Routine assimilation of ground-based ozone observations

Case study 2003 Q1 (VINTERSOL)

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Plan

- Project background: PROMOTE / MACC-GRG
- Motivation for the assimilation of ozone sonde data
- Reminder: results of OSSE (SPARC Toronto 2007)
- Introduction to VINTERSOL ozone sonde data
- Results of assimilation experiments with fixed R
- Relevance of Background and Observational errors (B, R)
- Tuning of observational errors using correlation with error tracer field
- Application of tuned R values on VINTERSOL test episode
- Summary

PROMOTE and MACC GRG satellite data assimilation project

Stratosphere

- 4Dvar MLS/GOME/MIPAS BASCOE/SACADA
  - Errera, Q. and D. Fonteyn: Four–dimensional variational chemical assimilation of CRISTA stratospheric measurements, JGR 2001.
  - Elbern, H., J. Schwinger and R. Botchorishvili: Chemical state estimation for the middle atmosphere by 4-dimensional variational data assimilation, Part 1+2, JGR 2009.

- Kalman filter GOME/SCIA/OMI TM3DAM
  - Eskes, H., P. van Velthoven, P. Valks and H. Kelder: Assimilation of GOME total ozone satellite observations in a three-dimensional tracer transport model, Q.J.R. Met. Soc., 2003

Troposphere

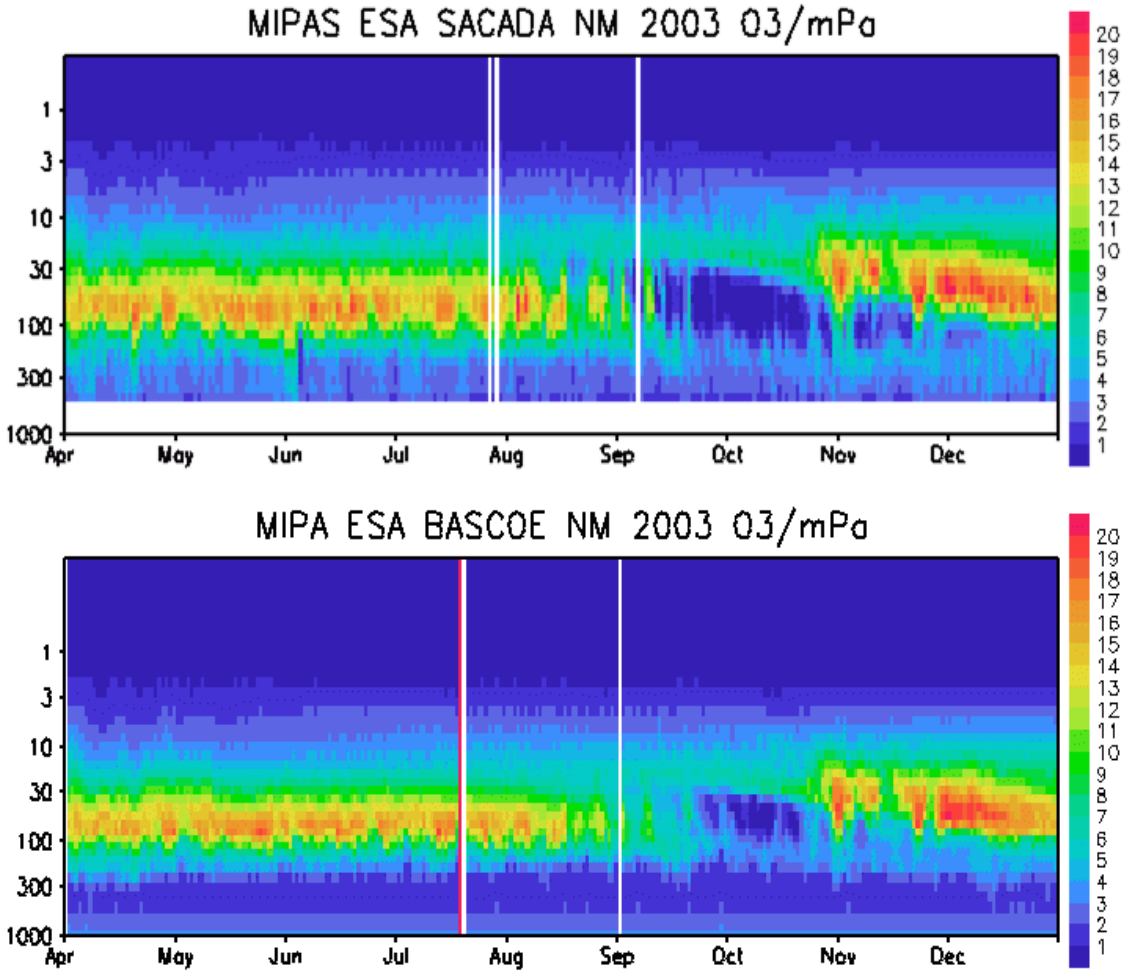
- RAM* TM4DAM approach for tropospheric NO2 column
  - Boersma, K.F., H.J. Eskes and E.J. Brinksma: Error Analysis for Tropospheric NO2 Retrieval from Space, JGR, 2004.

Strat+Trop

- 4Dvar MACC-IFS: MOZART-3/MOCAGE/TM5 with multiple satellite instruments
  - Flemming, J., A. Innes, H. Flentje, V. Huijnen, P. Moint, M.G. Schultz and O. Stein: Coupling global chemistry transport models to ECMWF's integrated forecast system

***RAM= Retrieval-Assimilation-Modelling**

Results from model cross-comparison 2003



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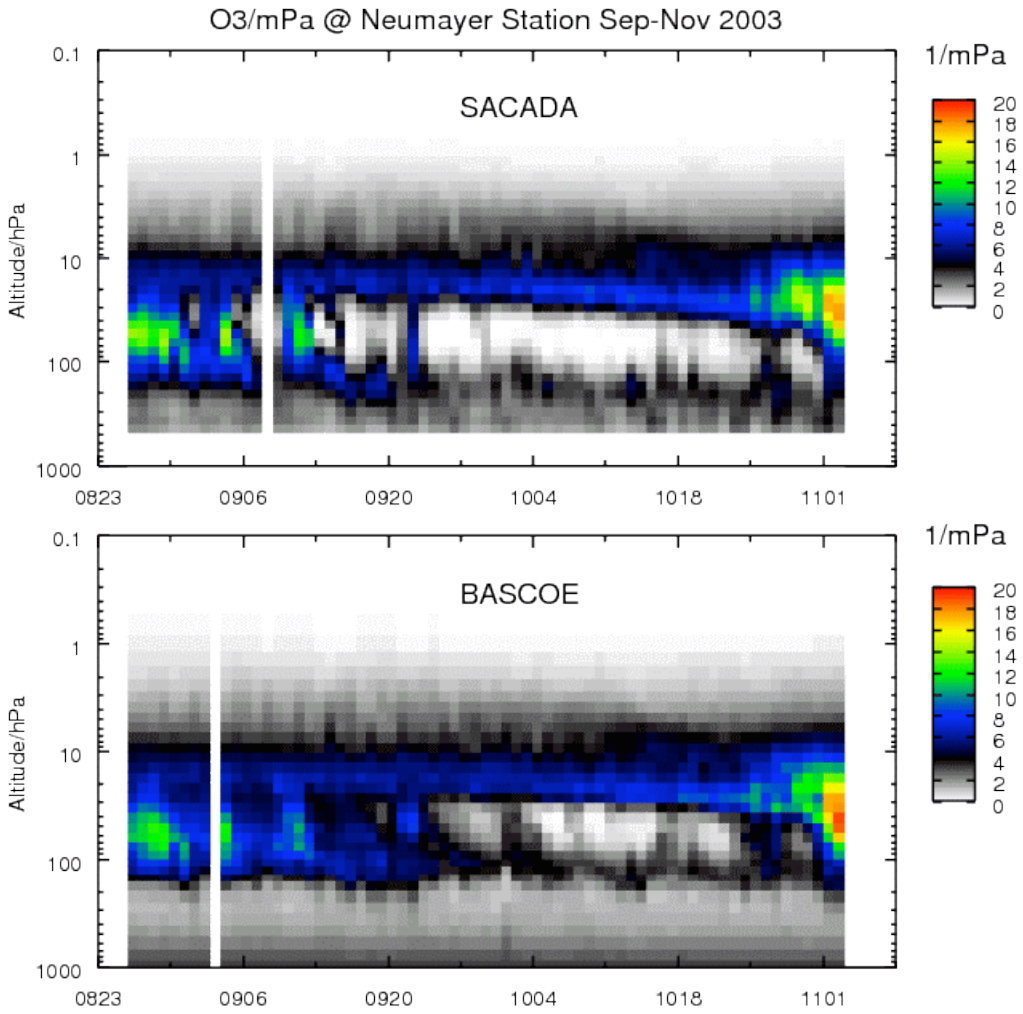

MPE/SACADA

MPE/BASCOE

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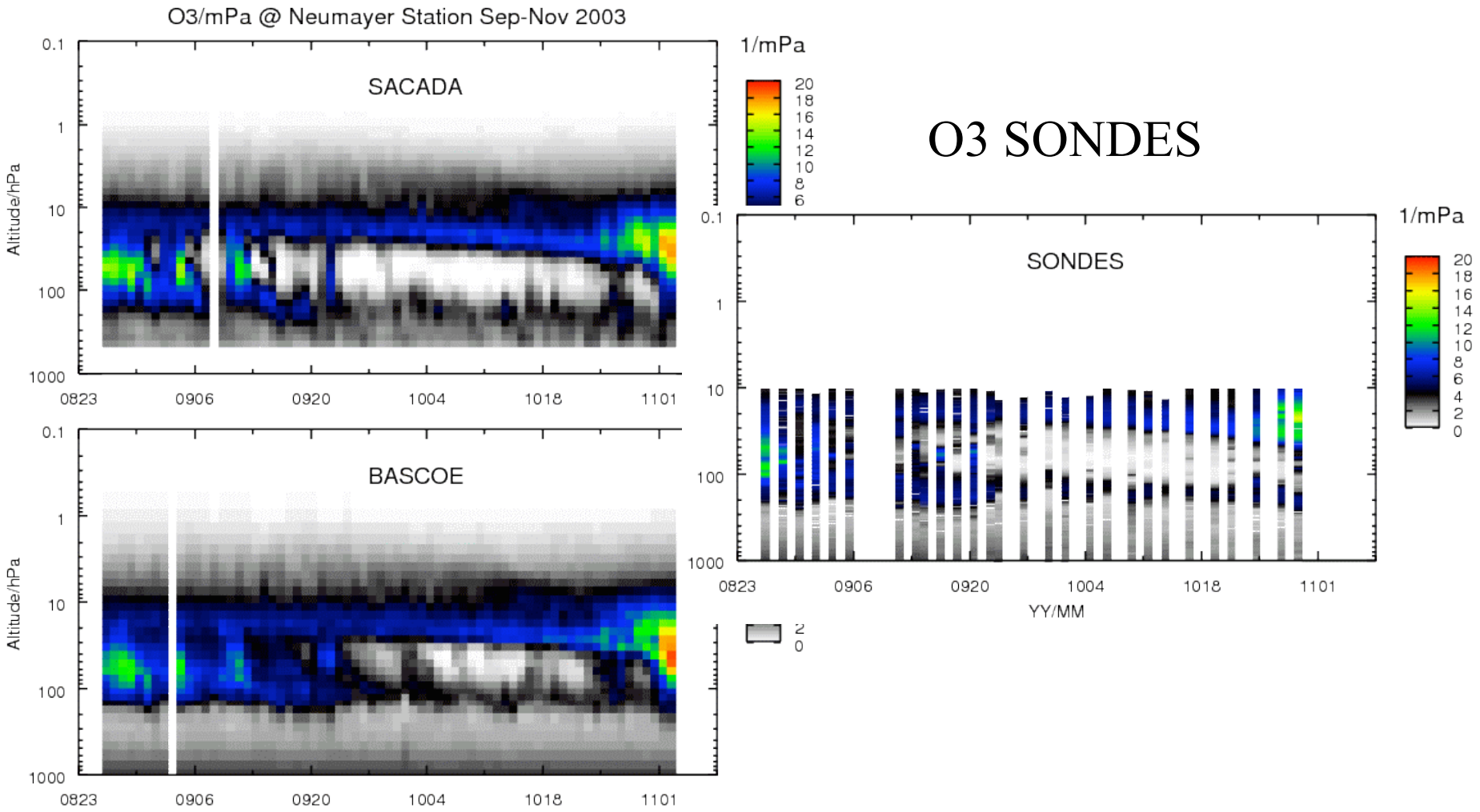


Motivation for assimilation of ozone sonde data

- Satellite instruments: expensive (~100M$ each),
  lack of high vertical resolution, only very few occultation sounder (e.g. GOMOS)
- LIDAR: few instruments, expensive in sustained operation
- Umkehr retrieval: high potential but only low vertical resolution
- Ozone sondes: mature, relatively cheap (~1000$ total costs per sounding*), many stations in NH

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

Bulk of ozone below 10 hPa!

→ assess current ozone sonde networks (this study), e.g. OSSE study by F. Baier (SPARC Toronto 2007)

→ assess impact of existing station network: VINTERSOL, this study

*depends on localities, e.g. effort for maintenance, contracts, etc

Observation Simulation System Experiments (SPARC Toronto, 2007)

Two experiment sets

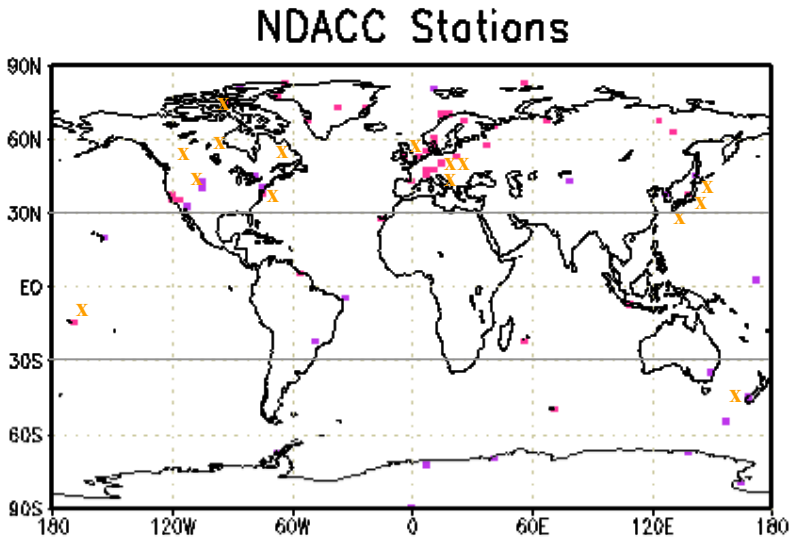
'short-term'

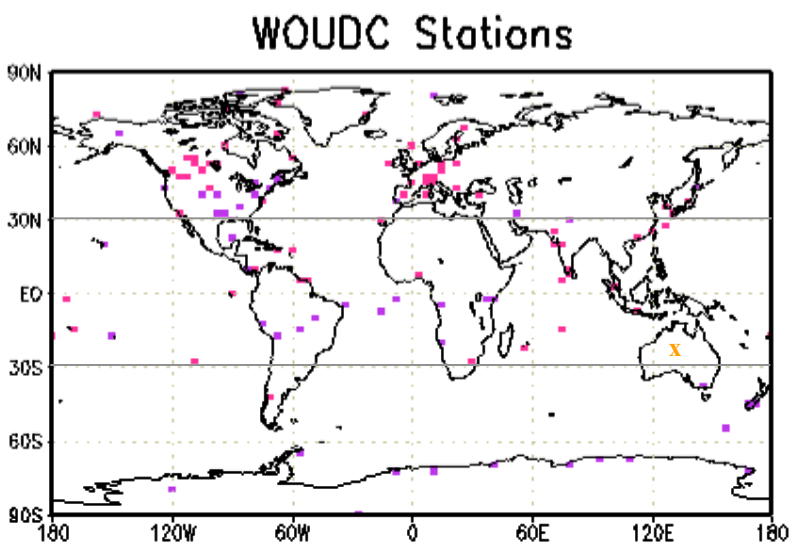
1997 April 01-18th:	network	WOUDC	1/day	>30°N
1998 Febr. 01-18th:		WOUDC	1/day	<30°NS
2002 Sept. 11-28th:		WOUDC	1/day	>30°S

'long-term'

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

OSSE: Analyzed ozone sonde station networks





x : active GAW stations

Summary of mean results: OSSE - HALOE*
(*>100hPa)

