Why is IAGOS important to the scientific community?

Michael J. Prather
Earth System Science Dept., UC Irvine

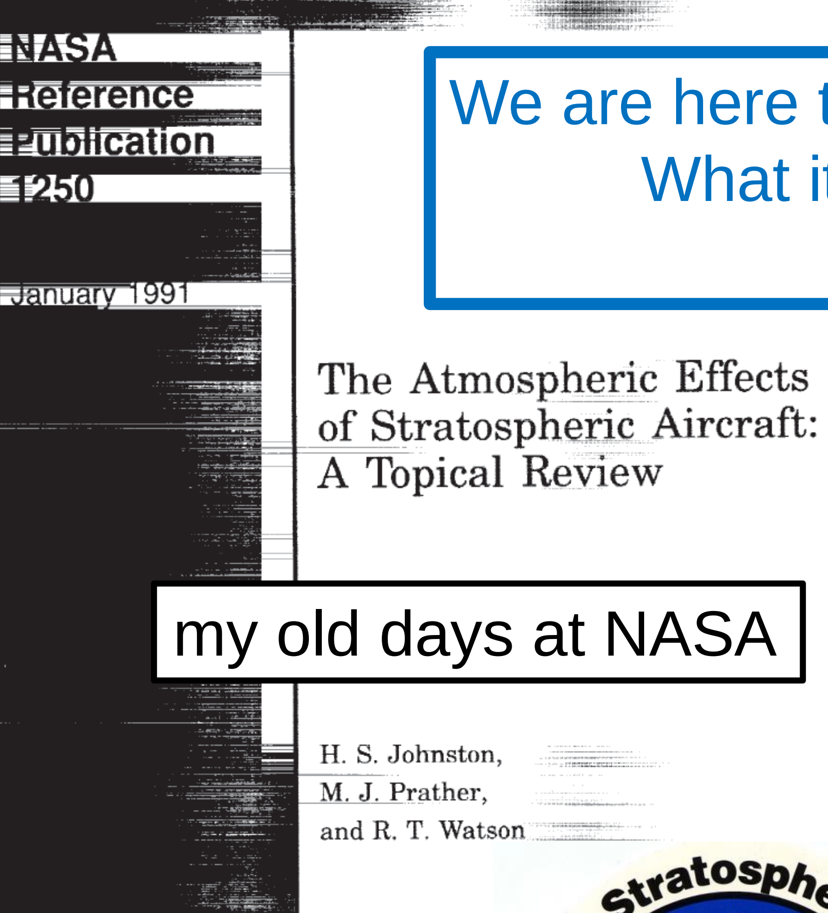
IAGOS Annual Meeting, Toulouse, 18-19 Jun 2018

?

UCIrvine

LA and HOLLYWOOD sign from UCIrvine 7 Mar 2010 1147h

We are here today because we respect aviation.
What it does for our lives and imagination.
What it does for our science!

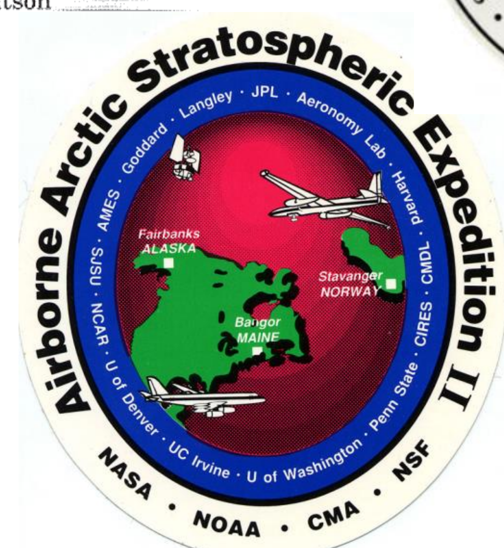

NASA
Reference
Publication
1250

January 1991

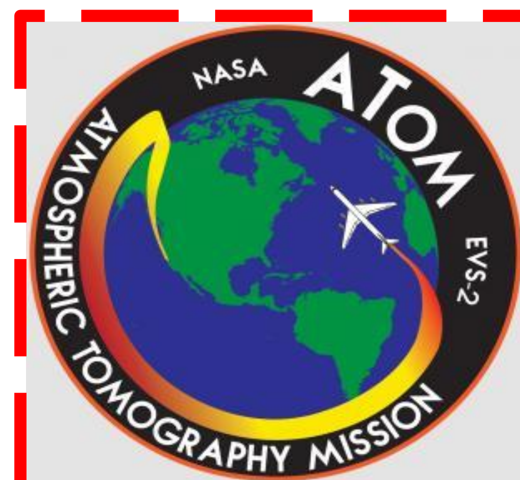
The Atmospheric Effects of Stratospheric Aircraft: A Topical Review

H. S. Johnston,
M. J. Prather,
and R. T. Watson

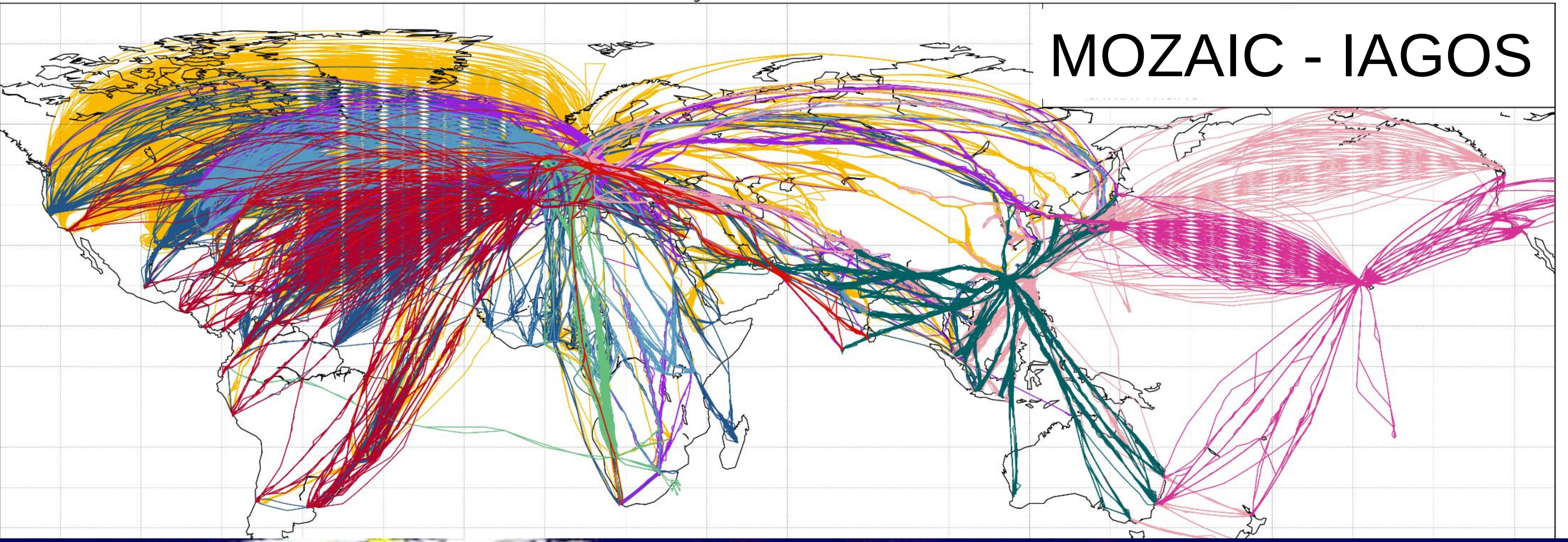
my old days at NASA

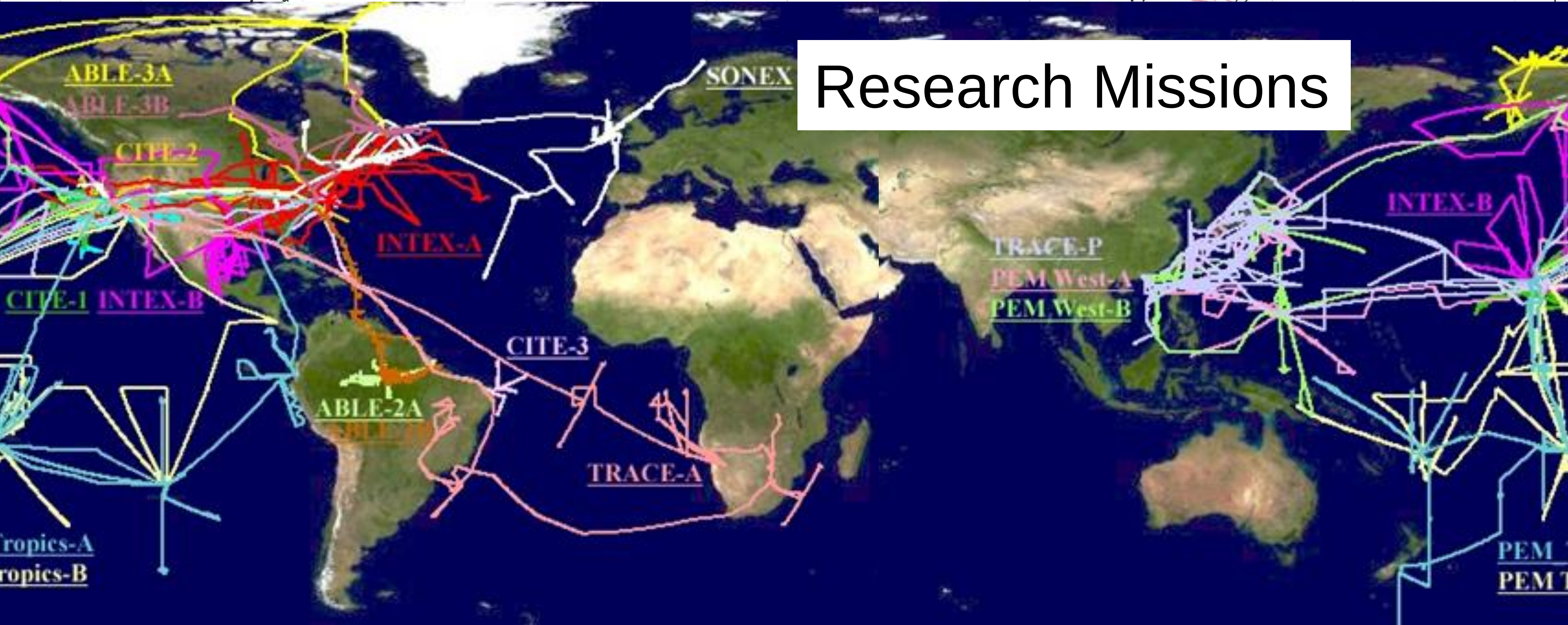


new



56502 Flights from 19940801 to 20180607

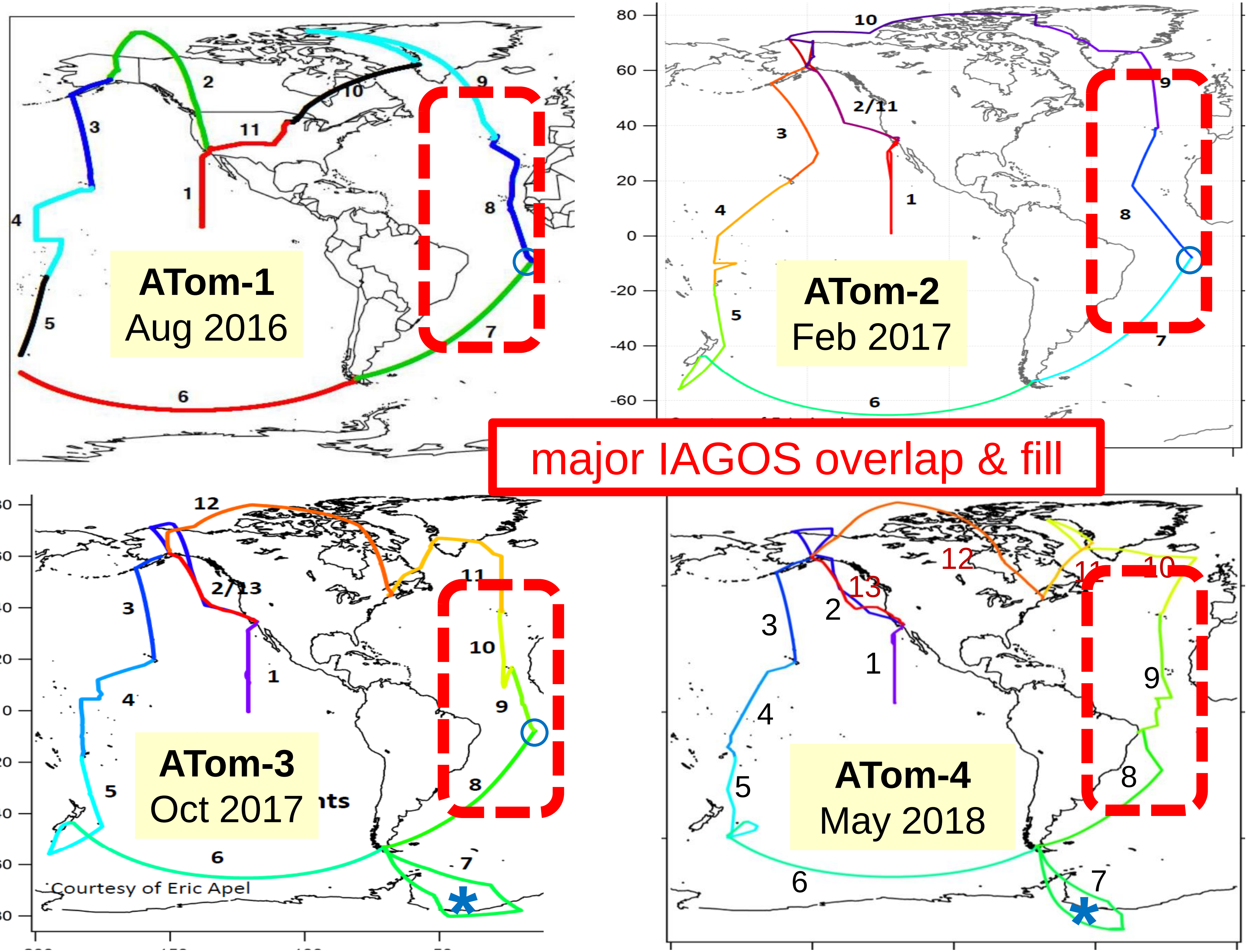




Atom-1 departs Palmdale CA
July 2016

NASA
ATOM
ATMOSPHERIC TOMOGRAPHY MISSION
EVS-2

Atom-4 returns to Palmdale CA
May 2018


ATom-1
Aug 2016
ATom-2
Feb 2017
ATom-3
Oct 2017
ATom-4
May 2018
major IAGOS overlap & fill
Courtesy of Eric Apel
1
2
3
4
5
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7
8
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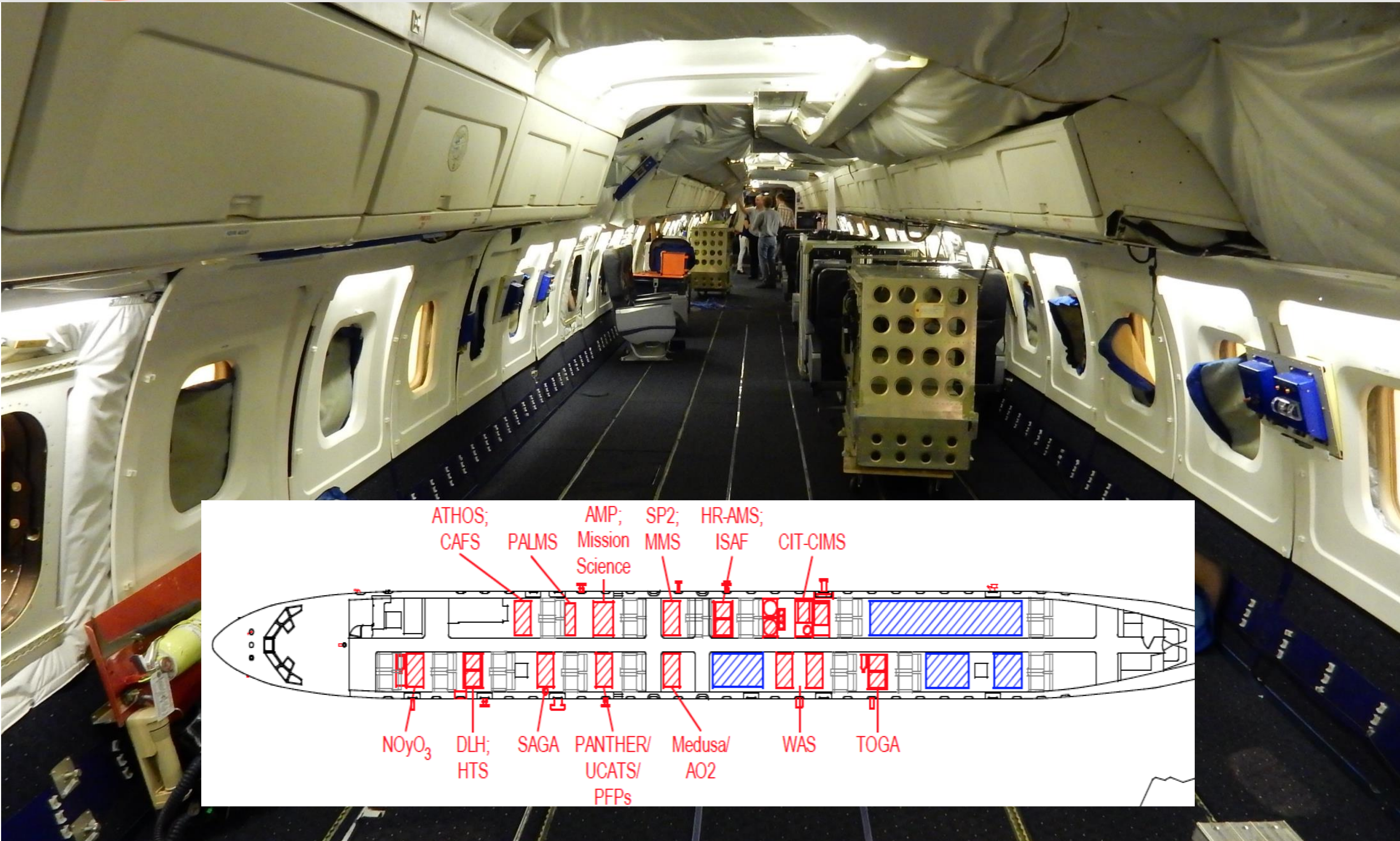
10
11
2/11
2/13
12
13
80
60
40
20
0
-20
-40
-60
-80

