Validation and support of space-based measurements with the Pandonia Global Network of ground-based spectrometers

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[6]National Institute of Environmental Research, Incheon, Korea
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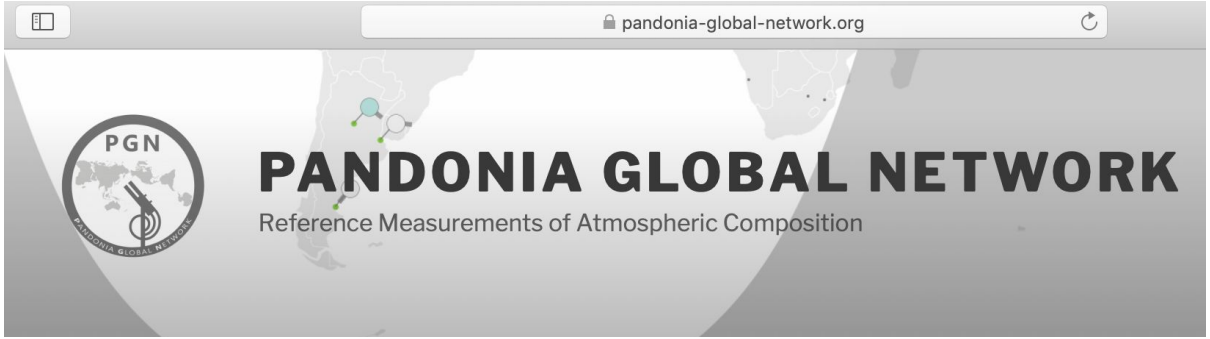
[8]AEMET- Meteorological State Agency, Spain
[9]EPA Research Triangle Park, Charllotte, NC, USA
[10]BIRA-IASB, Brussels, Belgium

18-September, 2024

AERONET Science and Application Exchange

Pandonia Global Network: Reference measurements of O_3, NO_2, and HCHO

1) Calibration and Quality Assurance:
   a) Laboratory and Field calibration of instruments
2) Network operation
   a) Remote monitoring and repair of instruments
3) Retrieval
   a) Production of O_3, NO_2 and HCHO Columns/Profiles

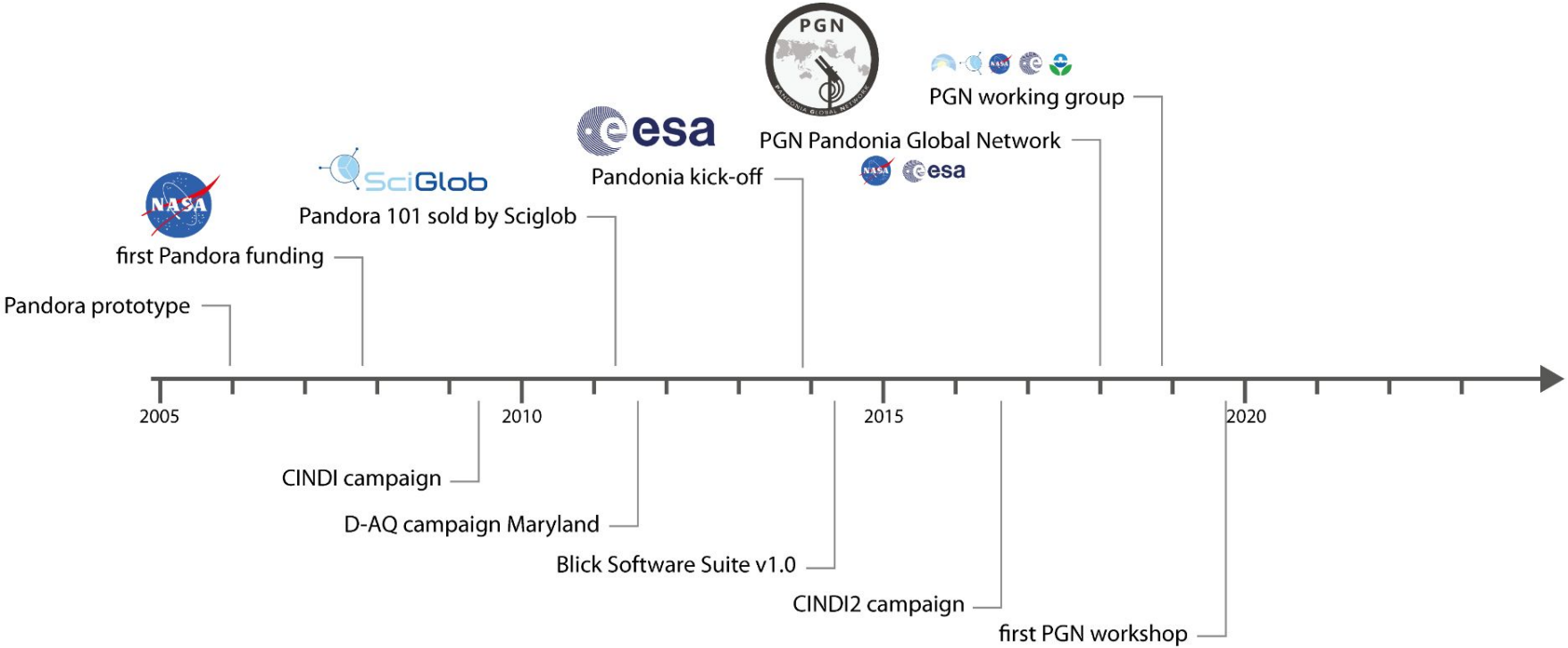


The PGN operates 175+ Pandora instruments

https://www.pandonia-global-network.org/
Thomas.Hanisco@nasa.gov, alexander.cede@luftblick.at

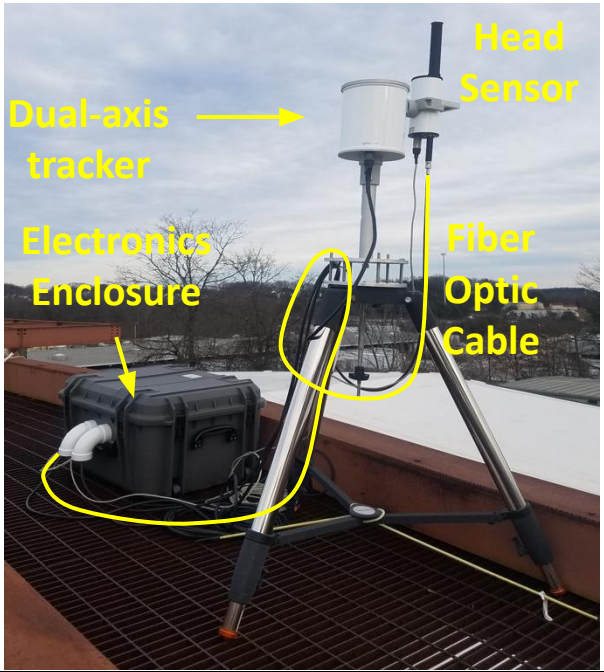
Time Evolution of Pandora and the PGN

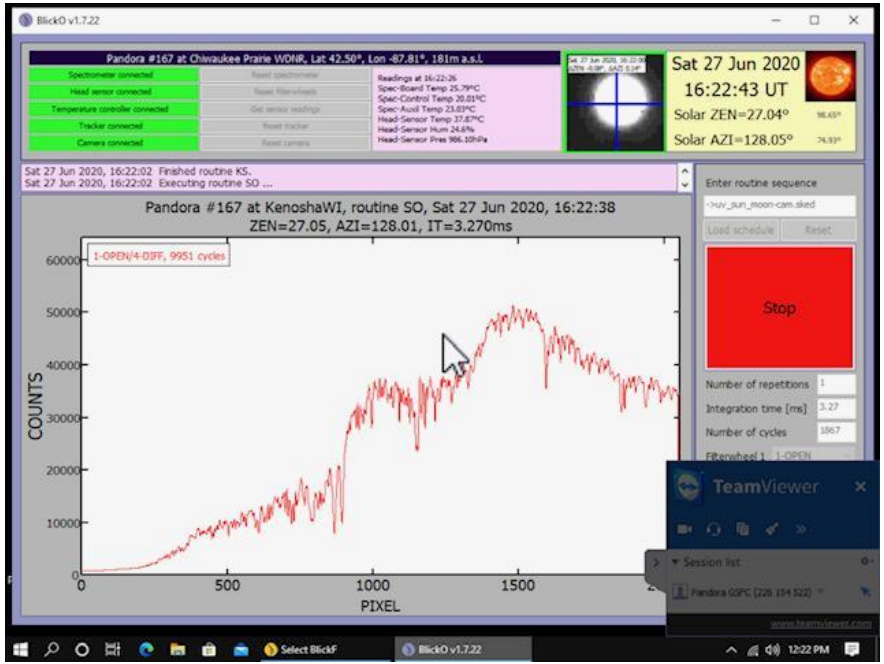
Principles in this timeline: Jay Herman, Alexander Cede, Nader Abuhassan, Elena Lind, Bob Swap