Reference Q1

	#	mean	bias	rms
SH	27064	3.46	-5.43	23.83
TP	16942	3.73	-8.04	26.20
NH	25279	3.71	-4.24	17.17

GAW Q1 NH: -10% rms

#	mean	bias	rms
27064	3.46	-5.45	23.15
16942	3.73	-7.97	25.36
25279	3.71	-4.18	15.36

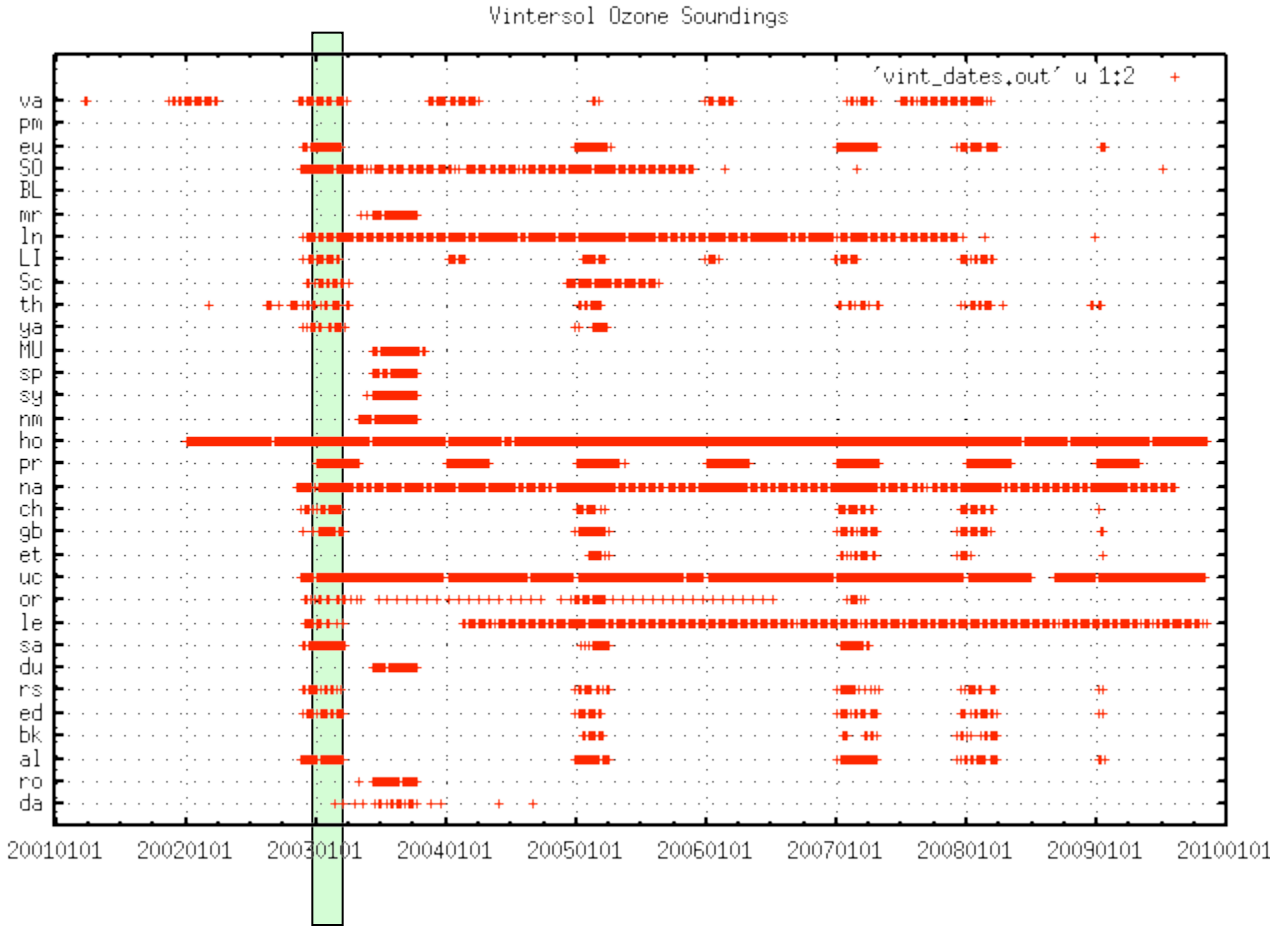
NDACC Q1 NH: -16% rms

	#	mean	bias	rms
SH	31801	3.43	-3.28	19.14
TP	17014	3.82	-5.34	21.03
NH	29948	3.72	-3.57	14.40

WOUDC Q1 NH: -17% rms

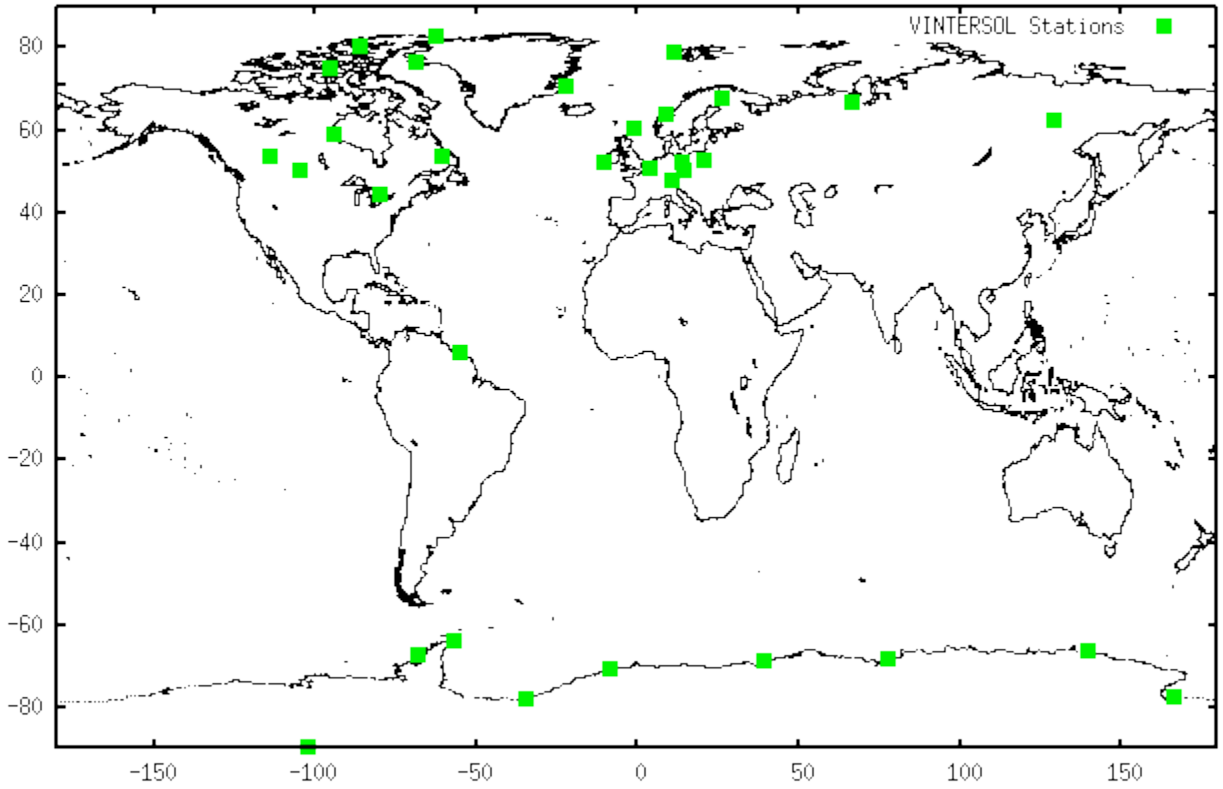
#	mean	bias	rms
31801	3.45	-2.93	18.13
17014	3.84	-4.72	19.70
29948	3.71	-3.69	14.33

VINTERSOL ozone sonde station coverage



this study

VINTERSOL ozone sonde station network

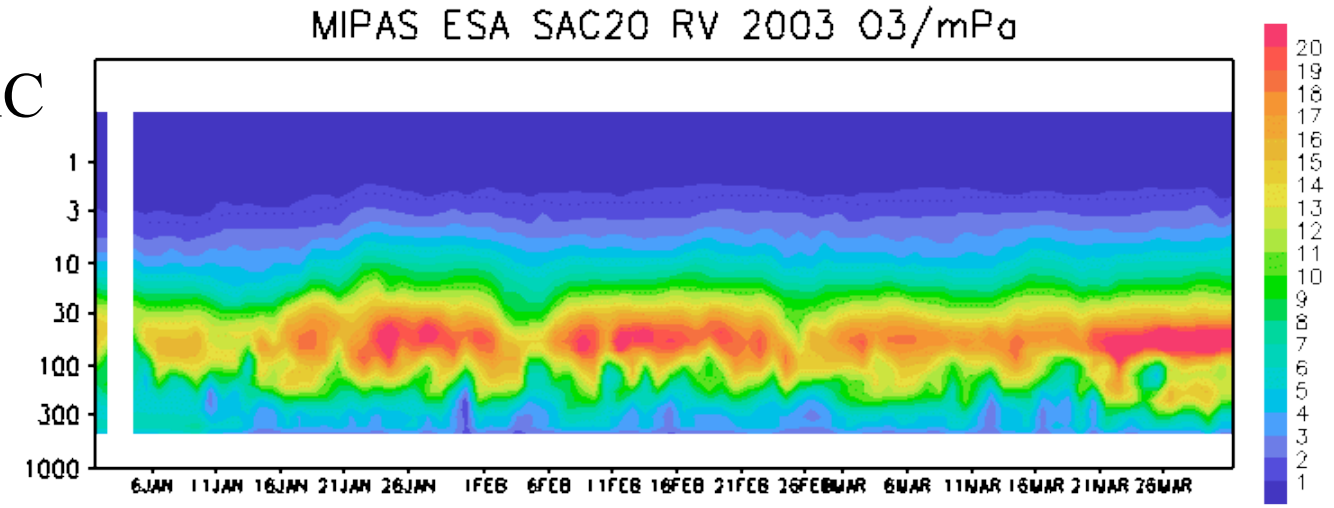


Assimilation experiments

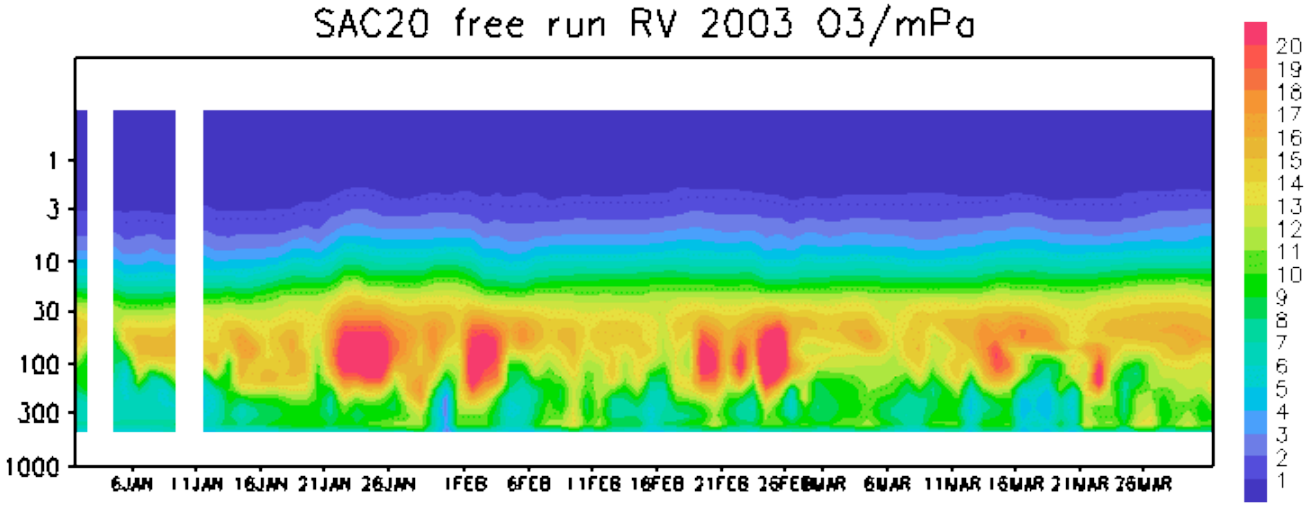
- Assimilation period: 2003-01-01 – 2003-03-31
- 32 VINTERSOL ozone stations (valid altitude range 1000-10hPa)
- SACADA 2.0 with 5 daily iterations, R=5%, B=30% and L_h=600km and L_v=3km for horizontal and vertical correlation
- **MPE/SAC**: MIPAS/SACADA analyses using MIPAS ESA level 2 v4.61 daily products for 2003
- **VIN/SAC**: VINTERSOL/SACADA ozone sonde assimilation
- **free run**: SACADA 2.0 without observational constraints

