0.008]	0.999	(0.999,-0.011)	747
POM_IT					
POM_DE					
POM_JP					
SPO_US_1					
SPO_AU_1	+0.000 ± 0.003	[-0.003 , +0.007]	0.996	(1.009,-0.000)	1939
MFR_US_1					
MFR_US_2					
MFR_US_3					
MFR_DE					
PSR_004	-0.007 ± 0.009	[-0.009 , +0.005]	0.999	(1.005,-0.008)	1318
PSR_006	+0.005 ± 0.007	[+0.002 , +0.008]	0.996	(1.009,0.005)	822
PSR_007	+0.014 ± 0.008	[+0.003 , +0.025]	0.987	(0.926,0.019)	1329
SIM_CA_SN102	+0.027 ± 0.010	[+0.006 , +0.037]	0.949	(0.921,0.031)	1291
SIM_CA_SN103	+0.020 ± 0.005	[+0.015 , +0.026]	0.997	(1.055,0.016)	1156
SIM_CA_SN112	+0.018 ± 0.007	[+0.004 , +0.024]	0.987	(0.921,0.023)	1628
SIM_CA_SN113	+0.026 ± 0.010	[+0.004 , +0.039]	0.956	(0.850,0.036)	1628
MIC_GR					

Wavelength: 412±3nm

Instrument	Median ±1σ	Percentile [5,95]	Correlation Coefficient	Linear Fit (Slope, Intercept)	Number of Data
PFR_CH_N06_IZO	-0.001 ± 0.001	[-0.002 , -0.000]	1.000	(0.990,-0.000)	1790
PFR_CH_N21_IZO	+0.001 ± 0.000	[+0.000 , +0.001]	1.000	(1.007,0.000)	1994
PFR_CH_N24_MLO	+0.000 ± 0.000	[-0.000 , +0.001]	1.000	(1.006,-0.000)	1924
PFR_CH_N01	-0.001 ± 0.001	[-0.002 , +0.000]	1.000	(1.005,-0.002)	1999
PFR_CH_N25	+0.001 ± 0.000	[+0.000 , +0.001]	1.000	(1.001,0.001)	2008
PFR_CH_N27	-0.001 ± 0.000	[-0.002 , -0.000]	1.000	(1.004,-0.001)	2006
PFR_SE_N35	+0.003 ± 0.008	[+0.001 , +0.005]	0.999	(0.994,0.003)	1938
PFR_DE_N44	+0.000 ± 0.001	[-0.001 , +0.003]	0.999	(1.035,-0.001)	1745
PFR_MS_N11	+0.003 ± 0.003	[-0.002 , +0.007]	0.981	(0.963,0.006)	367
CIM_CH_354	-0.003 ± 0.002	[-0.005 , +0.000]	0.999	(1.021,-0.004)	332
CIM_ES_627_VLD	-0.008 ± 0.002	[-0.009 , -0.002]	0.997	(1.005,-0.008)	114
CIM_ES_917_IZO	-0.005 ± 0.001	[-0.007 , -0.004]	0.999	(0.999,-0.005)	747
POM_IT					
POM_DE					
POM_JP					
SPO_US_1	+0.002 ± 0.005	[-0.004 , +0.012]	0.981	(0.964,0.004)	1795
SPO_AU_1	-0.003 ± 0.002	[-0.006 , +0.001]	0.997	(0.974,-0.001)	1941
MFR_US_1	+0.005 ± 0.022	[-0.008 , +0.012]	0.979	(0.907,0.007)	649
MFR_US_2	-0.003 ± 0.004	[-0.006 , +0.007]	0.987	(0.845,0.007)	1110
MFR_US_3	-0.002 ± 0.003	[-0.005 , +0.004]	0.995	(0.955,0.001)	1388
MFR_DE					
PSR_004	-0.010 ± 0.009	[-0.013 , +0.001]	0.998	(0.998,-0.010)	1318
PSR_006	-0.000 ± 0.007	[-0.003 , +0.002]	0.997	(1.020,-0.001)	822
PSR_007	+0.006 ± 0.009	[-0.001 , +0.019]	0.984	(0.888,0.013)	1328
SIM_CA_SN102	+0.014 ± 0.006	[+0.001 , +0.019]	0.979	(0.920,0.018)	1291
SIM_CA_SN103	+0.011 ± 0.005	[+0.007 , +0.016]	0.996	(1.012,0.011)	1156
SIM_CA_SN112	+0.010 ± 0.005	[+0.000 , +0.014]	0.992	(0.910,0.015)	1627
SIM_CA_SN113	+0.011 ± 0.006	[-0.000 , +0.019]	0.983	(0.882,0.018)	1628
MIC_GR					

Wavelength: 500±3nm

Instrument	Median ±1σ	Percentile [5,95]	Correlation Coefficient	Linear Fit (Slope, Intercept)	Number of Data
PFR_CH_N06_IZO	-0.000 ± 0.000	[-0.001 , +0.000]	1.000	(0.995,-0.000)	1763
PFR_CH_N21_IZO	+0.000 ± 0.000	[+0.000 , +0.001]	1.000	(1.001,0.000)	2000
PFR_CH_N24_MLO	-0.000 ± 0.000	[-0.000 , +0.000]	1.000	(1.006,-0.000)	1962
PFR_CH_N01	-0.000 ± 0.000	[-0.001 , +0.000]	1.000	(1.002,-0.000)	1968
PFR_CH_N25	+0.001 ± 0.000	[+0.000 , +0.001]	1.000	(0.999,0.001)	2004
PFR_CH_N27	-0.000 ± 0.000	[-0.001 , +0.000]	1.000	(1.008,-0.001)	1983
PFR_SE_N35	+0.004 ± 0.007	[+0.001 , +0.006]	0.998	(0.993,0.004)	1943
PFR_DE_N44	+0.001 ± 0.002	[+0.000, +0.007]	0.999	(1.022,0.001)	1755
PFR_MS_N11	-0.000 ± 0.002	[-0.003 , +0.004]	0.982	(1.037,-0.002)	366
CIM_CH_354	-0.002 ± 0.001	[-0.003 , +0.000]	0.999	(1.033,-0.003)	332
CIM_ES_627_VLD	-0.003 ± 0.001	[-0.006 , -0.001]	0.998	(1.023,-0.003)	114
CIM_ES_917_IZO	-0.003 ± 0.001	[-0.004 , -0.002]	0.999	(1.026,-0.004)	747
POM_IT	-0.007 ± 0.001	[-0.009 , -0.005]	0.998	(0.988,-0.006)	1165
POM_DE	-0.006 ± 0.001	[-0.008 , -0.004]	0.998	(1.010,-0.006)	1176
POM_JP	-0.007 ± 0.006	[-0.009 , -0.001]	0.993	(1.012,-0.007)	1797
SPO_US_1	-0.001 ± 0.001	[-0.003 , +0.000]	0.999	(1.004,-0.002)	1795
SPO_AU_1	-0.003 ± 0.001	[-0.005 , -0.001]	0.998	(1.006,-0.004)	1945
MFR_US_1	+0.007 ± 0.012	[-0.000 , +0.011]	0.988	(0.926,0.008)	616
MFR_US_2	-0.002 ± 0.003	[-0.004 , +0.004]	0.988	(0.866,0.005)	1110
MFR_US_3	-0.002 ± 0.003	[-0.006 , +0.004]	0.986	(0.952,-0.000)	1389
MFR_DE	+0.014 ± 0.008	[-0.001 , +0.020]	0.944	(1.179,0.006)	1438
PSR_004	-0.004 ± 0.009	[-0.006 , +0.007]	0.999	(1.002,-0.004)	1318
PSR_006	+0.000 ± 0.007	[-0.003 , +0.003]	0.993	(1.037,-0.001)	822
PSR_007	+0.004 ± 0.007	[+0.001 , +0.014]	0.994	(0.958,0.006)	1328
SIM_CA_SN102	-0.000 ± 0.003	[-0.003 , +0.003]	0.998	(0.939,0.003)	1282
SIM_CA_SN103	+0.001 ± 0.005	[-0.003 , +0.006]	0.992	(0.988,0.002)	1152
SIM_CA_SN112	+0.000 ± 0.004	[-0.003 , +0.004]	0.997	(0.943,0.003)	1616
SIM_CA_SN113	-0.004 ± 0.004	[-0.005 , +0.001]	0.998	(0.941,-0.001)	1623
MIC_GR	+0.000 ± 0.005	[-0.006 , +0.007]	0.980	(0.997,0.000)	345

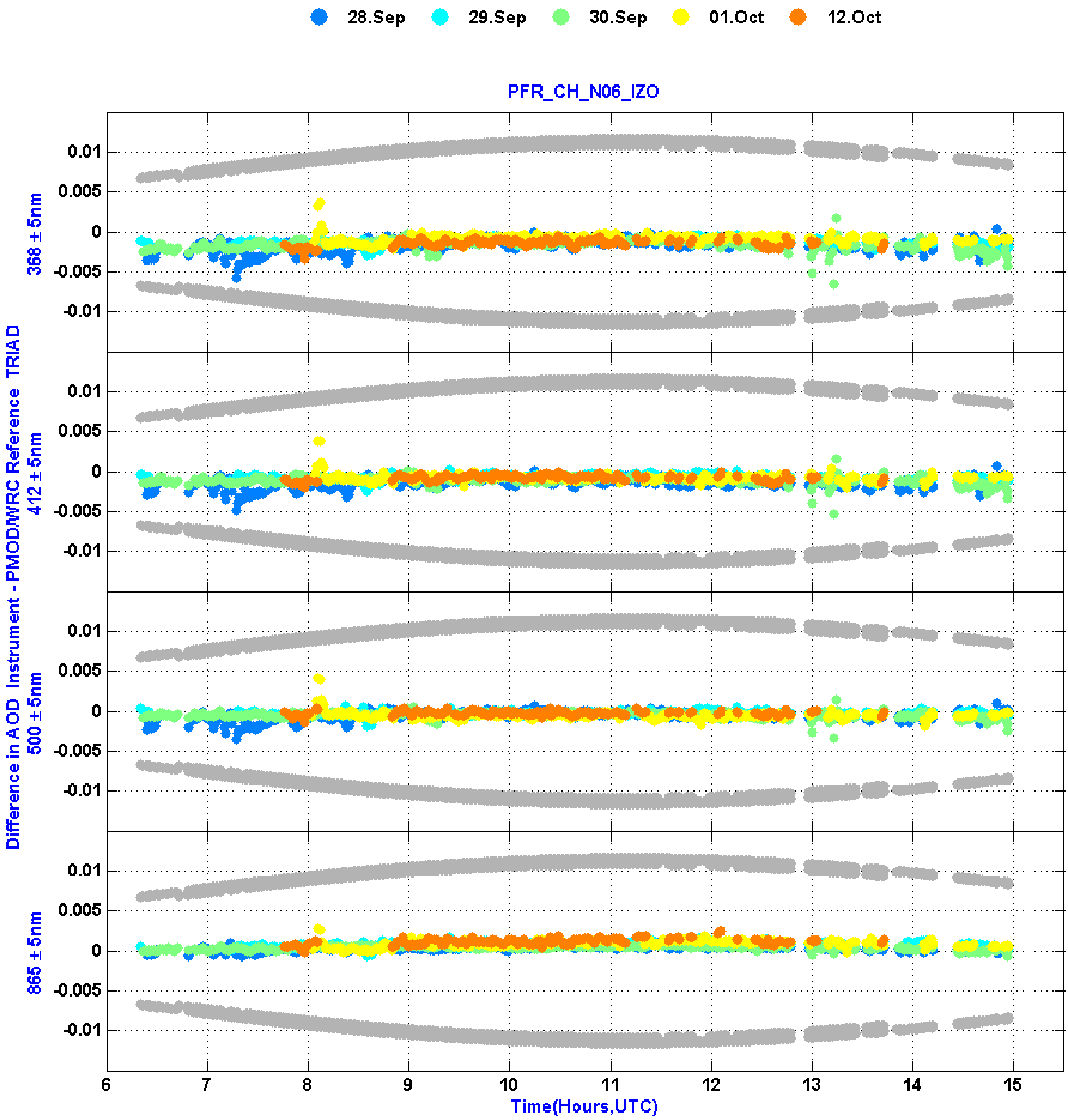
Wavelength: 865±5nm

Instrument	Median ±1σ	Percentile [5,95]	Correlation Coefficient	Linear Fit (Slope, Intercept)	Number of Data
PFR_CH_N06_IZO	+0.001 ± 0.000	[-0.000 , +0.001]	0.999	(0.952,0.001)	1783
PFR_CH_N21_IZO	+0.000 ± 0.000	[-0.000 , +0.001]	0.999	(0.991,0.001)	1963
PFR_CH_N24_MLO	-0.001 ± 0.000	[-0.002 , -0.000]	0.998	(1.028,-0.001)	2003
PFR_CH_N01	-0.001 ± 0.000	[-0.001 , -0.000]	0.998	(1.000,-0.001)	2003
PFR_CH_N25	-0.002 ± 0.001	[-0.003 , -0.001]	0.995	(1.032,-0.003)	2012
PFR_CH_N27	-0.001 ± 0.000	[-0.001 , +0.000]	0.998	(1.012,-0.001)	1983
PFR_SE_N35	+0.002 ± 0.008	[+0.001 , +0.004]	0.997	(0.990,0.002)	1943
PFR_DE_N44	+0.000 ± 0.001	[-0.001 , +0.003]	0.997	(0.977,0.000)	1724
PFR_MS_N11	-0.000 ± 0.001	[-0.002 , +0.001]	0.983	(1.063,-0.002)	366
CIM_CH_354	+0.004 ± 0.001	[+0.002 , +0.005]	0.993	(0.943,0.004)	332
CIM_ES_627_VLD	-0.001 ± 0.001	[-0.003 , +0.001]	0.988	(0.960,-0.000)	114
CIM_ES_917_IZO	+0.001 ± 0.001	[-0.000 , +0.002]	0.998	(0.943,0.001)	746
POM_IT	+0.000 ± 0.001	[-0.001 , +0.002]	0.987	(0.896,0.002)	1156
POM_DE	-0.001 ± 0.001	[-0.002 , -0.000]	0.995	(0.962,-0.001)	1172
POM_JP	-0.000 ± 0.006	[-0.001 , +0.001]	0.994	(0.982,0.000)	1781
SPO_US_1	+0.001 ± 0.008	[-0.001 , +0.021]	0.996	(0.898,0.001)	1795
SPO_AU_1	+0.001 ± 0.001	[-0.001 , +0.002]	0.991	(0.942,0.001)	1934
MFR_US_1	+0.003 ± 0.019	[-0.004 , +0.008]	0.977	(0.734,0.006)	651
MFR_US_2	-0.004 ± 0.003	[-0.006 , +0.001]	0.899	(0.683,0.001)	1105
MFR_US_3	-0.005 ± 0.002	[-0.009 , -0.001]	0.918	(0.837,-0.003)	1387
MFR_DE	+0.007 ± 0.006	[-0.001 , +0.014]	0.903	(1.343,0.003)	1436
PSR_004	+0.001 ± 0.009	[+0.000 , +0.012]	0.998	(1.061,0.000)	1318
PSR_006	+0.004 ± 0.008	[+0.002 , +0.006]	0.983	(1.102,0.002)	822
PSR_007	+0.008 ± 0.006	[+0.005 , +0.016]	0.887	(0.750,0.013)	1329
SIM_CA_SN102	-0.005 ± 0.003	[-0.006 , -0.002]	0.978	(0.935,-0.003)	1290
SIM_CA_SN103	-0.004 ± 0.005	[-0.007 , -0.001]	0.984	(0.866,-0.002)	1156
SIM_CA_SN112	-0.004 ± 0.004	[-0.006 , -0.001]	0.987	(0.939,-0.003)	1628
SIM_CA_SN113	-0.003 ± 0.004	[-0.005 , -0.001]	0.986	(0.937,-0.002)	1628
MIC_GR	-0.004 ± 0.007	[-0.009 , +0.010]	0.849	(1.086,-0.004)	338