the ATom timeline much shorter than IAGOS but much more intense

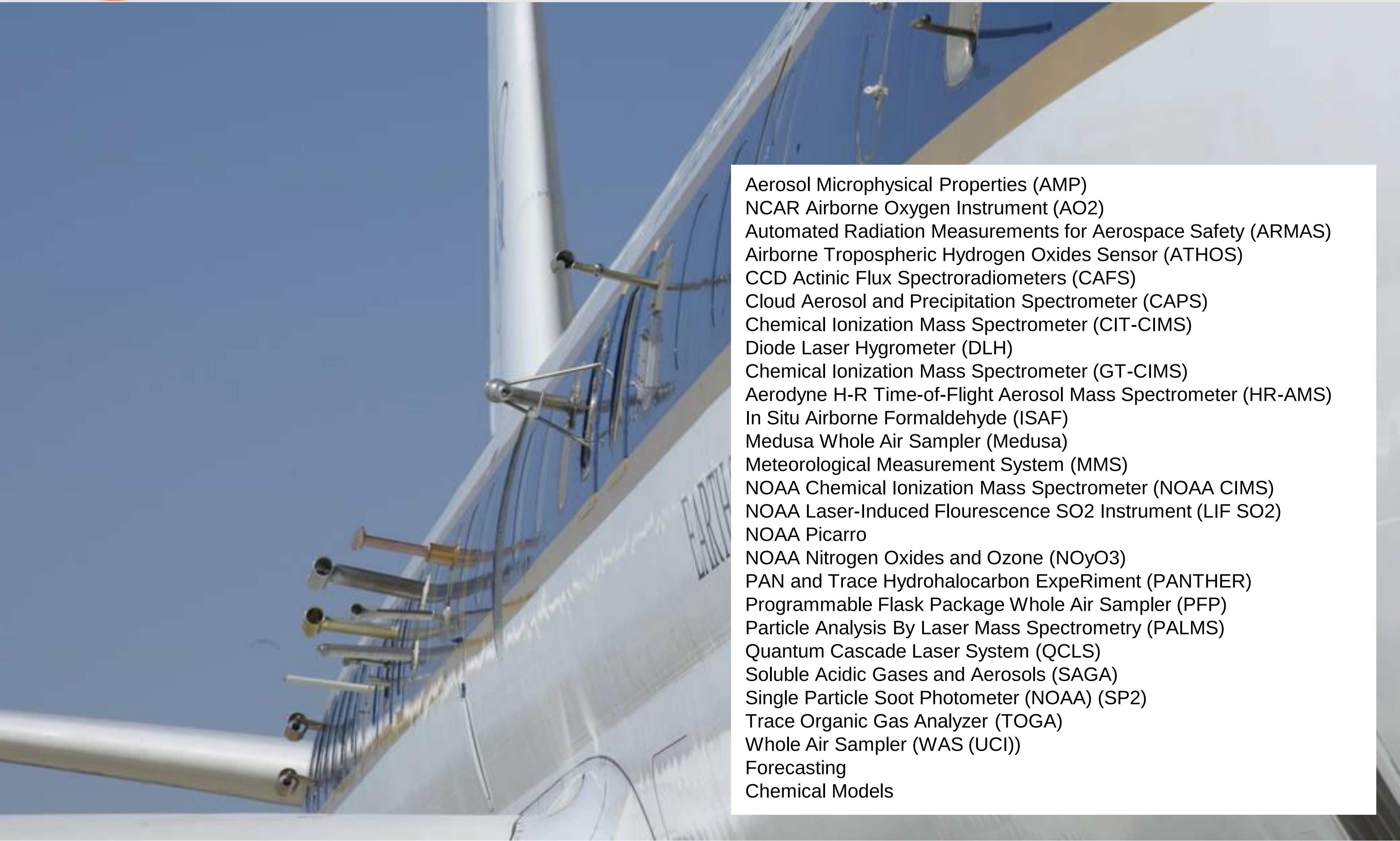
NASA's Atmospheric Tomography EVS-2 Mission	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015				**ATom start**								
2016								**ATom-1**				
2017		**ATom-2**				**ATom-1 data release**				**ATom-3**		**ATom-2 data release**
2018					**ATom-4**							
2019												
2020				**ATom end**								

Mission	ATom1	ATom2
Flts / Hrs Length Days	11 / 94 26	11 / 97 27
Kilometers	65700	70040
Profiles	148	142
Instruments	34	35
Parameters	450	~460

NASA DC-8 looks a little different from the IAGOS aircraft (even when empty)



NASA DC-8 looks a little different from the IAGOS aircraft (bristles when full)



Aerosol Microphysical Properties (AMP)
NCAR Airborne Oxygen Instrument (AO2)
Automated Radiation Measurements for Aerospace Safety (ARMAS)
Airborne Tropospheric Hydrogen Oxides Sensor (ATHOS)
CCD Actinic Flux Spectroradiometers (CAFS)
Cloud Aerosol and Precipitation Spectrometer (CAPS)
Chemical Ionization Mass Spectrometer (CIT-CIMS)
Diode Laser Hygrometer (DLH)
Chemical Ionization Mass Spectrometer (GT-CIMS)
Aerodyne H-R Time-of-Flight Aerosol Mass Spectrometer (HR-AMS)
In Situ Airborne Formaldehyde (ISAF)
Medusa Whole Air Sampler (Medusa)
Meteorological Measurement System (MMS)
NOAA Chemical Ionization Mass Spectrometer (NOAA CIMS)
NOAA Laser-Induced Flourescence SO2 Instrument (LIF SO2)
NOAA Picarro
NOAA Nitrogen Oxides and Ozone (NOyO3)
PAN and Trace Hydrohalocarbon ExpeRiment (PANTHER)
Programmable Flask Package Whole Air Sampler (PFP)
Particle Analysis By Laser Mass Spectrometry (PALMS)
Quantum Cascade Laser System (QCLS)
Soluble Acidic Gases and Aerosols (SAGA)
Single Particle Soot Photometer (NOAA) (SP2)
Trace Organic Gas Analyzer (TOGA)
Whole Air Sampler (WAS (UCI))
Forecasting
Chemical Models

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Reactive Nitrogen			
Nitric oxide (NO)	NO_yO_3	1 s	6 ppt + 3%
Nitrogen dioxide (NO_2)	NO_yO_3	1 s	15 ppt + 5%
NO_x (NO + NO_2)	NO_yO_3	30 s	10 ppt +5%
Nitric acid (HNO_3)	SAGA MC/IC	1.5 min	5 ppt + 10%
Nitric acid (HNO_3)	CIT-CIMS	1 s	50 ppt + 30%
Pernitric acid (HNO_4)	CIT-CIMS	1 s	50 ppt + 30%
Total reactive nitrogen (NO_y)	NO_yO_3	1 s	40 ppt + 12%
VOCs			
C_2–C_4 alkanes	PFP	15-30 s every 25 min$^+$	2 ppt + 10%
Benzene	PFP	15-30 s every 25 min$^+$	2 ppt + 10%
Ethane (C_2H_6), Ethene (C_2H_4)	WAS	15-90 s every 6 min‡	3 pptv or 2% (whichever is larger) precision, 5% accuracy
i-Butane (C_4H_{10}), Toluene (C_7H_8)	WAS	15-90 s every 6 min‡	3 ppt, 3% (whichever is larger) precision, 10% accuracy

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
VOCs			
Ethyne (C_2H_2), Propane (C_3H_8), Propene (C_3H_6), n-Butane (C_4H_{10}), n-Pentane (C_5H_{12}), i-Pentane (C_5H_{12}), Isoprene (C_5H_8), Benzene (C_6H_6)	WAS	15-90 s every 6 min‡	3 ppt, 2% (whichever is larger) precision, 10% accuracy
trans-2-Butene, cis-2-Butene, 1-Butene, i-Butene, Neopentane, 1,3-Butadiene, 1-Pentene, Isoprene, 2,3-Dimethylbutane, 2-Methylpentane, 3-Methylpentane, n-Hexane, Heptane, Ethylbenzene, m-Xylene, o-Xylene, α-Pinene, β-Pinene	WAS	15-90 s every 6 min‡	3 ppt or 2% (whichever is larger) precision, 10% for accuracy
Benzene	TOGA	30 s every 2 min	± 15% or 2 pptv
Toluene	TOGA	30 s every 2 min	± 15% or 1 pptv
Ethylbenzene+m-/p-Xylene	TOGA	30 s every 2 min	± 20% or 0.6 pptv
o-Xylene	TOGA	30 s every 2 min	± 20% or 0.4 pptv

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Benzene	TOGA	30 s every 2 min	± 15% or 2 pptv
Toluene	TOGA	30 s every 2 min	± 15% or 1 pptv
Ethylbenzene+m-/p-Xylene	TOGA	30 s every 2 min	± 20% or 0.6 pptv
o-Xylene	TOGA	30 s every 2 min	± 20% or 0.4 pptv
Benzene	TOGA	30 s every 2 min	± 15% or 2 pptv
Toluene	TOGA	30 s every 2 min	± 15% or 1 pptv
Ethylbenzene+m-/p-Xylene	TOGA	30 s every 2 min	± 20% or 0.6 pptv
Photoproducts and Oxygenates			
Ozone (O_3)	NO_yO_3	1 s	0.2 ppb + 2%
Ozone (O_3)	UCATS	5 s	2 ppb + 2%
Formaldehyde (HCHO)	ISAF	1 s	20 ppt + 10%
Formaldehyde (HCHO)	TOGA	30 s every 2 min	± 40% or 40 pptv
Acetone (CH_3COCH_3)	TOGA	30 s every 2 min	± 20% or 40 pptv

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Photoproducts and Oxygenates			
Methyl ethyl ketone, MEK, ($CH_3COC_2H_5$), MVK, Methacrolein	TOGA	30 s every 2 min	± 20% or 2 pptv
Methanol (CH_3OH)	TOGA	30 s every 2 min	± 30% or 40 pptv
Ethanol (C_2H_5OH)	TOGA	30 s every 2 min	± 30% or 20 pptv
α-Pinene	TOGA	30 s every 2 min	± 30% or 0.4 pptv
β-Pinene	TOGA	30 s every 2 min	± 30% or 1 pptv
Acetaldehyde, Propanal	TOGA	30 s every 2 min	± 20% or 10 pptv
Butanal, Acrolein	TOGA	30 s every 2 min	± 30% or 2 pptv
Methyl t-butyl ether (MTBE)	TOGA	30 s every 2 min	± 20% or 2 pptv
Ethyl Nitrate ($C_2H_5ONO_2$)	TOGA	30 s every 2 min	± 30% or 2 pptv
i-Propyl Nitrate ($iC_3H_7ONO_2$)	TOGA	30 s every 2 min	± 15% or 2 pptv
Methyl ethyl ketone, MEK, ($CH_3COC_2H_5$), MVK, Methacrolein	TOGA	30 s every 2 min	± 20% or 2 pptv

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Photoproducts and Oxygenates			
2-Butyl Nitrate + n-Butyl Nitrate	TOGA	30 s every 2 min	± 30% or 2 pptv
Hydrogen peroxide (HOOH)	CIT-CIMS	10 s	50 ppt + 30%
Methyl peroxide (CH_3OOH)	CIT-CIMS	10 s	50 ppt + 30%
Formic acid (HCOOH)	CIT-CIMS	1 s	100 ppt + 30%
Acetic acid (CH_3COOH)	CIT-CIMS	10 s	100 ppt + 30%
Hydroxyl radical (OH)	ATHOS	30 s	0.02 ppt + 20%
Hydroperoxyl radical (HO_2)	ATHOS	30 s	0.2 ppt + 20%
OH loss rate	ATHOS	30 s	1 s^{-1} + 10%
Methyl nitrate (CH_3ONO_2), Ethyl nitrate ($C_2H_5ONO_2$), i-Propyl nitrate ($C_3H_7ONO_2$), n-Propyl nitrate ($C_3H_7ONO_2$), 2-Butyl nitrate ($C_4H_9ONO_2$), 2-Pentyl nitrate ($C_5H_{11}ONO_2$), 3-Pentyl nitrate ($C_5H_{11}ONO_2$)	WAS	15-90 s every 6 min‡	0.02 pptv or 3% (whichever is larger) precision, 20% accuracy

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Aerosols			
Particle distribution (4–1000 nm)	NMASS; UHSAS	1 s	Number: 8 cm^3, 9% Surface Area: 2 $\mu m^2 cm^{-3}$, 26% Volume: 0.1 $\mu m^3 cm^3$, 36%
Cloud drop distribution (2–50 µm)	CDP	1 s	TBD
Black carbon mass and coating state	SP2	1 s	12 ng/kg + 30%
SO_4^{2-}, NO_3^-, Cl^-, NH_4^+	HR-AMS	1 s	0.1 $\mu g/m^3$ ± 34%
Organic aerosol	HR-AMS	1 s	0.5 $\mu g/m^3$ ± 38%
Particle O/C	HR-AMS	1s	± 25%
Particle H/C	HR-AMS	1s	± 15%
Particle OM/OC	HR-AMS	1s	± 20%
Single particle composition (200-4000 nm). Particle type fractions for sulfate/organic/nitrate, biomass burning, elemental carbon, sea salt, mineral dust, meteoric, oil combustion	PALMS	3 min	0 +15%

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Aerosols			
Particle type vol concentration	PALMS	5 min	0.1 µm^3 cm^{-3} +30%
Sub micron SO_4^{2-}	SAGA MC/IC	1.5 min	0.05 µg/m^3 + 10%
Bulk Cl^-, Na^+, Ca^{2+}	SAGA filters	5 - 15 min	0.05 µg/m^3 + 10%
Bulk SO_4^{2-}, NO_3^-, Br^-, $C_2O_4^{2-}$, NH_4^+, K^+, Mg^+	SAGA filters	5 - 15 min	0.02 µg/m^3 + 10%
^7Be	SAGA filters	5 – 15 min	25 fCi/m^3 + 5%
^{210}Pb	SAGA filters	5 – 15 min	0.5 fCi/m^3 + 10%
GHGs and ODSs			
Carbon dioxide (CO_2)	HTS	2 s	± 0.1 ppm, ± 0.02 ppm
Carbon dioxide (CO_2)	AO2	1 s	0.2 ppm
Carbon dioxide (CO_2)	MEDUSA	32 flasks/flight	0.1 ppm
Carbon dioxide (CO_2)	PFP	15-30 s every 25 min$^+$	0.2 ppm
Methane (CH_4)	HTS	2 s	± 1 ppb, ± 0.5 ppb