Results for Reykjavic city

MPE/SAC

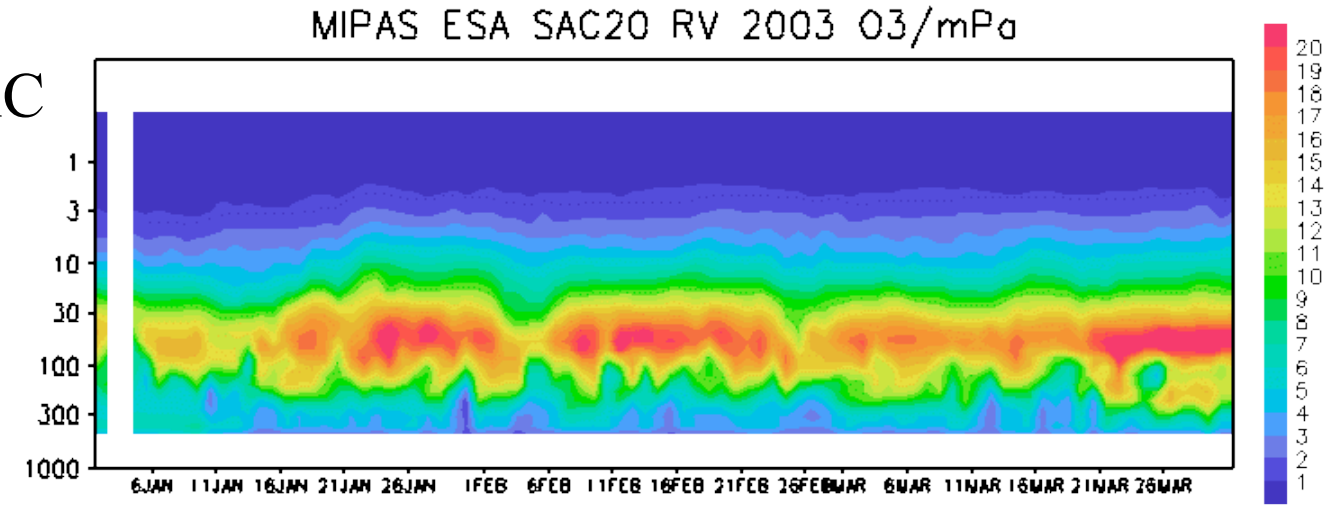


free run

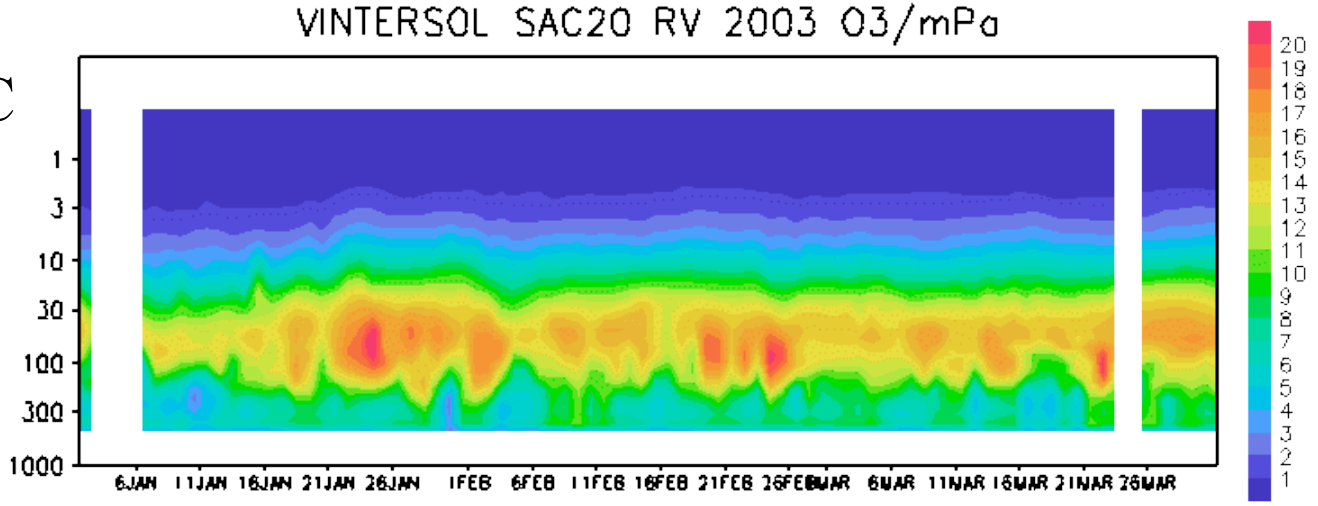


Results for Reykjavic city

MPE/SAC

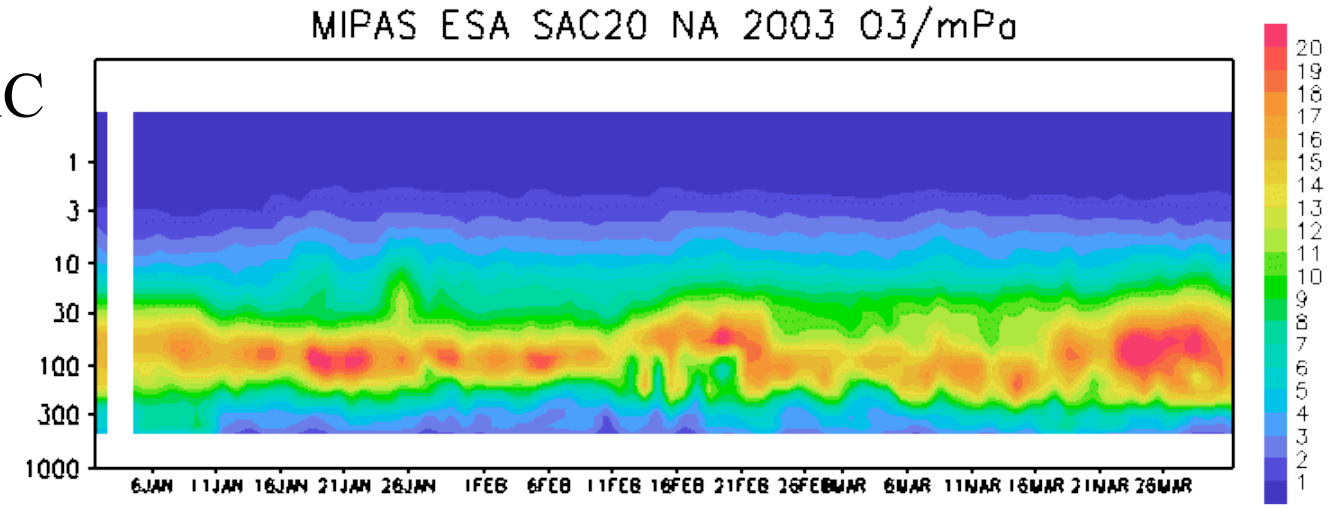


VIN/SAC

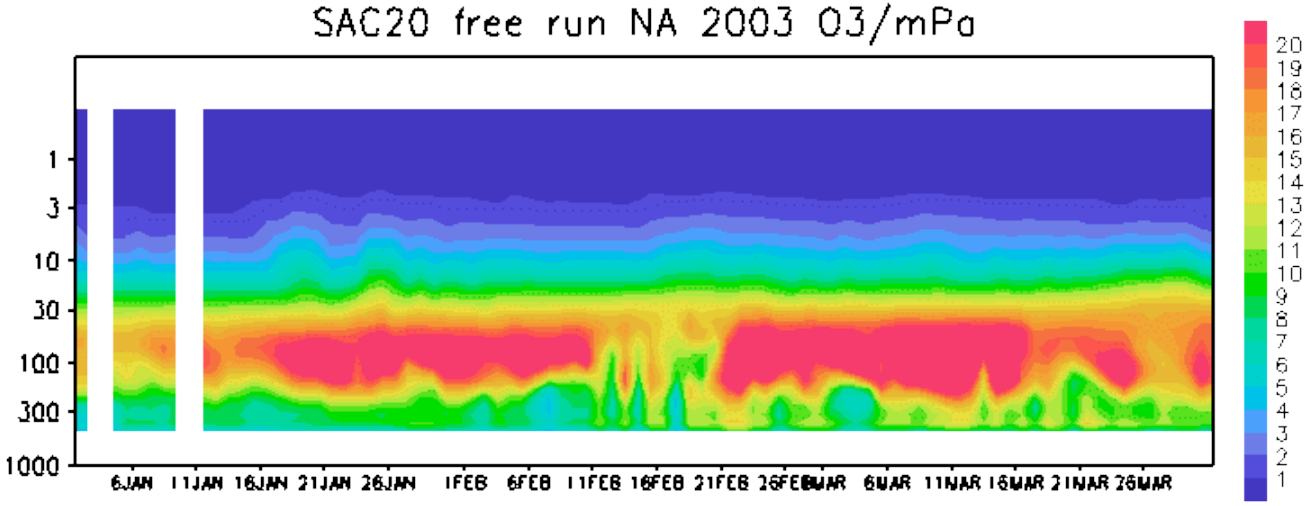


Results for Ny-Ålesund station

MPE/SAC

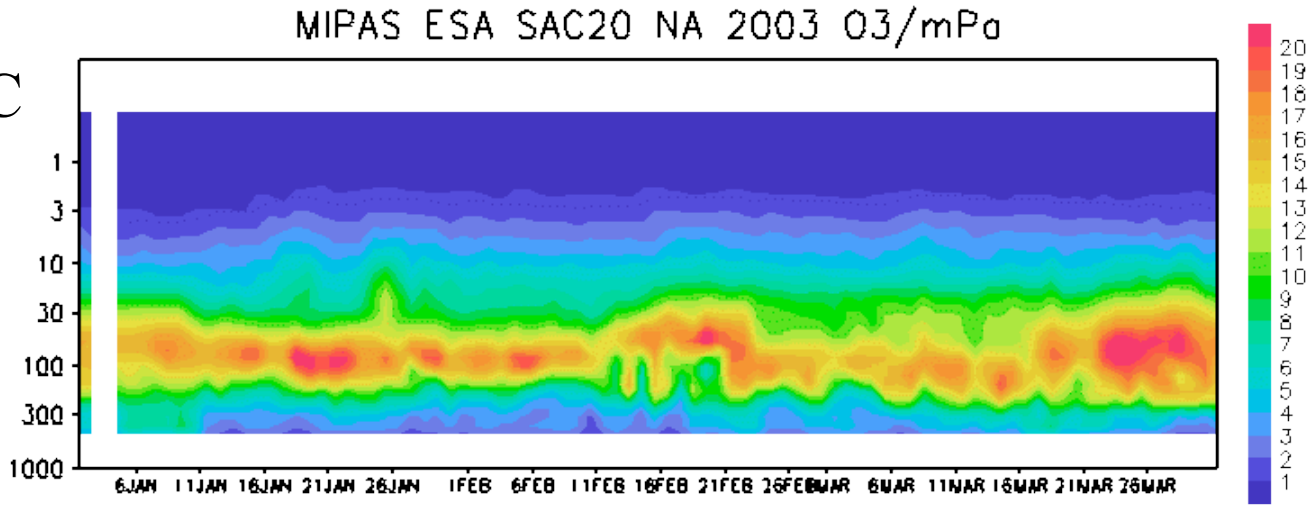


free run

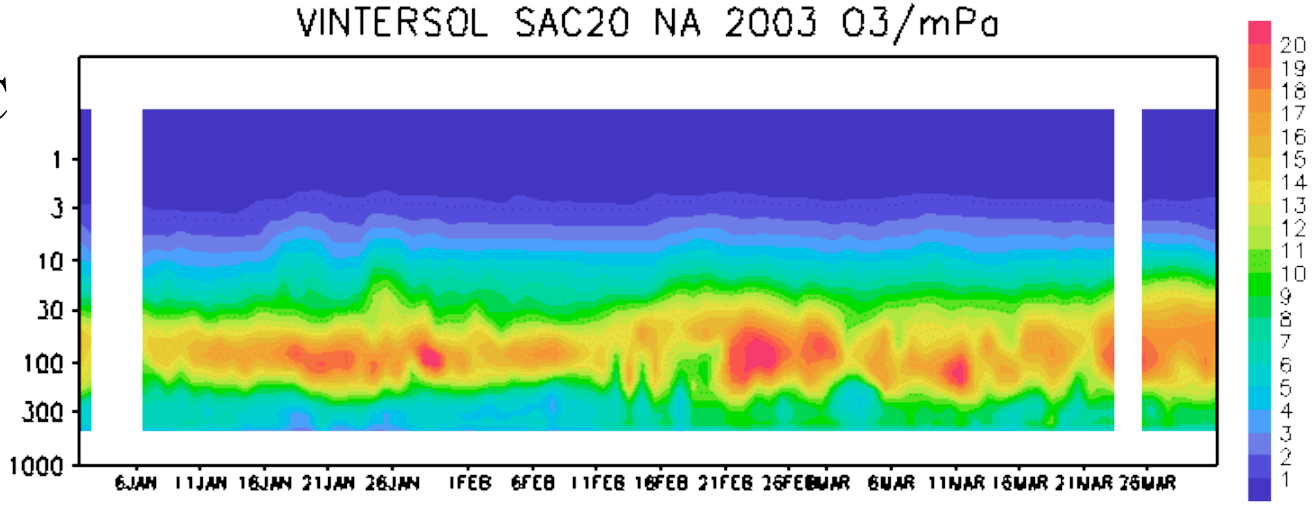


Results for Ny-Ålesund station

MPE/SAC

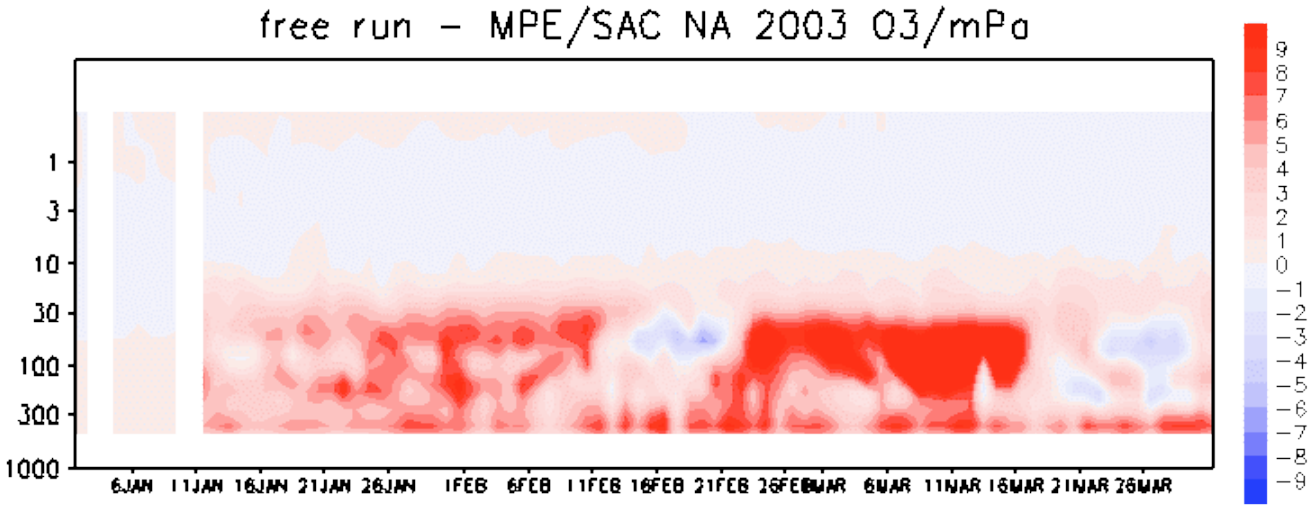


VIN/SAC

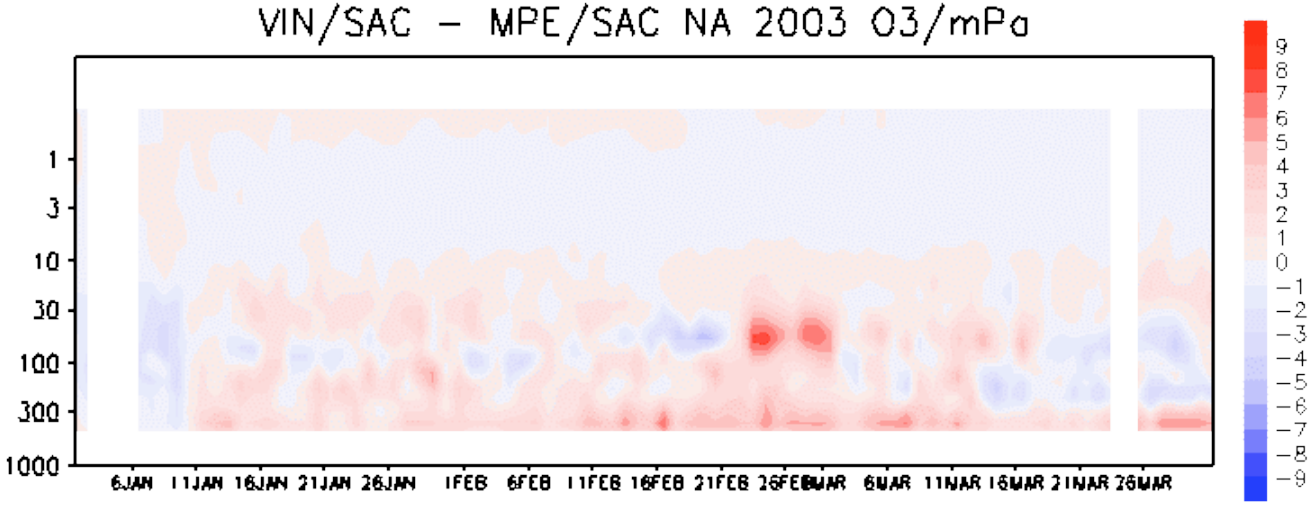


Results for Ny-Ålesund station

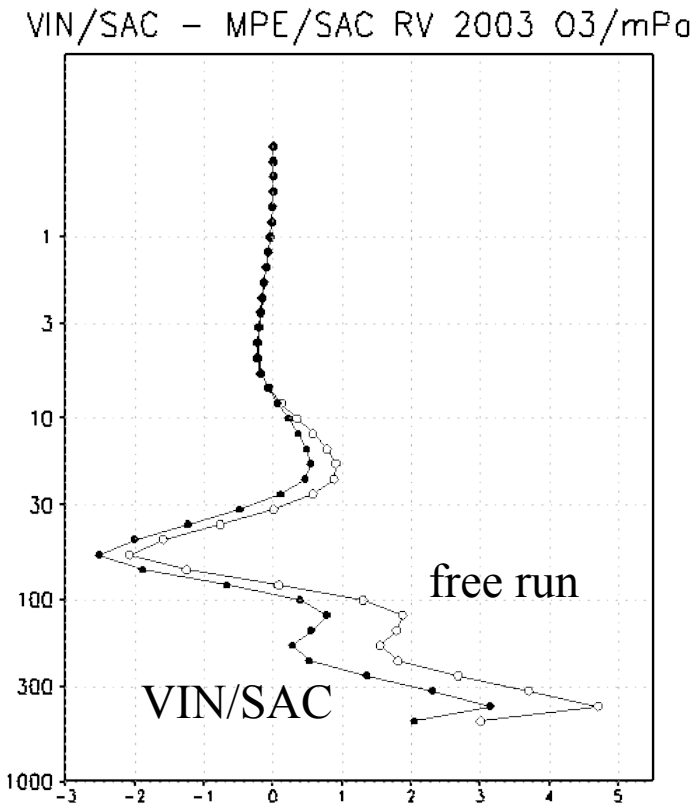
free run

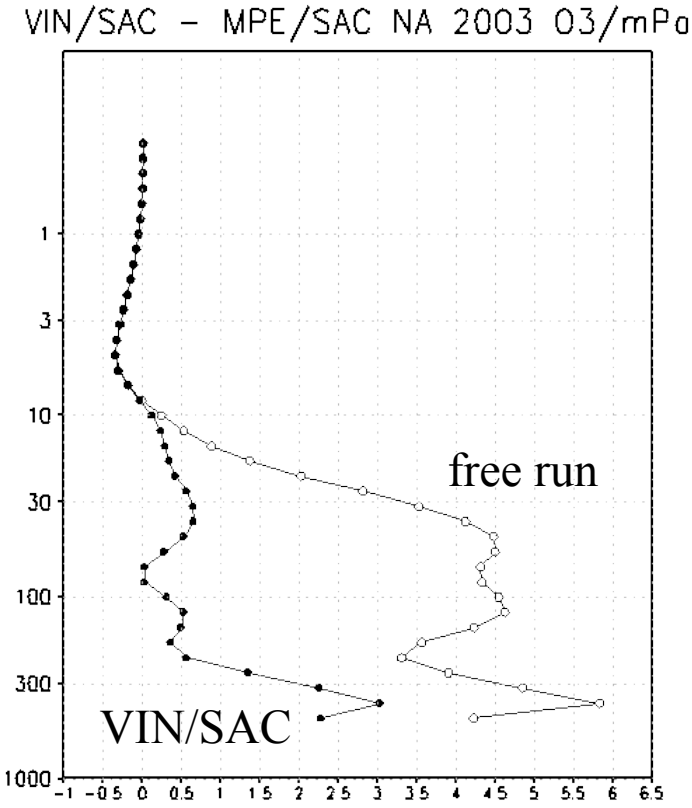


VIN/SAC



Results for Ny-Ålesund station and Reykjavic city





Relevance of Background and Observational errors

- Schwinger, 2006 PhD thesis: parameterize **B** using flow dependent and anisotropic correlations
- Ménard et al., 2000 MWR: tuning of **B** and **R** values using χ^2 test
- Désroziers et al., 2005 QJRMS: diagnosis of **B**, **R** and analysis error

BLUE condition

$x_a = x_{fg} + G\,(y - Hx_{fg})$

$G = BH^T / (HBH^T + R)$ describes impact on analysis

Rational: B and R are i.g. not known but error fields, e.g. FMO, hold information that can be used to better describe a priories.

This study: tuning R, to reduce analysis error, by using (possible) correlation with error tracer field (from 24h ozone tracer forecast)

Not shown: results from analysis of adjoint tracer field. First results show poor correlation with a priories.