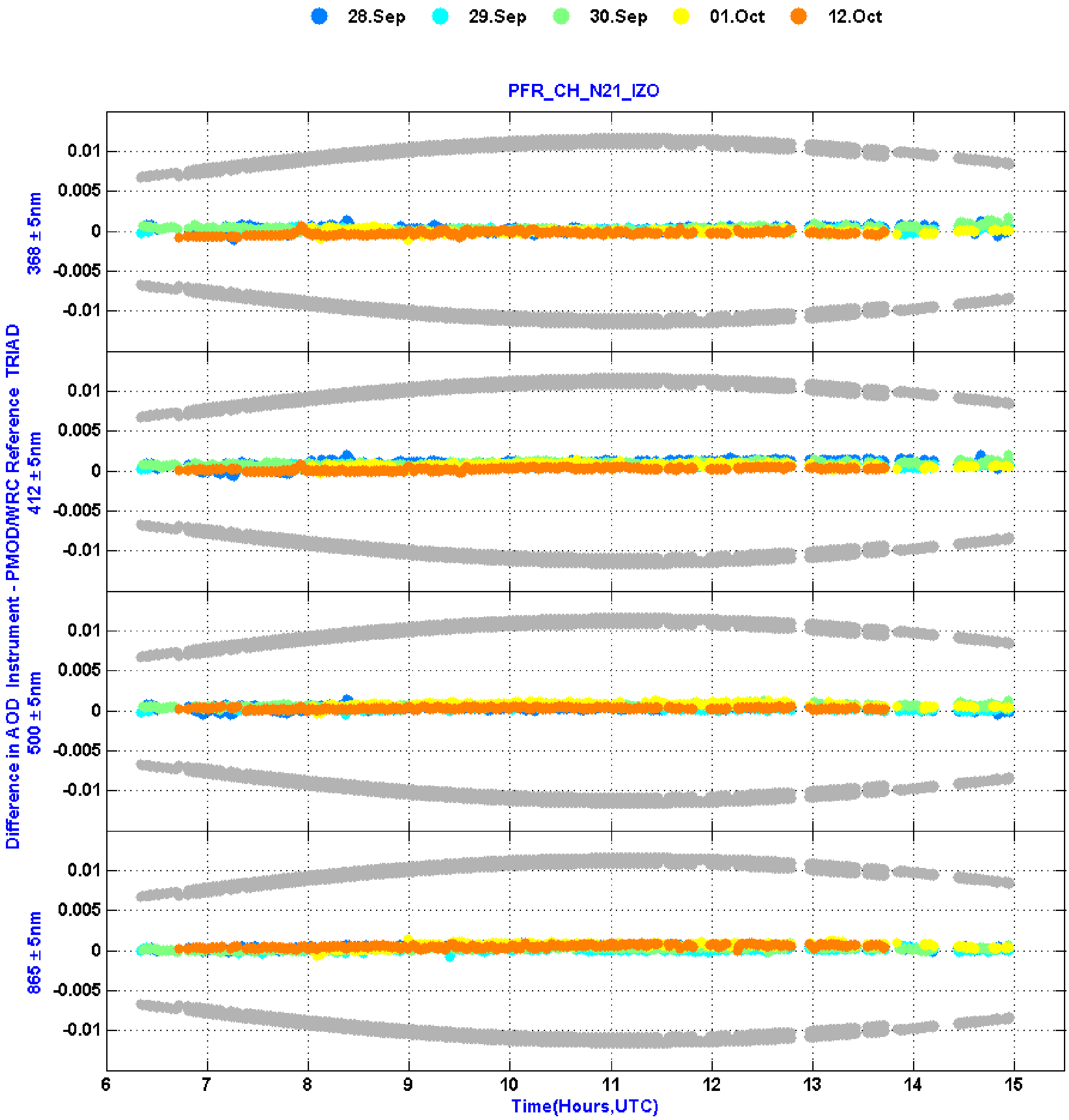
ANNEX 2c

INSTRUMENT INDIVIDUAL PERFORMANCE

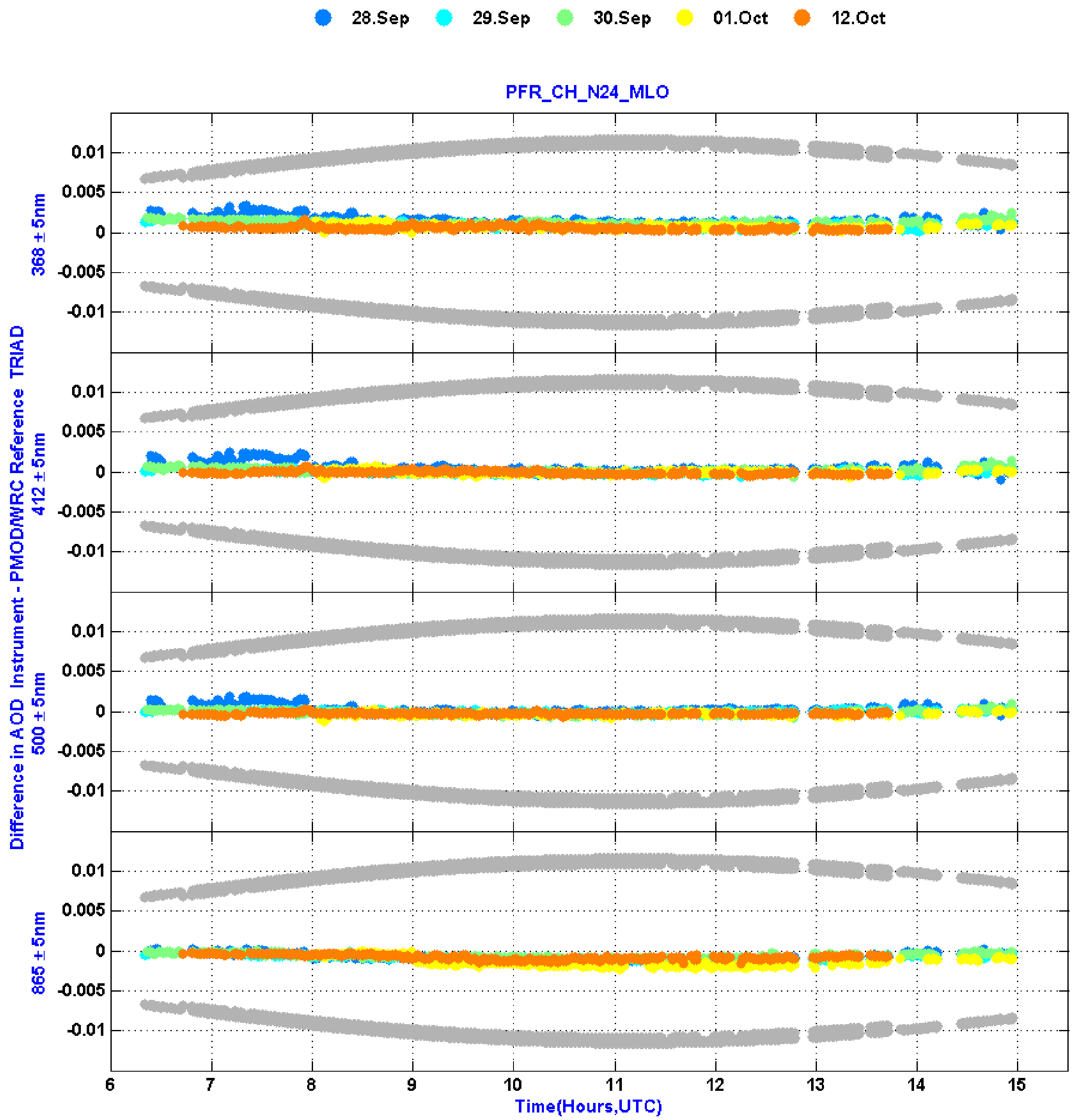
The following figures show differences between individual instruments and the WORCC triad for each of the comparison days and each of their measuring wavelengths. Grey lines represent the WMO U95 criterion (formula 1).



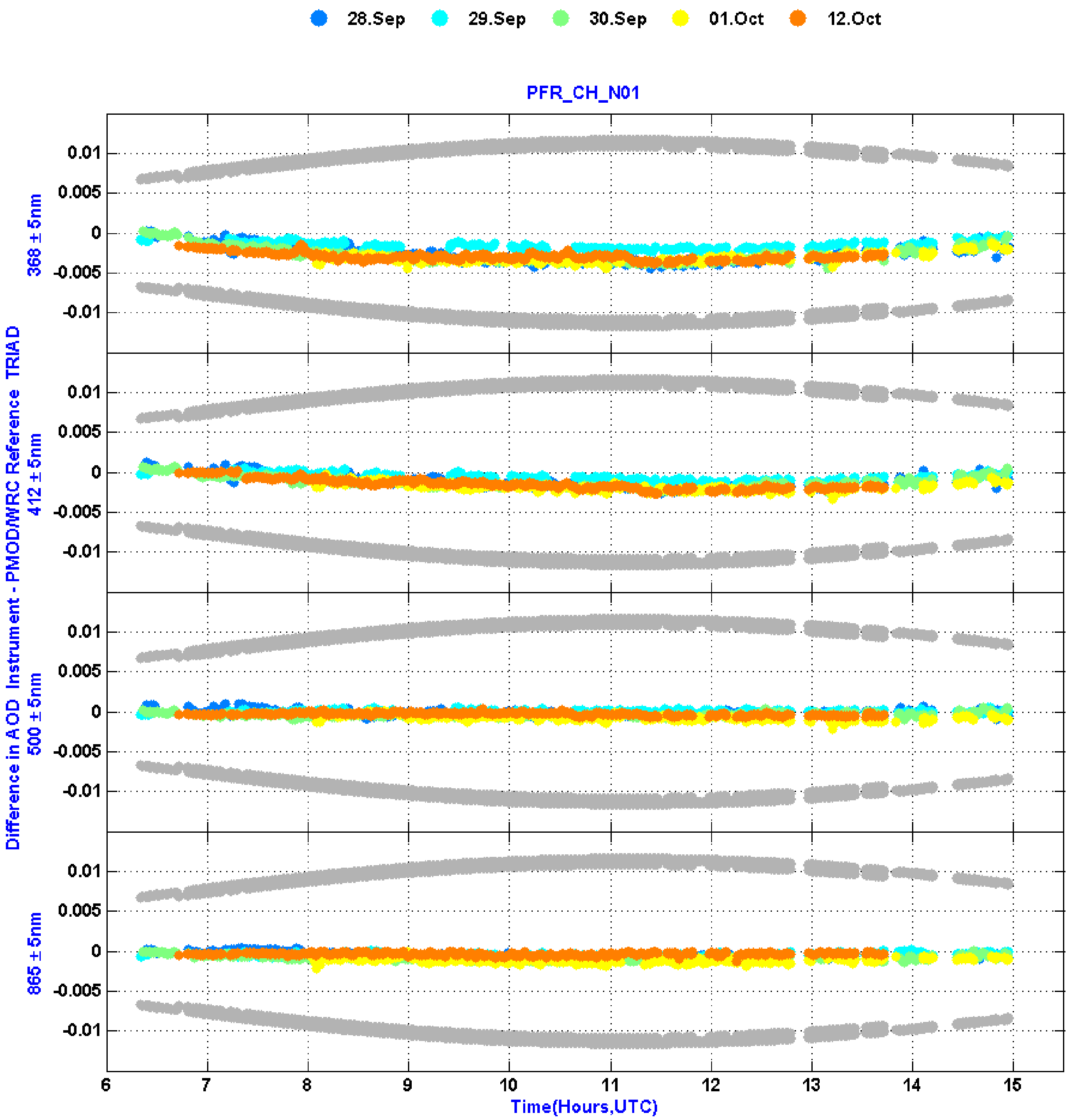
PFR_CH_N21_IZO



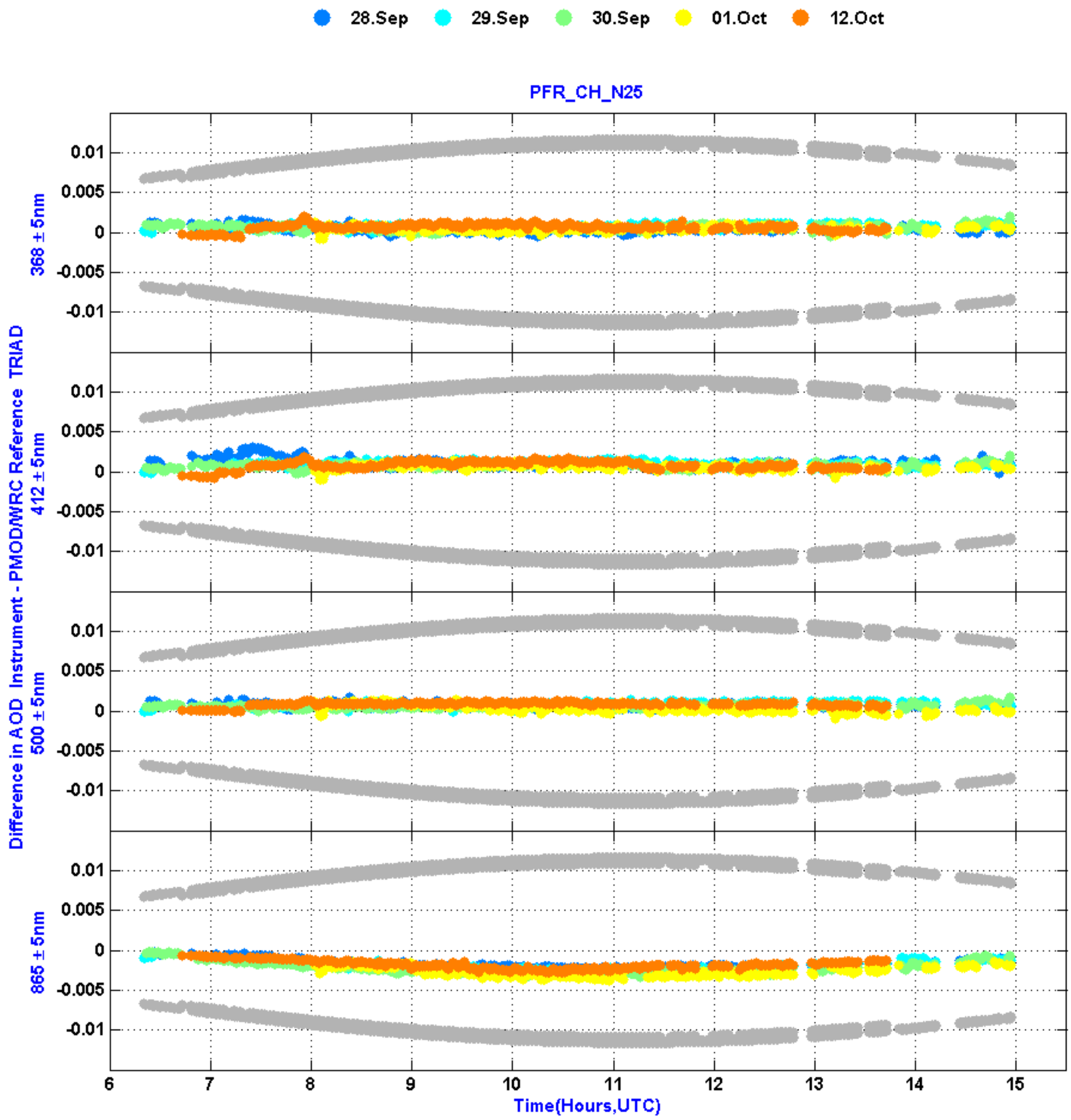
PFR_CH_N24_MLO



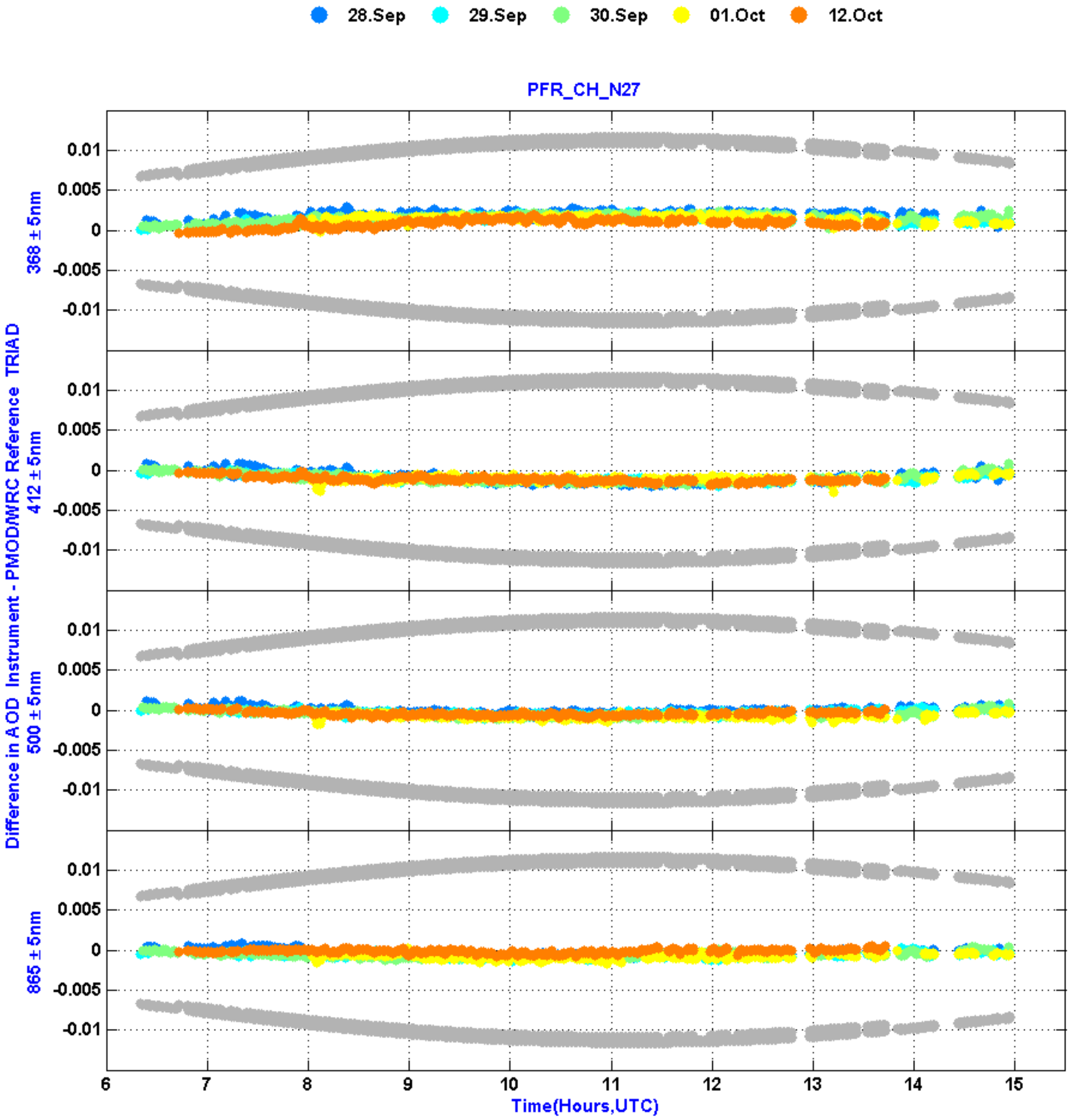
PFR_CH_N01


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_CH_N01
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

