The impact of ground based ozone monitoring on stratospheric ozone assessments:

A case study using sequential and variational data assimilation

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Motivation

- Satellite instruments: lack of limb/occultation sounder >2010 ?
- LIDAR: few instruments, expensive in sustained operation
- Ozone sondes: mature, relatively cheap, many stations (500-700$ total costs per sounding)
- Umkehr retrieval: high potential but only low vertical resolution

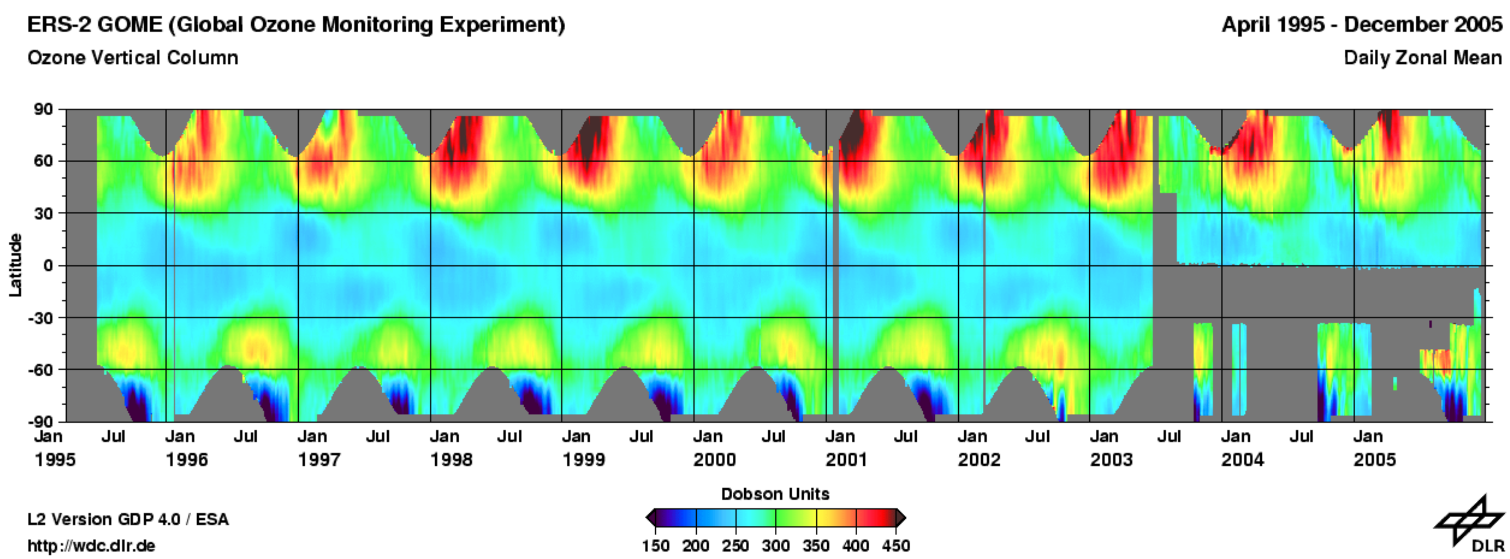
(see, e.g., WMO/IGACO ozone and UV recommendations)

Bulk of ozone below 10 hPa!

--> assess current ozone sonde networks (this study)

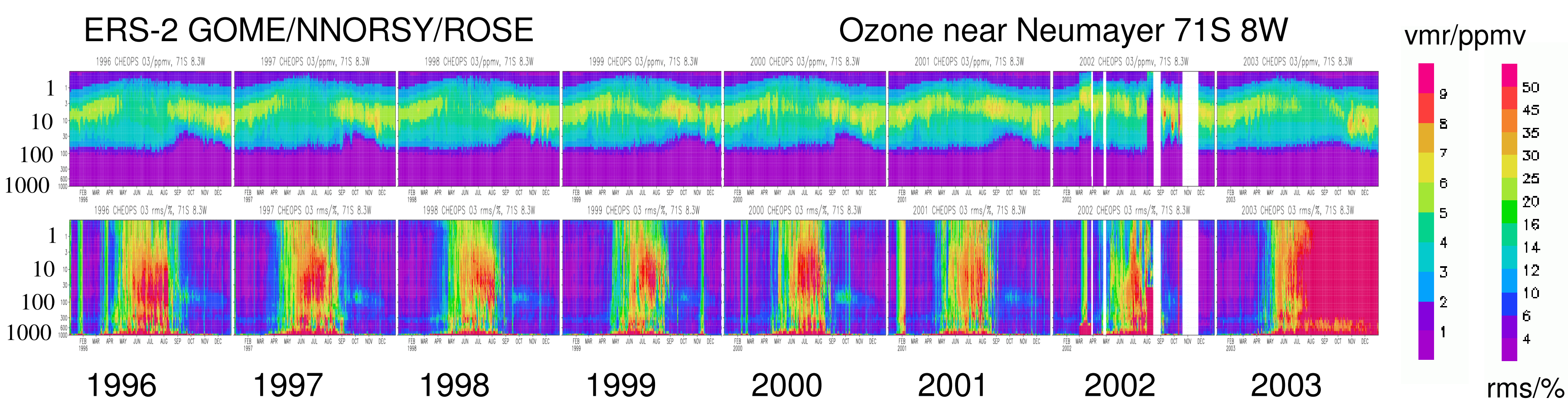
ERS-2 GOME total ozone column heritage

- Nadir looking UV instrument giving 320 x 40km² footprints
- Global coverage / 3 days since January 1996, reduced since July 2003
- Retrieval version 4 data within 5% c.t. NDSC (e.g., Spurr et al., 2005)
- Application projects: ESA CHEOPS, GSE PROMOTE



CHEOPS vertical ozone profile record

- Vertical O3 profiles using neural network approach (NNORSY) (Müller et al., 2003)
- Approximately 10 years of data available since 1996
- Sequential assimilation as consistency check / fill gaps
- Analyzed profiles show very low bias with most rms <10%



PROMOTE long-term 3D stratospheric ozone record

a joined service by BIRA and DLR

Best affordable description of chemical state by combination of satellite data, meteorological data and chemistry-transport models

Long-term synoptic 3D ozone analyses to identify trends in reactive trace gases and inorganic reservoir species

Target products:

- O3 and related (destructive) species (ClOx, NOx, BrOx)
- Polar-stratospheric clouds (PSCs)
- Reservoir species: eg., Cly,Bry
- Quantification of chemical ozone loss

Temporal coverage: 1992-2004 (phase 1) , 2005 – to date

Core user: SPARC CCMval, WMO (negociations)

GOME/NNORSY V3 ozone profiles

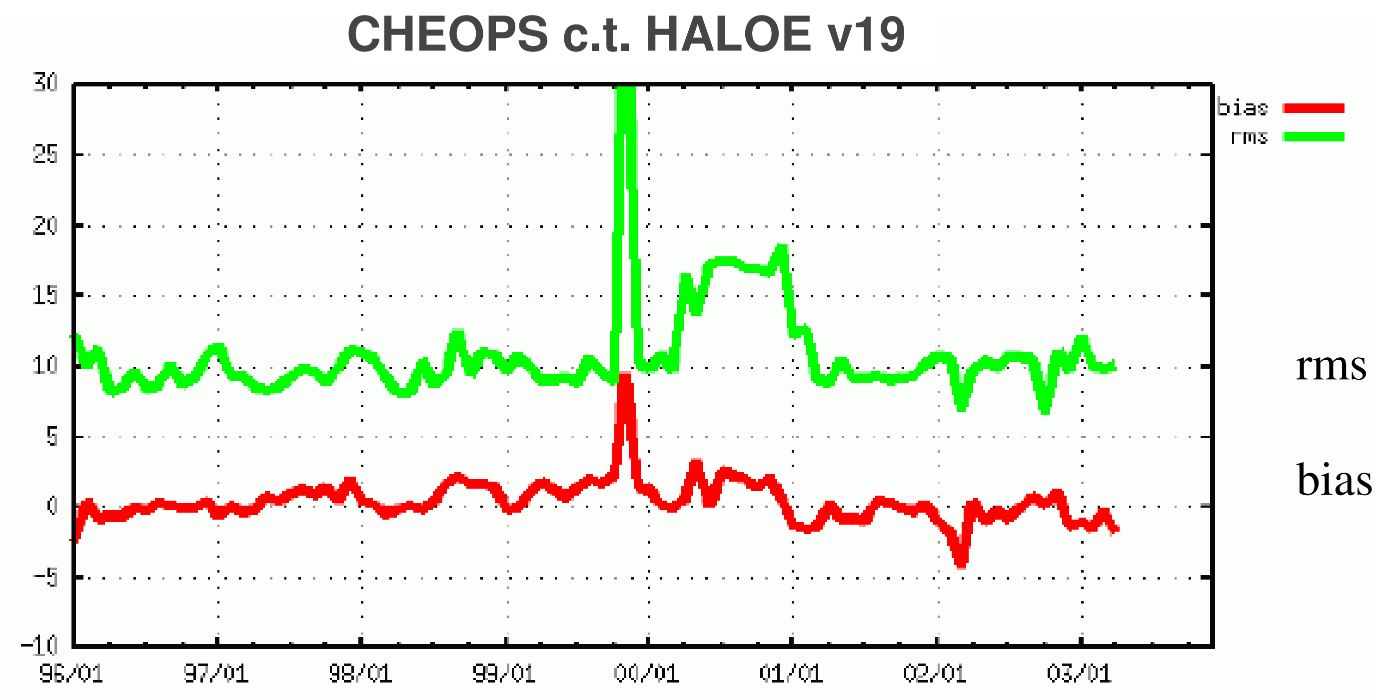
Neural Network Ozone Retrieval System (Müller et al., 2003)

- feed forward 3-layer neural network
- spectral, temperature (GEOS4) and climate data as input
- trained by additional spectral and profile measurements

Training data	GAW and NDACC ozone sondes HALOE, SAGE II, POAM III and SBUV
Data volume	ca. 30,000 profiles per day
Spatial resolution	320km x 40km, 3-5km between 15-32km alt.
Profile errors	bias <<5%, rms <10% for stratosphere independent study (Meijer et al. 2006): 5-10%
Caveats	tropopause region, high zenith angles

CHEOPS analyzed ozone record 1996-2003:

GOME/NNORSY/ROSE sub-opt KF approach



rms ~10%

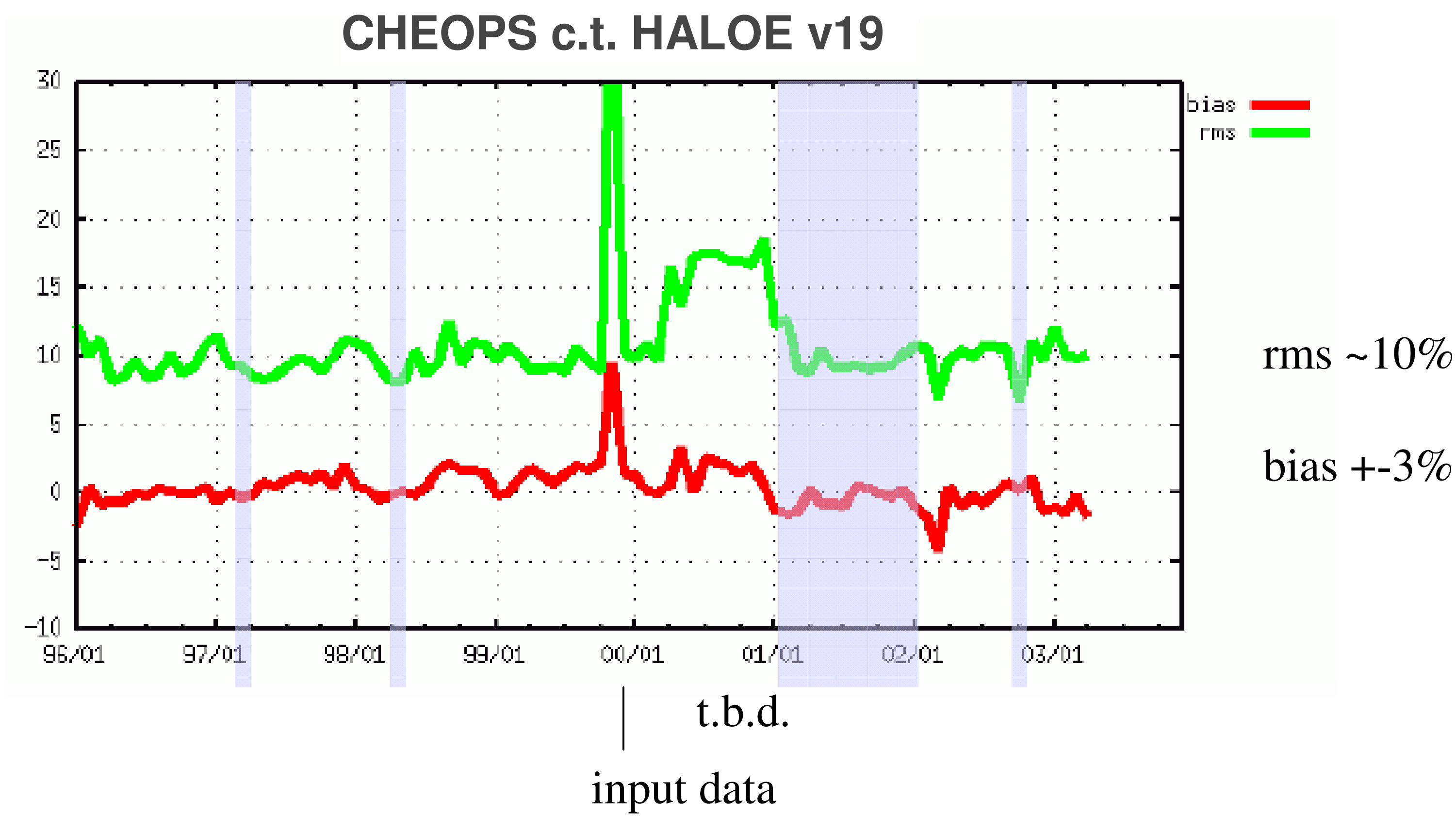
bias +-3%

t.b.d.

input data

CHEOPS analyzed ozone record 1996-2003:

GOME/NNORSY/ROSE sub-opt KF approach



data used for this study

Observation Simulation System Experiments (OSSEs)

Simulated ozone soundings using CHEOPS data

Ozone radio sondes

several networks, currently ca. 2 soundings per day

10hPa max altitude

ca. 30min per ascend, >100km drift possible

-> instantaneous ‘measurement’ on 2.5° model grid

WMO and NASA registered stations (#15, 73, 125 total)

location derived from WOUDC data center: http://www.msc-smc.ec.gc.ca/woudc

Observation Simulation System Experiments (OSSEs)

Two experiment sets

‘short-term’

1997 April 01-18th:	low-ozone streamer from north of Europe
1998 Febr. 01-18th:	North Atlantic low-ozone streamer
2002 Sept. 11-28th:	Antarctic vortex-split episode

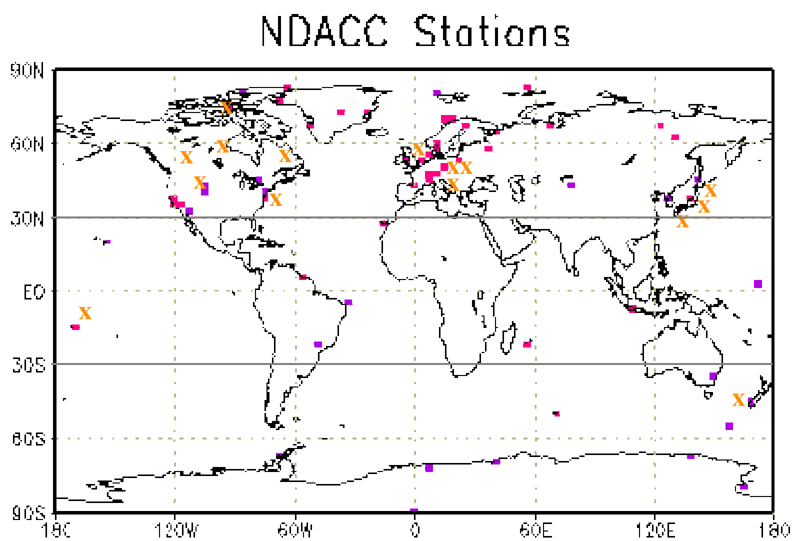
‘long-term’

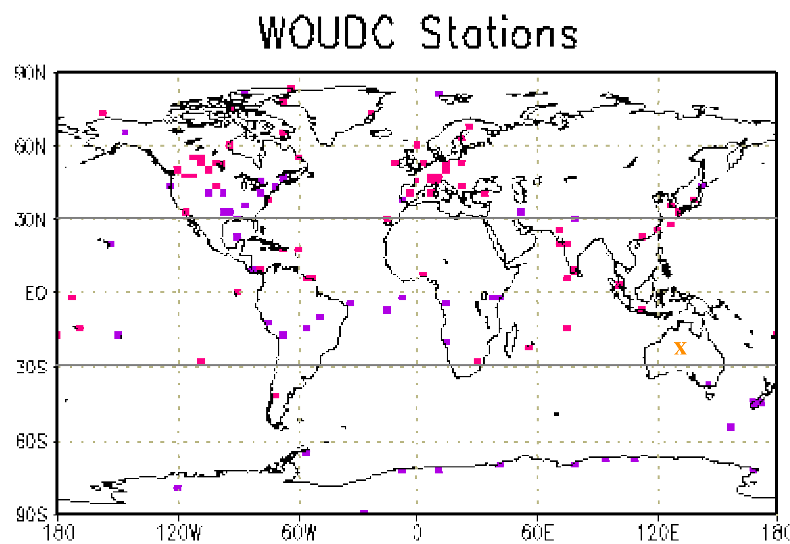
2001 January-September (Q1-Q3): cold persistent both hemispheres

Three *pseudo* networks (CHEOPS ozone record as input)

GAW(A)	15 active stations, mostly North America and Europe
NDACC	73 stations, global, Greenland, Scandinavia, Antarctica
WOUDC	125 stations, global, all registered including SHADOZ

Ozone sonde station networks





x : active GAW stations

Observation Simulation System Experiments (OSSEs)

Two experiment sets

'short-term'

1997 April 01-18th:	network	WOUDC	1/day	>30°N
1998 Febr. 01-18th:		WOUDC	1/day	<30°NS
2002 Sept. 11-28th:		WOUDC	1/day	>30°S

'long-term'

2001 01-09:	network	GAW	1/day
		NDACC	1/week
		WOUDC	1/week
		Reference	no sounding

CHEOPS/ROSE ozone sonde profile OSSE

Resolution = 2.5°x 3.7°, 1.3km, 43 levels (1000-0.3hPa)

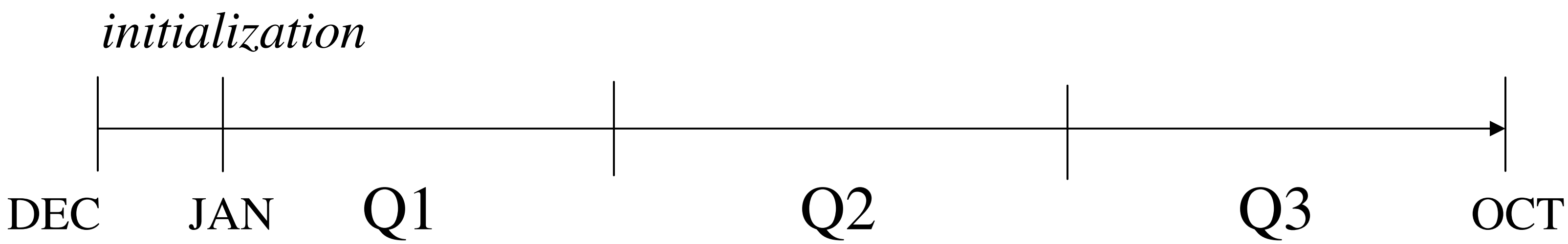
Meteorological analyses: UKMO 24h wind and temp. fields

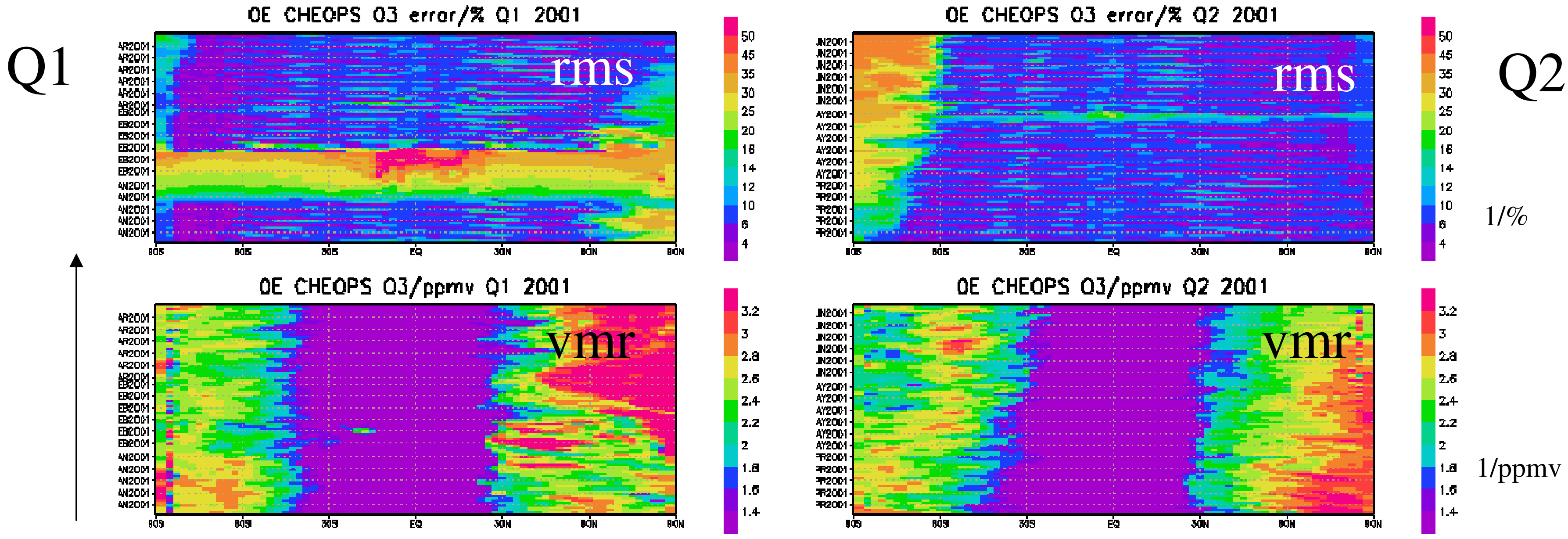
Finite-volume transport scheme (Lin and Rood, 1996)
Non-QSSA chemistry (JPL14), NAT, ICE, sulphate aerosols