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
GHGs and ODSs			
Methane (CH_4)	PANTHER/UCATS	3 s sample every 2 min	5 ppb + 0.5%
Methane (CH_4)	PFP	15-30 s every 25 min$^+$	1.5 ppb [a]
Methane (CH_4)	WAS	15-90 s every 6 min‡	0.1%, 1%
Nitrous oxide (N_2O)	HTS	1 s	± 0.2 ppb, ± 0.10 ppb
Nitrous oxide (N_2O)	PANTHER/UCATS	3 s sample every 1 min	1 ppb + 0.5%
Nitrous oxide (N_2O)	PFP	15-30 s every 25 min$^+$,	0.5 ppb [a]
Sulfur hexafluoride (SF_6)	PANTHER/UCATS	3 s sample every 1 min	0.05 ppt + 0.5%
Sulfur hexafluoride (SF_6)	PFP	15-30 s every 25 min$^+$	0.06 ppt [a]
CFCs	PANTHER	3 s sample every 1 min	1 ppt + 0.5%
HCFCs and HFCs	PANTHER	2.8 min sample every 3 min	0.5 ppt + 1.5%
CFCs, HCFCs, and HFCs	PFP	15-30 s every 25 min$^+$	0.1 to 5%, depending on chemical
C_1 halides	PFP	15-30 s every 25 min$^+$	0.2 to 10%, depending on chemical

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
GHGs and ODSs			
Halons: H-1211, H-1301, H-2402	PFP	15-30 s every 25 min$^+$	1 to 2% depending on chemical
Halon H-1211	PANTHER	3 s sample every 1 min	0.05 ppt + 1%
Chloromethane (CH_3Cl), Methylbromide (CH_3Br)	PANTHER	2.8 min sample every 3 min	0.1 ppt + 2%
Other halogenated hydrocarbons: CH_3CCl_3, CCl_4, C_2Cl_2, $CHCl_3$, C_2Cl_4, $CHBr_3$, CH_2Br_2, CF_4, C_2F_6	PFP	15-30 s every 25 min$^+$	0.2 to 10% depending on chemical
CFC-11	WAS	15-90 s every 6 min‡	1% precision, 2% accuracy
CFC-113	WAS	15-90 s every 6 min‡	2% precision, 2% accuracy
CFC-12	WAS	15-90 s every 6 min‡	1% precision, 2% accuracy
CFC-11	TOGA	30 s every 2 min	± 20% or 10 pptv
CFC-113	TOGA	30 s every 2 min	± 20% or 2 pptv
HCFC-22	WAS	15-90 s every 6 min‡	3% precision, 5% accuracy
H-1211 ($CBrClF_2$)	WAS	15-90 s every 6 min‡	0.1 pptv or 3% (whichever is larger) precision, 5% accuracy
CFC-114, HCFC-142b, HCFC-141b, HFC-134a	WAS	15-90 s every 6 min‡	3% precision, 10% accuracy

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
GHGs and ODSs			
HFC-152a	WAS	15-90 s every 6 min‡	5% precision, 20% accuracy
H-2402, H-1301	WAS	15-90 s every 6 min‡	5% precision, 10% accuracy
Methyl bromide (CH_3Br)	WAS	15-90 s every 6 min‡	3% precision, 5% accuracy
Dibromethane (CH_2Br_2)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 10% accuracy
Bromoform ($CHBr_3$)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 20% accuracy
Chloroform ($CHCl_3$)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 10% accuracy
Methyl chloride (CH_3Cl)	WAS	15-90 s every 6 min‡	5 pptv or 3% (whichever is larger) precision, 5% accuracy
Methyl iodide (CH_3I)	WAS	15-90 s every 6 min‡	0.01 pptv or 3% (whichever is larger) precision, 10% accuracy
Dichloromethane (CH_2Cl_2)	WAS	15-90 s every 6 min‡	0.3 pptv or 4% (whichever is larger) precision, 20% accuracy
Trichloroethylene (C_2HCl_3)	WAS	15-90 s every 6 min‡	0.1 pptv, 5% precision, 20% accuracy
Bromodichloromethane ($CHBrCl_2$), Dibromochloromethane ($CHBr_2Cl$)	WAS	15-90 s every 6 min‡	0.1 pptv or 10% (whichever is larger) precision, 20% accuracy

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
GHGs and ODSs			
Carbon tetrachloride (CCl_4)	WAS	15-90 s every 6 min‡	2% precision, 5% accuracy
Tetrachloroethene (C_2Cl_4)	WAS	15-90 s every 6 min‡	0.05 pptv or 3% (whichever is larger) precision, 10% accuracy
Methyl chloroform (CH_3CCl_3)	WAS	15-90 s every 6 min‡	1 pptv or 3% (whichever is larger) precision, 5% accuracy
1,2-dichloroethene	WAS	15-90 s every 6 min‡	1 pptv, 5% precision, 50% accuracy
Methyl bromide (CH_3Br)	TOGA	30 s every 2 min	± 20% or 2 pptv
Dibromomethane (CH_2Br_2)	TOGA	30 s every 2 min	± 15% or 0.06 pptv
Bromoiodomethane (CH_2BrI)	TOGA	30 s every 2 min	± 30% or 0.06 pptv
Chloroform ($CHCl_3$)	TOGA	30 s every 2 min	± 15% or 2 pptv
Bromoform ($CHBr_3$)	TOGA	30 s every 2 min	± 30% or 0.4 pptv
Bromodichloromethane ($CHBrCl_2$)	TOGA	30 s every 2 min	± 20% or 0.06 pptv
Dibromochloromethane ($CHBr_2Cl$)	TOGA	30 s every 2 min	± 15% or 0.06 pptv
Chloroiodomethane (CH_2ClI)	TOGA	30 s every 2 min	± 20% or 0.14 pptv

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
GHGs and ODSs			
Diiodomethane (CH_2I_2)	TOGA	30 s every 2 min	± 40% or 0.1 pptv
Chlorobenzene (C_6H_5Cl)	TOGA	30 s every 2 min	± 15% or 0.2 pptv
Tetrachloroethylene (C_2Cl_4)	TOGA	30 s every 2 min	± 15% or 0.6 pptv
Tracers and other species			
Carbon monoxide (CO)	HTS	1 s	± 3.5 ppb, ± 0.15 ppb
Carbon monoxide (CO)	PANTHER/UCATS	3 s every 2 min	3 ppb + 2%
Carbon monoxide (CO)	PFP	15-30 s every 25 min^{+}	1.2 ppb
Carbon monoxide (CO)	WAS	15-90 s every 6 min‡	3% precision, 5% accuracy
Acetonitrile (CH_3CN)	TOGA	30 s every 2 min	± 40% or 2 pptv
DMS (CH_3SCH_3)	TOGA	30 s every 2 min	± 15% or 1 pptv
Oxygen (O_2/N_2)	AO2	1 s	3 per meg
Oxygen (O_2/N_2)	MEDUSA	32 flasks/flight	3 per meg

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Tracers and other species			
Argon (Ar/N_2)	MEDUSA	32 flasks/flight	6 per meg
Hydrogen cyanide (HCN)	CIT-CIMS	1 s	50 ppt + 30%
Hydrogen cyanide (HCN)	TOGA	30 s every 2 min	± 50% or 20 pptv
Water vapor (H_2O)	DLH	1 s	0.2 ppm + 10%
Water vapor (H_2O)	UCATS	1 s	1 ppm + 5%
Hydrogen (H_2)	PANTHER/UCATS, PFP	3 s sample every 2 min, 15-30 s every 25 min⁺	2 ppb + 1%, 4 ppb
Sulfur dioxide (SO_2)	CIT-CIMS	1 s	250 ppt + 30%
Carbonyl sulfide (OCS)	PFP	15-30 s every 25 min⁺	1%
Carbonyl Sulfide (OCS)	WAS	15-90 s every 6 min‡	3% precision, 10% accuracy
Carbonyl sulfide (OCS)	PANTHER	2.8 min sample every 3 min	2 ppt + 1.5%
DMS (CH_3SCH_3)	WAS	15-90 s every 6 min‡	0.5 ppt or 1% (whichever is larger) precision, 10% accuracy
DMDS (CH_3SSCH_3)	WAS	15-90 s every 6 min‡	0.1 ppt or 3%, (whichever is larger) precision, 20% accuracy

List of ATom measured species

Species	Instrument(s)	Sampling interval	Data Quality
Tracers and other species			
Methyl iodide (CH_3I), Carbon disulfide (CS_2)	PANTHER	2.8 min sample every 3 min	TBD
Isotopes: $\delta^{13}CH_4$	PFP	15-30 s every 25 min⁺	0.1 per mil
Solar Radiation			
Spectrally-resolved actinic flux (280-650 nm)	CAFS	3 s	5 x $10^{-5}s^{-1}$ + 12% for jNO_2
Meteorological Data			
Static P, static T, 3D winds; turbulence	MMS	0.05 s	0.3 mb, 0.3K, 1 m/s

‡WAS sampling interval is based on 100 canisters and a nominal 10-hour flight time.
⁺PFP sampling interval based on 24 flasks being filled during a nominal 10-hour flight, though actual sampling will most likely be triggered at specific pressure/altitude points.
[a]These values represent the sum of repeatability plus reproducibility.

Actually, ATom has added several new instruments and measurements: PAN, a 2nd NO_2, SO_2, …

BACK TO BASICS

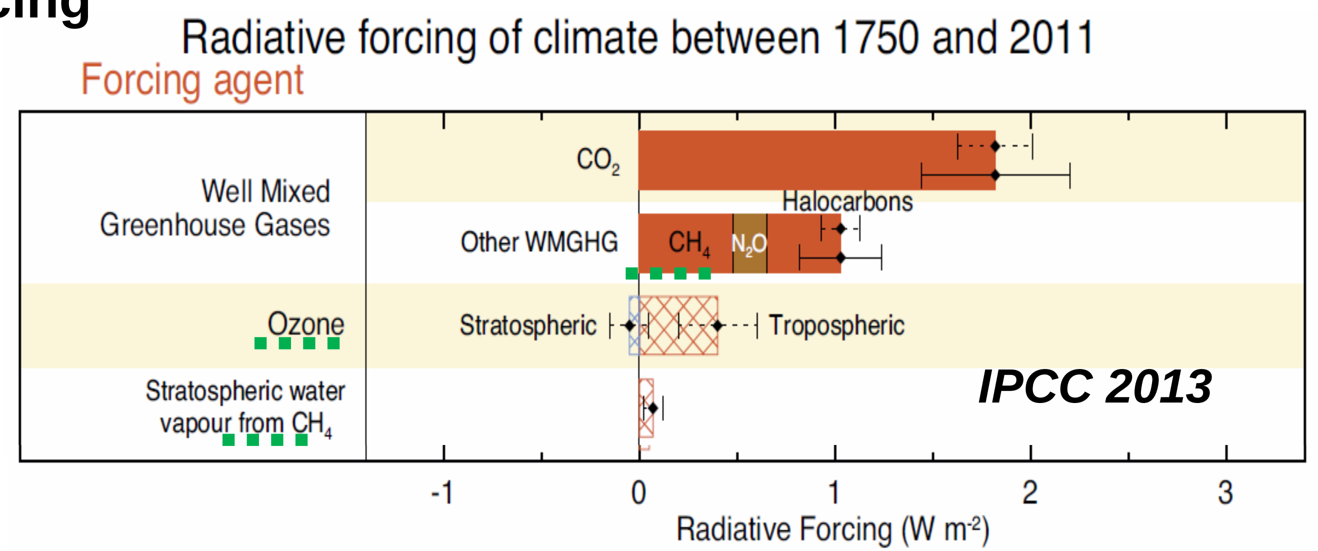
What are the fundamental SCIENCE-POLICY questions?

- evolution of greenhouse gases (O_3, CH_4) and air quality
- response to human activities and to climate change

◆ **CH_4** and **tropospheric O_3** are #2 and #3 human influenced Greenhouse Gases (GHGs), a.k.a. ***Short-Lived Climate Forcers (SLCF).***

GHG climate forcing

1750-2011 (W m^{-2})	
CO_2	1.82
CH_4	**0.48**
trop O_3	**0.40**
CFCs	0.33
N_2O	0.17
HFCs	0.02
PFCs	0.01



◆ **Global-scale O_3 pollution** *primes the engine for photochemical oxidants and SOA in urban areas—another dimension of the SLCFs.*

The need to address CH_4 and tropospheric O_3 pollution is recognized in USA and international partnerships.

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants

16 Feb 2012

U.S. DEPARTMENT OF STATE

DIPLOMACY IN ACTION

Efforts to reduce short-lived climate pollutants strengthened at COP21

The CCAC releases communique, adopts a five year strategy, and receives $12 million in new funding.

BY CCAC SECRETARIAT - 9 DECEMBER, 2015

34 Ministers attended the 7th CCAC High Level Assembly at COP21, Paris

https://news.un.org/en/story/2018/05/1011071

WMO & WHO

UN agencies join forces against environmental risks that cause 12.6 million deaths a year

31 May 2018 | Climate Change

Two United Nations agencies are combining their expertise to counter the growing threat of extreme weather, climate change and air pollution, which cause more than 12.6 million deaths a year, it was announced on Thursday.

IPCC Inventory Task Force is thinking of including emissions of air quality related pollutants

INTERGOVERNMENTAL PANEL ON climate change

Task Force on National Greenhouse Gas Inventories (TFI)

Ref. No.201803/TFI/SLCF/1

29 March 2018

INVITATION TO THE

Expert Meeting on Short-lived Climate Forcers (EM-SLCF)

Geneva, Switzerland, 28-31 May 2018

Dear Mr.

I have the pleasure to invite you to the Expert Meeting on Short-lived Climate Forcers (EM-SLCF), to be held in Geneva, Switzerland, on 28-31 May 2018. It will start at 9:00am on Monday, 28 May and will end before lunch time on Thursday, 31 May. Provisional agenda of this meeting will be sent to you soon.

SCIENCE QUESTION: What do we use for SLCFs?

- chemistry-climate models (CCMs)

How do we know CCMs are any good?

- incorporate more (realistic) processes
- run at more realistic scales
- compare and test with observations

What kind of observations are needed?

- **chemical climatologies**, only way for CCMs

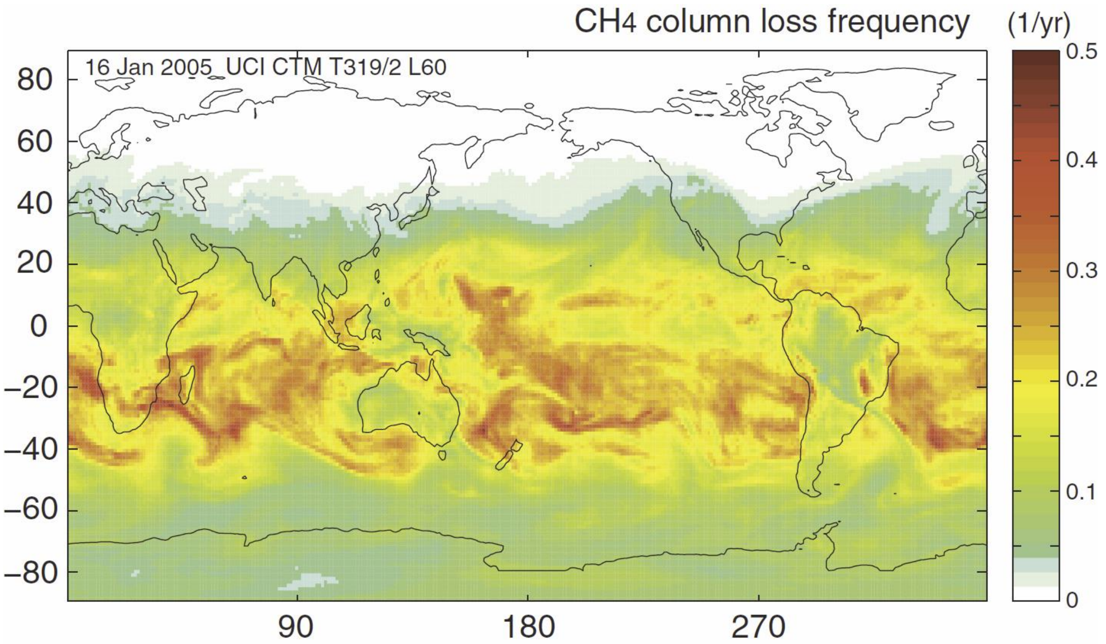
IAGOS & ATom

and not process-based missions

For CH_4 & O_3, What really do we need to measure?

- profiles of species are good, but inadequate.
- profiles of photochemical *reactivity* is what matters.
  reactivity = 24-hr production/loss of O_3 & CH_4.
- ? can we even measure *reactivity*

Looking at UCI model,
we see ***rivers of CH_4 loss***,
with adjacent 1° grid cells
having <u>column-average</u>
losses differ by <u>factor of 5</u>.



- would the real atmosphere not be even more granular?