Relevance of Background and Observational errors

Estimate 24h Fractional Analysis Error (FAE) and Impact Area (FIA) using multiple analysis cycles with one ozone tracer per sounding station

$FAE = \Sigma \mid x_r - x_{mpe} \mid / x_{mpe}$ sum Fractional Impact Error over each layer for model time t=24:00 with varying R

$FIA = \Sigma \mid x_R - x_{tracer} \mid / x_{tracer}$ sum Fractional Impact Area over each layer for model time t=24:00 with R=5% fixed

x_r = 24h ozone tracer analysis, varying R values [1– 30%]

x_R = 24h ozone tracer analysis, fixed R [=5%]

x_{mpe} = MIPAS/SACADA analysis results (reference)

x_{tracer} = 24h ozone tracer forecast (reference)

Time weigthing: $FAE' = FAE * t_{obs}/T_{24h}$

R minimum * FIA correlation analysis

step-0: calculate FAE for different obs. errors R from 24h ozone tracer analysis compared to reference data (here, MPE/SAC)

step-1: determine R minimum value, i.e. R that gives minimum FAE

step-2: derive FIA from 24h ozone tracer analysis compared to ozone tracer

step-3: linear fit of Rmin values to FIA numbers using Rmin error (step-0)
(use relative Rmin error = 1 – (Rmax – Rmin)/Rmax for weighting)

step-4: use fit function R(FIA) with fit parameters (a,b) and actual FIA from a single ozone tracer run for routine assimilation of ozone sonde data

step-4 can be easily integrated with standard routine 4dvar cycle!

This study: 12 day period experiment with VINTERSOL ozone sonde data

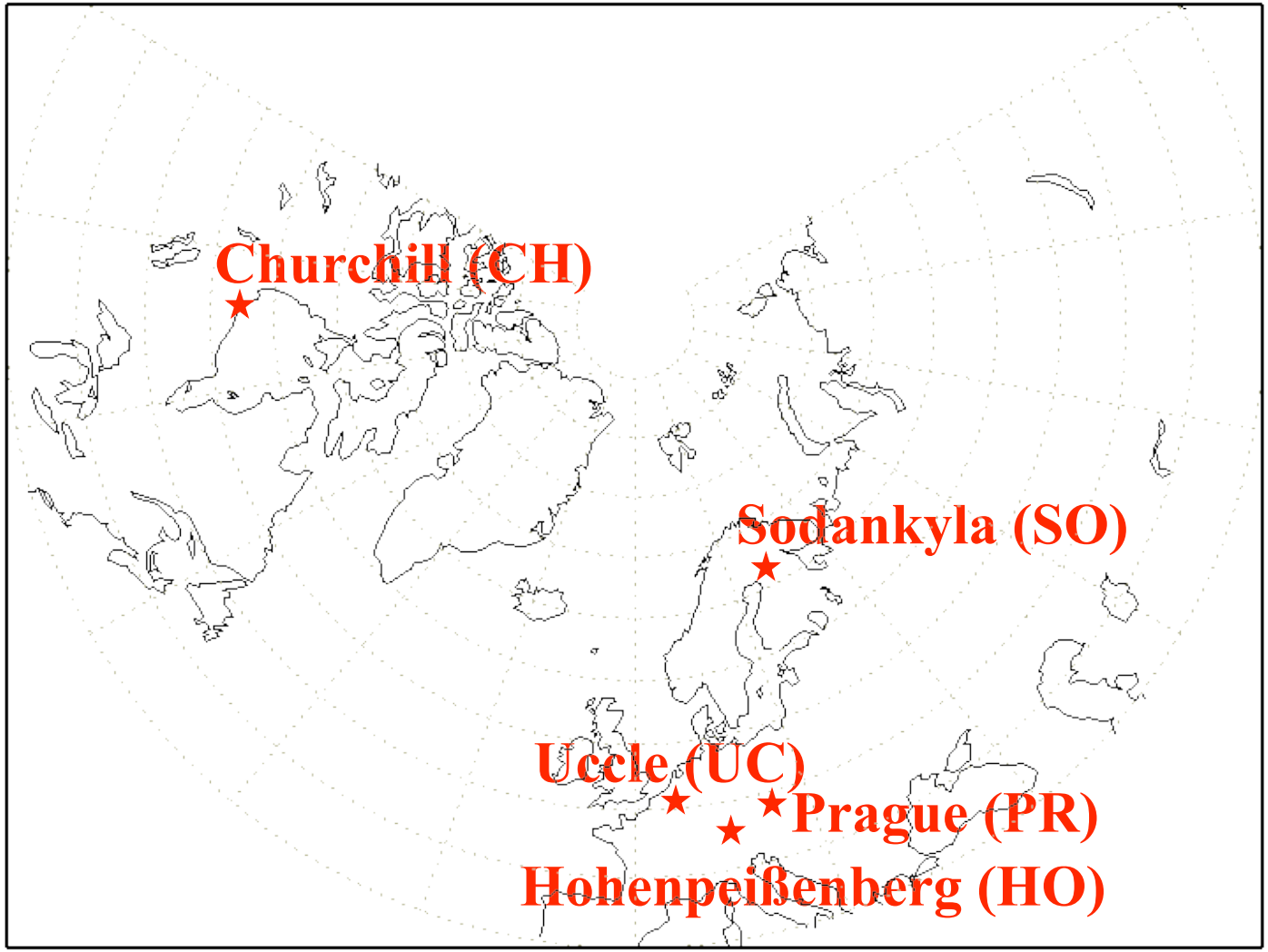
Application of tuned R-values to test episode Feb 5 – 16th, 2003

Data base for correlation sample

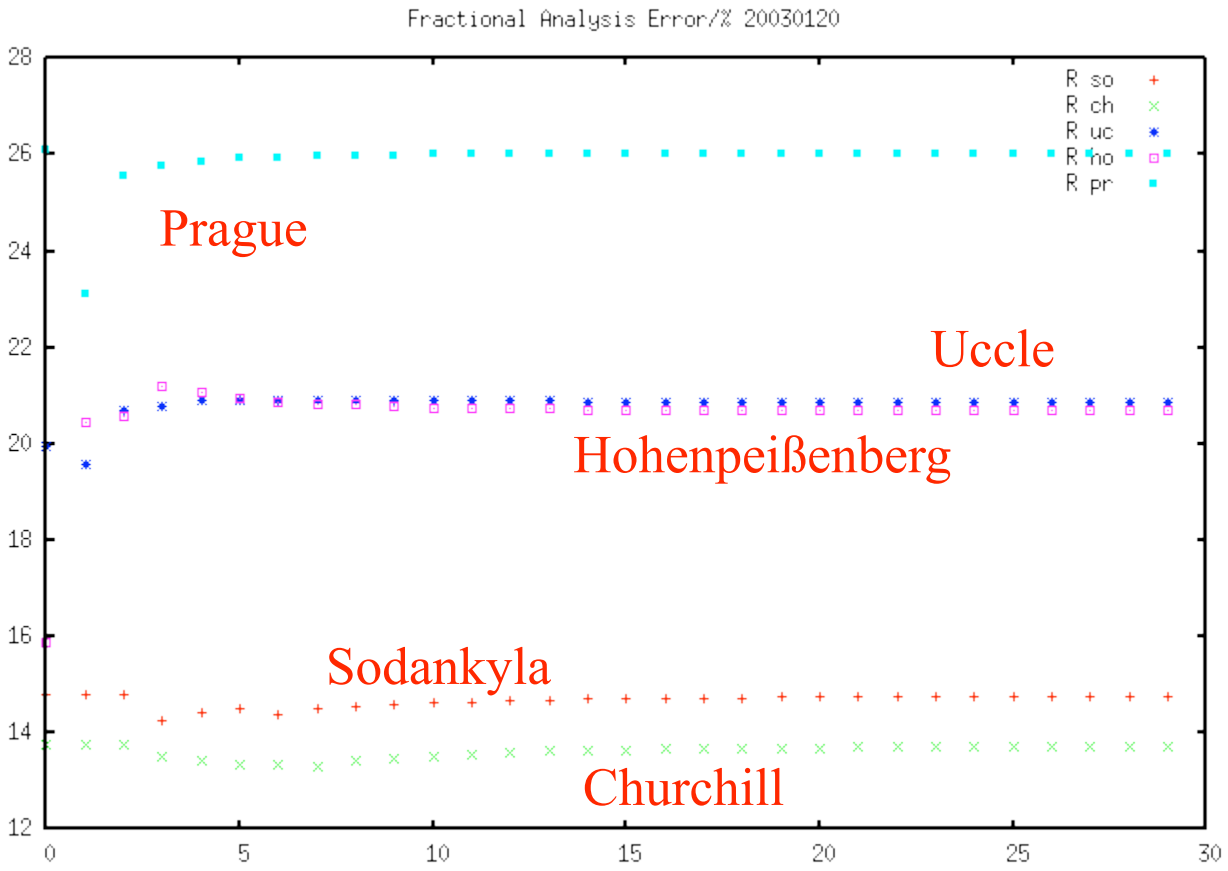
- 5 sample stations: SO, CH, UC, HO, PR
- 3 sample dates: 2003-01-20, 02-05, 03-12
- 5 sample model layers: 160, 116, 56, 26, 16 hPa
- -> #75 data pairs

Assimilation experiments

- 32 VINTERSOL ozone stations (valid altitude range 1000-10hPa)
- **MPE/SAC**: MIPAS/SACADA analyses as reference with fixed R=5%
- **VIN/SAC**: VINTERSOL/SACADA analyses as reference with fixed R=5%
- **R tuned**: VINTERSOL/SACADA with tuned R-values

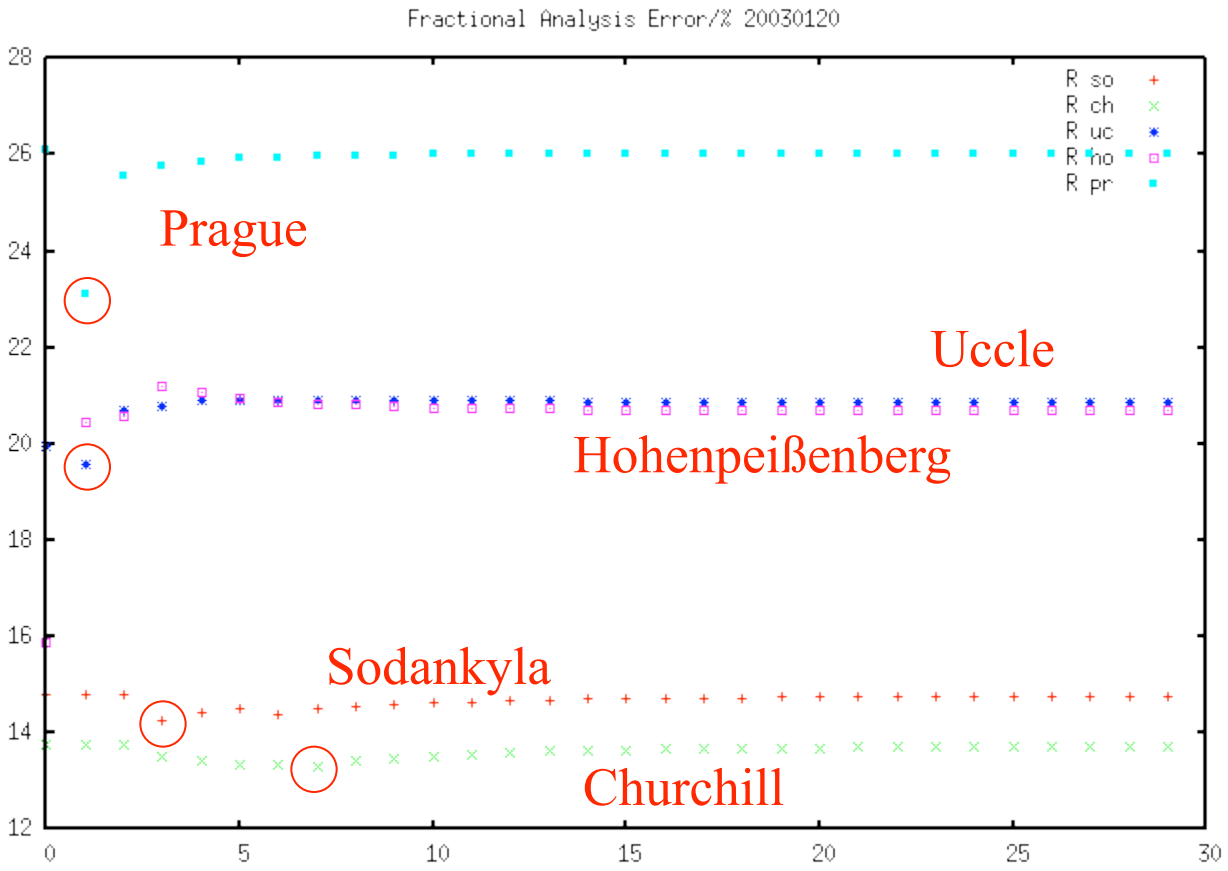

Churchill (CH)
Sodankyla (SO)
Uccle (UC)
Prague (PR)
Hohenpeißenberg (HO)