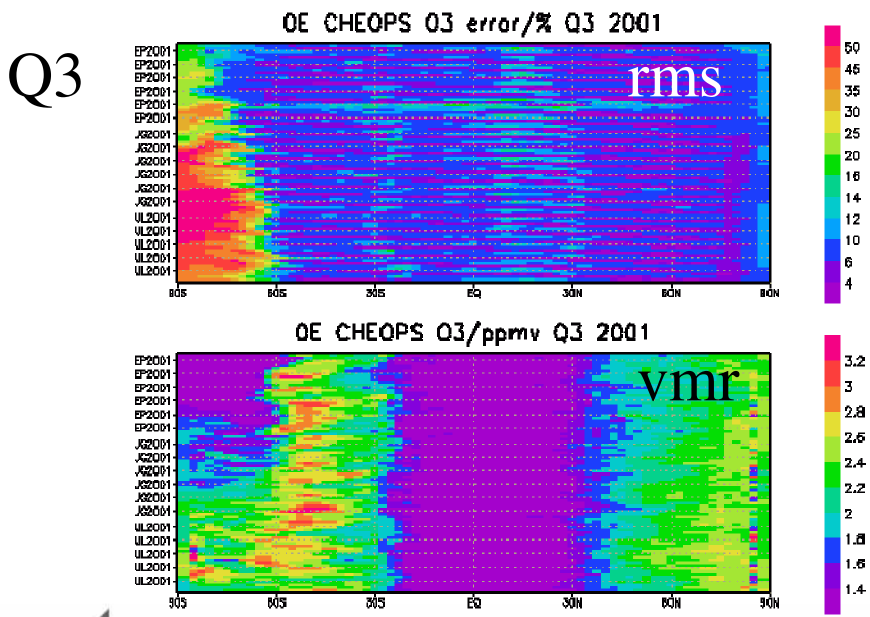
Sequential assimilation of vmr/rms from CHEOPS analyses
(instantaneous ‘observations’ from surface up to 10 hPa at 7am LT)

KF: propagation of analysis errors (e.g., Khattatov et al., 2002)

‘long-term’ experiments: 2001 Q1-Q3







CHEOPS 56hPa ozone

Total residuals: Reference - HALOE* (>100hPa)

	Reference Q1				Reference Q2			
	#	mean	bias	rms	#	mean	bias	rms
SH	27064	3.46	-5.43	23.83	28333	3.67	5.07	16.89
TP	16942	3.73	-8.04	26.20	24471	3.82	-3.62	21.56
NH	25279	3.71	-4.24	17.17	7527	3.54	-1.04	12.87

	Reference Q3			
	#	mean	bias	rms
SH	14733	3.82	7.88	19.77
TP	8961	3.96	-0.74	20.43
NH	18186	3.25	-1.07	15.26

Total residuals: GAW - HALOE

	GAW Q1				GAW Q2			
	#	mean	bias	rms	#	mean	bias	rms
SH	27064	3.46	-5.45	23.15	28333	3.65	4.40	16.22
TP	16942	3.73	-7.97	25.36	24471	3.81	-3.75	21.12
NH	25279	3.71	-4.18	15.36	7527	3.51	-2.10	11.21

	GAW Q3			
	#	mean	bias	rms
SH	14733	3.77	6.66	17.82
TP	8961	3.92	-1.25	19.85
NH	18186	3.23	-1.79	14.64

Total residuals: NDACC - HALOE

	NDACC Q1				NDACC Q2			
	#	mean	bias	rms	#	mean	bias	rms
SH	31801	3.43	-3.28	19.14	28333	3.60	3.12	15.03
TP	17014	3.82	-5.34	21.03	24471	3.87	-2.05	18.14
NH	29948	3.72	-3.57	14.40	7527	3.48	-2.83	11.07

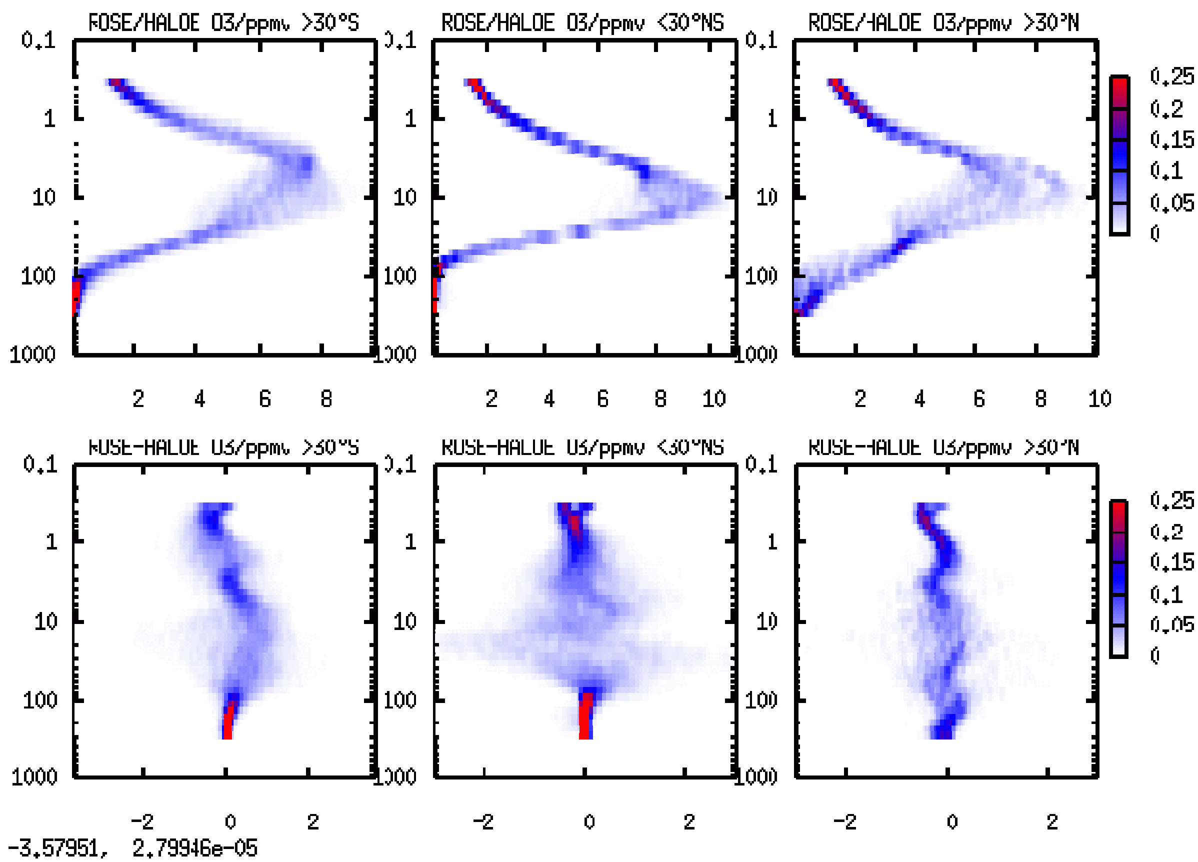
	NDACC Q3			
	#	mean	bias	rms
SH	12468	3.82	5.53	15.49
TP	1314	3.80	2.75	17.45
NH	6986	3.01	-1.48	11.04

Total residuals: WOUDC - HALOE

	WOUDC Q1				WOUDC Q2			
	#	mean	bias	rms	#	mean	bias	rms
SH	31801	3.45	-2.93	18.13	28333	3.60	3.12	14.89
TP	17014	3.84	-4.72	19.70	24471	3.89	-1.75	16.90
NH	29948	3.71	-3.69	14.33	7527	3.50	-2.30	10.92

	WOUDC Q3			
	#	mean	bias	rms
SH	12468	3.83	5.61	15.49
TP	1314	3.84	3.69	16.90
NH	6986	3.00	-1.99	11.18

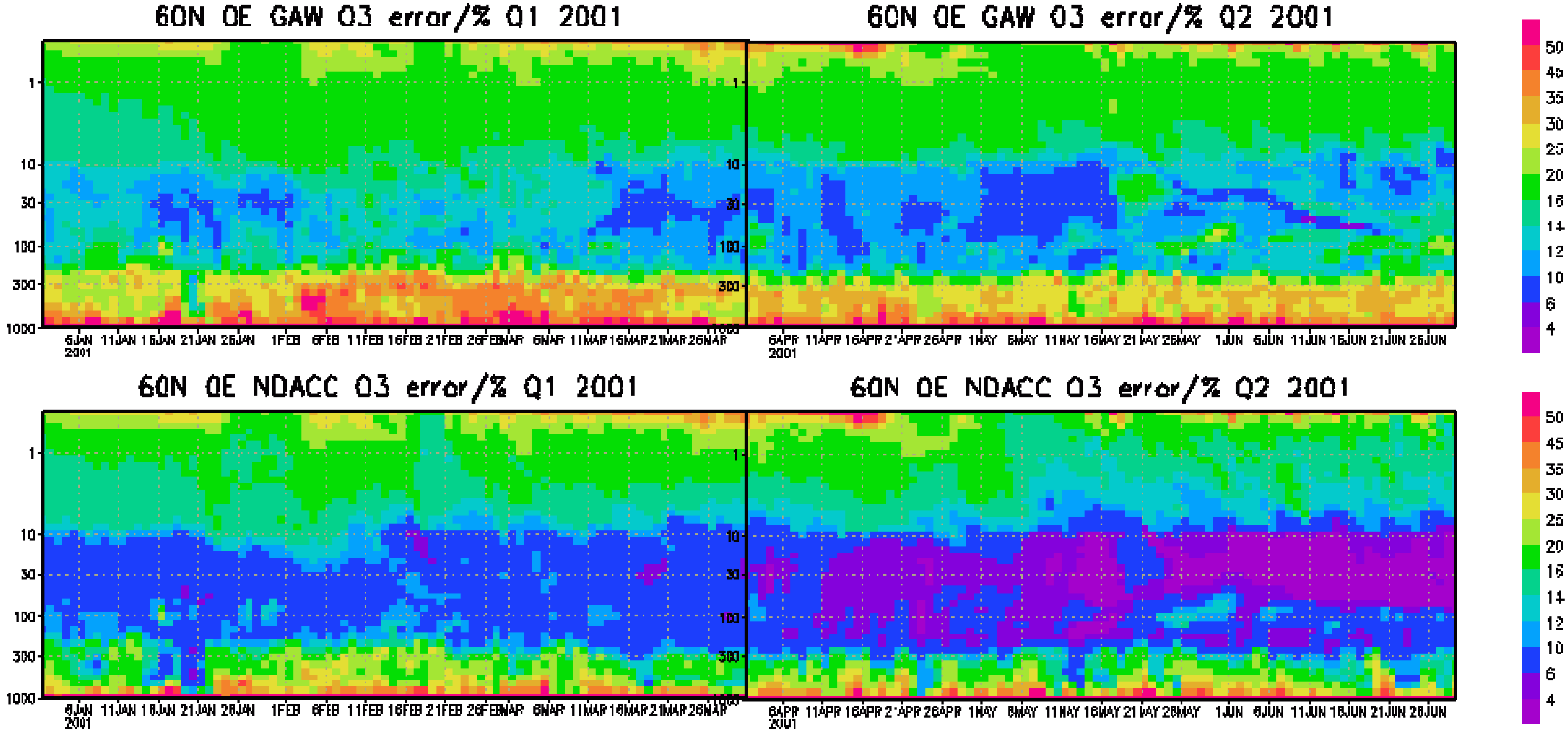
PDF analysis Q2: Reference/WOUCD - HALOE