PFR_CH_N25

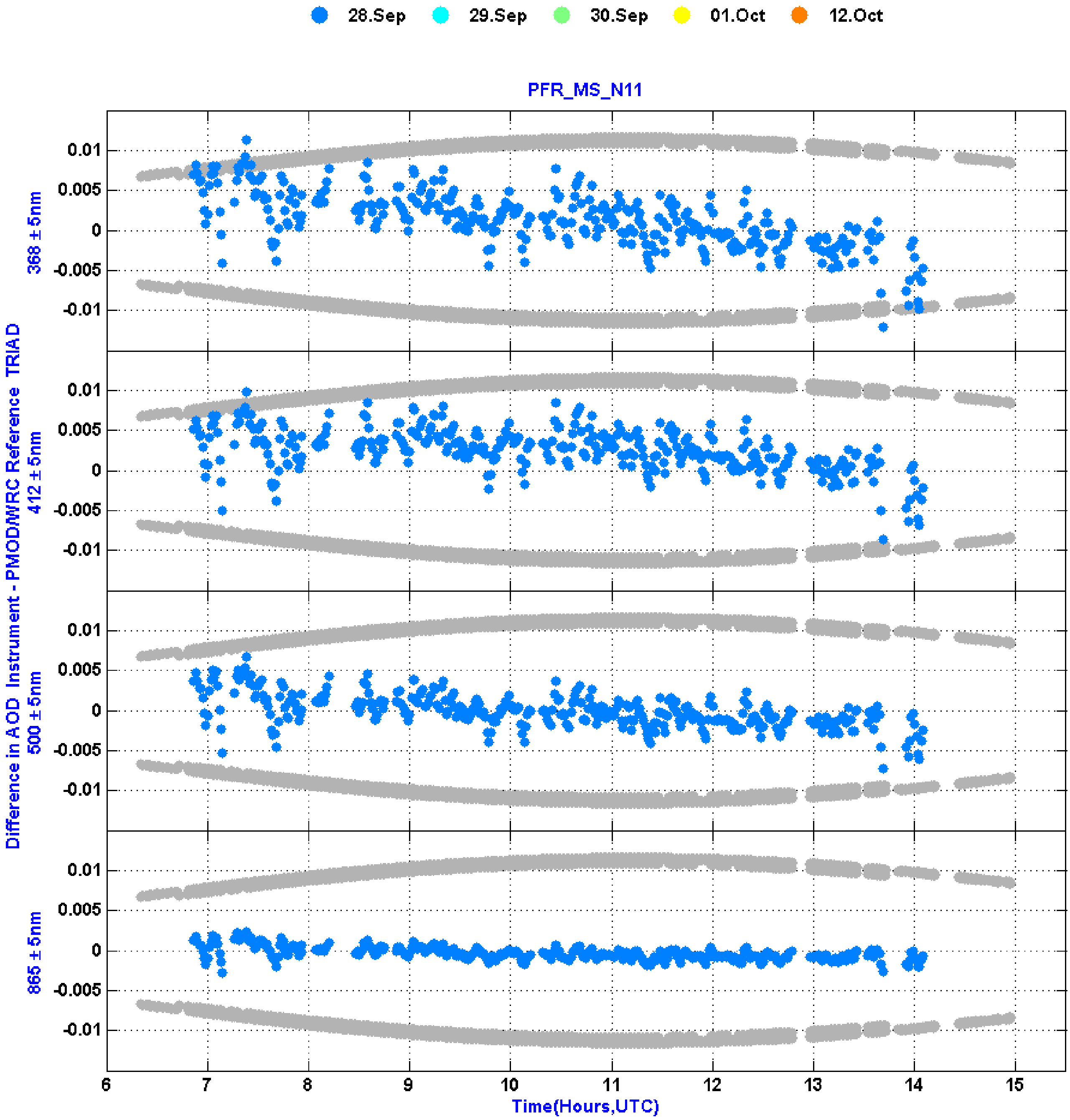

28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_CH_N25
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

PFR_CH_N27

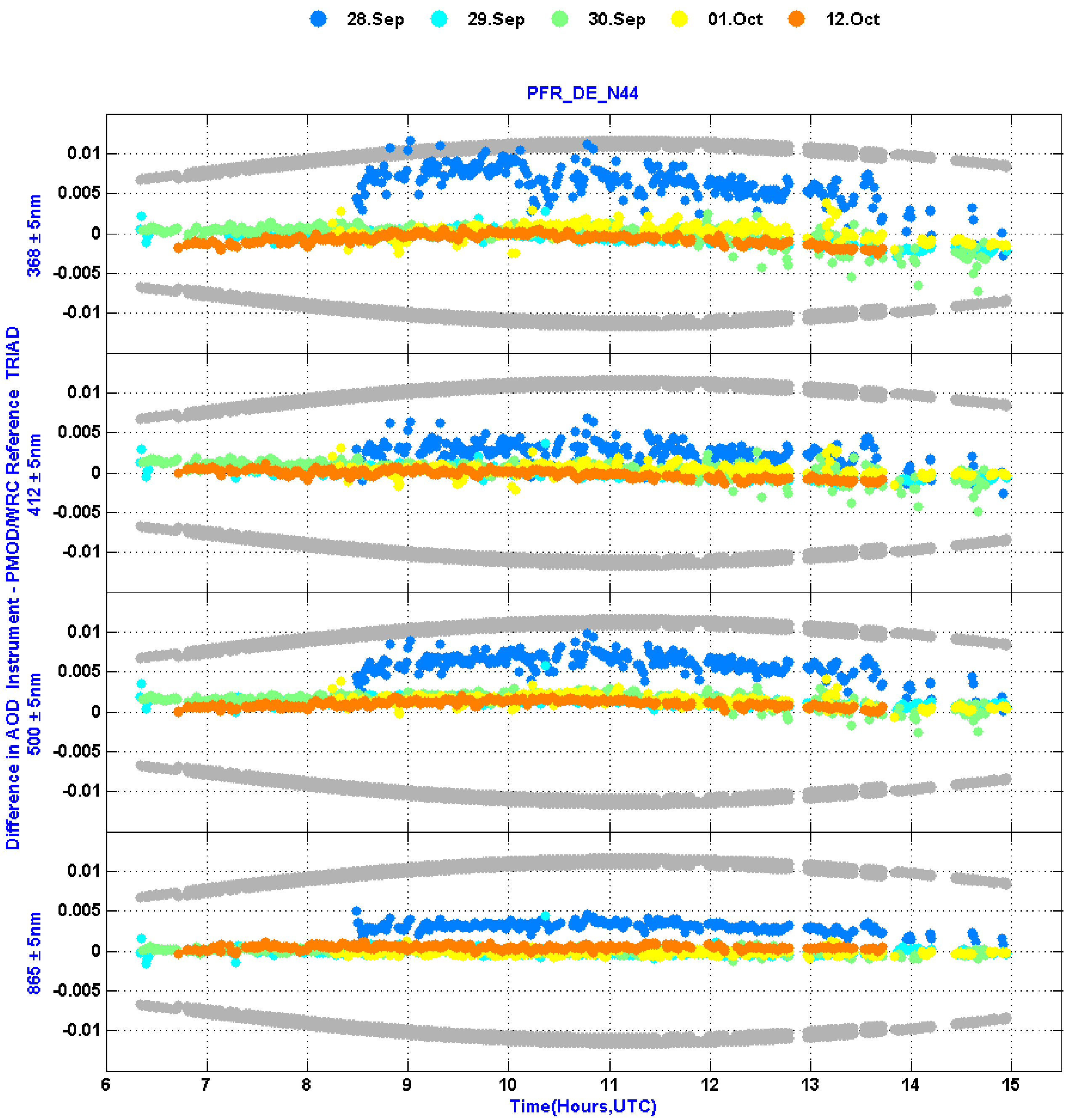


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_CH_N27
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

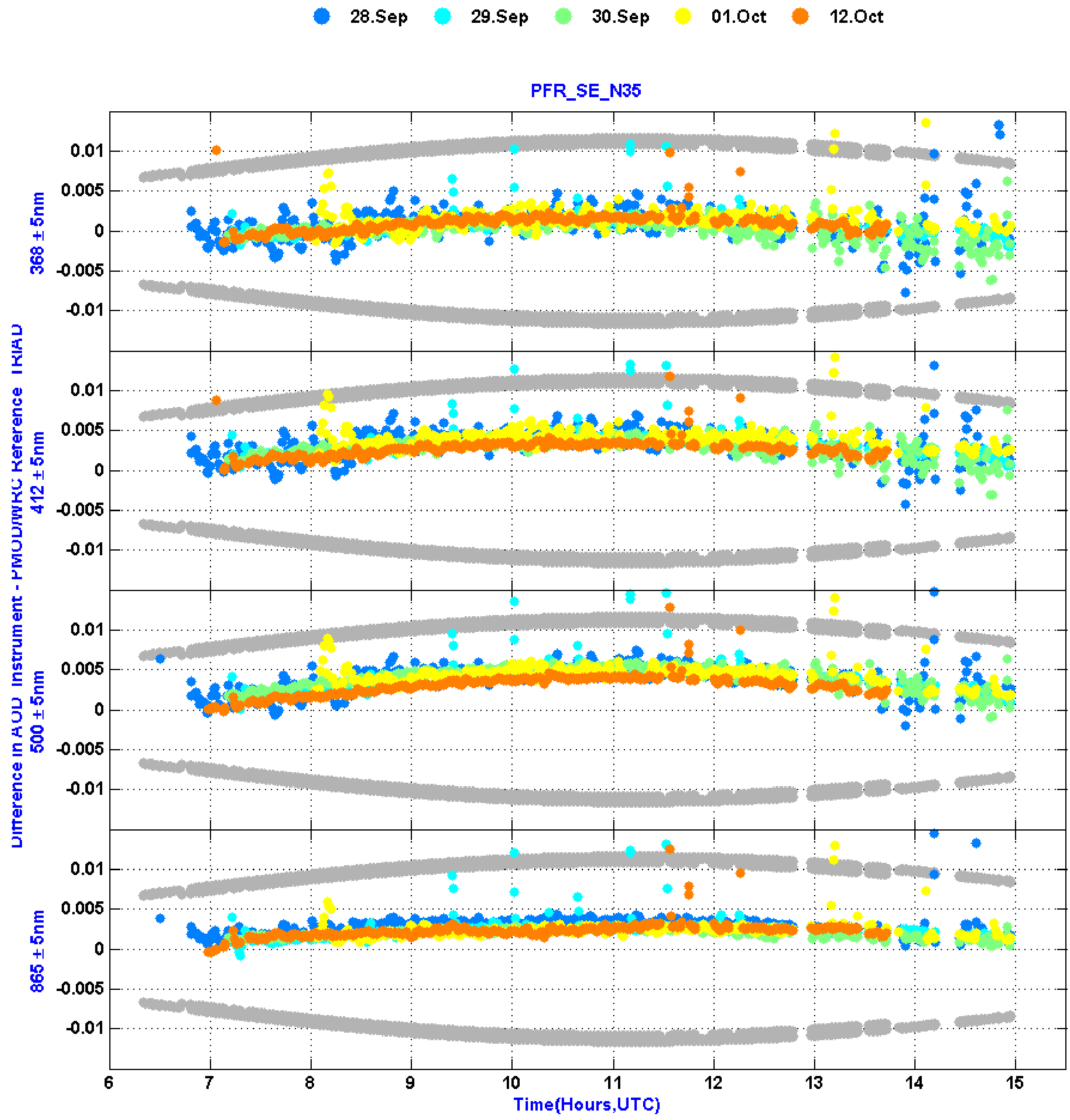
PFR_MS_N11


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_MS_N11
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

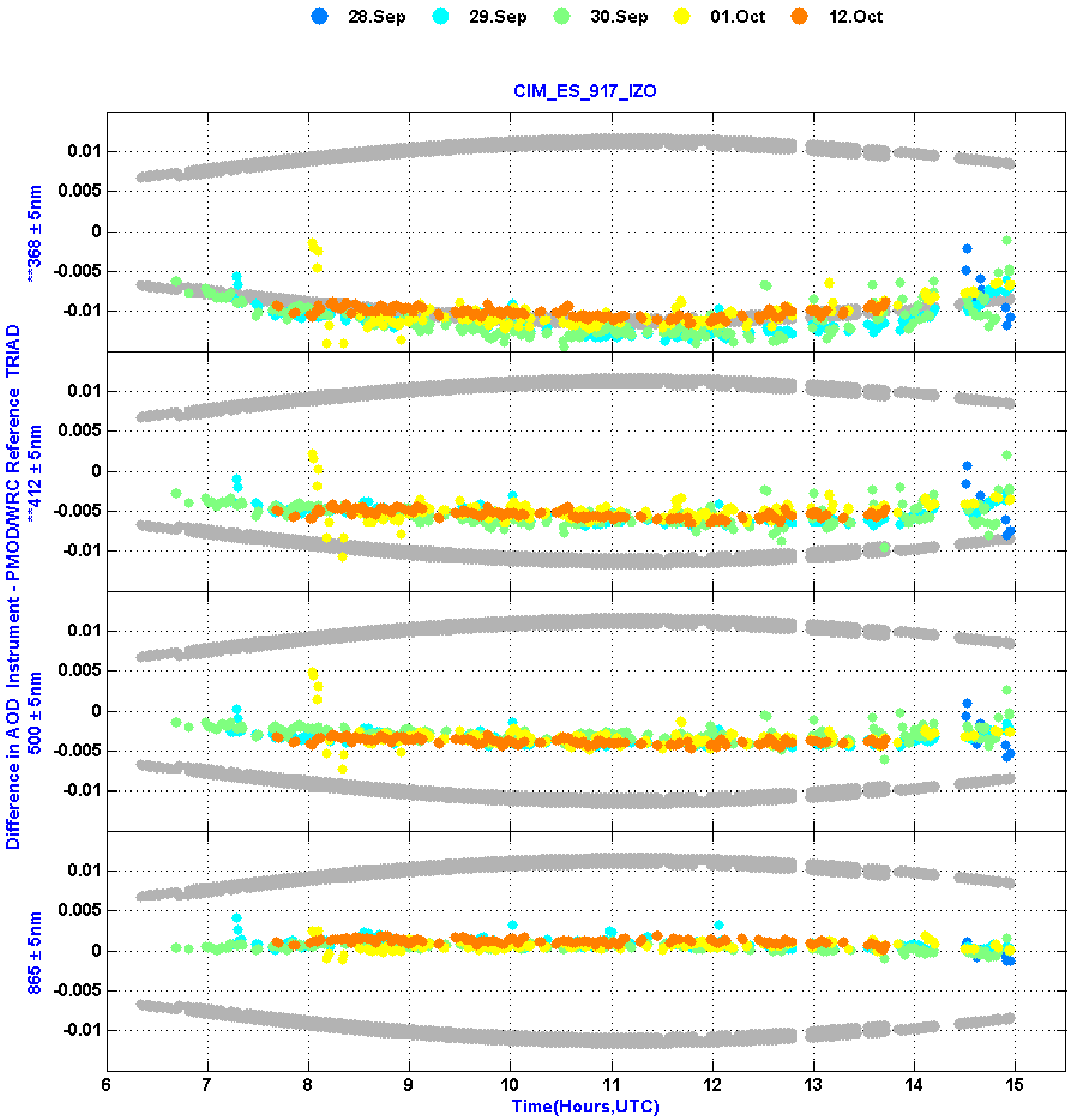
PFR_DE_N44


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_DE_N44
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

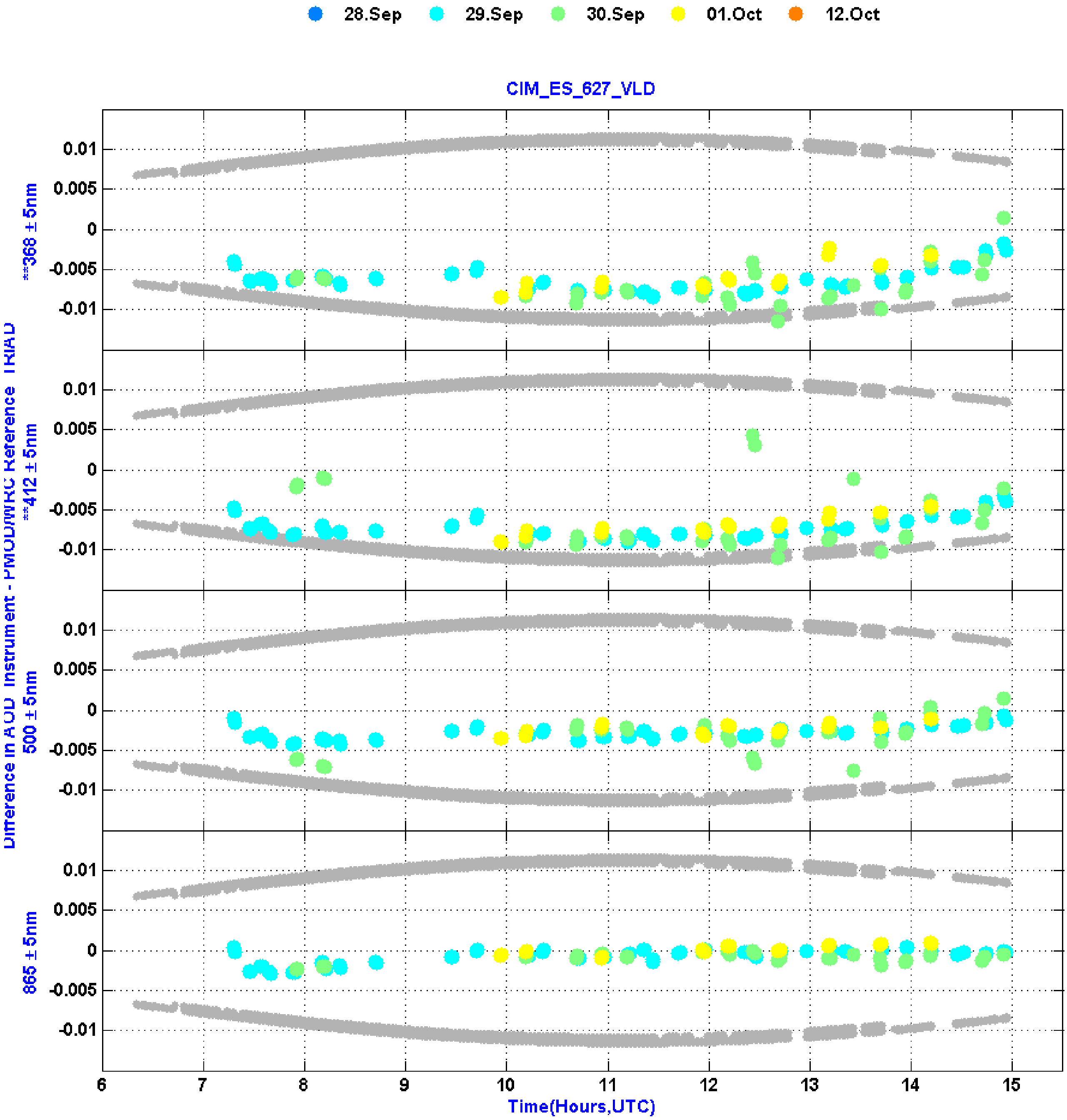
PFR_SE_N35


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
PFR_SE_N35
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