Fractional Analysis Error for 5 sample stations

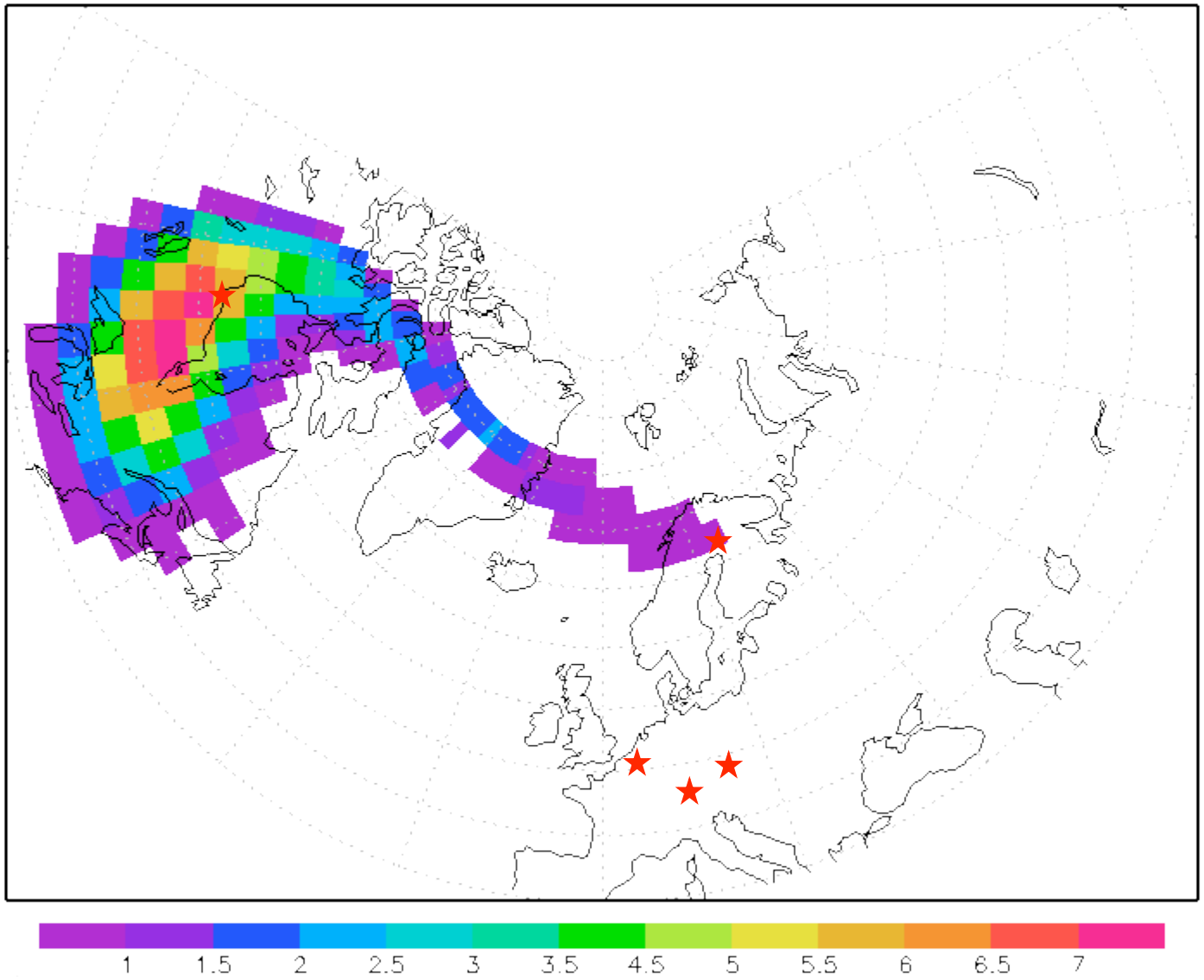


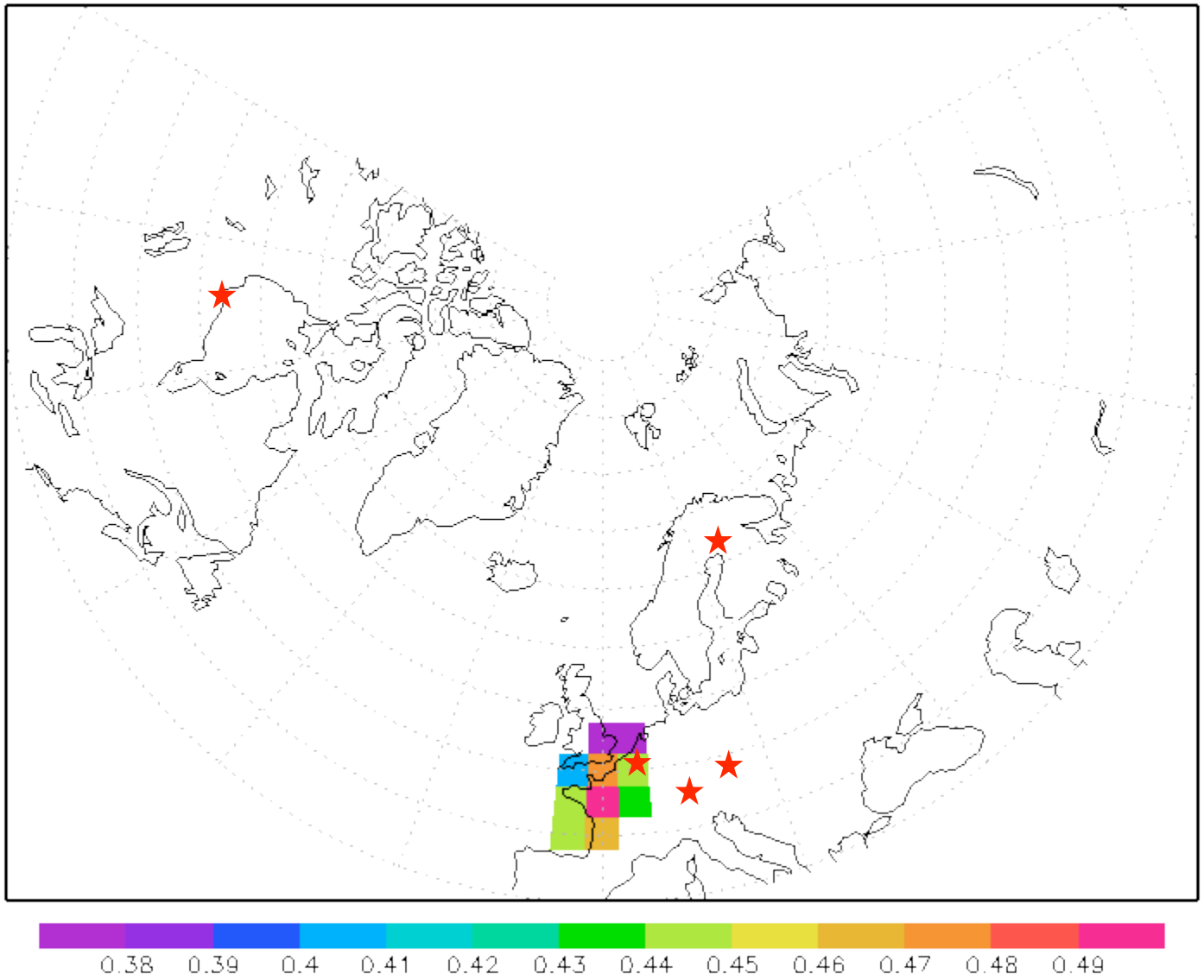
20030102
56 hPa

Fractional Analysis Error for 5 sample stations

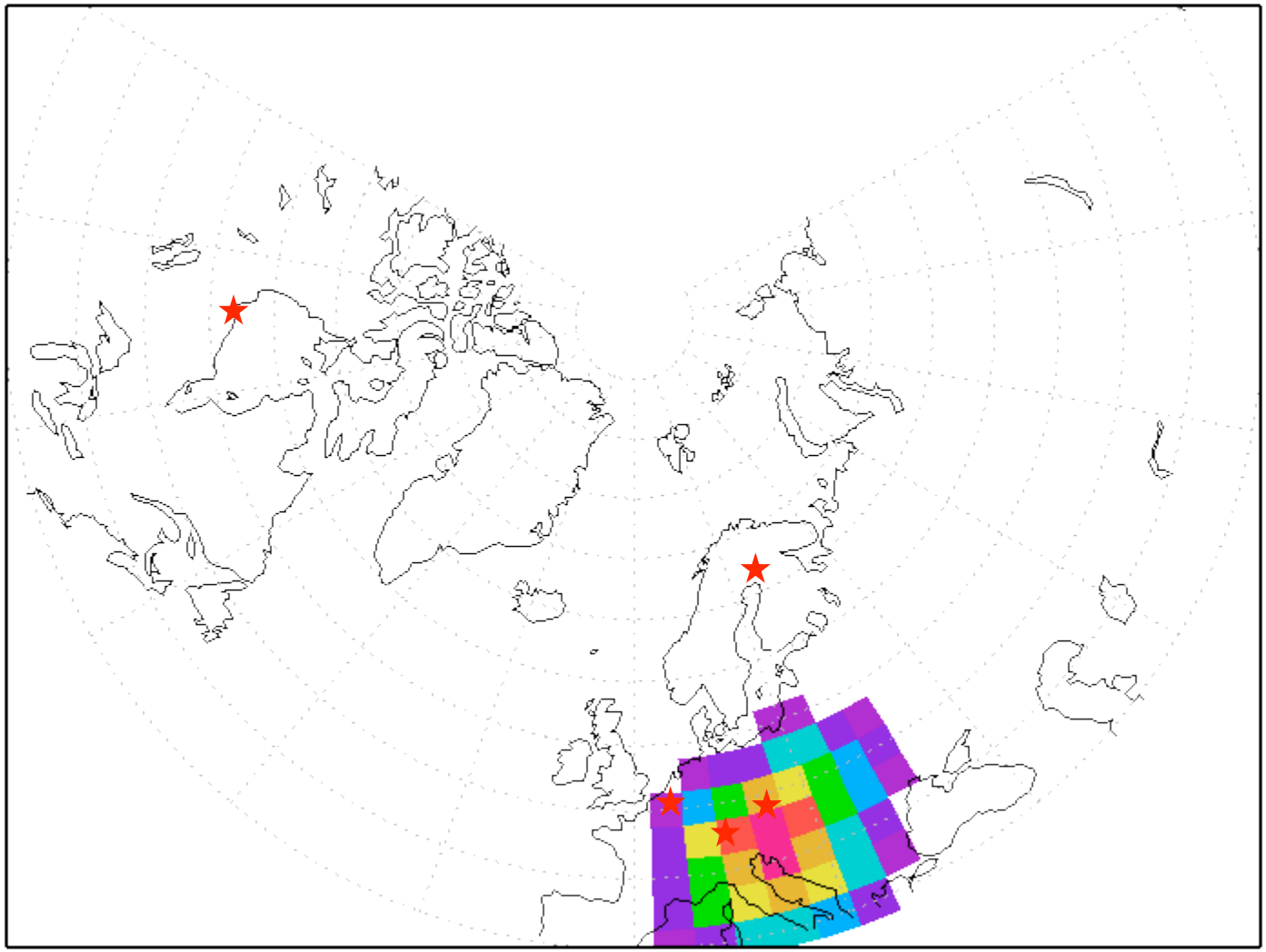


20030102
56 hPa

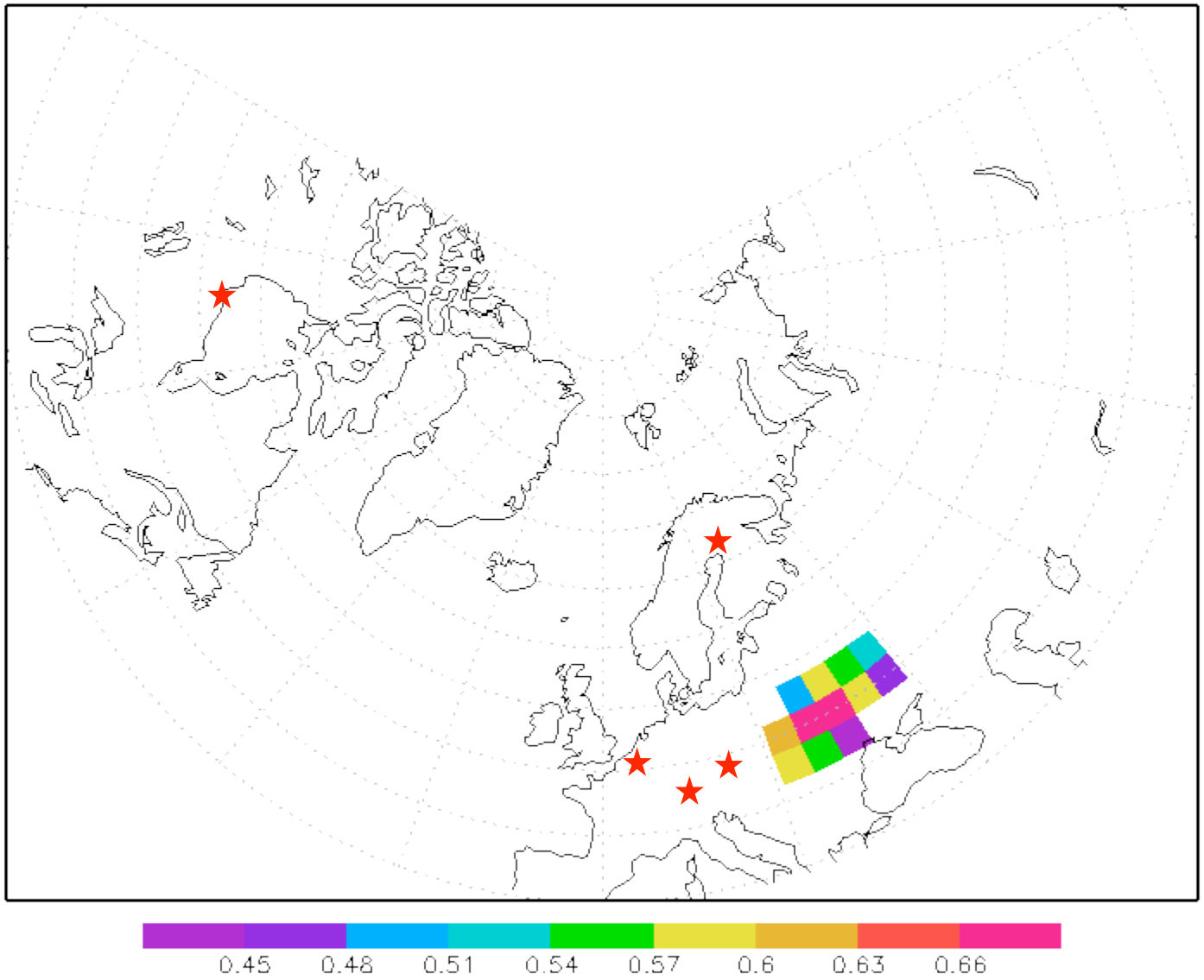

VINTERSOL Churchill 56hPa FIA/% 2003-01-20
1
1.5
2
2.5
3
3.5
4.5
5
5.5
6
6.5
7


VINTERSOL Uccle 56hPa FIA/% 2003-01-20
0.38 0.39 0.4 0.41 0.42 0.43 0.44 0.45 0.46 0.47 0.48 0.49

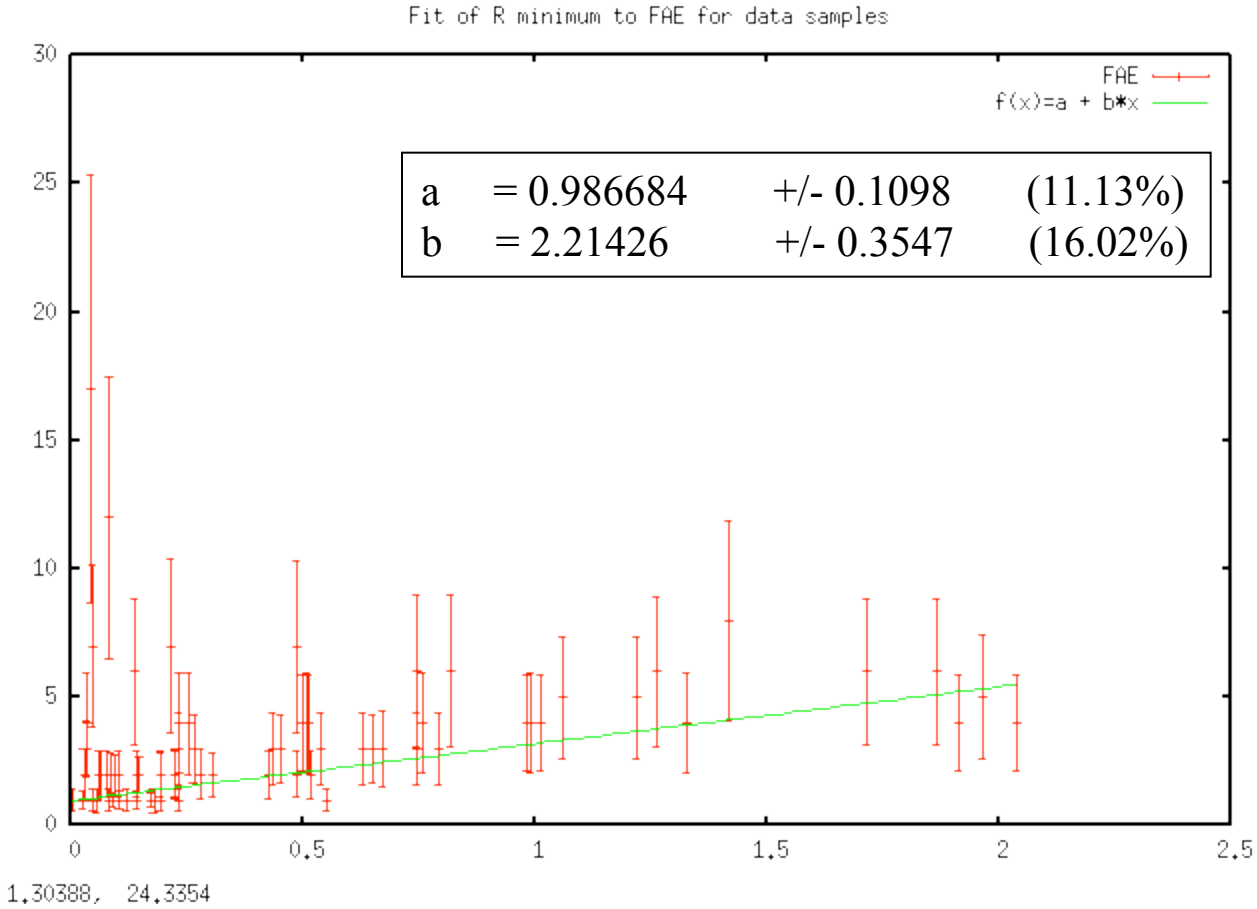
VINTERSOL Hohenpeissenberg 56hPa FIA/% 2003-01-20