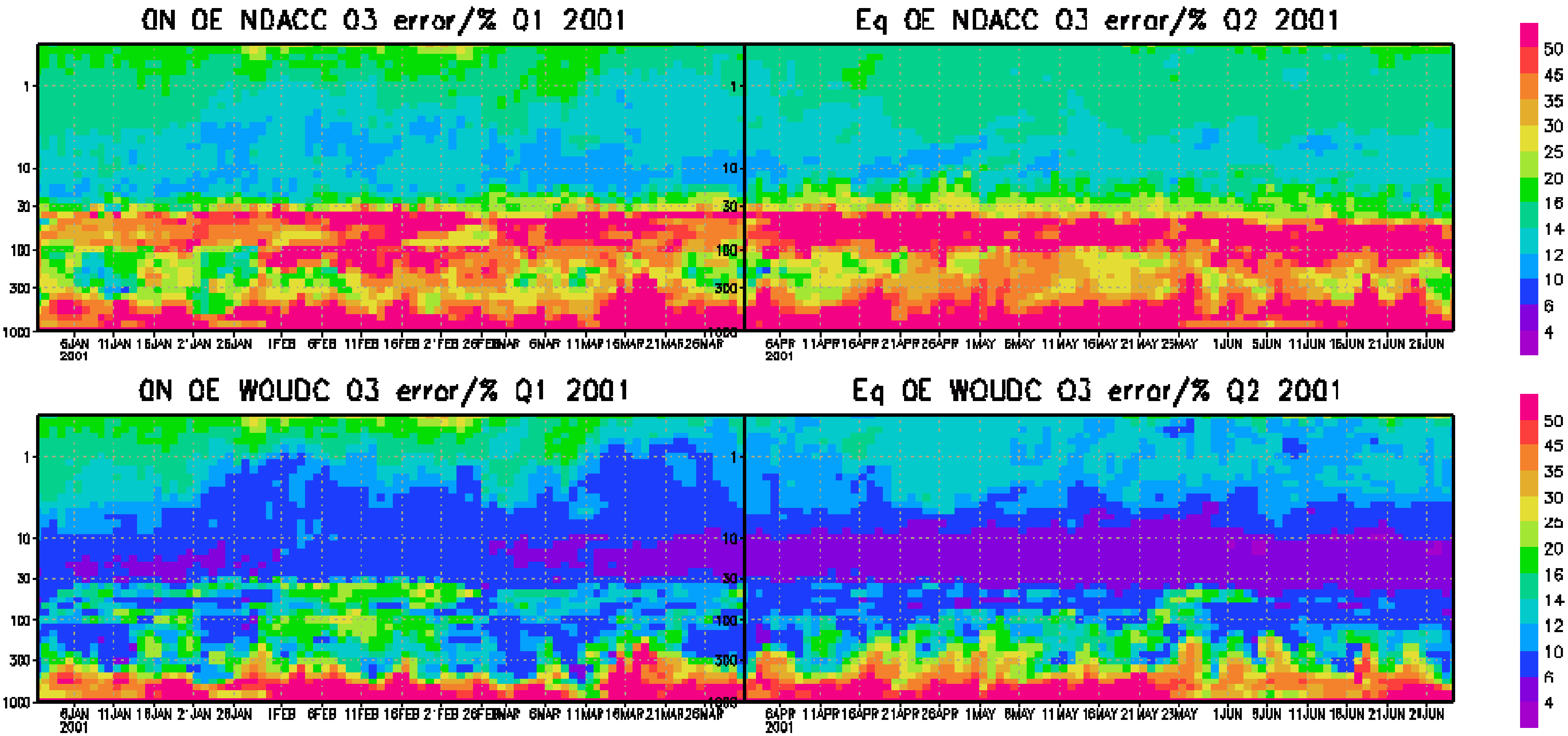
reference

WOUDC

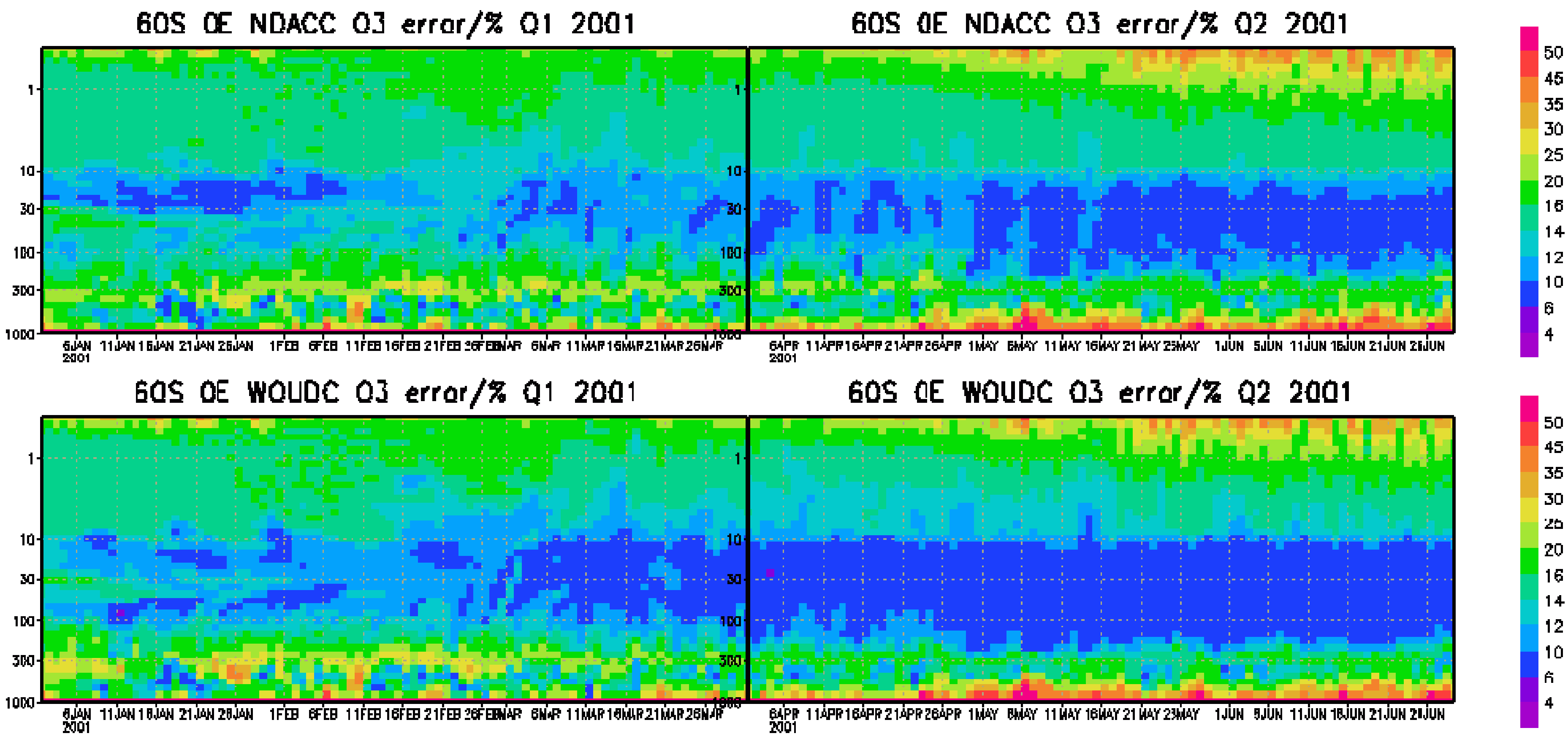
Analysis error GAW/NDACC Q1, Q2 60°N



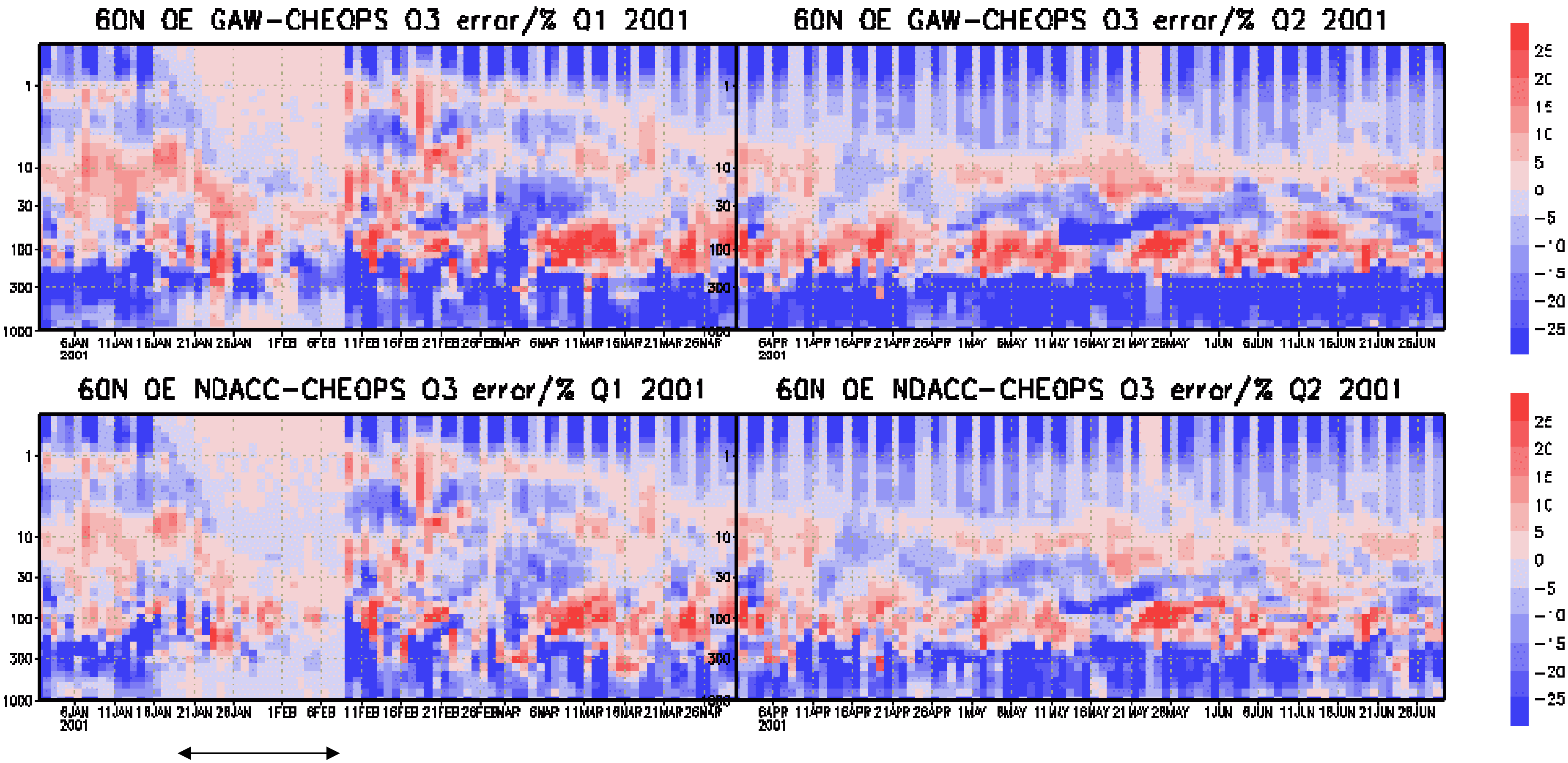
Analysis error NDACC/WOUDC Q1, Q2 Eq



Analysis error NDACC/WOUDC Q1, Q2 60°S

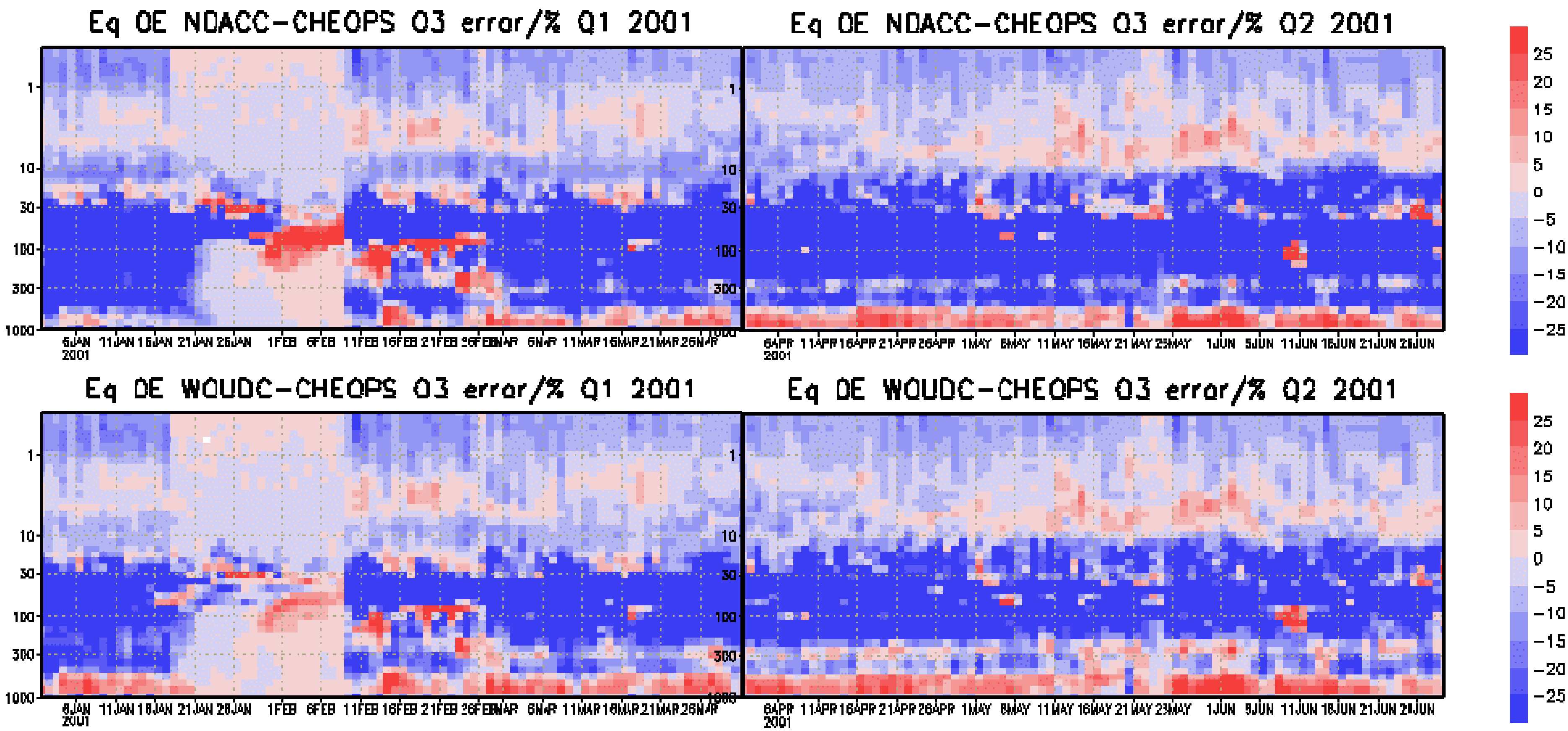


FMO errors GAW/NDACC Q1, Q2 60°N

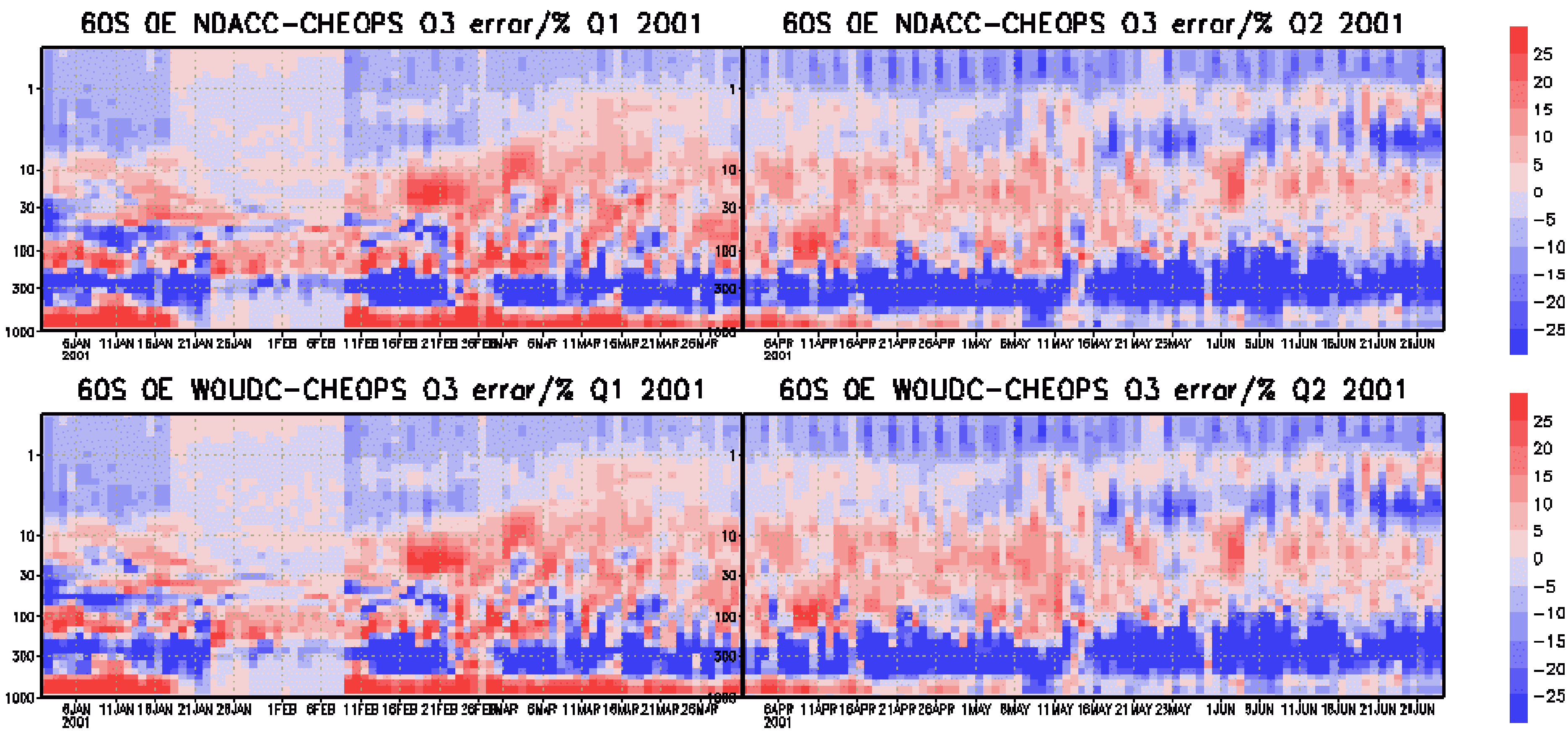


GOME data gap

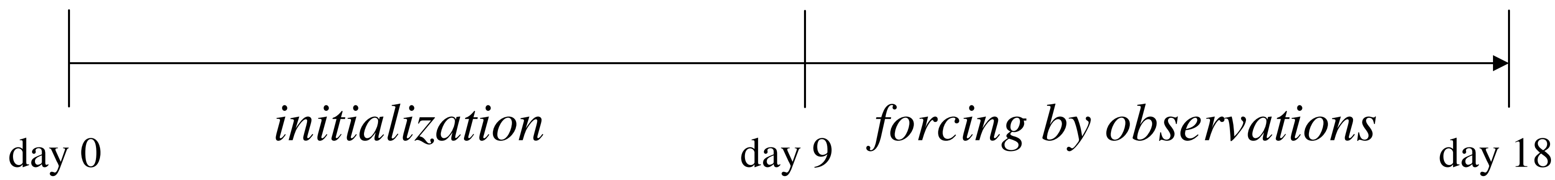
FMO errors NDACC/WOUDC Q1, Q2 Eq



FMO errors NDACC/WOUDC Q1, Q2 60°S

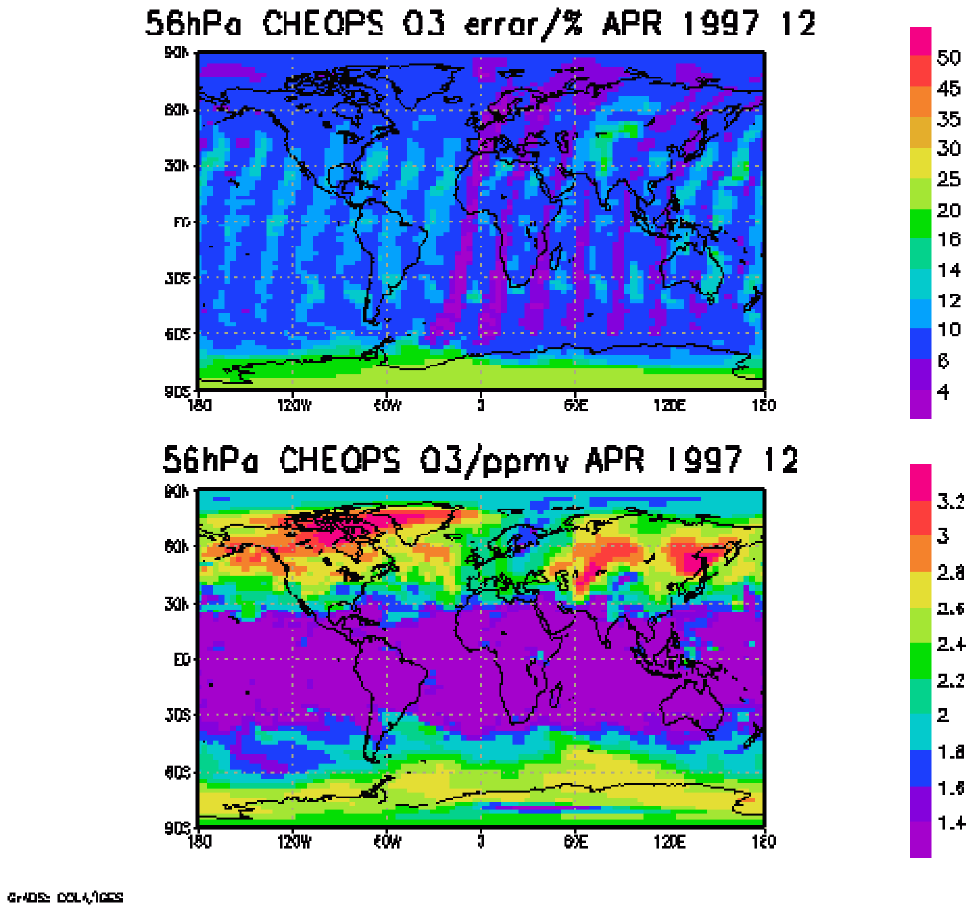


‘short-term’ experiments:
1997 APR 01-18, 1998 FEB 01-18, 2002 SEP 11-28