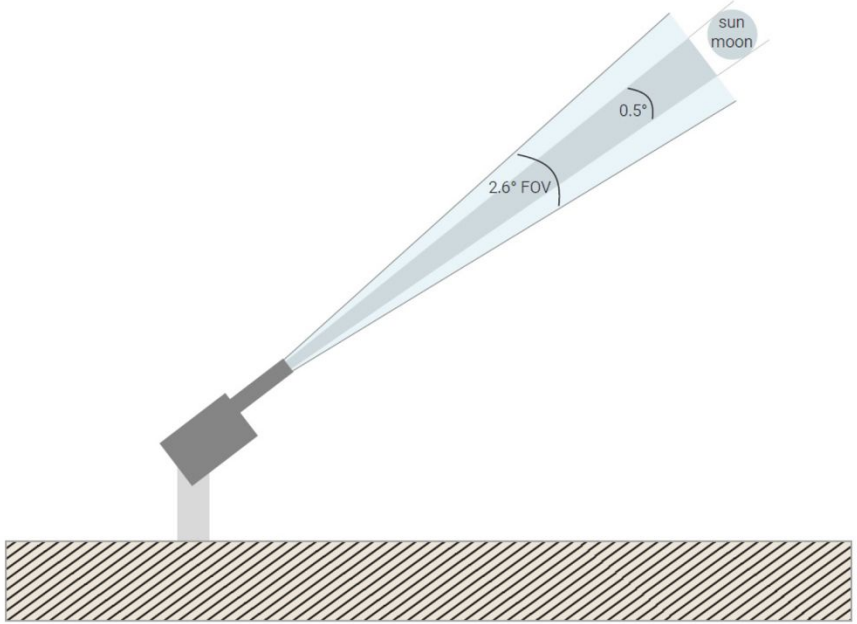
Instrumentation

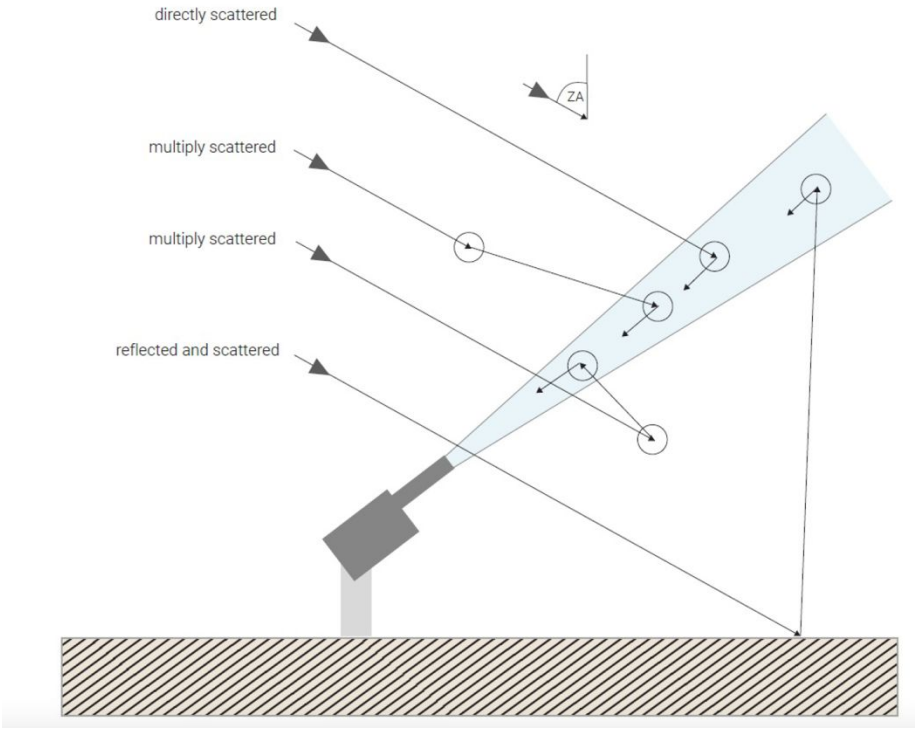
- Pandora is a ground-based sun/sky/moon viewing spectrometer system
- The sensor head (light collector) is mounted on a 2-axis tracker.
- Sun/sky/moon-light is directed to the input of a ccd spectrometer with a fiber optic cable.
- Control electronics for semi-autonomous operation in all-weather conditions
- Pixels (wavelength) and Counts (intensity) are used to derive trace gas abundance





Pandora measurements

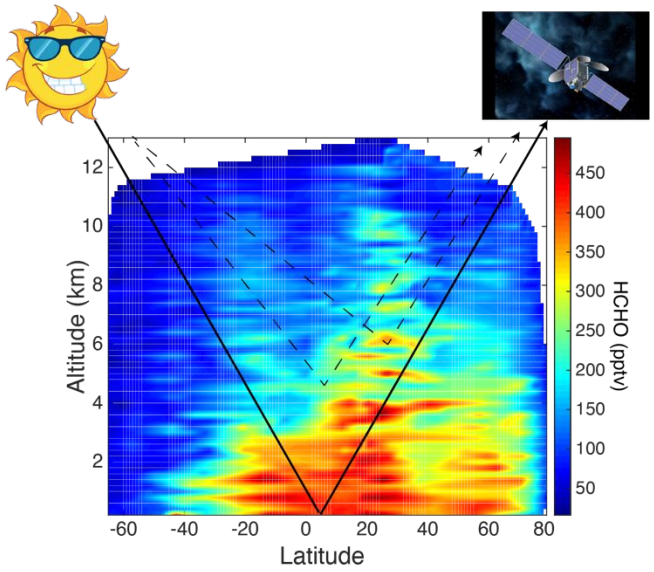




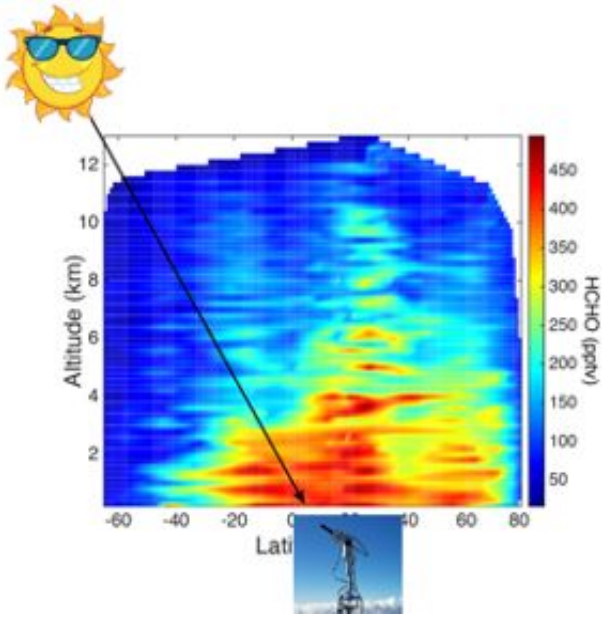
Direct sun: mostly BEER's Law.
Total absorption used to derive the column abundance between the instrument and the top of atmosphere

MAX-DOAS: multiple angle BEER's Law
Differential measurements used to derive the abundance at multiple elevations

Motivation



NASA Satellites measure sunlight reflected from the earth's surface and scattered from the atmosphere. This is complicated and requires assumptions *(a priori*) that are not always correct. Even harder with Geostationary!