VINTERSOL Prague 56hPa FIA/% 2003-01-20



Results from correlation analysis



Application of tuned R-values to test episode Feb 5 – 16th, 2003

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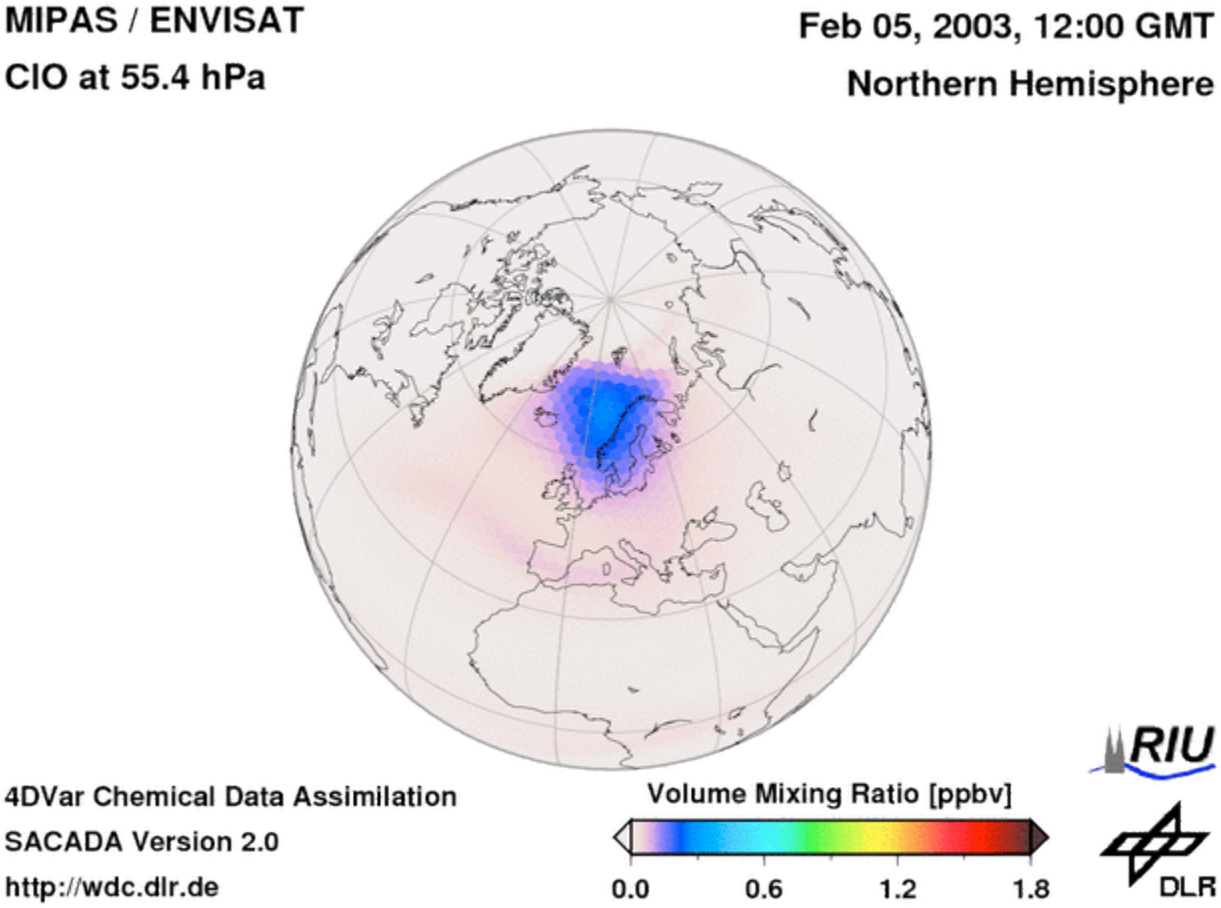
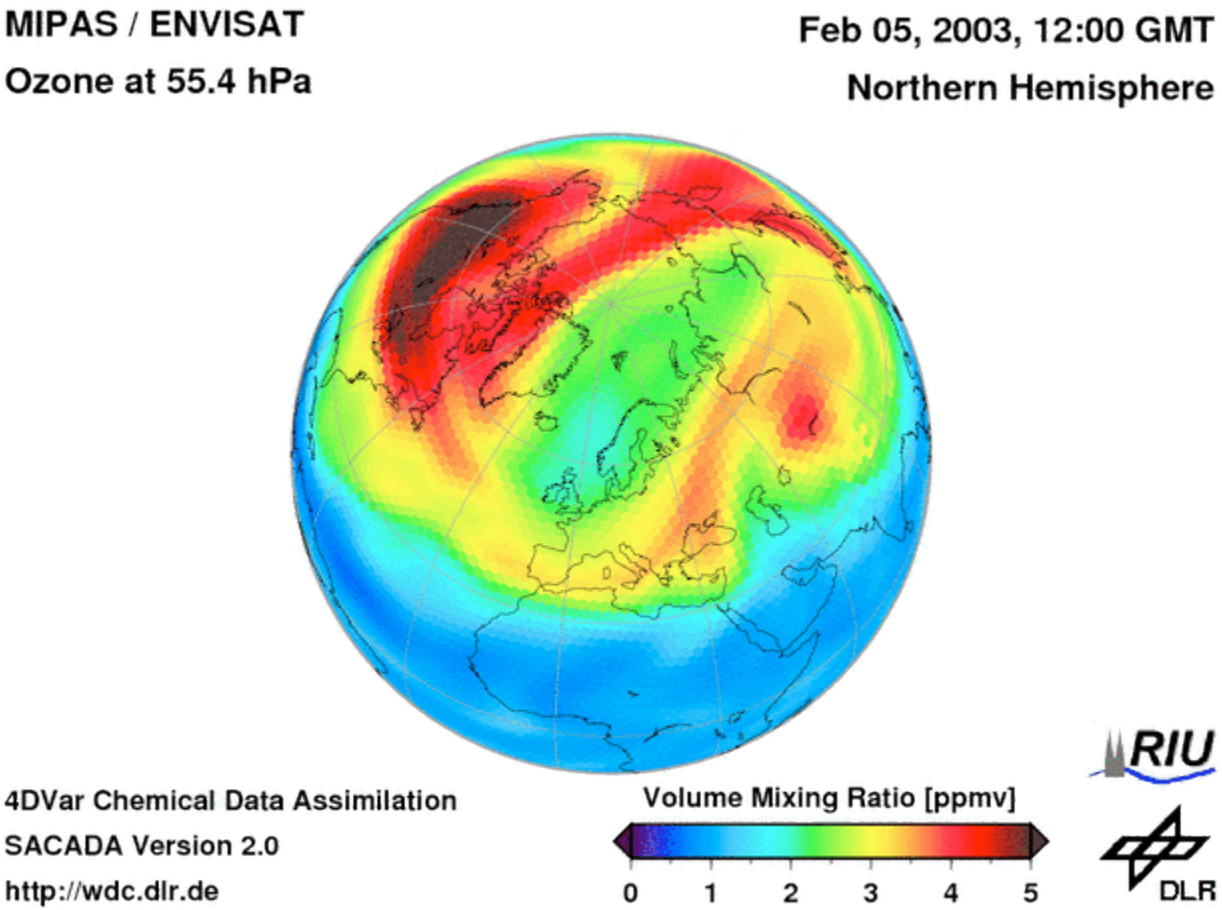
- **VIN/SAC**: VINTERSOL/SACADA analyses as reference with fixed R=5%
- **R tuned**: VINTERSOL/SACADA with tuned R-values

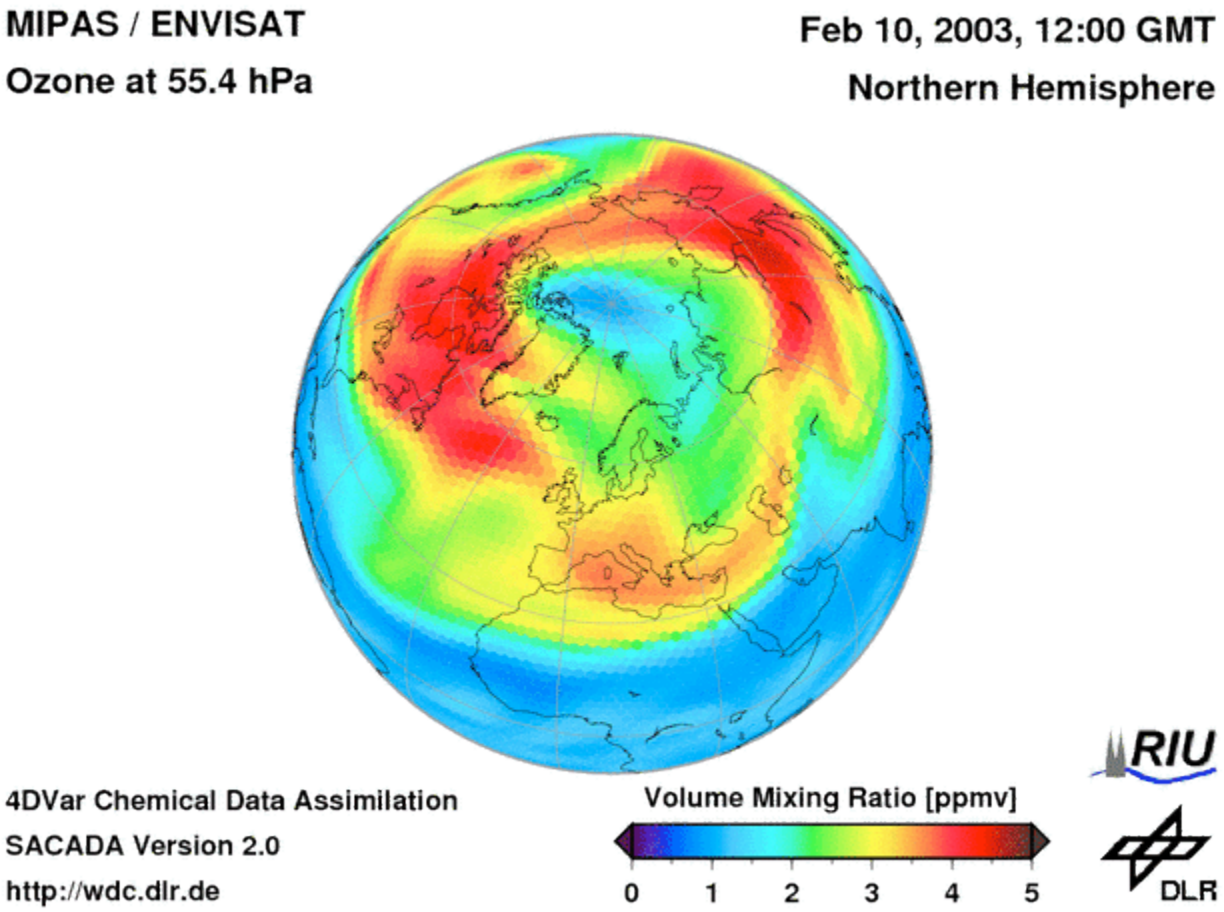
Synoptic situation in 56hPa on Feb 5th



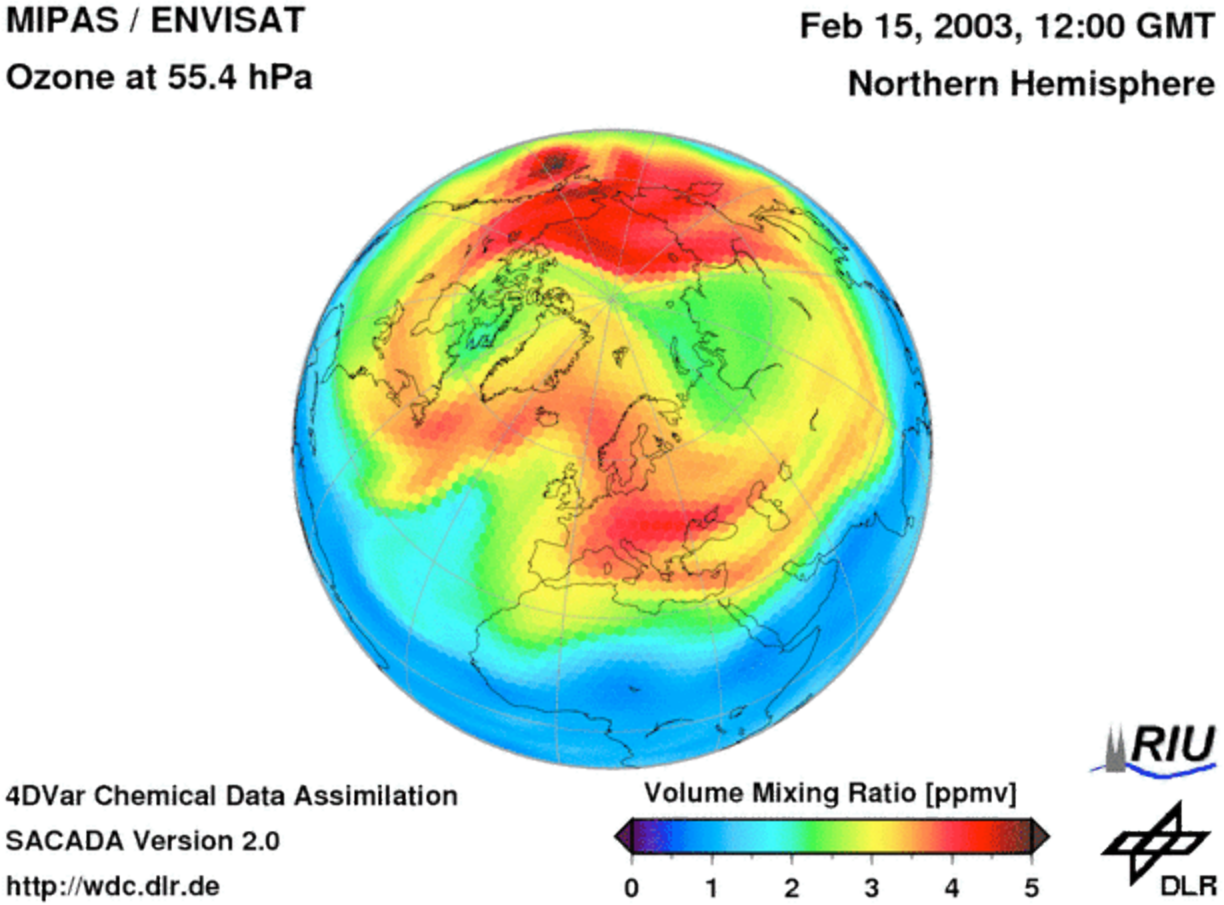
Strong chemical O3 depletion d.t. very low temp. over NE