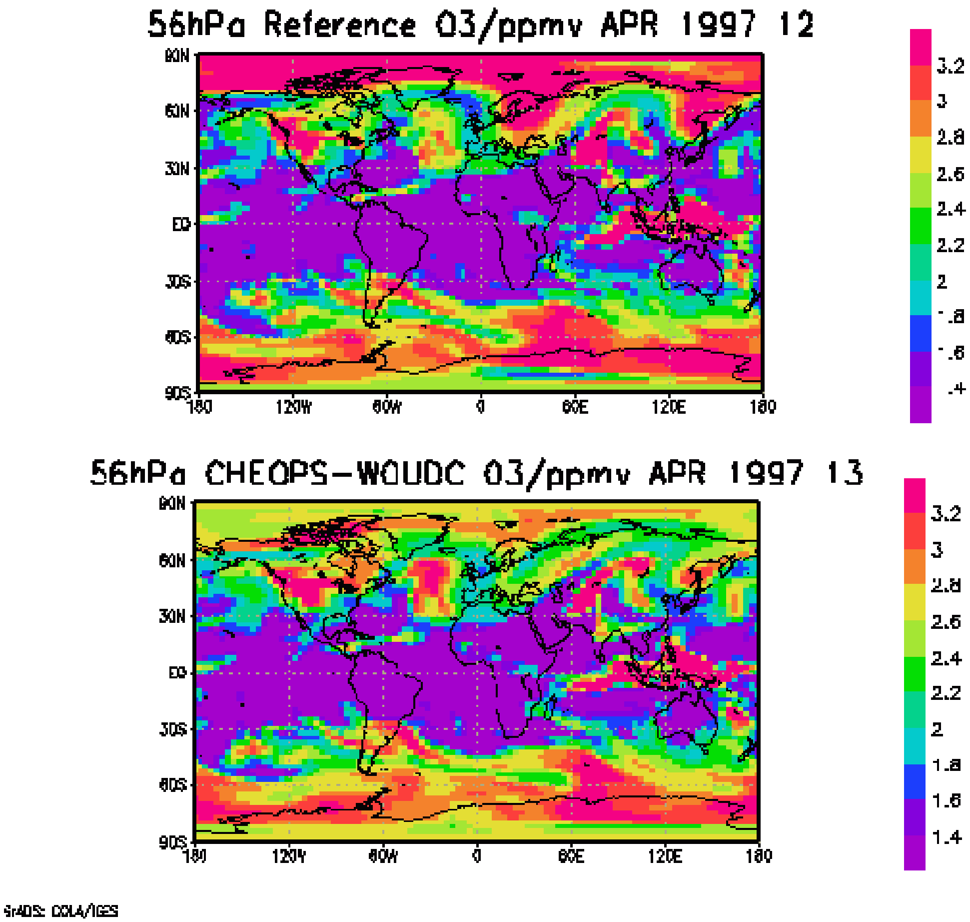
1997 April 01-18th:	network	WOUDC	1/day	>30°N
1998 Febr. 01-18th:		WOUDC	1/day	<30°NS
2002 Sept. 11-28th:		WOUDC	1/day	>30°S

CHEOPS ozone record 1997 April 9-12th



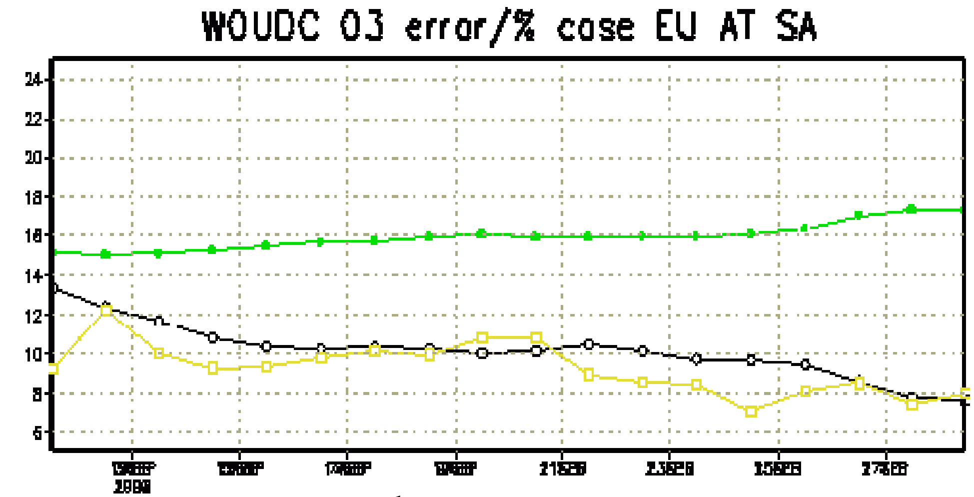
northern intrusion event

WOUDC/Reference 1997 April 12th

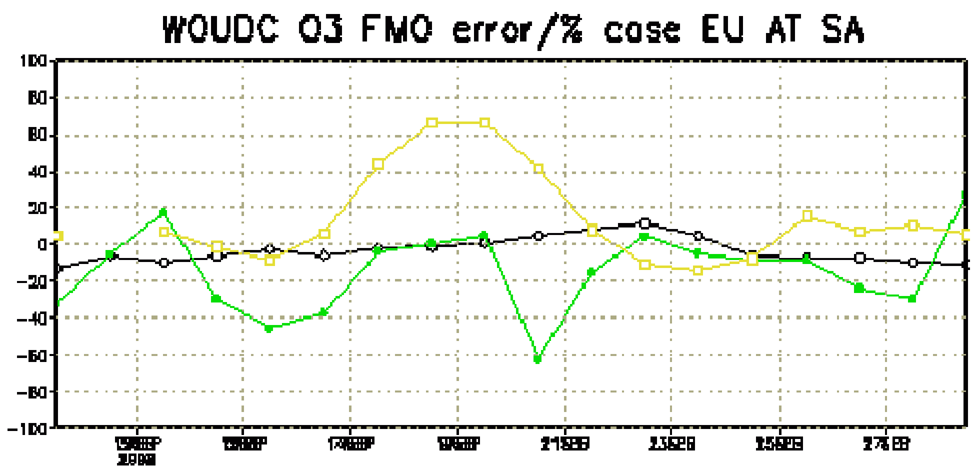


ozone bias >60°N

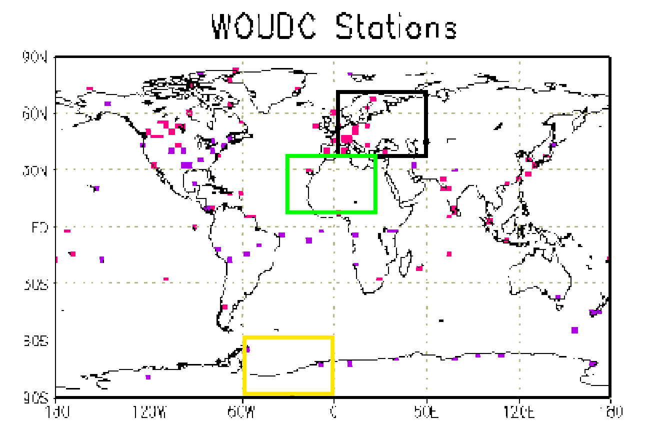
‘short-term’ aggregated results: three test areas



1 days → 18



EU	40-70°N/0°E-60°E
AT	10-40°N/30°W-30°E
SA	60-90°S/60°W-0°E



CHEOPS/SACADA adjoint receptor analysis

Resolution = 250km (icosaeder), 43 sigma levels (top at 65 km)