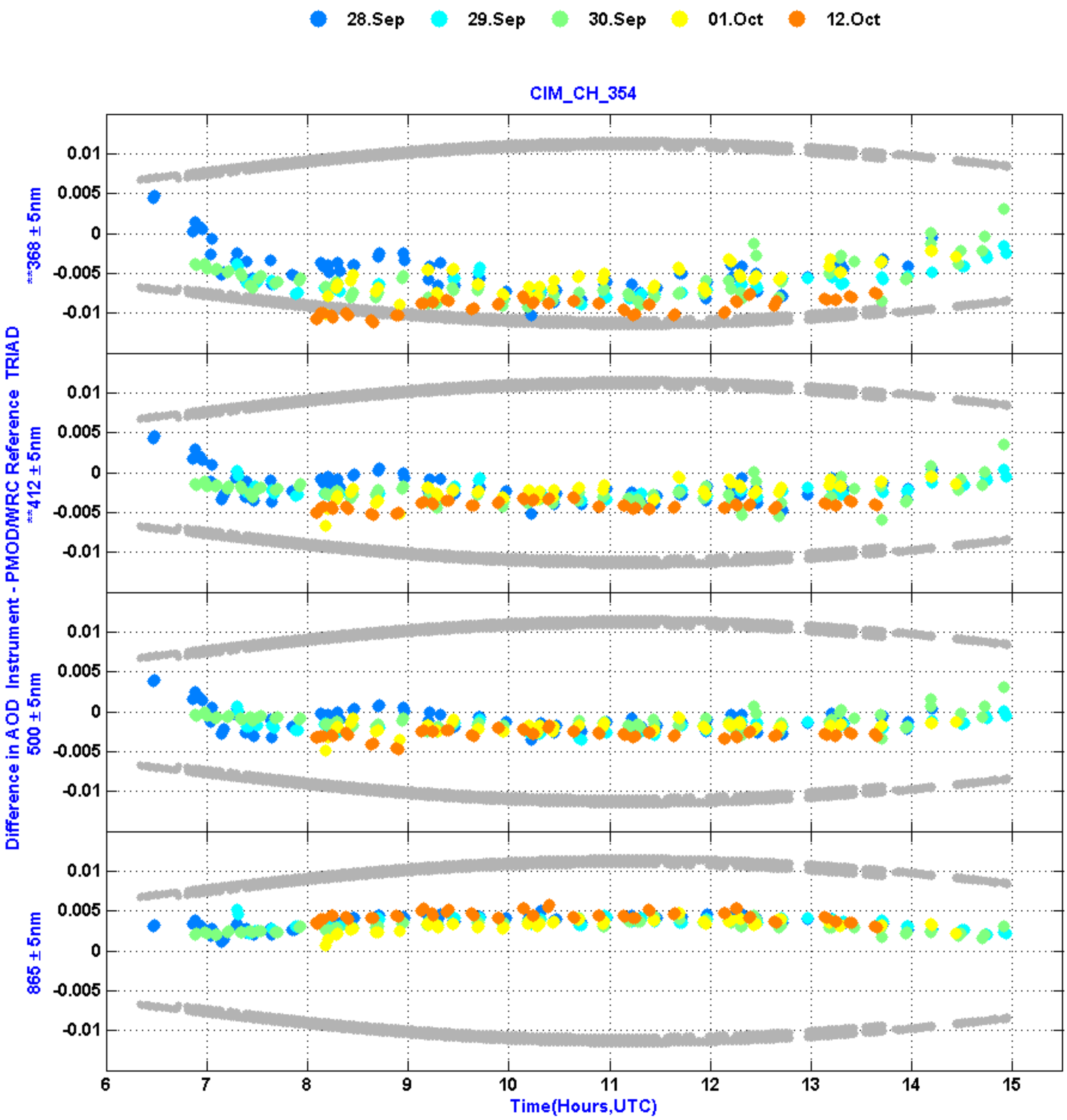
CIMEL
CIM_ES_917_IZO



CIM_ES_627_VLD



CIM_CH_354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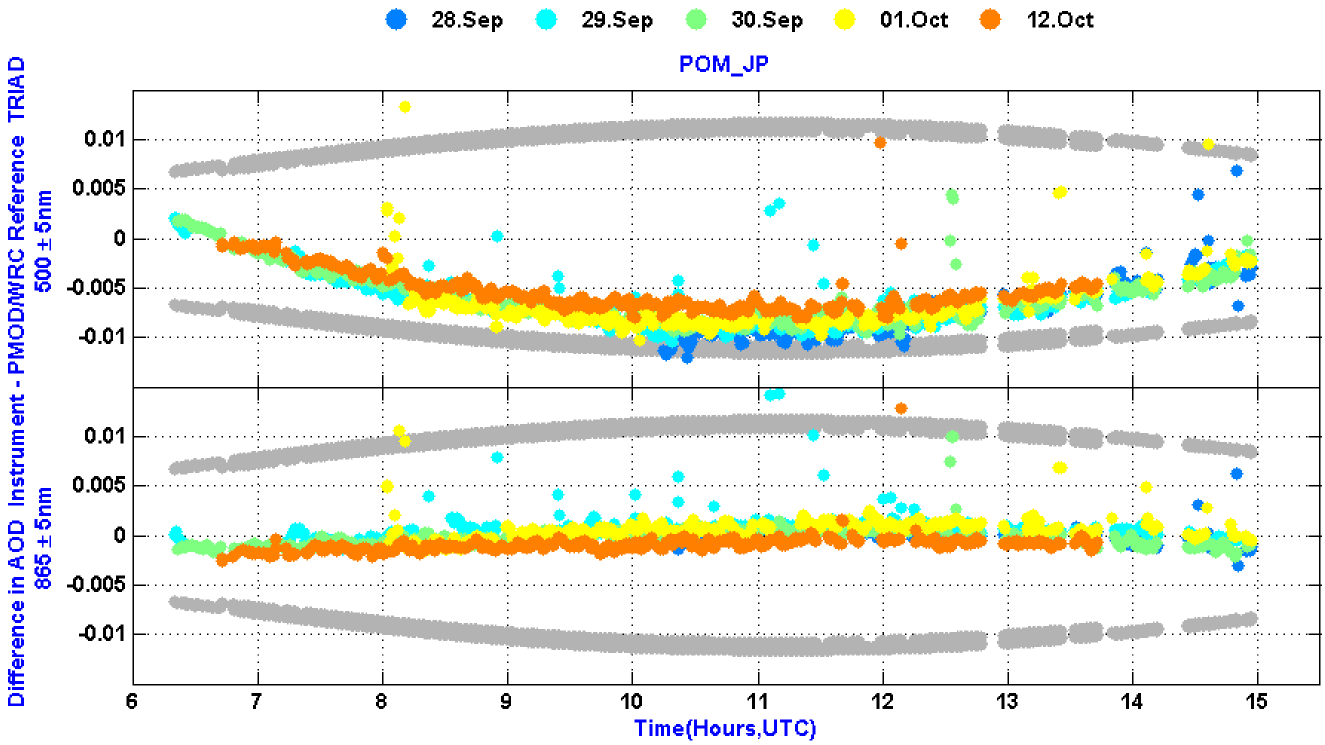
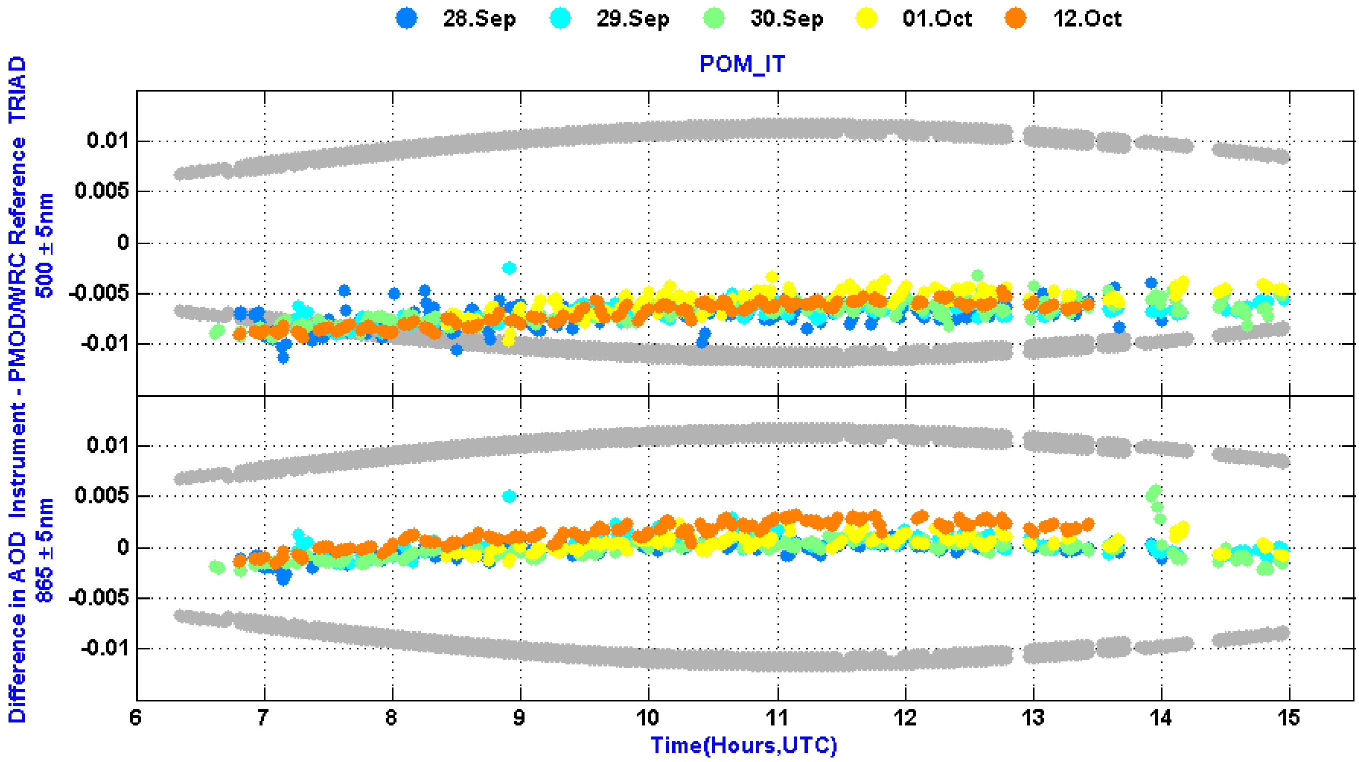
29.Sep
30.Sep
01.Oct
12.Oct
CIM_CH_354
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
**368 ± 5nm
**412 ± 5nm
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

POM_JP


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
POM_JP
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

POM_IT



28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
POM_IT
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
500 ± 5nm
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
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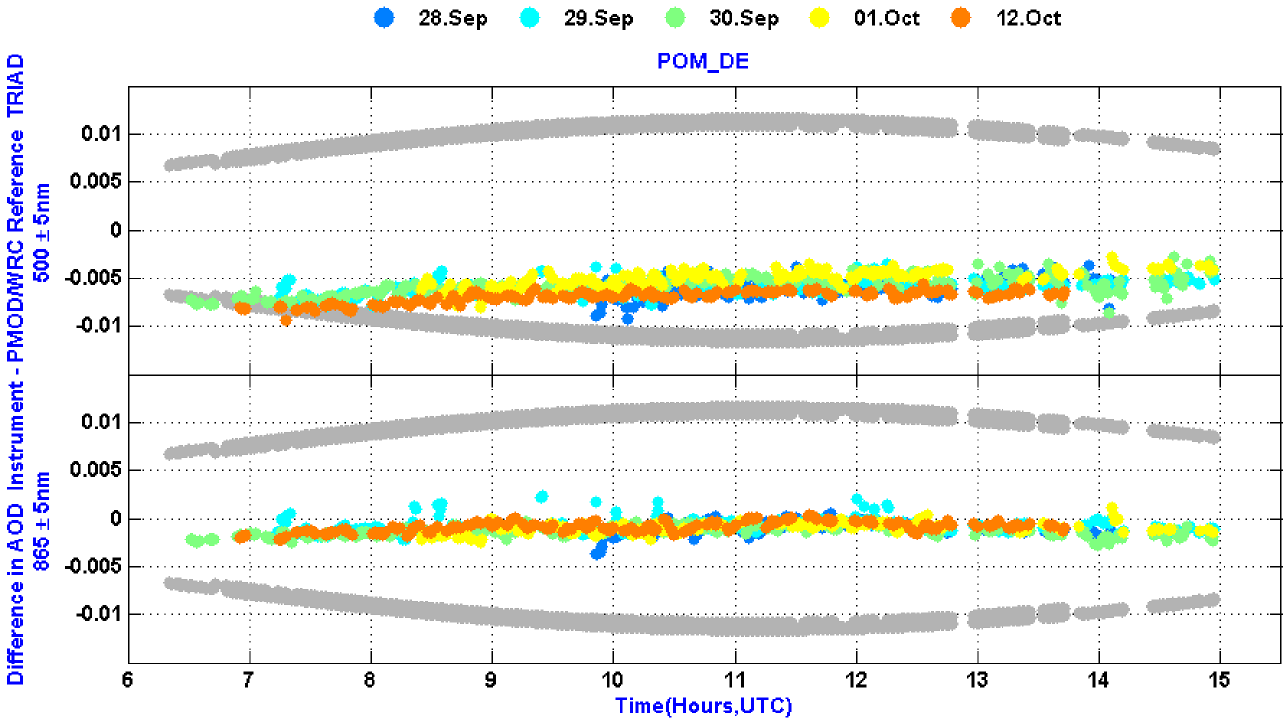
11
12
13
14
15
Time(Hours,UTC)

POM_DE


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
POM_DE
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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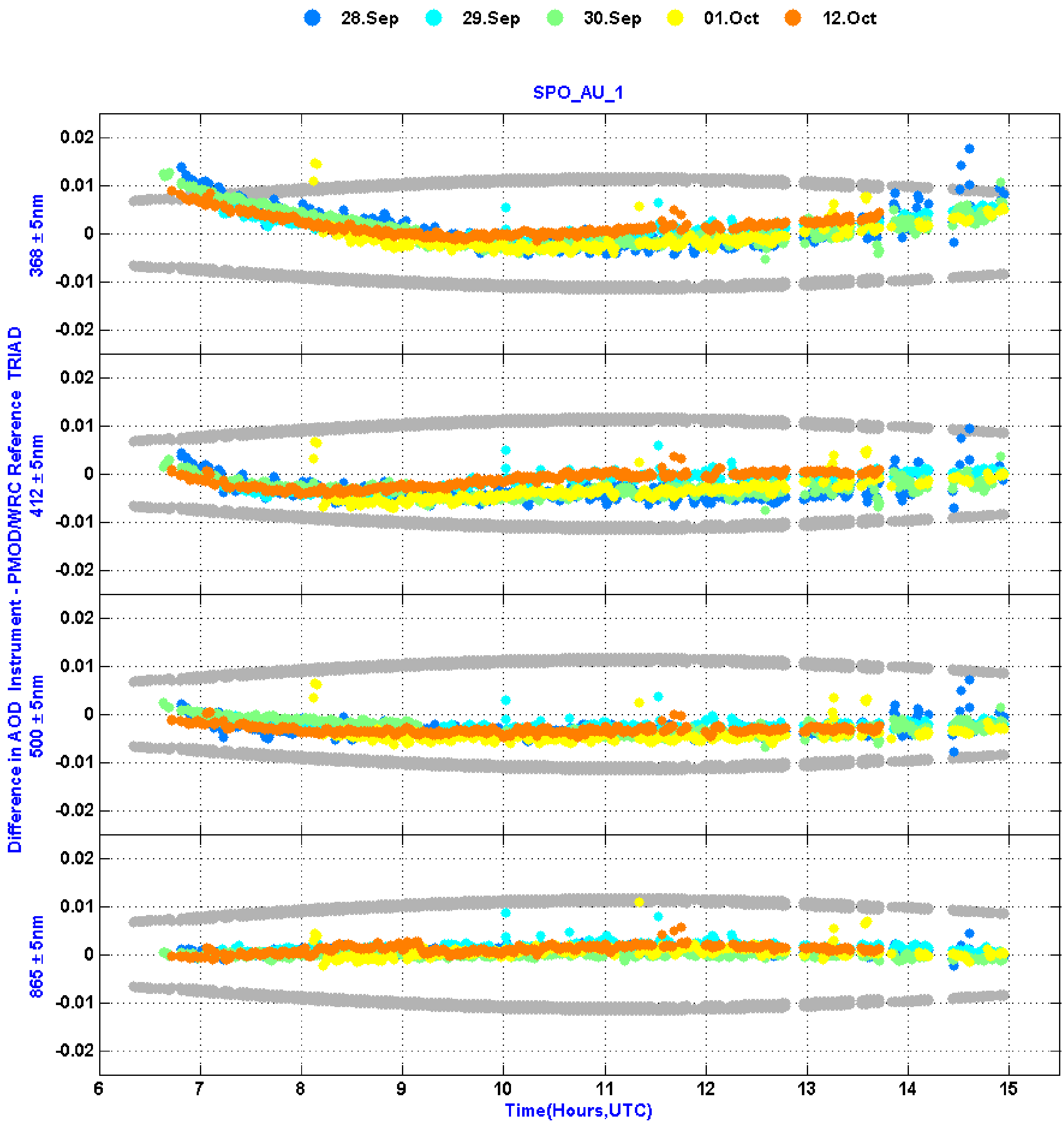
865 ± 5nm
0.01
0.005
0
-0.005
-0.01
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