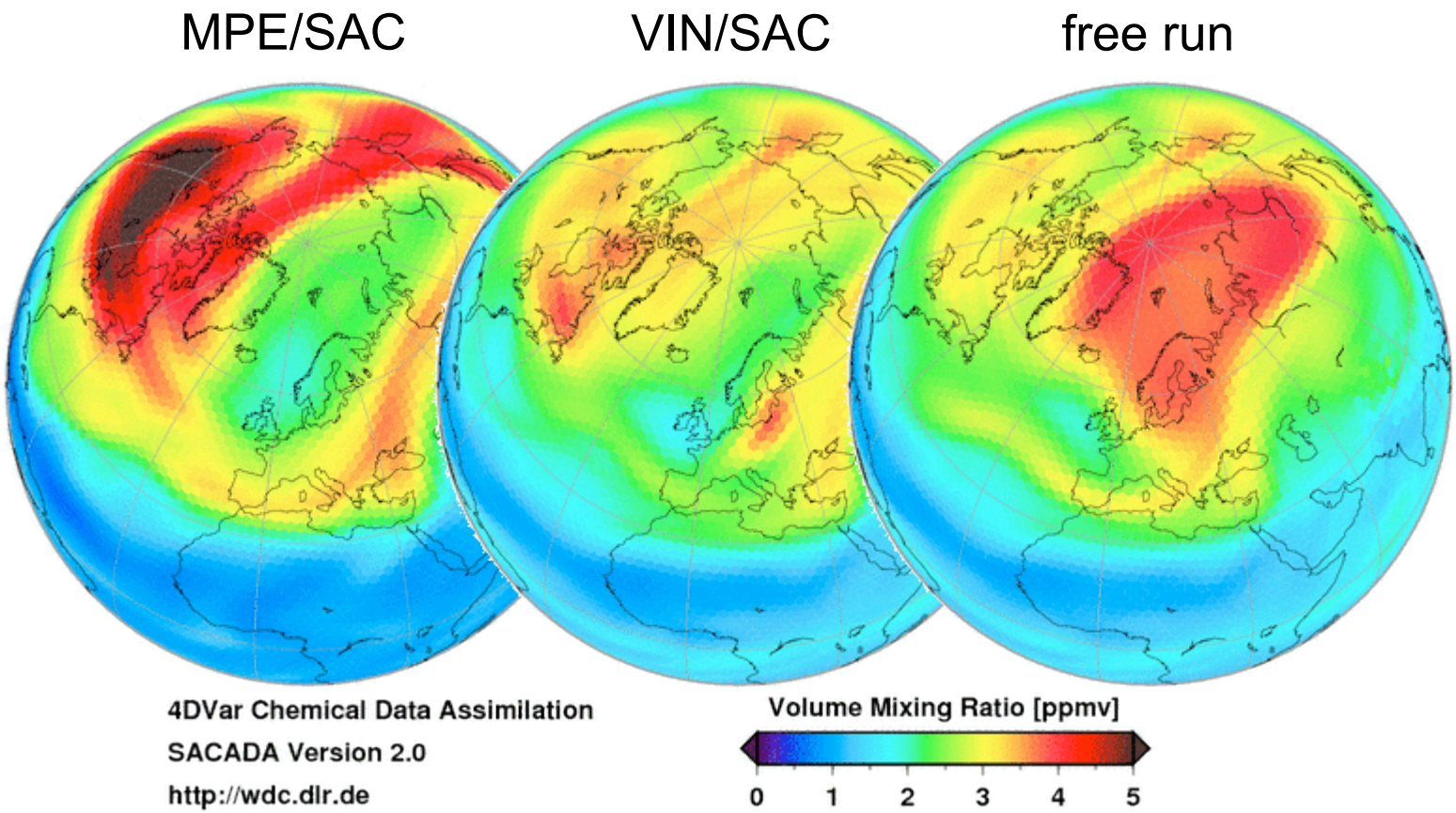
further cooling and…



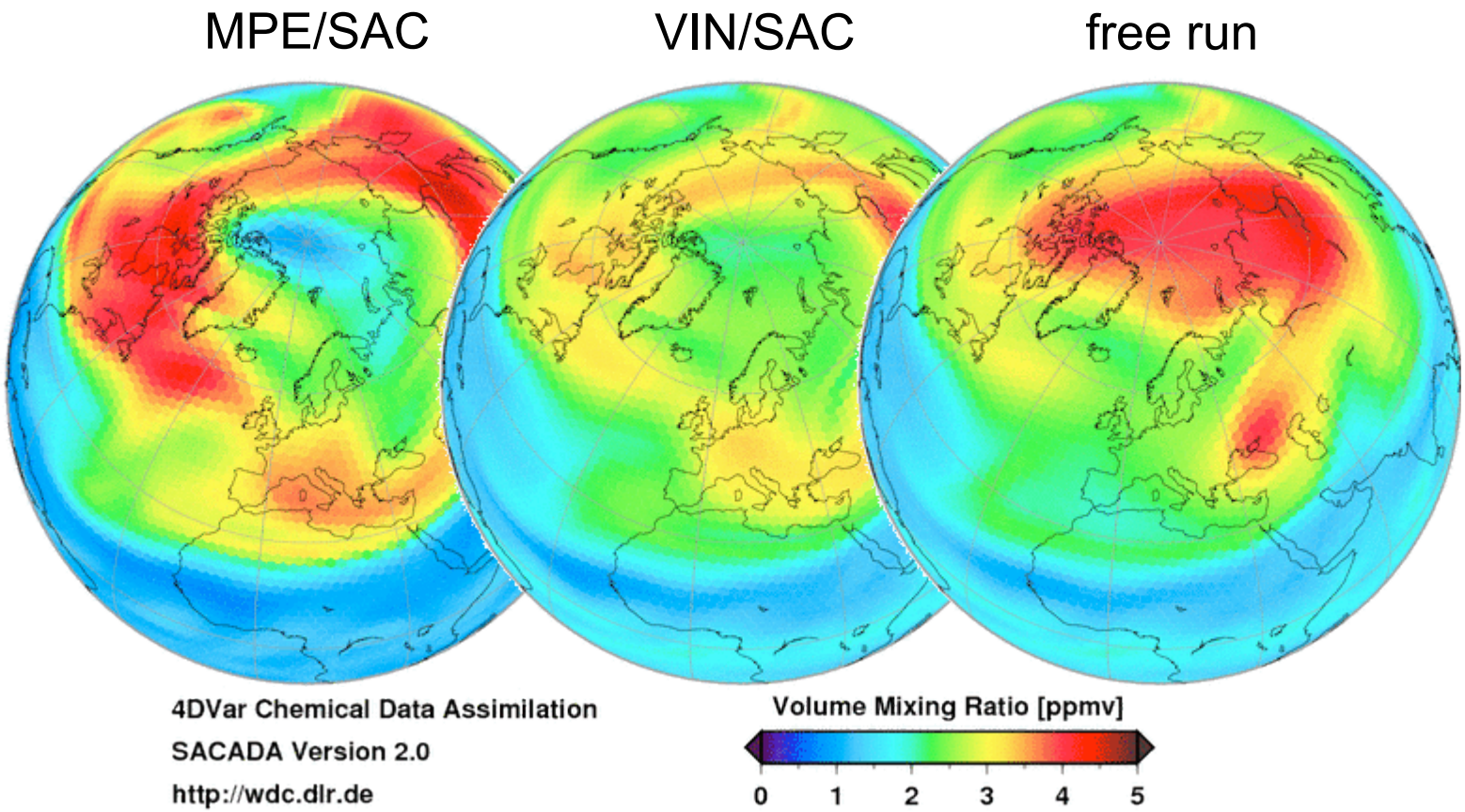
…subsequent minor warming



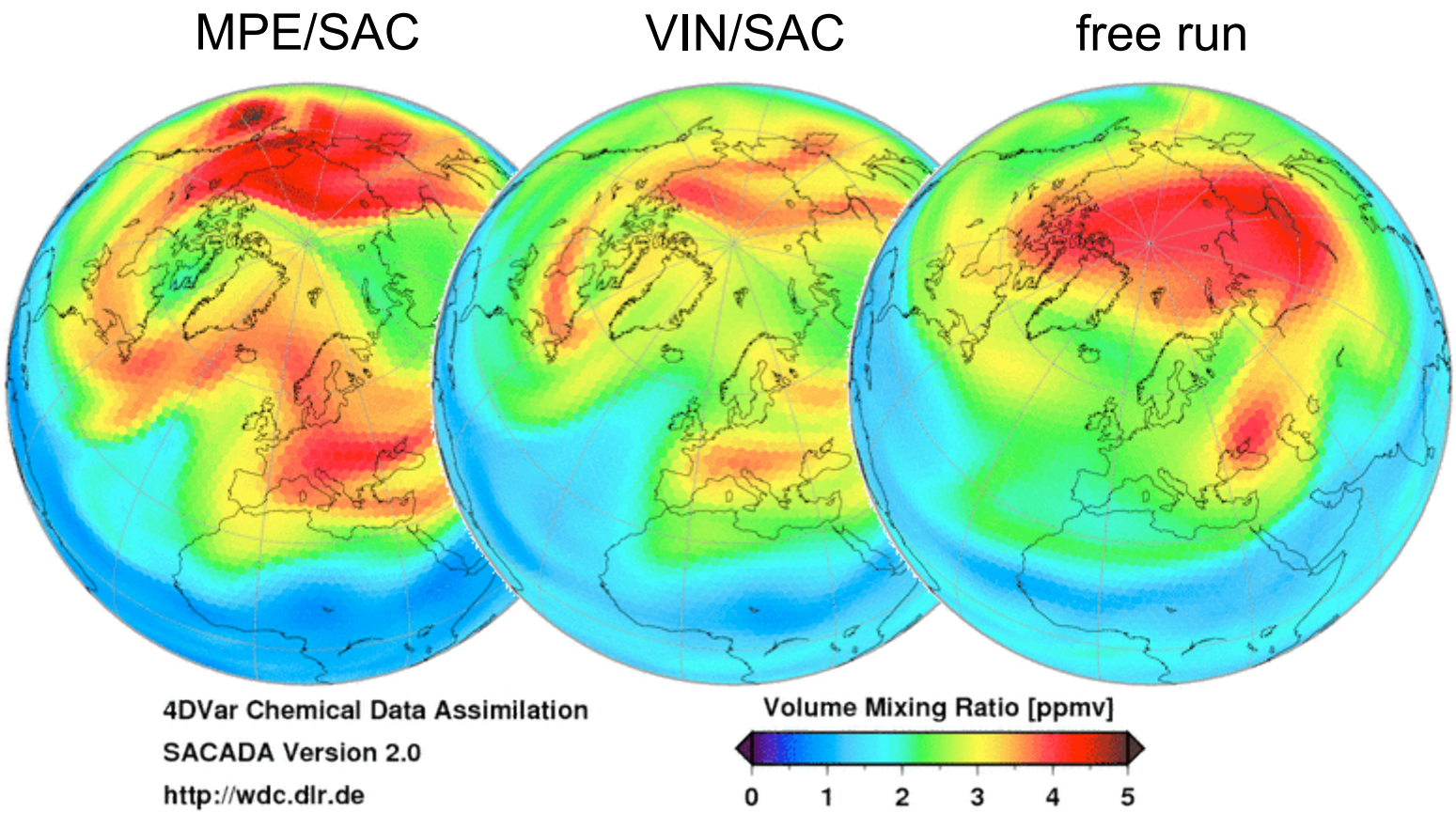
Results of assimilation experiments



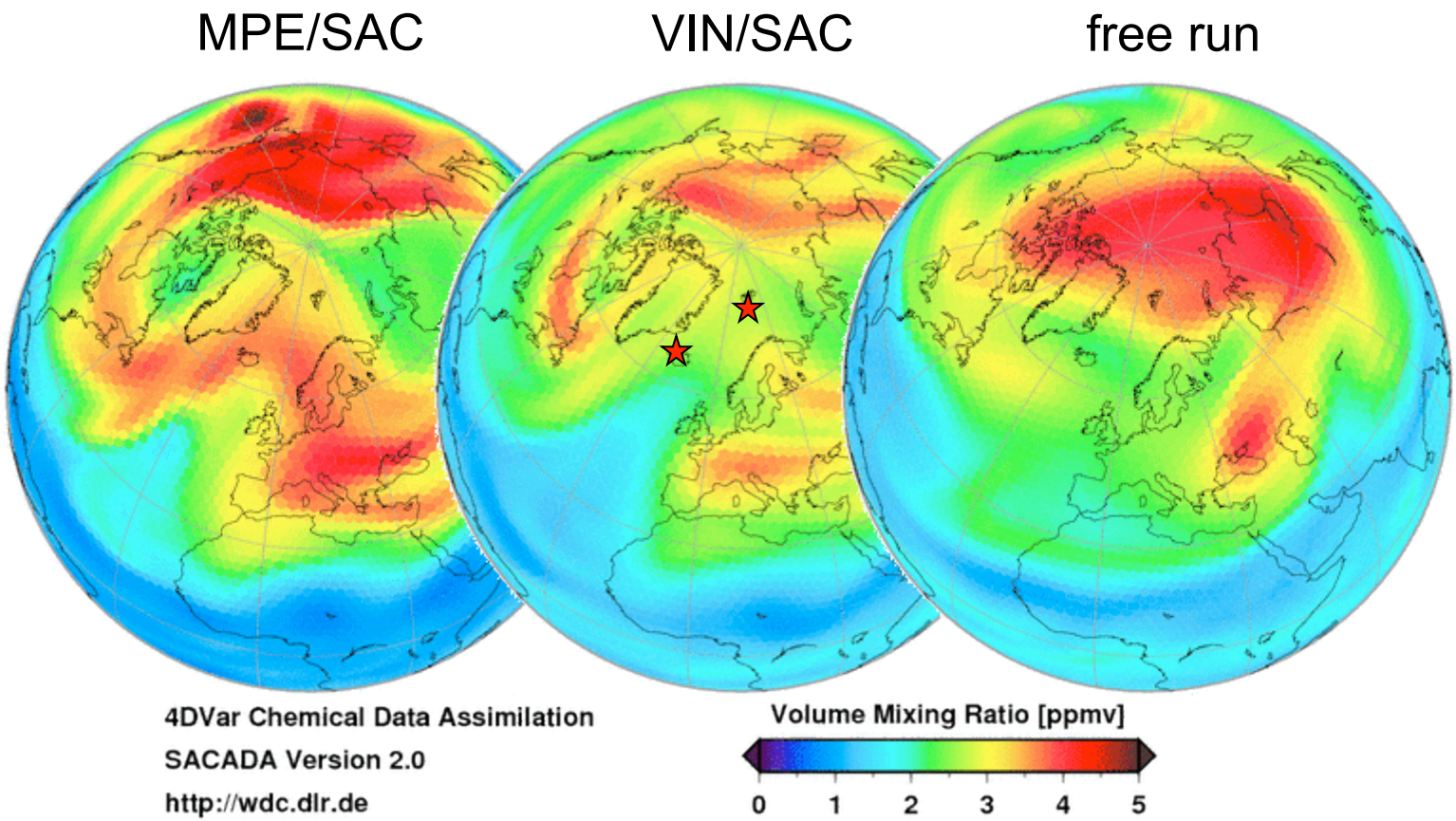
Results of assimilation experiments



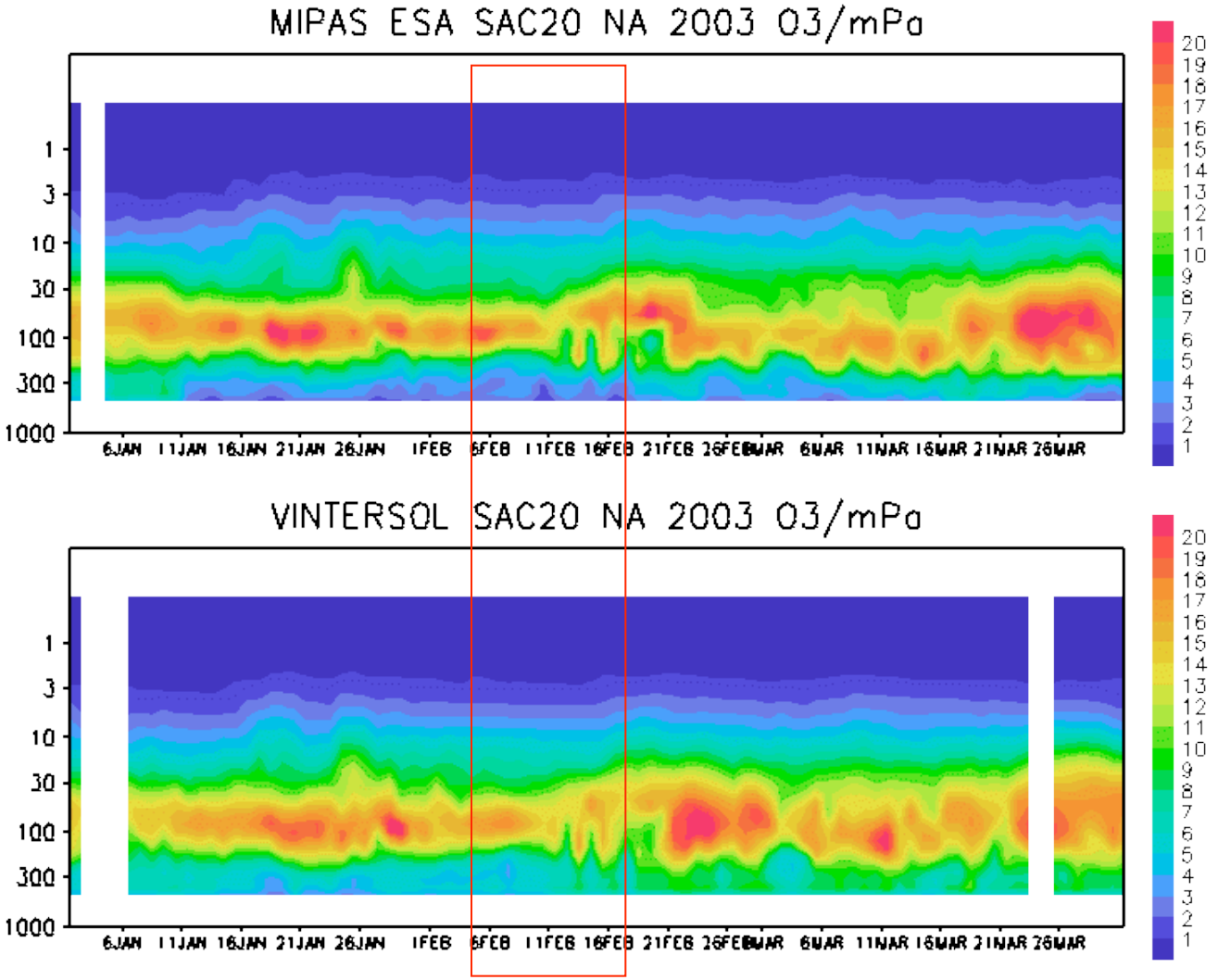
Results of assimilation experiments



Results of assimilation experiments



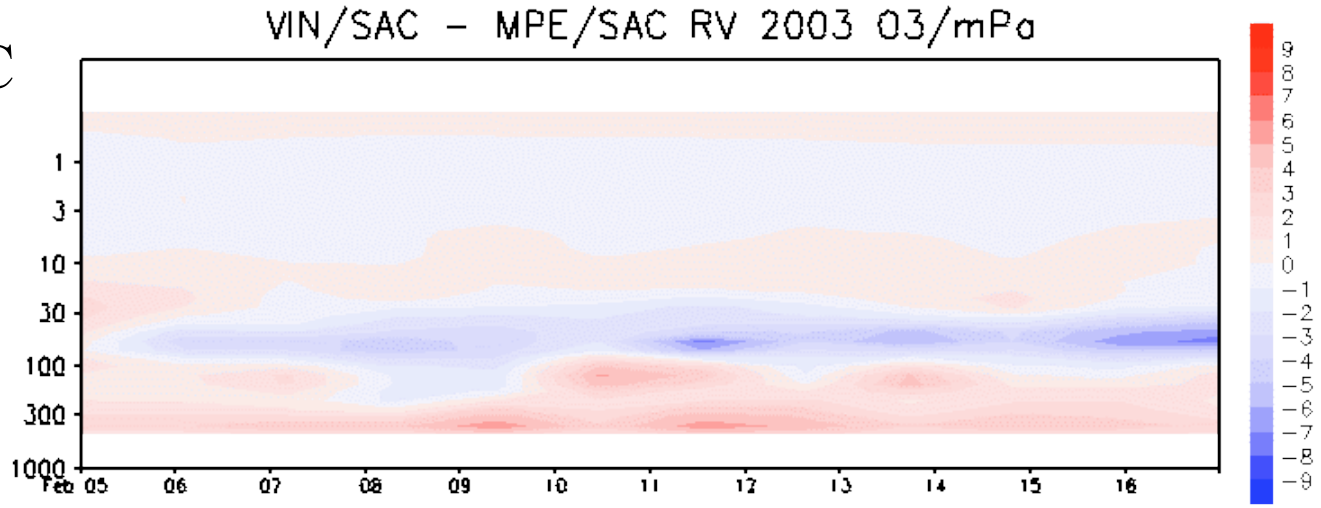
Test episode for ‘tuned’ observational error (R)