Need to focus on the reactivity of air parcels: ***Which Air Matters?***

Atmos. Chem. Phys., 17, 9081–9102, 2017
https://doi.org/10.5194/acp-17-9081-2017

Atmospheric Chemistry and Physics
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EGU

Global atmospheric chemistry – which air matters

Michael J. Prather[1], Xin Zhu[1], Clare M. Flynn[1], Sarah A. Strode[2,3], Jose M. Rodriguez[2], Stephen D. Steenrod[2,3], Junhua Liu[2,3], Jean-Francois Lamarque[4], Arlene M. Fiore[5], Larry W. Horowitz[6], Jingqiu Mao[7], Lee T. Murray[8], Drew T. Shindell[9], and Steven C. Wofsy[10]

reactivities

P-O3 (ppb/day)

$$HO_2 + NO \rightarrow NO_2 + OH,$$
$$RO_2 + NO \rightarrow NO_2 + RO,$$
$$O_2 + h\nu \rightarrow O + O(\times 2),$$

L-O3 (ppb/day)

$$O_3 + OH \rightarrow O_2 + HO_2,$$
$$O_3 + HO_2 \rightarrow HO + O_2 + O_2,$$
$$O(^1D) + H_2O \rightarrow OH + OH,$$

L-CH4 (ppb/day)

$$CH_4 + OH \rightarrow CH_3 + H_2O$$

ATom needs to measure the key chemical species and physics that control the reactivity, including ***O_3, CH_4, CO, C_2H_6, other alkanes, alkenes, aromatics, NO_x, HNO_3, HO_2NO_2, PAN, other organic nitrates, H_2O, HCHO, H_2O_2, CH_3OOH, plus temperature and pressure***.

Atom needs to collect statistics that enable us to establish a representative chemical climatology. This means regular profiling from 0 to 12 km without chasing ‘events’ or ‘processes’.

= *Atmospheric Tomography*

Thus begins *"ATom-think"*

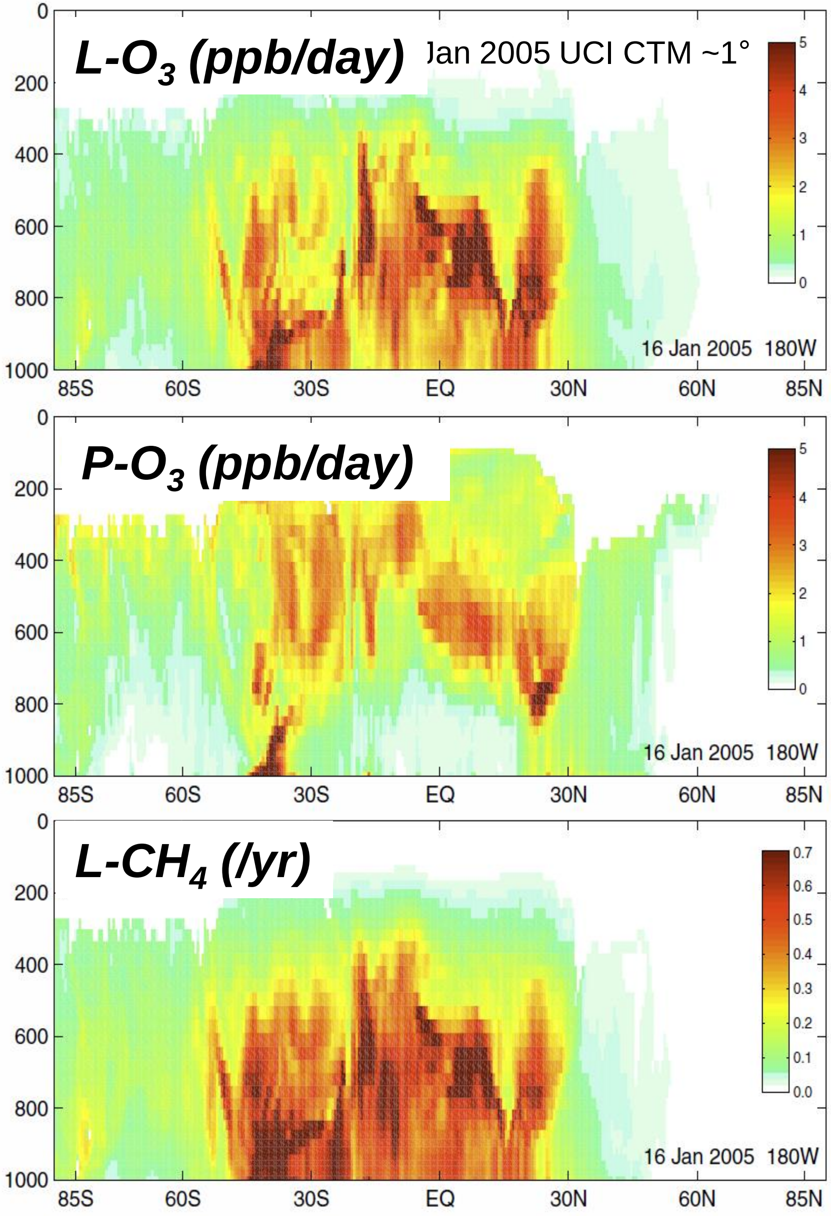
What to measure?
How to model it?
Which new way to look at it?

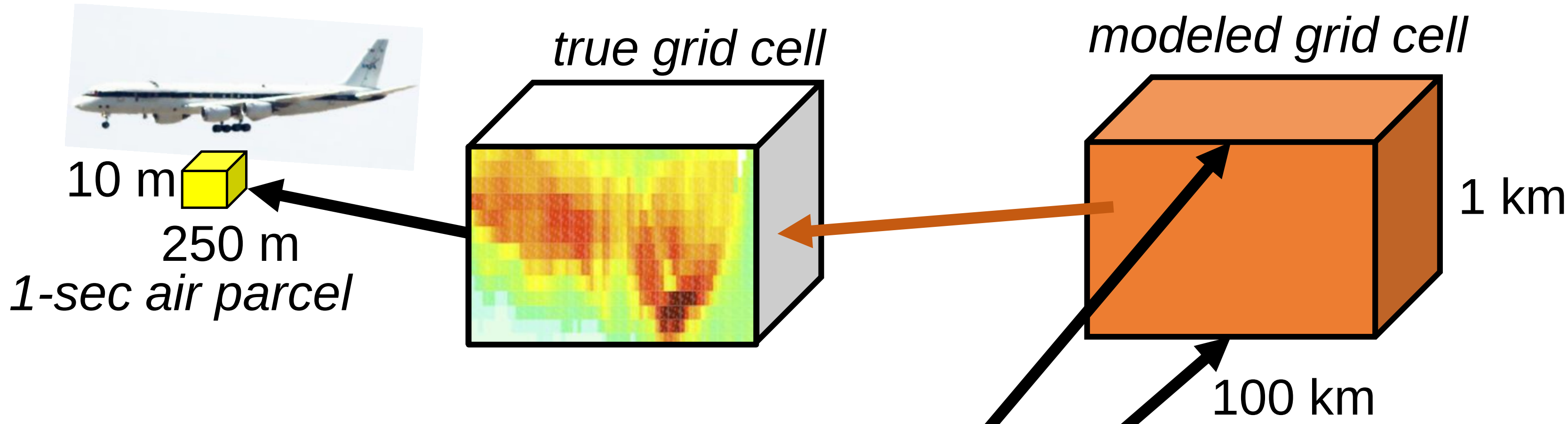
A Tomographic slice down the dateline in UCI CTM shows large variations in reactivity

(***L-O$_3$, P-O$_3$, L-CH$_4$***)

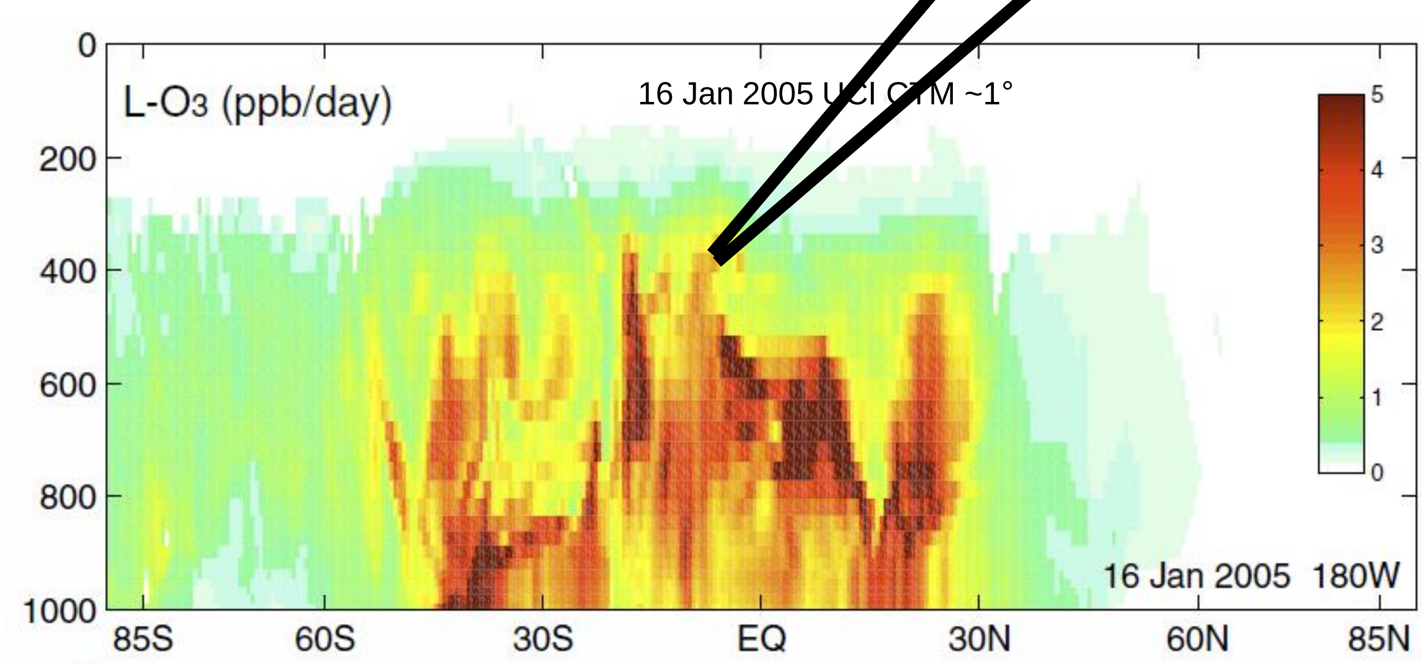
across neighboring air parcels in the model.

How can we characterize this granularity? How can we measure it?



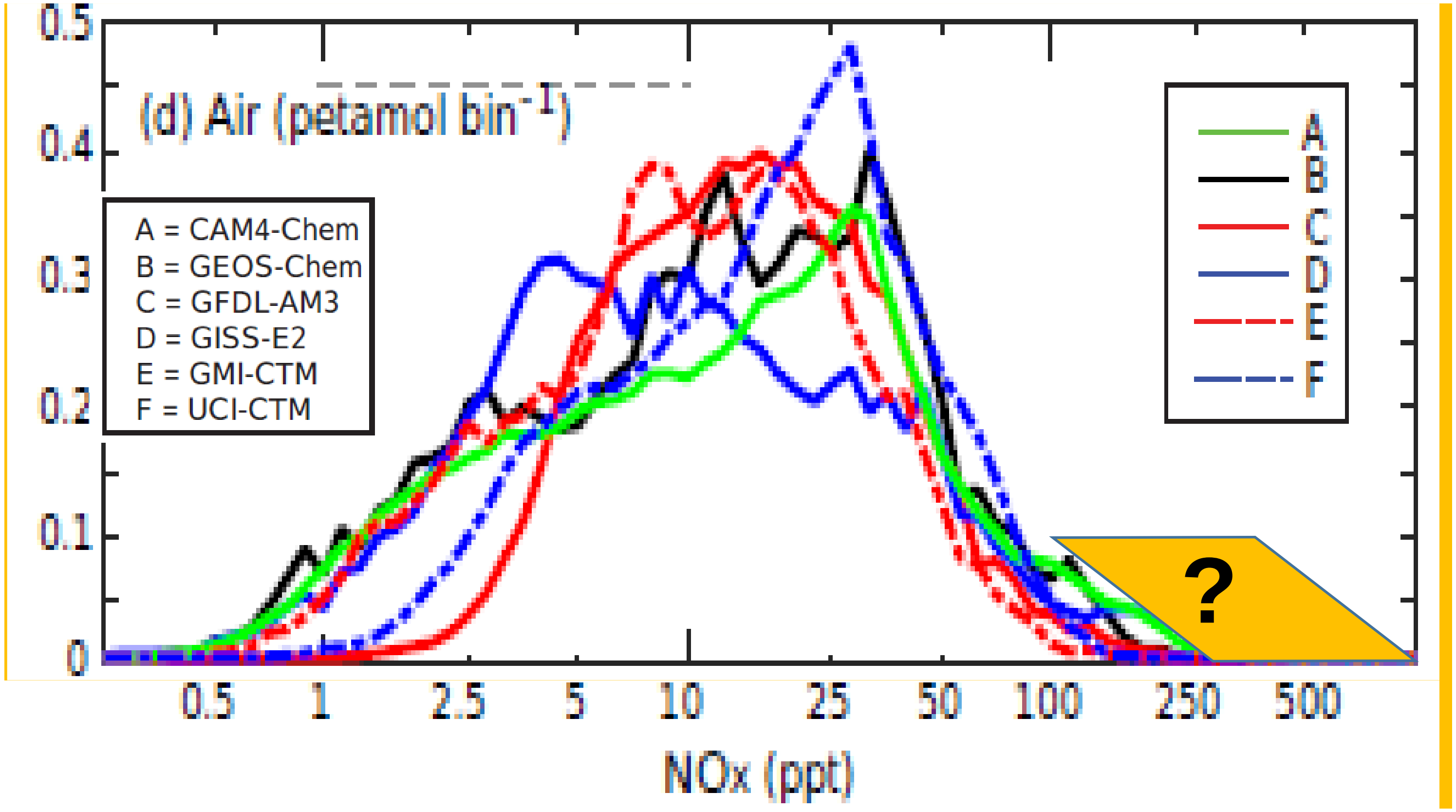


From aircraft in situ measurements,
we see structure down to 1 sec air parcels



Modeled 1D probability distrib. vs. **log(NO_X)**

- do models truncate the high NOx in small structures ?
- high NOx values favor O_3 production.
- do models miss regions of high P-O3 ?
- is the model PDF good enough for net chemical rates ?



Home > Data Archive > ATom-1 > DC-8 > ATom-1 files

Notice: Only ATom data prior to 3/1/2017 has been made public. Data collected after 3/1/2017 is currently only available to science team members.

ATom-1 files

- **Mission:** ATom, ATom-1 Deployment (Mission Website)
- **Measurement Platform:** DC-8 (Aircraft Webpage)

ATom-2 files

- **Mission:** ATom, ATom-2 Deployment (Mission Website)
- **Measurement Platform:** DC-8 (Aircraft Webpage)

  - MER-PFP: Data merge to PFP sampling interval (Download as zip, 989.86 KB)
  - MER-SAGA-AERO: Data merge to SAGA-AERO sampling interval (Download as zip, 1.72 MB)
  - MER-TOGA: Data merge to TOGA sampling interval, from 1s merge file (Download as zip, 7.82 MB)
  - MER-WAS: Data merge to WAS sampling interval (Download as zip, 5.35 MB)
  - MER10: Merge file, 10s means (Download as zip, 67.23 MB)

All Available Files

- **Download zip** (423.27 MB) containing main dataset.