SPO_AU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29.Sep
30.Sep
01.Oct
12.Oct
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Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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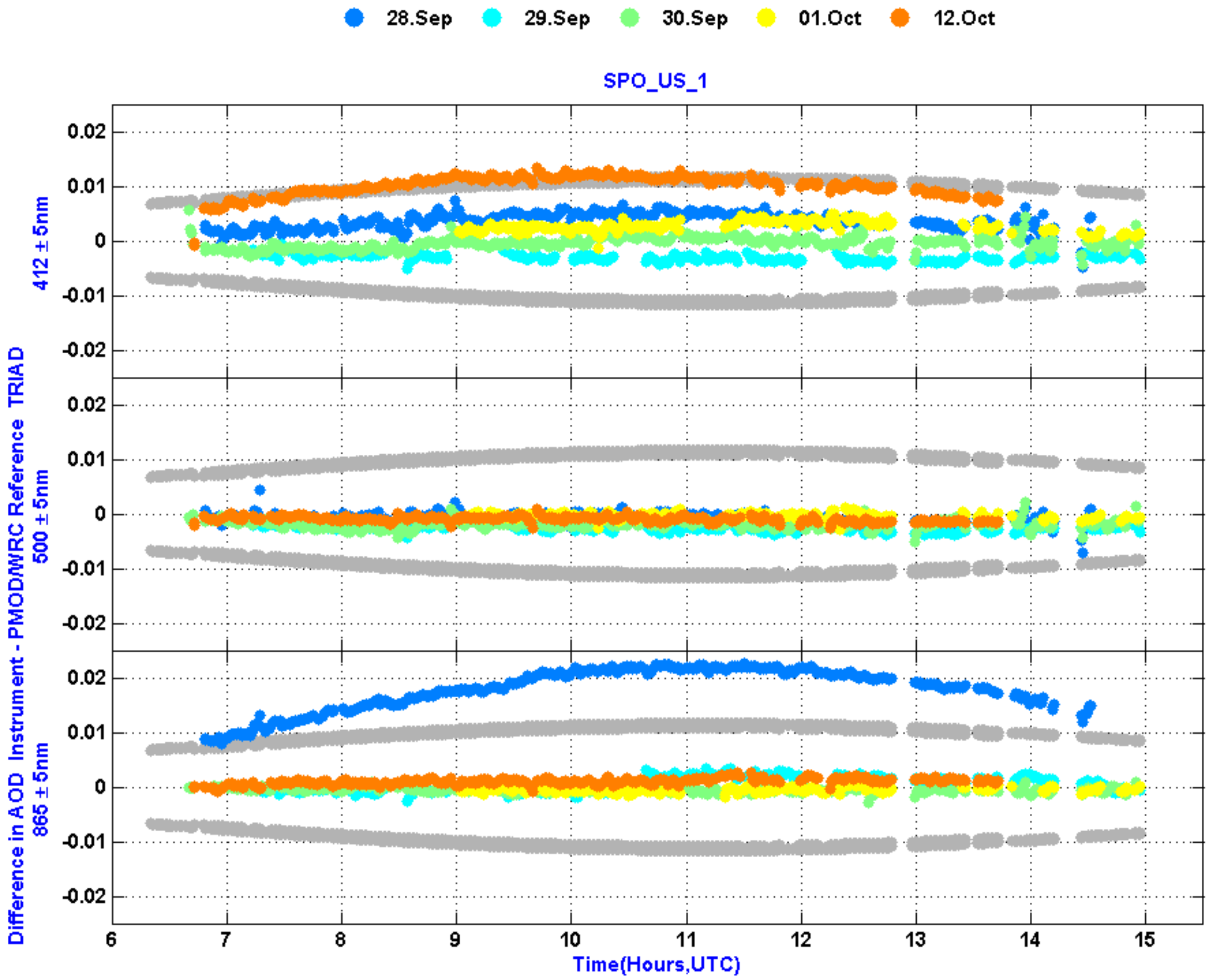
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

SPO_US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29.Sep
30.Sep
01.Oct
12.Oct
SPO_US_1
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412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
6
7
8
9
10
11
12
13
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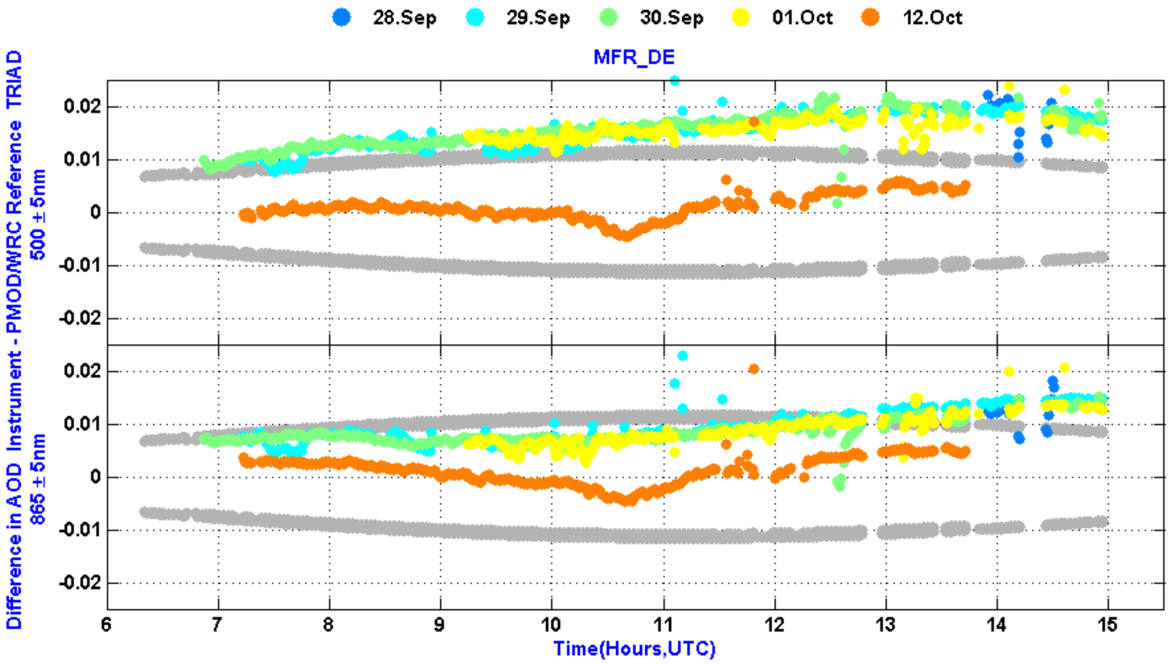
15
Time(Hours,UTC)

MFR_DE


28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
MFR_DE
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
6
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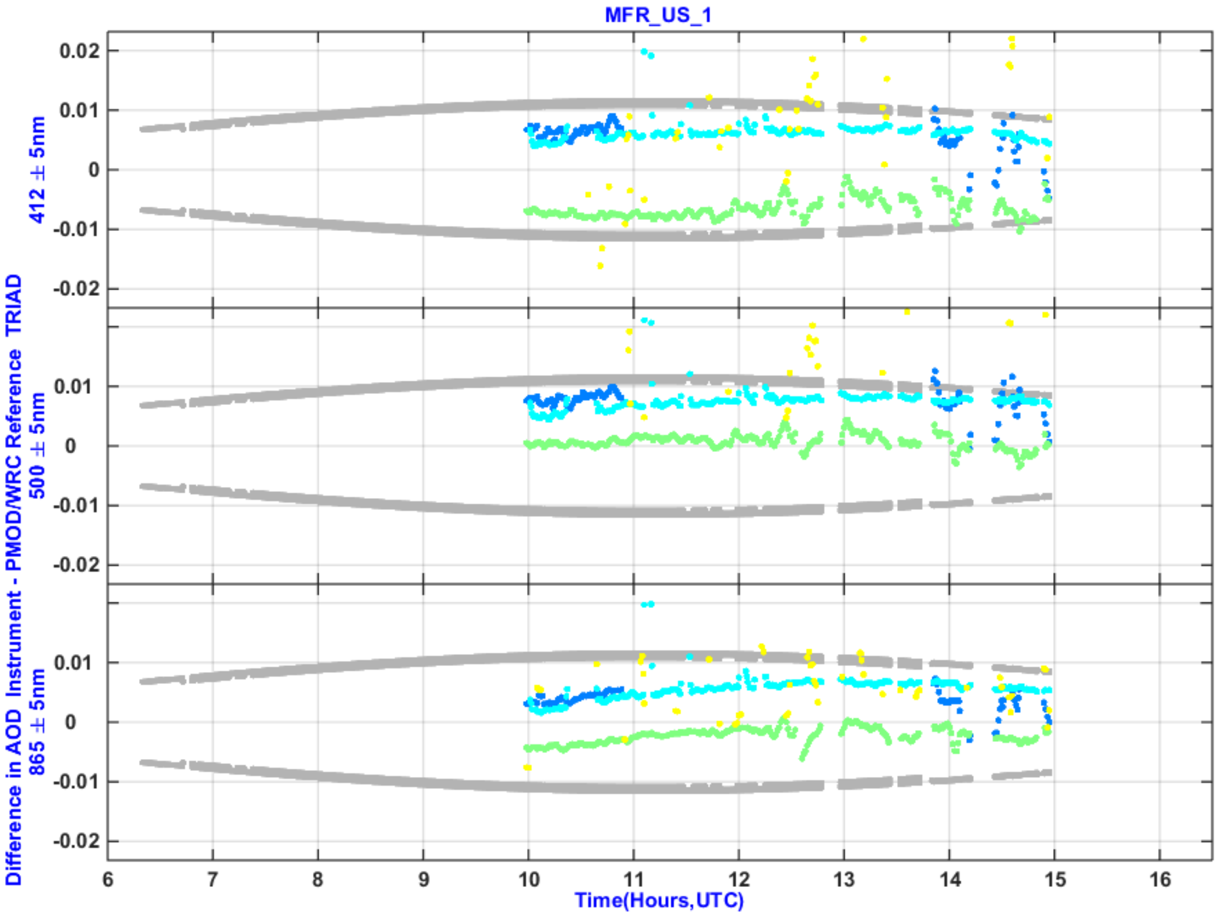
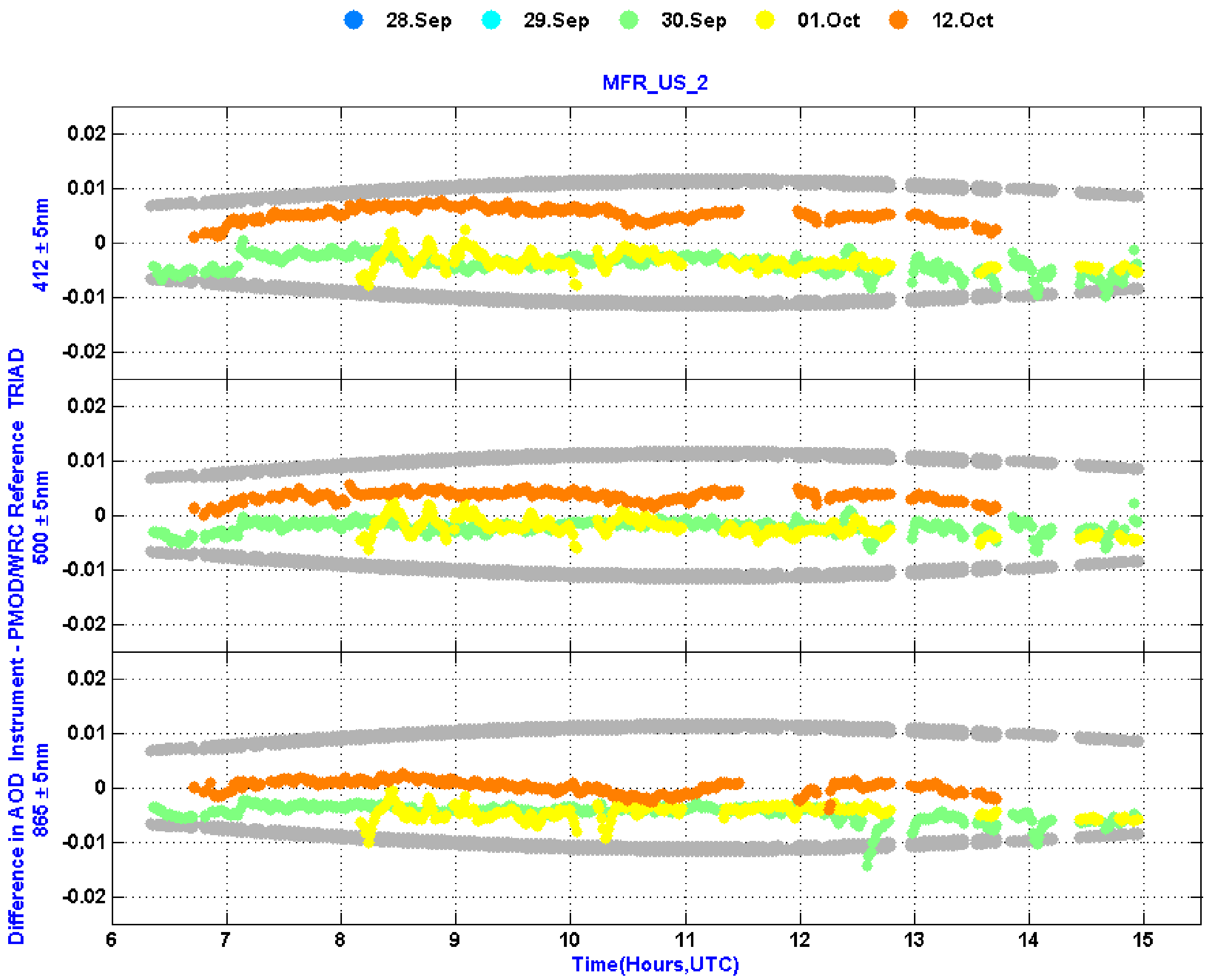
11
12
13
14
15
Time(Hours,UTC)

MFR_US_1


MFR_US_1
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
6
7
8
9
10
11
12
13
14
15
16
Time(Hours,UTC)

MFR_US_2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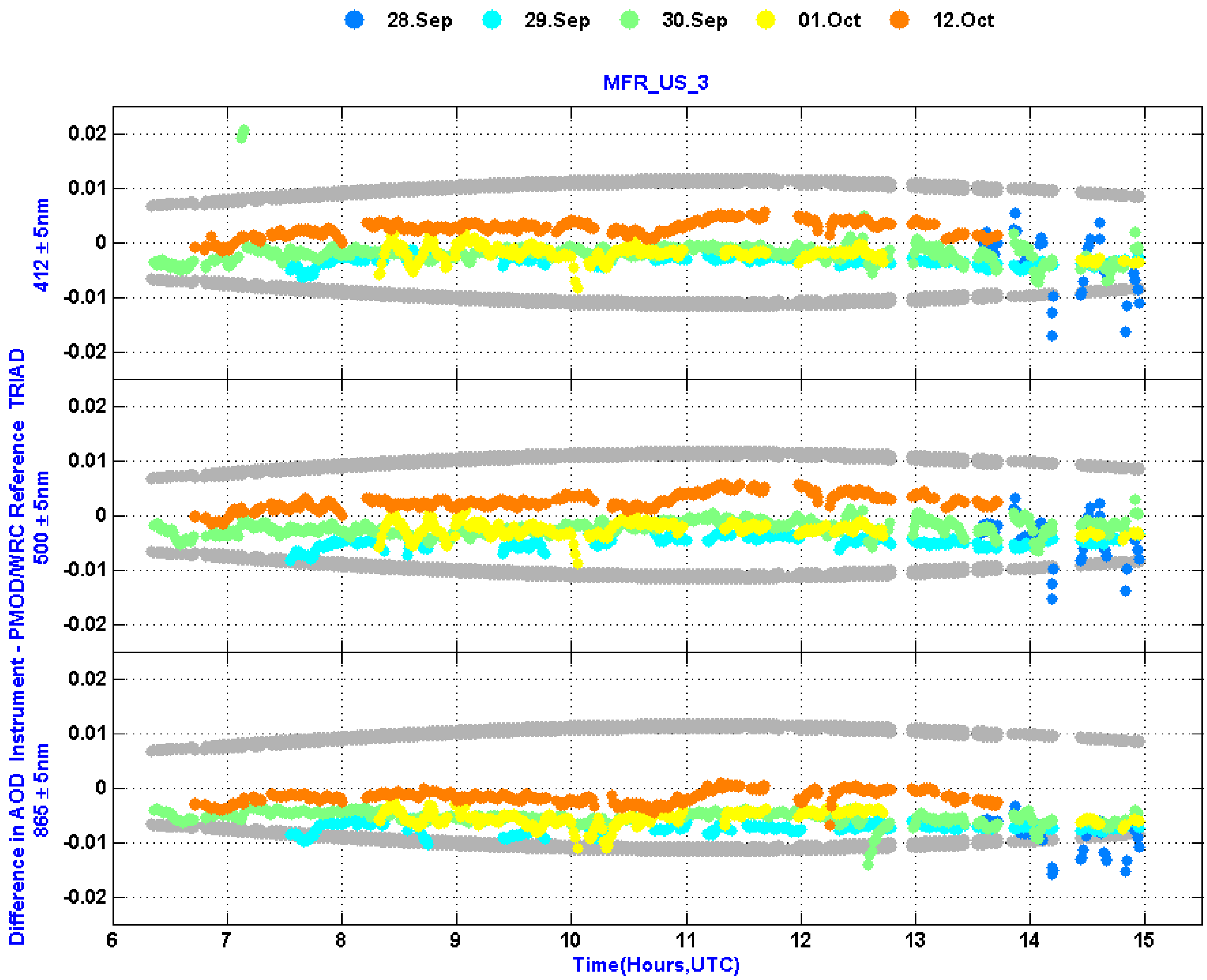
29.Sep
30.Sep
01.Oct
12.Oct
MFR_US_2
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

