Status and plans for FRM activities in NDACC/MAX-DOAS context

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Fiducial Reference Measurements (FRM)

ESA projects supporting the development of ground-based reference systems dedicated to satellite validation. 3 projects on atmospheric composition:

✓ **Pandonia FRM** http://pandonia.net ⇒ ESA contribution to **PGN**

- Ground-based remote sensing network using Pandora-2S and Pandora spectrometers
- Target products: total & tropospheric column O_3 & NO_2 + SO_2, HCHO columns

✓ **FRM$_4$GHG** http://frm4ghg.aeronomie.be

- Inter-comparison of ground based transportable FTIR systems with reference to TCCON as standard system – goal to complement the TCCON network as GHG validation standard

✓ **FRM$_4$DOAS** http://frm4doas.aeronomie.be

- Harmonization of retrievals from UV-Vis ground based spectrometers (MAX-DOAS) and development of centralised processing system
- Target products: total and tropospheric NO_2, tropospheric HCHO, stratospheric NO_2 & O_3, AOD and aerosol extinction

FRM_4DOAS scope and status

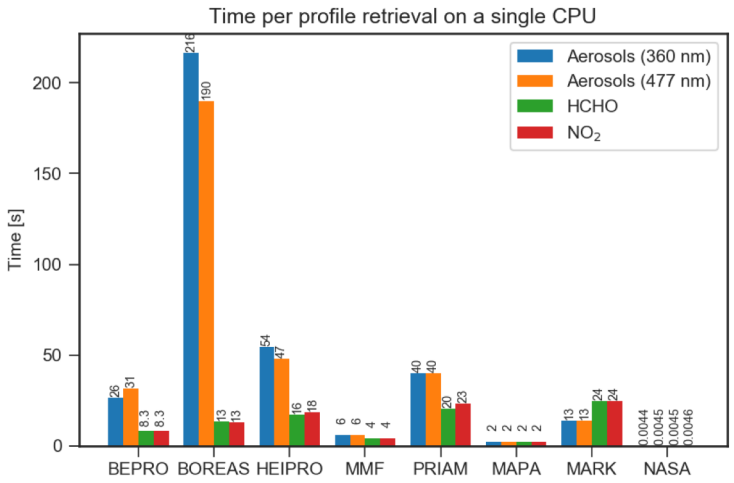
Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations

- **Scope of first phase of FRM_4DOAS (2016-2018):**
  - ✓ Support to preparation of CINDI-2 campaign (Sep 2016)
  - ✓ Select algorithm baseline for MAX-DOAS retrievals of NO_2, HCHO and aerosol extinction (FRM_4DOAS Round-Robin)
  - ✓ Develop prototype Central Processing System (CPS) for MAX-DOAS retrievals of tropospheric NO_2, HCHO and aerosols + total NO_2, O_3 (NDACC)
  - ✓ Demonstrate functional CPS working in NRT on selected sites, and validate the system and associated geophysical products

- **Status and plans**
  - First phase successfully completed
  - Ongoing (2019) → kick-off of NDACC MAX-DOAS service scheduled by end of 2019 (few sites, NRT only)
  - Next Phase (2020-2023) → full operationalisation of NDACC MAX-DOAS service (NRT + OFFL + REPROC) + extension to more target products (e.g. tropospheric O_3, SO_2, glyoxal, H_2O, …)

Round-Robin algorithm selection

Numerical performance



Friess et al., Intercomparison of MAX-DOAS Vertical Profile Retrieval Algorithms: Studies using Synthetic Data, AMT, 12, 2155-2181, 2019

***MAPA:** Beirle et al., The Mainz Profile algorithm, AMT, 12, 1785-1806, 2019*

***MMF:** Friedrich et al., NO_2 vertical profiles and column densities from MAX-DOAS measurements in Mexico City, AMT, 12, 2545-2565, 2019*

Performance Assessment Matrix

Selected algorithms:

- ✓ **BIRA-MMF (OEM)**
- ✓ **MPIC-MAPA (param.)**

		Aerosol - 360 nm						Aerosol - 477 nm						HCHO						NO_2					
		dSCD	Profile	Surface	Column	Speed	Valid	dSCD	Profile	Surface	Column	Speed	Valid	dSCD	Profile	Surface	Column	Speed	Valid	dSCD	Profile	Surface	Column	Speed	Valid
		v1																							
BIRA-BEPRO	a	5	1	1	4	5	100%	6	8	8	9	5	85%	1	4	3	3	3	87%	6	9	9	9	3	77%
	f	5	2	1	5	5		6	2	2	6	5		1	4	4	3	3		4	5	4	1	3	
BIRA-MMF	a	1	4	2	2	4	100%	2	1	3	1	4	100%	2	2	4	4	6	100%	2	1	2	1	6	94%
	f	1	4	2	4	4		2	4	5	3	4		2	3	3	4	6		1	1	3	3	6	
IUPB	a	4	2	3	5	9	94%	4	2	1	3	9	93%	5	8	9	5	4	94%	5	8	8	8	4	85%
	f	4	1	3	3	9		4	1	1	5	9		5	8	9	5	4		5	9	9	7	4	
IUPHD	a	3	5	7	1	8	100%	3	3	4	2	8	100%	3	5	6	6	7	100%	1	4	5	5	8	100%
	f	3	5	7	2	8		3	6	7	4	8		3	5	6	6	7		3	4	5	6	8	
KNMI	a	2	7	5	7	3	83%	1	6	5	4	3	90%	6	9	5	9	8	84%	3	6	4	4	7	89%
	f	2	7	5	7	3		1	9	6	7	3		6	9	5	7	8		6	8	6	5	7	
MPIC_PARAM	a		8	8	8	6	94%		9	9	8	6	86%		1	1	2	9	99%		2	1	2	9	99%
	f		8	8	8	6			3	3	1	6			2	1	1	9			3	2	2	9	
MPIC_PAR_MC	a		3	4	3	2	97%		7	2	6	2	89%		3	2	1	2	83%		3	3	3	2	79%
	f		3	4	1	2			5	4	2	2			1	2	2	2			2	1	4	2	
MPIC_PRIAM	a	6	6	6	6	7	97%	5	4	7	5	7	88%	4	7	7	7	5	97%	4	7	7	6	5	85%
	f	6	6	6	6	7		5	7	9	8	7		4	7	7	8	5		2	7	8	8	5	
NASA	a								5	6	7	1	100%		6	8	8	1	100%		5	6	7	1	96%
	f								8	8	9	1			6	8	9	1			6	7	9	1	

Data Processing Status

NRT Mode:

STATION	Type	Channel nr.	Daily submission start date
XIANGHE	Custom-build	2	01/07/2018
UCCLE	Custom-build	2	01/07/2018
HARESTUA	Custom-build	2	29/06/2018
NY.ALESUND	Custom-build	2	01/07/2018
BREMEN	Custom-build	2	01/07/2018
ATHENS	Custom-build	1	01/07/2018
DE BILT	Mini-DOAS Hof.	1	19/07/2018
MAINZ	Custom-build	4 Az.	31/07/2018
HEIDELBERG	EnviMes - SkySpec	2	01/08/2018
LAUDER	Custom-build	2	10/02/2019
NEUMAYER	Custom-build	2	Offline

CINDI-2 reprocessing:

Instrument number	Type	Channel nr.	MMF/ MAPA	Total O_3	Strat. NO_2
aiofm-1	Custom-build	1	x	N/A	x
auth-3	Custom-build	2	x	N/A	x
bira-4	Custom-build	2	x	x	x
boku-6	Custom-build	2	x	x	x
cma-7	Mini-DOAS Hof.	1	x	N/A	x
cma-8	Mini-DOAS Hof.	1	x	x	x
dlrustc-13	EnviMes - SkySpec	2	x	x	x
dlrustc-14	EnviMes - SkySpec	2	x	x	x
iupb-18	Custom-build	2	x	x	x
iuph-19	EnviMes - SkySpec	2	x	x	x
knmi-23	Pandora	2	x	N/A	x
luftblick-27	Pandora	2	x	x	x
mpic-28	Custom-build	1	x	N/A	x
lmumim-35	EnviMes - SkySpec	2	x	x	x

Processing system validation

2 approaches:

- **Use a subset of data from 4 CINDI-2 instruments (IUP-Bremen, BIRA, DLR, AUTH):**
  - ✓ Evaluation of the FRM_4DOAS retrieval data for consistency, plausibility and coverage, and comparison to ancillary data available from the campaign
- **Use one month of NRT data from the IUP Bremen MAX-DOAS instruments in Bremen, Athens and Ny-Alesund:**
  - ✓ Evaluation of the FRM_4DOAS retrieval data for consistency, plausibility and coverage, and comparison to the standard data evaluation performed at IUP Bremen

Validation based on CINDI-2 data

Algorithm	Institute	Code	Symbol
MAPA (0.8)	BIRA	BIR	●
	IUP-Bremen	IUP	▲
	AUTH	AUT	■
	DLR/USTC	DLR	▲
MAPA (1.0)	BIRA	BIR	●
	IUP-Bremen	IUP	▲
	AUTH	AUT	■
	DLR/USTC	DLR	▲
MAPA (free)	BIRA	BIR	●
	IUP-Bremen	IUP	▲
	AUTH	AUT	■
	DLR/USTC	DLR	▲
MMF	BIRA	BIR	●
	IUP-Bremen	IUP	▲
	AUTH	AUT	■
	DLR/USTC	DLR	▲