Tables listing all individual data files are available at:

- DC-8 ATom-1 Deployment (7/29/2016-8/23/2016): 662 files available
- DC-8 ATom-2 Deployment (1/27/2017-2/21/2017): 571 files available
- Model: 13 files available
- Sonde: 8 files available

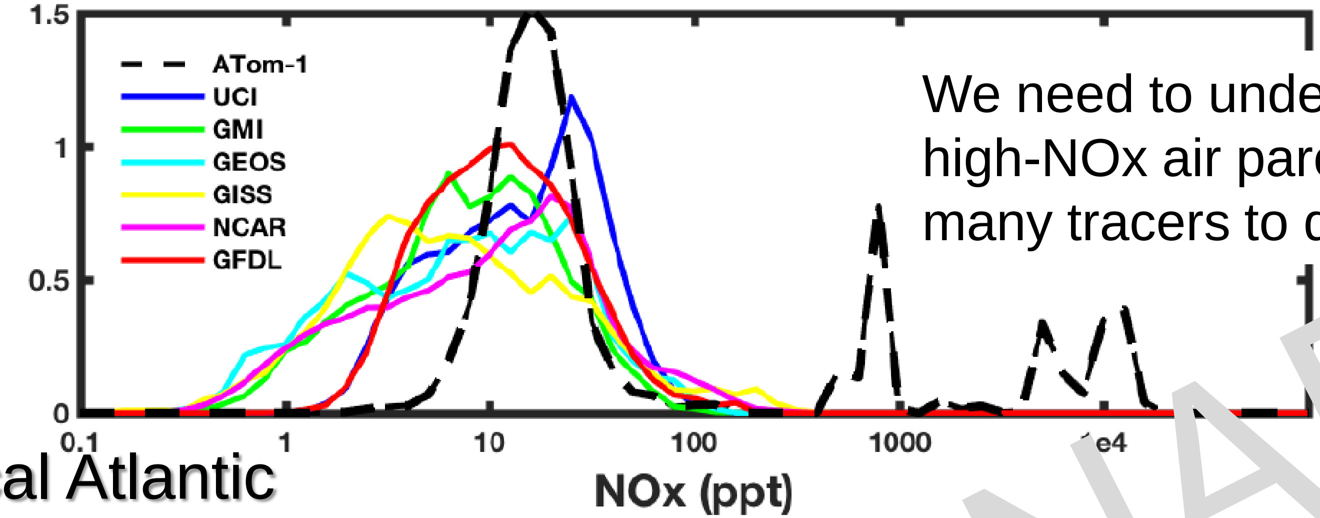
▸ **List of Science Flights**

ATom-1 & ATom-2 are now available;

ATom-3 & -4, in 8 months.

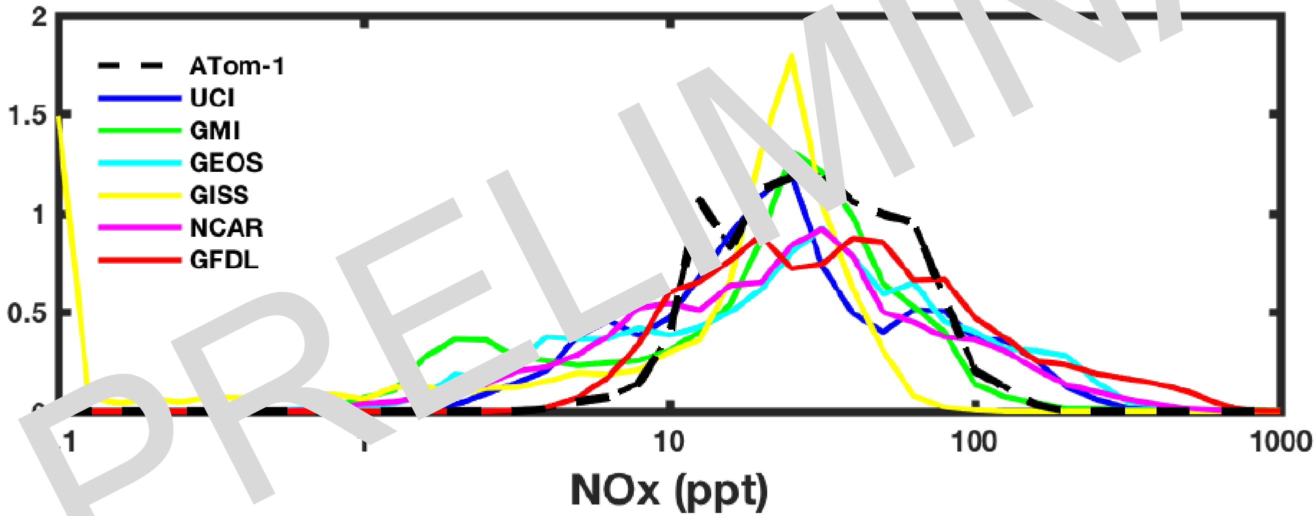
ATom-1 vs. 6 Models August 1D climatologies – NO_X

Tropical Pacific vs.



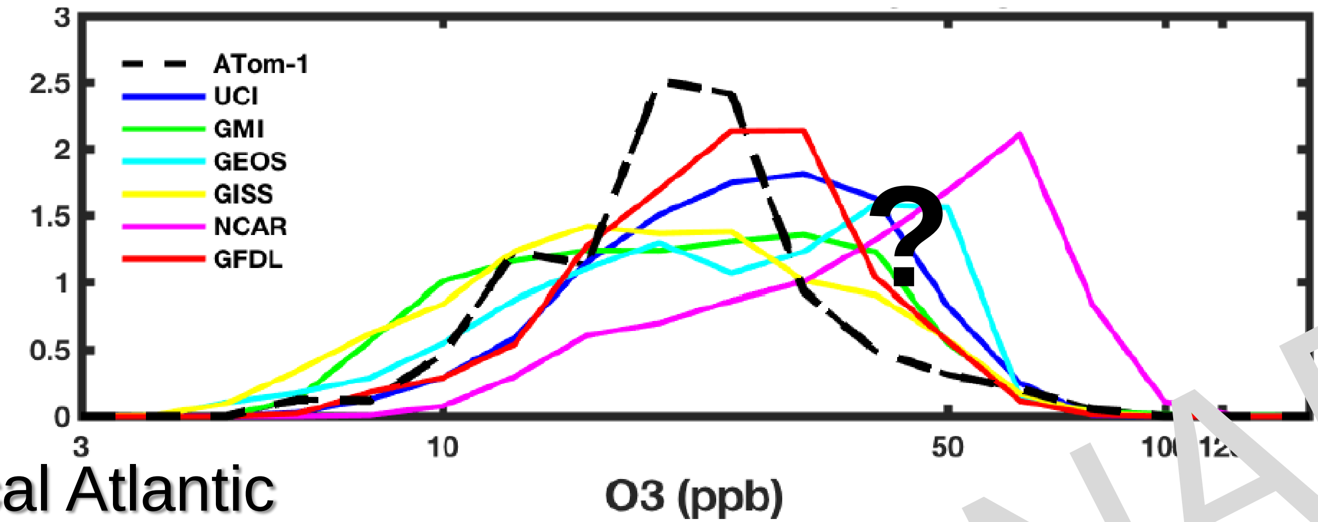
We need to understand these high-NOx air parcels (have many tracers to do so).

Tropical Atlantic

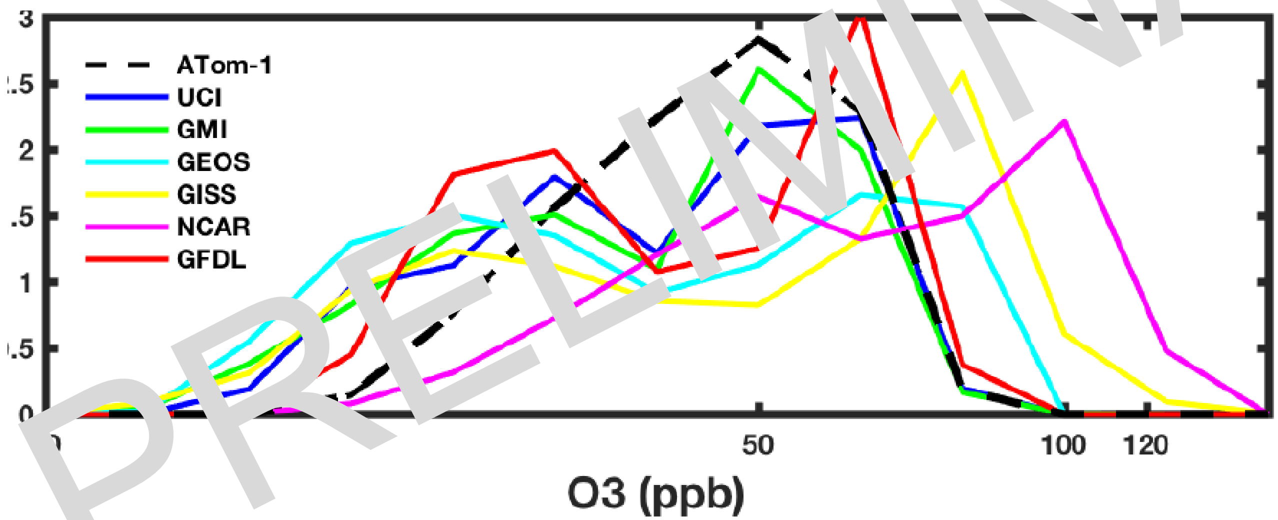


ATom-1 vs. 6 Models August 1D climatologies – O_3

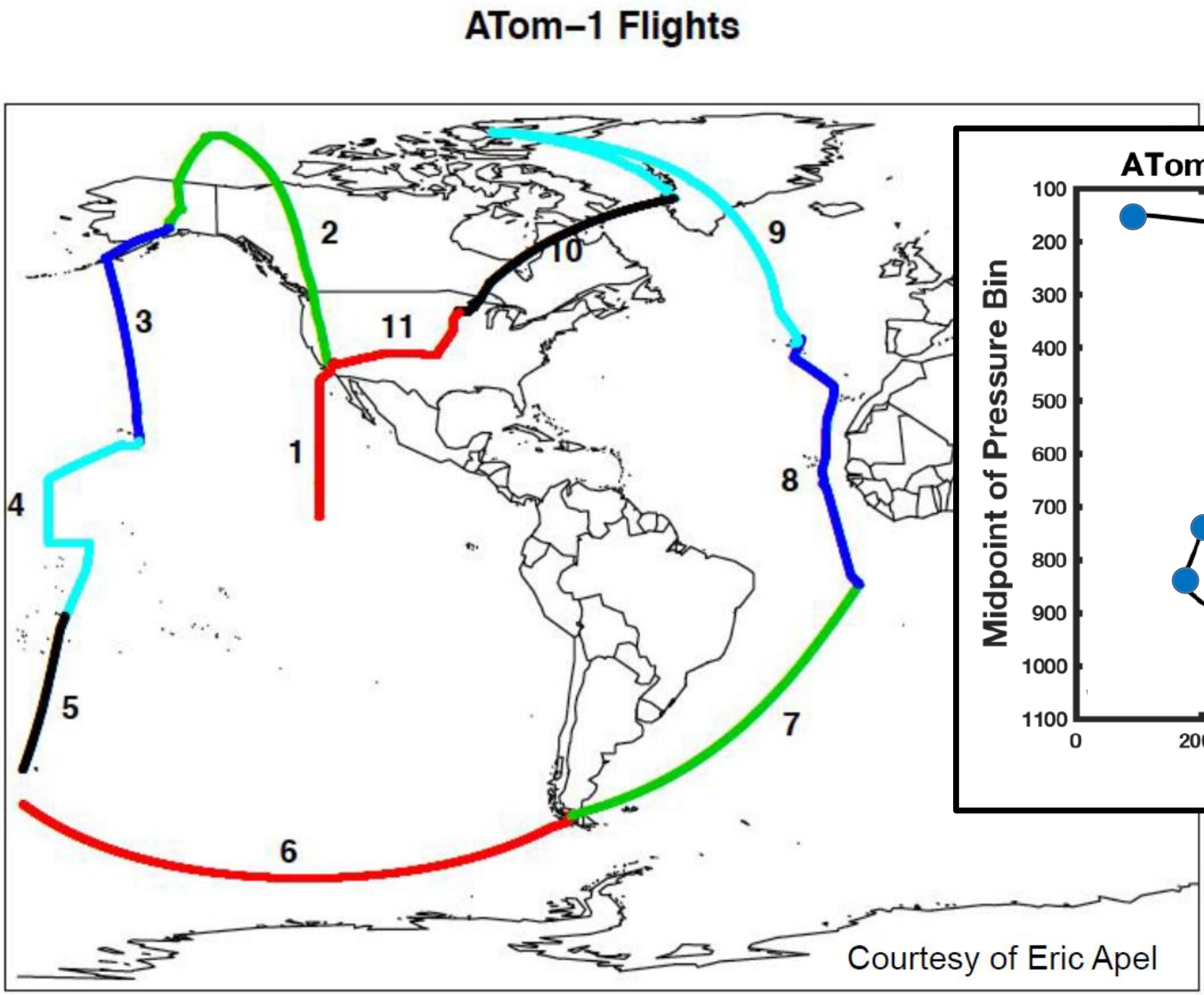
Tropical Pacific vs.

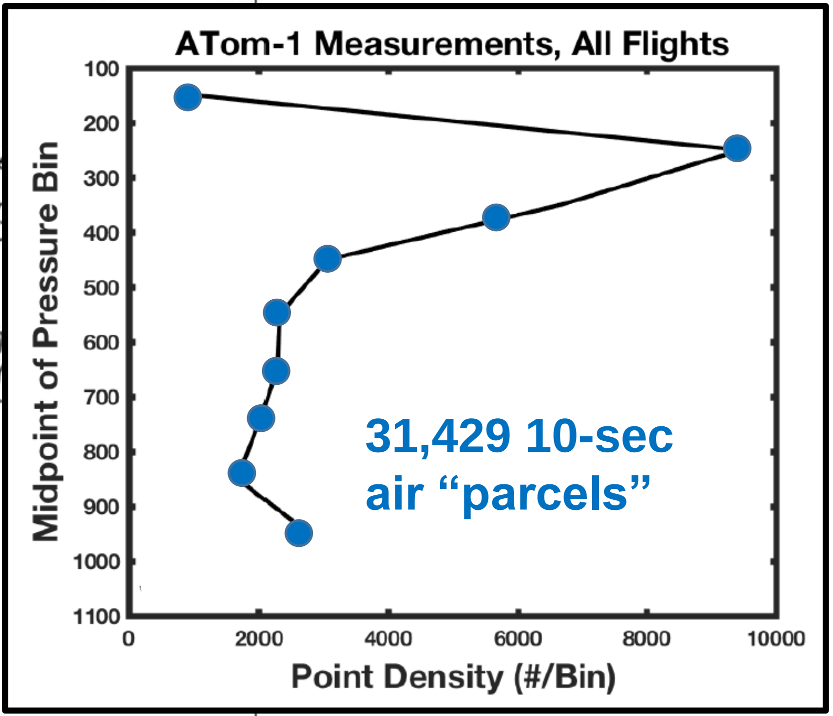


Tropical Atlantic

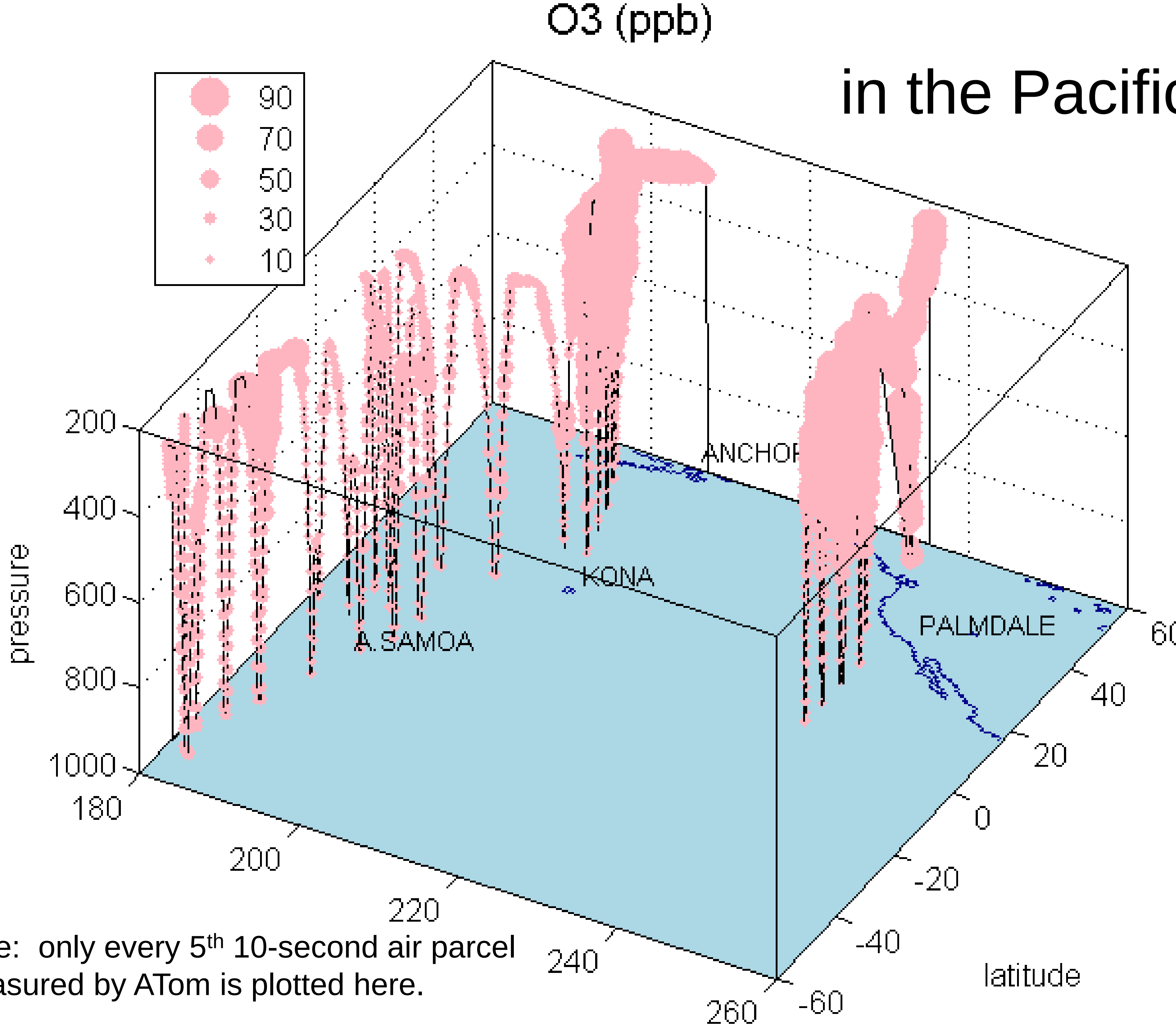


ATom has the most extensive coverage of remote ocean basins, with the most uniform vertical sampling of any a large mission.