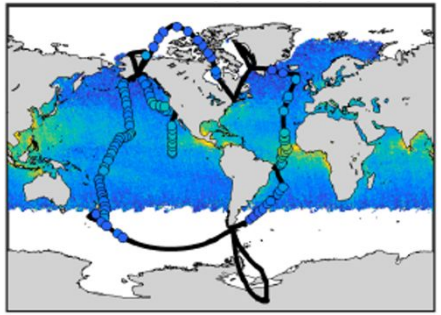


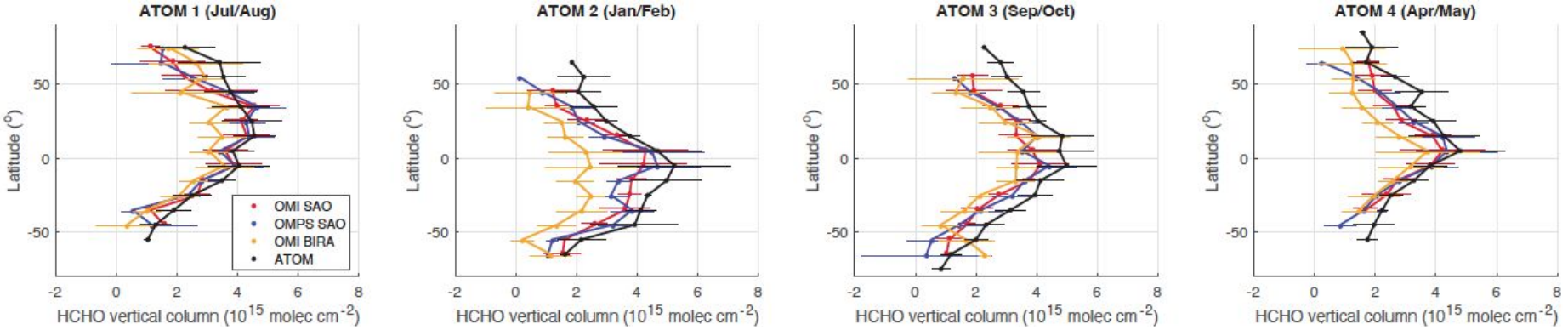
Pandora provides direct sun with lower sensitivity to scattered light.
MAX-DOAS profiles can be used to validate the *a priori* assumptions.

Applications

Currently: Use integrated *in situ* columns to evaluate HCHO

Goal: Use Pandora PGN profiles to evaluate TEMPO and Sentinel 4

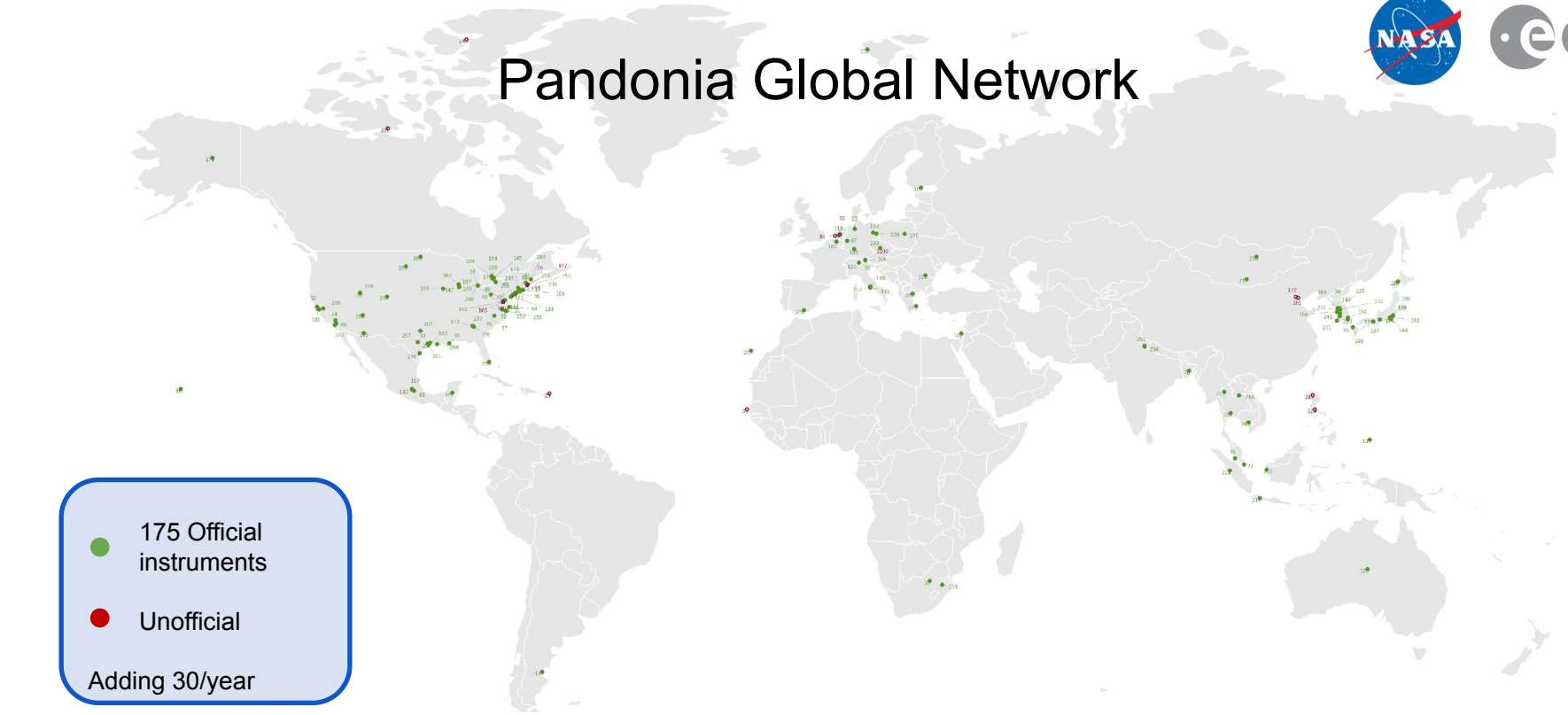




Validation of formaldehyde products from three satellite retrievals (OMI SAO, OMPS-NPP SAO, and OMI BIRA) in the marine atmosphere with four seasons ATom aircraft observations

Jin Liao, Glenn M Wolfe, Alex E. Kotsakis, Julie Nicely, Jason M. St. Clair, Thomas F. Hanisco, Gonzalo González Abad, Caroline Nowlan, Zolal Ayazpour, Isabelle De Smedt, Eric C. Apel, Rebecca S. Hornbrook, *Atmos. Meas. Tech.* amt-2024-72.

Pandonia Global Network



175 Official instruments

Unofficial

Adding 30/year

211 Agam
190 Bangkok
134 BristolPA
249 ChicagoIL
103 Downsview*
200 GrandForksND
120 Innsbruck-FKS
143 LibertyTX
34 MountainViewCA
187 PittsburghPA
72 SaltLakeCityUT-Hawthorne
231 Suwon-USW
176 Tsukuba-NIES
140 WashingtonDC

61 AldineTX
78 Banting
162 Brussels-Uccle
67 Cologne
100 Durham
153 GreenbeltMD*
1000nnsbruck-HAF
130 Lindenberg
197 Nagoya
212 Pontianak
181 SanJoseCA
182 Tel-Aviv
163 Tsukuba-NIES-West
177 WestportCT

129 AliceSprings
38 BayonneNJ
111 Bucharest
180 ColumbiaMD
185 EastProvidenceRI
37 HamptonVA
246 IowaCityIA-WHS
183 LondonderryNH
251 Nainital-ARIES
53 Potchefstroom-METSI
196 Sapporo
240 Thessaloniki
254 TubaCityAZ
247 WhittierCA

65 Altzomoni
172 Beijing
206 BuffaloNY
124 ComodoroRivadavia
74 EdwardsCA
156 HamptonVA-HU
73 Islamabad-NUST
186 MadisonCT
69 NewBrunswickNJ
55 QueensNY
164 Seosan
192 Tokyo-Sophia
253 TucsonAZ
208 Windsor-West

207 ArlingtonTX
171 Beijing-RADI
20 Busan
179 CornwallCT
169 Egbert
105 Helsinki
101 Izana*
135 ManhattanNY-CCNY
64 NewHavenCT
52 RichmondCA
54 Seoul
194 Tokyo-TMU
248 TurlockCA
68 WrightwoodCA

119 Athens-NOA
80 BeltsvilleMD
118 Cabauw
258 CorpusChristiTX
174 FairbanksAK
25 HoustonTX
252 KenoshaWI
56 MaunaLoaHI
236 NewLondonCT
138 Rome-IIA
235 Seoul-KU
243 Toronto-CNTower
150 Ulsan
161 Xianghe

158 AtlantaGA*
132 Berlin
260 CameronLA
36 Dakar
29 Fajardo
261 HoustonTX-SanJacinto
239 Kosetice
142 MexicoCity-UNAM
152 NyAlesund
115 Rome-ISAC
149 Seoul-SNU
145 Toronto-Scarborough
218 Vientiane
146 Yokosuka