Custom-build, high S/N

Custom-build, low S/N

EnviMes

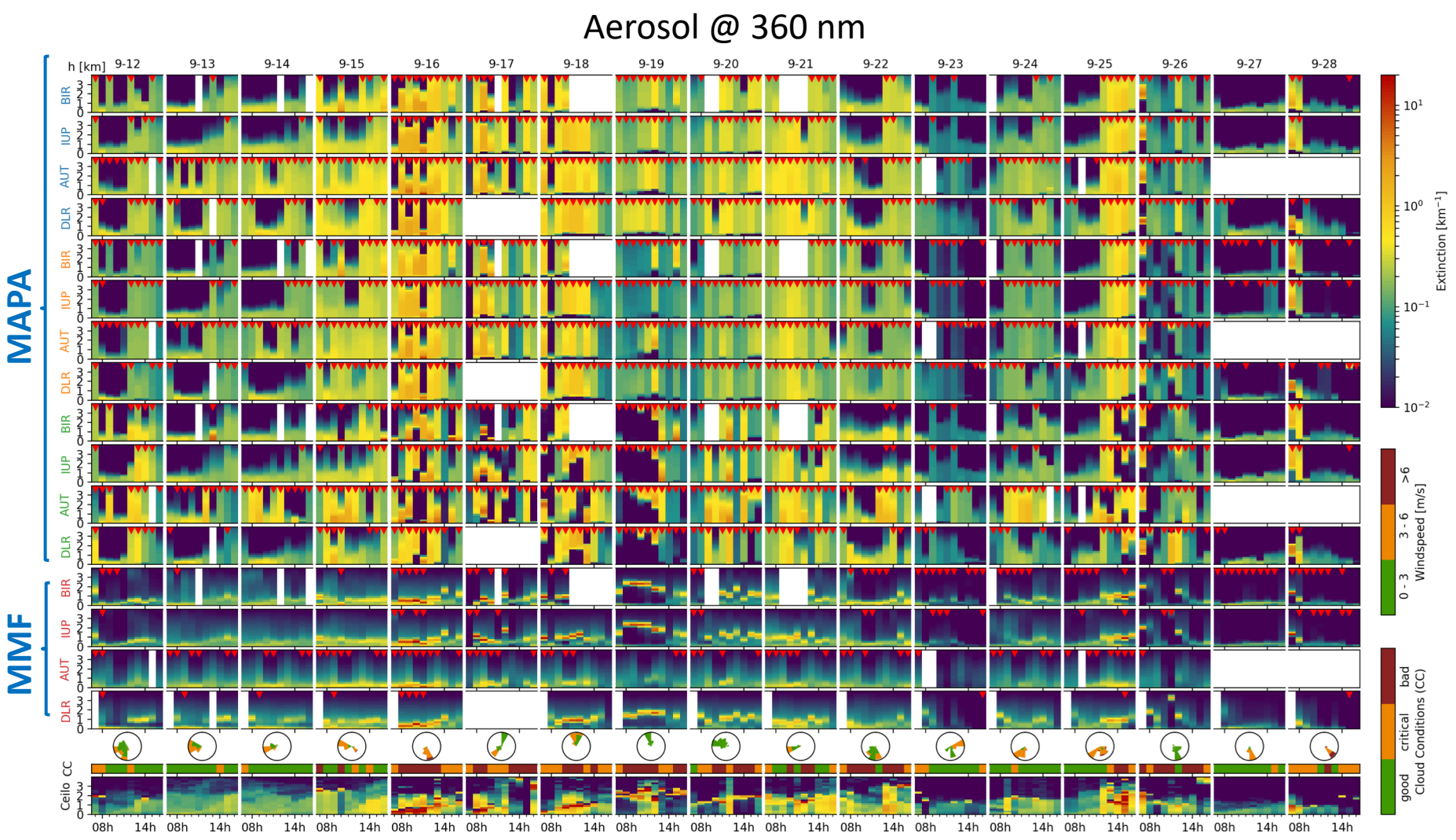
Data processed through CPS:

NO_2, HCHO and aerosol in the UV and visible spectral ranges. For NO_2, only the visible retrievals were evaluated. For AUTH, no visible data were available.

Ancillary measurements:

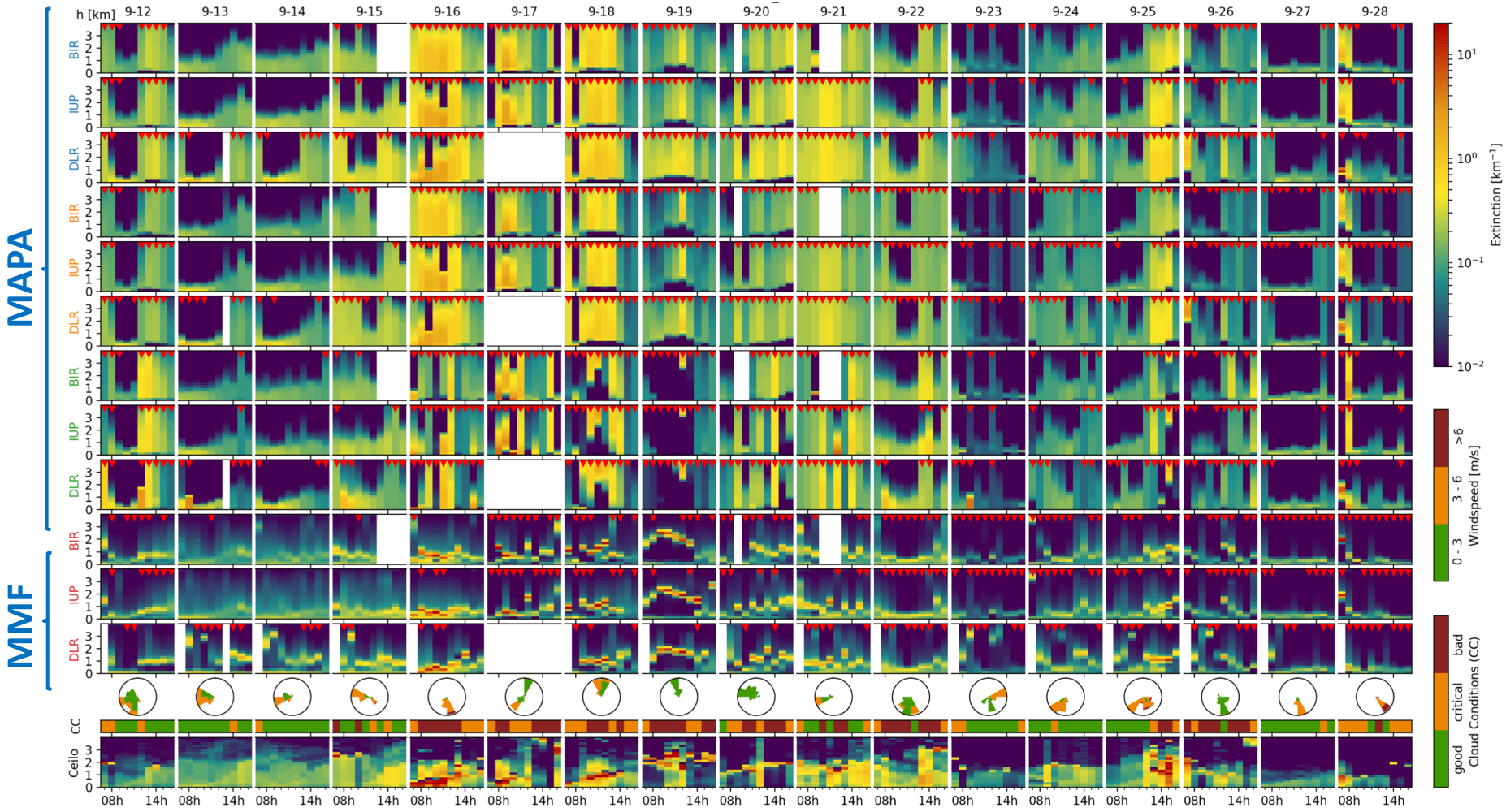
- Long-path DOAS → NO_2 and HCHO surface concentrations
- Direct-sun DOAS → NO_2 and HCHO columns
- Sun-photometer → AOD at different wavelengths
- Ceilometer data for relative extinction profiles
- NO_2 vertical profiles from the KNMI NO_2 sondes and the RIVM NO_2 lidar observations for a few short time periods during the campaign