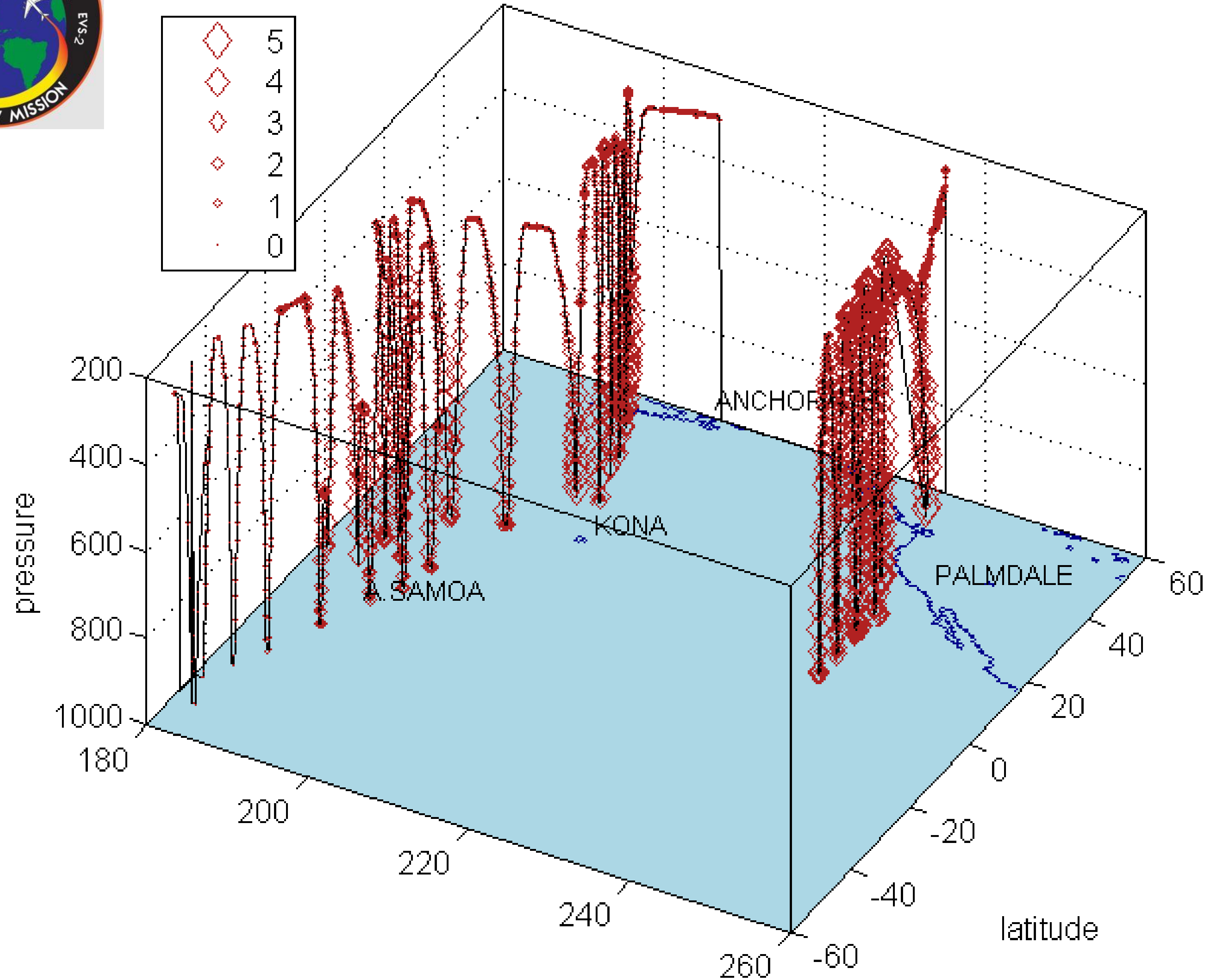


in the Pacific

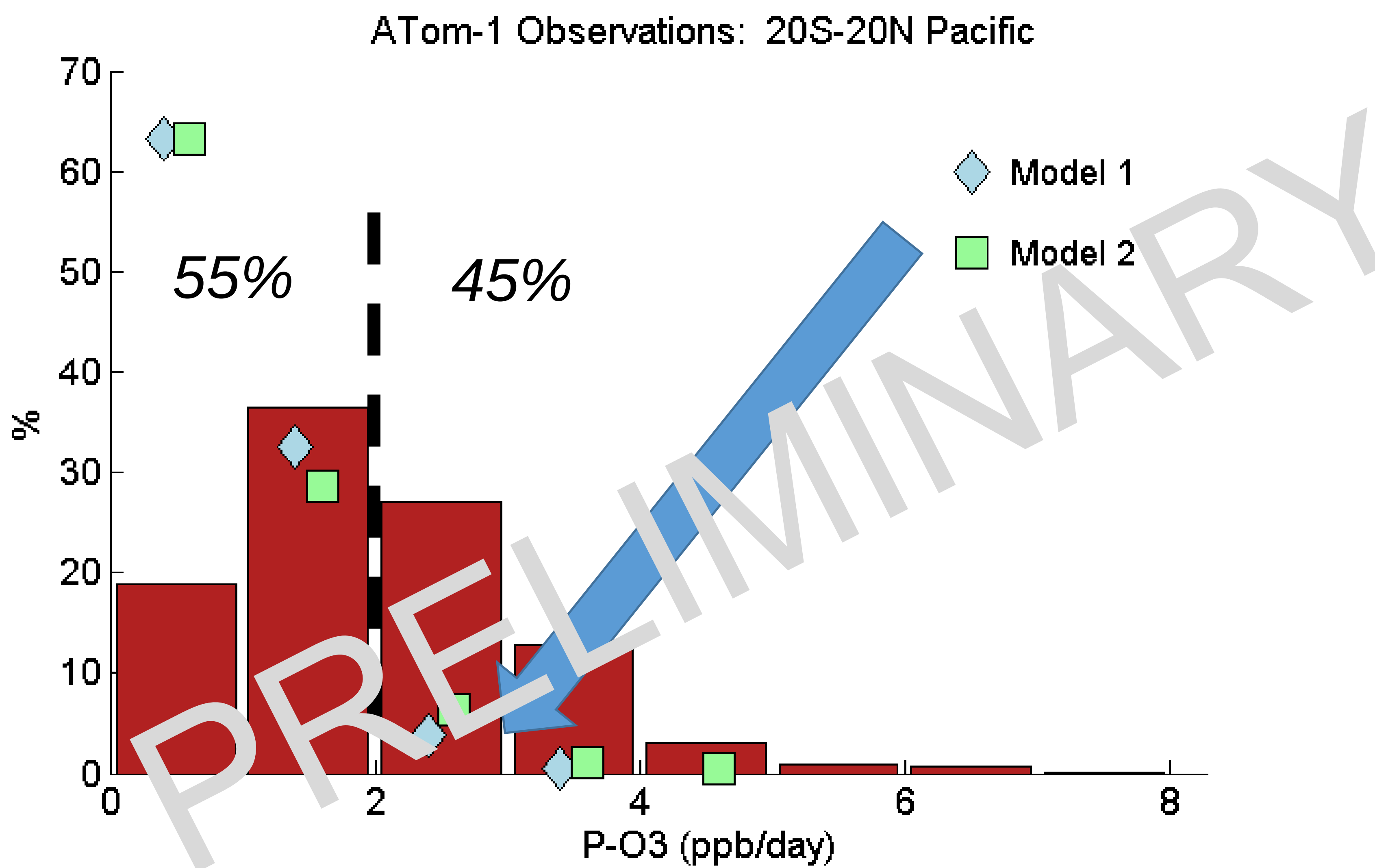


Note: only every 5th 10-second air parcel measured by ATom is plotted here.

ATom 'measures' production of O_3 (P-O3, ppb/day)



ATom can demonstrate the models' failure to match the P-O3 magnitude and variability: *i.e., models fail to predict the large fraction (45%) of air parcels with P-O3 greater than 2 ppb/day.*



We can look at 2D probability distributions (again $\log_{10}$ in species)

2D

Plotted in log-log space for 2 species.

20 bins per decade in $\log_{10}$.

Bins explicitly plotted (no contours!), so we see the density of points.

Density scaled to 1 for a 1x1 (decade) square, shown lower left.

Ellipse Fitting allows simple comparison of 2D densities, but loses extremes.

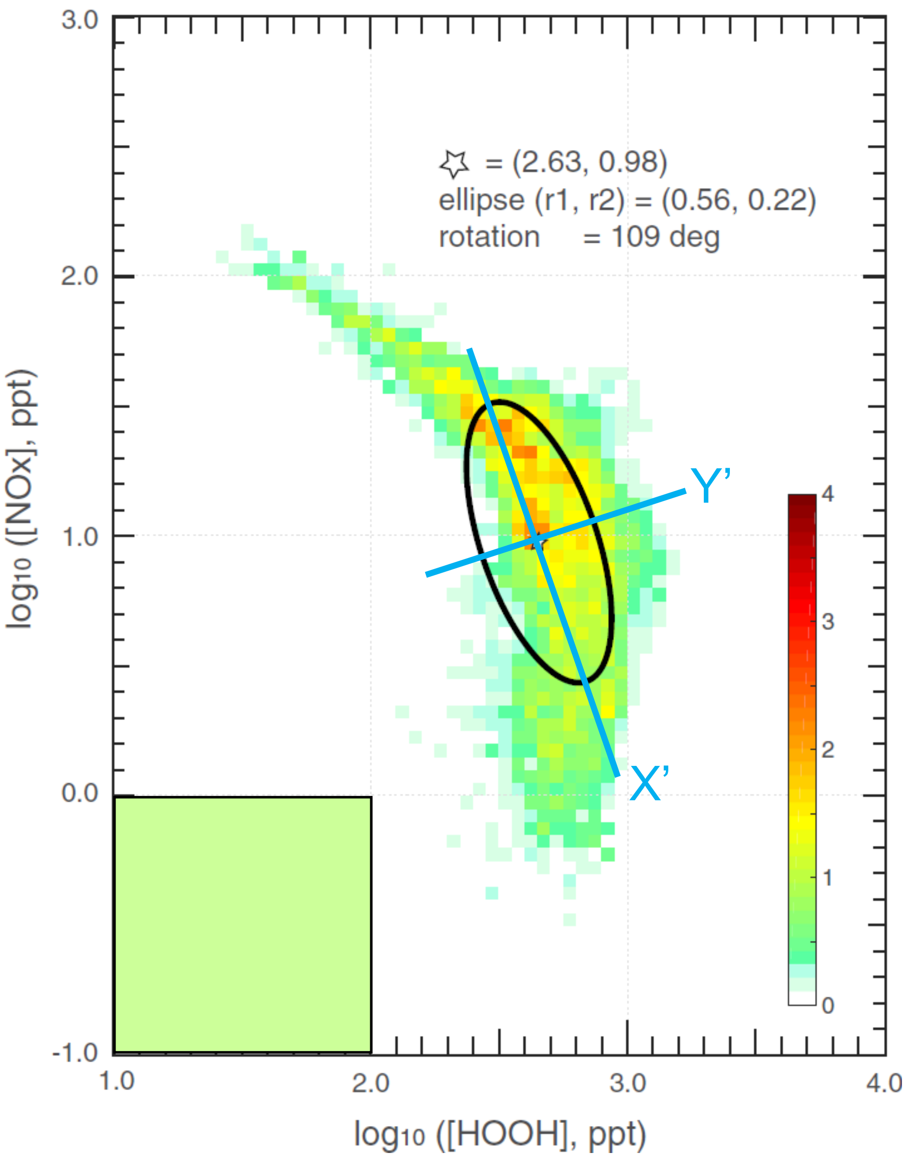
simplest stats for 2D probabilities

rotate axis to get min $\sigma_{Y'} / \sigma_{X'}$

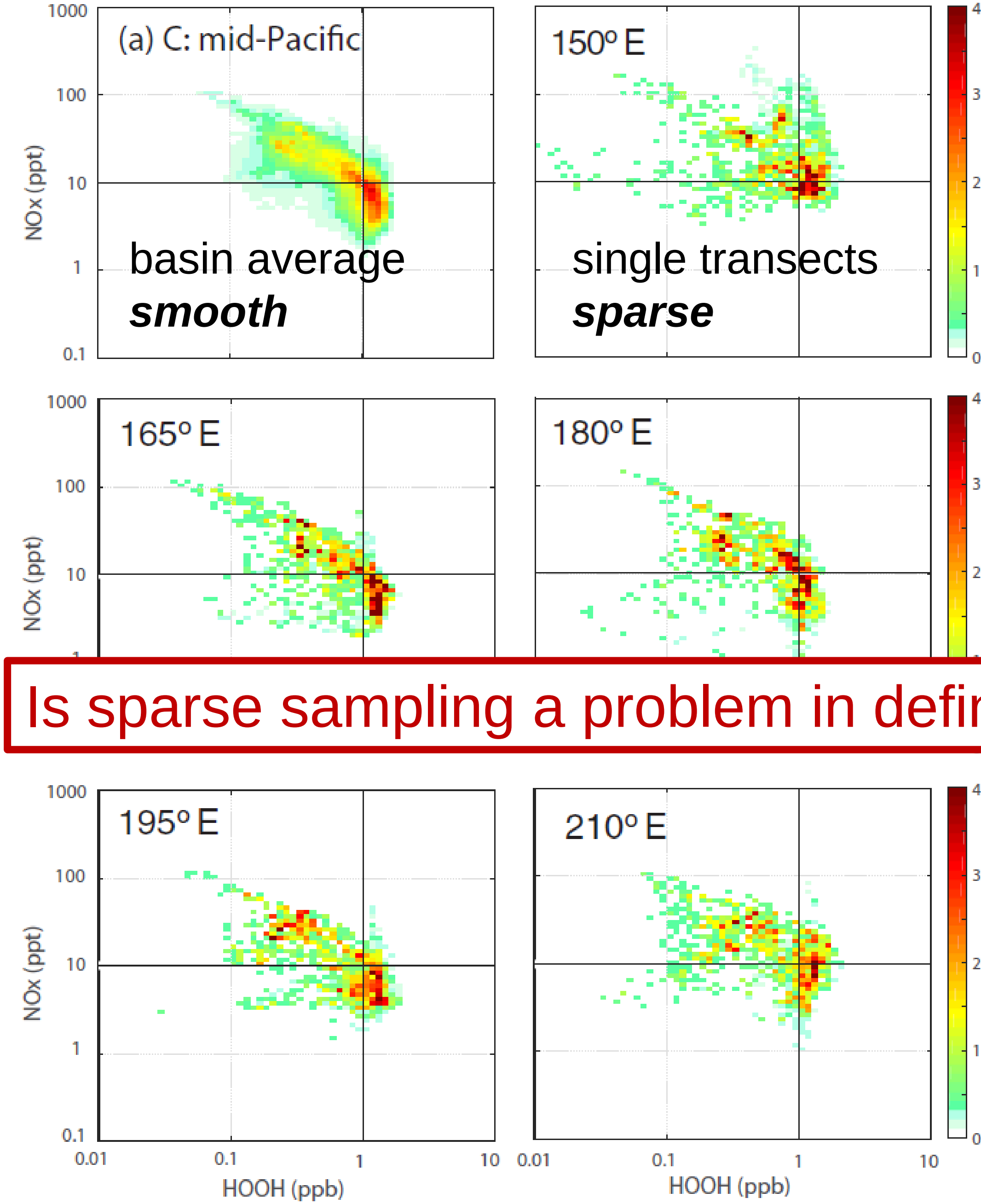
X_0, Y_0

$\sigma_{X'}$, $\sigma_{Y'}$

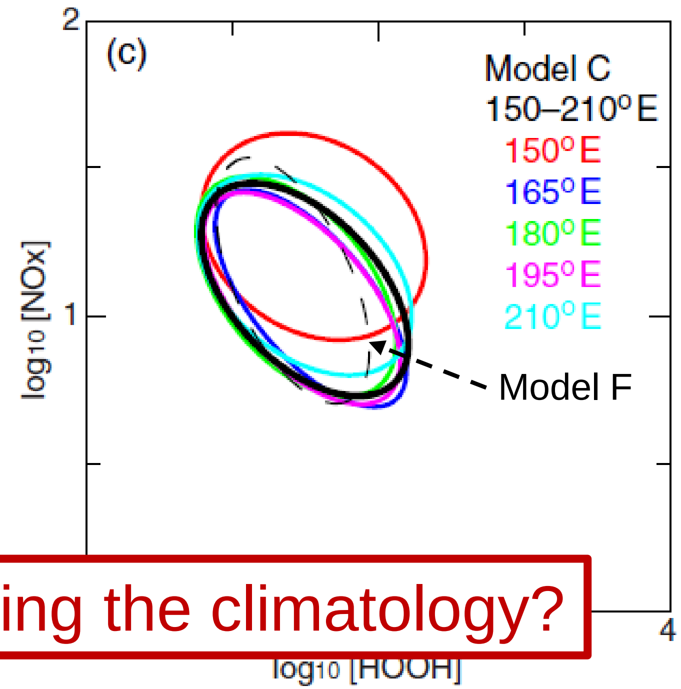
α = *rotation angle*



Q: Is the NO_X - HOOH prob. distrib. different across the Pacific?