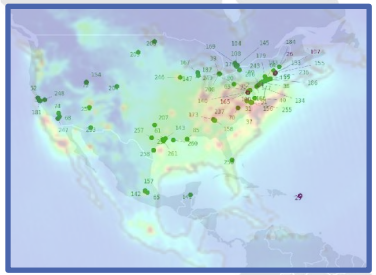
237 AtlantaGA-SouthDeKalb
57 BoulderCO
184 CapeElizabethME
217 Dalanzadgad
199 Fukuoka
66 HuntsvilleAL
63 LaPorteTX
157 MexicoCity-Vallejo
51 OldFieldNY
117 Rome-SAP
77 Singapore-NUS
108 Toronto-West
255 VirginiaBeachVA-CBBT
232 Yongin

257 AustinTX
204 BoulderCO-NCAR
70 ChapelHillNC
39 DearbornMI
230 Gongju-KNU
189 Incheon-ESC*
133 LabLuftBlick*
256 MiamiFL-FIU
131 Palau
147 SWDetroitMI
139 SouthJordanUT
242 Trollhaugen
159 Wakkerstroom

210 Bandung
21 Bremen
31 CharlesCityVA*
76 Dhaka
238 Granada
30 Innsbruck*
188 LapwaiID
24 MilfordCT
166 PhiladelphiaPA
154 SaltLakeCityUT
170 StGeorge
193 Tsukuba
270 Warsaw-UW

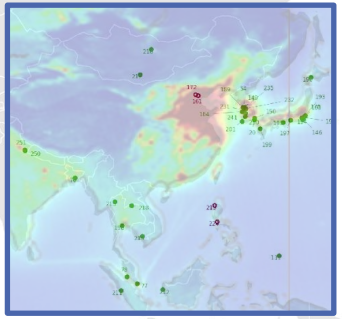
* more than one instrument

Pandonia Global Network



TEMPO

SENTINEL-4



GEMS

- 175 Official instruments
- Unofficial

Adding 30/year

211 Agam	61 AldineTX	129 AliceSprings	65 Altzomoni	207 ArlingtonTX	119 Athens-NOA	158 AtlantaGA*	237 AtlantaGA-SouthDeKalb	257 AustinTX	210 Bandung
190 Bangkok	78 Banting	38 BayonneNJ	172 Beijing	171 Beijing-RADI	80 BeltsvilleMD	132 Berlin	57 BoulderCO	204 BoulderCO-NCAR	21 Bremen
134 BristolPA	162 Brussels-Uccle	111 Bucharest	206 BuffaloNY	20 Busan	118 Cabauw	260 CameronLA	184 CapeElizabethME	70 ChapelHillNC	31 CharlesCityVA*
249 ChicagoIL	67 Cologne	180 ColumbiaMD	124 ComodoroRivadavia	179 CornwallCT	258 CorpusChristiTX	36 Dakar	217 Dalanzadgad	39 DearbornMI	76 Dhaka
103 Downsview*	100 Durham	185 EastProvidenceRI	74 EdwardsCA	169 Egbert	174 FairbanksAK	29 Fajardo	199 Fukuoka	230 Gongju-KNU	238 Granada
200 GrandForksND	153 GreenbeltMD*	37 HamptonVA	156 HamptonVA-HU	105 Helsinki	25 HoustonTX	261 HoustonTX-SanJacinto	66 HuntsvilleAL	189 Incheon-ESC*	30 Innsbruck*
120 Innsbruck-FKS	1000nnsbruck-HAF	246 IowaCityIA-WHS	73 Islamabad-NUST	101 Izana*	252 KenoshaWI	239 Kosetice	63 LaPorteTX	133 LabLuftBlick*	188 LapwaiID
143 LibertyTX	130 Lindenberg	183 LondonderryNH	186 MadisonCT	135 ManhattanNY-CCNY	56 MaunaLoaHI	142 MexicoCity-UNAM	157 MexicoCity-Vallejo	256 MiamiFL-FIU	24 MilfordCT
34 MountainViewCA	197 Nagoya	251 Nainital-ARIES	69 NewBrunswickNJ	64 NewHavenCT	236 NewLondonCT	152 NyAlesund	51 OldFieldNY	131 Palau	166 PhiladelphiaPA
187 PittsburghPA	212 Pontianak	53 Potchefstroom-METSI	55 QueensNY	52 RichmondCA	138 Rome-IIA	115 Rome-ISAC	117 Rome-SAP	147 SWDetroitMI	154 SaltLakeCityUT
72 SaltLakeCityUT-Hawthorne	181 SanJoseCA	196 Sapporo	164 Seosan	54 Seoul	235 Seoul-KU	149 Seoul-SNU	77 Singapore-NUS	139 SouthJordanUT	170 StGeorge
231 Suwon-USW	182 Tel-Aviv	240 Thessaloniki	192 Tokyo-Sophia	194 Tokyo-TMU	243 Toronto-CNTower	145 Toronto-Scarborough	108 Toronto-West	242 Trollhaugen	193 Tsukuba
176 Tsukuba-NIES	163 Tsukuba-NIES-West	254 TubaCityAZ	253 TucsonAZ	248 TurlockCA	150 Ulsan	218 Vientiane	255 VirginiaBeachVA-CBBT	159 Wakkerstroom	270 Warsaw-UW
140 WashingtonDC	177 WestportCT	247 WhittierCA	208 Windsor-West	68 WrightwoodCA	161 Xianghe	146 Yokosuka	232 Yongin		

* more than one instrument

PGN Organization by June 2024

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- A. Kelly
- W. Lo
- A. Soliman

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- M. Gebetsberger
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- A. Pandey
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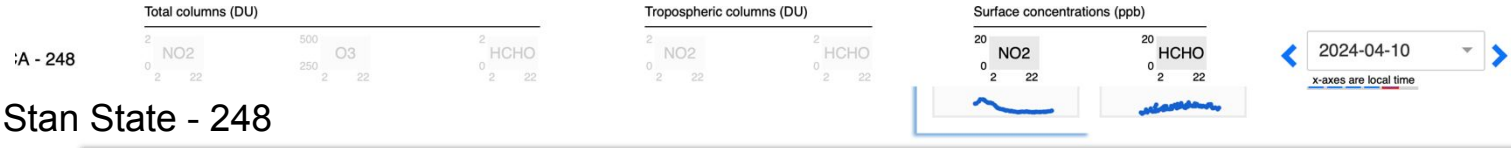
member of PGN-AG

funding SciGlob
EPA
국립환경과학원 National Institute of Environmental Research
LUFTBLICK
funding esa

PGN Real Time Data: BlickV http://blickv.pandonia-global-network.org/



Stan State - 248

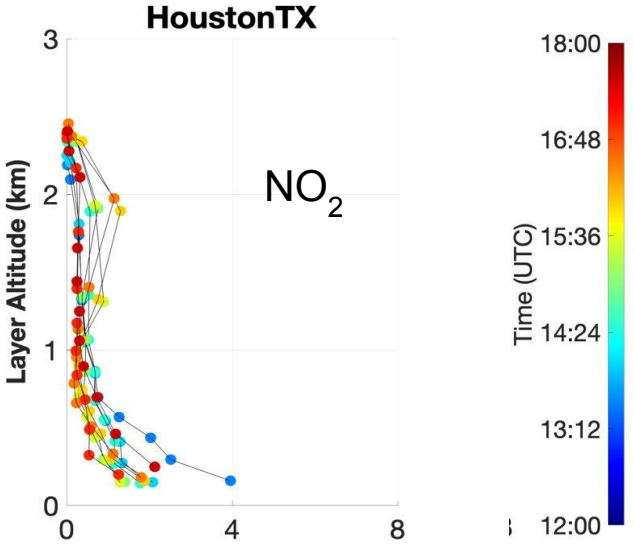
All products are available for download on BlickV.