MFR_US_3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29.Sep
30.Sep
01.Oct
12.Oct
MFR_US_3
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
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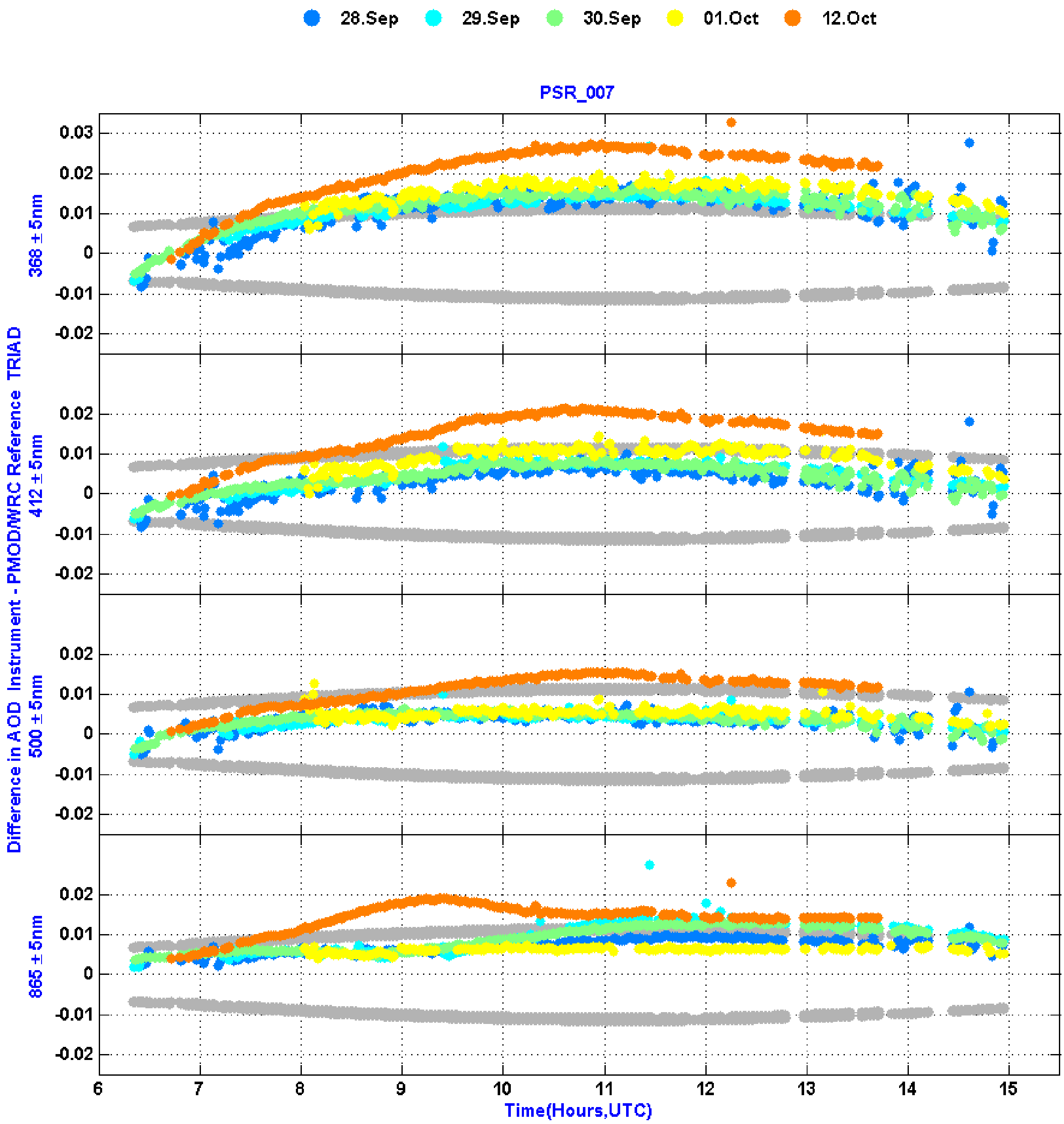
Time(Hours,UTC)

PSR_007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29.Sep
30.Sep
01.Oct
12.Oct
PSR_007
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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412 ± 5nm
500 ± 5nm
865 ± 5nm
0.03
0.02
0.01
0
-0.01
-0.02
6
7
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9
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13
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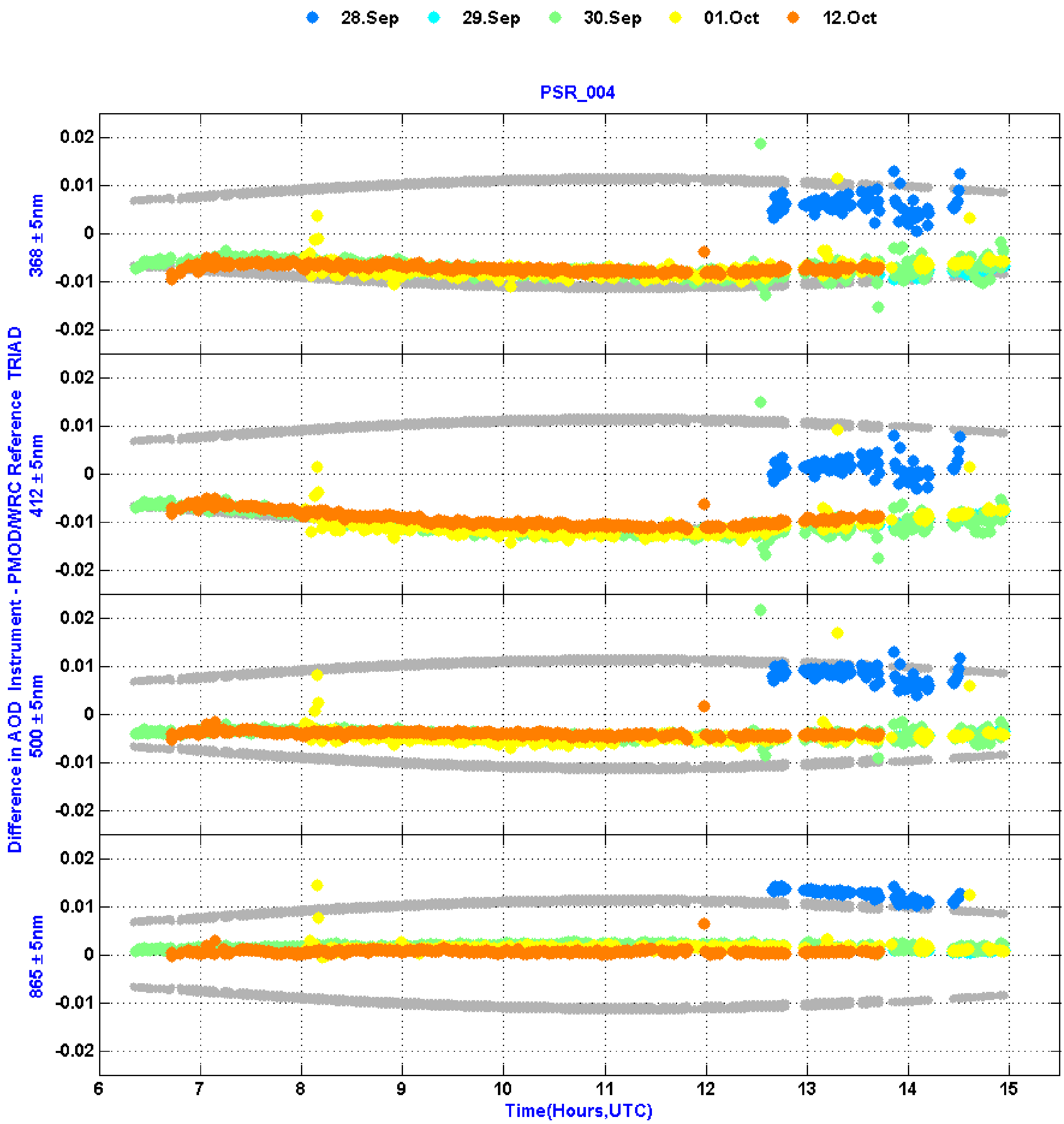
Time(Hours,UTC)

PSR_004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30.Sep
01.Oct
12.Oct
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Difference in AOD Instrument - PMOD/WRC Reference TRIAD
368 ± 5nm
412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
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9
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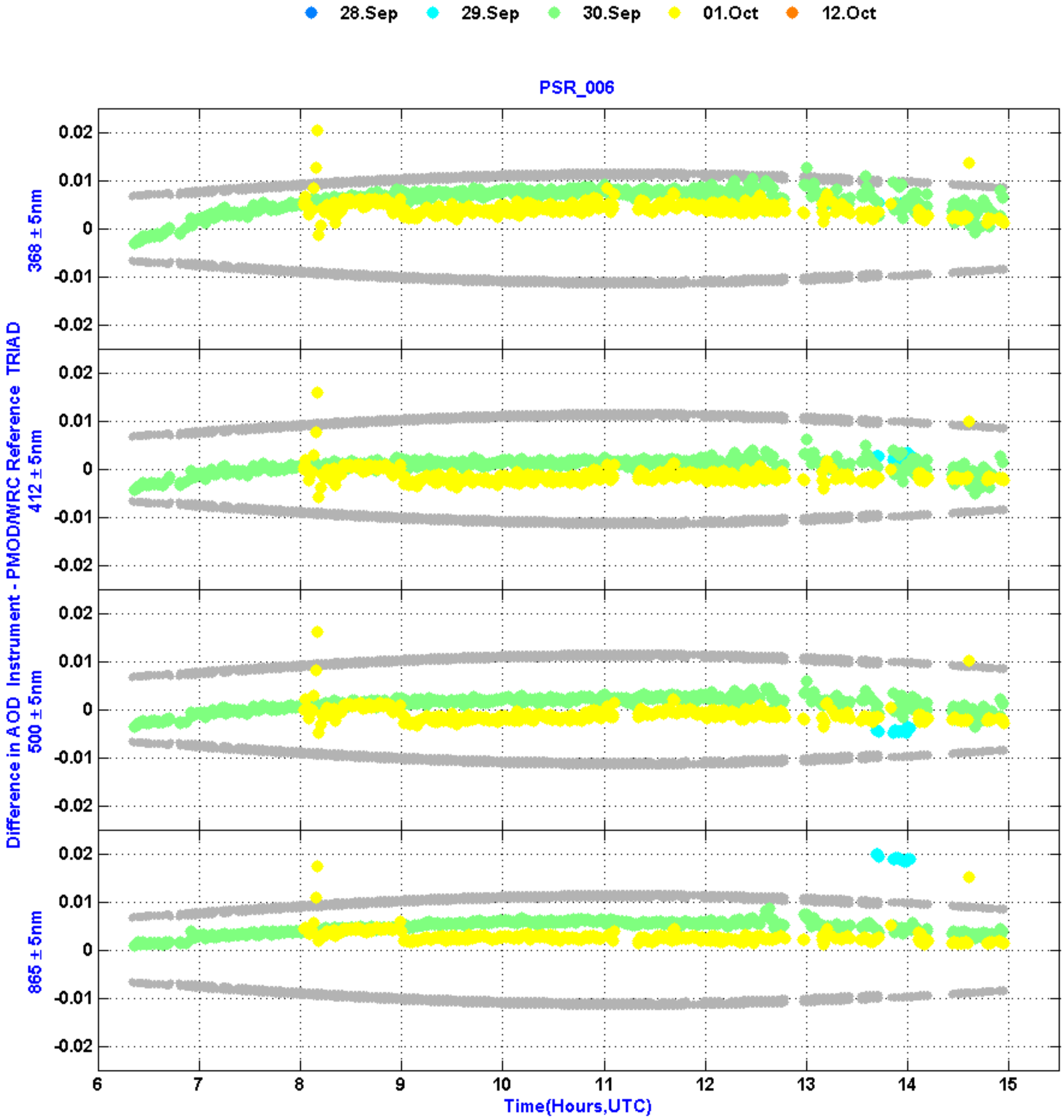
12
13
14
15
Time(Hours,UTC)

PSR_006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01.Oct
12.Oct
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Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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412 ± 5nm
500 ± 5nm
865 ± 5nm
0.02
0.01
0
-0.01
-0.02
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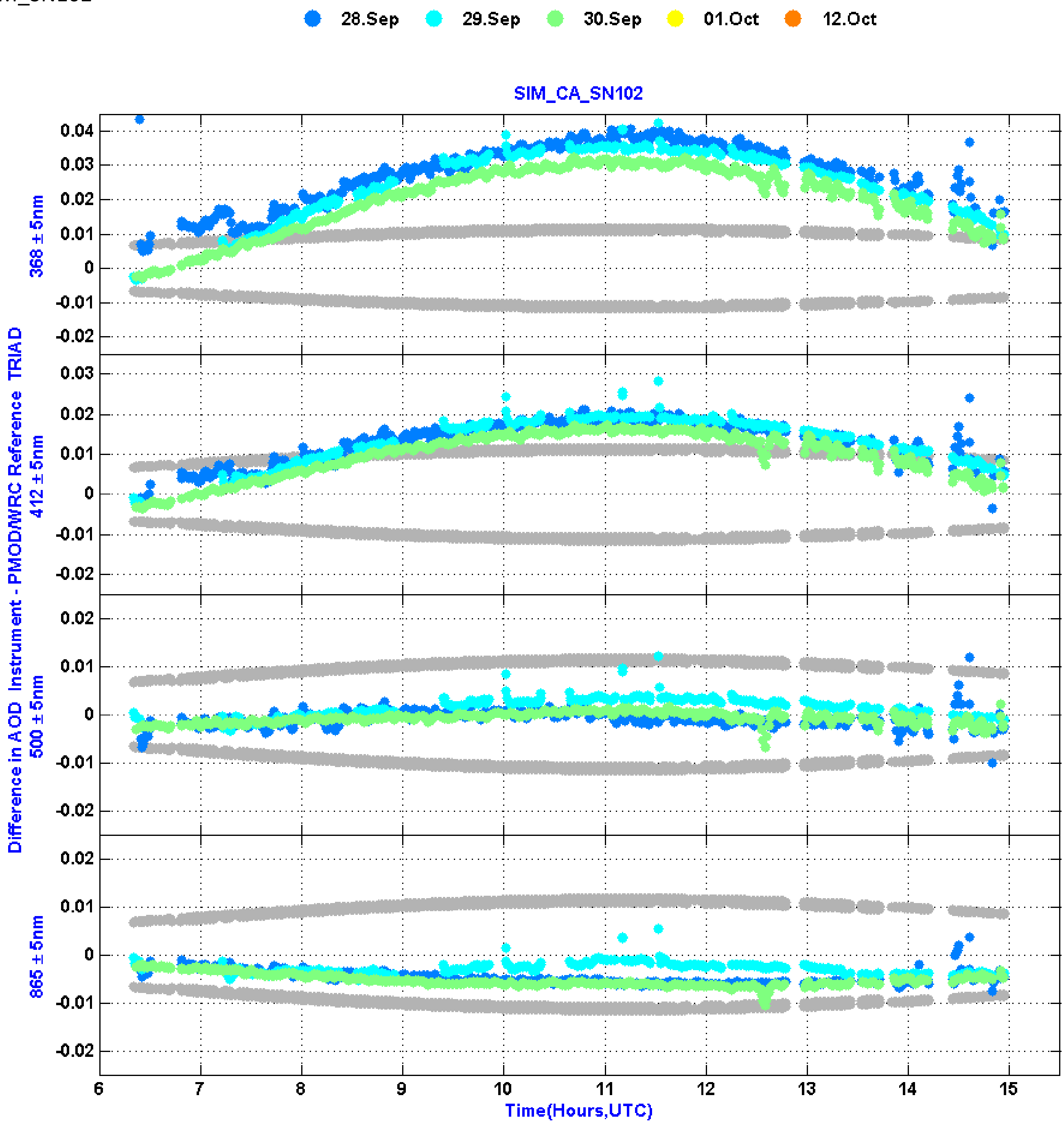
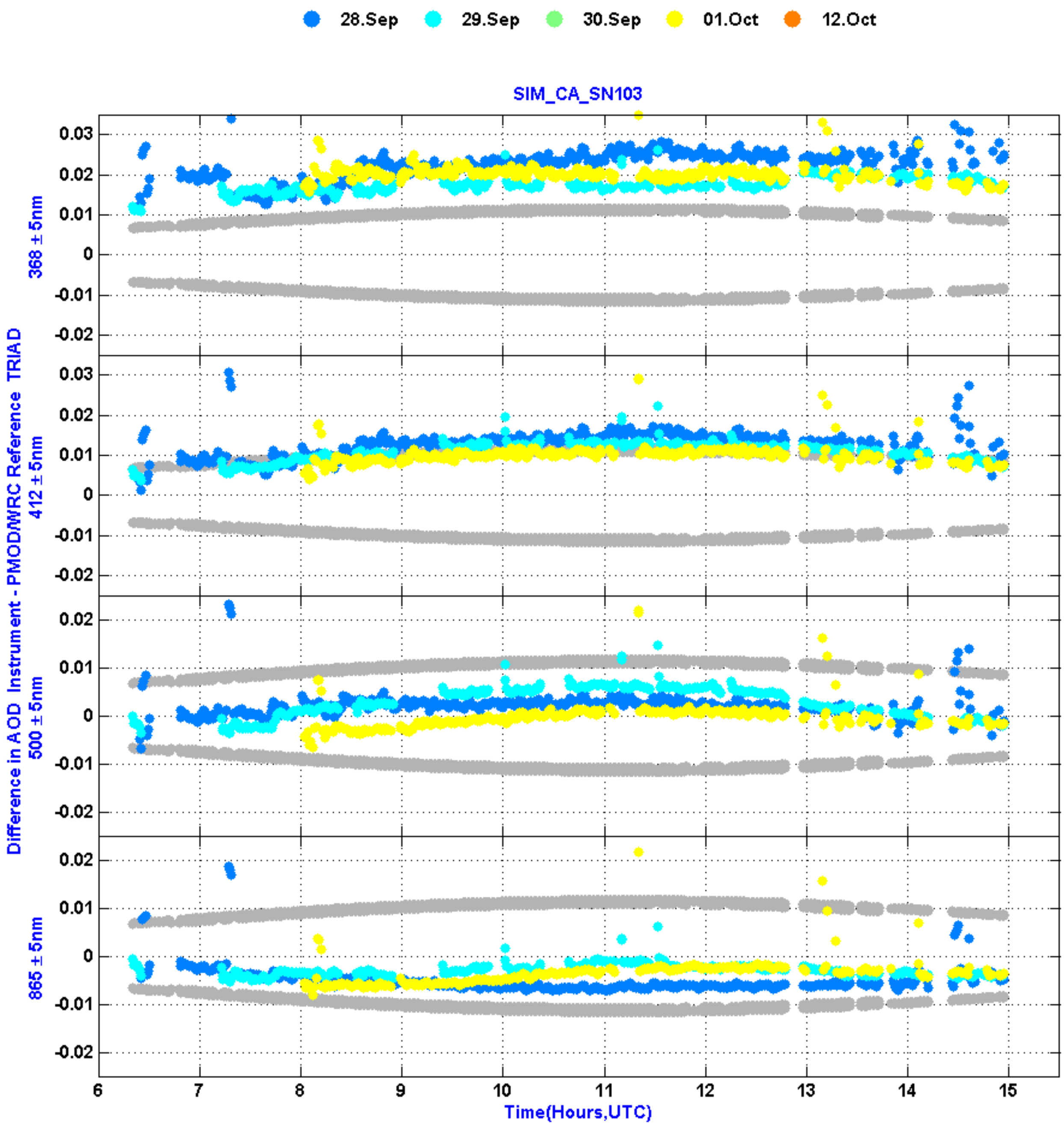
14
15
Time(Hours,UTC)