ECMWF analysis as init for GME multi-day forecasts

Semi-Lagrange transport scheme
Non-QSSA chemistry, NAT, ICE PSCs (not this study) and aerosols

4Dvar: incremental with isotropic background covariances (Courtier, 1997)

Instantaneous ‘observations’ using CHEOPS data at 7 LT up to 10 hPa

CHEOPS/SACADA adjoint receptor analysis

Resolution = 250km (icosaeder), 43 sigma levels (top at 65 km)

ECMWF analysis as init for GME multi-day forecasts

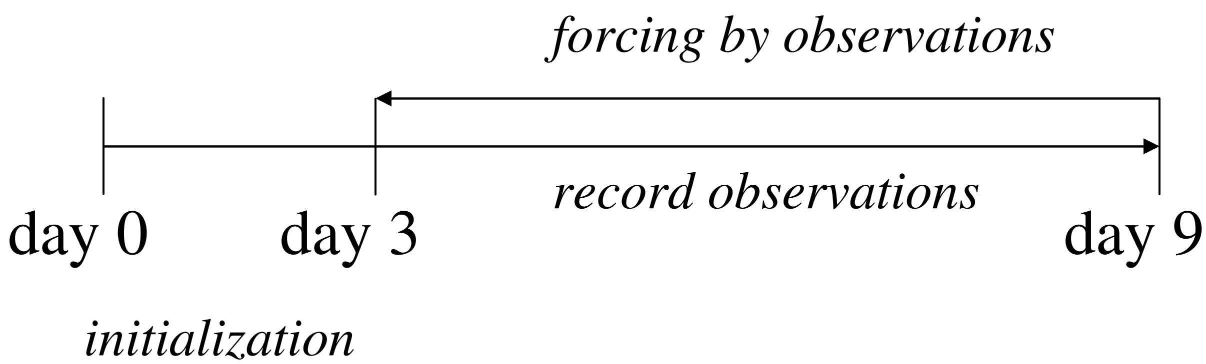
Semi-Lagrange transport scheme
Non-QSSA chemistry, NAT, ICE PSCs (not this study) and aerosols

4Dvar: incremental with isotropic background covariances (Courtier, 1997)