A: only at 150ºE



Is sparse sampling a problem in defining the climatology?

No, A single transect is representative of the mid-Pacific (at least in this model)

ATom needs IAGOS' perspective

- ATom has followed MOZAIC-IAGOS concept of regular sampling over standard routes.
- IAGOS provides high-frequency sampling along routes and thus can define a true *chemical climatology*.
- ATom needs the overlap with IAGOS to determine the *representativeness* of it flights.
- IAGOS can use the extensive chemical measurements, mid-ocean profiling, and reactivities of ATom to extend its own data set.

IAGOS - a unique measure of global change

- IAGOS data record the true heterogeneous granularity of the atmosphere (seen down to 200m x 10m scales) with the global scale and repeatability that no aircraft mission has achieved.

- Satellite global measurements of chemical composition cannot see this; their resolution is 24km x 6km at best; hence their trends may be compromised.

- Some of IAGOS' unique contribution to the science of SLCFs (O_3 and CO) are summarized in closing.

Wide international use of IAGOS data by outside researchers

Changes in ozone over Europe: Analysis of ozone measurements from sondes, regular aircraft (MOZAIC) and alpine surface sites

J. A. Logan,[1] J. Staehelin,[2] I. A. Megretskaia,[1] J.-P. Cammas,[3,4] V. Thouret,[3,4] H. Claude,[5] H. De Backer,[6] M. Steinbacher,[7] H.-E. Scheel,[8] R. Stübi,[9] M. Fröhlich,[10] and R. Derwent[11]

Received 29 September 2011; revised 28 March 2012; accepted 28 March 2012; published 4 May 2012.

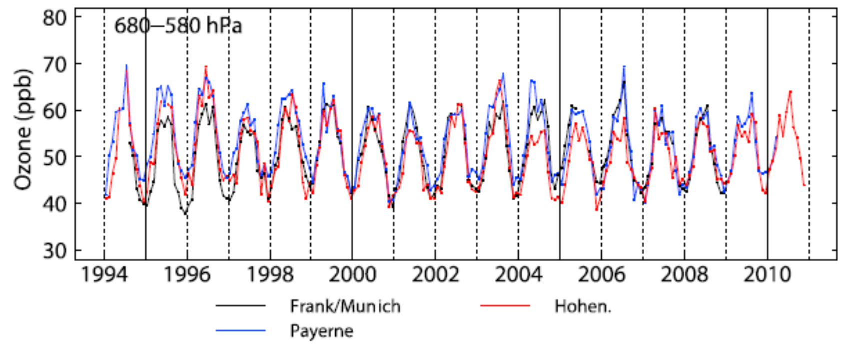


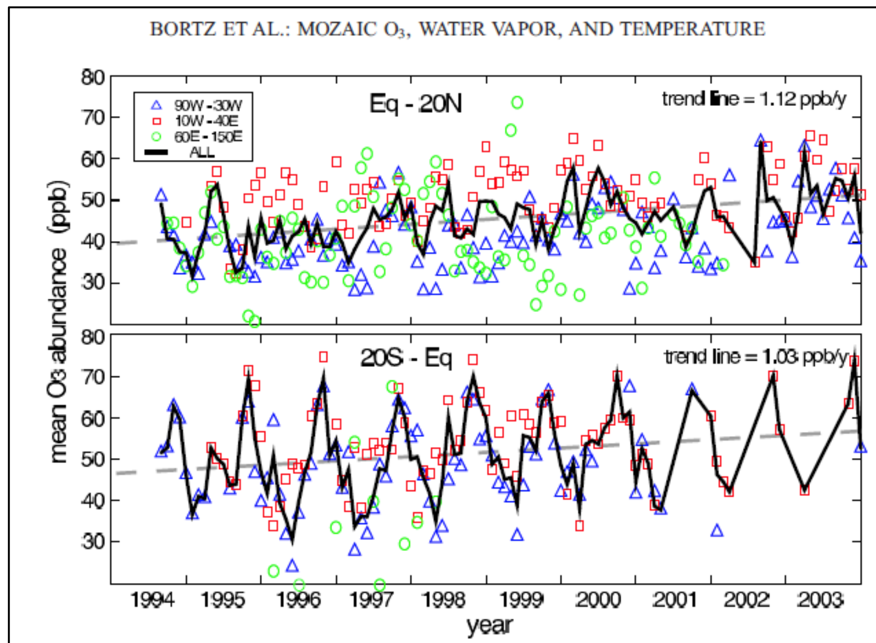
Figure 7. Comparison of monthly mean MOZAIC time series for Frankfurt/Munich with those for sondes at Payerne and Hohenpeissenberg, for the mean of two layers centered at 681 and 584 hPa

Ozone has decreased slowly since 1998, with an annual mean trend of -0.15 ppb / yr at 3 km, largest decrease in summer.

Ozone, water vapor, and temperature in the upper tropical troposphere: Variations over a decade of MOZAIC measurements

Sarah E. Bortz,[1] Michael J. Prather,[1] Jean-Pierre Cammas,[2] Valérie Thouret,[2] and Herman Smit[3]

Received 19 July 2005; revised 16 September 2005; accepted 7 November 2005; published 3 March 2006.



…a clearly linear increase in ozone over the north tropics with a trend fit of 1.12 ± 0.05 ppb/yr. In the south tropics, with large seasonal range (> 25 ppb), trend is less obvious but still robust, 1.03 ± 0.08 ppb/yr.

ELEMENTA
Science of the Anthropocene

Gaudel, A, et al. 2018. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. *Elem Sci Anth*, 6: 39. DOI: https://doi.org/10.1525/elementa.291

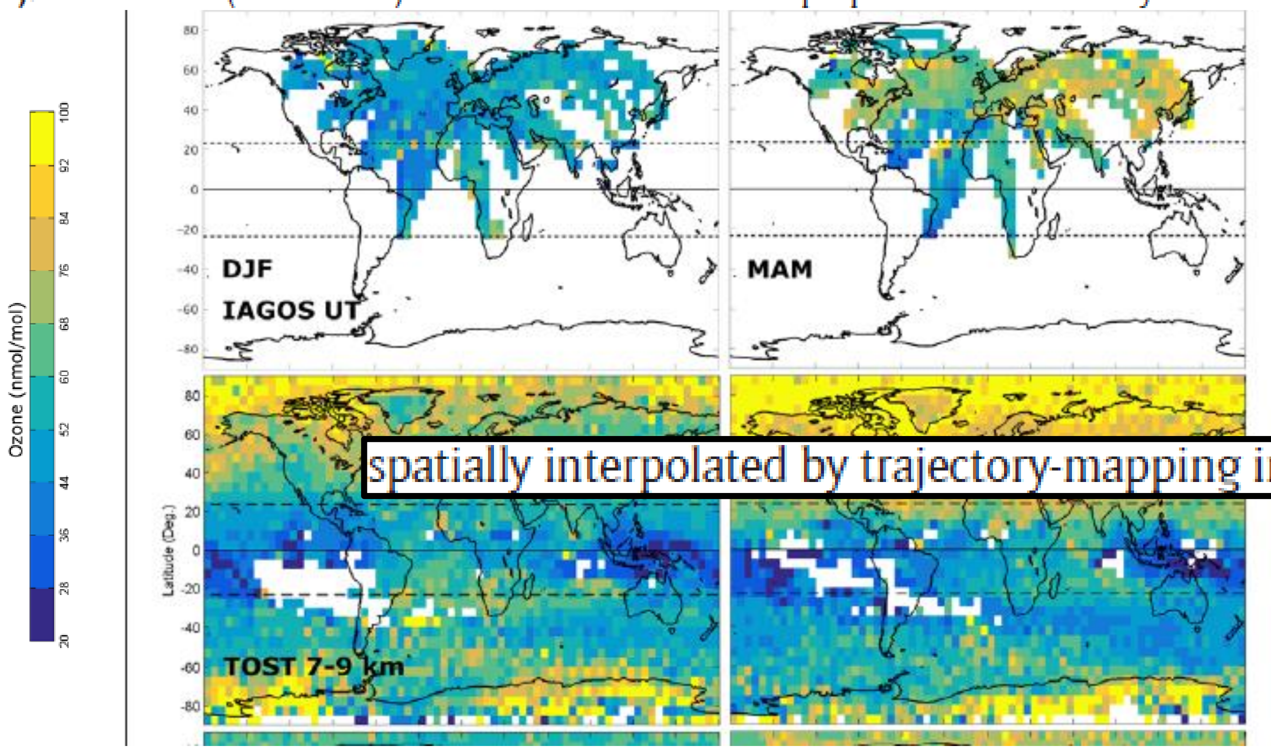
2017-2018 IAGOS publications address key science problems

RESEARCH ARTICLE

Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation

IAGOS data is key part of international O_3 assessment

Figure 4: Seasonal mean ozone (nmol mol^{-1}) as measured by IAGOS commercial aircraft and by ozonesondes (TOST). Mean ozone (nmol mol^{-1}) at four levels in the free troposphere as measured by IAGOS commercial aircraft



Atmos. Chem. Phys., 18, 5415–5453, 2018
https://doi.org/10.5194/acp-18-5415-2018

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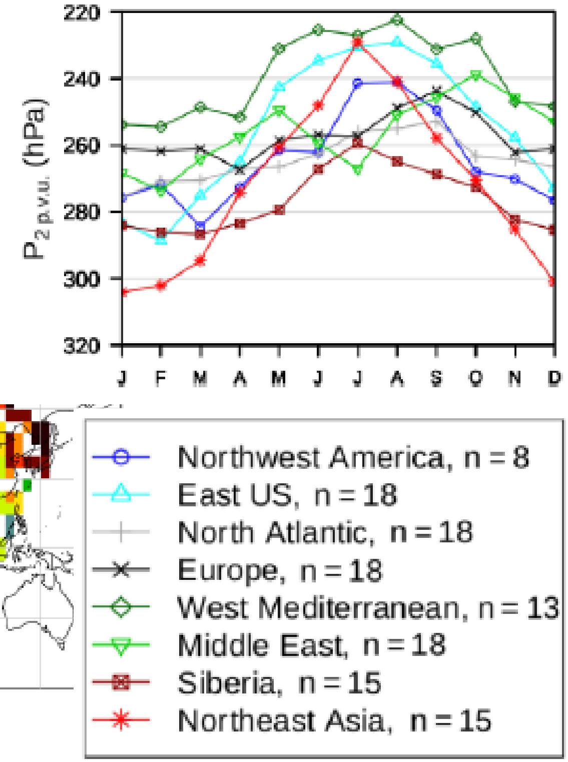
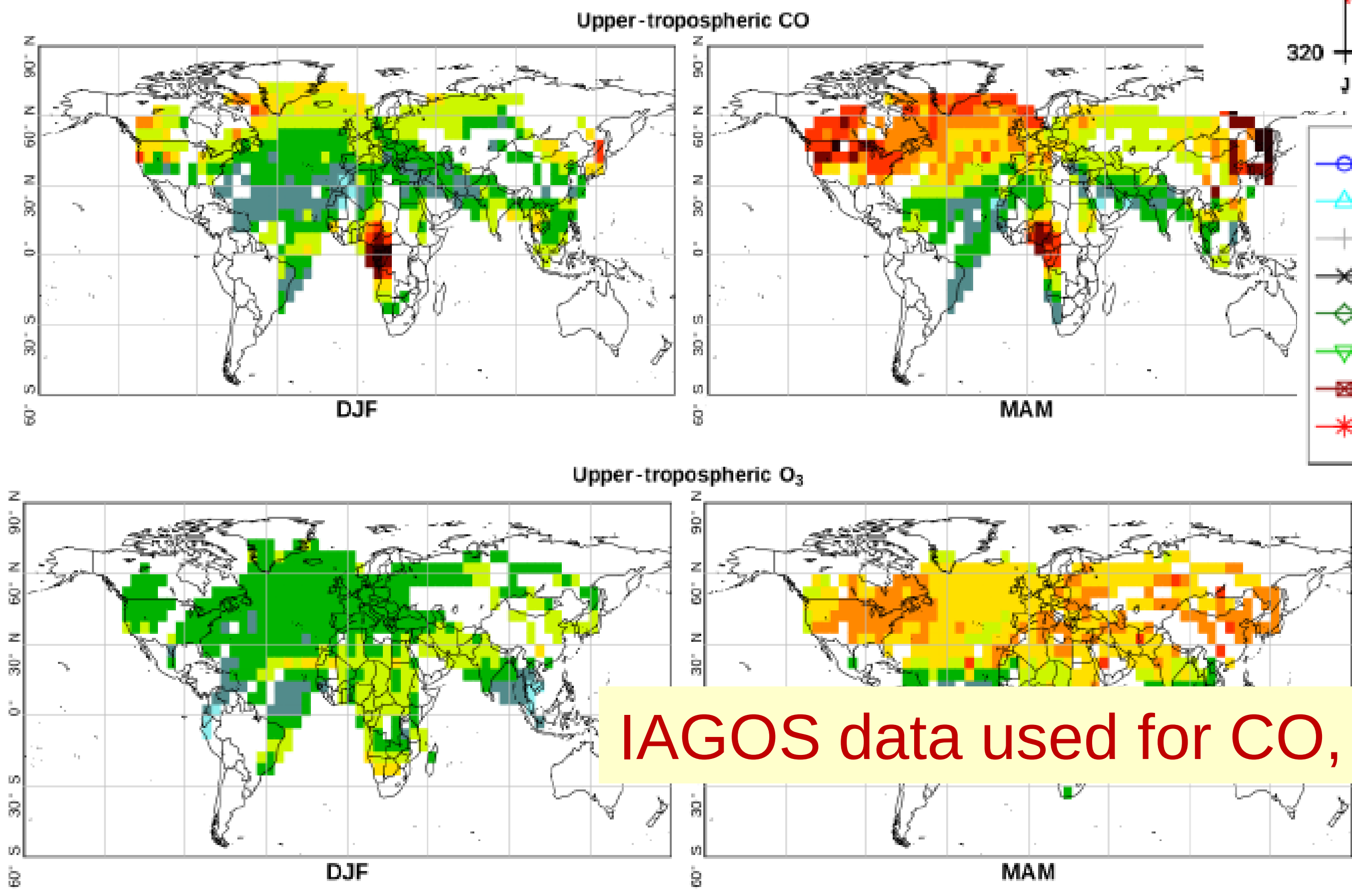
Figure 5. Mean seasonal cycles of $P_{2\,pvu}$ (hPa) in each region.