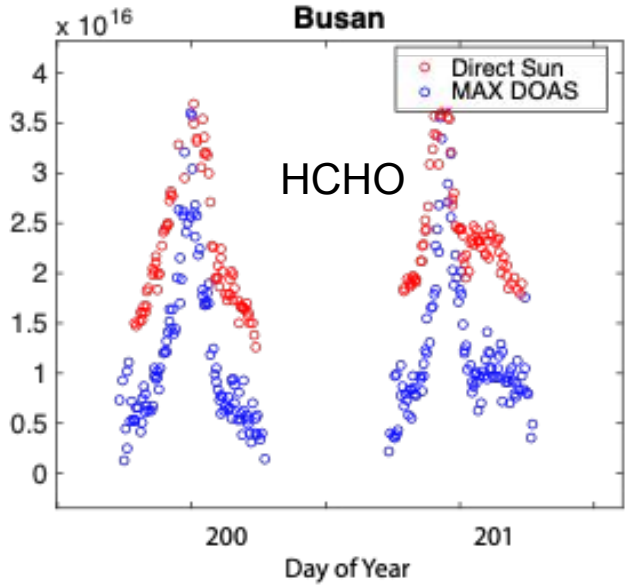
Quality assured total column NO_2 and O_3 are archived at the EVDC.

“Out of the Box” MAX-DOAS products provided without a field calibration.

Data quality

- Direct sun NO_2 and O_3 are "validation quality". These products have been validated with airborne (DISCOVER-AQ), balloon (O_3 sonde), and ground remote (Brewers). High quality data is on the EVDC.
- Profiles (MAX-DOAS) of NO_2 and HCHO and direct sun HCHO are not fully understood.

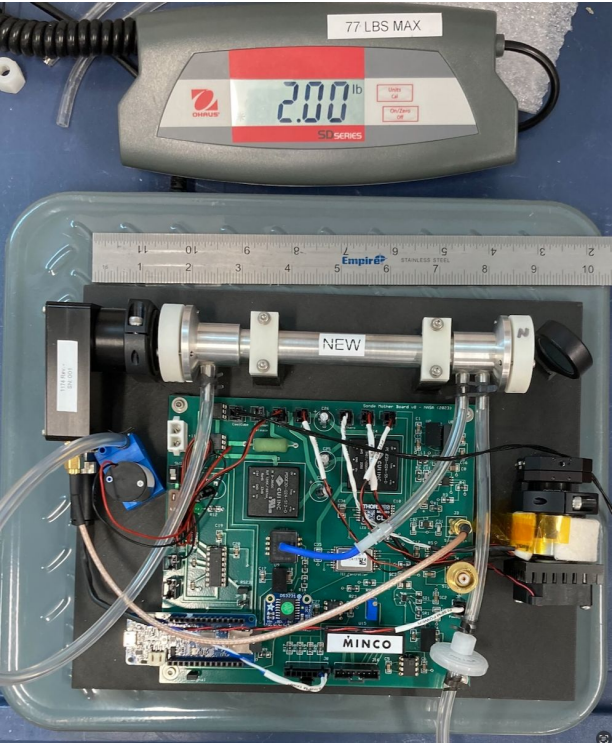


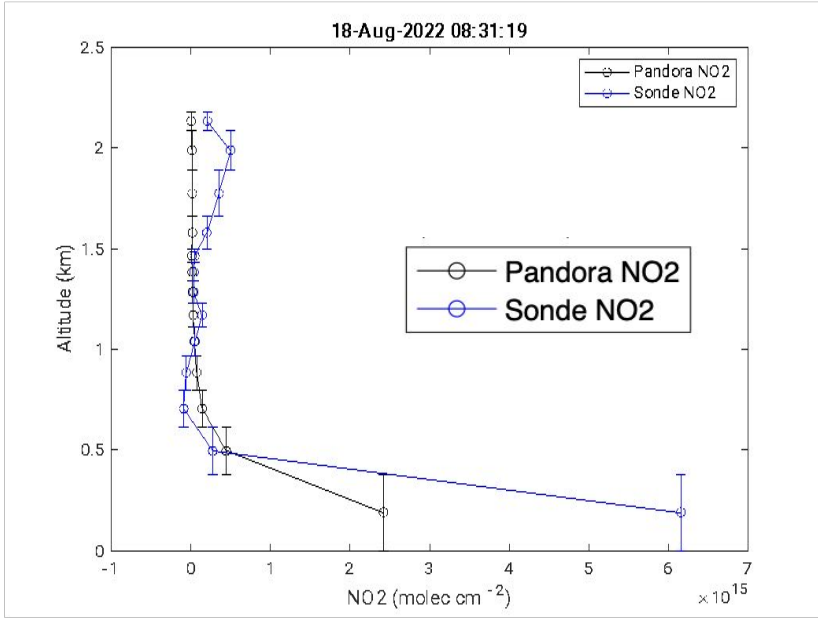


Validation of MAX-DOAS products: NO_2

Airborne, balloon and ground-based *in situ* comparisons to MAX-DOAS NO_2.

Measurements of NO_2 columns are robust but our understanding of the spatial distribution needs improvement.

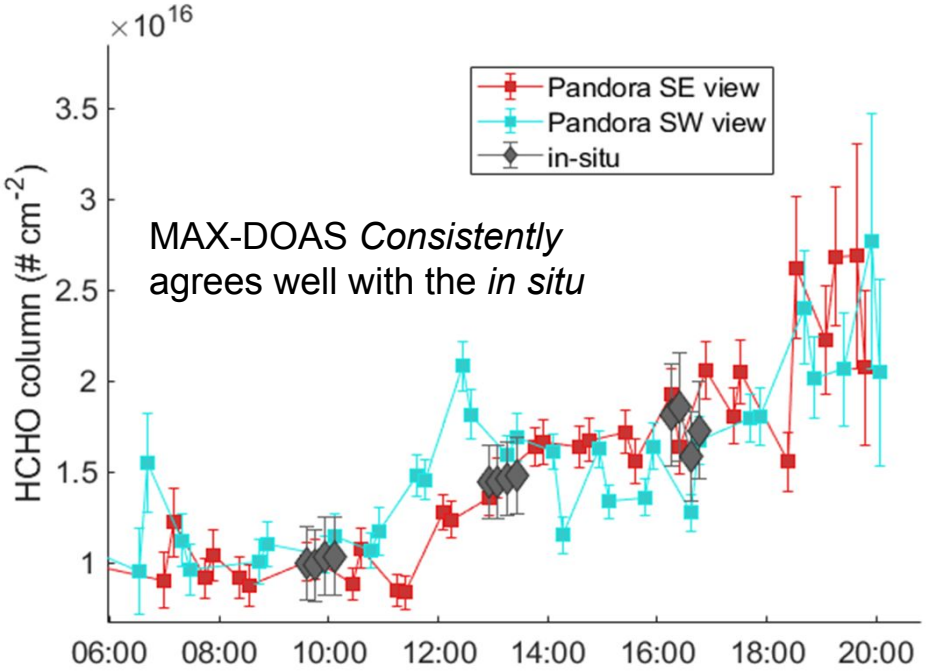


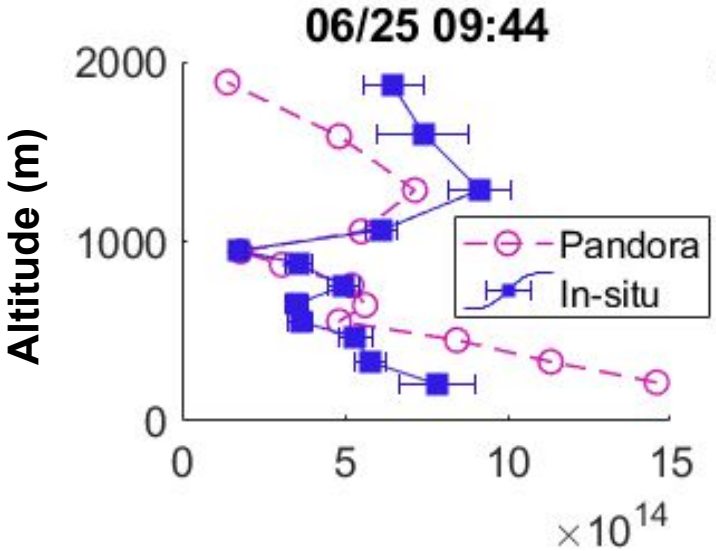


Bryan Place NASA/SciGlob

Validation of MAX-DOAS products: HCHO

NASA (SARP) and EPA (ALEGROS) airborne *in situ* profiles over Pandora sites in 2024. More flights planned for 2025.