Validation based on CINDI-2 data



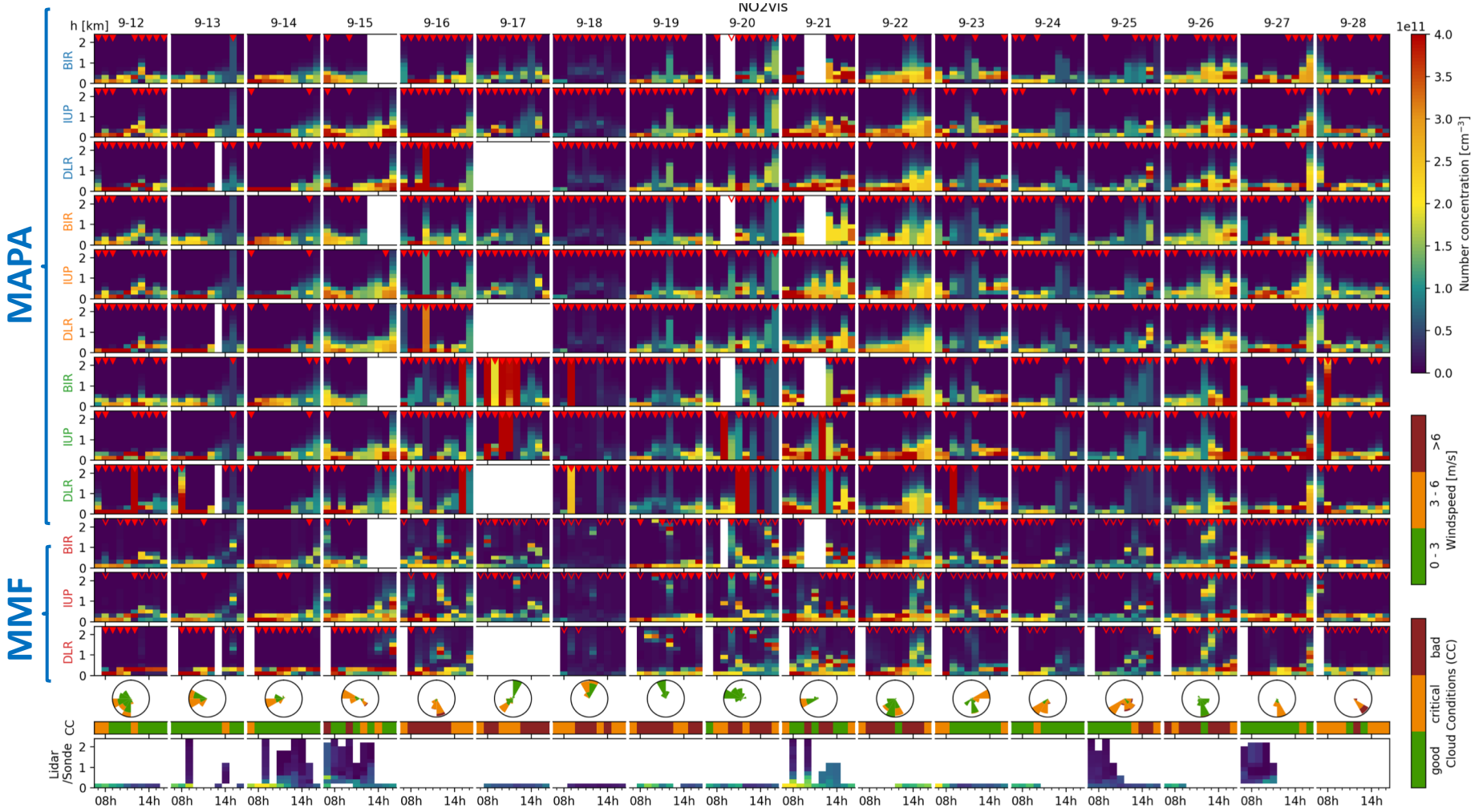
Validation based on CINDI-2 data

Aerosol @ 477 nm



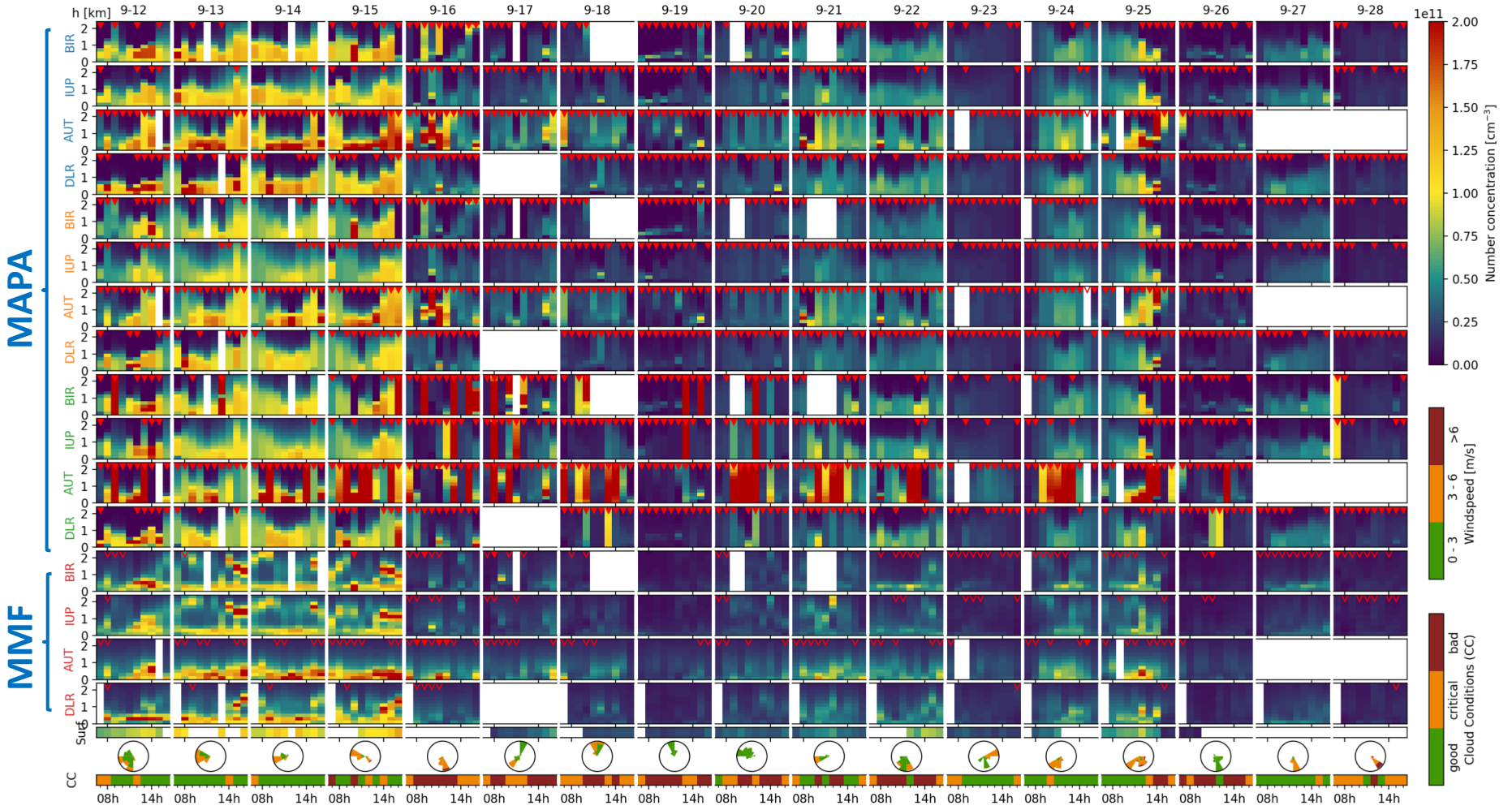
Validation based on CINDI-2 data

NO_2 @ 457 nm



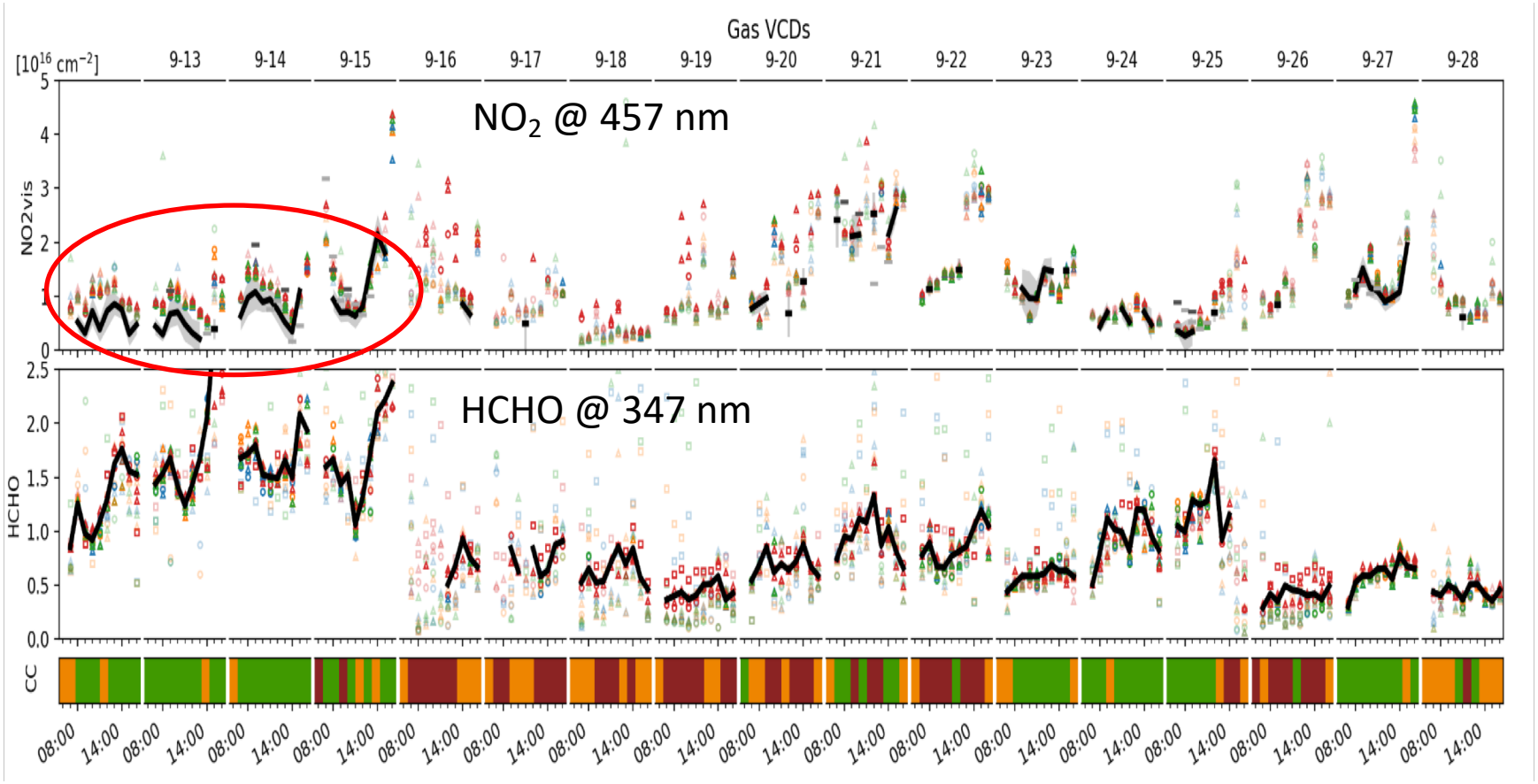
Validation based on CINDI-2 data

HCHO @ 347 nm



Validation of tropospheric columns

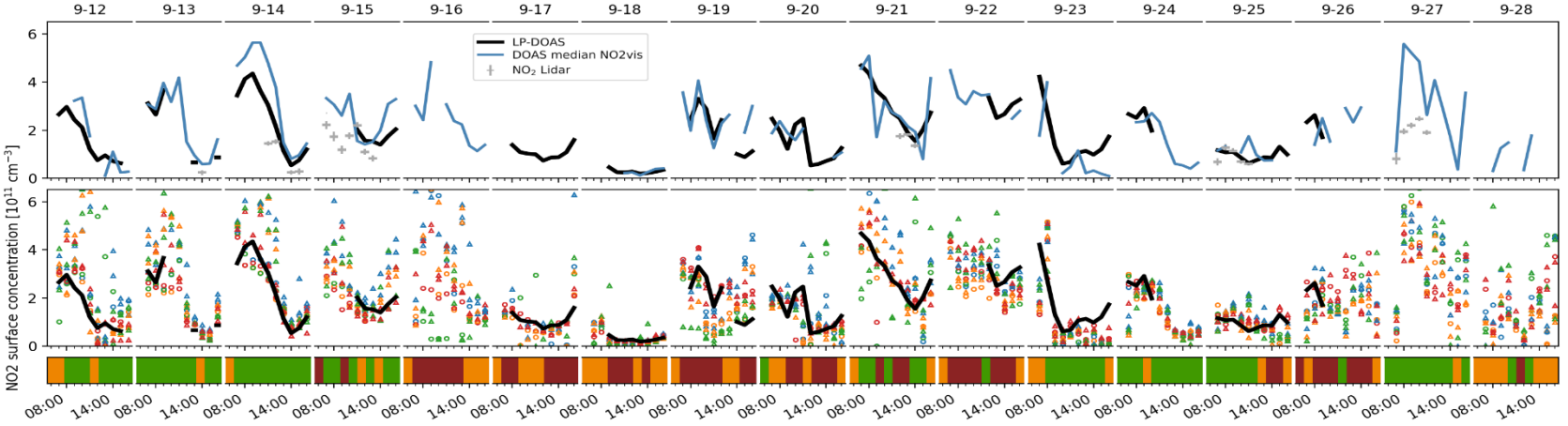
DS-DOAS



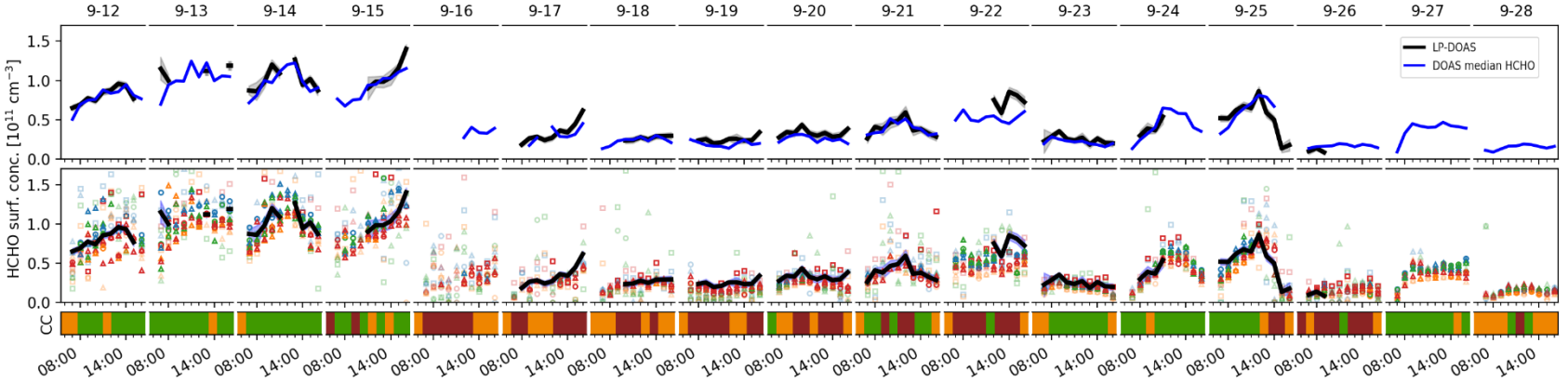