SIM_CA
SIM_SN102



SIM_SN103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30.Sep
01.Oct
12.Oct
SIM_CA_SN103
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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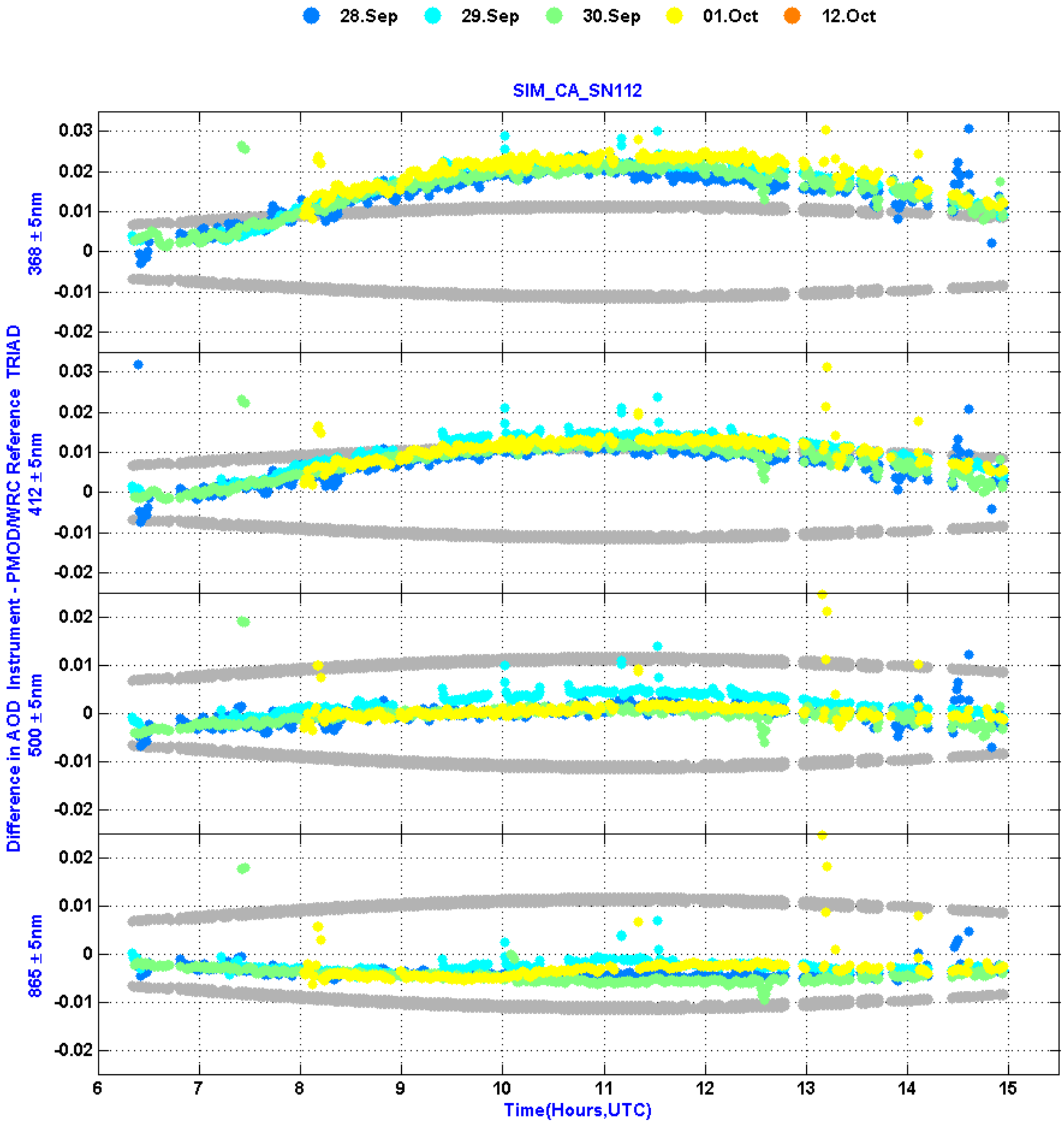
412 ± 5nm
500 ± 5nm
865 ± 5nm
Time(Hours,UTC)

SIM_SN112



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29.Sep
30.Sep
01.Oct
12.Oct
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500 ± 5nm
865 ± 5nm
0.03
0.02
0.01
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-0.02
6
7
8
9
10
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12
13
14
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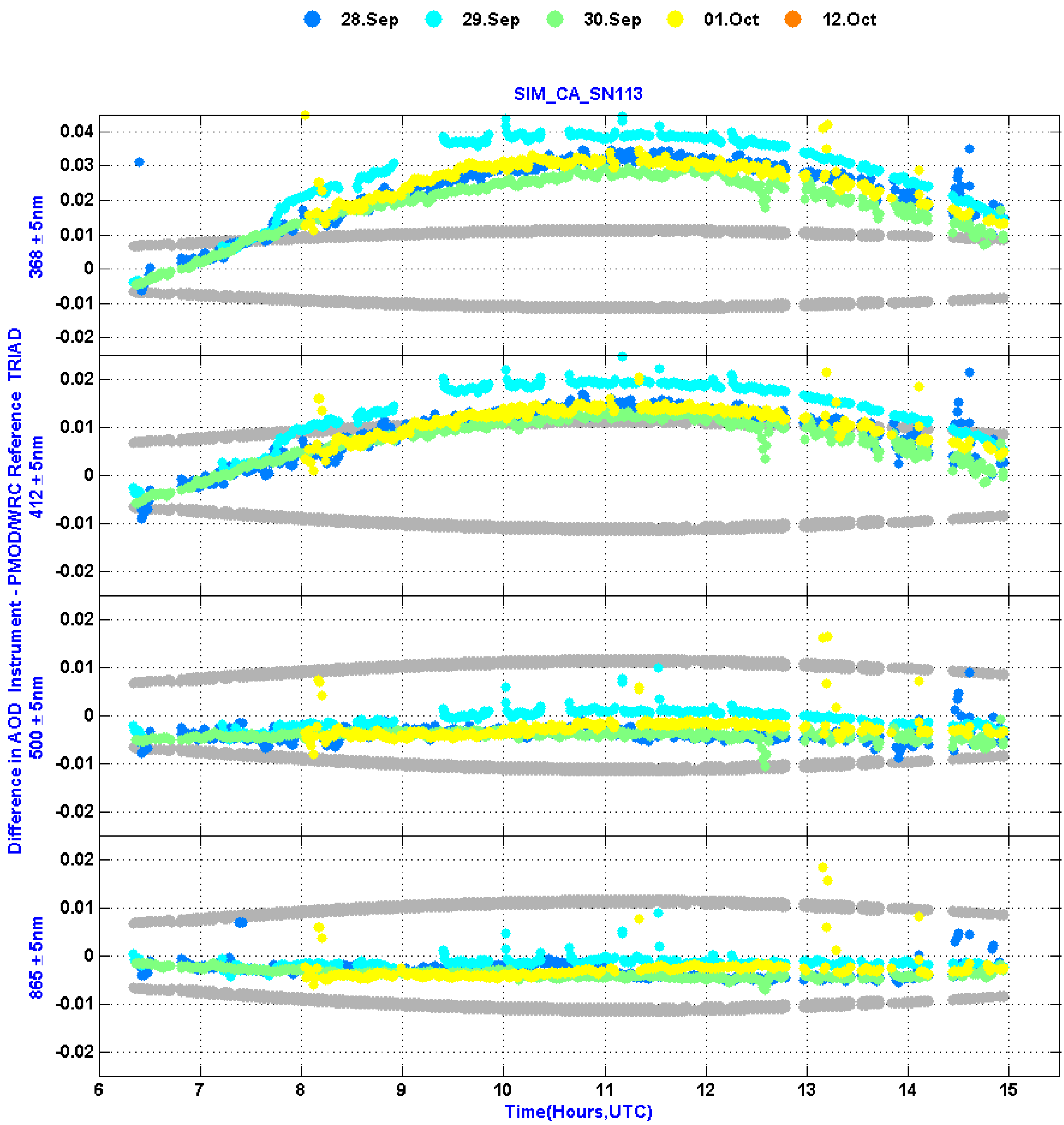
Time(Hours,UTC)

SIM_SN113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01.Oct
12.Oct
SIM_CA_SN113
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
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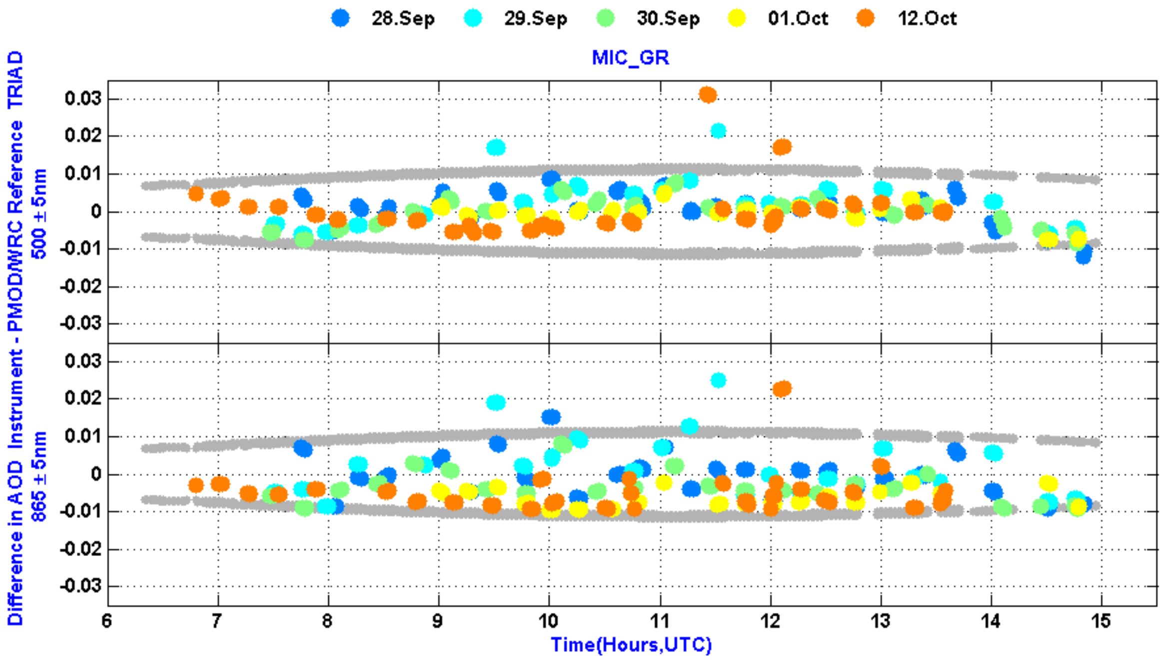
412 ± 5nm
500 ± 5nm
865 ± 5nm
Time(Hours,UTC)