This study: assess impact of observations via gradient of cost function

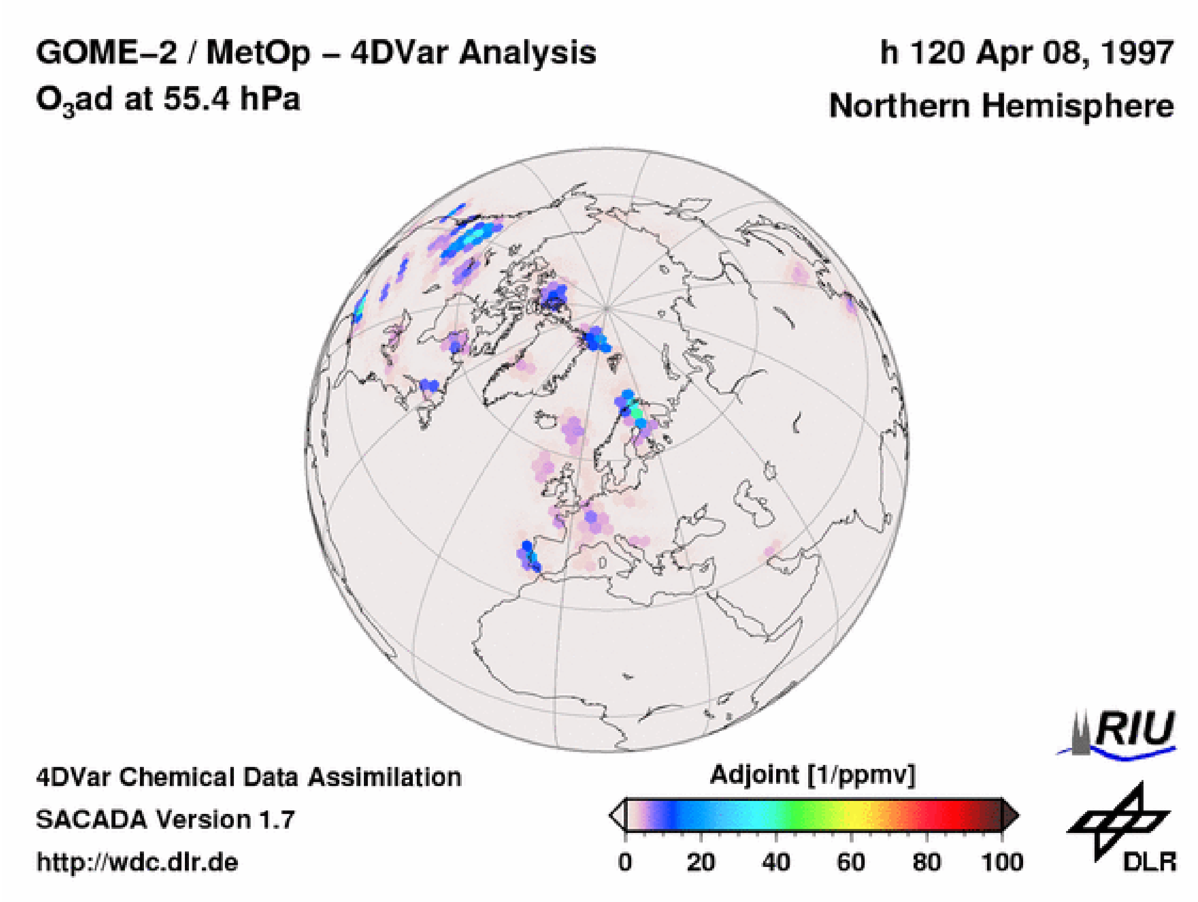
$$J(x_N) = 1/2 \sum \delta x_i \; \underbrace{1/O \; M\delta x_o}_{\text{observation inc.}} \rightarrow \partial J/\partial x_o = M^T \; \underbrace{1/O \; \delta x_N}_{\text{adjoint variable}} \quad \text{with } O = \sigma^2 \text{ (obs. error)}$$

CHEOPS/SACADA adjoint receptor analysis



WOUDC:
one sounding per day

CHEOPS/SACADA adjoint receptor analysis



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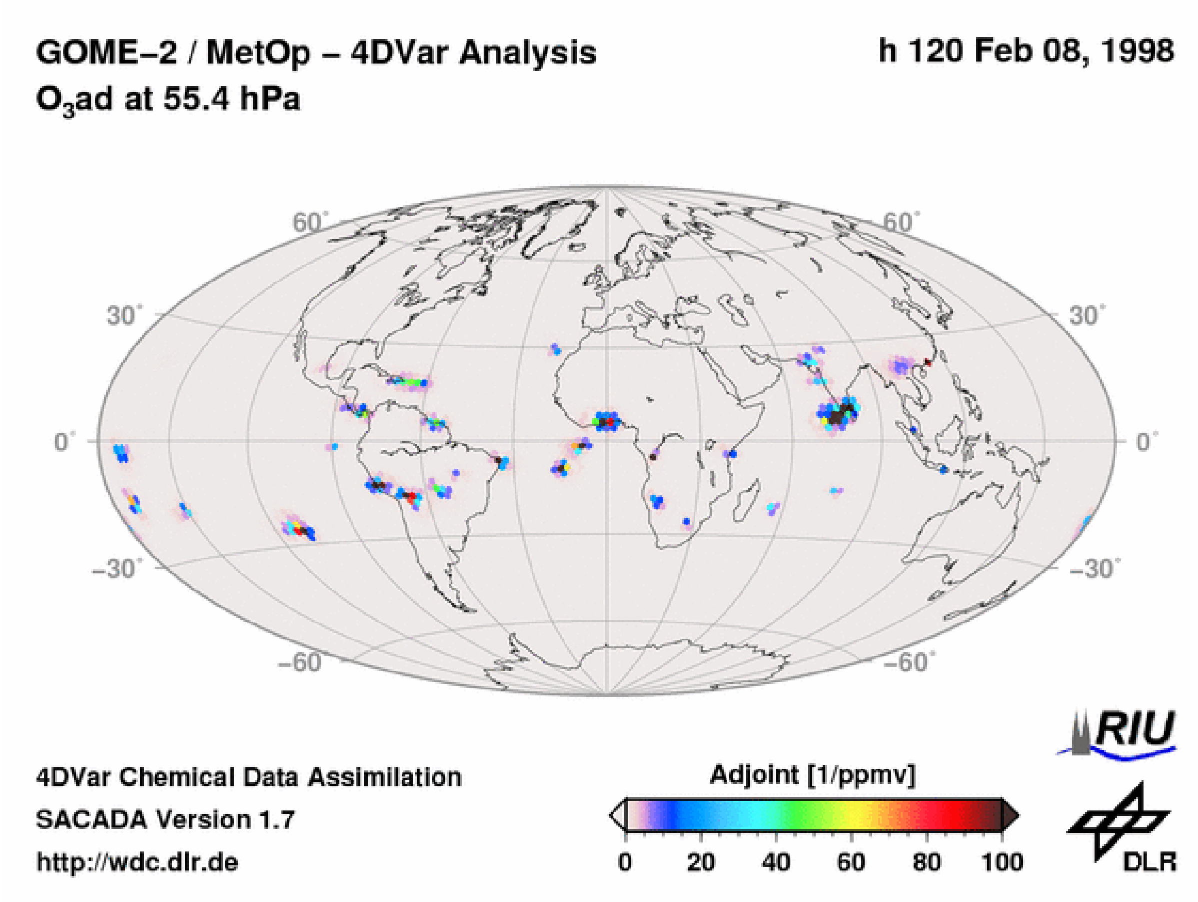
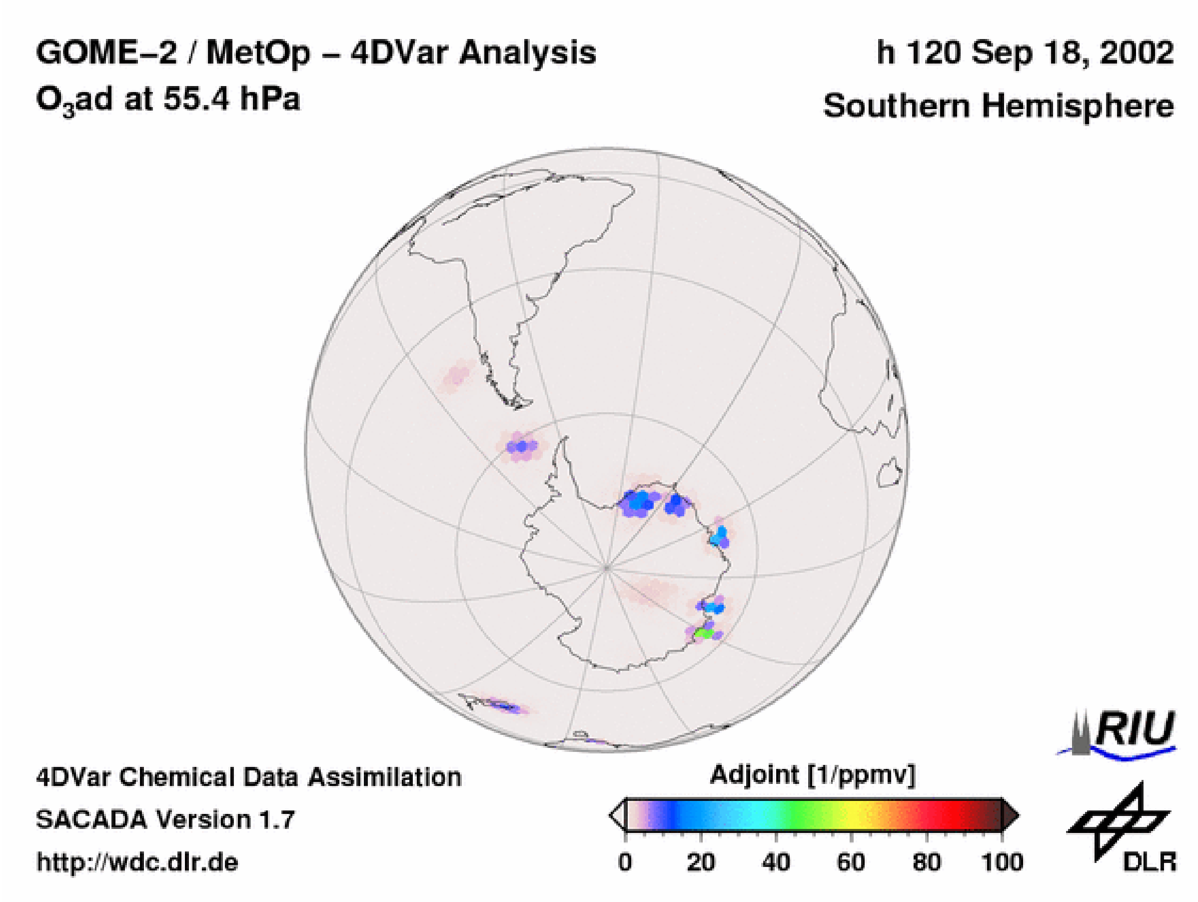
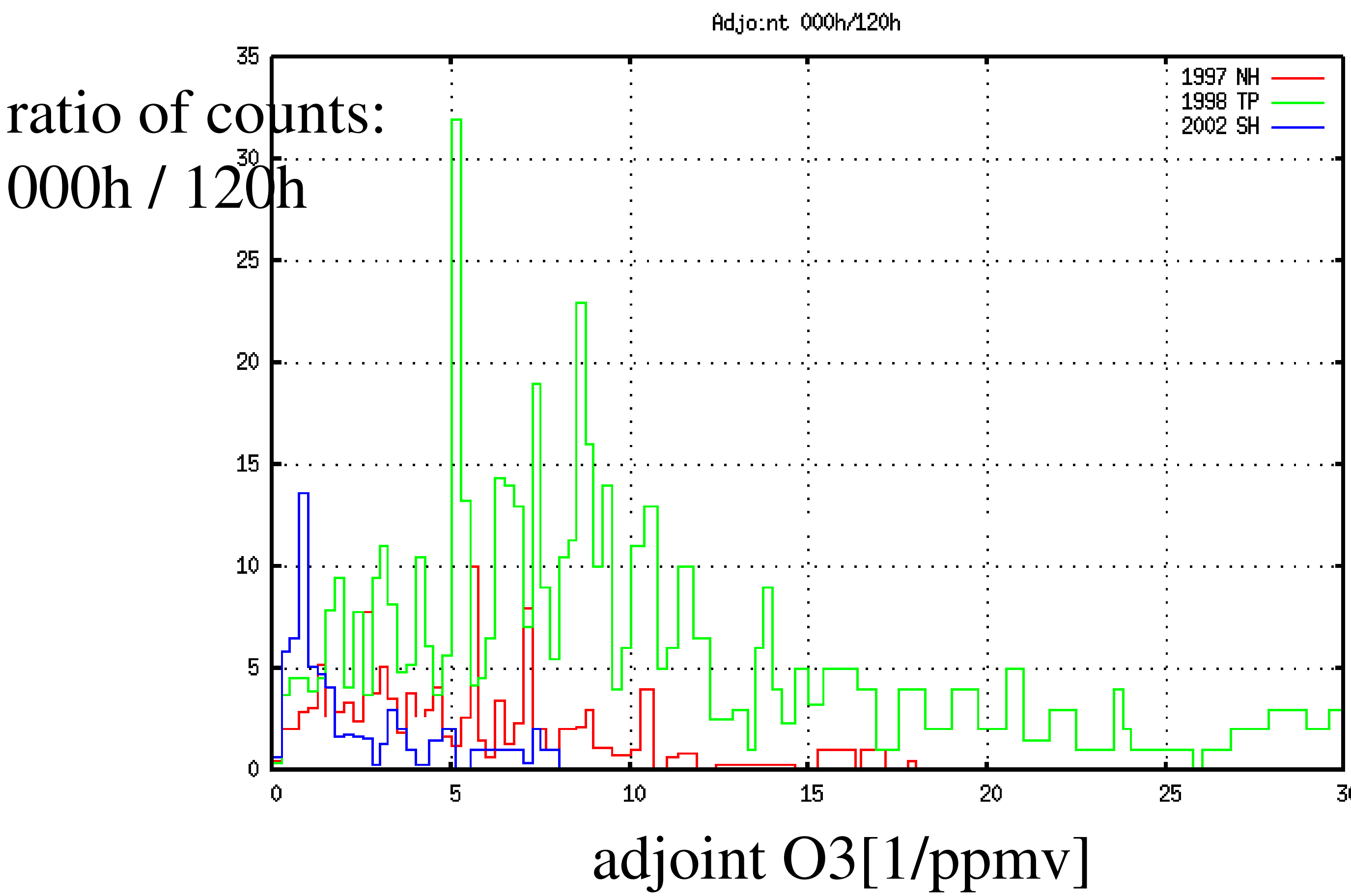