Climatology and long-term evolution of ozone and carbon monoxide in the upper troposphere–lower stratosphere (UTLS) at northern midlatitudes, as seen by IAGOS from 1995 to 2013

Yann Cohen[1,2], Hervé Petetin[1], Valérie Thouret[1], Virginie Marécal[2], Béatrice Josse[2], Hannah Clark[1], Bastien Sauvage[1], Alain Fontaine[1], Gilles Athier[1], Romain Blot[1], Damien Boulanger[3], Jean-Marc Cousin[1], and Philippe Nédélec[1]



IAGOS data used for CO, another SLCF

ELEMENTA Science of the Anthropocene

Petetin, H, et al. 2018 Representativeness of the IAGOS airborne measurements in the lower troposphere. *Elem Sci Anth*, 6: 23. DOI: https://doi.org/10.1525/elementa.280

IAGOS: representativeness and trends in CO and O_3

RESEARCH ARTICLE

Representativeness of the IAGOS airborne measurements in the lower troposphere

H. Petetin*, M. Jeoffrion*, B. Sauvage*, G. Athier*, R. Blot*, D. Boulanger†, H. Clark*, J.-M. Cousin*, F. Gheusi*, P. Nedelec*, M. Steinbacher‡ and V. Thouret*

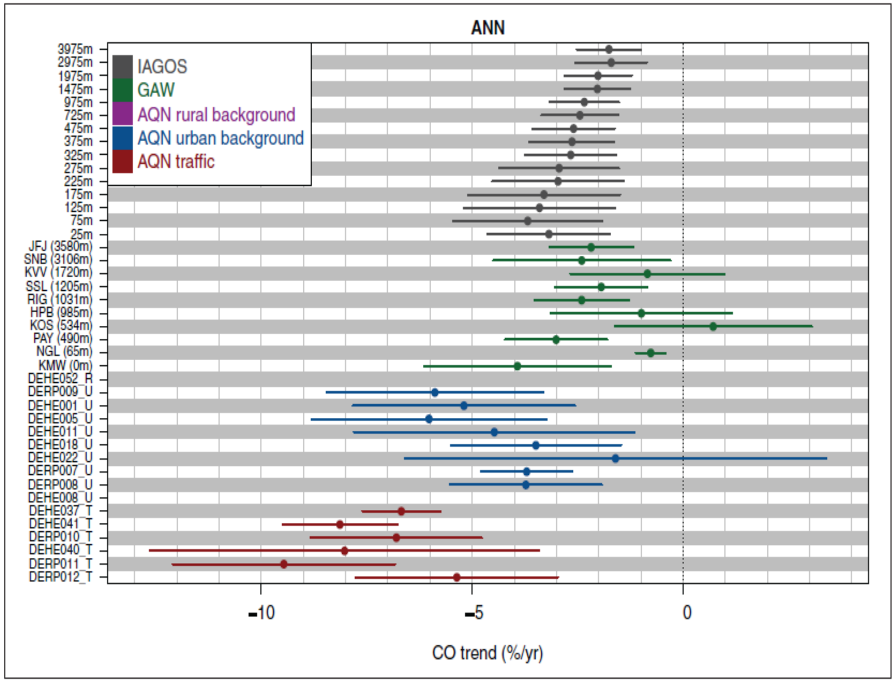


Figure 9: Relative annual trends of CO mixing ratios at Frankfurt, over the period 2002–2012. Trends are

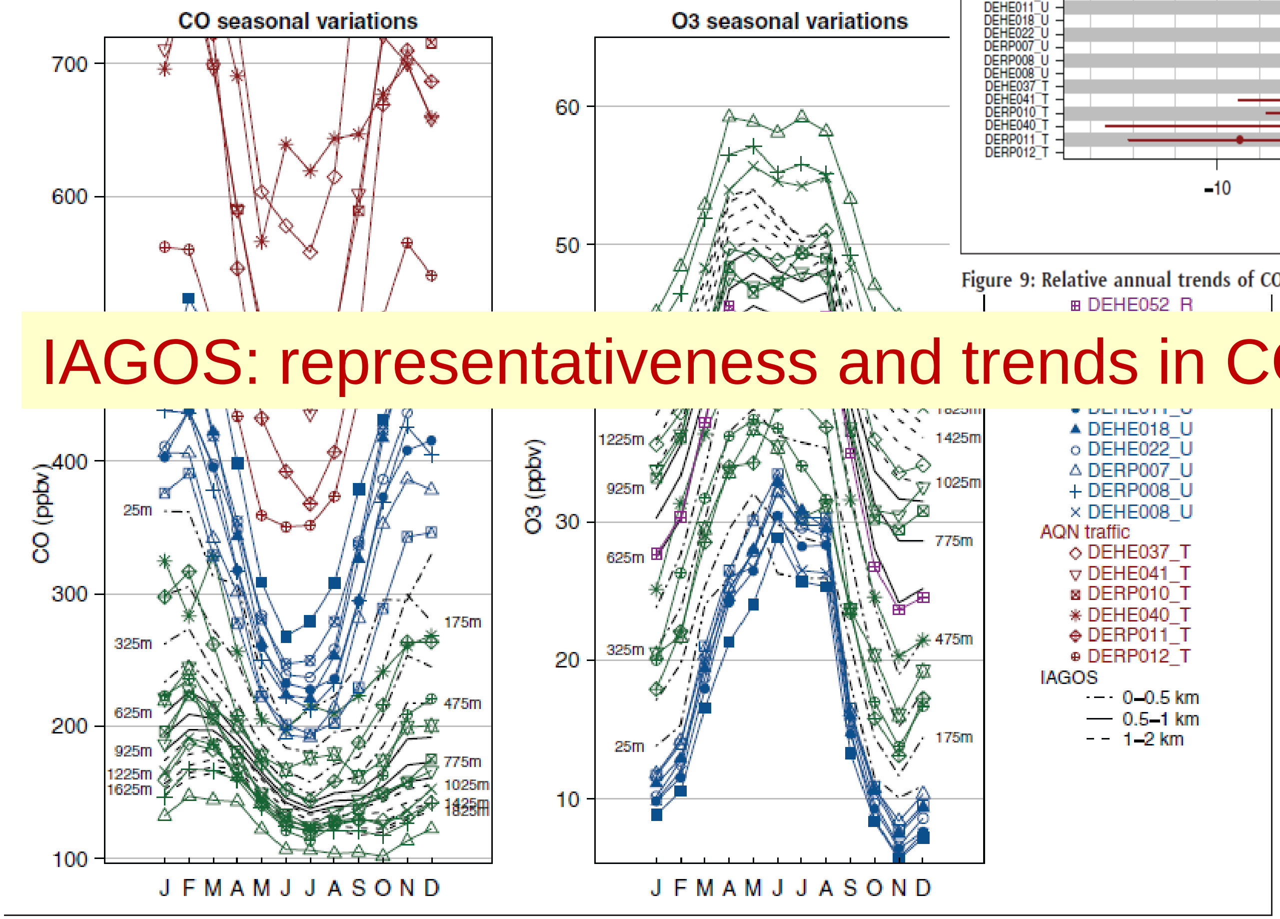


Figure 6: Average monthly variations of CO and O_3 mixing ratios. This Figure includes observations from IAGOS

Atmos. Chem. Phys., 17, 2775–2794, 2017
www.atmos-chem-phys.net/17/2775/2017/
doi:10.5194/acp-17-2775-2017

Atmospheric Chemistry and Physics

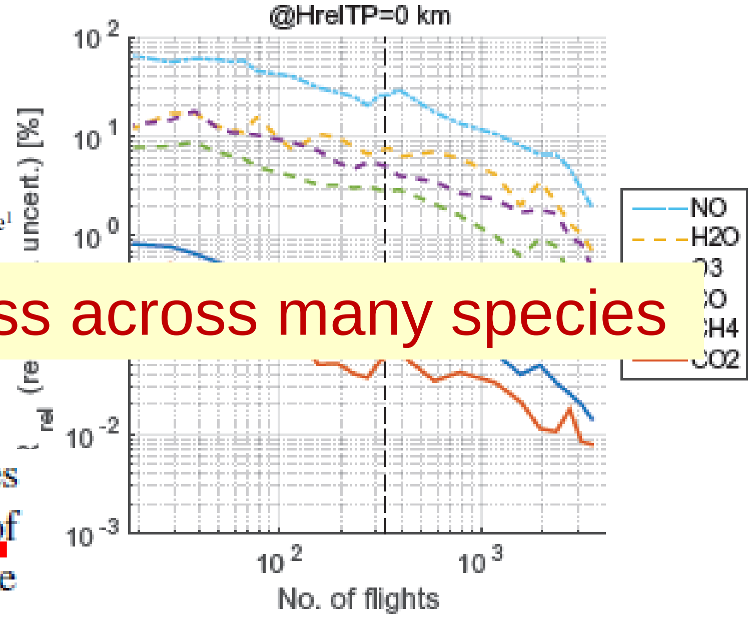
An assessment of the climatological representativeness of IAGOS-CARIBIC trace gas measurements using EMAC model simulations

Johannes Eckstein[1], Roland Ruhnke[1], Andreas Zahn[1], Marco Neumaier[1], Ole Kirner[2], and Peter Braesicke[1]

IAGOS-CARIBIC: representativeness across many species

model and measurements. We find that the model reaches 50–100 % of the measurement variability. The tendency of the model to underestimate the variability is caused by the relatively coarse spatial and temporal model resolution.

In conclusion, we provide representativeness uncertainties for several species for tropopause-referenced climatologies. Long-lived species like CO_2 have low uncertainties (≤ 0.4 %), while shorter-lived species like O_3 have larger uncertainties (10–15 %). Finally, we translate the representativeness score into a number of flights that are necessary to achieve a certain degree of representativeness. For example, increasing the number of flights from 334 to 1000 would reduce the uncertainty in CO to a mere 1 %, while the uncertainty for shorter-lived species like NO would drop from 80 to 10 %.



11. Representativeness uncertainty for different numbers of 'or some species. The number of flights in $MEAS_{CARIBIC}$ is d by the vertical dashed line. Other species can be deduced eir value of τ^* with the help of Fig. 2.

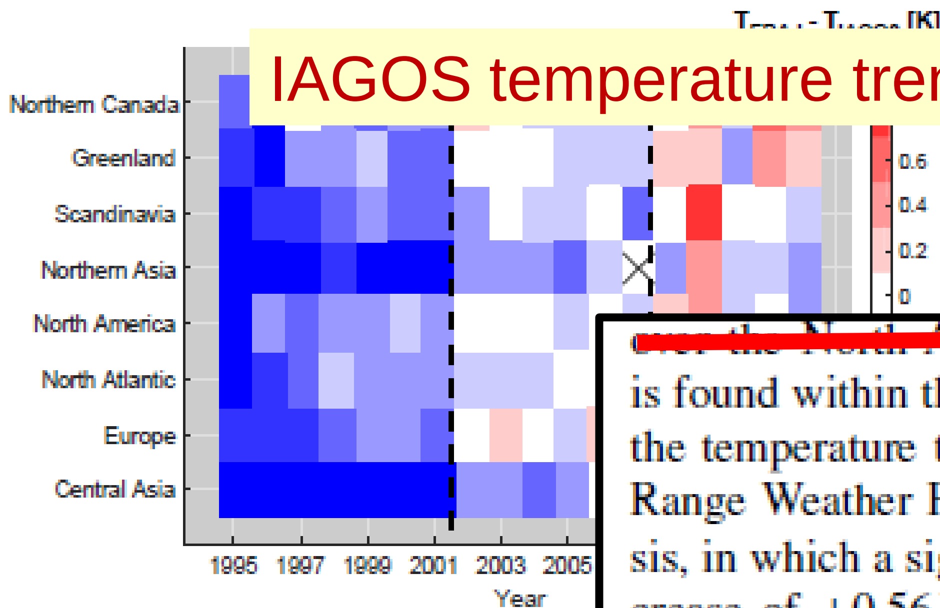
Atmos. Chem. Phys., 17, 12495–12508, 2017
https://doi.org/10.5194/acp-17-12495-2017

Atmospheric Chemistry and Physics

In situ temperature measurements in the upper troposphere and lowermost stratosphere from 2 decades of IAGOS long-term routine observation

Florian Berkes[1], Patrick Neis[1], Martin G. Schultz[1], Ulrich Bundke[1], Susanne Rohs[1], Herman G. J. Smit[1], Andreas Wahner[1], Paul Konopka[2], Damien Boulanger[3], Philippe Nédélec[3], Valerie Thouret[3], and Andreas Petzold[1]

IAGOS temperature trends: questions ERA analysis



~~over the North Atlantic.~~ Here, a neutral temperature trend is found within the lowermost stratosphere. This contradicts the temperature trend in the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis, in which a significant (95 % confidence) temperature increase of $+0.56\,\mathrm{K\,decade^{-1}}$ is found. ~~Differences between~~

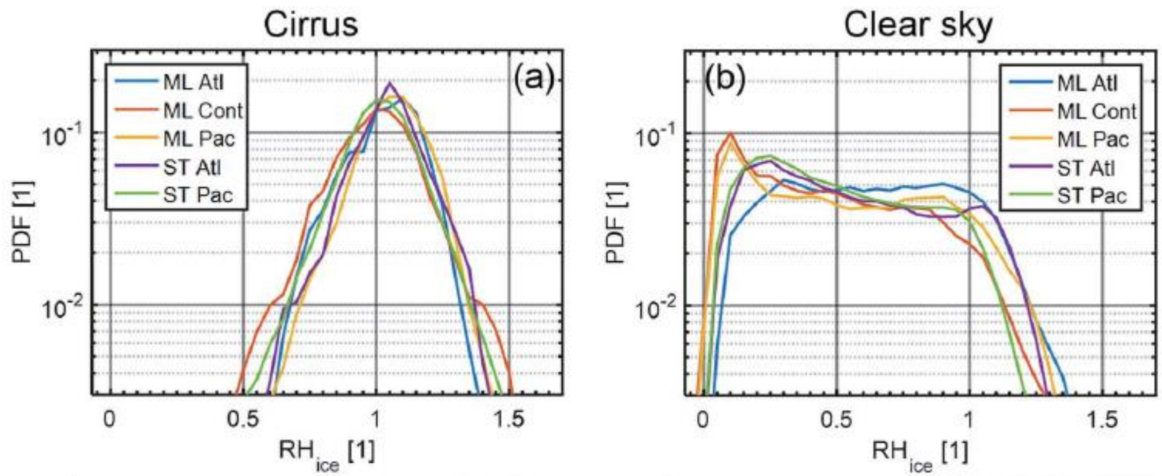
Figure 10. Annual mean of the monthly mean difference between the observations and ERA-I for different regions in the Northern Hemisphere in the lowermost stratosphere from 1995 to 2014. The red colors show that ERA-I temperature is warmer than IAGOS temperature and in blue colors vice versa. The dashed lines show clear break points within the time series. The cross marks a year when the annual mean could not be calculated.

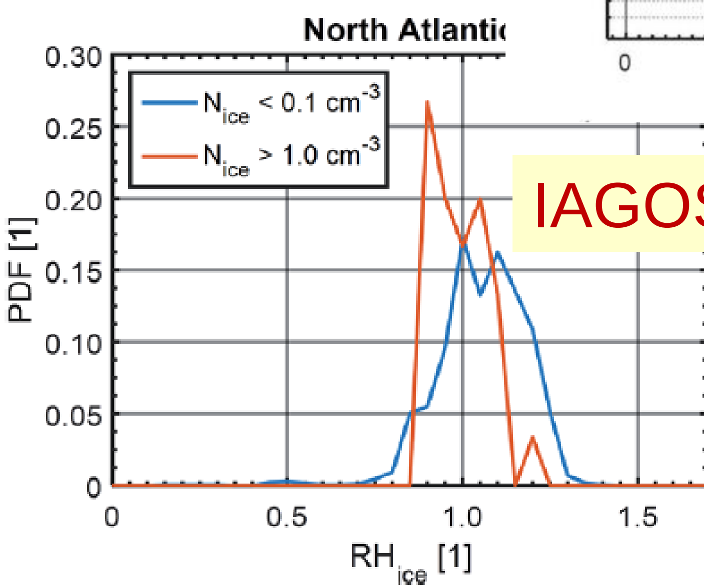
Faraday Discussions
Cite this: *Faraday Discuss.*, 2017, **200**, 229
PAPER

The radiative impact of cirrus clouds is one of the largest sources of uncertainty in the Earth's energy balance, and even fundamental details of ice cloud processes are still poorly understood.[1] Model studies demonstrate that the magnitude and even sign of the net effect depend crucially on microphysical properties of ice crystals, *e.g.* size or shape,[2,3] and ice-supersaturation in clouds.[1,4,5] Besides its

Upper tropospheric water vapour and its interaction with cirrus clouds as seen from IAGOS long-term routine *in situ* observations

Andreas Petzold,*[a] Martina Krämer,[b] Patrick Neis,[ae] Christian Rolf,[b] Susanne Rohs,[a] Florian Berkes,[a] Herman G. Martin Gallagher,[c] Karl Beswick,[c] Gary Lloyd,[c] Darrel Bau Peter Spichtinger,[e] Philippe Nédélec,[f] Volker Ebert,[gh] Bernhard Buchholz,[gh] Martin Riese[b] and Andreas Wahner[a]





IAGOS study of Rel.Humidity vs. Cirrus

Probability distribution function of RH_{ice} over the North Atlantic Flight Corridor

IAGOS is a critical component of our science in studying climate change and global air quality

LA and HOLLYWOOD sign from UCIrvine 7 Mar 2010 1147h