Validation of surface concentrations

LP-DOAS

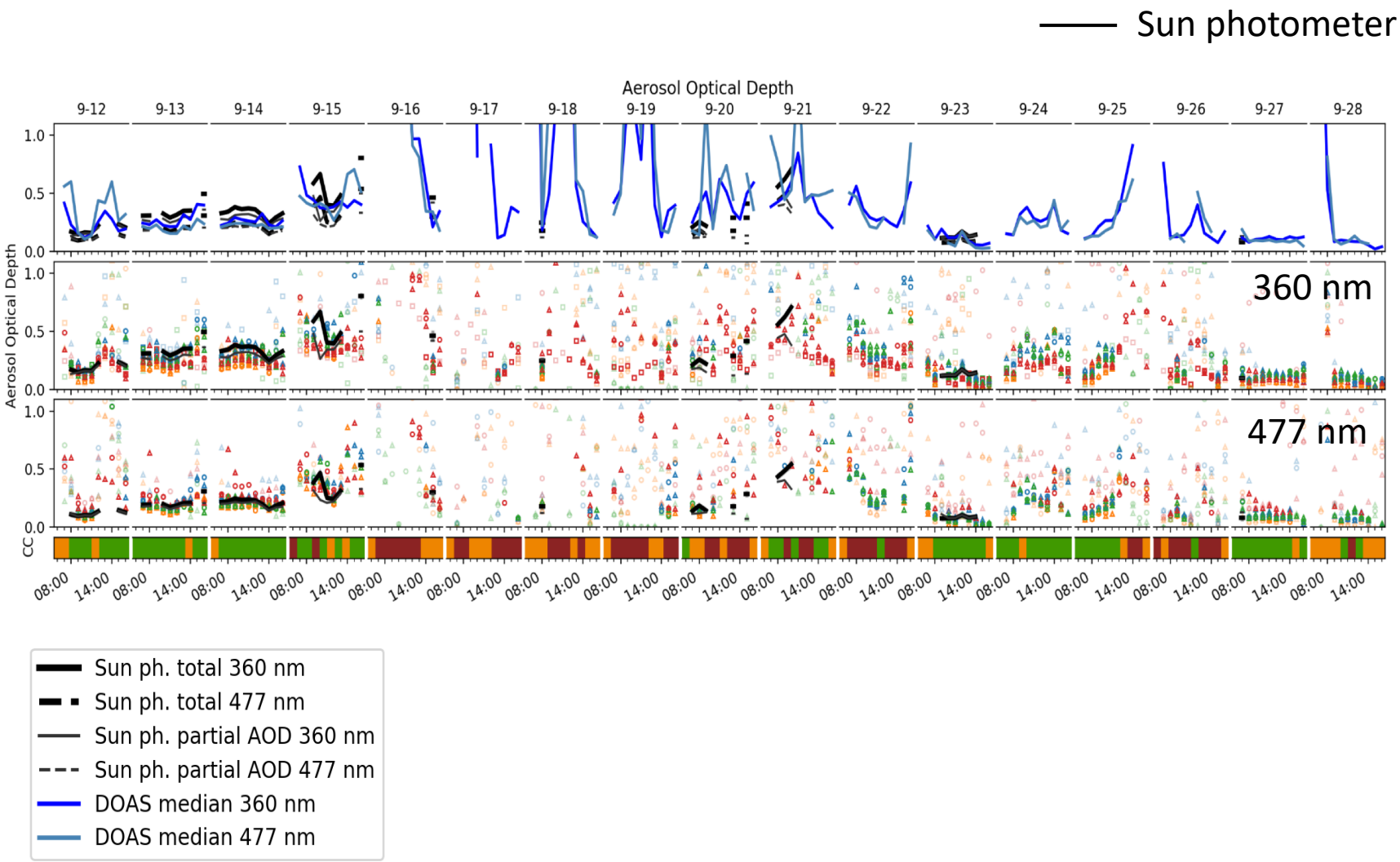
NO_2 @ 457 nm



HCHO @ 347 nm



Validation of AOD retrievals



Lessons learned and next steps

- Central Processing of data from different instrument types works but requires good interactions with data providers in the initial phase
- Selection and implementation of 2 different MAX-DOAS algorithms → internal QA/QC. Both algorithms have own strengths and weaknesses, e.g. no a-priori used in MAPA, but AKs only available from MMF (OE)
- Data flagging (incl. clouds) is highly critical and must be further elaborated
- Pandora data can easily be ingested in FRM$_4$DOAS CPS
- Remaining steps to move into MAX-DOAS operations within NDACC:
  - Transfer CPS to HPC (High Performance Computing System)
  - Establish instruments and data protocols (MAX-DOAS specific), allowing for NDACC certification of new MAX-DOAS participants
  - Establish full data processing chain to NDACC and EVDC data bases
  - Further develop on-line system dashboard (data monitoring, quality flags, processing statistics, etc)

NDACC candidate stations

- Approximately 60 existing stations are candidates for being included in the NDACC MAX-DOAS network (most of them would use the CPS)
- Results based on consultation with MAX-DOAS community (performed in 2017)