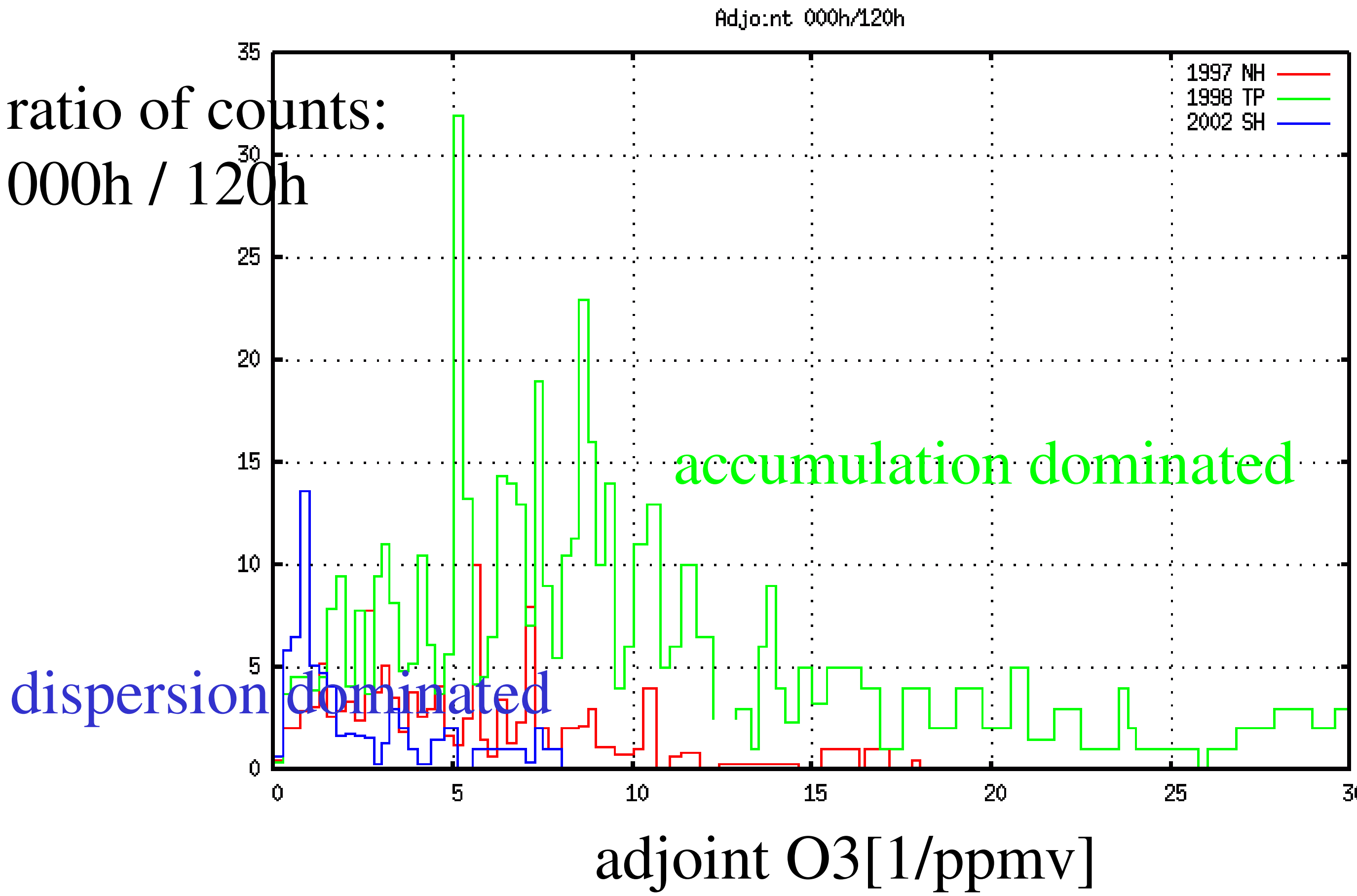
CHEOPS/SACADA adjoint receptor analysis



CHEOPS/SACADA adjoint receptor analysis



CHEOPS/SACADA adjoint receptor analysis



Summary

- OSSE experiments using CHEOPS ozone profile analyses
- Test of different ozone sonde networks and sounding frequencies
- Multi-day adjoint analysis of sounding sensitivity

Long-term experiment 2001

- Up to 25% rms error reduction c.t. HALOE for tropics and SH
- Increase of soundings per stations does not compensate for lack of cover.
- Model results without observations already at 15% level for NH
- Tropics: results obstructed by poor model performance - noisy wind fields

Short-term experiments '97 '98 '02

- NH: model bias reduced: improved streamer forecast
- Tropics: weak dispersion of observations, resulting in poor coverage
- SH: current network layout not adequate during dynamic events (v-split)

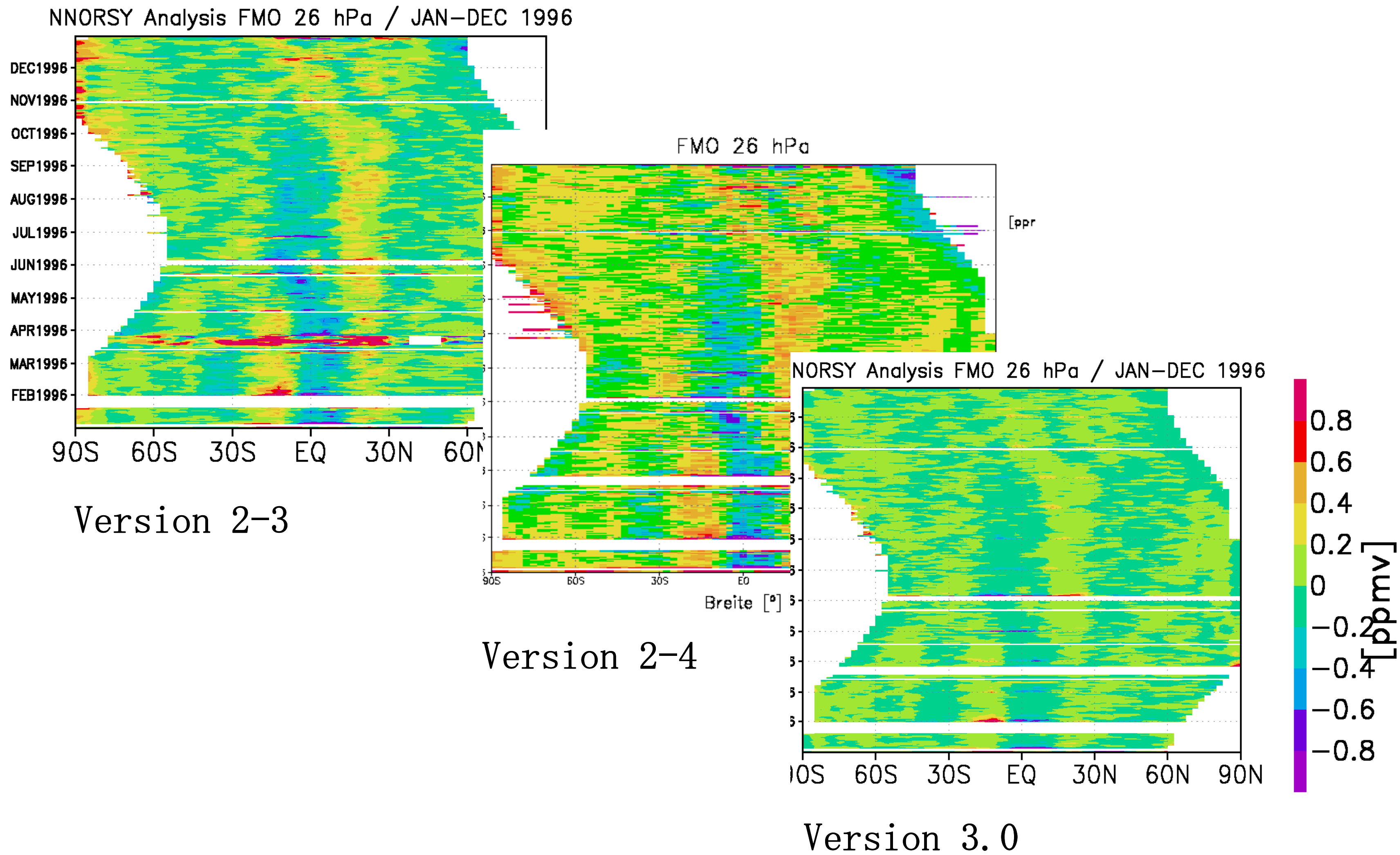
Recommendations

- Increase number of regular soundings at base stations
- Better distributed soundings in tropics to improve coverage
- Use Umkehr/satellites etc. to reduce model bias
- Coordinated measurements to better capture dynamic events

Many thanks to:
NCAR (National Center for Atmospheric Research)
WMO/IGACO (Integrated Global Atmospheric Chemistry Observations)
GAW/ (Global Atmospheric Watch)
NDACC (Network for the. Detection of. Atmospheric Change)
WOUDC (World Data Center for Ozone and UV)

First-guess minus observation (FMO) errors:

Improvements of GOME/NNORSY from v2.3 to 3.0



HALOE 2003/2004 comparison results

ROSE-UKMO c.t. HALOE (100-2 hPa)

obs		mean	bias/%	rms/%
O3	48776	5.10	0.29	13.71
H2O	48778	5.05	4.29	9.30
Nox	41478	7.79	0.97	26.30
CH4	48576	4.26	7.77	15.19
HCl	41484	1.82	-9.02	19.61

SACADA c.t. HALOE (100–2 hPa)

obs		mean	bias/%	rms/%
O3	65582	4.99	-0.43	13.09
H2O	65584	5.11	4.47	10.00
Nox	55761	6.85	-11.75	24.25
CH4	65452	4.05	6.49	12.45
HCl	55768	1.27	-59.36	75.64

ROSE-GME c.t. HALOE (100-2 hPa)

obs		mean	bias/%	rms/%
O3	54252	5.16	1.64	8.81
H2O	54254	5.09	5.01	9.14
Nox	46137	7.99	2.73	24.86
CH4	54050	4.21	7.49	13.56
HCl	46142	1.92	-4.28	15.23