Apoorva Pandey, Poster 49

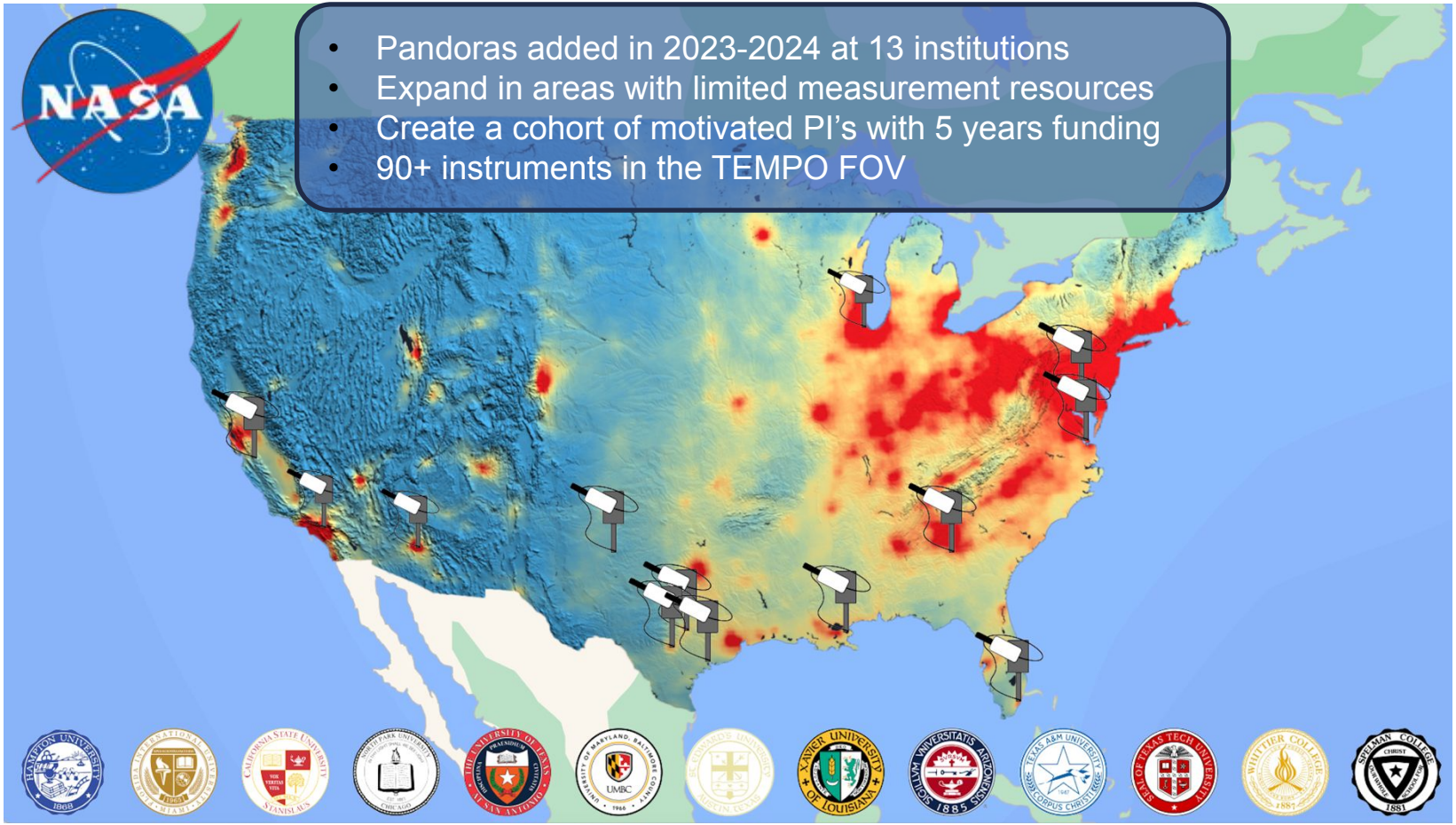
Expansion programs

- Leverage other agencies and objectives
    - For example, the United Nations UNESCO funded 23 instruments to be managed by KOICA and NIER in southeast ASIA.

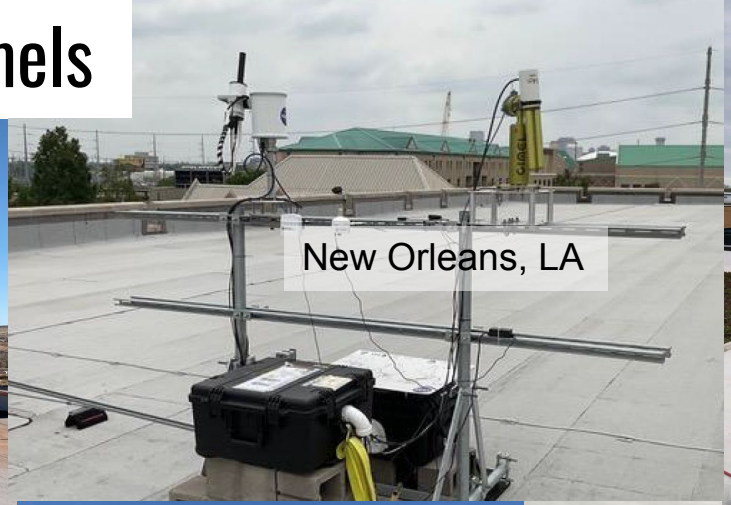
- EPA 25+ instruments
- NASA IPMSI – 13 instruments
- NASA Satellite needs Working Group (SNWG) - Hard to reach rural and developing nation sites
    - 10 US department of Agriculture rural sites
    - 10 US State Department embassy locations
- NOAA starting investment with interest for GEO-XO.

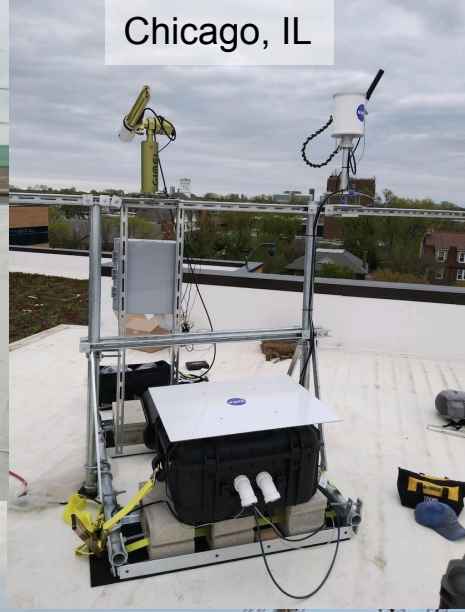
    - Installed at Essex, Maryland MDE site in June 2024

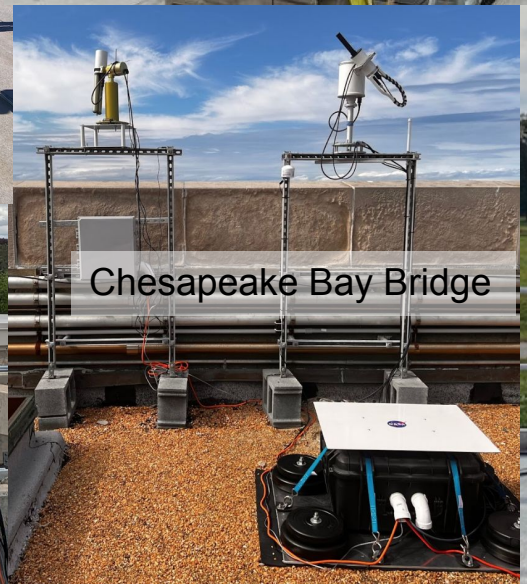
Increasing Participation in Minority Serving Institutions (IPMSI)