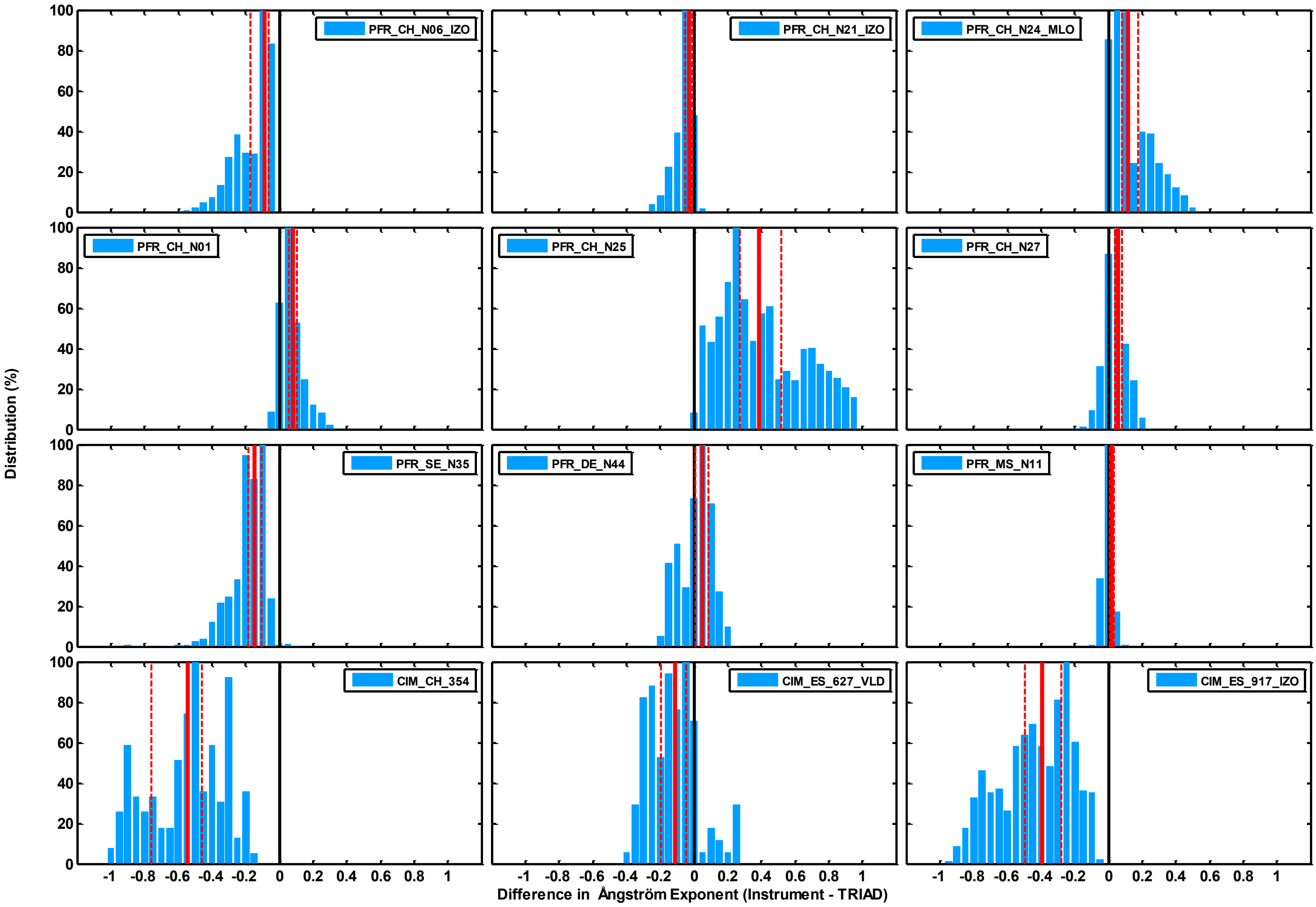
Microtops

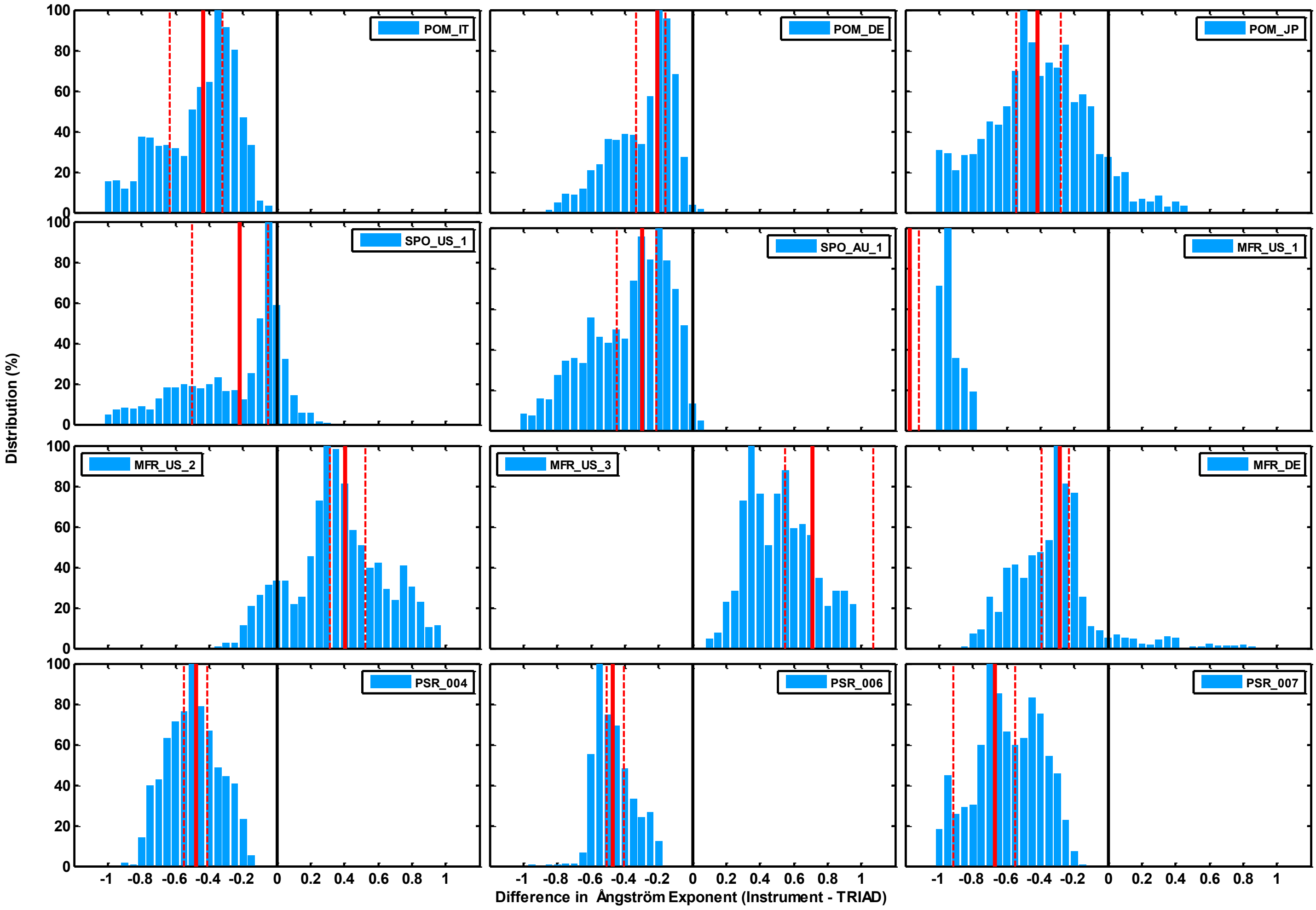

28.Sep
29.Sep
30.Sep
01.Oct
12.Oct
MIC_GR
Difference in AOD Instrument - PMOD/WRC Reference TRIAD
500 ± 5nm
865 ± 5nm
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
6
7
8
9
10
11
12
13
14
15
Time(Hours,UTC)

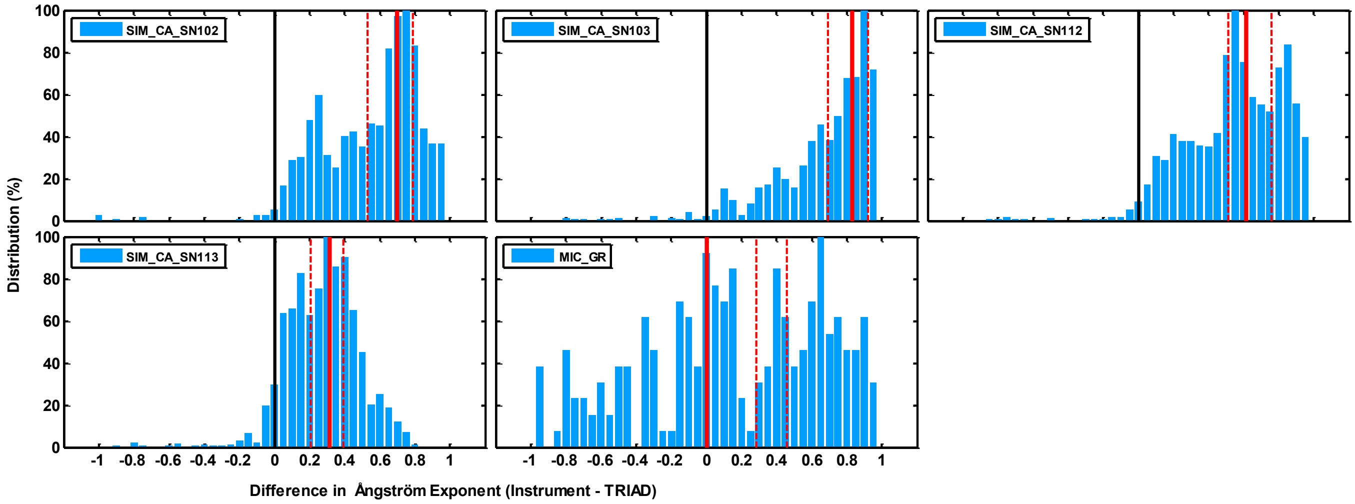
Annex 2d

ÅNGSTRÖM EXPONENT RESULTS

The following figures show the % distribution of AE differences from the triad during the 5 comparison days for each individual instrument.




POM_IT
POM_DE
POM_JP
SPO_US_1
SPO_AU_1
MFR_US_1
MFR_US_2
MFR_US_3
MFR_DE
PSR_004
PSR_006
PSR_007
Distribution (%)
Difference in Ångström Exponent (Instrument - TRIAD)


SIM_CA_SN102
SIM_CA_SN103
SIM_CA_SN112
SIM_CA_SN113
MIC_GR
Distribution (%)
100
80
60
40
20
0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
Difference in Ångström Exponent (Instrument - TRIAD)

LIST OF RECENT GLOBAL ATMOSPHERE WATCH REPORTS*

149. Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (prepared by J. Staehelin, J. Kerr, R. Evans and K. Vanicek) (WMO TD No. 1147).

150. Updated Guidelines for Atmospheric Trace Gas Data Management (Prepared by Ken Maserie and Pieter Tans (WMO TD No. 1149).

151. Report of the First CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 18-19 March 2003) (WMO TD No. 1181).

152. Current Activities of the Global Atmosphere Watch Programme (as presented at the 14th World Meteorological Congress, May 2003). (WMO TD No. 1168).

153. WMO/GAW Aerosol Measurement Procedures: Guidelines and Recommendations. (WMO TD No. 1178) (superseded by GAW Report No. 227).

154. WMO/IMEP-15 Trace Elements in Water Laboratory Intercomparison. (WMO TD No. 1195).

155. 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies (Gif sur Yvette, France, 3-5 June 2003) (WMO TD No. 1201).

156. Addendum for the Period 2005-2007 to the Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), GAW Report No. 142 (WMO TD No. 1209).

157. JOSIE-1998 Performance of EEC Ozone Sondes of SPC-6A and ENSCI-Z Type (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1218).

158. JOSIE-2000 Jülich Ozone Sonde Intercomparison Experiment 2000. The 2000 WMO international intercomparison of operating procedures for ECC-ozone sondes at the environmental simulation facility at Jülich (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1225).

159. IGOS-IGACO Report - September 2004 (WMO TD No. 1235), 68 pp. September 2004.

160. Manual for the GAW Precipitation Chemistry Programme (Guidelines, Data Quality Objectives and Standard Operating Procedures) (WMO TD No. 1251), 186 pp. November 2004.

161 12th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Toronto, Canada, 15-18 September 2003), 274 pp. May 2005.

162. WMO/GAW Experts Workshop on a Global Surface-Based Network for Long Term Observations of Column Aerosol Optical Properties, Davos, Switzerland, 8-10 March 2004 (edited by U. Baltensperger, L. Barrie and C. Wehrli) (WMO TD No. 1287), 153 pp, November 2005.

163. World Meteorological Organization Activities in Support of the Vienna Convention on Protection of the Ozone Layer (WMO No. 974), 4 pp. September 2005.

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* *(A full list is available at http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html)*

164. Instruments to Measure Solar Ultraviolet Radiation: Part 2: Broadband Instruments Measuring Erythemally Weighted Solar Irradiance (WMO TD No. 1289), 55 pp. July 2008, electronic version 2006.

165. Report of the CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2005 Workshop, 14-18 March 2005, Geneva, Switzerland (WMO TD No. 1302), 189 pp. March 2005.

166. Joint WMO-GAW/ACCENT Workshop on The Global Tropospheric Carbon Monoxide Observations System, Quality Assurance and Applications (EMPA, Dübendorf, Switzerland, 24 – 26 October 2005) (edited by J. Klausen) (WMO TD No. 1335), 36 pp. September 2006.

167. The German Contribution to the WMO Global Atmosphere Watch Programme upon the 225th Anniversary of GAW Hohenpeissenberg Observatory (edited by L.A. Barrie, W. Fricke and R. Schleyer (WMO TD No. 1336), 124 pp. December 2006.

168. 13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Boulder, Colorado, USA, 19-22 September 2005) (edited by J.B. Miller) (WMO TD No. 1359), 40 pp. December 2006.

169. Chemical Data Assimilation for the Observation of the Earth's Atmosphere – ACCENT/WMO Expert Workshop in support of IGACO (edited by L.A. Barrie, J.P. Burrows, P. Monks and P. Borrell) (WMO TD No. 1360), 196 pp. December 2006.

170. WMO/GAW Expert Workshop on the Quality and Applications of European GAW Measurements (Tutzing, Germany, 2-5 November 2004) (WMO TD No. 1367).

171. A WMO/GAW Expert Workshop on Global Long-Term Measurements of Volatile Organic Compounds (VOCs) (Geneva, Switzerland, 30 January – 1 February 2006) (WMO TD No. 1373), 36 pp. February 2007.

172. WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015 (WMO TD No. 1384), 108 pp. August 2008.

173. Report of the CAS Joint Scientific Steering Committee on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 11-12 April 2007) (WMO TD No.1410), 33 pp. June 2008.

174. World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide (WMO TD No. 1416), 50 pp. January 2008.

175. The Ninth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Delft, Netherlands, 31-May – 3 June 2005) (WMO TD No. 1419), 69 pp. March 2008.

176. The Tenth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Northwich, United Kingdom, 4-8 June 2007) (WMO TD No. 1420), 61 pp. March 2008.

177. Joint Report of COST Action 728 and GURME – Overview of Existing Integrated (off-line and on-line) Mesoscale Meteorological and Chemical Transport Modelling in Europe (ISBN 978-1-905313-56-3) (WMO TD No. 1427), 106 pp. May 2008.

178. Plan for the implementation of the GAW Aerosol Lidar Observation Network GALION, (Hamburg, Germany, 27 - 29 March 2007) (WMO TD No. 1443), 52 pp. November 2008.

179. Intercomparison of Global UV Index from Multiband Radiometers: Harmonization of Global UVI and Spectral Irradiance (WMO TD No. 1454), 61 pp. March 2009.

180. Towards a Better Knowledge of Umkehr Measurements: A Detailed Study of Data from Thirteen Dobson Intercomparisons (WMO TD No. 1456), 50 pp. December 2008.

181. Joint Report of COST Action 728 and GURME – Overview of Tools and Methods for Meteorological and Air Pollution Mesoscale Model Evaluation and User Training (WMO TD No. 1457), 121 pp. November 2008.

182. IGACO-Ozone and UV Radiation Implementation Plan (WMO TD No. 1465), 49 pp. April 2009.

183. Operations Handbook – Ozone Observations with a Dobson Spectrophotometer (WMO TD No. 1469), 91 pp. March 2009.

184. Technical Report of Global Analysis Method for Major Greenhouse Gases by the World Data Center for Greenhouse Gases (WMO TD No. 1473), 29 pp. June 2009.

185. Guidelines for the Measurement of Methane and Nitrous Oxide and their Quality Assurance (WMO TD No. 1478), 49 pp. September 2009.

186. 14^{th} WMO/IAEA Meeting of Experts on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques (Helsinki, Finland, 10-13 September 2007) (WMO TD No. 1487), 31 pp. April 2009.

187. Joint Report of COST Action 728 and GURME – Review of the Capabilities of Meteorological and Chemistry-Transport Models for Describing and Predicting Air Pollution Episodes (ISBN 978-1-905313-77-8) (WMO TD No. 1502), 69 pp. December 2009, electronic version - July 2009.

188. Revision of the World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide (WMO TD No.1507), 55 pp. November 2009.

189. Report of the MACC/GAW Session on the Near-Real-Time Delivery of the GAW Observations of Reactive Gases, Garmisch-Partenkirchen, Germany, 6-8 October 2009, (WMO TD No. 1527), 31 pp. August 2010.

190. Instruments to Measure Solar Ultraviolet Radiation Part 3: Multi-channel filter instruments (lead author: G. Seckmeyer) (WMO TD No. 1537), 55 pp. November 2010.

191. Instruments to Measure Solar Ultraviolet Radiation Part 4: Array Spectroradiometers (lead author: G. Seckmeyer) (WMO TD No. 1538), 43 pp. November 2010.

192. Guidelines for the Measurement of Atmospheric Carbon Monoxide (WMO TD No. 1551), 49 pp. July 2010.

193. Guidelines for Reporting Total Ozone Data in Near Real Time (WMO TD No. 1552), 19 pp, April 2011 *(electronic version only).*

194. 15^{th} WMO/IAEA Meeting of Experts on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques (Jena, Germany, 7-10 September 2009) (WMO TD No. 1553). 330 pp. April 2011.

195. WMO/GAW Expert Workshop on Global Long-term Measurements of Nitrogen Oxides and Recommendations for GAW Nitrogen Oxides Network (Hohenpeissenberg, Germany,
8-9 October 2009) (WMO TD No. 1570), 45 pp. February 2011.

196. Report of the Second Session of the CAS JSC OPAG-EPAC and GAW 2009 Workshop (Geneva, Switzerland, 5-8 May 2009), (WMO TD No. 1577).

197. Addendum for the Period 2012 – 2015 to the WMO Global Atmosphere Watch (GAW) Strategic Plan 2008 – 2015, 57 pp. May 2011.

198. Data Quality Objectives (DQO) for Solar Ultraviolet Radiation Measurements (Part I). Addendum to WMO/GAW Report No. 146 - Quality Assurance in Monitoring Solar Ultraviolet Radiation: State of the Art (*electronic version only*).

199. Second Tropospheric Ozone Workshop. Tropospheric Ozone Changes: observations, state of understanding and model performances (Météo France, Toulouse, France, 11-14 April 2011), 226 pp. September 2011.

200. WMO/GAW Standard Operating Procedures for In-Situ Measurements of Aerosol Mass Concentration, Light Scattering and Light Absorption (Edited by John A. Ogren), 134 pp. October 2011.

201. Quality Assurance and Quality Control for Ozonesonde Measurements in GAW (Prepared by Herman Smit and ASOPOS Panel), 95 pp. October 2014

202. Workshop on Modelling and Observing the Impacts of Dust Transport/Deposition on Marine Productivity (Sliema, Malta, 7-9 March 2011), 50 pp. November 2011.

203. The Atmospheric Input of Chemicals to the Ocean. Rep. Stud. GESAMP No. 84/GAW Report No. 203. 69 pp. (ISSN: 1020-4873).

204. Standard Operating Procedures (SOPs) for Air Sampling in Stainless Steel Canisters for Non-Methane Hydrocarbons Analysis (Prepared by Rainer Steinbrecher and Elisabeth Wei*ß*), 25 pp. September 2012.

205. WMO/IGAC Impacts of Megacities on Air Pollution and Climate, 309 pp. September 2012 (ISBN: 978-0-9882867-0-2).

206. 16th WMO/IAEA Meeting of Experts on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques (GGMT-2011), Wellington, New Zealand, 25-28 October 2011, 67 pp. October 2012.

207. Recommendations for a Composite Surface-Based Aerosol Network, Emmetten, Switzerland, 28-29 April 2009, 66 pp. November 2012.

208. WMO GURME Workshop on Urban Meteorological Observation Design, (Shanghai, China, 11-14 December 2011).

209. Guidelines for Continuous Measurements of Ozone in the Troposphere (Prepared by Ian E. Galbally and Martin G. Schultz), 80 pp. February 2013 (WMO-No. 1110, ISBN: 978-92-63-11110-4).

210. Report of the Third Session of the CAS Joint Scientific Committee of the Open Programme Area Group on Environmental Polllution and Atmospheric Chemistry (JSC OPAG-EPAC), (Geneva, Switzerland, 27-29 April 2011) (*electronic version only*).

211. Rationalizing Nomenclature for UV Doses and Effects on Humans (CIE209:2014/GAW Report No. 211) (ISBN: 978-3-902842-35-0).

212. Standard Operating Procedures (SOPs) for Spectral Instruments Measuring Spectral Solar Ultraviolet Irradiance, 21 pp. June 2014.

213. 17th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques (GGMT-2013), (Beijing, China, 10-13 June 2013), 168 pp. July 2014.

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