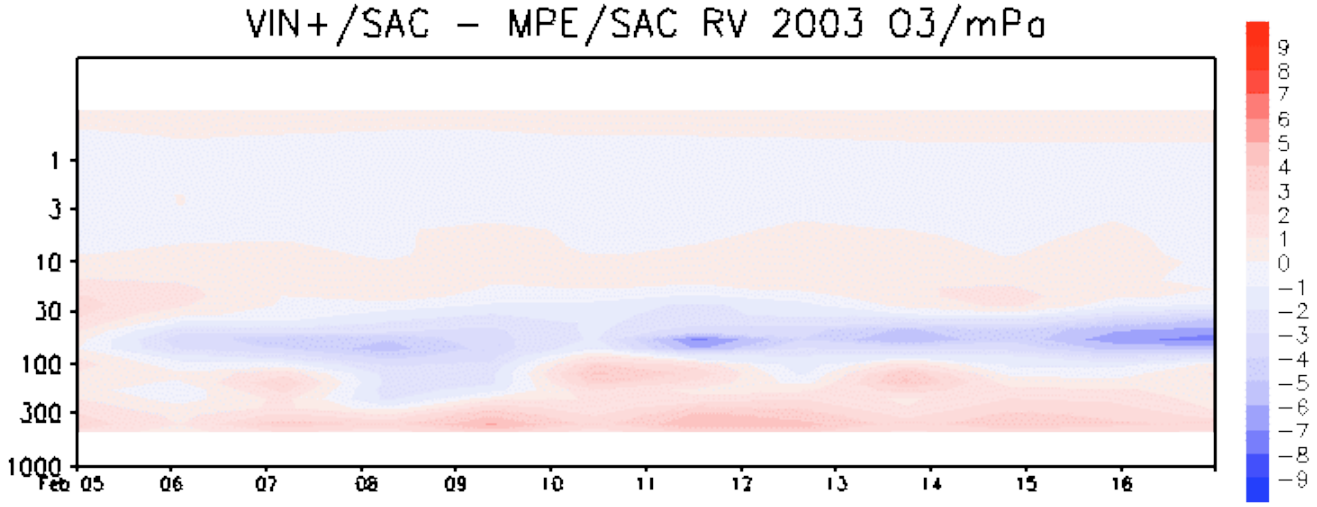
Feb 5 – 16

Results for Reykjavic city

VIN/SAC

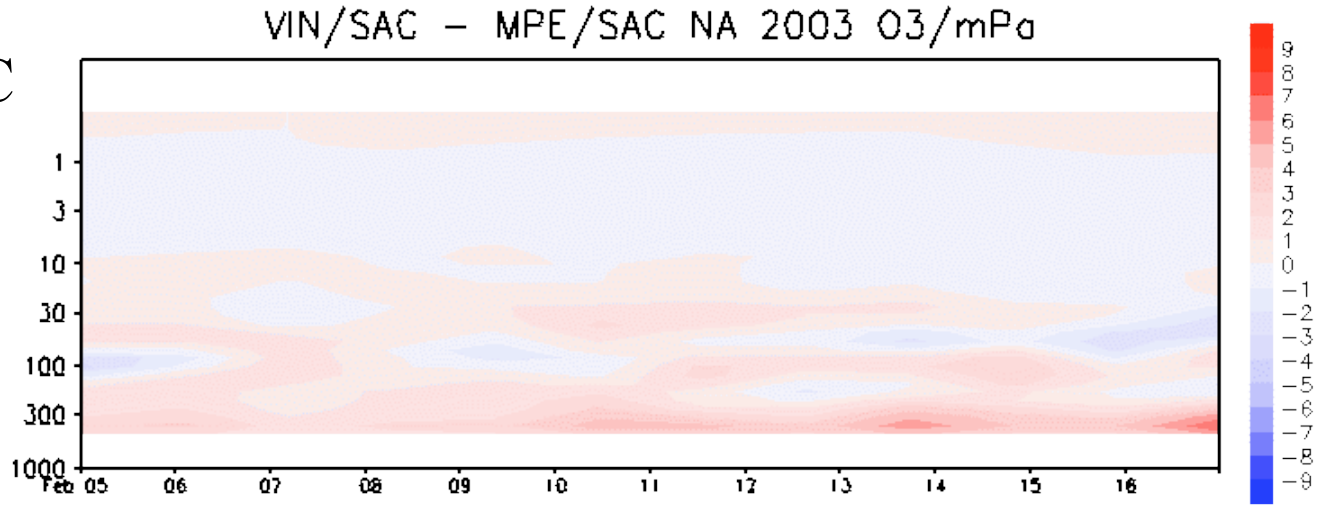


R tuned

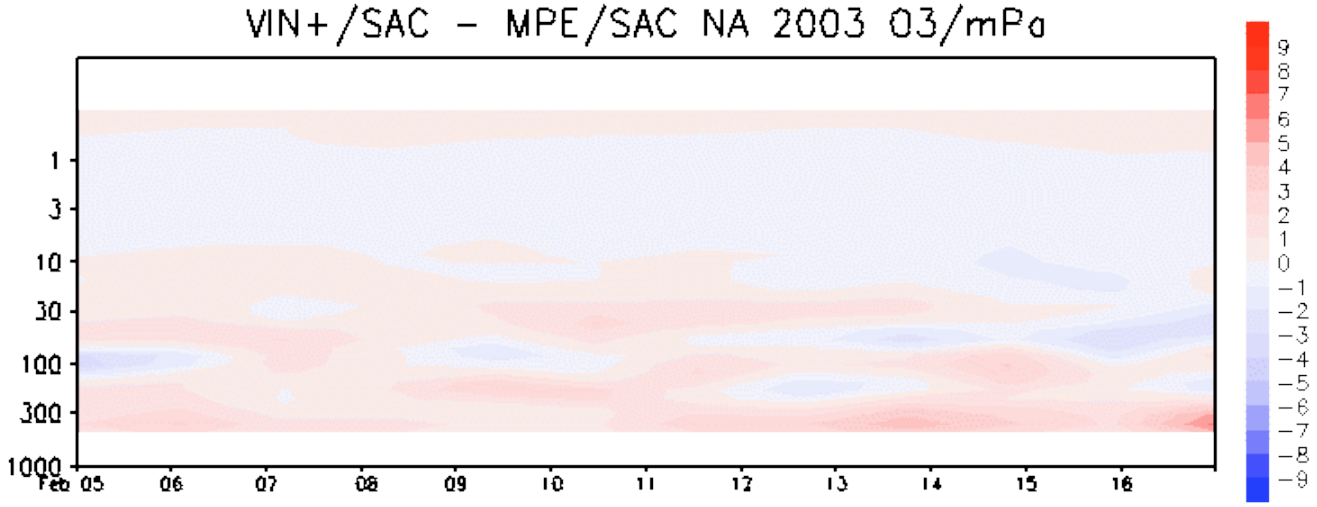


Results for Ny-Ålesund station

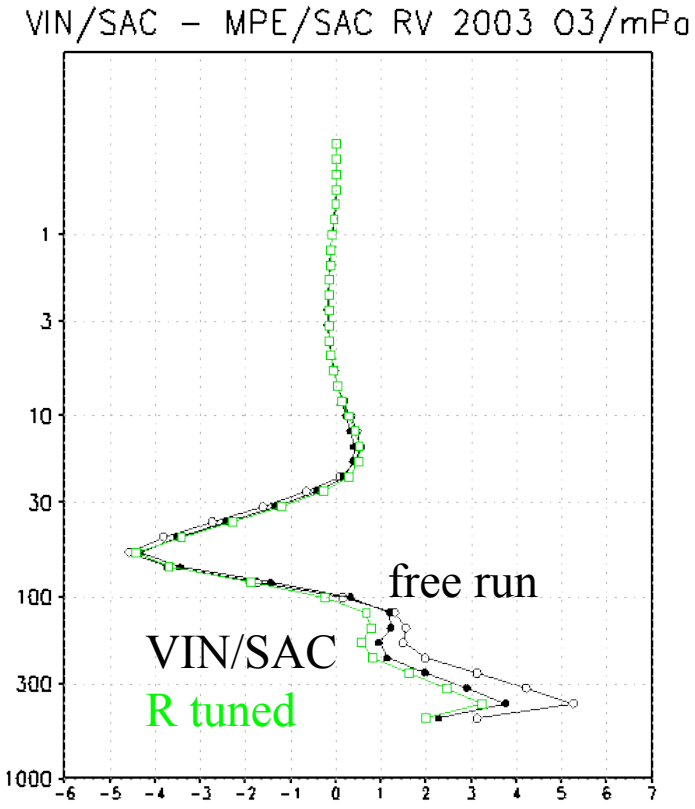
VIN/SAC

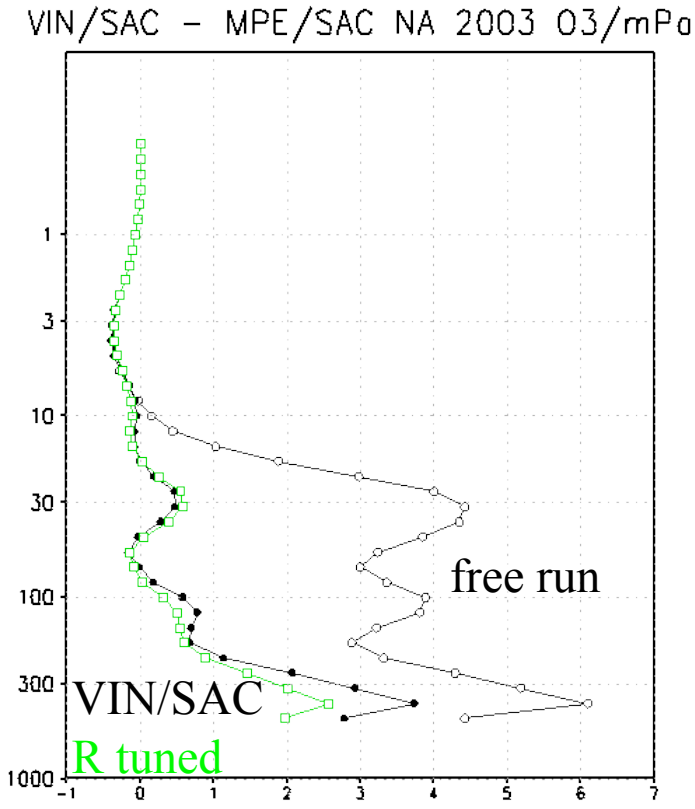


R tuned

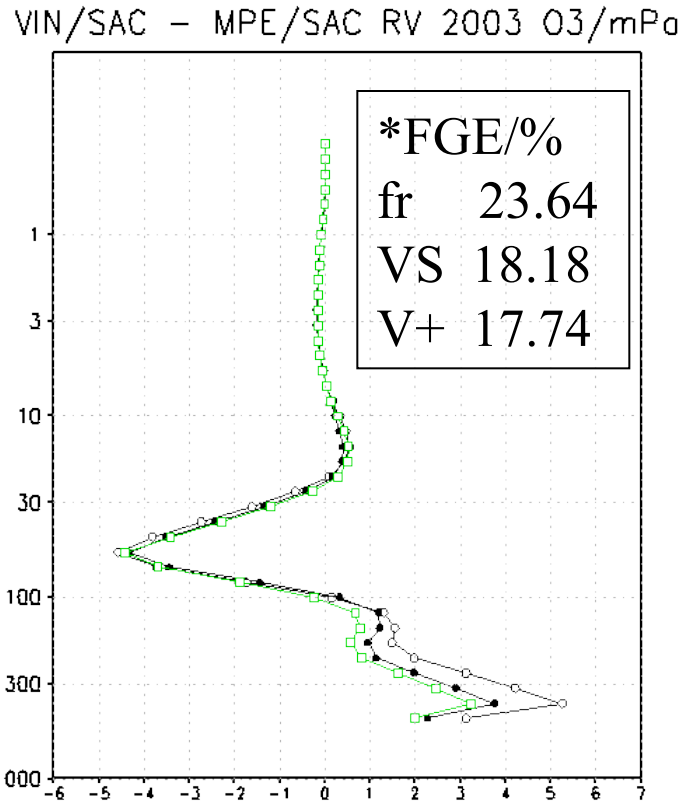


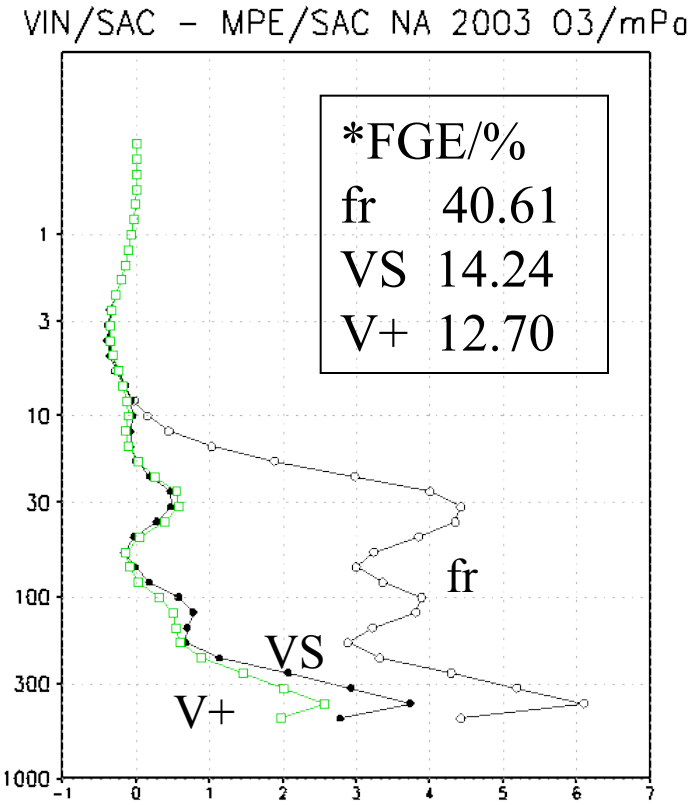
Results for Ny-Ålesund station and Reykjavic city





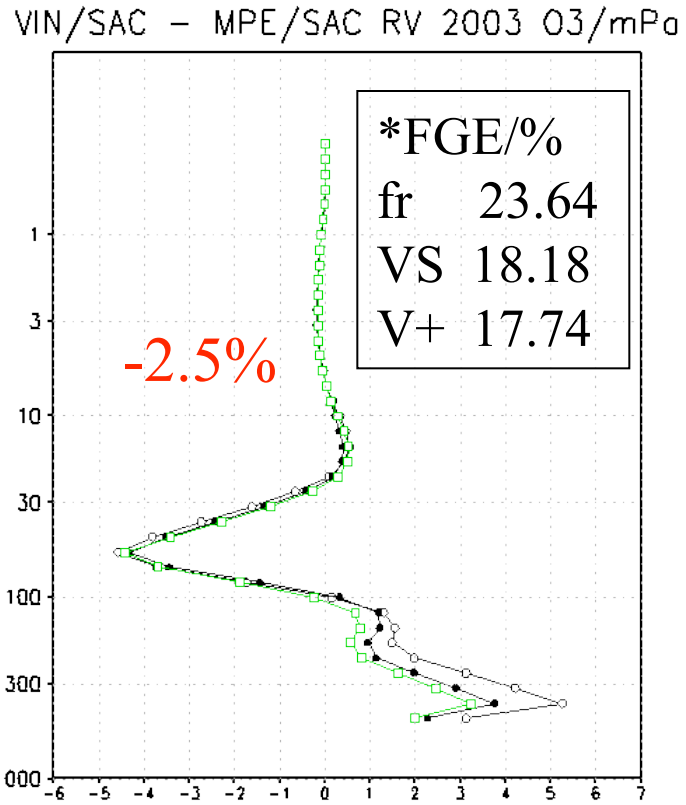
Results for Ny-Ålesund station and Reykjavic city

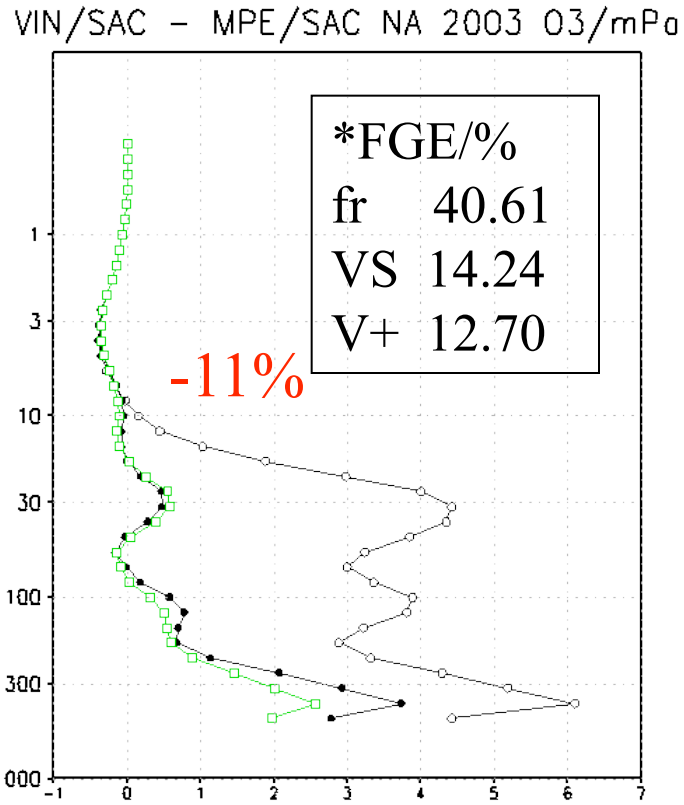




*FGE = $\Sigma\ |x_{vin}-x_{mpe}| / x_{mpe}$ over all model layers

Results for Ny-Ålesund station and Reykjavic city





*FGE = $\Sigma\ |x_{vin}-x_{mpe}| / x_{mpe}$ over all model layers

Summary

- MACC GRG project on global assimilation of reactive gases based on satellite level 2 data – sonde data for validation only
- OSSE study: Ozone sonde data could be useful for routine applications depending on station network
- 2003Q1: Assimilation of VINTERSOL ozone sonde data improves model forecasts near stations
- Positive hemispheric effect d.t. persistency of observed values
- Tuning of observational errors (R) via Rmin * ozone tracer correlation
- Test episode: tuned R values further improve results depending on distance to observing station (2 – 11%)

Further work

- Increase application time period – integrate method with routine process.
- Show that fixed but small R-values (<5%) are worse than tuned values in the long run
- NRT application: Currently coverage by sondes is lower c.t. VINTERSOL. Is the impact still significant?

Thank You!

- many thanks to NILU, especially Trygve Barde, for providing the data access!
- many thanks to all colleagues providing observations and model data!