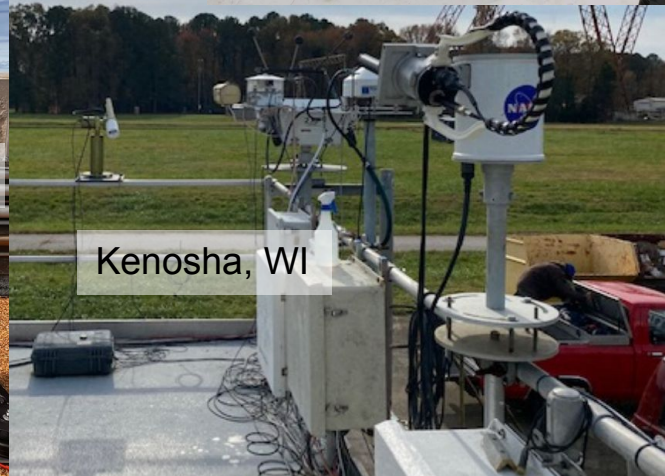


Colocated Pandora and Cimels



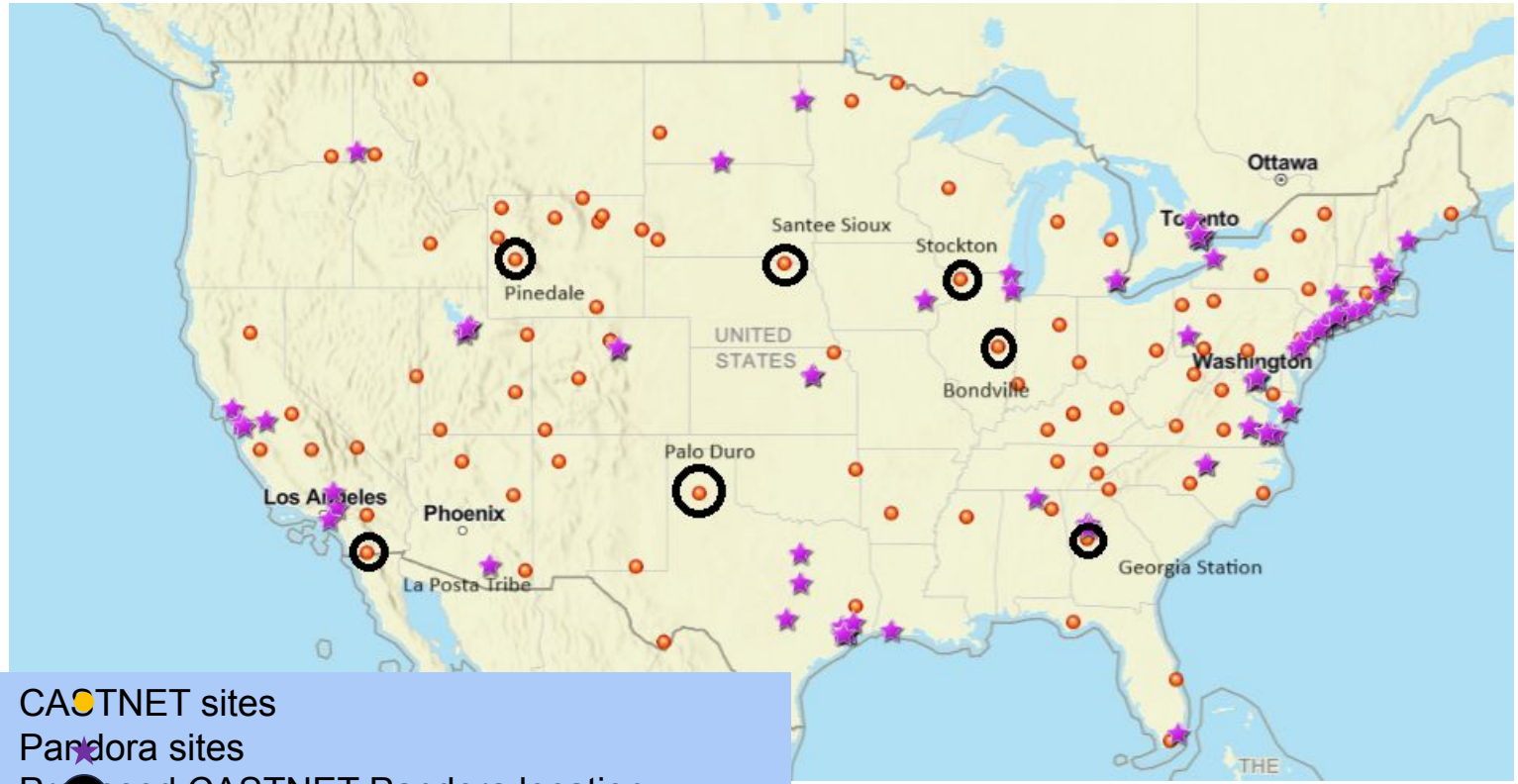






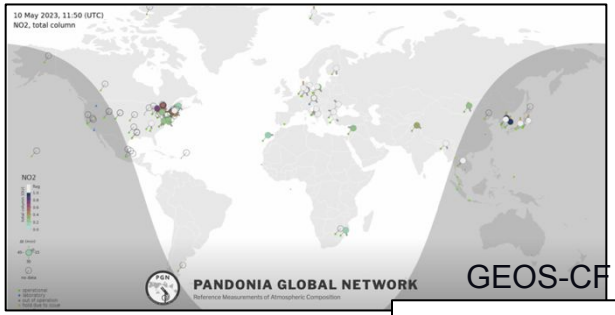
SNWG rural and agricultural sites

- SNWG US department of Agriculture, US Forestry Service, US Environmental Protection Agency

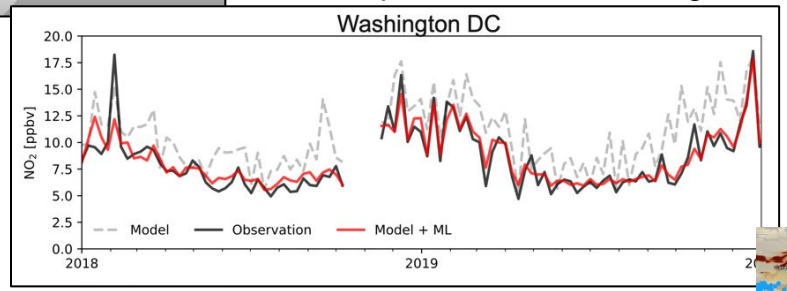


SNWG: localized NO_2 forecasts by combining PANDORA observations with GEOS model output

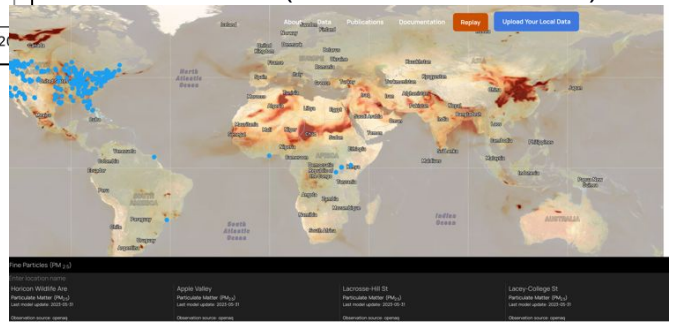
Pandora observations



GEOS-CF model output + machine learning



Public access (historical & forecasts)



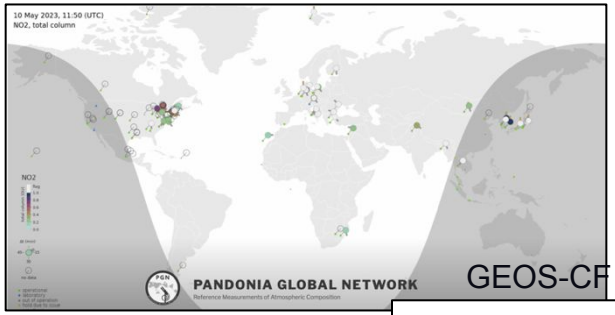
- Adapt ML method developed for surface observations (Christoph Keller et al., ACP 2021).
- Method is limited to locations with at least 1 year of historical data

GODDARD EARTH SCIENCES

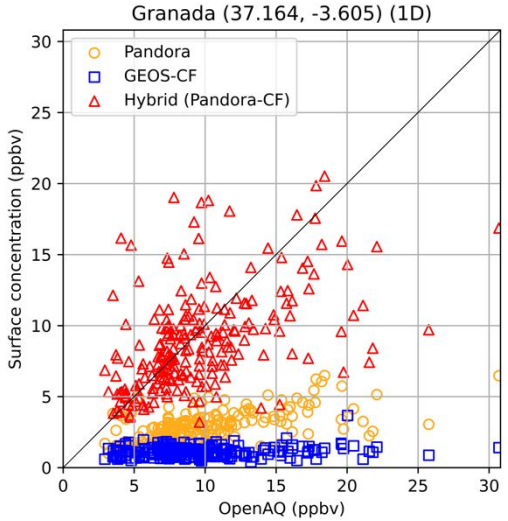
PI Emma Knowland, GMAO

SNWG: Produce localized NO_2 forecasts by combining PANDORA observations with GEOS model output

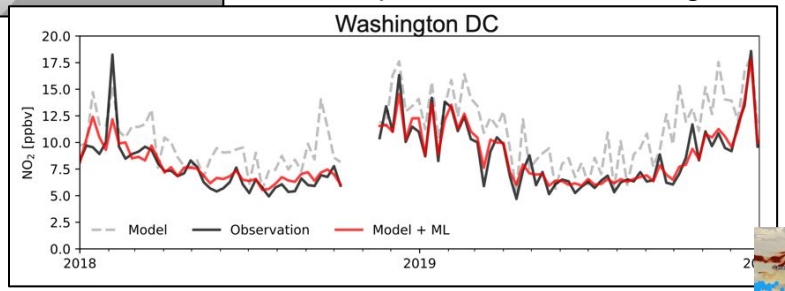
Pandora observations

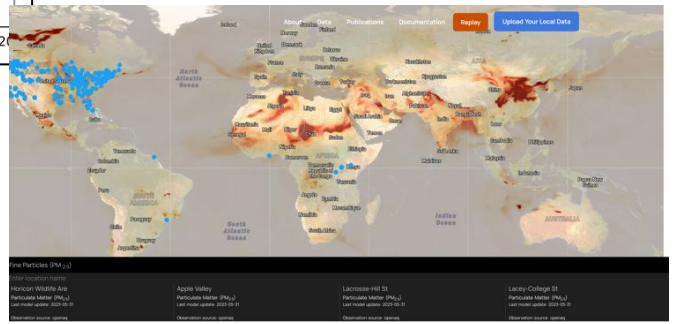


PGN +
GEOS_CF trop columns
-> Surface concentration



GEOS-CF model output + machine learning



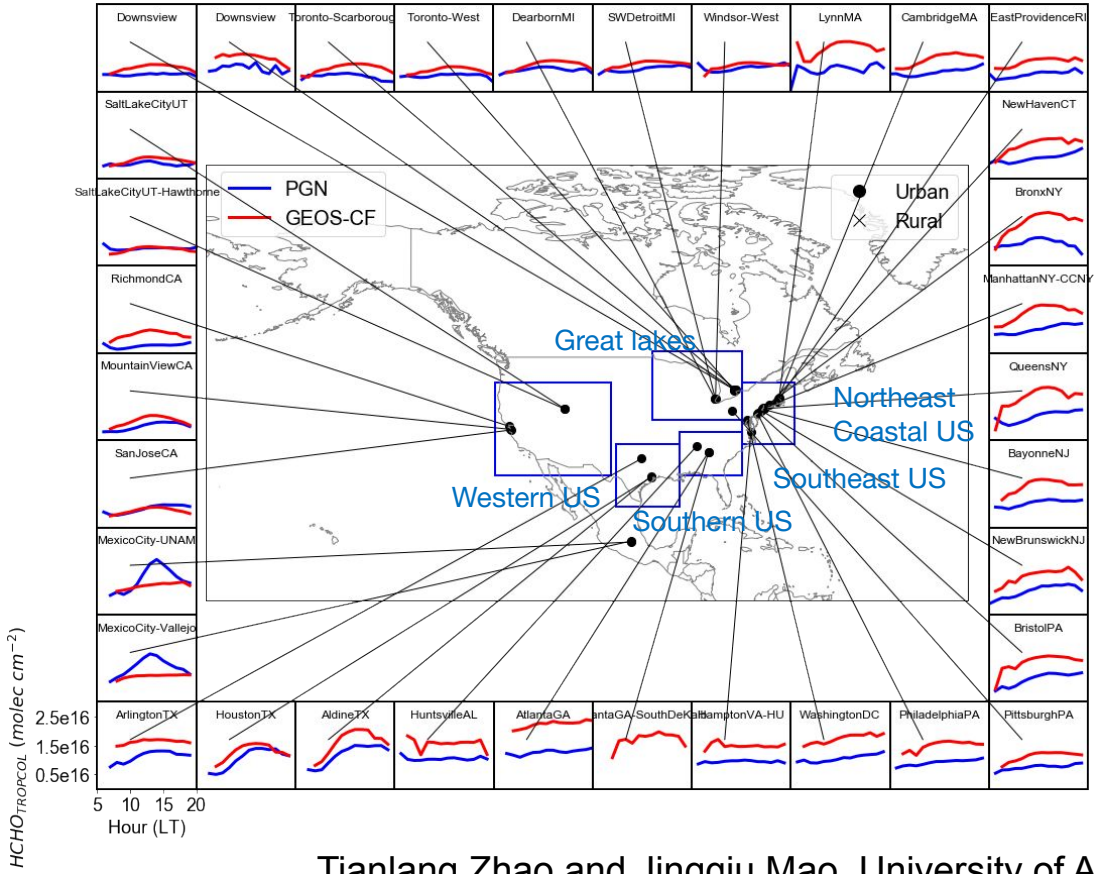


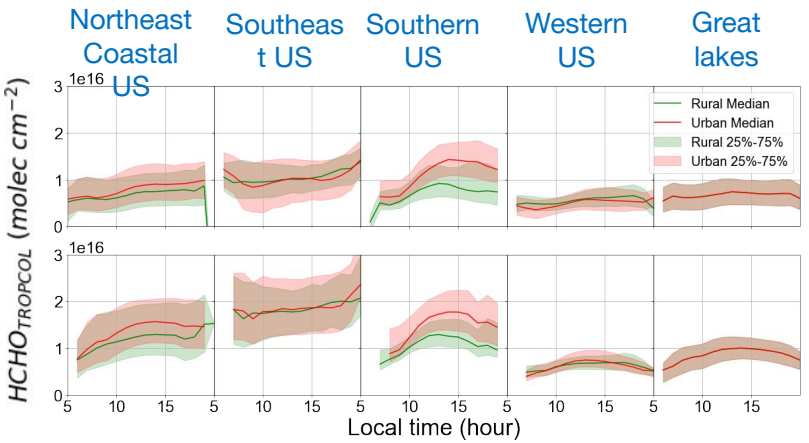
- Adapt ML method developed for surface observations (Christoph Keller et al., ACP 2021)
- Method is limited to locations with at least 1 year of historical data

GODDARD EARTH SCIENCES

PI Emma Knowland, GMAO

PGN vs GEOS-CF: Diurnal variation of HCHO tropospheric column, in urban sites of North America (2021-2023 summer)





- Flat diurnal pattern, except in Southern US;
- No clear urban-rural difference, except in Southern US;
- Larger PGN-model discrepancy in northeast coastal and southeast US than other regions;
- GEOS-CF reproduces PGN HCHO diurnal pattern and urban-rural similarity.

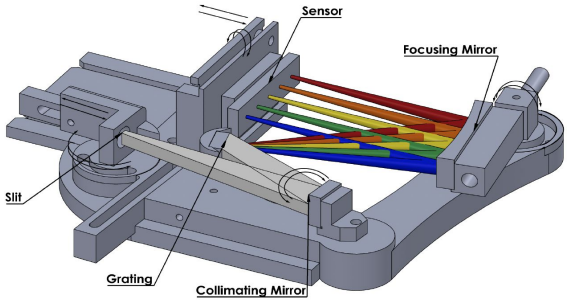
Tianlang Zhao and Jingqiu Mao, University of Alaska.

Instrumentation & Technology

- Delrin -> Nylon in sensor head. **Complete**
- Upgraded tracker. **Complete**
  - Still working on trackers with brakes
- Upgraded sensor head cables on all new instruments/repairs.
- New optical diffusers in all new instruments/repairs.
- Dehumidifier in spectrometer box
  - Humidity is still #1 failure mode
  - All new NASA instruments have the dehumidifier

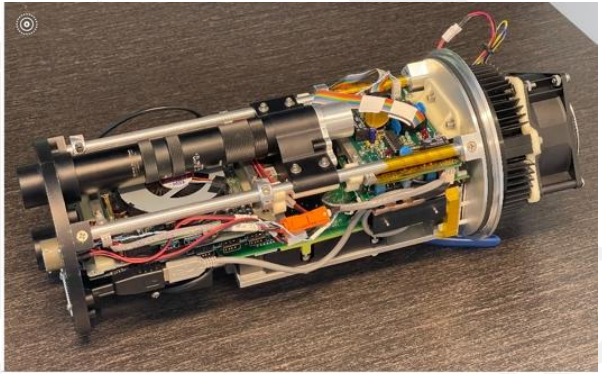
- Custom spectrometer development through NASA SBIR
  - Low stray light
  - Temperature controlled detector
  - Fiber adapter
- New PAN-C all in one in GSFC lab for calibration

Electrolytic membrane dehumidifier



SciGlob NASA SBIR Ph-II Spectrometer prototype

THANKS!



Pan-C NASA SBIR

Optical NO_2 Sonde
HCHO and O_3 in development
2 kg
100 ppt/s
Bailey et al., *AMT*